CLEAN by Design

NRDC'S 10 BEST PRACTICES FOR TEXTILE MILLS TO SAVE MONEY AND REDUCE POLLUTION

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A PRACTICAL GUIDE FOR RESPONSIBLE SOURCING

Version 2.0

NRDC

www.nrdc.org/cleanbydesign
July 2013

Acknowledgments

The authors are grateful to the Richard and Rhoda Goldman Fund and to the Pisces Foundation for financial support of this work. We thank the apparel retailers and brands that partnered with NRDC on the Responsible Sourcing Initiative and provided assistance, support, and advice to our work.

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NRDC (Natural Resources Defense Council) is a national nonprofit environmental organization with more than 1.4 million members and online activists. Since 1970, our lawyers, scientists, and other environmental specialists have worked to protect the world's natural resources, public health, and the environment. NRDC has offices in New York City, Washington, D.C., Los Angeles, San Francisco, Chicago, Montana, and Beijing. Visit us at www.nrdc.org.

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EXECUTIVE SUMMARY

From the clothes on our backs to the curtains in our homes, thousands of everyday items we rely on are produced by the world's textile industry. With the industry now centered in countries with still-developing environmental regulatory systems, such as China, Bangladesh, India, and Vietnam, textile manufacturing has a huge environmental footprint. Dyeing and finishing one ton of fabric can result in the pollution of up to 200 tons of water with a suite of harmful chemicals and can consume tremendous amounts of fuel for steam and hot water.

To address the rapidly increasing global effect of this industry, in 2009 NRDC approached a group of multinational apparel retailers and brands to create the Responsible Sourcing Initiative (RSI), a "green supply chain" effort to curb pollution and resource use in the sector while saving the industry money. The Responsible Sourcing Initiative is part of the larger Clean by Design effort NRDC has undertaken to reduce the environmental impacts of the fashion and apparel industries. Clean by Design addresses all major impacts—from fiber growth to dye selection, fabric sourcing to consumer care.

Starting in China, the world's largest center of manufacturing, NRDC assessed more than a dozen textile mills and conducted in-depth studies of five to identify 10 simple, cost-saving opportunities to reduce water, energy (fuel and electricity), and chemical use via improvements in manufacturing efficiency. In 2011 and 2012, we visited 17 more mills representing a large range of sizes and conditions to apply the 10 Best Practices identified for the mills in the original study and to assess the results. Appendix A provides details on how these assessments were undertaken.

We found that all participating mills could benefit substantially from application of the 10 Best Practices, whether large or small, new or old, producing woven or knit goods. Nearly all the facilities—19 out of 22—could benefit from better insulation of their steam pipes, for example, and nearly as many could benefit from better-maintained steam traps. Insulation of dye tanks provided a valuable opportunity for nearly three-quarters of the mills. Half or more of the facilities could benefit from repairing air leaks in their compressed air systems, which would allow them to reduce the target pressure level and save electricity costs. And half of the mills also had opportunities to recover heat from their air compressor systems or to reuse their condensate.

In addition, we found that our best practices could save even more water and energy than we had originally calculated. **We now estimate that implementation of the 10 Best Practices can potentially save a mill as much as 45 percent of the water and 45 percent of the fuel it uses in manufacturing, and this can be achieved by pursuing only the "low hanging fruit"—opportunities that generally cost very little up front and return their investment in less than a year.** In our study, up-front costs typically ranged between $110,000 and $300,000, and savings were typically between $230,000 and $730,000 per year. Mills often found additional savings opportunities beyond the 10 Best Practices once they began to identify improvements.

This second edition of the best-practice manual updates and broadens the scope of some of the original 10 Best Practices on the basis of our experience with the 17 additional showcase mills in China. Work undertaken in Bangladesh confirms that the measures are widely applicable. We summarize and characterize the results using a range around the median value for resource savings and cost. Appendix B provides a more detailed accounting of the applicability of the best practices to each of the 22 participating mills.

Table 1: Clean by Design's 10 Best Practices

Practice	Typical* Percentage Resources Saved	Largest Savings Seen at Any Mill	Cost	Savings	Payback Period
Water leak detection, preventive maintenance, improved cleaning	Water: 1.1–5%; Fuel: N/A–1%	Water: 6.1%; Fuel: 2.2%	Insignificant	< $1,000–$20,000	< 1 month
Reuse cooling water**	Water: 2–8.9%; Fuel: N/A–0.3%	Water: 18.6%; Fuel: 0.5%	$2,000–$3,000	$2,000–$18,000	2–7 months
Reuse condensate**	Water: 0.2–5.4%; Fuel: 0.6–3.1%	Water: 20.3%; Fuel: 7%	$12,000–$33,000	$8,000–$78,000	4–18 months
Reuse process water**	Water: 1.1–6%; Fuel: N/A–0.9%	Water: 21.1%; Fuel: 2.9%	< $1,000–$24,000	$6,000–$48,000	1–10 months
Recover heat from hot water**	Fuel: 6.6–10.4%	Fuel: 29.7%	$35,000–$79,000	$119,000– $265,000	4–7 months
Improve boiler efficiency **Prescreen coal** **Insulate boiler and economizer**	Fuel: 2.6–4.3%; Electricity: N/A–1% Fuel: 1.6–2.4% Fuel: 0.6–1.8%	Fuel: 19.7%; Electricity: 2.3% Fuel: 3.9% Fuel: 15.1%	$12,000–$22,000 $5,000–$6,000	$23,000–$49,000 $10,000–$18,000	6–9 months 4–8 months
Maintain steam traps and system **Maintain steam traps** **Repair steam leaks**	Water: N/A–0.1%; Fuel: 1–4.3% Fuel: 0.4–1.2% Fuel: 0.3–1.9%	Water: 0.8%; Fuel: 10.2% Fuel: 3.9% Fuel: 5.1%	$2,000–$5,000 $0–$1,000	$7,000–$28,000 $4,000–$16,000	2–6 months < 1–2 months
Insulate equipment and tanks	Fuel: 1.4–3.2%	Fuel: 19.2%	$15,000–$47,000	$34,000–$72,000	6–10 months
Recover heat from hot air**	Fuel: 0.7–2.8%	Fuel: 5.7%	$16,000–$36,000	$11,000–$38,000	7–18 months
Optimize compressed-air system	Electricity: 1–3.9%	Electricity: 15.4%	$0–$19,000	$9,000–$36,000	< 1–12 months
Total	Electricity: 1–5% Fuel: 12.9–30% Water: 4.3–25.4%		$110,000– $300,000	$230,000– $730,000	3–10 months

*Ranges given as 1 quartile around the median to show typical savings; 25% of factories experienced higher and 25% experienced lower savings and costs.
** Some best practices may require new equipment and increase electricity use not reflected in these figures.

NRDC's 10 Best Practices initiative does not call for large-scale retooling of the textile industry. To the contrary, the opportunities summarized here are all easy-to-implement and low-cost opportunities that almost always pay for themselves in less than a year. Even absent concerns about environmental impacts or government requirements, these opportunities should be pursued because they enhance the productivity of mills and are good for the bottom line. Other excellent references for increasing the efficiency of manufacturing processes in textile mills have recently become available. Clean by Design particularly recommends the Lawrence Berkeley National Laboratory's *Energy Efficiency Improvement Opportunities for the Textile Industry* and the European Commission's *Best Available Techniques for the Textile Industry*.[1,2]

This new edition of *10 Best Practices for Textile Mills to Save Money and Reduce Pollution* is organized into four parts. First, the guide recommends that metering to measure resource use be the point of entry into the improvement program. It then summarizes the 10 Best Practices that save water, fuel, and electricity (Table 1). For mills ready for more, there are additional recommendations for greater automation, dye recipe and equipment upgrades, and process management improvement. Finally, this guide presents a list of very simple housekeeping methods that will increase savings and efficiency at all mills with very little effort, even at those mills not yet ready to undertake other recommended improvements.

OVERVIEW

China has more than 50,000 textile mills that manufacture fabric used in products found in closets, cupboards, and kitchens across America and around the world. According to surveys measuring natural resource use across all industries, textile dyeing and finishing mills in China use considerably more water than most in the developing world—as much as 200 tons of water for every ton of textiles produced. Steam used in the manufacturing process is often generated in inefficient and polluting coal-fired industrial boilers. And then there are the chemicals used in textile processing, which include toxic and oxygen-depleting constituents that have harmful impacts on human health and the environment when not properly handled. These factors, along with tremendous production inefficiencies, cause many textile mills in developing nations to fall far below global standards for the use of resources—whether it be water, coal, electricity, time, or money.[3] The enormous growth of the textile sector abroad means that its environmental footprint is very large. China's textile sector, for example, emits more carbon than most countries. If ranked by total carbon emissions, China's textile sector alone would rank as the 24th-largest country in the world, emitting more than Turkey, the Netherlands, or many other nations.[4]

China and most other developing nations generally lack the government capacity either to adequately monitor manufacturing or to enforce environmental standards. In response to this problem, NRDC partnered with seven pioneering multinational apparel retailers and brands to launch the Responsible Sourcing Initiative (RSI), part of the larger Clean by Design effort, to address the environmental impacts of the fashion industry. RSI's purpose is to close the gap between the scale of industrial manufacturing in the developing world and governments' capacities to address the mounting environmental impacts. The best way to achieve this goal is to target resource inefficiencies in the manufacturing process, thereby reducing waste and enhancing the profitability of mills while shrinking their environmental footprint.

In 2009–2010, through expert efficiency assessments of real-world manufacturing practices in five typical Chinese mills, NRDC first identified best practices that would immediately make textile dyeing and finishing processes more efficient and deliver substantial environmental improvement at the same time: a practical win-win framework to benefit both the environment and the bottom line (see Table 1). After two years of implementing this program in 17 additional locations, we've now seen how our best practices can be adapted to a diverse set of mills. As we encountered mills with different configurations and levels of manufacturing efficiency, we broadened some of the best practice definitions to make them more applicable industry-wide. As a result, many of the best practices now save more water and energy than we originally estimated. We now believe that the 10 Best Practices, taken together, can save as much as 45 percent of the water and 45 percent of the fuel used in a typical dyeing mill—all with initiatives that usually pay for themselves in less than one year.

Of course, since even the best-run and most efficient manufacturing practices will still generate pollution that must be treated prior to discharge, compliance with local environmental emission and discharge standards remains crucial for all textile manufacturing. Multinational apparel buyers must insist on compliance as a prerequisite for doing business. This guide will not substitute for or eliminate the need for effective wastewater treatment, but its water reduction recommendations will reduce volume throughput and operating costs, allowing struggling treatment systems to keep up.

Since 2009 we have completed 22 RSI assessments in 21 textile mills, with two assessments performed in different dyeing factories on the same campus. The mills process a range of fiber and fabric types (cotton, blends, and wool) and perform a variety of steps in production, including fiber dyeing, fabric weaving and knitting, and printing and finishing. They also represent a wide range of sizes, with the largest facility 70 times the size of the smallest. Most mills fall in a middle range of resource use efficiency—neither the worst performers nor the best state-of-the-art operations, although some have made high-tech investments. Therefore, the opportunities identified in these mills should be very widely applicable to thousands of mills across China and elsewhere in the developing world. A short description of all the facilities studied in depth is provided in Appendix A.

FIRST THINGS FIRST: INSTALL METERS TO MEASURE SAVINGS, AND READ THEM

The first step necessary to begin improving manufacturing efficiency—and the activity that underpins all of the other opportunities recommended by NRDC—is to routinely measure consumption of water, steam, and electricity, in total and at the process and equipment levels. These measurements allow a mill to create a baseline from which hot spots of resource use can be identified and against which improvements can be measured. Meters at key locations inside a mill, supplemented with measurement software to automate data collection and analysis, best enable factory management to closely track resource and energy consumption for specific processes and to identify those resource-intensive processes where efforts to improve efficiency should be focused.

RSI assessments revealed that most textile mills in China have not realized the importance of a comprehensive metering system. Many mill workers also lack adequate training to properly collect and review the data that meters provide. Most mills track total water, coal, and electricity consumption, but many do not know specifically how resources are used in different areas inside the factory or in particularly resource-intensive equipment. As shown in Table 2, only 5 out of 20 mills investigated by RSI had full metering systems for electricity, 5 had them for water, and 4 had them for steam. Despite the fact that such meters are required by law in China, many mills either did no metering or metered only total factory consumption.

RSI recommends metering at the workshop level at a minimum. We found that a little more than half the mills (55 to 60 percent) did meter all workshops (some also metered major pieces of equipment), but many mills either did no metering or metered only total factory consumption. There is thus an enormous opportunity to improve metering systems within the industry.

Table 2: Metering at 20 RSI Factories

Metering Type	Electricity	Steam	Water
None	0	1	2
Only Total Factory	6	3	4
Some Workshops	2	5	2
All Workshops	7	7	7
All Workshops & All Major Equipment	5	4	5

The installation and proper operation of accurate meters, along with the training of employees to read and use the information they yield, are fundamental to benchmarking performance and initiating efficiency improvements. Metering allows mills to identify and respond to leaks and to detect unusual spikes in resource use. It also provides positive feedback on the effectiveness of steps taken to improve mill processes, thereby reinforcing the benefits of efficiency measures and encouraging continuous improvement.

Networked meters with measurement software automate the meter-reading process and allow process efficiency information to be electronically sent to a central location in the mill or to off-site managers, thus enabling the benchmarking of performance and identification of best-in-practice mills in an accurate, objective, and straightforward manner. In the past few years, the rapid expansion of wireless and satellite-based networks alongside technology advances has dropped the price and expanded the availability of computerized "smart" meters. Facilities poised to upgrade their metering capacity should invest in smart meters and a networked monitoring system rather than add basic mechanical meters; this upgrade will provide much higher-quality data and reduce the labor costs of reading meters and analyzing results.

Since 2006, the Chinese government has required all major industrial energy users to have three levels of metering, though enforcement of this requirement has been weak.[5,6]

- Level 1: Metering of total energy used in the factory.
- Level 2: Metering of individual workshops, with factory coverage of 95 percent for water meters, 80 percent for steam meters, and 100 percent for electricity meters.
- Level 3: Metering of main energy-consuming equipment, with factory coverage of 80 percent for water meters, 70 percent for steam meters, and 95 percent for electricity meters.

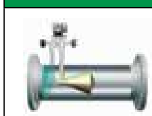
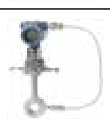
Since 2010, the dyeing and printing industry is specifically required to have a three-level metering system for water and energy use as well as a management system for metering and specific personnel to handle it.[7] Given this government requirement, the RSI recommendation for metering is not only a key cornerstone of best practices, but also an essential element of compliance.

At a minimum, NRDC recommends a full move to smart metering for electricity. For water, factories should use electromagnetic meters on main lines but may use less expensive equipment for submetering. For steam, we recommend orifice meters throughout the factory.

Metering Equipment[8]

Electricity Meters		Price (RMB/ Unit)	Accuracy (+/–)	Life Span (if correctly installed)
	Mechanical meters are the most common electricity meters found in older textile factories. Mechanical meters require manual reading and logging of consumption data and ideally should only be used on lines without active energy management, such as dormitories, outdoor lighting, or small-power equipment like extraction fans.	150–450	2.0%	25 yrs.
	Electrical smart meters can record consumption over set intervals of an hour or less, and can be integrated with a computer server through a network for regular logging and analysis. The more in-depth information gathered by smart meters makes them essential on main lines for billing purposes, but these meters should be used as widely as possible across a factory.	800– 2,000	0.5–1.0%	15 yrs.
	Both mechanical and smart meters gather information from electrical lines via Current Transformers. Where smart meters are replacing a mechanical meter, the existing CT can be used, which reduces the overall price of switching to smart meters.	150– 400	0.1–0.5%	25 yrs.

Water Meters		Price (RMB/ Unit)	Accuracy (+/–)	Life Span (if correctly installed)	Installation and Maintenance
	Mechanical meters use a spinning part installed into the water pipe to record accumulated flow. Because these meters create pressure reductions within the pipe they are not commonly used on major pipes for large volume measurements.	1,000	full pipe: 5% not full pipe: 5%	10 yrs.	Difficult: Physical removal requires flow to be halted, unless bypass is installed.
	Electromagnetic flow meters are much more accurate and do not disrupt water flow, they measure velocity based on the relative disruption of an electrical current passing perpendicular to the water flow. These meters should be used on major inlet and outlet pipes to the facility and workshops.	16,000– 25,000	full pipe: 0.2– 0.5% not full pipe: 1–3%	15 yrs.	Difficult: Physical removal requires flow to be halted, unless bypass is installed.
	Ultrasonic flow meters are a cheaper option for nonintrusive metering, and can be easily installed without removing pipes. The ultrasonic meters do not accurately read flow through thick pipes or high flows and should not be relied on for billing main pipes.	6,000– 8,000	full pipe: 1% not full pipe: 10%	15 yrs.	Easy: mounted externally

Steam Meters		Price (RMB/ Unit)	Accuracy (+/–)	Life Span (if correctly installed)	Installation and Maintenance
	Orifice flow meters are accurate enough to be used for billing purpose, and are recommended for use throughout the factory.	5,000– 8,000	1– 2%	15 yrs.	Easy: can usually be clamped between existing pipe flanges
	V-cone flow meters are more accurate, and remain so at higher temperatures and pressures. When testing new equipment, configurations, or validating energy savings, v-cone meters can be used.	15,000– 30,000	0.5– 2%	15 yrs.	Difficult: Shutdown is required.

10 BEST PRACTICES FOR SAVING WATER, ENERGY, AND MONEY

Although some improvements in textile manufacturing require relatively large investments in updated equipment, Clean by Design's Responsible Sourcing Initiative (RSI) specifically highlights opportunities that are practical, low-cost (or even no-cost) improvement measures as first steps for efficiency improvement in this industry. RSI particularly focuses on factory infrastructure enhancements that improve the production of steam and hot water, reuse process water, and recover condensate, cooling water, and heat. These infrastructure initiatives provide an easy starting point for increasing manufacturing efficiency when compared with process optimization methods. For each opportunity identified, RSI evaluated:

- Costs—both up-front investment and ongoing operational costs;
- Payback period—the time required to recoup up-front investment through savings in water, materials, and energy; and
- Resource savings (water, energy, chemicals).

Cost, return, and impact estimations were initially calculated from 5 factories in the first edition of the 10 Best Practices report. This second edition considers 17 additional factory audits. Combining those evaluations with the first-edition audits, we have revised the scope of activity covered by, and the extent of the resource-use reductions expected from, many of the original Top 10 Practices. Table 3 summarizes the changes between the first and second editions of the 10 Best Practices reports. As Table 3 indicates, we narrowed the focus of the leak detection effort to water leaks, and we expanded the opportunities in boiler efficiency, steam system maintenance, insulation, and hot air utilization. (See Appendix B for full list of 79 practices evaluated for the second edition.) Practices not listed in Table 3 are unchanged from the first edition.

Table 3: Changes Made to the 10 Best Practices

1st Edition Best Practice	Changes	Revised Best Practice
Leak detection, preventive maintenance, improved cleaning	We moved consideration of steam and air leaks to the practices labeled Maintain Steam Traps and System and Optimize Compressed Air System, respectively. This practice now focuses only on water leaks.	Water leak detection, preventive maintenance, improved cleaning
Prescreen coal	Prescreening coal was a big resource saver in our original assessments but not as widely applicable in subsequent facilities. We investigated additional efficiency improvements on the boilers we encountered and found excellent high-value measures including oxygen trim control, and insulation on boilers, pipes, and economizers.	Improve boiler efficiency
Maintain steam traps	We expanded this practice to include repairing steam leaks, insulating steam pipes, reducing steam pressure, and optimizing layout.	Maintain steam traps and steam system
Insulate pipes, valves, and flanges	We expanded this practice to include insulation of other hot equipment, which we often found lacking insulation. Steam pipes were moved to Maintain Steam Traps and System, while hot water pipes remain in this best practice.	Insulate equipment and tanks
Recover heat from hot smokestacks	We expanded beyond smokestacks to include heat capture from hot exhaust air at a variety of equipment.	Recover heat from hot air

Four of the 10 Best Practices are particularly low-cost initiatives: One is typically no-cost for all factories, another is no-cost for many factories, and two others require small investments—less than $3,000 and $15,000 (see Table 1). For the average factory, nearly all 10 of the best practices will be fully paid back in under a year, although two are now estimated to often require 18 months for payback. At each factory we studied, there were multiple best practices paying back in a matter of months or less. From an environmental standpoint, each of the best practices delivered average savings of at least 2 tons of water, 20 kg of coal, and/or 30 kWh of electricity per ton of fabric. The maximum savings at any mill was 45 percent savings in water, 45 percent savings in fuel, and 15 percent savings in electricity. More typically, average savings from the 10 Best Practices are estimated to deliver a 4 to 25 percent reduction in water use, a 13 to 30 percent reduction in fuel, and a 1 to 5 percent reduction in electricity.

WATER SAVING BEST PRACTICES

Water consumption varies by fabric type and quality requirements and also depends on a mill's particular processes, machine types, and setup. Recycling and reuse measures yield great water savings, and since the water recovered is often hot, these improvements save fuel costs as well. Collection and reuse of condensate and non-contact cooling water (such as water used to cool a singeing machine) is a second, very valuable area of improvement because water from these sources is high in both quality and temperature. Finally, more careful use of water in general washing and cleaning throughout the factory, such as by routine policing for leaks in valves and hoses, can substantially reduce wasteful use of water as well.

RSI identified four best practices to conserve water, and one fuel best practice that periodically leads to water savings (see Table 4). These five practices could save as much as 45 percent of water use, a substantial reduction given the heavy use of water in this industry. More typically, mills that implement all of the water best practices would save 2 to 15 tons of water per ton of production, or 4 to 25 percent of its total water use.

Table 4: Water Best Practices

Practice	Range of Typical Water Savings* (ton/ton fabric)	Range of Typical Percentage Savings*	Largest % Savings Seen at Any Mill
Water leak detection, preventive maintenance, improved cleaning	0.6–3.1	1.1–5%	6.1%
Reuse cooling water	0.7–3.9	2–8.9%	18.6%
Reuse condensate	0.2–3.9	0.2–5.4%	20.3%
Reuse process water	0.9–4.4	1.1–6%	21.1%
Water savings from maintaining steam traps and system	N/A–0.1	N/A–0.1%	0.8%
Total	2.4–15.4	4.3–25.4%	

*Ranges given as 1 quartile around the median to show typical savings; 25% of factories experienced higher and 25% experienced lower savings.

Water leak detection, preventive maintenance, improved cleaning

Although individual water leaks may not seem important in the overall consumption picture, they can be responsible for a surprisingly significant loss of resources over the course of a year. At the nine mills where the leak inspection program was assessed, most facilities were losing between 1 and 5 percent of total water consumption to leaks. The relevant literature suggests water loss from leaks may be even higher across the industry.[9] Additional savings can be expected from routine inspection for leaks and improved oversight of the water used in cleaning operations—for example, by installing shutoff valves and turning off hoses when they are not in use.

This best practice consists of routinely investigating sources of water leaks and implementing an effective preventive maintenance program. Factories can reduce water purchases by up to 6 percent with virtually no investment and thus benefit from an instant payback.

Reuse non-contact cooling water from singeing, preshrink systems, and circulating pumps

Non-contact cooling water should always be recycled. It is high in quality and temperature and can thus be reused beneficially in various processes, such as in desizing, scouring, washing, or rinsing. Furthermore, given the typical discharge temperature of 45°C and the considerable water volume, discharge of hot cooling water stresses the wastewater treatment system. It is thus highly beneficial to keep such large quantities of hot, clean water out of the treatment system. RSI found that some mills were either not reusing this water at all or reusing it in cold-water processes that did not benefit from the heat.

RSI identified three important sources of non-contact cooling water that can be most beneficially captured and reused: singeing machines, preshrink machines, and circulating pumps. (Cooling tower water generally cannot be reused in processing because it contains biocides and salts that could be transferred to fabric.) RSI found 10 facilities where cooling water could be reused. Most facilities can expect a 2 to 9 percent reduction in water use and savings of $2,000 to $18,000, which will pay back costs in 2 to 7 months (see Table 1). At three large facilities this practice would reuse 33,000 to 85,000 tons of water per year. Other sources of cooling water may be available elsewhere in the mill, such as from batch jet dyeing machines.[10]

This best practice starts by separating cooling water from other effluent streams with the installation of a water reuse system that includes pipes, valves, a pump, holding tanks, and a control system. Investment costs are low (many factories spent less than $3,000), and return on investment can be nearly immediate (less than a month). Insulating the holding tanks further increases the savings in this improvement since it keeps the water hot.

Reuse condensate

Textile mills rely on a large amount of saturated steam in the dyeing process. Some of that steam condenses into water (condensate) over the course of its use. This condensate is very high in temperature and purity. One of the best places to collect large volumes of condensate in woven fabric mills is in the drying cylinders, which use steam heat. Knit fabric mills find large sources of condensate primarily in steam traps.

The most efficient use of condensate is to return it to the boiler and convert it back into new steam. However, for companies that buy their steam from an outside supplier or whose boiler is located too far from the process, the condensate can be reused in washing or desizing operations, thereby recovering both water and heat.

Poor management of steam processes often results in large waste; this should be reviewed first to determine low- or no-cost opportunities for improvement. Where management suffices, this best practice can require one of the larger up-front investments in equipment. However, the hot water and cost savings produced by a condensate recovery system can be enormous. RSI found ways to recover condensate at 15 mills, where typical savings were 0.2 to 5.4 percent of water consumption. At the 3 mills saving the most water, this practice could reduce consumption by more than 12 percent, and one mill could save 20.3 percent. Where RSI facilities could reuse condensate in hot processes, steam heating needs could be reduced by as much as 7 percent (see Table 5).

This best practice requires installation of pipes and lines to capture and return condensate. Estimates of investment costs range widely and were difficult to pinpoint in RSI mills because they depend on the particular layout of the mill and the proximity of condensate sources to the boiler or other specific process equipment. Many mills can expect to invest $12,000 to $33,000 and to see payback in 4 to 18 months.

Reuse process water

Some sources of process water can be collected and reused for other processes instead of discharged directly to wastewater treatment. For example, after dyeing, fabric must be rinsed multiple times: at some factories darker colors go through eight rinsings, with each rinse consuming 6 or 7 tons of water per ton of fabric. With each successive rinse, the effluent is cleaner. Factories that reuse the last rinse water as feed for the first rinse can save huge amounts of water. The two largest facilities could save more than 11 percent of total water consumption with this practice. While even the smallest presence of dye may make this water unsuitable for reuse in some equipment, this practice is a safe way to reuse rinsing water at least during the same color run. Process water from bleaching and mercerizing must be evaluated for water quality before reuse, but where it meets quality requirements, it can beneficially be reused in scouring after simple removal of fibers. RSI found 11 mills that could reuse process water, and typical savings were 1.1 to 6 percent of water consumption

Reuse of process water should begin with an examination of opportunities to reuse water from final rinses in earlier rinses, or to cascade rinse water—that is, to use the final rinse for the next-to-last rinse, the next-to-last rinse for the previous rinse, etc. In other circumstances, this best practice requires purchasing pipes, water tanks, and electrical pumps to store and return rinse water to the process. Estimates of investment cost range from less than $1,000 to $24,000 per dye machine for most mills, with payback in 1 to 10 months. Some mills will not need to purchase new equipment but can adapt existing equipment and systems to this use, thereby greatly reducing the cost.[11]

FUEL BEST PRACTICES

The generation of steam is by far the largest fuel-consuming activity in a textile mill. Usually done in an on-site industrial boiler, steam generation contributes global warming gases (mainly carbon dioxide) to the atmosphere, as well as other air pollutants harmful to human health, such as particulate matter, mercury, and sulfur dioxide. With this in mind, RSI best practices for fuel usage focus on two areas: (1) improving the operation and efficiency of the boiler itself and (2) increasing efficiency in the use of steam in the production process to reduce the quantity of steam the boiler must generate.

The cost of fuel is a particularly important driver for improvements in mill energy efficiency. In China, the cost of fuel for textile dyeing and finishing has increased over the past decade from 8 percent of the total cost of production to an estimated 30 to 40 percent today.[12] Further, energy-saving measures support China's recent commitment in its 12th Five-Year Plan to reduce its energy intensity, as measured by energy use per unit of production. Clean by Design used a price ranging from 700 to 1,000 RMB per ton of coal for its cost calculations, varying by factory according to what the factory reported to us as the price it paid during the year of the assessment.

RSI identified five best practices for conserving fuel (see Table 5). Substantial additional fuel is saved with four of the best practices for water efficiency (described above), and we note those savings in the table below. A mill that implemented all of the recommended fuel best practices could save as much as 45 percent of fuel consumption. More typically, mills that implement all the best practices would save between 169 and 550 kg of coal per ton of production—representing between 13 and 30 percent of its total fuel use.[13]

Table 5: Fuel Best Practices

Practice	Range of Typical Fuel Savings (kg coal/ton fabric)	Range of Typical Percentage Savings* (steam)	Largest % Savings Seen at Any Mill
Recover heat from hot water	78–249	6.6–10.4%	29.7%
Improve boiler efficiency	39–89	2.6–4.31%	19.7%
Maintain steam traps and system	12–54	1–4.3%	10.3%
Recover heat from hot air	11–39	0.7–2.8%	5.7%
Insulate equipment and tanks	21–56	1.4–3.2%	19.2%
Fuel savings from reuse of condensate	6–40	0.6–3.1%	7%
Fuel savings from leak detection, preventive maintenance, improved cleaning	N/A–9	N/A–1%	2.2%
Fuel savings from reuse of process water	N/A–10	N/A–0.9%	2.9%
Fuel savings from reuse of cooling water	N/A–5	N/A–0.3%	0.5%
Total	169–550	12.9–30.4%	

*Ranges given as 1 quartile around the median to show typical savings; 25% of factories experienced higher and 25% experienced lower savings.

** Note that while the fuel saving best practices were calculated on the basis of the use of coal as a fuel, these measures would also save energy at mills using natural gas, wood, or other fuels to generate steam.[14]

Recover heat from hot water

During manufacturing, large quantities of very hot water (as high as 80°C) are used to dye, rinse, and finish fabric. If this water is too poor in quality to reuse directly, the heat from this water can be beneficially captured and used to preheat incoming water for the next hot rinse or process use. The capturing of heat from hot water also provides an important second benefit of reducing the temperature of wastewater prior to treatment. Nearly half of the facilities we visited were not recovering heat from hot rinse water or effluent. With such large quantities of hot water available, steam heating needs can be drastically reduced. In the majority of RSI facilities considering this measure, steam heating could be reduced by 6.6 to 10.4 percent; at two facilities with large proposed heat recovery systems, total steam consumption could be reduced by 10 to 30 percent.

This best practice requires the purchase of a plate heat exchanger that can transfer the heat energy in wastewater to the incoming cold freshwater. Simple heat exchangers suffice for continuous processes. In discontinuous processes, the heat exchanger would have to be fitted with buffer tanks and process control devices. This can be a relatively expensive RSI opportunity, and a full heat recovery system across a factory will generally cost between $35,000 and $79,000 depending on mill size and layout. However, facilities can expect large steam savings, and even with high costs, these measures all pay back in 4 to 7 months.

Improve boiler efficiency

At many facilities, on-site coal-fired boilers provide major opportunities to improve resource use and reduce environmental impacts. In the initial RSI assessments, this best practice focused on improving boiler efficiency by prescreening coal, which standardizes the feed size and allows more efficient combustion. Prescreening reduces coal consumption by 2.2 to 5.2 percent but was applicable in only 4 of the boiler setups we assessed. To make this best practice relevant to a larger range of situations, we expanded it to include annual boiler burner calibration, insulating the boiler casing and doors, and installing automated oxygen trim controls on the combustion feed inlets. The average reduction in annual coal consumption with these additions was similar—2.9 to 7 percent—but more widely applicable to typical factories in the industry.

Boiler improvements can be expensive and require higher-technology equipment upgrades than the other best practices. With ever-increasing fuel costs, however, the savings reward from more efficient fuel use can be quite significant. Most facilities could save 2.9 to 7 percent of coal consumption with an investment of $23,000 to $39,000 that would pay back in 5 to 13 months.

Maintain steam traps and steam system

Mills have extensive steam systems that distribute heat and energy to processes in every corner of the factory. The small leaks and inefficiencies that inevitably occur across the factory can add up to significant resource waste, while improved maintenance and repairs usually require little up-front investment. According to industry data, the energy loss from 1 meter of uninsulated steam pipe would typically be equivalent to 3 tons of wasted coal annually.[15]

Many facilities we visited had programs in place to find and fix steam leaks, and most had insulated a great percentage of their steam pipes. However, nearly every facility still had good opportunities to further improve the steam management system and reduce costs. Nearly all (19 of 22) RSI facilities would benefit by going beyond insulating pipes to also insulate the steam valves and flanges. In addition, most facilities could benefit from a regular regime for repairing steam leaks, replacing or repairing traps, and regulating steam flow to equipment that is not continuously in use. Regular inspections for leaks and faulty steam traps can have a large impact on the entire steam system; traps remove moisture (i.e., condensate) from the steam lines and prevent further condensation, thereby reducing heat loss and fuel consumption. In steam systems that have not been adequately maintained, between 15 and 30 percent of the traps may have failed.[16] RSI found malfunctioning traps at 15 of 22 mills, including 8 mills where 1 percent or more of steam consumption was lost to faulty traps. Proper regulation of steam pressure will eliminate unnecessary loss of energy as well as improve process equipment performance.

Replacing or repairing steam traps and fixing steam leaks are at the heart of this best practice. When combined with other measures such as pipe, valve, and flange insulation, the typical facility can save 1 to 4.3 percent of steam consumption with an investment of $5,000 to $15,000 that will pay back in 2 to 7 months.

Insulate equipment and tanks

Textile mills use steam in a variety of machines and processes. All of the factories we visited in the second round of RSI assessments had opportunities to further insulate equipment operating at high temperatures and significantly reduce steam consumption. The equipment that most consistently lacked insulation were dye vats; at 15 of the mills we assessed, these vats could have use increased insulation. Other highly valuable insulation opportunities include the roller ends on dyeing machines, which operate at very high temperatures, and the hot water and hot oil pipes flowing in and out of finishing equipment. Equipment insulation measures are generally more expensive than most in the best practices but typically lead to large reductions in steam and fuel consumption.

Most factories can expect to lower steam consumption by 1.4 to 3.2 percent by spending $15,000 to $47,000 to insulate dye tanks and other tanks and piping that carries hot liquids. At factories where very little insulation currently exists, returns from such insulation can be large; one facility stood to lower its steam consumption by 19 percent with these measures. These large savings can yield swift paybacks, typically in 6 to 10 months.

Recover heat from hot air

Hot flue gas leaving a stack of boilers and finishing machines is a large source of heat energy that can be beneficially captured and used. Boiler stacks without economizers to create steam or hot water represent the largest untapped opportunity for recovering heat energy from hot air at a textile mill. Captured energy from the boiler flue alone can be equivalent to 0.8 to 3.8 percent of a year's steam consumption. Air compressors, dryers, and setting machines also provide excellent opportunities for recovery of exhaust heat at textile mills. Across the many sources of hot exhaust air, RSI found opportunities at 17 factories. Most could reduce steam heating needs by 0.7 to 2.8 percent, and one facility could save 5.7 percent.

Diverting hot exhaust gas from compressors or process equipment into boiler air inlets is a popular and low-cost measure in this best practice. Installing a system for heating water with hot boiler stack air is more expensive but can be cost-effective due to the high temperature of boiler exhaust air. Most facilities can expect to spend $16,000 to $36,000 to recover heat from hot air and will see a payback on investment in 7 to 18 months.

China's 12th Five-Year Plan

The Chinese central government has prioritized the textile sector as one of the growing industries that need to reduce their energy and resource intensity and has developed reduction goals for the industry in a specific Five-Year Plan.[17] In response to requirements for energy reduction in the 12th Five-Year Plan, running from 2011 through 2015, the textile industry is expected to upgrade process and monitoring technology to international standards; to set national standards on energy conservation; and to double production efficiency relative to a 2010 benchmark. Specifically, the current Five-Year Plan challenges the textile sector to decrease its energy consumption per unit GDP by 16 percent. Existing cotton fiber and woven fabric mills must reach 4.2 tonnes of coal equivalent (TCE) per 10,000 meters of fabric, and the standard for new facilities is 3.5 TCE/10,000m. Yarn and knit fabric mills must meet a standard of 150 TCE/ton fabric, while new yarn and knit facilities must be at 120TCE/ton fabric.[18] The overall goal for the dyeing and printing industry is to reduce energy consumption per unit of industrial added value by 20 percent from 2010 to 2015.[19]

NRDC's 10 Best Practices will enable textile mills around the country to meet the requirements in China's current Five-Year Plan while reducing their costs.

Best Practice to Reduce Electricity Consumption

Electricity is estimated to account for no more than 20 percent of total energy consumption at a typical dyeing and finishing textile mill.[20] Thus, even large savings of electricity will tend to make only a minor contribution to the overall energy consumption at a mill. Nevertheless, one practice, optimizing the compressed air system, results in sufficient electricity savings to qualify as an RSI best practice.

Some mills that implemented this electricity best practice would save as much as 15 percent of their electricity. More typically, we estimate mills will save between 11 and 48 kWh per ton of production—between 1 and 4 percent of total electricity use (see Table 6). At a few select mills, improving boiler efficiency (optimizing boiler feed air), a fuel best practice, offered noticeable electricity savings, and we show those savings in the table below.

Table 6: Electricity Best Practice

Practice	Range of Typical Electricity Savings* (kWh/ton fabric)	Typical Range of Percentage Savings*	Largest % Savings at Any Mill
Optimize compressed air system	11–48	1–3.9%	15.4%
Electricity savings from improved boiler efficiency	N/A–17	N/A–1.1%	2.3%
Total	11–64	1–5%	

*Ranges given as 1 quartile around the median to show typical savings; 25% of factories experienced higher and 25% experienced lower savings.

Optimize compressed air system

Instrumentation consumes large amounts of compressed air at many individual locations in a textile mill, and the large distribution systems are susceptible to leakage. Most such leaks are at threaded connection points, rubber hose connections, valves, regulators, seals, and in old pneumatic equipment. In all, compressed air leaks can account for 20 to 75percent of air demand in a plant that has no regular maintenance policy.[21]

Working pressure is commonly set to the maximum pressure in textile mills to compensate for pressure drop between the compressor and the target equipment. However, it is often possible to reduce this pressure without negative effects on manufacturing. Optimizing pressure settings—almost always a zero-cost practice—saves energy and reduces the volume of air loss through leaks. In 11 facilities, point pressure was set too high, and total electricity consumption could be reduced just by lowering pressure settings. Further, 17 of the 22 mills could benefit from improved maintenance programs to reduce compressed air leaks.

RSI found opportunities to optimize the compressed air system at 20 of 22 facilities by repairing leaks, reducing set pressure, and using electronic controls and variable-speed drives to reduce idling energy use. The median facilities were estimated to reduce total electricity consumption by 1 to 3.9 percent, with investments between $0 and $19,000. Many compressed air system improvements have no costs: six of the 20 facilities optimized their compressors and fixed leaks with zero investment.

This best practice requires fixing leaks in the air system and checking and optimizing pressure settings on a regular basis, at least annually. The option costs virtually nothing and pays for itself immediately.

PROCESS IMPROVEMENT: RECOMMENDATIONS FOR MILLS READY TO DO MORE

The Clean by Design 10 Best Practices deliver results through specific improvements to factory infrastructure that provides the steam, hot water, electricity, and compressed air to a dyeing mill and also through such green initiatives as recycling and reusing water and capturing heat wherever possible.[22]

When mills are ready to consider more, there are a number of other promising ways to substantially reduce resource use—through improvements in automation, upgrades in equipment and dye recipes, and improvements in process management. Managers can choose to investigate changes in these areas themselves or with in-house project teams, or they can enlist the help of outside experts and consultants. Outside experts have the advantage of years of experience as well as the ability to focus exclusively on finding efficiency opportunities, whereas in-house staff typically know the processes well but have many other responsibilities.

Below we briefly describe some of the most valuable opportunities for improvement beyond the 10 Best Practices for those mills that are ready for more. Other excellent references for increasing the efficiency of manufacturing processes in textile manufacturing have recently become available. Clean by Design particularly recommends the Lawrence Berkeley National Laboratory's *Energy Efficiency Improvement Opportunities for the Textile Industry*[23] and the European Commission's *Best Available Techniques for the Textile Industry*.[24]

Table 7: Process Improvements for Mills Ready to Do More

Automation	Automation to monitor and control dyeing and printing processes
Recipe upgrades	Enzymes to pretreat and finish cotton fabric
	Increased reliance on higher-quality dyes and chemicals, high fixation, and environmentally friendly dyes
Equipment upgrades	Cold pad batch processing
	Low-liquor-ratio dyeing machines
	Digital printing machines
	Continuous wash (open width) for knit fabrics
	Foam finishing
Improved process management	Benchmark energy and water use and set concrete reduction targets
	Monitor continuously to ensure implementation of improvements
	Undertake failure analysis when things go wrong
	Standardize optimal methods and recipes
	Improve machine utilization, particularly for the most energy-intensive machines
	Schedule colors more carefully to minimize the need for extensive cleaning between batches
	Work with dye/chemical suppliers to optimize process and completely exhaust dyes and finishes
	Sequence dye baths to stagger machine times and cut down maximum mill steam loading needs

Automation

Automation to monitor and control dyeing and printing processes: Traditionally, the dyeing and printing industry in China manages production without electronic process monitoring; dye masters oversee implementation of dye recipes without electronic tools. This approach often creates difficulties for product quality and right-first-time dyeing rates, which in turn wastes time and money and increases environmental impact (because much of the water, energy, and chemicals used the first time have been wasted). Computer technology now enables dyeing machines to be precisely controlled according to a predetermined set of process specifications. Salt content, pH, temperature, and rate of temperature rise have a huge impact on the dyeing result; automated monitoring of these four parameters and routine calibration of measuring equipment should receive the highest priority.

Once a predetermined optimized process is programmed into the computer, process parameters can be handled automatically, dramatically improving right-first-time processing and thereby reducing resource use. The *Outline for Science & Technology Progress in the Textile Industry in the 12th Five-Year Plan Period*[25] recommends that the dyeing and finishing industry automate the auxiliary agent distribution system and the sizing system and also use online technologies to test fabric moisture content, humidity of the hot air, liquid level, width, coil diameter, edge, length, temperature, speed difference, and preshrinking rate in order to reduce water usage and effluent discharge.

Modern technology also offers important advances for improving accuracy in the laboratory. Measuring color with instruments (spectrophotometers) is far more reliable than using the naked eye, for example, and automatic dosing pipettes are far more accurate than manual glass pipettes.

Recipe upgrades

Enzymes to pretreat and finish cotton fabric: Conventional pretreatment processes rely on high-temperature and concentrated alkali solutions that are extremely water and energy intensive and require extensive rinsing. Furthermore, detergents and scouring formulations are a large source of the chemical oxygen demand (COD) loading to a wastewater treatment plant. The new enzyme formulations, such as amylase used for de-sizing cotton fabric, cellulase used for scouring, and catalase used in bleaching, as well as other ecologically friendly auxiliary agents, can save money by substantially reducing fuel, water, and chemical usage, which reduces environmental impact at the same time.

Increased reliance on higher-fixation dyes: Major dye manufacturing companies sell higher-fixation dyes—bi-reactive dyes, for example—that have a higher affinity for fabric than average. These dyes may cost more per kilogram of dye but often cost less per ton of fabric. Because more dye adheres to the fabric, less dye is needed, less rinsing is required, and less dye waste is delivered to the wastewater treatment plant. It is important to calculate the full costs of using certain dyes and chemicals—including the cost of dye used per square meter or ton of fabric, the amount of auxiliary chemicals used to improve dyeing outcome, the frequency with which fabric needs to be re-run to get the color right, and the cost of water, fuel, and dyes needed during re-runs—rather than just the cost of dye per se.

Equipment upgrades

Cold pad batch processing: This is a superb method of reducing resource use in textile mills during pretreatment and dyeing. In this approach, dyes, or hydrogen peroxide in the case of pretreatment, are embedded into the fabric using a padder, after which the fabric is stored for approximately 8 to 20 hours to allow complete reaction between fabric and chemicals prior to rinse. Experts report that as much as 50 percent of the water and 40 percent of the steam used in pretreatment can be saved with this method, with overall reduced costs of about 50 percent.[26] Newly developed high-efficiency liquor applicators help reduce chemical consumption by nearly 30 percent when compared with traditional methods and further improve fuel savings and emissions reductions.

Results for dyeing are similarly impressive, particularly for energy savings because cold pad batch dyeing does not require drying and steam. Both dye penetration and fixation rates are high (15 to 25 percent better than with traditional methods), which also reduces dye consumption and wastewater color problems.[27] Cold pad batch technology is currently limited to woven fabric and works best with heavyweight fabric and dark colors.

Low-liquor-ratio dyeing: Older overflow dyeing machines use excessive water for batch dyeing. Lower-liquor-ratio dyeing machines—such as air-flow machines, which circulate fabric within a dyeing vat using compressed air instead of water—can greatly reduce the use of water and auxiliary agents. The liquor bath ratio of these new dyeing machines is only 1:3 or 1:4, which is much more fuel and water efficient than older machines, which achieve ratios of 1:8 or even 1:12. Air-flow, even-flow, and other low-liquor-ratio dyeing machines can save as much as 50 percent of water, 15 percent of steam, and 15 to 50 percent of auxiliary agents used during dyeing, while eliminating about 2 to 3 hours of production time per vat.[28] Air-flow dyeing technology is one of the four key projects listed for improving textile dyeing in China's *Cleaner Production Technology Guideline Directory for the National Priority Enterprises*, issued in 2006.[29] Its *Guiding Catalogue for the Adjustment of Industrial Structure* heavily promotes the conversion of the dyeing industry to low-liquor-ratio machines.[30]

Digital printing: Digital printing is very environmentally friendly because it applies printing inks directly onto fabrics and produces no waste. It is particularly suitable for factories with small-batch, short-cycle, high-quality, and individualized products. It can be used for printing on a wide range of fabrics including cotton, linen, silk, wool, and polyester. The *Outline for Science & Technology Progress in the Textile Industry in the 12th Five-Year Plan Period* considers digital printing to be a mature technology ready for adoption and promotes it, as do the *Industrial Energy Efficiency Plan for the 12th Five-Year Plan* and the *Guiding Catalogue for the Adjustment of Industrial Structure*.[32]

Continuous wash (open width) for knit fabric: More than 50 percent of the water used in dyeing and finishing textiles is used to wash excess dye from fabric. Knit fabrics, which are conventionally processed by batch, use considerably more water per ton of fabric than do woven fabrics, which are processed continuously. Open-width washing allows for a continuous process suitable for knits; it can save an estimated 50 percent of the water, electricity, and steam needed to dye fabric. This technology is specifically promoted in the 12th Five-Year Plan for textiles.

Foam finishing: Foam finishing and processing replaces water with foam to transfer chemicals onto fabric and has the potential to save 50 percent of the energy and 30 to 90 percent of the water used in finishing.[33] Foam finishing is used mainly for procedures such as soft finishing, resin finishing, shrink-proof finishing, and other finishes. It is also highly recommended in China's *Outline for Science & Technology Progress in the Textile Industry in the 12th Five-Year Plan Period*, as well as in the *Guiding Catalogue for the Adjustment of Industrial Structure*.

Improved Process Management

For many mills, perhaps the most promising way to reduce cost and resource use in manufacturing is to improve process oversight and management routines, which leads to better right-first-time dyeing rates and on-time delivery while substantially reducing the environmental impact associated with reprocessing fabric to correct mistakes. These improvements require a change in thinking rather than a change in equipment or maintenance schedules, both on the part of management and on the factory floor. It requires improved worker discipline and standardization to ensure that improvements become routine. For these reasons, process improvements are sometimes a more difficult starting point for textile mills. Mills can most easily begin process improvement with the following initiatives:

Monitor continuously to ensure implementation of improvements: It is what gets measured that gets addressed. For this reason, efforts to improve process management must begin with the establishment of a quantitative performance benchmark. Production inputs (water, electricity, fuel, chemicals, and fabric/yarn) and outputs (product, textile waste, emissions, etc.) should be monitored/measured/documented at the outset to provide information for baseline performance and then monitored over time as improvements are implemented in order to quantify results. It is important to continue monitoring after improvements have been put in place in order to ensure that these improvements are institutionalized; an annual "checkup" (energy and water audit, etc.) can be useful to ensure that progress continues. Third-level metering on key equipment can provide very valuable before and after data for monitoring the impact of improvements on mill performance.

Undertake failure analysis when things go wrong: Correcting mistakes and reprocessing fabric wastes a massive amount of resources. If a mill gets a color wrong, all the dyes, water, and energy used to process the fabric in the first instance can be wasted. When things go off track, systematic failure analysis allows the mill to investigate whether it has problems with particular fibers, colors, dye combinations, machines, etc.—and whether these failures occur during particular times of day or year or in specific weather conditions. Improvements can then be targeted to the key problem areas identified. Improved metering in the mill can provide very valuable data for informative failure analysis.

Standardize optimal methods and recipes: It is very important that mills be systematic about dyeing procedures and recipes. Successful recipes for dyeing and finishing a certain fabric a certain color (specifying the time allotted for contact between dye and fabric, precise quantities of dyes and chemicals, pH, temperature, etc.) should be carefully documented and rigorously replicated for repeat orders without subsequent ad hoc changes.

Improve machine utilization, particularly for the most energy-intensive machines: It is common for machines to run continuously in textile mills even if they are in use for only a portion of the day. Improving use patterns by turning off machines that are not in use can save considerable cost and energy. Machines that consume the most energy—such as dryers (which often account for half of the energy consumption of a dyeing and finishing mill), stenters, bakers, and steamers—should receive the highest priority for attention. Better factory production planning can improve machine utilization and create opportunities to turn off machines, delivering greater product output for the same total energy cost. Savings will be particularly significant during low-order months.

Schedule colors more carefully to minimize the need for extensive cleaning between batches: In continuous dyeing operations, color changes, start-ups, and stops often require time- and chemical-intensive cleanings for machines and the use of a large volume of rinsing water. A well planned dyeing schedule reduces the number of machine cleanings and the resulting pollution and water costs. The ideal sequence is to run the same color repeatedly on a particular machine. If that is not possible, it is best to group colors within families (red, yellow, blue, etc.) and then run the orders within each color family from light to darker values and from bright to duller shades. A schedule that runs light colors first in each machine, then transitions to darker colors, offers the opportunity to reuse dye baths and rinses as well. Orders from buyers should be given to the dye house as early as possible to facilitate optimized production scheduling.

GOOD HOUSEKEEPING

Many textile mills can take significant steps toward reducing waste and cost by implementing small changes in housekeeping behavior, regardless of whether they also implement the RSI best practice list. These good housekeeping initiatives require little or no investment beyond improved management and attention to detail, but they did not qualify as best practices because their savings are difficult to quantify or because they promise only modest environmental benefits.

However, good housekeeping recommendations are easy to understand and implement and should prove to be an appealing starting point for some mills. Adopting these quick and easy opportunities will help mills develop a "clean production" mentality that can translate into the managerial commitment needed to support more substantial improvements. And they can have a big impact: as much as 5 to 10 percent savings in resources, in the experience of some experts.[34]

The RSI factory audits found nearly a dozen promising, easy-to-implement opportunities for improved housekeeping at the mills assessed:

- Unmarked stored goods. Confusion about unmarked stored goods can lead to selection of the wrong chemicals. Mills should also mark clearly where goods are to be placed.
- Poor storage practices. Materials that are stored in a workshop have a higher risk of being water-damaged or contaminated. It is good practice to demarcate special storage areas in the workplace, raise the floor level of the storage areas to keep their contents dry, and improve management there so as to reduce breakage and leakage. Dyes should be stored in a centralized area in dry and clean conditions.
- Poor chemical inventory management. A first-in, first-out system will reduce waste from shelf-life expiration of certain chemicals.
- Unclean work sites. Unclean work sites can lead to rework through contamination of process baths or textile products. Regular cleaning of the workplace should be the responsibility of the staff at each workstation.
- Leaks and running water. Water is commonly wasted when hoses or cooling water pumps are left running after machinery is shut down. Rather than relying on workers to reduce water use, low-flow and shutoff valves should be installed on hoses, and thermally controlled shutoff valves can be installed on process units.
- Inefficient and inconsistent bulk chemical preparation. Bulk chemicals are best prepared in a solution that is pumped to dyeing machines as needed.
- Inadequate scoops. Dyeing chemicals should be taken only with scoops that are dedicated to each separate color to avoid cross-contamination.
- Preparation of excess chemical solutions. Only the required amounts of chemicals or prepared solutions should be taken to the production areas, with minimal surplus.
- Uncalibrated equipment (such as scales used to weigh dyes and chemicals). Unreliable data lead to errors and poor outcomes. It is important to calibrate equipment and monitor the quality of measurements by weekly checks of recorded data. Scoops of different sizes and buckets with marked volumes are also very helpful in improving measurement accuracy.
- Poor boiler blow-down practices. Boiler water contains impurities that increase in concentration over time, eventually forming a sludge that impairs boiler efficiency. Facility managers should optimize blow-down (water bleed-off) frequencies. A boiler efficiency study should be conducted annually to optimize the boiler system.
- Wasteful lighting. Switching lights off when they are not in use and replacing old, inefficient bulbs with new, energy-saving models can substantially reduce electricity costs. It is helpful to measure brightness in different areas of the mill and remove unnecessary light tubes as well.

APPENDIX A: DESCRIPTION OF AUDIT ASSESSMENTS AND PARTICIPATING MILLS

The 5 mill assessments done for the first edition of the 10 Best Practices were conducted by BECO consulting of Rotterdam and the Jiangsu Academy of Environmental Science, Nanjing. The remaining efficiency audits for the showcase mills were undertaken by RESET Carbon Ltd. of Hong Kong; these assessments were initiated with a questionnaire to each mill to benchmark baseline performance. Two or three expert assessors then spent two days at each mill to assess opportunities. Mills were provided with drafts of the reports to provide missing data and correct any inaccuracies. Opportunities to reduce energy consumption were investigated more closely than opportunities to reduce water consumption in a few mills.

The 22 Chinese textile mills that have participated in the Responsible Sourcing Initiative to date are described in this appendix. Most of these mills process cotton fiber or fabric, including denim, although a few handle synthetics or wool. Table A gives an overview of the production type, size, and age of the participating mills.

The 22 factories differ in the way they procure energy for production. Some mills produce their own steam with coal-fired boilers, while others purchase steam from an off-site location. Most mills purchase electricity from utilities, but a small number cogenerate some of their own electricity from combined heat and power boilers. RSI benchmarked resource use per ton of production by converting all the forms of energy consumption (steam, natural gas, and heat value in thermal oil) into standard coal equivalents. These figures were then added to get the total coal equivalent used for dyeing and finishing fabric.[35]

This appendix provides a short description of each mill and its best improvement opportunities.

Table A: Production and Savings in the 22 Textile Mills

	Factory Type	Annual Production (Tons)	Year Established	% Water Reduction Possible	% Fuel* Reduction Possible	% Electricity Reduction Possible**
(KH)	Knit Fabric	33,229	1997	8.1%	17.1%	1.2%
(KH)	Knit Fabric	33,229	1997	NA	1.4%	1.4%
(BP)	Denim	28,604	2010	3.2%	4.6%	7.5%
(LF)	Fiber & Woven Fabric	23,875	2002	0.8%	3.6%	0.9%
(LT)	Denim	17,937	2003	2.1%	15.0%	1.5%
(BD)	Denim	15,000	2010	21.3%	8.8%	3.7%
(LS)	Knit Fabric	12,217	1990	1.5%	7.3%	NA
(RB)	Woven Fabric	10,000	1994	24.3%	11.0%	NA
(HY)	Denim	9,473	2005	36.4%	10.7%	14.9%
(AC)	Fiber	8,800	2002	5.3%	21.2%	3.0%
(GX)	Fiber	8,724	2000	0.1%	24.4%	0.8%
(DY)	Denim	8,580	2003	21.0%	16.1%	1.4%
(HF)	Fiber	6,790	2006	10.3%	5.0%	0.8%
(XL)	Fiber	6,684	2003	0.2%	35.5%	2.8%
(KT)	Woven Fabric	5,655	2004	1.1%	3.9%	2.3%
(NX)	Woven Fabric	5,000	1989	13.1%	8.1%	0.3%
(LG)	Fiber	3,956	1993	1.0%	11.2%	6.8%
(TS)	Denim	3,400	2004	0.5%	6.7%	5.1%
(GT)	Woven Fabric	2,895	2004	45.3%	26.1%	2.9%
(XW)	Woven Fabric	1,757	2010	NA	44.7%	3.8%
(ZX)	Fiber	1,200	2005	4.8%	21.2%	15.4%
(DH)	Fiber	506	2010	NA	34.7%	1.3%

*Includes steam and coal savings standardized as % of total fuel use based on factory-specific fuel characteristics.
** Implementation of some best practices may add new equipment and increase electricity use beyond what is reflected in these figures.

(KH) – *Guangdong province, China*
KH is a very large, vertically integrated factory that knits fabric and dyes both yarns and fabric. In 2010 the yarn dyeing section produced 6,854 tons and the fabric dyeing section produced 26,375 tons. The factory complex includes an on-site coal-fired power plant that produces steam and electricity for the factory, with excess production sold to outside customers. Water is pumped directly from a nearby river.

This is the only facility that RSI visited twice. The first audit focused on the yarn dyeing section and the second focused on the fabric dyeing section. The mill's three largest improvement opportunities were to reuse process water, recover heat from hot water, and maintain steam traps and the steam system, which would reduce steam consumption by 15.4 percent and save the mill $1,130,000 per year at a cost of only $237,000. This factory was already practicing several measures in line with the 10 Best Practices, including condensate reuse.

(BP) – *Jiangsu province, China*
BP is a large factory that spins and dyes denim fiber. In 2011 the facility produced 28,604 tons of denim. Steam and electricity are purchased from a local utility, and water is withdrawn directly from a river. The factory's three largest improvement opportunities were to insulate equipment, maintain the steam system, and optimize the compressed air system, which would reduce steam consumption by 5 percent and electricity by 7.5 percent, saving the mill $150,000 per year at a cost of only $92,000.

(LF) – *Jiangsu province, China*
LF is a large vertically integrated facility that produces and dyes fibers and fabrics. In 2010 the fiber dyeing section produced 8,710 tons and the yarn dyeing section produced 15,165 tons. Steam and electricity are produced by the group's on-site power plant, and water is pumped from both a nearby river and on-site wells. This factory was already practicing 3 of the 10 Best Practices including heat recovery from hot water and hot air, as well as condensate reuse. Its three largest improvement opportunities were to insulate equipment, maintain the steam system, and recover additional heat from hot air, which would further reduce steam consumption by 3.3 percent and save the mill $210,000 per year at a cost of only $180,000.

(LT) – *Guangdong province, China*
LT is a large denim dyeing factory. In 2010 the factory produced 17,937 tons of denim. The factory generates steam from on-site boilers and purchases electricity and water from local utilities. This factory was already practicing several measures in line with 6 of the 10 Best Practices, including extensive heat recovery from hot water and reuse of process water; some reuse of condensate and cooling water; some hot air heat recovery; and prescreening coal. Its three largest improvement opportunities were to recover additional heat from hot water, insulate equipment, and improve boiler efficiency. These additional measures were estimated to reduce fuel consumption by 14.3 percent and save the mill $550,000 per year at a cost of only $410,000.

(BD) – *Hebei province, China*
BD is a large denim dyeing factory that was recommissioned from another facility on the company's property in November 2010. In 2011 the factory dyed 15,000 tons of denim. The factory purchases steam and electricity from off-site utilities and pumps water on-site from wells. Its three largest improvement opportunities were to reuse process water, reuse condensate, and reuse cooling water, which would reduce water consumption by 21.2 percent and save the mill $160,000 per year at a cost of only $45,000.

(LS) – *Jiangsu province, China*
LS is a large, integrated textile mill engaged in knitting, dyeing, embroidering, and garment manufacturing. Its maximum production capacity is 20,000 tons of knit fabric (and 45 million pieces of clothing) per year. The company dyed 12,217 tons of textiles in 2008, the year of the RSI assessment. This factory purchases steam and electricity from an outside source and uses coal only for heating oil. Its two largest improvement opportunities were to recover heat from hot water and maintain the steam system, which would reduce steam consumption by 7.3 percent and save the mill $140,000 per year at a cost of only $50,000.

(RB) – *Jiangsu province, China*
RB is a medium-size factory engaged mainly in woven fabric dyeing and fine jute fiber processing. Although the

maximum dyeing production capacity is 45.7 million meters per year, the actual annual output during the RSI assessment in 2007 was 36.6 million meters (roughly 10,000 tons) of fabric.[36] This factory produces its own steam using coal-fired boilers and purchases electricity from the grid. Its three largest improvement opportunities were to reuse process water, reuse condensate, and reuse cooling water, which would reduce water consumption by 24.3 percent and save the mill $910,000 per year at a cost of only $78,000.

(HY) – *Shandong province, China*
HY is a denim dyeing factory built in 2005. In 2010 it produced 9,473 tons of denim. The factory purchases steam and electricity from off-site utilities and pumps water on-site from wells. Its three largest improvement opportunities were to reuse process water, reuse condensate, and reuse cooling water, which would reduce water consumption by 35.3 percent and save the mill $86,000 per year at a cost of only $74,000.

(AC) – *Jiangsu province, China*
AC is a medium-size textile company engaged in the dyeing of bobbin yarn and hank yarn in batch equipment. Its designed production capacity is 18,000 tons of bobbin yarn and 6,600 tons of hank yarn per year. Due to economic conditions, the company was working half-time during the RSI efficiency audit, and its actual annual output was only 6,800 tons of bobbin yarn and 2,000 tons of hank yarn. This factory generates its own steam by coal-fired boiler and purchases its electricity from the grid. Its three largest improvement opportunities were to recover heat from hot water, maintain steam traps and the steam system, and improve boiler efficiency, which would reduce steam consumption by 18.1 percent and save the mill $510,000 per year at a cost of only $130,000.

(GX) – *Jiangsu province, China*
GX is a large fiber dyeing factory built in 2000. In 2010 it dyed 8,724 tons of yarn and fiber. The factory purchases electricity and most steam from off-site utilities and pumps water from a nearby river. This factory was already practicing several measures in line with 5 of the 10 Best Practices, including heat recovery from hot water and hot air as well as reuse of cooling water from dyeing machines and reuse of condensate. Its three largest improvement opportunities were to recover additional heat from hot water, maintain steam traps the steam system, and improve boiler efficiency, which would reduce steam consumption by 17.42 percent and save the mill $260,000 per year at a cost of only $150,000.

(DY) – *Shandong province, China*
DY is a denim dyeing factory built in 2003. In 2011 the factory dyed 8,580 tons of denim. Steam and electricity come from an on-site power plant owned by the group, and water is pumped directly from on-site wells. Its three largest improvement opportunities were to do leak detection and preventive maintenance, reuse condensate, and reuse cooling water, which would reduce water consumption by 20.7 percent and save the mill $78,000 per year at a cost of only $8,000.

(HF) – *Zhejiang province, China*
HF is a large fiber dyeing factory in operation since 2006. In 2010 the factory dyed 6,790 tons of cotton and synthetic fiber, but in December 2010, new dyeing equipment was installed, increasing production capacity. Resources are purchased from off-site utilities. Its two largest improvement opportunities were to do leak detection and preventive maintenance and reuse process water, which would reduce water consumption by 10.3 percent and save the mill $50,000 per year at a cost of only $29,000.

(XL) – *Jiangsu province, China*
The XL factory dyes and processes yarn and fiber. In 2010 the yarn output was 6,684 tons. Steam is produced in an on-site boiler, and water is pumped from a river and from underground supplies. Its three largest improvement opportunities were to recover heat from hot water, insulate equipment, and improve boiler efficiency, which would reduce steam consumption by 33.8 percent and save the mill $570,000 per year at a cost of only $350,000.

(KT) – *Shandong province, China*
KT is a factory that dyes, prints, and finishes woven fabric. In 2010 the facility produced 5,655 tons of fabric. KT purchases steam and electricity from off-site utilities and pulls water from on-site wells. This factory was already practicing several measures in line with 5 of the 10 Best Practices, including heat recovery from hot water, reuse

of condensate, some process water and cooling water recovery, and prescreening coal. Its three largest additional improvement opportunities were to better insulate equipment, maintain steam traps the steam system, and improve boiler efficiency, which would reduce fuel consumption by 3.8 percent and save the mill $95,000 per year at a cost of only $80,000.

(NX) – *Guangdong province, China*
NX is a small textile company engaged in the dyeing and printing of woven textile. Although its maximum production capacity is about 7,500 tons per year, the actual output was about 5,000 tons per year during the RSI assessment.[37] This factory produces both electricity and steam in on-site boilers and also uses a coal-fired boiler for heating oil. Its three largest improvement opportunities were to do leak detection and preventive maintenance, reuse condensate, and reuse cooling water, which would reduce water consumption by 12.3 percent and save the mill $78,000 per year at a cost of only $3,500.

(LG) – *Jiangsu province, China*
LG is a large fiber dyeing and yarn spinning company that dyes woolen and synthetic fabrics. The factory had an output of more than 3,900 tons in 2009. Steam, electricity, and water are purchased off site. Its three largest improvement opportunities were to do leak detection and preventive maintenance, insulate equipment, and maintain steam traps and the steam system, which would reduce steam consumption by 8.7 percent and save the mill $62,000 per year at a cost of only $22,000.

(TS) – *Jiangsu province, China*
TS is a denim mill built in 2004. In 2010 the factory produced 3,400 tons of denim fabric. Steam, electricity, and water are purchased from local utilities. This factory was already reusing its condensate across its facility, in line with one of RSI's best practices. Its three largest improvement opportunities were to insulate equipment, maintain steam traps and the steam system, and optimize the compressed air system, which would reduce steam consumption by 6.2 percent and electricity use by 5.1 percent, saving the mill $140,000 per year at a cost of only $57,000.

(GT) – *Jiangsu province, China*
GT is a factory established in 2005 that dyes and finishes woven fabric. In 2010 it produced 2,895 tons of fabric. This factory purchases electricity and most steam from off-site utilities and pulls water from on-site wells. Its three largest improvement opportunities were to recover heat from hot water, insulate equipment, and recover heat from hot air, which would reduce steam consumption by 16.5 percent and save the mill $120,000 per year at a cost of only $85,000.

(XW) – *Jiangsu province, China*
XW is a factory where dyeing and finishing of woven synthetic fabric started in July 2010. It produces more than 1,700 tons of dyed fabric a year. This factory purchases steam and water from utilities but also generates heat with a boiler and pumps some river water. It recovers some heat from hot water heat exchangers. Its three largest additional improvement opportunities were to insulate equipment, maintain steam traps and the steam system, and improve boiler efficiency, which would reduce steam consumption by 44 percent and save the mill $76,000 per year at a cost of only $49,000.

(ZX) – *Jiangsu province, China*
The ZX facility is a bulk fiber dyeing operation within a medium-size textile operation. In 2009 the factory dyed 1,200 tons of fiber. The larger textile group operates a combined heat and power facility and pumps river water for its own use and for sale. Its three largest improvement opportunities were to insulate equipment, maintain steam traps and the steam system, and recover heat from hot air, which would reduce steam consumption by 18.1 percent and save the mill $57,000 per year at a cost of only $35,000.

(DH) – *Shandong province, China*
DH is a small fiber dyeing factory originally built as an old-brand state-run company. In 2010 the factory dyed more than 460 tons of yarn and fabric. Utilities were purchased from off-site sources. Its three largest improvement opportunities were to recover heat from hot water, insulate equipment, and recover heat from hot air, which would reduce steam consumption by 34.4 percent and save the mill $210,000 per year at a cost of only $100,000.

APPENDIX B: IDENTIFICATION AND SELECTION OF BEST PRACTICES

The 22 factory assessments to date have provided 395 opportunities to reduce resource use and save money. These 395 recommendations were grouped into 79 distinct measures, which were evaluated against a set of cost, return, and effectiveness criteria to determine eligibility for inclusion on our best practice list. Table B lists the 53 distinct measures used as part of the 10 Best Practicies, representing 260 individual opportunities for the participating factories.

The second round of factory assessments illuminated several important areas in which we could expand the 10 Best Practices with good results; among them were insulation, steam delivery, boilers, and hot air heat recovery. Opportunities to reduce resource use and environmental impact through insulation practices were expanded to include insulation of hot equipment tanks and casings. Steam system practices were broadened beyond simple steam trap replacement/repair to include cutting off unused valves and installing steam controls on specific equipment. Boiler practices were expanded beyond prescreening coal with the addition of oxygen trim control and various insulation measures. Finally, practices focused on opportunities to recover heat from hot air were broadened far beyond boiler stacks to include heat recovery from exhausts at air compressors, dryers, setting machines, WWTP blowers, and more. With these expansions, while some factories may still implement only one measure per best practice, others will now have 3 or 4 distinct and complementary ways of improving their steam system, for instance, or insulating their hot equipment. The savings estimates also grew in range and diversity as we encountered mills with low-efficiency starting points as well as enormous mills using far more resources than many of the others combined.

Because of the real differences among factories, some of the costs and savings became hard to summarize with simple ranges. **Throughout this report, we present ranges from one quartile below the median to one quartile above the median values found in our population of mills**. We used percentiles around the median rather than standard deviations from the average because our sample size was small and we had a number of outlier values that we felt skewed average values. The full list of measures used is in Table B:

Table B: Measures Assessed and Used in Best Practices

	Measure	Factories Applicable
Leak Detection	Repair water leaks	9
	Repair water level control systems	1
Reuse Condensate	Reuse condensate	10
	Reuse condensate from finishing machines	5
	Reuse condensate from dryers	1
Reuse Cooling Water	Reuse cooling water from singeing machine	6
	Reuse cooling water from preshrinking	5
	Reuse cooling water from circulating pump	2
	Reuse cooling water from air compressor	1
	Reuse cooling water from mercerizing machine	1
Reuse Process Water	Reuse last-stage rinse water	6
	Reuse process water from mercerizing/bleaching	3
	Use gray water instead of clean water in singeing scrubber	2
	Reuse printer rinse water in closed loop	2
	Use gray water instead of clean water in toilets	1

Table B: Measures Assessed and Used in Best Practices (continued)

Recover Heat from Hot Water	Recover heat from hot dye/rinse water	7
	Recover heat from all water before WWTP	2
	Recover heat from hot process water	1
Insulate Equipment	Insulate casing of dye tanks	15
	Insulate roller ends	9
	Insulate hot water/oil pipes, valves, and fittings	6
	Insulate finishing machines	5
	Insulate casing of condensate collection equipment	3
	Insulate casing of washing machines /dryers	3
Maintain Steam Traps and System	Insulate steam pipes, valves, and flanges	19
	Repair steam traps	15
	Repair steam leaks	14
	Cut off steam valves not in use	5
	Install steam control for dryers or finishing equipment	5
	Reduce steam pressure	2
Improve Boiler Efficiency	Install oxygen trim control	5
	Insulate economizer casing	5
	Insulate hot oil boiler casing	4
	Prescreen coal	4
	Install VFD on hot oil circulating pumps	2
	Clean boiler scale	1
	Install economizer	1
	Destratify boiler feed water tank	1
	Preheat combustion air	1
	Repair leak in combustion air to hot oil furnace	1
	Upgrade chain grate boiler to circulating fluidized bed boiler	1
Optimize Compressed Air System	Repair air leaks	17
	Reduce set point pressure	10
	Electronic regroup of compressor network to reduce idling energy use	5
	Install VFD control system to reduce idling energy use	5
	Add small compressor or install inverter	4
	Optimize compressor layout	1
Recover Heat from Hot Air	Recover heat from air compressors	11
	Recover heat from dryer exhaust	5
	Recover heat from setting machine exhaust	4
	Recover heat from boiler exhaust	3
	Recover heat from WWTP blowers	2
	Recover heat from singeing machine	1

Endnotes

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13 It is difficult to recover heat from the stack gas of coal-fired boilers because of corrosion problems. For this reason, we do not include reductions from recovering heat from smokestacks in the low end of our reduction range.

14 Some common fuels and their energy contents are shown in the table below.

Fuel	Energy value	
	Joules	**BTUs**
Coal [1]	15–27 mj/kg	8,000–14,000 btu/lb
Natural gas [2]	37–41 mj/ft^3	1,000–1,100 btu/ft^3
Wood [3]	18–22 gj/ton	7,600–9,600 btu/lb

Sources:
(1) hypertextbook.com/facts/2006/LunChen.shtml
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33 Jiang Denghui et al., "Low Liquor Application Foam Finishing Technology," *2010 Weishibang National Dyeing and Printing Energy Saving Conference Article Collection*, p. 667.

34 BECO Institute for Sustainable Business, Responsible Sourcing Initiative: *Cleaner Production Opportunity Assessments in Four Chinese Textile Companies*, final report, 2009, p. 6.

35 1 tce = 1 ton standard coal equivalent = 7,000,000 kcal = 29.3076 MJ. Conversion coefficients are as follows: 1 ton raw coal = 0.7143 tce; 1 tce = 6.5 ton steam; 1,000 m3 natural gas = 1.33 tce.

36 The company measures its woven production in yards, which is a length unit. RSI converted length to weight for the purposes of establishing a consistent baseline using a conversion factor provided by the company: 150-350g/yard. This creates a large range in the calculation of production quantities. In this report we have used a value of 250g/yard for conversion of length to weight.

37 Weight conversion was done as described in note 36.

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