Cotton Incorporated

THE LIFE CYCLE INVENTORY & LIFE CYCLE ASSESSMENT OF COTTON FIBER & FABRIC

EXECUTIVE SUMMARY

Life Cycle Assessment of Cotton Fiber and Fabric was prepared for VISION 21, a project of The Cotton Foundation and managed by Cotton Incorporated, Cotton Council International and The National Cotton Council. The research was conducted by Cotton Incorporated and PE International.

CONTENTS

OVERVIEW



Life Cycle Assessment (LCA) is a systematic evaluation of the potential environmental impact and resource utilization of a product, starting at the raw material stage and ending with disposal at the end of the product's life.

A fundamental component of LCA is the Life Cycle Inventory or LCI. An LCI is a quantification of the relevant energy and material inputs and environmental release or emissions data associated with product creation and use. The primary purpose of this project was to compile a robust and current LCI dataset for global cotton fiber production and textile manufacturing. A secondary objective was to use the LCI data to conduct a complete Life Cycle Impact Assessment (LCIA) of a hypothetical knit shirt and woven pant to better understand the environmental impact of cotton textiles so the cotton industry can effectively direct research and resources towards reducing future impacts.

The Cotton Foundation commissioned PE International to perform these studies according to the principles of the International Organization for Standardization (ISO) 14040 series of standards for Life Cycle Assessment (ISO, 2006). Because the LCI will be published in proprietary and open source LCA databases, the entire study was reviewed by a third-party Critical Review Team comprised of agricultural, LCA, and textile experts. The LCI data have also been submitted to The Carbon Trust, a not-for-profit company in the United Kingdom, for certification and to bring additional third-party review and credibility to the data. The project was managed by The National Cotton Council of America, Cotton Incorporated, and Cotton Council International.

METHODOLOGY

The LCI consists of primary and secondary data collected in the following categories: cotton fiber production, textile manufacturing, transportation, garment creation, use, and end-of-life. Primary data were collected by Cotton Incorporated through partnerships with researchers, industry, and co-operators. The data are representative of the crop years 2005 through 2009 and textile manufacturing in 2009–2010. Primary data were supplemented with literature and industry averages (secondary data).

The LCA model was originally created using the GaBi 4 software system developed by PE International, and the analysis was updated when the GaBi software was upgraded to version 5 in 2011. (GaBi 4, 2006; GaBi 5, 2011). The databases within the GaBi software were the source of the secondary LCI data upon which energy production, raw and process materials, transport, and wastewater treatment were modeled. These data were used to account for regional differences for similar processes. For example, China, India, Turkey and Latin America (the locations chosen for textile production) produce larger Acidification Potential (AP), Eutrophication Potential (EP), Global Warming Potential (GWP), and Photochemical Ozone Creation Potential (POCP) per kilowatt-hour when compared to the emissions profile of the U.S. electrical grid. However, Ozone Depletion Potential (ODP) is much higher in the U.S. emissions profile, which is the location for all of the assumed consumer use in this study. These factors will be important when comparing the overall contributions for each phase to each potential impact.

LCI data for fiber production represents a global average of U.S., China and India for the years 2005–2009 and was based on regional production-weighted averages. The U.S., China and India represented 67% of the world's cotton fiber production in 2010 (USDA, 2011). Data covers raw material production from field through ginning (cradle-to-gate) and includes soil types, climate, seed and chemical inputs, fuel use, and dates of key operations (e.g., planting, fertilizer application, and harvest). These data were entered into a cultivation model developed by PE International to estimate the nitrogen and carbon cycles in each of the regions. Impacts were calculated for a functional unit of 1,000 kilograms (kg) of cotton fiber.

Data on fabric production for both knit and woven fabrics, also represented as a global average, were collected from representative mills in four regions: Turkey, India, China, and Latin America. These areas represented 66% of knit and 51% of woven world fabric manufacturing in 2009 (ITMF, 2009). Candidate textile mills were identified by first reviewing interviews from site visits to more than 40 cotton textile companies in regions of China, India, Turkey, Southeast Asia, and the Americas during a previous study conducted by Cotton Incorporated. This information was combined with Cotton Incorporated staff technical service experiences to identify "typical" mills that would accurately represent the overall textile production practices in the countries of interest. The data cover the fiber LCI plus bale opening; yarn preparation; spinning; knitting or weaving; wet preparation; dyeing and finishing, and included raw material inputs and outputs; energy inputs by source; dye/chemical input, output, and emissions; and solid waste (e.g. recycled, sold, and landfill). Impacts for fabric manufacturing are calculated for 1,000 kg of knit fabric or 1,000 kg of woven fabric, as appropriate.

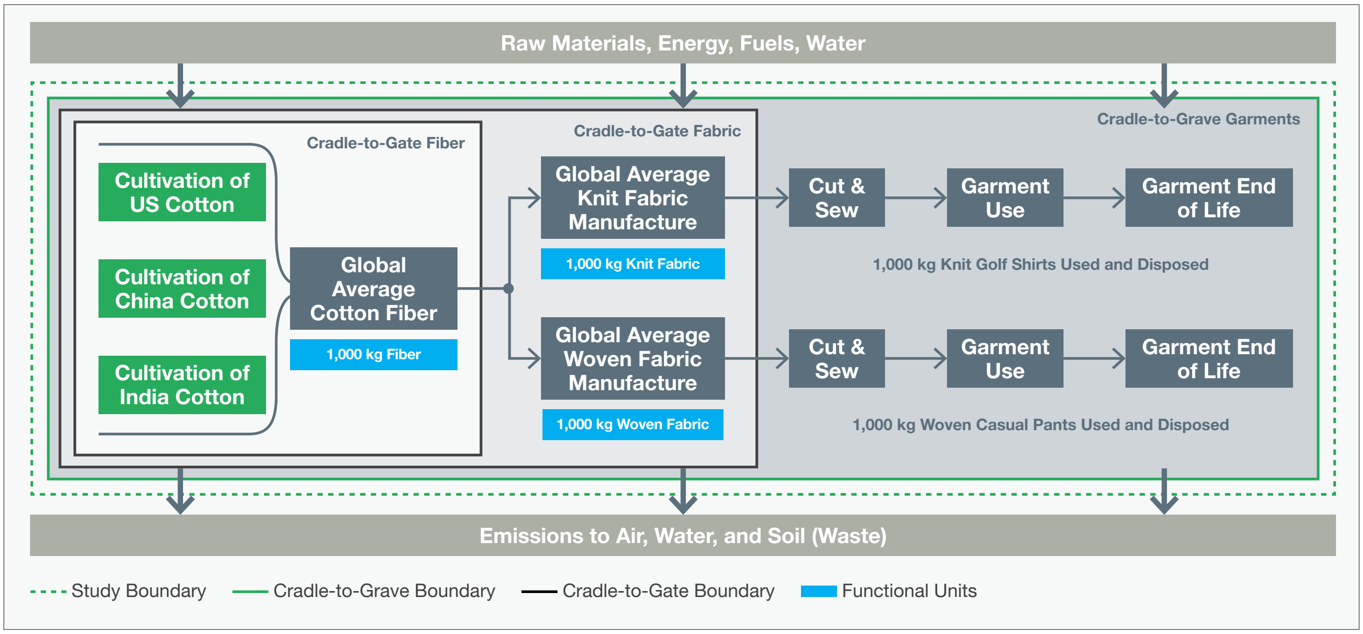
Additionally, cradle-to-grave LCA's that encompassed fiber production through consumer use and disposal were conducted for 1,000 kg of golf shirts and 1,000 kg of casual pants. After accounting for cut-and-sew losses, it was calculated that 1,000 kg of knit fabric would yield 2,780 golf shirts, and 1,000 kg of woven fabric would yield 1,764 pairs of casual pants.

The mill data for textile production and for cut-and-sew processes were supplemented with process energy calculations from machinery manufacturers and data available from Cotton Incorporated experts. Background data on ancillary materials, energy and fuels, transportation, and end-of-life were taken from PE International's GaBi databases. Background data on use phase energy and materials were taken from existing government publications, literature values and PE International GaBi data. Those data were combined with consumer behavior data from Cotton Incorporated's *Lifestyle Monitor*™ survey, an ongoing Internet survey of U.S. consumers who are representative of the U.S. Census based on education, income, ethnicity, marital status, and geography. U.S. consumers surveyed were 60% female, 40% male, between the ages of 13 and 70 years old. Approximately 1,000 people were asked questions about their use and laundering practices for knit shirts and woven pants. The number of washings during the lifetime that a consumer owned and used a garment was calculated to be 56 times per knit shirt and 72 times per woven pant. The calculation was based on the number of times a garment was worn per week, the number of weeks in a year that the garment was used, the lifetime (in years) of a garment and the number of times the garment was worn before washing.

The life cycle of a cotton garment was modeled as three overall phases: 1) Agricultural Production; 2) Textile Manufacturing); and 3) Consumer Use (wearing and washing to the end of life including disposal). Primary data collection for the LCI ended with Textile Manufacturing so the cut-and-sew operations were included with the Consumer Use phase. The system boundaries of the LCA encompass fiber production, fabric production, garment creation, transportation, consumer use, and end-of-life (Figure 1.)

Figure 1

LCA System Boundaries and Functional Units



A summary of inclusions and exclusions in the LCA is shown in Table 1. Items were included or excluded from the study based on their relevance to the environmental profiles measured. For example, in the case of human labor, social issues were outside the scope of the study and were therefore excluded.

Table 1

Summary of Inclusions and Exclusions

Included	Excluded
+ Cotton growth, cultivation and ginning	– Human labor
+ Ancillary material production (dyes, chemicals, etc.)	– Construction of capital equipment
+ Energy and emissions for fabric production, including facility overhead	– Maintenance and operation of support equipment
+ Energy and materials for garment creation (cut-and-sew)	– Production and transport of packaging materials
+ Transport of intermediate and finished products	
+ Transport of finished fabric for cut-and-sew	
+ Transport from retail to customer	
+ Fabric use phase washing and drying (in homes only—no dry cleaning considered)	
+ Fabric end-of-life	

When a system yields more than one valuable output, as is the case for cotton production, environmental burden is shared, or allocated, between the co-products. During cotton production, two valuable co-products are produced, cotton fiber and cottonseed, thus the environmental burden was allocated to both the fiber and seed. Several allocation methods are used in LCA studies: mass-based (the heavier product is assigned more burden), substitution (subtracting off the environmental impact of a product that is replaced by the co-product, for example, accounting for the amount of soybeans replaced by cottonseed), and economic (splitting the burden based on monetary values). It was determined that economic allocation was the most suitable method to use for this study. The data requirements for a substitution method (soybean example noted above) were determined to be overly complex and dependent on factors heavily influenced by market changes. A mass-based allocation would have placed most of the burden on the cottonseed, and, as cotton is perceived as a fiber crop, this approach seemed implausible. Thus, for economic allocation, data on the value of cotton fiber and cottonseed from the United States from 2005 to 2009, as reported by the USDA, were used. The allocation took into account that 1.4 units of cottonseed are produced per unit of cotton fiber. The economic allocation resulted in 84% of the agricultural burden assigned to the fiber and 16% to the seed. No burden was assigned to the stalks or gin waste.

Noils, a co-product from fabric manufacturing, are too valuable to be considered waste (approximately $0.75 per kg compared to $1.50 per kg for fiber) and are subjected to the same production and textile manufacturing systems as primary fabric. For this reason an economic allocation of impact was deemed reasonable in this case. In contrast, lower value waste material generated throughout the textile manufacturing processes, such as start-up fabric from knitting or weaving, for example, are usually recycled internally or sold offsite for a low price. These types of wastes were considered to be byproducts and no allocation of burden was deemed necessary in these cases.

To ensure that all relevant environmental impacts were represented in the study the following cut-off criteria were used:

→ **Mass**—If a flow was less than 1% of the cumulative mass of all the inputs and outputs of the LCI model, it was excluded, provided its environmental relevance was not a concern.

→ **Energy**—If a flow was less than 1% of the cumulative energy of all the inputs and outputs of the LCI model, it was excluded, provided its environmental relevance was not a concern.

→ **Environmental relevance**—If a flow met the above criteria for exclusion yet was thought to potentially have a significant environmental impact, it was evaluated with proxies identified by chemical and material experts within PE International. If the proxy for an excluded material had a significant contribution to the overall Life Cycle Impact Assessment (LCIA), more information was collected and evaluated in the system.

→ The sum of the neglected material flows shall not exceed 2% of mass or energy.

Unlike LCI's which only report individual emissions, LCIA assigns individual emissions to impact categories based on established characterization of the emissions factors. The end result is a single indicator for quantifying each potential impact, such as "Global Warming Potential." The environmental impact categories that were evaluated in this study are listed in Table 2. It should be noted that the impact categories represent *potential* impact, in other words, they are approximations of environmental impacts that could occur if the emitted molecules would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks. In addition, energy demand, water used and water consumed are reported as Environmental Indicators only and no further impact methodology was applied.

Table 2

Environmental Impact Categories

Abbreviation	Technical Term	Example
AP	Acidification Potential	Acid rain
EP	Eutrophication Potential	Water pollution
GWP	Global Warming Potential	Greenhouse gas emitted
ODP	Ozone Depletion Potential	Ozone hole over polar ice caps
POCP	Photochemical Ozone Creation Potential	Smog
PED	Primary Energy Demand	Electricity & fuel needed
WU	Water Used (Gross Volume)	Water used in washing machine
WC	Water Consumed (Net Volume)	Water evaporated in dryer
ETP	Ecotoxicity Potential	Animal health
HTP	Human Toxicity Potential	Human health

It is important to note that an LCA considers both direct and indirect water use. Direct water use refers to water used directly in the production of cotton products such as irrigation water, water to dye and finish textile products, and water used in the washing machine. Indirect water use can come from several sources, but a major source is the water associated with power generation. For example, a process that involves no direct water use, such as spinning a fiber into a yarn, can have a significant amount of indirect water use due to power generation.

Several new metrics to describe water use from an LCA perspective are undergoing development; however, at the present time there are two primary methods of modeling and reporting water. Both are reported in this study:

Water Used (WU) refers to all of the water applied, both directly and indirectly, in any phase of the product's life. It can be considered the gross amount of water used.

Water Consumed (WC) refers to water that leaves the watershed from where it was taken, and like WU, consists of both direct and indirect water. WC includes the groundwater, river and surface water used for cotton irrigation and the cooling water evaporated during electricity (energy) production. In cases where water is returned to the same watershed, a credit is applied. To illustrate, all irrigation water is considered to be consumed since the water taken up by the cotton plant evaporates and falls later as rainfall into the ocean or into a different watershed; however, the treated wastewater from textile processes and consumer laundering is returned to the same watershed, therefore, a credit is given for this water. For these reasons, WC can be thought of as the net amount of water used. Rainfall is not typically included in LCA.

To further illustrate both definitions, consider the direct water used and consumed when washing a shirt. WU is defined as all of the water that flows through the washing machine during every cycle. WC is the water that was retained in the shirt and then evaporated during drying. Finally, the indirect water is associated with the production of the electricity to run the washing machine and is added to both WU and WC.

RESULTS AND DISCUSSION

The potential environmental impacts associated with the production and use of 1,000 kg of knit and 1,000 kg of woven fabric over the entire cotton life cycle are summarized in Figure 2 and Figure 3. The absolute values for each phase and impact category are provided in the Appendix.

When the entire cotton life cycle was considered, two phases dominated the impact profile of the LCA: Textile Manufacturing and Consumer Use. The potential impacts from these phases are predominately attributed to energy use during fiber processing, wet preparation and dyeing, and laundering of garments. On a relative basis, there was little difference in the results for a knit shirt and woven pant. The consumer phase tended to be slightly higher for the woven pant due to the increased number of washes during its life (72) compared to the knit shirt (56) but this difference was not significant.

Country energy grid data, commonly referred to as background data, figures prominently when comparing the overall contributions of each phase to each potential impact. Note that the Consumer Use phase was modeled with U.S. consumer data only. If global use scenarios were included in the analysis the relative contribution from the Consumer Use phase could be very different. As stated in the Methodology section, the relative contribution to ODP for the Consumer Use phase appears much larger due to the larger ODP emission profile of the U.S. energy grid. It is also important to note the actual values for ODP were quite small in this study and entirely related to energy production. This is due to the phase out of all ozone depleting chemicals worldwide.

Figure 2

Relative Contribution to Impact Category for Batch-Dyed Knit Fabric Life Cycle

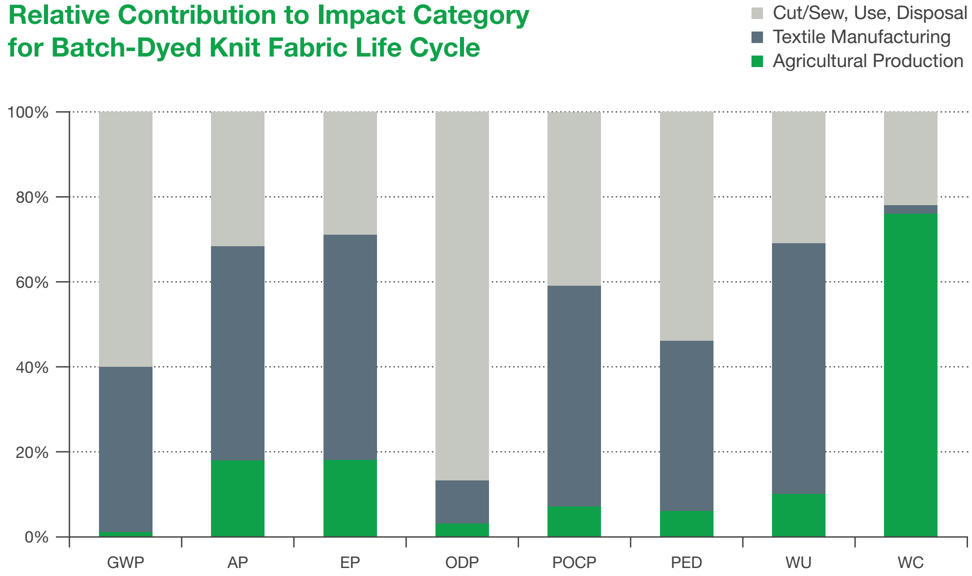
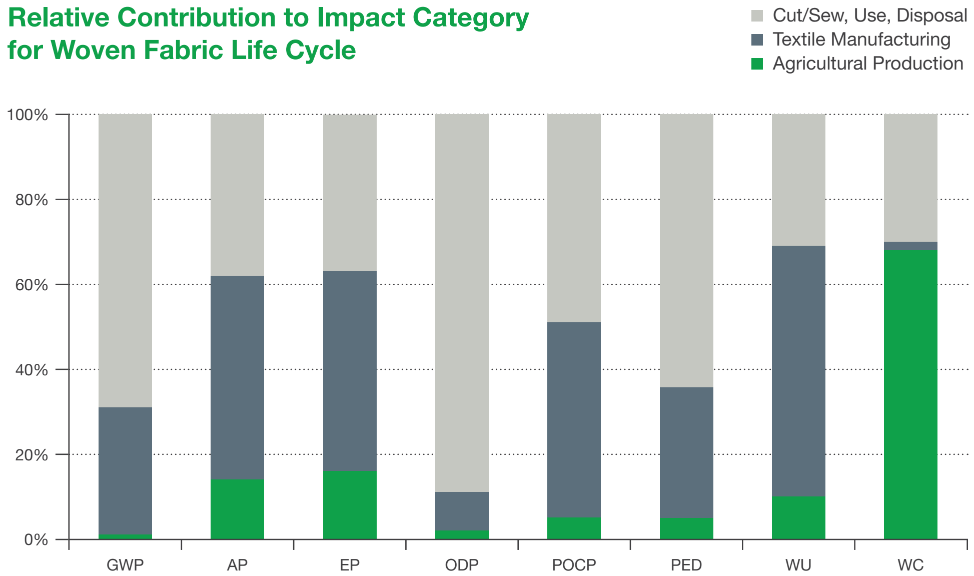


Figure 3

Relative Contribution to Impact Category for Woven Fabric Life Cycle



The Agricultural Production phase had the lowest relative impact of the three life cycle phases in all categories except Water Consumed. In this category, Agricultural Production had a high relative impact compared to other phases owing primarily to irrigation. In contrast, Agricultural Production exhibits a much lower proportion of the Water Used category. In this study, WU is highly related to energy production which is predominantly linked to textile processing and consumer laundering. For this reason, the relative contribution of Agricultural Production to the WU category is similar to that of other categories such as AP which are related to energy.

AGRICULTURAL PRODUCTION PHASE

A key objective of this LCA was to identify areas within the life cycle upon which to improve. Therefore, the potential impacts associated with the processes within the Agricultural Production and Textile Manufacturing phases were evaluated. The inputs included in the processes associated with the Agricultural Production phase and the contribution of these processes to each of the impact areas are shown in Table 3 and Figure 4.

With the exception of water, the analyses showed that field emissions (tractor/equipment operations) were the primary contributors to overall agricultural impact. The source of these field emissions is related to fertilizer use, specifically nitrogen. Once nitrogen is applied to the field, it has the potential to be emitted as nitrous oxide (a greenhouse gas), or it may be leached from the root zone in heavy rains. Because the production of nitrogen fertilizer is an energy-intensive process,

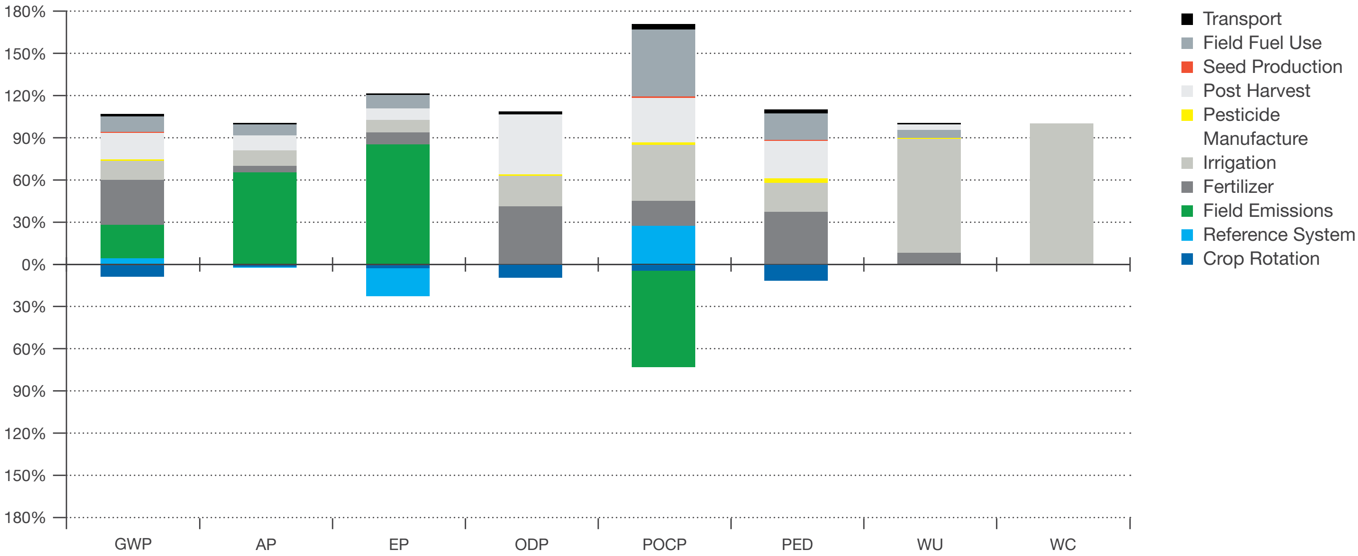
Table 3

Definition of Agricultural Processes

Agricultural Process	Included inputs
Transport	Fuel used to transport seed cotton from field to gin
Field Fuel Use	All field operations such as: planting, cultivation, fertilizer application, and harvest
Seed Production	Production of planting seeds
Post-harvest	All ginning operations and materials (cleaning, ginning, baling, ties, bags)
Pesticide manufacture	Pesticide production, including potential impacts associated with raw materials
Irrigation	Water used for irrigation as well as energy associated with its application and conveyance
Fertilizer	Fertilizer production, including potential impacts associated with raw materials
Field emission	Impacts associated with the estimated loss of fertilizer and pesticides to the air, water or soil outside the root zone
Reference system	Accounts for emissions that would occur in the natural environment if cotton were not produced
Crop Rotation	Primarily associated with fertilizer credit of unused nutrients

Figure 4

Relative Contribution to Impact Category by Agricultural Process Step



fertilizer was also a significant contributor to Global Warming Potential (GWP), Ozone Depletion Potential (ODP), and Primary Energy Demand (PED). The combined impact of field emissions and fertilizer manufacture accounted for a majority of the impacts in the categories considered. Water Consumed was the only category in the Agricultural phase (for irrigation) that exceeded use in the Textile phase or Consumer phases. Water for irrigation in all crops (not just cotton) is a dominant global use of water (FAO, 2011); however, irrigation results in more consistent yields from season to season, thus less risk to the farmer and higher overall input use efficiency. Water Used was also dominated by water for irrigation, as indirect water use in the Agricultural phase is small largely due to the low energy requirements of this phase relative to the total life cycle.

TEXTILE MANUFACTURING PHASE

Production steps for both knit and woven fabrics were also examined to determine the source of highest potential impact within the Textile Manufacturing phase of the life cycle. The steps and the fabric type to which each is applied are defined in Table 4.

As indicated in Figures 5 and 6, which illustrate the potential impacts by specific processes for knit fabric, there was little difference between batch-dyed and yarn-dyed knits. Opening through yarn spinning accounted for more than 50% of the textile impact in five of the eight categories considered. GWP, AP, POCP, and PED are all directly related to energy use. Although water use would not necessarily be a power-related indicator, as explained previously, the high water use in the Textile Manufacturing phase is, in fact, attributed to the high energy demand in the fiber processing step and in wet preparation and dyeing, even more than direct water withdrawal for those wet processing steps. This higher energy demand in the fiber processing step may be partially attributed to the fact that a majority of the mills participating in this study used ring spinning and produced combed yarns, which required additional steps in the yarn making process. As expected, the preparation, dyeing and finishing processes contributed to ODP, PED, EP, and WC. Unlike the WU metric, EP and WC are more related to the wet processing steps due to the water and wastewater use.

In Figure 7, fiber processing again dominated the chart in five of the eight metrics due to the energy involved in yarn production. For the woven fabric, EP is dominated by the finishing step, probably due to the biological oxygen demand of the chemicals involved. Although ODP seems to be attributed to preparation, dyeing and finishing, this result is somewhat misleading as there are no direct emissions during manufacturing, and the burden is instead related to energy and to upstream manufacturing of proxies chosen for some chemicals. In contrast to knits, the WC inventory is spread across many of the textile processes: water for electricity generation during opening through yarn spinning, weaving (due to power needs), processing water for the beaming/slashing/drying steps and continuous dyeing.

Table 4

Definition of Textile Processes

Textile Process	Included Inputs
Bale Opening–Spinning *(knits & wovens)*	Energy for opening, cleaning, mixing, carding, pre-drawing, combing, drawing, and spinning cotton fiber into yarn
Yarn Dyeing (includes preparation) *(knits)*	Energy, dyes and chemicals, emissions to water, and wastewater treatment processes related to scouring, bleaching, dyeing, extraction and drying, and repackaging greige yarn into colored yarn
Batch Dyeing (includes preparation) *(knits)*	Energy, dyes and chemicals, emissions to water, and wastewater treatment processes related to inversion, staging, jet prep, jet dyeing, softening in the jet, extraction, and relax drying
Knitting *(knits)*	Energy for knitting yarn into fabric
Compaction *(knits)*	Energy for compacting fabric to reduce length shrinkage
Beaming/Slashing/Drying *(wovens)*	Energy and chemicals for beaming, slashing, and drying warp yarn
Weaving *(wovens)*	Energy for weaving warp and fill yarn into fabric
Continuous Dyeing (includes preparation) *(wovens)*	Energy, dyes, chemicals, emissions to water, and wastewater treatment processes related to singeing, desizing, scouring, bleaching, mercerizing, drying, dyeing, and redrying of greige yarn into colored yarn
Sanforizing *(wovens)*	Energy and water used for shrinkage control of the finished fabric
Finishing *(knits & wovens)*	Energy, chemicals, and emissions to water related to the wet finishing, drying, and curing of fabric

Figure 5

Relative Impact Contribution by Textile Process Step for Batch-Dyed Knit Fabric

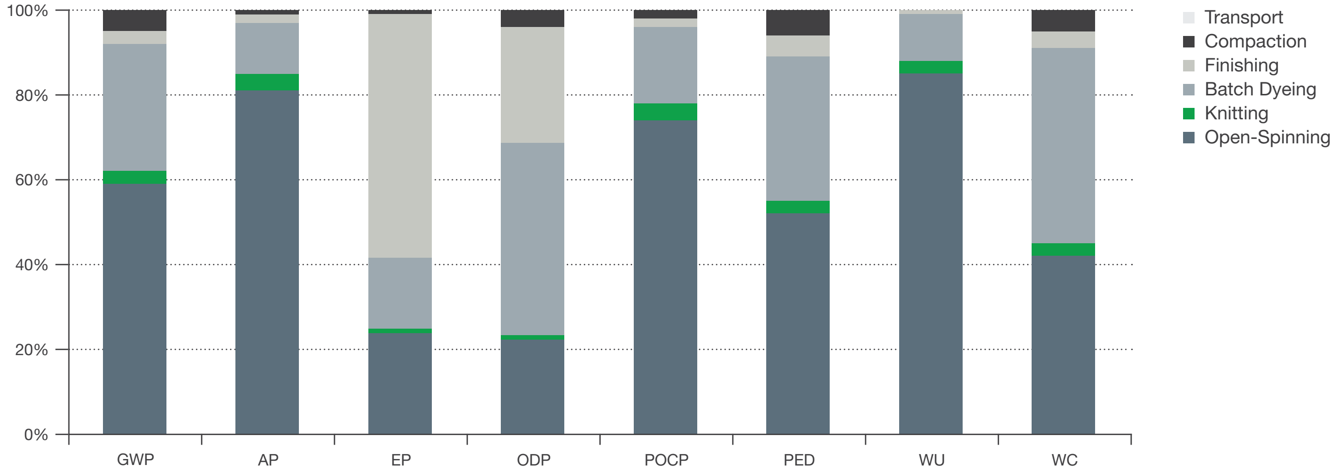


Figure 6

Relative Impact Contribution by Textile Process Step for Yarn-Dyed Knit Fabric

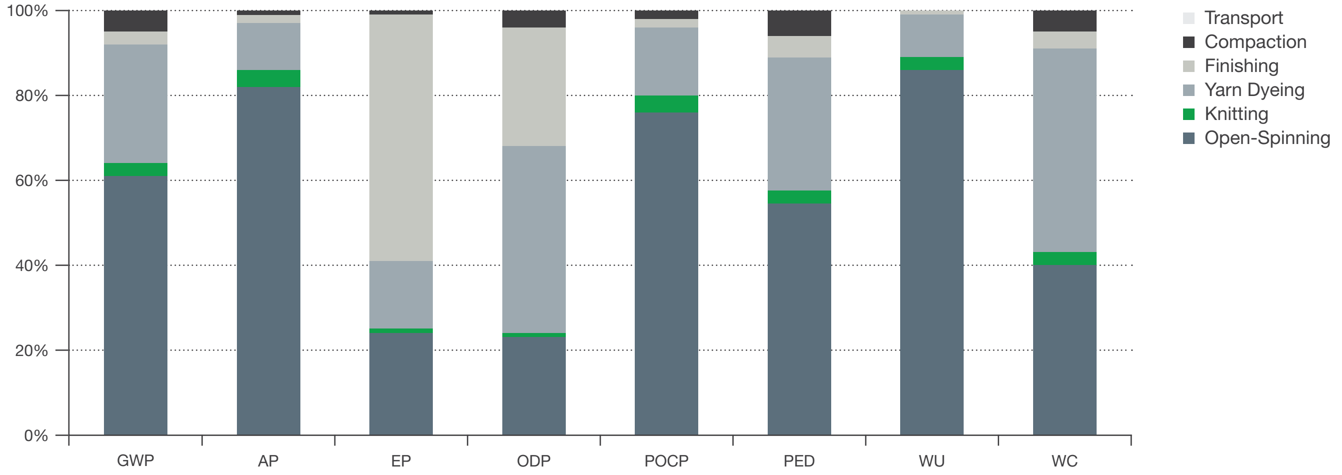
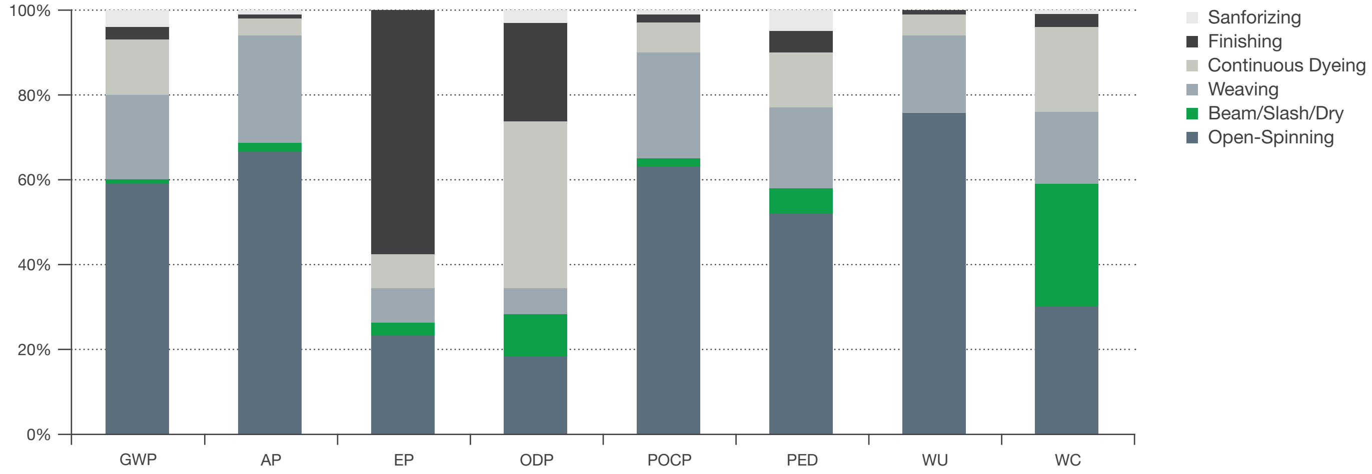


Figure 7

Percent Impact Contribution by Textile Process Step for Woven Fabric



CONSUMER USE PHASE

Although the Consumer Use phase included cut-and-sew and end-of-life, these components produced negligible impacts to the use phase. Therefore, attention was focused on consumer care choices. Since the energy and water used to launder garments over their life can be an important contributor to life cycle impacts, Consumer Use phase impacts were modeled using three Use phase scenarios: best case, average, and worst case. The average use case was created by converting consumer behavior into a statistical average of reported behavior. These consumer use scenarios are described in Table 5. An example of the format of the results for this portion of the study is shown in Figure 8. As might be expected, energy demand is highly influenced by laundering behavior.

Table 5

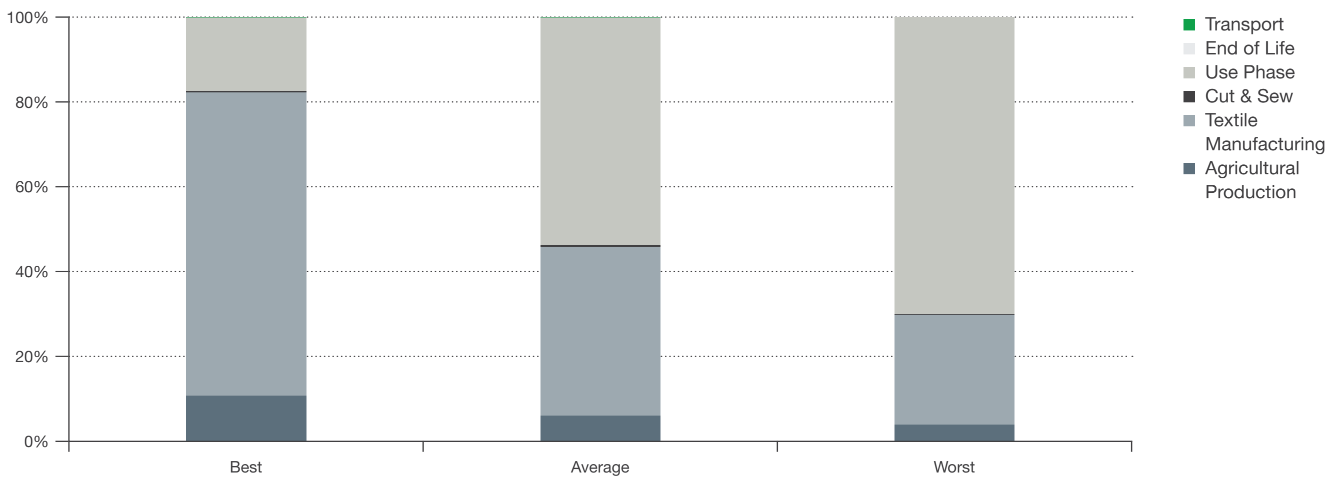
Consumer Use Scenarios

	Use Phase	Best Case	Average (Knit)[1]	Average (Woven)[1]	Worst Case
Washing	Wash Temperature	Cold Wash	54% Cold, 46% Heated	52% Cold, 48% Heated	Heated Wash
Washing	Load Size	Extra Large	5% Small, 84% Medium, 11% XL	3% Small, 86% Medium, 11% XL	Small
Washing	Washer Efficiency	Energy Star	70% Conv. 30% Energy Star	70% Conv. 30% Energy Star	Conventional
Washing	Water Heater Type	Natural Gas	50% Elec 50% Nat Gas	50% Elec 50% Nat Gas	Electric
Drying	Drying Method	Air Dry	16% Air Dry 84% Dryer	17% Air Dry 83% Dryer	Electric Dryer
Drying	Dryer Efficiency	n/a2	70% Conv. 30% Energy Star[3]	70% Conv. 30% Energy Star[3]	Conventional

[1] Percentage of consumers who use the practice indicated for either a knit shirt or woven pant.
[2] Intentionally left blank because the “best case” would be air drying with no dryer efficiency.
[3] Hypothetical High Energy (HE) dryer used with an HE washer.
Takes into consideration effects of washer on other parameters (i.e. lower residual moisture content).

Figure 8

Relative Contribution to Energy Demand [MJ] of 1000 kg Batch-dyed Knit Fabric for Each Life Cycle Phase by Consumer Use Scenario



TOXICITY POTENTIAL

Two additional impact categories, Ecotoxicity Potential (ETP) and Human Toxicity Potential (HTP) were included in the LCA to evaluate the potential toxic impacts of chemical compounds used during the life cycle of a cotton product. The UNEP-SETAC USEtox® characterization model was used for both ETP and HTP modeling (Rosenbaum, 2008). Results show that over the entire cradle-to-grave life cycle of cotton, nearly all of ETP is associated with pesticide application during the Agricultural Production phase. It should be noted that the precision of the current USEtox® characterization factors is less robust than all other impact categories. For example, toxicity impacts can be caused by numerous embedded substances and emissions. The number of "elementary flows" (substances) related to toxicity can range from 1,000 to 10,000, and the variation in toxic impact of those substances can vary by orders of magnitude. In addition, emission profiles for some of the substances may be incomplete. In contrast, non-toxicity related impact categories such as energy or GWP are comprised of fewer embedded substances (10–500). Therefore, the uncertainties for toxicity assessment are greater than for other impact categories since there are many more substances to study and model. For this reason, the USEtox® characterization factors were used in this study only as a means to identify the key contributors within a product life cycle that significantly influence the product's toxicity potential. Materials were noted as 'substances of high concern' but comparative assertions across products or across impact categories were not made. Additional studies are currently underway to assess the accuracy of the USEtox® parameters for agriculture.

NEXT STEPS

The value of this study lies primarily in the LCI data, as existing cotton LCI data was obsolete, and the data sources, in some cases, cannot be verified.

By undertaking this study the cotton industry has a clear understanding of the data sources, as well as the data gaps, and now has a solid foundation upon which to further build the dataset. Impact assessment results, although important, should be regarded as a snapshot based on the data for the years of 2005–2010, and are not only subject to interpretation but will change as the LCI expands. However, at this point, the following next steps have been identified as most critical:

- → Continue to conduct research to improve cotton's water and nitrogen use efficiencies.
- → Work with mills to measure energy demand and water use of alternative spinning and wet processing technologies, which will identify opportunities for further reductions in the burdens associated with textile manufacturing.
- → Continue to support wastewater reduction research.
- → Educate and engage with consumers to significantly reduce the impacts at the use phase level.

REFERENCES

FAO. 2011. AQUASTAT: FAO's Information System on Water and Agriculture. Food and Agricultural Organization of the United Nations. http://www.fao.org/nr/water/aquastat/water_use/index.stm

GaBi 4. 2006. Software and Databases for Life-Cycle-Assessment and Life-Cycle-Engineering, LBP University of Stuttgart and PE INTERNATIONAL GmbH, Leinfelden-Echterdingen.

GaBi 5. 2011. Software and Databases for Life-Cycle-Assessment and Life-Cycle-Engineering, LBP University of Stuttgart and PE INTERNATIONAL GmbH, Leinfelden-Echterdingen.

International Organization for Standardization (ISO). 2006. ISO 14040 series: Environmental Management—Life Cycle Assessment.

International Textile Manufacturers Federation (ITMF). 2009. International Textile Machinery Shipment Statistics. Vol 32.

Rosenbaum et al. (2008). USEtox—the UNEP-SETAC toxicity model: recommended characterization factors for Human Toxicity and freshwater Ecotoxicity in life cycle impact assessment, *International Journal of Life Cycle Assessment*, Retrieved October 6, 2010 at: http://potency.berkeley.edu/pdfs/Setac.pdf

United States Department of Agriculture (USDA). 2011. Official USDA estimates, Retrieved from http://www.fas.usda.gov/psdonline/psdQuery.aspx.

APPENDIX

Tables A1 to A3 represent cotton LCA data resulting from a software upgrade of GaBi version 4 to GaBi version 5 and are current as of 30 March 2012. All of the agricultural and textile data are meant to reflect global average impacts for cotton fiber (Table A1), a knit fabric suitable for a typical golf shirt (Table A2), and woven fabric suitable for a typical casual pant (Table A3). These data should be useful as a benchmark against which product-specific LCI data can be compared; however, in many cases, the actual values for a specific garment construction may vary by more than 50% due to factors such as fiber condition, thread count, and textile mill efficiencies. As noted within the body of this report, the data for the Consumer Use phase of this study are limited to the United States.

Further, note that in all three tables, a Global Warming credit was applied to the Agricultural Production phase but then added back to the Consumer Use phase to account for carbon captured by the fiber and released back into the atmosphere at the end of garment life. Cotton fiber is approximately 42% carbon, thus there are 1540 kg CO2-Equiv. stored in 1000 kg of fiber.

Table A1

Impact Totals for Production of 1000 kg of fiber.

Measure (all per 1000 kg of fiber)	Agricultural Production
Acidification [kg SO2-Equiv.]	18.7
Eutrophication [kg phosphate-Equiv.]	3.84
Global Warming [kg CO2-Equiv.]	268
Ozone Depletion [kg R11-Equiv.]	7.6E-06
Smog Creation [kg Ethene-Equiv.]	0.408
Energy Demand [MJ]	15,000
Water Consumption [m3]	2,120
Water Use [m3]	2,740

Table A2

Impact Total per Life Cycle Phase for a Knit Shirt (Average U.S. Consumer)

Measure (all per 1000 kg of fabric)	Agricultural Production[1]	Textile Manufacturing	Consumer Use	Total
Acidification [kg SO_2-Equiv.]	21.3	61.4	38.3	121
Eutrophication [kg phosphate-Equiv.]	4.4	12.6	6.8	23.8
Global Warming [kg CO_2-Equiv.]	305	9070	14,025	23,400
Ozone Depletion [kg R11-Equiv.]	8.66E-06	2.66E-05	2.21E-04	2.56E-04
Smog Creation [kg Ethene-Equiv.]	0.46	3.6	2.85	6.91
Energy Demand [MJ]	17,000	114,000	155,000	286,000
Water Consumption [m^3]	2,410	49.4	694	3,160
Water Use [m^3]	3,120	16,141	6150	25,500

[1] Note agricultural data reflects the cotton needed to produce 1000 kg of fabric. 1133 kg of fiber was required to produce 1000 kg of knit fabric due to processing losses based on data collected in this study.

Table A3

Impact Total per Life Cycle Phase for a Woven Pant (Average U.S. Consumer)

Measure (all per 1000 kg of fabric)	Agricultural Production[2]	Textile Manufacturing	Consumer Use	Total
Acidification [kg SO^2-Equiv.]	20.4	72.04	57.36	150
Eutrophication [kg phosphate-Equiv.]	4.19	12.60	9.97	26.8
Global Warming [kg CO_2-Equiv.]	293	8,760	20,131	29,200
Ozone Depletion [kg R11-Equiv.]	8.30E-06	3.07E-05	3.21E-04	3.60E-04
Smog Creation [kg Ethene-Equiv.]	0.45	4.06	4.26	8.77
Energy Demand [MJ]	16,300	109,743	230,974	357,000
Water Consumption [m^3]	2,310	67	1,000	3,380
Water Use [m^3]	3,000	17,496	9,118	29,600

[1] Note agricultural data reflects the cotton fiber needed to produce 1000 kg of fabric. 1086 kg of fiber is needed to produce a woven fabric due to processing losses based on data collected in this study.

Additional information on The Life Cycle Inventory & Life Cycle Assessment o f Cotton Fiber & Fabric can be found in an Executive Summary, available at **http://cottontoday.cottoninc.com**.

The Life Cycle Inventory & Life Cycle Assessment of Cotton Fiber & Fabric is a facet of the VISION 21 Project of The Cotton Foundation, and managed by the Cotton Board, Cotton Incorporated and Cotton Council International.

For more information, contact James Pruden at **jpruden@cottoninc.com**.

The Cotton Foundation | National Cotton Council of America
Cotton Incorporated | Cotton Council International

Cotton Incorporated