



Life cycle assessment of United States *cotton* fiber production



Cotton Incorporated | May 2026 | Conducted by WSP

OVERVIEW

Cotton Incorporated commissioned WSP USA Inc. (WSP) to conduct the most comprehensive, data-driven life cycle assessment (LCA) of U.S. cotton fiber production conducted to date. The study evaluates the cradle-to-gate environmental impacts of Upland cotton fiber — from seed in the ground to the ginned bale — using primary data collected directly from U.S. cotton growers across all major producing regions. The study was conducted in accordance with International Organization for Standardization standards ISO 14040, ISO 14044, and ISO 14071, and underwent critical review by an independent three-person expert panel.

This LCA study focused exclusively on U.S. cotton fiber production. Its findings will inform internal research priorities, support external stakeholders across the cotton value chain and provide updated life cycle inventory (LCI) data for use in sustainability tools and databases. Results are not intended for direct comparison to other LCA studies, as differences in system boundaries, allocation methods and background datasets make such comparisons methodologically inappropriate.

SCOPE AND METHODOLOGY

Functional Unit: 1 kilogram of cotton fiber packaged in bales at the ginning gate (6%–7.5% moisture content).

System Boundary: Cradle to gate — encompassing raw material extraction, on-farm production, field-to-gin transportation and ginning operations.

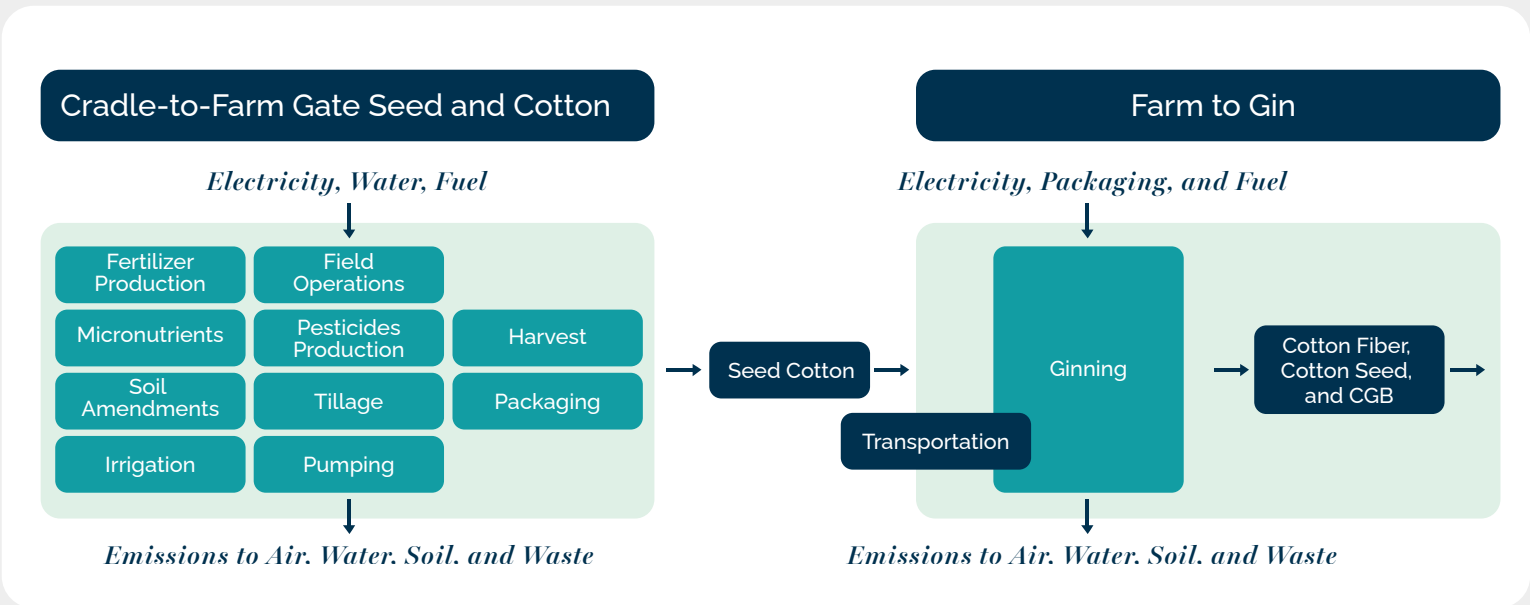







Figure 1. The system boundaries of the cotton production system

Primary Data Source: This is the most comprehensive and data-driven LCA of U.S. cotton fiber production conducted to date — built on primary data from real farms, reviewed by independent experts, and conducted to international standards. The 2023 Cotton Growers' Natural Resource Survey (NRS), developed by Cotton Incorporated, collected 2021/22 crop year data from 753 cotton growers across 17 states — representing approximately 9.2% of U.S. cotton acreage. Survey data were aggregated into four production regions: Far West, Southwest, Midsouth and Southeast.

Secondary Data: Sourced from USDA National Agricultural Statistics Service (NASS), the U.S. Geological Survey, IPCC national greenhouse gas (GHG) inventory guidelines, and the LCA for Experts (LCA FE) database.

Allocation: Economic allocation was applied as the baseline method, attributing 83% of impacts to cotton fiber and 17% to cottonseed. Mass, biophysical and cereal unit allocation methods were assessed in sensitivity analyses.

Impact Categories Assessed: Global warming potential (GWP), primary energy demand (PED), blue water use (BWU), blue water consumption (BWC), water scarcity (Available Water Remaining, or AWARE), abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), ozone depletion potential (ODP), photochemical ozone creation potential (POCP), human health particulate air (HHPA), land occupation (LO) and toxicity metrics.

 753 U.S. growers surveyed	 17 states 4 producing regions	 ~9.2% of U.S. cotton acreage	 ISO 14040/44 conformant methodology	 3-expert panel independent review
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KEY FINDINGS

Climate Impact: *Biogenic Carbon Dioxide Changes the Picture*

Producing 1 kg of U.S. cotton fiber generates 1.45 kg of fossil CO₂ equivalent emissions (GWP, excluding biogenic carbon dioxide). However, cotton's natural fiber composition creates biogenic carbon dioxide storage — a distinction that separates it from petroleum-based synthetic fibers.

When accounting for carbon stored in both soil (via changes in farming practices, including reduced tillage and manure application) and the cotton fiber itself, cotton production removes approximately 1.71 kg CO₂e per kilogram of fiber, resulting in a net cradle-to-gate emissions of -0.264 kg CO₂e per kilogram of fiber when temporary storage in the fiber is included.

GWP Waterfall: Fossil Emissions to Net Carbon Balance (kg CO₂e/kg fiber)

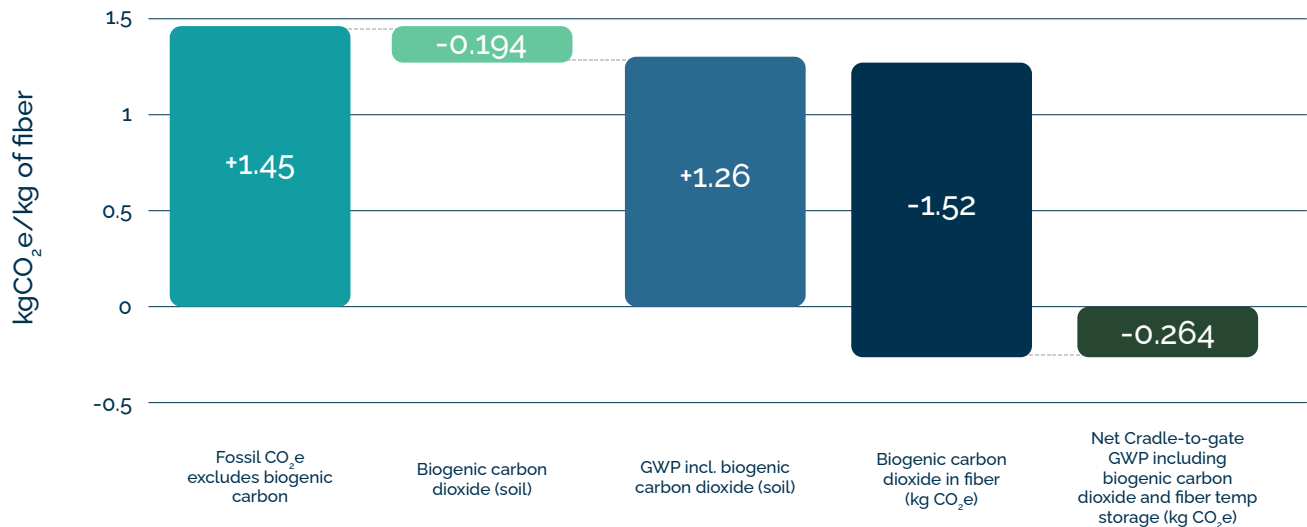


Figure 2. GWP (IPCC AR6 GWP 100), including biogenic carbon dioxide, including and excluding temporary storage of fiber (kg CO₂e per kg of cotton fiber)

Contribution Analysis: *Where Impacts Originate*

Across nearly all impact categories, field emissions and fertilizer production emerged as the primary drivers of environmental impact, while irrigation dominated all water-related categories, accounting for 84% of blue water use (1,480 liters/kg cotton). Importantly, 64% of U.S. cotton is grown without irrigation, and adoption of efficient practices has continued to increase since 2015.^{1,2,3}

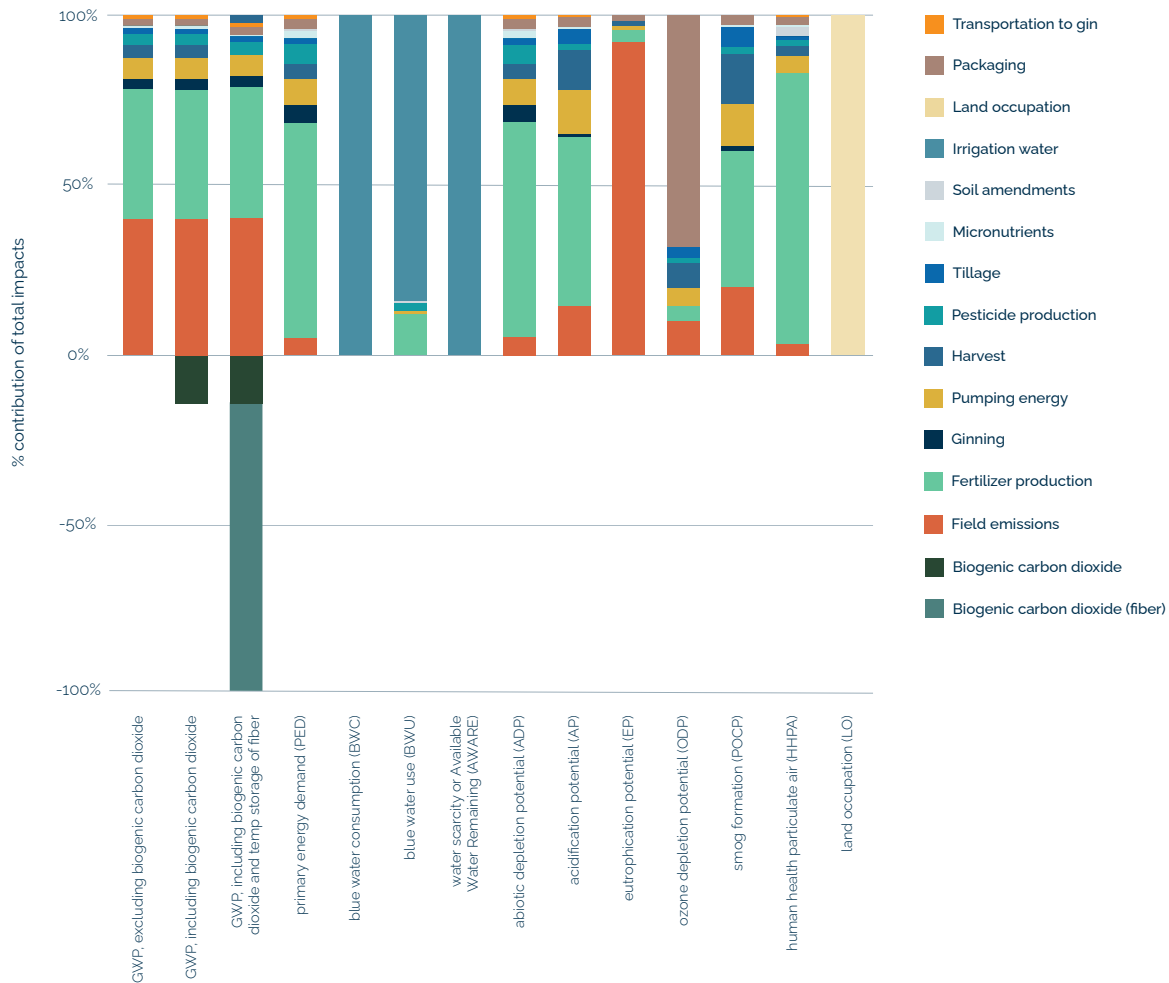


Figure 3. Contribution analysis for U.S. cotton fiber production

SENSITIVITY AND UNCERTAINTY ANALYSIS

Sensitivity analyses demonstrated that methodological choices substantially affect LCA results. Compared to the baseline economic allocation method, mass allocation reduced impacts by 53%, biophysical allocation by 58%, and cereal unit allocation by 24%. These variations underscore that the presented results reflect the most conservative, worst-case scenario regarding allocation methods.

Additionally, the choice of background datasets significantly influenced results; GHG emissions increased by 34% when switching from LCA FE to ecoinvent datasets, primarily due to differences in electricity and fertilizer emission factors.

This highlights the importance of transparent methodological documentation to ensure accurate interpretation and prevent inappropriate comparisons between studies.

The uncertainty analysis showed that baseline results are statistically robust, with relative standard deviations ranging from approximately ±5% to ±20% across impact categories. This supports confidence in the overall findings despite the acknowledged data limitations associated with survey-based primary data collection.

For results coming from the sensitivity analysis, see the full LCA report at cottontoday.com/LCA.

¹ United States Department of Agriculture National Agricultural Statistics Service (2023). 2023 Irrigation and Water Management Survey. https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/Farm_and_Ranch_Irrigation_Survey/iwms.pdf

² Barnes et al. (2020). Forty Years of Increasing Cotton's Water Productivity and Why the Trend Will Continue. American Society of Agricultural and Biological Engineers. <https://elibrary.asabe.org/abstract.asp?aid=51675>

³ Jalota, S. K., Sood, A., Vitale, J. D., & Srinivasan, R. (2007). Simulated crop yields response to irrigation water and economic analysis: Increasing irrigated water use efficiency in the Indian Punjab. *Agronomy Journal*, 99(4), 1073–1084. <https://doi.org/10.2134/agronj2006.0054>

LIMITATIONS

The interpretation of results is subject to several limitations:

- Potential inaccuracies from grower-reported data and reliance on secondary modeling for inputs such as irrigation energy and farm fuel consumption.
- The exclusive focus on environmental impacts without evaluating social or economic dimensions limits comprehensive sustainability assessment.
- Variability in methodological approaches, particularly in allocation methods and background dataset choices, complicates direct comparisons with other LCAs.
- Plastic leakage and pollution were not assessed due to ongoing methodological development in these areas.

RECOMMENDATIONS AND PATH FORWARD

To improve future LCA studies and the environmental sustainability of cotton production, the following actions are recommended:

1. Enhance primary data collection, especially detailed data on nitrous oxide emissions from fertilizer application, specific fertilizer types, and precise on-farm fuel consumption.
2. Promote region-specific precision agriculture practices such as optimized nutrient application, irrigation management, and regular soil testing to reduce environmental impacts and improve resource use efficiency.
3. Support the wider adoption of conservation agricultural practices, including reduced or no-till farming and cover cropping, to improve soil health, enhance water retention, and reduce erosion.
4. Improve irrigation efficiency by upgrading pumping systems and, over the longer term, transition toward renewable energy sources to further reduce greenhouse gas emissions associated with irrigation water utilization.
5. Encourage the development and use of lower-impact fertilizers (green⁴ and blue fertilizers⁵) to decrease the environmental footprint associated with fertilizer production.

CONCLUSION

This study represents the most comprehensive and data-driven evaluation of U.S. cotton fiber production conducted to date. Drawing on primary data from 753 cotton growers across 17 states, it provides a rigorous, ISO-conformant baseline for tracking continuous improvement in cotton's environmental performance.

The findings demonstrate that U.S. cotton production — when biogenic carbon dioxide flows are fully accounted for — achieves a net negative cradle-to-gate carbon footprint of -0.264 kg CO₂e per kilogram of fiber. This result reflects not only the carbon sequestration potential of agricultural land managed by U.S. cotton growers, but also the meaningful climate benefit of temporarily storing biogenic carbon in the fiber itself. Although biogenic carbon storage may not be permanent, a portion of this carbon can remain sequestered long-term, and opportunities exist to enhance cotton circularity and further improve the permanence of this storage.

Fertilizer production and field emissions remain the primary environmental hotspots across most impact categories, while irrigation drives water-related impacts. These findings provide clear, science-based direction for research investment and grower outreach.

As precision agriculture practices advance, as data quality improves and as lower-impact inputs become more widely available, U.S. cotton is positioned to further reduce its environmental footprint — strengthening its role as a credible, science-backed natural fiber choice for brands, retailers and consumers seeking textiles made with sustainability in mind.



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⁴ Green fertilizers are nitrogen fertilizers produced from green ammonia, where hydrogen is made using renewable-powered electrolysis, resulting in low-carbon nitrogen inputs (RMI, 2023).

⁵ Blue fertilizers are nitrogen fertilizers produced from blue ammonia, where hydrogen is derived from natural gas but the resulting CO₂ emissions are captured and stored through CCS, lowering the carbon footprint relative to conventional production (Wood Group, 2021).