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Product Carbon Footprint Analysis Report

Product: Nitrocellulose

Protocol Data (Accounting Standard): **GHG Protocol**

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This report is generated based on available data and industry standards, providing an estimate of the Product Carbon Footprint. Actual results may vary with primary data availability and specific operational details.

Generated Date: September 8, 2026

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Executive Summary

This report presents a high-detail Product Carbon Footprint (PCF) analysis for Nitrocellulose, conducted by Senior Sustainability Consultant Arno, adhering strictly to the Greenhouse Gas (GHG) Protocol. The analysis covers a "factory-gate" system boundary for a functional unit of 1.0 unit of Nitrocellulose, with final production in Brazil and a supply chain focus on Asia. Key updates from the 2026 GHG Protocol Land Sector and Removals (LSR) Standard and the 95% Scope 3 coverage requirement have been integrated. The study meticulously maps the lifecycle, identifies primary material and energy inputs, calculates emissions across Scope 1, 2, and 3 categories using industry-standard emission factors, and highlights key carbon hotspots and data reliability considerations. The primary hotspots are identified within the upstream supply chain, particularly the production of key chemical raw materials.

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1. Scope Definition

This section defines the fundamental parameters for the Product Carbon Footprint (PCF) analysis of Nitrocellulose, ensuring clarity and consistency with the GHG Protocol.

1.1 Functional Unit

The functional unit for this PCF analysis is defined as **1.0 unit of Nitrocellulose**. This unit serves as the reference basis to which all input and output flows, and thus all environmental impacts, are related.

1.2 System Boundary: Factory-Gate

The system boundary for this assessment is "factory-gate" (cradle-to-gate). This encompasses all lifecycle stages from the extraction and processing of raw materials, through their transportation to the manufacturing facility, and all processes occurring at the manufacturing facility up to the point where the finished Nitrocellulose product leaves the factory gate. This includes:

- Raw material acquisition and pre-processing (e.g., cellulose pulp production, nitric acid, sulfuric acid manufacturing).
- Transportation of raw materials and intermediate products to the Nitrocellulose production facility.
- Manufacturing processes at the Nitrocellulose plant, including energy consumption, process emissions, and waste generation.

The following stages are explicitly excluded from this "factory-gate" boundary:

- Product distribution to the customer.
- The use phase of the Nitrocellulose product.
- End-of-life treatment or disposal of the product.

1.3 Geographic Scope

- **Final Production Country: Brazil** - Direct emissions (Scope 1) and purchased electricity emissions (Scope 2) are based on the energy mix and operational specifics of a manufacturing facility located in Brazil.
- **Supply Chain Focus: Asia Focused** - Upstream raw material production (e.g., cellulose, nitric acid, sulfuric acid) and associated transportation are modeled primarily considering sourcing from Asian regions, reflecting common global supply chains for these commodities.

1.4 Accounting Standard

This Product Carbon Footprint analysis strictly adheres to the principles and requirements of the **GHG Protocol**, specifically the Corporate Value Chain (Scope 3) Accounting and Reporting Standard. This includes compliance with anticipated 2026 updates, such as the [Land Sector and Removals (LSR) Standard] for land-related emissions and removals, and the enhanced requirements for Scope 3 completeness and data quality.

1.5 Allocation

Where co-products or by-products are generated within the system boundary, mass-based allocation is applied in accordance with GHG Protocol guidelines. This approach attributes environmental burdens proportionally to the mass of each co-product, ensuring a fair distribution of impacts.

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2. Lifecycle Mapping & 3. Data Collection

These two steps are presented together as the identification of lifecycle stages (mapping) directly informs the data required (collection). Nitrocellulose, also known as cellulose nitrate, is a highly flammable compound produced by nitrating cellulose with a mixture of nitric acid and sulfuric acid. The production process involves several critical stages, each contributing to the overall carbon footprint.

2.1 Nitrocellulose Production Process Overview

The manufacturing of Nitrocellulose fundamentally involves the esterification of cellulose fibers with a strong acid mixture. Key stages typically include:

1. **Cellulose Preparation:** Purification of raw cellulose (e.g., wood pulp or cotton linters) is crucial, as impurities can reduce the quality of the final product.
2. **Acid Mixture Preparation:** Nitric acid provides the nitrate groups, while sulfuric acid acts as a dehydrating agent, absorbing water produced during the nitration reaction and promoting the reaction\'s efficiency.
3. **Nitration:** Cellulose fibers are immersed in the mixed acid, leading to the replacement of hydroxyl (-OH) groups with nitrate

($-ONO_2$) groups. The degree of nitration determines the properties and applications of the Nitrocellulose.

4. **Washing and Stabilization:** After nitration, the product undergoes extensive washing to remove residual acids and impurities. This is vital for safety, preventing self-decomposition, and ensuring product stability. Boiling in water is often employed for thorough cleansing.
5. **Dehydration and Blending:** Excess water is removed, often through mechanical means, and the nitrocellulose may be blended or densified for specific applications.

2.2 Detailed Material Inputs (Supply Chain Focus: Asia)

The following materials are key inputs for Nitrocellulose production, with a significant portion of their upstream lifecycle impacts attributed to Asian supply chains, as specified in the geographic scope:

- **Cellulose (Wood Pulp):** The primary raw material. Given the Asia-focused supply chain, sourcing from major pulp-producing regions in Asia is assumed. Purity is paramount for the final product quality.
    - **Typical Inputs for Wood Pulp Production:** Wood (forestry, harvesting, debarking), chemicals (e.g., caustic soda, chlorine dioxide for pulping and bleaching), water, energy (electricity, steam).
- **Nitric Acid (HNO_3):** A critical reactant. Its production is energy and resource-intensive.
    - **Typical Inputs for Nitric Acid Production:** Anhydrous ammonia (produced from natural gas via Haber-Bosch process), air, water, significant energy (electricity, steam for heating/cooling).
- **Sulfuric Acid (H_2SO_4):** Used as a dehydrating agent. Its production is also significant.
    - **Typical Inputs for Sulfuric Acid Production:** Sulfur (often from crude oil/natural gas desulfurization), water, air, energy (electricity, steam). The process generates SO_2 and SO_3 emissions.

- **Water:** Used extensively for reaction, washing, cooling, and steam generation. While the final production is in Brazil, the upstream water treatment for raw material production in Asia is considered.
- **Other Process Chemicals:** Includes smaller quantities of chemicals for pH adjustment, stabilization, or effluent treatment (e.g., caustic soda).

2.3 Detailed Energy Inputs (Final Production Country: Brazil)

Energy consumption at the Nitrocellulose manufacturing facility in Brazil is a critical input.

- **Electricity:** Used for pumps, mixers, centrifuges, cooling systems, lighting, and general facility operations. Brazil\'s electricity grid mix is predominantly hydroelectric, making it relatively low-carbon compared to fossil-fuel-intensive grids, but still includes thermal sources.
- **Heat/Steam:** Required for various heating processes, including the washing and stabilization stages. This is typically generated on-site, often through the combustion of fossil fuels such as natural gas.

2.4 Waste Outputs

Waste streams generated at the factory gate typically include:

- **Wastewater:** Effluent from washing and other processes, requiring treatment before discharge.
- **Spent Acids:** Residual acid mixtures from the nitration process, often recovered or treated.

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4. Emission Calculation

The calculation of Greenhouse Gas (GHG) emissions follows the GHG Protocol methodology, quantifying emissions across Scope 1, Scope 2, and Scope 3 categories. Emissions are calculated using the formula: Activity Data × Emission Factor = CO_2e. Industry-standard emission factors, primarily sourced from Ecoinvent and other credible databases like DEFRA, are applied, considering the specific geographic scope and supply chain focus.

4.1 GHG Protocol Scopes Categorization

- **Scope 1: Direct Emissions**

  Emissions from sources directly owned or controlled by the reporting company at the Brazilian production facility.

  - On-site combustion of natural gas for heat and steam generation.
  - Minor process emissions from the nitration reaction (if not fully captured or recycled).
- **Scope 2: Purchased Energy Emissions**

  Indirect emissions from the generation of purchased electricity consumed by the reporting company at the Brazilian production facility.

  - Electricity drawn from the Brazilian national grid, reflecting its specific generation mix (predominantly hydroelectric, with some thermal contribution).
- **Scope 3: Value Chain (Indirect) Emissions**

  All other indirect emissions that occur in the value chain of the reporting company, both upstream and downstream. Given the "factory-gate" boundary, the focus is on upstream Scope 3 categories.

  - **Category 1: Purchased goods and services** - Emissions from the extraction, production, and transportation of all raw materials (cellulose, nitric acid, sulfuric acid, other chemicals) purchased by the company. This is anticipated to be the largest Scope 3 category, reflecting the Asia-focused supply chain.
  - **Category 4: Upstream transportation and distribution** - Emissions from the transportation of raw materials and intermediate products from suppliers (primarily in Asia) to the Nitrocellulose production facility in Brazil.

- **Category 5: Waste generated in operations** - Emissions from the disposal and treatment of operational waste, including spent acids and wastewater.
- Other relevant upstream categories may include capital goods and fuel- and energy-related activities not included in Scope 1 or Scope 2.

4.2 2026 Land Sector and Removals (LSR) Standard Update

The GHG Protocol\'s Land Sector and Removals (LSR) Standard, finalized on January 30, 2026, and effective January 1, 2027, provides comprehensive guidance for accounting and reporting GHG emissions and CO_2 removals from land-based activities. For this PCF, the LSR Standard is applied to capture emissions and potential removals associated with the upstream production of cellulose (wood pulp). This includes emissions from land use change (LUC), land management practices, and the biogenic carbon stored in harvested wood products. While calculation guidance is still being developed (expected mid-2026), the principles of the LSR Standard are integrated to ensure traceability and appropriate accounting for biogenic carbon flows, especially given the agricultural or forestry origin of cellulose.

4.3 Scope 3 Compliance: 95% Coverage

In line with the proposed 2026 GHG Protocol updates for Scope 3 reporting, this analysis aims to ensure at least **95% coverage** of total relevant Scope 3 emissions to claim conformance. This rigorous approach prevents selective disclosure and emphasizes a comprehensive assessment of the value chain. Furthermore, data quality is prioritized, with an emphasis on disaggregating data by source type (primary, hybrid, activity-based, or spend-based) to enhance transparency and comparability. In this report, secondary data from databases is predominantly used, serving as a foundation for a robust estimate in the absence of primary supplier-specific data.

4.4 Illustrative Emission Factors and Sample Calculation

For illustration purposes, representative emission factors (EFs) are adopted from Ecoinvent v3.8 / v3.10 and other recognized sources. Actual Ecoinvent datasets are often premium or region-specific, so these values serve as plausible estimates based on available public information.

Illustrative Emission Factors:

- **Cellulose (Wood Pulp, Asia):** Approx. 0.5 - 1.0 kg CO_2e/kg. (Range based on general pulp production, e.g., similar to cellulose fibre production from waste paper).
- **Nitric Acid (70%, Asia):** Approx. 4.62 kg CO_2e/kg.
- **Sulfuric Acid (98%, Asia):** Approx. 0.3 - 0.6 kg CO_2e/kg. (Range based on sulfuric acid production, depending on source of sulfur).
- **Electricity (Brazil Grid Mix, Average):** Approx. 0.06 - 0.15 kg CO_2e/kWh. (Brazil\'s grid is lower carbon due to hydro, but includes thermal components).
- **Natural Gas (for heat/steam):** Approx. 0.2 kg CO_2e/MJ (or ~2.3 kg CO_2e/m^3).
- **Water (Treated, Global Average):** Approx. 0.0005 - 0.001 kg CO_2e/kg (or m^3).
- **Wastewater Treatment (Average):** Approx. 0.1 - 0.3 kg CO_2e/m^3.

Sample Calculation Table for 1.0 unit of Nitrocellulose (Illustrative Inputs)

Assuming typical mass ratios for nitrocellulose production (e.g., approximately 0.69 tons of cellulose, 0.75 tons of nitric acid, and 0.07 tons of sulfuric acid for 1 ton of nitrocellulose). Let\'s assume the "unit" is 1 kg of Nitrocellulose for this example.

Lifecycle Stage / Input	Activity Data (per 1 kg NC)	Emission Factor (Illustrative)	Total CO_2e (kg)	GHG Scope
Upstream (Scope 3)				
Cellulose (Wood Pulp) Production (Asia)	0.69 kg	0.8 kg CO_2e/kg	0.552	Scope 3, Cat 1
Nitric Acid Production (Asia)	0.75 kg	4.62 kg CO_2e/kg	3.465	Scope 3, Cat 1
Sulfuric Acid Production (Asia)	0.07 kg	0.4 kg CO_2e/kg	0.028	Scope 3, Cat 1
Water (Upstream for material production)	10 kg (example)	0.0008 kg CO_2e/kg	0.008	Scope 3, Cat 1
Transportation of Raw Materials (Asia to Brazil)	(e.g., 1.51 kg materials * 10,000 km ocean freight)	(e.g., 0.00001 kg CO_2e/kg·km)	0.151	Scope 3, Cat 4
Manufacturing (Brazil)				
Electricity Consumption	0.5 kWh	0.1 kg CO_2e/kWh (Brazil average)	0.050	Scope 2
Natural Gas Combustion (for heat/steam)	0.1 MJ	0.2 kg CO_2e/MJ	0.020	Scope 1
Process Emissions (Minor, e.g. fugitive)	N/A (direct est.)	N/A	0.005	Scope 1
Wastewater Treatment	0.8 kg	0.2 kg CO_2e/m^3 (assuming water density 1kg/L)	0.160	Scope 3, Cat 5
Total Estimated PCF per 1 kg Nitrocellulose:			**4.439 kg CO_2e**	

Note: These values are illustrative and based on generic factors. A precise PCF would require specific primary data from suppliers, detailed process data, and region-specific, up-to-date Ecoinvent or DEFRA datasets.

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5. Review & Report

This section provides an interpretation of the calculated emissions, identifies key hotspots, and discusses the reliability of the assessment.

5.1 Carbon Hotspots

Based on the illustrative calculation, the primary carbon hotspots for Nitrocellulose production within a factory-gate boundary, with an Asia-focused supply chain for raw materials and Brazilian manufacturing, are:

- **Nitric Acid Production (Scope 3, Category 1):** The production of nitric acid is notably energy and resource-intensive, contributing a substantial portion of the overall footprint. This is a common hotspot for many chemical products.
- **Cellulose Production (Scope 3, Category 1):** While typically less intensive than strong acids, the sourcing and processing of cellulose (wood pulp) still represent a significant upstream impact, particularly when considering land use and land use change as per the LSR Standard.
- **Transportation of Raw Materials (Scope 3, Category 4):** The long-distance transportation of raw materials from Asia to Brazil via ocean freight contributes significantly to upstream emissions.
- **Wastewater Treatment (Scope 3, Category 5):** Emissions from the treatment of industrial wastewater can be considerable, depending on the treatment technologies and energy use.
- **Electricity Consumption (Scope 2):** While Brazil\'s grid is relatively clean due to a high share of hydropower, electricity consumption at the factory remains a notable contributor, and

its footprint could be higher if relying on more carbon-intensive grids.

5.2 Reliability and Limitations

The reliability of this PCF analysis is influenced by the data sources and assumptions made:

- **Data Quality:** This report relies on secondary data from publicly available Ecoinvent versions (e.g., v3.8, v3.10) and other industry sources for emission factors. While these are industry standards, primary, supplier-specific data would significantly enhance the accuracy and robustness of the assessment. The GHG Protocol\'s 2026 updates emphasize mandatory data disaggregation by source type (primary vs. secondary) to improve transparency.
- **Geographic Specificity:** General emission factors for "Asia" and "Brazil" are used where highly specific country-level data was not universally available or accessible within the scope of this simulation. More granular regional data, especially for raw material production in specific Asian countries, would refine the results.
- **LSR Standard Implementation:** While the principles of the 2026 LSR Standard are applied conceptually, the detailed calculation guidance for its full implementation is still forthcoming (expected mid-2026). Future analyses should incorporate this guidance as it becomes available.
- **Allocation Method:** Mass-based allocation is a common and accepted method under the GHG Protocol but may not fully capture specific environmental burdens if economic value or other causal relationships are significantly different from mass.
- **System Boundary:** The "factory-gate" boundary provides a comprehensive view of upstream impacts but deliberately excludes downstream stages (product use, end-of-life) which could be significant depending on the Nitrocellulose\'s application.

5.3 Recommendations for Improvement

To further reduce the PCF of Nitrocellulose and enhance reporting accuracy, the following recommendations are provided:

- **Supplier Engagement:** Work closely with raw material suppliers (especially for nitric acid, sulfuric acid, and cellulose) to collect primary, activity-specific data. This would dramatically improve the accuracy of Scope 3, Category 1 emissions.
- **Optimized Sourcing:** Investigate opportunities for sourcing raw materials from suppliers with lower carbon footprints or from regions with cleaner production mixes, even within the "Asia-focused" scope.
- **Energy Efficiency:** Implement further energy efficiency measures at the Brazilian production facility to reduce electricity and natural gas consumption.
- **Renewable Energy Procurement:** Explore options for purchasing renewable energy directly (e.g., through Power Purchase Agreements) or investing in on-site renewable energy generation to further decarbonize Scope 2 emissions.
- **Waste Minimization and Circularity:** Optimize processes to reduce waste generation (especially spent acids and wastewater) and explore possibilities for recycling or beneficial reuse of these waste streams.
- **Life Cycle Thinking:** While outside the current "factory-gate" scope, consider extending the PCF analysis to include downstream stages in future assessments to gain a holistic understanding of the product\'s total environmental impact.
