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Product Carbon Footprint Analysis Report

Pigment Blue 15:3

Protocol Data (Accounting Standard): GHG Protocol

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Executive Summary

This report presents a high-detail Product Carbon Footprint (PCF) analysis for Pigment Blue 15:3, conducted under the guidance of Arno de Groot, a Senior Sustainability Consultant specializing in GHG Protocol. The analysis adheres to the GHG Protocol Product Standard, with a cradle-to-gate (factory_gate) system boundary for a functional unit of 1.0 unit (kilogram) of Pigment Blue 15:3 produced in India, with an Asia-focused supply chain. This assessment includes direct emissions (Scope 1), indirect emissions from purchased energy (Scope 2), and a comprehensive evaluation of value chain emissions (Scope 3), targeting at least 95% coverage as per 2026 requirements. Furthermore, the analysis considers the implications of the newly introduced 2026 Land Sector and Removals (LSR) Standard. The objective is to identify key emission hotspots across the product\'s lifecycle up to the factory gate and provide a foundational understanding for future emission reduction strategies.

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1. Define Scope

1.1 Functional Unit

The functional unit for this Product Carbon Footprint analysis is **1.0 kilogram (kg) of Pigment Blue 15:3**. This unit serves as the reference flow to which all input and output data are normalized, allowing for a standardized assessment of its environmental performance.

1.2 System Boundary

The defined system boundary is **"Cradle-to-Gate" (factory_gate)**. This encompasses all relevant lifecycle stages from the extraction and processing of raw materials, their transportation to the manufacturing facility, and all manufacturing processes at the production site, up to the point the finished Pigment Blue 15:3 product leaves the factory gate. The use phase and end-of-life stages of the pigment are excluded from this analysis.

1.3 Geographic Scope

The geographic scope specifies the **final production country as India**, with a primary focus on an **Asia-focused supply chain** for raw material sourcing and upstream processes. This geographical context is crucial for selecting appropriate regional emission factors for energy and transportation.

1.4 Accounting Standard

This Product Carbon Footprint analysis strictly adheres to the **GHG Protocol Product Standard**. The GHG Protocol provides a comprehensive global standardized framework for measuring and managing greenhouse gas (GHG) emissions from product value chains, ensuring consistency and comparability.

1.5 Allocation

For any multi-output processes or co-product generation within the defined system boundary, a **mass-based allocation approach** is applied. This method distributes environmental burdens proportionally based on the mass of the primary product (Pigment Blue 15:3) relative to other co-products.

2. Map Lifecycle (LCI Inventory Stages) & 3. Collect Data (Primary/Secondary Data Points)

The production of Pigment Blue 15:3, a beta-form copper phthalocyanine pigment, involves a complex multi-stage chemical synthesis and finishing process. The primary raw materials typically include phthalic anhydride, urea, and a copper source (e.g., copper chloride or sulfate). Catalysts like ammonium molybdate and various organic solvents are also critical inputs. The process generally starts with the synthesis of crude copper phthalocyanine, followed by intricate purification and pigment finishing steps to achieve the desired crystal form and particle size, which are crucial for the pigment\'s performance characteristics like shade, strength, and stability. Finally, the pigment undergoes drying, grinding, and packaging.

Data collection for this analysis relies on a combination of representative secondary data, drawing from recognized life cycle assessment (LCA) databases and publicly available emission factor sources, in lieu of specific primary data for a hypothetical facility. Emission factors from Ecoinvent and DEFRA equivalents, along with region-specific data for India\'s electricity grid, are utilized.

2.1 Detailed Breakdown of Materials and Energy Inputs (Illustrative per 1 kg Pigment Blue 15:3)

2.1.1 Key Raw Materials

The table below provides an illustrative breakdown of the primary raw materials required for producing 1 kg of Pigment Blue 15:3, along with their estimated quantities.

Material Input	Estimated Quantity per 1 kg Pigment Blue 15:3	Primary Use
Phthalic Anhydride	1.0 kg	Key precursor for phthalocyanine ring synthesis.

Material Input	Estimated Quantity per 1 kg Pigment Blue 15:3	Primary Use
Urea	0.5 kg	Nitrogen source for the synthesis reaction.
Copper Chloride (or similar copper salt)	0.3 kg	Source of copper for the central metal ion in phthalocyanine.
Organic Solvents (e.g., Xylene, Trichlorobenzene)	0.1 kg	Reaction medium, purification, pigment finishing (e.g., solvent milling).
Catalysts (e.g., Ammonium Molybdate)	0.01 kg	Facilitate the synthesis reaction.
Water (Process Water)	10.0 kg	Washing, purification, cooling.

2.1.2 Energy Inputs

Energy is consumed throughout the manufacturing process for heating, mixing, grinding, drying, and general facility operations.

Energy Input	Estimated Quantity per 1 kg Pigment Blue 15:3	Primary Use
Electricity (Grid Mix, India)	5.0 kWh	Mechanical processes (mixing, grinding), lighting, general utilities.
Natural Gas	10.0 MJ	Heating for reaction vessels, steam generation for drying.

4. Calculate Emissions (Activity * Emission Factor = CO2e)

Greenhouse gas emissions are calculated by multiplying the activity data (quantities of materials, energy, and transportation) by their respective emission factors (CO2e/unit). Emissions are categorized according to the GHG Protocol into Scope 1, Scope 2, and Scope 3. The 2026 Land Sector and Removals (LSR) Standard is also considered in the context of the supply chain.

4.1 Emission Factors Used

The following industry-standard emission factors (or representative values from recognized databases like Ecoinvent, DEFRA, and CEA for India) have been applied in this analysis:

Activity	**Emission Factor (kg CO2e/unit)**	**Source/Basis**
Phthalic Anhydride Production (Cradle-to-gate)	4.0 kg CO2e/kg	Illustrative, based on generic chemical intermediate data. Climatiq mentions production mix factors but specific values are often behind paywalls.
Urea Production (Cradle-to-gate)	0.73 kg CO2e/kg	Direct CO2 emissions from urea, IPCC default based on carbon content.
Copper Chloride Production (Cradle-to-gate)	5.0 kg CO2e/kg	Illustrative, representing copper chemical production. A deprecated factor for elemental copper was 4.04 kg CO2e/kg.
Organic Solvents Production (e.g., Xylene)	2.5 kg CO2e/kg	Illustrative, based on typical organic solvent production.
Ammonium Molybdate Production	10.0 kg CO2e/kg	Illustrative, for specialized chemical catalysts.
India Grid Electricity	0.727 kg CO2e/kWh	

Activity	Emission Factor (kg CO2e/unit)	Source/Basis
(2023-24 average)		Central Electricity Authority (CEA) for Indian Power Sector (2023-24 weighted average).
Natural Gas Combustion	0.0501 kg CO2e/MJ	Derived from EIA data (52.91 kg CO2 per Million Btu, converted to MJ).
Truck Transport (average, heavy duty)	0.1 kg CO2e/ tkm	Illustrative, based on general transport emission factors (DEFRA equivalents).
Waste Disposal (non-hazardous to landfill)	0.05 kg CO2e/ kg	Illustrative, for inert waste disposal.

4.2 Emissions Breakdown by Scope (Illustrative)

4.2.1 Scope 1 Emissions (Direct Emissions from Owned or Controlled Sources)

For a Pigment Blue 15:3 manufacturing facility in India, direct emissions primarily arise from on-site combustion of natural gas for process heating and steam generation.

- Natural Gas Combustion: 10.0 MJ * 0.0501 kg CO2e/MJ = 0.501 kg CO2e

Total Scope 1 Emissions: 0.501 kg CO2e per 1 kg Pigment Blue 15:3

4.2.2 Scope 2 Emissions (Indirect Emissions from Purchased Energy)

These emissions result from the generation of purchased electricity consumed by the manufacturing facility.

- Purchased Electricity (India Grid): 5.0 kWh * 0.727 kg CO2e/kWh = 3.635 kg CO2e

Total Scope 2 Emissions: 3.635 kg CO2e per 1 kg Pigment Blue 15:3

4.2.3 Scope 3 Emissions (Other Indirect Emissions from the Value Chain)

Scope 3 emissions are typically the most significant category for chemical products and are crucial for comprehensive reporting. This analysis aims for at least 95% coverage as per 2026 requirements, focusing on the most impactful categories for Pigment Blue 15:3.

- **Category 1: Purchased Goods and Services (Raw Materials)**
  - Phthalic Anhydride: 1.0 kg * 4.0 kg CO2e/kg = 4.0 kg CO2e
  - Urea: 0.5 kg * 0.73 kg CO2e/kg = 0.365 kg CO2e
  - Copper Chloride: 0.3 kg * 5.0 kg CO2e/kg = 1.5 kg CO2e
  - Organic Solvents: 0.1 kg * 2.5 kg CO2e/kg = 0.25 kg CO2e
  - Ammonium Molybdate: 0.01 kg * 10.0 kg CO2e/kg = 0.1 kg CO2e
- **Category 4: Upstream Transportation and Distribution (Raw Materials)**
  - Assumed average transport of 2.0 kg total raw materials over 500 km by truck: (2.0 kg / 1000 kg/tonne) * 500 km * 0.1 kg CO2e/tkm = 0.1 kg CO2e
- **Category 5: Waste Generated in Operations**
  - Process waste (non-hazardous to landfill): 0.1 kg * 0.05 kg CO2e/kg = 0.005 kg CO2e
- **Other minor Scope 3 categories** (e.g., capital goods, business travel, employee commuting) are acknowledged but assumed to be comparatively negligible within this "factory_gate" boundary and relative to the main material and energy flows, contributing to the >95% coverage target through the comprehensive inclusion of primary inputs.

Total Scope 3 Emissions: 4.0 + 0.365 + 1.5 + 0.25 + 0.1 + 0.1 + 0.005 = 6.32 kg CO2e per 1 kg Pigment Blue 15:3

4.2.4 Application of the 2026 Land Sector and Removals (LSR) Standard

The GHG Protocol\'s Land Sector and Removals (LSR) Standard, effective January 1, 2027, provides comprehensive guidance for accounting for emissions and removals from land use and land use change. For a synthetic pigment like Pigment Blue 15:3, direct land-use change at the manufacturing site is generally not a significant contributor to its carbon footprint. However, the LSR Standard is relevant for upstream raw material extraction. For instance, the production of copper (for copper chloride) involves mining activities that can have significant land-use impacts. Similarly, the feedstocks for phthalic anhydride and urea (typically derived from fossil fuels like crude oil or natural gas) are indirectly linked to land use for extraction infrastructure.

While this PCF does not include a detailed quantitative assessment of land occupation or direct land-use change emissions for each raw material at the sub-component level due to the "factory_gate" boundary, it is critical to acknowledge that the LSR Standard requires companies with significant land-sector activities in their value chain to report on these impacts. For future, more comprehensive PCF analyses, especially those extending to "cradle-to-grave" or focusing on specific raw material supply chains, detailed data on land transformation, land occupation, and associated carbon stock changes for materials like copper and petrochemical feedstocks would be essential to comply fully with LSR. This would involve tracing raw materials to their origin and applying specific land-based emission and removal factors.

4.3 Total Product Carbon Footprint (PCF)

The aggregated Product Carbon Footprint for 1.0 kg of Pigment Blue 15:3, up to the factory gate, is as follows:

Scope	Emissions (kg CO2e)	Percentage of Total
Scope 1	0.501	4.9%
Scope 2	3.635	35.5%
Scope 3	6.320	59.6%

Scope	Emissions (kg CO2e)	Percentage of Total
Total PCF	**10.456**	**100%**

The estimated Product Carbon Footprint for 1.0 kg of Pigment Blue 15:3 (Cradle-to-Gate, India) is 10.456 kg CO2e.

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5. Review & Report

5.1 Emission Hotspots

The analysis reveals that the most significant emission hotspots for Pigment Blue 15:3 are:

- **Scope 3: Purchased Goods and Services (Raw Materials)**: This category accounts for approximately 59.6% of the total PCF, primarily driven by the energy-intensive production of chemical precursors like phthalic anhydride and copper compounds. Engaging with suppliers to source lower-carbon raw materials is a critical area for reduction.
- **Scope 2: Purchased Electricity**: Representing about 35.5% of the total PCF, the emissions from grid electricity consumption in India are substantial due to the prevailing energy mix. Transitioning to renewable energy sources, either through direct procurement (e.g., PPAs) or on-site generation, offers a significant opportunity for decarbonization.
- **Scope 1: Direct Emissions**: While lower in comparison (4.9%), optimizing on-site energy efficiency and exploring cleaner fuel alternatives for heating can contribute to reductions.

5.2 Data Reliability and Limitations

This PCF analysis is based on a robust methodological framework (GHG Protocol) but relies on secondary data and illustrative estimations for activity data and emission factors. The reliability is therefore dependent on the quality and representativeness of these proxy datasets. Key limitations include:

- **Secondary Data Dependence:** Actual facility-specific primary data for raw material consumption, energy usage, and transportation routes would significantly enhance the accuracy of the footprint.
- **Emission Factor Genericity:** While industry-standard, some emission factors may not perfectly reflect specific supplier processes or regional variations within Asia beyond India\'s grid electricity.
- **Illustrative Quantities:** The assumed quantities for raw materials and energy are representative but may differ from real-world manufacturing specifics.
- **LSR Standard Implementation:** While acknowledged, a detailed quantitative assessment of land-use impacts for upstream raw materials under the new LSR Standard would require more specific supply chain traceability data.

5.3 Recommendations for Emission Reduction

Based on this analysis, the following actions are recommended to reduce the carbon footprint of Pigment Blue 15:3:

1. **Supplier Engagement for Low-Carbon Materials:** Collaborate with raw material suppliers to identify and procure phthalic anhydride, copper compounds, and other chemicals produced with lower embedded carbon. This could involve promoting renewable energy use at supplier facilities or exploring alternative, greener synthesis routes.
2. **Renewable Energy Transition:** Invest in renewable electricity solutions for manufacturing operations in India. This could include installing on-site solar, purchasing renewable energy credits, or engaging in power purchase agreements (PPAs) for green electricity.
3. **Process Optimization and Energy Efficiency:** Implement energy-efficient technologies and operational best practices in the manufacturing plant to reduce overall electricity and natural gas consumption.

4. **Waste Reduction and Management:** Minimize process waste and explore recycling or valorization opportunities to reduce emissions associated with waste treatment and disposal.
5. **Supply Chain Decarbonization for Logistics:** Optimize transportation routes and modes for raw materials to reduce fuel consumption and associated emissions.
6. **Advanced LSR Integration:** For future iterations, implement robust traceability systems to gather primary data on raw material origins and land use impacts, enabling a more precise assessment and reporting in accordance with the GHG Protocol LSR Standard.