

**LIFE CYCLE ASSESSMENT (LCA)
OF TOTO AURORA TOILETS**

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EXECUTIVE SUMMARY

TOTO is a leading manufacturer of bathroom products, renowned for its innovation and quality. The company's product range includes toilets, bidets, faucets, showers, and bathroom accessories. Environmental sustainability is at the core of TOTO's philosophy, as they strive to develop eco-friendly products and practices, such as water-saving technologies, energy-efficient systems, and sustainable manufacturing processes. By combining innovation with environmental stewardship, TOTO aims to contribute to a healthier planet while enhancing the everyday lives of its customers. The company commissioned this study to evaluate the potential environmental impacts of its flagship product, the Aurora toilet, using a cradle-to-grave approach.

This study covers the entire Aurora toilet series, a collection of 10 models: CST686CEFGAT40#**, MS686124CEFG#**, MS686124CEF#**, MS686124CEFRG#**, CST686CUFGAT40#**, MS686124CUFG#**, MS686124CUF#**, MS686124CUFRG#**, MS686234CEFG#** and MS686234CUFG#**. These models all have the same material composition and differ only in the features offered and aesthetics (color). All are assembled in a single TOTO facility in Vietnam, with product parts coming from various suppliers.

A functional unit of one unit of product over the estimated service of the building was used for the assessment. The estimated service life of the building (ESL) is 75 years, and the reference service life (RSL) is 20 years (a residential toilet without a bidet seat). This life cycle assessment (LCA) was conducted conforming to the relevant PCRs and applicable ISO standards using a cradle-to-grave approach, including all life cycle stages from raw material extraction through final assembly, transportation of materials between supplier facilities and manufacturing facilities, manufacturing operations, distribution to end users, resource consumption during product use, and end-of-life disposal.

A high-level summary of the findings of this study is illustrated in the table below which shows impacts per functional unit. The table presents potential CO₂-equivalent emissions and SM single score results for the Aurora toilet. For other impact categories and a breakdown by each life cycle stage, refer to section 5.2 in the full report. Overall, the study found that environmental performance is driven primarily by the use phase of the product. The impacts within the use phase are dominated by the product replacements for toilet operations. The product must be replaced four times to meet the prescribed ESL of 75 years. The cumulative impact of manufacturing, distributing, and disposing of multiple units over the desired service period makes product replacement resource and energy intensive. Raw materials extraction, upstream transportation, and the manufacturing of the product also represent a considerable share, but it is minimal when compared to the impacts generated in the use phase.

Product	Impact categories	Unit	Production	Construction/ Installation	Use	End of life	Total
			A1-A3	A4-A5	B1-B7	C1-C4	
AURORA 1.28 gallons per flush toilet	Global warming potential	kg CO ₂ eq	1.89E+02	1.36E+01	2.32E+03	1.15E+00	2.52E+03
		%	7.48%	0.54%	91.93%	0.05%	100%
	SM single figure score	mPts	1.55E+01	1.94E+00	2.00E+02	8.21E-02	2.17E+02
		%	7.15%	0.89%	91.92%	0.04%	100%
AURORA 1.0 gallon per flush toilet	Global warming potential	kg CO ₂ eq	1.89E+02	1.36E+01	2.05E+03	1.15E+00	2.25E+03
		%	8.38%	0.61%	90.96%	0.05%	100%
	SM single figure score	mPts	1.55E+01	1.94E+00	1.76E+02	8.21E-02	1.94E+02
		%	10.45%	0.34%	89.14%	0.08%	100%

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1. BACKGROUND

1.1. Opportunity

TOTO is a leading manufacturer of bathroom products, renowned for its innovation and quality. The company's product range includes toilets, bidets, faucets, showers, and bathroom accessories, with its flagship product being the Aurora toilet, a toilet system with an integrated advanced flushing mechanism.

TOTO is committed to creating high-performance, technologically advanced, and environmentally sustainable products. Their goals in product innovation focus on improving hygiene, comfort, and convenience for users, while also reducing water and energy consumption. Environmental sustainability is at the core of TOTO's philosophy, as they strive to develop eco-friendly products and practices, such as water-saving technologies, energy-efficient systems, and sustainable manufacturing processes. By combining innovation with environmental stewardship, TOTO aims to contribute to a healthier planet while enhancing the everyday lives of its customers.

As part of the ongoing commitments to environmental sustainability, TOTO is embarking on a project to develop an Environmental Product Declaration (EPD) for its flagship product, Aurora toilet. TOTO wants to transparently communicate the potential environmental impacts and performance associated with the Aurora toilet. As a result, it is important to conduct life cycle assessments (LCAs) to evaluate the potential environmental impacts from raw materials acquisition through manufacturing. The goal is to explore the potential environmental impacts that the product has and to identify ways to improve processes and reduce impacts. This project is critical to TOTO's PeoplePlanetWater mission of innovating products for the benefit of people, planet, and water supply.

To understand the true impacts of the Aurora toilet, TOTO developed an LCA using a cradle-to-grave approach. TOTO is looking forward to having guidance for future product improvements that can be informed by the results of this study. TOTO is interested in having LCA data available for the toilet to be able to obtain a Sustainable Minds Transparency Report [EPD]TM (TR), which is an ISO 14025 Type III environmental declaration that can be used for communication with and amongst other companies, architects, and consumers, and that can also be utilized in whole building LCA tools in conjunction with the LCA background report and life cycle inventory (LCI). This study aims to conform to the requirements of ISO 14040/14044 [1] [2], ISO 21930:2017 [3], and Sustainable Minds Part A [4]. In addition, this study also aims to comply with the Sustainable Minds Part B for residential toilets [5].

1.2. Life cycle assessment (LCA)

LCA is performed to comprehensively explore, quantify, and interpret the potential environmental impacts associated with a product or service over the entire life cycle. A product's life cycle consists of various stages, starting from raw material acquisition and manufacturing to product use and maintenance, plus final product disposal. Depending on the inclusion and exclusion of life cycle stages, an LCA could be cradle to gate (from raw material acquisition to the manufactured product ready to be shipped), cradle to gate with options (which also optionally includes

other modules such as shipment and installation), and cradle to grave (which includes all other stages including the use phase and disposal once the useful life is over).

Any LCA conducted with the intention of publishing EPDs needs to conform to the internationally accepted ISO 14040 and ISO 14044 standards. ISO 14040 provides principles and frameworks for conducting a LCA [1], while ISO14044 specifies requirements and provides guidelines for an LCA [2]. ISO 14040 sets out a four-phase methodology framework for completing a LCA, as depicted in **Figure 1**.

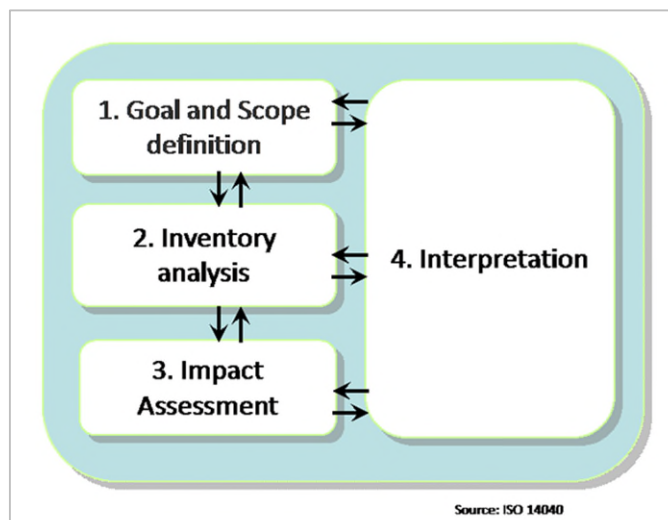


Figure 1. Phases of an LCA

- **Goal and scope definition:** Goals refer to establishing the purpose of the LCA, and they define the environmental aspects to be studied and the intended audience. Scope outlines the system boundaries, the functional unit of analysis, and the life cycle stages to be included. System boundaries set up inclusions and exclusions in an LCA. PCRs usually specify whether the boundary must be cradle-to-gate, cradle-to-installation, or cradle-to-grave.
- **Life cycle inventory analysis:** In this step, a detailed inventory of all the environmental inputs and outputs associated with each stage of the product's life cycle is compiled. Primary data about materials, energy, and emissions assessing the upstream supply chain, company's manufacturing operations, and downstream processes (after product leaves the factory gate) are collected via LCI data collection templates or tools. Annual data is suggested in most cases to be representative of the manufacturing operations. In the case of multi outputs, resources can be allocated to the product of interest via mass or volume, or as relevant. The inventory is then scaled to meet the functional unit of the LCA.
- **Life cycle impact assessment:** The compiled LCI is then modeled using an LCA software like SimaPro, GaBi, openLCA, or others using suitable background data sets available on their databases. Each is assigned to categories according to different impact methodologies, and the software provides final impact values for those different environmental impact categories. Several LCIA methodologies exist in the market including ReCiPe, TRACI, CML, and ILCD, which differ in terms of their approaches, characterization factors, evaluated impact categories, and modeling assumptions. Practitioners can choose a combination of LCIA methodologies to provide a holistic view of the environmental performance of a product.

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- **Interpretation of results:** In this step, the LCIA results are analyzed and presented via an LCA report. This stage helps draw conclusions about the environmental performance of the product, identify any environmental hotspots, make recommendations, and assess the significance of the findings. Sensitivity analysis, scenario studies, and uncertainty assessment are often included as a part of the interpretation to ensure the reliability and robustness of the results. LCA, if well interpreted and evaluated, presents a number of opportunities for the manufacturer in developing sustainability goals and initiatives.

This LCA study follows an attributional approach and uses a cradle-to-grave system boundary. This report incorporates LCA terminology. To assist the readers in understanding LCA, special attention has been given to list definitions of important terms used at the end of this report.

A critical review of the LCA and an independent verification of the TR are required for ISO 14025 Type III environmental declarations. Both are included in this project.

1.3. Team

This LCA report is the outcome of the efforts of the project team led by Gary Soe, Engineering Manager on behalf of TOTO, with support from TOTO and Sustainable Minds personnel during the data collection, reporting, and interpretation phases. Gary Soe led the development of the LCA results, LCA report, and TRs.

1.4. Status

All information in this report reflects the best possible data inventory by TOTO at the time it was collected, and Sustainable Minds and TOTO adhered to best practices in transforming the inventory into this report.

The data covers annual manufacturing data for January 2025 – December 2025 from TOTO's manufacturing facility in Vietnam. Where data was missing, assumptions were made for the facilities based on expertise from TOTO and its upstream suppliers.

This study includes primary data from processes at the upstream manufacturing facilities and background data to complete the inventory and fill gaps where necessary.

This is a supporting LCA report for the TOTO Transparency Report [EPD][™] and was evaluated for conformance to the PCRs according to the ISO 14025 [6] and ISO 14040/14044 [1][2] standards. The LCA review and verification of the Sustainable Minds Transparency Report [EPD][™] is to be carried out by Mr Jack Geibig, President, Ecoform on behalf of NSF.

2. GOAL AND SCOPE

This chapter explains the goal and scope of the study. The aim of the goal and scope is to define the product under study and the depth and breadth of the analysis.

2.1. Intended application and audience

This report intends to define the specific application of the LCA methodology to the life cycle of the Aurora toilets manufactured and distributed by TOTO. The report serves both internal and external purposes and is intended for a diverse audience. The intended audience includes the program operator (Sustainable Minds), TOTO's internal stakeholders involved in marketing and communications, operations, and design, and reviewers who will be assessing the LCA for conformance to the PCR.

The results presented in this document are not meant to support comparative claims. The outcomes will be made available to the public in a Sustainable Minds Transparency Report [EPD][™] (a Type III environmental declaration per ISO 14025), which are intended for communication between businesses and consumers (B2C).

2.2. Product description

TOTO's product range includes toilets, bidets, faucets, showers, and bathroom accessories. The product type covered in this study is its flagship product Aurora Toilet, an advanced toilet system. The major features are as follows:

- SanaGloss
- GHB, Gravity Hybrid, flushing system
- Computer designed, fully glazed trapway
- CEFIONTECT®: a nano-tech glaze
- Elongated bowl
- Chrome trip lever
- Universal height
- ADA compliant
- 12" Rough-in

There are 10 different models available within the Aurora toilet family as shown in **Table 1**, which all are covered in this study. These all are assembled in a single TOTO facility in Vietnam, with product parts coming from various suppliers, and shipped to TOTO distribution centers in the US. Since all toilet models have the same material composition and differ only on features and aesthetics (color), this report covers all models as tabulated in **Table 1**. The Aurora toilet parts are manufactured in Hanoi, Vietnam and shipped to TOTO Vietnam facility in Hanoi, Vietnam where they are assembled with the bowl, manufactured in-house at TVN, and later shipped to TOTO's distribution center in GA, USA.

Table 1. Evaluated Aurora toilet models

Product family	Product models
Aurora 1.28gpf Toilets	CST686CEFGAT40#**
	MS686124CEFG#**
	MS686124CEF#**
	MS686124CEFRG#**
	MS686234CEFG#**
Aurora 1.0gpf (1G) Toilets	CST686CUFGAT40#**
	MS686124CUFG#**
	MS686124CUF#**
	MS686124CUFRG#**
	MS686234CUFG#**

Figure 2 provides representative image for the product evaluated in this study.



Figure 2. Visual representation of product

Table 2 lists the product information in accordance with PCR, including declaration name, CSI MasterFormat® classification, manufacturing location, complaint standards, and the type of declaration. As shown in the table, a single Transparency Report [EPD]™ was developed from this study to represent TOTO's Aurora toilets.

Table 2. Declared product information and type of declaration

Transparency Report [EPD] TM name	CSI MasterFormat® classification	Manufacturing location	Standards/Certifications	Type of declaration
TOTO Aurora Toilets	22 42 13.13	TOTO Vietnam Plant	Meets and exceeds: ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC) Code compliance with UPC, IPC, NSPC, NPC Canada, and others.	Specific product from a manufacturer's plant

For more information about Aurora toilet, visit the TOTO website.

2.3. Functional unit

This LCA covers the cradle-to-grave stages for TOTO's Aurora toilet. A functional unit of one single flush toilet in an average residential environment, without an electronic bidet seat, over the estimated service life of the building was used.

The estimated service life of the building (ESL) is 75 years per the PCR. The reference service life (RSL) of the residential toilet without a bidet is 20 years.

2.4. System boundary

This section describes the system boundary for the analysis. The system boundary defines which life cycle stages are included and which are excluded.

This LCA's system boundary is from cradle to grave. Therefore, the life cycle activities and related processes shall include all life cycle stage modules from A1-C4 as illustrated in **Figure 3**. This includes raw materials extraction and preprocessing, transportation, manufacturing, distribution, installation, use stages, and end of life stages. This study follows the modularity principle, where all environmental impacts and potential impacts are declared in the life cycle stage where they can be attributed. **Table 3** lists specific inclusions and exclusions for the system boundary.

Scope	PRODUCTION STAGE			CONSTRUCTION STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
	Extraction and upstream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/Demolition	Transport to waste processing or disposal	Waste processing	Disposal of waste	Reuse, Recovery, Recycling Potential
Cradle to grave	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	MND

Figure 3. Applied system boundary

Table 3. System boundary inclusions and exclusions

Included	Excluded
<ul style="list-style-type: none"> Raw material extraction for components Transport of raw materials/ purchased components to the manufacturing facility Processing of raw materials into components (for externally purchased and in-house manufactured) 	<ul style="list-style-type: none"> Construction of major capital equipment Maintenance and operation of support equipment Human labor and employee transport

<ul style="list-style-type: none"> • Energy production • Manufacturing scrap and its disposal • Outbound transportation of product to users • Packaging for the final product and its disposal • Installation of the product • Use phase activities (maintenance, repair, replacement, refurbishment, & water use) • Product disposal after use 	<ul style="list-style-type: none"> • Manufacture, transport, and disposal of packaging materials not associated with final product • Energy consumption in the warehouses, distribution centers, and retail facilities during the course of transport to the final customer • Construction of water and wastewater infrastructure
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2.4.1. Product flow – Aurora toilet

The Aurora toilet in this study is assembled in TOTO's Vietnam (TVN) plant with all parts, except for the toilet bowl which is manufactured at the TVN plant, being purchased directly from suppliers. All parts are assembled, tested, and packaged in the facility and later shipped to the TOTO distribution center in Fairburn, GA. From there, the product is transported to the end user site and installed. Once the product is installed, it requires periodic cleaning and replacement (at the end of the RSL). Various parts need to be replaced within the RSL as well. Energy and water are consumed throughout the ESL for continuous operation of the product during the use phase. Per the PCR, the product is assumed to be landfilled at the end of life. **Figure 4** provides an overview of the product flow during its life cycle.

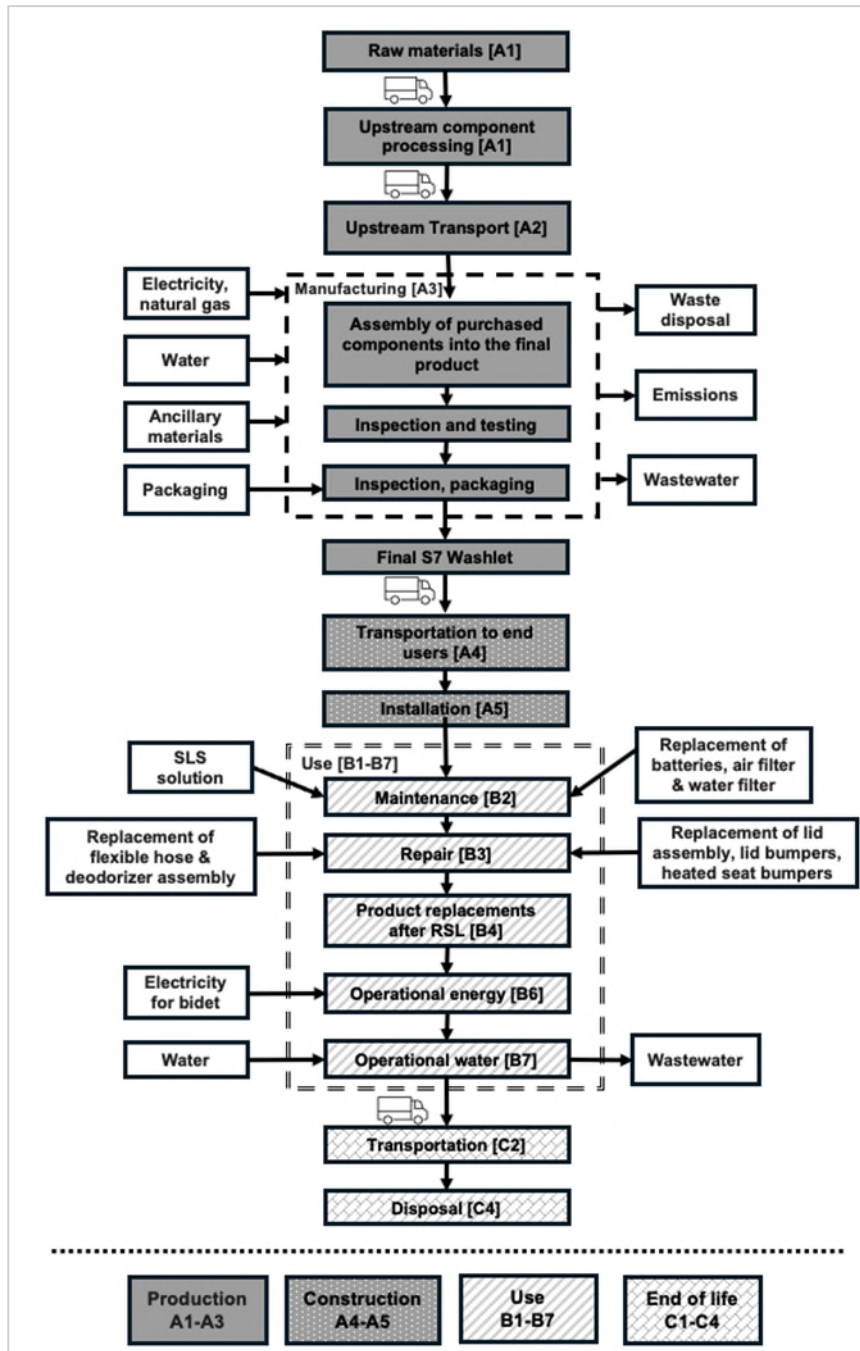


Figure 4. System boundary and product flow diagram of TOTO Aurora toilets

3. LIFE CYCLE INVENTORY ANALYSIS

This chapter includes an overview of the obtained data and data quality that has been used in this study. A complete life cycle inventory calculation workbook, which catalogs the flows crossing the system boundary and provides the starting point for life cycle impact assessment, can be found in the appendix.

3.1. Data collection procedures

Primary data was provided by TOTO representing the supply chain (A1-A2), manufacturing processes (A3), and distribution (A4) of the Aurora toilets. Data was collected in a consistent manner and level of detail to ensure high-quality data. All submitted data were checked for quality multiple times on the plausibility of inputs and outputs using mass balance and benchmarking. All questions regarding data, including gaps, outliers, and any inconsistencies, were resolved with TOTO and their suppliers. Assumptions for upstream processing operations regarding each purchased component were developed via suggestions from TOTO personnel and suppliers. Annual data for the year 2025 (January 2025 to December 2025) was collected at the manufacturing facility in Vietnam for the assembly of the toilet. It should be noted that all TOTO sister companies are under the same efficiency guidance by TOTO Japan and that the same manufacturing resources are consumed for the assembly of toilets in all TOTO facilities. The resulting inventory calculations were developed by an analyst at Sustainable Minds and TOTO and subsequently checked internally.

While the inventory for the production and construction/installation stage (A1-A5) was developed using primary data, the inventory for the use stage (B1-B7) and end-of-life stage (C1-C4) were developed using the assumptions prescribed by the PCRs and TOTO's product specifications.

Expert judgment was used in selecting appropriate data sets to model the associated activities in this study, including raw materials, upstream component processing, and energy, which have been noted in the subsequent sections. Databases adopted in the model include ecoinvent v3.11, US-EI 2.2, and Industry data 2.0 databases. Overall, the quality of the data used in this study is considered to be good and representative of the described systems. All appropriate means were employed to guarantee the data quality and representativeness as described below.

3.2. Primary data and PCR guidelines

Besides upstream component processing, primary data was collected for the A1-A4 modules. Appropriate upstream component processing was identified together with the TOTO team to best represent the manufacturing of each individual component being shipped to the TOTO facility for final product assembly. Primary data were collected using either direct measurement or the manufacturing facility personnel's best engineering estimates based on actual production if measurements were not available. PCR guidelines were used for the remaining product life cycle stages.

3.2.1. Raw materials acquisition and transportation (A1-A2)

These modules represent raw materials extraction, preprocessing/upstream processing, and transportation to the manufacturing facility. The full bill of materials (BOM) was provided with a detailed breakdown of product into parts/components and raw materials for each part. Raw materials are extracted by material suppliers, manufactured by suppliers, and transported to the component manufacturing plants. Components are then transported to the TOTO Vietnam where the individual components are assembled into the final product. Supply chain primary data, including information on component supplier locations, shipping distances, and transportation modes to the final manufacturing plants, were all provided. A single supplier is used for a specific component. It must be noted that the packaging materials used for the shipment of components to the final assembly plant in Vietnam were not included in this study.

For the ceramic bowls, the TVN plant provided an annual quantity of raw materials being shipped into the facility, which was normalized to input materials per kg of ceramic output and later scaled up to meet the mass of the specific ceramic bowl used in the Aurora toilets. Only the base ingredients and glazing materials are included in the analysis since the resin molds are reused 10,000+ times, making the impacts per unit of product negligible. Neither toilet contains hazardous substances according to the standards or regulations of the Resource Conservation and Recovery Act (RCRA), Subtitle C.

All components used in the Aurora toilet are purchased directly from suppliers. Shipment distances vary. The upstream road transport distance is ~224 km on average (on a per component basis). Upstream manufacturing activities have been modeled separately in addition to the raw material extraction. The raw material composition and total reference flow is reported below in **Table 4**. While the final corrugated packaging is included in the table below, it is included as a resource input to the manufacturing (A3) stage during analysis and result generation.

Table 4. Aurora toilet assemblies and raw material mass per functional unit and associated transportation

Assembly/material	Mass (g)	Mass % in final product	Mass (g)	Mass % in assembly	Road transport (km)	Sea transport (km)	Origin
Ceramic unit							
Silica	44200.43	74.04%	8840.09	20.00%	submitted	submitted	Vietnam
Feldspar			7956.08	18.00%	submitted	submitted	
English Kaolin			7072.07	16.00%	submitted	submitted	
Domestic Kaolin			5746.06	13.00%	submitted	submitted	
English Ball clay			3536.03	8.00%	submitted		
China Clay_Old Mine			2652.03	6.00%	submitted		
Kaolin			2210.02	5.00%	submitted		
Domestic Ball clay			1326.01	3.00%	submitted		
Feldspar II			1326.01	3.00%	submitted		
Dolomite			884.01	2.00%	submitted		
Silica II			884.01	2.00%	submitted		
Limestone			442	1.00%	submitted		
Zirconium Silicate			442	1.00%	submitted		
All others (materials with <1% contribution by weight)			884.01	2.00%		submitted	
Non-ceramic parts, the seat, rim and jet flush valves, fill valve, inner tank and trip lever parts							
Polyphenylene sulfide (PPS)	8702.41	14.58%	3770.00	43.32%	submitted	submitted	Vietnam
Polyphenylene (PP)			1590.00	18.27%			
Corrugated Board			900.00	10.34%			
Acrylonitrile butadiene styrene (ABS)			750.00	8.62%			
Ethylene propylene diene monomer (EPDM)			375.60	4.32%			
Polyoxymethylene (POM)			205.20	2.36%			
Polyvinyl chloride (PVC)			161.20	1.85%			
Stainless Steel, SUS430			112.40	1.29%			
paper			97.00	1.11%			
Zinc			95.00	1.09%			
Brass			71.00	0.82%			
Stainless steel			46.00	0.53%			
Polyethylene (PE)			8.00	0.09%			
Styrene-butadiene rubber (SBR)			3.00	0.03%			
fluoroelastomer, FKM	2.00	0.02%					
High density polyethylene (HDPE)	2.00	0.02%					
All others (materials with <1% contribution by weight)	514.00	5.91%					
Corrugated board packaging	6796.11	11.38%	-	-	submitted	-	Vietnam
Final product mass per functional unit / reference flow			59.69 kg	100%			

For the toilets, upstream processing operations for purchased components were identified with help from the TOTO team and depending on the material type, manufacturing method, and manufacturing country, components were categorized.

Once the raw materials reach the supplier processing plants, they are transformed into components. The TOTO team identified manufacturing operations for each component and depending on the material type, manufacturing method, and manufacturing country, components were categorized. Existingecoinvent data sets were modified manually, and embedded unit processes (mainly electricity and water) were appropriately substituted to represent the component production in a particular country. The Aurora toilet's parts are all made in Vietnam. As the transportation data sets represent load factors as an average of empty and fully loaded (i.e., average load factor), empty backhauls are accounted for in the model.

3.2.2. Manufacturing (A3)

This module incorporates the manufacturing operations in the product manufacturing facilities. The manufacturing stage for the Aurora toilets includes the production of the ceramic bowl at TVN facility in Hanoi, Vietnam, the production of the tank components in Hanoi, Vietnam and the assembly of the toilets at TVN facility in Hanoi, Vietnam.

For the rim and jet flush valves, fill valve, inner tank and trip lever, all are purchased from suppliers and shipped directly to the TOTO Vietnam manufacturing facility (TVN). All TOTO sister companies, including TVN, are under the same efficiency guidance by TOTO Japan, and it was assumed that the same manufacturing resources are consumed for the assembly of toilets (for all models) in all TOTO facilities. Resources (energy, water, and ancillary materials) consumed for the assembly of a complete toilet were calculated using the annual production units. Annual resources, covering the entire year for 2025, consumed for the toilet assembly lines were provided.

$$\text{Resource per unit product} = \frac{\text{Annual facility resource consumption for assembly}}{\text{Annual production units}}$$

Wastes generated during the assembly process are assumed to be 100% landfilled. Manufacturing inputs and outputs per unit product are listed in **Table 5**.

Table 5. Manufacturing inputs per functional unit of each toilet

Resource category	Flow	Amount	Unit
Energy	Electricity	submitted	kWh
Ancillary materials	Lubricants	submitted	kg
	Motor oil ¹	submitted	L
	Grease ²	submitted	kg
	Plastic wrap	submitted	kg
	Polypropylene plastic container	submitted	kg
	Stainless steel jig	submitted	kg
Waste generation	Non-hazardous waste, landfilled	submitted	kg
	Hazardous waste, landfilled	submitted	kg
Waste transport	Transport for waste disposal	submitted	km

Annual manufacturing data for the year 2025 was provided by the TVN facility for ceramic manufacturing. **Figure 5** illustrates all manufacturing activities involved in the production of ceramic bowls.

¹ Motor oil used is WD-40, a density of 875 kg/m³ has been used.

² Silicone grease is used, assumed to have a mass composition of 90% silicone oil and 10% fumed silica.

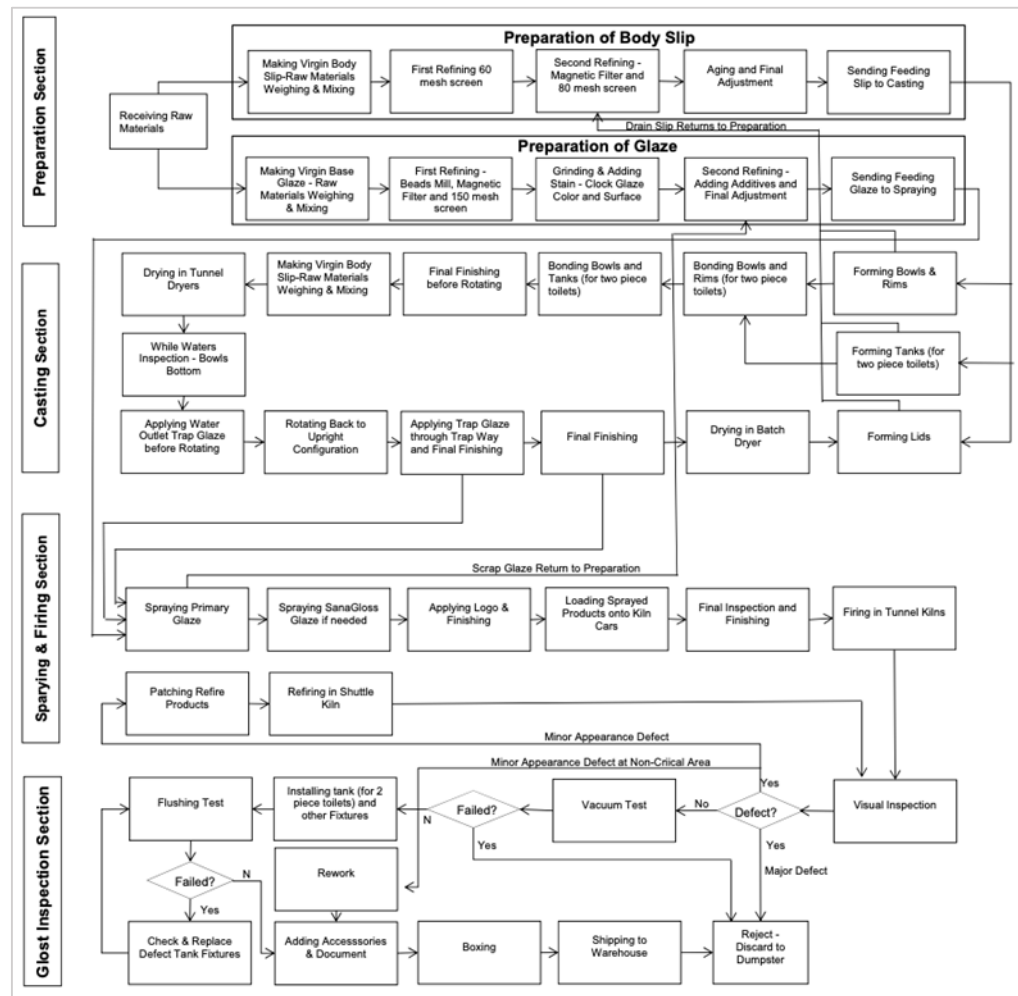


Figure 5. Bowl production in the TOTO Vietnam plant

The reported annual data was normalized based on the total annual ceramic output mass to develop the inventory per kg of ceramic output. The normalized manufacturing resource per kg ceramic mass output is tabulated in **Table 6**.

$$Resource\ per\ kg\ ceramic\ output = \frac{Annual\ facility\ resource\ consumption}{Annual\ ceramic\ production\ mass}$$

All waste, including hazardous waste, is reported to be recycled. The plant has on-site wastewater treatment plants, and the major chemicals used for wastewater treatment have been reported as shown in **Table 6**. The recovered water is sent back to the ceramic production processes. The TVN facility also reported waterborne emissions in its sewage, also included in the analysis.

Table 6. Manufacturing resources per kg ceramic unit

Resource category	Flow	Amount	Unit
Energy	Electricity (grid)	submitted	kWh
	Electricity (diesel generator)	submitted	kWh
	Heat, natural gas	submitted	m ³
	Heat, heavy oil	submitted	L
Water	Municipal supply	submitted	m ³
	River water	submitted	m ³
Ancillary materials (for wastewater treatment)	Aluminum sulfate	submitted	kg
	Aluminum chloride	submitted	kg
	Sodium hypochlorite	submitted	kg
	Calcium chloride	submitted	kg
	Soda ash	submitted	kg
	Hydrochloric acid	submitted	kg
Waste generation	Non-hazardous waste, recycled	submitted	kg
	Hazardous waste, recycled	submitted	kg
	Sewage	submitted	m ³
Waste transport	Transport for waste disposal sites (weighted average)	submitted	km

For the tank system used in the Aurora toilet, annual facility resources were provided and normalized using annual production units. Manufacturing resources per unit tank system are listed in

Table 7. Manufacturing resources per tank system

Resource category	Flow	Amount	Unit
Energy	Electricity (for arc welding)	submitted	kWh
Ancillary materials	Grease ³	submitted	kg
	Soldering rods ⁴	submitted	kg
Waste generation	Hazardous waste, landfilled	submitted	kg
Waste transport	Transport for waste disposal	submitted	km

3.2.3. Product distribution (A4)

This module refers to the transport and delivery of products from the manufacturing facility to the sites where the products are installed and used.

The Aurora toilets manufactured in Vietnam are first shipped to TOTO's distribution center in Georgia, US and then transported to end users and building sites. Shipment to end users can occur via trucks or rail with trucks contributing to 83% of the shipments in 2025. As the transportation data sets represent load factors as an average of empty and fully loaded (i.e., average load factor), empty backhauls are accounted for in the model. Average transportation distances are shown in **Table 8**.

³ Silicone grease was used, assumed to have a mass composition of 90% silicone oil and 10% fumed silica.

⁴ Steel welding rods have a >95% share of steel by mass.

Table 8. Aurora toilet distribution distances and methods per functional unit

Resource category	Flow	Value	Unit
Manufacturing facility (Vietnam) to GA, US	Road transport in Vietnam	submitted	km
	Sea transport	submitted	km
	Rail transport from port to GA, US	submitted	km
Transport to final users	Road transport (83% share)	submitted	km
	Rail transport (17% share)	submitted	km

3.2.4. Product installation (A5)

This module represents the installation of the product, making it ready for use.

Installation of the product is manual with no additional resources being consumed. The inputs in this module include the disposal of packaging waste (plastic bags and corrugated board) with a waste transportation distance of 100 km. The disposal scenario for corrugated board packaging is assumed to be 80.88% recycled, 15.37% landfilled, and the remaining incinerated, in alignment with US EPA's 2018 end of life data for paperboard containers and packaging⁵. Likewise, the disposal scenario for plastic packaging is assumed to be 13.63% recycled, 69.44% landfilled, and the remaining incinerated, in alignment with US EPA's 2018 end of life data for plastic containers and packaging⁶.

3.2.5. Product use (B1)

This module covers any activity related to product use which is not already included in other use modules (B2-B7). There are no activities in this module for the Aurora toilets.

3.2.6. Maintenance (B2)

This module covers all planned technical services and associated operations during the reference service life to maintain the product in a state where it can continue provide its required functional and technical services. A building estimated service life (ESL) of 75 years and reference service life (RSL) of 20 years were used per the PCR.

Maintenance activities as recommended by the PCR are taken into consideration. Sodium lauryl sulfate (SLS) solution is used for the periodic cleaning of product parts. Each liter of 1% SLS solution comprises 10 grams of SLS and 0.99 liters of water. The following maintenance activities have been included in this study:

- Toilet basin, bowl, seat, and lid cleaning – twice per month

All maintenance activity inputs have been quantified in **Table 9**.

⁵ Product specific data for paper and paperboard containers and packaging, EPA 2018. <https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/containers-and-packaging-product-specific#PaperandPaperboardC&P%20>

⁶ Product specific data for plastic containers and packaging, EPA 2018.

Table 9. Aurora toilet maintenance inputs per functional unit

Name	Value	Unit
Reference service life (RSL)	20	years
Estimated service life (ESL)	75	years
Number of uses over ESL	355,875	uses
Maintenance cycles		
<i>Toilet basin, bowl, seat, and lid cleaning</i>	1,800	per ESL
Water consumption	89.1	L
Auxiliary material (cleaning agent)	0.9	kg
Other resources	-	kg
Electricity	-	kWh
Other energy carriers	-	MJ
Maintenance waste	submitted	kg per ESL
Disposal sent for landfill	100	%

3.2.7. Repair (B3)

This module includes all technical services and associated operations during the service life of the product in the form of corrective, responsive, or reactive actions to return the product into an acceptable condition to continue to provide its services.

Repair components were identified in the product BOM of Aurora toilet with assistance from the TOTO Engineering team. The toilet has the trip lever, a rim flush valve seal, a jet flush valve seal and a fill valve seal require replacements per the PCR.

As prescribed by the PCR, a rim flush valve seal, a jet flush valve seal and a fill valve seal are assumed to be fully replaced once during the RSL. Those components were identified in the product BOM with assistance from TOTO team. Material inputs, upstream component processing (grouped by material type and processing operations), component transportation to users, and end disposal are all included. Since replacement components can be purchased separately by the user, an upstream transport distance of 2,000 km was assumed. The components are assumed to be sourced from within the US using road transport. The old components are assumed to be 100% sanitary landfilled with a waste transport distance of 100 km. The repair activity inputs have been listed in **Table 10**.

Table 10. Aurora Toilet repair inputs

Name	Value	Unit
Information on the repair process	Replacement of trip lever, rim flush valve seal, jet flush valve seal and fill valve seal once during the RSL.	
Repair cycle	1	cycle/RSL
	3.75	cycles/ESL
Repair waste	15.73	kg per ESL
Disposal sent for landfill	100	%

3.2.8. Replacement (B4)

Replacement covers all technical services and associated operations during the ESL associated with replacing the whole product once its RSL is over. Per the

PCR, replacements must be counted proportionally to the nearest tenth of a product and must include the sum of impacts from stages A1-A5 and C1-C4 multiplied by the number of replacements.

Since the RSL is 20 years, 2.75 product replacements are needed to fulfill the ESL. The replacement activity inputs have been listed in **Table 11**.

Table 11. Aurora Toilet replacement inputs per functional unit

Name	Value	Unit
Replacement cycles over ESL	2.75	toilets
Electricity consumption	0	kWh
Liters of fuel	0	L/100 km
Replacement of worn parts	0	kg
Auxiliary materials	0	kg

3.2.9. Refurbishment (B5)

This module covers any applicable restoration activities. Refurbishment is not expected to occur during the normal operation of the Aurora toilets; therefore, there is no activity in this stage.

3.2.10. Operational energy use (B6)

This module covers energy usage during the operation of the product and its associated environmental aspects and potential impacts. The Aurora toilets are manually operated and have no energy use. There are no activities in this module for the Aurora toilet.

3.2.11. Operational water use (B7)

This module covers water usage during the operation of the product and its associated environmental aspects and potential impacts. There is only one source of water consumption: water consumed during each toilet flush. It is assumed that incoming water is municipal tap water, and no filtration is required. For the water use, as reported in the product specifications⁷, Aurora toilets are single flush toilets with two flush capacities of 1.28gpf and 1.0gpf. Per the PCR, the total flushes per day is assumed to be 13.

An electricity factor of 0.000961 kWh per liter of water as prescribed by the PCR is used to represent energy for upstream municipal water collection, treatment, supply, and downstream sewage management. The operational water use inputs have been listed in **Table 12**.

⁷ TOTO Aurora Toilet specifications
<https://www.totousa.com/products/toilets>

Table 12. Aurora Toilets' operational water use consumption per functional unit

Name	Aurora Toilets (1.28gpf)	Aurora Toilets (1.0gpf)	Unit
Flushes over ESL	355,875		flushes
Flush water rate	1.28	1.0	gpf
Water consumption	455,520.00	355,875.00	gallons/ESL
Electricity consumption	1658.09	1295.39	kWh/ESL
Wastewater generation	455,520.00	355,875.00	gallons/ESL

3.2.12. Deconstruction/demolition (C1)

This module includes the dismantling or demolition of the product from the building and associated energy consumption. The Aurora toilets are assumed to be manually removed using common hand tools at the end of life; therefore, there is no activity in this module.

3.2.13. Transport to waste processing or disposal (C2)

This module refers to the transportation of the discarded product to the waste processing sites, either to a recycling site or for final product disposal. Per the PCR, the waste transportation distance is assumed to be 100 km.

3.2.14. Waste processing (C3)

This module represents the processing of waste generated resulting in materials for reuse, secondary materials, and secondary fuels. There is no activity considered in this module for the studied products.

3.2.15. Waste disposal (C4)

This module represents the final waste disposal including the physical treatment and management of the disposal site. Per the PCR, 100% of the discarded product is sent to sanitary landfills. End of life activity inputs have been reported in **Table 13**. Processes specific to each material type were selected.

Table 13. Aurora toilets' end of life inputs per functional unit

Name	Value	Unit
Transport from building site to landfill	100	km
Mixed construction waste	59.70	kg
Landfilling total	59.70	kg

3.3. Background data

This section details the background data sets used for modeling all relevant activities associated with the cradle to grave life cycle of the Aurora toilets. Each table lists the data set name, database, year of last update, and geography. The LCA model was created using the SimaPro Developer 10.3 software. The ecoinvent v3.11, US-EI 2.2, and Industry data 2.0 databases provided the life cycle inventory data for the raw materials and processes for modeling the products.

3.3.1. Materials

Data representing upstream and downstream raw materials were obtained from the ecoinvent v3.11 and Industry 2.0 database. Data sets matching each raw material were looked up in the available databases, and if not found, manual data sets or proxies were used. Where country-specific data were unavailable, global or rest-of-world averages were used to represent production in those locations. **Table 14** lists the most relevant LCI data sets used in modeling the raw materials.

Table 14. Key material data sets used in inventory analysis

Raw material(s)	Data set	Database	Technology	Year of last update	Geography ¹
Polypropylene & Polyphenylene ether	Polypropylene, granulate {GLO} market for polypropylene, granulate Cut-off, U	Ecoinvent v3.11	Appropriate technology	2024	GLO
Rubber, Epdm, FKM, Silicone foam	Synthetic rubber {GLO} market for synthetic rubber Cut-off, U	Ecoinvent v3.11	Appropriate technology	2024	GLO
Acrylonitrile butadiene styrene (ABS)	Acrylonitrile-butadiene-styrene copolymer {GLO} market for acrylonitrile-butadiene-styrene copolymer Cut-off, U	Ecoinvent v3.11	Appropriate technology	2024	GLO
Polyethylene terephthalate	Polyethylene terephthalate, granulate, amorphous {GLO} market for polyethylene terephthalate, granulate, amorphous Cut-off, U	Ecoinvent v3.11	Appropriate technology	2023	GLO
Instruction manuals	Printed paper, offset {RoW} offset printing, per kg printed paper Cut-off, U ²	Ecoinvent v3.11	Appropriate technology	2011	GLO
Polyphenylene sulfide	Polyphenylene sulfide {GLO} market for polyphenylene sulfide Cut-off, U	Ecoinvent v3.11	Appropriate technology	2023	GLO
Polyvinyl chloride (PVC)	Polyvinyl chloride {RoW} market for Polyvinyl chloride, granulate Cut-off, U	Ecoinvent v3.11	Appropriate technology	2023	RoW
Polyethylene	Polyethylene, high density, granulate {GLO} market for polyethylene, high density, granulate Cut-off, U	Ecoinvent v3.11	Appropriate technology	2023	GLO
Polyoxymethylene	Polyoxymethylene (POM)/EU-27	Industry data 2.0	Appropriate technology	2024	EUR
Styrene butadiene rubber	57.75% Polybutadiene: Polybutadiene {GLO} market for polybutadiene Cut-off, U 17.25% Styrene: Styrene {GLO} market for styrene Cut-off, U & 25% Carbon black: Carbon black {GLO} market for carbon black Cut-off, U	Manually developed	Appropriate technology	-	GLO
High density polyethylene	Polyethylene, high density, granulate {GLO} market for polyethylene, high density, granulate Cut-off, U	Ecoinvent v3.11	Appropriate technology	2023	GLO
Corrugated board	Corrugated board box {RoW} market for corrugated board box Cut-off, U	Ecoinvent v3.11	Appropriate technology	2023	GLO
Charcoal	Charcoal {GLO} market for charcoal Cut-off, U ²	Ecoinvent v3.11	Appropriate technology	2011	GLO
Stainless steel	Steel, chromium steel 18/8 {GLO} market for steel, chromium steel 18/8 Cut-off, U	Ecoinvent v3.11	Appropriate technology	2020	GLO
Stainless steel, SUS430	Stainless steel, SUS430, chromium steel {GLO} market for steel, chromium steel Cut-off, U	Ecoinvent v3.11	Appropriate technology	2020	GLO
Brass	Brass {RoW} market for brass Cut-off, U	ecoinvent v3.11	Appropriate technology	2023	RoW
Zinc	Zinc {GLO} market for Zinc Cut-off, U	Ecoinvent v3.11	Appropriate technology	2020	GLO
.Lubricating oil	Lubricating oil {RoW} market for lubricating oil Cut-off, U ²	Ecoinvent v3.11	Appropriate technology	2011	GLO

Silicone grease	90% silicone oil: Polydimethylsiloxane {GLO} market for polydimethylsiloxane Cut-off, U and 10% fumed silica: Silica fume, densified {GLO} market for silica fume, densified Cut-off, U	Manually developed	Appropriate technology	-	GLO
Sericite & Dolomite	Dolomite {RoW} dolomite production Cut-off, U; <i>manually updated for production in Japan</i>	ecoinvent v3.11	Appropriate technology	2022	Japan
Kaolin	Kaolin {RoW} kaolin production Cut-off, U; <i>manually updated for production in different countries</i>	ecoinvent v3.11	Appropriate technology	2023	RoW
Clay	Clay {RoW} clay pit operation Cut-off, U	ecoinvent v3.11	Appropriate technology	2016	RoW
Feldspar	Feldspar {RoW} feldspar production Cut-off, U	ecoinvent v3.11	Appropriate technology	2023	RoW
Alumina	Aluminium oxide, non-metallurgical {CN} aluminium oxide production Cut-off, U	ecoinvent v3.11	Appropriate technology	2019	China
Sodium silicate	Sodium silicate, without water, in 37% solution state {RoW} sodium silicate production, furnace liquor, product in 37% solution state Cut-off, U	ecoinvent v3.11	Appropriate technology	2023	RoW
Silica	Silica sand {RoW} silica sand production Cut-off, U	ecoinvent v3.11	Appropriate technology	2023	RoW
Lime	Lime {RoW} lime production, milled, loose Cut-off, U; <i>manually updated for production in Japan</i>	ecoinvent v3.11	Appropriate technology	2014	Japan
Zinc oxide	Zinc oxide {RoW} zinc oxide production Cut-off, U	ecoinvent v3.11	Appropriate technology	2023	RoW
Zircon	Zircon {RoW} heavy mineral sand quarry operation Cut-off, U	ecoinvent v3.11	Appropriate technology	2022	RoW
Frits	Frit, for ceramic tile {GLO} frit production, for ceramic tile Cut-off, U	ecoinvent v3.11	Appropriate technology	2014	RoW

¹ 'GLO' stands for global geography; 'EUR' stands for Europe, and 'RoW' stands for Rest of World (non-Europe) geography.

² Data sets older than 10 years were chosen because they closest represent the technology used to manufacture the material and are assumed to be more accurate than other potential proxies with more precise geography and temporal representativeness.

3.3.2. Upstream processing

For the components purchased directly from external suppliers, component processing was added separately. Manufacturing operations were identified for each component, and depending on the material type, manufacturing method, and manufacturing country, components were categorized. Existing ecoinvent data sets were modified manually, and embedded unit processes (mainly electricity and water) were appropriately substituted, as applicable, to represent the component production in a particular country. **Table 15** below shows the component categories developed and associated data set updates for representing the component processing.

Table 15. Upstream processing data sets, with manual modifications, used in inventory analysis

Component category	Base data set & manual updates applied	Database	Technology	Last updated	Geography ¹
Steel/ Brass casting (in Vietnam)	Base dataset Casting, brass {RoW} casting, brass Cut-off, U <i>Does not include the metal input for casting so same can be used for brass or steel casting.</i> <i>Updates made: Electricity datasets updated with Vietnam electricity to represent casting in Vietnam.</i>	Ecoinvent v3.11	Appropriate technology	2024	Vietnam (VN)
Metal extrusion (in Vietnam)	Base dataset: Sheet rolling, copper {RoW} sheet rolling, copper Cut-off, U <i>Updates made: Electricity datasets, water related inputs & outputs updated to VN.</i>	Ecoinvent v3.11	Appropriate technology	2024	Vietnam (VN)
Plastic extrusion (in Vietnam)	Base dataset: Extrusion, plastic pipes {CA-QC} extrusion, plastic pipes Cut-off, U <i>Updates made: Electricity datasets, water related inputs & outputs updated to VN.</i>	Ecoinvent v3.11	Appropriate technology	2024	Vietnam (VN)
Steel extrusion (in Vietnam)	Impact extrusion of steel, warm, 2 strokes {RoW} impact extrusion of steel, warm, 2 strokes Cut-off, U <i>Updates made: NO</i>	Ecoinvent v3.11	Appropriate technology	2024	RoW
Plastic foaming (in Vietnam)	Base dataset: Polymer foaming {CA-QC} polymer foaming Cut-off, U <i>Updates made: Electricity datasets, water related inputs & outputs updated to VN.</i>	Ecoinvent v3.11	Appropriate technology	2024	Vietnam (VN)
Plastic injection molding (in Vietnam)	Base dataset: Extrusion, plastic pipes {CA-QC} extrusion, plastic pipes Cut-off, U <i>Updates made: Electricity datasets, water related inputs & outputs updated to VN.</i>	Ecoinvent v3.11	Appropriate technology	2024	Vietnam (VN)
Average zinc metalworks (in Vietnam)	Metal working, average for zinc product manufacturing {RoW} metal working, average for zinc product manufacturing Cut-off, U <i>Updates made: NO</i>	Ecoinvent v3.11	Appropriate technology	2024	RoW
Average brass metalworks (in Vietnam)	Metal working, average for brass product manufacturing {RoW} metal working, average for brass product manufacturing Cut-off, U <i>Updates made: NO</i>	Ecoinvent v3.11	Appropriate technology	2024	RoW
Average steel metalworks ((in Vietnam)	Metal working, average for steel product manufacturing {RoW} metal working, average for steel product manufacturing Cut-off, U <i>Updates made: NO</i>	Ecoinvent v3.11	Appropriate technology	2024	RoW
Average metalworks ((in Vietnam)	Metal working, average for metal product manufacturing {RoW} metal working, average for metal product manufacturing Cut-off, U <i>Updates made: NO</i>	Ecoinvent v3.11	Appropriate technology	2024	RoW
Kaolin production (in Vietnam)	Base dataset: Kaolin {RoW} kaolin production Cut-off, U <i>Updates made: Electricity datasets, water related inputs & outputs updated to VN.</i>	Ecoinvent v3.11	Appropriate technology	2024	Vietnam (VN)
Dolomite production (in Vietnam)	Base dataset: Dolomite {RoW} dolomite production Cut-off, U <i>Updates made: Electricity datasets, water related inputs & outputs updated to VN.</i>	Ecoinvent v3.11	Appropriate technology	2024	Vietnam (VN)

¹ RoW¹ stands for Rest of World (non-Europe) geography.

3.3.3. Transportation

Raw materials and components are transported to the product manufacturing facility from the suppliers via different transportation modes. Final products are first shipped using container ships to the TOTO distribution center in GA, US and then transported to end users via either road or rails. Transportation distances from the production facility to the adjacent ports and from the destination port to the TOTO distribution center are included. As the transportation data sets represent load factors as an average of empty and fully loaded (i.e., average load factor), empty backhauls are accounted for in the model. Data sets matching each transportation mode were found in the available databases. Where country-specific data were unavailable, global or rest-of-world averages were used to represent transportation in those locations. **Table 16** shows the most relevant LCI data sets used in modeling transportation.

Table 16. Transportation data sets used in inventory analysis

Transport mode & legs	Data set	Database	Technology	Last updated	Geography ¹
Upstream road transport in Vietnam	Transport, freight, lorry, unspecified {RoW} transport, freight, lorry, all sizes, EURO6 to generic market for transport, freight, lorry, unspecified Cut-off, U	Ecoinvent v3.11	Appropriate technology	2021	RoW
Sea transport	Transport, freight, sea, container ship {GLO ¹ } market for transport, freight, sea, container ship Cut-off, U	Ecoinvent v3.11	Appropriate technology	2018	GLO
Road transport from Vietnam facility to seaport	Transport, freight, lorry 16-32 metric ton, EURO6 {RoW} market for transport, freight, lorry 16-32 metric ton, EURO6 Cut-off, U	Ecoinvent v3.11	Appropriate technology	2014	RoW
Rail transport (from US port to GA and to building sites)	Transport, freight, rail, diesel/US US-EI U	US-EI 2.2	Appropriate technology	2021	United States
Final road transport to building sites	Transport, lorry 3.5-16t, fleet average/US- US-EI U	US-EI 2.2	Appropriate technology	2021	United States
Overseas waste transport	Municipal waste collection service by 21 metric ton lorry {GLO} market for municipal waste collection service by 21 metric ton lorry Cut-off, U ²	Ecoinvent v3.11	Appropriate technology	2011	GLO
US waste transport	Transport, municipal waste collection, lorry 21t/US* US-EI U ²	US-EI 2.2	Appropriate technology	2021	United States

¹ 'GLO' stands for global geography; 'RoW' stands for Rest of World (non-Europe) geography.

² Data sets older than 10 years (light commercial vehicle, EURO5 16-32t lorry, EURO6 >32t lorry, and waste collection lorry) were chosen because they closest represent the technology used for transportation of the materials and are assumed to be more accurate than other potential proxies with more precise geography and temporal representativeness.

3.3.4. Fuels and energy

The fuel inputs and electricity grid mixes were obtained using the databases available in SimaPro. The final assembly occurs in Vietnam, so the electricity data set for Vietnam was used. For upstream processing of purchased components, relevant processing data sets from ecoinvent v3.11 were selected, and the embedded electricity unit process was modified to represent the supplier country. For example, for injection molded plastic components in Vietnam, the base RoW injection molding data set available in the ecoinvent database was manually updated using the electricity data set for Vietnam.

For electricity consumed during the use phase, the most recent eGRID average data set was used. **Table 17** shows the most relevant LCI data sets used in fuels and energy.

Table 17. Key energy data sets used in inventory analysis

Energy source	Data set	Database	Technology	Last updated	Geography ¹
Vietnam electricity	Electricity, medium voltage {VN} market for electricity, medium voltage Cut-off, U	Ecoinvent v3.11	Appropriate technology	2023	Vietnam
Natural gas	Heat, district or industrial, natural gas {RoW} market for heat, district or industrial, natural gas Cut-off, U	Ecoinvent v3.11	Appropriate technology	2022	RoW
Light fuel oil	Heat, district or industrial, other than natural gas {RoW} heat production, light fuel oil, at industrial furnace 1MW Cut-off, U	Ecoinvent v3.11	Appropriate technology	2022	RoW
Use phase electricity	Electricity mix 2021/US US-EI U	US-EI 2.2	Appropriate technology	2023	United States

¹ 'RoW' stands for Rest of World (non-Europe) geography

3.3.5. Disposal

Disposal processes were obtained from the ecoinvent v3.11 and US-EI 2.2 databases. Processes specific to waste types, if available, were selected to correspond to the disposal of facility waste streams, packaging waste during installation, product replacement waste, and end-of-life waste streams. Rest of world or global data sets were selected to represent disposal outside of the US, since country-specific data sets were not available. **Table 18** lists the relevant disposal data sets used in the model.

Table 18. Key disposal data sets used in inventory analysis

Material disposal	Data set	Database	Technology	Last updated	Geography ¹
Municipal waste, landfilled	Municipal solid waste {RoW} treatment of municipal solid waste, sanitary landfill Cut-off, U	Ecoinvent v3.11	Appropriate technology	2024	RoW
Landfilled, hazardous waste	Municipal solid waste {GLO} treatment of municipal solid waste, unsanitary landfill, moist infiltration class (300mm) Cut-off, U	Ecoinvent v3.11	Appropriate technology	2024	GLO
Household sewage	Treatment, sewage, from residence, to wastewater treatment, class 2/US* US-EI U <i>Energy consumption removed manually.</i>	US-EI 2.2	Appropriate technology	2024	United States
Landfilled, cardboard packaging	Disposal, packaging cardboard, 0% water, to sanitary landfill/US* US-EI U	US-EI 2.2	Appropriate technology	2023	United States
Incinerated, cardboard packaging	Disposal, packaging cardboard, 0% water, to municipal incineration/US* US-EI U	US-EI 2.2	Appropriate technology	2023	United States
Landfilled, aluminum	Disposal, aluminum, 0% water, to sanitary landfill/US* US-EI U	US-EI 2.2	Appropriate technology	2023	United States
Ceramics, landfilled	Disposal, inert material, 0% water, to sanitary landfill/US* US-EI U	US-EI 2.2	Appropriate technology	2024	United States
Landfilled, polyethylene	Disposal, polyethylene, to US sanitary landfill/US US-EI U	US-EI 2.2	Appropriate technology	2024	United States
Landfilled, polyethylene terephthalate	Disposal, polyethylene terephthalate, 0% water, to sanitary landfill/US* US-EI U	US-EI 2.2	Appropriate technology	2024	United States
Landfilled, polypropylene	Disposal, polypropylene, 0% water, to sanitary landfill/US* US-EI U	US-EI 2.2	Appropriate technology	2024	United States
Landfilled, polyurethane	Disposal, polyurethane, 0% water, to sanitary landfill/US* US-EI U	US-EI 2.2	Appropriate technology	2024	United States

Landfilled, plastics	Disposal, plastics, mixture, to US sanitary landfill/US US-EI U	US-EI 2.2	Appropriate technology	2024	United States
Landfilled, paper	Disposal, paper, 0% water, to sanitary landfill/US* US-EI U	US-EI 2.2	Appropriate technology	2024	United States
Landfilled, other waste streams	Disposal, municipal solid waste, 0% water, to sanitary landfill/US* US-EI U	US-EI 2.2	Appropriate technology	2024	United States

¹ 'GLO' stands for global geography; 'RoW' stands for Rest of World (non-Europe) geography

3.4. Cut-off criteria

The time period over which inputs to and outputs from the system shall be accounted for is 100 years from the year for which the data set is deemed representative.

The cut-off criteria on a unit process level can be summarized as follows:

- All inputs and outputs to a (unit) process shall be included in the calculation of the pre-set parameters results, for which data are available. Data gaps shall be filled by conservative assumptions with average, generic or proxy data. Any assumptions for such choices shall be documented. Assumptions and proxies, whenever used, have been explained in this report.
- Mass – If a flow is less than 1% of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern. No known mass flow has been omitted in this study.
- Energy – If a flow is less than 1% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern. No known energy flow has been omitted in this study.
- Environmental relevance – If a flow meets the above criteria for exclusion, yet it is thought to potentially have a significant environmental impact, it is included. No known mass or energy flow has been omitted in this study.
- Hazardous and toxic materials – The study shall include all hazardous and toxic materials in the inventory therefore the cutoff rules shall not apply to such substances. All known hazardous waste released from the manufacturing facility have been included in this study.
- The sum of the neglected material flows does not exceed 5% of mass, energy or environmental relevance for flows indirectly related to the process (e.g., operating materials). No known mass flow has been omitted in this study.

In this report, barring insignificant quantities of wastewater treatment chemicals and reused resin molds, no known flows are deliberately excluded; therefore, these criteria have been met. The completeness of the bill of materials defined in this report satisfies the above-defined cut-off criteria.

3.5. Allocation

Whenever a system boundary is crossed, environmental inputs and outputs must be assigned to the different products. Where multi-inputs or multi-outputs are considered, the same applies. The PCR prescribes where and how allocation occurs in the modeling of the LCA.

All toilets being manufactured in TOTO facilities follow the same assembly process and consume the same quantity of resources, and annual resources provided for the assembly were evenly distributed based on the annual production quantity. Similar allocation was used for the tank system being manufactured in the Vietnam plant; annual resources were evenly distributed based on the annual production quantities. The toilet assembly has dedicated assembly lines, and since annual resources were reported for each, there are no other co-products being

manufactured in each case. No co-product allocation or allocation of multi-input processes are required.

For ceramic production in the TOTO Vietnam plant, multiple products (ceramic bowls and tanks) are manufactured. Mass allocation of the resources was sufficient, since all products go through the same set of operations. No allocation situation occurred requiring the allocation of product inputs and outputs into each co-product. Annual resources used for ceramic processing were normalized using the annual ceramic output mass to develop the inventory for resources per kg of ceramic output.

The model used in this report ensures that the sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation. This means that no double counting or omissions of inputs or outputs through allocation is occurring.

Allocation of reuse, recycling, and energy recovery is not applicable for this study.

3.6. Discussion of data quality

Inventory data quality is judged by its precision (measured, calculated, or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied on a study serving as a data source), and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the ecoinvent v3.11, US-EI 2.2, and Industry data 2.0 databases were used.

Precision and completeness

- *Precision:* As the relevant foreground data is primary data or modeled based on primary information sources of the owner of the technology, precision is considered to be high. Background data are from the ecoinvent v3.11 and US-EI 2.2 databases with documented precision to the extent available.
- *Completeness:* TOTO worked with its manufacturing partners to obtain a comprehensive set of primary data associated with the manufacturing processes. The product system was checked for mass balance and completeness of the inventory. The data set was considered complete based on our understanding of the manufacturing site and a review with key stakeholders on the TOTO team, and cut-off criteria were observed consistent with those prescribed in the PCR. Besides capital equipment, no data was knowingly omitted.

Consistency and reproducibility

- *Consistency:* Primary data were collected with a similar level of detail, while background data were sourced primarily from the ecoinvent database. Other databases were used if data were not available in ecoinvent, or the data set was judged to be more representative. Other methodological choices were made consistently throughout the model.
- *Reproducibility:* Reproducibility is warranted as much as possible through the disclosure of input-output data, data set choices, and modeling approaches in this report. Based on this information, a knowledgeable third party should be able to approximate the results of this study using the same data and modeling approaches.

Representativeness

- *Temporal:* All primary data were collected for January 2025 – December 2025, ensuring the representativeness of the manufacturing process. Secondary data obtained from external databases are typically representative of recent years. Time coverage of this primary data is considered excellent. Data necessary to model cradle-to-grave unit processes were sourced from SimaPro v10.3.0.1. Time coverage of the secondary datasets ranges from 2019 to 2025 and is considered good. Data sets older than 10 years were chosen because the closest represent the technology used to manufacture the material and are assumed to be more accurate than other potential proxies with more precise geography and temporal representativeness.
- *Geographical:* Primary data are representative of production in Vietnam. The upstream manufacturing processes of purchased components have been represented with the country of production. In general, secondary data were collected specific to the country under study. Where country-specific data were unavailable, global or rest-of-world averages were used to represent production in those locations. Geographical representativeness is therefore considered to be high.
- *Technological:* All primary and secondary data were modeled to be specific to the technologies under study. Technological representativeness is considered to be high.
- *Treatment of missing data:* Primary data were used for all manufacturing processes. Whenever available, supplier data was used for raw materials used in the production process. When primary data did not exist, secondary data for raw material production were obtained from the SimaPro database, as shown in Tables (from 14 to 18) in Section 3. Any proxies used for raw materials have also been detailed in Tables (from 14 to 18) in Section 3.

3.7. Comparability

ISO 21930:2017 section 5.5 highlights the following limitations and clarifications in EPD comparability: EPDs are comparable only if they use the same PCR (or sub-category PCR where applicable), include all relevant information modules, and are based on equivalent scenarios with respect to the context of construction works [3]. Per Sustainable Minds Part A, EPDs are not comparative assertions; that is, no claim of environmental superiority can be inferred or implied [4].

EPDs can only be compared when the same functional requirements between products are ensured and the requirements of ISO 21930:2017 section 5.5 are met. However, variations and deviations are possible. For example, different LCA software and background LCI data sets may lead to different results for the life cycle stages declared.

One cannot compare 75 years of use of a toilet in an average US environment to another unless the following conditions are met, including but not limited to the materials being functionally equivalent (same strength, durability, thermal properties, etc.), the environment it is installed in being the same (same usage, maintenance cleaning schedule, etc.), and an equivalent installation method being used with the same structural integrity of the wall. While it is theoretically possible to compare functionally equivalent assemblies, it is difficult in practice to design two truly functionally equivalent systems using the multiple criteria by which performance can be analyzed. Therefore, the report is not intended for comparative assertions.

3.8. Assumptions and limitations

A life cycle assessment of a product system is broad and complex, and it inherently requires assumptions and simplifications. The following assumptions and limitations of the study should be recognized:

- Assumptions for upstream processing operations regarding each purchased component were developed via suggestions from TOTO personnel and suppliers.
- It was assumed that the same manufacturing resources were consumed for the assembly of toilets (for all models) in all TOTO facilities.
- It is assumed that incoming water is municipal tap water, and no filtration is required.
- Data sets older than 10 years were chosen because they closest represent the technology used to manufacture the material and are assumed to be more accurate than other potential proxies with more precise geography and temporal representativeness.
- Available ecoinvent data sets were manually updated to represent the upstream component production in the supplier country. However, actual manufacturing operations and resources consumed for each component might vary.
- Manufacturing yield has been considered for each upstream component production based on TOTO's internal discussions and outreach with suppliers, but actual material losses during production of components vary.
- Each product was torn down manually to develop/verify the BOM. Discrepancies are possible in the identification of materials and upstream processing technologies.
- Generic data sets used for material inputs, transportation, and waste processing are considered good quality, but actual impacts from material suppliers, transport carriers, and local waste processing may vary.
- The impacts of resin molds, expected to be minimal, in ceramic production is excluded from the study.
- Some chemicals used in wastewater treatment in ceramic production plant with minimal share (annual facility consumption ≤ 1 kg) has been excluded.
- For materials with unknown suppliers and transport distances, a generic value of 2,000 km was used as suggested by PCR. However, actual transport distances might vary.
- The impact assessment methodology categories do not represent all possible environmental impact categories.
- Characterization factors used within the impact assessment methodology may contain varying levels of uncertainty.
- LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

4. IMPACT ASSESSMENT METHODS

4.1. Impact assessment characterization

The environmental indicators as required by the PCR are included as well as other indicators required to use the SM2026 Methodology [7] (see **Table 19**). The impact indicators are derived using the 100-year time horizon⁸ factors, where relevant, as defined by TRACI 2.2 classification and characterization [8]. Long-term emissions (>100 years) are not taken into consideration in the impact estimate. USEtox indicators⁹ are used to evaluate toxicity. Emissions from waste disposal are considered part of the product system under study, according to the “polluter pays principle”.

Table 19. Selected impact categories and units

Impact category	Unit	Description
Acidification	kg SO ₂ eq (sulphur dioxide)	This examines the potential for the product or process to contribute to acid rain resulting in the acidification of ecosystems and water bodies. Included are the emissions of sulfur dioxide and nitrogen oxides.
Ecotoxicity	CTUe	This evaluates the potential harm of the product or process on the aquatic and terrestrial ecosystems. Included are the release of toxic substances to the environment.
Freshwater eutrophication	kg P eq (phosphorus)	This category represents nutrient enrichment of inland waters (lakes, rivers) leading to oxygen depletion, algal blooms, etc.
Marine eutrophication	kg N eq (nitrogen)	This category represents nutrient enrichment of coastal and marine environments, where nitrogen is typically the limiting nutrient.
Global warming	kg CO ₂ eq (carbon dioxide)	This category represents the total global warming potential as the sum of Global warming potential from fossil fuels (GWP _{fossil}), Global warming potential from biogenic (GWP _{biogenic}), and Global warming potential from land use and land use change (GWP _{luluc})
Ozone depletion	kg CFC-11 eq	This evaluates the potential of the product or process to deplete the earth's ozone layer. Included are the emissions of ozone-depleting substances.
Carcinogenics	CTUh	This measures the potential of the process or product to contribute to human cancer hazards. Included are the release of carcinogenic substances.
Non-carcinogenics	CTUh	This measures the potential of the process or product to contribute to non-cancerous human health hazards. Included are the release of non-carcinogenic substances.
Respiratory effects	kg PM _{2.5} eq (fine particulates)	This specifically accesses the potential health impacts of the process or product related to the exposure of fine particulate matters. Included are the release of particulate matters that are 2.5 microns or less in diameter and can penetrate deep into the respiratory systems.
Smog	kg O ₃ eq (ozone)	This measures the potential of the product or process to contribute to the formation of ground level ozone. Included are the substances like carbon monoxide, nitrogen oxides, and volatile organic substances (VOCs).

⁸ The 100-year period relates to the period in which the environmental impacts are modeled. This is different from the time period of the declared unit. The two periods are related as follows: all environmental impacts that are created in the period of the declared unit are modeled through life cycle impact assessment using a 100-year time horizon to understand the impacts that take place.

⁹ USEtox is available in TRACI and at <http://www.usetox.org/>

This LCA study follows the cut-off method. All environmental impacts associated with the production, use, and disposal of a product are allocated to the original product's life cycle. Secondary products (like recycled materials) enter the system with no burdens attached, as they do not carry over the environmental burdens from the original product. No credits are given for flows exiting the product system. With respect to global warming potential, biogenic carbon is included in impact category calculations. The biogenic carbon measured in this study originates from packaging materials, and no raw materials in the toilets are expected to contain biogenic carbon. Greenhouse gas emissions from land-use change are expected to be insignificant and were not reported. Carbon emissions during carbonation and calcination are also considered in this study, and no carbonation or calcination are expected to occur during the production and manufacture of the Aurora toilets.

It shall be noted that the above impact categories represent impact potentials. They are approximations of environmental impacts that could occur if the emitted molecules follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

The results from the impact assessment indicate potential environmental effects and do not predict actual impacts on category endpoints, the exceedance of thresholds, or safety margins or risks.

4.2. Normalization and weighting

To arrive at a single score indicator, normalization [9] and weighting [10] as shown in **Table 20** conforming to the SM 2026 Methodology were applied. The SM 2026 Methodology uses TRACI 2.2 impact categories developed by U.S. EPA, and North American normalization and weighting values developed by EPA and NIST respectively, to calculate single figure LCA results. Sustainable Minds recognizes that weighting is socially defined based on the importance that society attaches to the different environmental impact categories. However, these single score indicators serve as an easy starting point to get to know the product under consideration across all impact categories, rather than focusing all efforts on just one impact category (like global warming potential). The interpretation of the results starts with the Sustainable Minds single score results and then allows users to further explore the underlying impact categories individually. Details including the characterization models, factors, and methods used, including all assumptions and limitations, can be found in the SM 2026 Methodology Report [7].

Table 20. Normalization and weighting factors

Impact category	Normalization	Weighting (%)
Ozone Depletion	0.161	2.7
Global Warming	24200	39.8
Smog	1390	5.5
Acidification	90.8	4.1
Cacinogenics	5.07E-05	11
Non carcinogenics	1.05E-03	6.8
Respiratory effects	24.3	12.3
Ecotoxicity	11100	9.6
Freshwater eutrophication	0.438	4.1
Marine eutrophication	19.1	4.1

5. ASSESSMENT AND INTERPRETATION

This chapter includes the results from the LCA for the product studied. It details the results per functional unit, outlines the sensitivity analyses, and concludes with recommendations.

5.1. Resource use and waste flows

Resource use indicators, output flows and waste category indicators, and carbon emissions and removals are presented in this section. These life cycle inventory (LCI) indicators reflect the flows from and to nature for the product system, prior to characterization using an impact assessment methodology to calculate life cycle impact assessment (LCIA) results (as shown in section 5.2).

LCI flows were calculated with the help of American Center for Life Cycle Assessment's (ACLCA) guidance for calculating the ISO 21930:2017 metrics [11]. The consumption of freshwater indicator, which was calculated in accordance with this guidance, is reported in compliance with ISO 14046. Use of renewable and non-renewable energy resources with energy content were calculated using the Cumulative Energy Demand (LHV) impact assessment methodology [12]. Abiotic depletion potential was calculated using the CML impact assessment methodology [13]. LCI flows were reported in conformance to ISO 21930:2017 [3].

Resource use indicators represent the amount of materials consumed to produce not only the product itself but also the raw materials, electricity, natural gas, etc. that go into the product's life cycle.

Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process and is expressed in energy demand from renewable and non-renewable resources. Efficiencies in energy conversion are considered when calculating primary energy demand from process energy consumption. Water use represents the total water used over the entire life cycle. No renewable energy was used in production beyond that accounted for in the electricity grid mix used.

Hazardous and non-hazardous wastes are calculated based on the amount of waste generated during the life cycle of each product studied, mainly during the manufacturing of the products. All waste treatments in models were considered based on the local waste management code and the assumptions mentioned in the PCR. Waste treatments included within the system boundary are reported. Unrecyclable wastes either are disposed of in landfills or incinerated.

When transforming the inputs and outputs of combustible material into inputs and outputs of energy, the net caloric value specific to the material was applied based on scientifically accepted values. There is no biogenic carbon associated with the product, but biogenic carbon relevant to packaging materials has been reported per life cycle stage. CO₂ from calcination and carbonation does not apply to these studied products. **Table 21** represents all the resource use and waste flow indicators evaluated in this study, along with the acronyms used.

Table 21. Resource use and waste flow indicators

Indicator	Acronym used
<i>Resource use indicators</i>	
Renewable primary energy used as energy carrier (fuel)	RPR_E
Renewable primary resources with energy content used as material	RPR_M
Total use of renewable primary resources with energy content	RPR_{total}
Non-renewable primary resources used as an energy carrier (fuel)	NRPR_E
Non-renewable primary resources with energy content used as material	NRPR_M
Total use of non-renewable primary resources with energy content	NRPR_{total}
Secondary materials	SM
Renewable secondary fuels	RSF
Non-renewable secondary fuels	NRSF
Recovered energy	RE
Use of net fresh water resources	FW
Abiotic depletion potential (fossil)	ADP_f
<i>Output flows and waste category indicators</i>	
Hazardous waste disposed	HWD
Non-hazardous waste disposed	NHWD
High-level radioactive waste, conditioned, to final repository	HLRW
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW
Components for re-use	CRU
Materials for recycling	MR
Materials for energy recovery	MER
Exported energy	EE
<i>Carbon emissions and removals</i>	
Biogenic Carbon Removal from Product	BCRP
Biogenic Carbon Emission from Product	BCEP
Biogenic Carbon Removal from Packaging	BCRK
Biogenic Carbon Emission from Packaging	BCEK
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	CBCEW
Calcination Carbon Emissions	CCE
Carbonation Carbon Removals	CCR
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	CWNR

Resource use, output flows, waste categories, and carbon emissions & removals for each product type have been tabulated in the sections below.

5.1.1. Aurora Toilet: 1.28 gallons per flush (gpf)

Table 22 shows resource use, output and waste flows, and carbon emissions and removals for the Aurora toilet per functional unit.

Table 22. Resource use, output and waste flows, and carbon emissions and removals for the Aurora toilet per functional unit

Parameters	Unit	Production	Construction/Installation			Use							End of life				Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4		
Resource use indicators																	
RPR _E	MJ, NCV	5.79E+02	2.56E-01	3.35E-01	0	6.02E+00	2.05E+00	6.72E+03	0	0	2.09E+03	0	1.73E-02	0	6.09E-02	7.69E+03	
RPR _M	MJ, NCV	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
RPR _{total}	MJ, NCV	5.79E+02	2.56E-01	3.35E-01	0	6.02E+00	2.05E+00	6.72E+03	0	0	2.09E+03	0	1.73E-02	0	6.09E-02	7.69E+03	
NRPR _E	MJ, NCV	3.01E+03	1.30E+02	8.53E+00	0	8.15E+01	2.78E+01	6.77E+04	0	0	2.06E+04	0	3.96E+00	0	4.45E+00	7.47E+04	
NRPR _M	MJ, NCV	1.99E+01	3.86E+00	3.86E+00	0	3.86E+00	0.00E+00	5.88E+01	0	0	0.00E+00	0	3.86E+00	0	3.86E+00	9.80E+01	
NRPR _{total}	MJ, NCV	3.03E+03	1.34E+02	1.24E+01	0	8.53E+01	2.78E+01	6.78E+04	0	0	2.06E+04	0	7.82E+00	0	8.31E+00	7.48E+04	
SM	kg	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
RSF	MJ, NCV	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
NRSF	MJ, NCV	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
RE	MJ, NCV	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
FW	m ³	9.14E-04	1.70E-03	1.61E-03	0	1.02E-03	0.00E+00	3.05E-04	0	0	8.20E-04	0	7.30E-04	0	7.80E-04	7.96E-03	
ADP _f	MJ, LHV	2.72E+03	1.32E+02	1.15E+01	0	7.87E+01	9.01E+01	1.52E+04	0	0	1.46E+04	0	7.71E+00	0	8.11E+00	0.00E+00	
Output flows and waste category indicators																	
HWD	kg	6.40E-01	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	6.40E-01	
NHWD	kg	2.99E+01	1.20E+00	1.43E+00	0	2.93E+01	1.11E+00	1.32E+02	0	0	0.00E+00	0	5.40E-01	0	2.59E+01	2.22E+02	
HLRW	kg	7.81E-03	5.93E-04	3.89E-05	0	3.44E-04	0.00E+00	1.47E+01	0	0	1.51E+01	0	1.61E-06	0	4.81E-06	1.49E+01	
ILLRW	kg	4.07E-05	3.38E-07	1.25E-07	0	7.76E-07	4.14E-07	8.05E-05	0	0	5.58E-05	0	1.54E-08	0	2.46E-08	1.43E-03	
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
MR	kg	0.00E+00	0.00E+00	0.00E+00	0	2.93E+01	0.00E+00	4.45E+01	0	0	0.00E+00	0	2.20E-01	0	2.20E-01	7.42E+01	
MER	kg	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
EE	MJ	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
Carbon emissions and removals																	
BCRP	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
BCEP	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
BCRK	kg CO ₂	7.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	1.05E+01	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	7.00E+00	
BCEK	kg CO ₂	0.00E+00	0.00E+00	7.00E+00	0	0.00E+00	0.00E+00	1.05E+01	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	7.00E+00	
CBCEW	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
CCE	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
CCR	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
CWNR	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	

5.1.2. Aurora Toilet: 1.0gallon per flush (gpf)

Table 23 shows resource use, output and waste flows, and carbon emissions and removals respectively for the Aurora toilet 1.0gpf per functional unit.

Table 23. Resource use, output and waste flows, and carbon emissions and removals for the Aurora toilet per functional unit

Parameters	Unit	Production	Construction/ Installation			Use							End of life				Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4		
Resource use indicators																	
RPR _E	MJ, NCV	5.79E+02	2.56E-01	3.35E-01	0	6.02E+00	2.05E+00	5.47E+03	0	0	1.63E+03	0	1.73E-02	0	6.09E-02	3.16E+03	
RPR _M	MJ, NCV	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
RPR _{total}	MJ, NCV	5.79E+02	2.56E-01	3.35E-01	0	6.02E+00	2.05E+00	5.47E+03	0	0	1.63E+03	0	1.73E-02	0	6.09E-02	3.16E+03	
NRPR _E	MJ, NCV	3.01E+03	1.30E+02	8.53E+00	0	8.15E+01	2.78E+01	5.53E+04	0	0	1.61E+04	0	3.96E+00	0	4.45E+00	2.53E+04	
NRPR _M	MJ, NCV	1.99E+01	3.86E+00	3.86E+00	0	3.86E+00	0.00E+00	5.88E+01	0	0	0.00E+00	0	3.86E+00	0	3.86E+00	9.80E+01	
NRPR _{total}	MJ, NCV	3.03E+03	1.34E+02	1.24E+01	0	8.53E+01	2.78E+01	5.54E+04	0	0	1.61E+04	0	7.82E+00	0	8.31E+00	2.54E+04	
SM	kg	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
RSF	MJ, NCV	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
NRSF	MJ, NCV	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
RE	MJ, NCV	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
FW	m ³	1.20E-03	1.70E-03	1.61E-03	0	1.02E-03	0.00E+00	2.91E-04	0	0	6.40E-04	0	7.23E-04	0	7.80E-04	9.55E-03	
ADP _f	MJ, LHV	2.72E+03	1.32E+02	1.15E+01	0	7.87E+01	9.01E+01	1.52E+04	0	0	1.13E+04	0	7.71E+00	0	8.11E+00	0.00E+00	
Output flows and waste category indicators																	
HWD	kg	6.40E-01	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	6.40E-01	
NHWD	kg	2.99E+01	1.20E+00	1.43E+00	0	2.93E+01	1.11E+00	1.32E+02	0	0	0.00E+00	0	5.40E-01	0	2.59E+01	2.22E+02	
HLRW	kg	7.81E-03	5.93E-04	3.89E-05	0	3.44E-04	0.00E+00	1.47E+01	0	0	6.94E-02	0	1.61E-06	0	4.81E-06	1.62E-01	
ILLRW	kg	4.07E-05	3.38E-07	1.25E-07	0	7.76E-07	4.14E-07	8.05E-05	0	0	6.37E-04	0	1.54E-08	0	2.46E-08	1.43E-03	
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
MR	kg	0.00E+00	0.00E+00	0.00E+00	0	2.93E+01	0.00E+00	4.45E+01	0	0	0.00E+00	0	2.20E-01	0	2.20E-01	7.42E+01	
MER	kg	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
EE	MJ	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
Carbon emissions and removals																	
BCRP	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
BCEP	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
BCRK	kg CO ₂	7.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	1.05E+01	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	7.00E+00	
BCEK	kg CO ₂	0.00E+00	0.00E+00	7.00E+00	0	0.00E+00	0.00E+00	1.05E+01	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	7.00E+00	
CBCEW	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
CCE	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
CCR	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	
CWNR	kg CO ₂	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0	0	0.00E+00	0	0.00E+00	0	0.00E+00	0.00E+00	

5.2. Life cycle impact assessment (LCIA)

It shall be reiterated at this point that the reported impact categories represent impact potentials; they are approximations of environmental impacts that could occur if the emitted molecules follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen declared unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

Life cycle impact assessment (LCIA) results are shown per functional unit. Unlike life cycle inventories, which only report sums for individual inventory flows, the LCIA includes a classification of individual emissions with regard to the impacts they are associated with and subsequently a characterization of the emissions by a factor expressing their respective contribution to the impact category indicator. The end result is a single metric for quantifying each potential impact, such as "Global Warming Potential".

The impact assessment results are calculated using characterization factors published by the United States Environmental Protection Agency. The TRACI 2.2 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts 2.1) methodology is the most widely applied impact assessment method for U.S. LCA studies. The SM 2026 Methodology is also applied to come up with single score results for the sole purpose of representing total impacts per life cycle phase to explain where in the product life cycle greatest impacts are occurring and what is contributing to the impacts.

TRACI impact categories are globally deemed mature enough to be included in Type III environmental declarations. Other categories are being developed and defined and LCA should continue making advances in their development; however, the EPD users shall not use additional measures for comparative purposes. All impact categories from TRACI are used to calculate single score millipoints using the SM2026 Methodology, but it should be noted that there are known limitations related to these impact categories due to their high degree of uncertainty.

5.2.1. Aurora Toilet: 1.28 gallons per flush

In the cradle-to-grave life cycle of the product, when looking at individual life cycle modules, [B4], replacement module, during 75 years of building's life, has the most significant contributions to all categories: : smog (~63.52%), and ecotoxicity (~57.52%). A total of 2.75 product replacements are needed to meet the estimated service life of 75 years. Since each product replacement requires a complete set of new product manufacturing, distribution, installation, and disposal activities to replace the old product, the replacement impacts contribute significantly to the total life cycle impacts.

The contribution of the delivery and installation of the product [A4-A5] which are covered under the construction stage is associated with the transportation for delivery to the market and the disposal of packaging materials which are mainly corrugated cardboard. The impact from repair [B3], replacement of Trip lever handle, Flapper seal and Fill valve seal over 75 years, varies from 0.2 to 8.80 % in different categories.

Impacts in the product maintenance stage (B2) are driven by the use of SLS solution for cleaning various components. The replacement of other components has a minimal share of impacts within B2. The product repair (B3) stage also has

considerable impacts, but they are dispersed across various replaced components, so there is not a single standout component or process contributing heavily. Impacts coming from all other life cycle stages are minimal.

Operational water use (B7) leads impacts for three impact categories in the overall life cycle: ozone depletion (~55.43%), carcinogenics (~59.83%), and global warming (~49.55%). More than 98% of each of those comes from municipal sewage treatment of the sewage generated during B7.

The LCIA results of the Aurora toilet per functional unit are shown in **Table 24**.

Table 24. Life cycle impact assessment results for the Aurora 1.28gpf toilet per functional unit

Impact categories	Unit	Producti on	Construction/ Installation			Use						End of life				Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	
Ozone depletion	kg CFC-11 eq	3.51E-06	8.09E-09	1.03E-07	0	1.12E-07	4.33E-07	1.95E-05	0	0	2.94E-05	0	5.78E-10	0	9.47E-10	5.31E-05
Global warming	kg CO2 eq	1.89E+02	1.06E+01	3.09E+00	0	3.51E+00	5.49E+00	1.07E+03	0	0	1.25E+03	0	6.16E-01	0	5.30E-01	2.53E+03
Smog	kg O3 eq	1.95E+01	4.07E+00	1.01E+01	0	1.70E-01	4.58E-01	1.45E+02	0	0	4.93E+01	0	9.82E-02	0	6.83E-02	2.28E+02
Acidification	kg SO2 eq	9.31E-01	1.38E-01	2.85E-01	0	1.95E-02	6.16E-02	6.20E+00	0	0	5.02E+00	0	3.41E-03	0	2.42E-03	1.27E+01
Respiratory effects	kg PM2.5 eq	5.89E-02	2.26E-03	3.05E-03	0	1.68E-03	7.67E-03	3.26E-01	0	0	3.85E-01	0	5.32E-05	0	2.54E-04	7.85E-01
Freshwater eutrophication	kg P eq	4.16E-03	2.33E-05	2.28E-05	0	6.63E-05	2.65E-03	2.16E-02	0	0	2.76E-02	0	1.38E-06	0	4.54E-06	5.62E-02
Marine eutrophication	kg N eq	1.67E-01	3.39E-02	8.47E-02	0	1.63E-03	4.94E-03	1.23E+00	0	0	4.36E-01	0	8.21E-04	0	5.89E-04	1.96E+00
Additional impact categories																
Carcinogenics	CTUh	3.06E-06	1.46E-07	1.06E-08	0	7.15E-08	2.49E-07	1.68E-05	0	0	3.01E-05		8.52E-09	0	3.58E-09	5.05E-05
Non carcinogenics	CTUh	3.36E-05	1.37E-06	1.01E-07	0	7.01E-07	3.16E-05	1.86E-04	0	0	1.06E-04		7.95E-08	0	1.91E-08	3.60E-04
Ecotoxicity	CTUe	1.64E+02	2.62E+01	1.64E+00	0	1.72E+00	3.85E+01	9.74E+02	0	0	4.88E+02		1.52E+00	0	3.63E-01	1.70E+03

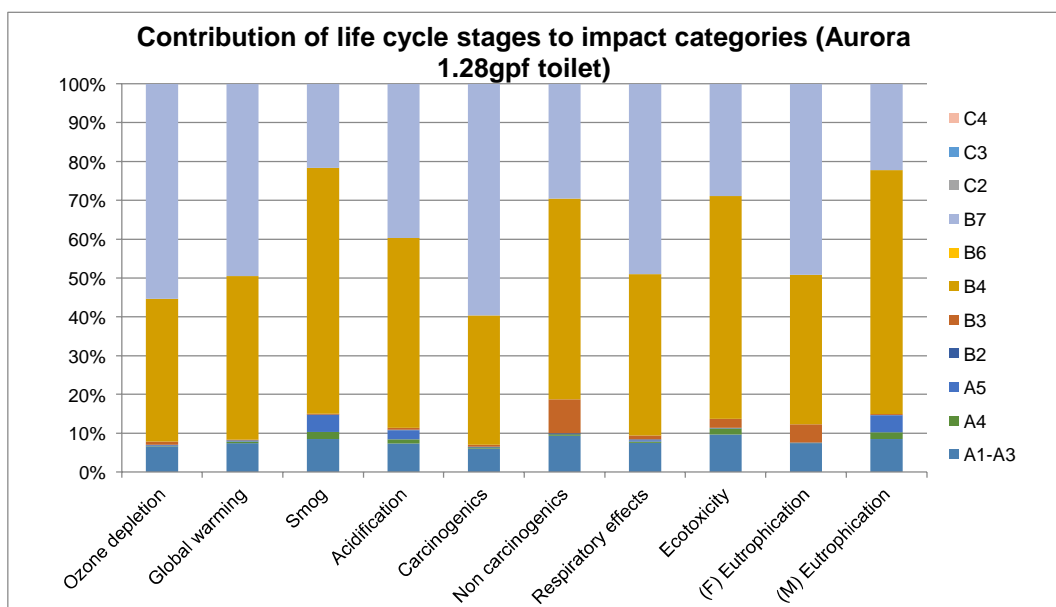
As evident in **Table 25**, the production stage (A1-A3) also demonstrates significant impacts across all impact categories. Product manufacturing (A3) follows the impacts from raw material acquisition (A1), with insignificant impacts from raw material transportation (A2). Most of the impacts within A3 come from energy usage in the ceramic manufacturing operations. Product distribution (A4) is also responsible for considerable impacts, with most impacts coming from sea transportation of the product from Vietnam to the US and road transportation to end users.

Table 25. Percent contributions of each life cycle module to each impact category for Aurora 1.28gpf toilet per functional unit

Impact categories	Unit	Production	Construction/Installation		Use							End of life				Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	
Ozone depletion	%	6.63	0.02	0.20	0.00	0.21	0.82	36.79	0.00	0.00	55.43	0.00	0.00	0.00	0.00	100%
Global warming	%	7.46	0.42	0.12	0.00	0.14	0.22	42.20	0.00	0.00	49.55	0.00	0.02	0.00	0.02	100%
Smog	%	8.55	1.79	4.42	0.00	0.07	0.20	63.52	0.00	0.00	21.65	0.00	0.04	0.00	0.03	100%
Acidification	%	7.37	1.09	2.26	0.00	0.15	0.49	49.08	0.00	0.00	39.80	0.00	0.03	0.00	0.02	100%
Respiratory effects	%	7.56	0.29	0.39	0.00	0.22	0.98	41.84	0.00	0.00	49.31	0.00	0.01	0.00	0.03	100%
Freshwater eutrophication	%	7.47	0.04	0.04	0.00	0.12	4.75	38.86	0.00	0.00	49.61	0.00	0.00	0.00	0.01	100%
Marine eutrophication	%	8.54	1.73	4.33	0.00	0.08	0.25	63.04	0.00	0.00	22.24	0.00	0.04	0.00	0.03	100%
Additional impact categories																
Carcinogenics	%	6.07	0.29	0.02	0.00	0.14	0.50	33.44	0.00	0.00	59.83	0.00	0.02	0.00	0.01	100%
Non carcinogenics	%	9.35	0.38	0.03	0.00	0.20	8.80	51.89	0.00	0.00	29.60	0.00	0.02	0.00	0.01	100%
Ecotoxicity	%	9.67	1.55	0.10	0.00	0.10	2.28	57.52	0.00	0.00	28.86	0.00	0.09	0.00	0.02	100%

Impacts in the product maintenance stage (B2) are driven by the use of SLS solution for cleaning various components. The replacement of other components has a minimal share of impacts within B2. The product repair (B3) stage also has small impacts, and they are dispersed across various replaced toilet components; there is not a single standout component or process contributing heavily. Impacts coming from all other life cycle stages are minimal.

The percent contribution of each of the cradle-to-grave life cycle modules to the total impacts is also presented in **Figure 6**.



F = Freshwater, M = Marine

Figure 6. Contribution analysis of each impact category for Aurora 1.28gpf toilet per functional unit

The SM2026 Methodology single figure millipoint (mPt) score by life cycle module for this product is presented in **Table 26**. In terms of single figure scores and overall environmental impacts, operational water use (B7) dominate the results (~48.53%). This is followed by product replacements (B4) which accounts for ~41.65% of the total. The production stage (A1-A3) contributes ~7.17% while repair parts (B3) contributes 1.45% of the total.

Table 26. SM millipoint scores for the Aurora 1.28gpf toilet per functional unit

Parameters	Unit	Production	Construction/Installation		Use							End of life				Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	
SM single figure score	mPts	1.55E+01	1.12E+00	8.21E-01	0	3.07E-01	3.35E+00	8.94E+01	0	0	1.07E+02	0	5.45E-02	0	2.76E-02	2.17E+02

5.2.2. Aurora Toilet: 1.0 gallons per flush

In the cradle-to-grave life cycle of the product, when looking at individual life cycle modules, product replacement (B4) contributes the most to impact results for five evaluated impact categories: smog (~66.68%), ecotoxicity (~61.39%), marine eutrophication (~66.26%), and acidification (~53.76%). A total of 2.75 product replacements are needed to meet the estimated service life of 75 years. Since each product replacement requires a complete set of new product manufacturing, distribution, installation, and disposal activities to replace the old product, the replacement impacts contribute significantly to the total life cycle impacts.

Operational water use (B7) dominates the impacts for three impact categories in the overall life cycle: ozone depletion (~49.28%), carcinogenics (~53.78%), and global warming (~43.42%). More than 98% of each of those comes from municipal sewage treatment of the sewage generated during B7.

The LCIA results of the Aurora 1.0gpf toilet per functional unit are shown in **Table 27**. The percent contribution of each of the cradle-to-grave life cycle modules to the total impacts is tabulated in **Table 28**.

Table 27. Life cycle impact assessment results for the Aurora 1.00gpf toilet per functional unit

Impact categories	Unit	Producti on	Construction/ Installation		Use							End of life				Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	
Ozone depletion	kg CFC-11 eq	3.51E-06	8.09E-09	1.03E-07	0.00	1.12E-07	4.33E-07	1.95E-05	0.00	0.00	2.30E-05	0.00	5.78E-10	0.00	9.47E-10	4.66E-05
Global warming	kg CO2 eq	1.89E+02	1.06E+01	3.09E+00	0.00	3.51E+00	5.49E+00	1.07E+03	0.00	0.00	9.79E+02	0.00	6.16E-01	0.00	5.30E-01	2.26E+03
Smog	kg O3 eq	1.95E+01	4.07E+00	1.01E+01	0.00	1.70E-01	4.58E-01	1.45E+02	0.00	0.00	3.85E+01	0.00	9.82E-02	0.00	6.83E-02	2.18E+02
Acidification	kg SO2 eq	9.31E-01	1.38E-01	2.85E-01	0.00	1.95E-02	6.16E-02	6.20E+00	0.00	0.00	3.93E+00	0.00	3.41E-03	0.00	2.42E-03	1.16E+01
Respiratory effects	kg PM2.5 eq	5.89E-02	2.26E-03	3.05E-03	0.00	1.68E-03	7.67E-03	3.26E-01	0.00	0.00	3.00E-01	0.00	5.32E-05	0.00	2.54E-04	7.01E-01
Freshwater eutrophication	kg P eq	4.16E-03	2.33E-05	2.28E-05	0.00	6.63E-05	2.65E-03	2.16E-02	0.00	0.00	2.16E-02	0.00	1.38E-06	0.00	4.54E-06	5.02E-02
Marine eutrophication	kg N eq	1.67E-01	3.39E-02	8.47E-02	0.00	1.63E-03	4.94E-03	1.23E+00	0.00	0.00	3.40E-01	0.00	8.21E-04	0.00	5.89E-04	1.87E+00
Additional impact categories																
Carcinogenics	CTUh	3.06E-06	1.46E-07	1.06E-08	0.00	7.15E-08	2.49E-07	1.68E-05	0.00	0.00	2.35E-05	0.00	8.52E-09	0.00	3.58E-09	4.39E-05
Non carcinogenics	CTUh	3.36E-05	1.37E-06	1.01E-07	0.00	7.01E-07	3.16E-05	1.86E-04	0.00	0.00	8.31E-05	0.00	7.95E-08	0.00	1.91E-08	3.37E-04
Ecotoxicity	CTUe	1.64E+02	2.62E+01	1.64E+00	0.00	1.72E+00	3.85E+01	9.74E+02	0.00	0.00	3.82E+02	0.00	1.52E+00	0.00	3.63E-01	1.59E+03

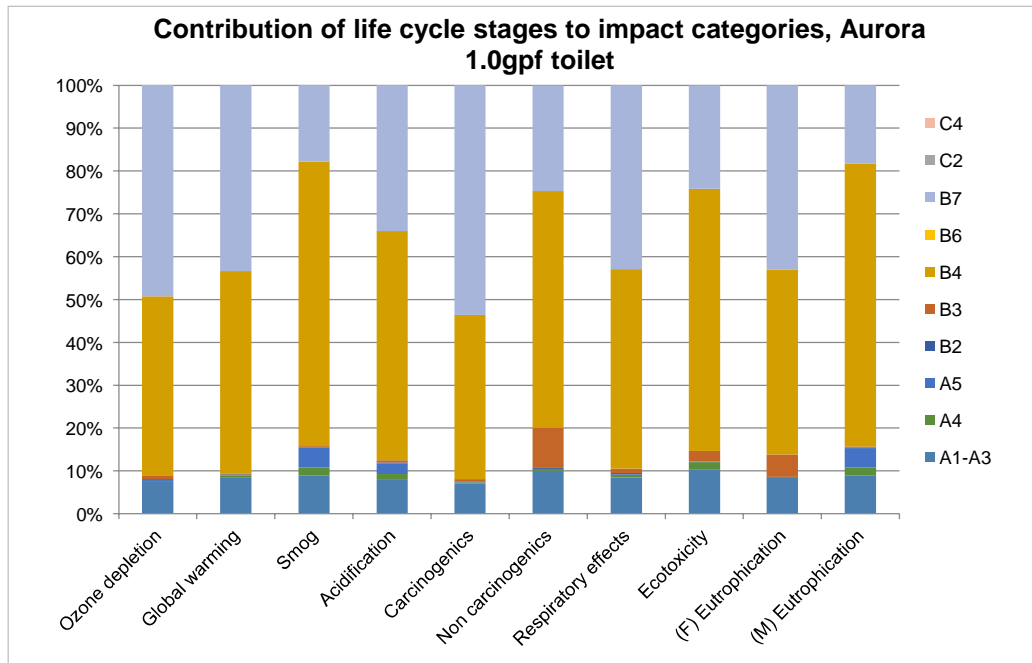
As evident in **Table 28**, the production stage (A1-A3) also demonstrates significant impacts across all impact categories. Product manufacturing (A3) follows the impacts from raw material acquisition (A1), with insignificant impacts from raw material transportation (A2). Most of the impacts within A3 come from energy usage in the ceramic manufacturing operations, while raw materials for the toilets make up the largest share within A1 followed by the raw materials for the tank components. Product distribution (A4) is also responsible for considerable impacts, with most impacts coming from sea transportation of the product and road transportation to end users.

Impacts in the product maintenance stage (B2) are driven by the use of SLS solution for cleaning various components. The replacement of other components has a minimal share of impacts within B2. The product repair (B3) stage also has considerable impacts, but they are dispersed across various replaced toilet components, so there is not a single standout component or process contributing heavily. Impacts coming from all other life cycle stages are minimal.

Table 28. Percent contributions of each life cycle module to each impact category for Aurora 1.0gpf toilet per functional unit

Impact categories	Unit	Production	Construction/Installation		Use							End of life				Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	
Ozone depletion	%	7.54	0.02	0.22	0.00	0.24	0.93	41.87	0.00	0.00	49.28	0.00	0.00	0.00	0.00	100%
Global warming	%	8.36	0.47	0.14	0.00	0.16	0.24	47.33	0.00	0.00	43.42	0.00	0.03	0.00	0.02	100%
Smog	%	8.97	1.87	4.64	0.00	0.08	0.21	66.68	0.00	0.00	17.76	0.00	0.05	0.00	0.03	100%
Acidification	%	8.07	1.20	2.48	0.00	0.17	0.53	53.76	0.00	0.00	34.06	0.00	0.03	0.00	0.02	100%
Respiratory effects	%	8.47	0.32	0.44	0.00	0.24	1.10	46.89	0.00	0.00	43.18	0.00	0.01	0.00	0.04	
Freshwater eutrophication	%	8.38	0.05	0.05	0.00	0.13	5.33	43.59	0.00	0.00	43.48	0.00	0.00	0.00	0.01	100%
Marine eutrophication	%	8.98	1.82	4.55	0.00	0.09	0.27	66.26	0.00	0.00	18.26	0.00	0.04	0.00	0.03	100%
Additional impact categories																
Fossil fuel depletion	%	6.99	0.33	0.02	0.00	0.16	0.57	38.48	0.00	0.00	53.78	0.00	0.02	0.00	0.01	100%
Ecotoxicity	%	10.00	0.41	0.03	0.00	0.21	9.41	55.48	0.00	0.00	24.73	0.00	0.02	0.00	0.01	100%
Carcinogenics	%	10.32	1.65	0.10	0.00	0.11	2.43	61.39	0.00	0.00	24.06	0.00	0.10	0.00	0.02	100%

The percent contribution of each of the cradle-to-grave life cycle modules to the total impacts is also presented in **Figure 7**.



F = Freshwater, M = Marine

Figure 7. Contribution analysis of each impact category for Aurora 1.0gpf toilet per functional unit

The SM2026 Methodology single figure millipoint (mPt) score by life cycle module for this product is presented in **Table 29**. In terms of single figure scores and overall environmental impacts, product replacements (B4) dominate the results (~46.60%). This is followed by operational water use (B7) which accounts for

~42.42% of the total. The production stage (A1-A3) contributes ~8.02% while repair parts (B3) contributes 1.62% of the total.

Table 29. SM millipoint scores for the Aurora 1.00gpf toilet per functional unit

Parameters	Unit	Production	Construction/ Installation		Use							End of life				Total
		A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	
SM single figure score	mPts	1.55E+01	1.12E+00	8.21E-01	0	3.07E-01	3.35E+00	8.94E+01	0	0.00E+00	8.33E+01	0	5.45E-02	0	2.76E-02	1.94E+02

5.2.3. Analysis of impact drivers

For each impact category of interest to TOTO, detailed analyses were performed to identify major unit processes that contribute significantly to the overall product life cycle impacts of both Aurora toilets in 1.28gpf and 1.0gpf. **Table 30** lists the major drivers with >5% contribution to the overall life cycle impacts of the product.

Table 30. Drivers of Aurora 1.28gpf and 1.0gpf toilet life cycle impacts

Impact categories	Major flows (with impacts greater than 5%)	Actual contribution	
		Aurora 1.28gpf	Aurora 1.0gpf
Ozone Depletion	Product replacement	41.71%	46.83%
	Sewage treatment	49.98%	43.84%
	Electricity for municipal upstream water supply, and downstream sewage treatment	49.98%	43.84%
Global warming	Product replacement	42.41%	47.54%
	Electricity for municipal upstream water supply, and downstream sewage treatment	49.34%	43.21%
	Sewage treatment	49.34%	43.21%
Smog	Product replacement	63.65%	66.79%
	Sewage treatment	21.50%	17.62%
	Electricity for municipal upstream water supply, and downstream sewage treatment	21.50%	17.62%
Acidification	Product replacement	49.26%	53.93%
	Sewage treatment	39.58%	33.85%
	Electricity for municipal upstream water supply, and downstream sewage treatment	39.58%	33.85%
Freshwater Eutrophication	Sewage treatment	48.47%	52.99%
Marine Eutrophication	Sewage treatment	47.33%	53.11%
Fossil fuel depletion	Sewage treatment	39.02%	33.33%
	Product replacement	39.02%	33.33%
	Electricity for municipal upstream water supply, and downstream sewage treatment	52.38%	57.04%

5.3. Sensitivity analysis

Two main parameters that influence the life cycle impacts of the Aurora toilets are the durability of the product which affects product replacement during the ESL and the consumption of water for toilet operations during product use. Electricity is also required for the municipal water supply and sewage systems.

Impacts due to this water and electricity consumption are expected to vary depending on the location and its available electricity grid mix. Similarly, with product replacements the durability of the product is also expected to change the

product impacts. Two sets of sensitivity analyses were performed, with the first varying the product use location and the second varying the product durability.

5.3.1. Change in product usage location

Sensitivity analyses were performed to check the impact of changing electricity grid mixes. After analyzing potential CO₂-equivalent emissions per unit of electricity for each of the 27 available eGRID subregions, the subregions with the highest and lowest impacts have been used for this analysis. MROE, *Midwest Reliability Organization – East*, is the regional mix with the highest CO₂ emissions per unit electricity. NYUP, *Northeast Power Coordinating Council – Upstate NY*, is the regional mix with the lowest. Life cycle impact assessment results have been generated for use of the Aurora toilets in both MORE and NYUP eGRID subregions and have been compared with the average results. Only the change in potential CO₂-equivalent emissions was evaluated; however, similar changes were expected to be observed in other impact categories.

As shown in **Table 31**, B7 CO₂-equivalent emissions increased in the MORE subregion, while the emissions decreased in the NYUP subregion. The total life cycle CO₂-equivalent emissions in MROE were ~30 % higher than the baseline, while they were ~32% lower in NYUP.

Table 31. Sensitivity analysis of electricity grid mix region choice on GWP emissions per functional unit

eGRID subregion	B7 (operational water use)		Total life cycle	
	kg CO ₂ -eq emissions	% change	kg CO ₂ -eq emissions	% change
Aurora 1.28gpf Toilet				
Baseline	1.25E+03	N/A	2.53E+03	N/A
NYUP	7.25E+02	-42.11%	1.74E+03	-31.12%
MROE	1.77E+03	41.32%	3.32E+03	31.11%
Aurora 1.0gpf Toilet				
Baseline	9.79E+02	N/A	2.26E+03	N/A
NYUP	5.73E+02	-41.45%	1.52E+03	-32.51%
MROE	1.39E+03	41.81%	2.88E+03	27.56%

The results of the sensitivity analyses show that the region of product use plays a significant role in the total life cycle impacts for the Aurora toilets, and the results are sensitive to the location where the product is used.

5.3.2. Change in product life

Sensitivity analyses were performed to check the impacts of changing product life. Product life is directly associated with the product replacements. The higher the product durability, the smaller number of product replacements would be needed to meet the ESL and vice versa. As shown in **Table 32**, increased product durability decreased the CO₂-equivalent emissions in the B4 stage, and decreased durability increased B4 emissions. For a Aurora 1.28gpf toilet with an RSL of 30 years, 1.5 times that of the baseline of 20 years, a significant reduction of ~15% was demonstrated for the total life cycle CO₂-equivalent emissions, and the reduction was ~13% for the Aurora 1.0gpf toilet.

Table 32. Sensitivity analysis of product durability on GWP emissions per functional unit

Product life (RSL)	Number of Product replacements (per ESL)	B4 (product replacement)		Total life cycle	
		kg CO ₂ -eq emissions	% change	kg CO ₂ -eq emissions	% change
Aurora 1.28gpf					
20 years (baseline)	2.75	1.07E+03	N/A	2.53E+03	N/A
25 years	2	7.83E+02	-26.63%	2.29E+03	-9.11%
30 years	1.5	5.90E+02	-44.69%	2.14E+03	-15.11%
15 years	4	1.54E+03	44.69%	2.90E+03	15.11%
10 years	6.5	2.58E+03	141.55%	3.61E+03	43.21%
Aurora 1.0gpf					
20 years (baseline)	2.75	1.07E+03	N/A	2.265E+03	N/A
25 years	2	7.83E+02	-26.63%	2.08E+03	-7.65%
30 years	1.5	5.90E+02	-44.69%	1.96E+03	-13.05%
15 years	4	1.54E+03	44.69%	2.52E+03	12.11%
10 years	6.5	2.58E+03	141.55%	3.07E+03	36.55%

The results of the sensitivity analyses show that the product lifetime plays a significant role in the total life cycle impacts for the Aurora toilets, and the results are sensitive to product durability.

5.4. Overview of relevant findings

This study assessed a multitude of inventory and environmental indicators. The primary finding for the TOTO Aurora toilets, across all environmental indicators, was that the product use phase (B1-B7) is responsible for most of the impacts across all impact categories.

With the use phase, environmental impacts are driven by the product replacement (B4), operational energy use (B6), and operational water use (B7) modules. Considerable impacts are generated from production (A1-A3), product distribution (A4), product maintenance (B2), and product repair (B3) stages. B6 and B7 impacts are driven by the water consumed by toilet operations and electricity consumed in municipal water systems respectively.

Production impacts are driven by the acquisition of raw materials making up the assemblies and the in-house manufacturing of ceramic bowls. B2 impacts are driven via the use of cleaning solution. Assembly of the final product has relatively very low impacts in comparison to upstream production of individual components. B2 impacts are driven via the use of cleaning solution.

All other life cycle stages have relatively insignificant impacts to the total life cycle results.

5.5. Conclusion and recommendations

The goal of this study was to conduct a cradle-to-grave LCA on TOTO's Aurora toilets so as to develop a Transparency Report [EPD]TM. This study covers TOTO's entire Aurora toilet series in 1.28 and 1.0gpf. The creation of this TR will allow consumers in the building and construction industry to make better informed decisions about the environmental impacts associated with the products they choose.

Overall, the study found that environmental performance is driven primarily by the use phase of the product. The product's PCR-prescribed lifespan necessitates frequent replacements, significantly increasing the demand for manufacturing resources and energy. Each replacement cycle involves the entire manufacturing

process from raw material extraction to assembly, multiplying the environmental footprint. Multiple product replacements require repeated transportation and logistics efforts, escalating fuel consumption and carbon emissions. Every product disposal adds to landfill waste, and if not properly managed, contributes to environmental pollution and resource depletion. The cumulative impact of manufacturing, distributing, and disposing of multiple units over the desired service period is substantially higher than that of a single, long-lasting product.

This also provides TOTO with the opportunity for reducing potential environmental impacts. Sensitivity analyses show that an Aurora 1.28gpf toilet with a product lifetime 1.5 times that of the baseline demonstrates a significant reduction of ~15% of the total life cycle CO₂-eq emissions, and that reduction is ~13% for an Aurora 1.0gpf toilet. Better product designs with enhanced durability and longevity reduces the need for frequent product replacements. Implementing modular designs allows the easy replacement of certain components instead of the entire product. Promoting and facilitating repairability by designing products with easily replaceable parts and providing comprehensive repair guides and services can also be helpful.

Another important opportunity lies in the water use phase for toilet operations. This water consumption during the use phase contributes to ~43% of potential CO₂-equivalent emissions across the life cycle of the product. It is recommended that TOTO look into strategies and technologies to engineer a toilet that uses less water per use. Focusing on energy and water efficiency and sustainable practices can significantly reduce the overall impacts. Water efficient designs with more efficient elements for water can reduce overall energy and water needs. Providing a display that shows real time energy and water consumption and suggesting ways for the users to reduce it can be beneficial.

Ceramics manufacturing is also responsible for significant contributions to the overall life cycle impacts of both products. Integrating renewable energy into the ceramic production facility will help avoid emissions from the use of fossil-dominated grid electricity. Renewable sources can be solar, wind, hydropower, or purchasing renewable electricity certificates (RECs). Using more energy-efficient kilns, optimizing firing schedules, recovering waste heat, and improving insulation in kilns can help reduce overall energy consumption. Implementing energy management systems in TOTO's own facilities and supplier plants can help control energy use throughout the facility and helps in identifying inefficiencies and optimizing energy consumption. Even though the toilet is comprised of parts, such as trip lever, jet and rim flush valves and fill valve being manufactured upstream where TOTO has little operational control, suppliers could be incentivized to adopt sustainable manufacturing practices and integrate renewable energy into their production facilities.

Since TOTO is assembling the product and all components are manufactured upstream, TOTO has little control over the impacts being generated upstream. However, it should incentivize suppliers to adopt sustainable manufacturing practices and integrate renewable energy into their production facilities. Renewable sources can be solar, wind, hydropower, or purchasing renewable electricity certificates (RECs). Implementing energy management systems in TOTO's own facilities and supplier plants can help control energy use throughout the facility and helps in identifying inefficiencies and optimizing energy consumption.

Additionally, an annual update to this LCA and the associated Transparency Report [EPD][™] would enable high-quality year-to-year comparisons and serve as the basis for potential optimized EPDs. A post-project review could provide opportunities for improving the data collection process in future years and for continuing to align with TOTO's goals for sustainability.

6. REFERENCES

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ACRONYMS

ACLCA	American Center for Life Cycle Assessment
BOM	Bill of materials
ESL	Estimated service life
ISO	International Standardization Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact analysis
PCR	Product Category Rule document
REC	Renewable energy certificates
RSL	Reference service life
TR	Transparency Report [EPD] [™]

GLOSSARY

For the purposes of this report, the terms and definitions given in ISO 14020, ISO 14025, the ISO 14040 series, and ISO 21930 apply. The most important ones are included here.

Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems
Close loop & open loop	A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.
Cradle to grave	Addresses the environmental aspects and potential environmental impacts (e.g., use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of life
Cradle to gate	Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of the production process ("gate of the factory"). It may also include transportation until use phase
Declared unit	Quantity of a product for use as a reference unit in an EPD based on one or more information modules
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal
Life cycle assessment - LCA	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle
Life cycle impact assessment - LCIA	Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product
Life cycle inventory - LCI	phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle
Life cycle interpretation	Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations

APPENDIX

- Aurora toilets_complete BOM_LCI_results.xlsx