LIFE CYCLE ASSESSMENT (LCA) OF TOTO SANITARY CERAMIC PRODUCTS

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Client TOTO USA

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1 INTRODUCTION

1.1 Opportunity

TOTO USA is committed to innovating products that make people's lives better, protect the environment and keep our water pure. To honor our commitment to sustainability, it is important that we conduct Life Cycle Assessments to evaluate the environmental impacts of our products in all stages of life, from raw materials to manufacturing and even through to disposal. The goal of conducting a Life Cycle Assessment is to explore the full range of environmental impacts our products have and to identify ways to improve processes and lessen any negative effects. This project is critical to TOTO's PeoplePlanetWater mission of innovating products for the benefit of people, the planet and our water supply.

In order to understand the true impact of our products throughout all life cycle stages, TOTO has chosen to conduct the Life Cycle Assessment using a cradle-to-grave approach. By factoring in all stages, we are more informed on how to reduce impacts on a broader scale. TOTO is the first company in the U.S. plumbing industry to conduct a cradle-to-gave LCA.

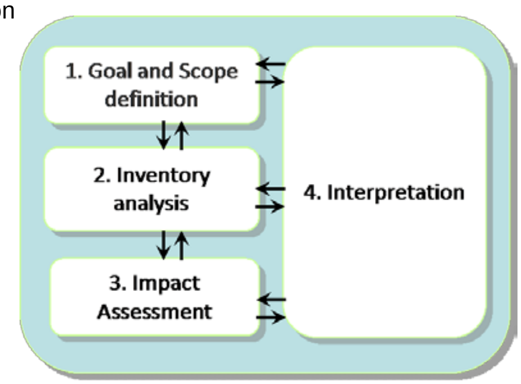
TOTO is interested in having Life Cycle Assessment (LCA) data available for the most important products to be able to obtain a SM Transparency Report, a type III environmental declaration, that can be used for communication with and amongst other companies, architects and consumer communication and also can be utilized in whole building LCA tools.

TOTO commissioned Sustainable Minds to help develop LCA's for the most important ceramic products. TOTO wants to develop the internal capacity to develop LCAs. This means an effort has been made to gather data and to train TOTO staff to model LCAs and how to report on them. TOTO wants to learn from the results and is looking forward to having guidance for future product improvements that can be deduced from the results.

1.2 Life Cycle Assessment

Performing a life cycle assessment (LCA) follows the Sustainable Minds Transparency Report Framework, which is based on ISO 14040-44 & 14025 standards. Such an LCA includes the following phases:

- Goal and Scope
- Inventory Analysis
- Impact Assessment
- Interpretation



Source: ISO 14040

This report includes all phases.

According to the Framework, a stakeholder procedure is required when LCA results are intended to be used for external communication *and* a comparison is made to products that are not produced by the commissioning party. This report concerns products from TOTO only; therefore a critical review is not required. An ISO 14040-44 third party review and a third party report certification for transparency reports are options in the Framework in order to be able to use transparency reports as a Type III environmental declaration. Both of these reviews will be completed in this project.

1.3 Status

All information in the report reflects the best possible inventory by TOTO at the time it was collected and best practice of Sustainable Minds to transform this information into this LCA report was conducted. The data covers annual manufacturing data for the time period between the years 2012 and 2013. The main reason is that TOTO is interested in learning the differences between 2012 and 2013 LCAs as they have implemented various programs aimed at reducing their products' overall impacts. Another reason is the 2012 data was used for specific products because relevant data related to production efficiency and other averaging calculations was available for 2012 and not 2013. Most data was supplied directly from energy providers or collected by TOTO employees especially that TOTO started submetering two years ago and the rest was calculated by TOTO specialists via engineering calculations and was validated and assured by Sustainable Minds.

This study includes primary data from the processes at TOTO, secondary data from suppliers that have been contracted and literature data to complete the inventory and fill the gaps. TOTO relies on vendors for the components of some of the ceramic products that are sold under its name.

TOTO has chosen to have the LCA data and report go through third party review against Parts A and Part B of the SM Transparency Report framework. A third party review has been performed by A third party review has been performed by Brad McAllister, WAP Director, who was contracted on behalf of NSF to critically review this report. The review concluded that the report is in conformance with ISO 14040-44. Several comments have been made and responses to them have all been included in this final report. A review statement is included in the appendices of this report.

TOTO has also chosen to have the Transparency Report third party certified against Parts A and Part B of the SM Transparency Report framework. A third party review has been performed by A third party review has been performed by Brad McAllister, WAP Director, who was contracted on behalf of NSF to critically review this report. The review concluded that the report is in conformance with the Sustainable Minds Transparency Report Framework. Several comments have been made and responses to them have all been included in this final report. A review statement is included in the appendices of this report.

1.4 Team

This report is based on the work of the following LCA project team members on behalf of TOTO:

- Bill Strang, Project Sponsor
- Kristen Girts, Project Manager & Associate Quality Engineer

They have been assisted by numerous TOTO employees during the product group definition, data collection, reporting and interpretation.

From Sustainable Minds:

- Naji Kasem, LCA Practitioner
- Millali Marcano, Project Manager
- Joep Meijer, LCA Technical Expert

1.5 Structure

This report follows the structure of the life cycle assessment methodology defined in the Sustainable Minds Framework as well as the Product Group Definitions (PGDs) of the respective products. It starts with the goals and scope in Chapter 2. Chapter 3 includes the inventory and the impact assessment can be found in Chapter 4. Chapter 5 details the interpretation phase.

This report includes LCA terminology. To assist the reader, special attention has been given to list definitions of important terms used at the end of this report.

2 GOAL AND SCOPE

This chapter lays down the starting points for the LCA. The aim of the goal and scope is to define the products under study and the depth and width 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 TOTO ceramics. It is intended for both internal and external purposes. A Sustainable Minds Transparency Report, a Type III Environmental Declaration per ISO 14025, will report the results of this study which is focused on products that are available in the US market.

2.2 TOTO products

TOTO USA is one of the world's largest plumbing products manufacturers and offers a complete line of commercial and decorative plumbing fixtures and fittings, faucets, accessories, shower and flush valves, as well as lavatories, toilets, air baths and urinals. Their products infuse style with substance, optimize water conservation and strive for consistent and high performance. TOTO embraced water and energy conservation years before government mandates. Through their consistently evolving manufacturing practices, they aim to develop and manufacture plumbing fixtures that are efficient and sustainable. For more information on TOTO products, go to www.totousa.com.

The products studied in this report are listed in Table 2.1a and Table 2.1b and include 10 ceramic products commonly referred to as 'China.' The categories of Transparency Reports and manufacturing locations as well as other products' information are presented in Tables 2.1c, 2.1d and 2.1e.

Table 2.1a Product codes and names and SM project concepts

Product(s) Code(s)	Product(s) Name(s)/Description(s)	SM project concept
CST744E	Eco Drake Two-Piece Toilet, 1.28 gpf	LCA of TOTO toilet
CST454CUFG	Drake II 1G Two-Piece Toilet, 1.0 gpf	LCA of TOTO toilet
CT708E(V)(G)	Commercial Toilet, 1.28 gpf	LCA of TOTO toilet
MS854114E	Eco Ultramax One-Piece Toilet, 1.28 gpf	LCA of TOTO toilet
MS654114MF	Aquia Dual Flush One-Piece Toilet, 1.6 gpf & 0.9 gpf	LCA of TOTO toilet
CST454CEFG	Drake II Two-Piece Toilet, 1.28 gpf	LCA of TOTO toilet
MS604114CEFG	Ultramax II One-Piece Toilet, 1.28 gpf	LCA of TOTO toilet
CST412MF	Aquia Dual Flush Two-Piece	LCA of TOTO toilet

	Toilet, 1.6 gpf & 0.9 gpf	
UT105U(V)(G)	Commercial Washout High-Efficiency Urinal, 0.125 gpf	LCA of TOTO urinal
UT445U(V)	Commercial Washout High Efficiency Urinal, 0.125 gpf	LCA of TOTO urinal

Table 2.1b Product codes and SM project concepts

Product(s)	SM project concept
EcoDrake CST744E	LCA of a toilet
Drake II 1G CST454CUFG & Drake II 1.28G CST454CEFG	LCA of two toilets
Toilet CT708E(V)(G)	LCA of a toilet
Ultramax MS854114E & Ultramax II MS604114CEFG	LCA of a toilet
Aquia MS654114MF & Aquia II CST412MF	LCA of two toilets
Urinal UT105U(V)(G)	LCA of a urinal
Urinal UT445U(V)	LCA of a urinal

Table 2.1c Vendors and manufacturing locations (confidential)

Product code	Part #	Production plant/vendors	Production Location(s)
CST744E	C744E bowl		
	ST743E tank		
CST454CUFG	C454CUF(G) bowl		
	ST453U tank		
CT708E(V)(G)	CT708E		
MS854114E	CST854E		
MS654114MF	CST654		
CST454CEFG	C454U bowl		
	ST453E tank		
MS604114CEFG	CST604E 1-Piece		
CST412MF	CT412F bowl		
	ST412M tank		
UT105U(V)(G)	UT105U		
UT445U(V)	UT445U		

Plant/Vendor Acronym Key	

Table 2.1d Categories of declarations

Product(s)	Category
EcoDrake CST744E	a declaration of a specific product as an average from several of the manufacturer's plants
Drake II 1G CST454CUFG & Drake II 1.28G CST454CEFG	a declaration of an average product as an average from several of the manufacturer's plants
Toilet CT708E(V)(G)	a declaration of a specific product as an average from several of the manufacturer's plants
Ultramax MS854114E & Ultramax II MS604114CEFG	a declaration of a specific product as an average from several of the manufacturer's plants
Aquia MS654114MF & Aquia II CST412MF	a declaration of a specific product as an average from several of the manufacturer's plants
Urinal UT105U(V)(G)	a declaration of a specific product from a manufacturer's plant
Urinal UT445U(V)	a declaration of a specific product from a manufacturer's plant

Table 2.1e Products' Information

Product code	Part #	CSI master format classification	ASTM or ANSI product specification	Physical properties and technical information or any other market identification
CST744E	C744E bowl	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
	ST743E tank	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
CST454CUFG	C454CUF (G) bowl	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
	ST453U tank	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
CT708E(V)(G)	CT708E	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
MS854114E	CST854E	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
MS654114MF	CST654	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
CST454CEFG	C454U bowl	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
	ST453E tank	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
MS604114CEFG	CST604E 1-Piece	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
CST412MF	CT412F bowl	10800	ASME A112.19.2/CSA B45.1 Certifications: IAPMO(cUPC)	Vitreous China Plumbing Fixture
	ST412M tank	10800	ASME A112.19.2/CSA B45.1	Vitreous China Plumbing Fixture
UT105U(V)(G)	UT105U	10800	ASME A112.19.2/CSA B45.1	Vitreous China Plumbing Fixture
UT445U(V)	UT445U	10800	ASME A112.19.2/CSA B45.1	Vitreous China Plumbing Fixture

Table 2.2 a, b and c list the 2012-2013 production volumes of the modeled products which are used in the declaration of the corresponding average product. Products and their components as well as the manufacturing plants and their locations are also listed. Additionally, the weights of the products are listed in Table 2.3 below.

Many of the toilets produced in 2012 and 2013 were manufactured in TOTO USA plants (TUS), at the Morrow (MW) and Lakewood (LW) plants. Some products are manufactured from TOTO and OEM vendors outside the United States. Names of other vendors are TOTO Vietnam (TVN), TOTO Mexico (TMX), TOTO Beijing (TBC), Surya TOTO Indonesia (STI), Edesa, and Siam Sanitary Ware (SSW).

Table 2.2a 2012 & 2013 production volumes of the modeled products (confidential)

2012			
Product code	**Product Name**	**Component**	**Production volume (pieces)**
CST744E	Eco Drake Toilet, 1.28 gpf	C744E Bowl	
		ST743E Tank	
CST454CUFG	Drake II 1G Toilet, 1.0 gpf	C454CUF Bowl	
		ST453U Tank	
CT708E(V)(G)	Commercial Toilet, 1.28 gpf	CT708E(V)	
MS854114E	Eco Ultramax Toilet, 1.28 gpf	CST854E	
MS654114MF	Aquia Dual Flush Toilet, 1.6 gpf & 0.9 gpf	CST654	
2013			
Product code	**Product Name**	**Component**	**Production volume (pieces)**
CST454CEFG	Drake II Toilet 1.28gpf	C454CUF(G) Bowl	
		ST453E Tank	
MS604114CEFG	Ultramax II 1.28gpf	CST604E	
CST412MF	Aquia Dual Flush Toilet	CT412F Bowl	
		ST412M Tank	
UT105U(V)(G)	Commercial High-Efficiency Urinal	UT105U	
UT445U(V)	Commercial High-Efficiency Urinal	UT445U	

Table 2.2b Production volume in 2012 from different plants and vendors (confidential)

Vendor Production Volume in 2012		**EDESA**	**LAKEWOOD**	**MORROW**	**STI**	**TVN**	**TBC**	**TMX**	**TOTAL**
Location		**Ecuador**	**US**	**US**	**Indonesia**	**Vietnam**	**China**	**Mexico**	
Most similar TOTO facility		**LW**	**LW**	**MW**	**LW**	**LW - 2pc MW - 1pc**	**MW**	**TMX**	
CST744E	**C744E(EG) bowl**								
	ST743E tank								
CST454CUF(G)	**C454CUFG bowl**								
	ST453U tank								
CT708	**CT708**								
MS854114E	**CST854**								

MS654114MF	**CST654**								

Table 2.2c Production volume in 2013 from different plants and vendors (confidential)

Vendor Production Volume in 2013		**MORROW**	**LAKEWOOD**	**TMX**	**TVN**	**SSW**	**TOTAL**
Location		**US**	**US**	**Mexico**	**Vietnam**	**Thailand**	
Most similar TOTO facility		**MW**	**LW**	**TMX**	**LW - 2pc MW - 1pc**	**TMX**	
CST454CEFG	C454U Bowl						
	ST454E tank						
MS604114CEFG	CST604E						
CST412MF	C412F Bowl						
	ST412M tank						
UT105U(V)(G)	UT105U						
UT445U(V)	UT445U						

Table 2.3 Ceramic products' weights

Product code	**Part #**	**Production plant(s)/ Vendor(s)**	**Weight of finished ceramic parts (kg)**	**Packaging weight (kg)**	**Seat weight (kg)**	**Parts: Tank trim, fittings, etc. (kg)**
CST744E	C744E(EG) bowl	TVN/TBC/ TMX	20.5	1.85	2.09	3.10
	ST743E tank	TUS LW/TMX	13.2			
CST454CUFG	C454CUFG bowl	TUS MW	25.9	6.49	2.09	3.13
	ST453U tank	TUS LW	11.6			
CT708E(V)(G)	CT708	EDESA/STI	18.00	1.39	2.27	2.51
MS854114E	CST854E	TUS MW	30.4	4.50	2.09	2.79
MS654114MF	CST654	TUS MW	41.0	4.86	2.09	3.46
CST454CEFG	C454U bowl	TUS MW/TVN	25.9	7.08	2.90	0.83
	ST453E tank	TUS LW	12.8			
MS604114CEFG	CST604E	TUS MW	38.0	4.51	2.09	2.80
CST412MF	CT412F Bowl	SSW/TMX	39.8	5.93	2.09	1.56
	ST412M tank	SSW/TMX	10.4			
UT105U(V)(G)	UT105U	TUS LW	15.5	2.05	No Seat	1.02
UT445U(V)	UT445U	TVN	22.0	2.64	No Seat	1.03

Manufacturing data has been collected and compiled for TOTO USA (Morrow and Lakewood) and for TOTO Mexico. Because manufacturing data is not available from all plants, we used plant data from TOTO USA and TMX to model products made in other facilities. We determined which plant data to use for each model based upon the technology, efficiency, age and process similarities of the products being modeled. Therefore, in the SimaPro, products are modeled based on the percentages of product volume from different facilities. Morrow plant data was used to model components produced in Morrow and in TBC. TBC is a newer facility and uses pressure casting similar to the Morrow plant, thereby having comparable efficiencies in the production process. The Lakewood plant is used to model components produced in Lakewood, Edesa, STI, and TVN. These facilities utilize manual bench casting similar to that applied in Lakewood. Edesa and STI are older, less efficient facilities and are as such similar to Lakewood. TVN uses both pressure and bench casting in the facility. However, the specific products produced in TVN for which we are modeling are produced using the bench casting method. The TMX plant is used to model components produced in TMX and SSW. SSW is similar to TMX in that the type of products manufactured and the processes used are similar. SSW used a bench casting method to produce each component. TMX uses bench casting and a similar method referred to a spagless casting. The products produced by SSW in 2013 are also produced by TMX. Table 2.4 displays the plant data used to model each component of the product.

Table 2.4 Percentage of product volume as modeled in SimaPro (confidential)

Vendor Production/Sold Volume in 2012		**EDESA**	**LAKEWOOD**	**MORROW**	**STI**	**TVN**	**TBC**	**TMX**
Location		**Ecuador**	**US**	**US**	**Indonesia**	**Vietnam**	**China**	**Mexico**
Most similar TOTO facility		**LW**	**LW**	**MW**	**LW**	**LW for 2pc** **MW for 1pc**	**MW**	**TMX**
EcoDrake CST744E	C744E(EG) bowl							
	ST743E tank							
Drake II 1G CST454CUF(G)	C454CUFG bowl							
	ST453U tank							
CT708	CT708							
Ultramax MS854114E	MS854							
Aquia MS654	MS654							

Vendor Production/Sold Volume in 2013		**MORROW**	**LAKEWOOD**	**TMX**	**TVN**	**SSW**
Location		**US**	**US**	**Mexico**	**Vietnam**	**Thailand**
Most similar TOTO facility		**MW**	**LW**	**TMX**	**LW for 2pc** **MW for 1pc**	**TMX**
Drake II 1.28gpf CST454CEFG	C454U Bowl					
	ST454E tank					
Ultramax II MS604114CEF(G)	C604E					
CST412MF two-pieces	C412F Bowl					
	ST412M tank					
UT105U(V)(G)	MS854					
UT445U(V)	MS654					

Below are some pictures and descriptions of the modeled products.

Table 2.5 Description of the modeled products

Eco Drake Two-Piece Toilet 	• E-Max Flushing System • Computer designed, fully glazed trapway • Elongated bowl • Chrome trip lever • 12" Rough-in See more at: http://www.totousa.com/eco-drake%C2%AE-two-piece-toilet-128-gpf-elongated-bowl#sthash.wBFXYNdp.dpuf
Drake II 1G Two-Piece Toilet 	• SanaGloss • Double Cyclone flushing system • Computer designed, fully glazed trapway • Elongated bowl • Chrome trip lever • Universal height • ADA compliant • 12" Rough-in See more at: http://www.totousa.com/drake%C2%AE-ii-1g-two-piece-toilet-10-gpf-elongated-bowl#sthash.OLKmuAkS.dpuf
Commercial Toilet 	• Siphon jet flush action • Elongated front rim • Wall-mounted • Designed to work with EcoPower flush valves See more at: http://www.totousa.com/commercial-flushometer-high-efficiency-toilet-128-gpf-elongated-bowl-0#sthash.SRB9N2gW.dpuf
Aquia Dual Flush One-Piece Toilet 	• Dual-Max flushing system • Elongated bowl • Skirted design • Chrome push button with Dual Flush option • Universal height • 12" Rough-in See more at: http://www.totousa.com/aquia%C2%AE-dual-flush-two-piece-toilet-16-gpf-09-gpf-elongated-bowl#sthash.0364HN7E.dpuf

Eco Ultramax One-Piece Toilet 	• E-Max flushing system • Elongated bowl with SoftClose seat • Chrome trip lever • 12" Rough-in See more at: http://www.totousa.com/ultimate%C2%AE-one-piece-toilet-16-gpf-elongated-bowl#sthash.3HOowPUL.dpuf
Drake II Two-Piece Toilet 	• SanaGloss • Double Cyclone flushing system • Computer designed, fully glazed trapway • Elongated bowl • Chrome trip lever • Universal height • ADA compliant • 12" Rough-in See more at: http://www.totousa.com/drake-II-two-piece-toilet-128-gpf-elongated-bowl#sthash.OwmKJ5Le.dpuf
Ultramax II One-Piece Toilet 	• SanaGloss • Double Cyclone flushing system • Computer designed, fully glazed trapway • Elongated bowl with SoftClose seat • Chrome trip lever • Universal height • ADA compliant • 12" Rough-in See more at: http://www.totousa.com/ultramax%C2%AE-II-one-piece-toilet-128-gpf-elongated-bowl#sthash.CigJ3x7o.dpuf
Aquia Dual Flush Two-Piece Toilet 	• Dual-Max flushing system • Elongated bowl • Skirted design • Chrome push button with dual flush option • Universal height • 12" Rough-in See more at: http://www.totousa.com/aquia%C2%AE-dual-flush-two-piece-toilet-16-gpf-09-gpf-elongated-bowl#sthash.pNS0VZxu.dpuf

UT105U(V)(G) 	• Compact urinal • Wall mounted • Concealed integral trap • Dome strainer • Sanagloss option • Top or back spud See more at:http://www.totousa.com/commercial-washout-high-efficiency-urinal-18-gpf-ada-sanagloss%C2%AE-0
UT445U(V) 	• Full size urinal • Wall mounted • Concealed integral trap • Dome strainer • Top or back spud See more at: http://www.totousa.com/commercial-washout-high-efficiency-urinal-0125-gpf-ada-0

2.3 Functional units

The results of the LCA in this report are expressed in terms of a functional unit as it covers the entire life cycle of the products (Table 2.6). The Transparency Reports of the corresponding products listed in Table 2.1a are expressed in terms of one respective piece of product as well as all life cycle modules which are presented later in this report. The reference units express the amount of a product and its function as it is applied and/or used in the United States of America and it includes the lifespan of the product. The list of functional units and their corresponding products is presented in Table 2.6. The functional units are taken from the product group definition (PGD) documents pursuant to Part B of the SM Transparency Report Framework [7, 8 &9]. TOTO products comply with the functional performance specifications laid down in the aforementioned PGDs.

Table 2.6 Functional units of the modeled products

Product (s)	Functional Unit
EcoDrake CST744E	10 years of use of a single or dual flush toilet in an average US household
Drake II 1G CST454CUFG & Drake II 1.28G CST454CEFG	10 years of use of a single or dual flush toilet in an average US household
Toilet CT708E(V)(G)	10 years of use of a toilet in an average U.S. commercial environment
Ultramax MS854114E & Ultramax II MS604114CEFG	10 years of use of a single or dual flush toilet in an average US household
Aquia MS654114MF & Aquia II CST412MF	10 years of use of a single or dual flush toilet in an average US household
Urinal UT105U(V)(G)	10 years of use of a urinal in an average U.S. commercial environment
Urinal UT445U(V)	10 years of use of a urinal in an average U.S. commercial environment

2.4 System boundaries

To define what is and what is not included in an LCA, the so-called system boundaries are drafted. In general, the system boundaries as laid down in Part A [6] are followed. This section details some of the aspects to assist the reader to understand what is included in the models.

The system boundaries reflect the life cycle phases that have been modeled. It defines which life cycle phases and processes are included and which are not. The LCA is modeled according to specific system boundaries and is quantified in such a way that they reflect the respective reference units of the modeled products.

This LCA's system boundaries include the following life cycle phases:

- Production
- Construction/Installation
- Use
- End of life
- Recovery

These boundaries apply to all the modeled products and can be referred to as "cradle-to-grave" which means that it includes all life cycle stages and modules as indentified in Part A [6].

The system boundaries for TOTO ceramic products are detailed below. Figure 2.1 represents the life cycle phases and stages for the entire life cycle of these products.

	Product assessment information																
	Product life cycle information																Supplementary information (benefits and loads) beyond the product life cycle
Transparency Report aggregated modules	**Production**			**Construction**		**Use**							**End of life**				**Recovery**
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Transparency Reports system boundary	Raw Materials	Transport	Manufacturing	Transport	Construction / installation stage	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
Cradle-to-grave Functional unit	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X = a declared module

Figure 2.1 Applied system boundaries for the modeled ceramic products

2.4.1. Production stage [A1-A3]

The product stage includes, where relevant, information modules for:

- A1: Extraction and processing of raw materials (e.g. mining processes) and biomass production and processing (e.g. agricultural or forestry operations)
- A1: Reuse of products or materials from a previous product system
- A1: Processing of secondary materials used as input for manufacturing the product, but not including those processes that are part of the waste processing in the previous product system
- A1: Generation of electricity, steam and heat from primary energy resources, including extraction, refining and transport thereof
- A1: Energy recovery and other recovery processes from secondary fuels, but not including those processes that are part of waste processing in the previous product system
- A2: Transportation up to the factory gate in addition to internal transport
- A3: Production of ancillary materials or pre-products
- A3: Manufacturing of packaging
- A1-A3: Processing up to the end-of-waste state or disposal of final residues including any packaging not leaving the factory gate with the product.

A description of the most important modeling parameters is included below.

2.4.1.1. Raw Materials

The toilet raw materials have been majorly grouped into three categories: body slip and glaze (ceramic materials), casting materials, and tank trim parts.

Ceramic constitutes the largest portion of the body of the toilet and inputs to the system are body slip and glaze. Fundamentally, the end products are the same but the recipe of raw materials may be different due to difference in the manufacturing processes. The recipe of raw materials for the body slip and glaze for the different ceramic products in MW, LW and TMX including the transportation mode and distances when purchased are comprised of the following:

Table 2.7 Ceramic production raw materials (confidential)

Table 2.7a Morrow ceramic body slip materials; total used kilograms in 2012 & 2013.

Constituent/material type	Percentage of materials in 2012	Percentage of materials in 2013	Transportation mode	Distance (km)

Table 2.7b Morrow ceramic glaze materials; total used kilograms in 2012 & 2013.

Constituent/material type	Percentage of materials in 2012	Percentage of materials in 2013	Transportation mode	Distance (km)

Table 2.7c Lakewood ceramic body slip materials; total used kilograms in 2012 & 2013.

Constituent/material type	Percentage of materials in 2012	Percentage of materials in 2013	Transportation mode	Distance (km)

Table 2.7d Lakewood ceramic glaze materials; total used kilograms in 2012 & 2013.

Constituent/material type	Percentage of materials in 2012	Percentage of materials in 2013	Transportation mode	Distance (km)

Table 2.7e TOTO Mexico ceramic slip materials; total used kilograms in 2012 & 2013.

Constituent/material type	Percentage of materials in 2012	Percentage of materials in 2013	Transportation mode	Distance (km)

Table 2.7f TOTO Mexico ceramic glaze materials; total used kilograms in 2012 & 2013.

Constituent/material type	Percentage of materials 2012	Percentage of materials 2013	Transportation mode	Distance (km)

Non-ceramic parts that make a toilet are tank trim and seat. All parts with a weight of >1% weight of the parts (excluding ceramic and packaging materials) are included in the LCA model. A check has been performed to make sure that the completeness of the overall material use is >98.5%wt. of the finished product after cut-off and including the ceramic and packaging materials. We assumed a yield loss for metals of 10% and 2% for plastics. Tables 2.8a&b show an aggregation of materials that make up the non-ceramic parts of the product.

Table 2.8a Tank trim and fixture product constituent (excluding ceramic) for 2012 products

Constituent	Ultramax MS8541	Aquia MS654	Drake CST454	CT708E	EcoDrake CST744E
ABS	0.00%	3.94%	11.59%	0.00%	0.00%
Brass	3.89%	0.00%	3.35%	8.38%	3.29%
EPDM	0.00%	1.48%	3.64%	0.00%	2.12%
PET	0.00%	0.00%	1.16%	0.00%	0.00%
POM	1.56%	1.23%	0.00%	0.00%	0.00%
PP	85.60%	73.92%	69.23%	90.38%	88.13%
PVC	1.95%	8.79%	3.21%	0.00%	3.00%
SBR	0.00%	0.00%	0.00%	1.24%	0.00%
Silicone	0.00%	0.00%	0.26%	0.00%	0.00%
Stainless Steel, SUS303	0.00%	0.00%	1.52%	0.00%	0.00%
Stainless Steel, SUS304	0.00%	7.56%	0.00%	0.00%	0.00%
Stainless Steel, SUS430	3.50%	3.06%	2.88%	0.00%	0.00%
Zinc	3.89%	0.00%	3.15%	0.00%	3.36%

Table 2.8b Tank trim and fixture product constituent (excluding ceramic) for 2013 products

Constituent	Ultramax CST604	Drake CST454	AquiaCST412	Urinals UT105 & UT445U
ABS	0.00%	0.00%	1.44%	0.00%

Brass	3.89%	3.54%	0.00%	86.87%
EPDM	0.00%	2.28%	2.59%	1.80%
Glass filled Polypropylene	0.00%	0.00%	3.71%	0.00%
POM	1.56%	1.37%	0.00%	0.00%
PP	85.60%	83.93%	71.66%	0.00%
PVC	1.95%	1.90%	9.46%	0.00%
Rubber	3.50%	0.00%	0.00%	2.30%
Stainless Steel, SUS303	0.00%	0.00%	8.28%	7.31%
Stainless Steel, SUS304	0.00%	0.00%	0.00%	0.00%
Stainless Steel, SUS316	0.00%	0.00%	0.00%	1.80%
Stainless Steel, SUS430	0.00%	3.31%	2.86%	0.00%
Zinc	3.89%	3.62%	0.00%	0.00%

Data on recycled content was not provided and as such primary materials were majorly assumed to be the case and modeled. A more detailed raw materials definition of the products as required by Part A is presented in appendix A (Tables A.1 through A.10). No primary data of unit processes except for the ceramics was used in the model, the unit processes used as required by Part A is presented in Appendix A (Table A.11 through A.17). Default allocations of Ecoinvent are assumed to apply in this model.

The specific numbers of completeness are listed below (Table 2.9).

Table 2.9 Completeness of the parts after 1% weight cut-off

Product code	%wt covered
CST744E	99.37%
CST454CUFG	99.75%
CT708E(V)(G)	99.97%
MS654114MF	98.76%
MS854114E	99.41%
CST454CEFG	99.39%
MS604114CEFG	99.61%
CST412MF	98.99%
UT105U(V)(G)	99.86%
UT445U(V)	99.87%

2.4.1.2. Manufacturing

The toilets and toilet bowls at the Morrow plant are manufactured as follows:

- Raw materials arrive by truck and are unloaded / stored into silos or designated area.
- The preparation materials, primarily materials that embody the mass of the toilet, are batched into two different clay slurries called *slip;* the first is *casting slip* and the second is *glazing slip*.
- The casting slip is pumped into molds and a portion of the water is squeezed out, producing separate body, rim, and tank pieces. While still wet, the body,

rim, and tank are bonded together, and the product is sent to the dryer to be dried.

- The dry product is inspected. Minor defects can often be repaired prior to glazing; However, products with irreparable defects are recycled back into casting slip and placed into the system. Products that pass inspection are then sprayed with glaze. The water in the glaze absorbs into the dry body and leaves a powder coat of glaze.
- The glazed product is fired in a process called *vitrification* during which organic components in the raw materials are burned out to form CO_2, NO_x, and SO_x and released with exhaust gas stream through wet scrubber to the atmosphere. During vitrification, the pores close up. The glassy raw materials melt and make the body solid and impermeable, and the same materials in the glaze make the surface shiny and hard.
- The fired product is inspected. Products that pass inspection have the fixtures installed, and are boxed. Products with defects are repaired and re-fired if possible. Products with irreparable defects are recycled as raw material for construction materials (e.g., tiles) or road bed aggregate.
- Finished products are boxed and shipped to the distribution center for distribution.

The toilet tanks at the Lakewood plant are manufactured as follows:

- Raw materials arrive by truck and are unloaded / stored into silos or designated area.
- The preparation materials, primarily materials that embody the mass of the toilet, are batched into two different clay slurries called *slip;* the first is *casting slip* and the second is *glazing slip*.
- The casting slip is pumped into plaster molds and a portion of the water diffuses out of the slip and into the plaster mold, producing the ceramic pieces. These pieces are then de-molded and sent to the dryer.
- The dry product is inspected. Minor defects can often be repaired prior to glazing; however, products with irreparable defects are recycled back into casting slip and placed into the system. Products that pass inspection are then sprayed with glaze. The water in the glaze absorbs into the dry body and leaves a powder coat of glaze.
- The dry product is then sprayed with the glaze slip. The water in the glaze slip absorbs into the dry body and leaves a powder coat of glaze.
- The glazed product is fired in a process called *vitrification* during which organic components in the raw materials are burned out to form CO_2, NO_x, and SO_x and released with exhaust gas stream through wet scrubber to the atmosphere. During vitrification, the pores close up. The glassy raw materials melt and make the body solid and impermeable, and the same materials in the glaze make the surface shiny and hard.
- The fired product is inspected. Products that pass inspection have the fixtures installed, and are boxed. Products with defects are repaired and re-fired if possible. Products with irreparable defects are recycled as raw material for construction materials (e.g., tiles) or road bed aggregate.
- Finished products are boxed and shipped to the distribution center for distribution.

When comparing the process in MW and LW, the Lakewood process is very similar, with the exception of the casting process. The difference is mainly these points: 1. Morrow uses epoxy-resin molds which do not absorb water. The casting machine uses pressure to squeeze the water out (this is called pressure casting) Lakewood, on the other hand uses plaster molds in which the plaster absorbs the water (this is called plaster casting or bench casting) Since no pressure is used, this is not done by a machine. 2. Lakewood does not make complex toilets. Instead, Lakewood products are more simplistic so there is no bonding of pieces. Lakewood makes Tanks and Lavatories that are manufactured as one piece, thus no bonding of separate pieces.

According to Table 2.4, we make assumptions regarding the similarities of processes among the different facilities. We assume that manufacturing process in TVN is similar with that in MW, and that manufacturing process in EDESA, STI, SSW, and TVN is similar with that LW within our scope in the modeling.

In order to allocate manufacturing data to the different products, it is necessary to have insight into the number of ceramic products made in the facilities as well as the yield percent of the plant. Yield is a composite of production losses at different stages in the manufacturing process. Product yield percentage is the percentage of final product compared to raw material input; while total plant yield is the average yield percentage for all the products manufactured in the plant.   Differences in yield percentages are due to complexity of the products produced and differences in process, for example, method of casting.

In order to compare the data across three facilities and assign inputs and outputs to different products, all the data reported below are based on data per weight of ceramics.

Total energy consumption and emissions in the plant are allocated for different products based on the production efficiency. Production efficiency is the efficiency of energy input embedded in the product and emissions out from the production. Energy input and emission output would firstly be reported in average and plant level, and the product specific data would be reported later for each product. All processes are assigned to the final product based on the yields presented in Table 2.10 a & b using the total yield and production efficiency, with the exception of natural gas use and associated emissions from the kiln. Natural gas usage and associated emissions are allocated by using the last column, the firing yield. In order to compare the data across three facilities and assign inputs and outputs to different products, all the data reported below are based on data per weight of ceramics.

For the most part, the casting materials are process aids. Exceptions are soluble salts majorly within the bonding slip, which are applied to the toilet during casting and do remain as part of the toilet body. However, compared to the rest of the ceramic part, bonding slip is less than 0.02% of total weight.

Table 2.10a Total Yield percentage for manufacturing plants (confidential)

Overall Plant Yield		
	2012	**2013**
Morrow		
Lakewood		
TMX		

Table 2.10b Yield percentage and production efficiency for ceramic products (confidential)

Product Yield for 2012				
Product code	**Part #**	**Total yield percentage**	**Average Production efficiency**	**Firing yield**
CST744E	C744E(EG) bowl			
	ST743E tank			
CST454CUFG	C454CUFG bowl			
	ST453U tank			
CT708E(V)(G)	CT708			
MS854114E	CST854E			
MS654114MF	CST654			
Product Yield for 2013				
Product code	**Part #**	**Total yield percentage**	**Production efficiency**	**Firing yield**
CST454CEFG	C454CUFG Bowl			
	ST453E tank			
MS604114CEFG	MS604E One-Piece			
CST412MF	C412F Bowl			
	ST412M Tank			
UT105U(V)(G)	UT105U			
UT445U(V)(G)	UT445U			

* estimated

**UT105U was a brand new product in 2013; the process had to be adjusted considerably in order to "dial it in." It has now stabilized at (confidential) and (confidential) respectively.

Another factor that influences the mass balance is the loss of ignition. The ceramic loses weight going through the process: water content, crystal water and organic material in the raw materials are removed during the firing process. The loss of ignition is a good measure for these weight losses. This factor is included in calculation the overall mass balance and is presented in the table below.

Table 2.11 Loss of ignition in 2012 & 2013

Loss of Ignition 2012		
Morrow	**Lakewood**	**TMX**
8.20%	4.66%	6.43%
Loss of Ignition 2013		
Morrow	**Lakewood**	**TMX**
8.25%	4.85%	6.43%

2.4.1.3. Energy Requirements

The major manufacturing processes were described in section 2.4.1.7. Table 2.12 below. provides the energy requirement to produce one kg of ceramic in MW, LW and TMX.

Table 2.12 Energy usage for toilet manufacturing (confidential)

Energy Source	Unit	2012		
		MW	LW	TMX
Electricity from grid	kWh/kg			
Natural gas	Cu.ft./kg			
		2013		
		MW	LW	TMX
Electricity from grid	kWh/kg			
Natural gas	Cu.ft./kg			

Electricity is purchased from Georgia Power for LW and MW. Generation sources, as reported by Georgia Power in 2012, are 39% from coal, 33% from oil and gas, 27% from nuclear power, 1% from hydro power[1]. Generation sources, as reported by Georgia Power in 2013 are 39% from oil and gas, 35% from coal, 23% from Nuclear power, and 3% from hydro power[2]. Impact factors for this electricity source were created when modeling in SimaPro. Electricity usage in MW is more than LW and TMX due to the fact that that Morrow uses substantially more automation than Lakewood and TMX. Morrow casting is done by machine, where Lakewood is manual. Morrow has an extensive conveyor system to move products, but Lakewood does not. The process in TMX is not as automated as in Morrow, but more so than in Lakewood. Morrow buys a large percentage of green electricity which is generated using biomass. This adds up to (confidential) MWh out of a total of (confidential) MWh, representing 22% of the purchased electricity in 2012. In 2013, (confidential) MWh of green electricity was purchased out of a total of (confidential) MWh, representing 44% of the purchased electricity for the year 2013. Electricity for TMX is modeled after the Mexican grid mix using Ecoinvent data. In the manufacturing process, drying takes 30-35 hours, at 140 degrees Fahrenheit (60 degrees Celsius). Firing takes 12-18 hours, with the hottest temperature at 2,200 degrees Fahrenheit (1,200 degrees Celsius). The Lakewood plant has a very old kiln of 60 years or more. It is made with brick walls and not insulated well. There has been some refurbishing, but it is not as efficient as Morrow and TOTO Mexico. Morrow's kiln is less than 20 years old, different construction, and therefore much more efficient than Lakewood. Also, Morrow uses a lot of heat from the kiln and redirects it to the dryer to save gas. TMX has a new kiln of approximately 8 years and is very efficient due to its newer construction.

2.4.1.4. Water consumption

The manufacturing operation requires the consumption of water. In 2012, Morrow consumed 14.85 liters per kilogram of ceramic, Lakewood consumed 2.92 liters per

[1] Georgia Power Facts and Figures 2012. http://www.georgiapower.com/about-us/facts-and-financials/facts-and-figures.cshtml

[2] Georgia Power Energy Sources 2013. http://www.georgiapower.com/about-energy/energy-sources/home.cshtml

kilogram of ceramic and TOTO Mexico consumed approximately 4.94 liters per kilogram of ceramic. In 2013, Morrow consumed 10.49 liters per kg of ceramic, Lakewood consumed 2.71 liters per kg of ceramic and TOTO Mexico consumed approximately 4.94 liters per kg of ceramic. Table 2.13 shows the amount of water per kilogram of ceramic used in each plant.

Table 2.13 Water usage per kilogram of ceramic (confidential)

Water usage – Liters per kilogram of ceramic	2012		
	TUS MW	**TUS LW**	**TMX**
	2013		
	TUS MW	**TUS LW**	**TMX**

Lakewood uses much less water in their operation due to less automation and less slip processing. Despite the relatively high water usage, TOTO's operations are always evolving in order to find ways to reduce the use of natural resources. For example, programs implemented in 2012 in the Morrow casting department (highest water consuming department) resulted in significant reductions in water use. This is evident by the difference in water use per kilogram of ceramic compared to the Morrow facility. Also, Morrow utilizes roughly 20,000 gallons of on-site recycled greywater per day and Lakewood utilizes 500 gallons of on-site recycled greywater per day. The remainder of water is treated and goes to the respective city or county water systems via the public sewer system.

Recycled water is processed on-site in the wastewater treatment plant (WWTP). Treatment utilizes a number of Cationic Polymer, Anionic Polymer, Polymer flocculants and Sodium Hydroxide for the process. These ancillary materials were included in the analysis and modeling.

2.4.1.5. Environmental outputs

The major air emission during manufacturing from materials is carbon dioxide, coming from natural gas combustion as well as through carbonate decomposition and organic combustion of raw materials during the firing process. Because the drying and firing temperature is high enough for carbonation, we assume that the worst case scenario that all possible raw materials are carbonated and combusted during the process, amounting to approximately (confidential) 5.1%, 0.3% and 1.1% compared to CO_2 emissions from natural gas accordingly.

Table 2.14 Air emissions from Morrow, Lakewood and TOTO Mexico in 2012 and 2013 (confidential)

Air emission	Grams per kg of ceramic in 2012		
	MW 2012	**LW 2012**	**TMX 2012**
NO_x			
SO_2			
CO			
CO_2			

Air emission	Grams per kg of ceramic in 2012		
	MW 2013	LW 2013	TMX 2013
NO_x			
SO_2			
CO			
CO_2			

Morrow, Lakewood, and TOTO Mexico's wastewater treatment plant treats all wastewater before it is returned to the city or county water authority. Discharged water is tested for various effluents in accordance with local ordinances. Wastewater emissions are listed in the table below:

Table 2.15 Water effluents for toilet manufacturing in Morrow, Lakewood and TOTO Mexico in 2012 and 2013. (confidential)

Water effluents	Grams per kg of ceramics					
	MW 2012	MW 2013	LW 2012	LW 2013	TMX 2012	TMX 2013
Chemical Oxygen Demand						
Total Kjeldahl Nitrogen (TKN)						
Phosphorous matter						
Aluminum						
Copper						
Zinc						
NO3-NO2						
Total Suspended Solids						
Biochemical Oxygen Demand						
Chloroform						
Bis(2-ethylhexyl)phthalate						
Grease & Oil						
Antimony						
Beryllium						
Cadmium						
Chromium						
Lead						

2.4.1.6. Other materials: parts and packaging

The finished product is packaged and ready for transportation to the distribution centers and ultimately to the US market. The specific numbers of the packaging materials' weights are listed below (Table 2.16). After the products are package, they are sent to the warehouse for final shipment. The boxes are stacked on pallets and wrapped in stretch wrap foil. Toilets are packed in carton boxes, most of which contain a top and bottom pad, along with some inserts and stickers. Since all the stickers and paper are less than 0.1kg, which is less than 1% of total weight, we only include the combined carton boxes and pads for each toilet. After packing, boxes are stapled, palletized and wrapped with stretch wrap.. The stretch wrap is below the cutoff of 1%wt and impact. The pallets are included based on purchasing data per facility. In 2012, Morrow purchased 32240 pallets and Lakewood purchased 8112. They are purchased in sizes of 48*48 and 54*48, with an average weight of 31.5lb per unit by engineers manual weighing. For TMX, we assume that they use the average data for MW and LW in 2012. In 2013, Morrow purchased 32173 pallets, Lakewood 9336 and TMX 22460.

Table 2.16 Packaging information

Product code	Packaging weight (kg)
CST744E	5.53
CST454CUFG	6.42
CT708E(V)(G)	1.37
MS654114MF	4.85
MS854114E	4.45
CST454CEFG	7.00
MS604114CEFG	4.45
CST412MF	5.87
UT105U(V)(G)	2.00
UT445U(V)	2.60

2.4.1.7. Transportation

Transportation distances of the toilet components and processing aids were provided by TOTO. In MW and LW, the majority of the materials purchased come from manufacturers located in the USA, and are transported by truck and trailer. One of the main materials (English Kaolin) is sourced from the U.K., and transportation by ocean freighter, rail and truck and trailer are calculated and included in the model.

In TMX, the majority of the materials is from Monterrey metropolitan area and transported by truck and trailer. Trucks and ocean freighters are assumed to be diesel-powered. No empty returns are accounted for in truck and trailer transportation.

2.4.1.8. Solid waste

Solid waste from facilities includes sludge, ceramic/slip scrap, mold scrap, carton boxes, metal scrap and other wastes. Among them, ceramic/slip scrap, mold scrap can all be reused, and carton box packaging is sent to off-site recycling facilities. All the wastes and their weight as well as their fate in MW, LW and TMX are listed below. Sludge contains approximately 30-40%wt. of water, as measured by samples taken from the Morrow and Lakewood plants. We assume the same water content percentage for TMX as an average since the same was not provided.

Transportation of solid wastes to the sites to treat is included in the model. We assumed that all the solid wastes are conveyed by diesel-powered trucks. Where transportation distances were not known, we used 75 miles for commingled, single stream waste recycling, 50 miles for pallet recycle, and 25 miles for metal and oil waste.

Table 2.17a Waste from the manufacturing facilities in 2012 (confidential)

Solid waste (g per kg of ceramic)	MW		LW		TMX	
	Weight	Fate	Weight	Fate	Weight	Fate

Table 2.17b Waste from the manufacturing facilities in 2013 (confidential)

Solid waste (g per kg of ceramic)	MW		LW		TMX	
	Weight	**Fate**	**Weight**	**Fate**	**Weight**	**Fate**

2.4.2. Construction/Installation stage [A4-A5]

The construction process stage includes the following information modules:

- A4: Transport to the building site
- A5: Construction / installation in the building

2.4.2.1. Transportation to site

After products are purchased by distributers, dealers, and showrooms for purchase by the end users, they are transported from the FAP warehouse to these purchasers. Transportation and distance would vary and are dependent on the locations of the purchasers and their choice of shipping mode. Table 2.18 details transportation distances and modes of the finished products prior to arriving at TOTO's warehouses. Transportation of finished packaged products to the warehouse from vendors is done by diesel trucks (average of 30mi). Outbound shipments to customers from FAP are transported by both diesel truck (average of 947mi) and rail (average of 1114mi). These numbers are estimated based on actual 2013 shipment averages.

All toilets and their components are packaged in the manufacturing plants and are shipped directly to TOTO owned distribution centers. The two distribution centers are the Fairburn Assembly Plant (FAP), located in Fairburn, GA (east distribution center) and the Ontario Assembly Plant (OAP), located in Ontario, CA (west distribution center). All Lakewood production goes to FAP and approximately 70% of Morrow's production goes to FAP, while the remaining 30% goes to OAP. Most toilet components arrive finished, although a small percentage may require assembly of the tank trim, such as the Aquia ST412M tank. Distance from Morrow and Lakewood to FAP is approximately 30 miles via diesel-powered trucks. FAP and OAP also receive products from other vendors. Approximately 70% of manufactured product goes to FAP and 30% to OAP, depending on the regional demand of certain products. Transportation modes and distances are different according to the locations of vendors. Transportation distances and modes from the various vendors is listed in Table 2.18.

Outbound shipments to customers travel via rail and/or diesel truck. In 2012, outbound shipments from FAP and OAP were transported by an average of 947 miles by diesel truck and an average of 1114 miles by rail. When factoring the quantity transported by truck and rail (95%and 5% respectively), the weighted average transported distance comes to approximately 949 miles. In 2013, outbound shipments from FAP and OAP were transported an average of 883 miles by diesel truck and an average of 1269 miles by rail. When factoring the quantity transported by truck and rail (83% and 17% respectively), the weighted average transported distance comes to approximately 949 miles. TOTO toilet sourcing data is based on actual 2012 and 2013 shipment averages. All transportation LCI data comes from the U.S. LCI database.

Table 2.18 Transportation distance and mode for different plants (confidential)

Vendor	**Transport to West OAP(30%)/km**		**Transport to East FAP(70%)/km**		
	Oceanic	Truck and trailer	Oceanic	Rail	Truck and trailer

2.4.2.2. Construction / Installation

After customers purchase the products from distribution centers, they are installed. Other than packaging, which is mainly compromised of cartons, becoming waste, nothing else is required or removed at this stage. Waste processing of the waste from product packaging up to the end-of-waste state or disposal of final residues is included in this module.

Materials needed for installation of residential toilets include a wax ring or wax-free gasket and flange. The weight of these materials may vary in size based on customer needs, and range from 0.15 kg to 0.27 kg. These are necessary for creating a seal between the toilet outlet and drain line to ensure no leakage of sewer gas into the bathroom. The wax ring is generally a high-grade petroleum wax and often includes a polyethylene sleeve. The wax-free gasket and flange consists of a rubber gasket affixed to a plastic flange. These are generally used to install toilets to a recessed floor drain or for a no-mess installation. Supply lines are needed to supply the toilet tank with water. These supply lines consist of braided polymer coated fibers surrounding an inner PVC tube. Each end includes a crimp and nut for connection to the water supply and to the fill valve of the tank. The nut connecting to the water supply is normally metal, while the nut connecting to the fill valve may be metal or plastic. The nut which connects to the fill valve will include an inner gasket for proper sealing. TOTO does not provide these materials and hence they are not included in the LCA. It is expected that these materials will have a low additional environmental impact as compared to the TOTO products.

2.4.3. Use stage [B1-B5]

The use stage includes the following information modules:

- B1: Use or application of the installed product
- B2: Maintenance
- B3: Repair
- B4: Replacement
- B5: Refurbishment
- B6-B7: Operational energy and water use

2.4.3.1. Use or application of the installed product

There are no additional activities or construction work needed or associated with the installation of the product during the use phase. Therefore, this is not included in the model.

2.4.3.2. Maintenance

The service life is defined in such as way that for a typical installation, no regular maintenance activities other than cleaning of the sanitary facilities as a whole is required. There is no maintenance as such included in the model.

2.4.3.3. Repair

The service life is defined in such as way that for a typical installation, no repair is required. Repair would be incidental. There is no repair as such included in the model.

2.4.3.4. Replacement

The service life is defined in such as way that for a typical installation, replacing a whole product in order to return product to a condition in which it can perform its required functional or technical performance is not required. Replacements are not relevant and therefore no calculation rules need to be defined. The model does not include replacements.

2.4.3.5. Refurbishment

The service life is defined in such as way that for a typical installation, no refurbishment is required. There is no refurbishment as such included in the model.

2.4.3.6. Operational energy and water use

The use stage related to the operation of the building includes:

- B6: Operational energy use
- B7: Operational water use

The use phase of the modeled products in this report follows the declared default life cycle use phase scenario in the approved Product Group Definitions (PGDs) of the Sustainable Minds Transparency Framework referenced herein [7, 8 &9].

The toilets and urinals are assumed to be used in an average U.S. household or commercial environment over a 10-year time period. The period of 10 years is modeled as the period of application based on the average economical lifespan for residential applications. The technical lifespan is longer. The economical lifespan of commercial applications can be longer or lower due to esthetic replacements or more intense use. The implication is that the LCA model assumes that the application ends at year 10 and that the materials will be treated in an end-of-life scenario.

Residential toilets are assumed to be used in an average U.S. household over a 10-year time period. With an average of 2.6 persons per household, 5.1 flushes per day per person,[3] we can calculate water usage of these toilets respectively, over the 10-year period. Commercial toilets and urinals are assumed to be used in an average commercial environment over a 10 year time period. With an average of 133 uses per day per 365 day year for toilets and 18 uses per day per 260 day year, we can calculate the water usage of these products. (in Table 2.19).

Table 2.19 Product functional unit

Product code	Product Name	Functional unit
CST744E	Eco Drake Toilet 1.28gpf	10-year of service delivered during the lifetime of the product. U.S. household over a 10-year time

[3] U.S. Environmental Protection Agency (EPA) Watersense, *Water-Efficient Single-Family New Home Specification* (Washington, DC, May 14, 2008), found at: www.epa.gov/watersense/docs/home_suppstat508.pdf. This document cites 5.1 flushes/day/person per Mayer. P, DeOreo, W. et al 2000 and 2003, and 2.6 persons per household per U.S. Department of Housing and Urban Development 2005.

		period. 1.28 gallon x 5.1 flushes x 2.6 people x 365 days x 10 years = 61,951 gallons.
CST454CUFG	Drake II 1G Toilet	10-year of service delivered during the lifetime of the product. U.S. household over a 10-year time period. 1.0 gallon x 5.1 flushes x 2.6 people x 365 days x 10 years = 48,399 gallons.
CT708E(V)(G)	Commercial Toilet	10-year of service delivered during the lifetime of the product. U.S. household over a 10-year time period. 1.28 gallon x 133 flushes x 365 days x 10 years = 621,376 gallons.
MS654114MF	Aquia Dual Flush One-Piece Toilet	10-year of service delivered during the lifetime of the product. U.S. household over a 10-year time period. Dual flush system with 0.9 gpf and 1.6 gpf. Using ratio of 2:1[4], (0.9*2+1.6)/3 gallons x 5.1 flushes x 2.6 people x 365 days x 10 years= 54,852 gallons
MS854114E	Eco Ultramax	10-year of service delivered during the lifetime of the product. U.S. household over a 10-year time period. 1.28 gallon x 5.1 flushes x 2.6 people x 365 days x 10 years = 61,951 gallons.
CST454CEFG	Drake II Toilet 1.28gpf	10-year of service delivered during the lifetime of the product. U.S. household over a 10-year time period. 1.28 gallon x 5.1 flushes x 2.6 people x 365 days x 10 years = 61,951 gallons.
MS604E114CEFG	Ultramax II 1.28gpf	10-year of service delivered during the lifetime of the product. U.S. household over a 10-year time period. 1.28 gallon x 5.1 flushes x 2.6 people x 365 days x 10 years = 61,951 gallons.
CST412MF	Aquia Dual Flush Two-Piece Toilet	10-year of service delivered during the lifetime of the product. U.S. household over a 10-year time period. Dual flush system with 0.9 gpf and 1.6 gpf. Using ratio of 2:1, (0.9*2+1.6)/3 gallons x 5.1 flushes x 2.6 people x 365 days x 10 years= 54,852 gallons
UT105U(V)(G)	Commercial High-Efficiency Urinal	10-year of service delivered during the lifetime of the product. U.S. commercial environment over a 10-year time period. 0.125 gallon x 18 flushes x 260 days x 10 years = 5,850 gallons
UT445U(V)	Commercial High-Efficiency Urinal	10-year of service delivered during the lifetime of the product. U.S. commercial environment over a 10-year time period. 0.125 gallon x 18 flushes x 260 days x 10 years = 5,850 gallons

Water usage in a residential or a commercial environment would also include electricity consumption for acquisition, treatment and distribution of water to households in addition to collection, conveyance and wastewater treatment of domestic wastewater. Electric Power Research Institute (EPRI) published this type of data in a study on water and sustainability. U.S. EPA data were used to establish weighted average composite factors, to obtain an electricity usage per gallon of water consumed. The foregoing is summarized in Table 2.20 below.

4 U.S. Environmental Protection Agency (EPA) Watersense, *Response to Comments on Labeling of Tank-Type High-Efficiency Toilets,* Nov 15, 2006. Retrieved from http://www.epa.gov/WaterSense/docs/comment_response_het508.pdf.

Table 2.20 Average National Electricity Usage Factors

Activity	*EPRI factors: kWh / MMgal*[Note 1]	*Weighted avg composite factors: kWh / MMgal*
Acquisition, treatment and distribution of surface water by a Public Water System (PWS)	1,406	1,540[Note 2]
Acquisition, treatment and distribution of ground water by a PWS	1,824	
Self-supply of drinking water (typically pumping from private wells)	700	700
Collection, conveyance and < secondary treatment of domestic wastewater	661	1,399[Note 3]
Collection, conveyance and secondary treatment of domestic wastewater	1,212	
Collection, conveyance and advanced treatment of domestic wastewater	1,726	
Collection, conveyance and zero discharge/other treatment of domestic wastewater	400	
	Total electricity per million gallons →	3,639
	Total kWh electricity per 1 gallon →	**0.0036**

Note 1: Source: EPRI, Water & Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment -- The Next Half Century, March 2002.
Note 2: 63% of population served by PWSs relies on surface water, 37% on ground water. Calculated from http://www.epa.gov/safewater/pws/factoids.html.
Note 3: 1.5% of POTW-served population receives < secondary treatment, 43.3% receives secondary treatment, 48.7% receives advanced treatment, and 6.5% receives zero discharge or other treatment. Source: EPA, 2004 Clean Watersheds Needs Survey.

The water usage of the products is calculated and a summary of the same is listed in Table 2.21.

Table 2.21 Toilet Use Phase Data Summarized

Product code	**Water usage (gallon)**	**Electricity Usage (kWh)**
CST744E	61,951	223
CST454CUF(G)	48,399	174
CT708E	621,376	2,237
MS854114E	61,951	223
MS654114MF	54,852	197
CST454CEFG	61,951	223
MS604114CEFG	61,951	223
CST412MF	54,852	197
UT105U(V)(G)	5,850	21
UT445U(V)	5,850	21

2.4.4. End-of-life stage [C1-C4]

The end-of-life stage includes:

- C1: Deconstruction / demolition
- C2: Transport to waste processing
- C3: Waste processing for reuse, recovery and/or recycling

- C4: Disposal

The toilets are assumed to have a useful life of beyond 10 years. At the end of life, it is assumed that the toilets are landfilled but most of their components follow the waste scenarios as outlined in Tables 2.23. TOTO ceramic materials can be recycled as aggregate in several applications; however this is not a common practice at the moment. According to the data from the U.S. EPA's Municipal Solid Waste Generation, Recycling, and Disposal in the United States Report for 2010[5], 62.5% of paper and paperboard, 33.8% of the steel, 70.50% of other non-ferrous metals, 15.0% of rubber and 7.6% of plastics in municipal wastes are recycled. We use these rates to define the waste scenario of metal and plastic parts in the toilets.

Table 2.23 List of waste scenarios for materials

Material	Waste scenario	
	Recycling	**Landfill**
Brass, Zinc	70.5%	29.5%
Ceramic	0.00%	100%
Corrugated board, Paper	62.5%	37.5%
PP, PVC, PET, Polymer, HDPE,	7.60%	92.4%
Pallet	14.5%	85.5%
SBR, EPDM rubber , Silicone rubber, ABS, POM	15.0%	85.0%
Silicone, silicone product	7.60%	92.4%

2.4.4.1. De-construction / demolition stage

At the end of life, de-construction of the products which include their dismantling as well as the initial on-site sorting is assumed to be manual. Therefore, no deconstruction activities were included in the model.

2.4.4.2. Transport to waste processing stage

The transport stage involves the transportation of the discarded products to waste processing either to recycling or to final disposal. The transport stage included in the model is based on the assumption that the product will travel 100 km on a truck either to a landfill as a final disposal or to a a recycling site.

2.4.4.3. Waste Processing stage

The waste processing of material flows transported to a recycling site following the waste scenarios of materials as listed in Table 2.23 were assumed to be intended for recycling and were included in the model. All processing including pre-sorting, crushing, and shredding were modeled.

2.4.4.4. Disposal stage

The disposal of material flows transported to a landfill following the waste scenarios of materials as listed in Table 2.23 were included in the model.

[5] United States Environmental Protection Agency, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2010. http://www.epa.gov/osw/nonhaz/municipal/pubs/msw_2010_factsheet.pdf.

2.4.5. Recovery stage [D]

Module D reports the environmental benefits or loads resulting from net flows of reusable products, recyclable materials and/or useful energy carriers leaving a product system (e.g. as secondary materials or fuels). It includes recycling potentials of materials expressed as net impacts and benefits. All recycled materials as shown in Table 2.23 is processed in the waste processing stage (i.e. Module [C3]). The transportation (500 miles) as well as the recycling processing of all recycled materials into new materials are included in this stage. It was assumed that on average a yield of 90-95% substitutes that amount of primary material (Table 2.24). There is no thermal recovery modeled for end of life as is defined in the scenarios in Table 2.23.

Table 2.24 Substitution in recovery stage

Material	% of substitution	Material substituted with
ABS	90%	HDPE
Brass, primary	95%	Brass
Cardboard, primary	95%	Sulphate pulp
EPDM	90%	HDPE
Epoxy resin	90%	HDPE
NBR	90%	HDPE
Paper	95%	Sulphate pulp
PET	90%	HDPE
Polyacetal	90%	HDPE
Polypropylene	90%	HDPE
PVC	90%	HDPE
SBR	90%	HDPE
Silicone	90%	HDPE
Stainless steel	95%	Steel
Synthetic Rubber	90%	HDPE
Zinc, primary	95%	Zinc

3 INVENTORY

This chapter includes an overview of the obtained data and data quality that has been used in this study.

3.1 Data categories

The impacts have been inventoried for the following data categories:

- energy inputs
- material inputs
- emissions to air, water and soil
- production of waste and treatment
- produced products

The abovementioned flows are called data categories. They define the scope of the inventory.

3.2 Data selection and quality

Most of the manufacturing data came from primary sources for the calendar years 2012 and 2013. TOTO USA Development Engineering department collected all data using electric bills, purchasing orders, TOTO USA's production volume, data on waste and damaged final products, and production yield and efficiency. The lead LCA practitioner and TOTO's project manager worked together from day one on collecting data and undergoing a data validation process using mass balances and other calculation methods. No materials, components, emissions or energy flows have been left out, except for minor parts where the primary sources' data was incomplete or contradictory to the average industry data. This follows the general rule that either specific data or average data derived from specific production processes shall be the first choice as outlined in Part A of the Framework. Where products are declared together weighted averages have been used based on the processes and materials for the individual products.

Materials Data and Modeling. The materials are modeled with facility and vendor data, most vendors of toilets and materials were contacted using standardized questionnaires and answers were pulled from bills and manufacturing documentation by manufacturing engineers in the facilities and provided to TOTO USA. Data from LW, MW and TMX were modeled first as data collection and validation was easier given that data from these plants was collected over two consecutive years. Data validation/verification was done using the know-how and information on processes, oven's age and efficiency, machines' power ratings, sites' conditions and labor force, electricity consumptions, yield and production efficiency information, production rates, and mass balances. The whole toilets are modeled according to the facility where their bowls or tanks are manufactured. Where data is missing or gaps existed in the vendor data, data from the other similar facility or product where we have data have been utilized. An overview of used data sources is presented in appendix D.

Product composition data have been provided by TOTO. TOTO suppliers have provided primary data for all the manufacturing processes that reflect the actual processes in an accurate and complete fashion. Sustainable Minds has provided questionnaires and feedback to warrant completeness and consistency. Some data was confidential and is therefore not included in this report, but has been part of a review by Sustainable Minds. We have used publicly available data on composition and manufacturing for upstream and missing data and have supplemented that with literature data that is representative for the products on the US market.

Electricity is modeled with country specific grid mixed based on EcoInvent 2.2 definitions. This relates to the country of the vendors and the use phase in America. When transforming the inputs and outputs of combustible material into inputs and outputs of energy, the lower caloric value specific to the material have been applied based on scientifically accepted values.

Scenarios have been used to model the use stage, as defined in the PGDs, and end-of-life phase. Details are provided in the description of the life cycle stages earlier on in this report.

All used primary data reflects data for the calendar years 2012 and 2013, with regional specific data. All used background data to model the LCA is reported in the appendix D. Literature data comprises of the best available data from consistent sources, but varies from material to material in geographical, time related and technology coverage due to limited availability of specific data. Data from the US EcoInvent database was aimed to be used mostly. However, this does not warrant full consistency between all data sets. Different data can result in differences per material and that can influence the comparison. By using the US EcoInvent data the report follows the data quality in these datasets as it relates to time period coverage. The main criterion for data selection was the technological coverage as to reflect the physical reality of the declared product or product group as close as possible.

3.3 Limitations

The LCA is limited in the following ways:

- Vendors have responded to the request for data and cooperated with the LCA practitioner in varying levels. That was what instigated most of the assumption listed below. However, this is the second time the vendors have been contacted with LCA related questions. It is therefore recommended that the vendors will be contacted and engaged for future LCA work again and focus on some more details for the most important processes.
- No data on recycled content for any component of the modeled products was provided by vendors. No assumption of secondary material was made even when information was provided informally. This is likely a worst-case scenario. These assumptions need to be revisited in future LCA projects. There is a significant improvement potential for using more recycled content.
- Scenarios have been used to model the use phase as defined by the PGDs.
- Scenarios have been used for the end of life treatment of the materials.

- Literature data has been used based on the USLCI database and the US-ecoinvent database. With future updates and more and more LCA information becoming available, more representative and less generic data should be used for future LCA projects where possible.

A short summary of the most relevant assumptions that were made is presented here:

- Loss of ignition in TMX is assumed from LW according to production experts for the years 2012. However, they are reported to the year 2013.
- Raw materials in MW are from actual use data, each material based on recipe.
- Raw materials in LW are from batch data; each material is based on recipe. Even though the usage was known, allocation calculations based on receipe were made.
- Casting materials, inspection materials and installation materials are cut off.
- Transportation of English Kaolin, products from vendors, is estimate based on rail lines, port information.
- In LW and TMX, water content of sludge is assumed from MW for the year 2012. For the year 2013, water content was measured and reported.
- Solid wastes are data from MW, LW, FAP together; we assume that they are all from MW and LW and pallets, carton, wastepaper, metals, plastics are allocated based on product volume of MW and LW.
- Water emissions from LW are assumed to be the same with MW based on the product volume for the year 2012. However, more reported data was used for the year 2013.
- Ceramic products from vendors that we don't have data, we use data we have that are most similar with that vendor.
- Some limited amount of data of other parts of toilets are estimated from other ceramic products because of similarity even though they have different part numbers.
- We use general waste treatment data of EPA to make waste scenarios of products.
- Water and electricity consumption in the use phase is using general person and flush data from EPA.
- Pallet use is assumed the average numbers per unit of product in MW and LW for TMX and other vendors.

These assumptions are further discussed in Section 5.6 herein.

3.4 Criteria for the exclusion of inputs and outputs

The time period over which inputs to and outputs from the system are 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:

- *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.
- *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.
- *Environmental relevance* – If a flow meets the above criteria for exclusion, yet is thought to potentially have a significant environmental impact, it is included. Material flows which leave the system (emissions) and whose environmental impact is greater than 1% of the whole impact of an impact category that has been

considered in the assessment have been covered. This judgment is done based on experience and documented as necessary, but also relies on the used literature data.

- 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).

In this report almost all flows for the primary data for TOTO and the vendors have been reported, therefore these criteria have been met. The completeness of the bill of materials is reported in the previous chapter (Table 2.9) and satisfies the above defined cut-off criteria.

3.5 Allocation

Whenever a system boundary is crossed environmental inputs and outputs have to be assigned to the different products. Where multi-inputs are considered or where multi-outputs are considered the same applies. Part A prescribes to report where and how allocation occurs in the modeling of the LCA. In this LCA the following rules have been applied:

The preferred way to avoid allocation when a system boundary is crossed is to expand the system boundaries, e.g. including the cut-off parts. In this LCA, system boundaries are crossed for the manufacturing processes and reuse or reclaiming components after use. Multi-input, multi-output and recycling allocations are described below.

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.

Manufacturing processes:
Allocation for the manufacturing processes is done on a process to process level, with different processes assigned to different parts. Allocation for upstream processes follows the US-ecoinvent and ecoinvent assumptions, most notably the co-product allocation is either based on value or, if not available, on mass.

Multi-input processes:
The preferred way to deal with assigning impacts to multi-inputs is to reflect the physical properties of the incoming flows. If a relationship can be established that is more suitable than mass, it should be used.

Waste treatment at the end-of-life:
Waste treatment is typically a multi-input process. Several waste streams come together and are processed. Where specific data are available the composition of the waste flows has been used to model the contribution to the impacts from the waste treatment, this includes substitution benefits for energy utilization for combustion processes where relevant. Where no specific data are at hand average values are used.

Multi-output processes:
Where multiple products are produced allocation is needed. Usually allocation is done by mass, unless another relation is more relevant. Allocation of the manufacturing data in this LCA includes the weight of the finished product and the yield of the specific product.

Reuse and recycling:
Recycled content is used in some of the metal parts and the cardboard for the boxes. All processes needed to be able to utilize recycled content in the used materials after collecting and sorting are assigned to the product utilizing the recycled content. However, the previous use is cut off.

Some process waste and parts of the finished product after use are also recycled. An example is the metal parts after the use of the product. Life cycle stage end-of-life includes transportation to sorting facilities and processing is included up to the point of material that is ready for recycling, such as shredded metal or granulated plastic.

All processes and transportation needed to actually recycle the materials are assigned to the recovery stage. This includes a credit given for the manufacturing of the primary material that is prevented by doing so. The credit varies for the different materials and is typically the scrap material that is used to make new product consistent with any other scenario for waste processing and is based on current average technology or practice. An example would be recycled fiber for cardboard. This is referred to as “up to the point of functional equivalence where the secondary material or fuel substitutes primary production and subtracting the impacts resulting from the substituted production of the product or substituted generation of energy from primary sources”.

4 IMPACT ASSESSMENT

4.1 Impact assessment

The environmental indicators (global warming, ozone layer depletion, summer smog, acidification and eutrophication and abiotic depletion for non fuel and fuel resources) as required by ISO 14025 are included as well as other indicators required by Part A of the Framework (see Table 4.1). The impact indicators are derived by using the 100 year time horizon[6] factors, where relevant, as defined by TRACI 2.1 classification and characterization[7]. Long-term emissions (> 100 years) are not taken into consideration in the impact estimate. This follows the approach from Part A of the Framework.

Table 4.1 Selected impact categories and units

Impact category	Unit
Ozone depletion	CFC-11 eq
Smog	O_3 eq (ozone)
Acidification	SO_2 eq (sulphur dioxide)
Fossil fuel depletion	MJ surplus
Eutrophication	N eq (nitrogen)
Respiratory effects	$PM_{2.5}$ eq (fine particulates)
Non carcinogenics	CTU_h
Carcinogenics	CTU_h
Ecotoxicity	CTU_e
Global warming	CO_2 eq (carbon dioxide)

A definition of these impact categories is included in appendix C. During the impact assessment stage of the modeling, the list of impacts, LCI, for substances that may have not been recognized by the impact assessment method was reviewed. SimaPro was used to perform the impact assessment.

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.

6 The 100 year period relates to the period in which the environmental impacts are modeled. This is different from the time period of the functional unit. The two periods are related as follows: all environmental impacts that are created in the period of the functional unit, are modeled through life cycle impact assessment using a 100 year time horizon to understand the impacts that take place.
7 J. Bare (2011) TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. Clean Technologies and Environmental Policy. 13(5); United States Environmental Protection Agency (2012). Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) User's Manual. Document ID: S-10637-OP-1-0.

4.2 Normalization and weighting

To arrive to the single score indicator, normalization[8] and weighting[9] conforming to Part A of the Framework was applied.

Table 4.2 Normalization and Weighting factors

Impact category	Normalization	Weighting (%)
Ozone depletion	6.20	2.4
Smog	7.18E-4	4.8
Acidification	1.10E-2	3.6
Fossil fuel depletion	5.79E-5	12.1
Eutrophication	4.63E-2	7.2
Respiratory effects	4.12E-2	10.8
Non carcinogenics	952	6.0
Carcinogenics	19,706	9.6
Ecotoxicity	9.05E-5	8.4
Global warming	4.13E-5	34.9

[8] A. Lautier, et al. (2010). Development of normalization factors for Canada and the United States and comparison with European factors. Science of the Total Environment. 409: 33-42.
[9] Bare, Jane; Gloria, Tom and Norris, Greg, Development of the Method and U.S. Normalization Database fro Life Cycle Impact Assessment and Sustainability Metrics, Environmental Science and Technology, / VOL. 40, NO. 16, 2006

5 INTERPRETATION

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

5.1 EcoDrake CST744E

Cradle-to-gate

Figure 5.1 shows the results for the finished product. It shows that the ceramic parts dominate all impact categories except for non-carcinogenics and eutrophication where zinc and brass parts together with brass turning process have significant contributions to these two categories. The other parts and processes contribute between 10% and 26% of the overall impacts in the remaining categories.

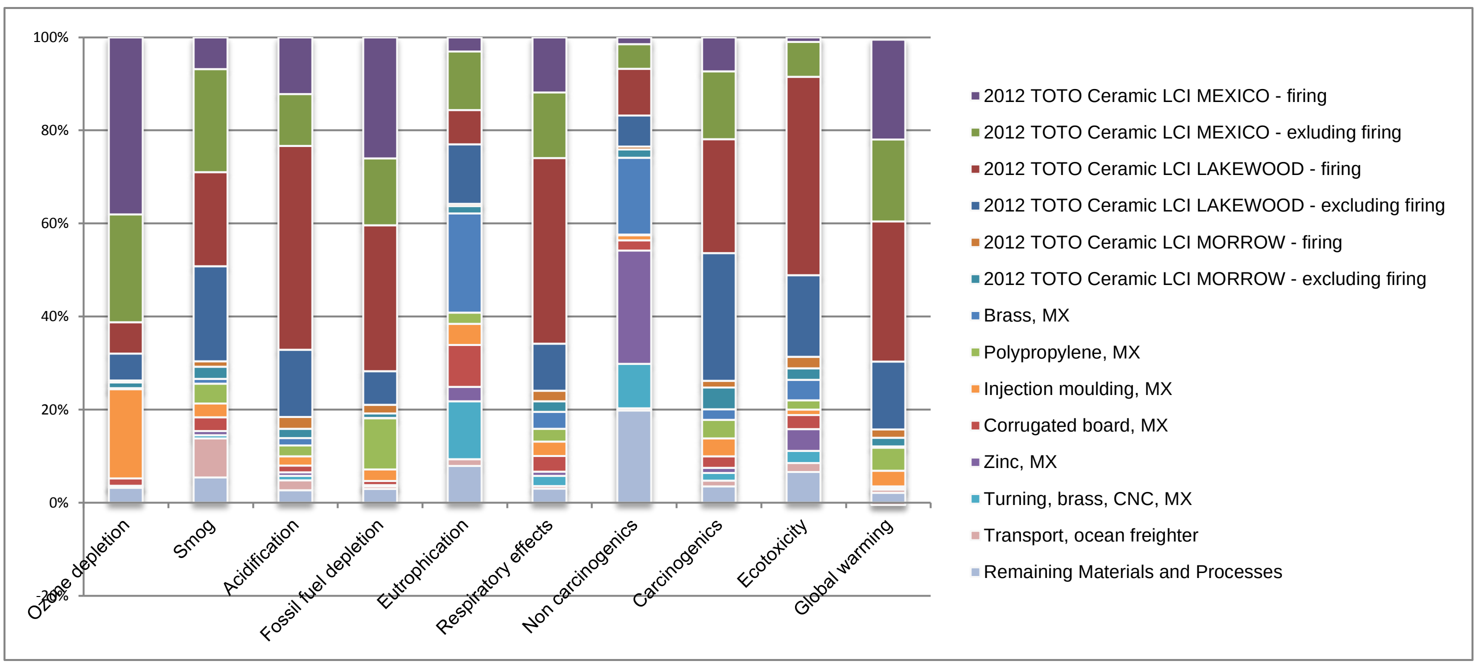


Figure 5.1 Cradle-to-gate impacts for CST744E – relative results

Variations

Not relevant.

Full life cycle

Figure 5.2 and Table 5.1 show the results for the full life cycle of the product. It shows that the use stage [B1-B7] and the product stage [A1-A3] are dominating the results for all impact categories. For the use phase, the significant contribution is mostly due to the embedded energy use (such as electricity) in the water used during the operation of the product (40-84%) [B6-B7]. For the product itself [A1-A3] has a significant contribution to ozone depletion (emissions from natural gas exploration and transportation as well as crude oil production and the enrichment of uranium in nuclear power plants), fossil fuel depletion (mostly defined by the natural gas at the kiln and its extraction together with crude oil production and the production of polypropylene) and non-carcinogens (mostly from the production of zinc and copper and disposal of hard coal ash in landfills). The impacts for the product itself [A1-A3] are discussed above in the cradle-to-gate section. The contribution of the delivery and installation of the product [A4-A5] which are covered under the construction stage is associated with the transportation by truck for delivery to the market. It shows up having a contribution 1 to 20% in the impact categories. The end-of-life scenario [D] includes recycling and benefits from this by preventing the need to produce primary materials. It shows up with a non-significant contribution to the results. The end-of-life stage that includes the processes for dismantling and final waste treatment [C1-C4] of the product does not have a significant impact.

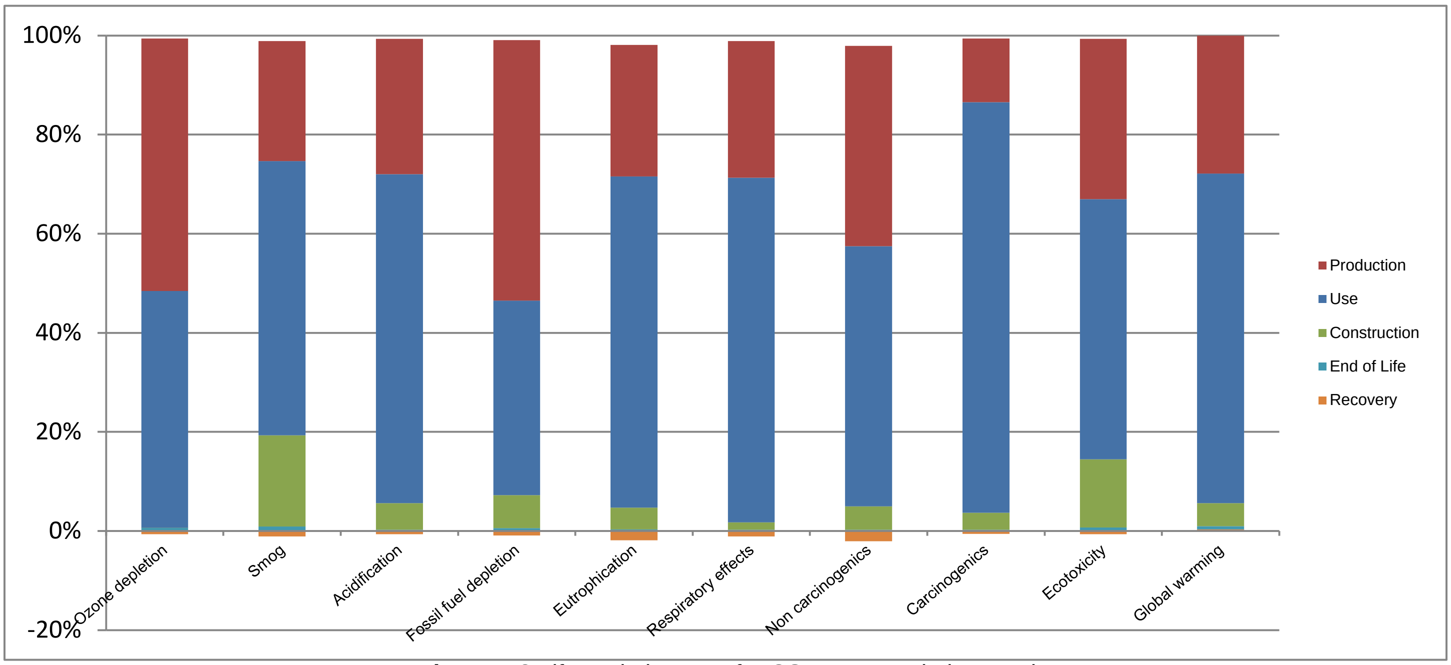


Figure 5.2 Life cycle impacts for CST744E – relative results

Table 5.1 Life cycle impacts for CST744E – absolute results

Impact category	Unit	Production	Construction	Use	End of life	Recovery	Total
Ecological damage							
Acidification	SO2 eq	5.84E-01	1.15E-01	1.42E+00	5.99E-03	-1.43E-02	2.11E+00
Ecotoxicity	CTUe	8.05E+01	3.41E+01	1.31E+02	1.85E+00	-1.62E+00	2.45E+02
Eutrophication	N eq (nitrogen)	4.74E-02	7.84E-03	1.19E-01	5.39E-04	-3.34E-03	1.72E-01
Global warming	CO2 eq (carbon dioxide)	8.82E+01	1.47E+01	2.11E+02	2.03E+00	1.01E+00	3.17E+02
Ozone depletion	CFC-11 eq	9.47E-06	6.05E-09	8.89E-06	1.16E-07	-1.15E-07	1.84E-05

Human health damage							
Carcinogenics	CTUh	6.93E-07	1.84E-07	4.46E-06	1.35E-08	-3.15E-08	5.32E-06
Non-carcinogenics	CTUh	1.52E-05	1.77E-06	1.98E-05	1.02E-07	-7.80E-07	3.61E-05
Respiratory effects	PM2.5 eq	3.73E-02	2.02E-03	9.41E-02	3.72E-04	-1.51E-03	1.32E-01
Smog	O3 eq (ozone)	4.30E+00	3.26E+00	9.82E+00	1.61E-01	-1.98E-01	1.73E+01
Resource depletion							
Fossil fuel depletion	MJ surplus	1.91E+02	2.42E+01	1.43E+02	2.03E+00	-3.36E+00	3.56E+02

Variations

Not relevant.

SM results

The SM millipoint score by life cycle phase for this product is presented below (Table 5.2). They confirm the trends in the results using the impact assessment results prior to normalization and weighting.

Table 5.2 SM millipoint scores for CST744E by life cycle phase – absolute results

Impact category	Unit	Total	Production	Construction	Use	End of life	Recovery
SM single figure	mPts	23.65	6.11	1.28	16.31	0.10	-0.16

5.2 Toilet CT708E

Cradle-to-gate

Figure 5.3 shows the results for the finished product. It shows that the ceramic parts dominate all impact categories except for ozone depletion, non-carcinogenics and eutrophication where brass parts together with injection molding process have dominating contributions to these three categories. The other parts and processes contribute between 4% and 23% of the overall impacts in the remaining categories.

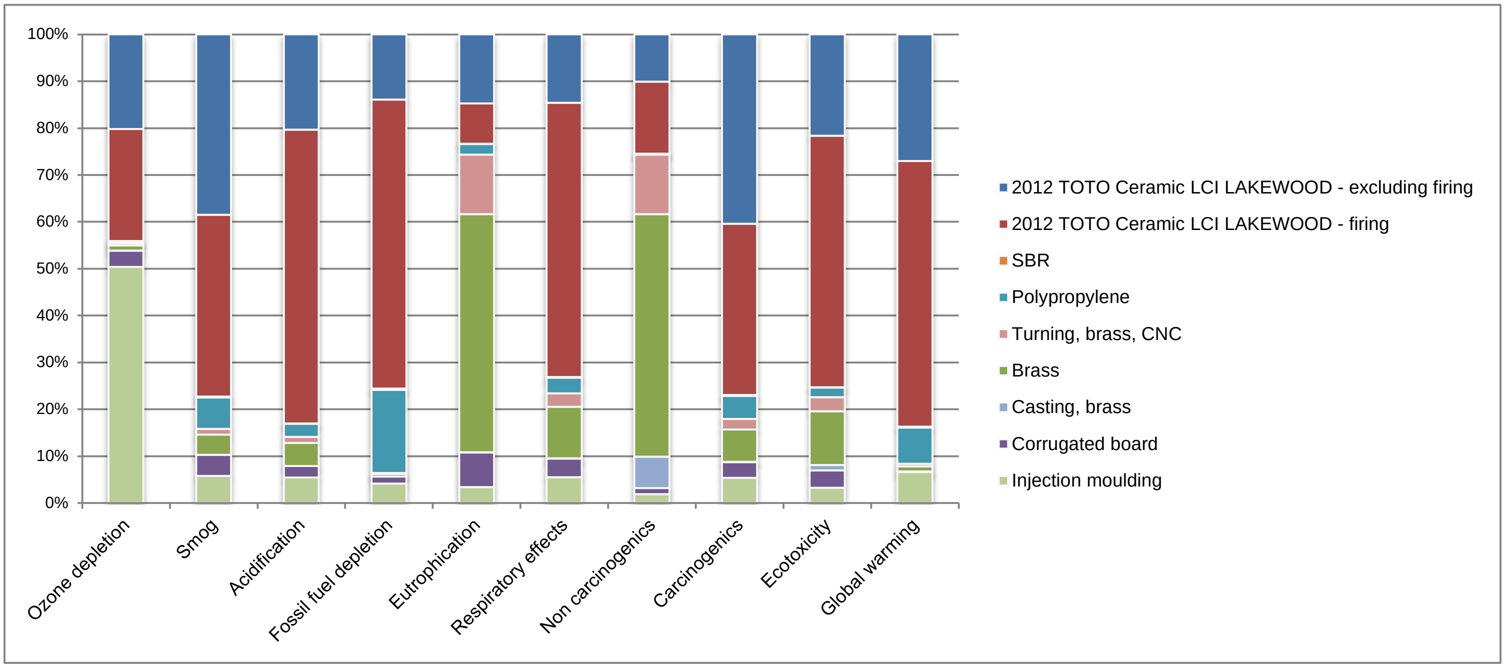


Figure 5.3 Cradle-to-gate impacts for CT708E – relative results

Variations

Not relevant.

Full life cycle

Figure 5.4 and Table 5.3 show the results for the full life cycle of the product. It shows that the use phase [B1-B7] is dominating the results for all impact categories. This is mostly due to the embedded energy use (such as electricity) in the water used during the operation of the product (91-98%) [B6-B7]. This is to be expected since this is a commercial product with a use phase that is the most intensive from all products in this report. The product itself [A1-A3] as well as the construction / installation stage [A4-A5] appear to be slightly significant but not dominant in any impact category. The impacts for the product itself [A1-A3] are discussed above in the cradle-to-gate section. The end-of-life scenario [D] includes recycling and benefits from this by preventing the need to primary materials. It does not show up as a relevant factor for any of the impact categories. The processes for dismantling and final waste treatment [C1-C4] of the product do not have a significant impact.

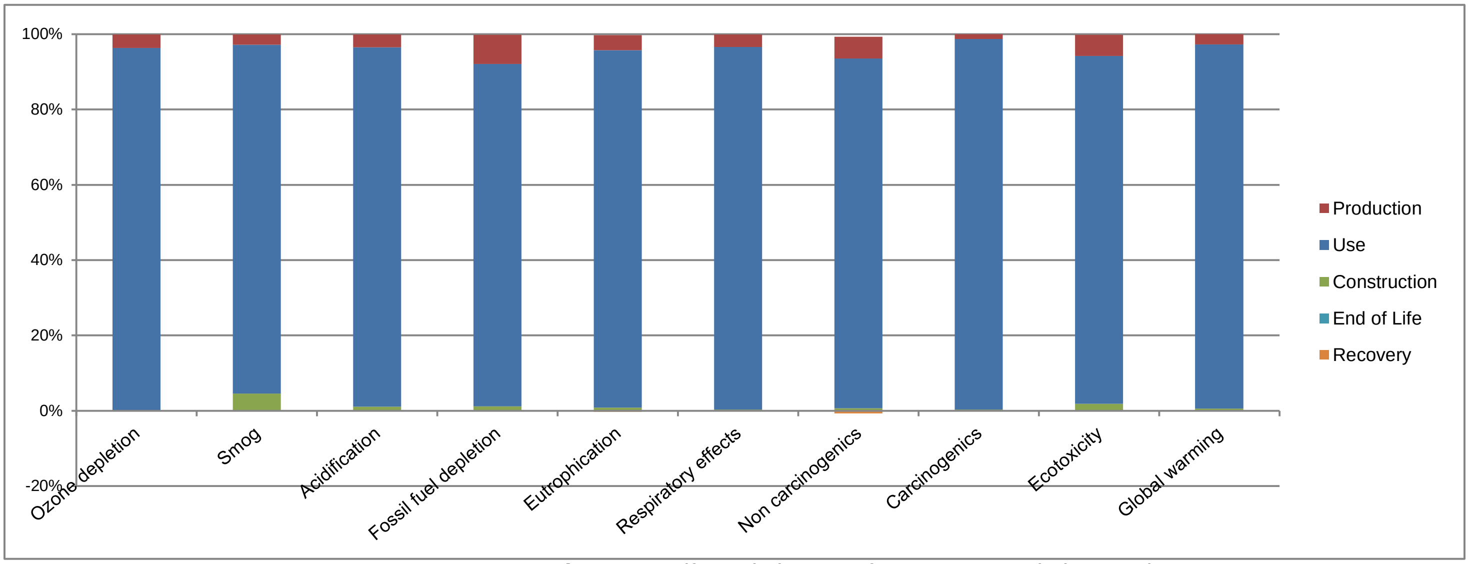


Figure 5.4 Life cycle impacts for CT708E – relative results

Table 5.3 Life cycle impacts for CT708E – absolute results

Impact category	Unit	Production	Construction	Use	End of life	Recovery	Total
Ecological damage							
Acidification	SO2 eq	5.12E-01	1.62E-01	1.42E+01	3.43E-03	-1.20E-02	1.49E+01
Ecotoxicity	CTUe	8.02E+01	2.48E+01	1.31E+03	1.13E+00	-2.39E+00	1.41E+03
Eutrophication	N eq (nitrogen)	5.07E-02	1.00E-02	1.20E+00	3.29E-04	-3.09E-03	1.25E+00
Global warming	CO2 eq (carbon dioxide)	5.93E+01	1.08E+01	2.11E+03	1.39E+00	5.94E-01	2.19E+03
Ozone depletion	CFC-11 eq	3.34E-06	4.47E-09	8.91E-05	6.54E-08	-9.19E-08	9.25E-05
Human health damage							
Carcinogenics	CTUh	5.82E-07	1.34E-07	4.47E-05	8.15E-09	-2.59E-08	4.54E-05
Non-carcinogenics	CTUh	1.24E-05	1.28E-06	1.98E-04	5.93E-08	-1.47E-06	2.11E-04
Respiratory effects	PM2.5 eq	3.18E-02	2.77E-03	9.43E-01	2.27E-04	-1.34E-03	9.77E-01
Smog	O3 eq (ozone)	2.81E+00	4.77E+00	9.84E+01	9.23E-02	-1.52E-01	1.06E+02
Resource depletion							
Fossil fuel depletion	MJ surplus	1.22E+02	1.76E+01	1.43E+03	1.14E+00	-2.80E+00	1.57E+03

Variations

Not relevant.

SM results

The SM millipoint score by life cycle phase for this product is presented below (Table 5.5). They confirm the trends in the results using the impact assessment results before normalization and weighting.

Table 5.4 SM millipoint scores for CT708E by life cycle phase – absolute results

Impact category	Unit	Total	Production	Construction	Use	End of life	Recovery
SM single figure	mPts	169.31	4.74	1.07	163.63	0.06	-0.19

5.3 Urinal UT105U

Cradle-to-gate

Figure 5.5 shows the results for the finished product. It shows that the ceramic parts dominate all impact categories except for eutrophication, non-carcinogenics and carcinogenics where brass parts together with turning brass process have dominating contributions to these three categories. The other parts and processes contribute between 2% and 32% of the overall impacts in the remaining categories.

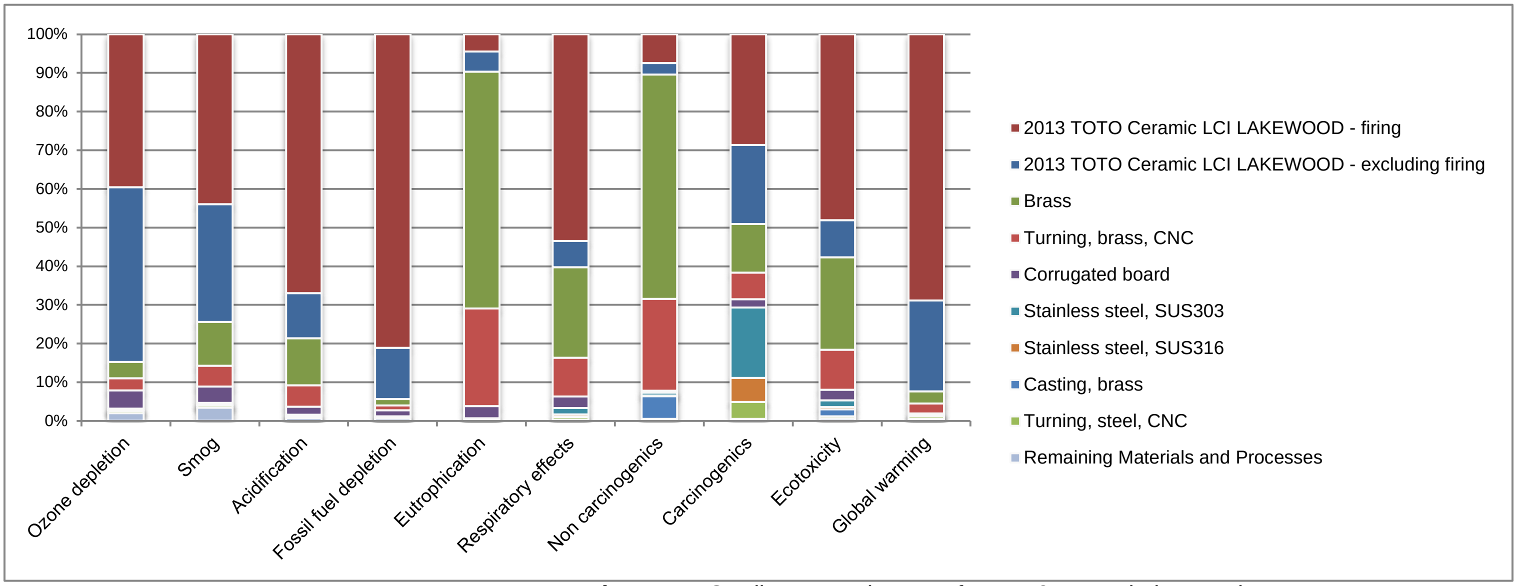


Figure 5.5 Cradle-to-gate impacts for UT105U – relative results

Variations

Not relevant.

Full life cycle

Figure 5.6 and Table 5.5 show the results for the full life cycle of the product. The product itself [A1-A3] is dominating all impact categories. The impacts for the product itself [A1-A3] are discussed above in the cradle-to-gate section. It is important to note that due to the fact that this product was a brand new product in 2013 and that the process had to be adjusted considerably in order to "dial it in." It has stabilized at (confidential) and (confidential) respectively in 2014. During the year 2013, it had low ceramic production yield and as such the production stage impacts are higher. Results show that the use phase [B1-B7] is less dominant compared to toilets due to the lower volume of water, but it is still significant for most of the impact categories. This is mostly due to the embedded energy use (such as electricity) in the water used during the operation of the product (4-26%) [B6-B7]. The contribution of the delivery and installation of the product [A4-A5] covered under the construction stage are associated with the transportation by truck for delivery to the market. The end-of-life scenario [D] includes recycling and benefits from this by preventing the need to primary materials for brass and cardboard. It shows up as a relevant factor for some of the impact categories offsetting part of the impacts caused by making the parts of the product. Additionally, the delivery and the processes for dismantling and final waste treatment [C1-C4] of the product show up slightly relevant in the global warming impact category.

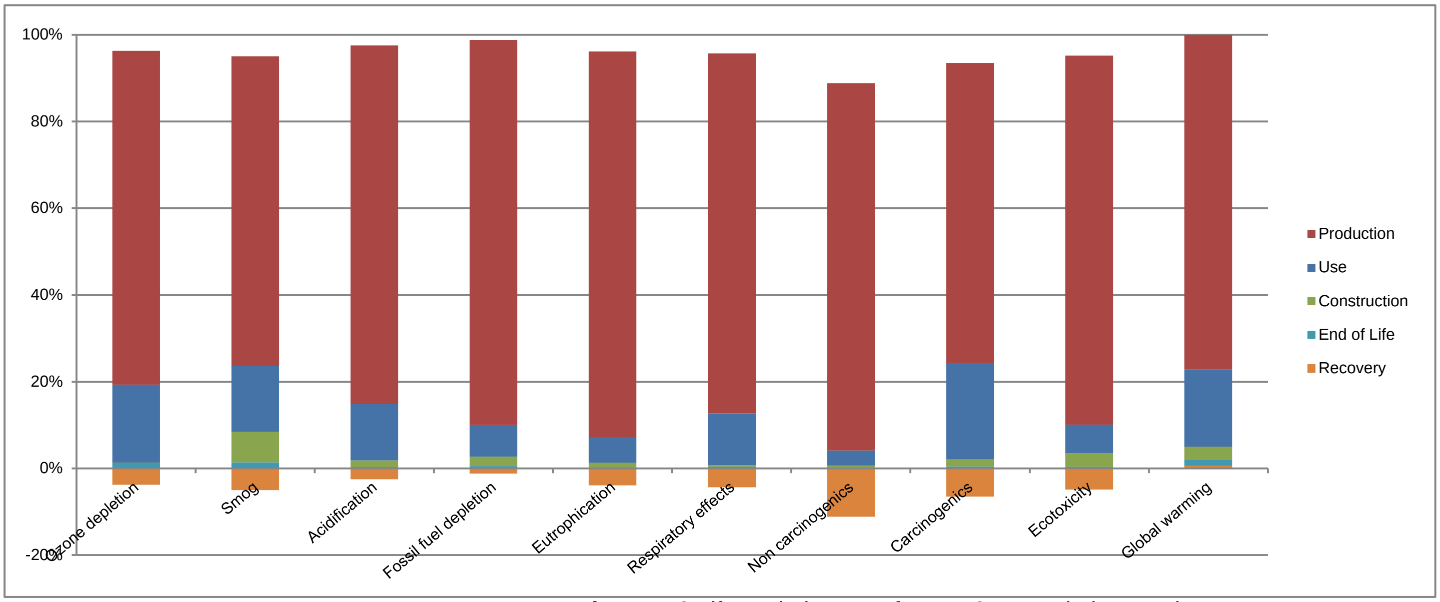


Figure 5.6 Life cycle impacts for UT105U – relative results

Table 5.5 Life cycle impacts for UT105U – absolute results

Impact category	Unit	Production	Construction	Use	End of life	Recovery	Total
Ecological damage							
Acidification	SO2 eq	8.50E-01	1.54E-02	1.34E-01	3.29E-03	-2.55E-02	9.77E-01
Ecotoxicity	CTUe	1.59E+02	5.77E+00	1.23E+01	7.63E-01	-9.01E+00	1.68E+02
Eutrophication	N eq (nitrogen)	1.74E-01	2.23E-03	1.13E-02	3.08E-04	-7.59E-03	1.80E-01
Global warming	CO2 eq (carbon dioxide)	8.60E+01	3.42E+00	1.99E+01	1.50E+00	6.44E-01	1.11E+02
Ozone depletion	CFC-11 eq	3.58E-06	3.71E-09	8.39E-07	5.75E-08	-1.73E-07	4.31E-06
Human health damage							
Carcinogenics	CTUh	1.31E-06	3.14E-08	4.21E-07	7.95E-09	-1.23E-07	1.65E-06
Non-carcinogenics	CTUh	4.54E-05	3.01E-07	1.87E-06	5.58E-08	-5.99E-06	4.17E-05
Respiratory effects	PM2.5 eq	6.18E-02	2.91E-04	8.88E-03	2.59E-04	-3.22E-03	6.80E-02
Smog	O3 eq (ozone)	4.37E+00	4.29E-01	9.27E-01	8.63E-02	-3.05E-01	5.51E+00
Resource depletion							
Fossil fuel depletion	MJ surplus	1.65E+02	4.10E+00	1.35E+01	9.86E-01	-2.23E+00	1.81E+02

Variations

Not relevant.

SM results

The SM millipoint score by life cycle phase for this product is presented below. They confirm the trends in the results using the impact assessment results before normalization and weighting.

Table 5.6 SM millipoint scores for UT105U by life cycle phase – absolute results

Impact category	Unit	Total	Production	Construction	Use	End of life	Recovery
SM single figure	mPts	11.13	10.01	0.23	1.54	0.06	-0.71

5.4 Urinal UT445U

Cradle-to-gate

Figure 5.7 shows the results for the finished product. It shows that the ceramic parts dominate half of all impact categories. Brass and stainless steel parts as well as turning brass process and ocean freighter transportation dominate the remaining impact categories. The other parts and processes contribute between 4% and 16% of the overall impacts in the remaining categories.

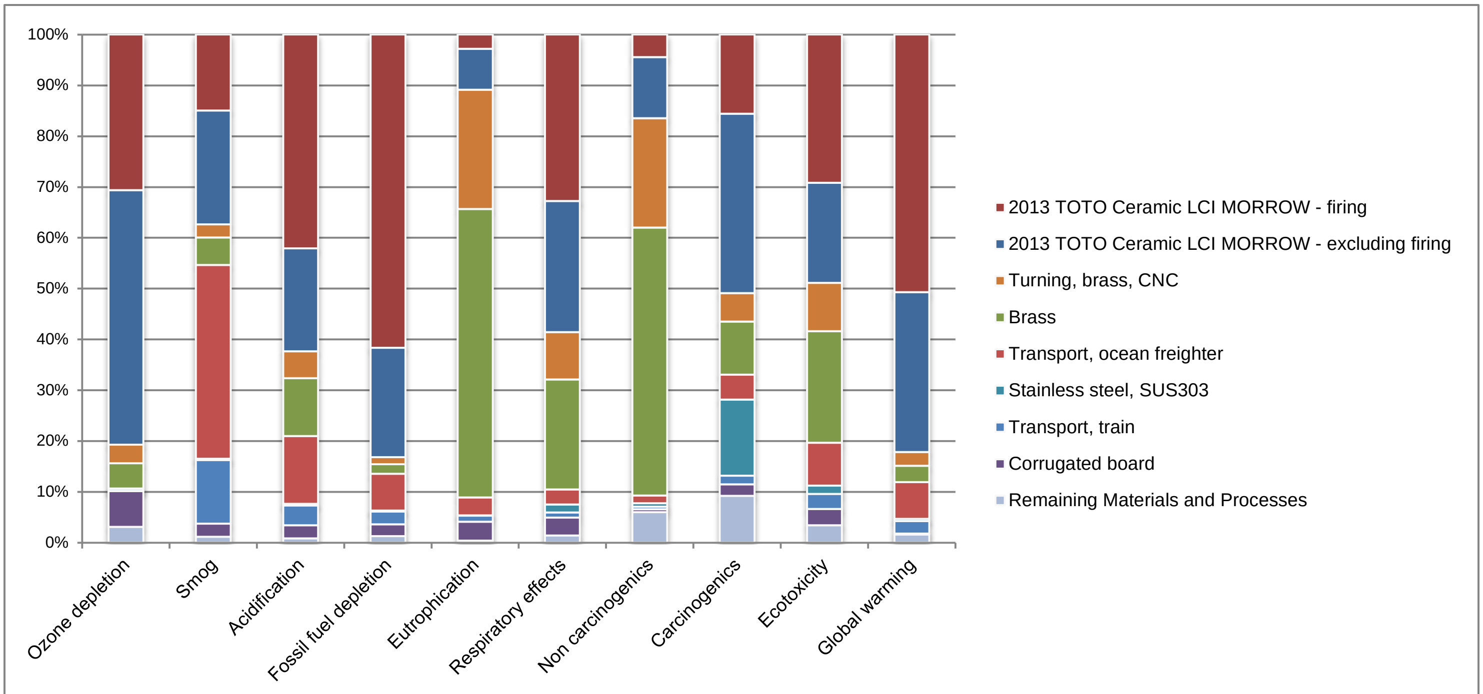


Figure 5.7 Cradle-to-gate impacts for UT445U – relative results

Variations

Not relevant.

Full life cycle

Figure 5.8 and Table 5.7 show the results for the full life cycle of the product. The product itself [A1-A3] is dominating all impact categories. The impacts for the product itself [A1-A3] are discussed above in the cradle-to-gate section. Results show that the use phase [B1-B7] is less dominant, but it is still significant for most of the impact categories. This is mostly due to the embedded energy use (such as electricity) in the water used during the operation of the product (4-22%) [B6-B7]. The contribution of the delivery and installation of the product [A4-A5] which is covered under the construction stage is associated with the transportation (truck, rail and ocean freighter) for delivery to the market. This product is produced in Asia and that is why the construction has higher impacts associated with the construction stage than that of UT105U. The end-of-life scenario [D] includes recycling and benefits from this by preventing the need to primary materials. It shows up as a relevant factor for some of the impact categories offsetting part of the impacts caused by making the parts of the product. Additionally, the delivery and the processes for dismantling and final waste treatment [C1-C4] of the product show up slightly relevant in the global warming impact category.

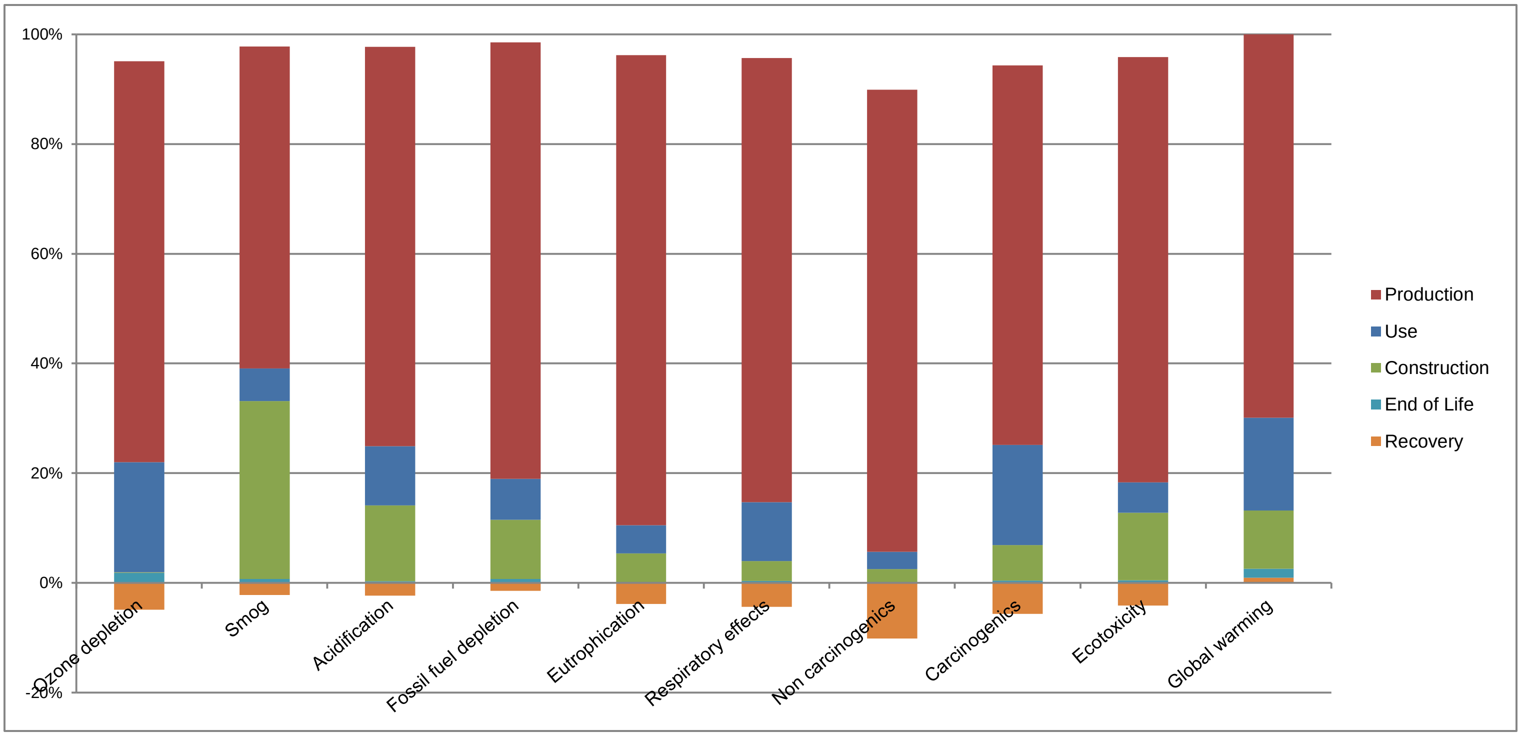


Figure 5.8 Life cycle impacts for UT445U – relative results

Table 5.7 Life cycle impacts for the UT445U – absolute results

Impact category	Unit	Production	Construction	Use	End of life	Recovery	Total
Ecological damage							
Acidification	SO2 eq	9.02E-01	1.71E-01	1.34E-01	4.14E-03	-2.86E-02	1.18E+00
Ecotoxicity	CTUe	1.73E+02	2.74E+01	1.23E+01	1.02E+00	-9.20E+00	2.04E+02
Eutrophication	N eq (nitrogen)	1.88E-01	1.14E-02	1.13E-02	3.27E-04	-8.37E-03	2.02E-01
Global warming	CO2 eq (carbon dioxide)	8.23E+01	1.25E+01	1.99E+01	1.91E+00	1.11E+00	1.18E+02
Ozone depletion	CFC-11 eq	3.06E-06	6.64E-09	8.39E-07	7.54E-08	-2.05E-07	3.78E-06
Human health damage							
Carcinogenics	CTUh	1.59E-06	1.48E-07	4.21E-07	1.05E-08	-1.30E-07	2.04E-06
Non-carcinogenics	CTUh	5.01E-05	1.42E-06	1.87E-06	7.14E-08	-6.02E-06	4.74E-05
Respiratory effects	PM2.5 eq	6.68E-02	2.96E-03	8.88E-03	3.00E-04	-3.57E-03	7.54E-02
Smog	O3 eq (ozone)	9.19E+00	5.07E+00	9.27E-01	1.13E-01	-3.47E-01	1.50E+01
Resource depletion							
Fossil fuel depletion	MJ surplus	1.43E+02	1.95E+01	1.35E+01	1.29E+00	-2.62E+00	1.75E+02

Variations

Not relevant.

SM results

The SM millipoint score by life cycle phase for this product is presented below. They confirm the trends in the results using the impact assessment results before normalization and weighting.

Table 5.8 SM millipoint scores for UT445U by life cycle phase – absolute results

Impact category	Unit	Total	Production	Construction	Use	End of life	Recovery
SM single figure	mPts	13.04	10.98	1.18	1.54	0.08	-0.73

5.5 Aquia MS654 & Aquia CST412

This section includes the weighted averaged results based on production volumes.

Cradle-to-gate

Figure 5.9 shows the results for the finished product. It shows that the ceramic parts, dominate the material contribution except for carcinogenics where stainless steel parts also have major contributions. Additionally, corrugated boards have significant contribution to eutrophication. The other parts and processes contribute between 7% and 16% of the overall impacts in the remaining categories.

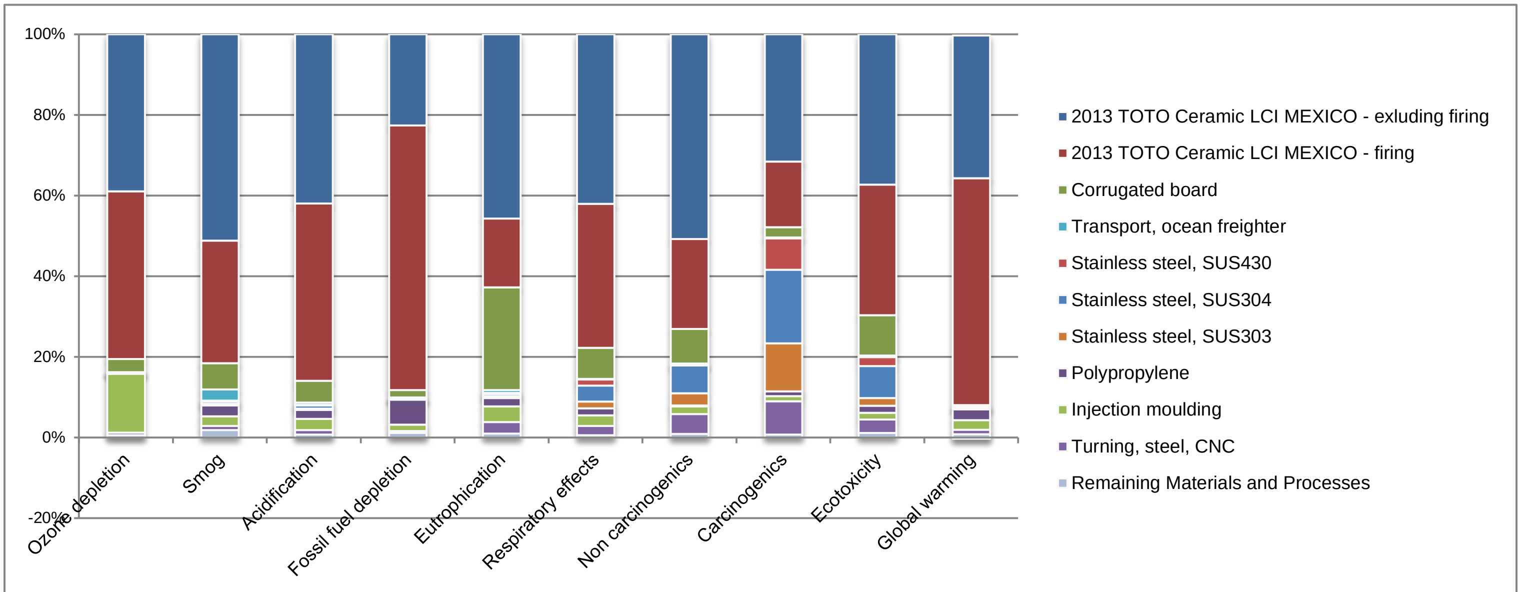


Figure 5.9 Cradle-to-gate impacts for the average of Aquia MS654 & Aquia CST412 – relative results

Variations

The variation in the bill of materials is presented in the Table 5.9 below. It shows some similarities, but many significant differences. Aquia CST412 uses more ceramic, corrugated board, EPDM and glass filled propylene and their associated manufacturing processes compared to Aquia MS654.

Table 5.9 Variations in the bill of materials for Aquia MS654 & Aquia CST412

Material	Average (kg)
Ceramic	45.09
Corrugated Board	5.30
PVC	0.27
EPDM	0.06
PP	2.14
SUS304	0.23
Glass Filled Polypropylene	0.05
POM	0.02
ABS	0.08
SUS430	0.09

Numbers shown in orange have a variation of 10 to 20%
Numbers shown in red have a variation greater than 20%

Full life cycle

Figure 5.10 and Table 5.10 show the results for the full life cycle of the product. It shows that the use phase [B1-B7] and the product stage [A1-A3] are equally important and dominate the results for all impact categories. The impact of the use stage is mostly due to the embedded energy use (such as electricity) in the water used during the operation of the product (26-62%) [B6-B7]. The product itself [A1-A3] is very relevant as it shows major contributions throughout. It has the most significant contributions to ozone depletion (emissions at the natural gas, hard coal and crude oil exploration and transportation), fossil fuel depletion (mostly defined by the natural gas used at the kiln and the use of fossil fuel based thermal power plants as well as the production of polypropylene) and ecotoxicity (mainly caused by stainless steel parts' production and electricity production using natural gas and crude oil and the disposal of slags). The impacts for the product itself [A1-A3] are discussed above in the cradle-to-gate section. The contributions of the delivery and installation of the product [A4-A5] which are covered under the construction stage is associated with the transportation (truck, rail and ocean freighter) for delivery to the market and the disposal of packaging materials which are mainly corrugated cardboard. The end-of-life scenario [D] includes recycling and benefits from this by preventing the need to primary materials. It shows up as a relevant factor for some of the impact categories offsetting part of the impacts caused by making the parts of the product. Additionally, the delivery and the processes for dismantling and final waste treatment [C1-C4] of the product show up slightly relevant in the carcinogenics, non-carcinogenics and ecotoxicity impact categories.

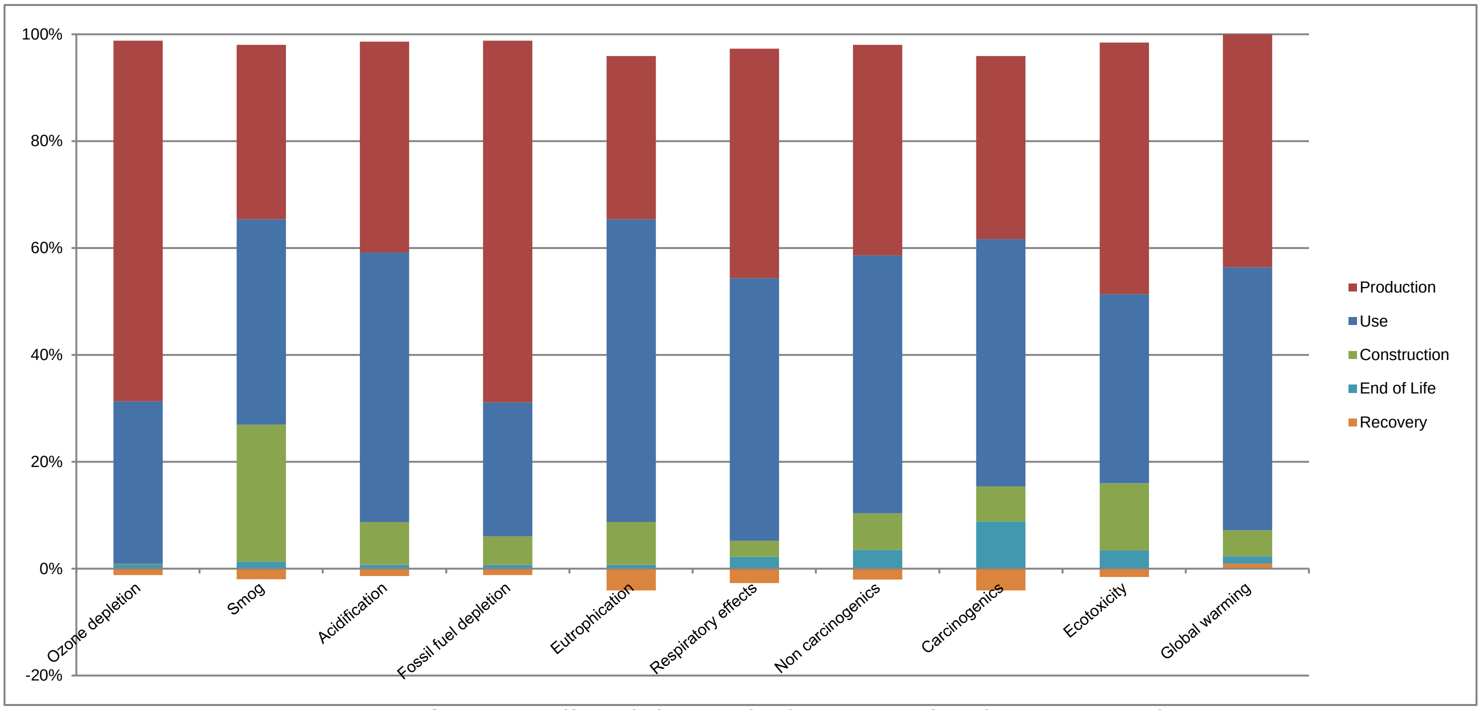


Figure 5.10 Life cycle impacts for the average of Aquia MS654 & Aquia CST412 – relative results

Table 5.10 Life cycle impacts for average of Aquia MS654 & Aquia CST412 – absolute results

Impact category	Unit	Production	Construction	Use	End of life	Recovery
Ecological damage						
Acidification	SO2 eq	9.77E-01	1.95E-01	1.25E+00	9.16E-03	-3.43E-02
Ecotoxicity	CTUe	1.49E+02	3.68E+01	1.16E+02	2.44E+00	-5.18E+00
Eutrophication	N eq (nitrogen)	5. 67E-02	1.46E-02	1.06E-01	8.28E-04	-7.62E-03
Global warming	CO2 eq (carbon dioxide)	1.65E+02	1.77E+01	1.87E+02	4.20E+00	3.57E+00
Ozone depletion	CFC-11 eq	1.74E-05	1.18E-08	7.87E-06	2.01E-07	-3.19E-07
Human health damage						
Carcinogenics	CTUh	2.56E-06	1.99E-07	3.95E-06	2.29E-08	-3.50E-07
Non-carcinogenics	CTUh	1.37E-05	1.91E-06	1.75E-05	1.57E-07	-7.36E-07
Respiratory effects	PM2.5 eq	7.11E-02	3.43E-03	8.33E-02	6.59E-04	-4.61E-03
Smog	O3 eq (ozone)	7.35E+00	5.76E+00	8.69E+00	2.46E-01	-4.47E-01
Resource depletion						
Fossil fuel depletion	MJ surplus	3.40E+02	2.61E+01	1.26E+02	3.07E+00	-6.03E+00

Numbers shown in orange have a variation of 10 to 20%
Numbers shown in red have a variation greater than 20%

Variations

Deviations are throughout and that is mainly because Aquia CST412 is larger in size ((50.20 kg of ceramic in Aquia CST412 compared to 41.03 kg in Aquia MS654) and thus consumes more packaging material than of Aquia MS654 (5.87 kg in Aquia CST412 compared to 4.85 kg in Aquia MS654). Both products use the same amount of water and so there is no deviation in the use stage. The life cycle impacts for the average of Aquia MS654 & Aquia CST412 excluding use phase are not reported as there is no variation in the use phase. As reported in Table 2.1c, Aquia CST412 is mainly produced outside the US (TMX & SSW) while Aquia MS654 is produced in TUS MW and the significant difference in transportation is contributing to the variations across the impact categories.

SM results

The SM millipoint score by life cycle phase for this product is presented below (Table 5.11). They confirm the trends in the results using the impact assessment results before normalization and weighting except in the recovery stage.

Table 5.11 Averaged SM millipoint scores for Aquia MS654 & Aquia CST412 by life cycle phase – absolute results

Impact category	Unit	Total	Production	Construction	Use	End of life	Recovery
SM single figure	mPts	27.95	12.60	1.54	14.44	0.17	-0.81

Numbers shown in orange have a variation of 10 to 20%

Numbers shown in red have a variation greater than 20%

5.6 Drake CST454 & Drake MS6041

This section includes the weighted averaged results based on production volumes.

Cradle-to-gate

Figure 5.11 shows the results for the finished product. It shows that the ceramic parts, dominate the material contribution except for non-carcinogenics and eutrophication where zinc and stainless steel parts together with corrugated board and turning brass process have major contributions to these three categories. Injection molding process has significant contribution to the ozone depletion impact category. The other parts and processes contribute between 2% and 11% of the overall impacts in the remaining categories.

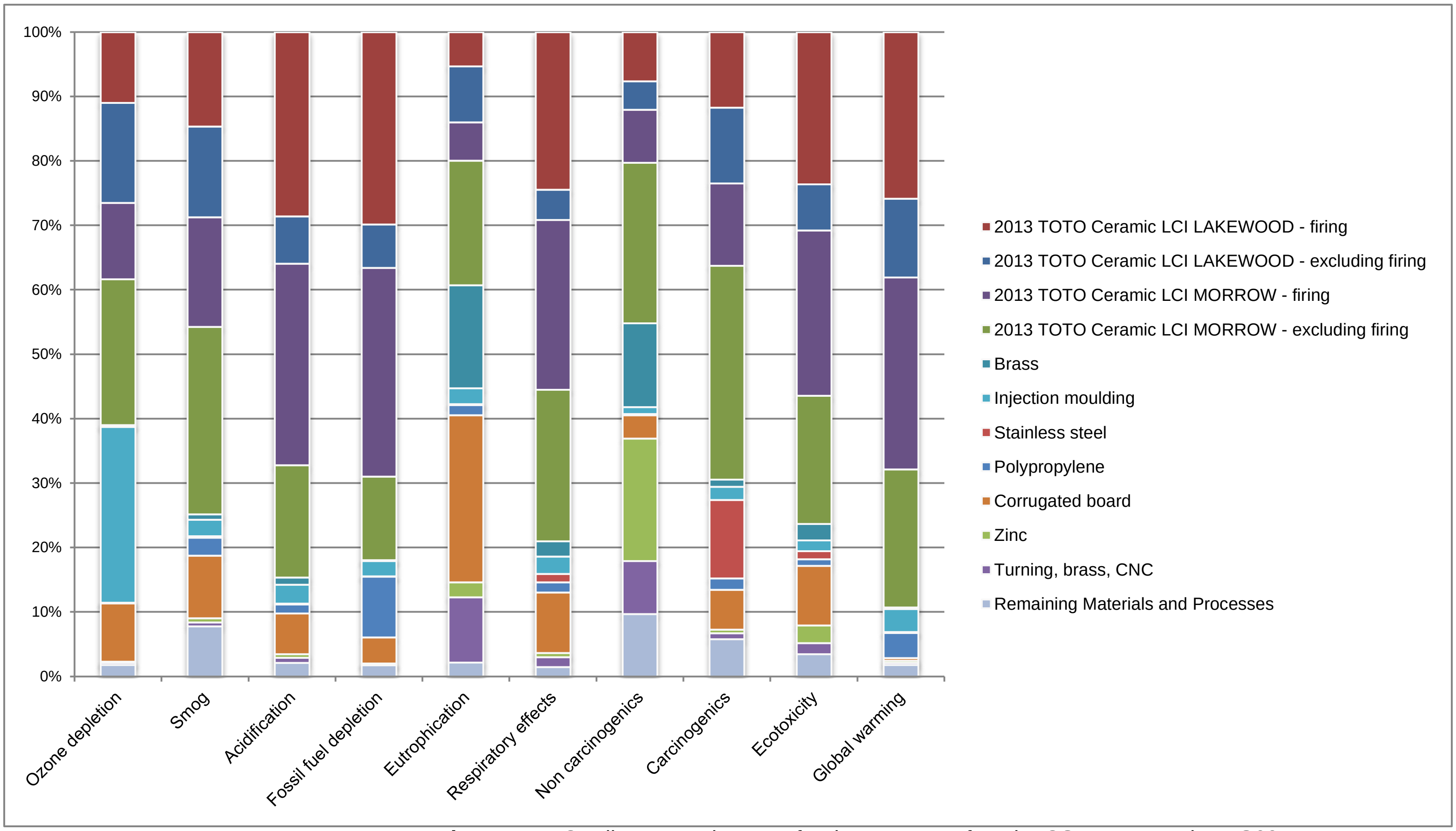


Figure 5.11 Cradle-to-gate impacts for the average of Drake CST454 & Drake MS6041 – relative results

Variations

The variation in the bill of materials is presented in the Table 5.12 below. It shows some similarities, but many differences. Drake MS6041 has significantly less to none of the materials consisting of ABS, PET, PVC, Silicone and Stainless steel and their associated manufacturing processes compared to Drake CST454. These differences, however, only appear at the recovery stage.

Table 5.12 Variations in the bill of materials for Drake CST454 & Drake MS6041

Material	Average (kg)
Ceramic	38.56
ABS	0.04
Brass	0.09
Corrugated Board	6.93
EPDM	0.07
PET	0.00
POM	0.03
PP	2.19
PVC	0.06
Silicone	0.00
Stainless Steel	0.01
SUS430	0.09
Zinc	0.10

Numbers shown in orange have a variation of 10 to 20%
Numbers shown in red have a variation greater than 20%

Full life cycle

Figure 5.12 and Table 5.13 show the results for the full life cycle of the product. It shows that the use phase [B1-B7] and the product stage [A1-A3] are equally important and dominate the results for all impact categories. The impact of the use stage is mostly due to the embedded energy use (such as electricity) in the water used during the operation of the product (40-60%) [B6-B7]. The product itself [A1-A3] is very relevant as it shows major contributions throughout. It has the most significant contributions to fossil fuel depletion (mostly defined by crude oil, hard coal, and natural gas extraction activities as well as polypropylene production and processing), non-carcinogenics (mostly defined by zinc production and processing as well as the natural gas used at the kiln and the disposal of hard coal ash) and ecotoxicity (mainly caused by electricity production using natural gas and crude oil as well as the disposal of slags and hard coal ash). The impacts for the product itself [A1-A3] are discussed above in the cradle-to-gate section. 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 end-of-life scenario [D] includes recycling and benefits from this by preventing the need to primary materials. It shows up as a relevant factor for some of the impact categories offsetting part of the impacts caused by making the parts of the product. Additionally, the delivery and the processes for dismantling and final waste treatment [C1-C4] of the product show up slightly relevant in the majority of the impact categories.

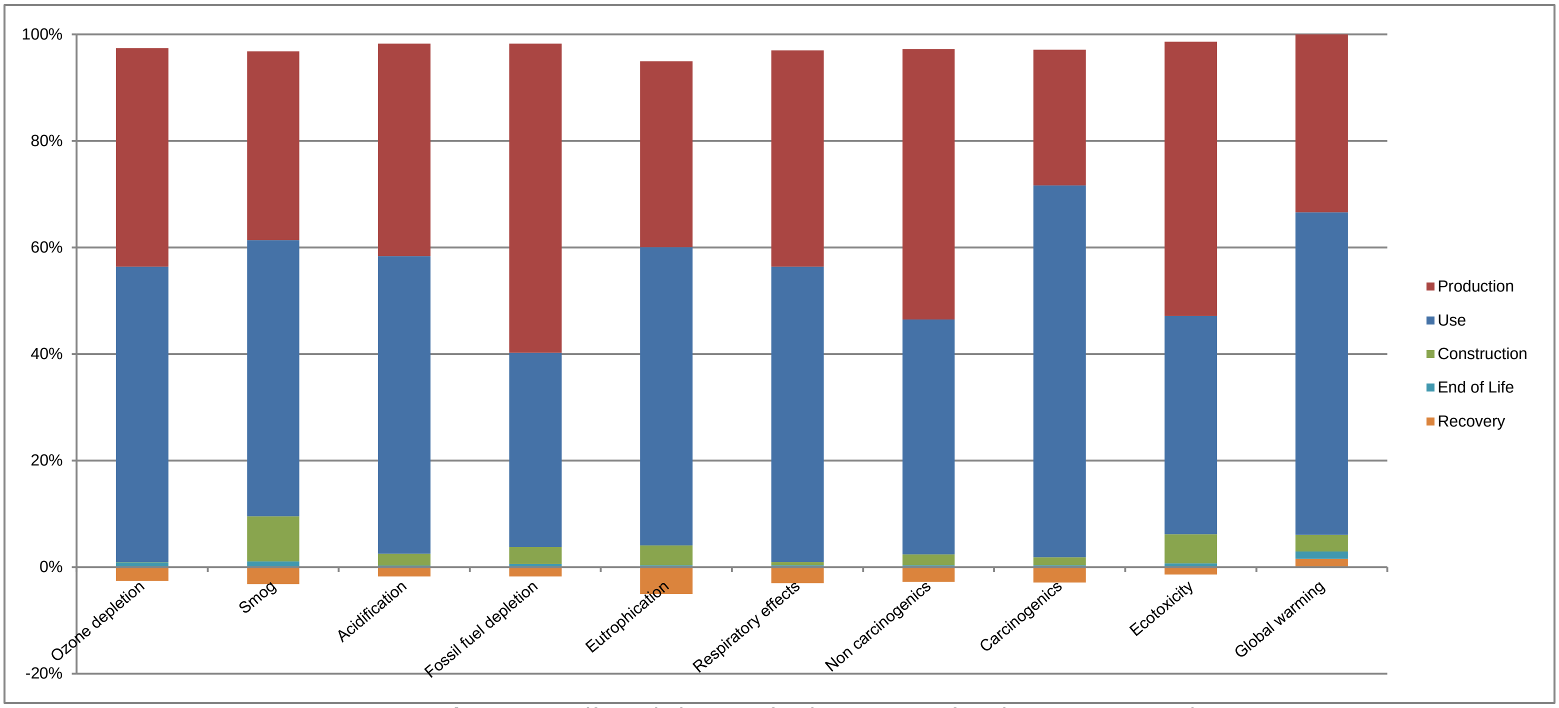


Figure 5.12 Life cycle impacts for the average of Drake CST454 & Drake MS6041 – relative results

Table 5.13 Life cycle impacts for average of Drake CST454 & Drake MS6041 – absolute results

Impact category	Unit	Production	Construction	Use	End of life	Recovery
Ecological damage						
Acidification	SO2 eq	9.85E-01	5.37E-02	1.38E+00	7.41E-03	-4.36E-02
Ecotoxicity	CTUe	1.60E+02	1.70E+01	1.27E+02	2.13E+00	-4.29E+00
Eutrophication	N eq (nitrogen)	7.23E-02	7.77E-03	1.16E-01	6.58E-04	-1.05E-02
Global warming	CO2 eq (carbon dioxide)	1.13E+02	1.07E+01	2.05E+02	4.74E+00	5.14E+00
Ozone depletion	CFC-11 eq	6.41E-06	1.26E-08	8.66E-06	1.38E-07	-4.10E-07
Human health damage						
Carcinogenics	CTUh	1.58E-06	9.27E-08	4.34E-06	2.19E-08	-1.82E-07
Non-carcinogenics	CTUh	2.22E-05	8.91E-07	1.93E-05	1.42E-07	-1.21E-06
Respiratory effects	PM2.5 eq	6.72E-02	1.02E-03	9.16E-02	5.64E-04	-5.03E-03
Smog	O3 eq (ozone)	6.53E+00	1.55E+00	9.56E+00	2.00E-01	-5.94E-01
Resource depletion						
Fossil fuel depletion	MJ surplus	2.21E+02	1.21E+01	1.39E+02	2.30E+00	-6.81E+00

Numbers shown in orange have a variation of 10 to 20%
Numbers shown in red have a variation greater than 20%

Variations

Deviations are throughout and that is mainly because Drake CST454 and Drake MS6041 is mainly due to the differences in the use phase in that Drake CST454 consumes approximately 22% less water during their life cycle. Other variations in the recovery phase are due to the variation in the materials content which is already discussed in the cradle-to-gate variation section of these two products.

SM results

The SM millipoint score by life cycle phase for this product is presented below (Table 5.14). They confirm the trends in the results using the impact assessment results before normalization and weighting except in the recovery stage.

Table 5.14 Averaged SM millipoint scores for Drake CST454 & Drake MS6041 by life cycle phase – absolute results

Impact category	Unit	Total	Production	Construction	Use	End of life	Recovery
SM single figure	mPts	26.01	9.77	0.70	15.89	0.16	-0.51

Numbers shown in orange have a variation of 10 to 20%
Numbers shown in red have a variation greater than 20%

5.7 Ultramax MS854 & Ultramax CST604

This section includes the weighted averaged results based on production volumes.

Cradle-to-gate

Figure 5.13 shows the results for the finished product. It shows that the ceramic parts, dominate the material contribution except for eutrophication where corrugated board and brass parts also have major contributions. Injection molding process has significant contribution to the ozone depletion impact category while zinc parts have significant contribution to the non-carcinogenics. The other parts and processes contribute between 1% and 19% of the overall impacts in the remaining categories.

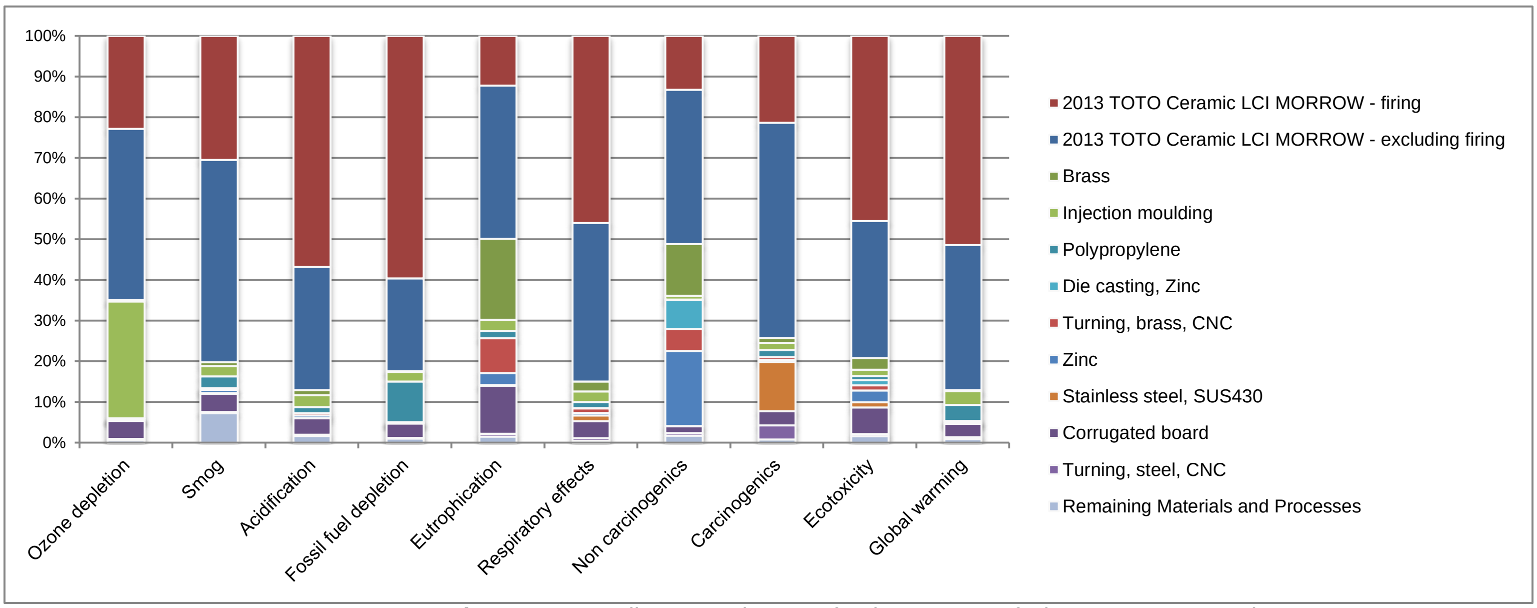


Figure 5.13 Cradle-to-gate impacts for the average of Ultramax MS854 & Ultramax CST604 – relative results

Variations

The variation in the bill of materials is presented in the Table 5.12 below. It shows extreme similarities, but very significant difference. The major driver of variation is the ceramic component of the two products in that Ultramax CST6041 uses 38.00kg compared to Ultramax MS8541 which only uses 30.36kg.

Table 5.12 Variations in the bill of materials for of Ultramax MS854 & Ultramax CST604

Material	Average (kg)
Ceramic	37.19
Brass	0.10
Corrugated Board	4.45

POM	0.04
PP	2.20
PVC	0.05
SUS430	0.09
Zinc	0.10

Numbers shown in orange have a variation of 10 to 20%
Numbers shown in red have a variation greater than 20%

Full life cycle

Figure 5.14 and Table 5.13 show the results for the full life cycle of the product. It shows that the use phase [B1-B7] and the product stage [A1-A3] are equally important and dominate the results for all impact categories. The impact of the use stage is mostly due to the embedded energy use (such as electricity) in the water used during the operation of the product (39-73%) [B6-B7]. The product itself [A1-A3] is very relevant as it shows major contributions throughout. It has the most significant contributions to fossil fuel depletion (mostly defined by crude oil, hard coal, and natural gas extraction activities as well as polypropylene manufacturing), non-carcinogenics (mostly defined by zinc production and processing as well as the natural gas used at the kiln and the disposal of hard coal ash) and ecotoxicity (mainly caused by electricity production using natural gas and crude oil as well as the disposal of slags and hard coal ash and zinc and copper production and processing). The impacts for the product itself [A1-A3] are discussed above in the cradle-to-gate section. The installation of the product [A5] is associated with the disposal of packaging materials which are mainly cardboard shows up relevant in almost all of the impact categories. The end-of-life scenario [D] includes recycling and benefits from this by preventing the need to primary materials. It shows up as a relevant factor for some of the impact categories offsetting part of the impacts caused by making the parts of the product. Additionally, the delivery and the processes for dismantling and final waste treatment [C1-C4] of the product show up slightly relevant in the majority of the impact categories.

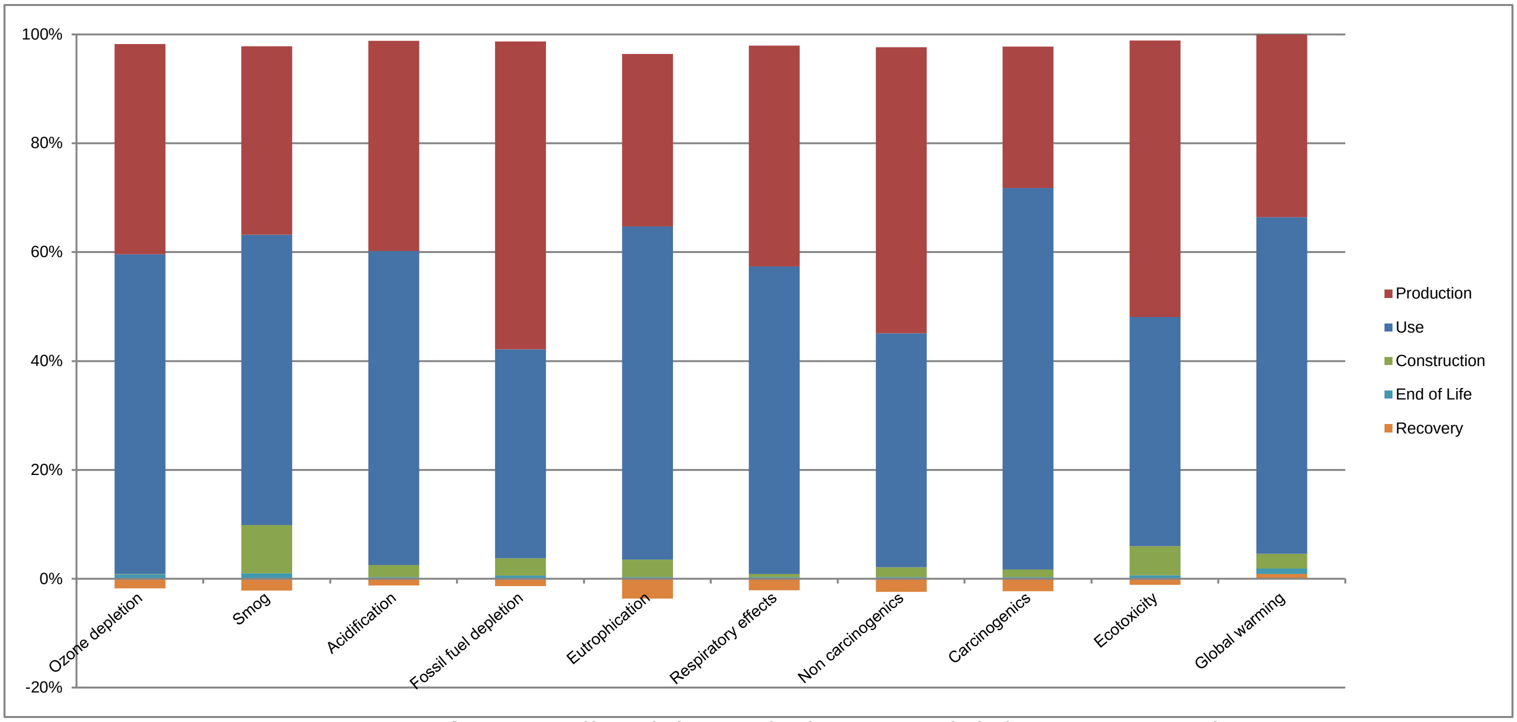


Figure 5.14 Life cycle impacts for the average of of Ultramax MS854 & Ultramax CST604– relative results

Table 5.13 Life cycle impacts for average of of Ultramax MS854 & Ultramax CST604 – absolute results

Impact category	Unit	Production	Construction	Use	End of life	Recovery
Ecological damage						
Acidification	SO2 eq	9.48E-01	5.54E-02	1.42E+00	6.79E-03	-2.98E-02
Ecotoxicity	CTUe	1.58E+02	1.65E+01	1.31E+02	2.01E+00	-3.46E+00
Eutrophication	N eq (nitrogen)	6.17E-02	6.25E-03	1.19E-01	5.92E-04	-7.08E-03
Global warming	CO2 eq (carbon dioxide)	1.14E+02	9.09E+00	2.11E+02	3.42E+00	3.10E+00
Ozone depletion	CFC-11 eq	5.85E-06	8.60E-09	8.89E-06	1.28E-07	-2.69E-07
Human health damage						
Carcinogenics	CTUh	1.65E-06	8.97E-08	4.46E-06	1.80E-08	-1.45E-07
Non-carcinogenics	CTUh	2.42E-05	8.62E-07	1.98E-05	1.24E-07	-1.10E-06
Respiratory effects	PM2.5 eq	6.76E-02	1.04E-03	9.41E-02	4.72E-04	-3.48E-03
Smog	O3 eq (ozone)	6.37E+00	1.63E+00	9.82E+00	1.83E-01	-4.05E-01
Resource depletion						
Fossil fuel depletion	MJ surplus	2.10E+02	1.17E+01	1.43E+02	2.19E+00	-4.97E+00

Numbers shown in orange have a variation of 10 to 20%
Numbers shown in red have a variation greater than 20%

Variations

The deviations at the production phase are not due to the variation in amount of the ceramic component of the two products (Ultramax CST604 uses 38.00kg compared to Ultramax MS8541 uses 30.36kg) but are due to the firing yield and firing yield as can be seen in Table 2.16b in Section 2.4.1.2 herein. The deviations at the construction phase and end of life phase is mainly due to the weight difference of the finished product after packaging (Ultramax MS8541 is 37.65kg while Ultramax CST604 is 45.25kg) which is driven by the difference in the mass of the ceramic component in the two products.

SM results

The SM millipoint score by life cycle phase for this product is presented below (Table 5.14). They confirm the trends in the results using the impact assessment results before normalization and weighting except in the recovery stage.

Table 5.14 Averaged SM millipoint scores for of Ultramax MS854 & Ultramax CST604 by life cycle phase – absolute results

Impact category	Unit	Total	Production	Construction	Use	End of life	Recovery
SM single figure	mPts	26.57	9.88	0.66	16.31	0.13	-0.42

Numbers shown in orange have a variation of 10 to 20%
Numbers shown in red have a variation greater than 20%

5.8 Sensitivity analysis

Part A mandates that a sensitivity analysis must be performed using the highest and lowest values for the most important choices and assumptions to check the robustness of the results of the LCA (disregarding outliers is appropriate). Identifying which choices or assumption influence the results in any environmental parameter by more than 20% shall be reported. The previous section includes the variations within the product groups which are dominated by the use phase and the product composition as indicated.

Additionally, the chosen approach for the following parameters must also be reported:

The impact of the geographical and technological variation on various production locations;	This is covered for the multiproduct reports by averaging both products and indicating the variations.
The variation due to using average composition;	This is covered for the multiproduct reports by averaging both products and indicating the variations.
The variation due to using a group-average using the highest and lowest values in the sensitivity analysis. Outliers can be disregarded.	This does not apply as only TOTO products are included.
Allocation of recycling processes	A sensitivity analyses is included below in this section.
Allocation of multi-input and multi-output processes.	Allocations follow a mass based approach in the collected data which is the most appropriate for the unit processes modeled. Allocation approaches in the background data follow the ecoinvent methodology.

Manufacturing of ceramics

The ceramic products are produced in different facilities, only three of which we had data for. The different products were modeled that they were made in ranging amounts split over these facilities. The figure below shows the differences of the ceramic manufactured in the three manufacturing facilities for the years 2013 and 2013. All results are shown in pairs per location. Differences have been extensively discussed with TOTO and can either be explained in terms of differences in technology, mainly affecting electricity and natural gas use or level of detail and accuracy of data provided. It could be observed that data from TUS LW and TUS MW are more consistent than that of TMX between 2012 and 2013. This can be improved in future updates of the LCI for the manufacturing facilities and obtaining more LCI from other vendors.

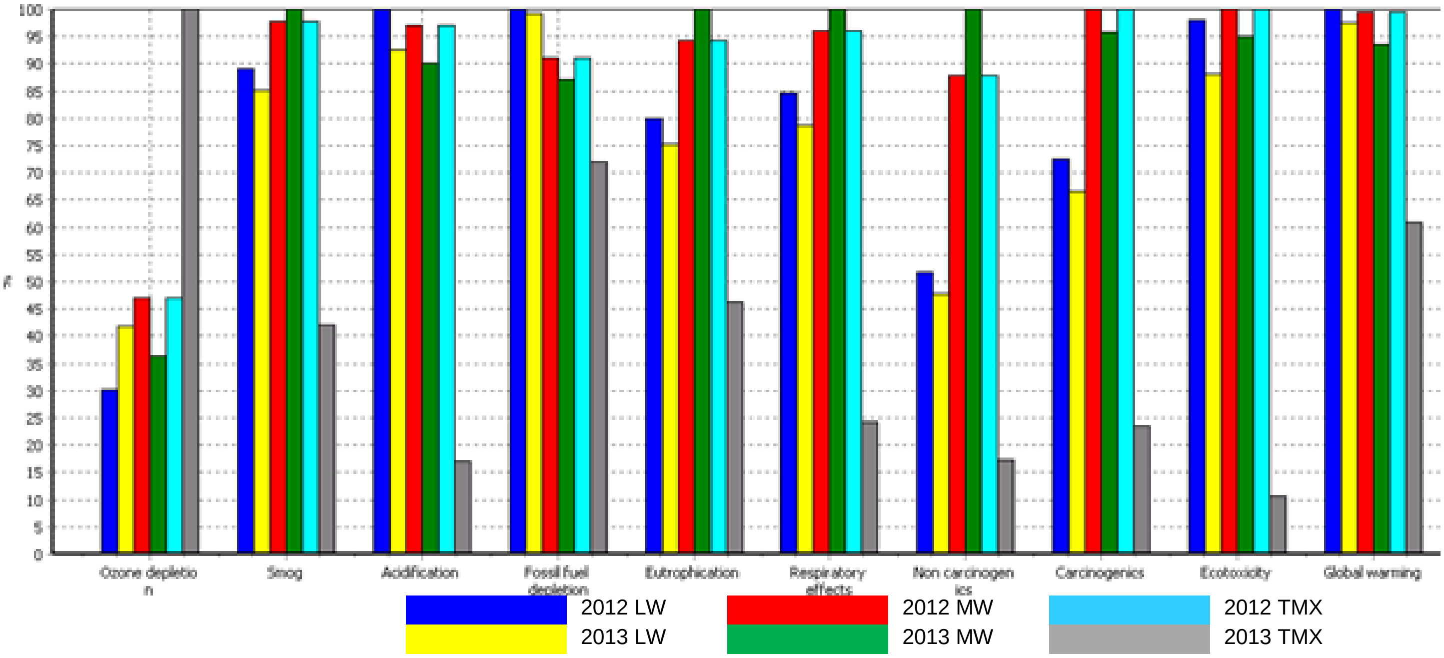


Figure 5.15 Variations in the cradle-to-gate results for the ceramic parts for the three studied locations (unweighted, 1kg mass-based comparison, not accounting for firing yield or production efficiency) – relative results

Ceramics and allocation for recycling and recycled content

Recycled content is a relevant factor in many LCA studies. Recycled content is modeled using materials that are processed to make new materials in this study. After use recycling is credited to the offset of virgin metals up to the point of intermediates before they are finished into products. This is a substitution based approach and it complies with Part A.

Another approach could be to model a full cut off and not to include the substitution at the end of use and only model the recycling benefits at the manufacturing stage by means of using recycling content and hence less virgin content. The impact of this allocation choice can be seen by looking at the graphs in the previous section. In essence this would eliminate the benefits that show up in the recovery stage. The impact is minimal for all products and in most impact categories.

The only instances where the impact is greater than 10% are in carcinogenics for UT105 (14.37%) and UT445 (12.69%).

5.9 Discussion on data quality

Discussion of the role of excluded elements

This study followed the completeness criteria stated in Section 2.4.1.1 herein. Small amounts of input materials have not been included based on the mass criteria. These materials were identified and evaluated on the environmental relevance and are deemed to have a negligible impact on the results of the LCA as the main driver of impacts of the modeled products is ceramics.

Discussion of the precision, completeness and representativeness of data

Not all vendors have responded to the same level of detail as the request for data entailed. For example, some vendors chose to fill their own bills of materials giving little insight to the LCA practitioner as to how data was calculated. The LCA practitioner used back calculations and mass balance calculations in order to assure data was plausible, consistent and complete. Another example was that some vendors refused to cooperate with the LCA practitioner because they had strict confidentiality and proprietary policy. In that case, missing data was estimated from other products whose data are known from other vendors. Another example was that no data on the recycled content of the components of the modeled products was provided. The LCA practitioner made no assumption in that regard and assumed worst-case scenario in that all materials were primary. The impact of this assumption is expected to be insignificant because the material inputs are not major drivers of the LCA results for the modeled products. This study used literature data where supplier data was not made available based on the USLCI database and the US-ecoinvent database. With future updates and more and more LCA information becoming available, more representative and less generic data should be used for future LCA projects where possible. The impact of this limitation could be relevant as it relates to recycled content, yield and processing energy which are relevant drivers of the LCA results. It is recommended that vendors shall be contacted and engaged for future LCA work especially as TOTO moves towards a more integrated People, Planet, Profit strategy.

The study used scenarios for the use phase and end of life. Since the use phase is important for the results of the LCA, it is recommended to discuss and validate the approach with industry stakeholders to establish a common practice. This has been established by use of the PGDs.

Discussion related to the impact of value judgments

The Sustainable Minds indicator expressed in millipoints is a part of the reporting requirements. However, it is important to note that the indicator is not only based on scientific impact assessment and normalization, but also on weighting which is based on expert judgment. This last step is a value judgment and can change between different experts and will likely change over time since environmental priorities change over time. This change is not annual but rather it takes a decade. With the limited validation of any LCA and the 3 years validity of a Transparency Report, any changes in these value judgments will be reflected in future updates. Other than the Sustainable Minds indicator, worst-case scenarios were adapted in the study and that was encouraged by TOTO USA.

5.10 Recommendations

During the process of compiling this report with the help of many TOTO employees, an insight into the environmental performance of a selection of TOTO products was gained. Additionally, the major contributions and differences were also learned.

Based on these insights we make the following recommendations to TOTO:

- Create a process for LCI data collection for the manufacturing process at the vendors. This should streamline the data collection for the different locations defining the primary sources for the data, and alignment of the reported data. There is a need for better processing data, like energy consumption and yield. One topic within this is the amount of recycled content which provides an opportunity for environmental performance improvement.
- Evaluate improvement options for the major contributions against required investments to drive down in the impact. Good candidates are the recycled content of the material input and the energy efficiency of the firing oven and electricity use and sourcing for the manufacturing processes and the product yield. The yield of one of the products is roughly 35% and of another is approximately 45%.
- Continue the reduction of the use of water for the products during the use phase.
- Evaluate the use of on-site sourced water or 100% water recycling process. A review of technologies, validated with LCA, can help TOTO USA have a better positioning in the market as being socially and environmentally responsible beyond using less water to actually eliminate its water sourcing.
- As a general approach, evaluate changes in the manufacturing process or supply chain using LCA technologies to choose the best alternative before making a purchasing or investment decision. This will inform the decision making process with upfront insight in how it will impact the LCA.

6 SOURCES

[1] ISO 14044, “Environmental management - Life cycle assessment - Requirements and guidelines”, ISO14044:2006

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[3] J. Bare (2011) TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. Clean Technologies and Environmental Policy. 13(5); United States Environmental Protection Agency (2012). Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) User's Manual. Document ID: S-10637-OP-1-0.

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[6] Sustainable Minds Transparency Report™ Framework, Part A: LCA calculation rules and report requirements. July 31, 2014, Draft for Friendly Review

[7] Product Group Definition, Commercial Toilets. July 06, 2014, Draft for public comment

[8] Product Group Definition, Commercial Urinals. July 06, 2014, Draft for public comment

[9] Product Group Definition, Residential Toilets. July 06, 2014, Draft for public comment

ACRONYMS

EPD	Environmental Product Declaration
ISO	International Standardization Organization
LCA	life cycle assessment
LCI	life cycle inventory
LCIA	life cycle impact analysis
LHV	Low Heating Value
PCR	Product Category Rule document
LW	Lakewood, TOTO manufacturing facility
MW	Morrow. TOTO manufacturing facility
TMX	TOTO Mexico, manufacturing facility

GLOSSARY

For the purposes of this report, the terms and definitions given in ISO 14020, ISO 14025, ISO 14040, ISO 14041, ISO 14042, ISO 14043, ISO 14044 and ISO 21930 apply. The most important ones are included here:

aggregation	aggregation of data
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
ancillary input	material input that is used by the unit process producing the product, but does not constitute part of the product
capital good	Means, for instance ancillary input needed for activities, and all handling equipment during the life cycle that can be characterized by a relative long lifespan and can be (re)used many times
category endpoint	attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern
characterization factor	factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator
comparative assertion	environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function
completeness check	process of verifying whether information from the phases of a life cycle assessment is sufficient for reaching conclusions in accordance with the goal and scope definition
consistency check	process of verifying that the assumptions, methods and data are consistently applied throughout the study and are in accordance with the goal and scope definition performed before conclusions are reached
co-product	any of two or more products coming from the same unit process or product system
critical review	process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment
cut-off criteria	specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study

data quality	characteristics of data that relate to their ability to satisfy stated requirements
elementary flow	material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation
energy flow	input to or output from a unit process or product system, quantified in energy units
environmental aspect	element of an organization's activities, products or services that can interact with the environment
environmental measure	series of certain quantities, based on economic flows and weighing of environmental effects.
environmental mechanism	system of physical, chemical and biological processes for a given impact category, linking the life cycle inventory analysis results to category indicators and to category endpoints
environmental profile	a series of environmental effects
evaluation	element within the life cycle interpretation phase intended to establish confidence in the results of the life cycle assessment
feedstock energy	heat of combustion of a raw material input that is not used as an energy source to a product system, expressed in terms of higher heating value or lower heating value
functional lifespan	the period or time during which a building or a building element fulfils the performance requirements
functional unit	quantified performance of a product system for use as a reference unit
impact category	class representing environmental issues of concern to which life cycle inventory analysis results may be assigned
impact category indicator	quantifiable representation of an impact category
Input	product, material or energy flow that enters a unit process
interested party	individual or group concerned with or affected by the environmental performance of a product system, or by the results of the life cycle assessment
intermediate flow	product, material or energy flow occurring between unit processes of the product system being studied
intermediate product	output from a unit process that is input to other unit processes that require further transformation within the system
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 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
life cycle inventory analysis LCI	phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle
life cycle inventory analysis result LCI result	outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment
multi-input process	a unit process where more than one flow enters from different product systems for combined processing
multi-output process	a unit process that results in more than one flow used in different product systems
output	product, material or energy flow that leaves a unit process

performance	behavior based on use
primary material	a material produced from raw materials
primary production	a production process that produces primary material
process	set of interrelated or interacting activities that transforms inputs into outputs
process energy	energy input required for operating the process or equipment within a unit process, excluding energy inputs for production and delivery of the energy itself
product	any goods or service
product flow	products entering from or leaving to another product system
product system	collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product
raw material	primary or secondary material that is used to produce a product
recycling	all processes needed to recycle a material, product or element as a material input
reference flow	measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit
releases	emissions to air and discharges to water and soil
return system	a system to collect waste material from the market for the purpose of recycling or reuse
reuse	all processes needed to reuse a material, product or element in the same function
secondary material	material input produced from recycled materials
secondary production	production process that produces secondary material
sensitivity analysis	systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study
system boundary	set of criteria specifying which unit processes are part of a product system
third party	person or body that is independent of the involved parties, and as such recognized
transparency	open, comprehensive and understandable presentation of information
type -III-environmental declaration	quantified environmental data of a product with a predefined set of categories based on the ISO 14040 standards, without excluding the presentation of supplementing relevant environmental data, provided within the scope of a type-III-environmental declaration framework
type -III-environmental declaration framework	voluntary process of an industrial sector or independent body to develop a type- III-environmental declaration, including a framework that defines the essential requirements, the selection of categories or parameters, the level of involvement of third parties and a template for external communication
uncertainty analysis	systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability
unit process	smallest element considered in the life cycle inventory analysis for which input and output data are quantified
waste	substances or objects which the holder intends or is required to dispose of

APPENDIX A. LCI AND OTHER STARTING POINTS FOR THE CERAMIC MANUFACTURING PROCESS

The LCI for the fittings are reported in a separate spreadsheet "Ceramics BOM". It includes all parts, processes and other LCI collected to model the products. An overview of the material list for the products as required by Part A is included herein. In addition to that, summary tables of the LCI data for the processing at the TOTO vendors for manufacturing is included.

Table A.1 Raw materials definition of Ultramax MS8541

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China body and lid	Ceramic	80.64%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	8.50%	No	Yes	0%	0%	USA	30
Right side pad	Corrugated Board	1.59%	No	Yes	0%	0%	USA	30
Seat	PP	2.62%	No	Yes	0%	0%	China	9165
Lid	PP	2.45%	No	Yes	0%	0%	China	9165
-	Remaining materials	4.19%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.2 Raw materials definition of Aquia MS654

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China body and lid	Ceramic	83.14%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	6.48%	No	Yes	0%	0%	USA	30
Front pad	Corrugated Board	1.22%	No	Yes	0%	0%	USA	30
Seat	PP	2.00%	No	Yes	0%	0%	China	9165
Lid	PP	1.87%	No	Yes	0%	0%	China	9165
-	Remaining materials	5.29%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.3 Raw materials definition of Drake CST454

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China bowl	Ceramic	83.14%	No	Yes	0%	0%	Miscellaneous	-
China tank and lid	Ceramic	24.62%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	12.51%	No	Yes	0%	0%	USA	30
Seat	PP	2.10%	No	Yes	0%	0%	China	9165
Lid	PP	1.96%	No	Yes	0%	0%	China	9165
-	Remaining materials	5.29%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.4 Raw materials definition of CT708E

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China bowl	Ceramic	82.17%	No	Yes	0%	0%	Indonesia	11,334
Carton Box	Corrugated Board	2.87%	No	Yes	0%	0%	Indonesia	11,334
Side insert 1	Corrugated Board	1.73%	No	Yes	0%	0%	Indonesia	11,334
Side insert 2	Corrugated Board	1.73%	No	Yes	0%	0%	Indonesia	11,334
Seat	PP	10.34%	No	Yes	0%	0%	Indonesia	11,334
-	Remaining materials	1.15%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.5 Raw materials definition of EcoDrake CST744E

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China bowl	Ceramic	53.07%	No	Yes	0%	0%	Miscellaneous	-
China tank and lid	Ceramic	34.14%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	3.41%	No	Yes	0%	0%	Mexico	-
Seat	PP	5.86%	No	Yes	0%	0%	China	9165
-	Remaining materials	3.53%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.6 Raw materials definition of Ultramax CST604

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China body and lid	Ceramic	83.97%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	7.07%	No	Yes	0%	0%	USA	30
Right side pad	Corrugated Board	1.33%	No	Yes	0%	0%	USA	30
Seat	PP	2.18%	No	Yes	0%	0%	China	9165
Lid	PP	2.04%	No	Yes	0%	0%	China	9165
-	Remaining materials	3.41%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.7 Raw materials definition of Drake CST454

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China body and lid	Ceramic	26.28%	No	Yes	0%	0%	Miscellaneous	-
China Bowl	Ceramic	53.17%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	12.10%	No	Yes	0%	0%	USA	27
Tank carton box	Corrugated Board	1.85%	No	Yes	0%	0%	USA	27
Seat	PP	2.03%	No	Yes	0%	0%	China	9165
Lid	PP	1.89%	No	Yes	0%	0%	China	9165
-	Remaining materials	2.67%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.8 Raw materials definition of Aquia CST412

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China body and lid	Ceramic	17.40%	No	Yes	0%	0%	Miscellaneous	-
China Bowl	Ceramic	66.59%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	2.68%	No	Yes	0%	0%	Thailand	9276
Top & bottom pad	Corrugated Board	1.00%	No	Yes	0%	0%	Thailand	9276
Front corner support	Corrugated Board	1.34%	No	Yes	0%	0%	Thailand	9276
Back corner support	Corrugated Board	1.34%	No	Yes	0%	0%	Thailand	9276
Tank carton box	Corrugated Board	1.36%	No	Yes	0%	0%	Thailand	9276
Seat	PP	1.65%	No	Yes	0%	0%	China	9165
Lid	PP	1.54%	No	Yes	0%	0%	China	9165

-	Remaining materials	5.11%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	100%						

Table A.9 Raw materials definition of Urinal UT105

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China body	Ceramic	83.47%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	8.61%	No	Yes	0%	0%	USA	27
Front and back layers	Corrugated Board	2.15%	No	Yes	0%	0%	USA	27
Nut	Brass	1.88%	No	Yes	0%	0%	China	8758
Flange body	Brass	1.75%	No	Yes	0%	0%	China	8758
-	Remaining materials	2.13%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.10 Raw materials definition of Urinal UT445

			Availability					
Component	**Material**	**Mass %**	**Renewable**	**Non-renewable**	**Recycled post-industrial**	**Recycled post-consumer**	**Origin of raw materials**	**Supply Distance (miles)**
China body	Ceramic	85.70%	No	Yes	0%	0%	Miscellaneous	-
Carton Box	Corrugated Board	7.01%	No	Yes	0%	0%	Vietnam	9927
Front and back layers	Corrugated Board	1.56%	No	Yes	0%	0%	Vietnam	9927
Nut	Brass	1.36%	No	Yes	0%	0%	China	8758
Flange body	Brass	1.27%	No	Yes	0%	0%	China	8758
-	Remaining materials	3.10%	No	Yes	0%	0%	Miscellaneous	-
	TOTAL	**100%**						

Table A.11 LCI data for zinc die casting process

Die casting, zinc	1	kg
Operating temperature is slightly higher than casting of brass and bronze. A small amount of zinc evaporates. The evaporation losses are estimated at 0.1%wt. Adapted from EcoInvent LCI for die casting of bronze.		
Materials/fuels		
Aluminum casting, plant	4.9E-11	p
Electricity, medium voltage, production	0.0205	kWh
Heat, heavy fuel oil, at industrial furnace 1MW	0.2952	MJ
Heat, natural gas, at industrial furnace >100kW	0.369	MJ
Emissions to air		
Heat, waste	0.0708	MJ
Zinc	0.001	kg

Table A.12 LCI data for turning brass CNC process

Turning, brass, CNC, average	1	kg
This dataset encompasses the direct electricity consumption of the machine as well as compressed air and lubricant oil. Furthermore, the metal removed is included. Machine as well as factory infrastructure and operation are considered as well. The disposal of the lubricant oil is also included while the metal removed is assumed to be recycled.		
Materials/fuels		
Electricity, low voltage, production	0.992	kWh
Compressed air, average installation, >30kW, 7 bar gauge, at supply network	1.28	m3
Lubricating oil, at plant	0.00382	kg
Metal working machine, unspecified, at plant	0.000174	kg
Metal working factory	2.02E-09	p
Metal working factory operation, average heat energy	4.41	kg
Brass, at plant	1	kg
Emissions to air		
Heat, waste	3.57	MJ
Waste to treatment		
Disposal, used mineral oil, 10% water, to hazardous waste incineration	0.00382	kg

Table A.13 LCI data for turning steel CNC process

Turning, steel, CNC, average	1	kg
This dataset encompasses the direct electricity consumption of the machine as well as compressed air and lubricant oil. Furthermore, the metal removed is included. Machine as well as factory infrastructure and operation are considered as well. The disposal of the lubricant oil is also included while the metal removed is assumed to be recycled.		
Materials/fuels		
Electricity, low voltage, production	1.78	kWh
Compressed air, average installation, >30kW, 7 bar gauge, at supply network	1.28	m3
Lubricating oil, at plant	0.00382	kg
Metal working machine, unspecified, at plant	0.000174	kg
Metal working factory	2.02E-09	p
Metal working factory operation, average heat energy	4.41	kg
Steel, low-alloyed, at plant	1	kg
Emissions to air		
Heat, waste	6.39	MJ
Waste to treatment		
Disposal, used mineral oil, 10% water, to hazardous waste incineration	0.00382	kg

Table A.14 LCI data for injection molding process

Injection molding	1	kg
This process contains the auxiliaries and energy demand for the mentioned conversion process of plastics. The converted amount of plastics is NOT included into the dataset.		
Resources		
Water, cooling, unspecified natural origin/m3	0.011	m3
Materials/fuels		
Lubricating oil, at plant	0.00303	kg
Solvents, organic, unspecified, at plant	0.0447	kg
Chemicals organic, at plant	0.0128	kg
Titanium dioxide, production mix, at plant	0.00199	kg
Pigments, paper production, unspecified, at plant	0.00756	kg
EUR-flat pallet	0.00146	p
Solid bleached board, SBB, at plant	9.94E-05	kg
Polyethylene, LDPE, granulate, at plant	0.00169	kg
Polypropylene, granulate, at plant	0.00358	kg
Electricity, medium voltage, production	1.48	kWh
Heat, natural gas, at industrial furnace >100kW	4.21	MJ
Heat, heavy fuel oil, at industrial furnace 1MW	0.229	MJ
Packaging box production unit	1.43E-09	p
Transport, lorry 3.5-16t, fleet average	0.142	tkm
Emissions to air		
Heat, waste	5.33	MJ
Emissions to water		
COD, Chemical Oxygen Demand	9.28E-06	kg
Suspended solids, unspecified	6.63E-06	kg
Waste to treatment		
Disposal, plastics, mixture, 15.3% water, to municipal incineration	0.00567	kg
Disposal, hazardous waste, 0% water, to underground deposit	3.31E-05	kg
Disposal, municipal solid waste, 22.9% water, to sanitary landfill	0.000895	kg

Table A.15 LCI data for brass die casting process

Die casting, brass	1	kg
Operating temperature is slightly higher than casting of brass. A small amount of Brass evaporates. The evaporation losses are estimated at 0.1%wt. Adapted from EcoInvent LCI for die casting of bronze.		
Materials/fuels		
Aluminum casting, plant	4.9E-11	p
Electricity, medium voltage, production	0.0197	kWh
Heat, heavy fuel oil, at industrial furnace 1MW	0.283	MJ
Heat, natural gas, at industrial furnace >100kW	0.354	MJ
Emissions to air		
Heat, waste	0.0708	MJ
Brass	0.000303	kg

Table A.16 LCI data for plastic pipes extrusion process

Injection molding	1	kg
This process contains the auxiliaries and energy demand for the mentioned conversion process of plastics. The converted amount of plastics is NOT included into the dataset.		
Resources		
Water, cooling, unspecified natural origin/m3	0.0197	m3
Materials/fuels		
Lubricating oil, at plant	0.000143	kg
Particle board, outdoor use, at plant	0.00000132	m3
EUR-flat pallet	0.00113	p
Polyethylene, LDPE, granulate, at plant	0.00139	kg
Polypropylene, granulate, at plant	0.000199	kg
Steel, low-alloyed, at plant	0.0012	kg
Electricity, medium voltage, production	0.508	kWh
Heat, natural gas, at industrial furnace >100kW	0.121	MJ
Heat, heavy fuel oil, at industrial furnace 1MW	0.683	MJ
Packaging box production unit	1.43E-09	p
Transport, lorry 3.5-16t, fleet average	0.0135	tkm
Emissions to air		
Heat, waste	1.83	MJ
Waste to treatment		
Disposal, plastics, mixture, 15.3% water, to municipal incineration	0.00369	kg

Table A.17 LCI data for plastic pipes extrusion process

Wire drawing, steel	1	kg
Included processes: Includes the process steps pre-treatment of the wire rod (mechanical descaling, pickling), dry or wet drawing (usually several drafts with decreasing die sizes), in some cases heat treatment (continuous-/discontinuous annealing, patenting, oil hardening) and Finishing. Does not include coating and the material being rolled.		
Resources		
Water, cooling, unspecified natural origin/m3	0.035	m3
Materials/fuels		
Chemicals inorganic, at plant	1.841E-08	kg

Chemicals organic, at plant	3.162E-05	kg
Sawn timber, softwood, raw, air dried, u=20%, at plant	1.6E-17	m3
Lead, at regional storage	0.0012845	kg
Lime, hydrated, loose, at plant	6.323E-05	kg
Sheet rolling, steel	2.359E-11	kg
Steel, converter, unalloyed, at plant	0.042762	kg
Hydrochloric acid, 30% in H2O, at plant	0.020009	kg
Soap, at plant	0.0025811	kg
Sulphuric acid, liquid, at plant	0.0088388	kg
Electricity, medium voltage, production at grid	0.14142	kWh
Natural gas, burned in industrial furnace >100kW	0.41286	MJ
Lubricating oil, at plant	0.0025811	kg
Transport, lorry >16t, fleet average	0.031635	tkm
Packaging film, LDPE, at plant	1.887E-11	kg
Light fuel oil, burned in industrial furnace 1MW, non-modulating	7.03E-05	MJ
Rolling mill	1.623E-09	p
Packaging, corrugated board, mixed fibre, single wall, at plant	4.718E-12	kg
Emissions to air		
Carbon monoxide, fossil	5.477E-06	kg
Heat, waste	0.50912	MJ
Hydrogen chloride	3.934E-06	kg
Lead	9.32E-09	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	2.21E-07	kg
Particulates, > 10 um	5.477E-08	kg
Sulfur dioxide	6.682E-07	kg
Particulates, > 2.5 um, and < 10um	1.369E-07	kg
Hydrogen	1.536E-09	kg
Sulfate	7.317E-08	kg
Emissions to water		
Aluminium	1.657E-06	kg
BOD5, Biological Oxygen Demand	4.813E-05	kg
Cadmium	1.75E-07	kg
Chloride	0.0011469	kg
Chromium VI	3.5E-08	kg
Chromium	6.3E-07	kg
COD, Chemical Oxygen Demand	4.813E-05	kg
Copper	3.386E-07	kg
DOC, Dissolved Organic Carbon	0.0000153	kg
Hydrocarbons, unspecified	2.204E-06	kg
Iron	0.0004989	kg
Lead	3.5E-07	kg
Manganese	7.139E-07	kg
Mercury	3.5E-08	kg
Nickel	9.9E-07	kg
Sulfate	7.346E-06	kg
Suspended solids, unspecified	0.0001858	kg
TOC, Total Organic Carbon	0.0000153	kg
Zinc	2.619E-07	kg

Waste to treatment		
Disposal, municipal solid waste, 22.9% water, to municipal incineration	7.078E-11	kg
Disposal, used mineral oil, 10% water, to hazardous waste incineration	0.062811	kg
Disposal, dust, unalloyed EAF steel, 15.4% water, to residual material landfill	0.0012845	kg
Disposal, basic oxygen furnace wastes, 0% water, to residual material landfill	0.0031623	kg
Disposal, sludge from steel rolling, 20% water, to residual material landfill	0.035	kg

APPENDIX B. ADDITIONAL RESULTS

No additional result view have been reported at this point.

APPENDIX C. IMPACT CATEGORIES

The impact assessment is based on the TRACI methodology and is reported in [Bare, 2011]. The contents of this publication are presented in this appendix. A definition of the impact categories within TRACI is available in the appendices of Part A [6].

APPENDIX D. USED DATASHEETS

To model the LCA different data sources have been used. This appendix includes a list of all datasheets that have been used. The list is included in a separate spreadsheet "LCA of TOTO Ceramics LCI-LCA modeling data and results 09-2014.xlsx".

APPENDIX E. LCI

The LCI results per functional unit for all products are included in a separate "LCA of TOTO Ceramics LCI-LCA modeling data and results 09-2014.xlsx".

APPENDIX F. LCIA METHOD

The LCIA characterization factors are included in a separate spreadsheet "LCA of TOTO Ceramics LCI-LCA modeling data and results 09-2014.xlsx".

APPENDIX G. PROCESS FLOW DIAGRAMS

A process flow diagram per functional unit of product is included in a separate spreadsheet "LCA of TOTO Ceramics LCI-LCA modeling data and results 09-2014.xlsx". It shows the modeled materials and energy flows.