CRADLE-TO-GATE LIFE CYCLE ANALYSIS OF POLYETHER POLYOL FOR RIGID FOAM POLYURETHANES

Final Report

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PREFACE

This life cycle assessment of Polyether Polyol for Rigid Foam resin was commissioned and funded by the American Chemistry Council (ACC) Plastics Division to update the original data in the 2011 report, **Cradle-to-Gate Life Cycle Inventory of Nine Plastic Resins and Four Polyurethane Precursors**, as well as the U.S. LCI plastics database. The report was made possible through the cooperation of ACC member and non-member companies, who provided data for the production of propylene, chlorine/sodium hydroxide, and polyether polyol for rigid foam polyurethanes.

This report was prepared for ACC by Franklin Associates, A Division of Eastern Research Group (ERG), Inc. as an independent contractor. This project was managed by Melissa Huff, Senior LCA Analyst and Project Manager, who was also lead for modeling, report writing, and review. Paige Weiler assisted with report writing and research. Anne Marie Molen assisted with data collection tasks and appendix preparation. Ben Young assisted with research.

Franklin Associates gratefully acknowledges the significant contribution to this project by Allison Chertack, Prapti Muhuri, Mike Levy (First Environment, Inc., formerly ACC), and Keith Christman of ACC in leading this project. Thank you to the companies who graciously provided data. Their effort in collecting data has added considerably to the quality of this LCA report.

Franklin Associates makes no statements other than those presented within the report.

January, 2023

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LIST OF ACRONYMS

(Alphabetical)

ACC	AMERICAN CHEMISTRY COUNCIL
AP	ACIDIFICATION POTENTIAL
BOD	BIOCHEMICAL OXYGEN DEMAND
COD	CHEMICAL OXYGEN DEMAND
CFC	CHLOROFLUOROCARBON
DOE	DEPARTMENT OF ENERGY
EGRID	EMISSIONS & GENERATION RESOURCE INTEGRATED DATABASE
EIA	ENERGY INFORMATION ADMINISTRATION
EP	EUTROPHICATION POTENTIAL
ERG	EASTERN RESEARCH GROUP, INC
EQ	EQUIVALENTS
GHG	GREENHOUSE GAS
GJ	GIGAJOULE
GREET	GREENHOUSE GASES, REGULATED EMISSIONS, AND ENERGY USE IN TECHNOLOGIES
GWP	GLOBAL WARMING POTENTIAL
HCFC	HYDROCHLOROFLUORCARBON
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
ISO	INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
LCA	LIFE CYCLE ASSESSMENT
LCI	LIFE CYCLE INVENTORY
LCIA	LIFE CYCLE IMPACT ASSESSMENT
LPG	LIQUEFIED PETROLEUM GAS
MJ	MEGAJOULE
MM	MILLION
NAPAP	NATIONAL ACID PRECIPITATION ASSESSMENT PROGRAM
NMVOC	NON-METHANE VOLATILE ORGANIC COMPOUNDS
NREL	NATIONAL RENEWABLE ENERGY LABORATORY

ODP	OZONE DEPLETION POTENTIAL
POCP	PHOTOCHEMICAL SMOG FORMATION (HISTORICALLY PHOTOCHEMICAL OXIDANT CREATION POTENTIAL)
RCRA	RESOURCE CONSERVATION AND RECOVERY ACT
SI	INTERNATIONAL SYSTEM OF UNITS
TRACI	TOOL FOR THE REDUCTION AND ASSESSMENT OF CHEMICAL AND OTHER ENVIRONMENTAL IMPACTS

CRADLE-TO-GATE LIFE CYCLE ASSESSMENT OF POLYETHER POLYOL FOR RIGID FOAM POLYURETHANES

INTRODUCTION

This study provides the American Chemistry Council (ACC), their members, users of the U.S. LCI Database, and the public at large with information about the life cycle inventory and impacts for the production of polyether polyol for rigid foam polyurethanes, which is a short chain polyether polyol. Rigid foam polyurethanes are used in a variety of end use applications including refrigerator and freezer thermal insulation systems and audio and thermal insulation on boats. Life cycle assessment (LCA) is recognized as a scientific method for making comprehensive, quantified evaluations of the environmental benefits and tradeoffs commonly for the entire life cycle of a product system, beginning with raw material extraction and continuing through disposition at the end of its useful life as shown in Figure 1 below. This cradle-to-gate LCA includes the life cycle stages shown in the dashed box including the "Raw Materials Acquisition" and "Materials Manufacture" boxes in the figure.

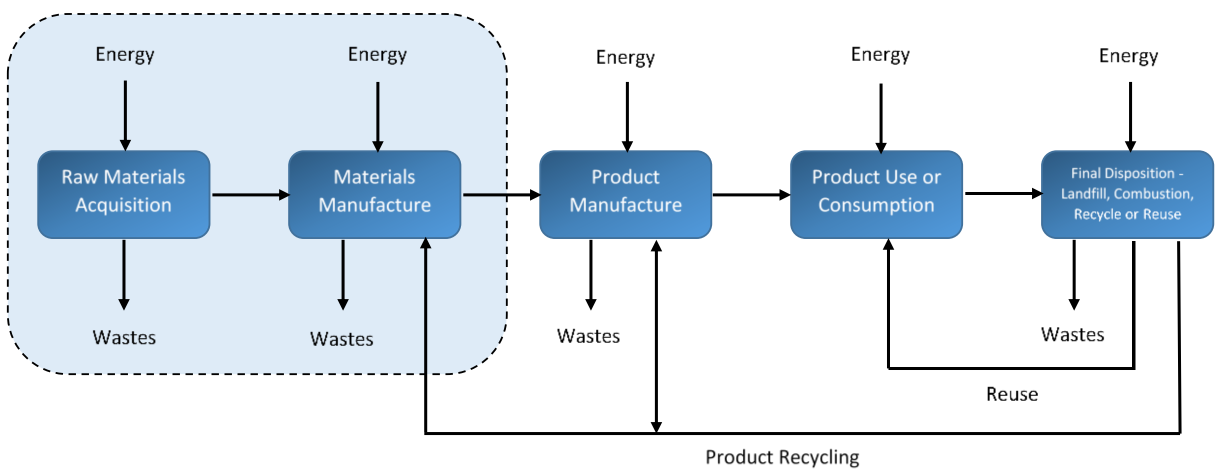

Figure 1. General materials flow for "cradle-to-grave" analysis of a product system. The dashed box indicates the boundaries of this analysis.

The results of this analysis are useful for understanding production-related impacts and are provided in a manner suitable for incorporation into full life cycle assessment studies. The information from an LCA can be used as the basis for further study of the potential improvement of resource use and environmental impacts associated with product systems. It can also pinpoint areas (e.g., material components or processes) where changes would be most beneficial in terms of reducing energy use or potential impacts.

A life cycle assessment commonly examines the sequence of steps in the life cycle of a product system, beginning with raw material extraction and continuing through material production, product fabrication, use, reuse, or recycling where applicable, and final disposition. This cradle-to-gate life cycle inventory (LCI) and life cycle impact assessment (LCIA) quantifies the total energy requirements, energy sources, water consumption, atmospheric pollutants, waterborne pollutants, and solid waste resulting from the production of the short-chain polyether polyol. It is considered a cradle-to-gate boundary system because this analysis ends with the polyether polyol production. The system boundaries stop at the polyether polyol production so that the data can be linked to a fabrication process, where it is an input material, and end-of-life data to create full life cycle inventories for a variety of applications, such as rigid foams insulations for use in households, consumer products, and the automotive industry. The method used for this inventory has been conducted following internationally accepted standards for LCI and LCA methodology as outlined in the International Organization for Standardization (ISO) 14040:2006 and 14044:2006 standard documents[1].

This LCA boundary ends at material production. An LCA consists of four phases:

- Goal and scope definition
- Life cycle inventory (LCI)
- Life cycle impact assessment (LCIA)
- Interpretation of results

The LCI identifies and quantifies the material inputs, energy consumption, water consumption, and environmental emissions (atmospheric emissions, waterborne wastes, and solid wastes) over the defined scope of the study. The LCI system process data for the cradle-to-gate polyether polyol for rigid foam polyurethane is shown separately in the attached Appendix. The LCI unit process data for the propylene system is shown in the appendix of a separate report, *Cradle-to-Gate Life Cycle Analysis of Olefins*[2]. The LCI unit process data for the chlorine/sodium hydroxide system is shown in the appendix of a separate report, *Cradle-to-Gate Life Cycle Analysis of Polyvinyl Chloride*[3]. The LCI unit process data for the glycerine, methanol, and propylene oxide is shown in the appendix of a separate report, *Cradle-to-Gate Life Cycle Analysis of Polyether Polyol for Flexible Foam Polyurethane*[4]. The cradle-to-gate system process for the short chain polyether polyol will be made available to the Department of Energy (DOE) National Renewable Energy Laboratory (NREL) who maintains the U.S. LCI Database.

In the LCIA phase, the inventory of emissions is classified into categories in which the emissions may contribute to impacts on human health or the environment. Within each

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[1] International Standards Organization. ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework, ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

[2] Cradle-to-Gate Life Cycle Analysis of Olefins. Franklin Associates. Submitted to the Plastics Division of the American Chemistry Council. April, 2020.

[3] Cradle-to-Gate Life Cycle Analysis of Polyvinyl Chloride (PVC) Resin. Franklin Associates. Submitted to the Plastics Division of the American Chemistry Council. December, 2021.

[4] Cradle-to-Gate Life Cycle Analysis of Polyether Polyol for Flexible Foam Polyurethane. Franklin Associates. Submitted to the Plastics Division of the American Chemistry Council. December, 2022.

impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance.

STUDY GOAL AND SCOPE

In this section, the goal and scope of the study is defined, including information on data sources used and methodology.

STUDY GOAL AND INTENDED USE

The purpose of this LCA is to document the LCI data and then evaluate the environmental profile of polyether polyol, which is a short chain polyol, for rigid foam polyurethanes. The intended use of the study results is twofold:

- To provide the LCA community and other interested parties with average North American LCI data for polyether polyol for rigid foam polyurethanes; and
- To provide information about the environmental burdens associated with the production of polyether polyol for rigid foam polyurethanes. The LCA results for polyether polyol production can be used as a benchmark for evaluating future updated polyether polyol results for North America.

According to ISO 14040 and 14044 standards, a peer review of this Cradle-to-Gate Life Cycle Analysis of Polyether Polyol for Rigid Foam Polyurethanes report is not required as no comparative assertions of competing materials or products are made in this study.

This report is the property of ACC acting on behalf of its Plastics Division and may be used by the trade association or members of ACC's Plastics Division or the general public at ACC's discretion.

FUNCTIONAL UNIT

The function of polyether polyol is its required inclusion to make rigid foam polyurethane products, for example, in insulation. As the study boundary concludes at the production of the polyether polyol, a mass functional unit has been chosen. Results for this analysis are shown on a basis of both 1,000 pounds and 1,000 kilograms of polyether polyol produced.

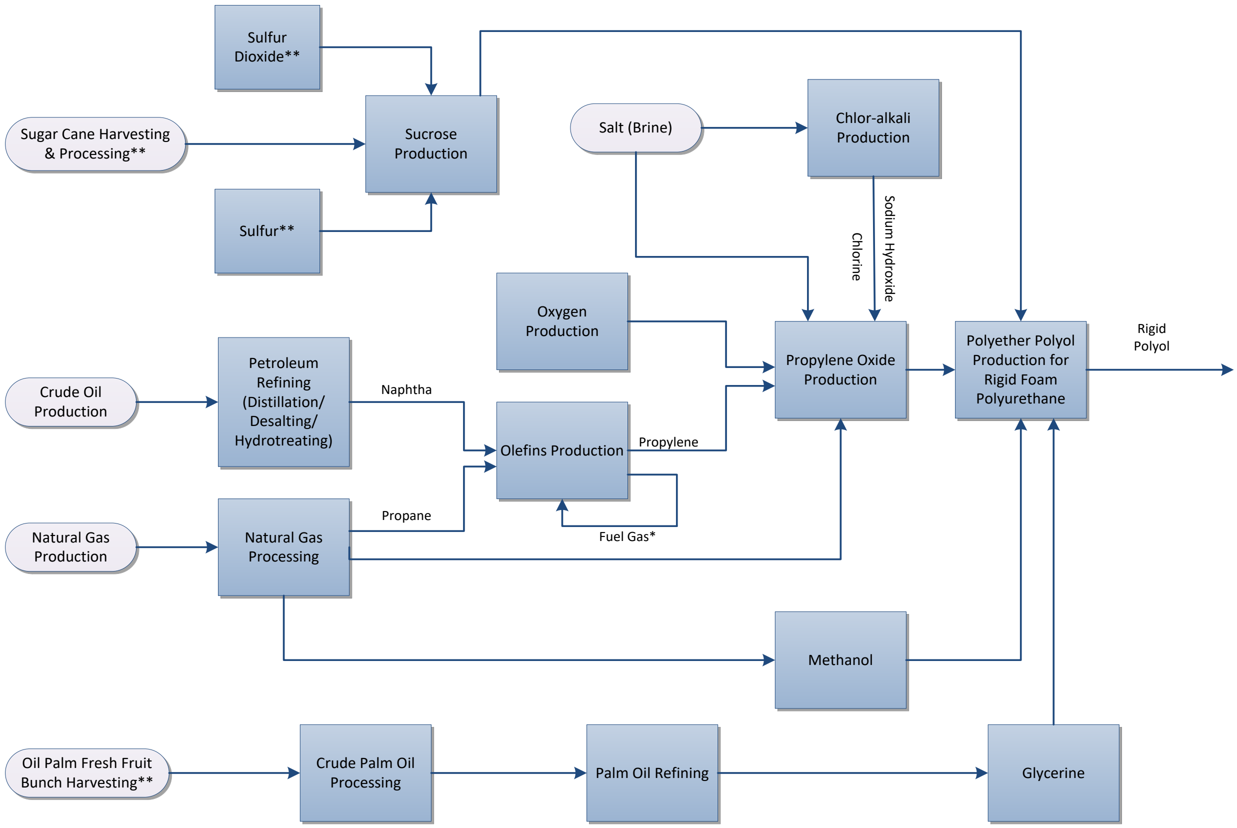
SCOPE AND BOUNDARIES

This LCA quantifies energy and resource use, water consumption, solid waste, and environmental impacts for the following steps in the life cycle of the polyether polyol manufacturing process:

- Raw material extraction (e.g., extraction of petroleum and natural gas as feedstocks) through glycerine, propylene oxide, and sucrose, as well as incoming transportation for each process; and
- Polyether polyol for rigid foam polyurethanes manufacture, including incoming transportation for each input material.

Because upstream olefin and chlor-alkali manufacture impacts the results for the production of propylene oxide used to produce polyether polyol for rigid foam polyurethanes, discussion of chlorine, sodium hydroxide, and propylene data and meta-data is included throughout this report. However, the LCI data for the olefins system is provided in the appendix of the separate report, *Cradle-to-Gate Life Cycle Analysis of Olefins*; the chlor-alkali system is provided in the appendix of the separate report*, Cradle-to-Gate Life Cycle Analysis of Polyvinyl Chloride;* and the glycerine and propylene oxide data is provided in the appendix of the separate report, *Cradle-to-Gate Life Cycle Analysis of Polyether Polyol for Flexible Foam Polyurethanes.* This report presents LCI results, as well as LCIA results, for the production of polyether polyol for rigid foam polyurethanes. Figure 2 presents the flow diagram for the production of polyether polyol for rigid foam polyurethanes. A unit process description and tables for each box shown in the flow diagram can be found in the attached appendix or in the mentioned reports previously released. The fuel gas shown in Figure 2 is created from offgas produced in the olefins process. The composition of the fuel gas was considered for each individual olefin plant and an appropriate higher heating value was used to best represent the fuel gas composition. In the case when the fuel gas was a mixed composition, a weighted average of the higher heating values was used.

In this report, a comparison section is included to analyze the 2011 and 2022 results for the polyether polyol for rigid foam polyurethanes unit process. It should be noted that the polyether polyol unit process results shown in the figures of the comparison section do not match those shown in the results section due to the inclusion of the results for the cradle-to-sucrose with the polyol plant results. This is discussed in detail in the comparison section.



* Fuel gas used for energy is created from off-gas produced in the process.
**Some upstream processes such as fertilizers, pesticides, and other inputs are not shown.

Figure 2. Flow diagram for the Production of Polyether Polyol for Rigid Foam Polyurethanes.

Technological Scope

The technology used to manufacture the polyether polyol used in rigid foam polyurethane production begins with the introduction of a potassium hydroxide catalyst to an initiator. In this analysis, sucrose was chosen as the initiator; however, glycerine and sorbitol are also common initiators used to produce polyether polyols for rigid foam polyurethane. This solution is then reacted with propylene oxide to form an intermediate. The catalyst is removed using an acid, which produces a salt that must be filtered. This acid amount is small and considered negligible in this analysis. Finally, the polyol is purified of side products and water through distillation. No coproducts are produced within polyether polyol manufacture. [5,6,&7]

The data collection methods for polyether polyol include direct measurements, information provided by purchasing and utility records, and engineering estimates. The technology represented by the data provided for this study is considered average to state-of-the-art compared to industry practices.

Temporal and Geographic Scope

As part of the data quality assessment, time period and geography were considered. All data submitted for polyether polyol represent the years 2015 or 2017. For the polyether polyol primary data, companies were requested to provide data for the year 2015, which is the most recent full year of polyether polyol production prior to the project initiation date. Companies providing data were given the option to collect data from the year preceding or following 2015 if either year would reflect more typical production conditions. One plant provided data for the year 2015, and one plant provided data for the year 2017, which was considered an average year for that company. After reviewing individual company data in comparison to the average, each manufacturer verified their data from 2015 or 2017 was representative of an average year for polyether polyol production at their company.

The geographic scope of the analysis is the manufacture of polyether polyol in North America. Polyether polyol data were collected from plants all located in the United States. Some input materials were modeled using North American databases such as the U.S. LCI database and Franklin Associates' private database, as well as ecoinvent. Datasets from ecoinvent were adapted to U.S. conditions to the extent possible (e.g., by using U.S. average grid electricity to model production of process electricity reported in the European data sets). The U.S. electricity grid from 2016 was taken from information in Emissions & Generation Resource Integrated Database (eGRID) 2016 database.

Exclusions from the Scope

The following are not included in the study:

- **Miscellaneous materials and additives.** Selected materials such as catalysts, initiators, ancillary materials, or other additives which total less than one percent by weight of the net process inputs are typically not included in assessments. This follows the ISO cut-off criteria rules in ISO 14040 and 14044. It is possible that

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[5] Arniza, M. Z., Hoong, S. S., Idris, Z., Yeong, S. K., Hassan, H. A., Din, A. K., & Choo, Y. M. (2015). Synthesis of Transesterified Palm Olein-Based Polyol and Rigid Polyurethanes from this Polyol. Journal of the American Oil Chemists' Society, 92(2), 243–255. https://doi.org/10.1007/s11746-015-2592-9

[6] Paciorek-Sadowska, J., & Czupryński, B. (2006). New compounds for production of polyurethane foams. *Journal of Applied Polymer Science*, *102*(6), 5918–5926. https://doi.org/10.1002/app.25093

[7] Suleman, S., Khan, S. M., Gull, N., Aleem, W., Shafiq, M., & Jamil, T. (2014). *A Comprehensive Short Review on Polyurethane Foam*. *12*(1), 6.

production of some substances used in small amounts may be energy and resource intensive or may release toxic emissions; however, the impacts would have to be very large in proportion to their mass in order to significantly affect overall results and conclusions. For this study, no use of resource-intensive or high-toxicity chemicals or additives was identified. Therefore, the results for the polyether polyol are not expected to be understated by any significant amount due to substances that may be used in small amounts.

- **Capital equipment, facilities, and infrastructure.** The energy and wastes associated with the manufacture of buildings, roads, pipelines, motor vehicles, industrial machinery, etc. are not included. The energy and emissions associated with production of capital equipment, facilities, and infrastructure generally become negligible when averaged over the total output of product or service provided over their useful lifetimes.
- **Space conditioning.** The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations when possible. For manufacturing plants that carry out thermal processing or otherwise consume large amounts of energy, space conditioning energy is quite low compared to process energy. The data collection forms developed for this project specifically requested that the data provider either exclude energy use for space conditioning or indicate if the reported energy requirements included space conditioning. Energy use for space conditioning, lighting, and other overhead activities is not expected to make a significant contribution to total energy use for the resin system.
- **Support personnel requirements**. The energy and wastes associated with research and development, sales, and administrative personnel or related activities have not been included in this study. Similar to space conditioning, energy requirements and related emissions are assumed to be quite small for support personnel activities.

INVENTORY AND IMPACT ASSESSMENT RESULTS CATEGORIES

The full inventory of emissions generated in an LCA study is lengthy and diverse, making it difficult to interpret emissions profiles in a concise and meaningful manner. LCIAs helps to interpret of the emissions inventory. LCIA is defined in ISO 14044 Section 3.4 as the "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." In the LCIA phase, the inventory of emissions is first classified into categories in which the emissions may contribute to impacts on human health or the environment. Within each impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance.

The LCI and LCIA results categories and methods applied in this study are displayed in Table 1. This study addresses global, regional, and local impact categories. For most of the impact categories examined, the TRACI 2.1 method, developed by the United States Environmental

Protection Agency (EPA) specific to U.S. conditions and updated in 2012, is employed.[8] For the category of Global Warming Potential (GWP), contributing elementary flows are characterized using factors reported by the Intergovernmental Panel on Climate Change (IPCC) in 2013 with a 100 year time horizon.[9] In addition, the following LCI results are included in the results reported in the analysis:

- Energy demand: this method is a cumulative inventory of all forms of energy used for processing energy, transportation energy, and feedstock energy. This analysis reports total energy demand, with renewable and non-renewable energy demand reported separately to assess consumption of fuel resources that can be depleted. Total energy demand is used as an indicator of overall consumption of resources with energy value. Energy is also categorized by individual fuel types, as well as by process/fuel vs. feedstock energy.
- Total solid waste is assessed as a sum of the inventory values associated with this category. This category is also broken into hazardous and non-hazardous wastes and their end-of-life (e.g., incineration, waste-to-energy, or landfill).
- Water consumption is assessed as a sum of the inventory values associated with this category and does not include any assessment of water scarcity issues. Consumed water does include removal of water from one watershed to another.

8 Bare, J. C. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), Version 2.1 - User's Manual; EPA/600/R-12/554 2012.

9 IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

Table 1. Summary of LCI/LCIA Impact Categories

	Impact/Inventory Category	Description	Unit	LCIA/LCI Methodology
LCI Categories	**Total energy demand**	Measures the total energy from point of extraction; results include both renewable and non-renewable energy sources.	Million (MM) Btu and megajoule (MJ)	Cumulative energy inventory
	Non-renewable energy demand	Measures the fossil and nuclear energy from point of extraction.	MM Btu and MJ	Cumulative energy inventory
	Renewable energy demand	Measures the hydropower, solar, wind, and other renewables, including landfill gas use.	MM Btu and MJ	Cumulative energy inventory
	Solid waste by weight	Measures quantity of fuel and process waste to a specific fate (e.g., landfill, waste-to-energy (WTE)) for final disposal on a mass basis	Lb and kg	Cumulative solid waste inventory
	Water consumption	Freshwater withdrawals which are evaporated, incorporated into products and waste, transferred to different watersheds, or disposed into the land or sea after usage	Gallons and Liters	Cumulative water consumption inventory
LCIA Categories	**Global warming potential**	Represents the heat trapping capacity of the greenhouse gases. Important emissions: CO_2 fossil, CH_4, N_2O	Lb CO_2 equivalents (eq) and kg CO_2 equivalents (eq)	IPCC (2013) GWP 100a*
	Acidification potential	Quantifies the acidifying effect of substances on their environment. Important emissions: SO_2, NO_x, NH_3, HCl, HF, H_2S	Lb SO_2 eq and kg SO_2 eq	TRACI v2.1
	Eutrophication potential	Assesses impacts from excessive load of macro-nutrients to the environment. Important emissions: NH_3, NO_x, chemical oxygen demand (COD) and biochemical oxygen demand (BOD), N and P compounds	Lb N eq and kg N eq	TRACI v2.1
	Ozone depletion potential	Measures stratospheric ozone depletion. Important emissions: chlorofluorocarbon (CFC) compounds and halons	Lb CFC-11 eq and kg CFC-11 eq	TRACI v2.1
	Smog formation potential	Determines the formation of reactive substances (e.g. tropospheric ozone) that cause harm to human health and vegetation. Important emissions: NO_x, benzene, toluene, ethylbenzene, xylene (BTEX), non-methane volatile organic compound (NMVOC), CH_4, C_2H_6, C_4H_{10}, C_3H_8, C_6H_{14}, acetylene, Et-OH, formaldehyde	Lb kg O_3 eq and kg O_3 eq	TRACI v2.1

DATA SOURCES

The purpose of this study is to develop a life cycle profile for polyether polyol using the most recent data available for each process. A production-weighted average was calculated for the polyether polyol data (production for the year 2015 and 2017) collected for this analysis. The propylene oxide data is an average of three different technologies from the 1990s. The technologies are all still in use in North America, and the weightings of each dataset have been updated to reflect recent use of these technologies. The propylene data was also calculated as a production-weighted average of primary datasets for 2015. Secondary data was researched in 2017 for crude oil extraction and refining and natural gas production and processing. Secondary sources were used for sugarcane growing and harvesting, sucrose, methanol, oxygen, palm kernel oil production and glycerine production. Due to confidentiality issues with the polyether polyol data, only a system process is shown in the appendix. Most of the unit processes used to produce this polyether polyol are shown in the appendix at the end of previously released reports.

LCI data for the production of polyether polyol were collected from two producers (2 plants) in North America within the United States. One company provided data for 2015 and the other provided data for 2017. A weighted average was calculated from the data collected and used to develop the LCA model. The captured polyether polyol production amount is approximately 44 percent of the polyether polyol production in North America in 2015[10]. This percentage was estimated using the amount of polyol used for rigid foam in the end use table in the Resin Review 2016. No coproducts are produced within polyether polyol manufacture.

LCI data for the production of propylene used in the manufacture of propylene oxide were collected from three producers (ten plants) in North America – all in the United States. All companies provided data for the year 2015. A weighted average was calculated from the data collected and used to develop the LCA model. Propylene and ethylene are coproducts during olefins production, and a mass basis was used to allocate the environmental burdens among these and other coproducts.

LCI data for the chlor-alkali process were collected from three producers (three plants) using the membrane technology in the United States. Two of the plants provided data for the year 2015, while one provided data for the year 2017. A weighted average was calculated from the data collected and used to develop the LCA model. A combination of stoichiometric and mass allocation was used for the chlorine, sodium hydroxide, and hydrogen coproducts from this process. Stoichiometric allocation was used for the material inputs, while mass allocation was used for all other inputs and outputs. This follows the same method used by Plastics Europe for their chlor-alkali process LCA. Small amounts of hydrogen were considered a coproduct at the plants. In some cases, much of the hydrogen created was used as a fuel in the chlor-alkali or down-stream PVC processes or it was used to make hydrochloric acid on-site.

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[10] American Chemistry Council, Resin Review 2016. Franklin Associates calculations.

DATA QUALITY ASSESSMENT

ISO 14044:2006 lists a number of data quality requirements that should be addressed for studies intended for use in public comparative assertions. The data quality goals for this analysis were to use data that are (1) geographically representative for the polyether polyol is based on the locations where material sourcing and production take place, and (2) representative of current industry practices in these regions. As described in the previous section, two companies each provided data from 2015 or 2017 in the United States, which was geographically and temporally representative data for all primary polyether polyol data collected for this LCA.

The incoming material and fuel datasets for polyether polyol manufacture were either updated using geographical and technologically relevant data from government or privately available statistics/studies within the US or drawn from either The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model or ecoinvent[11]. Datasets from ecoinvent were adapted to U.S. conditions to the extent possible (e.g., by using U.S. average grid electricity to model production of process electricity reported in the European data sets). The data sets used were the most current and most geographically and technologically relevant data sets available during the data collection phase of the project.

Consistency, Completeness, Precision: Data evaluation procedures and criteria were applied consistently to all primary data provided by the participating producers for all data collected. All primary data obtained specifically for this study were considered the most representative available for the systems studied. Data sets were reviewed for completeness and material balances, and follow-up was conducted as needed to resolve any questions about the input and output flows, process technology, etc. The aggregated averaged datasets were also reviewed by the providing companies as compared to the provided dataset. Companies were requested to comment on their own data normalized to 1000 pounds as well as the industry average dataset normalized to 1000 pounds.

Representativeness: Polyether polyol manufactured in North America is commonly produced using catalyzed propoxylation of multi-functional initiators within the United States. The two companies provided data from their facilities using an average technology for this output. After reviewing their individual company data, each manufacturer verified that their data from 2015 or 2017 was representative of an average year for the plant.

LCI data for the production of propylene oxide was taken from an older source for 3 types of technologies currently used; however, there are two newer technologies that make up approximately 10 percent of the production of propylene oxide in 2015. It is unknown

[11] Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230. Available at: <http://link.springer.com/10.1007/s11367-016-1087-8> [Accessed Sept, 2018].

whether not including these technologies will affect the LCI data for this unit process. It is also unknown whether the LCI data for the older technologies have changed significantly. ACC is advised to collect data for the propylene oxide unit process in future updates.

The LCI data for the propylene system is shown in the appendix of a separate report, *Cradle-to-Gate Life Cycle Analysis of Olefins*[12]. Primary data were collected from propylene manufacturers from the year 2015. Companies providing data were given the option to collect data from the year preceding or following 2015 if either year would reflect more typical production conditions. After reviewing individual company data in comparison to the average, each manufacturer verified data from 2015 was a representative year for propylene production in North America.

LCI data from the sources of input materials specific to each company providing data was not available for this analysis. Average U.S. statistics were used for refined petroleum products and processed natural gas to develop the average propylene unit process data. As impacts from crude oil and natural gas may vary depending on transportation requirements some variability in data and impact on LCA results should be expected.

The average polyether polyol unit process data was based on the best available data at the time the study was conducted. As in all LCA studies, the ability to develop a representative average is determined by the number of companies willing to participate. Data from this analysis was used to develop the most representative average for polyether polyol production as was possible.

Reproducibility: To maximize transparency and reproducibility, the report identifies specific data sources, assumptions, and approaches used in the analysis to the extent possible; however, reproducibility of study results is limited to some extent by the need to protect certain data sets that were judged to be high quality and representative data sets for modeling purposes but could not be shown due to confidentiality. Due to confidentiality issues, a system process LCI table was provided for polyether polyol for rigid foam polyurethanes in the appendix.

Uncertainty: Uncertainty issues and uncertainty thresholds applied in interpreting study results are described in the following section.

DATA ACCURACY AND UNCERTAINTY

In LCA studies with thousands of numeric data points used in the calculations, the accuracy of the data and how it affects conclusions is truly a complex subject, and one that does not lend itself to standard error analysis techniques. Techniques such as Monte Carlo analysis can be used to assess study uncertainty, but the greatest challenge is the lack of uncertainty data or probability distributions for key parameters, which are often only available as single

[12] Cradle-to-Gate Life Cycle Analysis of Olefins. Franklin Associates. Submitted to the Plastics Division of the American Chemistry Council. April, 2020.

point estimates. However, steps are taken to ensure the reliability of data and results, as previously described.

The accuracy of the environmental results depends on the accuracy of the numbers that are combined to arrive at that conclusion. For some processes, the data sets are based on actual plant data reported by plant personnel, while other data sets may be based on engineering estimates or secondary data sources. Primary data collected from actual facilities are considered the best available data for representing industry operations. In this study, primary data were used to model the polyether polyol, chlor-alkali products, and propylene from steam cracking. All data received were carefully evaluated before compiling the production-weighted average data sets used to generate results. Supporting background data were drawn from credible, widely used databases including the US LCI database, GREET, Agri-footprint, and ecoinvent.

METHOD

The LCA has been conducted following internationally accepted standards for LCA as outlined in the ISO 14040 and 14044 standards, which provide guidance and requirements for conducting LCA studies. However, for some specific aspects of LCA, the ISO standards have some flexibility and allow for choices to be made. The following sections describe the approach to each issue used in this study. Many of these issues are specific to the propylene produced at the steam crackers.

Raw Materials Use for Internal Energy in Steam Crackers

Some of the raw material inputs to the steam cracker create gases that are combusted to provide energy for the steam cracker, decreasing the amount of purchased energy required for the reaction. Data providers listed this energy as fuel gas or off-gas and, in many cases, supplied the heating value of this gas. Using this information, Franklin Associates calculated the amount of raw material combusted within the steam cracker to produce this utilized energy source.

This internally-created energy is included in the analysis by including the production of the raw materials combusted to produce the energy as well as the energy amount attributed to the combustion of those raw materials. Unlike the raw materials that become part of the product output mass, no material feedstock energy is assigned to the raw materials inputs that are combusted within the process.

Coproduct Allocation

An important feature of life cycle inventories is that the quantification of inputs and outputs are related to a specific amount of useful output from a process. However, it is sometimes difficult or impossible to identify which inputs and outputs are associated with individual products of interest resulting from a single process (or process sequence) that produces multiple useful products. The practice of allocating inputs and outputs among multiple products from a process is often referred to as coproduct allocation.

Environmental burdens are allocated among the coproducts when raw materials and emissions cannot be directly attributed to one of several product outputs from a system. It has long been recognized that the practice of allocating the environmental burdens among the coproducts is less desirable than being able to identify which inputs lead to specific outputs. In this study, co-product allocations are necessary because of multiple useful outputs from the "upstream" chemical process involved in producing chlorine/sodium hydroxide and propylene.

Franklin Associates follows the guidelines for allocating the environmental burdens among the coproducts as shown in the ISO 14044:2006 standard on life cycle assessment requirements and guidelines[13]. In this standard, the preferred hierarchy for handling allocation is (1) avoid allocation where possible, (2) allocate flows based on direct physical relationships to product outputs, (3) use some other relationship between elementary flows and product output. No single allocation method is suitable for every scenario. As described in ISO 14044:2006 section 4.3.4.2, when allocation cannot be avoided, the preferred partitioning approach should reflect the underlying physical relationships between the different products or functions.

Material Coproducts

Some processes lend themselves to physical allocation because they have physical parameters that provide a good representation of the environmental burdens of each co-product. Examples of various allocation methods are mass, stoichiometric, elemental, reaction enthalpy, and economic allocation. Simple mass and enthalpy allocation have been chosen as the common forms of allocation in this analysis. However, these allocation methods were not chosen as a default choice but made on a case-by-case basis after consideration of the chemistry and basis for production.

Material coproducts were created in all the intermediate chemical process steps collected for this analysis, but no coproducts were created in the primary polyether polyol production. The material coproducts from olefins production for all plants included propylene, pyrolysis gasoline, butadiene, ethylene, hydrogen, acetylene, crude benzene, and small amounts of various heavy end products. The material coproduct for the chlor-alkali process includes chlorine, sodium hydroxide, and hydrogen. No material coproducts were created in the polyether polyol production.

A portion of the inputs and outputs calculated for the coproducts were removed from the total inputs and outputs, so that the remaining inputs and outputs only represented the main product in each unit process. The ratio of the mass of the coproduct over the total mass output was removed from the total inputs and outputs of the process, and the remaining inputs and outputs are allocated over the material products (Equation 1).

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[13] International Standards Organization. ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

$$[IO] \times \left(1 - \frac{M_{CP}}{M_{Total}}\right) = [IO]_{attributed\ to\ remaining\ \ products} \qquad \text{(Equation 1)}$$

where
IO = Input/Output Matrix to produce all products/coproducts
M_{CP} = Mass of Coproduct
M_{Total} = Mass of all Products and Coproducts

Energy Coproducts Exported from System Boundaries

Some of the unit processes produce energy either as a fuel coproduct or as steam created from the process that is sent to another plant for use. To the extent possible, system expansion to avoid allocation was used as the preferred approach in the ISO 14044:2006 standard. Fuels or steam exported from the boundaries of the system would replace purchased fuels for another process outside the system. System expansion credits were given for avoiding the energy-equivalent quantity of fuel production and combustion displaced by the exported coproduct energy.

Chlor-Alkali Plant Allocations

The allocations for the chlor-alkali plant follow the allocations given in the Euro Chlor report, *An Eco-profile and Environmental Product Declaration of the European Chlor-Alkali Industry*[14]. These allocations were followed due to the likelihood that comparisons will be made between the North American and European LCAs by companies and LCA practitioners in both continents. This will ensure that the differences in datasets will not be caused by differing allocation methods. The original North American chlor-alkali LCI data used mass allocation on all inputs and outputs.

As avoiding allocation of coproducts is not possible since chlorine, sodium hydroxide, and hydrogen are all produced from the process, allocations have been made to focus on which product the inputs or outputs associate within the process. The following allocations are made to the chlor-alkali LCI data:

- The sodium chloride input was given stoichiometric allocation among the three products. As the plants providing data produced for sale only chlorine, sodium hydroxide and hydrogen, the sodium chloride input was split between the chlorine and sodium hydroxide using the stoichiometry of the chemical reaction.
- The sulfuric acid input was used specifically to dry the chlorine and so has been fully allocated to the chlorine product.
- All chlorine-based air emissions or waterborne wastes are allocated to the chlorine product.
- All sodium hydroxide emissions are allocated to the sodium hydroxide product.
- All hydrogen emissions are allocated to the hydrogen product.
- All other inputs or outputs of the chlor-alkali process are allocated by mass to all three products.

[14] An Eco-profile and Environmental Product Declaration of the European Chlor-Alkali Industry. Chlorine (The chlor-alkali process) Euro Chlor. September, 2013.

Electricity Grid Fuel Profile

Electricity production and distribution systems in North America are interlinked. Users of electricity, in general, cannot specify the fuels used to produce their share of the electric power grid. Data for this analysis was collected from plants in the United States and Mexico. The U.S. average fuel consumption by electrical utilities was used for the electricity within this analysis. This electricity data set uses the Emissions & Generation Resource Integrated Database (eGRID) 2016 database [15]. The 2016 grid was used for consistency with the age of the collected resin process data and previously published reports for the current update to other resins and polyurethane precursors. Table 2 provides a breakdown of energy sources and the contribution by percentage of each source to the grid mix.

Electricity generated on-site at a manufacturing facility is represented in the process data by the fuels used to produce it. If a portion of on-site generated electricity is sold to the electricity grid, credits for sold on-site electricity are accounted for in the calculations for the fuel mix.

Electricity/Heat Cogeneration

Cogeneration is the use of steam for generation of both electricity and heat. The most common configuration is to generate high temperature steam in a cogeneration boiler and use that steam to generate electricity. The steam exiting the electricity turbines is then used as a process heat source for other operations. Significant energy savings occur because in a conventional operation, the steam exiting the electricity generation process is condensed, and the heat is dissipated to the environment.

[15] Online database found at: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

Table 2. Average U.S. 2016 Electricity Grid Mix Profile

	2016 Grid Mix
Renewable Energy Sources	
Geothermal	0.4%
Kinetic (in wind)	5.6%
Solar (converted)	0.9%
Biomass	1.7%
Hydroelectric	6%
Unspecified	0.5%
Total Renewable Energy Sources	15%
Non-Renewable Energy Sources	
Coal (bituminous and lignite)	30%
Natural Gas	34%
Nuclear	20%
Oil Products (diesel and residual)	0.6%
Total Non-Renewable Energy Sources	85%
Total Renewable and Non-Renewable Energy Sources	**100%**

Note: Energy sources may not add to total shown due to rounding. Grid mix percentages do not include average national grid loss of 5.2%.

For LCI purposes, the fuel consumed and the emissions generated by the cogeneration boiler need to be allocated to the two energy-consuming processes: electricity generation and subsequent process steam. An energy basis was used for allocation in this analysis.

In order to allocate fuel consumption and environmental emissions to both electricity and steam generation, the share of the two forms of energy (electrical and thermal) produced must be correlated to the quantity of fuel consumed by the boiler. Data on the quantity of fuel consumed and the associated environmental emissions from the combustion of the fuel, the amount of electricity generated, and the thermal output of the steam exiting electricity generation must be known in order to allocate fuel consumption and environmental emissions accordingly. These three types of data are discussed below.

1. **Fuels consumed and emissions generated by the boiler:** The majority of data providers for this study reported natural gas as the fuel used for cogeneration. According to 2016 industry statistics, natural gas accounted for 75 percent of industrial cogeneration, while coal and biomass accounted for the largest portion of the remaining fuels used[16].

[16] U.S. Department of Energy. *Combined Heat and Power (CHP) Technical Potential in the United States.* March 2016.

2. **Kilowatt-Hours of Electricity Generated:** In this analysis, the data providers reported the kilowatt-hours of electricity from cogeneration. The Btu of fuel required for this electricity generation was calculated by multiplying the kilowatt-hours of electricity by 6,826 Btu/kWh (which utilizes a thermal to electrical conversion efficiency of 50 percent). This Btu value was then divided by the Btu value of fuel consumed in the cogeneration boiler to determine the electricity allocation factor.

   The 50 percent conversion efficiency was an estimate after reviewing energy information administration (EIA) fuel consumption and electricity net generation data from cogeneration plants in 2016.[17] The straight average conversion efficiency for 2016 for electricity production in cogeneration plants within this database is a little more than 55 percent; however, the range of efficiency calculated per individual cogeneration plant was 23% to 87%. The 50 percent estimate of conversion efficiency was used previously in the 2011 database and so was estimated for continued use within this analysis, due to the variability of the individual cogeneration plants. Unit process data for cogeneration of electricity is provided by kWh, so that a change of efficiency could easily be applied during modeling.

3. **Thermal Output of Steam Exiting Electricity Generation:** In this analysis, the data providers stated the pounds and pressure of steam from cogeneration. The thermal output (in Btu) of this steam was calculated from enthalpy tables (in most cases steam ranged from 1,000 to 1,200 Btu/lb). An efficiency of 80 percent was used for the industrial boiler to calculate the amount of fuel used[18]. This Btu value was then divided by the Btu value of fuel consumed in the cogeneration boiler to determine the steam allocation factor. The 80 percent efficiency used is common for a conventional natural gas boiler, which should not change when considering the steam portion of the cogeneration system. Pounds of steam, temperature and pressure were provided by participating plants. Steam tables were used to calculate energy amounts, which was divided by the efficiency and converted to natural gas amounts in cubic feet.

[17] U.S. Department of Energy, The Energy Information Administration (EIA). *EIA-923 Monthly Generation and Fuel Consumption Time Series File, 2016 Final Revision*

[18] United States Environmental Protection Agency (EPA). *Methods for Calculating CHP Efficiency*. Accessed online at https://www.epa.gov/chp/methods-calculating-chp-efficiency.

LIFE CYCLE INVENTORY AND IMPACT ASSESSMENT RESULTS

This section presents baseline results for the following LCI and LCIA results for both 1,000 pounds and 1,000 kilograms of polyether polyol (short chain) used in rigid foam polyurethane:

Life cycle inventory results:

- Cumulative energy demand
- Non-renewable energy demand
- Renewable energy demand
- Total energy by fuel type
- Solid waste by weight
- Water consumption

Life cycle impact assessment results:

- Global warming potential
- Acidification potential
- Eutrophication potential
- Ozone depletion potential
- Smog formation potential

Throughout the results sections, the tables and figures break out system results into the following unit processes, for polyether polyol:

- Cradle-to-incoming materials – includes the raw materials through the production of propylene oxide, sucrose, and glycerine.
- Polyether polyol for rigid foam polyurethanes production – is the gate-to-gate unit process and includes the production of fuels used in the process.

Tables and figures are provided for polyether polyol in each inventory and impact category section in this report. The phrases "cradle-to- "and "system" are defined as including all of the raw and intermediate chemicals required for the production of the chemical/resin stated in the term (e.g., cradle-to-polyether polyol and polyether polyol system are interchangeable). The phrase "gate-to-gate" is defined as including only the onsite process/fuels.

ENERGY DEMAND

Cumulative Energy Demand

Cumulative energy demand results include all renewable and non-renewable energy sources used for process and transportation energy, as well as material feedstock energy. Process energy includes direct use of fuels, including the use of fossil fuels, hydropower, nuclear, wind, solar, and other energy sources to generate electricity used by processes. Fuel energy is the energy necessary to create and transport the fuels to the processes. The feedstock energy is the energy content of the resources removed from nature and used as material feedstocks for the olefins production (e.g., the energy content of oil and gas used as material feedstocks), which are the main inputs to propylene oxide used to produce polyether polyol.

The average total energy required to produce the short chain polyether polyol is 32.1 million Btu per 1,000 pounds of polyether polyol or 74.6 gigajoule (GJ) per 1,000 kilograms of polyether polyol. Table 3 shows total energy demand for the life cycle of polyether polyol production. The polyether polyol production energy has been split out from the energy required for incoming materials, including the production of petroleum extraction and refining, natural gas production and processing, propylene, oxygen, brine, chlorine, sodium hydroxide, propylene oxide, oil palm fresh fruit cultivation and harvesting, crude palm oil processing, palm oil refining, sugar cane cultivation and harvesting, sucrose processing, methanol, and glycerine. Only approximately 5 percent of the total energy is required to produce the polyether polyol itself. The remaining 95 percent is used to create the raw and intermediate materials. Approximately 93 percent of the total required energy is used to create the propylene oxide (cradle-to-propylene oxide), which makes up 76 percent of the mass of incoming materials required to create polyether polyol.

Table 3. Total Energy Demand for Polyether Polyol for Rigid Foam Polyurethanes

	Basis: 1,000 pounds		
	Total Energy	**Non-Renewable Energy**	**Renewable Energy**
	MM Btu	***MM Btu***	***MM Btu***
Cradle-to-Incoming Materials	30.6	30.3	0.27
Rigid Polyol Production	1.49	1.45	0.036
Total	**32.1**	**31.8**	**0.30**
	Basis: 1,000 kilograms		
	Total Energy	**Non-Renewable Energy**	**Renewable Energy**
	GJ	***GJ***	***GJ***
Cradle-to-Incoming Materials	71.1	70.5	0.62
Rigid Polyol Production	3.46	3.38	0.084
Total	**74.6**	**73.9**	**0.70**
	Percentage		
	Total Energy	**Non-Renewable Energy**	**Renewable Energy**
	%	***%***	***%***
Cradle-to-Incoming Materials	95.4%	94.5%	0.8%
Rigid Polyol Production	4.6%	4.5%	0.1%
Total	**100%**	**99.1%**	**0.9%**

Non-renewable energy demand includes the use of fossil fuels (petroleum, natural gas, and coal) for process energy, transportation energy, and as material feedstocks (e.g., oil and gas used as feedstocks for the production of the propylene), as well as use of uranium to generate the share of nuclear energy in the average U.S. kWh. For the polyether polyol, 99.1 percent of the total energy comes from non-renewable sources. The renewable energy demand consists of landfill gas used for process energy in propylene production and electricity derived from renewable energy sources (primarily hydropower, as well as wind, solar, and other sources). The renewable energy (0.08 GJ/1000 kg) used at the polyether polyol plant comes solely from hydropower and other renewable sources (geothermal, solar, etc.) from electricity production.

The energy content of natural gas and petroleum used as raw material inputs for the production of propylene used to produce the incoming material propylene oxide for the polyether polyol is included in the cradle-to-incoming material amounts in Table 3. The energy inherent in these raw materials is called material feedstock energy. Of the total energy (74.6 GJ) for 1,000 kg of polyether polyol, 30.5 GJ is material feedstock energy. Figure 3 provides the breakdown of the percentage of total energy required for material feedstock energy versus the process and fuel energy amounts needed to produce the polyether polyol. Approximately 41 percent of the total energy is inherent energy in the natural gas and petroleum used as a feedstock to create propylene, which in turn are used to create propylene oxide making polyether polyol. Of the feedstock sources for propylene, 87 percent comes from natural gas, while 13 percent of the feedstock sources come from oil.

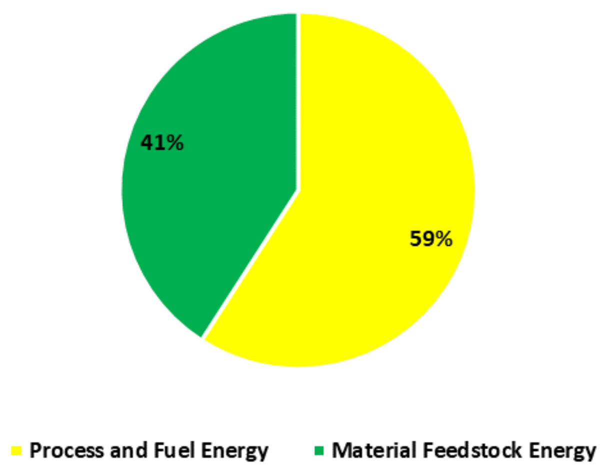

Figure 3. Process/Fuel and Material Feedstock Percentages for Polyether Polyol for Rigid Foam Polyurethanes

Energy Demand by Fuel Type

The total energy demand by fuel type for polyether polyol is shown in Table 4 and the percentage mix is shown in Figure 4. Natural gas and petroleum together make up almost 90 percent of the total energy used. As shown in Figure 3, this is partially due to the material feedstock energy used to create the propylene, which is an intermediate chemical input to polyether polyol. These material feedstock fuels are part of the energy shown in the natural gas and petroleum split out in the following table and figure. The gate-to-gate production energy for polyether polyol in the following table and figure represents the energy required for transportation of raw materials to polyether polyol manufacturers, the energy required to produce the polyether polyol, and the production of the fuels combusted during the polyether polyol manufacture.

Petroleum-based fuels (e.g., diesel fuel) are the dominant energy source for transportation. Natural gas, coal, and other fuel types, such as hydropower, nuclear and other (geothermal, wind, etc.) are used to generate purchased electricity. Other renewables include a small amount of landfill gas used for process energy in propylene production, besides other non-renewables used for electricity.

Of the results for polyether polyol production shown in Table 4 and Figure 4, 82 percent of the energy used (60.9 GJ/74.6 GJ) is from natural gas. At the polyether polyol plant, 68 percent of the energy used (2.35 GJ/3.46 GJ) comes from natural gas. Of that natural gas used at the polyether polyol plant, 46 percent is combusted on-site, while 53 percent is required to create electricity through the grid and cogeneration. Petroleum comprises approximately 8 percent (5.76 GJ/74.6 GJ) of the fuel used for the polyether polyol system. Over 86 percent of the petroleum used for the polyether polyol plant is combusted during transport of materials to the plant. The coal use shown is almost fully from combustion for electricity use throughout the system. A large amount of electricity is used in the chlor-alkali process, the products of which are major inputs to some of the technologies producing propylene oxide. The 2016 U.S. electricity grid is used for this study. In this grid, approximately 30 percent of the electricity production in the U.S. uses coal as a fuel source, while a third of the grid comes from natural gas and 20 percent from uranium. The hydropower, nuclear, and other energy are all used to create electricity, with the exception of a small amount of landfill gas used in propylene production shown within other renewables.

Table 4. Energy Demand by Fuel Type for Polyether Polyol for Rigid Foam Polyurethanes

	Total Energy	Natural Gas	Petroleum	Coal	Nuclear	Hydropower	Other Renewable
Basis: 1,000 pounds							
	MM Btu	*MM Btu*	*MM Btu*	*MM Btu*	*MM Btu*	*MM Btu*	*MM Btu*
Cradle-to-Incoming Materials	30.6	25.2	2.39	1.66	1.10	0.12	0.13
Rigid Polyol Production	1.49	1.01	0.084	0.21	0.14	0.015	0.021
Total	**32.1**	**26.2**	**2.48**	**1.87**	**1.24**	**0.14**	**0.15**
Basis: 1,000 kilograms							
	Total Energy	**Natural Gas**	**Petroleum**	**Coal**	**Nuclear**	**Hydropower**	**Other Renewable**
	GJ	*GJ*	*GJ*	*GJ*	*GJ*	*GJ*	*GJ*
Cradle-to-Incoming Materials	71.1	58.6	5.57	3.87	2.55	0.28	0.31
Rigid Polyol Production	3.46	2.35	0.19	0.49	0.33	0.035	0.050
Total	**74.6**	**60.9**	**5.76**	**4.36**	**2.88**	**0.31**	**0.36**
Percentage of Total							
	Total Energy	**Natural Gas**	**Petroleum**	**Coal**	**Nuclear**	**Hydropower**	**Other Renewable**
	%	*%*	*%*	*%*	*%*	*%*	*%*
Cradle-to-Incoming Materials	95.4%	78.5%	7.5%	5.2%	3.4%	0.4%	0.4%
Rigid Polyol Production	4.6%	3.2%	0.3%	0.7%	0.4%	0.0%	0.1%
Total	**100%**	**81.7%**	**7.7%**	**5.8%**	**3.9%**	**0.4%**	**0.5%**

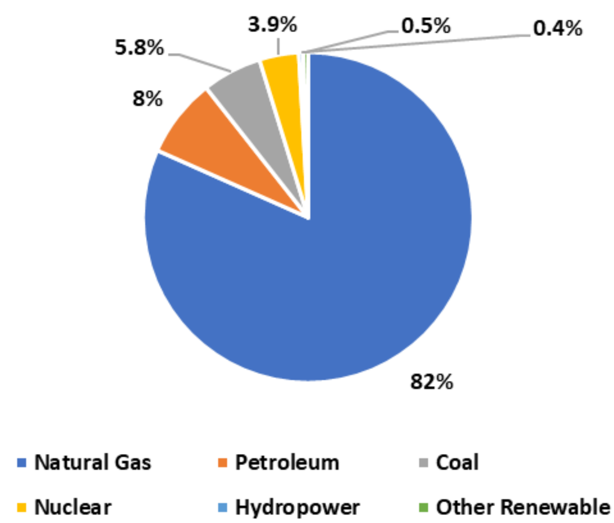

Figure 4. Percentage of Energy Separated by Fuel Type for Polyether Polyol for Rigid Foam Polyurethanes

SOLID WASTE

Solid waste results include the following types of wastes:

- **Process wastes** that are generated by the various processes from raw material acquisition through production of the resin (e.g., sludges and residues from chemical reactions and material processing steps)

- **Fuel-related wastes** from the production and combustion of fuels used for process energy and transportation energy (e.g., refinery wastes, coal combustion ash)

No postconsumer wastes of the polyether polyol are included in this analysis as the boundaries end with resin production and do not include production, use, or disposal of products made from the resin.

The process solid waste, those wastes produced directly from the production of materials, includes wastes that are incinerated both for disposal and for waste-to-energy, as well as landfilled. Some wastes that are recycled/reused or land applied are not included as solid wastes, and no credit is given. The categories of disposal type have been provided separately where possible. Solid wastes from fuel combustion (e.g., ash) are assumed to be landfilled.

Results for solid waste by weight for the polyether polyol system are shown in Table 5 and Figure 5. The solid wastes have been separated into hazardous and non-hazardous waste categories, as well as by the cradle-to-incoming materials and the polyether polyol plant. As shown in Figure 5, only 8 percent of the total solid waste is associated with the polyether polyol unit process. Of that amount at the plant, only 13 percent is process solid waste, while 80 percent of this amount comes from fuels combusted for the electricity used in the plant with the remaining from natural gas combustion or production of transport fuels.

The majority of solid waste, 92 percent, comes from the production of incoming materials used to produce polyether polyol. Focusing on direct input systems, the propylene oxide system (cradle-to-propylene oxide) creates more than 69 percent of the incoming solid wastes, while the sucrose system contributes to 22 percent of the incoming solid waste. Looking at specific unit processes, the coal extraction and combustion for the production of electricity accounts for almost 50 percent of the solid waste from incoming materials. Natural gas and crude oil extraction with refining/processing are used to create the main input materials used in polyether polyol. The solid wastes created from the extraction and processing of these raw materials create 24 percent of the solid wastes from the cradle-to-incoming materials. Sucrose production accounts for 21 percent of the total solid waste. The propylene plant process wastes make up 3 percent of the solid wastes of the incoming materials.

Solid wastes are shown separated by hazardous and non-hazardous wastes in Table 5. This separation was done only where primary data was collected, or if a secondary data source was clear that the solid waste was of a hazardous nature. The process solid wastes from oil and natural gas were classified as non-hazardous due to exclusions found in resource conservation and recovery act (RCRA) hazardous wastes regulations or other EPA hazardous wastes regulations. No solid wastes were stated as hazardous in the data sources for oil and gas. Only 1.5 percent of the total solid wastes were considered hazardous wastes. Of that percentage, 36 percent comes from the propylene plant and most of the remaining amount coming from the polyether polyol plant.

Table 5 also provides a breakout of the total solid wastes by the disposal fate. Of the total hazardous waste, approximately one-third (36 percent) is incinerated without energy capture and most of the remaining two-third is sent to waste-to-energy, with less than 1 percent going to landfill. Focusing specifically on the non-hazardous solid waste produced, 98 percent of the non-hazardous solid waste is landfilled, while most of the remainder is incinerated without energy capture.

Table 5. Total Solid Wastes for Polyether Polyol for Rigid Foam Polyurethanes

	Basis: 1,000 pounds								
		Hazardous Wastes				Non-Hazardous Wastes			
	Total Solid Waste	Waste-to-Energy	Incineration	Landfill	Hazardous Waste Total	Waste-to-Energy	Incineration	Landfill	Non-Hazardous Waste Total
	lb	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*	*lb*
Cradle-to-Incoming Materials	135	0	0.79	0.0021	0.79	3.5E-04	3.39	131	134
Rigid Polyol Production	11.1	1.40	0.00	0.00	1.40	0.00	0.00	9.69	9.69
Total	**146**	**1.40**	**0.79**	**0.0021**	**2.19**	**3.5E-04**	**3.39**	**141**	**144**
	Basis: 1,000 kilograms								
		Hazardous Wastes				**Non-Hazardous Wastes**			
	Total Solid Waste	**Waste-to-Energy**	**Incineration**	**Landfill**	**Hazardous Waste Total**	**Waste-to-Energy**	**Incineration**	**Landfill**	**Non-Hazardous Waste Total**
	kg	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*
Cradle-to-Incoming Materials	135	0	0.79	0.0021	0.79	3.5E-04	3.39	131	134
Rigid Polyol Production	11.1	1.40	0.00	0.00	1.40	0.00	0.00	9.69	9.69
Total	**146**	**1.40**	**0.79**	**0.0021**	**2.19**	**3.5E-04**	**3.39**	**141**	**144**
	Percentage of Total								
		Hazardous Wastes				**Non-Hazardous Wastes**			
	Total Solid Waste	**Waste-to-Energy**	**Incineration**	**Landfill**	**Hazardous Waste Total**	**Waste-to-Energy**	**Incineration**	**Landfill**	**Non-Hazardous Waste Total**
	%	*%*	*%*	*%*	*%*	*%*	*%*	*%*	*%*
Cradle-to-Incoming Materials	92%	0%	0.5%	0.0%	0.5%	0.0%	2.3%	90%	92%
Rigid Polyol Production	8%	1.0%	0.0%	0.0%	1.0%	0.0%	0.0%	6.6%	6.6%
Total	**100%**	**1.0%**	**0.5%**	**0.0%**	**1.5%**	**0.0%**	**2.3%**	**96%**	**99%**

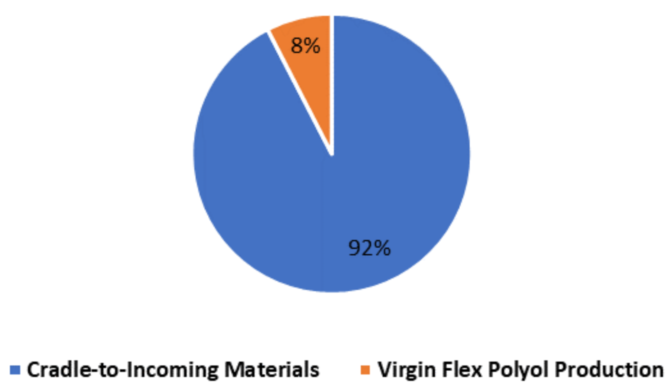

Figure 5. Percentage of Total Solid Wastes for Polyether Polyol for Rigid Foam Polyurethanes System

WATER CONSUMPTION

Consumptive use of water in this study includes freshwater that is withdrawn from a water source or watershed and not returned to that source. Consumptive water use includes water consumed in chemical reactions, water that is incorporated into a product or waste stream, water that becomes evaporative loss, and water that is discharged to a different watershed or water body than the one from which it was withdrawn. Water consumption results shown for each life cycle stage include process water consumption as well as water consumption associated with production of the electricity and fuels used in that stage. Electricity-related water consumption includes evaporative losses associated with thermal generation of electricity from fossil and nuclear fuels, as well as evaporative losses due to establishment of dams for hydropower. Water consumption attributed to hydropower generation does not include burdens for run-of-the-river hydroelectric plants. Run-of-the-river facilities produce power with no artificial reservoir and thus exhibit no water consumption burden.

Water consumption results for polyether polyol production are shown in Table 6 and Figure 6. The greatest portion of consumption of water within the polyether polyol comes from the cradle-to-incoming materials (99 percent). When looking at the individual unit processes, more than 60 percent of the total water consumption is required for the sugar cane cultivation used to make sucrose. The brine required for chlor-alkali and one of the propylene oxide technologies consumes 19 percent of the total water. Another large contributor for water consumption is the electricity used during all processes mostly due to evaporative losses in the use of hydropower, which makes up more than 11 percent of the total water consumption. The primary water consumption data for propylene, which consumes 5 percent of the total, does include some plants that release water to a different watershed than the initial water source, which is considered consumption in the methodology used. The polyether polyol average data also includes some plants that release water to a different watershed. The polyether polyol water consumption at the plant makes up less than one tenth of a percent of the total. Much of the water consumption for the polyether polyol production (1% of the total) comes from the electricity use or production of other fuels used at the plant.

Table 6. Water Consumption for Polyether Polyol for Rigid Foam Polyurethanes

	Total Water Consumption		
	Basis: 1,000 Pounds	**Basis: 1,000 kilograms**	**Percentage of Total**
	Gallons	***Liters***	***%***
Cradle-to-Incoming Materials	4,982	41,575	99%
Rigid Polyol Production	73.1	610	1%
Total	**5,055**	**42,184**	**100%**

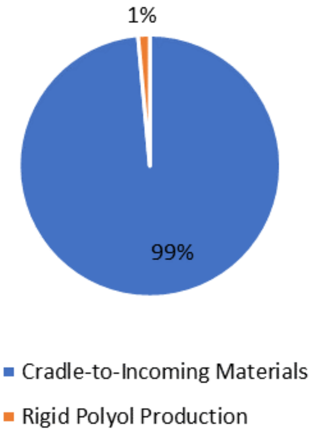

Figure 6. Water Consumption for Polyether Polyol for Rigid Foam Polyurethanes

GLOBAL WARMING POTENTIAL

The primary atmospheric emissions reported in this analysis that contribute over 99 percent of the total global warming potential for each system are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Other contributors include some hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs), but these contribute less than 0.01 percent of the total shown. Greenhouse gas emissions are mainly from combustion. In the primary data collected for propylene, chlor-alkali, and polyether polyol, combustion emissions from flare have been included as process emissions and so their totals may be overstated by small amounts due to the inclusion of combustion of fuel used during the flare. Data providers were asked to estimate percentages of greenhouse gases from flares or emission control processes apart from that of the combustion of fuels.

The 100-year global warming potential (GWP) factors for each of these substances as reported in the Intergovernmental Panel on Climate Change (IPCC) 2013[19] are: fossil carbon dioxide 1, fossil methane 28, and nitrous oxide 265. The GWP factor for a substance represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. The weights of each greenhouse gas are multiplied by its GWP factor to arrive at the total GWP results. Although normally GWP results are closely related to the energy results, the feedstock energy is not associated with GWP because feedstock energy is embodied in the resin material, not energy from combustion of the fuel. GWP factors from IPCC's Fifth Assessment Report are used due to it being the current report available at the time of project initiation, and it's consistency with the previously published reports for the current update of plastic resins and polyurethane precursors. No soil carbon sequestration is included in the GWP methodology used for this analysis.

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[19] IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

In Table 7 and Figure 7, the life cycle GWP results for the polyether polyol system are displayed. Of the total, 93 percent of the GWP are attributed to emissions associated with production of the incoming materials, including the system processes for each incoming material (propylene oxide, sucrose, and glycerine) with the remaining associated with the production of the polyether polyol. Approximately 90 percent of this total for the incoming materials is associated with the cradle-to-propylene oxide material, which accounts for 76 percent of the inputs by weight.

For the polyether polyol unit process, only 7 percent of the total GWP from greenhouse gases are released from the polyol unit process. The process greenhouse gases released on-site at the polyether polyol plants comprise 9 percent of the polyol unit process GWP; this is due to the thermal oxidizer, which is considered a mix of process and fuel-based emissions. The larger amounts of GWP from the polyether polyol plants are from either natural gas combustion (16 percent of the polyether polyol amount) or electricity (67 percent of the polyether polyol amount). While the remaining 7 percent of the polyether polyol GWP comes from fuel combustion for incoming transport of materials.

Table 7. Global Warming Potential for Polyether Polyol for Rigid Foam Polyurethanes

	Global Warming Potential		
	Basis: 1,000 Pounds	Basis: 1,000 kilograms	Percentage of Total
	lb CO2 eq	*kg CO2 eq*	*%*
Cradle-to-Incoming Materials	2,743	2,743	93%
Rigid Polyol Production	194	194	7%
Total	**2,937**	**2,937**	**100%**

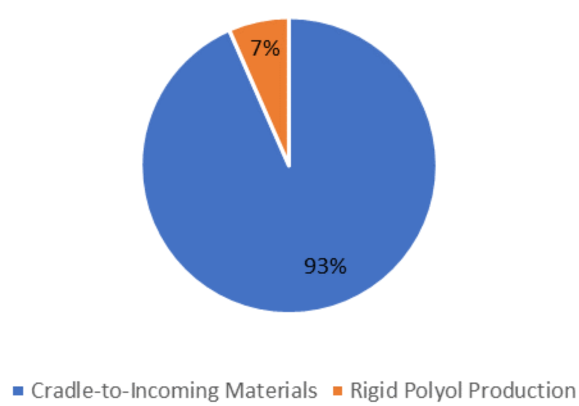

Figure 7. Global Warming Potential for Polyether Polyol for Rigid Foam Polyurethanes

Figure 8 displays the cradle-to-gate polyether polyol GWP separated by process contribution. This figure illustrates the percentages of GWP specific to process emissions at individual unit processes (e.g., propylene production), as well as to fuel-related emissions from the combustion of fuels and fuel combustion for transportation. Only processes creating at least one percent of the total GWP have been shown individually; all processes contributing less than one percent have been grouped into "all other processes."

The largest amount of the GWP is created by the combustion of natural gas in both industrial and utility boilers, which accounts for 43 percent of the total GWP. The steam cracking producing propylene, combustion of coal in utility boilers, and natural gas extraction, processing, and transport each produce approximately 14 percent of the GWP. A little more than 2 percent of the GWP total comes from oil extraction, while palm oil extraction and refining makes up 5 percent of the total. All other processes are less than 1 percent for any individual process and comprises more than 7 percent of the total GWP. The "all other processes" category includes the process greenhouse gases released at the polyether polyol plants, which account for only 0.6 percent of the total; this is due to flaring or emission control processes, which is considered a mix of process and fuel-based emissions.

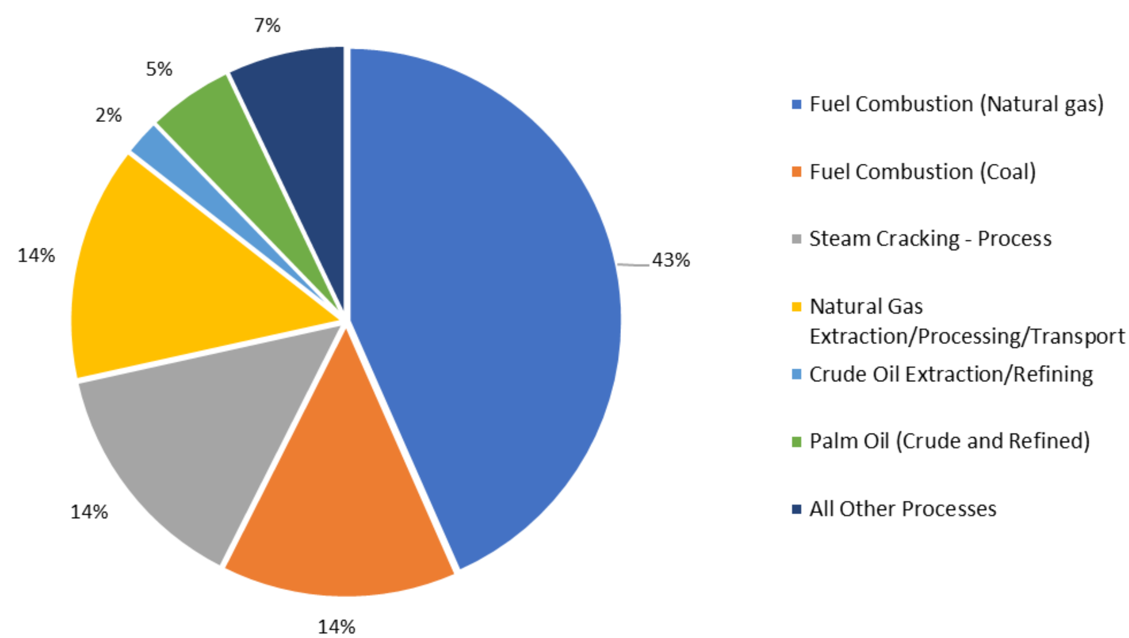

Figure 8. Global Warming Potential by Process Contribution

ACIDIFICATION POTENTIAL

Acidification assesses the potential of emissions to contribute to the formation and deposit of acid rain on soil and water, which can cause serious harm to plant and animal life as well as damage to infrastructure. Acidification potential modeling in TRACI incorporates the results of an atmospheric chemistry and transport model, developed by the U.S. National Acid Precipitation Assessment Program (NAPAP), to estimate total North American terrestrial deposition due to atmospheric emissions of NO_x and SO_2, as a function of the emissions location.[20,21]

Acidification potential (AP) impacts are typically dominated by fossil fuel combustion emissions or emissions from the extraction and processing of natural gas and oil, which release sulfur dioxide (SO_2) and nitrogen oxides (NO_x). The combustion emissions of all fuels make up almost half of the total AP throughout the cradle-to-gate production of polyether polyols with coal combustion in utility boilers comprising 40 percent of the total AP. The natural gas extraction and processing emissions contributed 34 percent of the total AP.

Table 8 shows total acidification potential results for the polyether polyol system. Results are shown graphically in Figure 9. In the AP category, only 8 percent of the AP is coming from polyether polyol production, while the remaining 92 percent comes from the raw and intermediate material unit processes. Process emissions from the polyether polyol plant produce 3.5 percent of the gate-to-gate polyether polyol AP amount. Of the rest of the gate-to-gate polyether polyol production, about 77 percent comes from electricity (combustion of coal and natural gas), 10 percent from the combustion of natural gas onsite, and 9 percent is produced by incoming transport.

Of the 92 percent of the AP category created by incoming materials, 80 percent of the total AP is created during the production of propylene oxide, which makes up 76 percent of the inputs by mass and includes all of the natural gas extraction/processing/transport amount stated previously. Glycerine and sucrose contribute 7 and 6 percent of the AP total, respectively.

Table 8. Acidification Potential for Polyether Polyol for Rigid Foam Polyurethanes

	Acidification Potential		
	Basis: 1,000 Pounds	**Basis: 1,000 kilograms**	**Percentage of Total**
	lb SO2 eq	***kg SO2 eq***	***%***
Cradle-to-Incoming Materials	8.37	8.37	92%
Rigid Polyol Production	0.69	0.69	8%
Total	**9.06**	**9.06**	**100%**

20 Bare JC, Norris GA, Pennington DW, McKone T. (2003). TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, *Journal of Industrial Ecology,* **6**(3–4): 49–78. Available at URL: http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf.

21 Bare JC. (2002). Developing a consistent decision-making framework by using the US EPA's TRACI, AICHE. Available at URL: http://www.epa.gov/nrmrl/std/sab/traci/aiche2002paper.pdf.

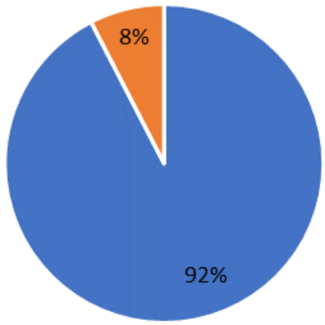

Figure 9. Acidification Potential for Polyether Polyol for Rigid Foam Polyurethanes

EUTROPHICATION POTENTIAL

Eutrophication occurs when excess nutrients (nitrates, phosphates) are introduced to surface water causing the rapid growth of aquatic plants. Excess releases of these substances may provide undesired effects on the waterways.[22] The TRACI characterization factors for eutrophication are the product of a nutrient factor and a transport factor.[23] The nutrient factor is based on the amount of plant growth caused by each pollutant, while the transport factor accounts for the probability that the pollutant will reach a body of water. Atmospheric emissions of nitrogen oxides (NO_x) as well as waterborne emissions of nitrogen, phosphorus, ammonia, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) are the main contributors to eutrophication impacts.

The greatest portion of the EP amount, over three-quarters, is attributed to farming of sugarcane and palm kernels. Irrigation is used in these farms which include fertilizer applications. Eutrophication potential (EP) results for polyether polyol are shown in Table 9 and illustrated in Figure 10. The production of the raw and intermediate materials used to create polyether polyol contributes 98 percent of the EP results, with 78 percent of the total coming from the farms in the glycerine system and sucrose system. The emissions coming from the cradle-to-gate propylene oxide system comprise 18 percent of the EP impact results. The extraction and processing of natural gas for the materials and fuels used throughout the cradle-to-gate polyether polyol system comprises over 8 percent of the total EP amount.

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22 Bare, J. C. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), Version 2.1 - User's Manual; EPA/600/R-12/554 2012.

23 Bare JC, Norris GA, Pennington DW, McKone T. (2003). TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, *Journal of Industrial Ecology,* **6**(3–4): 49–78. Available at URL: http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf.

Table 9. Eutrophication Potential for Polyether Polyol for Rigid Foam Polyurethanes

	Eutrophication Potential		
	Basis: 1,000 Pounds	Basis: 1,000 kilograms	Percentage of Total
	lb N eq	*kg N eq*	*%*
Cradle-to-Incoming Materials	1.64	1.64	98%
Rigid Polyol Production	0.032	0.032	2%
Total	**1.68**	**1.68**	**100%**

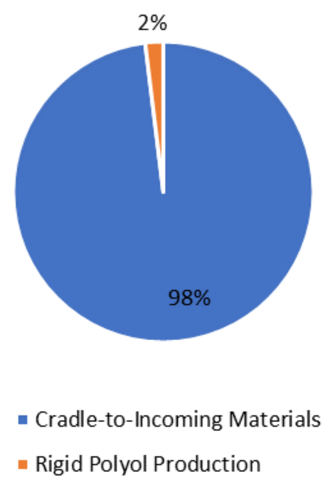


Figure 10. Eutrophication Potential for Polyether Polyol for Rigid Foam Polyurethanes

The gate-to-gate polyether polyol production generates 2 percent of the EP impact as seen in Table 9, with a little less than half of that amount released at the plant site. The emissions released include BOD and COD waterborne emissions, which are normally released from plants with wastewater. Waterborne releases are not always available from plants when the water released is sent to an offsite wastewater treatment plant. The emissions are modeled based on reported amounts in wastewater going to treatment and adjusted for wastewater treatment removal efficiencies (98% removal for BOD and 95% removal for COD). The remaining half of the EP impact for the gate-to-gate polyether polyol comes from emissions released during the creation of electricity and during the combustion of transportation fuels.

OZONE DEPLETION POTENTIAL

Stratospheric ozone depletion potential (ODP) is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substance (e.g., CFCs and halons). The ozone depletion impact category characterizes the potential to destroy ozone based on a chemical's reactivity and lifetime. Effects related to ozone depletion can include skin cancer, cataracts, material damage, immune system suppression, crop damage, and other plant and animal effects. For the polyether polyol system, the main sources of emissions contributing to ODP are minute amounts of a few CFCs, HCFCs, and halons emitted. Some are emitted during the extraction and refining of petroleum, which is used as fuel and material in the production of propylene, and some are associated with refrigerant leaks.

The greatest portion of the ODP amount, 57 percent, is attributed to HCFC (R-22) fugitive emissions at the polyether polyol plant. Table 10 shows total ODP results for the polyether polyol system, which are also shown graphically in Figure 11. The ODP amount shown in the cradle-to-incoming materials, 43 percent of the total ODP, with emissions from crude oil extraction and refining accounting for 30 percent of the total ODP. Much of the remaining ODP for those incoming materials are attributed to the production of the chlor-alkali required during the production of propylene oxide.

Ozone depletion results for the polyether polyol unit process are dominated by a small amount of refrigerant reported by less than 3 plants. This means there is a probability that this amount may be overstated or understated for any specific plant. Discussions with the plants revealed that refrigerant leaks do happen occasionally but are not common on a regular annual basis.

Table 10. Ozone Depletion Potential for Polyether Polyol for Rigid Foam Polyurethanes

	Ozone Depletion Potential		
	Basis: 1,000 Pounds	Basis: 1,000 kilograms	Percentage of Total
	lb CFC-11 eq	*kg CFC-11 eq*	*%*
Cradle-to-Incoming Materials	2.0E-06	2.0E-06	43%
Rigid Polyol Production	2.6E-06	2.6E-06	57%
Total	**4.7E-06**	**4.7E-06**	**100%**

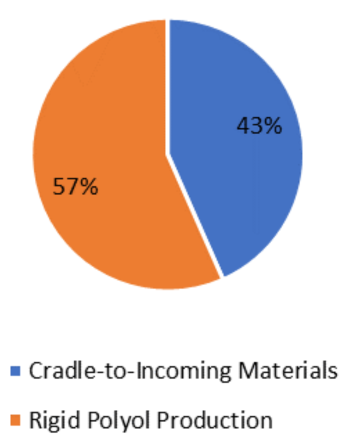


Figure 11. Ozone Depletion Potential for Polyether Polyol for Rigid Foam Polyurethanes

PHOTOCHEMICAL SMOG FORMATION

The photochemical ozone creation potential (POCP) impact category, also referred to as smog formation potential, characterizes the potential of airborne emissions to cause photochemical smog. The creation of photochemical smog occurs when sunlight reacts with NO_x and volatile organic compounds (VOCs), resulting in tropospheric (ground-level) ozone and particulate matter. Endpoint effects of such smog creation can include increased human mortality, asthma, and deleterious effects on plant growth.[24] Smog formation impact are generally dominated by emissions associated with fuel combustion, so that impacts are higher for life cycle stages and components that have higher process fuel and transportation fuel requirements. For cradle-to-resin production of polyether polyol, NO_x makes up 90 percent of the smog formation emissions, with VOCs consisting of almost 9 percent.

Smog formation potential results for polyether polyol are displayed in Table 11 and illustrated in Figure 12. Approximately 94 percent of the POCP impact results are associated with production of the raw and intermediate materials. The propylene and propylene oxide plants release 10 percent of the total emissions resulting the POCP. Natural gas and oil extraction and processing comprise half of the total POCP impacts. The combustion of fuels in boilers, equipment, and for transport release emissions that create 36 percent of the POCP total amount.

The remaining 6 percent of the POCP impact is from polyether polyol production. An estimated 0.4 percent of the total emissions resulting in the POCP impact results are released at the polyether polyol plant as process emissions. Of the remaining percentage in the polyether polyol unit process, 58 percent of the POCP comes from generation of electricity used at the plant, with the remainder coming equally from natural gas use at the plant and from the fuels used to transport incoming materials.

Table 11. Photochemical Smog Formation Potential for Polyether Polyol for Rigid Foam Polyurethanes

	Photochemical Smog Potential		
	Basis: 1,000 Pounds	Basis: 1,000 kilograms	Percentage of Total
	lb O3 eq	*kg O3 eq*	*%*
Cradle-to-Incoming Materials	176	176	94%
Rigid Polyol Production	11.8	11.8	6%
Total	**188**	**188**	**100%**

24 Bare, J. C. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), Version 2.1 - User's Manual; EPA/600/R-12/554 2012.

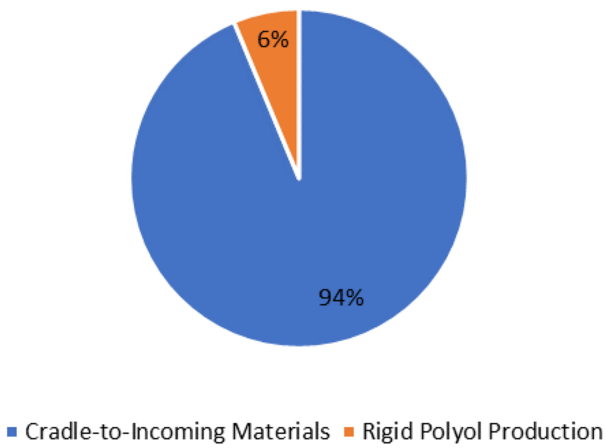


Figure 12. Photochemical Smog Formation Potential for Polyether Polyol for Rigid Foam Polyurethanes

COMPARISON OF 2022 AND 2011 LCI AND LCIA POLYETHER POLYOL FOR RIGID FOAM POLYURETHANE RESULTS

This section provides a comparison of life cycle inventory and impact assessment category results that were included in the original polyether polyol for rigid foam polyurethane system[25] with the current update. These categories include total energy, non-renewable energy, renewable energy, total solid waste, and global warming potential. No comparisons are available for water consumption, solid waste broken out as hazardous and non-hazardous categories, acidification potential, eutrophication potential, photochemical smog formation, or ozone depletion potential. These categories were not included in the original study.

Table 12 shows the comparable LCI and LCIA categories for the 2011 and 2022 polyether polyol results in both English and SI units and includes the percent change for each category. Percent change between systems is defined as the difference between the 2022 and 2011 totals divided by the 2011 total. The results in Table 12 show a decrease in all category totals. Comparisons of these results have been analyzed in this section focusing on the main differences causing the change in each category. It should be noted that all figures in this section provide the percent change above the comparable bars.

In order to compare results between the 2011 study and those of the current update, it should be noted that the sucrose system results were added to the 2022 polyether polyol unit process results. Therefore, results for the rigid polyol plant in the Results section of this report will not be consistent with the results displayed in the figures presented in this comparison section of the report. This 2022 sucrose addition allowed for comparable system boundaries. In the 2011 study, the confidential cradle-to-gate sucrose was aggregated with the confidential polyol unit process in order to keep the confidentiality of each primary dataset. However, in the 2022 analysis, secondary data was used for the sugarcane growing and harvesting and sucrose manufacture. This data changed due to the polyol manufacturers providing the sucrose source.

Broadly, differences in the results are due to the use of different or additional companies and manufacturing plants when updating the propylene and chlor-alkali primary data, the change in sources for the sucrose and glycerine inputs, and updated material input data for the polyether polyol plants. The polyol plant average input material data did vary from the 2011 average; however due to confidentiality issues, details are not provided. Also in the polyol plant update, the energy amount did decrease overall and amounts of greenhouse gas emissions released did change. The chlor-alkali input amounts were small, but it should be noted that the allocation methodology at these plants were changed from the 2011 method. The amalgamation of all these changes lead to differences affecting the results.

For propylene, some of the same plants provided data; however, some of the plants in the current average were not included in the original data collection in 2004-2006. Additional

[25] American Chemistry Council, Plastics Division, Cradle-to-Gate Life Cycle Inventory of Nine Plastic Resins and Four Polyurethane Precursors. Prepared by Franklin Associates, A Division of ERG. August, 2011.

plants participated in the data collection for this update for propylene. Also, the number of companies participating in this update for the polyether polyol decreased from 5 to 4, but all four plants provided data in the original and current average. One of the plants included in the original data collection was also included in this data collection albeit as property of a different company and one of the plants from the initial average was closed. The data from all four plants were similar to their original data. The recent collected data included a lower energy amount, which leads to a lower GWP amount.

Table 12. Comparison of 2011 and 2022 LCI and LCIA Results for Polyether Polyol for Rigid Foam Polyurethanes

	1000 pounds of Polyether Polyol for Rigid Foam Polyurethane				
	LCI Results				***LCIA Results***
	Total Energy	**Non-Renewable Energy**	**Renewable Energy**	**Total Solid Waste***	**Global Warming**
	MM Btu	***MM Btu***	***MM Btu***	***lb***	***lb CO_2 eq***
Rigid Polyol 2022	32.1	31.8	0.30	147	2,937
Rigid Polyol 2011	35.7	35.3	0.36	184	3,718
	1000 kilograms of Polyether Polyol for Rigid Foam Polyurethane				
	LCI Results				***LCIA Results***
	Total Energy	**Non-Renewable Energy**	**Renewable Energy**	**Total Solid Waste***	**Global Warming**
	GJ	***GJ***	***GJ***	***kg***	***kg CO_2 eq***
Rigid Polyol 2022	74.6	73.9	0.70	147	2,937
Rigid Polyol 2011	83.1	82.2	0.84	184	3,718
Percent Change	10%	10%	16%	23%	23%

*Total Solid Waste excludes hazardous solid waste for 2022 as this category was not included as Solid Waste in 2011.

ENERGY COMPARISON

Overall, the total energy for polyether polyol has decreased 8.5 GJ on a 1,000 kg basis (3.6 million (MM)Btu/1,000 lb). There is a 10 percent decrease in total energy as compared to the original study's results. When comparing the polyether polyol unit process average energy data, data from the plants that were collected for both studies had small changes with the electricity amounts changing by very little. The natural gas used onsite in boilers decreased, which possibly is due to the use of byproducts onsite from other processes available as fuels at the plants. The inclusion of sucrose accounts for a portion of the drop in energy shown for the rigid polyol. The sucrose source, which is included in the original 2011 rigid polyol unit process and so added to the 2022 rigid polyol results shown, has changed from beet sugar to sugarcane and so the source data changed as well. Much of the energy to create sucrose uses the waste from the sugarcane as a fuel source. Figure 13 provides a graphical perspective of the unit processes associated with this energy decrease from the original energy amounts.

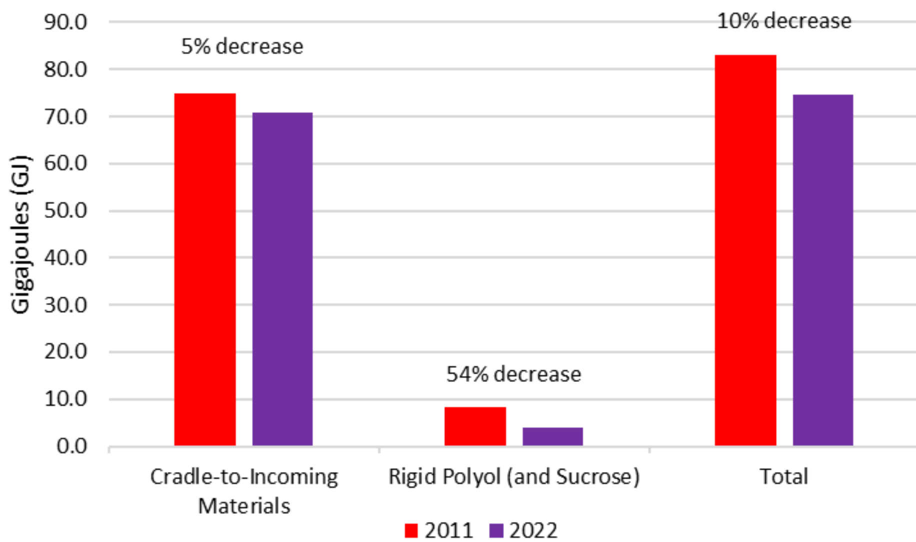


Figure 13. Change in Energy by Stage per 1,000 kg (GJ)

The energy of material resource, which pertains to the amount of inherent energy from the raw materials increased by a small amount for polyether polyol due to the changes in the amount of raw material inputs on compared to the data in the 2011 report. As the amount of material resource energy increased, but the total energy still decreased, it can be concluded that the difference in process energy decreased by a greater percentage than the 10 percent shown in the total. The previous propylene oxide data was reviewed and the weightings of technologies changed and the fuel types were updated to the common use of natural gas instead of a mix of natural gas and oil-based fuels, which likely decreased the propylene oxide unit process. However, much of this decrease is due to the energy decreases in the energy requirements for the propylene plants, as well as the oil and natural gas extraction and processing/refining.

The percent difference in renewable energy decreased about 16 percent from the original results. Although this seems quite large, the renewable energy makes up less than one percent of the total energy. Almost all of the renewable energy comes from the production of electricity. The U.S. average electricity grid was used for both the original study and the current update. Of the 2006 electricity grid, approximately 8 percent was created by renewable energy, whereas this renewable energy percentage has almost doubled in 2015 to 15.7 percent. Even though renewable source use has increased in the U.S. average electricity grid, the use of electricity in many of the raw material and intermediate processes required to manufacture polyether polyol has decreased. This decrease in the use of renewable energy is mainly due to decreases in the use of electricity (hydropower and other renewable resources for energy) within all processes required to manufacture polyether polyol.

SOLID WASTE COMPARISON

When compared to the 2011 polyether polyol total solid waste amount, the current polyether polyol study shows 37 kg per 1000 kg polyether polyol less solid waste, which is a 23 percent decrease from the original study. Almost 50 percent of the current solid waste amount is due to coal production and combustion from electricity. As the amount of coal used in the electricity grid mix is less than in the previous electricity grid used, plus the amount of electricity use has decreased, it can be concluded that much of this solid waste decrease is due to those decreases. Figure 14 provides a visual of the total solid waste amount split out by the polyether polyol unit process (including the sucrose system) and cradle-to-incoming materials. A large decrease occurs for the cradle-to-incoming materials, and a sizable increase is shown for the polyether polyol plant. It should be noted that the solid waste of the plant average was actually almost equivalent to the previous amount, but the change in source to sugarcane from beet sugar increased the solid waste amount. The total solid waste is overwhelmed by the decrease in fuel-related solid wastes throughout the cradle-to-gate production. The decrease in cradle-to-incoming materials is a mix of lower amounts of solid waste at the plants, as well as an overall decrease in the electricity use of the propylene plant and other unit processes. The electricity grid for the 2011 analysis used a much higher amount of coal than the electricity grid average for the 2022 analysis, which produces large amounts of ash as combusted. Process solid wastes from the natural gas and crude oil production also decreased by small amounts.

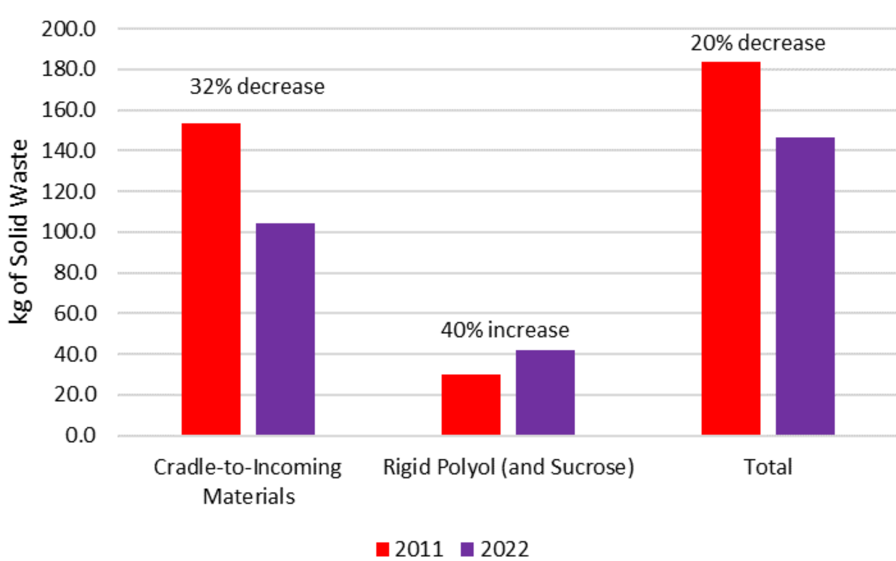


Figure 14. Change in Solid Waste Weight by Unit Process (kg Per 1,000 kg)

GLOBAL WARMING POTENTIAL COMPARISON

The total global warming potential decreased by 781 kg CO_2 equivalents (eq)/1000 kg polyether polyol, which calculates to a 23 percent decrease. Figure 15 displays a column chart with the polyether polyol (including the sucrose system) and cradle-to-incoming materials results that makeup the decrease when comparing the 2011 and 2022 GWP results. This overall decrease follows the trend shown in total energy, since much of the greenhouse gases are created from fuel production. The total energy amount includes the material resource energy, which has no greenhouse gases associated with it as it is not combusted.

The GWP specific to the polyether polyol plant including the sucrose system decreased by 61 percent, while the energy for the plant also decreased. Much of this drop is due to the changes in source of sucrose and the differences in the data used for sugarcane and sucrose. A good portion of the energy used to create sucrose is from the use of byproduct biomass from sugarcane, which releases biogenic instead of fossil carbon dioxide when combusted. The decrease in GWP for the cradle-to-incoming materials comes from decreases in energy use for the raw materials and for the propylene plant. The amount of coal combusted for the US average electricity grid has decreased over time with an increase in natural gas combustion. Coal production and combustion releases higher amounts of greenhouse gases compared to natural gas production and combustion.

It should also be noted that the characterization factors for the GWP have changed since the 2011 report. The methane amount increased from 25 to 28 lb CO_2eq/1 lb methane and the nitrous oxide amount decreased from 298 to 265 lb CO_2eq/1 lb. As the methane and nitrous oxide releases account for less than 10 percent of the GWP characterization, the change in results due to this characterization factor difference is small.

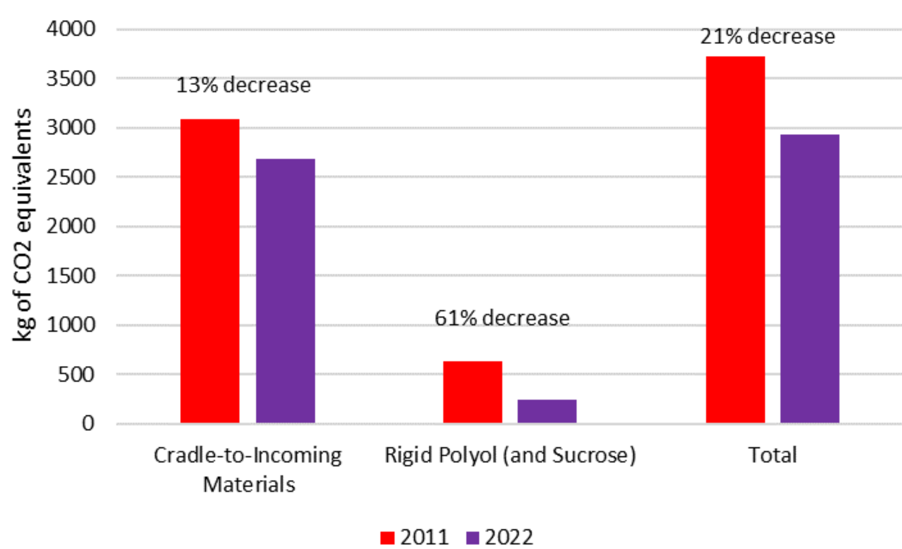


Figure 15. Change in Global Warming Potential by Unit Process (kg of CO2 eq. per 1,000 kg)

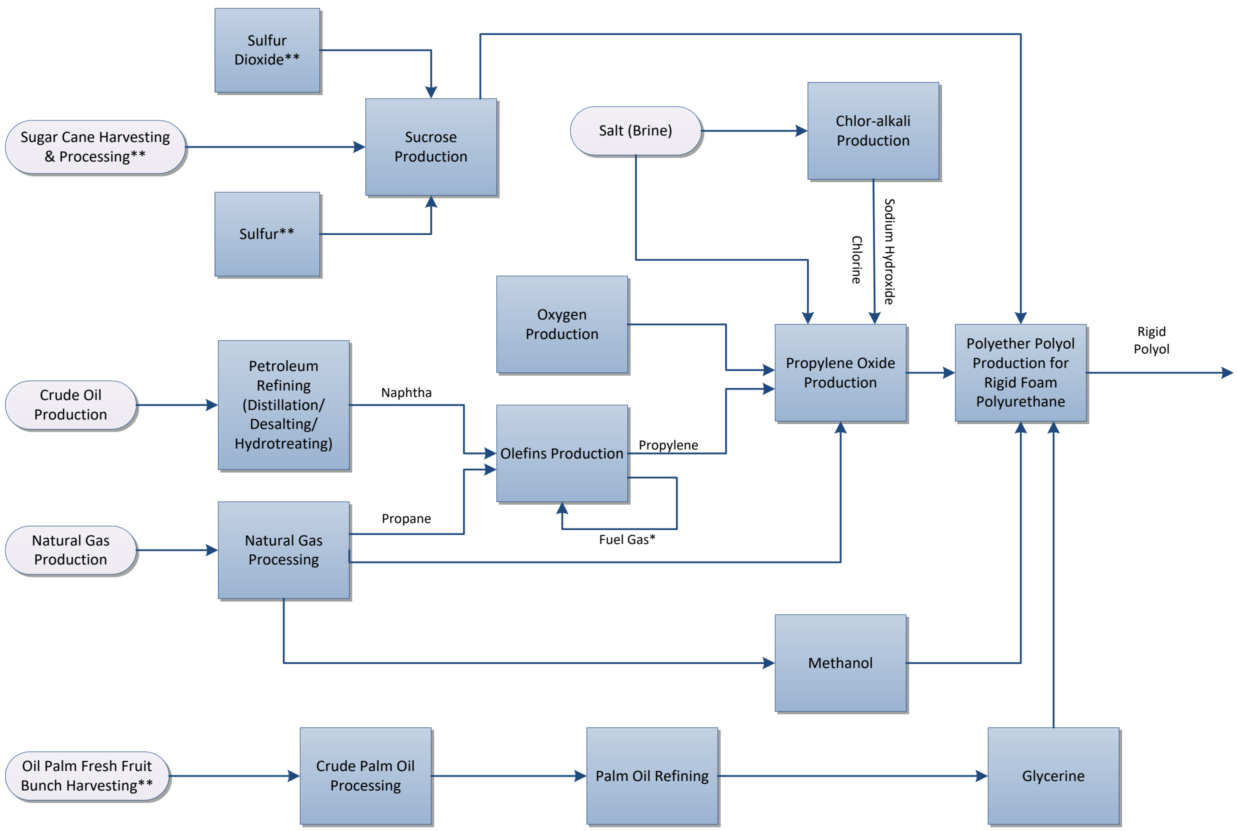
APPENDIX: POLYETHER POLYOL FOR RIGID FOAM POLYURETHANES MANUFACTURE

This appendix discusses the manufacture of polyether polyol for rigid foam polyurethanes. Polyether polyol is used in a variety of end use applications including polyurethane for cushions in furniture and automobiles, mattress pads and carpet pads. The captured polyether polyol production amount is approximately 44 percent of the polyether polyol production in North America in 2015 (ACC, 2016). This percentage was estimated using the amount of polyol used for rigid foam in the end use table in this document. The material flow for polyether polyol (short chain) for rigid foam polyurethane is shown in Figure 16.

Individual unit process tables on the bases of 1,000 pounds and 1,000 kilograms are also shown within this appendix. The following process is included in this appendix:

- Sugarcane cultivation and harvesting
- Sucrose processing
- Polyether polyol for rigid foam polyurethanes production

LCI data for propylene, chlor-alkali process (chlorine and sodium hydroxide), propylene oxide, and polyether polyol production were collected for this update to the U.S. LCI plastics database by member and non-member companies of the American Chemistry Council. Propylene oxide data was not updated from the original 2011 resins report; however, the weighting for the technologies included, as well as the input materials were updated. Updated secondary data was used for crude oil extraction and refining and natural gas production and processing, oil palm fresh fruit cultivation and harvesting, crude palm oil processing, palm oil refining, and glycerine production. Results and LCI data for the production of propylene, oil, and natural gas can be found in the report, ***Cradle-to-Gate Life Cycle Analysis of Olefins*** (Franklin, 2020). LCI data for the production of chlorine and sodium hydroxide are available in the report, ***Cradle-to-Gate Life Cycle Analysis of Polyvinyl Chloride (PVC) Resin*** (Franklin, 2021). LCI data for methanol production, oil palm fresh fruit cultivation and harvesting, crude palm oil processing, glycerine production, and propylene oxide are available in the report, ***Cradle-to-Gate Life Cycle Analysis of Polyether Polyol for Flexible Foam Polyurethanes*** (Franklin, 2022).



* Fuel gas used for energy is created from off-gas produced in the process.
**Some upstream processes such as fertilizers, pesticides, crude oil, and natural gas inputs are not shown.

Figure 16. Flow diagram for the Production of Polyether Polyol for Rigid Foam Polyurethanes.

SUGARCANE CULTIVATION AND HARVESTING

Sugarcane cultivation was modeled based on U.S. conditions using a dataset adapted from Agri-footprint (Blonk Consultants, 2019). This dataset includes electricity and water for irrigation as well as on-farm diesel combustion and incoming agricultural inputs such as starter material, organic and inorganic fertilizers, and pesticides. Atmospheric and waterborne emissions are released from the application and runoff of fertilizers. The dataset was adapted for this report by changing the sugarcane yield to an average of 2019 and 2020 US yields (FAO, 2022) and by changing background datasets such as electricity and transportation to be consistent with other datasets in this report. Infrastructure and land transformation were removed as we assumed that the sugarcane farms have been in operation for more than 20 years thus no land use change needs to be considered.

SUCROSE PRODUCTION

Harvested sugarcane is transported 25 km (approximately 16 miles) from farm to sucrose manufacturing. Sucrose manufacturing is modeled based on U.S. conditions using a dataset adapted from Agri-footprint (Blonk Consultants, 2019) which is based on data from Renouf et al., 2010. Bagasse, a byproduct of sugar production, supplies energy to the sugar cane processing facility, thus no additional feedstocks or incoming electricity are included in the model. Sulfur and sulfur dioxide are used during sugarcane processing. Water is mixed on a 1:1 basis with processed sugar cane to produce liquid sucrose. Liquid sucrose and molasses are coproducts of this system so flows are allocated on a mass basis, 85% of which is allocated to liquid sucrose. No soil carbon sequestration is included in the GWP methodology used for this analysis.

POLYETHER POLYOL FOR RIGID FOAM POLYURETHANES PRODUCTION

The technology used to manufacture the polyether polyol used in rigid foam polyurethane production begins with the introduction of a potassium hydroxide catalyst to an initiator. In this analysis, sucrose was chosen as the initiator; however, glycerine and sorbitol are also common initiators used to produce polyether polyols for rigid foam polyurethane. This solution is then reacted with propylene oxide to form an intermediate. The catalyst is removed using an acid, which produces a salt that must be filtered. This acid amount is small and considered negligible in this analysis. Finally, the polyol is purified of side products and water through distillation. No coproducts are produced within polyether polyol manufacture. (Arniza et al., 2015; Paciorek-Sadowska and Czupryński, 2006; Suleman et al., 2014)

Primary data submitted for polyether polyol represent the years 2015 or 2017. For the polyether polyol primary data, companies were requested to provide data for the year 2015, the most recent full year of polyether polyol production prior to the project initiation date. Companies providing data were given the option to collect data from the year preceding or following 2015 if either year would reflect more typical production conditions. One plant provided data for the year 2015, and one plant provided data for the year 2017, which was considered an average year for that company. After reviewing individual company data in comparison to the average, each manufacturer verified their data from 2015 or 2017 was representative of an average year for polyether polyol production at their company. The geographic scope of the analysis is the manufacture of polyether polyol in North America. Polyether polyol data were collected from plants all located in the United States.

Due to having fewer than three polyether polyol producers, this confidential data is unavailable for inclusion in the appendix as a unit process; however, the materials, energy requirements and environmental emissions for the production of polyether polyol for rigid foam polyurethanes are provided as a system process (cradle-to-polyether polyol) in Table 13. Due to the use of European databases for some unit processes, which sometimes include infrastructure or have no cutoff, *inputs to nature* that are less than 1E-8 are not shown in Table 13. However, all *emissions* have been included to assure their capture for any impact categories chosen.

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes

	1,000 lb	1,000 kg
Material Inputs/Energy Inputs		
Air	2.02E+01 lb	2.02E+01 kg
Aluminium	5.29E-06 lb	5.29E-06 kg
Barite	1.11E-02 lb	1.11E-02 kg
Basalt	1.27E-03 lb	1.27E-03 kg
Bauxite	1.91E-05 lb	1.91E-05 kg
Calcite	2.17E-06 lb	2.17E-06 kg
Calcium carbonate	5.92E+00 lb	5.92E+00 kg
Carbon dioxide, in air	3.60E-02 lb	3.60E-02 kg
Chromium	4.64E-06 lb	4.64E-06 kg
Clay	2.50E-01 lb	2.50E-01 kg
Clay, unspecified	2.50E-01 lb	2.50E-01 kg
Coal, 29.3 MJ per kg	2.32E-02 lb	2.32E-02 kg
Coal, brown	6.00E-05 lb	6.00E-05 kg
Coal, hard	3.37E-05 lb	3.37E-05 kg
Colemanite	1.05E-06 lb	1.05E-06 kg
Copper	8.62E-06 lb	8.62E-06 kg
Corn seed	8.89E-04 lb	8.89E-04 kg
Dolomite	1.08E-05 lb	1.08E-05 kg
Energy, from biomass	3.52E+01 Th Btu	8.18E+01 MJ
Energy, from coal	1.93E+00 Th Btu	4.48E+00 MJ
Energy, from coal, brown	1.19E+00 Th Btu	2.76E+00 MJ
Energy, from gas, natural	4.77E+01 Th Btu	1.11E+02 MJ
Energy, from hydro power	1.35E+02 Th Btu	3.15E+02 MJ
Energy, from oil	4.05E+01 Th Btu	9.43E+01 MJ
Energy, from oil sand (10% bitumen)	1.93E-05 Th Btu	4.49E-05 MJ
Energy, from oil sand (100% bitumen)	1.68E-05 Th Btu	3.92E-05 MJ
Energy, from peat	1.97E-02 Th Btu	4.58E-02 MJ
Energy, from pit methane	2.02E-03 Th Btu	4.70E-03 MJ
Energy, from uranium	4.16E+00 Th Btu	9.68E+00 MJ
Energy, from wood	7.30E-05 Th Btu	1.70E-04 MJ
Energy, geothermal	7.95E+00 Th Btu	1.85E+01 MJ
Energy, kinetic (in wind), converted	1.14E+02 Th Btu	2.66E+02 MJ
Energy, potential (in hydropower reservoir), converted	3.64E-03 Th Btu	8.46E-03 MJ
Energy, recovered	3.57E+01 Th Btu	8.30E+01 MJ
Energy, solar, converted	1.85E+01 Th Btu	4.31E+01 MJ
Energy, unspecified	9.84E+00 Th Btu	2.29E+01 MJ

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Fluorspar	1.20E-06 lb	1.20E-06 kg
Gas, mine, off-gas, process, coal mining/m3	5.26E-06 ft3	3.28E-07 m3
Gas, natural, 48.68 MJ per kg, in ground (EMR)	5.46E+02 lb	5.46E+02 kg
Gas, natural/m3	1.53E+04 ft3	9.54E+02 m3
Gravel	1.98E-05 lb	1.98E-05 kg
Gypsum	2.83E-04 lb	2.83E-04 kg
Iron	1.08E-02 lb	1.08E-02 kg
Iron ore	4.05E-08 lb	4.05E-08 kg
Kaolin ore	1.88E-06 lb	1.88E-06 kg
Lead	1.10E-04 lb	1.10E-04 kg
Limestone	5.58E-03 lb	5.58E-03 kg
Magnesite	1.04E-08 lb	1.04E-08 kg
Magnesium chloride	1.43E-03 lb	1.43E-03 kg
Manganese	3.06E-05 lb	3.06E-05 kg
Natural aggregate	4.43E-01 lb	4.43E-01 kg
Nickel	1.99E-06 lb	1.99E-06 kg
Nitrogen	7.43E-01 lb	7.43E-01 kg
Oil, crude	4.07E+01 lb	4.07E+01 kg
Oil, crude, 43.66 MJ per kg, in ground (EMR)	8.91E+01 lb	8.91E+01 kg
Oxygen	7.76E+01 lb	7.76E+01 kg
Phosphate ore	4.37E-02 lb	4.37E-02 kg
Phosphorus	5.58E-01 lb	5.58E-01 kg
Potassium	5.48E-06 lb	5.48E-06 kg
Potassium chloride	3.43E+00 lb	3.43E+00 kg
Pumice	5.29E-07 lb	5.29E-07 kg
Pyrite	1.05E-06 lb	1.05E-06 kg
Salt, unspecified	3.15E-06 lb	3.15E-06 kg
Sand	3.39E-01 lb	3.39E-01 kg
Shale	1.55E-07 lb	1.55E-07 kg
Sodium chloride	1.78E+03 lb	1.78E+03 kg
Sodium sulfate	1.65E-07 lb	1.65E-07 kg
Stone	8.22E-07 lb	8.22E-07 kg
Sulfur	1.18E-07 lb	1.18E-07 kg
Sulfur dioxide	7.36E-01 lb	7.36E-01 kg
Sylvinite and Brines	2.16E-02 lb	2.16E-02 kg
Talc	2.01E-08 lb	2.01E-08 kg
Tantalum	7.67E-07 lb	7.67E-07 kg
Titanium	4.49E-06 lb	4.49E-06 kg
Trona	1.51E-02 lb	1.51E-02 kg
Unprocessed bituminous coal, in ground	1.98E+02 lb	1.98E+02 kg
Unprocessed lignite	2.55E+01 lb	2.55E+01 kg
Uranium	1.10E-08 lb	1.10E-08 kg
Uranium oxide, 332 GJ per kg, in ore	8.65E-03 lb	8.65E-03 kg
Wood, dry matter	1.77E-05 lb	1.77E-05 kg
Zinc	2.35E-05 lb	2.35E-05 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Environmental Emissions		
Atmospheric Emissions		
1,2,3,4,7,8,9 Heptachlorodibenzofuran	1.71E-13 lb	1.71E-13 kg
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	6.44E-14 lb	6.44E-14 kg
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	4.21E-14 lb	4.21E-14 kg
1,3-Butadiyne	2.12E-07 lb	2.12E-07 kg
1,4-Butanediol	3.45E-17 lb	3.45E-17 kg
1,4-Dioxane	1.46E-08 lb	1.46E-08 kg
1-Butanol	9.73E-08 lb	9.73E-08 kg
1-Butene	2.12E-07 lb	2.12E-07 kg
1-Methyl-2-pyrrolidinone	5.13E-07 lb	5.13E-07 kg
1-Methylnapthalene	2.24E-08 lb	2.24E-08 kg
1-Pentanol	2.60E-18 lb	2.60E-18 kg
1-Pentene	1.76E-07 lb	1.76E-07 kg
1-Propanol	2.61E-17 lb	2.61E-17 kg
2-Aminopropanol	1.55E-19 lb	1.55E-19 kg
2-Butene	2.12E-07 lb	2.12E-07 kg
2-Butene, 2-methyl-	4.35E-22 lb	4.35E-22 kg
2-Chloroacetophenone	3.65E-10 lb	3.65E-10 kg
2-Methyl-1-propanol	8.80E-18 lb	8.80E-18 kg
2-Methyl-4-chlorophenoxyacetic acid	5.14E-05 lb	5.14E-05 kg
2-Nitrobenzoic acid	2.56E-19 lb	2.56E-19 kg
2-Pentene	1.76E-07 lb	1.76E-07 kg
2-Propanol	1.19E-10 lb	1.19E-10 kg
2-Propenal, 2-methyl-	4.33E-08 lb	4.33E-08 kg
3-Methylcholanthrene	1.14E-11 lb	1.14E-11 kg
4,4'-Diisocyanatodiphenylmethane	1.05E-08 lb	1.05E-08 kg
4,4'-Methylenebisbenzeneamine	3.55E-09 lb	3.55E-09 kg
4-Dimethylaminoazobenzene	6.84E-10 lb	6.84E-10 kg
4-Methyl-2-methoxyphenol	4.08E-09 lb	4.08E-09 kg
4-Methyl-2-pentanone	2.66E-05 lb	2.66E-05 kg
5-methyl Chrysene	2.11E-09 lb	2.11E-09 kg
Acenaphthene	5.19E-16 lb	5.19E-16 kg
Acenaphthylene	4.53E-08 lb	4.53E-08 kg
Acetaldehyde	1.01E-10 lb	1.01E-10 kg
Acetic acid	4.60E-10 lb	4.60E-10 kg
Acetone	1.38E-10 lb	1.38E-10 kg
Acetonitrile	9.86E-07 lb	9.86E-07 kg
Acetophenone	8.11E-08 lb	8.11E-08 kg
Acidity, unspecified	6.16E-10 lb	6.16E-10 kg
Acrolein	1.06E-11 lb	1.06E-11 kg
Acrylamide	4.31E-12 lb	4.31E-12 kg
Acrylic acid	5.44E-17 lb	5.44E-17 kg
Acrylonitrile	2.63E-09 lb	2.63E-09 kg
Actinides, radioactive, unspecified	2.88E-18 Cu	2.35E-07 Bq

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Adipate, bis(1-ethylhexyl)-	3.33E-26 lb	3.33E-26 kg
Aerosols, radioactive, unspecified	3.19E-17 Cu	2.60E-06 Bq
Alachlor	6.83E-19 lb	6.83E-19 kg
Aldehydes, unspecified	1.38E-03 lb	1.38E-03 kg
Alkanes, C10	1.02E-05 lb	1.02E-05 kg
Alkenes, C7	6.71E-07 lb	6.71E-07 kg
alpha-Pinene	9.62E-24 lb	9.62E-24 kg
Aluminium	5.90E-08 lb	5.90E-08 kg
Americium-241	1.63E-23 Cu	1.33E-12 Bq
Ammonia	2.48E-01 lb	2.48E-01 kg
Ammonium carbonate	1.66E-14 lb	1.66E-14 kg
Ammonium chloride	4.59E-04 lb	4.59E-04 kg
Ammonium, ion	7.09E-11 lb	7.09E-11 kg
Aniline	1.21E-07 lb	1.21E-07 kg
Anthracene	3.10E-08 lb	3.10E-08 kg
Anthranilic acid	1.88E-19 lb	1.88E-19 kg
Antimony	2.62E-06 lb	2.62E-06 kg
Antimony-124	3.93E-16 Cu	3.21E-05 Bq
Antimony-125	4.25E-20 Cu	3.47E-09 Bq
AOX, Adsorbable Organic Halogen as Cl	1.44E-11 lb	1.44E-11 kg
Argon	1.40E-07 lb	1.40E-07 kg
Argon-41	5.35E-10 Cu	4.36E+01 Bq
Arsenic	4.28E-05 lb	4.28E-05 kg
Arsenic trioxide	7.56E-13 lb	7.56E-13 kg
Arsenic V	5.76E-09 lb	5.76E-09 kg
Arsenic, ion	2.34E-07 lb	2.34E-07 kg
Arsine	6.27E-11 lb	6.27E-11 kg
Asbestos	9.86E-11 lb	9.86E-11 kg
Atrazine	1.99E-04 lb	1.99E-04 kg
Azadirachtin	2.45E-06 lb	2.45E-06 kg
Azoxystrobin	1.04E-05 lb	1.04E-05 kg
Barium	7.33E-06 lb	7.33E-06 kg
Barium compounds	2.50E-08 lb	2.50E-08 kg
Barium-140	2.76E-18 Cu	2.25E-07 Bq
Bentazone	5.70E-19 lb	5.70E-19 kg
Benz(a)acridine	9.47E-12 lb	9.47E-12 kg
Benzal chloride	2.74E-22 lb	2.74E-22 kg
Benzaldehyde	2.06E-07 lb	2.06E-07 kg
Benzene	3.66E-03 lb	3.66E-03 kg
Benzene, 1,2,3-trimethyl-	4.75E-08 lb	4.75E-08 kg
Benzene, 1,2,4-trichloro-	1.20E-09 lb	1.20E-09 kg
Benzene, 1,2,4-trimethyl-	2.78E-05 lb	2.78E-05 kg
Benzene, 1,2-dichloro-	8.61E-18 lb	8.61E-18 kg
Benzene, 1,3,5-trimethyl-	3.89E-08 lb	3.89E-08 kg
Benzene, 1,4-dichloro-	2.28E-07 lb	2.28E-07 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Benzene, 1-methyl-2-nitro-	2.21E-19 lb	2.21E-19 kg
Benzene, chloro-	1.14E-06 lb	1.14E-06 kg
Benzene, ethyl-	1.06E+00 lb	1.06E+00 kg
Benzene, hexachloro-	1.20E-09 lb	1.20E-09 kg
Benzene, pentachloro-	1.10E-13 lb	1.10E-13 kg
Benzidine	1.28E-08 lb	1.28E-08 kg
Benzidine, 3,3'-dichloro-	1.20E-09 lb	1.20E-09 kg
Benzidine, 3,3'-dimethoxy-	8.29E-09 lb	8.29E-09 kg
Benzidine, 3,3'-dimethyl-	5.79E-09 lb	5.79E-09 kg
Benzo(a)anthracene	3.93E-08 lb	3.93E-08 kg
Benzo(a)pyrene	1.45E-06 lb	1.45E-06 kg
Benzo(b)fluoranthene	2.40E-09 lb	2.40E-09 kg
Benzo(b,j,k)fluoranthene	1.06E-08 lb	1.06E-08 kg
Benzo(e)pyrene	4.19E-10 lb	4.19E-10 kg
Benzo(g,h,i)perylene	4.28E-07 lb	4.28E-07 kg
Benzo(k)fluoranthene	1.43E-09 lb	1.43E-09 kg
Benzofluoranthene	6.71E-10 lb	6.71E-10 kg
Benzyl chloride	3.65E-08 lb	3.65E-08 kg
Beryllium	2.31E-06 lb	2.31E-06 kg
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	3.73E-24 lb	3.73E-24 kg
Bifenthrin	3.52E-05 lb	3.52E-05 kg
Biphenyl	2.64E-06 lb	2.64E-06 kg
Bis(2-chloroethyl)ether	1.20E-09 lb	1.20E-09 kg
Bisphenol A	7.37E-07 lb	7.37E-07 kg
Boron	2.96E-06 lb	2.96E-06 kg
Boron carbide	1.97E-07 lb	1.97E-07 kg
Boron trifluoride	8.69E-24 lb	8.69E-24 kg
Bromide	5.74E-10 lb	5.74E-10 kg
Bromine	1.19E-06 lb	1.19E-06 kg
Bromoform	2.04E-09 lb	2.04E-09 kg
Bromoxynil	7.69E-19 lb	7.69E-19 kg
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspe	1.65E-06 lb	1.65E-06 kg
Butadiene	6.02E-05 lb	6.02E-05 kg
Butadiene, hexachloro-	1.20E-09 lb	1.20E-09 kg
Butane	3.02E-04 lb	3.02E-04 kg
Butane, 1,2-epoxy-	2.24E-08 lb	2.24E-08 kg
Butene	5.89E-09 lb	5.89E-09 kg
Butyl acetate	2.13E-12 lb	2.13E-12 kg
Butyrolactone	3.26E-19 lb	3.26E-19 kg
Cadmium	1.91E-05 lb	1.91E-05 kg
Calcium	6.87E-08 lb	6.87E-08 kg
Caprolactam	4.17E-13 lb	4.17E-13 kg
Captan	6.09E-05 lb	6.09E-05 kg
Carbaryl	1.17E-05 lb	1.17E-05 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Carbon dioxide, biogenic	6.35E-03 lb	6.35E-03 kg
Carbon dioxide, fossil	2.46E+03 lb	2.46E+03 kg
Carbon disulfide	5.35E-06 lb	5.35E-06 kg
Carbon monoxide, biogenic	4.37E+00 lb	4.37E+00 kg
Carbon monoxide, fossil	1.89E+00 lb	1.89E+00 kg
Carbon-14	2.55E-10 Cu	2.08E+01 Bq
Carbonyl sulfide	4.20E-05 lb	4.20E-05 kg
Catechol	1.58E-08 lb	1.58E-08 kg
Cerium-141	6.71E-19 Cu	5.47E-08 Bq
Cerium-144	3.35E-22 Cu	2.73E-11 Bq
Cesium-134	6.58E-14 Cu	5.36E-03 Bq
Cesium-137	1.34E-13 Cu	1.10E-02 Bq
Chloramine	9.41E-18 lb	9.41E-18 kg
Chloridazon	1.42E-04 lb	1.42E-04 kg
Chloride	5.64E-06 lb	5.64E-06 kg
Chlorinated fluorocarbons and hydrochlorinated fluorocarb	2.86E-25 lb	2.86E-25 kg
Chlorine	3.84E-02 lb	3.84E-02 kg
Chloroacetic acid	1.90E-16 lb	1.90E-16 kg
Chloroform	1.61E-06 lb	1.61E-06 kg
Chlorosilane, trimethyl-	7.71E-18 lb	7.71E-18 kg
Chlorosulfonic acid	1.61E-18 lb	1.61E-18 kg
Chlorothalonil	1.02E-04 lb	1.02E-04 kg
Chlorpropham	5.60E-05 lb	5.60E-05 kg
Chlorpyrifos	1.21E-04 lb	1.21E-04 kg
Chromium	4.32E-05 lb	4.32E-05 kg
Chromium III	4.64E-07 lb	4.64E-07 kg
Chromium VI	7.73E-06 lb	7.73E-06 kg
Chromium-51	4.30E-20 Cu	3.51E-09 Bq
Chrysene	2.32E-08 lb	2.32E-08 kg
Clean gas	2.85E-04 lb	2.85E-04 kg
Clomazone	1.31E-19 lb	1.31E-19 kg
Cobalt	1.35E-05 lb	1.35E-05 kg
Cobalt-58	5.70E-16 Cu	4.65E-05 Bq
Cobalt-60	1.08E-14 Cu	8.80E-04 Bq
Copper	3.43E-05 lb	3.43E-05 kg
Copper compounds	1.58E-07 lb	1.58E-07 kg
Cresol	3.29E-06 lb	3.29E-06 kg
Crotonaldehyde	9.08E-08 lb	9.08E-08 kg
Cumene	1.45E-05 lb	1.45E-05 kg
Curium alpha	2.58E-23 Cu	2.11E-12 Bq
Cyanamide	9.21E-05 lb	9.21E-05 kg
Cyanide	2.45E-07 lb	2.45E-07 kg
Cyanoacetic acid	1.32E-18 lb	1.32E-18 kg
Cyclohexane	3.68E-05 lb	3.68E-05 kg
Cyclopentadiene, hexachloro-	1.20E-09 lb	1.20E-09 kg
Cypermethrin	1.44E-05 lb	1.44E-05 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Decane	4.88E-07 lb	4.88E-07 kg
Dibenz(a,h)anthracene	1.68E-09 lb	1.68E-09 kg
Dibenzofuran	3.68E-09 lb	3.68E-09 kg
Dibenzofuran, 1,2,3,4,6,7,8,9-octachloro-	2.10E-13 lb	2.10E-13 kg
Dibenzofuran, 1,2,3,4,6,7,8-heptachloro-	7.23E-13 lb	7.23E-13 kg
Dibenzofuran, 1,2,3,4,7,8-hexachloro-	2.50E-13 lb	2.50E-13 kg
Dibenzofuran, 1,2,3,6,7,8-hexachloro-	2.63E-13 lb	2.63E-13 kg
Dibenzofuran, 1,2,3,7,8,9-hexachloro-	1.58E-13 lb	1.58E-13 kg
Dibenzofuran, 1,2,3,7,8-pentachloro-	1.84E-13 lb	1.84E-13 kg
Dibenzofuran, 2,3,4,6,7,8-hexachloro-	2.50E-13 lb	2.50E-13 kg
Dibenzofuran, 2,3,4,7,8-pentachloro-	2.24E-13 lb	2.24E-13 kg
Dibenzofuran, 2,3,7,8-tetrachloro-	1.58E-13 lb	1.58E-13 kg
Dicyclopentadiene	2.24E-07 lb	2.24E-07 kg
Diethanolamine	7.25E-06 lb	7.25E-06 kg
Diethylamine	3.87E-16 lb	3.87E-16 kg
Diisobutyl ketone	5.26E-07 lb	5.26E-07 kg
Dimethyl ether	4.24E-23 lb	4.24E-23 kg
Dimethyl formamide	4.87E-10 lb	4.87E-10 kg
Dimethyl malonate	1.66E-18 lb	1.66E-18 kg
Dimethylamine	3.26E-15 lb	3.26E-15 kg
Dinitrogen monoxide	4.01E-01 lb	4.01E-01 kg
Dioxin, 1,2,3,4,6,7,8,9-octachlorodibenzo-p-	2.89E-13 lb	2.89E-13 kg
Dioxin, 1,2,3,4,6,7,8-heptachlorodibenzo-p-	1.97E-13 lb	1.97E-13 kg
Dioxin, 1,2,3,4,7,8-hexachlorodibenzo-p	4.34E-14 lb	4.34E-14 kg
Dioxin, 1,2,3,7,8,9-hexachlorodibenzo-	5.39E-14 lb	5.39E-14 kg
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	7.57E-11 lb	7.57E-11 kg
Dioxins (unspecified)	6.90E-13 lb	6.90E-13 kg
Dipropylamine	3.54E-17 lb	3.54E-17 kg
Diquat dibromide	2.39E-04 lb	2.39E-04 kg
D-limonene	1.08E-24 lb	1.08E-24 kg
Epichlorohydrin	8.55E-07 lb	8.55E-07 kg
Epoxiconazole	4.57E-06 lb	4.57E-06 kg
Ethane	1.02E-03 lb	1.02E-03 kg
Ethane thiol	3.04E-09 lb	3.04E-09 kg
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	2.69E-11 lb	2.69E-11 kg
Ethane, 1,1,1-trichloro-, HCFC-140	1.75E-06 lb	1.75E-06 kg
Ethane, 1,1,2,2-tetrachloro-	1.75E-06 lb	1.75E-06 kg
Ethane, 1,1,2-trichloro-	1.03E-06 lb	1.03E-06 kg
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2.58E-18 lb	2.58E-18 kg
Ethane, 1,1,2-trifluoro-, HFC-143	1.02E-11 lb	1.02E-11 kg
Ethane, 1,1-dichloro-	7.68E-07 lb	7.68E-07 kg
Ethane, 1,1-difluoro-, HFC-152a	2.79E-17 lb	2.79E-17 kg
Ethane, 1,2-dibromo-	1.71E-06 lb	1.71E-06 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Ethane, 1,2-dichloro-	2.07E-07 lb	2.07E-07 kg
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1.27E-07 lb	1.27E-07 kg
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	1.48E-13 lb	1.48E-13 kg
Ethane, chloro-	1.25E-08 lb	1.25E-08 kg
Ethane, hexachloro-	1.20E-09 lb	1.20E-09 kg
Ethane, hexafluoro-, HFC-116	9.14E-12 lb	9.14E-12 kg
Ethane, pentafluoro-, HFC-125	1.14E-11 lb	1.14E-11 kg
Ethanol	1.37E-06 lb	1.37E-06 kg
Ethanol, 2-ethoxy-	9.14E-13 lb	9.14E-13 kg
Ethanol, 2-methoxy-	6.30E-08 lb	6.30E-08 kg
Ethanol, 2-propoxy-	5.92E-09 lb	5.92E-09 kg
Ethene	8.48E-05 lb	8.48E-05 kg
Ethene, 1,1-dichloro-	1.60E-10 lb	1.60E-10 kg
Ethene, chloro-	6.94E-07 lb	6.94E-07 kg
Ethene, tetrachloro-	7.66E-06 lb	7.66E-06 kg
Ethene, trichloro-	6.90E-07 lb	6.90E-07 kg
Ethofumesate	9.47E-05 lb	9.47E-05 kg
Ethoprop	4.35E-05 lb	4.35E-05 kg
Ethyl acetate	9.78E-14 lb	9.78E-14 kg
Ethyl cellulose	1.98E-16 lb	1.98E-16 kg
Ethylamine	3.24E-18 lb	3.24E-18 kg
Ethylene diamine	1.19E-16 lb	1.19E-16 kg
Ethylene glycol	1.98E-06 lb	1.98E-06 kg
Ethylene oxide	8.49E-12 lb	8.49E-12 kg
Ethyne	1.40E-06 lb	1.40E-06 kg
Fluoranthene	1.66E-07 lb	1.66E-07 kg
Fluorene	1.01E-07 lb	1.01E-07 kg
Fluoride	1.56E-05 lb	1.56E-05 kg
Fluorine	1.22E-08 lb	1.22E-08 kg
Fluosilicic acid	5.30E-14 lb	5.30E-14 kg
Folpet	1.03E-05 lb	1.03E-05 kg
Formaldehyde	3.35E-03 lb	3.35E-03 kg
Formamide	4.75E-18 lb	4.75E-18 kg
Formic acid	4.69E-02 lb	4.69E-02 kg
Furan	6.12E-10 lb	6.12E-10 kg
Glycidol	4.60E-09 lb	4.60E-09 kg
Glycol ethers	1.45E-06 lb	1.45E-06 kg
Glyphosate	2.96E-03 lb	2.96E-03 kg
Helium	1.62E-08 lb	1.62E-08 kg
Heptane	4.84E-06 lb	4.84E-06 kg
Hexadecane	8.63E-09 lb	8.63E-09 kg
Hexamethylene diamine	8.21E-13 lb	8.21E-13 kg
Hexane	4.24E-04 lb	4.24E-04 kg
Hexane, 1,6-diisocyanato-	6.84E-09 lb	6.84E-09 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Hydrazine	5.66E-11 lb	5.66E-11 kg
Hydrazine, methyl-	8.87E-09 lb	8.87E-09 kg
Hydrocarbons, aliphatic, alkanes, cyclic	1.76E-12 lb	1.76E-12 kg
Hydrocarbons, aliphatic, alkanes, unspecified	2.97E-09 lb	2.97E-09 kg
Hydrocarbons, aliphatic, unsaturated	2.21E-10 lb	2.21E-10 kg
Hydrocarbons, aromatic	8.90E-06 lb	8.90E-06 kg
Hydrocarbons, chlorinated	5.38E-14 lb	5.38E-14 kg
Hydrocarbons, unspecified	2.76E-03 lb	2.76E-03 kg
Hydrogen	9.92E-04 lb	9.92E-04 kg
Hydrogen bromide	2.95E-09 lb	2.95E-09 kg
Hydrogen chloride	1.16E-01 lb	1.16E-01 kg
Hydrogen cyanide	2.89E-04 lb	2.89E-04 kg
Hydrogen fluoride	1.44E-02 lb	1.44E-02 kg
Hydrogen iodide	3.11E-12 lb	3.11E-12 kg
Hydrogen peroxide	1.46E-16 lb	1.46E-16 kg
Hydrogen sulfide	1.82E-02 lb	1.82E-02 kg
Hydrogen-3, Tritium	1.07E-09 Cu	8.70E+01 Bq
Imidacloprid	1.10E-05 lb	1.10E-05 kg
Indeno(1,2,3-cd)pyrene	9.57E-09 lb	9.57E-09 kg
Indoxacarb	1.48E-05 lb	1.48E-05 kg
Iodide	1.83E-10 lb	1.83E-10 kg
Iodine-129	5.14E-13 Cu	4.19E-02 Bq
Iodine-131	3.13E-13 Cu	2.55E-02 Bq
Iodine-133	2.90E-17 Cu	2.36E-06 Bq
Iodine-135	7.77E-19 Cu	6.34E-08 Bq
Iron	5.86E-07 lb	5.86E-07 kg
Isobutane	7.26E-01 lb	7.26E-01 kg
Isocyanic acid	6.61E-16 lb	6.61E-16 kg
Isopentane	3.02E-08 lb	3.02E-08 kg
Isophorone	3.20E-08 lb	3.20E-08 kg
Isoprene	1.11E-06 lb	1.11E-06 kg
Isopropylamine	3.89E-19 lb	3.89E-19 kg
Isoproturon	1.08E-04 lb	1.08E-04 kg
Kerosene	2.20E-04 lb	2.20E-04 kg
Ketones, unspecified	2.89E-07 lb	2.89E-07 kg
Krypton-85	8.84E-06 Cu	7.21E+05 Bq
Krypton-87	9.15E-15 Cu	7.47E-04 Bq
Krypton-88	1.19E-14 Cu	9.74E-04 Bq
Krypton-89	5.00E-15 Cu	4.08E-04 Bq
Lactic acid	2.77E-17 lb	2.77E-17 kg
Lambda-cyhalothrin	2.30E-05 lb	2.30E-05 kg
Lanthanides	8.17E-17 lb	8.17E-17 kg
Lanthanum-140	4.55E-19 Cu	3.71E-08 Bq
Lead	4.96E-05 lb	4.96E-05 kg
Lead compounds	1.95E-26 lb	1.95E-26 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Lead dioxide	5.42E-13 lb	5.42E-13 kg
Lead-210	2.08E-14 Cu	1.70E-03 Bq
Linuron	7.77E-05 lb	7.77E-05 kg
Magnesium	1.06E-03 lb	1.06E-03 kg
Mancozeb	3.70E-04 lb	3.70E-04 kg
Maneb	1.10E-05 lb	1.10E-05 kg
Manganese	5.43E-05 lb	5.43E-05 kg
Manganese compounds	1.05E-27 lb	1.05E-27 kg
Manganese-54	2.20E-20 Cu	1.80E-09 Bq
m-Cresol	5.00E-09 lb	5.00E-09 kg
Mercaptans, unspecified	1.03E-05 lb	1.03E-05 kg
Mercury	1.16E-05 lb	1.16E-05 kg
Metals, unspecified	1.38E-12 lb	1.38E-12 kg
Metamitron	4.07E-04 lb	4.07E-04 kg
Metazachlor	7.37E-05 lb	7.37E-05 kg
Methane, biogenic	4.09E+00 lb	4.09E+00 kg
Methane, bromo-, Halon 1001	4.95E-07 lb	4.95E-07 kg
Methane, bromochlorodifluoro-, Halon 1211	1.76E-13 lb	1.76E-13 kg
Methane, bromotrifluoro-, Halon 1301	6.68E-12 lb	6.68E-12 kg
Methane, chlorodifluoro-, HCFC-22	5.35E-05 lb	5.35E-05 kg
Methane, chlorotrifluoro-, CFC-13	1.62E-08 lb	1.62E-08 kg
Methane, dichloro-, HCC-30	3.66E-05 lb	3.66E-05 kg
Methane, dichlorodifluoro-, CFC-12	2.58E-08 lb	2.58E-08 kg
Methane, dichlorofluoro-, HCFC-21	2.84E-20 lb	2.84E-20 kg
Methane, difluoro-, HFC-32	1.71E-12 lb	1.71E-12 kg
Methane, fossil	9.64E+00 lb	9.64E+00 kg
Methane, monochloro-, R-40	3.42E-08 lb	3.42E-08 kg
Methane, tetrachloro-, CFC-10	1.70E-06 lb	1.70E-06 kg
Methane, tetrafluoro-, CFC-14	5.09E-10 lb	5.09E-10 kg
Methane, trichlorofluoro-, CFC-11	1.20E-07 lb	1.20E-07 kg
Methane, trifluoro-, HFC-23	7.82E-11 lb	7.82E-11 kg
Methanesulfonic acid	1.33E-18 lb	1.33E-18 kg
Methanol	3.33E-04 lb	3.33E-04 kg
Methiocarb	3.40E-05 lb	3.40E-05 kg
Methomyl	1.15E-05 lb	1.15E-05 kg
Methyl acetate	5.92E-20 lb	5.92E-20 kg
Methyl acrylate	4.52E-15 lb	4.52E-15 kg
Methyl borate	9.71E-19 lb	9.71E-19 kg
Methyl ethyl ketone	1.43E-06 lb	1.43E-06 kg
Methyl formate	1.49E-18 lb	1.49E-18 kg
Methyl lactate	3.05E-17 lb	3.05E-17 kg
Methyl methacrylate	1.04E-09 lb	1.04E-09 kg
Methylamine	1.93E-17 lb	1.93E-17 kg
Metolachlor	1.33E-18 lb	1.33E-18 kg
Metolachlor, (S)	1.07E-03 lb	1.07E-03 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Metribuzin	8.47E-05 lb	8.47E-05 kg
Molybdenum	2.35E-08 lb	2.35E-08 kg
Molybdenum trioxide	1.58E-07 lb	1.58E-07 kg
Monocrotophos	7.75E-07 lb	7.75E-07 kg
Monoethanolamine	1.45E-12 lb	1.45E-12 kg
m-Xylene	2.96E-07 lb	2.96E-07 kg
Naphthalene	3.53E-05 lb	3.53E-05 kg
Naphthalene, 2-methyl-	5.89E-08 lb	5.89E-08 kg
Naphthalene, beta-chloro-	8.42E-15 lb	8.42E-15 kg
Napropamide	6.03E-05 lb	6.03E-05 kg
Nickel	9.73E-05 lb	9.73E-05 kg
Nickel compounds	2.03E-23 lb	2.03E-23 kg
Nickel refinery dust	2.76E-12 lb	2.76E-12 kg
Niobium-95	1.12E-20 Cu	9.16E-10 Bq
Nitrate	5.26E-13 lb	5.26E-13 kg
Nitric oxide	3.13E-02 lb	3.13E-02 kg
Nitrobenzene	2.24E-08 lb	2.24E-08 kg
Nitrogen	3.42E-18 lb	3.42E-18 kg
Nitrogen dioxide	8.07E-03 lb	8.07E-03 kg
Nitrogen fluoride	6.51E-13 lb	6.51E-13 kg
Nitrogen monoxide	1.14E-02 lb	1.14E-02 kg
Nitrogen oxides	6.81E+00 lb	6.81E+00 kg
Nitrogen, atmospheric	7.64E-03 lb	7.64E-03 kg
Nitrogen, total	6.05E-25 lb	6.05E-25 kg
NMHC, non-methane hydrocarbons	5.50E-04 lb	5.50E-04 kg
NMVOC, non-methane volatile organic compounds, unspecif	2.77E+00 lb	2.77E+00 kg
N-Nitrosodimethylamine	1.20E-09 lb	1.20E-09 kg
Noble gases, radioactive, unspecified	1.75E-09 Cu	1.43E+02 Bq
N-octane	2.66E-06 lb	2.66E-06 kg
Nonane	2.16E-07 lb	2.16E-07 kg
o-Cresol	4.60E-14 lb	4.60E-14 kg
Octadecane	8.63E-09 lb	8.63E-09 kg
Organic acids	1.69E-06 lb	1.69E-06 kg
Organic substances, unspecified	1.52E-03 lb	1.52E-03 kg
o-Toluidine	2.37E-09 lb	2.37E-09 kg
Oxamyl	2.28E-05 lb	2.28E-05 kg
Oxygen	5.03E-03 lb	5.03E-03 kg
o-Xylene	3.34E-07 lb	3.34E-07 kg
Ozone	4.87E-06 lb	4.87E-06 kg
PAH, polycyclic aromatic hydrocarbons	1.97E-05 lb	1.97E-05 kg
Palladium	3.26E-16 lb	3.26E-16 kg
Particulates	3.53E-07 lb	3.53E-07 kg
Particulates, < 10 um	2.79E-01 lb	2.79E-01 kg
Particulates, < 2.5 um	1.58E-01 lb	1.58E-01 kg
Particulates, > 10 um	3.53E-02 lb	3.53E-02 kg
Particulates, > 2.5 um, and < 10um	4.91E-02 lb	4.91E-02 kg
Particulates, unspecified	3.99E-01 lb	3.99E-01 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
p-Cresol	2.07E-14 lb	2.07E-14 kg
Pendimethalin	3.81E-04 lb	3.81E-04 kg
Pentane	1.38E-04 lb	1.38E-04 kg
Pentane, 2,2,4-trimethyl-	4.50E-05 lb	4.50E-05 kg
Perylene	2.72E-12 lb	2.72E-12 kg
PFC (perfluorocarbons)	2.03E-22 lb	2.03E-22 kg
Phenanthrene	1.30E-06 lb	1.30E-06 kg
Phenol	1.14E-05 lb	1.14E-05 kg
Phenol, 2,4,5-trichloro-	1.20E-09 lb	1.20E-09 kg
Phenol, 2,4,6-trichloro-	1.32E-09 lb	1.32E-09 kg
Phenol, 2,4-dichloro-	1.83E-17 lb	1.83E-17 kg
Phenol, 2,4-dimethyl-	2.37E-08 lb	2.37E-08 kg
Phenol, 2,4-dinitro-	1.20E-09 lb	1.20E-09 kg
Phenol, 4-nitro-	1.20E-09 lb	1.20E-09 kg
Phenol, pentachloro-	2.63E-09 lb	2.63E-09 kg
Phenols, unspecified	3.98E-06 lb	3.98E-06 kg
Phosphate	3.85E-10 lb	3.85E-10 kg
Phosphine	1.16E-12 lb	1.16E-12 kg
Phosphoric acid	3.45E-16 lb	3.45E-16 kg
Phosphorus	4.23E-06 lb	4.23E-06 kg
Phthalate, dibutyl-	3.42E-08 lb	3.42E-08 kg
Phthalate, dimethyl-	1.20E-09 lb	1.20E-09 kg
Phthalate, dioctyl-	4.85E-08 lb	4.85E-08 kg
Pirimicarb	6.51E-05 lb	6.51E-05 kg
Platinum	2.38E-14 lb	2.38E-14 kg
Plutonium	7.63E-18 Cu	6.22E-07 Bq
Plutonium-238	2.63E-23 Cu	2.15E-12 Bq
Plutonium-alpha	2.47E-19 Cu	2.02E-08 Bq
Polonium-210	3.19E-14 Cu	2.60E-03 Bq
Polychlorinated biphenyls	2.03E-10 lb	2.03E-10 kg
Polycyclic organic matter, unspecified	2.34E-12 lb	2.34E-12 kg
Potassium	6.44E-09 lb	6.44E-09 kg
Potassium-40	6.87E-16 Cu	5.61E-05 Bq
p-Phenylenediamine	5.13E-09 lb	5.13E-09 kg
Propamocarb	4.39E-05 lb	4.39E-05 kg
Propanal	9.27E-07 lb	9.27E-07 kg
Propane	1.12E-03 lb	1.12E-03 kg
Propane, 1,1,1,3,3-pentafluoro-, HFC-245fa	2.03E-10 lb	2.03E-10 kg
Propane, 1,2-dichloro-	8.81E-07 lb	8.81E-07 kg
Propane, 2-nitro-	1.13E-08 lb	1.13E-08 kg
Propargite	1.08E-05 lb	1.08E-05 kg
Propene	4.24E-04 lb	4.24E-04 kg
Propene, 1,3-dichloro-	8.62E-07 lb	8.62E-07 kg
Propiconazole	5.51E-06 lb	5.51E-06 kg
Propionic acid	2.56E-09 lb	2.56E-09 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Propylamine	1.50E-18 lb	1.50E-18 kg
Propylene	1.36E-01 lb	1.36E-01 kg
Propylene glycol methyl ether acetate	3.89E-11 lb	3.89E-11 kg
Propylene oxide	5.23E-01 lb	5.23E-01 kg
Propyne	3.46E-08 lb	3.46E-08 kg
Prosulfocarb	5.02E-04 lb	5.02E-04 kg
Protactinium-234	7.50E-17 Cu	6.11E-06 Bq
p-Xylene	3.11E-07 lb	3.11E-07 kg
Pyrene	1.59E-07 lb	1.59E-07 kg
Pyriproxyfen	1.16E-05 lb	1.16E-05 kg
Quinoline	2.24E-09 lb	2.24E-09 kg
Radioactive species, other beta emitters	6.78E-17 Cu	5.53E-06 Bq
Radioactive species, unspecified	6.65E-05 Cu	5.43E+06 Bq
Radionuclides (Including Radon)	1.23E-02 lb	1.23E-02 kg
Radium-226	2.66E-10 Cu	2.17E+01 Bq
Radium-228	3.53E-16 Cu	2.88E-05 Bq
Radon-220	7.01E-15 Cu	5.72E-04 Bq
Radon-222	1.37E-07 Cu	1.12E+04 Bq
Rhodium	3.14E-16 lb	3.14E-16 kg
Ruthenium-103	5.74E-22 Cu	4.68E-11 Bq
Scandium	4.72E-12 lb	4.72E-12 kg
Selenium	1.26E-04 lb	1.26E-04 kg
Silicon	1.20E-09 lb	1.20E-09 kg
Silicon tetrafluoride	1.40E-13 lb	1.40E-13 kg
Silver	4.09E-11 lb	4.09E-11 kg
Silver compounds	7.89E-07 lb	7.89E-07 kg
Silver-110	5.69E-21 Cu	4.64E-10 Bq
Sodium	6.75E-09 lb	6.75E-09 kg
Sodium chlorate	5.33E-13 lb	5.33E-13 kg
Sodium dichromate	1.75E-14 lb	1.75E-14 kg
Sodium formate	2.24E-15 lb	2.24E-15 kg
Sodium hydroxide	5.99E-05 lb	5.99E-05 kg
Strontium	9.34E-10 lb	9.34E-10 kg
Strontium-90	1.63E-21 Cu	1.33E-10 Bq
Styrene	3.52E-06 lb	3.52E-06 kg
Sulfate	4.24E-09 lb	4.24E-09 kg
Sulfosate	3.71E-18 lb	3.71E-18 kg
Sulfur	2.51E-10 lb	2.51E-10 kg
Sulfur dioxide	2.92E+00 lb	2.92E+00 kg
Sulfur hexafluoride	8.25E-11 lb	8.25E-11 kg
Sulfur monoxide	3.09E-04 lb	3.09E-04 kg
Sulfur oxides	7.04E-01 lb	7.04E-01 kg
Sulfur trioxide	3.46E-04 lb	3.46E-04 kg
Sulfur, total reduced	1.77E-15 lb	1.77E-15 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Sulfuric acid	3.21E-04 lb	3.21E-04 kg
Sulfuric acid, dimethyl ester	2.50E-09 lb	2.50E-09 kg
Tar	2.24E-08 lb	2.24E-08 kg
t-Butyl alcohol	2.63E-08 lb	2.63E-08 kg
t-Butyl methyl ether	4.08E-06 lb	4.08E-06 kg
t-Butylamine	1.26E-18 lb	1.26E-18 kg
Tebuconazole	1.51E-05 lb	1.51E-05 kg
Technetium-99	2.10E-25 Cu	1.71E-14 Bq
Tellurium	2.62E-11 lb	2.62E-11 kg
Terbuthylazin	9.62E-05 lb	9.62E-05 kg
Terpenes	1.57E-13 lb	1.57E-13 kg
Thallium	1.12E-09 lb	1.12E-09 kg
Thorium	6.60E-15 lb	6.60E-15 kg
Thorium-228	2.83E-16 Cu	2.31E-05 Bq
Thorium-230	2.80E-14 Cu	2.29E-03 Bq
Thorium-232	1.82E-16 Cu	1.49E-05 Bq
Thorium-234	7.51E-17 Cu	6.13E-06 Bq
Tin	1.03E-07 lb	1.03E-07 kg
Tin oxide	4.72E-14 lb	4.72E-14 kg
Titanium	1.96E-09 lb	1.96E-09 kg
TOC, Total Organic Carbon	2.17E-03 lb	2.17E-03 kg
Toluene	2.48E-03 lb	2.48E-03 kg
Toluene, 2,4-dinitro-	1.21E-09 lb	1.21E-09 kg
Toluene, 2-chloro-	4.96E-17 lb	4.96E-17 kg
Toluene, 2-ethyl-	4.75E-08 lb	4.75E-08 kg
Toluene, 3-ethyl-	1.12E-07 lb	1.12E-07 kg
Toluene, 4-ethyl-	5.18E-08 lb	5.18E-08 kg
Trichloroethane	1.47E-20 lb	1.47E-20 kg
Triethyl amine	7.61E-26 lb	7.61E-26 kg
Trifluralin	7.35E-18 lb	7.35E-18 kg
Trimethylamine	1.07E-19 lb	1.07E-19 kg
Tungsten	3.69E-12 lb	3.69E-12 kg
Uranium	8.78E-15 lb	8.78E-15 kg
Uranium alpha	1.80E-15 Cu	1.47E-04 Bq
Uranium-234	5.69E-13 Cu	4.64E-02 Bq
Uranium-235	2.16E-12 Cu	1.76E-01 Bq
Uranium-238	2.93E-12 Cu	2.39E-01 Bq
Vanadium	3.98E-06 lb	3.98E-06 kg
Vanadium compounds	3.03E-07 lb	3.03E-07 kg
Vinyl acetate	1.13E-08 lb	1.13E-08 kg
VOC, volatile organic compounds	9.47E-01 lb	9.47E-01 kg
Warfarin	1.49E-07 lb	1.49E-07 kg
Xenon-131m	1.38E-11 Cu	1.13E+00 Bq
Xenon-133	1.32E-09 Cu	1.07E+02 Bq
Xenon-133m	1.82E-15 Cu	1.48E-04 Bq

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Atmospheric Emissions		
Xenon-135	5.57E-10 Cu	4.54E+01 Bq
Xenon-135m	4.36E-13 Cu	3.55E-02 Bq
Xenon-137	2.51E-11 Cu	2.05E+00 Bq
Xenon-138	4.08E-11 Cu	3.33E+00 Bq
Xylene	8.51E-04 lb	8.51E-04 kg
Zinc	7.47E-07 lb	7.47E-07 kg
Zinc compounds	3.68E-06 lb	3.68E-06 kg
Zinc oxide	9.43E-14 lb	9.43E-14 kg
Zinc-65	1.10E-19 Cu	8.96E-09 Bq
Zirconium	3.62E-12 lb	3.62E-12 kg
Zirconium-95	1.07E-19 Cu	8.76E-09 Bq
Waterborne Releases		
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	6.71E-15 lb	6.71E-15 kg
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	5.26E-15 lb	5.26E-15 kg
1,4-Butanediol	1.38E-17 lb	1.38E-17 kg
1-Butanol	3.66E-16 lb	3.66E-16 kg
1-Methyl-2-pyrrolidinone	1.97E-09 lb	1.97E-09 kg
1-Pentanol	6.23E-18 lb	6.23E-18 kg
1-Pentene	4.71E-18 lb	4.71E-18 kg
1-Propanol	9.91E-18 lb	9.91E-18 kg
2-Aminopropanol	3.86E-19 lb	3.86E-19 kg
2-Butene, 2-methyl-	1.04E-21 lb	1.04E-21 kg
2-Hexanone	9.05E-10 lb	9.05E-10 kg
2-Methyl-1-propanol	2.11E-17 lb	2.11E-17 kg
2-Methyl-4-chlorophenoxyacetic acid	5.71E-06 lb	5.71E-06 kg
2-Propanol	3.41E-18 lb	3.41E-18 kg
3-Methylcholanthrene	5.95E-07 lb	5.95E-07 kg
4-Methyl-2-pentanone	3.45E-09 lb	3.45E-09 kg
7,12-Dimethylbenz(a)anthracene	5.95E-06 lb	5.95E-06 kg
Acenaphthene	2.16E-08 lb	2.16E-08 kg
Acenaphthylene	8.27E-09 lb	8.27E-09 kg
Acephate	4.40E-06 lb	4.40E-06 kg
Acetaldehyde	3.26E-14 lb	3.26E-14 kg
Acetic acid	2.34E+00 lb	2.34E+00 kg
Acetone	1.03E-09 lb	1.03E-09 kg
Acetonitrile	5.00E-08 lb	5.00E-08 kg
Acetyl chloride	4.89E-18 lb	4.89E-18 kg
Acidity, unspecified	6.81E-05 lb	6.81E-05 kg
Acids, unspecified	1.74E+00 lb	1.74E+00 kg
Aclonifen	2.79E-05 lb	2.79E-05 kg
Acrylate	1.29E-16 lb	1.29E-16 kg
Acrylonitrile	4.82E-11 lb	4.82E-11 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Actinides, radioactive, unspecified	2.96E-16 Cu	2.42E-05 Bq
Alachlor	2.93E-20 lb	2.93E-20 kg
Aldehydes, unspecified	1.96E-28 lb	1.96E-28 kg
Aluminium	3.62E-03 lb	3.62E-03 kg
Aluminum, ion	6.07E-18 lb	6.07E-18 kg
Americium-241	2.40E-13 Cu	1.95E-02 Bq
Ammonia	7.90E-04 lb	7.90E-04 kg
Ammonium, ion	9.82E-05 lb	9.82E-05 kg
Aniline	3.00E-16 lb	3.00E-16 kg
Anthracene	1.55E-08 lb	1.55E-08 kg
Antimony	1.28E-08 lb	1.28E-08 kg
Antimony compounds	2.89E-07 lb	2.89E-07 kg
Antimony-122	1.64E-18 Cu	1.34E-07 Bq
Antimony-124	1.12E-14 Cu	9.10E-04 Bq
Antimony-125	1.13E-14 Cu	9.23E-04 Bq
AOX, Adsorbable Organic Halogen as Cl	3.77E-05 lb	3.77E-05 kg
Arsenic	5.97E-06 lb	5.97E-06 kg
Arsenic V	1.82E-07 lb	1.82E-07 kg
Asbestos	8.66E-15 lb	8.66E-15 kg
Atrazine	2.22E-05 lb	2.22E-05 kg
Azadirachtin	2.73E-07 lb	2.73E-07 kg
Azoxystrobin	1.15E-06 lb	1.15E-06 kg
Barite	5.32E-12 lb	5.32E-12 kg
Barium	1.80E-01 lb	1.80E-01 kg
Barium compounds	3.81E-07 lb	3.81E-07 kg
Barium-140	7.20E-18 Cu	5.87E-07 Bq
Bentazone	2.44E-20 lb	2.44E-20 kg
Benzene	5.95E-03 lb	5.95E-03 kg
Benzene, 1,2,4-trimethyl-	9.08E-08 lb	9.08E-08 kg
Benzene, 1,2-dichloro-	2.03E-16 lb	2.03E-16 kg
Benzene, 1-methyl-4-(1-methylethyl)-	1.01E-11 lb	1.01E-11 kg
Benzene, chloro-	3.80E-15 lb	3.80E-15 kg
Benzene, ethyl-	5.95E-04 lb	5.95E-04 kg
Benzene, pentamethyl-	7.55E-12 lb	7.55E-12 kg
Benzenes, alkylated, unspecified	2.12E-08 lb	2.12E-08 kg
Benzo(a)anthracene	8.73E-09 lb	8.73E-09 kg
Benzo(a)pyrene	4.08E-09 lb	4.08E-09 kg
Benzo(b)fluoranthene	1.22E-23 lb	1.22E-23 kg
Benzo(g,h,i)perylene	1.16E-08 lb	1.16E-08 kg
Benzo(k)fluoranthene	5.27E-09 lb	5.27E-09 kg
Benzoic acid	1.38E-07 lb	1.38E-07 kg
Beryllium	3.10E-08 lb	3.10E-08 kg
Bicarbonate, ion	1.28E+00 lb	1.28E+00 kg
Bifenthrin	3.91E-06 lb	3.91E-06 kg
Biphenyl	5.95E-04 lb	5.95E-04 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
BOD5, Biological Oxygen Demand	1.47E-01 lb	1.47E-01 kg
Borate	4.87E-16 lb	4.87E-16 kg
Boron	9.20E-04 lb	9.20E-04 kg
Bromate	2.67E-09 lb	2.67E-09 kg
Bromide	1.83E-05 lb	1.83E-05 kg
Bromine	7.78E-08 lb	7.78E-08 kg
Butadiene	5.95E-04 lb	5.95E-04 kg
Butene	1.97E-11 lb	1.97E-11 kg
Butyl acetate	4.61E-16 lb	4.61E-16 kg
Butyrolactone	7.82E-19 lb	7.82E-19 kg
Cadmium	2.86E-06 lb	2.86E-06 kg
Cadmium compounds	1.45E-10 lb	1.45E-10 kg
Calcium	2.42E-01 lb	2.42E-01 kg
Captan	6.76E-06 lb	6.76E-06 kg
Carbaryl	1.29E-06 lb	1.29E-06 kg
Carbon disulfide	1.45E-07 lb	1.45E-07 kg
Carbon-14	1.97E-11 Cu	1.61E+00 Bq
Carbonate	1.44E-03 lb	1.44E-03 kg
Carboxylic acids, unspecified	4.66E-07 lb	4.66E-07 kg
Cerium-141	2.88E-18 Cu	2.35E-07 Bq
Cerium-144	9.59E-19 Cu	7.82E-08 Bq
Cesium	1.09E-10 lb	1.09E-10 kg
Cesium-134	1.21E-11 Cu	9.87E-01 Bq
Cesium-136	5.11E-19 Cu	4.17E-08 Bq
Cesium-137	1.12E-10 Cu	9.17E+00 Bq
Chloramine	8.41E-17 lb	8.41E-17 kg
Chlorate	2.39E-08 lb	2.39E-08 kg
Chloridazon	1.59E-05 lb	1.59E-05 kg
Chloride	2.14E+00 lb	2.14E+00 kg
Chlorinated solvents, unspecified	4.05E-13 lb	4.05E-13 kg
Chlorine	2.10E-05 lb	2.10E-05 kg
Chloroacetic acid	2.27E-14 lb	2.27E-14 kg
Chloroacetyl chloride	5.15E-19 lb	5.15E-19 kg
Chloroform	5.14E-06 lb	5.14E-06 kg
Chlorosulfonic acid	4.02E-18 lb	4.02E-18 kg
Chlorothalonil	1.13E-05 lb	1.13E-05 kg
Chlorpropham	6.23E-06 lb	6.23E-06 kg
Chlorpyrifos	1.35E-05 lb	1.35E-05 kg
Chromium	2.63E-04 lb	2.63E-04 kg
Chromium compounds	6.74E-08 lb	6.74E-08 kg
Chromium III	3.74E-08 lb	3.74E-08 kg
Chromium VI	5.28E-07 lb	5.28E-07 kg
Chromium-51	5.38E-16 Cu	4.39E-05 Bq
Chrysene	2.88E-08 lb	2.88E-08 kg
Clomazone	5.62E-21 lb	5.62E-21 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Cobalt	1.48E-06 lb	1.48E-06 kg
Cobalt compounds	8.81E-08 lb	8.81E-08 kg
Cobalt-57	1.62E-17 Cu	1.32E-06 Bq
Cobalt-58	1.45E-13 Cu	1.18E-02 Bq
Cobalt-60	5.17E-11 Cu	4.22E+00 Bq
COD, Chemical Oxygen Demand	4.89E-01 lb	4.89E-01 kg
Copper	1.46E-04 lb	1.46E-04 kg
Copper compounds	5.13E-08 lb	5.13E-08 kg
Cresol	6.08E-06 lb	6.08E-06 kg
Cumene	5.42E-08 lb	5.42E-08 kg
Curium alpha	3.14E-13 Cu	2.56E-02 Bq
Cyanamide	5.66E-08 lb	5.66E-08 kg
Cyanide	6.34E-07 lb	6.34E-07 kg
Cyclohexane	4.87E-08 lb	4.87E-08 kg
Cypermethrin	1.60E-06 lb	1.60E-06 kg
Decane	4.39E-05 lb	4.39E-05 kg
Detergent, oil	2.29E-08 lb	2.29E-08 kg
Dibenz(a,h)anthracene	2.37E-09 lb	2.37E-09 kg
Dibenz(a,j)acridine	5.95E-07 lb	5.95E-07 kg
Dibenzofuran	1.92E-11 lb	1.92E-11 kg
Dibenzofuran, 1,2,3,4,6,7,8-heptachloro-	5.39E-14 lb	5.39E-14 kg
Dibenzofuran, 1,2,3,4,7,8-hexachloro-	4.34E-14 lb	4.34E-14 kg
Dibenzofuran, 2,3,4,6,7,8-hexachloro-	6.97E-15 lb	6.97E-15 kg
Dibenzofuran, 2,3,4,7,8-pentachloro-	1.01E-14 lb	1.01E-14 kg
Dibenzofuran, 2,3,7,8-tetrachloro-	4.60E-15 lb	4.60E-15 kg
Dibenzothiophene	1.96E-11 lb	1.96E-11 kg
Dichromate	6.42E-14 lb	6.42E-14 kg
Diethanolamine	7.63E-08 lb	7.63E-08 kg
Diethylamine	1.33E-16 lb	1.33E-16 kg
Dimethyl phthalate	5.95E-05 lb	5.95E-05 kg
Dimethylamine	6.49E-17 lb	6.49E-17 kg
Dioxin, 1,2,3,7,8,9-hexachlorodibenzo-	6.31E-15 lb	6.31E-15 kg
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	9.35E-14 lb	9.35E-14 kg
Dipropylamine	8.50E-17 lb	8.50E-17 kg
Diquat dibromide	2.66E-05 lb	2.66E-05 kg
Dissolved solids	1.28E+01 lb	1.28E+01 kg
DOC, Dissolved Organic Carbon	1.10E-05 lb	1.10E-05 kg
Docosane	1.08E-10 lb	1.08E-10 kg
Dodecane	7.50E-09 lb	7.50E-09 kg
EDTA	4.77E-13 lb	4.77E-13 kg
Eicosane	2.06E-09 lb	2.06E-09 kg
Epoxiconazole	5.08E-07 lb	5.08E-07 kg
Ethane, 1,1,2-trichloro-	1.95E-16 lb	1.95E-16 kg
Ethane, 1,2-dibromo-	1.32E-11 lb	1.32E-11 kg
Ethane, hexachloro-	3.55E-20 lb	3.55E-20 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Ethanol	1.94E-15 lb	1.94E-15 kg
Ethanol, 2-ethoxy-	2.76E-08 lb	2.76E-08 kg
Ethene	5.95E-03 lb	5.95E-03 kg
Ethene, chloro-	1.28E-11 lb	1.28E-11 kg
Ethene, tetrachloro-	1.04E-08 lb	1.04E-08 kg
Ethene, trichloro-	5.39E-15 lb	5.39E-15 kg
Ethofumesate	1.05E-05 lb	1.05E-05 kg
Ethoprop	4.83E-06 lb	4.83E-06 kg
Ethyl acetate	1.42E-16 lb	1.42E-16 kg
Ethylamine	7.77E-18 lb	7.77E-18 kg
Ethylene diamine	2.88E-16 lb	2.88E-16 kg
Ethylene glycol	5.98E-04 lb	5.98E-04 kg
Ethylene oxide	2.27E-15 lb	2.27E-15 kg
Fluoranthene	5.73E-09 lb	5.73E-09 kg
Fluorene	6.67E-10 lb	6.67E-10 kg
Fluorene, 1-methyl-	1.15E-11 lb	1.15E-11 kg
Fluorenes, alkylated, unspecified	1.23E-09 lb	1.23E-09 kg
Fluoride	2.11E-03 lb	2.11E-03 kg
Fluorine	9.54E-09 lb	9.54E-09 kg
Fluosilicic acid	9.54E-14 lb	9.54E-14 kg
Folpet	1.15E-06 lb	1.15E-06 kg
Formaldehyde	1.58E-11 lb	1.58E-11 kg
Formamide	1.14E-17 lb	1.14E-17 kg
Formic acid	2.04E+00 lb	2.04E+00 kg
Furan	1.19E-22 lb	1.19E-22 kg
Glutaraldehyde	2.10E-13 lb	2.10E-13 kg
Glyphosate	3.28E-04 lb	3.28E-04 kg
Hexadecane	8.20E-09 lb	8.20E-09 kg
Hexane	9.73E-08 lb	9.73E-08 kg
Hexanoic acid	2.86E-08 lb	2.86E-08 kg
Hydrazine	2.19E-13 lb	2.19E-13 kg
Hydrocarbons, aliphatic, alkanes, unspecified	1.41E-08 lb	1.41E-08 kg
Hydrocarbons, aliphatic, unsaturated	1.30E-09 lb	1.30E-09 kg
Hydrocarbons, aromatic	2.19E-05 lb	2.19E-05 kg
Hydrocarbons, chlorinated	1.83E-07 lb	1.83E-07 kg
Hydrocarbons, unspecified	2.51E+00 lb	2.51E+00 kg
Hydrogen chloride	2.47E-10 lb	2.47E-10 kg
Hydrogen cyanide	3.11E-17 lb	3.11E-17 kg
Hydrogen fluoride	2.76E-07 lb	2.76E-07 kg
Hydrogen peroxide	2.64E-08 lb	2.64E-08 kg
Hydrogen sulfide	2.00E-04 lb	2.00E-04 kg
Hydrogen-3, Tritium	3.61E-07 Cu	2.94E+04 Bq
Hydroxide	6.54E-09 lb	6.54E-09 kg
Hypochlorite	1.49E-10 lb	1.49E-10 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Imidacloprid	1.23E-06 lb	1.23E-06 kg
Indoxacarb	1.64E-06 lb	1.64E-06 kg
Inorganic salts and acids (unspecified)	4.00E-23 lb	4.00E-23 kg
Iodide	1.12E-08 lb	1.12E-08 kg
Iodine-129	3.42E-11 Cu	2.79E+00 Bq
Iodine-131	1.36E-12 Cu	1.11E-01 Bq
Iodine-133	4.52E-18 Cu	3.69E-07 Bq
Iron	8.81E-03 lb	8.81E-03 kg
Iron-59	1.24E-18 Cu	1.01E-07 Bq
Isoprene	5.96E-05 lb	5.96E-05 kg
Isopropylamine	9.33E-19 lb	9.33E-19 kg
Isoproturon	1.20E-05 lb	1.20E-05 kg
Lactic acid	6.66E-17 lb	6.66E-17 kg
Lambda-cyhalothrin	2.56E-06 lb	2.56E-06 kg
Lanthanum-140	7.67E-18 Cu	6.25E-07 Bq
Lead	3.34E-05 lb	3.34E-05 kg
Lead compounds	1.45E-07 lb	1.45E-07 kg
Lead-210	4.34E-16 Cu	3.54E-05 Bq
Linuron	8.62E-06 lb	8.62E-06 kg
Lithium	8.89E-05 lb	8.89E-05 kg
Magnesium	2.37E-02 lb	2.37E-02 kg
Mancozeb	4.11E-05 lb	4.11E-05 kg
Maneb	1.22E-06 lb	1.22E-06 kg
Manganese	1.15E-02 lb	1.15E-02 kg
Manganese compounds	1.22E-07 lb	1.22E-07 kg
Manganese-54	8.00E-12 Cu	6.52E-01 Bq
Manganese-55	7.23E-20 Cu	5.90E-09 Bq
Mercury	2.53E-07 lb	2.53E-07 kg
Mercury compounds	5.52E-09 lb	5.52E-09 kg
Metallic ions, unspecified	8.38E-08 lb	8.38E-08 kg
Metamitron	4.52E-05 lb	4.52E-05 kg
Metazachlor	8.16E-06 lb	8.16E-06 kg
Methane	1.50E-14 lb	1.50E-14 kg
Methane, dibromo-	3.27E-27 lb	3.27E-27 kg
Methane, dichloro-, HCC-30	6.20E-11 lb	6.20E-11 kg
Methane, monochloro-, R-40	6.36E-10 lb	6.36E-10 kg
Methane, trichlorofluoro-, CFC-11	1.26E-18 lb	1.26E-18 kg
Methanol	7.37E-06 lb	7.37E-06 kg
Methiocarb	3.78E-06 lb	3.78E-06 kg
Methomyl	1.27E-06 lb	1.27E-06 kg
Methyl acetate	1.42E-19 lb	1.42E-19 kg
Methyl acrylate	1.21E-15 lb	1.21E-15 kg
Methyl ethyl ketone	8.11E-12 lb	8.11E-12 kg
Methyl formate	5.97E-19 lb	5.97E-19 kg
Methylamine	4.63E-17 lb	4.63E-17 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Metolachlor	5.71E-20 lb	5.71E-20 kg
Metolachlor, (S)	1.19E-04 lb	1.19E-04 kg
Metribuzin	9.39E-06 lb	9.39E-06 kg
Molybdenum	3.81E-07 lb	3.81E-07 kg
Molybdenum trioxide	2.89E-07 lb	2.89E-07 kg
Molybdenum-99	2.64E-18 Cu	2.16E-07 Bq
Monocrotophos	8.61E-08 lb	8.61E-08 kg
Morpholine	2.32E-12 lb	2.32E-12 kg
m-Xylene	6.80E-09 lb	6.80E-09 kg
Naphthalene	8.46E-07 lb	8.46E-07 kg
Naphthalene, 2-methyl-	5.01E-09 lb	5.01E-09 kg
Naphthalenes, alkylated, unspecified	3.48E-10 lb	3.48E-10 kg
Napropamide	6.70E-06 lb	6.70E-06 kg
n-Hexacosane	6.73E-11 lb	6.73E-11 kg
Nickel	1.06E-05 lb	1.06E-05 kg
Nickel compounds	7.23E-07 lb	7.23E-07 kg
Niobium-95	1.05E-17 Cu	8.55E-07 Bq
Nitrate	4.02E+00 lb	4.02E+00 kg
Nitrate compounds	1.58E-03 lb	1.58E-03 kg
Nitric acid	9.39E-12 lb	9.39E-12 kg
Nitrite	4.00E-09 lb	4.00E-09 kg
Nitrobenzene	6.71E-16 lb	6.71E-16 kg
Nitrogen	1.63E-03 lb	1.63E-03 kg
Nitrogen dioxide	2.06E-19 lb	2.06E-19 kg
Nitrogen, organic bound	1.90E-07 lb	1.90E-07 kg
Nitrogen, total	6.33E-03 lb	6.33E-03 kg
Nitrogenous Matter (unspecified, as N)	3.19E-15 lb	3.19E-15 kg
o-Cresol	3.90E-09 lb	3.90E-09 kg
Octadecane	2.03E-09 lb	2.03E-09 kg
Oils, unspecified	6.26E-04 lb	6.26E-04 kg
Organic substances, unspecified	3.33E-27 lb	3.33E-27 kg
Oxamyl	2.53E-06 lb	2.53E-06 kg
o-Xylene	2.88E-08 lb	2.88E-08 kg
PAH, polycyclic aromatic hydrocarbons	2.44E-07 lb	2.44E-07 kg
Particulates, < 10 um	1.35E-02 lb	1.35E-02 kg
p-Cresol	4.22E-09 lb	4.22E-09 kg
Pendimethalin	4.23E-05 lb	4.23E-05 kg
Petroleum oil	3.67E-05 lb	3.67E-05 kg
Phenanthrene	1.22E-08 lb	1.22E-08 kg
Phenanthrenes, alkylated, unspecified	1.44E-10 lb	1.44E-10 kg
Phenol	7.25E-05 lb	7.25E-05 kg
Phenol, 2,4-dimethyl-	2.35E-08 lb	2.35E-08 kg
Phenols, unspecified	1.44E+00 lb	1.44E+00 kg
Phosphate	7.10E-02 lb	7.10E-02 kg
Phosphoric acid	1.67E-09 lb	1.67E-09 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Phosphorus	2.49E-02 lb	2.49E-02 kg
Phosphorus compounds, unspecified	9.55E-18 lb	9.55E-18 kg
Phosphorus, total	8.73E-05 lb	8.73E-05 kg
Pirimicarb	7.24E-06 lb	7.24E-06 kg
Plutonium	9.30E-13 Cu	7.59E-02 Bq
Plutonium-alpha	1.17E-14 Cu	9.51E-04 Bq
Polonium-210	5.83E-16 Cu	4.75E-05 Bq
Potassium	1.11E-01 lb	1.11E-01 kg
Potassium-40	2.19E-16 Cu	1.79E-05 Bq
Process solvents, unspecified	1.97E-11 lb	1.97E-11 kg
Propamocarb	4.88E-06 lb	4.88E-06 kg
Propanal	9.02E-18 lb	9.02E-18 kg
Propane, 1,2-dichloro-	6.59E-16 lb	6.59E-16 kg
Propargite	1.20E-06 lb	1.20E-06 kg
Propene	4.88E-08 lb	4.88E-08 kg
Propiconazole	6.12E-07 lb	6.12E-07 kg
Propionic acid	4.46E-17 lb	4.46E-17 kg
Propylamine	3.61E-18 lb	3.61E-18 kg
Propylene glycol	5.95E-04 lb	5.95E-04 kg
Propylene oxide	9.18E-12 lb	9.18E-12 kg
Prosulfocarb	5.57E-05 lb	5.57E-05 kg
Protactinium-234	4.42E-14 Cu	3.61E-03 Bq
p-Xylene	3.85E-09 lb	3.85E-09 kg
Pyrene	2.37E-09 lb	2.37E-09 kg
Pyriproxyfen	1.28E-06 lb	1.28E-06 kg
Radioactive species, alpha emitters	4.94E-19 Cu	4.03E-08 Bq
Radioactive species, Nuclides, unspecified	1.75E-07 Cu	1.43E+04 Bq
Radium-224	6.84E-14 Cu	5.58E-03 Bq
Radium-226	4.09E-09 Cu	3.34E+02 Bq
Radium-228	1.37E-13 Cu	1.12E-02 Bq
Rubidium	1.12E-09 lb	1.12E-09 kg
Ruthenium-103	5.56E-19 Cu	4.53E-08 Bq
Ruthenium-106	4.45E-12 Cu	3.63E-01 Bq
Salts, unspecified	7.36E-17 lb	7.36E-17 kg
Scandium	5.79E-10 lb	5.79E-10 kg
Selenium	3.45E-05 lb	3.45E-05 kg
Selenium compounds	2.37E-07 lb	2.37E-07 kg
Silicate	3.97E-04 lb	3.97E-04 kg
Silicon	4.07E-04 lb	4.07E-04 kg
Silver	1.83E-07 lb	1.83E-07 kg
Silver compounds	7.10E-13 lb	7.10E-13 kg
Silver-110	1.32E-14 Cu	1.08E-03 Bq
Sodium	6.08E-01 lb	6.08E-01 kg
Sodium Bisulfate	5.95E-06 lb	5.95E-06 kg
Sodium dichromate	4.98E-16 lb	4.98E-16 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Sodium formate	5.38E-15 lb	5.38E-15 kg
Sodium hydroxide	1.59E+00 lb	1.59E+00 kg
Sodium-24	2.00E-17 Cu	1.63E-06 Bq
Solids, inorganic	3.25E-07 lb	3.25E-07 kg
Strontium	1.45E-05 lb	1.45E-05 kg
Strontium-89	4.54E-17 Cu	3.70E-06 Bq
Strontium-90	1.17E-11 Cu	9.56E-01 Bq
Styrene	5.95E-03 lb	5.95E-03 kg
Sulfate	9.48E-01 lb	9.48E-01 kg
Sulfide	2.73E-04 lb	2.73E-04 kg
Sulfite	3.43E-07 lb	3.43E-07 kg
Sulfosate	1.59E-19 lb	1.59E-19 kg
Sulfur	3.69E-07 lb	3.69E-07 kg
Sulfuric acid	5.16E-04 lb	5.16E-04 kg
Surfactants	5.48E-08 lb	5.48E-08 kg
Suspended solids, unspecified	5.03E-02 lb	5.03E-02 kg
Tantalum	3.74E-16 lb	3.74E-16 kg
Tar	6.46E-15 lb	6.46E-15 kg
t-Butyl alcohol	8.55E-10 lb	8.55E-10 kg
t-Butyl methyl ether	3.09E-10 lb	3.09E-10 kg
t-Butylamine	3.02E-18 lb	3.02E-18 kg
Tebuconazole	1.68E-06 lb	1.68E-06 kg
Technetium-99	2.57E-19 Cu	2.10E-08 Bq
Technetium-99m	6.05E-17 Cu	4.94E-06 Bq
Tellurium-123m	6.40E-18 Cu	5.22E-07 Bq
Tellurium-132	1.53E-19 Cu	1.25E-08 Bq
Terbuthylazin	1.07E-05 lb	1.07E-05 kg
Tetradecane	3.24E-09 lb	3.24E-09 kg
Thallium	1.08E-07 lb	1.08E-07 kg
Thorium-228	2.74E-13 Cu	2.23E-02 Bq
Thorium-230	4.43E-12 Cu	3.61E-01 Bq
Thorium-232	3.45E-17 Cu	2.81E-06 Bq
Thorium-234	4.42E-14 Cu	3.61E-03 Bq
Tin	7.61E-07 lb	7.61E-07 kg
Titanium	1.64E-07 lb	1.64E-07 kg
TOC, Total Organic Carbon	8.46E-02 lb	8.46E-02 kg
Toluene	5.95E-03 lb	5.95E-03 kg
Toluene, 2-chloro-	1.04E-16 lb	1.04E-16 kg
Tribufos	2.11E-16 lb	2.11E-16 kg
Tributyltin compounds	1.04E-10 lb	1.04E-10 kg
Tributyltin oxide	9.25E-13 lb	9.25E-13 kg
Triethylene glycol	6.66E-09 lb	6.66E-09 kg
Trifluralin	1.90E-19 lb	1.90E-19 kg
Trimethylamine	2.56E-19 lb	2.56E-19 kg
Tungsten	1.06E-10 lb	1.06E-10 kg

Table 13. LCI Data for the Production of Polyether Polyol for Rigid Foam Polyurethanes (Continued)

	1,000 lb	1,000 kg
Uranium alpha	3.52E-14 Cu	2.87E-03 Bq
Uranium-234	1.54E-13 Cu	1.26E-02 Bq
Uranium-235	8.99E-15 Cu	7.33E-04 Bq
Uranium-238	6.90E-11 Cu	5.63E+00 Bq
Urea	1.05E-17 lb	1.05E-17 kg
Vanadium	4.21E-06 lb	4.21E-06 kg
Vanadium compounds	2.24E-06 lb	2.24E-06 kg
VOC, volatile organic compounds, unspecified origin	3.61E-07 lb	3.61E-07 kg
Warfarin	1.66E-08 lb	1.66E-08 kg
Xylene	5.99E-04 lb	5.99E-04 kg
Yttrium	9.15E-10 lb	9.15E-10 kg
Zinc	5.31E-04 lb	5.31E-04 kg
Zinc compounds	3.55E-06 lb	3.55E-06 kg
Zinc-65	2.71E-16 Cu	2.21E-05 Bq
Zirconium-95	3.14E-18 Cu	2.56E-07 Bq
Solid Wastes		
Hazardous waste to incineration	7.91E-01 lb	7.91E-01 kg
Hazardous waste to landfill	2.16E-03 lb	2.16E-03 kg
Hazardous waste to WTE	1.40E+00 lb	1.40E+00 kg
Hazardous waste, recovery	9.38E-05 lb	9.38E-05 kg
Solid waste process, to incineration	3.39E+00 lb	3.39E+00 kg
Solid waste process, to landfill	1.41E+02 lb	1.41E+02 kg
Solid waste process, to WTE	3.45E-04 lb	3.45E-04 kg
Solid Waste Sold for Recycling or Reuse	1.50E-01 lb	1.50E-01 kg
Water Consumption*	5.06E+03 gal	4.22E+04 l

*Water consumption includes ground water, surface water, and water from unspecified origin.

Source: Primary Data, 2022 (short-chain Polyether Polyol)

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