

Life Cycle Assessment of Alkaline Copper Quaternary (ACQ) and Micronized Copper Azole (MCA) Wood Treatment Chemicals

Prepared for:
Koppers Performance Chemicals

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1. Summary of Life Cycle Assessment Update

This report presents findings of a life cycle assessment (LCA) prepared by SCS Global Services, Inc. (SCS), for the production of MicroPro® wood treatment chemical manufactured at the Koppers Performance Chemical's (Koppers) Millington, Tennessee and Rock Hill, South Carolina facilities.

In the original 2008 LCA assessment conducted by SCS and FFK Ltd, as well as subsequent assessment updates, Koppers' MicroPro® Micronized Copper Azole (MCA) wood treatment chemical was found to have lower impacts in all environmental impact categories, as compared to the reference baseline chemical against which it was compared, Alkaline Copper Quaternary (ACQ), thereby meriting certification as an Environmentally Preferable Wood Treatment Process. Since the initial LCA assessment, the MicroPro® formulation has been refined and a second production facility started operations at Rock Hill, South Carolina. These changes have included: consolidation from a pair of chemicals (micronized copper + tebuconazole solutions) into a single treatment solution; concentration of the formula; and changes to inert co-formulants and suppliers of chemicals. Assessment results based on these changes have been documented previously¹.

Additionally, current life cycle inventory (LCI) and advanced life cycle impact assessment (LCIA) algorithms were used to refine the characterization of environmental impacts. Since the original LCA assessment, these revisions have included: use of EPA eGRID NERC subregion energy mix data for regional power generation; integration of black carbon emission data; updated global warming factors to account for tipping point projections; addition of an indicator to account for ocean thermal loading impacts; and use of air dispersion modeling to assess regional impacts to soil acidification, ground level ozone exposures, and PM2.5 exposures. Assessment results based on these updates and revisions were documented in a previous LCA report².

This report serves as an update to the May 2021 final LCA report and summarizes the updated findings of the 2020 LCA. Updated LCA results are based on data and information provided by Koppers for the production period of April 1, 2020 to March 31, 2021. This report includes an update to the functional unit, based on changes in market preferences between ground contact and above ground rated treated lumber.

1.1 General Objective

The main objective of the study was to evaluate the MicroPro® (MCA) formulation in order to determine whether it continued to qualify for certification as an Environmentally Preferable Wood Treatment Process (EPWTP), comparing its environmental impacts to a reference baseline chemical. As in the

¹ Report Addendum: Life Cycle Assessment of Alkaline Copper Quaternary (ACQ) and Micronized Copper Azole (MCA) Lumber Treatment Chemicals. Prepared by Scientific Certification Systems for Osmose, Inc. November 2011

² Life Cycle Assessment of Alkaline Copper Quaternary (ACQ) and Micronized Copper Azole (MCA) Wood Treatment Chemicals. Final Report prepared for Koppers Performance Chemicals. SCS Global Services. February 2018.

previous study conducted in 2020, the Alkaline Copper Quaternary (ACQ) formulation, NatureWood 100C, was chosen as the reference baseline chemical. An update to the previous assessment was required to assess whether or not changes in the MicroPro® formulation and suppliers have resulted in significant changes to its environmental impacts as compared to the ACQ baseline.

1.2 Summary of Assessment Methods and Data

The assessment was conducted in accordance with ISO 14044³, and the draft standard for consequential life cycle assessment, SCS-002.⁴ The water footprint of the product system was also assessed in conformance to ISO 14046.⁵ Unit processes were developed within the OpenLCA life cycle model drawing upon data from multiple sources. Koppers provided production and raw material consumption and transport data. Existing generic chemical production information was used from various databases available to SCS. The Ecoinvent⁶ database provided emissions data and resource requirements for fuel extraction and processing, and power generation. Confidential primary data on input streams and energy consumption for upstream chemicals used in the ACQ wood treatment product were supplied by the manufacturer and used in the life cycle modeling. These data sources were integrated as unit processes into the OpenLCA software tool to generate the life cycle inventory for the Koppers wood treatment chemical processes, as well as for the baseline product. The assessment evaluated and compared the environmental impacts of MCA with those of the reference, or baseline, product.

From the life cycle inventory data, impact assessment is conducted using the environmental impact characterizations and methodologies described in the October 2018 version of the SCS-002 standard for Type III Life-Cycle Impact Profile Declarations for Materials, Products, Services and Systems (hereafter referred to as SCS-002:2018). This standard provides a framework for life cycle impact assessment that augments the international ISO 14044 LCA standard to support environmental declarations, ratings and claims. This report was reviewed by an internal expert for conformance to ISO 14044 and the SCS-002:2018 standards, as per ISO 14044, Section 6.3, and is provided to Koppers to aid in their understanding of the life cycle assessment conducted by SCS.

³ ISO 14044:2006 Environmental management – Life Cycle Assessment – Requirements and guidelines

⁴ Consequential Life Cycle Assessment Framework and Guidance for Establishing Environmental Product Declarations and Key Issue Declarations. Consequential Life Cycle Framework. SCS-002. October 2018.

⁵ ISO 14046 Environmental management – Water footprint – Principles, requirements and guidelines

⁶ Ecoinvent v3.7 Swiss Center for Life Cycle Inventories, 2020. <http://www.Ecoinvent.org>

1.3 ACQ and MCA Descriptions

Koppers provided the following information about the reference baseline chemical, ACQ, and the subject chemical, MCA.

Alkaline Copper Quaternary

Alkaline Copper Quaternary (ACQ) is a water-based wood preservative that protects wood from fungal decay and insect attack; it is a fungicide and insecticide. ACQ contains two active ingredients, copper or a copper compound and a quaternary ammonium compound in which copper is complexed with an organic chemical, monoethanolamine (MEA), to form a water soluble copper solution. To ensure complete dissolution of copper, the minimum weight ratio of MEA to copper is 3.4.

There are currently four types of ACQ formulations, the most widely used of which is ACQ type D, where the ratio of copper expressed as cupric oxide (CuO) to quaternary ammonium compound is 2 to 1. Wood treated with ACQ has a dark bluish green color and little or no odor.

Micronized Copper Azole

Micronized Copper Azole (MCA) is a new generation of water-based wood preservative that protects wood from fungal decay and termite/insect attack. Like ACQ, it is a fungicide and insecticide; but unlike ACQ, MCA does not use the organic solvent, monoethanolamine, to solubilize copper. Instead, MCA uses minimally water soluble copper compounds, such as basic copper carbonate. The copper compound is micronized, or finely ground, into a stable dispersion of submicron copper particles with the aid of a dispersant.

In addition to micronized copper, MCA also contains a triazole compound, such as tebuconazole. The weight ratio of copper expressed as elemental copper to tebuconazole is 25:1.

Wood treated with MCA has a light green color and no odor. MCA is now being used extensively in the USA, and increasingly expands its market in Europe, Asia, and Australia/New Zealand.

2. Scope of Life Cycle Assessment

2.1 Scope of the Project and Systems Studied

SCS conducted a “cradle-to-delivered product” life cycle assessment of the Koppers MicroPro® (MCA) wood treatment chemical products in comparison to a reference baseline treatment chemical. As noted above, Environmentally Preferable Wood Treatment Process certification recognizes reduced environmental impacts of a manufacturer’s product in comparison to a reference (baseline) product. To determine eligibility for EPWTP status, the life cycle impact assessment was conducted in accordance with ISO 14044 and SCS-002:2018. Impacts from manufacturer’s product system are compared to the baseline on a functionally equivalent basis over the following life cycle phases: material extraction and processing, manufacturing and transportation. Unit processes were modeled upstream from the Millington, Tennessee, and Rock Hill, South Carolina, manufacturing facilities (see Figures 1 and 2, below). No wood treatment, use or disposal impacts were quantified; however, product performance and leachate rates during use were compared for the two impregnation chemicals to ensure MicroPro® met or exceeded the performance of the reference chemical ACQ. Impregnation operations at the wood treatment plants were not included in the scope since these operations do not significantly vary between the assessed ACQ and MCA processes.

As per ISO 14044, and discussed in §4.6, the data used in the assessment must be sufficient to evaluate the life cycle impacts of the product with respect to the functional unit and be of such quality to support the EPWTP determination. When necessary, mass-based allocation is used while cut-off criteria for inclusion of input and output flows are based on impact indicator results as per SCS-002:2018.

Koppers manufactures several variations of the MicroPro® wood treatment chemicals, using alternative formulations. These variations involve small differences in ingredient concentration, inert material components and material suppliers. Koppers provided the production data for two of the MicroPro® formulations for the current assessment. Impact results were calculated using a production-weighted estimate for the MicroPro® product based on results for each of the two product variations and compared with the baseline ACQ treatment chemical.

2.2 Functional Unit

The functional unit for the LCA is the production of impregnation chemical sufficient for treatment of one billion (10⁹) board feet (BF) of impregnated wood. The total treated wood market in the US is about 8 billion BF per year. This functional unit was chosen as it is of the same order of magnitude as the annual market shares of the leading producers of wood treatment chemicals.

In accordance with SCS-002:2018, functional units are selected which provide an approximate annual production value, thereby representing the environmental impacts from the product system. Koppers

provided April 1, 2020 through March 31, 2021 production data from the Millington, TN and Rock Hill, SC manufacturing facilities for the two MCA formulations considered in the assessment. A production-weighted average for the two MCA products (i.e., MicroPro® and MicroPro® MCA) was estimated using data from both Koppers manufacturing facilities for comparison with the ACQ baseline. Additionally, each MCA formulation is manufactured by Koppers using a number of alternative chemical formulations and/or material suppliers. Based on data provided by Koppers defining the percentage of each formulation produced, a weighted average for each MCA product was calculated and used for the assessment.

In order to provide a meaningful comparison, the functional unit for the baseline product is the same as for MCA. However, as discussed below, the material reference flow for the baseline is larger based on the difference in product retention rates (see Table 1). Therefore, the material reference flow for the Koppers MCA treatment chemical system is approximately 13,000,000 lb (5,900,000 kg) treatment chemical per billion board feet (BBF) of treated wood and 76,900,000 lb (34,900,000 kg) of ACQ per BBF treated wood for the baseline product system.

2.3 Product Performance (Retention Rates)

The impregnation amounts for the wood treatment systems were based on the retention values, as shown in Table 1. Based on estimates of treated wood sales, it was assumed that 40% of wood is treated for Above Ground use, with the remaining 60% treated as Ground Contact. As reflected in the table, the ACQ formulation consists of a copper containing solution, and a second biocide solution, a carboquat. The MCA formulation includes a single solution of copper and an organic triazole, tebuconazole.

Table 1. Treatment Chemical Retention Values

Parameter	Unit	Baseline Naturewood 100 (ACQ)	MicroPro® (MCA)
Average total actives retention	PCF (lb/cu ft)	0.300	
Copper oxide actives	PCF (lb/cu ft)	0.291	
Copper oxide actives	lb/1000 BF	16.5	
Concentrated treatment solution as delivered to the plant	lb/1000 BF	148	
Copper oxide in solution	%	11.3	
Average Carboquat actives retention	PCF (lb/cu ft)	0.144	
Carboquat actives	lb/1000 BF	8.3	
Concentrated treatment solution as delivered to the plant	lb/1000 BF	17.3	
Carboquat in solution	%	48	
Average total actives retention	PCF (lb/cu ft)		0.115
Copper (as metal) actives	PCF (lb/cu ft)		0.110
Tebuconazole actives	PCF (lb/cu ft)		0.005
Copper actives	lb/1000 BF		6.30
Tebuconazole actives	lb/1000 BF		0.28
Concentrated treatment solution as delivered to the plant	lb/1000 BF		27.9
Copper in solution	%		33%
Tebuconazole in solution	%		1.5%

2.4 Koppers MicroPro® Production System

Koppers’ wood treatment chemical products were modeled using facility specific data with a weighted average of production for the two facilities, as discussed above. Using twelve months of production data, the percentages of each MCA product manufactured at Koppers Millington, TN and Rock Hill, SC facilities were calculated and used for the assessment. Raw material extraction and processing, transportation and manufacturing processes were modeled using OpenLCA v1.10 LCA software.

Figure 1 provides a flowchart illustrating the life cycle phases included in the assessment for the Koppers MicroPro® product system.

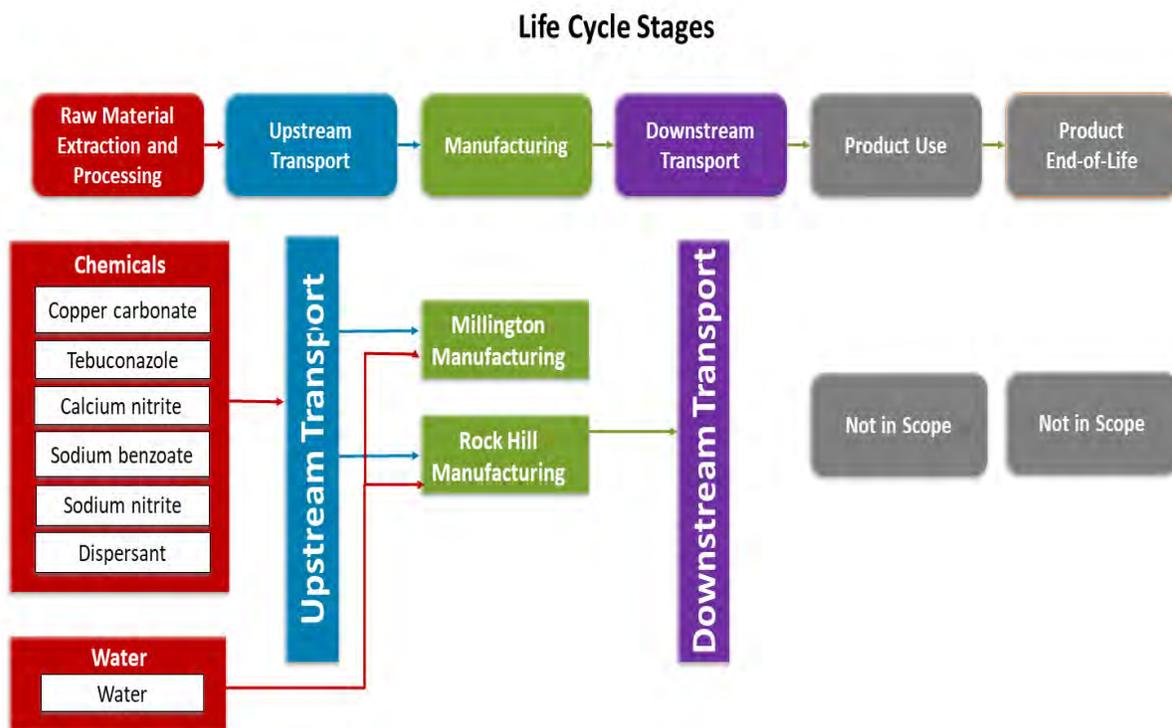


Figure 1. Flow diagram for LCA modeling of Koppers MicroPro® wood treatment chemical production system.

2.5 Baseline ACQ Production System

The baseline production system was modeled in a manner similar to the MCA formulations. The ACQ treatment chemicals were assumed to be manufactured within the SRVC eGRID power sub-region.

Figure 2 provides a flowchart illustrating the life cycle phases included in the assessment for the baseline ACQ product system.

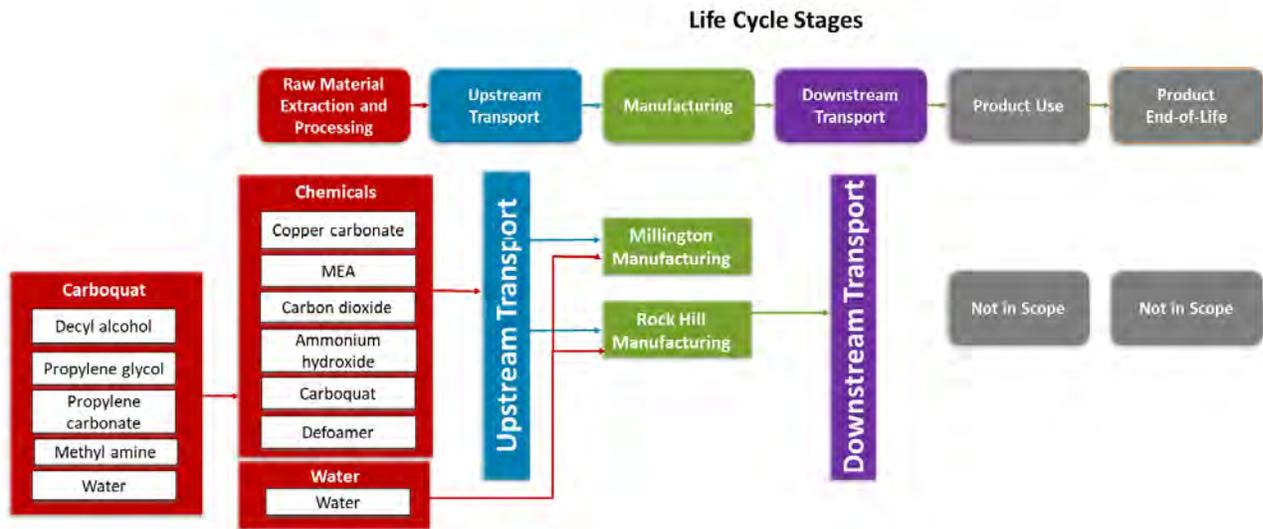


Figure 2. Flow diagram for LCA modeling of the baseline ACQ wood treatment chemical production system

3. Life Cycle Inventory Analysis / Life Cycle Modeling

The process flow networks for life cycle modeling of the wood treatment chemical production systems were presented in Figures 1 and 2. The networks are constructed from individual unit processes as represented in the OpenLCA modeling software. Each unit process has an associated life cycle inventory. Data sources for these inventories include data provided by Koppers, as well as generic lifecycle datasets from the Ecoinvent⁷ databases. Key output parameters from the LCI modeling are used to calculate environmental impacts through the Life Cycle Impact Assessment summarized in Section 4.

3.1 Key Assumptions and Data Sources

Modeling of the Koppers' and baseline product systems required several assumptions. The use of secondary (generic) data was necessary where primary data were not available. The life cycle databases used in the assessment are thoroughly investigated and documented generic models, which provide more accurate results than an extemporaneously compiled or incomplete set of data for the actual operations. Key assumptions and data sources are summarized below

- The two treatments were assumed to be functionally comparable. This was based on review of soil⁸ and water⁹ leachability testing for ACQ and MCA, which showed reduced leaching to soil and water for MCA as compared to ACQ.
- In addition to the resource consumption and emission data reported by Koppers from its own manufacturing facilities, the system modeling requires corresponding unit operations data from other upstream suppliers. Such data were pursued by both Koppers and SCS.
- The most important upstream chemical in both formulations is the copper carbonate. Koppers gathered sufficiently representative data on this unit operation from its main copper carbonate supplier.
- For ACQ, the Carbo NT is an important upstream chemical. Confidential data on input streams and energy consumption were supplied by Lonza, Inc. For two of the Carbo NT unit operations upstream from Lonza, unit operations were represented with surrogate data, chosen from Ecoinvent datasets for their similarity to the actual processes.
- For the modeled ACQ system, the use of naturally derived oils as a feedstock for the production of carboquat represents a land use issue in tropical regions. Endangered species may suffer from

⁷ Ecoinvent Centre (2020) Ecoinvent data from v3.7. Swiss Center for Life Cycle Inventories, Dübendorf, 2020
<http://www.Ecoinvent.org>

⁸ AWPA E20 Leachability Testing, Timber Products Project No. 07-1127. Timber Products Inspection. November 15, 2007.

⁹ AWPA E11 Leachability Testing, Timber Products Project No. 07-1126. Timber Products Inspection. November 8, 2007.

continuous transformation of natural habitats for the production of oil crops. In the absence of any data indicating that carboquat in this system was derived from environmentally certified oil plantations, a 100% disruption was assumed. (Future studies of ACQ should investigate this assumption further). By contrast, the MCA system uses no naturally derived oil inputs.

- Supplier specific data were used for the gate-to-gate production of the MicroPro® preservative, sodium benzoate. Upstream operations utilized generic datasets derived from Ecoinvent for benzoic acid and sodium hydroxide, which were included based on stoichiometric calculations.
- In the ACQ system, data were not available for the anti-foam agent and only transportation was modeled. The anti-foam agent represents ~0.1% of the ACQ formula and is expected to have a small contribution to the overall impacts. Alkyl dimethyl benzyl ammonium chloride in the ACQ system was omitted from the modeling due to a lack of available upstream energy data and anticipated minor contribution to impacts because of the small volumes used. In both cases, inclusion of these additional processes would have resulted in higher impacts to the ACQ system.
- Because MicroPro® is produced at both Millington, Tennessee, and Rock Hill, South Carolina, regional eGRID energy mix data were used to model the emissions from electricity generation for both Millington and Rock Hill, using the southeastern US SRTV (SERC Tennessee Valley) and SRVC (SERC Virginia/Carolina) subregional electricity grids, respectively. The SRVC subregional electricity grid was used for production of the baseline chemical, ACQ.
- For MCA, transport distances and modes of transport were modeled for the transport of formulation raw materials to the Millington and Rock Hill locations, and for product delivery to treatment sites based on data provided by Koppers. Transport data for ACQ were provided by Koppers during the original assessment.
- The investigated production systems contain upstream energy consuming unit operations, which not only use energy for transport and as fuel and electricity inputs, but also energy in the form of feedstock, mainly used for organic chemical manufacturing. The most prominent examples of such organic chemicals are the monoethanol amine (MEA) raw material used in the ACQ formulation. The use of feedstock material is counted as energy resource depletion if the consumption process does not preserve the feedstock material in such form that it can be used in a later stage as a raw material or fuel for other processes. (An example of such a feedstock use is the manufacturing of plastics, where energy raw materials such as oil or natural gas feedstock are preserved and may be at least partly used for the production of energy or recycled plastic.) In the lumber treatment case, post-utilization is rarely considered possible. For this reason, the feedstock components of the resource inputs are considered energy consumption and energy resource depletion.
- Similarly, use of copper for copper carbonate production was considered as metal resource depletion.

- Wood is impregnated at different concentrations (retentions) depending on the intended application. To calculate an average retention for both MCA and ACQ, it was assumed that 40% of the treated wood is used for above ground applications, and 60% is used in ground contact applications.
- Out of the 25 impact categories reviewed, the following core impact category indicators were identified, based on their environmental relevance to the systems studied: Energy Resource Depletion, Copper Resource Depletion, Terrestrial Biome Disturbance, Aquatic (River) Biome Disturbance, Aquatic (Lake) Biome Disturbance, Riparian/Wetland Biome Disturbance, Loss of Key Species, Global Climate Change, Arctic Climate Change, Ocean Acidification, Ocean Thermal loading, Ground Level Ozone Exposure Risks, PM_{2.5} Exposure Risks, Regional Acidification, and Risks from Radioactive Wastes.
- This assessment evaluated available data related to the toxicity of tebuconazole, used in the MCA wood treatment system. Based upon the likely routes of exposure, leachability studies, environmental fate and transport, risk assessment, and toxicity studies, tebuconazole used in treated wood is not likely to present a concern to human health and the environment. A more detailed discussion of this evaluation is provided in Appendix 1.
- Development of detailed site-specific environmental characterization factors (E-CF) at specific locations for upstream suppliers was not possible. Most of the basic chemical factories involved in upstream operations could not be modeled with actual process information, as data were unavailable. Instead, the processes were modeled with surrogate data from the Ecoinvent life cycle databases.
- Lacking detailed supplier information, much of the upstream raw materials extraction and processing could not be modeled with actual process information. Representative data from Ecoinvent databases were utilized as appropriate.

3.2 Product Formulation and Raw Materials

Koppers provided a material ingredient listing for their product which includes primarily basic copper carbonate and a triazole compound (e.g., tebuconazole, MTZ). While micronized copper is a primary fungicide and insecticide, the triazole compounds provide additional fungicide and insect resistance. Minor ingredients include calcium nitrite, sodium nitrite and proprietary dispersants. As noted previously, Koppers manufactures each of the two MCA products using alternative formulations primarily involving variations in concentration, changes to inert co-formulants and alternative chemical suppliers. Data for the alternative chemical formulations for each of the MCA products were provided by Koppers. Each of the MicroPro[®] product formulations vary with respect to material components and amounts, while formulations for the MicroPro[®] 200 products utilize an alternative supplier for copper carbonate.

A summary of materials and amounts (as a weight percentage of the final product) for each of the two MCA treatment chemicals is presented in Table 2, as provided by Koppers. For the MicroPro® product, the range of material amounts across alternative formulations is presented. Materials and amounts for the baseline ACQ treatment chemicals are summarized in Table 3.

Table 2. Koppers MCA material amounts.

Material	Percent of Final Weight	
	MicroPro® MCA (Millington)	MicroPro® MCA (Rock Hill)
Basic Copper Carbonate	49.5% - 59.0%	63.0%
Calcium Nitrite	0% - 1.3%	-
MTZ (tebuconazole)	1.4% - 4.3%	-
Sodium Benzoate	0% - 0.5%	-
Sodium Nitrite	1.3% - 2.0%	5.5%
Proprietary dispersant	6.2% - 9.0%	6.4%
Water	30.1% - 39.4%	25.1%

Table 3. Baseline ACQ material amounts.

Material	Percent of Final Weight
Copper Carbonate	13%
MEA	25%
Carbon Dioxide	6.5%
Ammonium Hydroxide	0.64%
Carboquat	10%
Antifoaming agent	~0.1%
Water	45%

3.3 Upstream Transportation

Transportation for the main input chemicals, from the first tier of the supply chain, was modeled based upon the distance to the production location in Millington, Tennessee, for ACQ and to both Millington and Rock Hill, South Carolina, for MCA. Transport modes and approximate transport distances were provided by the manufacturer. Second tier supplier transportation data were also available for some of the ACQ components and were used for the assessment. Product distribution assumed a 500 km transport distance by diesel truck for all products.

3.4 Inventory Results

Unit processes were developed within the OpenLCA v1.10 model, drawing upon data from multiple sources. Primary data were provided by Koppers in multiple documents as requested by SCS. The principal sources of secondary LCI data were the Ecoinvent life cycle inventory databases. Output of the unit process modeling is a life cycle inventory for the Koppers and baseline products.

The life cycle inventory data are summarized in Table 4 through Table 6 by separate life cycle phases for raw material extraction, transportation, including product distribution, and product manufacture. Inventory results are presented separately for each of the Koppers MCA products (MicroPro®; and MicroPro® 200) as well as the baseline ACQ product. Note that only inventory results relevant to the impact category indicators considered in this assessment are presented. The life cycle inventory data represent the net inputs and outputs associated with the material reference flows required to satisfy the functional unit of the modeled system (i.e., 1 billion board feet of impregnated wood). These inventory values were used to characterize the impact indicators in the impact assessment.

Table 4. Life cycle inventory of Koppers’ MicroPro® wood treatment chemical system (Millington manufacturing) for the treatment of 1 billion board feet (5,900 metric tons treatment chemical).

Parameter	Unit	Total*	Material Extraction	Transportation	Manufacturing
Emissions (outputs)					
Ammonia	metric tons	18.3	18.3	2.86x10 ⁻²	1.52x10 ⁻²
Carbon dioxide, fossil	metric tons	17,400	15,100	1,590	726
Carbon monoxide, fossil	metric tons	48.6	45.4	2.95	0.234
Dinitrogen monoxide	metric tons	1.81	1.76	3.78x10 ⁻²	1.25x10 ⁻²
Methane, fossil	metric tons	44.5	42.7	1.20	0.553
HFC-134a	metric tons	3.03x10 ⁻⁵	2.74x10 ⁻⁵	2.46x10 ⁻⁷	2.66x10 ⁻⁶
Hydrogen chloride	metric tons	2.68	2.51	3.76x10 ⁻²	0.132
Hydrogen fluoride	metric tons	0.268	0.250	3.84x10 ⁻³	1.45x10 ⁻²
Hydrogen sulfide	metric tons	0.183	0.159	2.33x10 ⁻²	3.62x10 ⁻⁴
Nitrogen oxides	metric tons	146	136	8.04	1.88
Organic carbon	metric tons	9.75x10 ⁻⁵	8.53x10 ⁻⁵	1.21x10 ⁻⁵	8.12x10 ⁻⁸
Sulfur dioxide	metric tons	11.0	10.4	0.610	9.36x10 ⁻³
Sulfur hexafluoride	metric tons	1.91x10 ⁻³	1.88x10 ⁻³	2.79x10 ⁻⁵	7.49x10 ⁻⁶
Sulfuric acid	metric tons	3.39x10 ⁻³	3.38x10 ⁻³	4.53x10 ⁻⁶	3.03x10 ⁻⁷
Particulates, < 2.5 um	metric tons	36.1	35.0	0.635	0.464
Particulates, < 10 um	metric tons	46.5	45.9	0.601	7.14x10 ⁻²
Volatile organic compounds	metric tons	23.7	22.3	1.29	5.03x10 ⁻²
Resources (inputs)					
Hard coal	metric tons	4,760	4,420	91.1	249
Lignite	metric tons	1,290	1,240	15.2	32.9
Natural gas	metric tons	1,710	1,580	30.6	91.8
Crude oil	metric tons	1,570	1,080	487	3.93
Uranium ore	metric tons	5.25x10 ⁻²	4.19x10 ⁻²	5.31x10 ⁻⁴	1.01x10 ⁻²
Copper	metric tons	1,700	1,700	0.209	0.109
Water	m ³	1,720	1,620	19.7	75.4

*totals may not agree due to rounding.

Table 5. Life cycle inventory of Koppers' MicroPro®MCA200 wood treatment chemical system (Rock Hill manufacturing) for the treatment of 1 billion board feet (5,900 metric tons treatment chemical).

Parameter	Unit	Total*	Material Extraction	Transportation	Manufacturing
Emissions (outputs)					
Ammonia	metric tons	21.4	20.3	2.56x10 ⁻²	1.14
Carbon dioxide, fossil	metric tons	53,500	16,900	1,690	34,800
Carbon monoxide, fossil	metric tons	64.0	46.3	3.16	14.5
Dinitrogen monoxide	metric tons	2.52	1.78	3.90x10 ⁻²	0.709
Methane, fossil	metric tons	82.6	47.1	1.29	34.2
HFC-134a	metric tons	2.81x10 ⁻⁴	3.01x10 ⁻⁵	2.66x10 ⁻⁷	2.50x10 ⁻⁴
Hydrogen chloride	metric tons	7.24	2.78	3.99x10 ⁻²	4.42
Hydrogen fluoride	metric tons	0.766	0.278	4.08x10 ⁻³	0.484
Hydrogen sulfide	metric tons	0.219	0.164	2.54x10 ⁻²	2.92x10 ⁻²
Nitrogen oxides	metric tons	236	151	7.75	76.9
Organic carbon	metric tons	1.13x10 ⁻⁴	9.44x10 ⁻⁵	1.33x10 ⁻⁵	4.94x10 ⁻⁶
Sulfur dioxide	metric tons	12.6	11.4	0.661	0.557
Sulfur hexafluoride	metric tons	2.61x10 ⁻³	2.12x10 ⁻³	3.02x10 ⁻⁵	4.63x10 ⁻⁴
Sulfuric acid	metric tons	3.76x10 ⁻³	3.73x10 ⁻³	4.81x10 ⁻⁶	2.11x10 ⁻⁵
Particulates, < 2.5 um	metric tons	56.0	38.9	0.666	16.4
Particulates, < 10 um	metric tons	54.7	50.7	0.628	3.32
Volatile organic compounds	metric tons	29.0	24.5	1.34	3.14
Resources (inputs)					
Hard coal	metric tons	13,400	4,940	98.6	8,370
Lignite	metric tons	2,530	1,400	16.5	1,120
Natural gas	metric tons	9,160	1,770	32.9	7,360
Crude oil	metric tons	1,950	1,130	520	306
Uranium ore	metric tons	0.897	4.75x10 ⁻²	5.74x10 ⁻⁴	0.849
Copper	metric tons	1,890	1,880	0.226	7.10
Water	m ³	6,820	1,830	21.3	4,970

*totals may not agree due to rounding.

Table 6. Life cycle inventory of the reference ACQ wood treatment chemical system for the treatment of 1 billion board feet (34,900 metric tons treatment chemical).

Parameter	Unit	Total*	Material Extraction	Transportation	Manufacturing
Emissions (outputs)					
Ammonia	metric tons	37.4	36.4	0.505	0.493
Carbon dioxide, fossil	metric tons	104,000	54,900	32,300	16,800
Carbon monoxide, fossil	metric tons	163	91.2	65.6	6.62
Dinitrogen monoxide	metric tons	4.90	3.81	0.759	0.324
Methane, fossil	metric tons	257	213	25.2	19.3
HFC-134a	metric tons	4.31x10 ⁻⁴	3.17x10 ⁻⁴	5.32x10 ⁻⁶	1.08x10 ⁻⁴
Hydrogen chloride	metric tons	9.17	6.45	0.805	1.91
Hydrogen fluoride	metric tons	0.925	0.634	8.21x10 ⁻²	0.210
Hydrogen sulfide	metric tons	1.83	1.34	0.460	2.42x10 ⁻²
Nitrogen oxides	metric tons	450	252	164	34.1
Organic carbon	metric tons	4.22x10 ⁻⁴	1.82x10 ⁻⁴	2.39x10 ⁻⁴	2.22x10 ⁻⁶
Sulfur dioxide	metric tons	30.9	17.6	12.5	0.758
Sulfur hexafluoride	metric tons	6.15x10 ⁻³	5.33x10 ⁻³	6.08x10 ⁻⁴	2.09x10 ⁻⁴
Sulfuric acid	metric tons	4.81x10 ⁻³	4.72x10 ⁻³	8.99x10 ⁻⁵	9.21x10 ⁻⁶
Particulates, < 2.5 um	metric tons	90.7	70.4	13.1	7.16
Particulates, < 10 um	metric tons	85.1	69.7	12.1	3.31
Volatile organic compounds	metric tons	83.6	54.8	26.8	1.89
Resources (inputs)					
Hard coal	metric tons	19,100	13,500	1,960	3,620
Lignite	metric tons	4,210	3,390	335	487
Natural gas	metric tons	12,300	7,880	633	3,810
Crude oil	metric tons	17,700	7,780	9,780	136
Uranium ore	metric tons	0.505	0.127	1.17x10 ⁻²	0.366
Copper	metric tons	2,280	2,270	4.54	3.08
Water	m ³	8,320	5,740	421	2,150

*totals may not agree due to rounding.

4. Environmental Impact Profile and Discussion of Results

4.1 Life Cycle Impact Assessment Methodology

Utilizing the data collected and analyzed during the LCI stage, category indicator results were calculated in accordance with the three mandatory LCIA elements in ISO 14044 and SCS-002:2018, 1) selection of impact categories, and category indicators; 2) assignment of LCI results to the selected impact categories (classification); and 3) calculation of category indicator results (characterization).

All category indicators representing the 25 impact categories identified in SCS-002:2018 standard were screened for their environmental relevance to the product systems. This standard uses the ISO 14044 definition of environmental relevance, which in §4.4.2.2.2 is defined as “the ability of the category indicator to reflect the consequences of the LCI results on the category endpoint.” Indicator results were screened to see if impacts to the environment or human health were occurring on a scale which was observable.

Core Impact Categories

Fifteen core impact categories were identified based on their relevance to the modeled systems:

- Energy Resource Depletion
- Water Resource Depletion
- Metals (Copper) and Mineral Resource Depletion
- Terrestrial Biome Disturbance
- Freshwater Biome Disturbance
- Riparian/Wetland Biome Disturbance
- Loss of Key Species
- Global Climate Change
- Arctic Climate Change
- Ocean Acidification Loading
- Ocean Warming
- Regional Acidification
- Ground Level Ozone Exposure Risks
- Particulate Matter (PM2.5) Exposure Risks
- Risks from Radioactive Wastes

The core impact categories for the product and baseline are primarily related to air emissions and resource depletion arising from resource use, electricity consumption, and transportation. The indicator results for the impact categories identified in Table 7 are summarized for the MicroPro® product system. Additionally, the water footprint for the product systems is estimated in conformance with ISO 14046.

Table 7. Core impact categories for the Koppers MicroPro® and ACQ production systems.

Core Impact?	Group 1. Resource Depletion	Core Impact?	Group 4. Regional Environmental Impacts from Emissions
√	Energy Resource Depletion		Stratospheric ODC Loading
√	Water Resource Depletion	√	Regional Acidification Loading
√	Minerals and Metals Resource Depletion		Ecotoxicity
	Biobased Resource Depletion		Eutrophication
	Group 2. Land Use Ecological Impacts		Group 5. Human Health Impacts from Emissions
√	Terrestrial Biome Disturbance	√	Ground Level Ozone Exposures
√	Freshwater Biome Disturbance	√	PM 2.5 Exposures
√	Riparian/Wetland Biome Disturbance		Toxic Emission – Effects from Inhalation (Chronic, non-carcinogenic)
√	Loss of Key Species (% by species)		Toxic Emission – Effects from Inhalation (Carcinogenic)
	Group 3. Impacts from GHG/BC Emissions		Indoor Air Toxic Emissions - Inhalation
√	Global Climate Change		Toxic Emission – Effects from Ingestion (Chronic, non-carcinogenic)
√	Arctic Climate Change		Toxic Emission – Effects from Ingestion (Carcinogenic)
√	Ocean Acidification		Group 6. Risks from Untreated Hazardous and Radioactive Wastes
√	Ocean Warming		Risks from Hazardous Waste (by Type)
		√	Risks from Radioactive Waste

The results of the LCI modeling, representing resource consumption and emissions, were then classified as required by Annex A of SCS-002:2018. See Appendix 3 of this report for which substances (life cycle inventory) were classified into which impact categories.

4.2 Indicator Calculations

Two types of characterization factors were used to calculate indicator results — stressor characterization factors (S-CFs) and environmental characterization factors (E-CFs). The amount of a substance (life cycle inventory) is multiplied by the S-CF and E-CF to produce an indicator result. The data that contributed to the assessment of these factors are discussed in detail for each impact category.

S-CFs represent the relative potency of individual stressors that contribute to a common environmental or human health midpoint. The S-CF establishes an equivalency among these stressors, making it possible to aggregate inventory results to establish Node 1 “potentials.”

E-CFs are applied to characterize both the providing and receiving environments, depending on the impact category. E-CFs allow for the integration of four types of environmental characterization data:

- *Temporal Characterization* – accounting for the duration, residence time, persistence, and timing of onset;

- *Spatial Characterization* – accounting for the geographic area affected by the identified stressor-effect network;
- *Characterization of Severity of Damage, Depletion or Disturbance* – measuring the intensity of specific midpoint or endpoint; and
- *Threshold Characterization* – accounting for the degree to which established human health and environmental threshold(s) have been or are projected to be exceeded.

A description of the core impact categories assessed and the characterization methodology for each are summarized in Appendix 2.

4.3 Summary of Indicator Results

Table 8 presents category indicator results for a production-weighted MicroPro® formulation of the Koppers Micronized Copper Azole (MCA) and the baseline Alkaline Copper Quaternary (ACQ) wood treatment chemicals. The percent reductions in impacts with respect to the baseline are also shown. Detailed impact category indicator calculation tables are provided in Appendix 3 for each of the Koppers MCA formulations, as well as for the baseline ACQ treatment chemical.

Table 8. Impact category indicator summary for Koppers MicroPro® MCA wood treatment chemical system and comparison to the baseline ACQ treatment chemical system*.

Impact Category	Units	MicroPro® MCA	ACQ	% Reduction in Impacts
Global Climate Change	Metric ton CO ₂ eq.	38,300	178,000	78%
Arctic Climate Change	Metric ton CO ₂ eq.	37,300	170,000	78%
Ocean Acidification	Metric ton CO ₂ eq.	32,700	186,000	82%
Ocean Warming	Metric ton CO ₂ eq.	36,600	158,000	77%
Regional Acidification	Metric ton SO ₂ eq.	166	481	65%
Ground Level Ozone Exposures	Persons*hrs*ppb O ₃	4,280	13,000	67%
PM-2.5 Exposures	Persons*hrs*µg/m ³ PM _{2.5}	20.9	48.4	57%
Risks from Radioactive Wastes	GBq eq.	1.43	10.1	86%
Energy Resource Depletion	MJ eq.	116,000	910,000	87%
Copper Resource Depletion	Metric ton Cu eq.	991	1,320	25%
Water Scarcity	m ³	2,340	9,900	76%
Land Use Ecological Disturbance ⁽¹⁾	Percent	1,830	8,320	78%

* Values calculated per 1 billion board feet of treated wood. Results rounded to three significant figures.

⁽¹⁾ Though it was not possible to calculate hectares disturbed, or species loss, and there were no data to suggest that oil plantations were environmentally certified, it was assumed that all land used to produce oils for carboquat production were transformed from its natural baseline condition, with resulting impacts on biomes and species.

4.4 Life Cycle Impact Profile

The environmental impacts of Koppers’ MCA wood treatment chemicals were quantified for 15 core impact categories. Impact category indicator results for MCA were calculated based on a production-weighted average of the manufacturer’s wood treatment chemical formulations. All impact categories result in reduced environmental impacts compared to the baseline ACQ treatment chemicals. Accordingly, SCS finds no environmental tradeoffs for MicroPro® as compared to the ACQ baseline for these indicators, and therefore the Koppers MicroPro® micronized copper azole (MCA) wood treatment chemicals qualify for certification as *Environmentally Preferable Wood Treatment Process*.

The impacts associated with the Koppers MCA product system compared to those of the reference ACQ baseline are illustrated in the Life Cycle Impact Profile shown in Figure 3 below. Impact reductions demonstrated by MCA ranges from 25% to 87% as compared to the ACQ baseline, depending on the indicator.

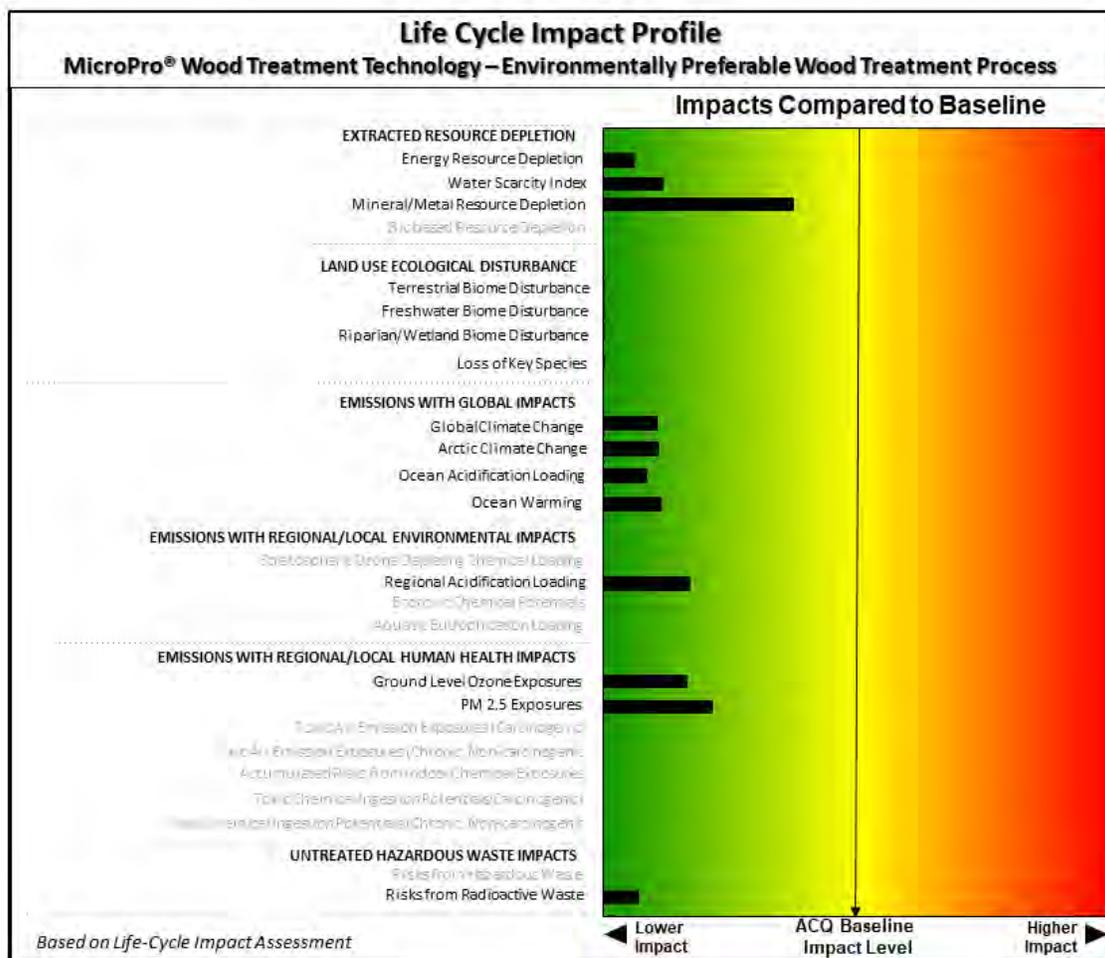


Figure 3. Life Cycle Impact Profile of the Koppers MicroPro® MCA wood treatment chemicals, based on production-weighted product formulations.

4.5 Contribution Analysis

Life cycle modeling of the MCA and ACQ treatment chemical systems was divided into distinct life cycle phases, including raw material extraction and processing, transportation and manufacturing. A detailed examination of the environmental impacts provides some insight into the relative contributions from each of the product's life cycle phases. Category indicator results, by life cycle phase, are summarized in Table 9 and Table 10 for the MicroPro® MCA and ACQ products, respectively.

Table 9. Impact category indicator summary for Koppers MicroPro® MCA wood treatment chemical system by life cycle phase*. Results shown as absolute values and as percent contribution.

Impact Category	Units	Total	Raw Materials	Transport	Manufacturing
Energy Resource Depletion	MJ	116,000	86,000	11,200	18,500
	%	100%	74%	9.7%	16%
Global Climate Change	Metric ton CO ₂ eq.	38,300	33,700	2,530	2,070
	%	100%	88%	6.6%	5.4%
Arctic Climate Change	Metric ton CO ₂ eq.	37,300	32,800	2,520	1,990
	%	100%	88%	6.8%	5.3%
Ocean Acidification	Metric ton CO ₂ eq.	32,700	27,200	2,840	2,660
	%	100%	83%	8.7%	8.1%
Ocean Warming	Metric ton CO ₂ eq.	36,600	32,500	2,380	1,740
	%	100%	89%	6.5%	4.7%
Regional Acidification	Metric ton SO ₂ eq.	166	155	7.48	3.55
	%	100%	93%	4.5%	2.1%
Ground Level Ozone Exposure	Persons*ppb O ₃ *hrs	4,280	3,980	233	67.9
	%	100%	93%	5.5%	1.6%
PM-2.5 Exposure	Persons*µg/m ³ PM _{2.5} *hrs	20.9	20.1	0.471	0.288
	%	100%	96%	2.3%	1.4%
Risks from Radioactive Wastes	GBq eq.	1.43	0.841	1.06x10 ⁻²	0.578
	%	100%	59%	0.74%	40%
Copper Resource Depletion	Metric ton	991	990	0.121	0.154
	%	100%	100%	0.012%	0.016%
Water Consumption	m ³	1,830	1,630	19.8	186
	%	100%	89%	1.1%	10%
Water Scarcity	m ³	2,340	2,050	26.6	258
	%	100%	88%	1.1%	11%

* Values calculated per 1 billion board feet (BBF) of treated wood.

Table 10. Impact category indicator summary for the baseline ACQ wood treatment chemical system by life cycle phase*. Results shown as absolute values and as percent contribution.

Impact Category	Units	Total	Raw Materials	Transport	Manufacturing
Energy Resource Depletion	MJ	910,000	437,000	226,000	248,000
	%	100%	48%	25%	27%
Global Climate Change	Metric ton CO ₂ eq.	178,000	104,000	51,500	22,800
	%	100%	58%	29%	13%
Arctic Climate Change	Metric ton CO ₂ eq.	170,000	97,100	51,300	22,000
	%	100%	57%	30%	13%
Ocean Acidification	Metric ton CO ₂ eq.	186,000	98,600	57,600	29,900
	%	100%	53%	31%	16%
Ocean Warming	Metric ton CO ₂ eq.	158,000	90,500	48,300	19,000
	%	100%	57%	31%	12%
Regional Acidification	Metric ton SO ₂ eq.	481	292	152	36.7
	%	100%	61%	32%	7.6%
Ground Level Ozone Exposure	Persons*ppb O ₃ *hrs	13,000	7,580	4,760	665
	%	100%	58%	37%	5.1%
PM-2.5 Exposure	Persons*µg/m ³ PM _{2.5} *hrs	48.4	35.3	9.61	3.52
	%	100%	73%	20%	7.3%
Risks from Radioactive Wastes	GBq eq.	10.1	2.54	0.234	7.32
	%	100%	25%	2.3%	72%
Copper Resource Depletion	Metric ton	1,320	1,320	2.63	1.79
	%	100%	100%	0.2%	0.14%
Water Consumption	m ³	8,320	5,740	421	2,150
	%	100%	69%	5.1%	26%
Water Scarcity	m ³	9,900	6,350	565	2,990
	%	100%	64%	5.7%	30%

* Values calculated per 1 billion board feet (BBF) of treated wood.

4.6 Data Quality Assessment

The data quality assessment addresses the following parameters:

- Time related (temporal) coverage
- Geographic (spatial) coverage
- Technology coverage
- Precision
- Completeness
- Representativeness
- Consistency
- Reproducibility
- Sources of Data
- Uncertainty

For the life cycle inventory and environmental characterization data used in this study, the overall data quality for data quality indicators are considered to be good.

Specific data were provided by Koppers for raw materials and manufacturing energy and resource use, together representing the key unit operations responsible for the largest contributions to all indicator results. Regional energy supply mixes for electricity production for all unit operations were based on regional eGRID data for 2018; inventory related to electricity production is high quality according to all data quality indicators. Inventory data representing upstream unit operations other than electricity were representative overall based on the use of data for similar processes from the Ecoinvent database. The data quality for inventory used in these upstream processes is of high quality when considering technological coverage, precision, and completeness, and of medium quality when considering temporal and geographical coverage, as well as representativeness. Inventory data were also considered to be complete for the indicators relevant to the comparison, with sources of data considered to be from documented and transparent sources.

For the environmental characterization data used in the life cycle assessment phase, overall data quality is high for the indicators addressed. Characterization factors can be globally applied for several indicators (e.g., Global Climate Change and Ocean Acidification) with the data quality considered to be very high as applied to all unit operations.

Inventory data for most unit operations, have data quality indicator ratings of medium or medium-low overall primarily due to the broad geographic regions over which impacts due to upstream transportation and material extraction and processing are associated. Environmental characterization data is complete for indicators relevant to the comparison, with transparent documentation of the derivation of E-CFs (see Appendix 3).

With respect to the overall EPWTP claim, the data quality should be considered high and accompanying uncertainty low. The uncertainty of this study does not affect the finding of the EPWTP claim; there is a high degree of confidence that the Koppers MicroPro® wood preservative chemical treatment system has a demonstrated lower environmental impact profile than the reference baseline system.

Data quality ratings were assigned to each of the 10 data quality parameters evaluated. The data quality ratings range from 1 (highest) to 4 (lowest) and are summarized for the Koppers LCA study in Table 11.

Table 11. Data quality ratings for the Koppers wood preservative LCA study.

Data Quality Parameter	Parameter Description	Data Quality Rating
Time-Related Coverage	Age of data and the minimum length of time over which data should be collected	2
Geographical Coverage	Geographical area from which data for unit processes should be collected to satisfy the goal of the study	2
Technology Coverage	Specific technology or technology mix	1
Precision	Measure of the variability of the data values for each data expressed (e.g., variance)	1
Completeness	Percentage of flow that is measured or estimated	1
Representativeness	Qualitative assessment of the degree to which the data set reflects the true population of interest (i.e., geographical coverage, time period and technology coverage)	2
Consistency	Qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis	1
Reproducibility	Qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study	1
Sources of the Data	Description of all primary and secondary data sources	2
Uncertainty of the Information	Uncertainty related to data, models, and assumptions	3
Overall data Quality	Overall assessment of data quality across all parameters and processes (average rating)	1.3

5. Summary and Conclusions

A “cradle-to-delivered product” life cycle assessment was conducted to evaluate the environmental impacts of Koppers’ MicroPro® (MCA) wood treatment chemical products in comparison to a reference baseline treatment chemical for certification as an Environmentally Preferable Wood Treatment Process (EPWTP). The result of the assessment is an environmental impact profile for each of the products evaluated. The assessment was conducted in accordance with ISO 14044 guidelines for conducting life cycle assessments and the SCS-002:2018 standard for Type III Life-Cycle Impact Profile Declarations for Materials, Products, Services and Systems. Impact assessments were estimated using client-supplied resource, energy use, and emissions data, generic life cycle inventory data, and various assumptions, as noted. Fifteen core impact categories were selected based on their relevance to the modeled system. Impact assessments comparing Koppers’ MicroPro® wood treatment chemical product(s) to competing baseline product demonstrated impact reduction in all categories.

The overall impact reduction demonstrated by MCA ranges from 25% to 87% as compared to the ACQ baseline. All impact category indicators assessed show lower values than the baseline, thus achieving the status of “Environmentally Preferable Wood Treatment System” as compared to the baseline product systems.

Appendix 1: The Toxicity of Tebuconazole

This assessment evaluated available data for the toxicity of the fungicide, tebuconazole, beyond its target microorganisms. Reports from the Canadian Pest Management Regulatory Agency,¹⁰ a UN FAO pesticide report,¹¹ MCA leachate studies,^{12,13} a U.S. EPA risk assessment,¹⁴ and several chemical databases were reviewed in order to ascertain the potential for tebuconazole to negatively impact human health, non-target organisms, and ecosystems. Data for tebuconazole was reviewed for leachability, bioaccumulation, biotransformation, environmental persistence, human and organismal toxicity, and chemical properties.

Tebuconazole has low water solubility, which is important to consider as it reduces the potential for leaching into groundwater and runoff. The American Wood Protection Association (AWPA) E11¹⁵ and E20¹⁶ leachability testing results conducted by Timber Products Inspection, Inc. compared the loss of tebuconazole as leachate from MCA treated wood with the loss of carboquat as leachate from ACQ treated wood. The MCA treated wood demonstrated similar percentage losses of tebuconazole as compared with the loss of carboquat from the ACQ product in both tests. The leachability testing also evaluated the loss of copper, the primary biocide component for both wood treatment systems. The MCA treated wood demonstrated a reduction in concentrations of copper leaching of over twenty-fold as compared to the ACQ treated wood.

In aqueous environments, tebuconazole will preferentially partition into sediments, and will persist for several years due to the relatively long degradation time. Tebuconazole is relatively stable and abiotic transformation and biotransformation was not found to be important transformation routes in the environment. Tebuconazole adsorbs to sediments, particularly soils high in clay content, and as such is not readily mobilized. Tebuconazole could not be detected in deeper soils and would not be expected to contaminate groundwater.¹⁷ Although the fungicide is persistent in the environment, toxicity tests in earthworms, bluegill sunfish,¹⁸ and rats¹⁹ demonstrated that the fungicide does not bioaccumulate and is rapidly removed from the organisms.

¹⁰ *Regulatory Notice REG2006-11*. Pest Management Regulatory Agency. Health Canada. 2006.

¹¹ Joint Meeting of the FAO Panel of Experts on Pesticide Residues in Food and the Environment and the WHO Expert Group on Pesticide Residues. FAO/WHO. pg. 1055 – 1096. 1994.

¹² *AWPA E11 Leachability Testing*. Timber Products Inspection Inc. Nov. 8, 2007.

¹³ *AWPA E20 Leachability Testing*. Timber Products Inspection Inc. Nov. 15, 2007.

¹⁴ Tebuconazole: Residential Exposure and Risk Assessment of Existing Antimicrobial Uses on Wood Products and in Paints. U.S. EPA Memorandum: EPA-HQ-OPP-2005-0097. Nov. 26, 2007.

¹⁵ *AWPA E11 Leachability Testing*. Timber Products Inspection Inc. Nov. 8, 2007.

¹⁶ *AWPA E20 Leachability Testing*. Timber Products Inspection Inc. Nov. 15, 2007.

¹⁷ *Regulatory Notice REG2006-11*. Pest Management Regulatory Agency. Health Canada. 2006.

¹⁸ *Regulatory Notice REG2006-11*. Pest Management Regulatory Agency. Health Canada. 2006.

Tebuconazole was found to be minimally irritating to the eyes, non-irritating to the skin, and to not result in dermal sensitization.²⁰ The fungicide is relatively non-volatile and inhalation would not be an expected route of exposure. Ingestion of tebuconazole from treated wood would not be expected; however, tebuconazole was found to have slight acute toxicity from oral exposure. The World Health Organization lists the fungicide as slightly hazardous for acute toxicity.²¹ A review of the following databases did not reveal any data suggesting tebuconazole presents a concern for reproductive or developmental toxicity: California Prop 65 Developmental and Reproductive Lists and the U.S. TRI Developmental and Reproductive Toxin Lists. Several prominent databases of carcinogens, including IARC, U.S. NTP, and California Prop 65, did not list tebuconazole as a known carcinogen; however, the U.S. EPA Office of Pesticide Programs Carcinogen List describes tebuconazole as a possible human carcinogen. The European Union Prioritization List for endocrine disruptors includes the fungicide as a Class III priority. This level of classification is for chemicals evaluated as “low concern in terms of human and wildlife exposure” and prioritizes them for further research.

The U.S. EPA conducted a risk assessment²² to evaluate the risk to human health from exposure to tebuconazole treated wood. The risk assessment modeled a conservative scenario of children playing on wooden playground equipment. Direct dermal contact with the wood and incidental oral exposure to the fungicide was modeled as the likely exposure routes. The risk assessment acknowledged that children may be exposed to higher concentrations of tebuconazole through ingestion of the soil; however, this pathway was seen as less likely and less frequent than direct contact with the wood surface. The report concluded that children were not at risk from exposure to tebuconazole treated wood containing 0.02 pounds per cubic foot (pcf) tebuconazole.

For this assessment, the treated wood tebuconazole loadings were all well below the EPA-reported “no concern” loading of 0.02 pcf. (Exceedance of that risk threshold would have been a barrier to achieving certified EPP status).

Based upon the likely routes of exposure, leachability studies, environmental fate and transport, risk assessment, and toxicity studies, it was determined that tebuconazole used in treated wood does not present a hazard to human health and the environment.

¹⁹ Joint Meeting of the FAO Panel of Experts on Pesticide Residues in Food and the Environment and the WHO Expert Group on Pesticide Residues. FAO/WHO. pg. 1055 – 1096. 1994.

²⁰ *Regulatory Notice REG2006-11*. Pest Management Regulatory Agency. Health Canada. 2006.

²¹ The WHO Recommended Classification of Pesticides by Hazards and Guidelines to Classification 2004. International Program on Chemical Safety. April 12, 2005.

²² Tebuconazole: Residential Exposure and Risk Assessment of Existing Antimicrobial Uses on Wood Products and in Paints. U.S. EPA Memorandum: EPA-HQ-OPP-2005-0097. Nov. 26, 2007.

Appendix 2: Impact Assessment Characterization Methodology

<i>Energy Resource Depletion</i>	28
<i>Global Climate Change</i>	30
<i>Arctic Climate Change</i>	32
<i>Ocean Acidification</i>	35
<i>Ocean Warming</i>	35
<i>Regional Acidification</i>	36
<i>Ground Level Ozone Exposure Risks</i>	38
<i>PM2.5 Exposure Risks</i>	40
<i>Risks from Radioactive Wastes</i>	43
<i>Copper Resource Depletion</i>	45
<i>Water Scarcity</i>	46

Energy Resource Depletion

Impact Category

This impact category reflects the relative abundance and depletion of feedstock reserves resulting from the net consumption of non-renewable energy resources used for electric power generation, operations and transport, and for incorporation into materials such as plastics. This indicator takes into account the amount of resources used for the function under study, the availability of economically recoverable reserves, the degree to which such resources may be replenished, the relative efficiency of power generation systems and fuel systems, and whether the resource is available for reuse at end of life (e.g., recycling). All energy resources which are consumed in a non-renewable fashion are included. For this study, this includes fossil fuels and uranium.

Indicator Calculations

For this category indicator, the S-CF characterizes the energy content of each energy resource using the lower heating value (LHV). The E-CF, or Resource Depletion Factor (RDF), is a unitless factor, defined by energy resource, which characterizes the projected total consumption by all users of the resource over the next 25 years, compared to its current reserve base.

Stressor Characterization Factors

The S-CF for this category indicator is characterized using two data sources:

- For fossil fuels, the average heat content of fossil fuel receipts in 2014 from the USEIA is used.²³ This distinguishes average heat content based on specific regions in the US.
- For uranium, data are from the Organization for Economic Cooperation and Development (OECD) and International Atomic Energy Agency (IAEA), specifying the thermal energy content per ton of uranium.²⁴ This data is not regionally specific.

The energy content of each energy resource type classified is shown in Table A.1. The S-CF values are defined based on lower heating value of the fuels.

²³ US Energy Information Administration: Electric Power Monthly, March 2014. *Appendix C: Technical Notes. Table C1: Average Heat Content of Fossil-Fuel Receipts, March 2014.*

http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_c_1

²⁴ Appendix 5 of OECD Nuclear Energy Agency and the International Atomic Energy Agency. Uranium 2009: Resources, Production and Demand.

Table A.1. Fuel energy content in metric units. Based on Lower Heating Values (LHV).

Resource	Heat Content (LHV)	Unit
Coal, brown	17.4	MJ / kg
Coal, hard	23.9	MJ / kg
Gas, mine, off-gas, process, coal mining	42.7	MJ / m ³
Gas, natural	42.7	MJ / m ³
Oil, crude	45.6	MJ / kg
Uranium	900,000	MJ / kg

Environmental Characterization Factors

The RDFs were calculated by evaluating the ratio of projected production of an energy resource, from 2010 through 2035, over its estimated reserve base.

The production levels and reserve bases included are those relevant to the North American situation, where the product systems under study are located. This includes natural gas and coal produced in the US, and crude oil and uranium produced globally. The USEIA has estimated that in the next 25 years, between 90% to 95% of natural gas and coal (including metallurgical coal) consumed in the US will be produced domestically. However, USEIA data shows that domestic consumption of crude oil and uranium is dependent in large part on global supplies.²⁵

For the RDF calculations, both proven and unproven reserves considered to be technically recoverable were included. The inclusion of reserves in the “unproven” reserve category leads to some uncertainty; however, the uncertainty from excluding these reserves is significantly larger, as most unconventional reserves of natural gas are considered “unproven.” For natural gas, these unproven unconventional reserves account for as much as five times the total amount of proven conventional reserves,²⁶ and their exclusion leads to an RDF value for natural gas which is significantly overestimated.

The RDFs for the classified energy resources are shown in Table A.2.

²⁵ US Energy Information Administration. *Annual Energy Outlook 2012*.

²⁶ US Geological Survey. *National Assessment of Oil and Gas Project: Continuous Gas Resources*. Updated August, 2012. Retrieved on 10/17/2012 from http://certmapper.cr.usgs.gov/data/noga00/natl/tabular/2012/Summary_12_Final.xls

Table A.2. RDF values for a 25-year time horizon (from 2010 to 2035) used in this study. Except for uranium production (based on data from OECD/IAEA), data on total production is from USEIA. Data regarding reserve bases are from multiple sources, listed in the table.

Reserve (Region of Reserve)	RDF25	Total Production 2010-2035	Reserve Base Estimate	Resources included in Reserve Base Estimate (Data Source)
Hard Coal* (US Reserves)	0.047	12.4 billion short tons	265 billion short tons	Demonstrated Reserve Base (USEIA)
Lignite Coal (US Reserves)	0.006	2.2 billion short tons	374 billion short tons	Demonstrated Reserve Base (USEIA)
Oil (Global Reserves)	0.46	953 billion barrels of oil	2,070 billion barrels of oil	Proved Reserves (USEIA), Conventional Undiscovered Reserves (USGS), Unproven technically recoverable reserves (USEIA)
Gas (US Reserves)	0.56	615.2 trillion cubic feet	1,106 trillion cubic feet	Total Gas Resources (USGS)
Uranium (Global Reserves)	0.42	2,647,275 tons Uranium	6,306,300 tons Uranium	Reasonably Assured and Inferred Reserves <USD 260/Kg U (OECD and IAEA)

*Includes both anthracite and bituminous coal.

Global Climate Change

Impact Category

This impact category addresses the many endpoints which are linked to global climate change. All results are calculated based on the integrated radiative forcing (IRF) occurring before the +1.5°C global mean temperature (GMT) anomaly threshold, projected to occur approximately 20 years in the future (by 2035). Beyond this threshold, irreversible changes are anticipated to occur to the global climate; this threshold was considered for use as the maximum temperature target defined in the 2009 Copenhagen Accord, under the United Nations Framework Convention on Climate Change (UNFCCC) process.

In this study, the +1.5° Celsius GMT anomaly threshold is the most appropriate, as the IRF resulting from the net additional burden of climate forcers in the atmosphere becomes uncertain over time horizons longer than 20 years. Results according to this threshold are therefore the most accurate and representative.

Indicator Calculations

Classification

All emissions which contribute to changes in global radiative forcing throughout the product system are classified.

Characterization

All emissions were characterized using Global Forcing Potentials, calculating using a 20-year time horizon (GFP-20). A summary of the GFP-20 values used in the study is shown in Table A.3.

Table A.3. The emissions causing climate forcing, the Global Forcing Potential over 20 years (including expected value and confidence interval representing the estimated standard deviation), and the source used to establish the GFP.

Emission	GFP (Over 20 years)	Radiative Effects Included	Basis of Global Forcing Potential
Black carbon, emitted from fossil fuel	3,081 ± 35%	<ul style="list-style-type: none"> • Direct radiative effect • Effects from deposition on ice and snow • Cloud absorption effects 	IRF is based on Specific Forcing Pulse (SFP) values from Bond (2011). ²⁷ The SFP values are converted to IRF using the method described in Section 2.5.2 of the Bond paper and compared to the IRF of pulse CO ₂ emissions from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). ²⁸ These SFPs only consider the direct radiative effect and effect on snow and ice. To estimate the cloud absorption effects, the percent increase in these effects is estimated from Table 1 of Bond, et al. (2013), ²⁹ which shows that combined cloud absorption effects increase the other two effects by roughly +23%, when considering all emissions. The estimate of the IRF resulting from cloud absorption effects is added linearly with the IRF for direct effects calculated from SFP values from Bond (2011). GFP values are calculated by normalizing black carbon IRF to the IRF for CO ₂ from the IPCC AR5.
Carbon dioxide	1	<ul style="list-style-type: none"> • Direct radiative effect • Effect on carbon cycle 	By definition, the GFP is 1 for CO ₂ .
Carbon monoxide	5.6	<ul style="list-style-type: none"> • Multiple effects 	Used Global Warming Potential over 20 years (GWP-20) from the IPCC AR5.
Methane	104 ± 12%	<ul style="list-style-type: none"> • Direct radiative effect • Formation of tropospheric ozone • Effect on stratospheric water vapor • Increase in methane lifetime • Reduction in sulfate cooling 	From Shindell (2009), ³⁰ adjusted for the updated IRF values for CO ₂ in the IPCC AR5.
Nitrogen oxides	122 ± 68%	<ul style="list-style-type: none"> • Short-term ozone formation • Effect on methane 	Based on IRF from the IPCC AR5, which characterizes effects on ozone, methane, sulfates, and stratospheric water vapor. The IRF for nitrate effects is from Bauer (2007) ³¹ and Collins, et al (2013). ³² The effect on the

²⁷ Bond, T., et al. Quantifying immediate RF by black carbon and organic matter with the Specific Forcing Pulse. *Atmos. Chem. Phys.*, 11, 1505-1525, 2011.

²⁸ Myhre, G., et al, 2013: Anthropogenic and Natural RF. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*

²⁹ Bond, T. C., et al. (2013), Bounding the role of black carbon in the climate system: A scientific assessment, *J. Geophys. Res. Atmos.*, 118, 5380–5552, doi:10.1002/jgrd.50171.

³⁰ Shindell, D.T., et al. *Improved Attribution of Climate Forcing to Emissions.* *Science*, Vol. 326, 716-720. Oct. 2009.

³¹ Bauer, S.E., et al (2007): Nitrate aerosols today and in 2030: a global simulation including aerosols and tropospheric ozone. *Atmos. Chem. Phys.*, 7, 5043-5059.

Emission	GFP (Over 20 years)	Radiative Effects Included	Basis of Global Forcing Potential
		lifetime <ul style="list-style-type: none"> • Long-term effect on ozone concentrations (result from effect on methane lifetime) • Effect on stratospheric H₂O • Effect on sulfate aerosol concentrations • Formation of nitrate aerosols • Effect on terrestrial carbon cycle 	terrestrial carbon cycle is calculated considering the radiative effect which results from the reduction in carbon uptake in plants as a result of exposure to ground level ozone, based on assumptions of high sensitivity in plants to ozone, modeled according to Figure 4 of Collins (2010). ³³ GFP values are calculated by normalizing NO _x IRF to the IRF for CO ₂ from the IPCC AR5.
Nitrous oxide	264 ± 11%	<ul style="list-style-type: none"> • Direct radiative effect 	Used GWP-20 from the IPCC AR5.
Sulfur dioxide	-313 ± 18%	<ul style="list-style-type: none"> • Direct radiative effect resulting from formation of sulfate aerosols • Aerosol-cloud interactions resulting from formation of sulfate aerosols 	The direct effects from sulfur dioxide emissions are from Table 1 of Collins, et al (2013), reporting the direct effect from emissions in North America. The radiative effect from aerosol-cloud interactions is estimated to augment the direct effect by 100%. ³⁴
Sulfur hexafluoride	17,500	<ul style="list-style-type: none"> • Direct radiative effect 	Used GWP-20 from the IPCC AR5.
Other Climate Forcers	Varies		Other climate forcers collectively account for less than 0.01% of final results. GWP-20s are based on those from the IPCC Fourth and Fifth Assessment Reports.

Arctic Climate Change

Impact Category

The impact category of Arctic Climate Change accounts for effects on the Arctic climate, using a model developed by Shindell and Faluvegi that characterizes the Arctic surface temperature response to an emission.^{35,36} This model is called the Absolute Regional Temperature Potential (ARTP). The method accounts for direct radiative forcing (RF) within the Arctic region, and the indirect transport of heat into the region from lower latitudes caused by RF elsewhere. For the purposes of this analysis, the Arctic is defined as the region of the Earth’s surface north of 60° North latitude. Results are calculated using a 20-

³² Collins, et al (2013): Global and regional temperature-change potentials for near-term climate forcers. *Atmos. Chem. Phys.*, 13, 2471-2485 2013.

³³ Collins, W.J., et al (2010): How vegetation impacts affect climate metrics for ozone precursors. *Journal of Geophysical Research*, Vol. 115, 2010.

³⁴ This is consistent with the approach used in Shindell (2009) to estimate the effect from SO₂ emissions resulting from aerosol-cloud interactions.

³⁵ Shindell, D., and G. Faluvegi. *Climate response to regional RF during the twentieth century*. *Nature Geoscience*, Vol 2., April 2009, 294-300.

³⁶ Shindell, D.T. Evaluation of the absolute regional temperature potential. *Atmos. Chem. Phys.*, 12, 7955-7960, 2012.

year time horizon, reflecting the immediate nature of impacts occurring and projected to occur to the Arctic climate.

Indicator Calculations

Classification

All emissions which contribute to increased radiative forcing in the Arctic region are classified.

Characterization

All emissions were characterized using Arctic Temperature Potentials, calculating using a 20-year time horizon (ATP-20), using the model established by Shindell and Faluvegi. A summary of the ATPs used in the study is shown in Table A.4.

Table A.4. The emissions causing climate forcing and subsequent effect on Arctic temperatures, the Arctic Temperature Potential using a 20-year time horizon (including expected value and confidence interval representing the estimated standard deviation), and the source used to establish the ATP. All ATP values assume emission occurs within the US and Canada. The radiative effects included are the same as those used to calculate GFP-20 values, shown in Table A.3.

Emission	ATP (Over 20 years)	Basis of Characterization Factor
Black carbon	1,528 ± 18%	ATPs are derived from SFP values from Bond et al. (2011). ³⁷ The characterization includes the direct and indirect effects of black carbon on ice and snow, and accounts for differences in fate and transport and underlying albedo based upon the region of emission. Cloud absorption effects are included based on the assumption that these effects increase the direct effect of BC by 13% to 40% (expected value uses the midpoint of 26.5%). ³⁸ Used climate response from Flanner (2013), assuming that most of the black carbon emitted far from the Arctic is transported to the Arctic above the surface mixing layer, at altitudes of 3 kilometers or higher. ³⁹
Carbon dioxide	1	The ATP-20 of CO ₂ is exactly one, by definition.
Nitrous oxide	274 ± 20%	The RF is calculated for these emissions using data on atmospheric lifetime and radiative efficiency from the IPCC AR5. The confidence interval is the confidence interval in the AGTP-20 for CH ₄ from Reisinger (2010), which is -26/+30%. ⁴⁰
Methane	69 ± 20%	The RF for methane emissions from Shindell (2009) ⁴¹ are used to establish ATP-20 values. Uncertainty in ATP is the confidence interval in the AGTP-20 for CH ₄ from Reisinger (2010), which is -26/+30%.
Nitrogen oxides	113 ± 42%	The effect from increased ozone formation and sulfate aerosol destruction (causing warming), and methane removal (causing cooling), is modeled using the ATP-20 values published in Collins (2013). The effect on nitrate aerosols is modeled from Bauer, et al. (2007), as described in Collins, et al., 2013. ⁴² The indirect effect on the carbon cycle resulting from NO _x emissions is based on Collins, et al., 2010. ⁴³
Sulfur dioxide	-118 ± 20%	The ATPs for SO ₂ are taken from Collins, et al., 2013. ⁴⁴ The aerosol indirect effect is estimated by assuming that this effect augments the direct effect by 100%, taking the uncertainty range to be 50% to 150%.
Other Emissions	Not included	ATPs were not available for the other climate forcers emitted from the product systems in the scope. However, the combined radiative effect of all other climate forcers accounts for less than 0.5% of the total, and this omission will have no effect on results, considering the uncertainty in ATP-20s for those forcers with significant effect on final results.

³⁷ Bond, T., et al. *Quantifying immediate RF by black carbon and organic matter with the Specific Forcing Pulse*. Atmos. Chem. Phys., 11, 1505-1525, 2011.

³⁸ Provided through personal communication with Mark Z. Jacobson, Professor of Civil and Environmental Engineering, Director, Atmosphere/Energy Program, at Stanford University. Received on 6/26/2013.

³⁹ Flanner, M.G. *Arctic climate sensitivity to local black carbon*. Journal of Geophysical Research: Atmospheres, Vol. 118, 1-12, 2013.

⁴⁰ Reisinger, A., et al., 2010: Uncertainties of global warming metrics: CO₂ and CH₄. Geophysical Research Letters, 37, L14707.

⁴¹ Shindell, D.T., et al. *Improved Attribution of Climate Forcing to Emissions*. Science, Vol. 326, 716-720. Oct. 2009.

⁴² W.J. Collins, et al. *Temperature-change potentials for near-term climate forcers*. Atmos. Chem. Phys., 13, 2471,2485, 2013.

⁴³ Collins, W.J., S. Sitch, and O. Boucher. *How vegetation impacts affect climate metrics for ozone precursors*. Journal of Geophysical Research, Vol. 115, D23308, 2010.

⁴⁴ W.J. Collins, et al. *Temperature-change potentials for near-term climate forcers*. Atmos. Chem. Phys., 13, 2471,2485, 2013.

Ocean Acidification

Impact Category

This impact category characterizes the degree to which increased atmosphere CO₂ levels linked to the product systems under study lead to increases in the burden of carbonic acid in the world's oceans, decreasing ocean pH levels.

Indicator Calculations

Classification

The only emissions which contribute to Ocean Acidification are carbon dioxide and methane. All emissions of carbon dioxide and methane are classified.

Characterization

The S-CF reflects the potential amount of carbonic acid (H₂CO₃) formed for a given emission. For carbon dioxide, the S-CF is 1.41; for methane, the S-CF is 3.87.

For absorption of carbon dioxide resulting from emissions in the product system, a CO₂ Absorption Factor of 0.25 is used, characterizing the current annual average absorption rate of carbon dioxide into the oceans.^{45,46} The Ocean Acidity Factor used is 1.26, reflecting a 0.1 decrease in pH of the oceans since pre-industrial times.^{47,48}

Ocean Warming

Impact Category

Approximately 80% of the heat trapped by greenhouse gases and black carbon is stored in the oceans, which has led to significant ecosystem impacts in ocean basins around the world. While the same climate forcers affecting global climate change are causing this impact, it is considered a distinct environmental mechanism, and so is accounted for separately under the SCS-002:2018 protocols.

Greenhouse gas and black carbon loadings contributing to ocean warming are calculated on a fifteen year time horizon (representing the time until the 2030 tipping point for irreversible damage to the

⁴⁵ Global Carbon Project. Global Carbon Budget. <http://www.globalcarbonproject.org/carbonbudget/12/data.htm>

⁴⁶ National Oceanic and Atmospheric Administration: PMEL Carbon Program. Ocean Acidification: The Other Carbon Dioxide Problem. <http://www.pmel.noaa.gov/co2/story/Ocean+Acidification>

⁴⁷ Pelejero, C., et al. *Paleo-perspectives on ocean acidification*. Trends in Ecology and Evolution. Volume 25, Issue 6, June 2010, Pages 332-344.

⁴⁸ Jacobson, M.Z. Studying ocean acidification with conservative, stable numerical schemes for nonequilibrium air-ocean exchange and ocean equilibrium chemistry. J. Geophys. Res., 110, D07302.

global ocean ecosystem) and are expressed in units of metric tons of carbon dioxide equivalents (Mg CO₂ eq.).

Indicator Calculations

This indicator was assessed with an E-CF which is applicable globally. S-CFs are based on the projected ocean exceedance of threshold in 2030 and used a 15-year time horizon.

Regional Acidification

Impact Category

Regional acidification occurs when acidifying emissions deposit on sensitive soils and major inland water bodies (i.e., as acid rain). Deposition of these strong acids in unbuffered soils results in a decrease in pH, which may cause heavy metals to become mobile in the environment and negatively affect exposed flora and fauna. Inland water bodies may also be affected by deposition of strong acids through changes in pH.

Deposition of these acids on buffered soils, such as limestone, does not result in changes to soil pH and mobilization of heavy metals. Therefore, only deposition of these acids in sensitive soils and inland water bodies are considered.

Indicator Calculations

Classification

All air emissions of acid precursors and strong acids are classified in this indicator. See Table A.5.

Characterization

Stressor Characterization Factors

The S-CFs represent the potential of substances to release hydrogen ions into the receiving environment, compared to the potential for the reference substance, sulfur dioxide, to release hydrogen ions into the receiving environment. The S-CFs used in this category indicator are shown in Table A.5., from Table 5.2 of Annex A of the draft SCS-002:2018 standard.⁴⁹

⁴⁹ The original source of the S-CFs is from the EDIP97 method: Environmental Design of Industrial Products (EDIP), in Danish UMIP. 1996.

Table A.5. Potential for release of hydrogen ions per kilogram of substance, compared to potential for release of hydrogen ions per kilogram of sulfur dioxide.

Substance	Formula	g SO ₂ eq / g substance
Ammonia	NH ₃	1.88
Hydrochloric acid	HCl	0.88
Hydrofluoric acid	HF	1.60
Hydrogen sulfide	H ₂ S	1.88
Nitric acid	HNO ₃	0.51
Nitric oxide	NO	1.07
Nitrogen dioxide	NO ₂	0.70
Nitrogen oxides	NO _x	1.07
Phosphoric acid	H ₃ PO ₄	0.98
Sulfur dioxide	SO ₂	1.00
Sulfuric acid	H ₂ SO ₄	0.65

Environmental Characterization Factors

The E-CF for this indicator represents the fraction of acidifying emissions which deposit into regions with sensitive soils and inland freshwater bodies. E-CFs are defined separately by key unit process, using air dispersion models on a site-specific basis, which assess the deposition of acidifying substances from emission plumes for all key unit operations. To assess the E-CFs, the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) dispersion model was used to assess the fraction of strong acids depositing into sensitive soils, mapped out using the Harmonized World Soil Database.

For the products under review, emissions of acidic precursors are dominated by contributions from the generation of electric power. The dispersion of these emissions can extend for hundreds of kilometers from their sources. As specified in the SCS-002:2018 methodology, the deposition of acidifying compounds in sensitive regions was estimated using site-specific air dispersion modeling, with the E-CF used in this indicator result characterizing the percentage of emissions depositing into soils in exceedance of their natural buffering capacity and inland freshwater bodies. It is assumed electricity for Koppers manufacturing facilities in Millington, TN and Rock Hill, SC is provided by the SRTV and SRVC power grid subregions, respectively. Electricity for the baseline manufacturing processes is assumed to be from the SRVC power grid subregion.

The Southeastern United States, where some of the manufacturing operations for Koppers are located, as well as the assumed region for production of the baseline products, is a hot spot for regional acidification. Soils and waterways in the region are extremely sensitive to the deposition of strong acids, and accordingly, most emissions from the unit processes result in deposition in areas in exceedance of threshold. The environmental characterization factors used for computing the contribution to the indicator result from each major unit process are shown in Table A.6. Note that regional modeling of impacts associated with transportation routes and product packaging was beyond the scope of the study and emissions from these activities are assumed to be distributed across the Southeastern US within the SERC power region (including SRSO, SRVC, SRTV, SRMW and SRMV subregions). The E-CF location describes the assumed source of the emissions.

Table A.6. Environmental characterization factors used for assessment of category indicator results for Regional Acidification. The E-CF is the fraction of acidifying emissions depositing in sensitive soils and freshwater bodies.

Unit Process	Material Extraction	Transportation	Manufacturing (Millington, TN)	Manufacturing (Rock Hill, SC)	Manufacturing (Baseline)
Location	SERC eGRID Region	SERC eGRID Region	SRTV eGRID Sub-Region	SRVC eGRID Sub-Region	SRVC eGRID Sub-Region
% deposition into regions of exceedance	80%	80%	79%	91%	91%

Ground Level Ozone Exposure Risks

Impact Category

Emissions of NO_x and certain volatile organic compounds (VOCs) undergo a complex series of photochemical reactions that lead to the formation of ozone (O₃). Human health impacts are widely recognized to occur when ground level ozone (GLO) is found at concentrations above critical threshold concentrations; in the US and European Union, emissions are regulated in recognition of these thresholds. For example, the USEPA has set National Ambient Air Quality Standards (NAAQS) to protect human health from several air pollutants, including ozone. The current NAAQS standard for ozone exposure limits ozone concentrations to 75 parts-per-billion (ppb), based on the 3-year average of the fourth highest daily maximum ozone concentrations over an 8-hour averaging period. These NAAQS threshold levels are also used to assess air quality with respect to human health, to invoke “spare the air days,” and to seek mitigation and controls from major sources of precursor emissions in a given region. However, this 75 ppb threshold does not address the chronic effects from GLO that occur at lower concentrations.

The SCS-002:2018 standard requires that in characterization of results for GLO Exposure Risks, the health threshold for ozone exposure, is based upon a threshold of chronic exposure effects to the most sensitive subpopulations, reflecting the health threshold determined by the World Health Organization (WHO). WHO has set the health threshold as an average of 60 ppb over an 8-hour period; this corresponds to chronic human exposures over 60 ppb. This is the regulatory guideline imposed in the European Union as well. Regions that exceed this 60 ppb 8-hour health guideline at any point during the ozone formation season are considered to be in exceedance of the threshold. Based on this threshold, this category indicator accounts for emission precursors that contribute to GLO formation in regions in which concentrations of GLO exceed the 60 ppb 8-hour health threshold at any point during the year.

The category indicator represents the accumulated exposure risks, as the total number of people exposed to an emission, multiplied by the hours of cumulative ozone exposure using the AOT60 metric. Using this measurement, the category indicator result is scaled by the cumulative risk factor (CRF) to reflect the severity of exceedance of threshold and accumulated risks from continued multi-year exposures over this defined threshold.

Indicator Calculations

Classification

All receiving environments in this study are assumed to be in NO_x-limited environments, with little or no incremental contribution to ozone formation occurring from emissions of VOCs. NO_x emissions are the only substances which contribute to ozone formation in these conditions, and are the only emissions classified. NO_x emissions which were classified included emissions to air of nitrogen dioxide, nitrogen oxide, and unspecified nitrogen oxides.

Characterization

Stressor Characterization Factors

Specific regional data regarding the conversion rates of ozone precursors are not available; an S-CF of 1.0 kg O₃/ kg nitrogen oxide is a reasonable estimate for nitrogen oxide-limited environments. This is consistent with research exploring the effect of ozone formation resulting from a pulse emission of NO_x; this research found that a pulse emission of one Teragram of NO_x leads to the formation of 0.9 Teragrams of ozone (0.5 to 1.3).⁵⁰

Environmental Characterization Factors

The indicator result characterizes, on a regional basis, the chronic exceedance of the 60 ppb 8-hour health threshold using the “AOT60” air quality metric, accumulated over an ozone season. E-CFs are calculated separately by key unit process with site-specific air dispersion modeling using the HYSPLIT dispersion model and integrated with population density data to quantify the number of individuals and severity of exposure to ground level ozone.

As with the regional acidification indicator, for the product systems under review, ozone precursor emissions are dominated by contributions from the generation of electric power; dispersion of these emissions can extend for hundreds of kilometers from their sources. It is assumed electricity for Koppers manufacturing facilities in Millington, TN and Rock Hill, SC is provided by the SRTV and SRVC power grid subregions, respectively, while electricity for the baseline manufacturing processes is assumed to be from the SRVC power grid region. The environmental characterization factors used for computing the contribution to the GLO exposure indicator result from each major unit process are shown in Table A.7. The E-CF location indicates the assumed source of the emissions.

⁵⁰ Fry, M.M. The influence of ozone precursor emissions from four world regions on tropospheric composition and radiative climate forcing. *Journal of Geophysical Research: Atmospheres*. Vol 117, issue D7. April 2012.

Table A.7. Environmental characterization factors used for assessment of category indicator results for GLO Exposure Risks.

Unit Process	Material Extraction	Transportation	Manufacturing (Millington, TN)	Manufacturing (Rock Hill, SC)	Manufacturing (Baseline)
Location	SERC eGRID Region	SERC eGRID Region	SRTV eGRID Sub-Region	SRVC eGRID Sub-Region	SRVC eGRID Sub-Region
pp*hr*ppb O ₃ /kg NO _x	27	27	18	19	19

PM_{2.5} Exposure Risks

Impact Category

Fine particles are emitted directly by coal burning power plants, diesel fuel combustion and other manufacturing activities. Sulfate and nitrogen compounds can undergo chemical reactions that transform them into small aerosol particles. Inhalation of particles less than 2.5 microns in diameter (PM_{2.5}) represents an exposure risk for pulmonary and systemic problems in exposed populations. Unlike exposure to ozone, human health effects begin to occur from exposure at any concentration.

The dispersion of particulate matter and precursors are assessed using site-specific air dispersion modeling to characterize the accumulated hours of PM_{2.5} exposure of a given population.

Indicator Calculations

Classification

All primary particulate emissions are classified, as well as emissions which can convert into particulate matter in the atmosphere to form secondary particulates. See Table A.8. for all of the substances classified.

Characterization

Stressor Characterization Factors

The S-CF for this impact category characterizes the mass of PM_{2.5} transported into the atmosphere as the result of an emission. This includes primary particulates, which are emitted directly from combustion sources, and secondary particulates, which form after the atmospheric oxidation of NO_x and SO₂ emissions into particulates containing nitrate and sulfate.

The S-CFs are based on the following:

- For primary particulates, the S-CF is one for PM under 2.5 μm in diameter, and zero for PM between 2.5 μm and 10 μm in diameter. For PM₁₀, and PM of unspecified diameter, an S-CF of 0.9 is used, corresponding to a fraction of 90% that is under 2.5 μm in diameter. This is the

cumulative percent of particulate matter that is under 2.5 μm for stationary internal combustion engines powered by gasoline and diesel fuel, according to the USEPA.⁵¹

- For secondary particulates, the S-CFs for NO_x and SO_2 emissions are based on estimated atmospheric conversion rates to particulate nitrates and sulfates, respectively.

The S-CF values used are summarized in Table A.8.

Table A.8. Stressor Characterization Factors used in calculation of category indicator results for $\text{PM}_{2.5}$.

Emission	Stressor Characterization Factor (<i>kgPM_{2.5} eq. per kg emission</i>)
$\leq \text{PM}_{2.5}$	1
$\text{PM}_{2.5} \geq \text{PM} < \text{PM}_{10}$	0
PM_{10} and unspecified PM	0.9
SO_2^*	0.36
NO_x^{**}	0.10

*Emissions of all oxides of sulfur are characterized with S-CF for SO_2 .

**Emissions of all oxides of nitrogen are characterization with S-CF for NO_x . This includes emissions of nitrogen dioxide, nitrogen monoxide, and unspecified nitrogen oxides.

S-CF for Oxides of Nitrogen and Sulfur

Once emitted to the atmosphere, NO_x and SO_2 can be oxidized to form particulate nitrates and particulate sulfates, respectively. The S-CF for NO_x and SO_2 characterizes the mass (in tons) of $\text{PM}_{2.5}$ formed per mass of emission. This rate of conversion varies based upon the region of emission, temporal factors, and is influenced by relative humidity, ozone concentration, temperature, and other factors. To help establish S-CFs, several data sources were collected which established the conversion rates of NO_x and SO_2 to particulates using the sulfur and nitrogen conversion ratios in several regions (see Table A.9.).

⁵¹ US EPA. Compilation of Air Pollutant Emissions Factors: Appendix B.2, Generalized Particle Size Distributions.
<http://www.epa.gov/ttn/chief/ap42/appendix/appb-2.pdf>

Table A.9 Conversion rates of NO_x and SO₂ to particulates from different sources in the literature.

Sulfur conversion ratio (as percentage)*	Nitrogen conversion ratio (as percentage)**	Source
7.55 ± 44% (winter) 16.77 ± 32% (summer)	2.86 ± 39% (winter) 8.48 ± 39% (summer)	Winter conversion rate from urban area in Egypt from Khoder (2002). ⁵²
24.9	6.2	Conversion rates from urban area in Mexico from Saldarriaga-Noreña, et al. (2012). ⁵³
32.18 (annual) 24.05 (winter) 42.74 (summer)	6.28 (annual) 4.30 (winter) 9.24 (summer)	Conversion rates in in Cairo, Egypt, from Hassan, et al., (2013). ⁵⁴
13 to 33.3 (July) 17.1 to 39.3 (October)	1.2 to 16.8 (July) 0.7 to 3.2 (October)	Gas-particle distribution factors from observations in two days in July and one day in October in Pasadena, California, in 1973, from Grosjean & Friedlander (1975). ⁵⁵

*This is the ratio of particulate SO₄ concentration (as mass of SO₂), to the sum of SO₂ and SO₄ concentrations, all expressed in units of in µg m⁻³. See Khoder (2002).⁵⁶

**The ratio of the sum of the particulate and gaseous NO₄ concentrations (as NO₂), to the sum of NO₂, particulate and gaseous NO₄ concentrations, all expressed in units of in µg m⁻³. See Khoder (2002).

Of all data points sampled, the average sulfur conversion ratio is 24%, with maximum and minimum values of 32% and 12%; the nitrogen conversion ratio has an average value of 5.9%, with maximum and minimum values of 6.3% and 5.5%. These factors are expressed in units of mass of particulate sulfates and nitrates formed, normalized to mass of SO₂ and NO₂, respectively. To convert to S-CF values (which are expressed in units of tons of PM_{2.5} formed per ton of SO₂ or NO_x emission), they must be multiplied by the ratio of the molar masses of SO₄ and SO₂, and NO₄ and NO₂, which are respectively 1.5 and 1.7. Using the average of sampled conversion rates, the resulting S-CFs are:

- For SO₂: 0.36 (0.18 to 0.48), in units of ton PM_{2.5} formed per ton SO₂ emitted.
- For NO_x: 0.10 (0.09 to 0.11), in units of ton PM_{2.5} formed per ton NO_x emitted.

Environmental Characterization Factors

The indicator result characterizes, on a regional basis, the exposure of humans to particulate matter. E-CFs are calculated separately by key unit process with site-specific air dispersion modeling using the HYSPLIT dispersion model and integrated with population density data to quantify the number of individuals and severity of exposure to ground level ozone.

⁵² Khoder, M.I. Atmospheric conversion of sulfur dioxide to particulate sulfate and nitrogen dioxide to particulate nitrate and gaseous nitric acid in an urban area. *Chemosphere* 49 (2002) 675-684.

⁵³ Saldarriaga-Noreña, H., et al. Acidic Gases and Nitrate and Sulfate Particles in the Atmosphere in the City of Guadalajara, México.

Bulletin of Environmental Contamination and Toxicology May 2012, Volume 88, Issue 5, pp 730-734.

⁵⁴ Hassan, S. K., et al. Characteristics of gas-phase nitric acid and ammonium-nitrate sulfate aerosol, and their gas-phase precursors in a suburban area in Cairo, Egypt. *Atmospheric Pollution Research* 4 (2013) 117-129.

⁵⁵ Daniel Grosjean & Sheldon K. Friedlander (1975) Gas-Particle Distribution Factors for Organic and Other Pollutants in the Los Angeles Atmosphere, *Journal of the Air Pollution Control Association*, 25:10, 1038-1044, DOI: 10.1080/00022470.1975.10470176

⁵⁶ Khoder, M.I. Atmospheric conversion of sulfur dioxide to particulate sulfate and nitrogen dioxide to particulate nitrate and gaseous nitric acid in an urban area. *Chemosphere* 49 (2002) 675-684.

Particulate matter pollution is a problem throughout the United States; while problems with ground-level ozone exposures are heavily focused in urban areas, particulate matter pollution is an issue throughout both urban and rural areas. As noted previously, it is assumed electricity for Koppers manufacturing facilities in Millington, TN and Rock Hill, SC is provided by the SRTV and SRVC power grid subregions, respectively, while electricity for the baseline manufacturing processes is assumed to be from the SRVC power grid region.

The environmental characterization factors used for computing the contribution to the PM_{2.5} exposure indicator result from each major unit process are shown in Table A.10.

Table A.10. Environmental characterization factors used for assessment of category indicator results for PM_{2.5} Exposure Risks.

Unit Process	Material Extraction	Transportation	Manufacturing (Millington, TN)	Manufacturing (Rock Hill, SC)	Manufacturing (Baseline)
Location	SERC eGRID Region	SERC eGRID Region	SRTV eGRID Sub-Region	SRVC eGRID Sub-Region	SRVC eGRID Sub-Region
pp*hr*µg PM _{2.5} /kg PM _{2.5}	0.21	0.21	0.18	0.25	0.25

Risks from Radioactive Wastes

Impact Category

Radioactive wastes are associated with the entire nuclear fuel cycle. The impact category consists of the human health and ecological impacts that would be predicted to occur in the event that radioactive wastes escape from containment. The following unit processes may cause measurable indicator results in this impact category:

- Uranium mining
- Uranium milling and tailings waste handling
- Fuel enrichment
- Fuel bundle production
- Waste management for spent nuclear fuel

The United States Nuclear Regulatory Agency regulates four main types of radioactive waste; low-level waste, waste incidental to reprocessing (WIR), high-level waste, and uranium mill tailings.⁵⁷

Indicator Calculations

⁵⁷ The US Nuclear Regulatory Commission defines these types of radioactive waste by source, rather than by half-life or by associated radioactivity. Governmental agencies in different countries may define waste in different terms. See the US NRC website for a full description of these waste types: <http://www.nrc.gov/waste.html>

Classification

While this impact category includes radioactive wastes in general (including both low-level and high-level wastes, and the production of mill tailings from uranium mining), in practice, the generation of spent nuclear fuel is the main source of risk. This impact category only considers the generation of spent nuclear fuel.

Characterization

From previous LCIA studies, more than 99% of the potential risk associated with the nuclear waste cycle comes from spent fuel rods; this high-level waste will remain radioactive for hundreds of thousands of years. The storage and containment of such wastes is therefore a critical issue. The uncertainty surrounding any modeling over long time periods is too high to accurately estimate fate and exposure, particularly since no spent fuel rods are in long-term depositories at this time. As a result of this uncertainty, the only possible method for calculating this category indicator is at the inventory stage (the first node), with stressor characterization factors evaluated for the radioactivity of each isotope of concern.

Stressor Characterization Factors

Each nuclide of concern is analyzed for its potential radioactivity over the entire storage time required to return wastes to a level of risk no higher than the original uranium ore (i.e., 100,000 years or more). The S-CF is the radioactivity per unit mass, evaluated in units of Becquerel or similar unit. For example, the amount of radioactivity per kilogram uranium may be taken as 20,000 GBq/kg for either PWR or BWR reactors at zero years out of the reactor.

The total radiation emitted from each substance will decline over time, as atomic nuclei decay into more stable elements and isotopes. The S-CF should be determined on time horizons relevant to the unit processes under consideration. For this impact category, this should include time horizons of one hundred years or more.

Copper Resource Depletion

Impact Category

The impact category reflects the net consumption of mineral and metals linked to unit process(es) in the product system under study, for which total supplies are projected to be scarce within reasonable planning timeframes. Recycling of a given mineral or metal should be factored into calculations of net consumption at the end-of-life.

For certain resources, due to large deposits of the mineral or metal and high recycling rates, the extent of technically recoverable reserves are essentially unlimited within reasonable planning timeframes. Consumption of these resources are not considered relevant in this impact category.

Indicator Calculations

Classification

Metals and minerals that are not considered inexhaustible (e.g. sand) and have limited technically recoverable reserve bases within reasonable planning timeframes are classified under this impact category, according to the requirements of Section 2.3.2.1 and 2.3.2.2. At a given unit process, only *net* consumption of a mineral or metal from its technically recoverable reserve base is classified, considering recycling which may occur at end-of-life.

Aggregation of different metals and minerals into a single category indicator is not permitted. Each mineral or metal is reported under a separate category indicator. A given material may be extracted from several different types of ore. Consumption of all ores containing a single material should be classified into the single relevant category indicator. In some instances, multiple materials are extracted from the same ore; in these instances, consumption of multiple material co-products may be classified into multiple category indicators.

Characterization

Stressor Characterization Factors

For each category indicator, the S-CF represents the mass of the relevant mineral or metal per mass of classified flow. The mass of an inventory flow multiplied with the S-CF gives results in units of mass of the mineral or metal which is considered in the category indicator. Because each mineral or metal covered under this impact category is accounted for separately, there is no need to establish a resource equivalency between materials.

Due to the uncertainty in estimates of technically recoverable reserve bases, and projections of consumption of minerals and metals, data is not sufficient to establish results past Node 2, which characterizes net consumption of minerals and metals.

Water Scarcity

Impact Category

The Water Scarcity Indicator (WSI), reported in m³, is calculated following the methodology of Hoekstra, et al.⁵⁸ The approach is based on a consumption-to-availability ratio (CTA) calculated as the fraction between consumed (referred to as blue water footprint) and available water. The latter considers all runoff water, of which 80% is subtracted to account for environmental water needs. The data is from

⁵⁸ Hoekstra AY, Mekonnen MM, Chapagain AK, Mathews RE, Richter BD (2012) Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability. PLoS ONE 7(2): e32688. doi:10.1371/journal.pone.0032688

Fekete et al. 2002 for water runoff and Mekonnen et al. for water consumption. Results are available for the main watersheds worldwide, but many outlying regions are not covered. The indicator is applied to the consumed water volume and only assesses consumptive water use.

The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute⁵⁹

Indicator Calculations

Classification

The inventory flows classified for Water Scarcity indicator calculations are summarized in Table A-11. Note that the ecoinvent v3.7 LCI data used for the assessment are available by region including the United States and Regional North America in (RNA) addition to individual countries across the globe as well as unspecified regional flows.

Table A.11. Flow classification for Water Scarcity category indicator calculations.

Inventory Flow	Compartment
Water, well, in ground	Raw (Input Resource)
Water, discharged	Water (Output)
Water, unspecified natural origin	Raw (Input Resource)
Water, turbine use, unspecified natural origin	Raw (Input Resource)
Water, river	Raw (Input Resource)
Water, lake	Raw (Input Resource)
Water, cooling, unspecified natural origin	Raw (Input Resource)

Characterization

Stressor Characterization Factors

Environmental characterization factors (ECFs) are based on a consumption-to-availability ratio calculated as the fraction between consumed and available water. Characterizations factors by region were applied to the inventory flows classified in Table A-11. Environmental characterization factors used to calculate the Water Scarcity Indicator are summarized by inventory flow and region in Table A-12.

⁵⁹ <http://www.worldwater.org/data.html>

Table A.12. Environmental Characterization Factors used in the calculation of Water Scarcity category indicator results.

Inventory Flow	Stressor Characterization Factor		
	United States (US)	Regional North America (RNA)	Rest of World (RoW)
Water, well, in ground	0.8929	0.8591	various
Water, discharged	-0.8929	-0.8591	various
Water, unspecified natural origin	0.8929	0.8591	various
Water, turbine RNA, unspecified natural origin	0.8929	0.8591	various
Water, river	0.8929	0.8591	various
Water, lake	0.8929	0.8591	various
Water, cooling, unspecified natural origin	0.8929	0.8591	various

Appendix 3: Life Cycle Impact Assessment Calculations

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Koppers MicroPro® Impact Assessment Calculations

Table B.1. Life Cycle Impact Assessment of Koppers' MicroPro® wood treatment chemical system. Results shown for a reference flow of 5,900 metric tons preservative.

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
Global Climate Change		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>	1.0	<i>(t CO₂-eq.)</i>
	Carbon Dioxide	17,400	1.0	17,400	1.0	17,400
	Carbon Monoxide	48.6	5.6	272	1.0	272
	Methane	44.5	104	4,630	1.0	4,630
	Nitrous Oxide	1.81	264	477	1.0	477
	Nitrogen oxides	146	122	17,800	1.0	17,800
	Organic carbon	9.75x10 ⁻⁵	-77	-7.49x10 ⁻³	1.0	-7.49x10 ⁻³
	Sulfur Dioxide	11.0	-313	-3,450	1.0	-3,450
	Sulfur Hexafluoride	1.91x10 ⁻³	17,500	33.5	1.0	33.5
HFC-134a	3.03x10 ⁻⁵	3,710	0.112	1.0	0.112	
Total		17,700		37,200		37,200
Arctic Climate Change		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>		<i>(t CO₂-eq.)</i>
	Carbon dioxide	17,400	1.0	17,400	1.0	17,400
	Methane	44.5	69	3,070	1.0	3,070
	Nitrous Oxide	1.81	274	495	1.0	495
	Nitrogen oxides	146	113	16,500	1.0	16,500
	Sulfur Dioxide	11.0	-118	-1,300	1.0	-1,300
Total		17,700		36,200		36,200
Ocean Acidification		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>		<i>(t CO₂-eq.)</i>
	Carbon Dioxide	17,400	1.41	24,600	1.26	31,000
	Methane	44.5	3.87	172	1.26	217
Total		17,500		24,800		31,200
Ocean Warming		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>		<i>(t CO₂-eq.)</i>
	Carbon dioxide	17,400	1.0	17,400	0.80	14,000
	Methane	44.5	82	3,630	0.80	2,900
	Nitrogen oxides	146	158	23,000	0.80	18,400
	Nitrous Oxide	1.81	285	515	0.80	412
Total		17,600		44,600		35,700
Regional Acidification		<i>(t)</i>	<i>(t SO₂-eq./t)</i>	<i>(t SO₂-eq.)</i>		<i>(t SO₂-eq.)</i>
Manufacturing	Nitrogen oxides	1.88	1.07	2.01	0.79	1.59
	Sulfur Dioxide	9.36x10 ⁻³	1.00	9.36x10 ⁻³	0.79	7.41x10 ⁻³
	Hydrogen chloride (HCl)	0.132	0.88	0.116	0.79	9.19x10 ⁻²
	Ammonia (NH ₃)	1.52x10 ⁻²	1.88	2.86x10 ⁻²	0.79	2.26x10 ⁻²

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
	Sulfuric acid (H2SO4)	3.03x10 ⁻⁷	0.65	1.97x10 ⁻⁷	0.79	1.56x10 ⁻⁷
	Hydrogen sulfide (H2S)	3.62x10 ⁻⁴	1.88	6.81x10 ⁻⁴	0.79	5.38x10 ⁻⁴
	Hydrogen fluoride (HFI)	1.45x10 ⁻²	1.60	2.32x10 ⁻²	0.79	1.83x10 ⁻²
Total		2.05		2.19		1.73
Other	Nitrogen oxides	144	1.07	154	0.80	123
	Sulfur Dioxide	11.0	1.00	11.0	0.80	8.81
	Hydrogen chloride (HCl)	2.55	0.88	2.24	0.80	1.80
	Ammonia (NH3)	18.3	1.88	34.4	0.80	27.5
	Sulfuric acid (H2SO4)	3.39x10 ⁻³	0.65	2.20x10 ⁻³	0.80	1.76x10 ⁻³
	Hydrogen sulfide (H2S)	0.182	1.88	0.343	0.80	0.274
	Hydrogen fluoride (HFI)	0.254	1.60	0.406	0.80	0.325
Total		176		203		162
Ground Level Ozone Exposures						
		<i>(t)</i>	<i>(t NOx eq./t)</i>	<i>(t NOx eq.)</i>	<i>(Persons*ppb O3*hours per t NOx eq)</i>	<i>(Persons*ppb O3*hours)</i>
Manufacturing	Nitrogen oxides	1.88	1.00	1.88	18.4	34.6
	Non-methane Hydrocarbons (NMHC)	5.03x10 ⁻²	0.55	2.77x10 ⁻²	18.4	0.509
	Methane	0.553	0.01	5.53x10 ⁻³	18.4	0.102
Total		2.49		1.92		35.3
Other	Nitrogen oxides	144	1.00	144	26.7	3,840
	Non-methane Hydrocarbons (NMHC)	23.6	0.55	13.0	26.7	346
	Methane	43.9	0.01	0.439	26.7	11.7
Total		212		158		4,200
PM-2.5 Exposures						
		<i>(t)</i>	<i>(t PM2.5 eq./t)</i>	<i>(t PM2.5 eq.)</i>	<i>(Persons*µg/m³ per kg PM2.5 eq.)</i>	<i>(Persons*µg/m³ *hours)</i>
Manufacturing	PM10	7.14x10 ⁻²	0.90	6.42x10 ⁻²	0.18	1.14x10 ⁻²
	PM2.5	0.464	1.00	0.464	0.18	8.24x10 ⁻²
	Sulfur Dioxide	9.36x10 ⁻³	0.36	3.37x10 ⁻³	0.18	5.99x10 ⁻⁴
	Nitrogen oxides	1.88	0.10	0.188	0.18	3.34x10 ⁻²
Total		2.43		0.719		0.128
Other	PM10	46.5	0.90	41.8	0.21	8.96
	PM2.5	35.6	1.00	35.6	0.21	7.63
	Sulfur Dioxide	11.0	0.36	3.96	0.21	0.849
	Nitrogen oxides	144	0.10	14.4	0.21	3.09
Total		237		95.8		20.5
Risks from Radioactive Wastes						
		<i>(t)</i>	<i>(GBq/t)</i>	<i>(GBq)</i>	<i>(GBq/t)</i>	<i>(GBq)</i>
	Uranium ore	5.25x10 ⁻²	1.00	5.25x10 ⁻²	20.0	1.05

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
Total		5.25x10⁻²		5.25x10⁻²		1.05
Energy Resource Depletion						
		Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Resource Depletion Factor (RDF)	Equivalent Resource Depletion
Inventory Resource		(t)	(MJ/t)	(MJ)	RDF-25 (normalized)	(MJ)
	Coal seam	4,760	24	114,000	0.047	5,370
	Brown coal	1,290	17	21,900	0.006	131
	Natural gas	1,710	48	81,900	0.560	45,900
	Crude oil	1,570	45	70,500	0.460	32,400
	Uranium ore	5.25x10 ⁻²	900,000	47,300	0.420	19,900
Total		9,320		336,000		104,000
Copper Resource Depletion						
		Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Resource Depletion Factor (RDF)	Equivalent Resource Depletion
Inventory Resource		(t)	(t/t)	(t)	RDF-25 (normalized)	(t)
	Copper	3,410	1.0	3,410	0.58	1,980
Total		3,410		3,410		1,980
Water Scarcity Indicator						
		Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Environmental Characterization Factor (ECF)	Equivalent Water Scarcity Indicator
Inventory Flow		(m³)	(m³/m³)	(m³)	(m³/m³)	(m³)
	WSI	2,180	1.0	2,180	1.0	2,180
Total		2,180		2,180		2,180

Koppers MicroPro® 200 Impact Assessment Calculations

Table B.2. Life Cycle Impact Assessment of Koppers' MicroPro®200 wood treatment chemical system. Results shown for a reference flow of 5,900 metric tons preservative.

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
Global Climate Change		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>	1.0	<i>(t CO₂-eq.)</i>
	Carbon Dioxide	53,500	1.0	53,500	1.0	53,500
	Carbon Monoxide	64.0	5.6	358	1.0	358
	Methane	82.6	104	8,610	1.0	8,610
	Nitrous Oxide	2.52	264	667	1.0	667
	Nitrogen oxides	236	122	28,700	1.0	28,700
	Organic carbon	1.13x10 ⁻⁴	-77	-8.66x10 ⁻³	1.0	-8.66x10 ⁻³
	Sulfur Dioxide	12.6	-313	-3,950	1.0	-3,950
	Sulfur Hexafluoride	2.61x10 ⁻³	17,500	45.8	1.0	45.8
HFC-134a	2.81x10 ⁻⁴	3,710	1.04	1.0	1.04	
Total		53,900		87,900		87,900
Arctic Climate Change		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>		<i>(t CO₂-eq.)</i>
	Carbon dioxide	53,500	1.0	53,500	1.0	53,500
	Methane	82.6	69	5,700	1.0	5,700
	Nitrous Oxide	2.52	274	692	1.0	692
	Nitrogen oxides	236	113	26,600	1.0	26,600
	Sulfur Dioxide	12.6	-118	-1,490	1.0	-1,490
Total		53,800		85,000		85,000
Ocean Acidification		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>		<i>(t CO₂-eq.)</i>
	Carbon Dioxide	53,500	1.41	75,400	1.26	95,000
	Methane	82.6	3.87	320	1.26	403
Total		53,500		75,700		95,400
Ocean Warming		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>		<i>(t CO₂-eq.)</i>
	Carbon dioxide	53,500	1.0	53,500	0.80	42,800
	Methane	82.6	82	6,740	0.80	5,390
	Nitrogen oxides	236	158	37,100	0.80	29,700
	Nitrous Oxide	2.52	285	719	0.80	575
Total		53,800		98,100		78,400
Regional Acidification		<i>(t)</i>	<i>(t SO₂-eq./t)</i>	<i>(t SO₂-eq.)</i>		<i>(t SO₂-eq.)</i>
Manufacturing	Nitrogen oxides	76.9	1.07	82.2	0.91	74.9
	Sulfur Dioxide	0.557	1.00	0.557	0.91	0.508
	Hydrogen chloride (HCl)	4.42	0.88	3.89	0.91	3.54
	Ammonia (NH ₃)	1.14	1.88	2.14	0.91	1.95

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
	Sulfuric acid (H2SO4)	2.11x10 ⁻⁵	0.65	1.37x10 ⁻⁵	0.91	1.25x10 ⁻⁵
	Hydrogen sulfide (H2S)	2.92x10 ⁻²	1.88	5.50x10 ⁻²	0.91	5.01x10 ⁻²
	Hydrogen fluoride (HFI)	0.484	1.60	0.774	0.91	0.705
Total		83.5		89.7		81.7
Other	Nitrogen oxides	159	1.07	170	0.80	136
	Sulfur Dioxide	12.0	1.00	12.0	0.80	9.64
	Hydrogen chloride (HCl)	2.82	0.88	2.48	0.80	1.99
	Ammonia (NH3)	20.3	1.88	38.1	0.80	30.5
	Sulfuric acid (H2SO4)	3.74x10 ⁻³	0.65	2.43x10 ⁻³	0.80	1.94x10 ⁻³
	Hydrogen sulfide (H2S)	0.190	1.88	0.357	0.80	0.286
	Hydrogen fluoride (HFI)	0.282	1.60	0.451	0.80	0.361
Total		194		223		179
Ground Level Ozone Exposures						
		<i>(t)</i>	<i>(t NOx eq./t)</i>	<i>(t NOx eq.)</i>	<i>(Persons*ppb O3*hours per t NOx eq)</i>	<i>(Persons*ppb O3*hours)</i>
Manufacturing	Nitrogen oxides	76.9	1.00	76.9	18.8	1,450
	Non-methane Hydrocarbons (NMHC)	3.14	0.55	1.73	18.8	32.5
	Methane	34.2	0.01	0.342	18.8	6.44
Total		114		78.9		1,490
Other	Nitrogen oxides	159	1.00	159	26.7	4,230
	Non-methane Hydrocarbons (NMHC)	25.9	0.55	14.2	26.7	379
	Methane	48.4	0.01	0.484	26.7	12.9
Total		233		173		4,630
PM-2.5 Exposures						
		<i>(t)</i>	<i>(t PM2.5 eq./t)</i>	<i>(t PM2.5 eq.)</i>	<i>(Persons*µg/m3 per kg PM2.5 eq.)</i>	<i>(Persons*µg/m3 *hours)</i>
Manufacturing	PM10	3.32	0.90	2.98	0.25	0.760
	PM2.5	16.4	1.00	16.4	0.25	4.18
	Sulfur Dioxide	0.557	0.36	0.201	0.25	5.11x10 ⁻²
	Nitrogen oxides	76.9	0.10	7.69	0.25	1.96
Total		97.2		27.3		6.95
Other	PM10	51.3	0.90	46.2	0.21	9.90
	PM2.5	39.6	1.00	39.6	0.21	8.48
	Sulfur Dioxide	12.0	0.36	4.34	0.21	0.929
	Nitrogen oxides	159	0.10	15.9	0.21	3.40
Total		262		106		22.7
Risks from Radioactive Wastes						
		<i>(t)</i>	<i>(GBq/t)</i>	<i>(GBq)</i>	<i>(GBq/t)</i>	<i>(GBq)</i>
	Uranium ore	0.897	1.00	0.897	20.0	17.9

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
Total		0.897		0.897		17.9
Energy Resource Depletion						
		Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Resource Depletion Factor (RDF)	Equivalent Resource Depletion
Inventory Resource		<i>(t)</i>	<i>(MJ/t)</i>	<i>(MJ)</i>	<i>RDF-25 (normalized)</i>	<i>(MJ)</i>
	Coal seam	13,400	24	322,000	0.047	15,100
	Brown coal	2,530	17	43,100	0.006	258
	Natural gas	9,160	48	440,000	0.560	246,000
	Crude oil	1,950	45	87,800	0.460	40,400
	Uranium ore	0.897	900,000	807,000	0.420	339,000
Total		27,000		1.70x10⁶		641,000
Copper Resource Depletion						
		Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Resource Depletion Factor (RDF)	Equivalent Resource Depletion
Inventory Resource		<i>(t)</i>	<i>(t/t)</i>	<i>(t)</i>	<i>RDF-25 (normalized)</i>	<i>(t)</i>
	Copper	3,780	1.0	3,780	0.58	2,190
Total		3,780		3,780		2,190
Water Scarcity Indicator						
		Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Environmental Characterization Factor (ECF)	Equivalent Water Scarcity Indicator
Inventory Flow		<i>(m³)</i>	<i>(m³/m³)</i>	<i>(m³)</i>	<i>(m³/m³)</i>	<i>(m³)</i>
	WSI	9,260	1.0	9,260	1.0	9,260
Total		9,260		9,260		9,260

Baseline ACQ Impact Assessment Calculations

Table B.3. Life Cycle Impact Assessment of baseline ACQ wood treatment chemical system. Results shown for a reference flow of 34,900 metric tons preservative.

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
Global Climate Change		<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>	1.0	<i>(t CO₂-eq.)</i>
	Carbon Dioxide	104,000	1.0	104,000	1.0	104,000
	Carbon Monoxide	163	5.6	915	1.0	915
	Methane	257	104	26,800	1.0	26,800
	Nitrous Oxide	4.90	264	1,290	1.0	1,290
	Nitrogen oxides	450	122	54,800	1.0	54,800
	Organic carbon	4.22x10 ⁻⁴	-77	-3.25x10 ⁻²	1.0	-3.25x10 ⁻²
	Sulfur Dioxide	30.9	-313	-9,670	1.0	-9,670
	Sulfur Hexafluoride	6.15x10 ⁻³	17,500	108	1.0	108
	HFC-134a	4.31x10 ⁻⁴	3,710	1.60	1.0	1.60
Total		160,000	105,000		178,000	
Arctic Climate Change		<i>(t)</i>	<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>	
	Carbon dioxide	104,000	1.0	104,000	1.0	104,000
	Methane	257	69	17,700	1.0	17,700
	Nitrous Oxide	4.90	274	1,340	1.0	1,340
	Nitrogen oxides	450	113	50,800	1.0	50,800
	Sulfur Dioxide	30.9	-118	-3,640	1.0	-3,640
Total		159,000	105,000		170,000	
Ocean Acidification		<i>(t)</i>	<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>	
	Carbon Dioxide	104,000	1.41	147,000	1.26	185,000
	Methane	257	3.87	995	1.26	1,250
Total		159,000	104,000		148,000	
Ocean Warming		<i>(t)</i>	<i>(t)</i>	<i>(t CO₂-eq./t)</i>	<i>(t CO₂-eq.)</i>	
	Carbon dioxide	104,000	1.0	104,000	0.80	83,200
	Methane	257	82	21,000	0.80	16,800
	Nitrogen oxides	450	158	70,900	0.80	56,700
	Nitrous Oxide	4.90	285	1,400	0.80	1,120
Total		159,000	105,000		197,000	
Regional Acidification		<i>(t)</i>	<i>(t)</i>	<i>(t SO₂-eq./t)</i>	<i>(t SO₂-eq.)</i>	
Manufacturing	Nitrogen oxides	34.1	1.07	36.5	0.91	33.3
	Sulfur Dioxide	0.758	1.00	0.758	0.91	0.691
	Hydrogen chloride (HCl)	1.91	0.88	1.69	0.91	1.54
	Ammonia (NH ₃)	0.493	1.88	0.926	0.91	0.844

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
	Sulfuric acid (H2SO4)	9.21x10 ⁻⁶	0.65	5.98x10 ⁻⁶	0.91	5.45x10 ⁻⁶
	Hydrogen sulfide (H2S)	2.42x10 ⁻²	1.88	4.55x10 ⁻²	0.91	4.15x10 ⁻²
	Hydrogen fluoride (HFI)	0.210	1.60	0.335	0.91	0.306
Total		57.0	37.5		40.2	
Other	Nitrogen oxides	416	1.07	445	0.80	356
	Sulfur Dioxide	30.1	1.00	30.1	0.80	24.1
	Hydrogen chloride (HCl)	7.26	0.88	6.39	0.80	5.11
	Ammonia (NH3)	36.9	1.88	69.3	0.80	55.5
	Sulfuric acid (H2SO4)	4.81x10 ⁻³	0.65	3.12x10 ⁻³	0.80	2.50x10 ⁻³
	Hydrogen sulfide (H2S)	1.80	1.88	3.39	0.80	2.71
	Hydrogen fluoride (HFI)	0.716	1.60	1.15	0.80	0.916
Total		749	492		555	
Ground Level Ozone Exposures						
		(t)	(t)	(t NOx eq./t)	(t NOx eq.)	(Persons*ppb O3*hours per t NOx eq)
Manufacturing	Nitrogen oxides	34.1	1.00	34.1	18.8	642
	Non-methane Hydrocarbons (NMHC)	1.89	0.55	1.04	18.8	19.5
	Methane	19.3	0.01	0.193	18.8	3.63
Total		84.0	55.3		35.3	
Other	Nitrogen oxides	416	1.00	416	26.7	11,100
	Non-methane Hydrocarbons (NMHC)	81.7	0.55	44.9	26.7	1,200
	Methane	238	0.01	2.38	26.7	63.4
Total		1,120	735		463	
PM-2.5 Exposures						
		(t)	(t)	(t PM2.5 eq./t)	(t PM2.5 eq.)	(Persons*µg/m ³ per kg PM2.5 eq.)
Manufacturing	PM10	3.31	0.90	2.98	0.25	0.759
	PM2.5	7.16	1.00	7.16	0.25	1.82
	Sulfur Dioxide	0.758	0.36	0.273	0.25	6.95x10 ⁻²
	Nitrogen oxides	34.1	0.10	3.41	0.25	0.868
Total		68.9	45.3		13.8	
Other	PM10	81.8	0.90	73.6	0.21	15.8
	PM2.5	83.5	1.00	83.5	0.21	17.9
	Sulfur Dioxide	30.1	0.36	10.8	0.21	2.32
	Nitrogen oxides	416	0.10	41.6	0.21	8.90
Total		929	611		210	
Risks from Radioactive Wastes						
		(t)	(t)	(GBq/t)	(GBq)	(GBq/t)
	Uranium ore	0.505	1.00	0.505	20.0	10.1

Impact Category	Inventory Emission	Life-Cycle Inventory Result	Stressor Characterization Factor (SCF)	Gross Emission Loading	Environmental Characterization Factor (ECF)	Net Emission Loading
Total		0.768	0.505		0.505	
Energy Resource Depletion						
		Resource Consumed	Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Resource Depletion Factor (RDF)
Inventory Resource		<i>(t)</i>	<i>(t)</i>	<i>(MJ/t)</i>	<i>(MJ)</i>	RDF-25 (normalized)
	Coal seam	19,100	24	458,000	0.047	21,500
	Brown coal	4,210	17	71,600	0.006	430
	Natural gas	12,300	48	591,000	0.560	331,000
	Crude oil	17,700	45	796,000	0.460	366,000
	Uranium ore	0.505	900,000	454,000	0.420	191,000
Total		81,100	53,300		2.37x10⁶	
Copper Resource Depletion						
		Resource Consumed	Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Resource Depletion Factor (RDF)
Inventory Resource		<i>(t)</i>	<i>(t)</i>	<i>(t/t)</i>	<i>(t)</i>	RDF-25 (normalized)
	Copper	4,550	1.0	4,550	0.58	2,640
Total		4,550		4,550		2,640
Water Scarcity Indicator						
		Resource Consumed	Resource Consumed	Stressor Characterization Factor (SCF)	Equivalent Resource Consumed	Environmental Characterization Factor (ECF)
Inventory Flow		<i>(m³)</i>	<i>(m³)</i>	<i>(m³/m³)</i>	<i>(m³)</i>	<i>(m³/m³)</i>
	WSI	9,900	1.0	9,900	1.0	9,900
Total		9,900		9,900		9,900