# Appendix

As part of the effort to apply LCA as a tool for environmental preferable purchasing within FRED, three pilots were undertaken to test how best to perform the FRED LCA system in order to make it:

- Easy to use
- Yield results in a timely manner
- Meet the needs of procurement officials and vendors
- Conform, as much as possible, to the requirements of DIS 14042 for comparative assertions
- Support the needs of the EPP program
- Support the needs of the National Institute of Standards and Technology (NIST) in its goals relating to the Technology Transfer Act.

Two of those pilots (found in Appendix A - Motor Oil and Appendix B - Wall Insulation) were based on the inventory data sets collected by the National Institute of Standards and Technology's Building for Environmental and Economic Sustainability (BEES) program. The third pilot (found in Appendix C - Asphalt Coating) was based on original data collection from a small vendor.

The first two pilots, derived from existing BEES life cycle inventory data, were used primarily in evaluating among environment and human health impact indicator models for inclusion in the FRED LCA system. The third pilot, which used predominately original data, was utilized to evaluate the resource requirements for a vendor to provide data for the FRED LCA system as well as to develop an approach to evaluating results from the FRED LCA system. Pursuant to these slightly different goals, the sections on interpretation of results and conclusions for the first two pilots are not as detailed as reported in the third pilot.

# Appendix A: Motor Oil Case Study

## Goal and Scope Definition

### *Goal*

The goal of this study was to determine the feasibility of evaluating the environmental performance of three different types of motor oil by using the FRED LCA system. The three types of oil evaluated were virgin oil, rerefined oil and bio-based oil.

### *Intended Applications and Audiences*

The LCA itself was intended to be used to support a comparative assertion of environmental superiority of a product over a competing product in the context of the Federal requirement for environmentally preferable purchasing. Audiences include purchasing agents as well as other federal and state officials. An ancillary use of the study is to support efforts towards environmental improvement.

## Scope

### *Description of the Product*

Motor oil is used to cool the engine and reduce friction. Historically, motor oil was created by extracting and refining crude oil. Due to technological advances, two alternatives to virgin oil are now commercially available: rerefined oil and "bio-based" oil. Rerefined oil is essentially used oil that has undergone the refining process a second time, with additives to remove impurities. Bio-based oil is an all-vegetable (in the case of this pilot project, soybean), highly biodegradable oil that performs comparably to petroleum-based oils.

### *System Function and Functional Unit*

The function provided by the alternative products is automobile engine protection and lubrication for 3,000 mile without viscosity breakdown. The functional unit is one quart,10W30 motor oil.

### *System Boundaries*

Data for all three products came from secondary sources according to the contractor for BEES. Virgin and refined oil data came from petroleum associations representing 90 % of manufacturers. Bio-based data was derived from an average of 14 states. Upstream materials and energy use data came from national sources. All data is less than 10 years old. The flow charts below identify the systems under study.

**Figure 1: Virgin Motor Oil Process Flow Diagram**

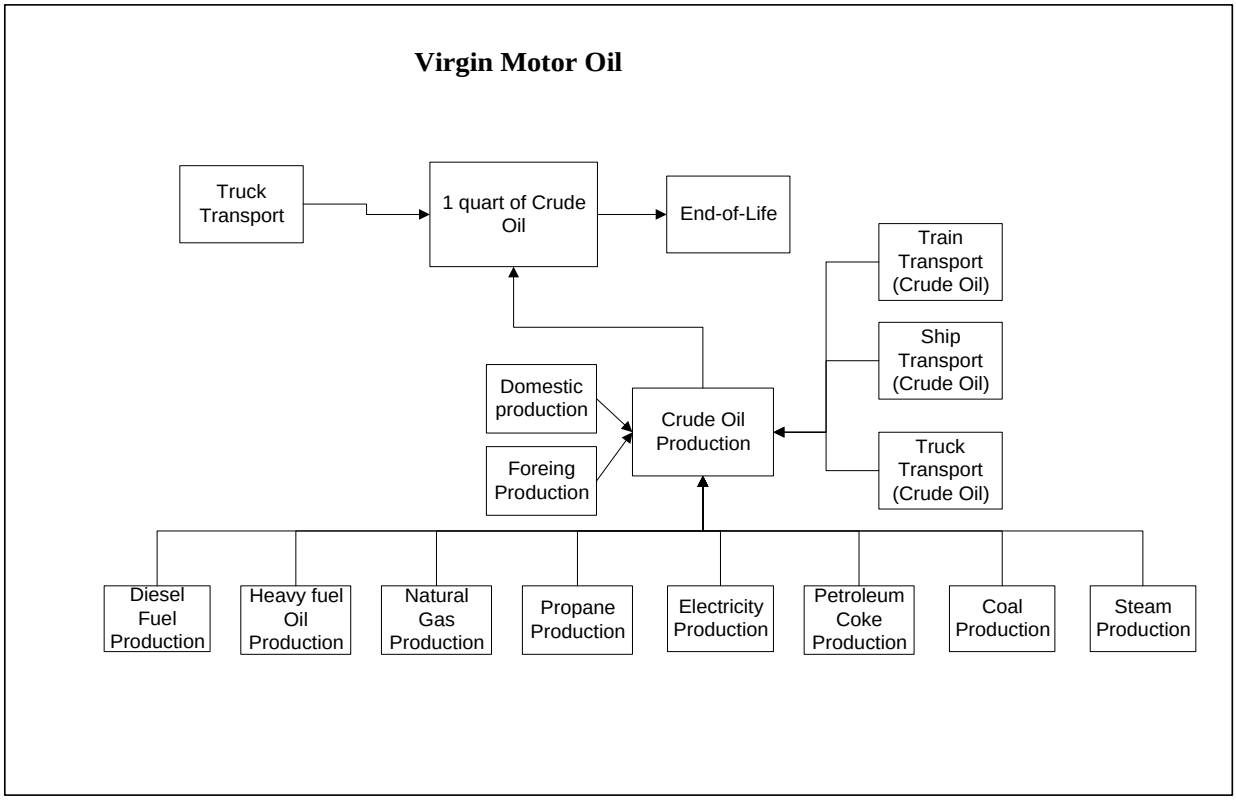


**Figure 2: Re-refined Oil Process Flow Diagram**

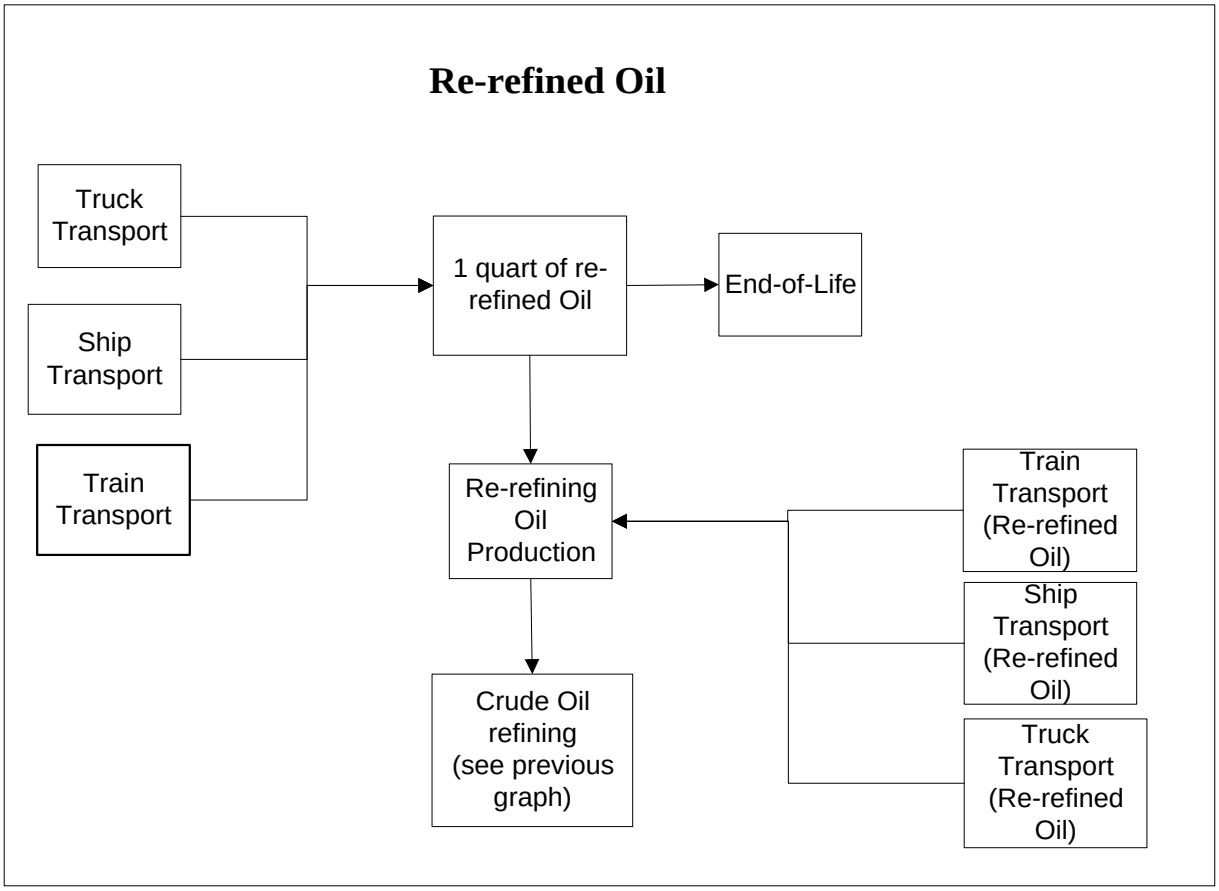
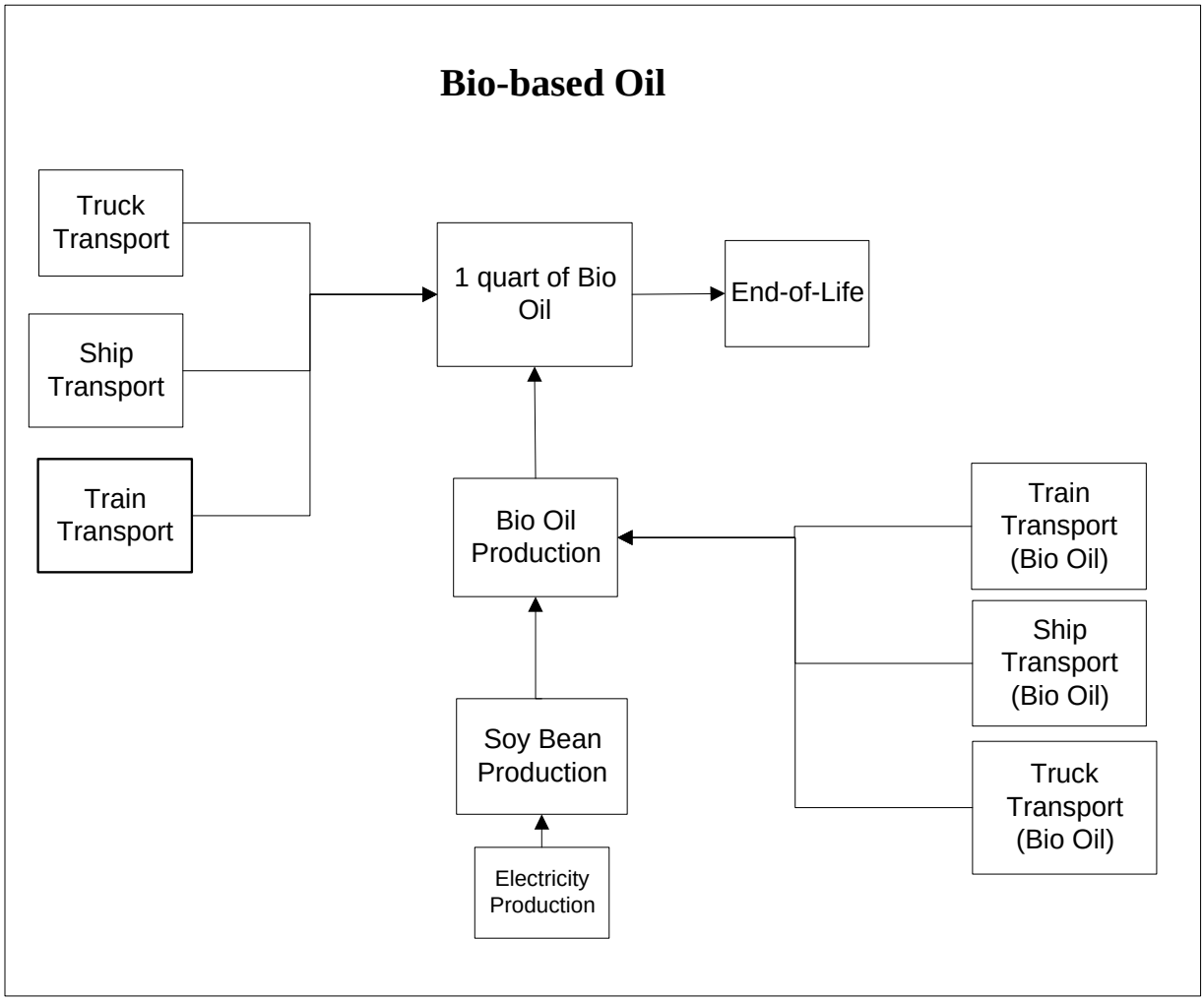


**Figure 3: Bio-Based Oil Process Flow Diagram**



## Data Gathering

The entire data gathering exercise for this project involved extracting data from the BEES database. According to NIST, the BEES database includes both primary data as well as industry average data.

### *Allocation*

All allocation of emissions and resource use was performed based on a mass basis. This was required for the production and transportation inventory results, but not for other inventory data.

### *Impact Assessment*

Impact assessment was performed using the FRED indicators, as described in the body of this work. The assignment of inventory data to impact categories is shown in the table below.

**Table 1 Assignment of Inventory Results to Impact Categories**

| Inventory Result | Impact Category | Justification |
|---|---|---|
| Fossil Fuels and Uranium | Resource Depletion | Although Uranium is not truly a fossil fuel, it is "used up" in a precisely comparable fashion |
| $CO_2$, $N_20$, Methane | Global Warming | These are important greenhouse gases which do not participate to a great extent in other impact categories |
| CO | Human Toxicity<br>Photochemical Smog Global Warming; | CO is a human and animal toxicant, as well as a precursor to ozone formation and a greenhouse gas. It can participate in the first two of these environmental mechanisms without losing its potency for the others. |
| CFC's, HCFC's, Halons | Global Warming 100%<br>Stratospheric Ozone Depletion 100% | These substances participate fully in both of these parallel environmental mechanisms |
| $SO_2$, | Acidification 100% | Although SO2 contributes to visibility deterioration, and human health effects through the formation of Particulate Matter, these environmental mechanisms are not addressed by FRED. |
| HCl, HF | Acidification 100%<br>Human Health 100% | These acid gases have minor human health effects as well as contributing to acidification. It was thought that double counting would not significantly skew results. |
| Toxic Air and Water Emissions | Human Toxicity 100%<br>Ecotoxicity 100% | Since it was not possible to evaluate the partitioning of these substances, they were double counted so as not to underestimate their impacts. |
| NOx | Acidification 100% | Since FRED does not currently evaluate |

| Inventory Result | Impact Category | Justification |
|---|---|---|
| | Eutrophication 100% | the fate and transport of NOx, this emission was double counted. |
| VOC's, ROG's | Photochemical Smog | These are the essential precursors to photochemically produced ozone. Although some of them are also toxic, unspeciated data does not permit a toxic evaluation. |
| $NH_4$ | Eutrophication (water emissions); acidification (air Emissions) | Although NH4 is not an acid gas, it undergoes changes in the soil leading to acidification effects. |
| $PO_4$ | Eutrophication 100% | Phosphate does not participate in any other environmental mechanism described by the FRED methodology |

**Inventory**

The table below shows the summary inventory for the three products compared. A full inventory by life cycle stage can be found in Tables 7, 8 and 9.

**Table 2 Summary Inventory**

| | | LCI Totals | | |
|---|---|---|---|---|
| **Article** | **Units** | **Virgin** | **Re-refined** | **Bio** |
| (r) Coal (in ground) | kg | 3.6e-02 | 7.6e-03 | 2.2e-02 |
| (r) Limestone (CaCO3, in ground) | kg | 6.8e-03 | 1.4e-03 | 4.1e-03 |
| (r) Natural Gas (in ground) | kg | 9.8e-02 | 1.5e-02 | 5.4e-02 |
| (r) Oil (in ground) | kg | 9.1e-01 | 2.5e-02 | 4.6e-02 |
| (r) Perlite (SiO2, ore) | kg | 3.2e-04 | 2.1e-04 | 8.9e-06 |
| (r) Phosphate Rock (in ground) | kg | 0.0e+00 | 0.0e+00 | 5.5e-02 |
| (r) Potash (K2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 3.2e-02 |
| (r) Uranium (U, ore) | kg | 8.5e-07 | 1.8e-07 | 6.9e-07 |
| Used Oil | kg | 0.0e+00 | 8.6e-01 | 0.0e+00 |
| Water Used (total) | liter | 1.3e-01 | 3.6e-03 | 5.9e+02 |
| (a) Aldehydes | g | 1.1e-04 | 2.4e-05 | 2.9e-04 |
| (a) Ammonia (NH3) | g | 2.3e-07 | 1.3e-07 | 1.6e-01 |
| (a) Benzene | g | 2.0e-04 | 5.5e-06 | 8.8e-06 |
| (a) Carbon Dioxide (CO2, biomass) | g | 0.0e+00 | 0.0e+00 | -2.5e+03 |
| (a) Carbon Dioxide (CO2, fossil) | g | 6.1e+02 | 3.2e+02 | 3.4e+02 |
| (a) Carbon Monoxide (CO) | g | 4.6e-01 | 2.6e-01 | 5.8e-01 |
| (a) Fluorides (F-) | g | 2.6e-12 | 4.5e-13 | 4.6e-03 |
| (a) Formaldehyde | g | 2.7e-03 | 7.3e-05 | 1.2e-04 |
| (a) Hydrocarbons (except methane) | g | 1.7e-01 | 3.9e-02 | 1.8e+00 |

| | | LCI Totals | | |
|---|---|---|---|---|
| **Article** | **Units** | **Virgin** | **Re-refined** | **Bio** |
| (a) Hydrocarbons (unspecified) | g | 1.5e+00 | 8.9e-01 | 4.8e-01 |
| (a) Hydrogen Chloride (HCl) | g | 1.9e-02 | 4.1e-03 | 1.0e-02 |
| (a) Hydrogen Fluoride (HF) | g | 2.4e-03 | 5.1e-04 | 1.2e-03 |
| (a) Hydrogen Sulfide (H2S) | g | 6.0e-03 | 1.8e-04 | 3.0e-04 |
| (a) Metals (unspecified) | g | 2.4e-04 | 9.0e-05 | 6.7e-06 |
| (a) Methane (CH4) | g | 1.1e+00 | 1.5e-01 | 4.6e-01 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 1.4e+00 | 7.0e-01 | 1.1e+00 |
| (a) Nitrous Oxide (N2O) | g | 4.7e-02 | 1.9e-02 | 1.8e-02 |
| (a) Organic Matter (unspecified) | g | 5.3e-04 | 1.1e-04 | 1.2e-02 |
| (a) Particulates (unspecified) | g | 9.9e-01 | 4.9e-01 | 7.4e-01 |
| (a) Sulfur Oxides (SOx as SO2) | g | 4.7e+00 | 1.6e+00 | 1.6e+00 |
| (w) Acids (H+) | g | 0.0e+00 | 0.0e+00 | 1.4e-04 |
| (w) Ammonia (NH4+, NH3, as N) | g | 1.4e-01 | 8.9e-02 | 4.0e-03 |
| (w) Benzene | g | 8.9e-14 | 1.9e-14 | 4.3e-14 |
| (w) BOD5 (Biochemical Oxygen Demand) | g | 9.5e-01 | 6.1e-01 | 3.0e-02 |
| (w) Chlorides (Cl-) | g | 1.3e+01 | 3.5e-01 | 5.8e-01 |
| (w) COD (Chemical Oxygen Demand) | g | 8.0e+00 | 5.1e+00 | 2.4e-01 |
| (w) Cyanides (CN-) | g | 3.0e-18 | 6.4e-19 | 1.5e-18 |
| (w) Dissolved Matter (unspecified) | g | 1.3e+00 | 1.1e+00 | 1.9e+00 |
| (w) Fluorides (F-) | g | 1.3e-04 | 2.7e-05 | 1.1e-04 |
| (w) Hydrocarbons (unspecified) | g | 8.4e-04 | 2.3e-05 | 8.2e-01 |
| (w) Metals (unspecified) | g | 2.9e-02 | 8.0e-03 | 1.1e-03 |
| (w) Nitrates (NO3-) | g | 3.0e-05 | 6.4e-06 | 2.5e-05 |
| (w) Nitrogenous Matter (unspecified, as N) | g | 0.0e+00 | 0.0e+00 | 6.2e+01 |
| (w) Oils (unspecified) | g | 4.3e-01 | 2.4e-01 | 1.4e-02 |
| (w) Phenols | g | 1.8e-02 | 1.2e-02 | 5.1e-04 |
| (w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P) | g | 0.0e+00 | 0.0e+00 | 9.7e+00 |
| (w) Sodium (Na+) | g | 1.7e+01 | 4.5e-01 | 7.4e-01 |
| (w) Sulfates (SO4--) | g | 2.7e-05 | 5.7e-06 | 2.3e-05 |
| (w) Suspended Matter (unspecified) | g | 4.3e+00 | 2.8e+00 | 1.6e+03 |
| Waste (50 years - prorated) | kg | 8.2e-01 | 8.2e-01 | 8.6e-01 |
| Waste (End-of-Life) | kg | 8.2e-01 | 8.2e-01 | 8.6e-01 |
| Waste (Mfg.) | kg | 2.1e-02 | 8.0e-03 | 1.6e-02 |
| Waste (non-recyclable, 50-year) | kg | 8.2e-01 | 8.2e-01 | 8.6e-01 |
| E Feedstock Energy | MJ | 3.4e+01 | -5.0e-02 | 2.5e-01 |
| E Fuel Energy | MJ | 1.0e+01 | 2.2e+00 | 5.4e+00 |
| E Non Renewable Energy | MJ | 4.5e+01 | 2.1e+00 | 5.6e+00 |
| E Renewable Energy | MJ | 5.4e-02 | 1.2e-02 | 3.9e-02 |
| E Total Primary Energy | MJ | 4.5e+01 | 2.1e+00 | 5.7e+00 |

## Indicator Results

The table below shows the indicator results for the three systems studied.

**Table 3: LCIA Results**

| | LCIA Totals | | |
|---|---|---|---|
| **Indicator** | **Virgin Oil** | **Rerefined Oil** | **Bio-based Oil** |
| GWP (kg CO2 equiv) | 649 | 332 | 353 |
| ODP (kg CFC-11) | 0 | 0 | 0 |
| Acidification (kg SO2) | 5 | 2 | 2 |
| Eutrophication (kg PO4) | 2 | 1 | 36 |
| Photochemical Smog (kg O3) | 0.74 | 0.17 | 7.16 |
| Human Toxicity | | | |
| Cancer | 2.12E-04 | 5.66E-06 | 9.13E-06 |
| NonCancer | 2.83E-02 | 4.29E-03 | 5.23E-01 |
| Ecotoxicity | 8.08E-03 | 4.31E-03 | 4.06E-02 |
| Resource Depletion | | | |
| Fossil (tons oil equivalent) | 1.70E+00 | 1.05E-01 | 3.23E-01 |
| Mineral (equiv tons) | 0 | 0 | 0 |
| Precious(equiv tons) | 0 | 0 | 0 |
| Other Indicators: | | | |
| Land Use (ha) | 0 | 0 | 0 |
| Water Use (kg) | 1.35E-01 | 3.59E-03 | 5.89E+02 |
| Solid Waste (kg) | 8.19E-01 | 8.19E-01 | 8.55E-01 |

## Interpretation

As one would expect, selecting either rerefined or bio-based oil potentially appears to reduce fossil fuel depletion. Comparing the two alternatives to Virgin Oil, rerefined oil leads (as preferable) in the categories for Eutrophication, Photochemical Smog, Non-Cancer, and Water Use, when looking at order of magnitude differences. Also, a decrease in cancer effects is indicated when moving from selecting virgin oil to either alternative product system. The differences are negligible in the other categories.

It is possible to evaluate the sources of the various impacts in order to identify opportunities for improvements. The table below shows the indicators for each product in term of percentage of the indicators in the different life cycle stages.

**Table 4: Percentage of Indicator by Life Cycle Stage, Virgin Oil**

| | Virgin Oil - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 17 | 73 | 10 | 0 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 28 | 70 | 2 | 0 | 0 |
| **Eutrophication** | 0 | 98 | 1 | 0 | 0 |
| **Photochemical Smog** | 78 | 5 | 17 | 0 | 0 |
| **Human Health** | | | | | |
| Cancer | 97 | 1 | 2 | 0 | 0 |
| NonCancer | 78 | 20 | 2 | 0 | 0 |
| **Eco Health** | | | | | |
| **Resource Depletion** | | | | | |
| Fossil | 83 | 15 | 2 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | 0 | 0 | 0 |
| Water Use (kg) | 97 | 1 | 2 | 0 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 100 |

**Table 5: Percentage of Indicator by Life Cycle Stage, Rerefined Oil**

| | Rerefined Oil - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 4 | 76 | 20 | 0 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 1 | 93 | 6 | 0 | 0 |
| **Eutrophication** | 0 | 98 | 2 | 0 | 0 |
| **Photochemical Smog** | 16 | 11 | 74 | 0 | 0 |
| **Human Health** | | | | | |
| Cancer | 16 | 7 | 76 | 0 | 0 |
| Non-Cancer | 3 | 85 | 13 | 0 | 0 |
| **Eco Health** | | | | | |
| **Resource Depletion** | | | | | |
| Fossil | 7 | 62 | 31 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | 0 | 0 | 0 |
| Water Use (kg) | 15 | 13 | 72 | 0 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 100 |

**Table 6: Percentage of Indicator by Life Cycle Stage, Bio-Based Oil**

| | Bio-Based Oil - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 30 | 51 | 19 | 0 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 32 | 62 | 5 | 0 | 0 |
| **Eutrophication** | 100 | 0 | 0 | 0 | 0 |
| **Photochemical Smog** | 11 | 88 | 2 | 0 | 0 |
| **Human Health** | | | | | |
| Cancer | 50 | 0 | 50 | 0 | 0 |
| Non-Cancer | 100 | 0 | 0 | 0 | 0 |
| **Eco Health** | | | | | |
| **Resource Depletion** | | | | | |
| Fossil | 24 | 65 | 11 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | 0 | 0 | 0 |
| Water Use (kg) | 100 | 0 | 0 | 0 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 100 |

For the most part, the majority of the three products indicator results can be found in the manufacturing and the transportation phases of the life cycle. This result supports the guidance of the FRED methodology, which recommends more intensive data gathering efforts in the manufacturing phase for products which are durable goods which are not energy intensive in the use phase.

**Conclusions**

This pilot project proved that existing LCA data sets can be used in the FRED LCA system. Concern that arose during this pilot project centered around lack of information regarding the LCA data sets. For example, more information regarding data sources, specificity, age, quality, etc. would have been useful in framing the applicability of the FRED LCA system results.

## Table 7: Life Cycle Inventory, Virgin Oil

| | | Virgin Oil- LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (r) Baryte (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bauxite (Al2O3.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bentonite (Al2O3.4SiO2.H2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Borax (Na2O.2B2O3.10H2O) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Clay (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Coal (in ground) | kg | 1.6e-02 | 1.9e-02 | 5.8e-04 | 0.0e+00 | 0.0e+00 |
| (r) Copper (Cu, Ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Diabase Rock | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Dolomite (CaCO3.MgCO3, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Feldspar (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Granite (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gravel (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gypsum (CaSO4: in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Ilmenite Ore (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Iron (Fe, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Jute | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Kaolin (Al2O3.2SiO2.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Limestone (CaCO3, in ground) | kg | 3.1e-03 | 3.6e-03 | 1.1e-04 | 0.0e+00 | 0.0e+00 |
| (r) Natural Gas (in ground) | kg | 4.6e-02 | 5.1e-02 | 1.6e-03 | 0.0e+00 | 0.0e+00 |
| (r) Oil (in ground) | kg | 8.8e-01 | 5.5e-03 | 1.9e-02 | 0.0e+00 | 0.0e+00 |
| (r) Perlite (SiO2, ore) | kg | 1.1e-06 | 3.2e-04 | 4.2e-06 | 0.0e+00 | 0.0e+00 |
| (r) Phosphate Rock (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pine Rosin | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potash (K2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potassium (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pyrite (FeS2, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sand (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sodium Chloride (NaCl, in ground or in sea) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Uranium (U, ore) | kg | 3.9e-07 | 4.5e-07 | 1.4e-08 | 0.0e+00 | 0.0e+00 |
| (r) Wastepaper | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Wood (standing) | m3 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Cullet (from stock) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Fly Ash | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Iron Ore Slag | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Recovered Solids (iron scraps) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Used Oil | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | Virgin Oil- LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| Water Used (total) | liter | 1.3e-01 | 1.2e-03 | 2.6e-03 | 0.0e+00 | 0.0e+00 |
| (a) Aldehydes | g | 4.9e-05 | 5.8e-05 | 1.9e-06 | 0.0e+00 | 0.0e+00 |
| (a) Ammonia (NH3) | g | 7.4e-08 | 8.1e-08 | 7.9e-08 | 0.0e+00 | 0.0e+00 |
| (a) Benzene | g | 2.0e-04 | 1.1e-06 | 4.2e-06 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, biomass) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, fossil) | g | 8.5e+01 | 4.6e+02 | 6.2e+01 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Monoxide (CO) | g | 8.7e-02 | 3.2e-01 | 5.4e-02 | 0.0e+00 | 0.0e+00 |
| (a) Fluorides (F-) | g | 9.5e-13 | 1.6e-12 | 4.0e-14 | 0.0e+00 | 0.0e+00 |
| (a) Formaldehyde | g | 2.7e-03 | 1.5e-05 | 5.6e-05 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (except methane) | g | 1.4e-01 | 3.5e-03 | 3.1e-02 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (unspecified) | g | 1.5e-01 | 1.4e+00 | 2.4e-02 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Chloride (HCl) | g | 8.7e-03 | 1.0e-02 | 3.1e-04 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Fluoride (HF) | g | 1.1e-03 | 1.3e-03 | 3.9e-05 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Sulfide (H2S) | g | 5.9e-03 | 4.8e-05 | 1.4e-04 | 0.0e+00 | 0.0e+00 |
| (a) Lead (Pb) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Metals (unspecified) | g | 6.5e-06 | 1.9e-05 | 2.5e-05 | 0.0e+00 | 0.0e+00 |
| (a) Methane (CH4) | g | 6.8e-01 | 4.0e-01 | 2.1e-02 | 0.0e+00 | 0.0e+00 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 2.6e-01 | 9.7e-01 | 1.4e-01 | 0.0e+00 | 0.0e+00 |
| (a) Nitrous Oxide (N2O) | g | 2.7e-02 | 9.4e-03 | 1.1e-02 | 0.0e+00 | 0.0e+00 |
| (a) Organic Matter (unspecified) | g | 2.4e-04 | 2.8e-04 | 8.8e-06 | 0.0e+00 | 0.0e+00 |
| (a) Particulates (unspecified) | g | 2.4e-01 | 6.0e-01 | 1.5e-01 | 0.0e+00 | 0.0e+00 |
| (a) Phenolics | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Sulfur Oxides (SOx as SO2) | g | 1.3e+00 | 3.3e+00 | 9.1e-02 | 0.0e+00 | 0.0e+00 |
| (a) Volatile Organic Compounds (VOCs) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Acids (H+) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Ammonia (NH4+, NH3, as N) | g | 5.2e-04 | 1.4e-01 | 1.8e-03 | 0.0e+00 | 0.0e+00 |
| (w) AOX (Adsordable Organic Halogene) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Benzene | g | 4.0e-14 | 4.7e-14 | 1.4e-15 | 0.0e+00 | 0.0e+00 |
| (w) BOD5 (Biochemical Oxygen Demand) | g | 3.4e-03 | 9.3e-01 | 1.2e-02 | 0.0e+00 | 0.0e+00 |
| (w) Calcium (Ca++) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Chlorides (Cl-) | g | 1.3e+01 | 7.9e-02 | 2.7e-01 | 0.0e+00 | 0.0e+00 |
| (w) COD (Chemical Oxygen Demand) | g | 2.9e-02 | 7.9e+00 | 1.1e-01 | 0.0e+00 | 0.0e+00 |
| (w) Cyanides (CN-) | g | 1.4e-18 | 1.6e-18 | 4.9e-20 | 0.0e+00 | 0.0e+00 |
| (w) Dissolved Matter (unspecified) | g | 2.4e-01 | 2.5e-01 | 8.4e-01 | 0.0e+00 | 0.0e+00 |
| (w) Fluorides (F-) | g | 5.8e-05 | 6.8e-05 | 2.1e-06 | 0.0e+00 | 0.0e+00 |
| (w) Hydrocarbons (unspecified) | g | 8.2e-04 | 5.1e-06 | 1.7e-05 | 0.0e+00 | 0.0e+00 |
| (w) Metals (unspecified) | g | 1.7e-02 | 1.2e-02 | 5.1e-04 | 0.0e+00 | 0.0e+00 |
| (w) Nitrates (NO3-) | g | 1.4e-05 | 1.6e-05 | 4.9e-07 | 0.0e+00 | 0.0e+00 |
| (w) Nitrogenous Matter (unspecified, as N) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | Virgin Oil- LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (w) Oils (unspecified) | g | 6.7e-02 | 3.6e-01 | 6.2e-03 | 0.0e+00 | 0.0e+00 |
| (w) Phenols | g | 6.5e-05 | 1.8e-02 | 2.4e-04 | 0.0e+00 | 0.0e+00 |
| (w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Sodium (Na+) | g | 1.6e+01 | 1.0e-01 | 3.4e-01 | 0.0e+00 | 0.0e+00 |
| (w) Sulfates (SO4--) | g | 1.2e-05 | 1.4e-05 | 4.4e-07 | 0.0e+00 | 0.0e+00 |
| (w) Suspended Matter (unspecified) | g | 1.5e-02 | 4.2e+00 | 5.7e-02 | 0.0e+00 | 0.0e+00 |
| 1 quart (Bio-Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| 1 quart (Re-refine Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| 1 quart (Virgin Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.0e+00 | 0.0e+00 |
| Bio-oil | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Component 2 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Component 3 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Lubricants (kg) | kg | 0.0e+00 | 8.2e-01 | 8.2e-01 | 0.0e+00 | 0.0e+00 |
| Waste (50 years - prorated) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.2e-01 |
| Waste (End-of-Life) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.2e-01 |
| Waste (first replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (installation) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (Mfg.) | kg | 5.9e-03 | 1.5e-02 | 3.2e-04 | 0.0e+00 | 0.0e+00 |
| Waste (non-recyclable, 50-year) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.2e-01 |
| Waste (second replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Feedstock Energy | MJ | 3.8e+01 | -3.1e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Fuel Energy | MJ | 2.6e+00 | 6.7e+00 | 8.9e-01 | 0.0e+00 | 0.0e+00 |
| E Non Renewable Energy | MJ | 4.0e+01 | 3.6e+00 | 8.8e-01 | 0.0e+00 | 0.0e+00 |
| E Renewable Energy | MJ | 2.5e-02 | 2.9e-02 | 8.8e-04 | 0.0e+00 | 0.0e+00 |
| E Total Primary Energy | MJ | 4.0e+01 | 3.6e+00 | 8.9e-01 | 0.0e+00 | 0.0e+00 |

## Table 8: Life Cycle Inventory, Rerefined Oil

| | | Rerefined Oil - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (r) Baryte (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bauxite (Al2O3.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bentonite (Al2O3.4SiO2.H2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Borax (Na2O.2B2O3.10H2O) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Clay (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Coal (in ground) | kg | 1.2e-04 | 6.9e-03 | 5.8e-04 | 0.0e+00 | 0.0e+00 |
| (r) Copper (Cu, Ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Diabase Rock | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Dolomite (CaCO3.MgCO3, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Feldspar (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Granite (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gravel (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gypsum (CaSO4: in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Ilmenite Ore (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Iron (Fe, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Jute | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Kaolin (Al2O3.2SiO2.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Limestone (CaCO3, in ground) | kg | 2.3e-05 | 1.3e-03 | 1.1e-04 | 0.0e+00 | 0.0e+00 |
| (r) Natural Gas (in ground) | kg | 3.4e-04 | 1.3e-02 | 1.6e-03 | 0.0e+00 | 0.0e+00 |
| (r) Oil (in ground) | kg | 3.9e-03 | 2.0e-03 | 1.9e-02 | 0.0e+00 | 0.0e+00 |
| (r) Perlite (SiO2, ore) | kg | 8.9e-07 | 2.0e-04 | 4.2e-06 | 0.0e+00 | 0.0e+00 |
| (r) Phosphate Rock (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pine Rosin | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potash (K2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potassium (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pyrite (FeS2, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sand (iound) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sodium Chloride (NaCl, in ground or in sea) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Uranium (U, ore) | kg | 2.9e-09 | 1.6e-07 | 1.4e-08 | 0.0e+00 | 0.0e+00 |
| (r) Wastepaper | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Wood (standing) | m3 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Cullet (from stock) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Fly Ash | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Iron Ore Slag | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Recovered Solids (iron scraps) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | Rerefined Oil - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| Used Oil | kg | 8.6e-01 | 8.6e-01 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Water Used (total) | liter | 5.5e-04 | 4.6e-04 | 2.6e-03 | 0.0e+00 | 0.0e+00 |
| (a) Aldehydes | g | 4.0e-07 | 2.1e-05 | 1.9e-06 | 0.0e+00 | 0.0e+00 |
| (a) Ammonia (NH3) | g | 1.7e-08 | 3.0e-08 | 7.9e-08 | 0.0e+00 | 0.0e+00 |
| (a) Benzene | g | 8.8e-07 | 4.0e-07 | 4.2e-06 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, biomass) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, fossil) | g | 1.3e+01 | 2.5e+02 | 6.2e+01 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Monoxide (CO) | g | 1.1e-02 | 1.9e-01 | 5.4e-02 | 0.0e+00 | 0.0e+00 |
| (a) Fluorides (F-) | g | 8.5e-15 | 4.0e-13 | 4.0e-14 | 0.0e+00 | 0.0e+00 |
| (a) Formaldehyde | g | 1.2e-05 | 5.4e-06 | 5.6e-05 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (except methane) | g | 6.6e-03 | 1.3e-03 | 3.1e-02 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (unspecified) | g | 5.2e-03 | 8.6e-01 | 2.4e-02 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Chloride (HCl) | g | 6.6e-05 | 3.7e-03 | 3.1e-04 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Fluoride (HF) | g | 8.2e-06 | 4.6e-04 | 3.9e-05 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Sulfide (H2S) | g | 2.9e-05 | 1.8e-05 | 1.4e-04 | 0.0e+00 | 0.0e+00 |
| (a) Lead (Pb) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Metals (unspecified) | g | 5.4e-07 | 6.9e-05 | 2.5e-05 | 0.0e+00 | 0.0e+00 |
| (a) Methane (CH4) | g | 4.5e-03 | 1.2e-01 | 2.1e-02 | 0.0e+00 | 0.0e+00 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 3.1e-02 | 5.2e-01 | 1.4e-01 | 0.0e+00 | 0.0e+00 |
| (a) Nitrous Oxide (N2O) | g | 2.4e-03 | 5.4e-03 | 1.1e-02 | 0.0e+00 | 0.0e+00 |
| (a) Organic Matter (unspecified) | g | 1.9e-06 | 1.0e-04 | 8.8e-06 | 0.0e+00 | 0.0e+00 |
| (a) Particulates (unspecified) | g | 3.2e-02 | 3.1e-01 | 1.5e-01 | 0.0e+00 | 0.0e+00 |
| (a) Phenolics | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Sulfur Oxides (SOx as SO2) | g | 1.9e-02 | 1.5e+00 | 9.1e-02 | 0.0e+00 | 0.0e+00 |
| (a) Volatile Organic Compounds (VOCs) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Acids (H+) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Ammonia (NH4+, NH3, as N) | g | 3.8e-04 | 8.7e-02 | 1.8e-03 | 0.0e+00 | 0.0e+00 |
| (w) AOX (Adsordable Organic Halogene) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Benzene | g | 3.0e-16 | 1.7e-14 | 1.4e-15 | 0.0e+00 | 0.0e+00 |
| (w) BOD5 (Biochemical Oxygen Demand) | g | 2.6e-03 | 5.9e-01 | 1.2e-02 | 0.0e+00 | 0.0e+00 |
| (w) Calcium (Ca++) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Chlorides (Cl-) | g | 5.6e-02 | 2.9e-02 | 2.7e-01 | 0.0e+00 | 0.0e+00 |
| (w) COD (Chemical Oxygen Demand) | g | 2.2e-02 | 5.0e+00 | 1.1e-01 | 0.0e+00 | 0.0e+00 |
| (w) Cyanides (CN-) | g | 1.0e-20 | 5.8e-19 | 4.9e-20 | 0.0e+00 | 0.0e+00 |
| (w) Dissolved Matter (unspecified) | g | 1.8e-01 | 9.2e-02 | 8.4e-01 | 0.0e+00 | 0.0e+00 |
| (w) Fluorides (F-) | g | 4.4e-07 | 2.5e-05 | 2.1e-06 | 0.0e+00 | 0.0e+00 |
| (w) Hydrocarbons (unspecified) | g | 3.6e-06 | 1.9e-06 | 1.7e-05 | 0.0e+00 | 0.0e+00 |
| (w) Metals (unspecified) | g | 1.1e-04 | 7.3e-03 | 5.1e-04 | 0.0e+00 | 0.0e+00 |
| (w) Nitrates (NO3-) | g | 1.0e-07 | 5.8e-06 | 4.9e-07 | 0.0e+00 | 0.0e+00 |

| | | Rerefined Oil - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (w) Nitrogenous Matter (unspecified, as N) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Oils (unspecified) | g | 1.3e-03 | 2.3e-01 | 6.2e-03 | 0.0e+00 | 0.0e+00 |
| (w) Phenols | g | 5.1e-05 | 1.1e-02 | 2.4e-04 | 0.0e+00 | 0.0e+00 |
| (w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Sodium (Na+) | g | 7.2e-02 | 3.7e-02 | 3.4e-01 | 0.0e+00 | 0.0e+00 |
| (w) Sulfates (SO4--) | g | 9.3e-08 | 5.2e-06 | 4.4e-07 | 0.0e+00 | 0.0e+00 |
| (w) Suspended Matter (unspecified) | g | 1.2e-02 | 2.7e+00 | 5.7e-02 | 0.0e+00 | 0.0e+00 |
| 1 quart (Bio-Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| 1 quart (Re-refine Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| 1 quart (Virgin Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.0e+00 | 0.0e+00 |
| Bio-oil | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Component 2 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Component 3 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Lubricants (kg) | kg | 0.0e+00 | 8.2e-01 | 8.2e-01 | 0.0e+00 | 0.0e+00 |
| Waste (50 years - prorated) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.2e-01 |
| Waste (End-of-Life) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.2e-01 |
| Waste (first replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (installation) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (Mfg.) | kg | 6.7e-05 | 7.6e-03 | 3.2e-04 | 0.0e+00 | 0.0e+00 |
| Waste (non-recyclable, 50-year) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.2e-01 |
| Waste (second replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Feedstock Energy | MJ | 0.0e+00 | -5.0e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Fuel Energy | MJ | 1.9e-01 | 1.1e+00 | 8.9e-01 | 0.0e+00 | 0.0e+00 |
| E Non Renewable Energy | MJ | 1.9e-01 | 1.0e+00 | 8.8e-01 | 0.0e+00 | 0.0e+00 |
| E Renewable Energy | MJ | 1.9e-04 | 1.0e-02 | 8.8e-04 | 0.0e+00 | 0.0e+00 |
| E Total Primary Energy | MJ | 1.9e-01 | 1.0e+00 | 8.9e-01 | 0.0e+00 | 0.0e+00 |

**Table 9: Life Cycle Inventory, Bio-Based Oil**

| | | Bio-Based Oil - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (r) Baryte (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bauxite (Al2O3.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bentonite (Al2O3.4SiO2.H2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Borax (Na2O.2B2O3.10H2O) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Clay (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Coal (in ground) | kg | 5.3e-03 | 1.6e-02 | 6.0e-04 | 0.0e+00 | 0.0e+00 |
| (r) Copper (Cu, Ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Diabase Rock | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Dolomite (CaCO3.MgCO3, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Feldspar (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Granite (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gravel (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gypsum (CaSO4: in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Ilmenite Ore (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Iron (Fe, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Jute | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Kaolin (Al2O3.2SiO2.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Limestone (CaCO3, in ground) | kg | 9.2e-04 | 3.0e-03 | 1.1e-04 | 0.0e+00 | 0.0e+00 |
| (r) Natural Gas (in ground) | kg | 9.3e-03 | 4.3e-02 | 1.7e-03 | 0.0e+00 | 0.0e+00 |
| (r) Oil (in ground) | kg | 2.4e-02 | 2.6e-03 | 1.9e-02 | 0.0e+00 | 0.0e+00 |
| (r) Perlite (SiO2, ore) | kg | 4.5e-06 | 0.0e+00 | 4.4e-06 | 0.0e+00 | 0.0e+00 |
| (r) Phosphate Rock (in ground) | kg | 5.5e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pine Rosin | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potash (K2O, in ground) | kg | 3.2e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potassium (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pyrite (FeS2, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sand (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sodium Chloride (NaCl, in ground or in sea) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Uranium (U, ore) | kg | 3.0e-07 | 3.8e-07 | 1.4e-08 | 0.0e+00 | 0.0e+00 |
| (r) Wastepaper | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Wood (standing) | m3 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Cullet (from stock) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Fly Ash | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Iron Ore Slag | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Recovered Solids (iron scraps) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Used Oil | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | Bio-Based Oil - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| Water Used (total) | liter | 5.9e+02 | 3.5e-03 | 2.7e-03 | 0.0e+00 | 0.0e+00 |
| (a) Aldehydes | g | 1.7e-04 | 1.2e-04 | 2.0e-06 | 0.0e+00 | 0.0e+00 |
| (a) Ammonia (NH3) | g | 1.6e-01 | 4.0e-05 | 8.3e-08 | 0.0e+00 | 0.0e+00 |
| (a) Benzene | g | 4.4e-06 | 0.0e+00 | 4.4e-06 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, biomass) | g | -1.4e+03 | -1.1e+03 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, fossil) | g | 1.0e+02 | 1.7e+02 | 6.5e+01 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Monoxide (CO) | g | 4.7e-01 | 5.2e-02 | 5.7e-02 | 0.0e+00 | 0.0e+00 |
| (a) Fluorides (F-) | g | 4.6e-03 | 1.4e-12 | 4.2e-14 | 0.0e+00 | 0.0e+00 |
| (a) Formaldehyde | g | 6.0e-05 | 2.6e-12 | 5.8e-05 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (except methane) | g | 1.8e-01 | 1.6e+00 | 3.3e-02 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (unspecified) | g | 4.5e-01 | 1.3e-03 | 2.6e-02 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Chloride (HCl) | g | 1.4e-03 | 8.6e-03 | 3.2e-04 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Fluoride (HF) | g | 4.1e-05 | 1.1e-03 | 4.1e-05 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Sulfide (H2S) | g | 1.4e-04 | 1.0e-05 | 1.4e-04 | 0.0e+00 | 0.0e+00 |
| (a) Lead (Pb) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Metals (unspecified) | g | 2.8e-07 | 2.5e-08 | 2.7e-07 | 0.0e+00 | 0.0e+00 |
| (a) Methane (CH4) | g | 1.2e-01 | 3.2e-01 | 2.2e-02 | 0.0e+00 | 0.0e+00 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 6.7e-01 | 3.2e-01 | 1.5e-01 | 0.0e+00 | 0.0e+00 |
| (a) Nitrous Oxide (N2O) | g | 4.7e-03 | 1.6e-03 | 1.2e-02 | 0.0e+00 | 0.0e+00 |
| (a) Organic Matter (unspecified) | g | 1.1e-02 | 2.4e-04 | 9.2e-06 | 0.0e+00 | 0.0e+00 |
| (a) Particulates (unspecified) | g | 3.6e-01 | 2.3e-01 | 1.6e-01 | 0.0e+00 | 0.0e+00 |
| (a) Phenolics | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Sulfur Oxides (SOx as SO2) | g | 3.2e-01 | 1.2e+00 | 9.5e-02 | 0.0e+00 | 0.0e+00 |
| (a) Volatile Organic Compounds (VOCs) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Acids (H+) | g | 1.4e-04 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Ammonia (NH4+, NH3, as N) | g | 2.1e-03 | 5.1e-05 | 1.9e-03 | 0.0e+00 | 0.0e+00 |
| (w) AOX (Adsordable Organic Halogene) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Benzene | g | 1.5e-15 | 4.0e-14 | 1.5e-15 | 0.0e+00 | 0.0e+00 |
| (w) BOD5 (Biochemical Oxygen Demand) | g | 1.7e-02 | 2.2e-04 | 1.3e-02 | 0.0e+00 | 0.0e+00 |
| (w) Calcium (Ca++) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Chlorides (Cl-) | g | 2.9e-01 | 7.7e-03 | 2.8e-01 | 0.0e+00 | 0.0e+00 |
| (w) COD (Chemical Oxygen Demand) | g | 1.2e-01 | 1.8e-03 | 1.1e-01 | 0.0e+00 | 0.0e+00 |
| (w) Cyanides (CN-) | g | 5.2e-20 | 1.4e-18 | 5.1e-20 | 0.0e+00 | 0.0e+00 |
| (w) Dissolved Matter (unspecified) | g | 9.6e-01 | 4.8e-02 | 8.8e-01 | 0.0e+00 | 0.0e+00 |
| (w) Fluorides (F-) | g | 4.7e-05 | 5.7e-05 | 2.2e-06 | 0.0e+00 | 0.0e+00 |
| (w) Hydrocarbons (unspecified) | g | 4.1e-02 | 7.8e-01 | 1.8e-05 | 0.0e+00 | 0.0e+00 |
| (w) Metals (unspecified) | g | 5.5e-04 | 1.3e-05 | 5.4e-04 | 0.0e+00 | 0.0e+00 |
| (w) Nitrates (NO3-) | g | 1.1e-05 | 1.4e-05 | 5.1e-07 | 0.0e+00 | 0.0e+00 |
| (w) Nitrogenous Matter (unspecified, as | g | 6.2e+01 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | Bio-Based Oil - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| N) | | | | | | |
| (w) Oils (unspecified) | g | 7.3e-03 | 4.2e-04 | 6.4e-03 | 0.0e+00 | 0.0e+00 |
| (w) Phenols | g | 2.5e-04 | 3.9e-06 | 2.5e-04 | 0.0e+00 | 0.0e+00 |
| (w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P) | g | 9.7e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Sodium (Na+) | g | 3.7e-01 | 1.0e-02 | 3.6e-01 | 0.0e+00 | 0.0e+00 |
| (w) Sulfates (SO4--) | g | 1.0e-05 | 1.2e-05 | 4.6e-07 | 0.0e+00 | 0.0e+00 |
| (w) Suspended Matter (unspecified) | g | 1.6e+03 | 9.4e-04 | 5.9e-02 | 0.0e+00 | 0.0e+00 |
| 1 quart (Bio-Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.0e+00 | 0.0e+00 |
| 1 quart (Re-refine Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| 1 quart (Virgin Oil) | quart | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Bio-oil | kg | 0.0e+00 | 0.0e+00 | 8.6e-01 | 0.0e+00 | 0.0e+00 |
| Component 2 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Component 3 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Lubricants (kg) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (50 years - prorated) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.6e-01 |
| Waste (End-of-Life) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.6e-01 |
| Waste (first replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (installation) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (Mfg.) | kg | 2.2e-03 | 1.3e-02 | 3.3e-04 | 0.0e+00 | 0.0e+00 |
| Waste (non-recyclable, 50-year) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 8.6e-01 |
| Waste (second replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Feedstock Energy | MJ | 2.1e-01 | 3.5e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Fuel Energy | MJ | 1.6e+00 | 2.9e+00 | 9.2e-01 | 0.0e+00 | 0.0e+00 |
| E Non Renewable Energy | MJ | 1.8e+00 | 2.9e+00 | 9.2e-01 | 0.0e+00 | 0.0e+00 |
| E Renewable Energy | MJ | 1.4e-02 | 2.4e-02 | 9.2e-04 | 0.0e+00 | 0.0e+00 |
| E Total Primary Energy | MJ | 1.8e+00 | 3.0e+00 | 9.2e-01 | 0.0e+00 | 0.0e+00 |

# Appendix B: Wall Insulation Case Study

**Goal and Scope Definition**

## *Goal*

The goal of this pilot study was to determine the feasibility of evaluating the environmental performance of four different types of wall insulation by using the FRED LCA system. The four types of wall insulation evaluated were R-13 blown cellulose insulation, R-11 fiberglass batt insulation, R-15 fiberglass batt insulation and R-12 blown mineral wool insulation. Life cycle inventory data for this analysis was taken from NIST's Building for Environmental and Economic sustainability program.

## *Intended Applications and Audiences*

The LCA itself was intended to be used to support a comparative assertion of environmental superiority of a product over a competing product in the context of the Federal requirement for environmentally preferable purchasing. Audiences include purchasing agents as well as other federal and state officials. An ancillary use of the study is to support efforts towards environmental improvement.

## Scope

## *Description of the Product*

The products evaluated represented several types of wall insulation with varying levels of thermal resistance. Blown cellulose insulation is produced primarily from post-consumer wood pulp and is treated with fire retardant. Fiberglass batt insulation is made by forming spun-glass fibers into batts. Blown mineral wool insulation is made from forming fibers from either natural rock or iron ore blast furnace slag.

## *System Function and Functional Unit*

The system function for the alternative products is to provide a constant thermal performance (for both heating and cooling) for a house of 9600 cubic feet with an environment of 70 degrees F, given a typical wood frame-residential construction, when the outside annual temperature is 55 degrees F, with average winter temperature of 32 degrees F and average summer temperature of 85 degrees F. The functional unit is quantity of each insulation product required to maintain the desired thermal performance over a 50-year period.

## *System Boundaries*

The system studied included all unit processes for the manufacture of the insulation products as well as the heating/cooling energy requirements associated with their use.

**Data Gathering**

The entire data gathering exercise for this project involved extracting data from the BEES database. According to NIST, the BEES database includes both primary data as well as industry average data.

**Allocation**

According to the contractor for BEES, all allocation of emissions and resource use was performed based on a mass basis.

**Impact Assessment**

Impact assessment was performed based on the FRED LCA system indicators, as described in the body of this work. The assignment of inventory data to impact categories is shown in the table below.

**Table 1: Assignment of Inventory Results to Impact Categories**

| Inventory Result | Impact Category | Justification |
|---|---|---|
| Fossil Fuels and Uranium | Resource Depletion | Although Uranium is not truly a fossil fuel, it is "used up" in a precisely comparable fashion |
| $CO_2$, $N_20$, Methane | Global Warming | These are important greenhouse gases which do not participate to a great extent in other impact categories |
| CO | Human Toxicity<br>Photochemical Smog<br>Global Warming; | CO is a human and animal toxicant, as well as a precursor to ozone formation and a greenhouse gas. It can participate in the first two of these environmental mechanisms without losing its potency for the others. |
| CFC's, HCFC's, Halons | Global Warming 100%<br>Stratospheric Ozone Depletion 100% | These substances participate fully in both of these parallel environmental mechanisms |
| $SO_2$, | Acidification 100% | Although SO2 contributes to visibility deterioration, and human health effects through the formation of Particulate Matter, these environmental mechanisms are not addressed by FRED. |
| HCl, HF | Acidification 100%<br>Human Health 100% | These acid gases have minor human health effects as well as |

| Inventory Result | Impact Category | Justification |
|---|---|---|
| | | contributing to acidification. It was thought that double counting would not significantly skew results. |
| Toxic Air and Water Emissions | Human Toxicity 100%<br>Ecotoxicity 100% | Since it was not possible to evaluate the partitioning of these substances, they were double counted so as not to underestimate their impacts. |
| NOx | Acidification 100%<br>Eutrophication 100% | Since FRED does not currently evaluate the fate and transport of NOx, this emission was double counted. |
| VOC's, ROG's | Photochemical Smog | These are the essential precursors to photochemically produced ozone. Although some of them are also toxic, unspeciated data does not permit a toxic evaluation. |
| $NH_4$ | Eutrophication (water emissions); acidification (air Emissions) | Although NH4 is not an acid gas, it undergoes changes in the soil leading to acidification effects. |
| $PO_4$ | Eutrophication 100% | Phosphate does not participate in any other environmental mechanism described by the FRED methodology |

**Inventory**

The table below shows the summary inventory for the four products compared. A full inventory by life cycle stage can be found in Tables 8, 9, 10 and 11.

**Table 2: Summary Inventory**

| | | LCI Totals | | | |
|---|---|---|---|---|---|
| Article | Units | Blown Cellulose | R-11 Fiberglass | R-15 Fiberglass | Mineral Wool |
| (r) Bauxite (Al2O3.2H2O, ore) | kg | 2.4e-05 | 1.0e-06 | 3.4e-06 | 3.0e-06 |
| (r) Borax (Na2O.2B2O3.10H2O) | kg | 5.1e-02 | 3.5e-03 | 1.1e-02 | 0.0e+00 |

| | | LCI Totals | | | |
|---|---|---|---|---|---|
| **Article** | **Units** | **Blown Cellulose** | **R-11 Fiberglass** | **R-15 Fiberglass** | **Mineral Wool** |
| (r) Clay (in ground) | kg | 2.2e-06 | 7.8e-08 | 2.6e-07 | 2.2e-07 |
| (r) Coal (in ground) | kg | 9.3e-02 | 2.2e-02 | 6.0e-02 | 8.9e-02 |
| (r) Diabase Rock | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 6.7e-02 |
| (r) Iron (Fe, ore) | kg | 2.7e-05 | 7.7e-07 | 2.5e-06 | 2.1e-06 |
| (r) Limestone (CaCO3, in ground) | kg | 1.7e-02 | 1.7e-02 | 5.5e-02 | 1.3e-03 |
| (r) Natural Gas (in ground) | kg | 2.5e-01 | 4.2e-02 | 1.1e-01 | 1.5e-01 |
| (r) Oil (in ground) | kg | 1.5e-01 | 1.8e-01 | 1.9e-01 | 1.8e-02 |
| (r) Perlite (SiO2, ore) | kg | 1.6e-05 | 1.7e-05 | 1.7e-05 | 1.6e-06 |
| Cullet (from stock) | kg | 0.0e+00 | 3.7e-03 | 1.2e-02 | 0.0e+00 |
| Iron Ore Slag | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 2.7e-01 |
| Water Used (total) | liter | 1.2e+00 | 2.5e-01 | 4.7e-01 | 3.0e-01 |
| (a) Aldehydes | g | 2.7e-04 | 1.2e-04 | 2.5e-04 | 8.8e-04 |
| (a) Ammonia (NH3) | g | 6.4e-06 | 2.1e-05 | 2.2e-05 | 2.0e-05 |
| (a) Benzene | g | 1.6e-05 | 4.0e-05 | 4.0e-05 | 1.6e-06 |
| (a) Carbon Dioxide (CO2, fossil) | g | 9.4e+02 | 1.8e+02 | 4.7e+02 | 1.2e+02 |
| (a) Fluorides (F-) | g | 6.5e-08 | 5.0e-09 | 1.6e-08 | 6.5e-03 |
| (a) Formaldehyde | g | 2.1e-04 | 9.0e-02 | 3.0e-01 | 8.0e-03 |
| (a) Hydrocarbons (except methane) | g | 2.5e-01 | 9.1e-02 | 1.8e-01 | 1.9e+00 |
| (a) Hydrocarbons (unspecified) | g | 1.1e+00 | 1.8e-01 | 2.9e-01 | 1.6e-01 |
| (a) Hydrogen Chloride (HCl) | g | 5.2e-02 | 1.1e-02 | 3.1e-02 | 4.0e-03 |
| (a) Hydrogen Fluoride (HF) | g | 5.8e-03 | 1.4e-03 | 3.9e-03 | 5.2e-04 |
| (a) Hydrogen Sulfide (H2S) | g | 1.1e-03 | 1.4e-03 | 1.5e-03 | 9.7e-05 |
| (a) Methane (CH4) | g | 1.6e+00 | 4.2e-01 | 1.0e+00 | 7.4e-01 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 2.9e+00 | 5.4e-01 | 1.4e+00 | 3.9e-01 |
| (a) Nitrous Oxide (N2O) | g | 5.1e-02 | 9.2e-03 | 1.3e-02 | 4.0e-02 |
| (a) Organic Matter (unspecified) | g | 1.3e-03 | 3.9e-04 | 9.7e-04 | 1.8e-03 |
| (a) Particulates (unspecified) | g | 1.9e+00 | 2.4e+00 | 7.8e+00 | 1.4e+00 |
| (a) Phenolics | g | 0.0e+00 | 5.0e-01 | 1.6e+00 | 0.0e+00 |
| (a) Sulfur Oxides (SOx as SO2) | g | 5.5e+00 | 1.7e+00 | 4.5e+00 | 3.7e+00 |
| (w) Acids (H+) | g | 1.3e-02 | 2.3e-04 | 7.5e-04 | 6.6e-04 |
| (w) Ammonia (NH4+, NH3, as N) | g | 9.7e-03 | 7.2e-03 | 7.6e-03 | 7.8e-04 |
| (w) AOX (Adsordable Organic Halogene) | g | 0.0e+00 | 1.1e-05 | 1.1e-05 | 0.0e+00 |
| (w) Benzene | g | 2.2e-13 | 5.2e-14 | 1.4e-13 | 1.7e-14 |
| (w) BOD5 (Biochemical Oxygen Demand) | g | 1.1e-01 | 1.0e-01 | 2.1e-01 | 1.0e-01 |
| (w) Chlorides (Cl-) | g | 1.7e+00 | 2.5e+00 | 2.6e+00 | 1.1e-01 |
| (w) COD (Chemical Oxygen Demand) | g | 6.2e-01 | 5.2e-01 | 7.3e-01 | 2.1e-01 |
| (w) Cyanides (CN-) | g | 7.3e-18 | 1.8e-18 | 4.9e-18 | 5.7e-19 |
| (w) Dissolved Matter (unspecified) | g | 3.4e+00 | 8.0e+00 | 8.2e+00 | 3.5e-01 |

| | | LCI Totals | | | |
|---|---|---|---|---|---|
| Article | Units | Blown Cellulose | R-11 Fiberglass | R-15 Fiberglass | Mineral Wool |
| (w) Fluorides (F-) | g | 3.2e-04 | 7.6e-05 | 2.1e-04 | 2.6e-05 |
| (w) Hydrocarbons (unspecified) | g | 9.0e-03 | 4.9e-04 | 1.2e-03 | 9.5e-04 |
| (w) Metals (unspecified) | g | 4.3e-02 | 5.3e-03 | 8.1e-03 | 3.5e-03 |
| (w) Nitrates (NO3-) | g | 6.4e-02 | 2.6e-05 | 7.6e-05 | 3.7e-05 |
| (w) Nitrogenous Matter (unspecified, as N) | g | 1.1e-03 | 3.9e-05 | 1.3e-04 | 1.1e-04 |
| (w) Oils (unspecified) | g | 9.3e-02 | 3.3e-02 | 3.5e-02 | 3.8e-03 |
| (w) Phenols | g | 9.4e-04 | 9.5e-04 | 9.9e-04 | 1.0e-04 |
| (w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P) | g | 0.0e+00 | 4.9e-06 | 1.6e-05 | 2.4e-05 |
| (w) Sodium (Na+) | g | 1.5e+00 | 3.3e+00 | 3.3e+00 | 1.4e-01 |
| (w) Sulfates (SO4--) | g | 8.9e-02 | 6.8e-04 | 2.0e-03 | 1.2e-03 |
| (w) Suspended Matter (unspecified) | g | 2.6e-01 | 2.9e-01 | 4.4e-01 | 1.5e-01 |
| Waste (50 years - prorated) | kg | 1.3e+00 | 2.3e-01 | 3.8e-01 | 3.3e-01 |
| Waste (End-of-Life) | kg | 1.3e+00 | 2.3e-01 | 3.8e-01 | 3.3e-01 |
| Waste (installation) | kg | 4.0e-01 | 1.2e-02 | 2.0e-02 | 2.2e-02 |
| Waste (Mfg.) | kg | 3.5e-02 | 1.3e-02 | 3.8e-02 | 7.7e-02 |
| E Feedstock Energy | MJ | 5.4e+00 | 7.4e+00 | 7.7e+00 | 7.6e-01 |
| E Fuel Energy | MJ | 1.7e+01 | 3.4e+00 | 8.7e+00 | 1.0e+01 |
| E Non Renewable Energy | MJ | 2.3e+01 | 1.1e+01 | 1.6e+01 | 1.1e+01 |
| E Renewable Energy | MJ | 1.6e-01 | 1.9e-01 | 2.5e-01 | 2.1e-02 |
| E Total Primary Energy | MJ | 2.3e+01 | 1.1e+01 | 1.6e+01 | 1.1e+01 |
| E Fuel Energy | MJ | 1.0e+01 | 2.2e+00 | 5.4e+00 | |
| E Non Renewable Energy | MJ | 4.5e+01 | 2.1e+00 | 5.6e+00 | |
| E Renewable Energy | MJ | 5.4e-02 | 1.2e-02 | 3.9e-02 | |
| Total Primary Energy | MJ | 4.5e+01 | 2.1e+00 | 5.7e+00 | |

**Indicator Results**

The table below shows the indicator results for the four systems studied.

**Table 3: LCIA Results**

| | LCIA Results | | | |
|---|---|---|---|---|
| **Indicator** | **Blown Cellulose** | **Fiberglass R-11** | **Fiberglass R-15** | **Mineral Wool** |
| **GWP (kg $CO_2$ equiv)** | 986 | 193 | 492 | 153 |
| **ODP (kg CFC-11)** | 0 | 0 | 0 | 0 |

| | LCIA Results | | | |
|---|---|---|---|---|
| **Indicator** | **Blown Cellulose** | **Fiberglass R-11** | **Fiberglass R-15** | **Mineral Wool** |
| **Acidification (kg $SO_2$)** | 8 | 2 | 5 | 4 |
| **Eutrophication (kg $PO_4$)** | 0.1452 | 0.1169 | 0.1621 | 0.0471 |
| **Photochemical Smog (kg $O_3$)** | 1.08 | 2.10 | 6.45 | 7.62 |
| **Human Toxicity** | | | | |
| Cancer | 1.66E-05 | 3.09E-04 | 9.27E-04 | 2.57E-05 |
| NonCancer | 2.19E-03 | 6.52E-01 | 2.14E+00 | 5.64E-02 |
| **Ecotoxicity** | 1.94E-02 | 1.49E-02 | 4.69E-02 | 2.84E-03 |
| **Resource Depletion** | | | | |
| Fossil (tons oil equivalent) | 1.40E+00 | 4.48E-01 | 7.99E-01 | 7.42E-01 |
| Mineral (equiv tons) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Precious(equiv tons) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Other Indicators:** | | | | |
| Land Use (ha) | 0 | 0 | 0 | 0 |
| Water Use (kg) | 1.15E+00 | 2.53E-01 | 4.73E-01 | 3.00E-01 |
| Solid Waste (kg) | 1.26E+00 | 2.25E-01 | 3.77E-01 | 3.26E-01 |
| | | | | |

**Interpretation**

This is an example of when it may be difficult to make a decision based on the FRED LCA model outputs. For instance, blown cellulose has a lower indicated impact in the Human Toxicity category, but the other products have lower indicator results for Water Use and Solid Waste. Mineral wool also has the lowest indicator result, by an order of magnitude, for Ecotoxicity.

It is also possible to evaluate the sources of the various impacts in order to identify opportunities for improvements. The table below shows the indicators in term of percentage for the different life cycle stages.

**Table 4: Percentage of Indicator by Life Cycle Stage, Blown Cellulose**

| | Blown Cellulose - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 75 | 21 | 2 | 1 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 76 | 21 | 1 | 2 | 0 |
| **Eutrophication** | 90 | 1 | 5 | 3 | 0 |
| **Photochemical Smog** | 93 | 1 | 4 | 3 | 0 |
| **Human Health** | | | | | |
| Cancer | 86 | 0 | 8 | 6 | 0 |
| NonCancer | 87 | 0 | 8 | 5 | 0 |
| **Eco Health** | N/A | N/A | N/A | N/A | N/A |
| **Resource Depletion** | | | | | |
| Fossil | 96 | 3 | 1 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | 0 | 0 | 0 |
| Water Use (kg) | 100 | 0 | 0 | 0 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 100 |

**Table 5: Percentage of Indicator by Life Cycle Stage, R-11 Fiberglass**

| | R-11 Fiberglass - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 6 | 93 | 1 | 0 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 4 | 96 | 0 | 0 | 0 |
| **Eutrophication** | 16 | 84 | 1 | 0 | 0 |
| **Photochemical Smog** | 9 | 91 | 0 | 0 | 0 |
| **Human Health** | | | | | |
| Cancer | 4 | 96 | 0 | 0 | 0 |
| Non-Cancer | 4 | 96 | 0 | 0 | 0 |
| **Eco Health** | N/A | N/A | N/A | N/A | N/A |
| **Resource Depletion** | | | | | |
| Fossil | 6 | 94 | 0 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | 0 | 0 | 0 |
| Water Use (kg) | 38 | 62 | 0 | 0 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 0 |

**Table 6: Percentage of Indicator by Life Cycle Stage, R-15 Fiberglass**

| | R-15 Fiberglass - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 8 | 91 | 1 | 0 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 5 | 94 | 0 | 0 | 0 |
| **Eutrophication** | 38 | 61 | 2 | 0 | 0 |
| **Photochemical Smog** | 9 | 91 | 0 | 0 | 0 |
| **Human Health** | | | | | |
| Cancer | 4 | 96 | 0 | 0 | 0 |
| Non-Cancer | 4 | 96 | 0 | 0 | 0 |
| **Eco Health** | N/A | N/A | N/A | N/A | N/A |
| **Resource Depletion** | | | | | |
| Fossil | 12 | 88 | 0 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | 0 | 0 | 0 |
| Water Use (kg) | 66 | 33 | 0 | 0 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 0 |

**Table 7: Percentage of Indicator by Life Cycle Stage, Mineral Wool**

| | Mineral Wool - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 34 | 56 | 7 | 2 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 9 | 90 | 1 | 1 | 0 |
| **Eutrophication** | 88 | 1 | 8 | 3 | 0 |
| **Photochemical Smog** | 6 | 94 | 0 | 0 | 0 |
| **Human Health** | | | | | |
| Cancer | 96 | 0 | 3 | 1 | 0 |
| Non-Cancer | 100 | 0 | 0 | 0 | 0 |
| **Eco Health** | N/A | N/A | N/A | N/A | N/A |
| **Resource Depletion** | | | | | |
| Fossil | 11 | 88 | 1 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | 0 | 0 | 0 |
| Water Use (kg) | 100 | 0 | 0 | 0 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 0 |

For the most part, the majority of the four products indicator results can be found in the manufacturing and the transportation phases of the life cycle. This result supports the guidance of the FRED methodology, which recommends more intensive data gathering efforts in the manufacturing phase for products which are durable goods which are not energy intensive in the use phase.

**Conclusions**

Like the pilot project described in Appendix A, this pilot proved that existing LCA data sets can be used in the FRED LCA system. Concern that arose during this pilot project centered around lack of information regarding the LCA data sets. For example, more information regarding data sources, specificity, age, quality, etc., would have been useful in framing the applicability of the FRED LCA system results.

**Table 8: Life Cycle Inventory, Blown Cellulose**

| | | Blown Cellulose - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (r) Baryte (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bauxite (Al2O3.2H2O, ore) | kg | 2.4e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bentonite (Al2O3.4SiO2.H2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Borax (Na2O.2B2O3.10H2O) | kg | 5.1e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Clay (in ground) | kg | 2.2e-06 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Coal (in ground) | kg | 2.9e-02 | 6.3e-02 | 1.8e-04 | 1.2e-04 | 0.0e+00 |
| (r) Copper (Cu, Ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Diabase Rock | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Dolomite (CaCO3.MgCO3, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Feldspar (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Granite (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gravel (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gypsum (CaSO4: in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Ilmenite Ore (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Iron (Fe, ore) | kg | 2.7e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Jute | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Kaolin (Al2O3.2SiO2.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Limestone (CaCO3, in ground) | kg | 4.5e-03 | 1.2e-02 | 3.5e-05 | 2.3e-05 | 0.0e+00 |
| (r) Natural Gas (in ground) | kg | 2.4e-01 | 6.9e-03 | 5.0e-04 | 3.4e-04 | 0.0e+00 |
| (r) Oil (in ground) | kg | 1.3e-01 | 2.2e-03 | 5.9e-03 | 3.9e-03 | 0.0e+00 |
| (r) Perlite (SiO2, ore) | kg | 1.4e-05 | 0.0e+00 | 1.3e-06 | 9.0e-07 | 0.0e+00 |
| (r) Phosphate Rock (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pine Rosin | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potash (K2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potassium (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pyrite (FeS2, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sand (in ground) | kg | 4.6e-06 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sodium Chloride (NaCl, in ground or in sea) | kg | 1.4e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Uranium (U, ore) | kg | 5.4e-07 | 1.5e-06 | 4.4e-09 | 2.9e-09 | 0.0e+00 |
| (r) Wastepaper | kg | 1.1e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Wood (standing) | m3 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Cullet (from stock) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | Blown Cellulose - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| Fly Ash | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Iron Ore Slag | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Recovered Solids (iron scraps) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Water Used (total) | liter | 1.2e+00 | 1.9e-03 | 8.2e-04 | 5.5e-04 | 0.0e+00 |
| Sq Foot of Insulation (Cellulose) | Sq Ft | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.0e+00 |
| Cellulose Insulation | kg | 0.0e+00 | 1.3e+00 | 1.3e+00 | 1.3e+00 | 0.0e+00 |
| Component 2 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Component 3 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Aldehydes | g | 7.6e-05 | 1.9e-04 | 6.1e-07 | 4.1e-07 | 0.0e+00 |
| (a) Ammonia (NH3) | g | 6.2e-06 | 2.3e-07 | 2.5e-08 | 1.7e-08 | 0.0e+00 |
| (a) Benzene | g | 1.4e-05 | 0.0e+00 | 1.3e-06 | 8.8e-07 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, biomass) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, fossil) | g | 7.1e+02 | 2.0e+02 | 2.0e+01 | 1.4e+01 | 0.0e+00 |
| (a) Carbon Monoxide (CO) | g | 1.0e+00 | 4.3e-02 | 1.7e-02 | 5.6e-02 | 0.0e+00 |
| (a) Fluorides (F-) | g | 6.5e-08 | 0.0e+00 | 1.3e-14 | 8.6e-15 | 0.0e+00 |
| (a) Formaldehyde | g | 1.8e-04 | 1.0e-11 | 1.8e-05 | 1.2e-05 | 0.0e+00 |
| (a) Hydrocarbons (except methane) | g | 2.3e-01 | 1.6e-03 | 9.9e-03 | 6.8e-03 | 0.0e+00 |
| (a) Hydrocarbons (unspecified) | g | 1.1e+00 | 5.2e-03 | 7.7e-03 | 5.2e-03 | 0.0e+00 |
| (a) Hydrogen Chloride (HCl) | g | 1.7e-02 | 3.4e-02 | 9.8e-05 | 6.6e-05 | 0.0e+00 |
| (a) Hydrogen Fluoride (HF) | g | 1.5e-03 | 4.3e-03 | 1.2e-05 | 8.3e-06 | 0.0e+00 |
| (a) Hydrogen Sulfide (H2S) | g | 1.0e-03 | 4.1e-05 | 4.3e-05 | 2.9e-05 | 0.0e+00 |
| (a) Lead (Pb) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Metals (unspecified) | g | 8.4e+03 | 9.8e-04 | 8.0e+02 | 5.4e+02 | 0.0e+00 |
| (a) Methane (CH4) | g | 1.1e+00 | 4.7e-01 | 6.8e-03 | 4.9e-03 | 0.0e+00 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 2.1e+00 | 6.1e-01 | 4.6e-02 | 2.1e-01 | 0.0e+00 |
| (a) Nitrous Oxide (N2O) | g | 4.3e-02 | 3.6e-03 | 3.6e-03 | 4.4e-04 | 0.0e+00 |
| (a) Organic Matter (unspecified) | g | 3.4e-04 | 9.4e-04 | 2.8e-06 | 1.9e-06 | 0.0e+00 |
| (a) Particulates (unspecified) | g | 9.6e-01 | 8.9e-01 | 4.7e-02 | 7.0e-03 | 0.0e+00 |
| (a) Phenolics | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Sulfur Oxides (SOx as SO2) | g | 4.3e+00 | 1.1e+00 | 2.9e-02 | 1.9e-02 | 0.0e+00 |
| (a) Volatile Organic Compounds | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Acids (H+) | g | 1.3e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Ammonia (NH4+, NH3, as N) | g | 8.5e-03 | 2.0e-04 | 5.8e-04 | 3.9e-04 | 0.0e+00 |
| (w) AOX (Adsordable Organic Halogene) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Benzene | g | 5.6e-14 | 1.6e-13 | 4.6e-16 | 3.1e-16 | 0.0e+00 |
| (w) BOD5 (Biochemical Oxygen | g | 1.0e-01 | 8.2e-04 | 3.9e-03 | 2.6e-03 | 0.0e+00 |

| | | Blown Cellulose - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| Demand) | | | | | | |
| (w) Calcium (Ca++) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Chlorides (Cl-) | g | 1.6e+00 | 3.1e-02 | 8.4e-02 | 5.7e-02 | 0.0e+00 |
| (w) COD (Chemical Oxygen Demand) | g | 5.5e-01 | 6.9e-03 | 3.3e-02 | 2.2e-02 | 0.0e+00 |
| (w) Cyanides (CN-) | g | 1.9e-18 | 5.4e-18 | 1.6e-20 | 1.0e-20 | 0.0e+00 |
| (w) Dissolved Matter (unspecified) | g | 2.9e+00 | 9.7e-02 | 2.7e-01 | 1.8e-01 | 0.0e+00 |
| (w) Fluorides (F-) | g | 9.3e-05 | 2.3e-04 | 6.6e-07 | 4.4e-07 | 0.0e+00 |
| (w) Hydrocarbons (unspecified) | g | 9.0e-03 | 2.0e-06 | 5.4e-06 | 3.6e-06 | 0.0e+00 |
| (w) Metals (unspecified) | g | 4.2e-02 | 5.2e-05 | 1.6e-04 | 1.1e-04 | 0.0e+00 |
| (w) Nitrates (NO3-) | g | 6.4e-02 | 5.4e-05 | 1.6e-07 | 1.1e-07 | 0.0e+00 |
| (w) Nitrogenous Matter (unspecified, as N) | g | 1.1e-03 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Oils (unspecified) | g | 9.0e-02 | 4.7e-04 | 2.0e-03 | 1.3e-03 | 0.0e+00 |
| (w) Phenols | g | 8.0e-04 | 1.6e-05 | 7.6e-05 | 5.1e-05 | 0.0e+00 |
| (w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Sodium (Na+) | g | 1.2e+00 | 4.0e-02 | 1.1e-01 | 7.3e-02 | 0.0e+00 |
| (w) Sulfates (SO4--) | g | 8.9e-02 | 4.8e-05 | 1.4e-07 | 9.3e-08 | 0.0e+00 |
| (w) Suspended Matter (unspecified) | g | 2.3e-01 | 3.7e-03 | 1.8e-02 | 1.2e-02 | 0.0e+00 |

| | | Blown Cellulose - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| Waste (50 years - prorated) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.3e+00 |
| Waste (End-of-Life) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.3e+00 |
| Waste (first replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (installation) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 3.3e-01 | 6.6e-02 |
| Waste (Mfg.) | kg | 1.1e-02 | 2.3e-02 | 1.0e-04 | 6.8e-05 | 0.0e+00 |
| Waste (non-recyclable, 50-year) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (second replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Feedstock Energy | MJ | 5.4e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Fuel Energy | MJ | 1.4e+01 | 3.1e+00 | 2.8e-01 | 1.9e-01 | 0.0e+00 |
| E Non Renewable Energy | MJ | 1.9e+01 | 3.0e+00 | 2.8e-01 | 1.9e-01 | 0.0e+00 |
| E Renewable Energy | MJ | 6.1e-02 | 9.7e-02 | 2.8e-04 | 1.9e-04 | 0.0e+00 |
| E Total Primary Energy | MJ | 1.9e+01 | 3.1e+00 | 2.8e-01 | 1.9e-01 | 0.0e+00 |
| E Fuel Energy | MJ | | | | | |
| E Non Renewable Energy | MJ | | | | | |
| E Renewable Energy | MJ | | | | | |

**Table 9: Life Cycle Inventory, R-11 Fiberglass**

| | | R-11 Fiberglass - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (r) Baryte (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bauxite (Al2O3.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bentonite (Al2O3.4SiO2.H2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Borax (Na2O.2B2O3.10H2O) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Clay (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Coal (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Copper (Cu, Ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Diabase Rock | kg | 7.5e-07 | 1.4e-08 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Dolomite (CaCO3.MgCO3, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Feldspar (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Granite (in ground) | kg | 1.3e-02 | 3.8e-03 | 3.6e-06 | 0.0e+00 | 0.0e+00 |
| (r) Gravel (in ground) | kg | 4.8e-03 | 3.7e-02 | 5.3e-05 | 0.0e+00 | 0.0e+00 |
| (r) Gypsum (CaSO4: in ground) | kg | 3.4e-03 | 1.8e-01 | 6.2e-04 | 0.0e+00 | 0.0e+00 |
| (r) Ilmenite Ore (in ground) | kg | 7.4e-08 | 1.6e-05 | 1.4e-07 | 0.0e+00 | 0.0e+00 |
| (r) Iron (Fe, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Jute | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Kaolin (Al2O3.2SiO2.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Limestone (CaCO3, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Natural Gas (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Oil (in ground) | kg | 3.7e-02 | 6.1e-09 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Perlite (SiO2, ore) | kg | 1.1e-04 | 1.8e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Phosphate Rock (in ground) | kg | 3.3e-08 | 4.7e-07 | 4.6e-10 | 0.0e+00 | 0.0e+00 |
| (r) Pine Rosin | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potash (K2O, in ground) | kg | 0.0e+00 | 1.1e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potassium (ore) | kg | 3.7e-03 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pyrite (FeS2, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sand (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sodium Chloride (NaCl, in ground or in sea) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Uranium (U, ore) | kg | 9.5e-02 | 1.6e-01 | 8.6e-05 | 0.0e+00 | 0.0e+00 |
| (r) Wastepaper | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.0e+00 | 0.0e+00 |
| (r) Wood (standing) | m3 | 0.0e+00 | 7.0e-02 | 6.9e-02 | 0.0e+00 | 0.0e+00 |
| Cullet (from stock) | kg | 0.0e+00 | 1.7e-01 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Fly Ash | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Iron Ore Slag | kg | 1.2e-05 | 1.0e-04 | 6.4e-08 | 0.0e+00 | 0.0e+00 |
| Recovered Solids (iron scraps) | kg | 2.0e-07 | 2.1e-05 | 2.6e-09 | 0.0e+00 | 0.0e+00 |

| | | R-11 Fiberglass - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| Water Used (total) | liter | 7.3e-08 | 3.9e-05 | 1.4e-07 | 0.0e+00 | 0.0e+00 |
| Sq Foot of Insulation (Cellulose) | Sq Ft | 0.0e+00 | 3.5e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Cellulose Insulation | kg | 1.1e+01 | 1.7e+02 | 2.1e+00 | 0.0e+00 | 0.0e+00 |
| Component 2 | NA | 5.1e-03 | 7.3e-02 | 1.8e-03 | 0.0e+00 | 0.0e+00 |
| Component 3 | NA | 5.0e-09 | 1.1e-12 | 1.3e-15 | 0.0e+00 | 0.0e+00 |
| (a) Aldehydes | g | 3.9e-03 | 8.6e-02 | 1.9e-06 | 0.0e+00 | 0.0e+00 |
| (a) Ammonia (NH3) | g | 3.7e-02 | 5.3e-02 | 1.0e-03 | 0.0e+00 | 0.0e+00 |
| (a) Benzene | g | 4.6e-02 | 1.3e-01 | 8.1e-04 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, biomass) | g | 7.2e-04 | 1.1e-02 | 1.0e-05 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, fossil) | g | 7.7e-05 | 1.3e-03 | 1.3e-06 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Monoxide (CO) | g | 2.3e-05 | 1.3e-03 | 4.5e-06 | 0.0e+00 | 0.0e+00 |
| (a) Fluorides (F-) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Formaldehyde | g | 4.4e+01 | 9.9e+03 | 8.4e+01 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (except methane) | g | 2.6e-02 | 4.0e-01 | 7.1e-04 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (unspecified) | g | 5.2e-02 | 4.8e-01 | 4.8e-03 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Chloride (HCl) | g | 4.6e-04 | 8.4e-03 | 3.8e-04 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Fluoride (HF) | g | 3.0e-05 | 3.6e-04 | 2.9e-07 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Sulfide (H2S) | g | 1.0e+00 | 1.4e+00 | 5.0e-03 | 0.0e+00 | 0.0e+00 |
| (a) Lead (Pb) | g | 0.0e+00 | 5.0e-01 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Metals (unspecified) | g | 5.0e-02 | 1.7e+00 | 3.0e-03 | 0.0e+00 | 0.0e+00 |
| (a) Methane (CH4) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 2.2e-04 | 8.2e-06 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Nitrous Oxide (N2O) | g | 5.5e-05 | 7.1e-03 | 6.0e-05 | 0.0e+00 | 0.0e+00 |
| (a) Organic Matter (unspecified) | g | 0.0e+00 | 1.1e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Particulates (unspecified) | g | 2.8e-15 | 4.9e-14 | 4.8e-17 | 0.0e+00 | 0.0e+00 |
| (a) Phenolics | g | 4.8e-02 | 5.1e-02 | 4.1e-04 | 0.0e+00 | 0.0e+00 |
| (a) Sulfur Oxides (SOx as SO2) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Volatile Organic Compounds (VOCs) | g | 9.6e-03 | 2.5e+00 | 8.8e-03 | 0.0e+00 | 0.0e+00 |
| (w) Acids (H+) | g | 8.4e-02 | 4.3e-01 | 3.5e-03 | 0.0e+00 | 0.0e+00 |
| (w) Ammonia (NH4+, NH3, as N) | g | 9.6e-20 | 1.7e-18 | 1.6e-21 | 0.0e+00 | 0.0e+00 |
| (w) AOX (Adsordable Organic Halogene) | g | 1.9e-02 | 8.0e+00 | 2.8e-02 | 0.0e+00 | 0.0e+00 |
| (w) Benzene | g | 5.0e-06 | 7.1e-05 | 6.9e-08 | 0.0e+00 | 0.0e+00 |
| (w) BOD5 (Biochemical Oxygen Demand) | g | 3.2e-04 | 1.6e-04 | 5.7e-07 | 0.0e+00 | 0.0e+00 |
| (w) Calcium (Ca++) | g | 1.2e-03 | 4.0e-03 | 1.7e-05 | 0.0e+00 | 0.0e+00 |
| (w) Chlorides (Cl-) | g | 9.0e-06 | 1.7e-05 | 1.6e-08 | 0.0e+00 | 0.0e+00 |
| (w) COD (Chemical Oxygen Demand) | g | 3.9e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Cyanides (CN-) | g | 5.7e-04 | 3.2e-02 | 2.0e-04 | 0.0e+00 | 0.0e+00 |

| | | R-11 Fiberglass - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (w) Dissolved Matter (unspecified) | g | 6.5e-06 | 9.3e-04 | 7.9e-06 | 0.0e+00 | 0.0e+00 |
| (w) Fluorides (F-) | g | 4.9e-06 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Hydrocarbons (unspecified) | g | 7.3e-03 | 3.3e+00 | 1.1e-02 | 0.0e+00 | 0.0e+00 |
| (w) Metals (unspecified) | g | 5.5e-04 | 1.3e-04 | 1.5e-08 | 0.0e+00 | 0.0e+00 |
| (w) Nitrates (NO3-) | g | 6.5e-02 | 2.2e-01 | 1.9e-03 | 0.0e+00 | 0.0e+00 |
| (w) Nitrogenous Matter (unspecified, as N) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Oils (unspecified) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Phenols | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.2e-02 | 0.0e+00 |
| (w) Sodium (Na+) | g | 5.2e-03 | 8.1e-03 | 1.1e-05 | 0.0e+00 | 0.0e+00 |
| (w) Sulfates (SO4--) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 2.3e-01 |
| (w) Suspended Matter (unspecified) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (50 years - prorated) | kg | 1.3e-01 | 7.3e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (End-of-Life) | kg | 3.2e-01 | 3.1e+00 | 2.9e-02 | 0.0e+00 | 0.0e+00 |
| Waste (first replacement) | kg | 4.4e-01 | 1.0e+01 | 2.9e-02 | 0.0e+00 | 0.0e+00 |
| Waste (installation) | kg | 3.0e-03 | 1.9e-01 | 2.9e-05 | 0.0e+00 | 0.0e+00 |
| Waste (Mfg.) | kg | 4.5e-01 | 1.0e+01 | 2.9e-02 | 0.0e+00 | 0.0e+00 |
| Waste (non-recyclable, 50-year) | kg | | | | | |
| Waste (second replacement) | kg | | | | | |
| E Feedstock Energy | MJ | | | | | |
| E Fuel Energy | MJ | | | | | |
| E Non Renewable Energy | MJ | | | | | |
| E Renewable Energy | MJ | | | | | |
| E Total Primary Energy | MJ | | | | | |
| E Fuel Energy | MJ | | | | | |
| E Non Renewable Energy | MJ | | | | | |
| E Renewable Energy | MJ | | | | | |
| E Total Primary Energy | MJ | | | | | |

**Table 10: Life Cycle Inventory, R-15 Fiberglass**

| | | R-15 Fiberglass - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (r) Baryte (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bauxite (Al2O3.2H2O, ore) | kg | 3.4e-06 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bentonite (Al2O3.4SiO2.H2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Borax (Na2O.2B2O3.10H2O) | kg | 1.1e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Clay (in ground) | kg | 2.6e-07 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Coal (in ground) | kg | 5.5e-03 | 5.4e-02 | 6.3e-05 | 0.0e+00 | 0.0e+00 |
| (r) Copper (Cu, Ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Diabase Rock | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Dolomite (CaCO3.MgCO3, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Feldspar (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Granite (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gravel (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gypsum (CaSO4: in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Ilmenite Ore (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Iron (Fe, ore) | kg | 2.5e-06 | 1.4e-08 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Jute | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Kaolin (Al2O3.2SiO2.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Limestone (CaCO3, in ground) | kg | 4.4e-02 | 1.0e-02 | 1.2e-05 | 0.0e+00 | 0.0e+00 |
| (r) Natural Gas (in ground) | kg | 1.6e-02 | 9.5e-02 | 1.7e-04 | 0.0e+00 | 0.0e+00 |
| (r) Oil (in ground) | kg | 1.1e-02 | 1.8e-01 | 2.0e-03 | 0.0e+00 | 0.0e+00 |
| (r) Perlite (SiO2, ore) | kg | 2.4e-07 | 1.6e-05 | 4.6e-07 | 0.0e+00 | 0.0e+00 |
| (r) Phosphate Rock (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pine Rosin | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potash (K2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potassium (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pyrite (FeS2, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sand (in ground) | kg | 1.2e-01 | 6.1e-09 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sodium Chloride (NaCl, in ground or in sea) | kg | 3.5e-04 | 1.8e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Uranium (U, ore) | kg | 1.1e-07 | 1.3e-06 | 1.5e-09 | 0.0e+00 | 0.0e+00 |
| (r) Wastepaper | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Wood (standing) | m3 | 0.0e+00 | 1.1e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Cullet (from stock) | kg | 1.2e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Fly Ash | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Iron Ore Slag | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Recovered Solids (iron scraps) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | R-15 Fiberglass - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| Water Used (total) | liter | 3.1e-01 | 1.6e-01 | 2.8e-04 | 0.0e+00 | 0.0e+00 |
| Sq Foot of Insulation (Cellulose) | Sq Ft | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.0e+00 | 0.0e+00 |
| Cellulose Insulation | kg | 0.0e+00 | 2.3e-01 | 2.3e-01 | 0.0e+00 | 0.0e+00 |
| Component 2 | NA | 0.0e+00 | 1.7e-01 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Component 3 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Aldehydes | g | 4.0e-05 | 2.1e-04 | 2.1e-07 | 0.0e+00 | 0.0e+00 |
| (a) Ammonia (NH3) | g | 6.7e-07 | 2.1e-05 | 8.7e-09 | 0.0e+00 | 0.0e+00 |
| (a) Benzene | g | 2.4e-07 | 3.9e-05 | 4.6e-07 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, biomass) | g | 0.0e+00 | 3.5e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, fossil) | g | 3.6e+01 | 4.2e+02 | 6.8e+00 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Monoxide (CO) | g | 1.7e-02 | 1.2e-01 | 6.0e-03 | 0.0e+00 | 0.0e+00 |
| (a) Fluorides (F-) | g | 1.6e-08 | 2.9e-12 | 4.4e-15 | 0.0e+00 | 0.0e+00 |
| (a) Formaldehyde | g | 1.3e-02 | 2.8e-01 | 6.1e-06 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (except methane) | g | 1.2e-01 | 5.4e-02 | 3.4e-03 | 0.0e+00 | 0.0e+00 |
| (a) Hydrocarbons (unspecified) | g | 1.5e-01 | 1.3e-01 | 2.7e-03 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Chloride (HCl) | g | 2.4e-03 | 2.9e-02 | 3.4e-05 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Fluoride (HF) | g | 2.5e-04 | 3.6e-03 | 4.3e-06 | 0.0e+00 | 0.0e+00 |
| (a) Hydrogen Sulfide (H2S) | g | 7.6e-05 | 1.4e-03 | 1.5e-05 | 0.0e+00 | 0.0e+00 |
| (a) Lead (Pb) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Metals (unspecified) | g | 1.5e+02 | 9.9e+03 | 2.8e+02 | 0.0e+00 | 0.0e+00 |
| (a) Methane (CH4) | g | 8.6e-02 | 9.1e-01 | 2.3e-03 | 0.0e+00 | 0.0e+00 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 1.7e-01 | 1.2e+00 | 1.6e-02 | 0.0e+00 | 0.0e+00 |
| (a) Nitrous Oxide (N2O) | g | 1.5e-03 | 1.1e-02 | 1.2e-03 | 0.0e+00 | 0.0e+00 |
| (a) Organic Matter (unspecified) | g | 9.9e-05 | 8.7e-04 | 9.6e-07 | 0.0e+00 | 0.0e+00 |
| (a) Particulates (unspecified) | g | 3.3e+00 | 4.5e+00 | 1.6e-02 | 0.0e+00 | 0.0e+00 |
| (a) Phenolics | g | 0.0e+00 | 1.6e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Sulfur Oxides (SOx as SO2) | g | 1.7e-01 | 4.3e+00 | 1.0e-02 | 0.0e+00 | 0.0e+00 |
| (a) Volatile Organic Compounds (VOCs) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Acids (H+) | g | 7.4e-04 | 8.2e-06 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Ammonia (NH4+, NH3, as N) | g | 1.8e-04 | 7.2e-03 | 2.0e-04 | 0.0e+00 | 0.0e+00 |
| (w) AOX (Adsordable Organic Halogene) | g | 0.0e+00 | 1.1e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Benzene | g | 9.3e-15 | 1.3e-13 | 1.6e-16 | 0.0e+00 | 0.0e+00 |
| (w) BOD5 (Biochemical Oxygen Demand) | g | 1.6e-01 | 5.2e-02 | 1.4e-03 | 0.0e+00 | 0.0e+00 |
| (w) Calcium (Ca++) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Chlorides (Cl-) | g | 3.2e-02 | 2.5e+00 | 2.9e-02 | 0.0e+00 | 0.0e+00 |
| (w) COD (Chemical Oxygen Demand) | g | 2.8e-01 | 4.4e-01 | 1.2e-02 | 0.0e+00 | 0.0e+00 |
| (w) Cyanides (CN-) | g | 3.2e-19 | 4.6e-18 | 5.4e-21 | 0.0e+00 | 0.0e+00 |

| | | R-15 Fiberglass - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (w) Dissolved Matter (unspecified) | g | 6.2e-02 | 8.0e+00 | 9.2e-02 | 0.0e+00 | 0.0e+00 |
| (w) Fluorides (F-) | g | 1.7e-05 | 1.9e-04 | 2.3e-07 | 0.0e+00 | 0.0e+00 |
| (w) Hydrocarbons (unspecified) | g | 1.1e-03 | 1.6e-04 | 1.9e-06 | 0.0e+00 | 0.0e+00 |
| (w) Metals (unspecified) | g | 4.0e-03 | 4.1e-03 | 5.6e-05 | 0.0e+00 | 0.0e+00 |
| (w) Nitrates (NO3-) | g | 3.0e-05 | 4.6e-05 | 5.4e-08 | 0.0e+00 | 0.0e+00 |
| (w) Nitrogenous Matter (unspecified, as N) | g | 1.3e-04 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Oils (unspecified) | g | 1.9e-03 | 3.2e-02 | 6.8e-04 | 0.0e+00 | 0.0e+00 |
| (w) Phenols | g | 2.1e-05 | 9.4e-04 | 2.6e-05 | 0.0e+00 | 0.0e+00 |
| (w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P) | g | 1.6e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Sodium (Na+) | g | 2.4e-02 | 3.3e+00 | 3.8e-02 | 0.0e+00 | 0.0e+00 |
| (w) Sulfates (SO4--) | g | 1.8e-03 | 1.6e-04 | 4.8e-08 | 0.0e+00 | 0.0e+00 |
| (w) Suspended Matter (unspecified) | g | 2.1e-01 | 2.2e-01 | 6.2e-03 | 0.0e+00 | 0.0e+00 |
| Waste (50 years - prorated) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (End-of-Life) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (first replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (installation) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 2.0e-02 | 0.0e+00 |
| Waste (Mfg.) | kg | 1.7e-02 | 2.1e-02 | 3.5e-05 | 0.0e+00 | 0.0e+00 |
| Waste (non-recyclable, 50-year) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 3.8e-01 |
| Waste (second replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Feedstock Energy | MJ | 4.3e-01 | 7.3e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Fuel Energy | MJ | 1.0e+00 | 7.6e+00 | 9.7e-02 | 0.0e+00 | 0.0e+00 |
| E Non Renewable Energy | MJ | 1.5e+00 | 1.5e+01 | 9.7e-02 | 0.0e+00 | 0.0e+00 |
| E Renewable Energy | MJ | 9.9e-03 | 2.4e-01 | 9.7e-05 | 0.0e+00 | 0.0e+00 |
| E Total Primary Energy | MJ | 1.5e+00 | 1.5e+01 | 9.7e-02 | 0.0e+00 | 0.0e+00 |
| E Fuel Energy | MJ | | | | | |
| E Non Renewable Energy | MJ | | | | | |
| E Renewable Energy | MJ | | | | | |
| E Total Primary Energy | MJ | | | | | |

**Table 11: Life Cycle Inventory, Mineral Wool**

| | | Mineral Wool - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (r) Baryte (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bauxite (Al2O3.2H2O, ore) | kg | 3.0e-06 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Bentonite (Al2O3.4SiO2.H2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Borax (Na2O.2B2O3.10H2O) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Clay (in ground) | kg | 2.2e-07 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Coal (in ground) | kg | 7.1e-03 | 8.2e-02 | 9.5e-05 | 3.2e-05 | 0.0e+00 |
| (r) Copper (Cu, Ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Diabase Rock | kg | 6.7e-02 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Dolomite (CaCO3.MgCO3, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Feldspar (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Granite (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gravel (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Gypsum (CaSO4: in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Ilmenite Ore (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Iron (Fe, ore) | kg | 2.1e-06 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Jute | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Kaolin (Al2O3.2SiO2.2H2O, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Limestone (CaCO3, in ground) | kg | 1.1e-03 | 1.5e-04 | 1.8e-05 | 6.0e-06 | 0.0e+00 |
| (r) Natural Gas (in ground) | kg | 1.3e-02 | 1.3e-01 | 2.6e-04 | 8.8e-05 | 0.0e+00 |
| (r) Oil (in ground) | kg | 1.2e-02 | 2.0e-03 | 3.0e-03 | 1.0e-03 | 0.0e+00 |
| (r) Perlite (SiO2, ore) | kg | 6.2e-07 | 8.0e-08 | 6.9e-07 | 2.3e-07 | 0.0e+00 |
| (r) Phosphate Rock (in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pine Rosin | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potash (K2O, in ground) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Potassium (ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Pyrite (FeS2, ore) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sand (in ground) | kg | 5.7e-08 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Sodium Chloride (NaCl, in ground or in sea) | kg | 2.4e-04 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Uranium (U, ore) | kg | 1.5e-07 | 1.9e-08 | 2.3e-09 | 7.6e-10 | 0.0e+00 |
| (r) Wastepaper | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (r) Wood (standing) | m3 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Cullet (from stock) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Fly Ash | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Iron Ore Slag | kg | 2.7e-01 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Recovered Solids (iron scraps) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Water Used (total) | liter | 3.0e-01 | 7.2e-05 | 4.2e-04 | 1.4e-04 | 0.0e+00 |
| Sq Foot of Insulation (Cellulose) | Sq Ft | 0.0e+00 | 0.0e+00 | 0.0e+00 | 1.0e+00 | 0.0e+00 |
| Cellulose Insulation | kg | 0.0e+00 | 3.4e-01 | 3.4e-01 | 3.4e-01 | 0.0e+00 |
| Component 2 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Component 3 | NA | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | Mineral Wool - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| (a) Aldehydes | g | 8.8e-05 | 7.9e-04 | 3.1e-07 | 1.1e-07 | 0.0e+00 |
| (a) Ammonia (NH3) | g | 2.0e-05 | 4.4e-09 | 1.3e-08 | 4.4e-09 | 0.0e+00 |
| (a) Benzene | g | 6.1e-07 | 7.9e-08 | 6.8e-07 | 2.3e-07 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, biomass) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Carbon Dioxide (CO2, fossil) | g | 5.0e+01 | 6.1e+01 | 1.0e+01 | 3.5e+00 | 0.0e+00 |
| (a) Carbon Monoxide (CO) | g | 2.1e-02 | 7.3e-02 | 8.9e-03 | 1.5e-02 | 0.0e+00 |
| (a) Fluorides (F-) | g | 1.0e-08 | 6.5e-03 | 6.6e-15 | 2.2e-15 | 0.0e+00 |
| (a) Formaldehyde | g | 8.0e-03 | 1.1e-06 | 9.1e-06 | 3.1e-06 | 0.0e+00 |
| (a) Hydrocarbons (except methane) | g | 8.8e-02 | 1.8e+00 | 5.1e-03 | 1.8e-03 | 0.0e+00 |
| (a) Hydrocarbons (unspecified) | g | 1.6e-01 | 1.4e-03 | 4.0e-03 | 1.3e-03 | 0.0e+00 |
| (a) Hydrogen Chloride (HCl) | g | 3.5e-03 | 4.2e-04 | 5.1e-05 | 1.7e-05 | 0.0e+00 |
| (a) Hydrogen Fluoride (HF) | g | 4.0e-04 | 1.1e-04 | 6.4e-06 | 2.1e-06 | 0.0e+00 |
| (a) Hydrogen Sulfide (H2S) | g | 6.4e-05 | 3.1e-06 | 2.2e-05 | 7.5e-06 | 0.0e+00 |
| (a) Lead (Pb) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Metals (unspecified) | g | 3.7e+02 | 4.8e+01 | 4.2e+02 | 1.4e+02 | 0.0e+00 |
| (a) Methane (CH4) | g | 8.3e-02 | 6.5e-01 | 3.5e-03 | 1.3e-03 | 0.0e+00 |
| (a) Nitrogen Oxides (NOx as NO2) | g | 1.9e-01 | 1.2e-01 | 2.4e-02 | 5.4e-02 | 0.0e+00 |
| (a) Nitrous Oxide (N2O) | g | 3.1e-03 | 3.5e-02 | 1.9e-03 | 1.1e-04 | 0.0e+00 |
| (a) Organic Matter (unspecified) | g | 1.9e-04 | 1.6e-03 | 1.4e-06 | 4.8e-07 | 0.0e+00 |
| (a) Particulates (unspecified) | g | 6.2e-01 | 8.0e-01 | 2.4e-02 | 1.8e-03 | 0.0e+00 |
| (a) Phenolics | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (a) Sulfur Oxides (SOx as SO2) | g | 2.0e-01 | 3.5e+00 | 1.5e-02 | 4.9e-03 | 0.0e+00 |
| (a) Volatile Organic Compounds (VOCs) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Acids (H+) | g | 6.6e-04 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Ammonia (NH4+, NH3, as N) | g | 3.4e-04 | 3.7e-05 | 3.0e-04 | 1.0e-04 | 0.0e+00 |
| (w) AOX (Adsordable Organic Halogene) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Benzene | g | 1.4e-14 | 1.9e-15 | 2.4e-16 | 7.9e-17 | 0.0e+00 |
| (w) BOD5 (Biochemical Oxygen Demand) | g | 1.0e-01 | 2.5e-04 | 2.0e-03 | 6.8e-04 | 0.0e+00 |
| (w) Calcium (Ca++) | g | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Chlorides (Cl-) | g | 5.1e-02 | 5.4e-03 | 4.4e-02 | 1.5e-02 | 0.0e+00 |
| (w) COD (Chemical Oxygen Demand) | g | 1.9e-01 | 2.1e-03 | 1.7e-02 | 5.8e-03 | 0.0e+00 |
| (w) Cyanides (CN-) | g | 4.9e-19 | 6.6e-20 | 8.0e-21 | 2.7e-21 | 0.0e+00 |
| (w) Dissolved Matter (unspecified) | g | 1.5e-01 | 1.7e-02 | 1.4e-01 | 4.6e-02 | 0.0e+00 |
| (w) Fluorides (F-) | g | 2.3e-05 | 2.8e-06 | 3.4e-07 | 1.1e-07 | 0.0e+00 |
| (w) Hydrocarbons (unspecified) | g | 9.5e-04 | 3.5e-07 | 2.8e-06 | 9.4e-07 | 0.0e+00 |
| (w) Metals (unspecified) | g | 3.4e-03 | 1.0e-05 | 8.4e-05 | 2.8e-05 | 0.0e+00 |
| (w) Nitrates (NO3-) | g | 3.6e-05 | 6.6e-07 | 8.1e-08 | 2.7e-08 | 0.0e+00 |
| (w) Nitrogenous Matter (unspecified, as N) | g | 1.1e-04 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| (w) Oils (unspecified) | g | 2.3e-03 | 1.2e-04 | 1.0e-03 | 3.4e-04 | 0.0e+00 |
| (w) Phenols | g | 4.3e-05 | 4.7e-06 | 3.9e-05 | 1.3e-05 | 0.0e+00 |
| (w) Phosphates (PO4 3-, HPO4--, | g | 2.4e-05 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |

| | | Mineral Wool - LC Stage | | | | |
|---|---|---|---|---|---|---|
| **Article** | **Units** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **End-of-life** |
| H2PO4-, H3PO4, as P) | | | | | | |
| (w) Sodium (Na+) | g | 5.5e-02 | 7.0e-03 | 5.6e-02 | 1.9e-02 | 0.0e+00 |
| (w) Sulfates (SO4--) | g | 1.2e-03 | 5.9e-07 | 7.2e-08 | 2.4e-08 | 0.0e+00 |
| (w) Suspended Matter (unspecified) | g | 1.4e-01 | 1.1e-03 | 9.3e-03 | 3.1e-03 | 0.0e+00 |
| Waste (50 years - prorated) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (End-of-Life) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (first replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| Waste (installation) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 2.2e-02 | 0.0e+00 |
| Waste (Mfg.) | kg | 8.1e-03 | 6.8e-02 | 5.2e-05 | 1.7e-05 | 0.0e+00 |
| Waste (non-recyclable, 50-year) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 3.3e-01 |
| Waste (second replacement) | kg | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Feedstock Energy | MJ | 7.5e-01 | 2.3e-03 | 0.0e+00 | 0.0e+00 | 0.0e+00 |
| E Fuel Energy | MJ | 7.1e-01 | 9.5e+00 | 1.5e-01 | 4.9e-02 | 0.0e+00 |
| E Non Renewable Energy | MJ | 1.4e+00 | 9.5e+00 | 1.5e-01 | 4.9e-02 | 0.0e+00 |
| E Renewable Energy | MJ | 1.3e-02 | 7.9e-03 | 1.4e-04 | 4.9e-05 | 0.0e+00 |
| E Total Primary Energy | MJ | 1.5e+00 | 9.5e+00 | 1.5e-01 | 4.9e-02 | 0.0e+00 |
| E Fuel Energy | MJ | | | | | |
| E Non Renewable Energy | MJ | | | | | |
| E Renewable Energy | MJ | | | | | |
| E Total Primary Energy | MJ | | | | | |

# Appendix C: Asphalt Coating Case Study

## Goal and Scope Definition

### *Goal*

An important goal of this study was to evaluate whether a small vendor would be capable of gathering the data necessary for a life cycle assessment, in a timely fashion. If this proved to be impossible, the application of LCA for EPP would present a significant barrier for small businesses seeking to sell goods to the Federal government. Asphalt Systems, a small manufacturer of asphalt emulsions in Utah, participated in providing site specific information on the manufacture, application and use of asphalt emulsions and hot mix asphalt.

### *Intended Applications and Audiences*

The LCA itself was intended to be used to support a comparative assertion of environmental superiority of a product over a competing product in the context of the Federal requirement for environmentally preferable purchasing. Audiences include purchasing agents as well as other federal and state officials. An ancillary use of the study is to support efforts towards environmental improvement.

## Scope

### *Description of the Product*

The products evaluated represented two methods of maintaining roads: applying a thin layer (1.5 inches thick) of asphalt cement and applying an asphalt emulsion containing a natural mineral product, gilsonite. Both of these products are applied to asphalt roads before significant deterioration has occurred (three to five years into the life of the road), and neither adds structural strength to the road. Each extends the life of the road considerably. In the case of the asphalt emulsion, for three to five years, and in the case of the asphalt cement thin layer, seven to nine years. There are some other specialized methods for maintaining asphalt cement roadways, but these tend to be based on trade secret chemical compositions, and were not included in this study.

Asphalt emulsion is applied by spraying diluted emulsion from a distributor truck that simultaneously spreads sand onto the emulsion. Application is at ambient temperature. A thin layer of asphalt cement is applied by first spreading a tack coat (consisting of a simple asphalt emulsion) with a distributor truck, then applying a layer of asphalt, and finally rolling the layer of asphalt to assure a smooth surface. Typically, the asphalt cement is manufactured near the construction site at a hot-mix asphalt cement plant, which heats the asphalt and mixes it with aggregate, which is then trucked to the road

site and applied as above. Asphalt cement must be applied at 165$^{O}$F or above. Traffic can ensue one to two hours after application is complete**.**

***System Function and Functional Unit***

The function provided by the alternative products is the maintenance of good quality roads (five on a scale of ten). The functional unit is twenty years of one lane mile. The inventory includes two application of the thin layer of asphalt cement, and five applications of the asphalt emulsion.

***System Boundaries***

The system studied included all unit processes except those used for the production of hydrochloric acid. This material comprised less that one percent of the total mass of the products, and it was expected from the composition of the materials that the acid would be neutralized in use.

All inputs and outputs were accounted for as long as they comprised at least:
1. One percent of the mass
2. One percent of the energy, or
3. One percent of the expected toxicity scores

Primary data was not available for the asphalt production, but was gathered from published sources. Information on the production of the asphalt emulsion and the tack coat was obtained from the manufacturer, as was information on the application of the asphalt emulsion, the tack coat and the thin layer of asphalt cement. The flow charts below identify the systems under study.

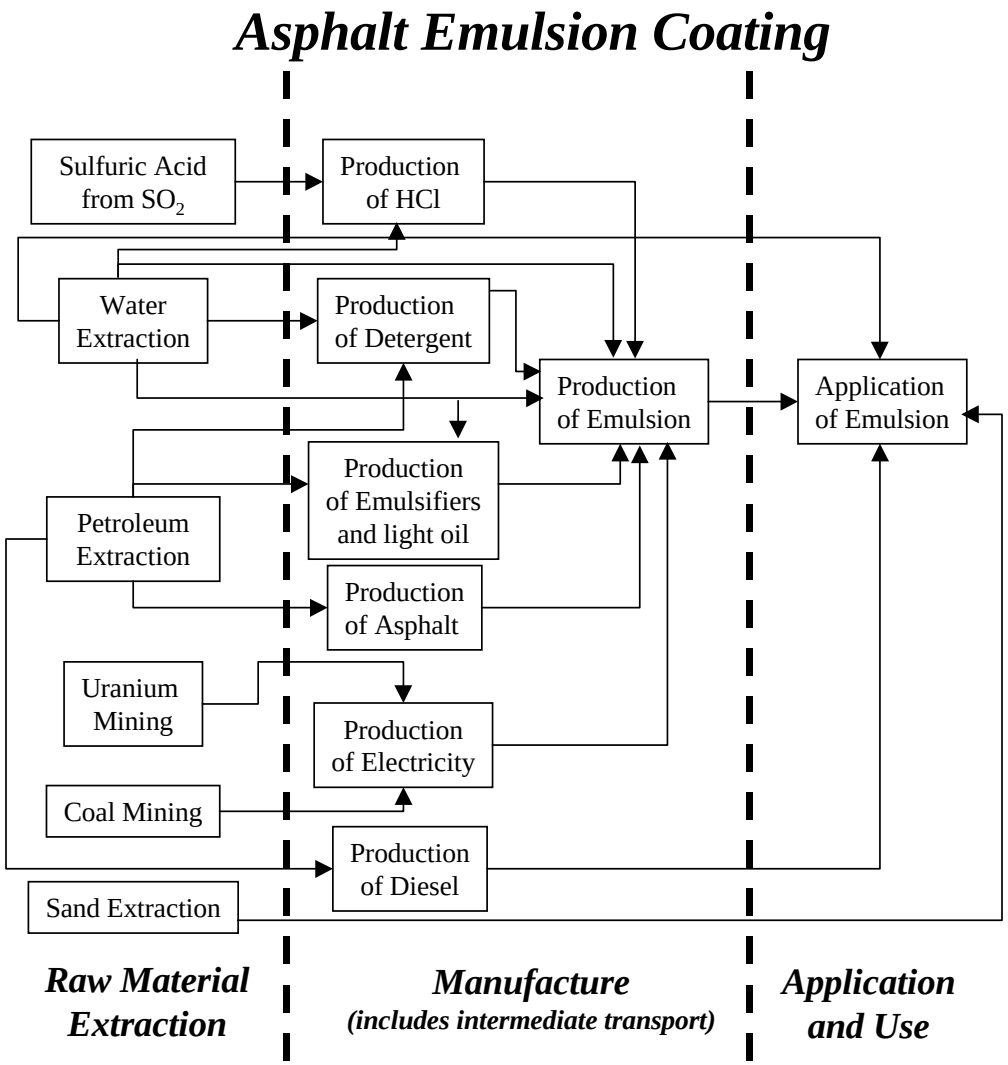
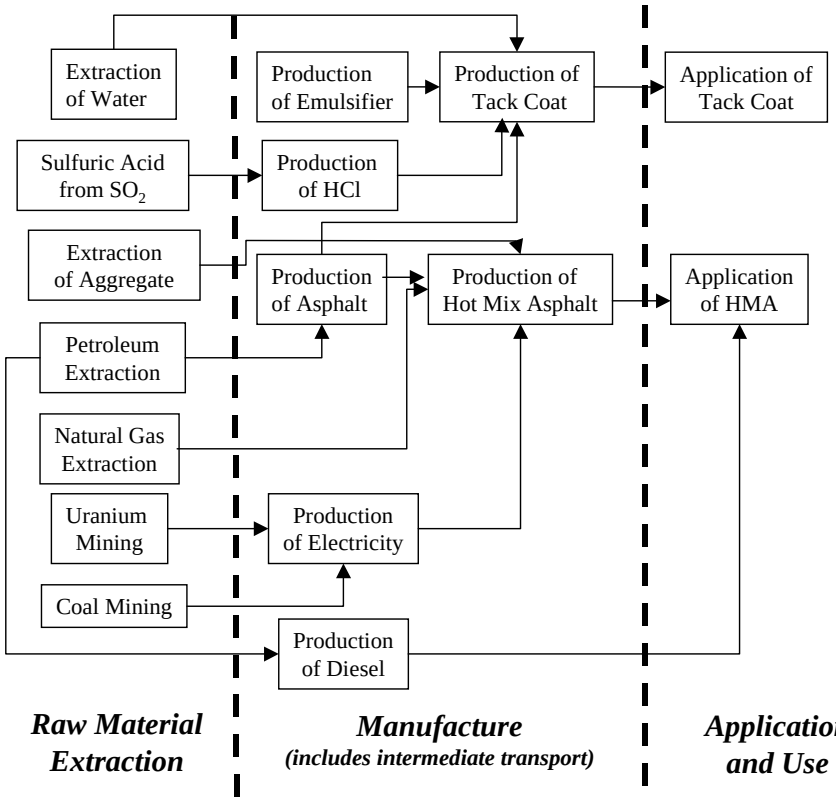

Asphalt Emulsion Coating
Sulfuric Acid from $SO_2$
Production of HCl
Water Extraction
Production of Detergent
Production of Emulsion
Application of Emulsion
Production of Emulsifiers and light oil
Petroleum Extraction
Production of Asphalt
Uranium Mining
Production of Electricity
Coal Mining
Production of Diesel
Sand Extraction
Raw Material Extraction
Manufacture
(includes intermediate transport)
Application and Use

Figure 1

## *Thin-Layer Hot Mix Asphalt Overlay*



## Data Gathering

In general, data gathering was quite rapid. The entire data gathering exercise for this project took place over two months (January-March 1999). This situation was aided by the simple nature of the materials under study. However, there were some difficulties that were encountered. For example, the source of the asphalt in the emulsions and tack coat (a large refining company) was not willing to provide site-specific information to this small vendor. Consequently, industry average data, obtained from the American Petroleum Institute (API) was used for estimating the inventories of this material.

Secondly, it was not possible to obtain site-specific information from any vendor that was not a direct vendor to the manufacturer. Thus the inventory results from some products that were obtained from a distributor (e.g. HCl and some detergents) were derived from data bases.

Finally, the contents of some materials (emulsifiers) are considered to be trade secrets. The issue of trade secrets is a common one in LCA's, no matter what size of vendor one might be evaluating. Some of the trade secret material are considered to be potentially ecotoxic, and that is reflected in the analysis reported here.

### *Allocation*

All allocation of emissions and resource use was performed based on a mass basis. This was required for the production of asphalt, and for transportation inventory results, but not for other inventory data.

### *Impact Assessment*

Impact assessment was performed based on the FRED LCA system indicators, as described in the body of this work. The assignment of inventory data to impact categories is shown in the table below.

**Table 1. Assignment of Inventory Results to Impact Categories**

| Inventory Result | Impact Category | Justification |
|---|---|---|
| Fossil Fuels and Uranium | Resource Depletion | Although Uranium is not truly a fossil fuel, it is "used up" in a precisely comparable fashion |
| $CO_2$, $N_20$, Methane | Global Warming | These are important greenhouse gases which do not participate to a great extent in other impact categories |
| CO | Human Toxicity<br>Photochemical Smog<br>Global Warming; | CO is a human and animal toxicant, as well as a precursor to ozone formation and a greenhouse gas. It can participate in the first two of these environmental mechanisms without losing its potency for the others. |
| CFC's, HCFC's, Halons | Global Warming 100%<br>Stratospheric Ozone Depletion 100% | These substances participate fully in both of these parallel environmental mechanisms |
| $SO_2$, | Acidification 100% | Although SO2 contributes to visibility deterioration, and human health effects through the formation of Particulate Matter, these environmental mechanisms are not addressed by FRED. |
| HCl, HF | Acidification 100%<br>Human Health 100% | These acid gases have minor human health effects as well as contributing to acidification. It was thought that double counting would not significantly skew results. |
| Toxic Air and Water Emissions | Human Toxicity 100%<br>Ecotoxicity 100% | Since it was not possible to evaluate the partitioning of these substances, they were double counted so as not to underestimate their impacts. |
| NOx | Acidification 100%<br>Eutrophication 100% | Since FRED does not currently evaluate the fate and transport of NOx, this emission was double counted. |
| VOC's, ROG's | Photochemical Smog | These are the essential precursors |

| Inventory Result | Impact Category | Justification |
|---|---|---|
| | | to photochemically produced ozone. Although some of them are also toxic, unspeciated data does not permit a toxic evaluation. |
| $NH_4$ | Eutrophication (water emissions); acidification (air Emissions) | Although NH4 is not an acid gas, it undergoes changes in the soil leading to acidification effects. |
| $PO_4$ | Eutrophication 100% | Phosphate does not participate in any other environmental mechanism described by the FRED methodology |

The table below shows the gross inventory for the two options, normalized to the functional unit. The functional unit is twenty years of one lane mile. The inventory includes two application of the thin layer of asphalt cement, and five applications of the asphalt emulsion. Because the information about asphalt cement was obtained from published sources rather than from primary data, it was not possible to estimate the amount of land that was used to manufacture the asphalt. Since this product uses aggregate, it is likely that the mining of gravel/aggregate produced somewhat higher land use than the manufacture of the emulsion, perhaps ten times as much. However, the land use during manufacturing of materials is very small. Even assuming that the production of hot mix asphalt used ten times as much land, this would still be much smaller than the land use associated with the road itself. Thus, the land use difference between the two products is probably not significant.

**Inventory**

The Table below shows the Summary inventory for the two products compared. A full inventory by life cycle stage can be found in Tables 6 and 7.

## Table 2. Summary Inventory

| System Description<br>Raw Materials | Asphalt Cement<br>Thin Layer (2applic)<br>lb/lane mile/20yr | Asphalt Emulsion<br>GSB88 (5 applic)<br>lb/lane mile/20yr |
|---|---|---|
| Asphalt | 122,621 | 47,790 |
| Aggregate | 2,181,960 | 0 |
| Diesel (application) | 3,063 | 15 |
| Diesel to prep hotmix | 884 | 0 |
| Sand | 0 | 17,600 |
| Gilsonite | 0 | 21,500 |
| HCl | 32 | 24 |
| Water | 4,779 | 173,317 |
| NP-40 (Detergent) | 0 | 285 |
| Surfactant | 156 | 29 |
| Light Cycle Oil | 0 | 585 |
| Land use (road, $m^2$) | 5888 | 5888 |
| Land use (mfg, $m^2$) | ??? | 2 |

**Indicator Results**

The table below shows the indicator results for the two systems studied.

**Table 3: LCIA Results**

| | LCIA Totals | |
|---|---|---|
| **Indicator** | **Asphalt Emulsion** | **Asphalt Cement** |
| **GWP (kg $CO_2$ equiv)** | 16547 | 44368 |
| **ODP (kg CFC-11)** | 0 | 0 |
| **Acidification (kg $SO_2$)** | 145 | 344 |
| **Eutrophication (kg $PO_4$)** | 0.0065 | 0.0151 |
| **Photochemical Smog (kg $O_3$)** | 36 | 77 |
| **Human Toxicity** | | |
| Cancer | 7.97E-02 | 1.78E-01 |
| NonCancer | 2.02E+00 | 4.51E+00 |
| **Ecotoxicity** | 6.61E+04 | 2.12E+03 |
| **Resource Depletion** | | |
| Fossil (tons oil equivalent) | 3.86E+04 | 8.55E+04 |
| Mineral (equiv tons) | 0 | 0 |
| Precious(equiv tons) | 0 | 0 |
| **Other Indicators:** | | |
| Land Use (ha) | 0.6 | 0.6 |
| Water Use (kg) | 76982 | 2292 |
| Solid Waste (kg) | 31729 | 816165 |
| | | |

**Interpretation**

We can make several interesting observations about the two products based on the total indicator values noted in the table above. Of the 14 indicators and sub indicators evaluated, the numbers for asphalt emulsion were significantly lower than those for asphalt cement in 11 categories, equal in two categories (Stratospheric Ozone Depletion and Land Use) and greater in one category (Water Use). However, given the overall uncertainty of these numbers, it is important to also look where an order of magnitude difference occurs. An order of magnitude difference is seen between the results for Ecotoxicity (cement is lower), Water Use (cement is lower) and Solid Waste (emulsion is lower).

It is also possible to evaluate the sources of the various impacts in order to identify opportunities for improvements. The table below shows the asphalt emulsion and asphalt cement indicators in term of percentage of the indicators in the different life cycle stages.

**Table 4. Percentage of Indicator by Life Cycle Stage, Asphalt Emulsion**

| | Emulsion - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 12 | 34 | 54 | 0 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 15 | 17 | 69 | 0 | 0 |
| **Eutrophication** | 0 | 91 | 9 | 0 | 0 |
| **Photochemical Smog** | 20 | 7 | 73 | 0 | 0 |
| **Human Health** | | | | | |
| Cancer | 13 | 78 | 10 | 0 | 0 |
| NonCancer | 10 | 81 | 9 | 0 | 0 |
| **Eco Health** | 90 | 1 | 10 | 0 | 0 |
| **Resource Depletion** | | | | | |
| Fossil | 85 | 6 | 9 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | | 100 | 0 |
| Water Use (kg) | 0 | 28 | 0 | 72 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 100 |

**Table 5: Percentage of Indicator by Life Cycle Stage, Thin Layer Asphalt Cement**

| | Cement - by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | 9 | 76 | 14 | 1 | 0 |
| **ODP** | 0 | 0 | 0 | 0 | 0 |
| **Acidification** | 13 | 66 | 19 | 2 | 0 |
| **Eutrophication** | 0 | 98 | 2 | 0 | 0 |
| **Photochemical Smog** | 20 | 20 | 59 | 0 | 0 |
| **Human Health** | | | | | |
| Cancer | 12 | 85 | 3 | 0 | 0 |
| Non-Cancer | 9 | 88 | 2 | 0 | 0 |
| **Eco Health** | 26 | 50 | 21 | 2 | 0 |
| **Resource Depletion** | | | | | |
| Fossil | 82 | 16 | 2 | 0 | 0 |
| Mineral | 0 | 0 | 0 | 0 | 0 |
| Precious | 0 | 0 | 0 | 0 | 0 |
| **Other Indicators:** | | | | | |
| Land Use | 0 | 0 | 0 | 100 | 0 |
| Water Use (kg) | 0 | 100 | 0 | 0 | 0 |
| Solid Waste (kg) | 0 | 0 | 0 | 0 | 100 |

For the most part, the majority of the two products indicator results can be found in the manufacturing and the transportation phases of the life cycle. This result supports the guidance of the FRED methodology, which recommends more intensive data gathering efforts in the manufacturing phase for products which are durable goods which are not energy intensive in the use phase.

## Conclusions

Although there were some issues around gathering primary data for the performance of this LCA, overall, the data gathering went quite smoothly. This was true especially for data gathered from the primary vendor and from one step up and one step down the vendor chain (i.e. from manufacturers of ingredients and from contractors/customers using the materials under study). For goods that have a very long or complicated vendor chain, (e.g., electronics) this may not be the case.

## Table 6: Life Cycle Inventory, Asphalt Emulsion

| Asphalt Emulsion | | | Sum | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| **Product** | 20 year-lane mile | | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | | | |
| **Inputs** | | | | | | | | |
| **Resources** | Coal,Bituminous | Kg | 430 | 167 | 170 | 93 | 1.34E-01 | 0 |
| | Coal,Lignite | Kg | 79 | 31 | 31 | 17 | 2.46E-02 | 0 |
| | Coal,Subbituminous | Kg | 235 | 92 | 92 | 51 | 7.32E-02 | 0 |
| | Crude Oil | Kg | 25,972 | 23,282 | 311 | 2,372 | 7 | 0 |
| | Gilsonite | Kg | 9,336 | 0 | 9,336 | 0 | 0 | 0 |
| | Natural Gas | Kg | 725 | 270 | 381 | 74 | 2.03E-01 | 0 |
| | UO2 | Kg | 2.41E-03 | 9.43E-04 | 9.46E-04 | 5.25E-04 | 7.53E-07 | 0 |
| | Fresh Water | Kg | 76,982 | 0 | 21,845 | 0 | 55,136 | 0 |
| | Land Use | ha | 0.6 | | .002 | | 0.6 | |
| | | | | | | | | |
| **Fuels** | Coke,Petroleum | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Crude Oil | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Distillate Oil | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Distillate Oil,#1 | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Distillate Oil,#2 | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Electricity | kWh | 0 | 0 | 0 | 0 | 0 | 0 |
| | Fuel,Other | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Gasoline,Automotive | Kg | 0 | 0 | 0 | 0 | 0 | 0 |

| Asphalt Emulsion | | | Sum | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| | LPG | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Natural Gas | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Residual Oil | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Steam,Low Pressure | btu | 8.57E-01 | 3.96E-04 | 7.77E-01 | 7.92E-02 | 2.39E-04 | 0 |
| | Still Gas | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | |
| **Air Emissions** | 1,2,4-Trimethylbenzene | Kg | 1.25E-02 | 5.79E-06 | 1.14E-02 | 1.16E-03 | 3.49E-06 | 0 |
| | Aldehydes,Unspeciated | Kg | 2.98E+00 | 4.12E-02 | 1.85E-03 | 2.94E+00 | 1.34E-05 | 0 |
| | Ammonia | Kg | 1.12E-01 | 5.16E-05 | 1.01E-01 | 1.03E-02 | 3.11E-05 | 0 |
| | Benzene | Kg | 7.97E-02 | 9.98E-03 | 6.21E-02 | 7.60E-03 | 2.22E-05 | 0 |
| | Carcinogen,Unspeciated | Kg | 6.91E-03 | 3.18E-06 | 6.27E-03 | 6.35E-04 | 1.92E-06 | 0 |
| | CO | Kg | 73 | 16 | 11 | 46 | 8.07E-03 | 0 |
| | CO2 | Kg | 15846 | 1509 | 5421 | 8914 | 2.48 | 0 |
| | Cyclohexane | Kg | 2.52E-02 | 1.16E-05 | 2.29E-02 | 2.33E-03 | 7.01E-06 | 0 |
| | Ethyl Benzene | Kg | 2.47E-02 | 2.49E-03 | 1.99E-02 | 2.34E-03 | 6.90E-06 | 0 |
| | Ethylene | Kg | 3.04E-02 | 1.40E-05 | 2.76E-02 | 2.81E-03 | 8.46E-06 | 0 |
| | HCl | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Iso-Octane | Kg | 2.63E-03 | 9.78E-04 | 1.38E-03 | 2.67E-04 | 7.37E-07 | 0 |
| | Methane | Kg | 33.38 | 19.86 | 9.05 | 4.46 | 9.20E-03 | 0 |
| | Methanol | Kg | 1.19E-02 | 5.49E-06 | 1.08E-02 | 1.10E-03 | 3.31E-06 | 0 |
| | MTBE | Kg | 2.80E-02 | 1.29E-05 | 2.54E-02 | 2.58E-03 | 7.79E-06 | 0 |
| | n-Hexane | Kg | 1.71E-02 | 6.36E-03 | 8.99E-03 | 1.74E-03 | 4.79E-06 | 0 |
| | NOx | Kg | 154 | 21.81 | 15.08 | 117.57 | 1.12E-02 | 0 |
| | Organic Acids | Kg | 2.45E-03 | 9.56E-04 | 9.60E-04 | 5.33E-04 | 7.64E-07 | 0 |

| Asphalt Emulsion | | | Sum | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| | Organic Compounds,Unspeciated | Kg | 9.25E-03 | 3.61E-03 | 3.63E-03 | 2.01E-03 | 2.89E-06 | 0 |
| | Particulate | Kg | 2.61E+00 | 3.42E-01 | 1.16E+00 | 1.11E+00 | 7.78E-04 | 0 |
| | PM10 | Kg | 15.69 | 1.91E-01 | 5.77E-01 | 14.92 | 5.13E-04 | 0 |
| | Propylene | Kg | 9.75E-02 | 4.50E-05 | 8.84E-02 | 8.99E-03 | 2.71E-05 | 0 |
| | SOx | Kg | 35.66 | 5.65 | 13.45 | 16.55 | 6.02E-03 | 0 |
| | TNMOC,Unspeciated | Kg | 7.71E+00 | 1.56007433 | 3.81E-01 | 5.7682512 | 2.15E-03 | 0 |
| | Toluene | Kg | 1.55E-01 | 1.38E-02 | 1.26E-01 | 1.46E-02 | 4.31E-05 | 0 |
| | VOC,Unspeciated | Kg | 27.04 | 0.17414189 | 9.91 | 16.95 | 3.15E-03 | 0 |
| | Xylene | Kg | 1.00E-01 | 7.83E-03 | 8.29E-02 | 9.44E-03 | 2.79E-05 | 0 |
| | | | | | | | | |
| **Water Emissions** | Ammonia | Kg | 1.94E-02 | 8.9449E-06 | 1.76E-02 | 1.79E-03 | 5.39E-06 | 0 |
| | BOD | Kg | 5.32E-04 | 0 | 5.32E-04 | 0 | 0 | 0 |
| | Carcinogen,Unspecia | Kg | 2.71E-05 | 1.3144E-07 | 6.713E-07 | 2.625E-05 | 7.92E-08 | 0 |
| | COD | Kg | 6.83E-04 | 0 | 6.83E-04 | 0 | 0 | 0 |
| | Dissolved Solids | Kg | 3.55 | 1.32 | 1.87 | 0.36 | 0.000995 | 0 |
| | Oil & Grease | Kg | 0.56 | 0 | 0 | 5.59E-01 | 0 | 0 |
| | Methanol | Kg | 3.45E-04 | 1.7316E-07 | 3.10E-04 | 3.459E-05 | 1.04E-07 | 0 |
| | MTBE | Kg | 1.16E-03 | 5.4019E-07 | 1.05E-03 | 1.08E-04 | 3.25E-07 | 0 |
| | Oil & Grease | Kg | 5.91E-02 | 2.94E-04 | 1.59E-03 | 5.71E-02 | 1.72E-04 | 0 |
| | Phosphate | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Produced Water | Kg | 9,780 | 8,758 | 116 | 904 | 2.72 | 0 |
| | Surfactant | Kg | 3.51 | | | | 3.51 | |

| Asphalt Emulsion | | | Sum | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| **Solid Wastes** | 1,2,4-Trimethylbenzene | Kg | 1.36E-04 | 5.9119E-08 | 1.24E-04 | 1.181E-05 | 3.56E-08 | 0 |
| | Ammonia | Kg | 1.50E-03 | 6.8698E-07 | 1.37E-03 | 1.37E-04 | 4.14E-07 | 0 |
| | Ash, Bottom | Kg | 13.87 | 5.42 | 5.44 | 3.02 | 4.33E-03 | 0 |
| | Ash, Fly | Kg | 44.21 | 17.26 | 17.32 | 9.61 | 1.38E-02 | 0 |
| | Carcinogen,Unspeciated | Kg | 6.18E-04 | 2.9683E-07 | 5.58E-04 | 5.928E-05 | 1.79E-07 | 0 |
| | Cyclohexane | Kg | 2.72E-04 | 1.1884E-07 | 2.48E-04 | 2.374E-05 | 7.16E-08 | 0 |
| | Ethyl Benzene | Kg | 4.08E-04 | 1.7735E-07 | 3.72E-04 | 3.543E-05 | 1.07E-07 | 0 |
| | FGD Sludge | Kg | 14 | 5.47 | 5.49 | 3.05 | 0.004367 | 0 |
| | Solid Waste,Drilling | Kg | 939 | 826 | 25 | 86.98 | 0.26 | 0 |
| | Solid Waste,Hazardous | Kg | 8.44E-01 | 3.90E-04 | 7.65E-01 | 7.78E-02 | 2.35E-04 | 0 |
| | Solid Waste.Refiner | Kg | 22 | 1.03E-02 | 20 | 2.06 | 6.20E-03 | 0 |
| | Spent Fuel,Nuclear | Kg | 4.21E-03 | 1.64E-03 | 1.65E-03 | 9.15E-04 | 1.31E-06 | 0 |
| | Toluene | Kg | 1.23E-03 | 5.582E-07 | 1.12E-03 | 1.11E-04 | 3.36E-07 | 0 |
| | Xylene | Kg | 1.64E-03 | 7.7116E-07 | 1.49E-03 | 1.54E-04 | 4.65E-07 | 0 |
| | | | | | | | | |
| | Landfilled Waste | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Mining Waste | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Waste in waste roadway | Kg | 31,729 | 0 | 0 | 0 | 0 | 31,729 |

**Table 7: Life Cycle Inventory, Thin Layer Asphalt Cement**

| AsphaltCement | | | Total | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| **Product** | 20 year-lane mile | | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | | | |
| **Inputs** | | | | | | | | |
| **Resources** | Coal,Bituminous | Kg | 897 | 355 | 411 | 128 | 3 | 0 |
| | Coal,Lignite | Kg | 164 | 66 | 75 | 24 | 1 | 0 |
| | Coal,Subbituminous | Kg | 490 | 195 | 223 | 70 | 2 | 0 |
| | Crude Oil | Kg | 57,493 | 49,601 | 6,451 | 1,290 | 151 | 0 |
| | Gilsonite | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Natural Gas | Kg | 1,612 | 575 | 984 | 50 | 4 | 0 |
| | UO2 | Kg | 5.04E-03 | 2.01E-03 | 2.29E-03 | 7.23E-04 | 1.59E-05 | 0 |
| | Land Use | Ha | .6 | NA | NA | NA | NA | NA |
| | Fresh Water | Kg | 2,292 | 0 | 2,292 | 0 | 0 | 0 |
| | | | | | | | | |
| **Fuels** | Coke,Petroleum | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Crude Oil | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Distillate Oil | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Distillate Oil,#1 | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Distillate Oil,#2 | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Electricity | kWh | 0 | 0 | 0 | 0 | 0 | 0 |
| | Fuel,Other | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Gasoline,Automotive | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | LPG | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Natural Gas | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Residual Oil | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Steam,Low Pressure | btu | 1.92 | 0.001 | 1.87 | 0.043 | 0.005 | 0 |
| | Still Gas | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Land Use | ha | 0.6 | | | | 0.6 | |
| | | | | | | | | |
| **Air Emissions** | 1,2,4-Trimethylbenzene | Kg | 2.80E-02 | 1.24E-05 | 2.73E-02 | 6.29E-04 | 7.35E-05 | 0 |
| | Aldehydes,Unspeciated | Kg | 1.88 | 0.087795277 | 1.53E-02 | 1.59 | 1.87E-01 | 0 |

| AsphaltCement | | | Total | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| | Ammonia | Kg | 2.50E-01 | 1.10E-04 | 2.44E-01 | 5.61E-03 | 6.55E-04 | 0 |
| | Benzene | Kg | 1.78E-01 | 2.13E-02 | 1.52E-01 | 4.50E-03 | 4.69E-04 | 0 |
| | Carcinogen,Unspeciated | Kg | 1.54E-02 | 6.79E-06 | 1.50E-02 | 3.46E-04 | 4.04E-05 | 0 |
| | CO | Kg | 126 | 3.44E+01 | 6.22E+01 | 2.63E+01 | 2.86E+00 | 0 |
| | CO2 | Kg | 42,793 | 3,215 | 32,956 | 6,106 | 516 | 0 |
| | Cyclohexane | Kg | 5.64E-02 | 2.48E-05 | 5.50E-02 | 1.27E-03 | 1.48E-04 | 0 |
| | Ethyl Benzene | Kg | 5.52E-02 | 5.31E-03 | 4.84E-02 | 1.37E-03 | 1.45E-04 | 0 |
| | Ethylene | Kg | 6.80E-02 | 3.00E-05 | 6.63E-02 | 1.53E-03 | 1.78E-04 | 0 |
| | HCl | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Iso-Octane | Kg | 5.84E-03 | 2.08E-03 | 3.56E-03 | 1.81E-04 | 1.55E-05 | 0 |
| | Methane | Kg | 75.00 | 42.32 | 29.05 | 3.39 | 2.44E-01 | 0 |
| | Methanol | Kg | 2.66E-02 | 1.17E-05 | 2.59E-02 | 5.97E-04 | 6.97E-05 | 0 |
| | MTBE | Kg | 6.27E-02 | 2.76E-05 | 6.11E-02 | 1.41E-03 | 1.64E-04 | 0 |
| | n-Hexane | Kg | 3.80E-02 | 1.35E-02 | 2.32E-02 | 1.18E-03 | 1.01E-04 | 0 |
| | NOx | Kg | 236 | 46 | 108 | 75 | 7.04 | 0 |
| | Organic Acids | Kg | 5.11E-03 | 2.04E-03 | 2.32E-03 | 7.33E-04 | 1.61E-05 | 0 |
| | Oranic Compounds,Unspeciated | Kg | 1.93E-02 | 7.70E-03 | 8.78E-03 | 2.77E-03 | 6.08E-05 | 0 |
| | Particulate | Kg | 26.63 | 7.29E-01 | 23.92 | 1.96 | 1.64E-02 | 0 |
| | PM10 | Kg | 210 | 4.07E-01 | 9.91 | 9.37 | 8.98E-01 | 0 |
| | Propylene | Kg | 2.18E-01 | 9.61E-05 | 1.90E+02 | 4.89E-03 | 5.72E-04 | 0 |
| | SOx | Kg | 176 | 12.04 | 151 | 11.46 | 9.54E-01 | 0 |
| | TNMOC,Unspeciated | Kg | 17.23 | 3.32 | 2.70 | 11.16 | 4.53E-02 | 0 |
| | Toluene | Kg | 3.45E-01 | 2.95E-02 | 3.07E-01 | 8.45E-03 | 9.09E-04 | 0 |
| | VOC,Unspeciated | Kg | 58.51 | 3.71E-01 | 47.87 | 9.19 | 1.08 | 0 |
| | Xylene | Kg | 2.24E-01 | 1.67E-02 | 2.01E-01 | 5.42E-03 | 5.89E-04 | 0 |
| | Napthalene | Kg | 4.72E-02 | 0 | 4.72E-02 | 0 | 0 | 0 |
| | 2-methyl napthalene | Kg | 6.29E-02 | 0 | 6.29E-02 | 0 | 0 | 0 |
| | Phenanthrene | Kg | 3.88E-02 | 0 | 3.88E-02 | 0 | 0 | 0 |
| | Fluoranthrene | Kg | 2.52E-02 | 0 | 2.52E-02 | 0 | 0 | 0 |
| | Pyrene | Kg | 5.76E-02 | 0 | 5.76E-02 | 0 | 0 | 0 |
| | Formaldehyde | Kg | 3.35 | 0 | 3.35 | 0 | 0 | 0 |
| | | | | | | | | |
| **Water Emissions** | Ammonia | Kg | 4.33E-02 | 1.91E-05 | 4.22E-02 | 9.72E-04 | 1.14E-04 | 0 |
| | BOD | Kg | 2.13E-03 | 0 | 2.13E-03 | 0 | 0 | 0 |
| | Carcinogen,Unspeciated | Kg | 8.79E-05 | 2.80478E-07 | 7.162E-05 | 1.43E-05 | 1.67E-06 | 0 |
| | COD | Kg | 3.85E-03 | 0 | 3.85E-03 | 0 | 0.00E+00 | 0 |

| AsphaltCement | | | Total | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| | Dissolved Solids | Kg | 7.89 | 2.81 | 4.81 | 2.44E-01 | 2.10E-02 | 0 |
| | Oil & Grease | Kg | 1.19 | 0 | 0 | 1.19 | 0 | 0 |
| | Methanol | Kg | 7.75E-04 | 3.70E-07 | 7.53E-04 | 1.88E-05 | 2.20E-06 | 0 |
| | MTBE | Kg | 2.60E-03 | 1.15E-06 | 2.54E-03 | 5.87E-05 | 6.86E-06 | 0 |
| | Oil & Grease | Kg | 1.92E-01 | 6.27E-04 | 1.56E-01 | 3.15E-02 | 3.62E-03 | 0 |
| | Phosphate | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Produced Water | Kg | 21,861 | 18,658 | 2,652 | 494 | 57.34 | 0 |
| | Surfactant | Kg | 19.78 | 0 | 0 | 0 | 19.78 | |
| | | | | | | | | |
| **Solid Wastes** | 1,2,4-Trimethylbenzene | Kg | 3.03E-04 | 1.26E-07 | 2.96E-04 | 6.42E-06 | 7.51E-07 | 0 |
| | Ammonia | Kg | 3.36E-03 | 1.47E-06 | 3.27E-03 | 7.47E-05 | 8.73E-06 | 0 |
| | Ash, Bottom | Kg | 28.94 | 11.54 | 13.16 | 4.15 | 9.12E-02 | 0 |
| | Ash, Fly | Kg | 92.22 | 36.77 | 41.93 | 13.23 | 2.91E-01 | 0 |
| | Carcinogen,Unspeciated | Kg | 1.38E-03 | 6.33E-07 | 1.35E-03 | 3.23E-05 | 3.77E-06 | 0 |
| | Cyclohexane | Kg | 6.07E-04 | 2.54E-07 | 5.92E-04 | 1.29E-05 | 1.51E-06 | 0 |
| | Ethyl Benzene | Kg | 9.09E-04 | 3.78E-07 | 8.88E-04 | 1.93E-05 | 2.25E-06 | 0 |
| | FGD Sludge | Kg | 29.22 | 11.65 | 13.28 | 4.19 | 9.20E-02 | 0 |
| | Solid Waste,Drilling | Kg | 2,098 | 1,760 | 284 | 47.92 | 5.51 | 0 |
| | Solid Waste,Hazardous | Kg | 1.89 | 8.31E-04 | 1.84 | 4.23E-02 | 4.95E-03 | 0 |
| | Solid Waste.Refiner | Kg | 49.84 | 2.20E-02 | 48.57 | 1.12 | 1.31E-01 | 0 |
| | Spent Fuel,Nuclear | Kg | 8.78E-03 | 3.50E-03 | 3.99E-03 | 1.26E-03 | 2.77E-05 | 0 |
| | Toluene | Kg | 2.75E-03 | 1.19E-06 | 2.68E-03 | 6.07E-05 | 7.09E-06 | 0 |
| | Xylene | Kg | 3.68E-03 | 1.65E-06 | 3.58E-03 | 8.38E-05 | 9.79E-06 | 0 |
| | Landfilled Waste | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Mining Waste | Kg | 0 | 0 | 0 | 0 | 0 | 0 |
| | Waste Roadway | Kg | 816,165 | 0 | 0 | 0 | 0 | 816,165 |

**Table 8: Data Collection Tables**

| ***Resource Consumption*** | | | | | |
|---|---|---|---|---|---|
| *Facility Name* | | | | | |
| | | | | | |
| | **Amount** | **Units** | **Date used** | **Source of data** | **Estimated Error** |
| ***Fuel usage*** | | | | | |
| Diesel | | | | | |
| Fuel Oils (list type) | | | | | |
| 1 | | | | | |
| 2 | | | | | |
| Gasoline | | | | | |
| Natural Gas | | | | | |
| | | | | | |
| Electricity | | | | | |
| Coal | | | | | |
| | | | | | |
| ***Minerals (list)*** | | | | | |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| | | | | | |
| ***Chemical Usage (list)*** | | | | | |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| | | | | | |
| ***Freshwater use*** | | | | | |
| (provide source , e.g. well, river) | | | | | |
| | | | | | |
| ***Land Use*** | | | | | |
| Area Paved | | | | | |
| Area Disturbed (e.g. by mining) | | | | | |

## *Air Emissions*

| *Facility Name* | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| **Emission** | **Amount** | **Units** | **Dates of emissions** | **Data Source** | **Estimated Error** |
| | | | | | |
| **$CO_2$ (Carbon Dioxide)** | | | | | |
| **CO (Carbon monoxide)** | | | | | |
| **$CH_4$ (Methane)** | | | | | |
| **$N_2O$ (Nitrous Oxide)** | | | | | |
| | | | | | |
| **CFC/HCFC's (list)** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| **3** | | | | | |
| **4** | | | | | |
| | | | | | |
| **SOx (Oxides of Sulfur)** | | | | | |
| **NOx (Oxides of Nitrogen)** | | | | | |
| **HCl (Hydrogen Chloride)** | | | | | |
| **HF (Hydrogen fluoride)** | | | | | |
| **NH4 (Ammonia)** | | | | | |
| **Other acid gases (list)** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| | | | | | |
| **Volatiles (list)** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| **3** | | | | | |
| | | | | | |
| **Hazardous Air Pollutants** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| | | | | | |
| **PM-10** | | | | | |

## *Water Emissions*

| *Facility Name* | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| **Emission** | **Amount** | **Units** | **Dates of emissions** | **Data Source** | **Estimated Error** |
| | | | | | |
| **Suspended Solids** | | | | | |
| **Coliforms** | | | | | |
| **Ammonia** | | | | | |
| **Phosphate** | | | | | |
| **Cyanide** | | | | | |
| **Oil & Grease** | | | | | |
| **BOD** | | | | | |
| **COD** | | | | | |
| | | | | | |
| **Heavy Metals (list)** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| **3** | | | | | |
| **4** | | | | | |
| **5** | | | | | |
| **6** | | | | | |
| | | | | | |
| **Hazardous Substances** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| **3** | | | | | |
| **4** | | | | | |
| **5** | | | | | |
| **6** | | | | | |
| | | | | | |
| **Total Water released** | | | | | |
| | | | | | |
| Does water go to POTW? | | | | | |
| | | | | | |
| If direct discharge, what is water body? | | | | | |
| | | | | | |

## *Solid Wastes*

| *Facility Name* | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | **Amount** | **Units** | **Dates of emissions** | **Data Source** | **Estimated Error** |
| **Total Solid Waste (landfilled)** | | | | | |
| | | | | | |
| **Mining wastes (managed on property)** | | | | | |
| | | | | | |
| **Hazardous wastes (list)** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| **3** | | | | | |
| **4** | | | | | |
| **5** | | | | | |
| | | | | | |
| **Distance to Landfills (list)** | | | | | |
| **1** | | | | | |
| **2** | | | | | |
| **3** | | | | | |

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