# Life Cycle Assessment of Canada's Polymer Bank Notes and Cotton-Paper Bank Notes

## Final report

---

Submitted: May 27, 2011

Prepared by:

PE AMERICAS
*A joint venture of Five Winds and PE*

Tryskele
ENVIRONMENT HEALTH & SAFETY

Prepared for:

BANK OF CANADA

**234 Wellington Street, 8th Floor West**

**Ottawa, ON K1A 0G9**

PE AMERICAS
A joint venture of Five Winds and PE
Tryskele
ENVIRONMENT
HEALTH & SAFETY

Coppelia Marincovic
Kathy Pritchard
Marc Binder
Nuno da Silva

PE Americas
344 Boylston Street
Boston, MA 02116
USA

Phone +1 [617] 247-4477
Fax +1 [617] 236-2033

Contact Information
c.marincovic@pe-international.com
kathy.pritchard@tryskele.ca
m.binder@pe-international.com
n.dasilva@pe-international.com

# TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

# ABBREVIATIONS

| | |
|---|---|
| ATM | Automated Teller Machine |
| AP | Acidification Potential |
| BOPP | Bi-axially oriented polypropylene |
| CAD | Canadian dollar |
| CFC-11 | Trichlorofluoromethane |
| $CH_4$ | Methane |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| CTU | Comparative Toxic Unit |
| EP | Eutrophication Potential |
| EPA | Environmental Protection Agency |
| GaBi | Ganzheitlichen Bilanzierung (German meaning holistic Balancing) |
| GHG | Greenhouse gases |
| GWP | Global Warming Potential |
| $H^+$ | Hydrogen ion |
| IEA | International Energy Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| ISO | International Organization of Standardization |
| Kg | kilogram |
| LCA | Life Cycle Assessment |
| LCIA | Life Cycle Impact Assessment |
| MJ | Megajoule |
| N | Nitrogen |
| NO | Nitric monoxide |
| $NO_2$ | Nitrogen dioxide |
| $NO_x$ | Oxides of nitrogen |
| $O_3$ | Ozone |
| P | Phosphorous |
| PED | Primary Energy Demand |
| PET | Polyethylene terephthalate |
| POCP | Photochemical Ozone Creation Potential |
| $SO_2$ | Sulfur dioxide |
| $SO_x$ | Sulfur oxides |
| TRACI | Tool for the Reduction and Assessment of Chemical and other Environmental Impacts |
| VOC | Volatile organic compound |

# GLOSSARY (ISO 14040/44:2006)

The following terms are adapted from: ISO 14040:2006, Environmental management - Life cycle assessment - Principles and framework, International Organization for Standardization (ISO), Geneva.

Allocation

Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems

Functional Unit

Quantified performance of a product system for use as a reference unit

Closed-loop & open loop

A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.

An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.

Cradle-to-grave

Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of life.

Cradle-to-gate

Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of the production process (“gate of the factory”). It may also include transportation until use phase.

Life cycle

A unit operations view of consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal. This includes all materials and energy input as well as waste generated to air, land and water.

Life Cycle Assessment - LCA

Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

Life Cycle Inventory - LCI

Phase of Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Life Cycle Impact assessment - LCIA

Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life Cycle Interpretation

Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Surplus

Bank notes in excess in the branches; replenishments: combination of new bank notes and reusable bank notes

Unfit

Bank notes that are returned to the financial institutions branches and cannot be re-circulated

# EXECUTIVE SUMMARY

The Bank of Canada will be changing the substrate material of bank notes from cotton paper to polymer, and is interested in evaluating the environmental impacts of producing and distributing Canadian bank notes based on those two different substrates. This was done by identifying substances of concern, whether in the form of bank note components or emissions arising from bank note production, revealing those aspects of bank note production and distribution that could be targeted to further reduce environmental impact and ensuring that Canada's new polymer bank notes are in line with established or prospective Canadian health, safety and environmental legislation and any related treaties to which Canada is a signatory.

Therefore, The Bank of Canada commissioned PE Americas and Tryskele to undergo a "Cradle-to-Grave" Life Cycle Assessment (LCA) of the current "Canadian Journey Series" cotton paper bank notes and the new polymer bank note design configuration to evaluate the environmental impacts of the two types of bank notes (current and new design). This analysis is intended to support external communication, and to be shared with the public. It is compliant with the ISO 14040 standards for Life Cycle Assessment (LCA), and has been critically reviewed by a Critical Review Panel as indicated in the ISO 14044 guidelines.

The functional unit for this study is a "Provision of $2,000 (CDN) of cash value over a time span of 7.5 years." Accordingly, the reference flows are chosen to be multiples of a $20 (CDN) bank note. The cotton paper substrate bank note has been considered to have a lifetime of 3 years, and the impact associated with manufacturing and End of Life has been adjusted accordingly. The polymer substrate bank note has been considered to have a lifetime of 7.5 years, which has been considered conservative according to other countries' statistics.

For all indicators under study (Primary Energy Demand, Global Warming Potential, Eutrophication Potential, Acidification Potential, Smog Potential, human and ecosystem toxicity ), most of the impacts are associated with the distribution and use phase. The polymer substrate shows benefits over cotton for all main phases of the life cycle: 1. for the manufacturing phase, since it has to be produced 2.5 fewer times than the cotton paper bank note; 2. for the distribution, since it has to be distributed 2.5 less times and its weight is lighter; 3. for end-of-life, since the contained carbon in cotton paper bank notes is released as GHG in the landfill.

# 1 GOAL OF THE STUDY

The Bank of Canada is interested in:

- Evaluating the environmental impacts of producing and distributing Canadian bank notes based on two different substrates – cotton-based paper vs. polymer
- Identifying substances of concern whether in the form of bank note components or emissions arising from bank note production
- Revealing those aspects of bank note production and distribution that could be targeted to further reduce environmental impact
- Ensuring that Canada's new polymer bank notes are consistent with established or prospective Canadian health, safety and environmental legislation and any related treaties to which Canada is a signatory.

In order to achieve these outcomes, the goals of this study are to:

- Calculate the environmental impacts, using Life Cycle Assessment (LCA), of the current "Canadian Journey Series" paper bank notes and the new polymer bank note design configuration
- Assess the LCA results of the two types of bank notes (current and new design)
- Report the Life Cycle Inventory (LCI) for each step of the life cycle, which compiles all resource consumption and emissions
- Identify the emissions and components of concern from that LCI
- Indicate whether the emissions and components are consistent with current and prospective Canadian regulations and treaties on Health & Safety and the Environment.

The primary audience for this study is the internal and external stakeholders of the Bank of Canada. This analysis is also intended to support external communication, and to be shared with the public. Therefore, PE Americas developed an ISO 14040 compliant Life Cycle Assessment (LCA) report, which has been critically reviewed by a Critical Review Panel as indicated in the ISO 14044 guidelines. The Due diligence Assessment is out of the scope of the LCA study, and therefore has not been critically reviewed.

# 2 SCOPE OF THE STUDY

The following section describes the general scope of the project to achieve the stated goals. This includes the identification of specific products to be assessed, the supporting product systems (e.g. printing, distribution, etc.), and the boundary of the study, allocation procedures and cut-off criteria.

## 2.1 SYSTEM BOUNDARIES

The system boundaries are presented in the figure below. This study is a "cradle-to-grave" life cycle assessment. Therefore, all steps of the life cycle are included in the assessment.

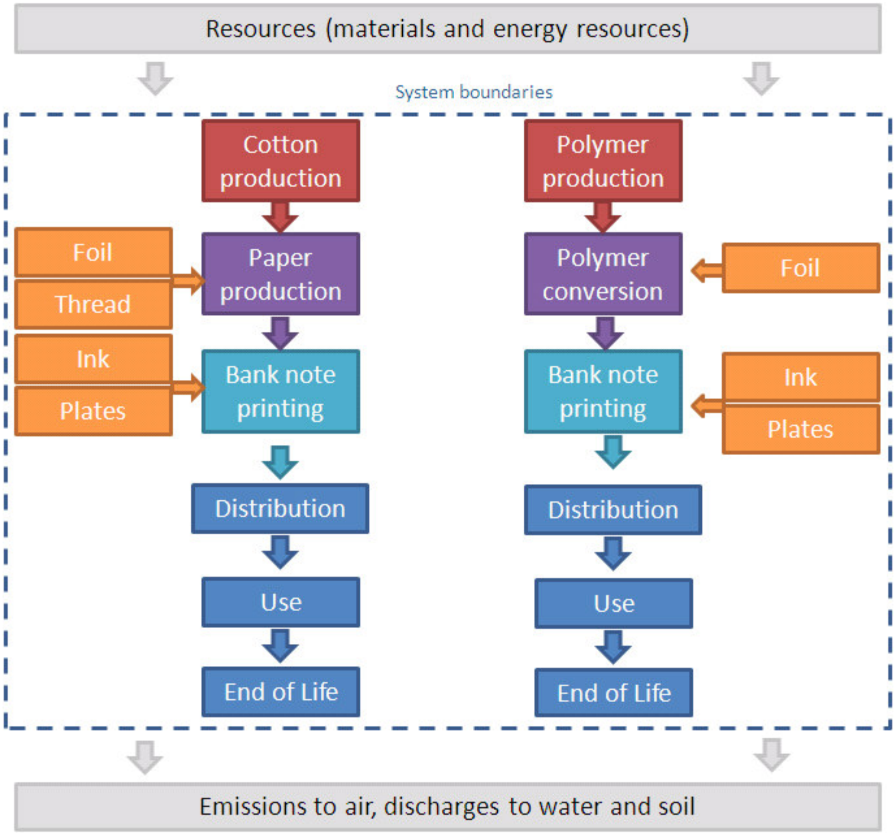


**Figure 2-1. System boundaries**[1] [2]

---

[1] The red boxes represent the main raw material for each bank note, orange boxes are secondary materials, and the purple boxes are "assembly" processes to make the bank notes. Printing is similar and Use/Distribution/ End of Life are common for both bank notes

[2] The resources and emissions are used in the calculation of the Impact Assessment

The **Cradle-to-Grave** assessment includes:

- Production of raw materials
- Transport of raw materials from production site to intermediate manufacturing facility
- Manufacturing of intermediate products (cotton paper and polymer substrate), including packaging
- Printing of bank notes
- Overhead (heating, lighting) of manufacturing facilities[3]
- Packaging of materials related to the final product
- On-site waste disposal at the suppliers' facilities
- Distribution:
    - Transport of finished bank notes from the printing facilities to the Bank of Canada
    - Sorting, internal transportation on conveyer belts, and storage of bank notes at the Bank's facilities
    - Transport of bank notes from Bank of Canada to financial institutions
    - Transport of bank notes from financial institutions to their branches
    - Transport of bank notes back to the Bank of Canada
- Use phase: Distribution of bank notes (through ATMs)
- End of Life of non-reusable bank notes (shredding and landfilling)[4]

The **Cradle-to-Grave** assessment excludes:

- Construction of capital equipment

### 2.1.1 TIME COVERAGE

Primary data were collected on bank note production and distribution for the year 2009. These data were based on annual average data for the year 2009. The representative background data (mainly raw materials, energies, fuels, and ancillary materials) were obtained from the GaBi 4 database 2006 and are representative of the years 2005-2010, in the absence of primary data and based on data availability. Future polymer note production volumes were based on 2009 manufacturing data with projections for volumes taking into consideration factors such as extended substrate life discussed in Section 2.2.

### 2.1.2 TECHNOLOGY COVERAGE

The table below shows an overview of the technology used at each step of the life cycle. The technology is representative of the current technology in use for the production of Canadian cotton paper bank notes, as well as the projected technology for the polymer bank notes.

---

[3] Data have been collected on "overhead". It has been included in the final assessment for both products.

[4] See section 4.5 for end-of-life assumptions

**Table 2-1. Overview of technological coverage**

| Life Cycle step | Specifications on technology |
|---|---|
| **Cotton production** | Agricultural production of cotton |
| **Polymer production** | Bubble PP production process |
| **Cotton paper production** | Cotton paper manufacture includes the production of the paper itself with addition of thread, foil and UV active fibers |
| **Thread manufacturing** | Coating process with metalized polymer (PET) |
| **Foil production** | Metalized polymer (PET) |
| **Polymer conversion** | Substrate production with biaxially oriented polypropylene (BOPP) and aluminum foil and opacification (gravure printing) |
| **Bank note printing** | Litho, Intaglio, and associated pre and post press activities and materials, bindery |
| **Inks** | Ink for Litho and Intaglio |
| **Plates** | Plates for Litho and Intaglio, overcoating plates for polymer |
| **Distribution** | Sorting and storage at the Bank's facilities, Armored cars |
| **Use** | ATM machines |
| **End of Life** | Shredding and then landfill |

### 2.1.3 GEOGRAPHICAL COVERAGE

The geographical coverage for distribution and use is Canada. The raw materials are produced in various areas of the world, and the geographical coverage varies depending of the location of the manufacturing plants.

## 2.2 FUNCTIONAL UNIT

The functional unit for this study is set to be:

"Provision of $2,000 (CDN) of cash value over a time span of 7.5 years"[5]

Accordingly, the reference flows are chosen to be multiples of a $20 (CDN) bank note since it is the most commonly used in Canada, and the predominant denomination (approximately 95%) distributed through ATMs. Inflation has been disregarded in the context of this study.

To be able to do a comparative study of two products with similar performances, this study takes into account the fact that the two types of bank notes have different lifetimes.

1. The **cotton paper substrate** bank note has been considered to have a **lifetime of 3 years**[6], and the impact associated with manufacturing and End of Life have been adjusted accordingly[7]. Its weight is 0.102 kg per 100 bank notes.

2. The **polymer substrate** bank note has been considered to have a **lifetime of 7.5 years**[8]**.** Its weight is 0.093 kg per 100 bank notes.

The distribution and use phase over 7.5 years are the same for both. The polymer substrate has one production phase and one end of life phase over the course of 7.5 years, whereas the cotton paper substrate bank notes have 2.5 production cycles and 2.5 end-of-life cycles in an equivalent amount of time.[9] [10] The two types of bank notes have the same dimensions, but their density and thickness are different, as indicated in the table below. These differences are assumed to have no impact on the use phase, since the energy consumption is related to one bank note.

---

[5] 2009 dollars (reference year)

[6] http://www.bankofcanada.ca/en/bank notes/facts.html

[7] The impacts of the production, distribution and end of life phases have been multiplied by 7.5/3 = 2.5

[8] One manufacture, distribution cycle and End of Life phase

[9] The lifetime of the polymer bank note is projected to be 2.5 times longer than the paper bank note, based on statistical data on currently used polymer bank notes in other countries. The authors are aware that this number can influence the outcome of the study and a sensitivity analysis has been done on this factor, within a reasonable range, provided by statistical data from other countries. The statistical numbers have been provided in appendix.

[10] Since it could also be considered that over 7.5 years there are 3 production cycles of the paper bank note, a sensitivity analysis has been carried out on lifetime and years of operations

Table 2-2. Summary of bank notes weight, lifetime and reference flow

| | Weight (kg/100 bank notes) | Lifetime (years) | Thickness | Reference flow |
|---|---|---|---|---|
| **Cotton paper bank note** | 0.102 | 3 | 115 µm | 250 pieces = (2000/20 *7.5/3) of 20 CAD with a lifetime of 3 years. |
| **Polymer bank note** | 0.093 | 7.5 | 91 µm | 100 pieces (2000/20 *7.5/7.5) of 20 CAD with a lifetime of 7.5 years. |

## 2.3 SELECTION OF LCIA METHODOLOGY AND TYPES OF IMPACTS

A comprehensive set of environmental impact categories was investigated. Within the standard state-of-the-practice of life cycle impact assessment this includes the following inventory flows and environmental categories: primary energy demand[11] (from non-renewable and from renewable resources), global warming potential, eutrophication potential, acidification potential, photochemical oxidant potential (smog formation potential), and toxicity. The details of each impact category are shown in Table 2-3. Additional information on these impact categories is provided in Appendix C. LCIA Descriptions.

The calculation methodology selected is TRACI (Tool for Reduction and Assessment Chemicals and other environmental Impacts)[12]. The TRACI impact categories were selected because they are specific to the US and therefore more largely used in North America. However, since a large portion of Bank of Canada's suppliers are located in Europe, the CML methodology (largely used in Europe) results are provided in Appendix B. The IPCC methodology has been used for the calculation of the Global Warming Potential. Finally, USEtox™ will be used for toxicity.

All selected indicators are based on scientific measurements of the effects on emissions on the environment. There is more uncertainty on the toxicity indicators, but the USEtox™ indicator has gained recognition among LCA practitioners, and is used in this study.

---

[11] Primary Energy Demand is not an impact but is included in this section as it is also a sum value indicating the total amount of energy extracted from earth or based on renewable resources.

[12] EPA http://www.epa.gov/nrmrl/std/sab/traci/

**Table 2-3. Life Cycle Impact Assessment categories, indicators of contribution to environmental issues, units of measure, & brief descriptions**

| Impact Category (issue) | Characterization Model | Description | Indicator Result Unit | Reference |
|---|---|---|---|---|
| **Climate Change** | Global Warming Potential (GWP) | A measure of greenhouse gas emissions, such as $CO_2$ and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect. | kg $CO_2$ equivalent | Intergovernmental Panel on Climate Change (IPCC). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. 2006. Updated version of 2009. |
| **Eutrophication** | TRACI, Eutrophication Potential (EP) | A measure of emissions that cause eutrophying effects to the environment. The eutrophication potential is a stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems. | kg Nitrogen equivalent | Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002. |
| **Acidification** | TRACI, Acidification Potential (AP) | A measure of emissions that cause acidifying effects to the environment. The acidification potential is assigned by relating the existing S-, N-, and halogen atoms to the molecular weight. | mol $H^+$ equivalent | Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002. |
| **Smog formation** | TRACI, Photochemical Oxidant Creation Potential (POCP)/ Smog | A measure of emissions of precursors that contribute to low level smog, produced by the reaction of nitrogen oxides and VOCs under the influence of UV light. | kg $NO_x$ equivalent | Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002. |
| **Human and Eco-toxicity** | USEtox ™ | Characterization of human and ecotoxic impacts in Life Cycle Impact Assessment and ranking of chemicals according to their inherent hazard characteristics. | CTU [13] equivalent | Rosenbaum et al., Int J Life Cycle Assess, USEtox—the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment, 2008. |
| **Ozone depletion** | TRACI, Ozone Depletion Potential (ODP) | A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays. | kg CFC-11 equivalent | Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002. |

---

[13] Comparative Toxic Unit

In addition to Impact categories, Primary Energy Demand (inventory category) is included in this section as it is a sum value indicating the total amount of energy extracted from earth or based on renewable resources.

**Table 2-4. Primary Energy Demand description**

| Inventory category | Description | Unit | Reference |
|---|---|---|---|
| **Primary Energy Demand (PED)** | A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account. | MJ (Lower Heating Value) | An operational guide to the ISO-standards (Guinée *et al.*) |

## 2.4 SOURCES OF DATA

The sources of data are a mix of primary data and use of GaBi database[14]. PE Americas and Tryskele contacted all the suppliers of the Bank of Canada, and whenever possible, the suppliers of those suppliers to get access to primary data. PE Americas collected as much data as possible on:

1. Production of the bank notes and its components (raw materials use, energy consumption, emissions to air and water), and printing (ink and plate manufacturing and usage, energy consumption, emissions to air and water). Suppliers' company names and locations are confidential.

2. Processing at facilities (energy consumption at the Bank's facilities, and raw materials use for packaging)

3. Distribution and Use: transport (distances, modes of transport, trucks fuel economy/types of engines/emissions), ATM (electricity use)

4. End-of-Life (shredding energy, landfill properties)

All data were collected in a consistent way: the data collection sheets enabled the suppliers to report the same type of data, with the same level of aggregation, and all data went through the same quality check procedure.

---

[14] http://www.gabi-software.com

### 2.4.1 FUELS AND ENERGY – BACKGROUND DATA

National averages for fuel inputs and electricity grid mixes were obtained from the GaBi 4 database 2006[15]. Country-specific datasets are used depending on the raw materials manufacturing plant location, and the specific grid mixes composition has been shared with the Critical Review Panel for validation. Moreover, if specific grid mixes are used (e.g. the supplier purchases renewable energy from local wind farms), a specific grid mix has been created.

In addition, region-specific datasets for electricity grid mixes in Canada were used, based on the energy mixes in the table below[16]:

**Table 2-5. Electricity grid mixes for different Canadian provinces**

| Province | Hydro | Nuclear | Coal | Natural gas | Petroleum | Wind |
|---|---|---|---|---|---|---|
| **Quebec** | 96.2% | 2.5% | 0% | 0.2% | 0.6% | 0.6% |
| **Ontario** | 22.3% | 49.1% | 19.3% | 7.9% | 0.8% | 0.6% |

### 2.4.2 RAW AND PROCESS MATERIALS – BACKGROUND DATA

Data for upstream raw materials were obtained from the GaBi 4 database.

### 2.4.3 ALLOCATION

When an allocation was necessary (if there was co- or by-product) during the data collection phase, the allocation rule most suitable for the respective product was applied. For most suppliers, no allocation was necessary. For the cotton paper production and printing, mass allocation was applied, since the products and co-products are similar.

Allocation of upstream data (energy and materials):

- For all refinery products, allocation by mass and net calorific value is applied. The manufacturing route of every refinery product is modeled and so the effort of the production of these products is calculated specifically. Two allocation rules are applied: 1. the raw material (crude oil) consumption of the respective stages, which is necessary for the production of a product or an intermediate product, is allocated by energy (mass of the product * calorific value of the product); and 2. the energy consumption (thermal energy, steam, electricity) of a process, e.g. atmospheric distillation, being required by a product or an intermediate product, are charged on the product according to the share of the throughput of the stage (mass allocation).

---

[15] http://www.gabi-software.com/support/gabi/gabi-lci-documentation/data-sets-by-database-modules/professional-database/

[16] Government of Canada 2008: Economic Scan of Canada's Energy Sector Produced for Energy Sector Sustainability Table; Chapter 4 Electricity, 4.3. Generation, Table 4.1- Net Electricity Generation by Source, by Province and Territory, 2005 (GWh).

- Materials and chemicals needed during manufacturing are modeled using the allocation rule most suitable for the respective product. For further information on a specific product see www.documentation.gabi-software.com.

### 2.4.4 EMISSIONS TO AIR, WATER AND SOIL

All emissions reported by suppliers for the manufacturing phase are taken into account in the study (data used for official reporting). If there was missing data, PE Americas engaged with the companies to obtain the data. All gate-to-gate emissions data were obtained from the suppliers, except in some cases greenhouse gas emissions (from natural gas burning), which were calculated based on emissions factors obtained in the EP-42 document[17]. Those emissions are only for the combustion of the fuel on-site, consequently there is no double-counting with the upstream greenhouse gas emissions (production of fuel or combustion of fuel to produce electricity for the grid mix). The energy supply emissions are provided by the GaBi LCI database.

Data for all upstream materials, electricity, and energy carriers were obtained from the GaBi 4 database 2006. The emissions ($CO_2$, etc.) due to the use of electricity are accounted for with the use of the database processes.

Emissions associated with transportation were determined by capturing the logistical operations of involved companies (data collected from the companies for the reference year). Energy use and the associated emissions were calculated using pre-configured transportation models from the GaBi 4 database 2006, adapted with transportation supplier data (specific fuel economy, specific emissions, etc.).

### 2.4.5 CUT-OFF CRITERIA

The cut-off criteria for including or excluding materials, energy and emissions data of the study are as follows:

- **Mass** – If a flow is less than 1% of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern.
- **Energy** – If a flow is less than 1% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern.
- **Environmental relevance** – If a flow meets the above criteria for exclusion, yet is thought to potentially have a significant environmental impact, it was included. Material flows which leave the system (emissions) and whose environmental impact is greater than 2% of the whole impact of an impact category that has been considered in the assessment must be covered. This judgment was made based on experience and documented as necessary.

---

[17] http://www.epa.gov/ttnchie1/ap42/

The sum of the excluded material flows must not exceed 5% of mass, energy or environmental relevance.

### 2.4.6 EXCEPTIONS

No exceptions to the scope of this study are reported.

## 2.5 SOFTWARE AND DATABASE

The LCA model was created using the GaBi 4 Software system for life cycle engineering, developed by PE INTERNATIONAL AG. The GaBi LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

## 2.6 CRITICAL REVIEW

Because the study is intended to comply with ISO standards and support external communications of a comparative assessment, a critical review has been performed.

A bio of these reviewers can be found below, and the critical review report can be found in appendix.

**Wayne Trusty (Chairman) – LCA expert**, President, Athena Institute

**Lindita Bushi** – **LCA expert**, Athena Institute

**Nick Pearson – Paper bank note expert**, Senior technical expert Notes Division – Quality and Research, Bank of England

**Neil Burnham – Polymer bank note expert**, Independent technical consultant, Smiths Gully, Australia

Wayne Trusty (Panel Chair)

With a master's degree in economics and almost 40 years of experience in such diverse fields as resource industry economics and policy, water resources, transportation, energy policy and markets, and regional development, Wayne Trusty now serves as President of the ATHENA Sustainable Materials Institute and its U.S. affiliate, Athena Institute International. He is also an Adjunct Associate Professor on the University of Calgary's Faculty of Environmental Design, a member of the board of the Green Building Initiative, and Chair of the Technical Committee established in the U.S. to take the Green Globes rating system through a full American National Standards Institute process.

He serves on the Metrics and Life Cycle Assessment task force for CaGBC and, until recently, on the LEED Resources and Materials Technical Advisory Group in the United States. Wayne is a member of several other standards setting organizations, is past chairman of an international technical committee examining the use of LCA with regard to building materials and products, and was a member of the U.S. National Academy of Sciences' Committee on Materials Flow Accounting.

Dr. Lindita Bushi, PhD Eng

Lindita Bushi, holds a doctoral engineering degree in Life Cycle Assessment from the University of Erlangen-Nürnberg, Germany. In 2004, she joined the Athena Sustainable Materials Institute, Canada as a Senior Research Associate. With over twelve years of international LCA experience, including economic evaluations, Dr. Bushi has conducted numerous LCAs in an effort to drive and determine sustainability benefits of industrial processes, products and services. Her LCA experience also extends to a large number of sectors (metals, construction materials, consumer products, energy, transport, recycling, and agriculture). She has extensive multi-national experience working with industrial clients, academia, and joint government-industry programs and taskforces.

Dr. Bushi also serves as peer reviewer for “The International Journal of LCA”, “Journal of Cleaner Production” and other interested organizations. Dr. Bushi has conducted and co-authored numerous carbon footprint projects over the last 7 years according to ISO 14064:2006-Part 1, WRI GHG Protocol: 2004, CDM 2010 Guide, British PAS 2050:2008 and the Natural Resources Canada (NRCan) TEAM Office methodology, System for Measurement and Reporting of Technology (SMART). She is a member of the ACLCA (American Center for LCA) committee for Product Category Rules (PCRs) in LCA. Dr. Bushi is proficient on the most widely used LCA software platforms such as SimaPro and Umberto. She has developed professional training courses in Life Cycle Assessment, Environmental Management Systems (ISO 14001, EMAS II), Risk Assessment, and environmental policy and economics, organized international conferences, and published a number of academic papers and journal articles.

Nick Pearson

Since 2006, Nick has been a Senior Technical Expert in the Notes Division - Quality & Research of the Bank of England. His current responsibilities include:

- £5 note durability - currently conducting an external circulation trial examining the potential for improving the durability of cotton paper notes
- Durability test method development
- Advise the bank on all paper related issues including Watermark development, QC defects etc.
- Assist with the selection of Bank note features and substrate as part of the R&D group

He previously worked on:

- 'Comet' - specification and production of a Polymer test note
- Analysis of previous Circulation trial

Prior to his current position, he was a Senior Project Scientist at the Overton Technology Centre with De La Rue Currency involved in various R&D projects at De La Rue's currency paper mill concentrating on paper manufacture improvements, new paper features and durability improvements. From 1992 to 2000, Nick worked as a Senior Scientist with Pira International on various paper making R&D projects (non-currency) in the areas of paper recycling, coating, refining and non-wood fibres. Nick holds a BSc (Hons) Chemistry Degree from Sussex University.

Neil Burnham

From 1971 to 1976, Neil was an Architectural Design Draftsman with Note Printing Australia (then Note Issue Department, Reserve Bank of Australia) in Fitzroy, Melbourne. He was responsible for the preparation of drawings for new production equipment, building modifications, and layouts for a new production facility. From 1977 to 1978, Neil worked on a building and agriculture project near Rabaul in Papua New Guinea, as part of the AVA (Australian Volunteers Abroad) program.

Between 1979 and 1981, he was employed by NPA as a design draftsman, working with the Department of Housing & Construction on detailed layouts for the new bank note plant in Craigieburn. He held the position of Premises officer with NPA from 1982 to 1986. In 1986 Neil commenced part time studies in mechanical engineering, and transferred to NPA's R&D section, which was charged with the development of the polymer note. The main focus of his work was the design of production processes for substrate and DOVD manufacture. The release of the $10 commemorative in 1988 was a defining moment for the company.

From 1989 to 1994, he held the position of Engineering Maintenance Group Manager, responsible for the maintenance and installation of production and utilities plant plus a number of engineering development projects on prepress and printing equipment. From 1995 to 2000, he established and managed the Product Development section, preparing product and process specifications for the Operations Department. He also managed Prepress, Design and Trade Waste areas and in the late 90’s, acted as Production Manager. During this period he became involved with NPA’s first technology transfer program and built the Design group capability in order to support the growing export market.

From 2001 to 2005, Neil worked for PolyTeQ Services, transferring polymer bank note technology to a number of overseas security printers, both private and State owned. Finally, from 2005 to 2010, Neil was appointed Senior Technical Advisor to Sales and Marketing, working directly with NPA’s customers. This role included assistance with specification and design development and press proofing for new note series for a number of countries in South America, South East Asia and the Pacific. He retired in July 2010 from NPA and commenced work as a Technical Consultant to the bank note industry.

Background on NPA

Note Printing Australia Limited (NPA) is a wholly owned subsidiary of the Reserve Bank of Australia and became a corporate entity on July 1, 1998. NPA prints bank notes and other security products for Australia and a rapidly growing export market. It is recognized as the world leader in polymer bank note printing and a centre for bank note innovation.

# 3 DATA COLLECTION AND QUALITY CHECK

Data used for this project represents a mix of primary data collected from the Bank of Canada and its suppliers for the life cycle of the bank note (gate-to-gate), and data from the GaBi databases. Overall, the quality of the data used in this study is considered to be high and representative of the described systems by the authors of this study. All appropriate means were employed to guarantee the data quality and representativeness as described below.

- Gate-to-gate

  Data on materials, energy use and emissions were collected in a consistent manner and level of detail for Bank of Canada's suppliers for both products to ensure high quality data. All submitted data were checked for quality multiple times, both on plausibility of inputs and outputs as well as comparison against similar processes and other data collected from other companies. All questions regarding data were resolved with individual companies. All calculations procedures have been applied consistently throughout this study.

- Upstream Data

  All data from the most updated version of the GaBi database were created with consistent system boundaries and upstream data. Expert judgment and advice was used in selecting appropriate datasets to model the materials and energy for this study and has been noted in the preceding sections. Detailed database documentation for GaBi datasets can be accessed at http://documentation.gabi-software.com/.

## 3.1 DATA COLLECTION PROCESS DESCRIPTION

The participating companies were sent data collection questionnaires, which were specific to their role in the life cycle, and they had to provide it completed to Tryskele and PE Americas. The data are confidential and were transmitted to Tryskele and PE Americas under a Non-Disclosure Agreement (NDA).

Each batch of data went through a data quality check process (described below), which includes benchmarking of the data, comparison to reference documents and expert knowledge. Each company was contacted individually to double check their data and/or provide more detailed data, and to ensure the best quality for the study.

## 3.2 DETAILED DESCRIPTION OF THE DATA COLLECTED

The table below is a summary of the sources of data collected for this study. The number of suppliers for each phase of the life cycle is less than three.

**Table 3-1. Summary of data collected for the study**

| Bank note life cycle step | Representa-tiveness of data collected | Data source | Description of data collected |
|---|---|---|---|
| **Cotton paper production** | 100% | Supplier (primary data) | Raw materials (including packaging, operating materials), energy, emissions, water usage, waste, waste water<br>Transportation of raw materials and final product (mode and distance) |
| **Polymer substrate production** | 100% | Supplier (primary data) | Raw materials (including packaging, operating materials), energy, emissions, water usage, waste, waste water<br>Transportation of raw materials and final product (mode and distance) |
| **Foil production** | 100% | Supplier (primary data) | Raw materials (including packaging, operating materials), energy, emissions, water usage, waste, waste water<br>Transportation of raw materials and final product (mode and distance) |
| **Thread production** | 100% | Supplier (primary data) | Raw materials (including packaging, operating materials), energy, emissions, water usage, waste, waste water<br>Transportation of raw materials and final product (mode and distance) |
| **Thread conversion** | 100% | Supplier (primary data) | Raw materials (including packaging, operating materials), energy, emissions, water usage, waste, waste water<br>Transportation of raw materials and final product (mode and distance) |
| **Printing** | 100% | Supplier (primary data) | Raw materials (inks, plates, wiping solution, packaging, operating materials, etc.), energy, emissions, water usage, waste, waste water<br>Transportation of raw materials and final product (mode and distance) |
| **Ink production** | 100% | Supplier (primary data) | Raw materials (including packaging, operating materials), energy, emissions, water usage, waste, waste water<br>Transportation of raw materials and final product (mode and distance) |

| | | | |
|---|---|---|---|
| **Distribution logistics** | 100% | Bank of Canada (primary data) | Logistics and transportation (mode and distances)<br>Energy usage at the facilities (for heating, sorting, etc.) |
| **Armored cars** | 100% | Contractor (primary data) | Vehicles specifications (fuel type, fuel economy, engine type, average age of vehicle, emissions standards, payload, utilization ratio) |
| **Use phase** | n/a | Bank notes equipment manufacturers (primary data) | Energy used and internal data on bank notes circulation.<br>The energy use is the one of an average ATM cash machine. |
| **End of Life - landfills** | 57% | Contractor (primary data) | Landfill specification (landfill area, permitted capacity of waste, operating life height of landfill, density of waste, recirculation of leachate, surface seal and base seal, thickness of drainage layer, thickness of plastic film, reclamation layer and clay, share of the gas that is flared/goes to electricity generation) |

## 3.3 DATA QUALITY REQUIREMENTS

Data quality is judged by its precision (measured, calculated or estimated), completeness (e.g. are there unreported emissions?), consistency (degree of uniformity of the methodology applied on a study serving as a data source) and representativeness (geographical, time period, technology). To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent, background LCA information from the GaBi LCI database are used. This background information from the GaBi LCI database is widely distributed and used with the GaBi 4 Software. The datasets have been used in LCA models worldwide for several years in industrial and scientific applications for internal as well as in many critically reviewed studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

Precision and completeness

- **Precision:** As the relevant foreground data is primary data or modeled based on primary information sources of the owner of the technology, no better precision is reachable within these projects. All background data is GaBi professional data with the documented (high) precision.
- **Completeness:** All relevant, specific processes for the different options are considered and modeled to represent each specific situation. Any background processes are taken from the GaBi databases (see GaBi 4 documentation).

Consistency and reproducibility

- **Consistency:** To ensure consistency only primary data of the same level of detail and the same background data from the GaBi databases are used. While building up the model cross-checks concerning the plausibility of mass and energy flows are continuously conducted.
- **Reproducibility:** The reproducibility is given for internal use since the owners of the technology provided the data and the models are stored and available in a database. Sub-systems are modeled by ´state of art´ technology using data from publicly available and internationally accepted databases. For the external audience it is possible that no full reproducibility in any degree of detail will be available for confidentiality reasons.

Representativeness

- **Time related coverage:**
  - Bank note primary data: 2009
  - Background data: 2005 to 2007
- **Geographical coverage:** The geographical coverage is Canada, and specific suppliers' countries
- **Technological coverage:** The technology is the one used at the manufacturing plants during the reference year for data collection.

Data were collected and modeled to ensure that:

- All materials are modeled according to the same boundary conditions,
- The analysis does not compare different background systems,
- The results represent current technology

# 4 LIFE CYCLE MODELING

This section describes the Life Cycle model and assumptions.

## 4.1 OVERVIEW OF LIFE CYCLE

The model has been created following the Life Cycle of the Bank note, as described below.

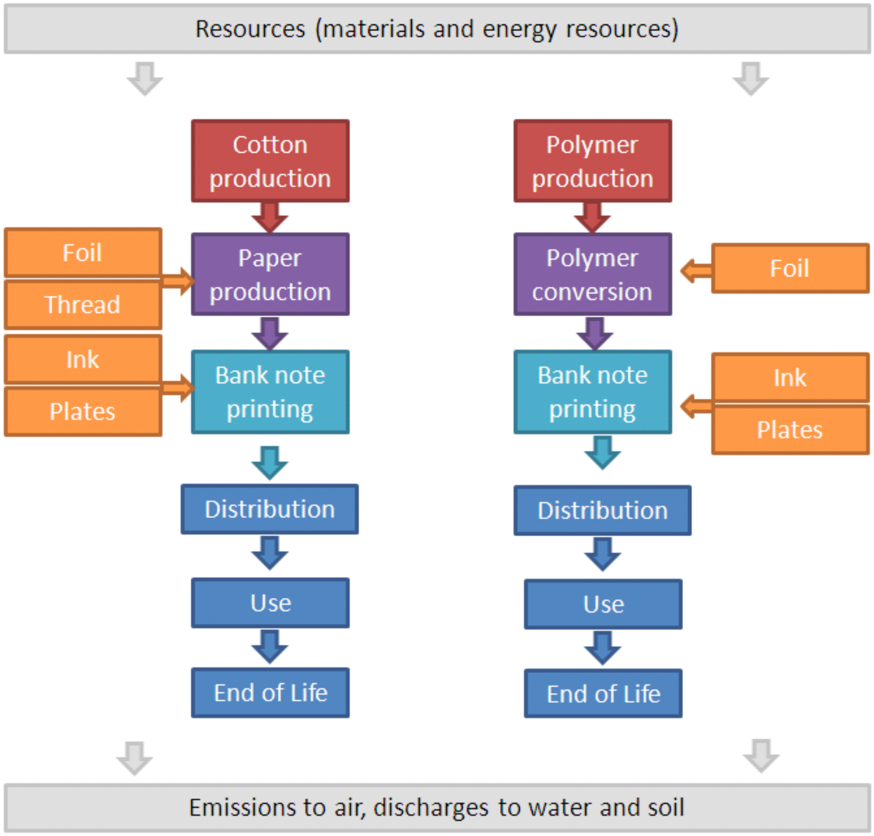


**Figure 4-1. Life Cycle Model**

## 4.2 PRODUCTION

The base material (cotton paper or polymer substrate) is produced, and security features are added: the holographic foil (for both the polymer and cotton paper substrates), and the thread (for cotton paper substrate only). The foil has a different width for the new design, compared to the current design, and this difference has been taken into account in the model by using the exact amount of foil for each design.

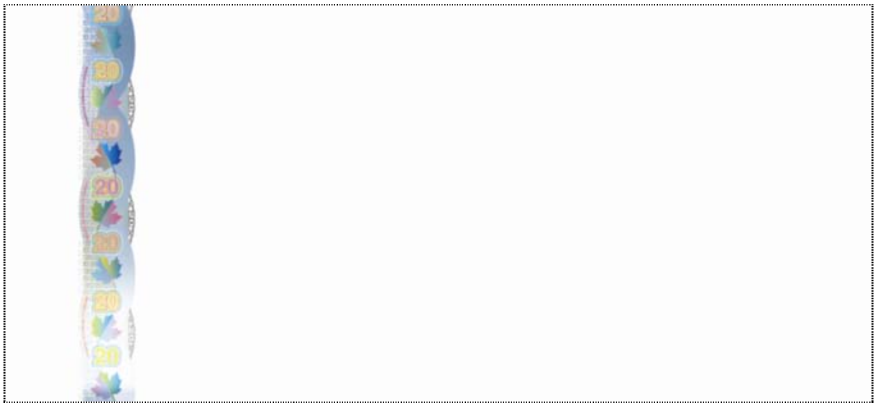


Figure 4-2. Schematic view of Holographic foil for the $20 denomination

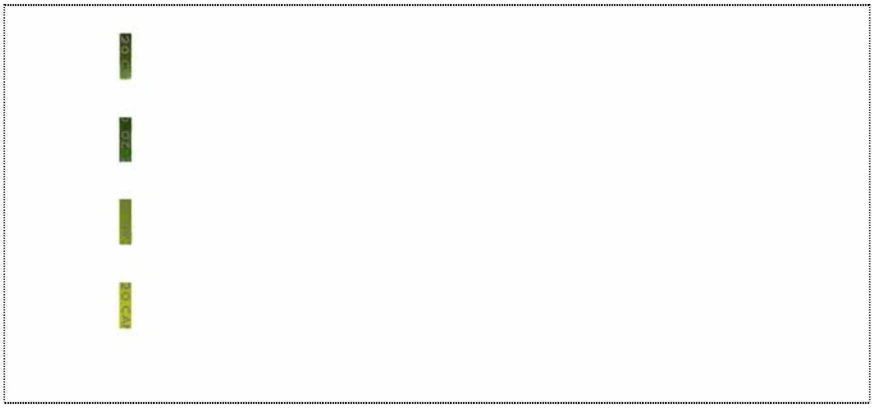


Figure 4-3. Schematic view of Thread for the $20 denomination

The bank note is then printed with several different printing processes, including Intaglio and Lithography. The final steps are numbering and varnish application to make the final bank note.

Figure 4-4. Schematic view of Lithography printing (offset) for the $20 denomination

Figure 4-5. Schematic view of Intaglio printing for the $20 denomination

Figure 4-6. Schematic view of final $20 denomination bank note (front and back)

### 4.2.1 BANK NOTE MATERIALS MANUFACTURING

The cotton paper and polymer substrates have been modeled as presented in the figure below.

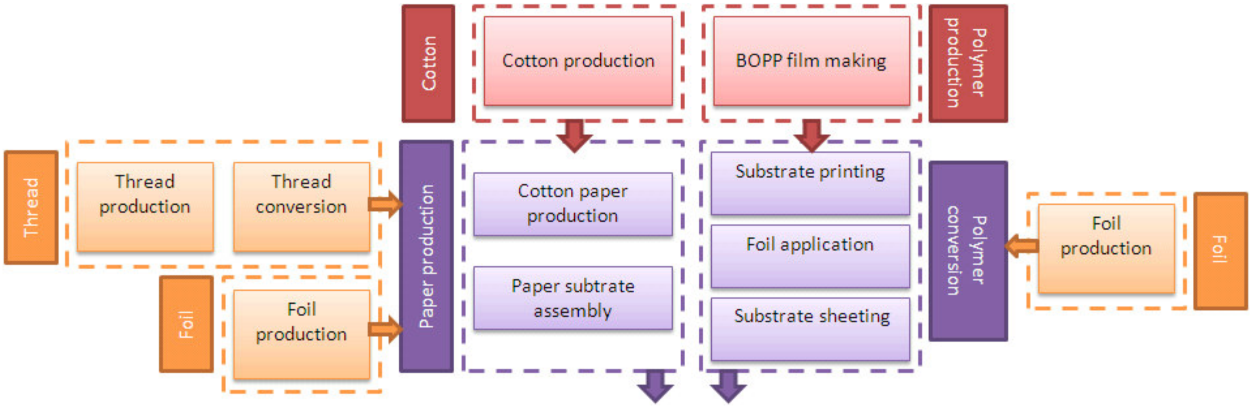


Figure 4-7. Bank notes materials manufacturing phase model

The foil is made out of a mix of aluminum and PET, to which some adhesives are added. The raw materials are transported from different places in the world, and the logistics have been modeled accordingly. The final foil is then sent to the substrate manufacturers.

The thread manufacturing is an energy-intensive vacuum deposition process, when silica blocks are vaporized and deposited onto a metallic alloy. The thread rolls are shipped by airplane from North America to Europe where they are converted by a different supplier into the final thread, by adding coatings and adhesives. The final thread is then sent to the cotton paper manufacturer.

The cotton paper production has been modeled according to the suppliers' data. The raw materials mainly consist of cotton (sourced from Europe and the US), and cotton linters (sourced from the US) which is a by-product of the cotton textile industry. The cotton paper is bleached with lye (a sodium hydroxide solution) and hydrogen peroxide. A white pigment is added, as well as some additional chemicals like glue. The foil and the thread are added to the cotton paper, and the quantities used in the model include waste. All the logistics between suppliers have been modeled to reflect the current state of the supply chain. The raw materials usage is specific to the cotton paper production, but the energy (electricity and fuel) has been allocated by mass of output of the manufacturing plant.

The polymer substrate is made out of a biaxially-oriented polypropylene film (BOPP) film. The main raw materials for the conversion step include an opacifier, solvents and resin. Those materials and the solvents used emit VOCs that are then combusted in a thermal oxidizer. The polymer substrate goes through a printing process, which includes the use of copper cylinders, and that are chromed with a chrome bath. The specific amount of chrome solution and cylinders has been collected per year. The foil is added (the foil usage is higher than the amount on the bank note because it includes production waste). The energy use (electricity and natural gas) has been collected by the supplier, as well as emissions to air and water. Finally, the final polymer substrate sheets are sent to the printers in wooden boxes.

### 4.2.2 PRINTING

The model follows the flow chart presented below, the arrows represent shipping:

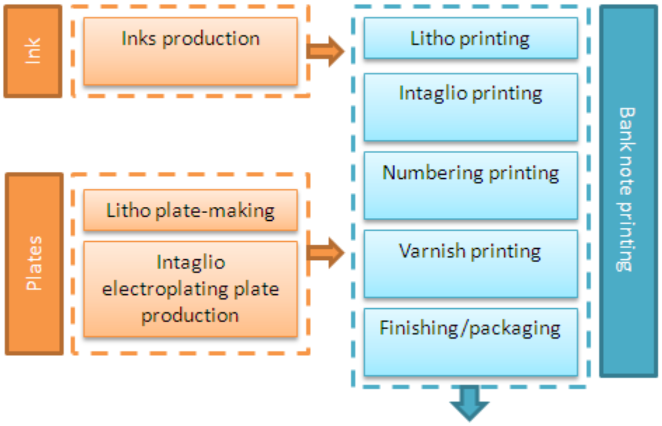


**Figure 4-8. Bank notes printing phase model**

The inks have been modeled specifically for each type of bank note (different compositions for cotton paper and polymer substrates inks) based on ink supplier data. The inks are a mixture of varnishes, pigments and additives. The polymer substrate also requires a specific protective varnish, for which specific data have been collected.

The printing process for Canadian bank notes involves a wide variety and combination of pre-press, printing and post printing operations, some unique to the security printing industry. Primary data for each stage of the process was collected from the printers and suppliers.

Pre-press involves the generation of plates and cylinders/rollers for the printing operations and includes the electroforming and electroplating processes for intaglio, wet and dry plates for lithographic and image/ink transfer plates (including development chemicals where applicable). Press cylinders and rollers that are coated or etched with surfaces that are unique to the job and are replaced as worn/damaged (for example PVC coated or etched cylinders) are included. Rollers and cylinders not included are those that are part of the press equipment (for example ink transfer rollers). The number of plates/cylinders used to produce the Canadian bank note series in 2009 was obtained and values of consumable materials such as nickel, chromium and developers were calculated based on production times (for example amp hours and thicknesses for intaglio plates) and prorated chemical consumption (based on the percentage of business the Bank of Canada represents for the process over 2009). Air emissions for the chromium process were based on amp hour, surface areas and pollution control equipment emission factors.

The printing process involves the transfer of inks onto a substrate and wash-up solutions for the inks. The printing ink consumption includes the total amount used for each process to print the bank notes, specific to the $20 denomination, and the ink used in the set-up of presses and used on overs (generated to replace notes not released as part of the normal quality control system). An alkaline aqueous wiping solution is used to remove inks from one of the printing processes and the flow rates per hour to the press and chemical composition of the wiping solution was used to generate data for this operation. Solvents used as press-washes or fountain solutions were calculated based on the percentage of business the Bank of Canada represents for the process over 2009. These materials are common aliphatic/aromatic solutions used in the printing industry and individual components were reviewed. Substrate for the cotton based-substrate processes include the bank note paper as well as wood pulp-based paper (used for the set-up of the presses). Substrate for the polymer printing processes is necessarily polymer-based substrate for both final product and set-up.

Bindery materials are those used to package the notes for shipping and include plastic wrap, strapping, skids wrap and skids in the evaluation.

Wastes generated include printing waste, chemicals waste and effluent treatment wastes from the water wiping solution used in the print operation. Secure wastes are shredded and transferred to landfill in bins. Primary data on substrate volumes destroyed were used in the process as well as information from landfills. Volumes of waste water treatment chemicals were used in the calculation of volumes to landfill as well as information on the number of bin collections. Cloth wipers are used to reduce flammable/combustible wastes generated and wipers are returned to the supplier for laundering and solvent recycling/blending. The Canadian Council of Ministers of Environment (CCME) recognized a factor of approximately 30% of solvent used is retained on the wipers and this value was used in the LCA calculation process.

Energy consumption was measured for printing, cutting, bindery, waste treatment and destruction equipment (shredder) and used in the calculation of electricity consumption. Ontario specific data for the grid mix were used for this electricity source. Natural gas values were based on a prorated value for percent of production the Bank of Canada represents, and therefore captures both the production and overhead consumption.

Since it has been assumed that the energy use by the equipment is allocated to the job, the energy consumption for the polymer substrate has been assumed to be the same as for the cotton substrate. Based on previous experience with a similar polymer substrate material, however, production rates may be different for the polymer substrate. It has been estimated that the speed of polymer printing, cutting, and shredding is approximately 70%, 60%, and 75% that of the cotton substrate, respectively. A sensitivity analysis has been added in section 7.1 to measure the effect of an additional energy use of 0% to 50% for polymer substrate printing.

## 4.3 DISTRIBUTION

The distribution model is described in the following sections for the logistics and secured transport models.

### 4.3.1 LOGISTICS MODELING

The Bank of Canada provided logistical information on the distribution portion of the Life Cycle. The model for distribution is displayed in the figure below.

The Agency Operations Centers (AOCs) are the major distribution centers. They centralize and coordinate the replenishments and the disposal of old bank notes. The AOCs receive new bank notes from the printers through the Central Bank and unfit/surplus from the branches through Regional Distribution Points (RDPs). The unfit/surplus bank notes are sorted at the AOCs, and the combination of reusable bank notes and new bank notes are sent to circulation (replenishments); whereas the unusable bank notes are shredded and sent to landfill.

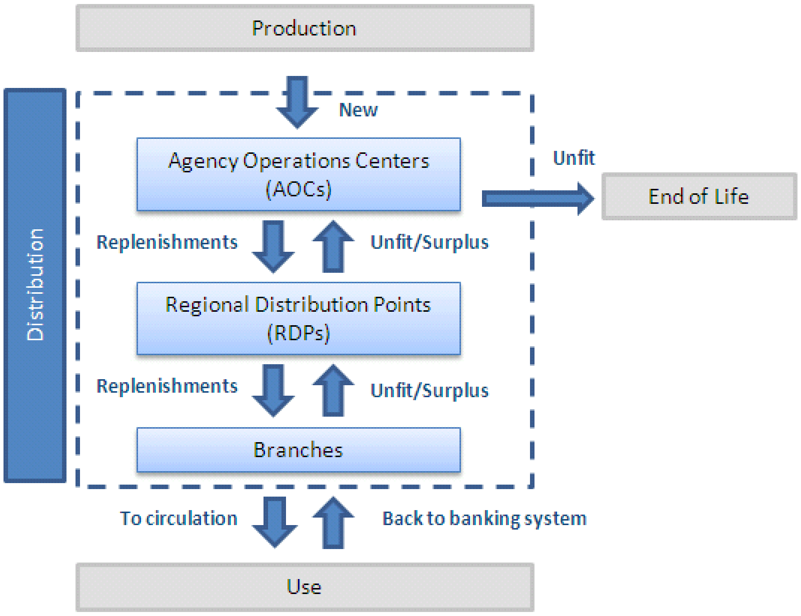


**Figure 4-9. Distribution logistics model**[18]

1. Printed Bank notes are transported to 2 "Agency Operation Centers" (AOC) in Montreal and Toronto by armored cars. The Bank provided primary data on transportation distances (confidential), electricity and fuel usage at the facilities.

2. Bank notes are then transported by airplane and/or armored cars to 10 "Regional Distribution Points" (RDP). The Bank provided primary data on transportation distances (confidential). Even if the distances are the same from and back to the AOC, the mass transported vary significantly. Consequently, the weighted average distance are different from and back to the AOCs.

   The average distances, weighted by volumes distributed are displayed in the table below:

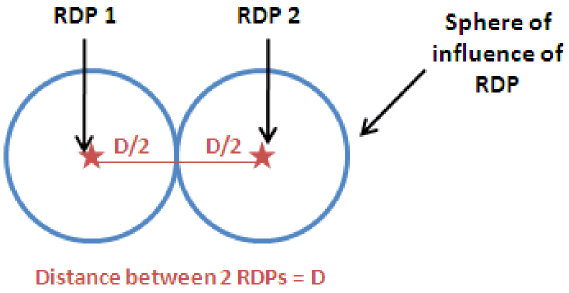
---

[18] New: fresh bank notes from printers; Unfit: bank notes that are returned to the financial institutions branches and cannot be re-circulated; surplus: bank notes in excess in the branches; replenishments: combination of new bank notes and reusable bank notes

**Table 4-1. Average transportation distance by mode, weighted by mass**[19]

| | Airplane (km) | Armored cars (km) |
|---|---|---|
| AOC to RDP | 807 | 17 |
| RDP to AOC | 664 | 99 |

3. Then, the bank notes are transported to the branches by armored cars. The Bank did not have access to the information on the average distance between the RDPs and branches, since the number of branches is large, and the transport is operated by a contractor. An estimation of this average distance was calculated, based on a "worst-case" scenario. The distance in the model is the average of half-distances between two closest RDPs. In other words, the model considers that the average distance between a RDP and branches is within a circular perimeter of half of the distance to the next RDP.



The calculated distance is:

**Table 4-2. Average distance from RDP to branches**

| | Armored cars (km) |
|---|---|
| RDP to Branches | 325 |

### 4.3.2 SECURED TRANSPORT MODEL

The datasets for trucks, ocean freight and airplane[20], as well as the fuels are from the GaBi 4 database. The trucks in the GaBi database are based on the US EPA (Environmental Protection Agency) data.

Primary data was collected on the armored cars (e.g. type of fuel, fuel efficiency, average age of the vehicles, emissions standards, engine type) from the Bank's transportation contractor, to ensure best representativeness.

---

[19] Values in the table are calculated with the following formula: distance 1 *% mass 1 + distance 2 * % mass 2 +…

[20] Link to documentation: http://gabi-dataset-documentation.gabi-software.com/

## 4.4 USE PHASE MODEL

The use phase has been modeled according to the following assumptions:

- The only impact is coming from the ATM energy usage over 7.5 years
- All notes withdrawn are $20 bank notes[21]
- All energy use at the ATM is allocated to withdrawals over 7.5 years
- All of the ATMs are cash dispensing machines

This is a simple but sufficient view of the Use phase, as this will be identical for cotton paper and polymer bank notes. A more detailed view of this phase could be done, however the complexity of the system would likely require a separate study unto itself.

Based on the data provided by the bank, the model runs the calculations presented below:

1. Energy used by a bank note during its use phase per year:

$$Energy\,used\,by\,a\,banknote\;at\;ATM\;\;per\;year=$$

$$\frac{(Energy\,used\,by\,one\,ATM\;\;per\;year)\times(Total\;No.of\;\;ATMs\,in\,CAN)}{(Total\;No.of\;\;banknotes\,in\,circulation\;per\;year\,in\,CAN)}$$

2. Energy used by one ATM per year:

$$Energy\,used\,by\,one\,ATM\;\;per\;year=\;power\;consumption\times hours\;in\;year$$

The result of this calculation is **0.152 MJ/bank note/year**.

**Table 4-3. Parameters for use phase calculations**

| Parameter | Description | Unit | Data source |
|---|---|---|---|
| **Energy used by bank note at ATM per year** | The energy (electricity) used ATMs by a bank note in order to be in circulation for 1 year | kWh | Calculated (see equation) |
| **Energy used by one ATM per year** | The energy (electricity) consumed by one ATM over the course of 1 year | kWh | Calculated (see equation) |

---

[21] This assumption is considered conservative and constitutes ~90-95% of ATMs available. According to the Bank, in 2009 (year of the study) only 1 financial institution plus casinos and airports dispense anything but $20s.

| | | | |
|---|---|---|---|
| **Total No. of ATMs in Canada** | Number of total ATMs in Canada | [-] | Bank of Canada |
| **Power consumption** | Power consumption of a cash dispensing machine | kW | ATM supplier |
| **Hours in year** | Numbers of hours in a year | hours | Calculated (see equation) |
| **Total No. of bank notes in circulation** | Number of $20 bank notes in circulation | [-] | Bank of Canada |

## 4.5 END-OF-LIFE MODEL

At the time of this study, the Bank of Canada had not chosen a specific end-of-life scenario for polymer bank notes. For the purposes of this model, in the absence of a specific scenario for polymer bank notes, landfill was assigned as the end-of-life scenario for both cotton paper and polymer waste.

Landfill specific data have been collected at the landfill site. The GaBi model for landfill has been adapted based on this information and also customized based on the composition of the two types of bank notes. A difference has been made between the "inactive" carbon and "active" carbon that degrades into landfill gas; those have been calculated based on the composition of the bank note (11%[22] inactive for cotton paper, 100% inactive for polymer, considering that biogenic carbon – cotton – is active and non-biogenic carbon – plastics – is inactive). The landfill gas composition depends on the composition of the material and its degradation in the landfill. The landfill site reports an average landfill gas composition of about 50% $CO_2$ and 50% methane. An estimated 75% of the landfill gas is captured; the exact percentage is not tracked. According to the landfill site, 21% of the captured landfill gas is flared and 79% is used for energy recovery with an efficiency of 97%. This energy recovery has been accounted for in the model.

The site includes landfill gas treatment, leachate treatment, and sludge treatment and deposition. The landfill has a height of 50 meters, landfill area of 53.9 hectares and a 25-year lifespan. The annual permitted capacity of waste is 850,000 tons/year over 20-25 years. The density of the waste in the landfill is about 1 ton/$m^3$.

The landfill does not have circulation of the leachate. Average yearly data from the area gives annual precipitation rate of 834mm/a. A rate of 60% transpiration/runoff is assumed.

The effort for sealing materials (clay, mineral coating, and polyethylene film) and diesel for the compactor is included in the data set. The landfill is designed based on Ontario regulation: 232/98 Double Generic Liner Design. The primary drainage layer for leachate collection is 300-550 mm thick and

---

[22] This is calculated based on the composition of the bank note (the inactive carbon portion of the paper bank notes comes from the use of glues and polyglycol)

520 mm thick for the secondary layer. The plastic film is a HDPE liner, for which the primary liner is 60 mm thick and the secondary liner is 80 mm thick. The leveling soil layer is at a minimum of 1 meter of the attenuation layer. Finally the primary clay liner is 750 mm thick and the secondary clay liner is 750 mm thick.

The leachate and landfill body are assumed to be homogeneous. The landfill body is assumed to be saturated. Leachate treatment includes active carbon and flocculation/precipitation processing, as well as sludge treatment and deposition.

# 5 LIFE CYCLE INVENTORY

The cradle-to-grave Life Cycle Inventory is provided in Appendix D. Cradle-to-grave Life Cycle Inventory. The gate-to-gate Life Cycle Inventory of the manufacturing phase for the cotton paper bank notes is not displayed for confidentiality reasons. Since the number of suppliers for each step is less than three, the confidentiality of the data provided would be not respected.

# 6 LIFE CYCLE IMPACT ASSESSMENT

## 6.1 HIGH LEVEL COMPARISON OF THE TWO TYPES OF BANK NOTES

The table and graph below show the comparison of the two bank notes, for the overall life cycle (cradle-to-grave). The results are displayed for the functional unit and reference flows detailed in the scope: 100 bank notes, over 7.5 years (1 manufacturing/ distribution/ end of life cycle for the new design, and 2.5 manufacturing/ distribution/ end of life cycles for the current design).

**Table 6-1. High level comparison (absolute values) of the two types of bank notes – 100 bank notes over 7.5 years**

| For 100 bank notes, over 7.5 years | Current Design | New Design |
|---|---|---|
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 3.78E+01 | 2.54E+01 |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 2.97E+02 | 2.06E+02 |
| Primary energy from resources (net cal. value) [MJ] | 7.91E+02 | 4.83E+02 |
| TRACI, Acidification Air [mol H+ Equiv.] | 1.05E+01 | 7.52E+00 |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 8.31E-03 | 3.32E-03 |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 9.99E-06 | 5.52E-06 |
| TRACI, Smog Air [kg NOx-Equiv.] | 1.03E-04 | 6.26E-05 |
| USETox2008, Ecotoxicity [PAF m3.day] | 1.65E-02 | 1.04E-02 |
| USETox2008, Human toxicity [cases] | 5.24E-10 | 3.62E-10 |

The graph below shows the relative comparison (in percentage) of the two types of bank notes over their life cycle.

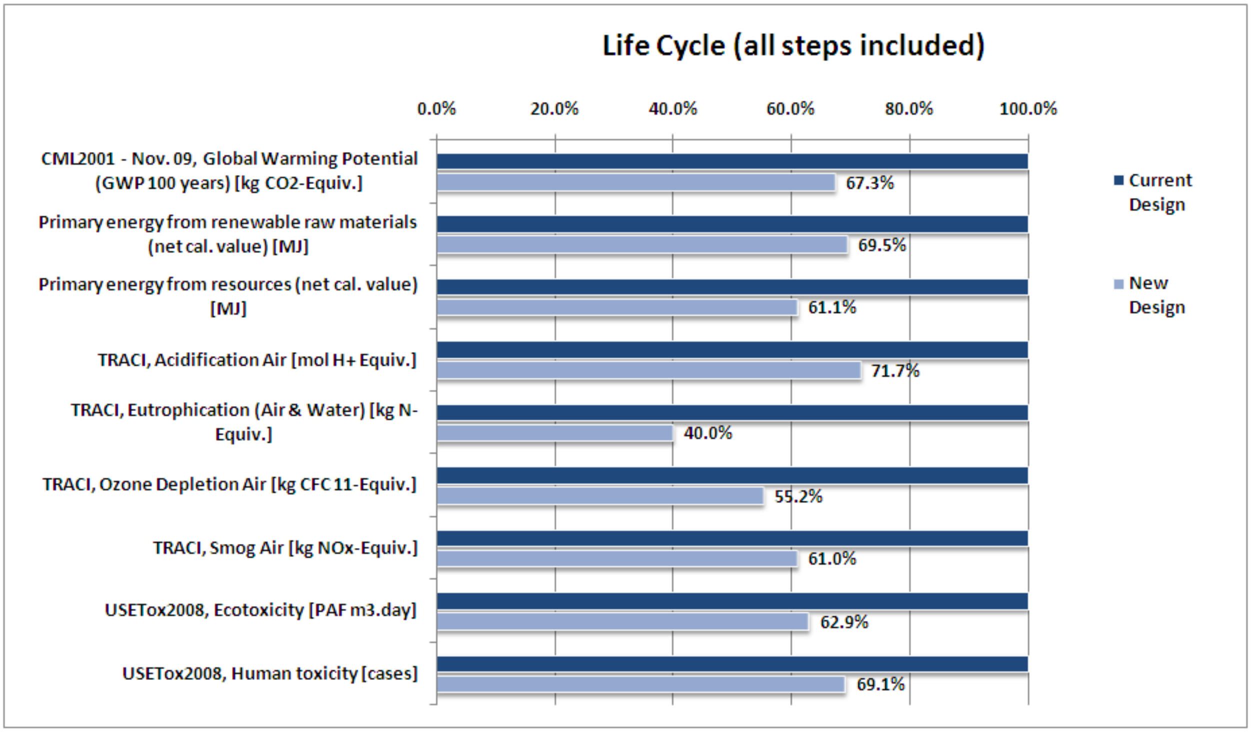


**Figure 6-1. High level comparison (relative) of the two types of bank notes – 100 bank notes over 7.5 years**

The results indicate that the new design (polymer bank note) shows benefit over the current design (cotton paper bank note) for the environment, for all indicators under study, for the chosen functional unit. More details on the breakdown of those impacts are given in the next sections.

## 6.2 DETAILED ANALYSIS OF MAIN PHASES OF THE LIFE CYCLE

The tables and graphs below show the breakdown of the environmental impacts for the main phases of the life cycle (1.Manufacturing; 2.Distribution; 3. Use; 4.End-of-life).

**Table 6-2. Results for main phases of the life cycle for the current design (absolute values) – 100 bank notes over 7.5 years**

| Environmental Indicators | Current Design | | | | |
|---|---|---|---|---|---|
| | 1.Paper Bank Note Manufacturing | 2.Distribution | 3. Use (ATM) | 4.End of Life | TOTAL |
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 1.59E+00 | 1.99E+01 | 1.62E+01 | 1.52E-01 | 3.78E+01 |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 1.41E+01 | 1.29E+02 | 1.54E+02 | -1.61E-01 | 2.97E+02 |
| Primary energy from resources (net cal. value) [MJ] | 4.94E+01 | 4.70E+02 | 2.72E+02 | 1.84E-01 | 7.91E+02 |
| TRACI, Acidification Air [mol H+ Equiv.] | 5.05E-01 | 4.51E+00 | 5.47E+00 | 5.20E-03 | 1.05E+01 |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 3.30E-03 | 3.02E-03 | 1.99E-03 | 4.59E-06 | 8.31E-03 |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 6.86E-07 | 6.42E-06 | 2.88E-06 | -1.45E-09 | 9.99E-06 |
| TRACI, Smog Air [kg NOx-Equiv.] | 5.42E-06 | 6.00E-05 | 3.71E-05 | 1.13E-07 | 1.03E-04 |
| USETox2008, Ecotoxicity [PAF m3.day] | 2.31E-03 | 9.35E-03 | 4.80E-03 | 1.31E-05 | 1.65E-02 |
| USETox2008, Human toxicity [cases] | 4.08E-11 | 2.50E-10 | 2.33E-10 | 4.93E-13 | 5.24E-10 |

**Table 6-3. Results for main phases of the life cycle for the new design (absolute values) – 100 bank notes over 7.5 years**

| Environmental Indicators | New Design | | | | |
|---|---|---|---|---|---|
| | 1.Polymer Bank Note Manufacturing | 2.Distribution | 3. Use (ATM) | 4.End of Life | TOTAL |
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 1.57E+00 | 7.71E+00 | 1.62E+01 | 1.25E-02 | 2.54E+01 |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 8.23E-01 | 5.17E+01 | 1.54E+02 | 5.35E-03 | 2.06E+02 |
| Primary energy from resources (net cal. value) [MJ] | 2.68E+01 | 1.84E+02 | 2.72E+02 | 1.81E-01 | 4.83E+02 |
| TRACI, Acidification Air [mol H+ Equiv.] | 3.08E-01 | 1.75E+00 | 5.47E+00 | 2.98E-03 | 7.52E+00 |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 1.81E-04 | 1.15E-03 | 1.99E-03 | 1.24E-06 | 3.32E-03 |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 6.62E-08 | 2.57E-06 | 2.88E-06 | 6.75E-10 | 5.52E-06 |
| TRACI, Smog Air [kg NOx-Equiv.] | 2.81E-06 | 2.27E-05 | 3.71E-05 | 2.40E-08 | 6.26E-05 |
| USETox2008, Ecotoxicity [PAF m3.day] | 2.00E-03 | 3.56E-03 | 4.80E-03 | 4.54E-06 | 1.04E-02 |
| USETox2008, Human toxicity [cases] | 2.93E-11 | 1.00E-10 | 2.33E-10 | 1.37E-13 | 3.62E-10 |

Note: the color coding indicates the lowest to highest impact phase for each indicator.

| **Lowest** | | | | | | | | | | **Highest** |
|---|---|---|---|---|---|---|---|---|---|---|
| 🟩 | 🟩 | 🟩 | 🟩 | 🟨 | 🟨 | 🟧 | 🟧 | 🟧 | 🟥 | 🟥 |

### Manufacturing

The manufacturing phase has a similar or slightly higher impact for the cotton paper bank note than for the polymer bank note for all indicators under study. This is mainly due to the fact that over the course of 7.5 years there are 2.5 manufacturing cycles of the cotton paper notes and only one production cycle for the polymer note. For Eutrophication the impact is significantly higher for the cotton paper bank notes, since Eutrophication is influenced by cotton cultivation, which requires the use of fertilizers (phosphates and nitrates release). For Global Warming Potential the impact is almost identical for both substrates.

### Distribution

The life cycle impacts of the two bank note options differ significantly in the distribution stage. Although the logistics of distribution are the same for both cotton paper and polymer notes, the cotton paper notes have a shorter life expectancy and need to be distributed more frequently (specifically, by a factor of 2.5). Additionally, shipments of bank notes are limited by the monetary value, not mass, of the shipment; because polymer notes are slightly lighter (i.e. they have a lower ratio of mass to monetary value), the environmental impact of a single shipment of polymer notes will be slightly less than the impact of a single shipment of cotton paper notes.

### Use

The use phase is the same for both substrates. The analysis shows that the use phase (ATMs) is the major source of impact for the whole life cycle for the polymer bank notes. It represents more than half of the impact of the life cycle. This is due to the fact that ATMs are running all day long, over the course of 7.5 years.

### End of Life

The end of life phase does not drive the environmental profile, but is higher for the cotton paper bank notes. This is due to the fact that the cotton paper decomposes at a faster rate than the polymer, and therefore emits greenhouse gas emissions to the atmosphere (active vs. inactive carbon).

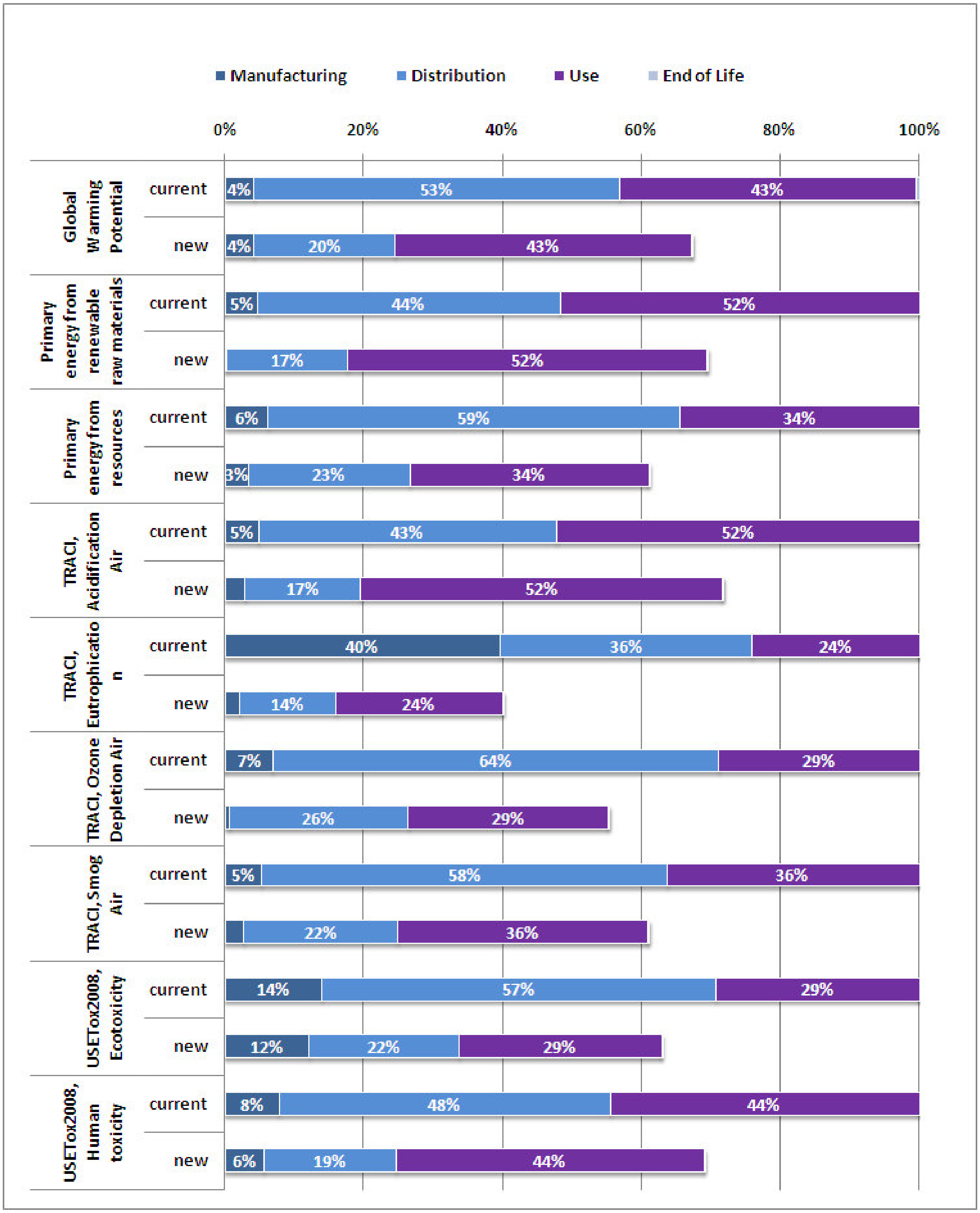


**Figure 6-2. Comparison and break down of impacts for the two designs (relative) – reference: 100% life cycle impact of current design**

## 6.3 DETAILED ANALYSIS OF THE MANUFACTURING PHASE

This section presents the results for the cotton paper substrate manufacturing and the polymer substrate manufacturing.

### 6.3.1 PRODUCTION OF THE CURRENT DESIGN (COTTON PAPER BANK NOTE)

The results below are shown for the functional unit: 100 bank notes, over 2.5 manufacturing cycles.

**Table 6-4. Detailed impact for the manufacturing phase of the cotton paper bank notes (absolute values)**

| For 100 paper bank notes (2.5 manufacturing cycles) | Cotton fibers production | Paper manufacturing | Thread | Foil | Printing | TOTAL |
|---|---|---|---|---|---|---|
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | -2.20E-02 | 6.58E-01 | 1.78E-01 | 2.02E-01 | 5.75E-01 | 1.59E+00 |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 5.49E+00 | 6.40E+00 | 2.33E-01 | 8.32E-02 | 1.85E+00 | 1.41E+01 |
| Primary energy from resources (net cal. value) [MJ] | 4.35E+00 | 2.44E+01 | 4.08E+00 | 3.53E+00 | 1.31E+01 | 4.94E+01 |
| TRACI, Acidification Air [mol H+ Equiv.] | 1.66E-01 | 1.58E-01 | 4.36E-02 | 3.70E-02 | 1.01E-01 | 5.05E-01 |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 2.15E-03 | 9.18E-04 | 2.98E-05 | 3.78E-05 | 1.60E-04 | 3.30E-03 |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 9.46E-09 | 4.89E-07 | 5.13E-08 | 1.22E-08 | 1.23E-07 | 6.86E-07 |
| TRACI, Smog Air [kg NOx-Equiv.] | 1.42E-06 | 1.92E-06 | 3.98E-07 | 6.13E-07 | 1.07E-06 | 5.42E-06 |
| USETox2008, Ecotoxicity [PAF m3.day] | 2.31E-04 | 6.63E-04 | 1.08E-04 | 2.57E-04 | 1.05E-03 | 2.31E-03 |
| USETox2008, Human toxicity [cases] | 3.35E-12 | 7.66E-12 | 3.51E-12 | 1.33E-12 | 2.50E-11 | 4.08E-11 |

Note: the color coding indicates the lowest to highest impact phase for each indicator.

**Lowest** **Highest**

The environmental impacts are driven by different phases of manufacturing.

The cotton cultivation dominates the Eutrophication Potential because of the use of fertilizers (release of nitrogen and phosphorous into the soil and water). It also dominates the Primary Energy Demand from renewable resources because the cultivation requires renewable energy resources like solar energy.

The cotton paper manufacturing carries an important share of the impact for most of the indicators under study. It significantly impacts Global Warming Potential because, as shown in the next section, of the materials used and energy. The significant contribution to ozone depletion is due to the use of electricity for the manufacturing, as explained in the next section.

The foil and thread manufacturing do not drive the impact. However, their overall impact is not insignificant given the small quantities used on bank notes. This is due to the fact that the main materials are metals, and that the energy required for the manufacturing is significant on a per kilogram basis.

Finally, printing carries the highest impact for toxicity (USETox™), especially human toxicity. This is due to the manufacturing of solvents and inks, especially the varnishes used in intaglio ink. It plays a significant role on Global Warming Potential as well.

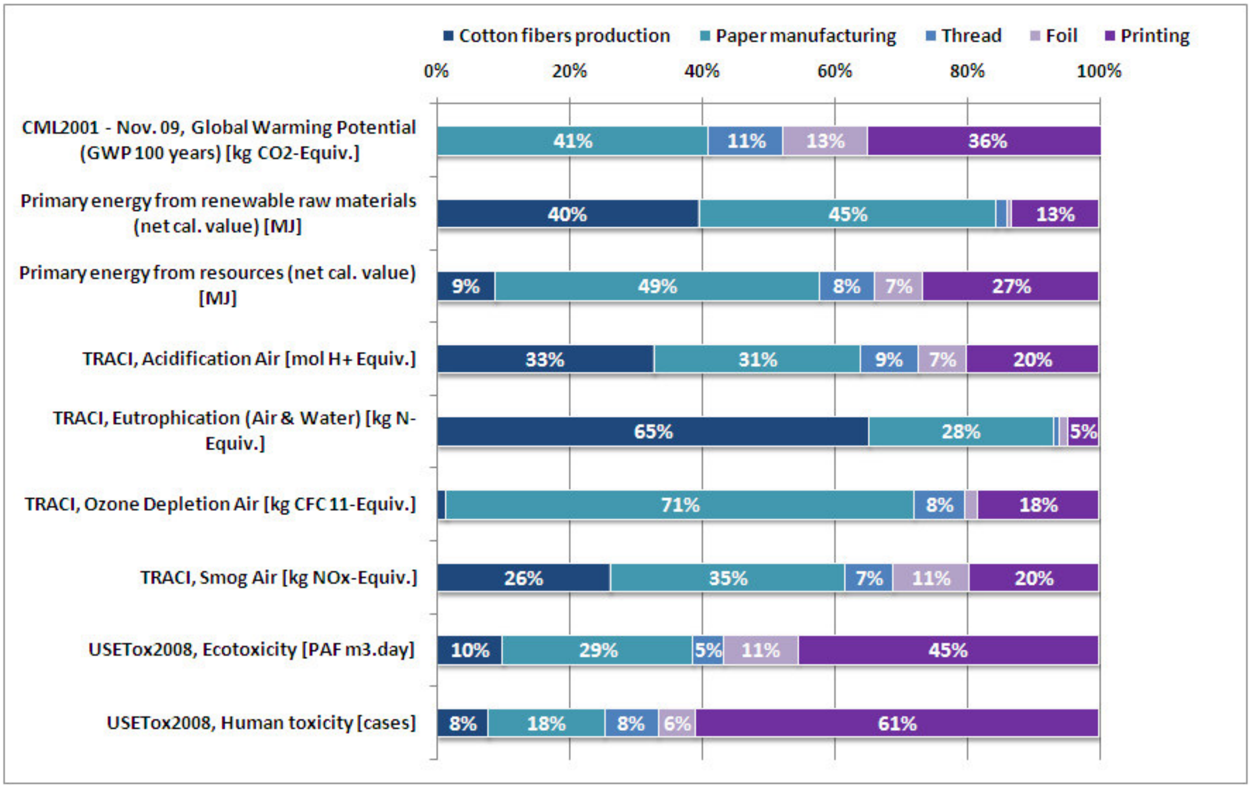


**Figure 6-3. Detailed impact for the manufacturing phase of the cotton paper bank notes (relative)**

#### 6.3.1.1 Cotton paper manufacturing

The table and graph below show the impact of the cotton paper manufacturing step (it does not include the cotton cultivation, the foil and the thread). It is only representative of the operations at the cotton paper manufacturer's facility. The raw materials are typically bleaching materials and glue. The energy is electricity and fuel oil. The plant operations' impacts are typically the emissions to air and water at the facility and the transport of materials include inbound and outbound transport, by containership and truck.

**Table 6-5. Cotton paper manufacturing (absolute values) – 100 bank notes, 2.5 manufacturing cycles**

| Cotton paper manufacturing (for 100 bank notes, 2.5 cycles) | Materials (other than cotton fibers) | Energy | Plant operations | Transport of materials | TOTAL |
|---|---|---|---|---|---|
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 3.96E-01 | 1.87E-01 | 2.02E-02 | 4.88E-02 | 6.52E-01 |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 9.45E-02 | 6.09E+00 | 0.00E+00 | 7.51E-04 | 6.19E+00 |
| Primary energy from resources (net cal. value) [MJ] | 6.50E+00 | 1.68E+01 | 0.00E+00 | 6.33E-01 | 2.40E+01 |
| TRACI, Acidification Air [mol H+ Equiv.] | 6.25E-02 | 2.64E-02 | 5.66E-04 | 6.79E-02 | 1.57E-01 |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 1.15E-04 | 2.51E-05 | 7.36E-04 | 4.01E-05 | 9.17E-04 |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 1.36E-08 | 4.60E-07 | 0.00E+00 | 8.46E-11 | 4.74E-07 |
| TRACI, Smog Air [kg NOx-Equiv.] | 6.71E-07 | 3.26E-07 | 1.41E-08 | 9.01E-07 | 1.91E-06 |
| USETox2008, Ecotoxicity [PAF m3.day] | 2.98E-04 | 2.48E-04 | 1.11E-06 | 1.16E-04 | 6.63E-04 |
| USETox2008, Human toxicity [cases] | 4.15E-12 | 2.96E-12 | 1.61E-60 | 4.06E-14 | 7.15E-12 |

Note: the color coding indicates the lowest to highest impact phase for each indicator.

**Lowest** **Highest**

For Global Warming Potential and toxicity, most of the impact comes from the materials, especially the glues. For Ozone Depletion, the energy carries the highest contribution because of power being the largest source of energy for the plant; the nuclear portion of the grid mix is the source of impact in this case.

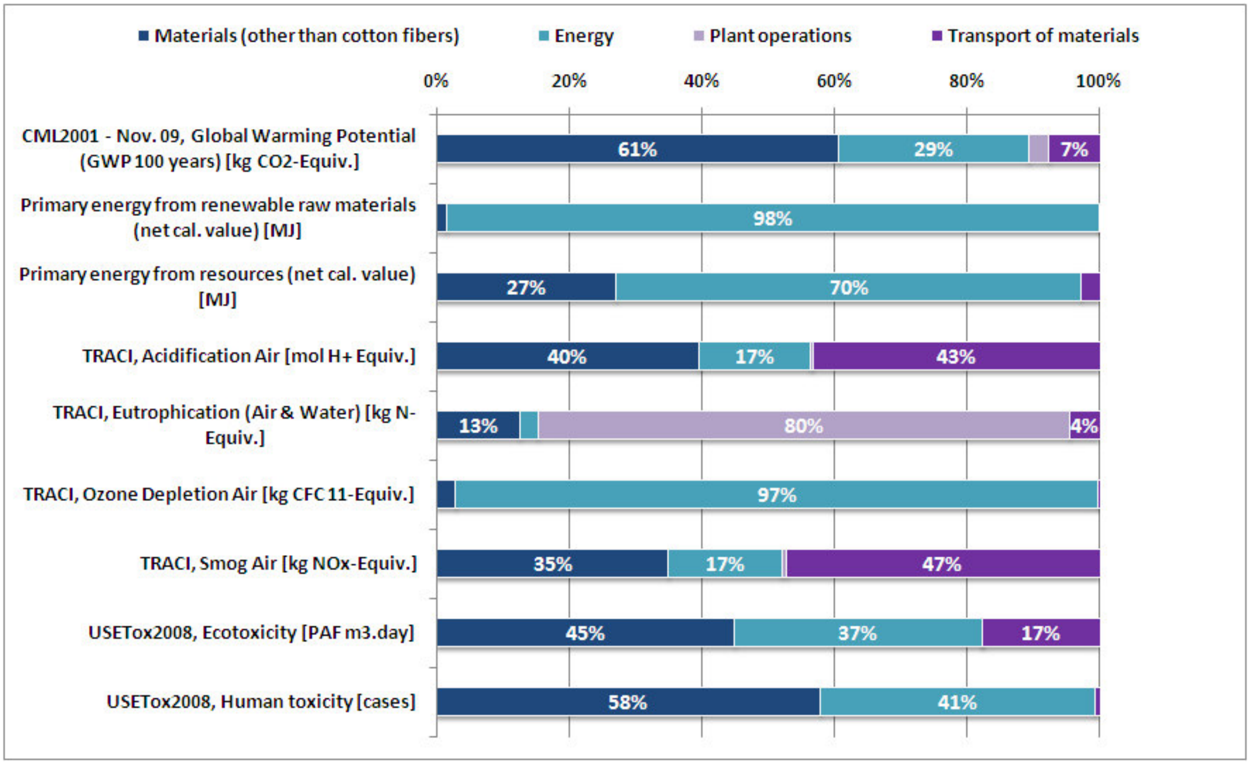


**Figure 6-4. Cotton paper manufacturing (relative) – 100 bank notes, 2.5 manufacturing cycles**

### 6.3.1.2 Thread manufacturing

The results for thread are displayed for the relative values only. The absolute contribution of thread is given specifically for each design in section 6.3.1. This graph is aggregated for the thread production and conversion steps.

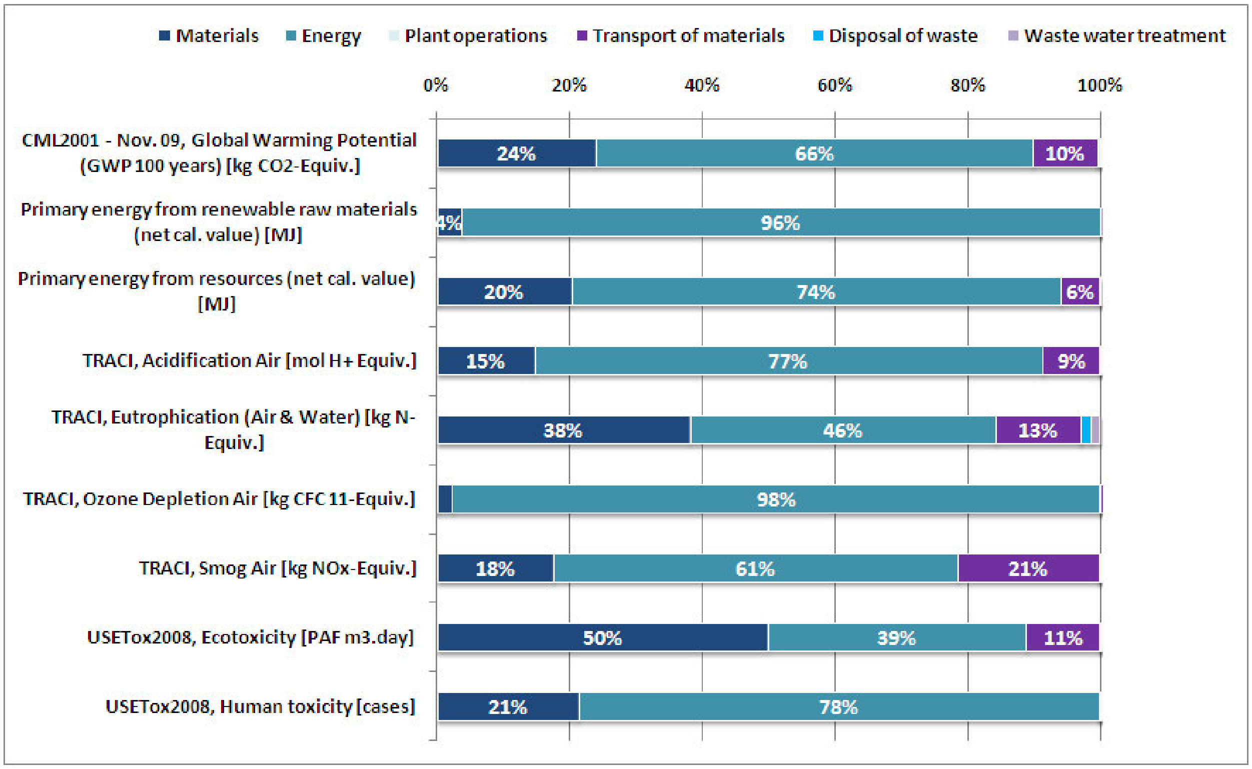


**Figure 6-5. Thread manufacturing for the cotton paper bank note (relative)**

The impact for thread manufacturing is mostly driven by energy use. The thread manufacturing is a very energy intensive process, which involves vaporizing the raw materials (notably silica blocks) to deposit onto a metal alloy. The contribution to Ecotoxicity from the raw materials is due to the use of glues and de-metalized carrier rolls.

#### 6.3.1.3 Foil manufacturing

The results for foil are displayed for the relative values only since it is applicable to both cotton paper substrate and polymer substrate. The absolute contribution of foil is given specifically for each design in section 6.3.1.

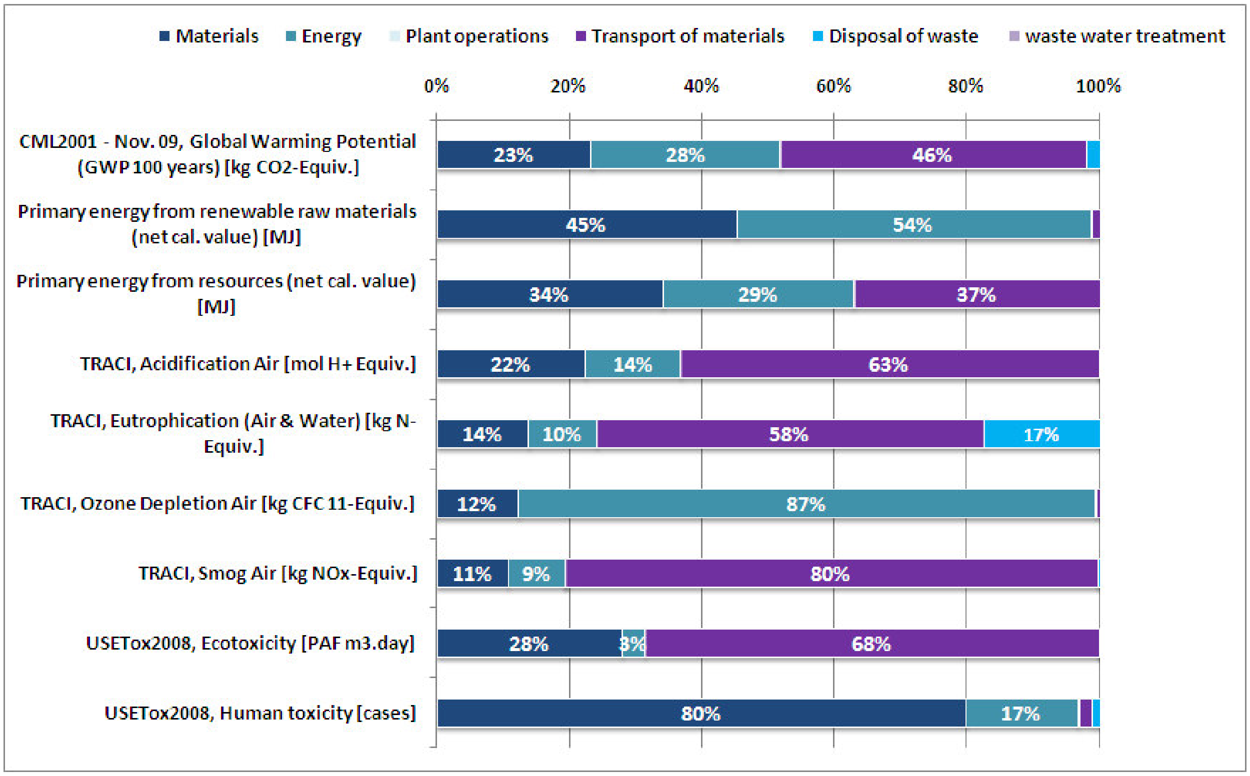


**Figure 6-6. Foil manufacturing for the cotton paper bank note (relative)**

The transport of materials contributes significantly to the overall foil environmental impacts. This is due to transport by plane between continents.

The impact on human toxicity coming from the raw materials is mainly due to the use of acrylates.

### 6.3.1.4 Printing

The table and graph below show the results for the cotton paper printing process. The inks are specific to the cotton paper substrate, the set-up substrate used for testing is paper, and bindery refers to the packaging materials. The solvent reflects the exact solvent mixture used in the printing process, as well as the wiping solution and ink preparation materials. Those are not detailed more specifically for confidentiality reasons.

**Table 6-6. Cotton substrate printing (absolute values) – 100 bank notes, 2.5 manufacturing cycles**

| Printing of 100 bank notes, 2.5 manufacturing cycles | Inks | Pre-press materials | Energy | Ink preparation and wiping solution | Solvents | Set-up substrate | Bindery | Waste disposal | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 6.99E-02 | 1.92E-03 | 4.59E-01 | 1.08E-02 | 6.74E-03 | -1.94E-02 | 1.16E-02 | 3.49E-02 | 5.75E-01 |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 7.94E-02 | 2.39E-03 | 6.65E-01 | 1.45E-02 | 1.36E-04 | 1.01E+00 | 1.15E-01 | -2.92E-02 | 1.85E+00 |
| Primary energy from resources (net cal. value) [MJ] | 1.48E+00 | 2.67E-02 | 1.02E+01 | 2.05E-01 | 6.57E-02 | 4.99E-01 | 4.44E-01 | 1.10E-01 | 1.31E+01 |
| TRACI, Acidification Air [mol H+ Equiv.] | 1.53E-02 | 4.57E-04 | 6.70E-02 | 5.09E-03 | 2.09E-04 | 7.41E-03 | 3.45E-03 | 2.36E-03 | 1.01E-01 |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 2.05E-05 | -3.04E-07 | 3.42E-05 | 4.45E-05 | 1.93E-07 | 5.21E-05 | 7.13E-06 | 1.42E-06 | 1.60E-04 |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 5.27E-09 | 8.77E-11 | 1.12E-07 | 3.35E-10 | 1.65E-11 | 4.17E-09 | 1.05E-09 | 4.65E-11 | 1.23E-07 |
| TRACI, Smog Air [kg NOx-Equiv.] | 2.40E-07 | 3.27E-09 | 6.28E-07 | 3.02E-08 | 2.23E-09 | 9.97E-08 | 3.30E-08 | 3.26E-08 | 1.07E-06 |
| USETox2008, Ecotoxicity [PAF m3.day] | 6.59E-04 | 1.95E-04 | 9.82E-05 | 3.57E-05 | 2.63E-06 | 2.32E-05 | 3.16E-05 | 4.19E-06 | 1.05E-03 |
| USETox2008, Human toxicity [cases] | 1.09E-11 | 3.89E-14 | 1.26E-11 | 5.94E-13 | 9.83E-15 | 2.90E-13 | 2.23E-13 | 1.62E-13 | 2.48E-11 |

Note: the color coding indicates the lowest to highest impact phase for each indicator.

**Lowest** **Highest**

The energy use (electricity and thermal energy) drives the environmental profile for most indicators under study. The equipment requires electricity, but the most significant contribution is thermal energy necessary to heat the facility in Canada. Electricity use dominates Ozone Depletion, and this is due to the large portion of nuclear power in the Ontario grid mix (almost 50%).

Inks dominate USETox™ (toxicity) because of the varnishes in the intaglio ink.

The set-up substrate contributes to Primary Energy Demand from renewable materials to eutrophication because it is paper (made out of a renewable resource).

The ink preparation and wiping solution have overall a low impact, except for eutrophication (water pollution), since emissions to water occur at this step (nitrogen, phosphorous, BOD, etc.).

The pre-press materials have a negligible impact for all indicators under study, except for Ecotoxicity. A detailed analysis shows that the impact comes from the chablons (intaglio dry plates) and the lithography dry offset plates.

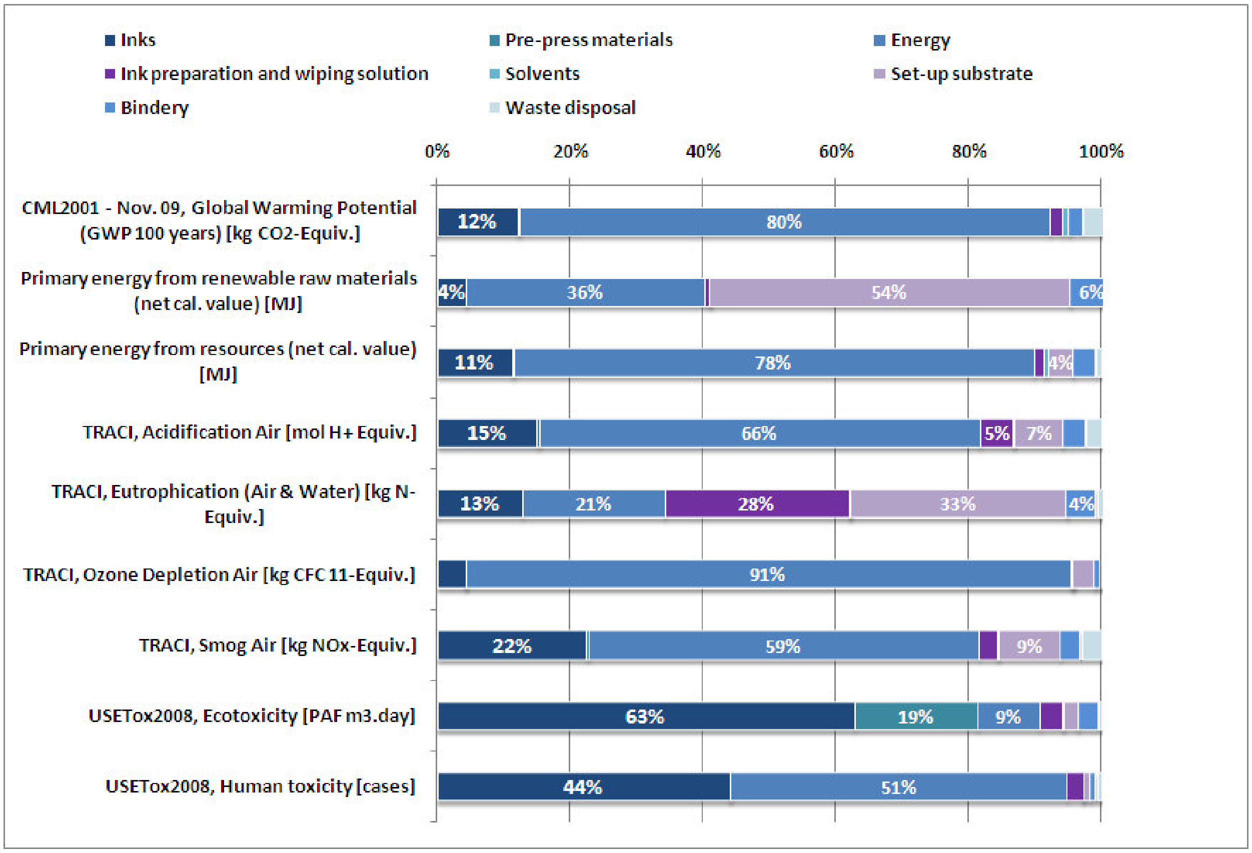


**Figure 6-7. Cotton substrate printing (relative) – 100 bank notes, 2.5 manufacturing cycles**

### 6.3.2 PRODUCTION OF THE NEW DESIGN (POLYMER BANK NOTE)

The results below are shown for the functional unit under study.

#### 6.3.2.1 Polymer substrate manufacturing

The table and graph below show the results for the polymer manufacturing.

**Table 6-7. Polymer substrate bank notes manufacturing (absolute values) – 100 bank notes, 1 manufacturing cycle**

| For 100 paper bank notes (1 manufacturing cycle) | BOPP film production | Polymer substrate conversion | Foil | Printing | TOTAL |
|---|---|---|---|---|---|
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 7.09E-01 | 4.66E-01 | 1.18E-01 | 2.79E-01 | 1.57E+00 |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 2.16E-01 | 2.12E-01 | 4.85E-02 | 3.47E-01 | 8.23E-01 |
| Primary energy from resources (net cal. value) [MJ] | 1.23E+01 | 6.11E+00 | 2.06E+00 | 6.29E+00 | 2.68E+01 |
| TRACI, Acidification Air [mol H+ Equiv.] | 1.42E-01 | 9.89E-02 | 2.16E-02 | 4.56E-02 | 3.08E-01 |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 6.85E-05 | 4.34E-05 | 2.20E-05 | 4.73E-05 | 1.81E-04 |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 7.64E-10 | 9.16E-09 | 7.11E-09 | 4.92E-08 | 6.62E-08 |
| TRACI, Smog Air [kg NOx-Equiv.] | 1.24E-06 | 7.50E-07 | 3.57E-07 | 4.65E-07 | 2.82E-06 |
| USETox2008, Ecotoxicity [PAF m3.day] | 1.10E-03 | 2.43E-04 | 1.50E-04 | 5.04E-04 | 2.00E-03 |
| USETox2008, Human toxicity [cases] | 1.20E-11 | 6.27E-12 | 1.33E-12 | 9.73E-12 | 2.93E-11 |

Note: the color coding indicates the lowest to highest impact phase for each indicator.

**Lowest** **Highest**

The BOPP film production dominates the environmental profile for most indicators under study. However Ozone Depletion is dominated by printing and this is due to the use of electricity from nuclear power (approximately 50% of the Ontario grid mix)[23].

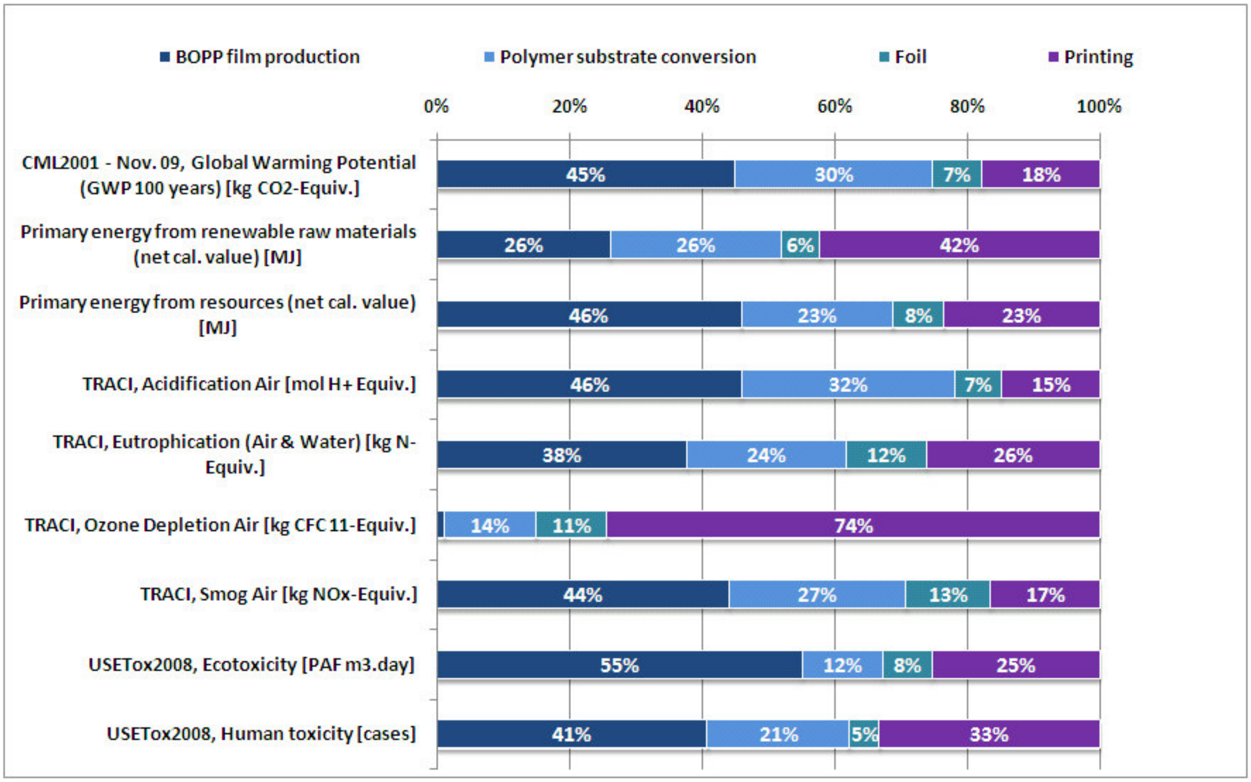


**Figure 6-8. Polymer substrate bank notes manufacturing (relative) – 100 bank notes, 1 manufacturing cycle**

### 6.3.2.2 Foil manufacturing

The foil usage is different for the two types of bank notes, so the absolute contribution is different and shown in section 6.3.2.1. However, since the underlying data are the same, the environmental profile for foil manufacturing (in percentage) is the same as for the current design. See section 6.3.1.3.

### 6.3.2.3 Printing

The printing process has been considered to be similar to the cotton paper bank notes. The main differences are the types of ink used, and a specific protective vanish for the polymer. The set-up substrate is different as well, being BOPP instead of paper.

---

[23] Nuclear power production is a source of dichlorotetrafluoroethane, which contributes significantly to Ozone Depletion

**Table 6-8. Polymer substrate printing (absolute values) – 100 bank notes, 1 manufacturing cycle**

| Printing of 100 bank notes, 1 manufacturing cycle | Inks | Pre-press materials | Energy | Ink preparation and wiping solution | Solvents | Set-up substrate | Bindery | Waste disposal | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 3.49E-02 | 7.67E-04 | 1.84E-01 | 4.32E-03 | 2.69E-03 | 3.50E-02 | 4.22E-03 | 1.40E-02 | 2.79E-01 |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 3.59E-02 | 9.54E-04 | 2.66E-01 | 5.80E-03 | 5.44E-05 | 7.93E-03 | 4.21E-02 | -1.17E-02 | 3.47E-01 |
| Primary energy from resources (net cal. value) [MJ] | 6.72E-01 | 1.07E-02 | 4.09E+00 | 8.18E-02 | 2.63E-02 | 1.20E+00 | 1.62E-01 | 4.40E-02 | 6.29E+00 |
| TRACI, Acidification Air [mol H+ Equiv.] | 7.90E-03 | 1.83E-04 | 2.68E-02 | 2.03E-03 | 8.38E-05 | 6.41E-03 | 1.26E-03 | 9.46E-04 | 4.56E-02 |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 9.02E-06 | -1.22E-07 | 1.37E-05 | 1.78E-05 | 7.74E-08 | 3.65E-06 | 2.60E-06 | 5.69E-07 | 4.73E-05 |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 2.58E-09 | 3.51E-11 | 4.49E-08 | 1.34E-10 | 6.61E-12 | 1.10E-09 | 3.82E-10 | 1.86E-11 | 4.92E-08 |
| TRACI, Smog Air [kg NOx-Equiv.] | 1.15E-07 | 1.31E-09 | 2.51E-07 | 1.21E-08 | 8.94E-10 | 5.93E-08 | 1.20E-08 | 1.30E-08 | 4.65E-07 |
| USETox2008, Ecotoxicity [PAF m3.day] | 2.54E-04 | 7.81E-05 | 3.93E-05 | 1.43E-05 | 1.05E-06 | 1.04E-04 | 1.15E-05 | 1.68E-06 | 5.04E-04 |
| USETox2008, Human toxicity [cases] | 3.81E-12 | 1.56E-14 | 5.03E-12 | 2.38E-13 | 3.93E-15 | 4.80E-13 | 8.13E-14 | 6.50E-14 | 9.73E-12 |

Note: the color coding indicates the lowest to highest impact phase for each indicator.

**Lowest** **Highest**

The results are similar to cotton paper printing, see section 6.3.1.4. However some differences are listed below:

The set-up substrate (polymer instead of paper) impacts very different environmental categories. It appears in Global Warming Potential (where it contributes for more than 10%), whereas the paper set-up substrate was “up-taking $CO_2$”. It has a very small contribution to Primary Energy Demand from renewable resources, and it contributes to toxicity indicators, which was not the case for paper.

The second difference is the ink types and usage. The amounts of inks are similar for both substrates, except that the polymer substrate printing uses more varnish.

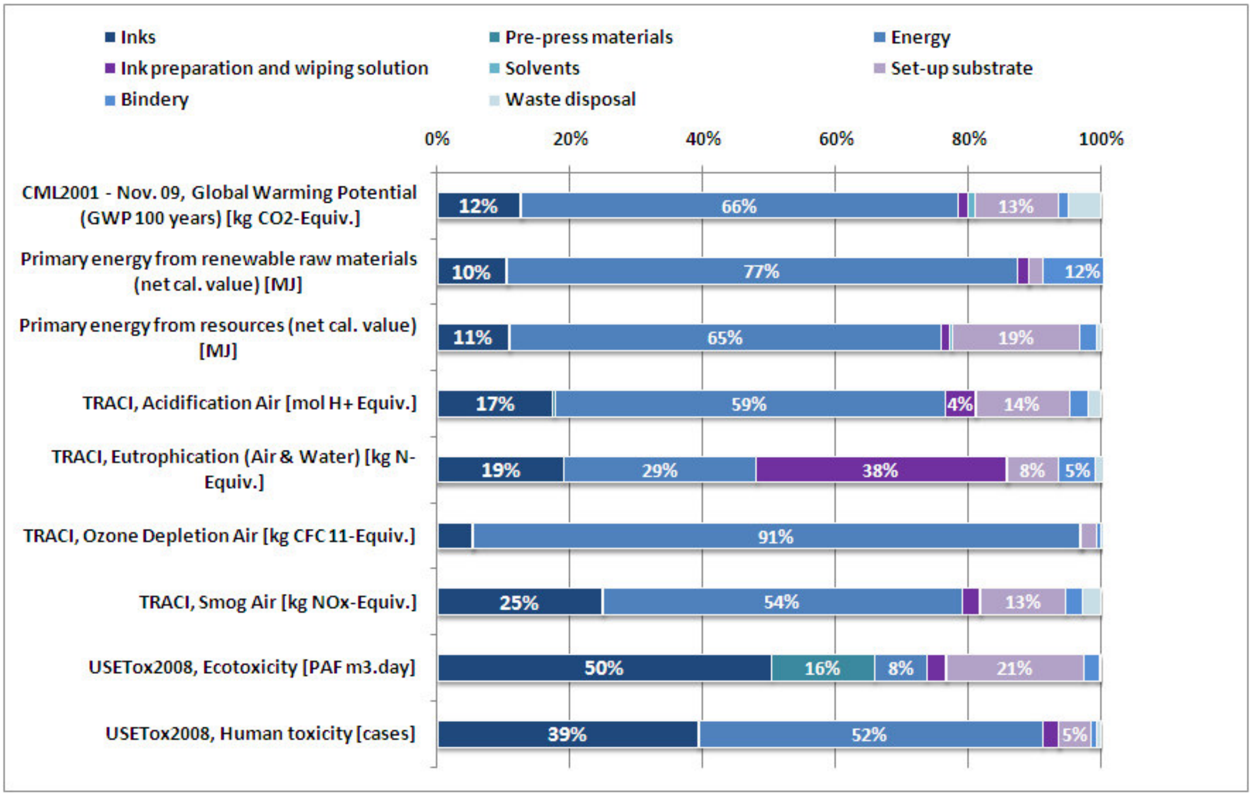


**Figure 6-9. Polymer substrate printing (relative) – 100 bank notes, 1 manufacturing cycle**

# 7 INTERPRETATION

This section shows the sensitivity analyses carried out and the overall conclusions of the study.

## 7.1 SENSITIVITY ANALYSIS

Analyses have been carried out to understand the influence of the lifetime of the new design bank note.

Furthermore, a sensitivity analysis has been carried out on printing energy use since there is some uncertainty around the difference in energy use during the printing process for the polymer bank note and the cotton paper bank note.

### 7.1.1 INFLUENCE OF LIFETIME OF NEW BANK NOTES ON MANUFACTURING, DISTRIBUTION AND END OF LIFE

The lifetime of the new polymer bank notes has been documented in other countries, where those bank notes have been in use for years. Because the lifetime can differ from one country to another (e.g. different environmental, behavioral, weather conditions), a sensitivity analysis has been carried out on the influence of the lifetime of the new bank note on the comparison.

For this analysis, the use phase has been ignored. Only the manufacturing, distribution and end of life (landfill) have been accounted for. The graph below shows the relative impacts of the current design, which has a known lifetime of 3 years, and the new design for several lifetime scenarios.

Summary of scenarios in graph:

- Base scenario (100%) – Current design: 3-year lifetime
- New design: 3-year lifetime
- New design: 4-year lifetime
- New design: 5-year lifetime
- New design: 6-year lifetime
- New design: 7-year lifetime
- New design: 8-year lifetime
- New design: 9-year lifetime
- New design: 10-year lifetime

**Table 7-1. Sensitivity analysis on the lifetime of the new design – Manufacturing + Distribution + End of life only (not use)**

| Lifetime | Current design (3 years) | New design (3 years) | New design (4 years) | New design (5 years) | New design (6 years) | New design (7 years) | New design (8 years) | New design (9 years) | New design (10 years) |
|---|---|---|---|---|---|---|---|---|---|
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 100% | 107% | 81% | 64% | 54% | 46% | 40% | 35% | 32% |
| Primary energy from renewable raw materials (net cal. value) [MJ] | 100% | 92% | 69% | 55% | 46% | 39% | 34% | 30% | 28% |
| Primary energy from resources (net cal. value) [MJ] | 100% | 102% | 76% | 61% | 51% | 44% | 38% | 34% | 31% |
| TRACI, Acidification Air [mol H+ Equiv.] | 100% | 102% | 77% | 61% | 51% | 44% | 38% | 34% | 31% |
| TRACI, Eutrophication (Air & Water) [kg N-Equiv.] | 100% | 53% | 40% | 32% | 26% | 23% | 20% | 17% | 16% |
| TRACI, Ozone Depletion Air [kg CFC 11-Equiv.] | 100% | 93% | 70% | 56% | 46% | 40% | 35% | 31% | 28% |
| TRACI, Smog Air [kg NOx-Equiv.] | 100% | 97% | 73% | 58% | 49% | 42% | 37% | 32% | 29% |
| USETox2008, Ecotoxicity [PAF m3.day] | 100% | 119% | 89% | 72% | 60% | 51% | 45% | 39% | 36% |
| USETox2008, Human toxicity [cases] | 100% | 111% | 83% | 67% | 55% | 48% | 42% | 37% | 33% |

Note: the color coding indicates the lowest to highest impact phase for each indicator.

**Lowest** **Highest**

🟩🟩🟩🟩🟨🟨🟧🟧🟧🟥🟥

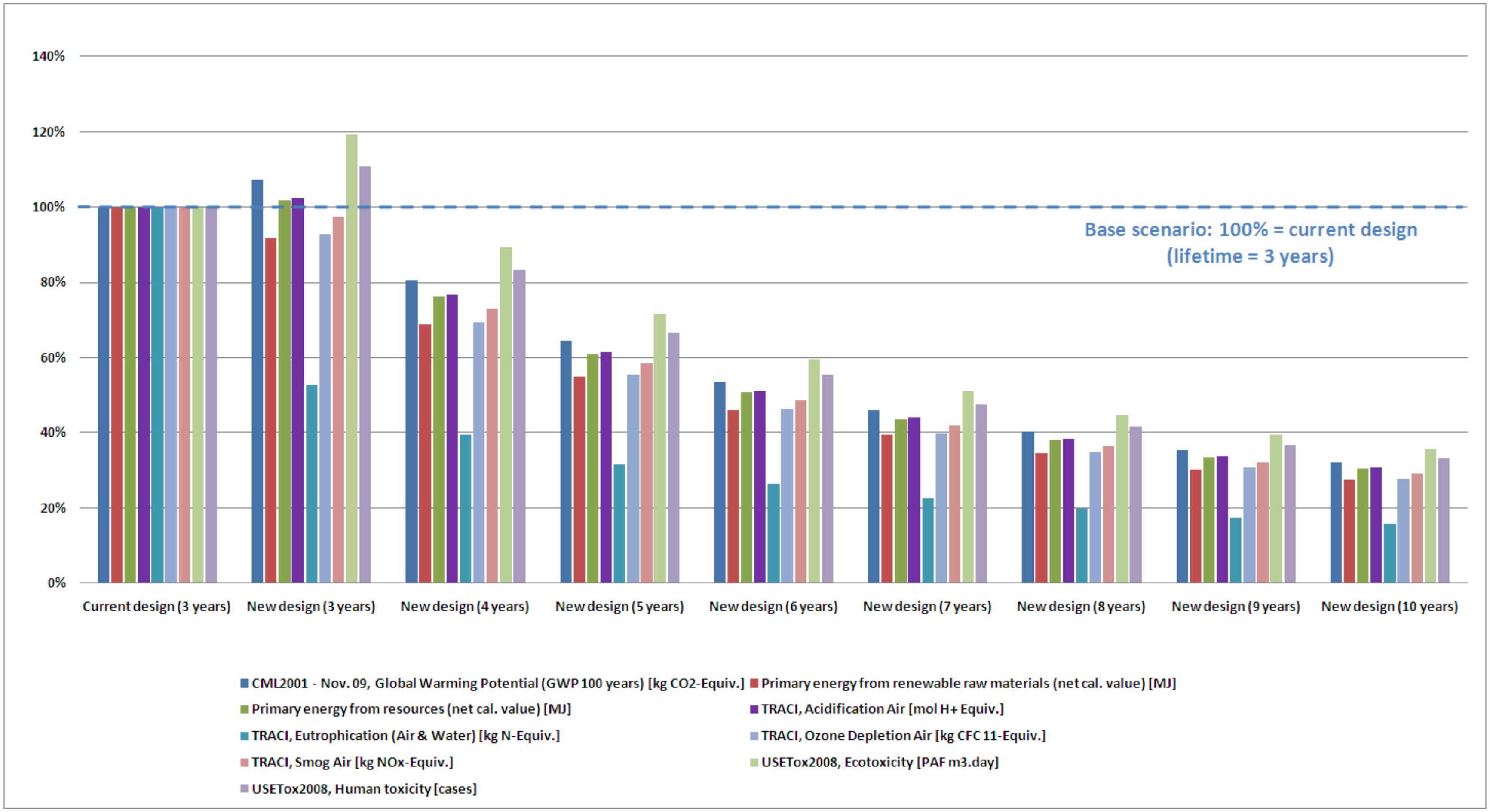


**Figure 7-1. Sensitivity analysis on the life time of the new design – Manufacturing + Distribution + End of life only (not use)**

The graphs and tables show that the "break-even" point, when the polymer substrate shows benefit for all environmental indicators under study is around 4 years of lifetime.

The polymer bank note would have a higher impact on the environment for some indicators, if it had the same lifetime as the cotton paper one. However, because of its extended lifetime, it shows environmental benefits in the long run.

### 7.1.2 INFLUENCE OF A NON-LINEAR APPROACH FOR FACTOR INCREASE

The concern has been raised that a "linear approach" to this problem may misrepresent reality (it is not physically possible to produce 2.5 bank notes). Therefore, this scenario analysis undertakes the following assumptions:

**Table 7-2. Assumptions for non-linear model**

| | **Bank note type** | **Years of operations** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 year | 2 years | 3 years | 4 years | 5 years | 6 years | 7 years |
| **Number of cycles** | Cotton paper bank note | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| | Polymer bank note | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

This means that the 1st year, the polymer and cotton paper bank notes are manufactured, then the cotton paper bank notes have to be manufactured again after 3 years of operation, whereas the polymer bank notes do not need to be manufactured again, etc.

Consequently, after 7.5 years, there have been 3 cycles for the cotton paper bank note, and only one for the polymer bank note in this approach.

The graph below shows the results for the 3 cycles (non-linear approach) for the current design, the 2.5 cycles (base scenario in the report) for the current design and 1 cycle (base scenario in the report) for the new design.

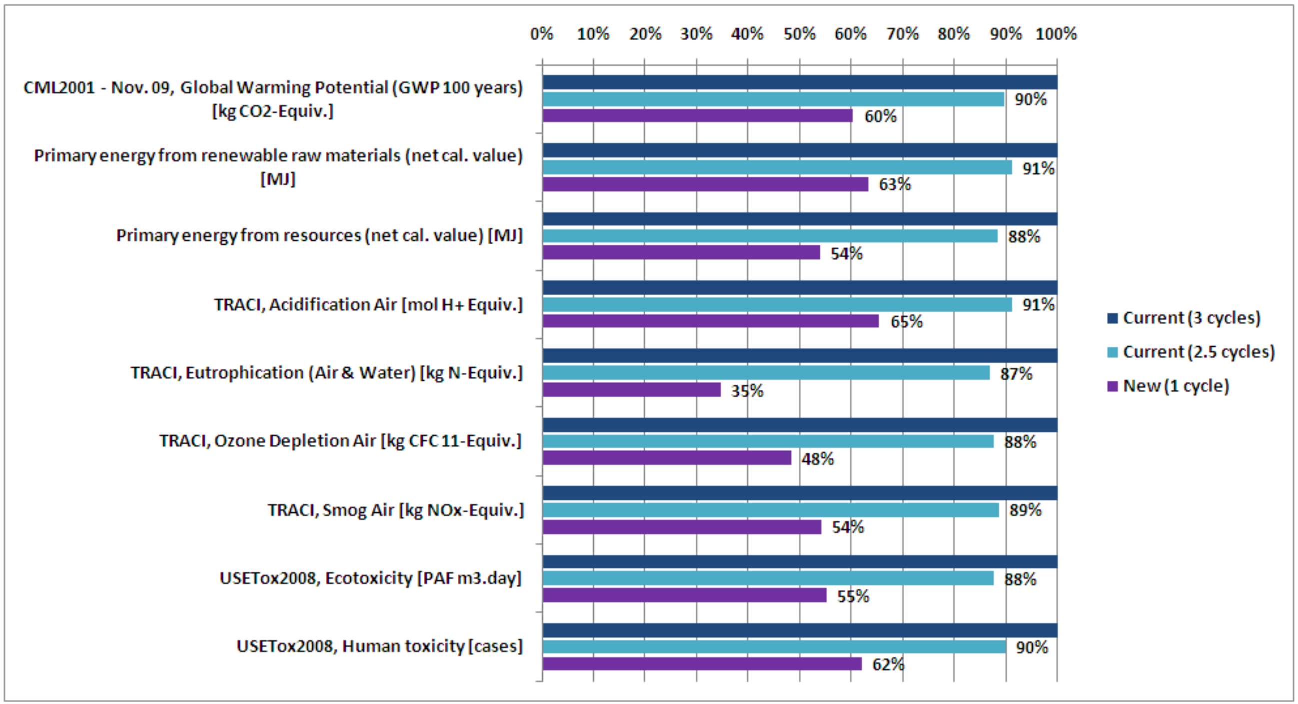


**Figure 7-2. Results for non-linear approach**

Because the non-linear approach increases the numbers of manufacturing/distribution/end-of-life cycles from 2.5 to 3, it actually increases the gap between the two substrates over the 7.5 years of operation.

### 7.1.3 POLYMER ENERGY COEFFICIENT FOR PRINTING

Since the polymer bank notes printing was still in trials at the time of this study, there is some uncertainty around the difference in energy use during the printing process for the polymer bank note and the cotton paper bank note, therefore a sensitivity analysis has been carried out. The base scenario of this analysis is that there is no difference between the energy use for printing between the two substrates. Additional scenarios have been calculated for a range of 0% to 50% more energy needed for the printing of the polymer bank note.

The scenarios take into account the differences in lifetime for the two designs, and therefore the fact that the cotton paper substrate is going through 2.5 manufacturing cycles. The base scenario is the current design (cotton paper substrate), printing phase only (figure 7-3), and entire life cycle (figure 7-4).

The graphs below show that this difference in energy usage influences the impact of printing on the polymer substrate. However, it does not inverse the trend regarding the benefits of polymer substrate versus cotton paper. The impact on the overall life cycle has been studied as well, and the results show that it does not influence at all the high level results.

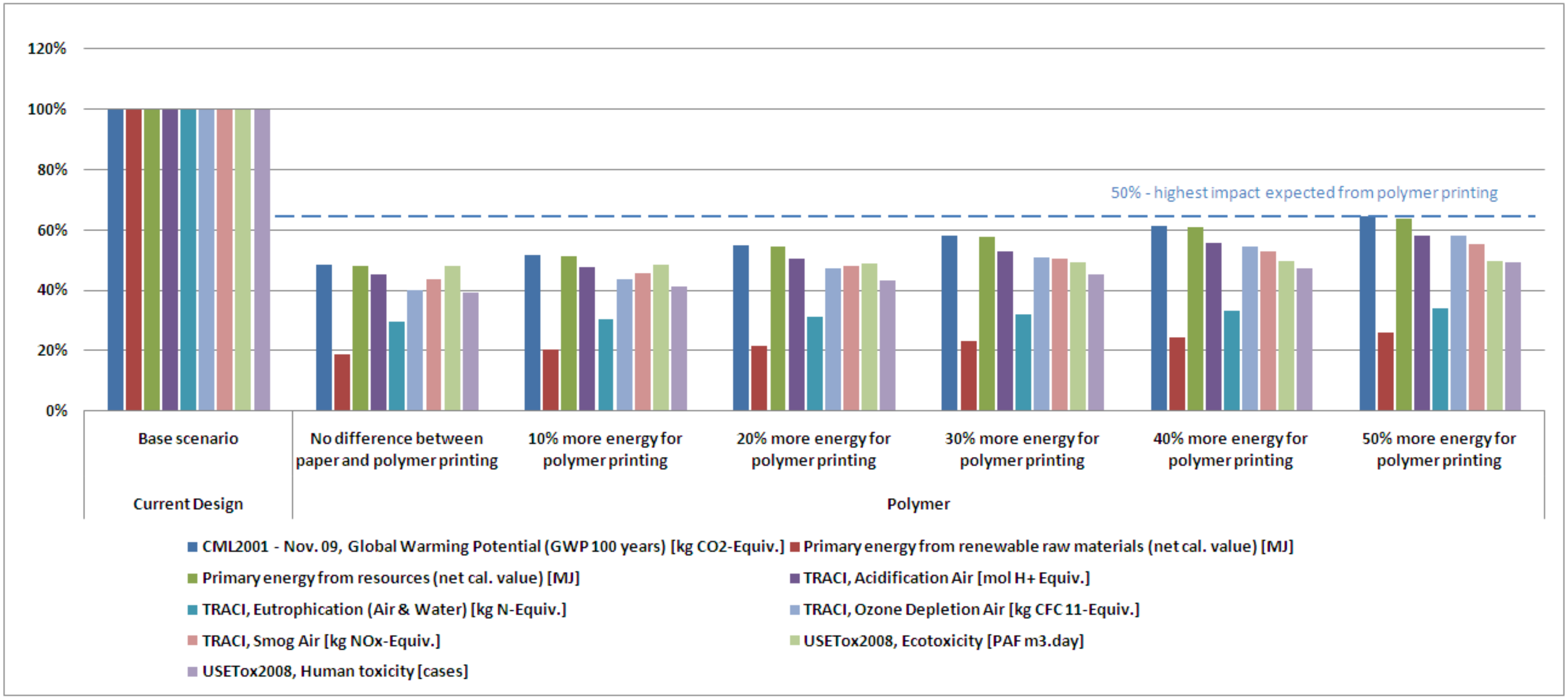


**Figure 7-3. Sensitivity analysis of the energy usage at the printing phase - printing phase ONLY**

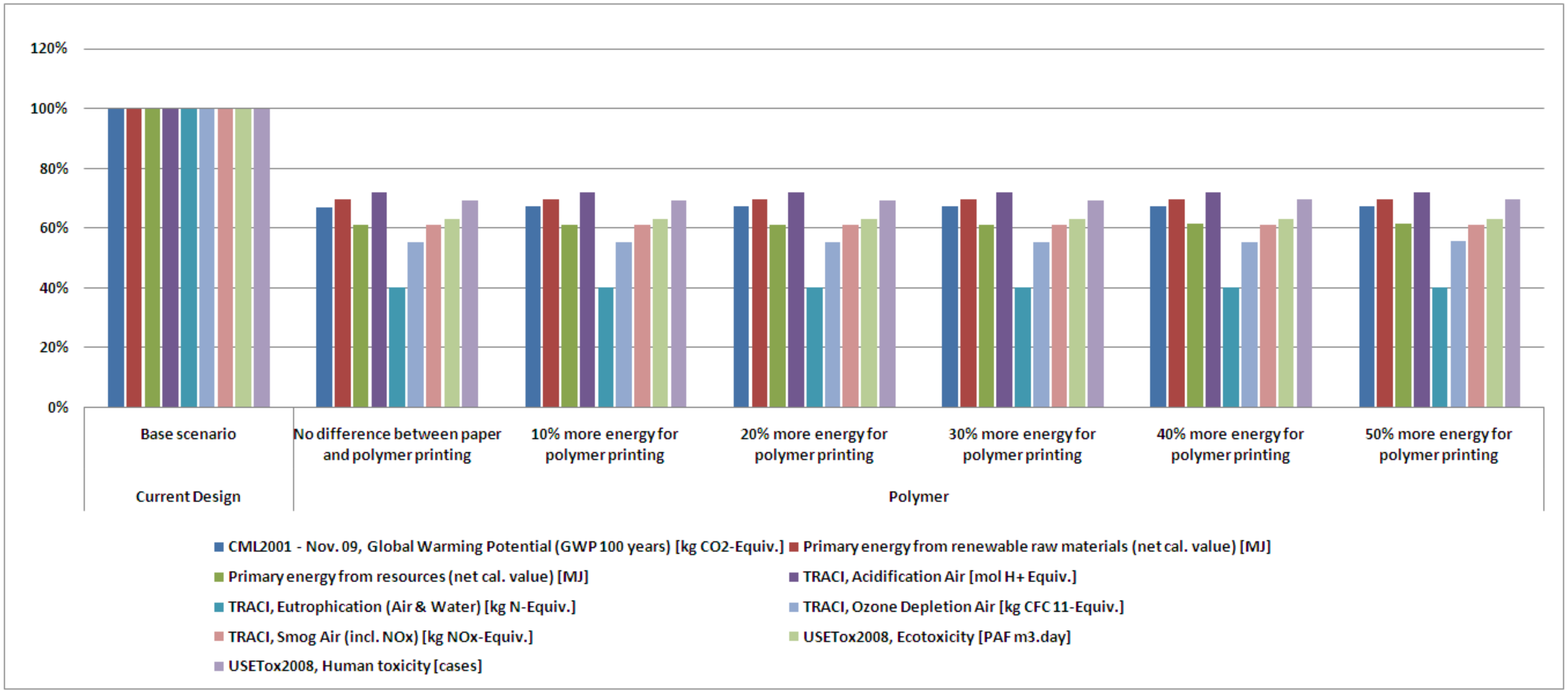


**Figure 7-4. Sensitivity analysis of the energy usage at the printing phase – Overall life cycle**

## 7.2 CONCLUSIONS AND LIMITATIONS

### 7.2.1 CONCLUSIONS

According to the assumptions in this report, the new design (based on a polymer substrate) shows benefits over the current design (based on a cotton paper substrate) because of:

1. Manufacturing: an increased lifetime compared to the cotton paper bank note contributes to a lower overall impact; even if the manufacturing of one polymer bank note has a higher environmental impact, the fact that it lasts longer offsets this effect

2. Distribution: the polymer bank note has to be transported 2.5 less times than the cotton paper bank notes. Because of its extended lifetime, it requires less transport of fresh notes to the system, and fewer unfit bank notes sent back to the banking system. Additionally, the weight of the polymer bank note is lighter; because shipments are limited by value and not weight, a lighter weight shows environmental benefit over time

3. End-of-life: the polymer is mostly made of inactive carbon, which in contrary to cotton paper, does not contribute to GHG emissions in landfill.

The results of the sensitivity analysis also show that the gap between the new design and the current design increases with the lifetime of the polymer bank note. The longer the polymer bank note is in circulation, the greater the advantage of polymer compared to the cotton paper bank note.

An interesting insight is that most of the impacts over the life cycle come from the distribution and use phase. Consequently, even if the manufacturing and design are important, improving the supply chain and ATMs energy usage would have the most significant benefit in reducing the environmental impact of bank notes.

### 7.2.2 LIMITATIONS

Most of the data have been collected from the suppliers and are considered to be of high quality, but the model contains a few assumptions, which could be refined in future studies. For instance, some assumptions have been made about ATMs (see section 4.4). Since the impact of ATMs is significant, the analysis could be refined, but would still be the same for both types of bank notes. Furthermore this study did not collect information on if ATM machines consume less energy per unit of polymer vs. cotton paper bank notes. This would be an interesting point to investigate for future projects.

In addition, all the designs and supply chain data represent the Canadian bank notes specific situation. The conclusions and recommendations are directed to the Bank of Canada. The environmental profile of the bank notes and the conclusions may differ in another country.

# 8 DUE DILIGENCE EVALUATION

This section is beyond the scope of the Life Cycle Assessment study (as defined by ISO 14040) and as such is not subject to review by the LCA Critical Review Panel.

The due diligence report is based on a review of:

1. the primary data provided by suppliers and database data available and contained within the LCA

2. environmental and product safety legislation in Canada.

Where components are identified by Canadian legislation as substances of concern, a summary evaluation is provided. The main focus concerns substances contained within the finished bank note.

The purpose of this due diligence evaluation is to provide information where materials of potential concern are identified, and does not represent either a legal, toxicological or detailed risk assessment, nor does it represent a due diligence audit. The evaluation may, in certain circumstances, identify areas for further investigation at some future point.

No samples were obtained or analyzed by PE Americas or Tryskele during the project.

The full due diligence evaluation is contained in a separate report.

# APPENDIX A. POLYMER VS. PAPER BANK NOTES LIFETIMES IN OTHER COUNTRIES

Central banks are responsible for tracking the performance of bank notes within their country. All of the data in this appendix were collected by the respective central banks and are publically available.

Each country has a unique circulation environment that contributes to bank note lifetimes. Influences on bank note lifetimes include weather, cultural habits, and distribution patterns within that country. In addition, central banks define the "fit-for-use" criteria depending on their specific circulation environment. The bank notes are assessed for criteria such as soiling, tears and ink wear. Each denomination within one country will have a different circulation lifetime; the highest denominations last considerably longer than the lowest denominations.

As there are a multitude of influential factors, it is very difficult to compare bank note lifetime results in different countries. However, it is important to give some context to the lifetimes assumed in this report.

The table below displays the lifetime of paper vs. polymer bank notes in countries where the polymer bank notes have been implemented. This table shows a wide range of countries, denominations, bank note designs and circulation environments. The paper bank note data were drawn prior to polymer introduction in that country.

**Table A-1. Ratio of polymer vs. paper bank notes lifetimes in countries currently using polymer bank notes**[24]

| | **Australia**<br>**$10**[25] | **New Zealand**<br>**$20**[26] | **Mexico**<br>**20 Peso**[27] | **Papua New Guinea**<br>**2 Kina**[28] |
|---|---|---|---|---|
| **Factor increase** (ratio polymer lifetime/paper lifetime) | 3.8 | 4.9 | 3.5 | 4.8 |

New Zealand converted from paper to polymer notes in 1999. The table below gives data for all paper and polymer denominations in their circulation environment. The $20 denomination is the ATM denomination, similar to the Canadian environment. The lifetime factor increase was calculated using the change in bank note destruction rates relative to the total volume of notes in circulation for paper and polymer.

---

[24] Source: data collected by the respective Central Banks

[25] http://www.noteprinting.com/banknotes_durability.html

[26] http://www.rbnz.govt.nz/research/bulletin/2007_2011/Mar10_73_1Langwasser.pdf

[27] http://www.banxico.org.mx/billetes-y-monedas/informacion-general/fabricacion-de-billetes-y-acunacion-de-moneda/material-educativo/%7BEC6DF766-7FF3-AAAF-FE2E-12D5D7831EFB%7D.pdf

[28] http://www.noteprinting.com/banknotes_durability.html

Table A-2. Ratio of polymer vs. paper bank notes lifetimes in New Zealand for all denominations

| Denomination | $5 | $10 | $20 | $50 | $100 |
|---|---|---|---|---|---|
| **Factor increase** (ratio polymer lifetime/paper lifetime) | 4.7 | 4.5 | 4.9 | 5.5 | 7.3 |

In New Zealand, the lifetime factor increase ranged from 4.5 to 7.3, depending on the denomination, when they switched from paper to polymer bank notes. Consequently, the Bank of Canada's assumption of 2.5 as a lifetime factor increase is conservative.

The Bank of Canada paper bank notes have lifetimes given by the data in the table below (as published on the Bank of Canada website[29]).

Table A-3. Paper bank notes lifetimes in Canada for all denominations

| Denomination | $5 | $10 | $20 | $50 | $100 |
|---|---|---|---|---|---|
| **Paper note lifetime (months)** | 12-24 | 12-24 | 24-48 | 48-72 | 72-108 |

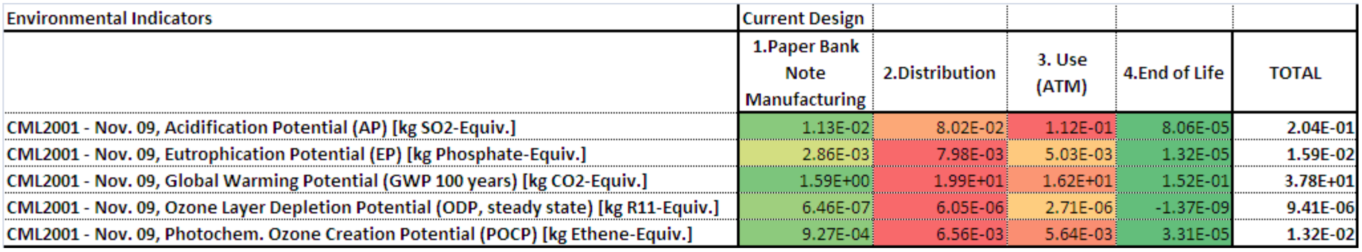
---

[29] http://www.bankofcanada.ca/en/banknotes/facts.html

# APPENDIX B. IMPACT ASSESSMENT WITH CML INDICATORS

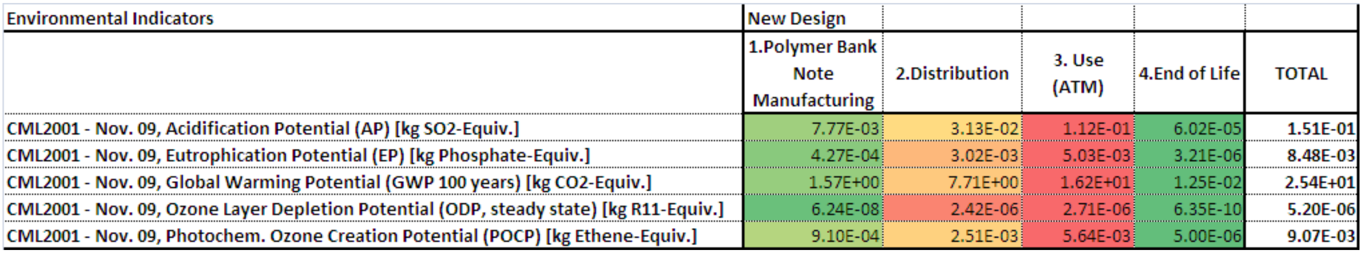
The results are displayed below for the CML methodology.

**Table B-1. Results with CML LCIA methodology for the current design (7.5 years)**



| Environmental Indicators | Current Design | | | | |
|---|---|---|---|---|---|
| | 1.Paper Bank Note Manufacturing | 2.Distribution | 3. Use (ATM) | 4.End of Life | TOTAL |
| CML2001 - Nov. 09, Acidification Potential (AP) [kg SO2-Equiv.] | 1.13E-02 | 8.02E-02 | 1.12E-01 | 8.06E-05 | 2.04E-01 |
| CML2001 - Nov. 09, Eutrophication Potential (EP) [kg Phosphate-Equiv.] | 2.86E-03 | 7.98E-03 | 5.03E-03 | 1.32E-05 | 1.59E-02 |
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 1.59E+00 | 1.99E+01 | 1.62E+01 | 1.52E-01 | 3.78E+01 |
| CML2001 - Nov. 09, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.] | 6.46E-07 | 6.05E-06 | 2.71E-06 | -1.37E-09 | 9.41E-06 |
| CML2001 - Nov. 09, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.] | 9.27E-04 | 6.56E-03 | 5.64E-03 | 3.31E-05 | 1.32E-02 |

**Table B-2. Results with CML LCIA methodology for the new design (7.5 years)**



| Environmental Indicators | New Design | | | | |
|---|---|---|---|---|---|
| | 1.Polymer Bank Note Manufacturing | 2.Distribution | 3. Use (ATM) | 4.End of Life | TOTAL |
| CML2001 - Nov. 09, Acidification Potential (AP) [kg SO2-Equiv.] | 7.77E-03 | 3.13E-02 | 1.12E-01 | 6.02E-05 | 1.51E-01 |
| CML2001 - Nov. 09, Eutrophication Potential (EP) [kg Phosphate-Equiv.] | 4.27E-04 | 3.02E-03 | 5.03E-03 | 3.21E-06 | 8.48E-03 |
| CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] | 1.57E+00 | 7.71E+00 | 1.62E+01 | 1.25E-02 | 2.54E+01 |
| CML2001 - Nov. 09, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.] | 6.24E-08 | 2.42E-06 | 2.71E-06 | 6.35E-10 | 5.20E-06 |
| CML2001 - Nov. 09, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.] | 9.10E-04 | 2.51E-03 | 5.64E-03 | 5.00E-06 | 9.07E-03 |

# APPENDIX C. LCIA DESCRIPTIONS

Life Cycle Impact categories included in this report were based on Impact categories and methods appropriate for use in the US. The current state of the science of life cycle impact methodology consists of the US EPA TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts) impact assessment methodology. The following is a summary description of the methods and applicable references.

- TRACI Impact Categories referenced in this report:
  - Acidification
  - Eutrophication
  - Photo-Oxidant Formation
  - Stratospheric Ozone Depletion
- IPCC
  - Climate Change
- USETox$^{TM}$

Primary Energy Demand is not an impact but is included in this section as it is also a sum value indicating the total amount of energy extracted from earth or based on renewable and fossil resources; it is not included in the TRACI methodology. Primary energy demand is a direct measure of the energy (both renewable and nonrenewable) required to perform an activity or operate a process. It is typically measured in units of megajoules (MJ).

A detailed description of the TRACI impact categories used in this report are described below.

## GLOBAL WARMING POTENTIAL/CLIMATE CHANGE

Global climate change refers to the potential change in the earth's climate caused by the build-up of chemicals (i.e. "greenhouse gases") that trap heat from the reflected sunlight that would have otherwise passed out of the earth's atmosphere. Since pre-industrial times atmospheric concentrations of $CO_2$, $CH_4$, and $N_20$ have climbed by over 30%, 145% and 15%, respectively. While "sinks" exist for greenhouse gases (e.g. oceans and land vegetation absorb carbon dioxide), the rate of emissions in the industrial age has been exceeding the rate of absorption.

Simulations by researchers within the research community of global warming are currently being conducted to try to quantify the potential endpoint effects of these exceedences, including increased droughts, floods, loss of polar ice caps, sea level rise, soil moisture loss, forest loss, change in wind and ocean patterns, changes in agricultural production, decreased biodiversity and increasing occurrences of extreme weather events.

TRACI uses Global Warming Potentials (GWPs) - a midpoint metric. The global warming potentials (GWPs) are based on recommendations contained within the Intergovernmental Panel on Climate

Change (IPCC) Third Assessment Report (TAR) (IPCC 2001) to adhere to the international agreement by parties of the United Nations Framework Convention on Climate Change (UNFCCC) (FCCC 1996) (EPA 2004):

The 100-year time horizons are recommended by the IPCC and are used by the U.S. for policy making and reporting, (EPA 2004) and are adopted within TRACI. The final sum, known as the Global Warming Index (GWI), indicates the potential contribution to global warming.

**Units of Global Warming Potential Results:** CO2 equivalents/kg emission

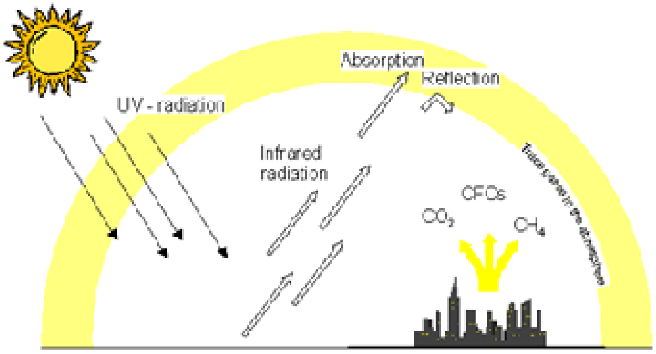


Figure C-1. Greenhouse Effect

### References

Framework Convention on Climate Change (FCCC). 1996. Report to the Conference of the Parties at its second session, held at Geneva from 8 to 19 July 1996: Addendum Part Two: Action taken by the Conference of the Parties at its second session. Document FCCC/CP/1996/15/Add.1. United Nations Framework Convention on Climate Change, Bonn, Germany.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate change 2000: The science of climate change. Edited by Intergovernmental Panel on Climate Change: J. T. Houghton, L. G. Meira Filho, B. A. Callander, N. Harris, A. Kattenberg, and K. Maskell. Cambridge, UK: Cambridge University Press.

U.S. Environmental Protection Agency (EPA). 2004. Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990 – 2002, Annex 6 Additional Information. Document EPA 430-R-04-003. U.S. Environmental Protection Agency, Washington, DC.

## ACIDIFICATION

Acidification refers literally to processes that increase the acidity (hydrogen ion concentration) of water and soil systems. The common mechanism for acidification is deposition of negatively charged ions (anions) that are then removed via leaching, or biochemical processes, leaving excess (positive) hydrogen ion concentrations (H+) in the system. The major acidifying emissions are oxides of nitrogen

(NOx) and sulfur dioxide (SO2), as well as ammonia emissions that lead to ammonium deposition. Acid rain generally reduces the alkalinity of lakes; changes in the alkalinity of lakes, related to their acid neutralizing capacity (ANC) are used as a diagnostic for freshwater systems analogous to the use of H+ budgets in terrestrial watersheds (Schlesinger 1997). Acid deposition also has deleterious (corrosive) effects on buildings, monuments, and historical artifacts.

The stressor-effects for acidification has three stages. Emissions lead to deposition (via a complex set of atmospheric transport and chemistry processes), which in turn can lead to a variety of site-dependent ecosystem impacts – damages to plant and animal populations (via a complex set of chemical and ecological processes). Deposition occurs through three routes: wet (rain, snow, sleet, etc.), dry (direct deposition of particles and gasses onto leaves, soil, surface water, etc.) and cloud water deposition (from cloud and fog droplets onto leaves, soil, etc.).

As described in Norris (2002), the acidification model in TRACI makes use of the results of an empirically calibrated atmospheric chemistry and transport model to estimate total North American terrestrial deposition of expected H+ equivalents due to atmospheric emissions of NOx and SO2, as a function of the emissions location.

The resulting acidification characterization factors are expressed in H+ mole equivalent deposition per kg emission. Characterization factors take account of expected differences in total deposition as a result of the pollutant release location. Factors for acidification are available for each U.S. state. In many LCIA applications the location of the emission source will be known with less precision than the state level for processes within the life cycle inventory. Therefore, additional characterization factors were developed for each of four U.S. regions, for two larger regional divisions (either east or west of the Mississippi river), and for the U.S. as a whole. For each of these larger regions, the composite factor was created using an annual emissions-weighted average of its constituent states.

As reported in (Norris 2002), regional characterization factors range from roughly 20% of the U.S. average to 160% of the U.S. average, and deviation from the U.S. average is variable between SO2 and NOx; that is, the effect of source region upon a characterization factors' deviation from the national average values varies somewhat between SO2 and NOx. Although the majority of acidic deposition in North America stems from emissions of NOx (NO and NO2) and SO2 (including SOx as SO2), significant amounts are also due to emissions of ammonia, and trace amounts from emissions of HCl, and HF. TRACI adopts U.S. average characterization factors for these trace emissions, based on their H+ formation potentials per kg emitted in relation to SO2.

The benefits of the new TRACI method for characterization of acidifying emissions, relative to prior non-regionalized method like Heijungs et al. (1992), are the increased ability for LCIA results to take into account location-based differences in expected impact. These benefits stem from the fact that the TRACI acidification factors pertain to a focused midpoint within the impact chain – total terrestrial deposition -- for which there is considerable, well-understood, and quantifiable variability among source regions.

There are at least two ways in which the regional variability in deposition potential can have an impact on the acidification potential. In the event that the alternatives have their processes (and thus their emissions) clustered in different regions, the overall deposition potentials for both SO2 and NOx can vary by as much as a factor of 5 or more (see Norris 2002). Another possibility is that the alternatives have their processes predominantly clustered in the same regions. If this is the case, then the relative deposition potentials of a kg of NOx versus SO2 emissions can vary by nearly a factor of two from one region to another. In this instance, using the region-appropriate characterization factors may be important to the overall study outcome.

The modeling stops at the midpoint in the cause-effect chain (deposition) because in the U.S. there is no regional database of receiving environment sensitivities (as is available in Europe). Thus, the source region-based variability in total terrestrial deposition has been captured, but not the receiving region-based variability in sensitivity or ultimate damage. Future advances of the TRACI acidification method may address regionalized transport and deposition of ammonia emissions, and investigate the potential to account for regional differentiation of receiving environment sensitivities.

**Units of Acidification Results**: H+ moles equivalent deposition/kg emission

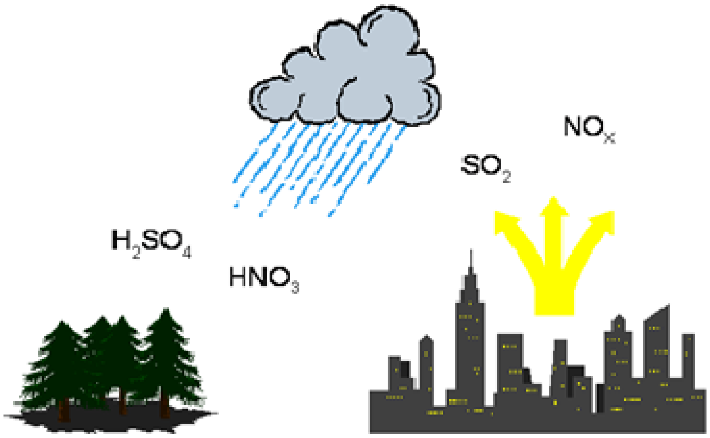


Figure C-2: Acidification Potential

## References

Heijungs, R., J. Guinée, G. Huppes, R. Lankreijer, H. Udo de Haes, A. Wegener Sleeswijk, A. Ansems, P. Eggels, R. van Duin, and H. de Goede. 1992. Environmental life cycle assessment of products. Vol. 1, Guide, Vol. 2, Backgrounds. Leiden, The Netherlands: Centre of Environmental Science, Leiden University.

Norris, G. 2002. Impact characterization in the tool for the reduction and assessment of chemical and other environmental impacts: Methods for acidification, eutrophication, and ozone formation. Journal of Industrial Ecology 6(3-4): 83–105.

Schlesinger, W. 1997. Biogeochemistry: An analysis of global change. Boston: Academic Press.

## EUTROPHICATION POTENTIAL

"The most common impairment of surface waters in the U.S. is eutrophication caused by excessive inputs of phosphorus (P) and nitrogen (N). Impaired waters are defined as those that are not suitable for designated uses such as drinking, irrigation, by industry, recreation, or fishing. Eutrophication is responsible for about half of the impaired lake area, 60% of the impaired rivers in the U.S., and is also the most widespread pollution problem of U.S. estuaries" (Carpenter et al, 1998).

Eutrophication means fertilization of surface waters by nutrients that were previously scarce. When a previously scarce (limiting) nutrient is added, it leads to proliferation of algae. This may lead to a chain of further consequences, potentially including foul odors or taste, death or poisoning of fish or shellfish, reduced biodiversity, or production of chemical compounds toxic to humans, marine mammals, or livestock. The limiting nutrient issue is key to characterization analysis of P and N releases within LCIA. If equal quantities of N and P are released to a freshwater system that is strictly P-limited, then the characterization factors for these two nutrients should account for this fact (e.g., the characterization factor for N should approach zero in this instance).

Prior to utilization of TRACI, it is important to determine the actual emissions that will be transported into water. As an example, fertilizers are applied to provide nutrition to the vegetation that covers the soil and therefore, only the run-off of fertilizer makes it into the waterways. The over-application rate is highly variable and may depend on soil type, vegetation, topography, and even the timing of the application relative to weather events. The TRACI characterization factors for eutrophication are the product of a nutrient factor and a transport factor. The nutrient factor captures the relative strength of influence on algae growth in the photic zone of aquatic ecosystems of 1 kg of N versus 1 kg of P, when each is the limiting nutrient. The location or context-based "transport factors" vary between 1 and zero, and take account of the probability that the release arrives in an aquatic environment (either initially or via air or water transport) to which it is a limiting nutrient. The TRACI characterization method for eutrophication is described in more detail in the companion paper (Norris 2002).

The characterization factors estimate the eutrophication potential of a release of chemicals containing N or P to air or water, per kg, relative to 1 kg N discharged directly to surface freshwater. The regional variability in the resulting eutrophication factors shows that the source location will influence not only the relative strength of influence for a unit emission of a given pollutant, but it will also influence the relative strength of influence among pollutants. The benefits of the new TRACI method for characterization of eutrophying emissions, relative to a prior non-regionalized method like Heijungs et al. (1992) are increased ability for life cycle impact assessment results to take into account the expected influence of location on both atmospheric and hydrologic nutrient transport, and thus the expected influence of release location upon expected nutrient impact. The combined influence of atmospheric transport and deposition along with hydrologic transport can lead to total transport factors differing by a factor of 100 or more (Norris 2002).

As with both acidification and photochemical oxidant formation, TRACI provides characterization factors for nine different groups of U.S. states which are known as Census Regions, (see, for example, http://www.eia.doe.gov/emeu/reps/maps/us_census.html) for eastern and western regions, and for the U.S. as a whole, for use when the location of the release is not more precisely known. For each of these larger regions, the composite factor was created using an average of those for its constituent states.

**Units of Eutrophication Results:** Nitrogen equivalents/kg emission

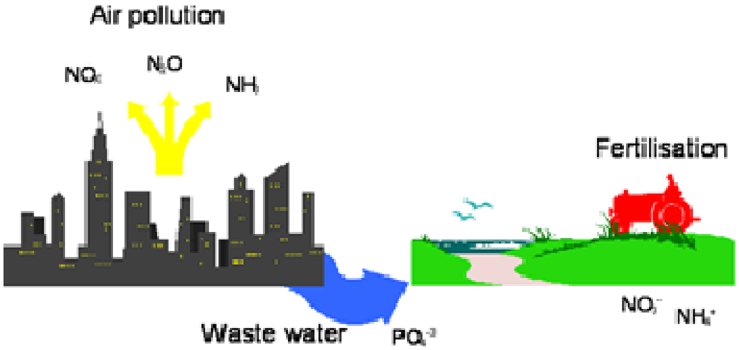


**Figure C-3: Eutrophication Potential**

### References

Carpenter, S., N. Caraco, D. Correll, R. Howarth, A. Sharpley, and V. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8(3): 559–568.

Heijungs, R., J. Guinée, G. Huppes, R. Lankreijer, H. Udo de Haes, A. Wegener Sleeswijk, A. Ansems, P. Eggels, R. van Duin, and H. de Goede. 1992. Environmental life cycle assessment of products. Vol. 1, Guide, Vol. 2, Backgrounds. Leiden, The Netherlands: Centre of Environmental Science, Leiden University.

Norris, G. 2002. Impact characterization in the tool for the reduction and assessment of chemical and other environmental impacts: Methods for acidification, eutrophication, and ozone formation. Journal of Industrial Ecology 6(3-4): 83–105.

## PHOTOCHEMICAL OZONE CREATION POTENTIAL (SMOG)

Ozone (O3) is a reactive oxidant gas produced naturally in trace amounts in the earth's atmosphere. Rates of ozone formation in the troposphere are governed by complex chemical reactions, which are influenced by ambient concentrations of oxides of nitrogen (NOx), volatile organic compounds (VOCs), the mix of OCs, temperature, sunlight, and convective flows. In addition, recent research in the Southern Oxidants Study (e.g., Chameides and Cowling 1995) indicates that carbon monoxide (CO) and methane (CH4) can play a role in ozone formation.

There are over 100 different types of VOC emitted to the atmosphere, and they can differ by more than an order of magnitude in terms of their estimated influence on photochemical oxidant formation (e.g., [Carter 1994]). Further complicating the issue is the fact that in most regions of the U.S., ambient VOC concentrations are due largely to biological sources (trees). For example, in urban and suburban regions of the U.S. at midday, biogenic VOCs can account for a significant fraction (e.g., 10-40%) of the total ambient VOC reactivity (NRC 1991). In rural areas of the eastern U.S., biogenic VOCs contribute more than 90% of the total ambient VOC reactivity in near-surface air.

Ozone in the troposphere leads to detrimental impacts on human health and ecosystems. The mid-point associated with photochemical oxidant formation is the formation of ozone molecules (O3) in the troposphere.

Conventional smog characterization factors for LCIA have been based on European modeling of the relative reactivities among VOCs, and have neglected NOx entirely. This neglect of NOx is a highly significant omission: throughout the past decade, numerous U.S. studies have found spatial and temporal observations of near-surface ozone concentrations to be strongly correlated with ambient NOx concentrations, and more weakly correlated with anthropogenic VOC emissions (see, for example, NRC 1991, Cardelino and Chameides 1995). Another omission in all existing smog characterization factors has been the potential influence of emission location.

The approach to smog characterization analysis for VOCs and NOx in TRACI has the following components: (1) relative influence of individual VOCs on smog formation; (2) relative influence of NOx concentrations versus average VOC mixture on smog formation; (3) impact of emissions (by release location) upon concentration by state; and (4) optional methods for aggregation of effects among receiving states – either by area or population-weighted area.

To characterize the relative influence on O3 formation among the individual VOCs, Carter’s latest maximum incremental reactivity calculations are used (Carter 2000). These reflect the estimated relative influence for conditions under which NOx availability is moderately high and VOCs are at their most influential upon O3 formation. For the relative influence of NOx emissions in comparison to the base reactive organic gas mixture a mid-range factor of 2 is used, which is in agreement with empirical studies on regional impacts for the eastern U.S. (e.g., Cardelino and Chameides 1995), and is at the middle of a range of model-based studies (Rabl and Eyre 1997, Seppälä 1997).

The influence of NOx emissions upon regional ambient levels has been modeled using source/receptor matrices that relate the quantity of seasonal NOx emissions in a given source region to changes in ambient NOx concentrations in each receiving region across North America. These source/receptor matrices were obtained from simulations of the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model (Shannon 1991, 1992, 1996). Source and receptor regions are the contiguous U.S. states, plus Washington, D.C., plus the 10 Canadian Provinces, plus northern Mexico. Recent empirical research (e.g., St. John et al. 1998, Kasibhatla et al. 1998) shows that average O3 concentrations exhibit strong and stable correlations with regional ambient NOx concentrations.

The assumption was made that VOC emission impacts on regional O3 concentrations have the same spatial distribution as the ambient NOx concentration impacts (i.e., similar regional transport for VOCs and NOx). Finally, the outcome of the source/transport modeling is proportional to estimated O3 concentration impacts (g/m2) per state, given an assumed linear relationship between the change in concentration in NOx (with VOC-concentrations converted to NOx equivalents).

Finally there is the question of how to aggregate the effects of estimated changes in smog concentration by state. Exposures leading to human health impacts will be related to the product of state level ambient concentrations times state populations, assuming uniform population density within a state, assuming linear relationship between dose and risk of impact. Damages from impacts on forest and agricultural productivity are related in part to the scale of sensitive agricultural and forest output per state. In the present version of TRACI, human health impacts are addressed, scaling the state level concentration outcomes by state population before aggregating across states. The TRACI method for photochemical oxidant formation is described in more detail in the companion paper (Norris 2002).

**Units of Smog Formation Results:** kg NOx equivalents/kg emission

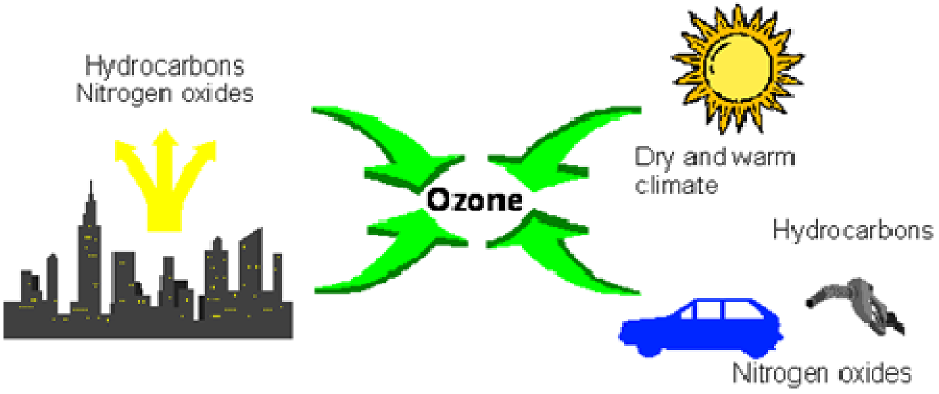


**Figure C-4: Photochemical Ozone Creation Potential**

## References

Cardelino, C. A. and W. L. Chameides. 1995. An observation-based model for analyzing ozone precursor relationships in the urban atmosphere. Journal of the Air and Waste Management Association 45: 161–180.

Carter, W. 1994. Development of ozone reactivity scales for volatile organic compounds. Journal of the Air and Waste Management Association 44:881–899.

Carter, W. 2000. Updated maximum incremental reactivity scale for regulatory applications. Sacramento, CA: California Air Resources Board.

Chameides, W. L. and E. B. Cowling, eds. 1995. The state of the southern oxidants study: Policyrelevant findings in ozone pollution research 1988 to 1994. Raleigh, NC: North Carolina State University.

Kasibhatala, P., W. L. Chameides, R. D. Saylor, and D.Olerud. 1998. Relationships between regional ozone pollution and emissions of nitrogen oxides in the eastern United States. Journal of Geophysical Research 103(D17): 22663–22669.

Norris, G. 2002. Impact characterization in the tool for the reduction and assessment of chemical and other environmental impacts: Methods for acidification, eutrophication, and ozone formation. Journal of Industrial Ecology 6(3-4): 83–105.

NRC (National Research Council). 1991. Rethinking the ozone problem in urban and regional air pollution. Washington, DC: National Academy Press.

Rabl, A. and N. Eyre. 1997. An estimate of regional and global O3 damage from precursor NOx and VOC emissions. Unpublished manuscript. Paris: Ecole des Mines.

Seppälä, J. 1997. Decision analysis as a tool for life cycle impact assessment. Helsinki: Finnish Environment Institute.

Shannon, J. D. 1991. Modeled sulfur deposition trends since 1900 in North America. In Air pollution modeling and its application, Vol. 8, edited by H. van Dop and G. Kallos. New York: Plenum.

Shannon, J. D. 1992. Regional analysis of S emission deposition trends in North America from 1979 through 1988. In Air pollution modeling and its application, Vol. 9, edited by H. van Dop and G. Kallos. New York: Plenum.

Shannon, J. D. 1996. Atmospheric pathways module. In Tracking and analysis framework (TAF) model documentation and user's guide: An interactive model for integrated assessment of Title IV of the Clean Air Act Amendments. ANL/DIS/TM-36. Argonne, IL: Argonne National Laboratory.

St. John, J. C.,W. Chameides, and R. Saylor. 1998. The role of anthropogenic NOx and VOC as ozone precursors: A case study from the SOS Nashville/Middle Tennessee ozone study. Journal of Geophysical Research 103(D17): 22415–22423.

## OZONE DEPLETION POTENTIAL

Most ozone resides in the upper part of the atmosphere.  This region, called the stratosphere, is more than 10 kilometers (6 miles) above Earth's surface. There, about 90% of atmospheric ozone is contained in the "ozone layer," which shields us from harmful ultraviolet radiation from the Sun.  However, it was discovered in the mid-1970s that some human-produced chemicals could destroy ozone and deplete the ozone layer. The resulting increase in ultraviolet radiation at Earth's surface may increase the incidences of skin cancer and eye cataracts.

Human activities cause the emission of halogen source gases that contain chlorine and bromine atoms. These emissions into the atmosphere ultimately lead to stratospheric ozone depletion. The source gases that contain only carbon, chlorine, and fluorine are called "chlorofluorocarbons," usually abbreviated as

CFCs. CFCs, along with carbon tetrachloride (CCl4) and methyl chloroform (CH3CCl3), historically have been the most important chlorine-containing gases that are emitted by human activities and destroy stratospheric ozone. These and other chlorine-containing gases have been used in many applications, including refrigeration, air conditioning, foam blowing, aerosol propellants, and cleaning of metals and electronic components.

In Life Cycle Assessments, Ozone Depletion Potential (ODP) is referred to in CFC-11-equivalents. Since most ozone depleting compounds were phased out by the Montreal Protocol in 1987, the stratospheric ozone layer has been recovering and there are very few ozone depleting emissions.

## USETox™

The USEtox™ model is an environmental model for characterization of human and ecotoxic impacts in Life Cycle Impact Assessment and for comparative assessment and ranking of chemicals according to their inherent hazard characteristics. The USEtox™ model has been developed under by a team of researchers from the Task Force on Toxic Impacts under the UNEP-SETAC Life Cycle Initiative.

The mission of the USEtox Team is to improve understanding and management of chemicals in the global environment by further developing, evaluating, applying and disseminating the model USEtox that describes the fate, exposure and effects of chemicals.

USEtox provides a parsimonious and transparent tool for human health and ecosystem characterization factor (CF) estimates. It has been carefully constructed as well as evaluated via comparison with other models and falls within the range of their results whilst being less complex. It may thus serve as an interface between the more sophisticated state-of-the-art expert models (such as those compared in this study and which frequently change due to latest scientific developments being included) and the need of practitioners for transparency, broad stakeholder acceptance and stability of factors and methods applied in LCA. Based on a referenced database, USEtox has been used to calculate CFs for several thousand substances and forms the basis of the recommendations from UNEP–SETAC's Life Cycle Initiative regarding characterization of toxic impacts in life cycle assessment. USEtox therefore provides the largest substance coverage presently available in term of numbers of chemicals covered. Furthermore, model uncertainty has partly been quantified. USEtox thus represents a significantly improved basis for a wider application of human health and ecotoxicity characterization factors in LCA.

**References**

Ralph K. Rosenbaum et al., USEtox—the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment, *Int J Life Cycle Assess* DOI 10.1007/s11367-008-0038-4

Michael Hauschild et al, International consensus model for comparative assessment of chemical emissions in LCA

Michael Hauschild et al, Building a Model Based on Scientific Consensus for Life Cycle Impact Assessment of Chemicals: The Search for Harmony and Parsimony, *Environ. Sci. Technol.* **2008,** *42,* 7032–7037
http://www.usetox.org

## PRIMARY ENERGY CONSUMPTION

Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere, geosphere, or energy source without any anthropogenic changes. It is a measure of the level resource used across the life cycle of a product.

For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e. the energy content of the raw material). For renewable resources, the energy-characterized amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e. from the height difference). As aggregated values, the following primary energies are designated:

The total **"Primary energy consumption non-renewable"**, given in MJ, essentially characterizes the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil were used both for energy production and as material constituents e.g. in plastics. Coal was primarily used for energy production. Uranium was only used for electricity production in nuclear power stations.

The total **"Primary energy consumption renewable"**, given in MJ, is generally accounted separately and comprises hydropower, wind power, solar energy, and biomass. It is important that the end energy (e.g. 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end energy has not been accounted for.

The energy content of the manufactured products is considered as feedstock energy content. It was characterized by the net calorific value of the product. It represents the still usable energy content.

# APPENDIX D. CRADLE-TO-GRAVE LIFE CYCLE INVENTORY

## Paper Bank note (current design)

**INPUTS**

| **Flow categories** | **Flows** | | | |
|---|---|---|---|---|
| **Energy resources** | | | | |
| | *Non renewable energy resources* | | | |
| | | Crude oil (resource) | 1.32E+02 | MJ |
| | | Hard coal (resource) | 1.33E+02 | MJ |
| | | Lignite (resource) | 7.13E+01 | MJ |
| | | Natural gas (resource) | 1.28E+02 | MJ |
| | | Uranium (resource) | 3.27E+02 | MJ |
| | *Renewable energy resources* | | | |
| | | Primary energy from hydro power | 2.79E+02 | MJ |
| | | Primary energy from solar energy | 1.60E+01 | MJ |
| | | Primary energy from waves | 2.70E-06 | MJ |
| | | Primary energy from wind power | 2.41E+00 | MJ |
| | | Renewable fuels | 3.94E-06 | MJ |
| | | Wood | 3.27E-03 | MJ |
| **Material resources** | | | | |
| | *Non renewable elements* | | | |
| | | Chromium | 8.00E-15 | kg |
| | | Copper | 5.02E-14 | kg |
| | | Iron | 6.71E-04 | kg |
| | | Lead | 9.20E-10 | kg |
| | | Magnesium | 3.41E-29 | kg |
| | | Mercury | 3.03E-09 | kg |
| | | Nickel | 4.28E-13 | kg |
| | | Phosphorus | 3.57E-12 | kg |
| | | Rhodium | 4.92E-14 | kg |
| | | Silicon | 2.54E-09 | kg |
| | | Sulphur | 2.28E-06 | kg |
| | | Zinc | 5.33E-11 | kg |
| | *Non renewable resources* | | | |
| | | Antimony - gold - ore (0.09%) | 1.36E-05 | kg |
| | | Barium sulphate | 1.35E-13 | kg |
| | | Basalt | 2.08E+00 | kg |

| | | |
|---|---|---|
| Bauxite | 1.88E-03 | kg |
| Bentonite | 2.46E-02 | kg |
| Calcium chloride | 1.38E-11 | kg |
| Chalk (Calciumcarbonate) | 1.34E-36 | kg |
| Chromium ore (39%) | 1.29E-03 | kg |
| Clay | 6.28E-02 | kg |
| Colemanite ore | 3.08E-05 | kg |
| Copper - Gold - Ore (1,07% Cu; 0,54 g/t Au) | 1.41E-05 | kg |
| Copper - Gold - Silver - ore (0,51% Cu; 0,6 g/t Au; 1,5 g/t Ag) | 4.08E-05 | kg |
| Copper - Gold - Silver - ore (1,0% Cu; 0,4 g/t Au; 66 g/t Ag) | 3.00E-03 | kg |
| Copper - Gold - Silver - ore (1,1% Cu; 0,01 g/t Au; 2,86 g/t Ag) | 4.02E-03 | kg |
| Copper - Gold - Silver - ore (1,13% Cu; 1,05 g/t Au; 3,72 g/t Ag) | 4.39E-04 | kg |
| Copper - Gold - Silver - ore (1,16% Cu; 0,002 g/t Au; 1,06 g/t Ag) | 2.27E-03 | kg |
| Copper - Gold - Silver - ore (1,7% Cu; 0,7 g/t Au; 3,5 g/t Ag) | 3.31E-05 | kg |
| Copper - Molybdenum - Gold - Silver - ore (1,13% Cu; 0,02% Mo; 0,01 g/t Au; 2,86 g/t Ag) | 2.50E-03 | kg |
| Copper - Silver - ore (3,3% Cu; 5,5 g/t Ag) | 2.29E-05 | kg |
| Copper ore (0.14%) | 1.49E-03 | kg |
| Copper ore (1.2%) | 3.11E-04 | kg |
| Copper ore (4%) | 6.50E-13 | kg |
| Copper ore (sulphidic, 1.1%) | 7.71E-10 | kg |
| Dolomite | 6.07E-07 | kg |
| Feldspar (aluminum silicates) | 3.74E-04 | kg |
| Ferro manganese | 1.15E-10 | kg |
| Fluorspar (calcium fluoride; fluorite) | 2.57E-04 | kg |
| Granite | 8.21E-18 | kg |
| Graphite | 8.25E-06 | kg |
| Gypsum (natural gypsum) | 5.38E-03 | kg |
| Heavy spar (BaSO4) | 5.90E-02 | kg |
| Ilmenite (titanium ore) | 2.38E-06 | kg |
| Inert rock | 1.10E+02 | kg |
| Iron ore (56,86%) | 3.08E-02 | kg |
| Iron ore (65%) | 1.62E-05 | kg |
| Kaolin ore | 1.15E-05 | kg |

| | | | | |
|---|---|---|---|---|
| | | Lead - Zinc - Silver - ore (5,49% Pb; 12,15% Zn; 57,4 gpt Ag) | 1.58E-06 | kg |
| | | Lead - zinc ore (4.6%-0.6%) | 4.94E-03 | kg |
| | | Limestone (calcium carbonate) | 5.14E-01 | kg |
| | | Magnesit (Magnesium carbonate) | 8.07E-03 | kg |
| | | Magnesium chloride leach (40%) | 2.82E-03 | kg |
| | | Manganese ore | 6.94E-05 | kg |
| | | Manganese ore (R.O.M.) | 1.24E-03 | kg |
| | | Molybdenite (Mo 0,24%) | 1.53E-03 | kg |
| | | Natural Aggregate | 9.13E-01 | kg |
| | | Nickel ore (1,5%) | 1.36E-02 | kg |
| | | Nickel ore (1.6%) | 3.93E-03 | kg |
| | | Olivine | 1.19E-09 | kg |
| | | Peat | 1.46E-04 | kg |
| | | Perlite (Rhyolithe) | 5.48E-03 | kg |
| | | Phosphate ore | 1.14E-01 | kg |
| | | Phosphorus minerals | 1.22E-06 | kg |
| | | Phosphorus ore (29% P2O5) | 2.87E-04 | kg |
| | | Potashsalt, crude (hard salt, 10% K2O) | 1.08E-01 | kg |
| | | Potassium chloride | 2.10E-03 | kg |
| | | Precious metal ore (R.O.M) | 1.60E-04 | kg |
| | | Quartz sand (silica sand; silicon dioxide) | 6.72E-02 | kg |
| | | Raw pumice | 1.11E-06 | kg |
| | | Rutile (titanium ore) | 1.92E-36 | kg |
| | | sand | 1.29E-07 | kg |
| | | Slate | 9.06E-12 | kg |
| | | Sodium chloride (rock salt) | 5.28E-02 | kg |
| | | Sodium nitrate | 1.02E-28 | kg |
| | | Sodium sulphate | 8.43E-08 | kg |
| | | Soil | 3.77E-01 | kg |
| | | Sulphur (bonded) | 3.11E-09 | kg |
| | | Talc | 1.92E-06 | kg |
| | | Tin ore | 1.17E-14 | kg |
| | | Titanium ore | 1.66E-02 | kg |
| | | Zinc - copper ore (4.07%-2.59%) | 1.66E-03 | kg |
| | | Zinc - lead - copper ore (12%-3%-2%) | 9.04E-04 | kg |
| | | Zinc - Lead - Silver - ore (8,54% Zn; 5,48% Pb; 94 g/t Ag) | 1.24E-05 | kg |
| | | Zinc - lead ore (4.21%-4.96%) | 2.22E-13 | kg |
| | | Zinc ore (sulphidic, 4%) | 5.85E-13 | kg |
| | *Renewable resources* | | | |
| | | Water | 3.24E+02 | kg |

| | | | | |
|---|---|---|---|---|
| | | Air | 1.62E+02 | kg |
| | | Carbon dioxide | 1.58E+00 | kg |
| **Emissions to air** | | | | |
| | | Organic emissions to air (group VOC) | 1.05E-14 | kg |
| | | Group NMVOC to air | 1.05E-14 | kg |
| | | Halogenated organic emissions to air | 1.05E-14 | kg |
| **Emissions to agricultural soil** | | | | |
| | | Chromium (unspecified) | 1.27E-07 | kg |
| | | Copper (+II) | 1.53E-06 | kg |
| | | Lead (+II) | 2.25E-08 | kg |
| | | Nickel (+II) | 7.55E-08 | kg |
| | | Zinc (+II) | 1.15E-05 | kg |

**OUTPUTS**

| **Flow categories** | **Flows** | | | |
|---|---|---|---|---|
| **Material resources** | | | | |
| | *Renewable resources* | | | |
| | | Water | 1.82E+02 | kg |
| | | Nitrogen | 7.62E-03 | kg |
| | | Oxygen | 8.19E-01 | kg |
| **Emissions to air** | | | | |
| | *Heavy metals to air* | | | |
| | | Antimony | 4.25E-07 | kg |
| | | Arsenic (+V) | 1.35E-06 | kg |
| | | Arsenic trioxide | 3.37E-12 | kg |
| | | Cadmium (+II) | 1.43E-07 | kg |
| | | Chromium (+III) | 6.20E-09 | kg |
| | | Chromium (+VI) | 6.42E-10 | kg |
| | | Chromium (unspecified) | 7.84E-07 | kg |
| | | Cobalt | 3.11E-07 | kg |
| | | Copper (+II) | 1.36E-06 | kg |
| | | Heavy metals to air (unspecified) | 2.57E-09 | kg |
| | | Hydrogen arsenic (arsine) | 2.80E-10 | kg |
| | | Iron | 2.43E-07 | kg |
| | | Lanthanides | 2.57E-11 | kg |
| | | Lead (+II) | 3.24E-06 | kg |
| | | Manganese (+II) | 2.83E-06 | kg |
| | | Mercury (+II) | 5.55E-07 | kg |
| | | Molybdenum | 1.64E-08 | kg |

| | | | |
|---|---|---|---|
| | Nickel (+II) | 1.70E-06 | kg |
| | Palladium | 3.82E-16 | kg |
| | Rhodium | 3.69E-16 | kg |
| | Selenium | 4.99E-06 | kg |
| | Silver | 1.21E-14 | kg |
| | Tellurium | 5.57E-10 | kg |
| | Thallium | 8.61E-09 | kg |
| | Tin (+IV) | 8.42E-07 | kg |
| | Titanium | 1.64E-09 | kg |
| | Vanadium (+III) | 1.23E-05 | kg |
| | Zinc (+II) | 1.12E-05 | kg |
| *Inorganic emissions to air* | | | |
| | Ammonia | 4.13E-04 | kg |
| | Ammonium | 1.16E-06 | kg |
| | Ammonium nitrate | 1.83E-11 | kg |
| | Argon | 1.77E-11 | kg |
| | Barium | 5.10E-05 | kg |
| | Beryllium | 3.58E-08 | kg |
| | Boron | 3.13E-14 | kg |
| | Boron compounds (unspecified) | 7.45E-05 | kg |
| | Bromine | 2.38E-05 | kg |
| | Carbon dioxide | 3.78E+01 | kg |
| | Carbon dioxide (biotic) | 4.76E-04 | kg |
| | Carbon dioxide (biotic) | 1.82E-02 | kg |
| | Carbon disulphide | 3.44E-10 | kg |
| | Carbon monoxide | 4.81E-02 | kg |
| | Chloride (unspecified) | 4.05E-06 | kg |
| | Chlorine | 1.59E-05 | kg |
| | Cyanide (unspecified) | 1.22E-07 | kg |
| | Fluoride | 1.59E-05 | kg |
| | Fluorides | 6.56E-07 | kg |
| | Fluorine | 1.27E-09 | kg |
| | Helium | 1.06E-07 | kg |
| | Hydrazine (H2N4) | 3.67E-13 | kg |
| | Hydrogen | 1.16E-04 | kg |
| | Hydrogen bromine (hydrobromic acid) | 4.64E-09 | kg |
| | Hydrogen chloride | 1.95E-03 | kg |
| | Hydrogen cyanide (prussic acid) | 3.81E-09 | kg |
| | Hydrogen fluoride | 2.99E-04 | kg |
| | Hydrogen iodide | 4.12E-12 | kg |
| | Hydrogen phosphorous | 9.75E-11 | kg |

| | | | | |
|---|---|---|---|---|
| | | Hydrogen sulphide | 5.59E-05 | kg |
| | | Lead dioxide | 1.27E-10 | kg |
| | | Magnesium | 5.17E-08 | kg |
| | | Nitrogen (atmospheric nitrogen) | 5.71E-03 | kg |
| | | Nitrogen dioxide | 5.27E-06 | kg |
| | | Nitrogen monoxide | 7.97E-05 | kg |
| | | Nitrogen oxides | 1.01E-01 | kg |
| | | Nitrous oxide (laughing gas) | 9.33E-04 | kg |
| | | Oxygen | 2.67E-02 | kg |
| | | Scandium | 1.21E-11 | kg |
| | | Steam | 9.54E+01 | kg |
| | | Strontium | 4.88E-10 | kg |
| | | Sulphur dioxide | 1.24E-01 | kg |
| | | Sulphur hexafluoride | 8.67E-09 | kg |
| | | Sulphuric acid | 2.53E-08 | kg |
| | | Tin oxide | 1.10E-11 | kg |
| | | Zinc oxide | 2.21E-11 | kg |
| | | Zinc sulphate | 7.01E-09 | kg |
| | *Organic emissions to air (group VOC)* | | | |
| | | Anthracene | 9.53E-10 | kg |
| | | Benzo{a}anthracene | 4.79E-10 | kg |
| | | Benzo{a}pyrene | 3.01E-09 | kg |
| | | Benzo{ghi}perylene | 4.27E-10 | kg |
| | | Benzofluoranthene | 8.55E-10 | kg |
| | | Chrysene | 1.18E-09 | kg |
| | | Dibenz(a)anthracene | 2.66E-10 | kg |
| | | Indeno[1,2,3-cd]pyrene | 3.18E-10 | kg |
| | | Naphthalene | 1.01E-07 | kg |
| | | Phenanthrene | 3.14E-08 | kg |
| | | Polycyclic aromatic hydrocarbons (PAH) | 1.45E-06 | kg |
| | *Halogenated organic emissions to air* | | | |
| | | 1,1,1-Trichloroethane | 1.88E-11 | kg |
| | | 1,2-Dibromoethane | 2.59E-15 | kg |
| | | bromoform (US LCI) | 8.41E-14 | kg |
| | | Carbon tetrachloride (tetrachloromethane) | 2.64E-12 | kg |
| | | Chlorobenzene | 4.74E-14 | kg |
| | | Chloromethane (methyl chloride) | 1.14E-12 | kg |
| | | Chlorotoluene (Benzylchloride) | 1.51E-12 | kg |
| | | Dichloroethane (1,2-Dichloroethane) | 8.63E-14 | kg |
| | | Dichloroethane (ethylene dichloride) | 4.73E-14 | kg |

| | | | | |
|---|---|---|---|---|
| | | Dichloromethane (methylene chloride) | 4.39E-09 | kg |
| | | Dioxins (unspec.) | 2.58E-14 | kg |
| | | Ethyl chloride | 9.06E-14 | kg |
| | | Halogenated hydrocarbons (unspecified) | 6.83E-12 | kg |
| | | Methyl bromide | 3.45E-13 | kg |
| | | Polychlorinated biphenyls (PCB unspecified) | 6.22E-10 | kg |
| | | Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) | 3.92E-12 | kg |
| | | R 11 (trichlorofluoromethane) | 4.30E-06 | kg |
| | | R 113 (trichlorofluoroethane) | 8.71E-15 | kg |
| | | R 114 (dichlorotetrafluoroethane) | 4.40E-06 | kg |
| | | R 116 (hexafluoroethane) | 1.43E-09 | kg |
| | | R 12 (dichlorodifluoromethane) | 9.24E-07 | kg |
| | | R 13 (chlorotrifluoromethane) | 5.80E-07 | kg |
| | | R 22 (chlorodifluoromethane) | 1.01E-06 | kg |
| | | Tetrachloroethene (perchloroethylene) | 2.47E-10 | kg |
| | | Tetrafluoromethane | 3.72E-08 | kg |
| | | Trichloroethene (isomers) | 1.87E-13 | kg |
| | | Trichloromethane (chloroform) | 1.27E-13 | kg |
| | | Vinyl chloride (VCM; chloroethene) | 2.02E-08 | kg |
| | *Other organic emissions* | | | |
| | | 2,4-Dinitrotoluene | 6.04E-16 | kg |
| | | Acentaphthene | 2.40E-12 | kg |
| | | Acetaldehyde (Ethanal) | 5.94E-06 | kg |
| | | Acetic acid | 2.54E-05 | kg |
| | | Acetone (dimethylcetone) | 5.73E-06 | kg |
| | | Acrolein | 8.29E-09 | kg |
| | | Acrylonitrile | 4.06E-06 | kg |
| | | Aldehyde (unspecified) | 1.15E-05 | kg |
| | | Alkane (unspecified) | 1.10E-04 | kg |
| | | Alkene (unspecified) | 9.31E-05 | kg |
| | | Aromatic hydrocarbons (unspecified) | 1.74E-06 | kg |
| | | Benzene | 2.79E-05 | kg |
| | | Biphenyl | 7.99E-12 | kg |
| | | Butadiene | 4.06E-06 | kg |
| | | Butane | 3.21E-04 | kg |
| | | Butane (n-butane) | 6.99E-05 | kg |
| | | Butanone (methyl ethyl ketone) | 5.21E-08 | kg |
| | | Cumene (isopropylbenzene) | 1.59E-12 | kg |
| | | Cyclohexane (hexahydro benzene) | 7.88E-09 | kg |
| | | Diethylamine | 1.32E-11 | kg |

| | | | |
|---|---|---|---|
| | Dioctylphthalate (DOP) | 1.57E-13 | kg |
| | Ethane | 1.02E-03 | kg |
| | Ethanol | 1.15E-05 | kg |
| | Ethene (ethylene) | 4.41E-07 | kg |
| | Ethyl benzene | 9.25E-05 | kg |
| | Fluoranthene | 3.10E-09 | kg |
| | Fluorene | 9.84E-09 | kg |
| | Formaldehyde (methanal) | 9.45E-05 | kg |
| | Furan | 2.14E-14 | kg |
| | Heptane (isomers) | 6.42E-06 | kg |
| | Hexamethylene diamine (HMDA) | 8.96E-12 | kg |
| | Hexane (isomers) | 1.09E-05 | kg |
| | Isoprene | 1.20E-05 | kg |
| | Mercaptan (unspecified) | 2.17E-07 | kg |
| | Methacrylate | 2.31E-08 | kg |
| | Methacrylic acid | 4.31E-14 | kg |
| | Methanol | 8.68E-06 | kg |
| | Methyl methacrylate (MMA) | 3.39E-06 | kg |
| | NMVOC (unspecified) | 3.99E-03 | kg |
| | Octane | 3.53E-06 | kg |
| | ortho-Cresol | 2.15E-08 | kg |
| | para-Cresol | 2.32E-08 | kg |
| | Pentane (n-pentane) | 2.72E-04 | kg |
| | Phenol (hydroxy benzene) | 9.61E-09 | kg |
| | Propane | 1.50E-03 | kg |
| | Propene (propylene) | 8.39E-06 | kg |
| | Propionaldehyde | 8.20E-13 | kg |
| | Propionic acid (propane acid) | 9.08E-11 | kg |
| | Styrene | 8.12E-06 | kg |
| | Toluene (methyl benzene) | 4.26E-05 | kg |
| | Trimethylbenzene | 1.08E-10 | kg |
| | Vinyl acetat | 1.64E-14 | kg |
| | Xylene (dimethyl benzene) | 3.86E-04 | kg |
| | Hydrocarbons (unspecified) | 1.09E-06 | kg |
| | Methane | 4.71E-02 | kg |
| | Organic chlorine compounds | 6.75E-11 | kg |
| | Polycyclic hydrocarbons | 4.26E-26 | kg |
| | tert-butyl methyl ether (US LCI) | 7.55E-14 | kg |
| | VOC (unspecified) | 8.05E-04 | kg |
| *Other emissions to air* | | | |
| | Exhaust | 1.34E+02 | kg |

| | | | | |
|---|---|---|---|---|
| | | Used air | 5.87E-01 | kg |
| | *Particles to air* | | | |
| | | Dust (> PM10) | 2.79E-03 | kg |
| | | Dust (PM10) | 1.66E-03 | kg |
| | | Dust (PM2,5 - PM10) | 1.34E-05 | kg |
| | | Dust (PM2.5) | 4.28E-03 | kg |
| | | Dust (unspecified) | 4.02E-03 | kg |
| | *Metals (unspecified)* | | 3.04E-09 | kg |
| | *Tar* | | 4.11E-13 | kg |
| | *Wood (dust)* | | 4.07E-09 | kg |
| | *Radioactive emissions to air* | | | |
| | | Uranium (total) | 5.03E-06 | kg |
| **Emissions to fresh water** | | | | |
| | *Analytical measures to fresh water* | | | |
| | | Adsorbable organic halogen compounds (AOX) | 2.43E-06 | kg |
| | | Biological oxygen demand (BOD) | 9.57E-03 | kg |
| | | Chemical oxygen demand (COD) | 1.15E-02 | kg |
| | | Solids (dissolved) | 3.41E-02 | kg |
| | | Total dissolved organic bounded carbon | 7.70E-08 | kg |
| | | Total organic bounded carbon | 2.87E-04 | kg |
| | *Heavy metals to fresh water* | | | |
| | | Antimony | 4.03E-08 | kg |
| | | Arsenic (+V) | 1.15E-06 | kg |
| | | Cadmium (+II) | 2.23E-06 | kg |
| | | Chromium (+III) | 3.27E-06 | kg |
| | | Chromium (+VI) | 4.88E-08 | kg |
| | | Chromium (unspecified) | 2.46E-06 | kg |
| | | Cobalt | 7.02E-09 | kg |
| | | Copper (+II) | 5.34E-06 | kg |
| | | Heavy metals to water (unspecified) | 1.58E-08 | kg |
| | | Iron | 8.90E-03 | kg |
| | | Lead (+II) | 1.64E-05 | kg |
| | | Manganese (+II) | 4.57E-05 | kg |
| | | Mercury (+II) | 5.41E-08 | kg |
| | | Molybdenum | 1.15E-05 | kg |
| | | Nickel (+II) | 6.55E-06 | kg |
| | | Selenium | 1.97E-06 | kg |
| | | Silver | 1.60E-06 | kg |

| | | | |
|---|---|---|---|
| | Strontium | 7.97E-05 | kg |
| | Thallium | 8.61E-09 | kg |
| | Tin (+IV) | 1.83E-07 | kg |
| | Titanium | 1.93E-06 | kg |
| | Vanadium (+III) | 3.84E-06 | kg |
| | Zinc (+II) | 6.67E-06 | kg |
| *Inorganic emissions to fresh water* | | | |
| | Acid (calculated as H+) | 1.09E-06 | kg |
| | Aluminum (+III) | 4.51E-04 | kg |
| | Ammonia | 1.59E-05 | kg |
| | Ammonium / ammonia | 2.44E-04 | kg |
| | Barium | 8.87E-04 | kg |
| | Beryllium | 2.65E-08 | kg |
| | Boron | 3.70E-05 | kg |
| | Bromate | 4.18E-12 | kg |
| | Bromine | 1.60E-04 | kg |
| | Calcium (+II) | 1.03E-02 | kg |
| | Carbonate | 8.26E-04 | kg |
| | Chlorate | 4.39E-07 | kg |
| | Chloride | 1.11E-01 | kg |
| | Chlorine (dissolved) | 5.38E-04 | kg |
| | Cyanide | 7.74E-08 | kg |
| | Fluoride | 1.51E-02 | kg |
| | Fluorine | 5.54E-08 | kg |
| | Hydrogen chloride | 2.57E-03 | kg |
| | Hydrogen cyanide (prussic acid) | 1.93E-10 | kg |
| | Hydrogen fluoride (hydrofluoric acid) | 1.05E-09 | kg |
| | Hydroxide | 8.70E-07 | kg |
| | Inorganic salts and acids (unspecified) | 3.28E-14 | kg |
| | Lithium | 3.83E-05 | kg |
| | Magnesium (+III) | 1.11E-03 | kg |
| | Magnesium chloride | 4.22E-07 | kg |
| | Magnesium ion (+II) | 4.69E-04 | kg |
| | Metal ions (unspecific) | 3.17E-06 | kg |
| | Metals (unspecified) | 6.07E-29 | kg |
| | Neutral salts | 2.92E-08 | kg |
| | Nitrate | 6.58E-03 | kg |
| | Nitric acid | 2.33E-10 | kg |
| | Nitrogen | 1.51E-05 | kg |
| | Nitrogen (as total N) | 4.81E-08 | kg |
| | Nitrogen organic bounded | 1.34E-03 | kg |

| | | | | |
|---|---|---|---|---|
| | | Phosphate | 3.97E-04 | kg |
| | | Phosphorus | 2.82E-06 | kg |
| | | Potassium | 9.06E-04 | kg |
| | | Silicate particles | 2.03E-10 | kg |
| | | Sodium (+I) | 2.21E-02 | kg |
| | | Sodium chloride (rock salt) | 2.71E-04 | kg |
| | | Sodium hypochlorite | 4.46E-07 | kg |
| | | Sodium sulphate | 5.13E-05 | kg |
| | | Sulphate | 4.96E-02 | kg |
| | | Sulphide | 2.29E-05 | kg |
| | | Sulphite | 1.01E-05 | kg |
| | | Sulphur | 2.44E-06 | kg |
| | | Sulphuric acid | 7.20E-07 | kg |
| | *Organic emissions to fresh water* | | | |
| | | 1,2-Dibromoethane | 1.85E-12 | kg |
| | | Chlorinated hydrocarbons (unspecified) | 1.53E-14 | kg |
| | | Chloromethane (methyl chloride) | 4.81E-09 | kg |
| | | Dichloroethane (ethylene dichloride) | 9.10E-16 | kg |
| | | Dichloropropane | 7.19E-15 | kg |
| | | Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) | 3.84E-17 | kg |
| | | Vinyl chloride (VCM; chloroethene) | 2.61E-10 | kg |
| | | Acenaphthene | 4.19E-10 | kg |
| | | Acenaphthylene | 1.71E-10 | kg |
| | | Acetic acid | 2.15E-07 | kg |
| | | Acrylonitrile | 2.03E-06 | kg |
| | | Anthracene | 4.98E-10 | kg |
| | | Aromatic hydrocarbons (unspecified) | 7.80E-07 | kg |
| | | Benzene | 2.07E-06 | kg |
| | | Benzo{a}anthracene | 6.75E-11 | kg |
| | | Benzo{a}pyrene | 3.28E-10 | kg |
| | | Benzofluoranthene | 4.77E-11 | kg |
| | | Chrysene | 3.27E-10 | kg |
| | | Cresol (methyl phenol) | 1.18E-08 | kg |
| | | Ethyl benzene | 1.10E-07 | kg |
| | | Fluoranthene | 7.86E-11 | kg |
| | | Formaldehyde (methanal) | 3.42E-10 | kg |
| | | Hexane (isomers) | 1.30E-09 | kg |
| | | Hydrocarbons (unspecified) | 7.27E-06 | kg |
| | | Methanol | 3.67E-05 | kg |
| | | Oil (unspecified) | 6.71E-04 | kg |

| | | | | |
|---|---|---|---|---|
| | | Phenanthrene | 2.08E-10 | kg |
| | | Phenol (hydroxy benzene) | 1.13E-06 | kg |
| | | Polycyclic aromatic hydrocarbons (PAH, unspec.) | 3.46E-05 | kg |
| | | Toluene (methyl benzene) | 1.71E-06 | kg |
| | | VOC (unspecified) | 9.33E-07 | kg |
| | | Xylene (isomers; dimethyl benzene) | 9.59E-07 | kg |
| | | Xylene (meta-Xylene; 1,3-Dimethylbenzene) | 2.26E-08 | kg |
| | | Acetone (dimethylcetone) | 7.47E-09 | kg |
| | | Biphenyl | 2.29E-09 | kg |
| | | Carbon, organically bound | 2.09E-02 | kg |
| | | Mineral oil (tetradecane) | 1.81E-08 | kg |
| | | Naphthalene | 4.82E-08 | kg |
| | | Organic chlorine compounds (unspecified) | 3.12E-05 | kg |
| | | Organic compounds (dissolved) | 1.84E-09 | kg |
| | | Organic compounds (unspecified) | 1.22E-10 | kg |
| | *Other emissions to fresh water* | | | |
| | | Detergent (unspecified) | 6.28E-07 | kg |
| | | Waste water | 4.69E+01 | kg |
| | *Particles to fresh water* | | | |
| | | Metals (unspecified) | 1.13E-08 | kg |
| | | Silicon dioxide (silica) | 9.06E-27 | kg |
| | | Soil loss by erosion into water | 2.05E-01 | kg |
| | | Solids (suspended) | 5.90E-02 | kg |
| | | Suspended solids, unspecified | 3.92E-06 | kg |
| **Emissions to sea water** | | | | |
| | *Analytical measures to sea water* | | | |
| | | Adsorbable organic halogen compounds (AOX) | 4.86E-12 | kg |
| | | Biological oxygen demand (BOD) | 5.36E-06 | kg |
| | | Chemical oxygen demand (COD) | 9.47E-05 | kg |
| | | Total organic bounded carbon | 5.36E-06 | kg |
| | *Heavy metals to sea water* | | | |
| | | Arsenic (+V) | 3.53E-07 | kg |
| | | Cadmium (+II) | 4.11E-07 | kg |
| | | Chromium (unspecified) | 5.64E-07 | kg |
| | | Cobalt | 1.75E-07 | kg |
| | | Copper (+II) | 7.98E-07 | kg |

| | | | | |
|---|---|---|---|---|
| | | Iron | 2.39E-06 | kg |
| | | Lead (+II) | 1.84E-07 | kg |
| | | Manganese (+II) | 2.47E-07 | kg |
| | | Mercury (+II) | 3.16E-09 | kg |
| | | Molybdenum | 3.43E-09 | kg |
| | | Nickel (+II) | 3.28E-07 | kg |
| | | Silver | 1.02E-08 | kg |
| | | Strontium | 8.26E-06 | kg |
| | | Tin (+IV) | 1.22E-08 | kg |
| | | Titanium | 1.24E-09 | kg |
| | | Vanadium (+III) | 1.10E-07 | kg |
| | | Zinc (+II) | 3.17E-06 | kg |
| | *Inorganic emissions to sea water* | | | |
| | | Aluminum (+III) | 3.99E-08 | kg |
| | | Ammonia | 1.19E-06 | kg |
| | | Barium | 8.52E-06 | kg |
| | | Beryllium | 8.86E-09 | kg |
| | | Boron | 6.46E-07 | kg |
| | | Calcium (+II) | 7.05E-05 | kg |
| | | Carbonate | 5.36E-04 | kg |
| | | Chloride | 4.25E-02 | kg |
| | | Magnesium | 1.80E-05 | kg |
| | | Nitrate | 6.95E-07 | kg |
| | | Sodium (+I) | 1.07E-04 | kg |
| | | Sulphate | 2.26E-04 | kg |
| | | Sulphide | 9.76E-05 | kg |
| | | Sulphur | 3.46E-07 | kg |
| | *Organic emissions to sea water* | | | |
| | | Acenaphthene | 7.90E-09 | kg |
| | | Acenaphthylene | 3.03E-09 | kg |
| | | Acetic acid | 7.08E-09 | kg |
| | | Anthracene | 2.54E-09 | kg |
| | | Aromatic hydrocarbons (unspecified) | 5.36E-08 | kg |
| | | Benzene | 2.18E-06 | kg |
| | | Benzo{a}anthracene | 1.74E-09 | kg |
| | | Benzofluoranthene | 1.90E-09 | kg |
| | | Chrysene | 9.76E-09 | kg |
| | | Cresol (methyl phenol) | 8.95E-09 | kg |
| | | Ethyl benzene | 1.85E-07 | kg |
| | | Fluoranthene | 2.03E-09 | kg |

| | | | | |
|---|---|---|---|---|
| | | Hexane (isomers) | 9.77E-10 | kg |
| | | Oil (unspecified) | 1.75E-05 | kg |
| | | Phenol (hydroxy benzene) | 3.64E-06 | kg |
| | | Toluene (methyl benzene) | 1.30E-06 | kg |
| | | Xylene (isomers; dimethyl benzene) | 9.19E-07 | kg |
| | | Naphthalene | 2.72E-07 | kg |
| | *Particles to sea water* | | | |
| | | Solids (suspended) | 4.26E-03 | kg |
| **Emissions to agricultural soil** | | | | |
| | *Heavy metals to agricultural soil* | | | |
| | | Cadmium (+II) | 4.81E-07 | kg |
| | | Chromium (+III) | 1.97E-09 | kg |
| | | Mercury (+II) | 1.97E-11 | kg |
| **Emissions to industrial soil** | | | | |
| | *Heavy metals to industrial soil* | | | |
| | | Antimony | 2.27E-12 | kg |
| | | Arsenic (+V) | 3.08E-10 | kg |
| | | Cadmium (+II) | 3.08E-09 | kg |
| | | Chromium (+III) | 4.90E-09 | kg |
| | | Chromium (+VI) | 7.87E-12 | kg |
| | | Chromium (unspecified) | 3.40E-07 | kg |
| | | Cobalt | 5.26E-09 | kg |
| | | Copper (+II) | 1.02E-08 | kg |
| | | Iron | 3.92E-06 | kg |
| | | Lead (+II) | 6.21E-09 | kg |
| | | Manganese (+II) | 3.30E-07 | kg |
| | | Mercury (+II) | 4.33E-11 | kg |
| | | Nickel (+II) | 1.06E-06 | kg |
| | | Selenium | 1.16E-11 | kg |
| | | Strontium | 5.53E-05 | kg |
| | | Zinc (+II) | 8.22E-08 | kg |
| | *Inorganic emissions to industrial soil* | | | |
| | | Aluminum (+III) | 9.69E-07 | kg |
| | | Ammonia | 1.20E-04 | kg |
| | | Beryllium | 1.08E-17 | kg |
| | | Bromide | 2.08E-08 | kg |
| | | Calcium (+II) | 1.36E-04 | kg |
| | | Chloride | 4.00E-05 | kg |

| | | | | |
|---|---|---|---|---|
| | | Chlorine | 8.32E-09 | kg |
| | | Fluoride | 6.94E-07 | kg |
| | | Magnesium (+III) | 1.88E-05 | kg |
| | | Phosphorus | 1.21E-05 | kg |
| | | Potassium (+I) | 5.87E-05 | kg |
| | | Sodium (+I) | 1.46E-05 | kg |
| | | Sulphate | 8.63E-06 | kg |
| | | Sulphide | 5.18E-05 | kg |
| | *Organic emissions to industrial soil* | | | |
| | | Oil (unspecified) | 6.38E-05 | kg |
| | | Polycyclic aromatic hydrocarbons (unspecified) | 1.07E-10 | kg |

## Polymer Bank note (new design)

**INPUTS**

| **Flow categories** | **Flows** | | | |
|---|---|---|---|---|
| **Energy resources** | | | | |
| | *Non renewable energy resources* | | | |
| | | Crude oil (resource) | 6.50E+01 | MJ |
| | | Hard coal (resource) | 8.87E+01 | MJ |
| | | Lignite (resource) | 7.18E+01 | MJ |
| | | Natural gas (resource) | 7.70E+01 | MJ |
| | | Uranium (resource) | 1.81E+02 | MJ |
| | *Renewable energy resources* | | | |
| | | Primary energy from hydro power | 1.96E+02 | MJ |
| | | Primary energy from solar energy | 8.78E+00 | MJ |
| | | Primary energy from wind power | 1.16E+00 | MJ |
| | | Renewable fuels | 9.43E-07 | MJ |
| | | Wood | 1.85E-03 | MJ |
| **Material resources** | | | | |
| | *Non renewable elements* | | | |
| | | Iron | 2.52E-04 | kg |
| | | Lead | 1.76E-15 | kg |
| | | Rhodium | 3.97E-20 | kg |
| | | Silicon | 1.00E-13 | kg |
| | | Sulphur | 3.48E-09 | kg |

| | | | |
|---|---|---|---|
| *Non renewable resources* | | | |
| | Antimony - gold - ore (0.09%) | 4.13E-09 | kg |
| | Barium sulphate | 1.81E-13 | kg |
| | Basalt | 1.49E+00 | kg |
| | Bauxite | 1.14E-03 | kg |
| | Bentonite | 1.34E-02 | kg |
| | Calcium chloride | 1.85E-11 | kg |
| | Chromium ore (39%) | 1.60E-02 | kg |
| | Clay | 2.60E-02 | kg |
| | Colemanite ore | 4.23E-06 | kg |
| | Copper - Gold - Ore (1,07% Cu; 0,54 g/t Au) | 5.64E-06 | kg |
| | Copper - Gold - Silver - ore (0,51% Cu; 0,6 g/t Au; 1,5 g/t Ag) | 1.62E-05 | kg |
| | Copper - Gold - Silver - ore (1,0% Cu; 0,4 g/t Au; 66 g/t Ag) | 2.11E-03 | kg |
| | Copper - Gold - Silver - ore (1,1% Cu; 0,01 g/t Au; 2,86 g/t Ag) | 2.16E-03 | kg |
| | Copper - Gold - Silver - ore (1,13% Cu; 1,05 g/t Au; 3,72 g/t Ag) | 1.75E-04 | kg |
| | Copper - Gold - Silver - ore (1,16% Cu; 0,002 g/t Au; 1,06 g/t Ag) | 1.22E-03 | kg |
| | Copper - Gold - Silver - ore (1,7% Cu; 0,7 g/t Au; 3,5 g/t Ag) | 1.32E-05 | kg |
| | Copper - Molybdenum - Gold - Silver - ore (1,13% Cu; 0,02% Mo; 0,01 g/t Au; 2,86 g/t Ag) | 1.77E-03 | kg |
| | Copper - Silver - ore (3,3% Cu; 5,5 g/t Ag) | 9.12E-06 | kg |
| | Copper ore (0.14%) | 7.55E-04 | kg |
| | Copper ore (1.2%) | 2.18E-04 | kg |
| | Copper ore (4%) | 1.15E-13 | kg |
| | Copper ore (sulphidic, 1.1%) | 1.37E-10 | kg |
| | Dolomite | 3.17E-07 | kg |
| | Feldspar (aluminum silicates) | 1.49E-04 | kg |
| | Ferro manganese | 8.82E-16 | kg |
| | Fluorspar (calcium fluoride; fluorite) | 5.42E-06 | kg |
| | Graphite | 3.30E-06 | kg |
| | Gypsum (natural gypsum) | 3.61E-03 | kg |
| | Heavy spar (BaSO4) | 3.20E-02 | kg |
| | Ilmenite (titanium ore) | 2.84E-08 | kg |
| | Inert rock | 9.48E+01 | kg |
| | Iron ore (56,86%) | 1.81E-02 | kg |
| | Iron ore (65%) | 1.52E-05 | kg |

| | | | |
|---|---|---|---|
| | Kaolin ore | 5.52E-06 | kg |
| | Lead - Zinc - Silver - ore (5,49% Pb; 12,15% Zn; 57,4 gpt Ag) | 3.15E-06 | kg |
| | Lead - zinc ore (4.6%-0.6%) | 2.69E-03 | kg |
| | Limestone (calcium carbonate) | 2.93E-01 | kg |
| | Magnesit (Magnesium carbonate) | 1.23E-06 | kg |
| | Magnesium chloride leach (40%) | 8.04E-04 | kg |
| | Manganese ore | 4.75E-05 | kg |
| | Manganese ore (R.O.M.) | 5.62E-04 | kg |
| | Molybdenite (Mo 0,24%) | 1.08E-03 | kg |
| | Natural Aggregate | 6.36E-01 | kg |
| | Nickel ore (1,5%) | 5.81E-03 | kg |
| | Nickel ore (1.6%) | 2.17E-03 | kg |
| | Olivine | 9.70E-15 | kg |
| | Peat | 2.38E-05 | kg |
| | Perlite (Rhyolithe) | 2.19E-03 | kg |
| | Phosphate ore | 1.50E-05 | kg |
| | Phosphorus minerals | 2.99E-07 | kg |
| | Phosphorus ore (29% P2O5) | 5.55E-06 | kg |
| | Potashsalt, crude (hard salt, 10% K2O) | 3.90E-05 | kg |
| | Potassium chloride | 1.22E-06 | kg |
| | Precious metal ore (R.O.M) | 8.45E-05 | kg |
| | Quartz sand (silica sand; silicon dioxide) | 2.15E-02 | kg |
| | Raw pumice | 5.70E-07 | kg |
| | Slate | 1.63E-14 | kg |
| | Sodium chloride (rock salt) | 1.20E-02 | kg |
| | Sodium sulphate | 1.11E-07 | kg |
| | Soil | 2.46E-01 | kg |
| | Sulphur (bonded) | 1.72E-09 | kg |
| | Talc | 1.97E-07 | kg |
| | Tin ore | 1.57E-14 | kg |
| | Titanium ore | 1.46E-02 | kg |
| | Zinc - copper ore (4.07%-2.59%) | 1.01E-03 | kg |
| | Zinc - lead - copper ore (12%-3%-2%) | 5.71E-04 | kg |
| | Zinc - Lead - Silver - ore (8,54% Zn; 5,48% Pb; 94 g/t Ag) | 4.95E-06 | kg |
| | Zinc - lead ore (4.21%-4.96%) | 3.94E-14 | kg |
| | Zinc ore (sulphidic, 4%) | 1.73E-13 | kg |
| *Renewable resources* | | | |
| | Water | 2.17E+02 | kg |
| | Air | 1.19E+02 | kg |
| | Carbon dioxide | 9.36E-01 | kg |

| | | | | |
|---|---|---|---|---|
| **Emissions to air** | | | | |
| | | Organic emissions to air (group VOC) | 4.34E-18 | kg |
| | | Halogenated organic emissions to air | 4.34E-18 | kg |
| | | | | |

| **OUTPUTS** | | | | |
|---|---|---|---|---|
| **Flow categories** | **Flows** | | | |
| **Material resources** | | | | |
| | *Renewable resources* | | | |
| | | Water | 1.59E+02 | kg |
| | | Nitrogen | 6.32E-04 | kg |
| | | Oxygen | 6.85E-01 | kg |
| **Emissions to air** | | | | |
| | *Heavy metals to air* | | | |
| | | Antimony | 3.18E-07 | kg |
| | | Arsenic (+V) | 1.06E-06 | kg |
| | | Arsenic trioxide | 1.84E-12 | kg |
| | | Cadmium (+II) | 1.08E-07 | kg |
| | | Chromium (+III) | 3.72E-09 | kg |
| | | Chromium (+VI) | 2.61E-10 | kg |
| | | Chromium (unspecified) | 7.34E-07 | kg |
| | | Cobalt | 2.46E-07 | kg |
| | | Copper (+II) | 1.32E-06 | kg |
| | | Heavy metals to air (unspecified) | 1.24E-09 | kg |
| | | Hydrogen arsenic (arsine) | 1.53E-10 | kg |
| | | Iron | 1.38E-07 | kg |
| | | Lanthanides | 1.49E-11 | kg |
| | | Lead (+II) | 2.89E-06 | kg |
| | | Manganese (+II) | 1.98E-06 | kg |
| | | Mercury (+II) | 5.23E-07 | kg |
| | | Molybdenum | 9.21E-09 | kg |
| | | Nickel (+II) | 1.75E-06 | kg |
| | | Palladium | 5.13E-16 | kg |
| | | Rhodium | 4.95E-16 | kg |
| | | Selenium | 4.14E-06 | kg |
| | | Silver | 8.56E-15 | kg |
| | | Tellurium | 3.74E-10 | kg |
| | | Thallium | 2.44E-09 | kg |
| | | Tin (+IV) | 6.61E-07 | kg |
| | | Titanium | 9.63E-10 | kg |

| | | | |
|---|---|---|---|
| | Vanadium (+III) | 9.99E-06 | kg |
| | Zinc (+II) | 1.07E-05 | kg |
| *Inorganic emissions to air* | | | |
| | Ammonia | 7.99E-05 | kg |
| | Ammonium | 5.64E-07 | kg |
| | Ammonium nitrate | 1.01E-11 | kg |
| | Argon | 6.97E-16 | kg |
| | Barium | 3.29E-05 | kg |
| | Beryllium | 3.21E-08 | kg |
| | Boron | 6.22E-14 | kg |
| | Boron compounds (unspecified) | 6.50E-05 | kg |
| | Bromine | 1.98E-05 | kg |
| | Carbon dioxide | 2.55E+01 | kg |
| | Carbon dioxide (biotic) | 1.96E-04 | kg |
| | Carbon dioxide (biotic) | 1.41E-02 | kg |
| | Carbon disulphide | 1.40E-09 | kg |
| | Carbon monoxide | 2.25E-02 | kg |
| | Chloride (unspecified) | 9.79E-07 | kg |
| | Chlorine | 3.92E-07 | kg |
| | Cyanide (unspecified) | 6.96E-08 | kg |
| | Fluoride | 8.38E-06 | kg |
| | Fluorides | 1.14E-07 | kg |
| | Fluorine | 7.02E-10 | kg |
| | Helium | 7.84E-08 | kg |
| | Hydrazine (H2N4) | 1.51E-13 | kg |
| | Hydrogen | 1.68E-05 | kg |
| | Hydrogen bromine (hydrobromic acid) | 1.77E-09 | kg |
| | Hydrogen chloride | 1.96E-03 | kg |
| | Hydrogen cyanide (prussic acid) | 2.43E-09 | kg |
| | Hydrogen fluoride | 2.97E-04 | kg |
| | Hydrogen iodide | 1.39E-12 | kg |
| | Hydrogen phosphorous | 6.82E-11 | kg |
| | Hydrogen sulphide | 5.25E-05 | kg |
| | Lead dioxide | 8.93E-11 | kg |
| | Magnesium | 2.12E-08 | kg |
| | Nitrogen (atmospheric nitrogen) | 3.39E-02 | kg |
| | Nitrogen dioxide | 1.02E-07 | kg |
| | Nitrogen monoxide | 2.61E-08 | kg |
| | Nitrogen oxides | 6.17E-02 | kg |
| | Nitrous oxide (laughing gas) | 3.87E-04 | kg |
| | Oxygen | 1.62E-02 | kg |

| | | | | |
|---|---|---|---|---|
| | | Scandium | 6.96E-12 | kg |
| | | Steam | 6.57E+01 | kg |
| | | Strontium | 2.82E-10 | kg |
| | | Sulphur dioxide | 9.71E-02 | kg |
| | | Sulphur hexafluoride | 6.10E-09 | kg |
| | | Sulphuric acid | 1.42E-08 | kg |
| | | Tin oxide | 7.77E-12 | kg |
| | | Zinc oxide | 1.55E-11 | kg |
| | | Zinc sulphate | 3.82E-09 | kg |
| | *Organic emissions to air (group VOC)* | | | |
| | | Anthracene | 4.53E-10 | kg |
| | | Benzo{a}anthracene | 2.28E-10 | kg |
| | | Benzo{a}pyrene | 1.86E-09 | kg |
| | | Benzo{ghi}perylene | 2.03E-10 | kg |
| | | Benzofluoranthene | 4.07E-10 | kg |
| | | Chrysene | 5.60E-10 | kg |
| | | Dibenz(a)anthracene | 1.27E-10 | kg |
| | | Indeno[1,2,3-cd]pyrene | 1.51E-10 | kg |
| | | Naphthalene | 4.79E-08 | kg |
| | | Phenanthrene | 1.49E-08 | kg |
| | | Polycyclic aromatic hydrocarbons (PAH) | 7.87E-07 | kg |
| | | 1,1,1-Trichloroethane | 7.74E-12 | kg |
| | | 1,2-Dibromoethane | 1.06E-15 | kg |
| | | bromoform (US LCI) | 3.45E-14 | kg |
| | | Carbon tetrachloride (tetrachloromethane) | 1.08E-12 | kg |
| | | Chlorobenzene | 1.95E-14 | kg |
| | | Chloromethane (methyl chloride) | 4.69E-13 | kg |
| | | Chlorotoluene (Benzylchloride) | 6.20E-13 | kg |
| | | Dichloroethane (1,2-Dichloroethane) | 3.54E-14 | kg |
| | | Dichloromethane (methylene chloride) | 1.80E-09 | kg |
| | | Dioxins (unspec.) | 1.39E-14 | kg |
| | | Ethyl chloride | 3.72E-14 | kg |
| | | Halogenated hydrocarbons (unspecified) | 3.55E-15 | kg |
| | | Methyl bromide | 1.42E-13 | kg |
| | | Polychlorinated biphenyls (PCB unspecified) | 3.40E-10 | kg |
| | | Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) | 2.87E-12 | kg |
| | | R 11 (trichlorofluoromethane) | 2.37E-06 | kg |
| | | R 113 (trichlorofluoroethane) | 3.48E-15 | kg |
| | | R 114 (dichlorotetrafluoroethane) | 2.43E-06 | kg |
| | | R 116 (hexafluoroethane) | 7.01E-10 | kg |

| | | | |
|---|---|---|---|
| | R 12 (dichlorodifluoromethane) | 5.10E-07 | kg |
| | R 13 (chlorotrifluoromethane) | 3.20E-07 | kg |
| | R 22 (chlorodifluoromethane) | 5.58E-07 | kg |
| | Tetrachloroethene (perchloroethylene) | 1.02E-10 | kg |
| | Tetrafluoromethane | 2.29E-08 | kg |
| | Trichloroethene (isomers) | 7.47E-14 | kg |
| | Trichloromethane (chloroform) | 5.23E-14 | kg |
| | Vinyl chloride (VCM; chloroethene) | 1.04E-08 | kg |
| | 2,4-Dinitrotoluene | 2.48E-16 | kg |
| | Acentaphthene | 9.85E-13 | kg |
| | Acetaldehyde (Ethanal) | 4.35E-06 | kg |
| | Acetic acid | 2.12E-05 | kg |
| | Acetone (dimethylcetone) | 4.31E-06 | kg |
| | Acrolein | 3.84E-09 | kg |
| | Acrylonitrile | 1.55E-06 | kg |
| | Aldehyde (unspecified) | 5.96E-06 | kg |
| | Alkane (unspecified) | 8.81E-05 | kg |
| | Alkene (unspecified) | 7.24E-05 | kg |
| | Aromatic hydrocarbons (unspecified) | 1.65E-06 | kg |
| | Benzene | 1.60E-05 | kg |
| | Biphenyl | 3.28E-12 | kg |
| | Butadiene | 1.55E-06 | kg |
| | Butane | 1.74E-04 | kg |
| | Butane (n-butane) | 4.27E-05 | kg |
| | Butanone (methyl ethyl ketone) | 2.08E-08 | kg |
| | Cumene (isopropylbenzene) | 6.91E-13 | kg |
| | Cyclohexane (hexahydro benzene) | 3.21E-08 | kg |
| | Diethylamine | 7.24E-12 | kg |
| | Dioctylphthalate (DOP) | 6.47E-14 | kg |
| | Ethane | 5.66E-04 | kg |
| | Ethanol | 9.80E-06 | kg |
| | Ethene (ethylene) | 5.84E-08 | kg |
| | Ethyl benzene | 7.16E-05 | kg |
| | Fluoranthene | 1.48E-09 | kg |
| | Fluorene | 4.68E-09 | kg |
| | Formaldehyde (methanal) | 6.50E-05 | kg |
| | Furan | 8.79E-15 | kg |
| | Heptane (isomers) | 3.17E-06 | kg |
| | Hexamethylene diamine (HMDA) | 4.31E-12 | kg |
| | Hexane (isomers) | 5.41E-06 | kg |
| | Isoprene | 4.91E-06 | kg |
| | Mercaptan (unspecified) | 1.12E-07 | kg |

| | | | | |
|---|---|---|---|---|
| | | Methacrylate | 5.94E-09 | kg |
| | | Methacrylic acid | 1.77E-14 | kg |
| | | Methanol | 8.26E-06 | kg |
| | | Methyl methacrylate (MMA) | 9.14E-07 | kg |
| | | NMVOC (unspecified) | 1.93E-03 | kg |
| | | Octane | 1.75E-06 | kg |
| | | ortho-Cresol | 8.83E-09 | kg |
| | | para-Cresol | 9.53E-09 | kg |
| | | Pentane (n-pentane) | 1.66E-04 | kg |
| | | Phenol (hydroxy benzene) | 5.45E-09 | kg |
| | | Propane | 8.17E-04 | kg |
| | | Propene (propylene) | 6.51E-06 | kg |
| | | Propionaldehyde | 3.37E-13 | kg |
| | | Propionic acid (propane acid) | 5.08E-11 | kg |
| | | Styrene | 3.11E-06 | kg |
| | | Toluene (methyl benzene) | 3.29E-05 | kg |
| | | Trimethylbenzene | 7.58E-11 | kg |
| | | Vinyl acetat | 6.73E-15 | kg |
| | | Xylene (dimethyl benzene) | 3.00E-04 | kg |
| | | Hydrocarbons (unspecified) | 3.21E-08 | kg |
| | | Methane | 2.63E-02 | kg |
| | | Organic chlorine compounds | 5.06E-12 | kg |
| | | Polycyclic hydrocarbons | 9.84E-27 | kg |
| | | VOC (unspecified) | 1.59E-03 | kg |
| | *Other emissions to air* | | | |
| | | Exhaust | 9.93E+01 | kg |
| | | Used air | 6.82E-01 | kg |
| | *Particles to air* | | | |
| | | Dust (> PM10) | 8.54E-09 | kg |
| | | Dust (PM10) | 5.60E-04 | kg |
| | | Dust (PM2,5 - PM10) | 5.49E-06 | kg |
| | | Dust (PM2.5) | 3.97E-03 | kg |
| | | Dust (unspecified) | 2.66E-03 | kg |
| | | Metals (unspecified) | 6.89E-11 | kg |
| | | Tar | 1.69E-13 | kg |
| | | Wood (dust) | 2.87E-09 | kg |
| | *Radioactive emissions to air* | | | |
| | | Uranium (total) | 2.78E-06 | kg |
| **Emissions to fresh water** | | | | |

| | | | | |
|---|---|---|---|---|
| | *Analytical measures to fresh water* | | | |
| | | Adsorbable organic halogen compounds (AOX) | 1.20E-06 | kg |
| | | Biological oxygen demand (BOD) | 3.79E-04 | kg |
| | | Chemical oxygen demand (COD) | 7.04E-03 | kg |
| | | Solids (dissolved) | 1.41E-02 | kg |
| | | Total dissolved organic bounded carbon | 2.17E-08 | kg |
| | | Total organic bounded carbon | 7.25E-05 | kg |
| | *Heavy metals to fresh water* | | | |
| | | Antimony | 1.66E-08 | kg |
| | | Arsenic (+V) | 6.83E-07 | kg |
| | | Cadmium (+II) | 1.35E-06 | kg |
| | | Chromium (+III) | 1.22E-05 | kg |
| | | Chromium (+VI) | 5.31E-09 | kg |
| | | Chromium (unspecified) | 1.30E-06 | kg |
| | | Cobalt | 3.02E-09 | kg |
| | | Copper (+II) | 2.69E-06 | kg |
| | | Heavy metals to water (unspecified) | 9.83E-09 | kg |
| | | Iron | 8.66E-03 | kg |
| | | Lead (+II) | 6.76E-06 | kg |
| | | Manganese (+II) | 2.62E-05 | kg |
| | | Mercury (+II) | 3.24E-08 | kg |
| | | Molybdenum | 6.37E-06 | kg |
| | | Nickel (+II) | 1.54E-06 | kg |
| | | Selenium | 1.09E-06 | kg |
| | | Silver | 6.57E-07 | kg |
| | | Strontium | 3.97E-05 | kg |
| | | Thallium | 3.55E-09 | kg |
| | | Tin (+IV) | 7.57E-08 | kg |
| | | Titanium | 9.75E-07 | kg |
| | | Vanadium (+III) | 2.12E-06 | kg |
| | | Zinc (+II) | 2.46E-06 | kg |
| | *Inorganic emissions to fresh water* | | | |
| | | Acid (calculated as H+) | 5.68E-07 | kg |
| | | Aluminum (+III) | 2.40E-04 | kg |
| | | Ammonia | 6.51E-06 | kg |
| | | Ammonium / ammonia | 1.29E-04 | kg |
| | | Barium | 3.65E-04 | kg |
| | | Beryllium | 1.30E-08 | kg |
| | | Boron | 2.36E-05 | kg |

| | | | |
|---|---|---|---|
| | Bromine | 6.58E-05 | kg |
| | Calcium (+II) | 5.17E-03 | kg |
| | Carbonate | 8.85E-05 | kg |
| | Chloride | 6.81E-02 | kg |
| | Chlorine (dissolved) | 2.97E-04 | kg |
| | Cyanide | 2.28E-07 | kg |
| | Fluoride | 1.02E-02 | kg |
| | Fluorine | 3.01E-08 | kg |
| | Hydrogen chloride | 2.28E-03 | kg |
| | Hydrogen cyanide (prussic acid) | 5.10E-11 | kg |
| | Hydrogen fluoride (hydrofluoric acid) | 5.39E-10 | kg |
| | Hydroxide | 4.97E-07 | kg |
| | Inorganic salts and acids (unspecified) | 9.67E-16 | kg |
| | Lithium | 1.57E-05 | kg |
| | Magnesium (+III) | 7.29E-04 | kg |
| | Magnesium chloride | 2.38E-07 | kg |
| | Magnesium ion (+II) | 1.93E-04 | kg |
| | Metal ions (unspecific) | 1.92E-06 | kg |
| | Metals (unspecified) | 2.29E-29 | kg |
| | Neutral salts | 5.84E-09 | kg |
| | Nitrate | 3.90E-04 | kg |
| | Nitric acid | 9.57E-11 | kg |
| | Nitrogen | 3.31E-06 | kg |
| | Nitrogen (as total N) | 1.93E-08 | kg |
| | Nitrogen organic bounded | 7.88E-06 | kg |
| | Phosphate | 3.04E-06 | kg |
| | Phosphorus | 7.07E-07 | kg |
| | Potassium | 1.42E-06 | kg |
| | Silicate particles | 1.08E-10 | kg |
| | Sodium (+I) | 1.43E-02 | kg |
| | Sodium chloride (rock salt) | 4.23E-08 | kg |
| | Sodium hypochlorite | 2.29E-08 | kg |
| | Sodium sulphate | 1.35E-05 | kg |
| | Sulphate | 3.66E-02 | kg |
| | Sulphide | 1.41E-05 | kg |
| | Sulphite | 6.78E-06 | kg |
| | Sulphur | 1.01E-06 | kg |
| | Sulphuric acid | 3.68E-07 | kg |
| *Organic emissions to fresh water* | | | |
| | 1,2-Dibromoethane | 7.55E-12 | kg |
| | Chlorinated hydrocarbons (unspecified) | 9.19E-15 | kg |

| | | | | |
|---|---|---|---|---|
| | | Chloromethane (methyl chloride) | 3.38E-09 | kg |
| | | Dichloropropane | 3.46E-15 | kg |
| | | Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) | 2.47E-19 | kg |
| | | Vinyl chloride (VCM; chloroethene) | 1.32E-10 | kg |
| | | Acenaphthene | 2.57E-10 | kg |
| | | Acenaphthylene | 1.04E-10 | kg |
| | | Acetic acid | 6.93E-08 | kg |
| | | Acrylonitrile | 7.77E-07 | kg |
| | | Anthracene | 3.63E-10 | kg |
| | | Aromatic hydrocarbons (unspecified) | 4.28E-07 | kg |
| | | Benzene | 1.02E-06 | kg |
| | | Benzo{a}anthracene | 3.62E-11 | kg |
| | | Benzo{a}pyrene | 1.31E-10 | kg |
| | | Benzofluoranthene | 2.13E-11 | kg |
| | | Chrysene | 1.66E-10 | kg |
| | | Cresol (methyl phenol) | 5.13E-09 | kg |
| | | Ethyl benzene | 5.52E-08 | kg |
| | | Fluoranthene | 5.34E-11 | kg |
| | | Formaldehyde (methanal) | 2.07E-10 | kg |
| | | Hexane (isomers) | 5.65E-10 | kg |
| | | Hydrocarbons (unspecified) | 4.34E-06 | kg |
| | | Methanol | 1.32E-05 | kg |
| | | Oil (unspecified) | 2.70E-04 | kg |
| | | Phenanthrene | 8.53E-11 | kg |
| | | Phenol (hydroxy benzene) | 7.61E-07 | kg |
| | | Polycyclic aromatic hydrocarbons (PAH, unspec.) | 2.44E-05 | kg |
| | | Toluene (methyl benzene) | 8.05E-07 | kg |
| | | VOC (unspecified) | 3.83E-07 | kg |
| | | Xylene (isomers; dimethyl benzene) | 4.83E-07 | kg |
| | | Xylene (meta-Xylene; 1,3-Dimethylbenzene) | 9.30E-09 | kg |
| | | Acetone (dimethylcetone) | 3.07E-09 | kg |
| | | Biphenyl | 9.40E-10 | kg |
| | | Carbon, organically bound | 4.33E-05 | kg |
| | | Mineral oil (tetradecane) | 7.44E-09 | kg |
| | | Naphthalene | 2.47E-08 | kg |
| | | Organic chlorine compounds (unspecified) | 5.09E-12 | kg |
| | | Organic compounds (dissolved) | 7.32E-10 | kg |
| | | Organic compounds (unspecified) | 5.02E-11 | kg |
| | *Other emissions to fresh water* | | | |

| | | | | |
|---|---|---|---|---|
| | | Detergent (unspecified) | 2.58E-07 | kg |
| | | Waste water | 2.88E-02 | kg |
| | *Particles to fresh water* | | | |
| | | Metals (unspecified) | 2.48E-10 | kg |
| | | Soil loss by erosion into water | 4.38E-05 | kg |
| | | Solids (suspended) | 3.18E-02 | kg |
| | | Suspended solids, unspecified | 1.59E-06 | kg |
| **Emissions to sea water** | | | | |
| | *Analytical measures to sea water* | | | |
| | | Adsorbable organic halogen compounds (AOX) | 2.36E-12 | kg |
| | | Biological oxygen demand (BOD) | 2.60E-06 | kg |
| | | Chemical oxygen demand (COD) | 4.78E-05 | kg |
| | | Total organic bounded carbon | 2.60E-06 | kg |
| | *Heavy metals to sea water* | | | |
| | | Arsenic (+V) | 1.93E-07 | kg |
| | | Cadmium (+II) | 2.44E-07 | kg |
| | | Chromium (unspecified) | 4.95E-07 | kg |
| | | Cobalt | 8.92E-08 | kg |
| | | Copper (+II) | 4.19E-07 | kg |
| | | Iron | 1.20E-06 | kg |
| | | Lead (+II) | 9.65E-08 | kg |
| | | Manganese (+II) | 1.25E-07 | kg |
| | | Mercury (+II) | 1.61E-09 | kg |
| | | Molybdenum | 1.48E-09 | kg |
| | | Nickel (+II) | 1.74E-07 | kg |
| | | Silver | 4.39E-09 | kg |
| | | Strontium | 3.57E-06 | kg |
| | | Tin (+IV) | 5.26E-09 | kg |
| | | Titanium | 5.36E-10 | kg |
| | | Vanadium (+III) | 5.72E-08 | kg |
| | | Zinc (+II) | 1.65E-06 | kg |
| | *Inorganic emissions to sea water* | | | |
| | | Aluminum (+III) | 1.72E-08 | kg |
| | | Ammonia | 5.13E-07 | kg |
| | | Barium | 4.51E-06 | kg |
| | | Beryllium | 4.63E-09 | kg |
| | | Boron | 2.79E-07 | kg |

| | | | | |
|---|---|---|---|---|
| | | Calcium (+II) | 3.05E-05 | kg |
| | | Carbonate | 2.84E-04 | kg |
| | | Chloride | 2.25E-02 | kg |
| | | Magnesium | 7.81E-06 | kg |
| | | Nitrate | 3.68E-07 | kg |
| | | Sodium (+I) | 5.19E-05 | kg |
| | | Sulphate | 1.20E-04 | kg |
| | | Sulphide | 5.16E-05 | kg |
| | | Sulphur | 1.49E-07 | kg |
| | *Organic emissions to sea water* | | | |
| | | Acenaphthene | 4.18E-09 | kg |
| | | Acenaphthylene | 1.60E-09 | kg |
| | | Acetic acid | 2.71E-09 | kg |
| | | Anthracene | 1.40E-09 | kg |
| | | Aromatic hydrocarbons (unspecified) | 2.60E-08 | kg |
| | | Benzene | 1.17E-06 | kg |
| | | Benzo{a}anthracene | 9.15E-10 | kg |
| | | Benzofluoranthene | 9.97E-10 | kg |
| | | Chrysene | 5.13E-09 | kg |
| | | Cresol (methyl phenol) | 3.87E-09 | kg |
| | | Ethyl benzene | 9.77E-08 | kg |
| | | Fluoranthene | 1.08E-09 | kg |
| | | Hexane (isomers) | 4.22E-10 | kg |
| | | Oil (unspecified) | 9.25E-06 | kg |
| | | Phenol (hydroxy benzene) | 1.93E-06 | kg |
| | | Toluene (methyl benzene) | 6.89E-07 | kg |
| | | Xylene (isomers; dimethyl benzene) | 4.86E-07 | kg |
| | | Naphthalene | 1.43E-07 | kg |
| | *Particles to sea water* | | | |
| | | Solids (suspended) | 2.07E-03 | kg |
| **Emissions to agricultural soil** | | | | |
| | *Heavy metals to agricultural soil* | | | |
| | | Cadmium (+II) | 1.11E-11 | kg |
| | | Chromium (+III) | 7.23E-10 | kg |
| | | Copper (+II) | 7.23E-10 | kg |
| | | Lead (+II) | 1.08E-09 | kg |
| | | Mercury (+II) | 7.23E-12 | kg |
| | | Nickel (+II) | 3.62E-10 | kg |
| | | Zinc (+II) | 2.89E-09 | kg |

| | | | | |
|---|---|---|---|---|
| **Emissions to industrial soil** | | | | |
| | *Heavy metals to industrial soil* | | | |
| | | Antimony | 9.85E-13 | kg |
| | | Arsenic (+V) | 1.86E-10 | kg |
| | | Cadmium (+II) | 2.01E-09 | kg |
| | | Chromium (+III) | 5.66E-10 | kg |
| | | Chromium (+VI) | 3.43E-12 | kg |
| | | Chromium (unspecified) | 2.11E-07 | kg |
| | | Cobalt | 2.41E-09 | kg |
| | | Copper (+II) | 3.00E-09 | kg |
| | | Iron | 1.52E-06 | kg |
| | | Lead (+II) | 3.78E-10 | kg |
| | | Manganese (+II) | 2.24E-07 | kg |
| | | Mercury (+II) | 3.40E-12 | kg |
| | | Nickel (+II) | 7.31E-07 | kg |
| | | Selenium | 5.04E-12 | kg |
| | | Strontium | 2.82E-05 | kg |
| | | Zinc (+II) | 4.42E-08 | kg |
| | *Inorganic emissions to industrial soil* | | | |
| | | Aluminum (+III) | 4.92E-07 | kg |
| | | Ammonia | 6.09E-05 | kg |
| | | Beryllium | 2.15E-17 | kg |
| | | Bromide | 1.04E-08 | kg |
| | | Calcium (+II) | 9.37E-05 | kg |
| | | Chloride | 2.14E-05 | kg |
| | | Chlorine | 3.39E-09 | kg |
| | | Fluoride | 3.46E-07 | kg |
| | | Magnesium (+III) | 1.30E-05 | kg |
| | | Phosphorus | 6.11E-06 | kg |
| | | Potassium (+I) | 3.69E-05 | kg |
| | | Sodium (+I) | 8.89E-06 | kg |
| | | Sulphate | 5.55E-06 | kg |
| | | Sulphide | 3.33E-05 | kg |
| | *Organic emissions to industrial soil* | | | |
| | | Oil (unspecified) | 5.39E-05 | kg |
| | | Polycyclic aromatic hydrocarbons (unspecified) | 4.25E-11 | kg |

# APPENDIX E. LCIA CHARACTERIZATION FACTORS

**Primary Energy Demand (non renewable)**

| *Flow* | *1 MJ = ** | *Unit* | *1 [Flow] = * MJ* |
|---|---|---|---|
| **Crude oil [Crude oil (resource)]** | 2.36E-02 | kg | 4.23E+01 |
| **Hard coal [Hard coal (resource)]** | 3.80E-02 | kg | 2.63E+01 |
| **Lignite [Lignite (resource)]** | 8.42E-02 | kg | 1.19E+01 |
| **Natural gas [Natural gas (resource)]** | 2.27E-02 | kg | 4.41E+01 |
| **Nuclear energy [Uranium (resource)]** | 1.00E+00 | MJ | 1.00E+00 |
| **Peat [Non renewable resources]** | 1.19E-01 | kg | 8.40E+00 |
| **Pit gas [Natural gas (resource)]** | 2.23E-02 | kg | 4.48E+01 |
| **Pit Methane [Natural gas (resource)]** | 2.01E-02 | kg | 4.98E+01 |
| **Raw hardcoal [Hard coal (resource)]** | 5.56E-02 | kg | 1.80E+01 |
| **Raw lignite [Lignite (resource)]** | 1.25E-01 | kg | 8.00E+00 |
| **Sulphur [Non renewable elements]** | 1.08E-01 | kg | 9.26E+00 |
| **Sulphur (bonded) [Non renewable resources]** | 1.08E-01 | kg | 9.26E+00 |
| **Uranium free ore [Uranium (resource)]** | 2.22E-06 | kg | 4.51E+05 |
| **Uranium natural [Uranium (resource)]** | 1.79E-06 | kg | 5.60E+05 |
| **Crude oil [Crude oil (resource)]** | 2.36E-02 | kg | 4.23E+01 |
| **Hard coal [Hard coal (resource)]** | 3.80E-02 | kg | 2.63E+01 |
| **Lignite [Lignite (resource)]** | 8.42E-02 | kg | 1.19E+01 |

**Primary Energy Demand (renewable)**

| *Flow* | *1 MJ = ** | *Unit* | *1 [Flow] = * MJ* |
|---|---|---|---|
| **Biomass [Renewable energy resources]** | 6.83E-02 | kg | 1.47E+01 |
| **Biomass (MJ) [Renewable energy resources]** | 1.00E+00 | MJ | 1.00E+00 |
| **conifer [Materials from renewable raw materials]** | 0.00E+00 | kg | 0.00E+00 |
| **Energy, geothermal, converted [Renewable energy resources]** | 1.00E+00 | MJ | 1.00E+00 |
| **Energy, potential (in hydropower reservoir), converted [Renewable energy resources]** | 1.00E+00 | MJ | 1.00E+00 |
| **Flax long fibre (8% H2O) [Materials from renewable raw materials]** | 6.45E-02 | kg | 1.55E+01 |
| **Flax, Whole plant (field retted, 10% H2O) [Renewable primary products]** | 5.62E-02 | kg | 1.78E+01 |
| **Hemp, Seeds (15% H2O) [Renewable primary products]** | 4.48E-02 | kg | 2.23E+01 |
| **Natural Rubber, Seeds (50% H2O) [Renewable primary products]** | 1.43E-01 | kg | 7.00E+00 |
| **Natural Rubber, Tapped latex, (not conserved, 36%) [Renewable primary products]** | 1.43E-01 | kg | 7.00E+00 |
| **Oil palm, Fruit bunches (20% Palmoil) [Renewable primary products]** | 8.17E-02 | kg | 1.22E+01 |
| **Pine log (44% water content) [Materials from renewable raw materials]** | 5.81E-02 | kg | 1.72E+01 |

| | | | |
|---|---|---|---|
| Pine log (79% humidity / 44% moisture content) [Materials from renewable raw materials] | 1.02E-01 | kg | 9.80E+00 |
| Primary energy from geothermics [Renewable energy resources] | 1.00E+00 | MJ | 1.00E+00 |
| Primary energy from hydro power [Renewable energy resources] | 1.00E+00 | MJ | 1.00E+00 |
| Primary energy from solar energy [Renewable energy resources] | 1.00E+00 | MJ | 1.00E+00 |
| Primary energy from waves [Renewable energy resources] | 1.00E+00 | MJ | 1.00E+00 |
| Primary energy from wind power [Renewable energy resources] | 1.00E+00 | MJ | 1.00E+00 |
| Renewable fuels [Renewable energy resources] | 6.67E-02 | kg | 1.50E+01 |
| Sisal, Leaves (4% Fibre) [Renewable primary products] | 7.19E-01 | kg | 1.39E+00 |
| Soy bean, Beans (13% H2O) [Renewable primary products] | 6.17E-02 | kg | 1.62E+01 |
| Spruce log (44% water content) [Materials from renewable raw materials] | 5.81E-02 | kg | 1.72E+01 |
| Spruce log (79% humidity / 44% moisture content) [Materials from renewable raw materials] | 1.02E-01 | kg | 9.80E+00 |
| Wood [Renewable energy resources] | 6.83E-02 | kg | 1.47E+01 |

**TRACI, Acidification Air [mol H+ Equiv.]**

| *Flow* | *1 mol H+ Equiv. = ** | *Unit* | *1 [Flow] = * mol H+ Equiv.* |
|---|---|---|---|
| Ammonia [Inorganic emissions to air] | 1.05E-02 | kg | 9.55E+01 |
| Hydrogen chloride [Inorganic emissions to air] | 2.24E-02 | kg | 4.47E+01 |
| Hydrogen fluoride [Inorganic emissions to air] | 1.23E-02 | kg | 8.13E+01 |
| Nitrogen dioxide [Inorganic emissions to air] | 2.50E-02 | kg | 4.00E+01 |
| Nitrogen monoxide [Inorganic emissions to air] | 1.63E-02 | kg | 6.13E+01 |
| Nitrogen oxides [Inorganic emissions to air] | 2.50E-02 | kg | 4.00E+01 |
| Sulphur dioxide [Inorganic emissions to air] | 1.97E-02 | kg | 5.08E+01 |

**TRACI, Eutrophication [kg N-Equiv.]**

| *Flow* | *1 kg N-Equiv. = ** | *Unit* | *1 [Flow] = ** |
|---|---|---|---|
| Ammonia [Inorganic emissions to air] | 8.43E+00 | kg | 1.19E-01 |
| Ammonium / ammonia [Inorganic emissions to fresh water] | 1.28E+00 | kg | 7.79E-01 |
| Biological oxygen demand (BOD) [Analytical measures to fresh water] | 2.00E+01 | kg | 5.00E-02 |
| Biological oxygen demand (BOD) [Analytical measures to sea water] | 2.00E+01 | kg | 5.00E-02 |
| Chemical oxygen demand (COD) [Analytical measures to sea water] | 2.00E+01 | kg | 5.00E-02 |
| Chemical oxygen demand (COD) [Analytical measures to fresh water] | 2.00E+01 | kg | 5.00E-02 |
| Nitrate [Inorganic emissions to sea water] | 4.22E+00 | kg | 2.37E-01 |
| Nitrate [Inorganic emissions to fresh water] | 4.22E+00 | kg | 2.37E-01 |
| Nitrogen [Inorganic emissions to fresh water] | 1.01E+00 | kg | 9.86E-01 |
| Nitrogen dioxide [Inorganic emissions to air] | 2.26E+01 | kg | 4.43E-02 |
| Nitrogen monoxide [Inorganic emissions to air] | 1.46E+01 | kg | 6.86E-02 |

| | | | |
|---|---|---|---|
| **Nitrogen oxides [Inorganic emissions to air]** | 2.26E+01 | kg | 4.43E-02 |
| **Phosphate [Inorganic emissions to fresh water]** | 4.20E-01 | kg | 2.38E+00 |
| **Phosphorus [Inorganic emissions to fresh water]** | 1.37E-01 | kg | 7.29E+00 |

| **CML2001 - Nov. 09, Global Warming Potential (GWP 100 years)** | ***1 kg CO2-Equiv. = **** | ***Unit*** | ***1 [Flow] = **** |
|---|---|---|---|
| **1,1,1-Trichloroethane [Halogenated organic emissions to air]** | 6.85E-03 | kg | 1.46E+02 |
| **Carbon dioxide [Inorganic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |
| **Carbon dioxide [Renewable resources]** | 1.00E+00 | kg | 1.00E+00 |
| **Carbon dioxide (biotic) [Inorganic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |
| **Carbon tetrachloride (tetrachloromethane) [Halogenated organic emissions to air]** | 7.14E-04 | kg | 1.40E+03 |
| **Chloromethane (methyl chloride) [Halogenated organic emissions to air]** | 7.69E-02 | kg | 1.30E+01 |
| **Dichloromethane (methylene chloride) [Halogenated organic emissions to air]** | 1.15E-01 | kg | 8.70E+00 |
| **Halon (1211) [Halogenated organic emissions to air]** | 5.29E-04 | kg | 1.89E+03 |
| **Halon (1301) [Halogenated organic emissions to air]** | 1.40E-04 | kg | 7.14E+03 |
| **HBFC-2402 (Halon-2402) [Halogenated organic emissions to air]** | 6.10E-04 | kg | 1.64E+03 |
| **HFE 7100 [Halogenated organic emissions to air]** | 3.37E-03 | kg | 2.97E+02 |
| **Hydrocarbons (unspecified) [Organic emissions to air (group VOC)]** | 1.33E-01 | kg | 7.50E+00 |
| **Methane [Organic emissions to air (group VOC)]** | 4.00E-02 | kg | 2.50E+01 |
| **Methyl bromide [Halogenated organic emissions to air]** | 2.00E-01 | kg | 5.00E+00 |
| **Nitrogentriflouride [Inorganic emissions to air]** | 5.81E-05 | kg | 1.72E+04 |
| **Nitrous oxide (laughing gas) [Inorganic emissions to air]** | 3.36E-03 | kg | 2.98E+02 |
| **Perfluoro-2-methylbutane [Halogenated organic emissions to air]** | 1.09E-04 | kg | 9.16E+03 |
| **Perfluorobutane [Halogenated organic emissions to air]** | 1.13E-04 | kg | 8.86E+03 |
| **Perfluorocyclobutane [Halogenated organic emissions to air]** | 9.71E-05 | kg | 1.03E+04 |
| **Perfluorodecalin [Halogenated organic emissions to air]** | 1.33E-04 | kg | 7.50E+03 |
| **Perfluorohexane [Halogenated organic emissions to air]** | 1.08E-04 | kg | 9.30E+03 |
| **Perfluoropentane [Halogenated organic emissions to air]** | 1.12E-04 | kg | 8.90E+03 |
| **Perfluoropolyether (unspecified) [Halogenated organic emissions to air]** | 9.71E-05 | kg | 1.03E+04 |
| **Perfluoropropane [Halogenated organic emissions to air]** | 1.13E-04 | kg | 8.83E+03 |
| **R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]** | 2.11E-04 | kg | 4.75E+03 |
| **R 113 (trichlorofluoroethane) [Halogenated organic emissions to air]** | 1.63E-04 | kg | 6.13E+03 |
| **R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]** | 1.00E-04 | kg | 1.00E+04 |
| **R 115  (chloropentafluoroethane) [Halogenated organic emissions to air]** | 1.36E-04 | kg | 7.37E+03 |
| **R 116 (hexafluoroethane) [Halogenated organic emissions to air]** | 8.20E-05 | kg | 1.22E+04 |
| **R 12 (dichlorodifluoromethane) [Halogenated organic emissions to** | 9.17E-05 | kg | 1.09E+04 |

| | | | |
|---|---|---|---|
| air] | | | |
| R 123 (dichlorotrifluoroethane) [Halogenated organic emissions to air] | 1.30E-02 | kg | 7.70E+01 |
| R 124 (chlorotetrafluoroethane) [Halogenated organic emissions to air] | 1.64E-03 | kg | 6.09E+02 |
| R 125 (pentafluoroethane) [Halogenated organic emissions to air] | 2.86E-04 | kg | 3.50E+03 |
| R 13 (chlorotrifluoromethane) [Halogenated organic emissions to air] | 6.94E-05 | kg | 1.44E+04 |
| R 134 [Halogenated organic emissions to air] | 9.09E-04 | kg | 1.10E+03 |
| R 134a (tetrafluoroethane) [Halogenated organic emissions to air] | 6.99E-04 | kg | 1.43E+03 |
| R 141b (dichloro-1-fluoroethane) [Halogenated organic emissions to air] | 1.38E-03 | kg | 7.25E+02 |
| R 142b (chlorodifluoroethane) [Halogenated organic emissions to air] | 4.33E-04 | kg | 2.31E+03 |
| R 143 (trifluoroethane) [Halogenated organic emissions to air] | 3.03E-03 | kg | 3.30E+02 |
| R 143a (trifluoroethane) [Halogenated organic emissions to air] | 2.24E-04 | kg | 4.47E+03 |
| R 152a (difluoroethane) [Halogenated organic emissions to air] | 8.06E-03 | kg | 1.24E+02 |
| R 22 (chlorodifluoromethane) [Halogenated organic emissions to air] | 5.52E-04 | kg | 1.81E+03 |
| R 225ca (dichloropentafluoropropane) [Halogenated organic emissions to air] | 8.20E-03 | kg | 1.22E+02 |
| R 225cb (dichloropentafluoropentane) [Halogenated organic emissions to air] | 1.68E-03 | kg | 5.95E+02 |
| R 227ea (septifluoropropane) [Halogenated organic emissions to air] | 3.11E-04 | kg | 3.22E+03 |
| R 23 (trifluoromethane) [Halogenated organic emissions to air] | 6.76E-05 | kg | 1.48E+04 |
| R 235da2 [Halogenated organic emissions to air] | 2.86E-03 | kg | 3.50E+02 |
| R 236fa (hexafluoropropane) [Halogenated organic emissions to air] | 1.02E-04 | kg | 9.81E+03 |
| R 245ca (pentafluoropropane) [Halogenated organic emissions to air] | 1.56E-03 | kg | 6.40E+02 |
| R 245fa [Halogenated organic emissions to air] | 9.71E-04 | kg | 1.03E+03 |
| R 41 [Halogenated organic emissions to air] | 1.03E-02 | kg | 9.70E+01 |
| R 43-10 (decafluoropentane) [Halogenated organic emissions to air] | 6.10E-04 | kg | 1.64E+03 |
| R E125 [Halogenated organic emissions to air] | 6.71E-05 | kg | 1.49E+04 |
| R E134 [Halogenated organic emissions to air] | 1.58E-04 | kg | 6.32E+03 |
| R E143a [Halogenated organic emissions to air] | 1.32E-03 | kg | 7.56E+02 |
| R E236ca12 (HG-10) [Halogenated organic emissions to air] | 3.57E-04 | kg | 2.80E+03 |
| R E245cb2 [Halogenated organic emissions to air] | 1.41E-03 | kg | 7.08E+02 |
| R E245fa2 [Halogenated organic emissions to air] | 1.52E-03 | kg | 6.59E+02 |
| R E254cb2 [Halogenated organic emissions to air] | 2.79E-03 | kg | 3.59E+02 |
| R E338pcc13 (HG-01) [Halogenated organic emissions to air] | 6.67E-04 | kg | 1.50E+03 |
| R E347mcc3 [Halogenated organic emissions to air] | 1.74E-03 | kg | 5.75E+02 |
| R E347pcf2 [Halogenated organic emissions to air] | 1.72E-03 | kg | 5.80E+02 |
| R E356pcc3 [Halogenated organic emissions to air] | 9.09E-03 | kg | 1.10E+02 |
| R E43-10pccc124 (H-Galden1040x) [Halogenated organic emissions to air] | 5.35E-04 | kg | 1.87E+03 |

| | | | |
|---|---|---|---|
| **R E569sf2 [Halogenated organic emissions to air]** | 1.69E-02 | kg | 5.90E+01 |
| **R32 (difluoromethane) [Halogenated organic emissions to air]** | 1.48E-03 | kg | 6.75E+02 |
| **Sulphur hexafluoride [Inorganic emissions to air]** | 4.39E-05 | kg | 2.28E+04 |
| **Tetrafluoromethane [Halogenated organic emissions to air]** | 1.35E-04 | kg | 7.39E+03 |
| **Trichloromethane (chloroform) [Halogenated organic emissions to air]** | 3.33E-02 | kg | 3.00E+01 |
| **Trifluoromethyl sulphur pentafluoride [Inorganic emissions to air]** | 5.65E-05 | kg | 1.77E+04 |
| **VOC (unspecified) [Organic emissions to air (group VOC)]** | 1.33E-01 | kg | 7.50E+00 |
| **VOC (unspecified) [Hydrocarbons to fresh water]** | 1.33E-01 | kg | 7.50E+00 |
| **VOC (unspecified) [Hydrocarbons to sea water]** | 1.33E-01 | kg | 7.50E+00 |

**TRACI, Ozone Depletion Air [kg CFC 11-Equiv.]**

| ***Flow*** | *1 kg CFC 11-Equiv. = ** | *Unit* | *1 [Flow] = * kg CFC 11-Equiv.* |
|---|---|---|---|
| **Carbon tetrachloride (tetrachloromethane) [Halogenated organic emissions to air]** | 1.37E+00 | kg | 7.30E-01 |
| **Dichloromonofluoromethane [Halogenated organic emissions to air]** | 2.50E+01 | kg | 4.00E-02 |
| **Halon (1211) [Halogenated organic emissions to air]** | 1.67E-01 | kg | 6.00E+00 |
| **Halon (1301) [Halogenated organic emissions to air]** | 8.33E-02 | kg | 1.20E+01 |
| **HBFC-1201 (Halon-1201) [Halogenated organic emissions to air]** | 1.35E+00 | kg | 7.40E-01 |
| **HBFC-2402 (Halon-2402) [Halogenated organic emissions to air]** | 1.16E-01 | kg | 8.60E+00 |
| **Methyl bromide [Halogenated organic emissions to air]** | 2.63E+00 | kg | 3.80E-01 |
| **R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |
| **R 111 [Halogenated organic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |
| **R 112 [Halogenated organic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |
| **R 113 (trichlorofluoroethane) [Halogenated organic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |
| **R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]** | 1.06E+00 | kg | 9.40E-01 |
| **R 115 (chloropentafluoroethane) [Halogenated organic emissions to air]** | 2.27E+00 | kg | 4.40E-01 |
| **R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |
| **R 123 (dichlorotrifluoroethane) [Halogenated organic emissions to air]** | 5.00E+01 | kg | 2.00E-02 |
| **R 124 (chlorotetrafluoroethane) [Halogenated organic emissions to air]** | 5.00E+01 | kg | 2.00E-02 |
| **R 13 (chlorotrifluoromethane) [Halogenated organic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |
| **R 141b (dichloro-1-fluoroethane) [Halogenated organic emissions to air]** | 8.33E+00 | kg | 1.20E-01 |
| **R 142b (chlorodifluoroethane) [Halogenated organic emissions to air]** | 1.43E+01 | kg | 7.00E-02 |
| **R 21 (Dichlorofluoromethane) [Halogenated organic emissions to air]** | 2.50E+01 | kg | 4.00E-02 |
| **R 211 [Halogenated organic emissions to air]** | 1.00E+00 | kg | 1.00E+00 |

| | | | |
|---|---|---|---|
| R 212 [Halogenated organic emissions to air] | 1.00E+00 | kg | 1.00E+00 |
| R 213 [Halogenated organic emissions to air] | 1.00E+00 | kg | 1.00E+00 |
| R 214 [Halogenated organic emissions to air] | 1.00E+00 | kg | 1.00E+00 |
| R 215 [Halogenated organic emissions to air] | 1.00E+00 | kg | 1.00E+00 |
| R 216 [Halogenated organic emissions to air] | 1.00E+00 | kg | 1.00E+00 |
| R 217 [Halogenated organic emissions to air] | 1.00E+00 | kg | 1.00E+00 |
| R 22 (chlorodifluoromethane) [Halogenated organic emissions to air] | 2.00E+01 | kg | 5.00E-02 |
| R 225ca (dichloropentafluoropropane) [Halogenated organic emissions to air] | 5.00E+01 | kg | 2.00E-02 |
| R 225cb (dichloropentafluoropentane) [Halogenated organic emissions to air] | 3.33E+01 | kg | 3.00E-02 |

TRACI, Smog Air [kg NOx-Equiv.]

| Flow | 1 kg NOx-Equiv. = * | Unit | 1 [Flow] = * kg NOx-Equiv. |
|---|---|---|---|
| 1,2,3-Trimethylbenzene [Group NMVOC to air] | 4.23E+02 | kg | 2.36E-03 |
| 1,2,4-Trimethylbenzene [Group NMVOC to air] | 6.71E+02 | kg | 1.49E-03 |
| 1,2-Butandiol [Group NMVOC to air] | 2.30E+03 | kg | 4.34E-04 |
| 1,3-Dimethylcyclohexane [Halogenated organic emissions to air] | 2.34E+03 | kg | 4.27E-04 |
| 1,3-Dimethylcyclopentane [Halogenated organic emissions to air] | 2.28E+03 | kg | 4.39E-04 |
| 1-Butanol [Group NMVOC to air] | 1.43E+03 | kg | 7.01E-04 |
| 1-Butylbenzene [Group NMVOC to air] | 2.39E+03 | kg | 4.18E-04 |
| 1-Butylene (Vinylacetylene) [Group NMVOC to air] | 4.66E+02 | kg | 2.15E-03 |
| 1-Ethoxy-2-propanol [Group NMVOC to air] | 1.25E+03 | kg | 7.97E-04 |
| 1-Heptanol [Group NMVOC to air] | 2.15E+03 | kg | 4.65E-04 |
| 1-Heptene [Group NMVOC to air] | 9.92E+02 | kg | 1.01E-03 |
| 1-Hexene [Group NMVOC to air] | 7.99E+02 | kg | 1.25E-03 |
| 1-Methoxy-2-propanol [Group NMVOC to air] | 1.56E+03 | kg | 6.41E-04 |
| 1-Methyl-2-pyrrolidone [Group NMVOC to air] | 1.81E+03 | kg | 5.53E-04 |
| 1-Nonene [Group NMVOC to air] | 7.29E+02 | kg | 1.37E-03 |
| 1-Octanol [Group NMVOC to air] | 2.30E+03 | kg | 4.35E-04 |
| 1-Octene [Group NMVOC to air] | 6.17E+02 | kg | 1.62E-03 |
| 1-Pentadecane [Group NMVOC to air] | 8.82E+03 | kg | 1.13E-04 |
| 1-Pentene [Group NMVOC to air] | 6.16E+02 | kg | 1.62E-03 |
| 1-Propanol [Group NMVOC to air] | 1.69E+03 | kg | 5.91E-04 |
| 1-Propylbenzene [Group NMVOC to air] | 2.14E+03 | kg | 4.67E-04 |
| 1-Tetradecane [Group NMVOC to air] | 8.32E+03 | kg | 1.20E-04 |
| 1-Tridecane [Group NMVOC to air] | 7.62E+03 | kg | 1.31E-04 |
| 1-Undecane [Group NMVOC to air] | 6.11E+03 | kg | 1.64E-04 |
| 2-(2-Ethoxyethoxy)-ethanol [Group NMVOC to air] | 1.30E+03 | kg | 7.70E-04 |
| 2,2,3 Trimethylbutane [Group NMVOC to air] | 3.19E+03 | kg | 3.13E-04 |
| 2,2,3,3-Tetramethylbutane [Group NMVOC to air] | 9.73E+03 | kg | 1.03E-04 |

| | | | |
|---|---|---|---|
| **2,2,4-Trimethylpentane [Group NMVOC to air]** | 2.98E+03 | kg | 3.35E-04 |
| **2,2,5-Trimethylhexane [Group NMVOC to air]** | 3.07E+03 | kg | 3.25E-04 |
| **2,2-Dimethylbutane [Group NMVOC to air]** | 3.31E+03 | kg | 3.02E-04 |
| **2,3 Dimethylpentane [Group NMVOC to air]** | 2.82E+03 | kg | 3.55E-04 |
| **2,3,3-Trimethyl-1-butene [Group NMVOC to air]** | 9.73E+02 | kg | 1.03E-03 |
| **2,3,4-Trimethylpentane [Group NMVOC to air]** | 3.31E+03 | kg | 3.02E-04 |
| **2,3-Dimethyl-2-butene [Group NMVOC to air]** | 3.33E+02 | kg | 3.00E-03 |
| **2,3-Dimethylbutane [Group NMVOC to air]** | 3.84E+03 | kg | 2.61E-04 |
| **2,3-Dimethylhexane [Group NMVOC to air]** | 2.82E+03 | kg | 3.54E-04 |
| **2,3-Dimethylnapthtalene [Group NMVOC to air]** | 9.58E+02 | kg | 1.04E-03 |
| **2,4-Dimethylheptane [Group NMVOC to air]** | 2.52E+03 | kg | 3.97E-04 |
| **2,4-Dimethylhexane [Group NMVOC to air]** | 2.18E+03 | kg | 4.59E-04 |
| **2,4-Dimethylpentane [Group NMVOC to air]** | 2.72E+03 | kg | 3.68E-04 |
| **2,5-Dimethylhexane [Group NMVOC to air]** | 2.27E+03 | kg | 4.40E-04 |
| **2-Butoxy-ethanol [Group NMVOC to air]** | 1.56E+03 | kg | 6.43E-04 |
| **2-Ethoxy-ethanol [Group NMVOC to air]** | 1.22E+03 | kg | 8.20E-04 |
| **2-Ethoxyethyl acetate [Group NMVOC to air]** | 2.10E+03 | kg | 4.77E-04 |
| **2-Ethyl-1-hexanol [Group NMVOC to air]** | 1.98E+03 | kg | 5.06E-04 |
| **2-Methoxy-ethanol [Group NMVOC to air]** | 1.52E+03 | kg | 6.58E-04 |
| **2-Methyl-1-butene [Group NMVOC to air]** | 7.05E+02 | kg | 1.42E-03 |
| **2-Methyl-1-pentene [Group NMVOC to air]** | 9.27E+02 | kg | 1.08E-03 |
| **2-Methyl-2-butene [Group NMVOC to air]** | 2.94E+02 | kg | 3.40E-03 |
| **2-Methylheptane [Group NMVOC to air]** | 3.27E+03 | kg | 3.06E-04 |
| **2-Methylhexane [Group NMVOC to air]** | 2.82E+03 | kg | 3.54E-04 |
| **2-Methylnonane [Group NMVOC to air]** | 5.12E+03 | kg | 1.95E-04 |
| **2-Methyloctane [Group NMVOC to air]** | 4.11E+03 | kg | 2.43E-04 |
| **2-Methylpentane [Group NMVOC to air]** | 2.43E+03 | kg | 4.12E-04 |
| **2-Octanol [Group NMVOC to air]** | 2.07E+03 | kg | 4.83E-04 |
| **2-Pentene [Group NMVOC to air]** | 4.73E+02 | kg | 2.11E-03 |
| **3-Carene [Group NMVOC to air]** | 1.40E+03 | kg | 7.14E-04 |
| **3-Methyl-1-butene [Group NMVOC to air]** | 6.24E+02 | kg | 1.60E-03 |
| **3-Methylheptane [Group NMVOC to air]** | 2.83E+03 | kg | 3.54E-04 |
| **3-Methylhexane [Group NMVOC to air]** | 2.27E+03 | kg | 4.41E-04 |
| **3-Methylpentane [Group NMVOC to air]** | 2.16E+03 | kg | 4.63E-04 |
| **3-Octene [Group NMVOC to air]** | 4.27E+02 | kg | 2.34E-03 |
| **3-Pentanol [Group NMVOC to air]** | 2.75E+03 | kg | 3.63E-04 |
| **4-Ethylheptane [Group NMVOC to air]** | 2.60E+03 | kg | 3.85E-04 |
| **4-Methylheptane [Group NMVOC to air]** | 2.57E+03 | kg | 3.89E-04 |
| **Acetaldehyde (Ethanal) [Group NMVOC to air]** | 6.92E+02 | kg | 1.44E-03 |
| **Acetic acid [Group NMVOC to air]** | 7.49E+03 | kg | 1.33E-04 |
| **Acetone (dimethylcetone) [Group NMVOC to air]** | 1.04E+04 | kg | 9.58E-05 |
| **Acrolein [Group NMVOC to air]** | 6.22E+02 | kg | 1.61E-03 |

| | | | |
|---|---|---|---|
| alpha-Methyl tetrahydrofuran [Group NMVOC to air] | 9.51E+02 | kg | 1.05E-03 |
| alpha-Pinene [Group NMVOC to air] | 1.02E+03 | kg | 9.81E-04 |
| Benzaldehyde [Group NMVOC to air] | -1.00E+04 | kg | -9.97E-05 |
| Benzene [Group NMVOC to air] | 5.03E+03 | kg | 1.99E-04 |
| Benzotrifluoride (Trifluorotoluene) [Halogenated organic emissions to air] | 8.87E+03 | kg | 1.13E-04 |
| Biacetyl [Group NMVOC to air] | 2.22E+02 | kg | 4.51E-03 |
| Butadiene [Group NMVOC to air] | 3.84E+02 | kg | 2.60E-03 |
| Butane [Group NMVOC to air] | 3.50E+03 | kg | 2.86E-04 |
| Butene [Group NMVOC to air] | 5.71E+02 | kg | 1.75E-03 |
| Butyraldehyde [Group NMVOC to air] | 7.13E+02 | kg | 1.40E-03 |
| C10 Cyclic ketones [Group NMVOC to air] | 2.29E+03 | kg | 4.37E-04 |
| C10 Ketones [Group NMVOC to air] | 2.02E+03 | kg | 4.95E-04 |
| C5 Ketones [Group NMVOC to air] | 1.67E+03 | kg | 5.97E-04 |
| C6 Cyclic ketones [Group NMVOC to air] | 2.91E+03 | kg | 3.43E-04 |
| C6 Ketones [Group NMVOC to air] | 1.35E+03 | kg | 7.39E-04 |
| C7 Cyclic ketones [Group NMVOC to air] | 3.33E+03 | kg | 3.00E-04 |
| C7 Ketones [Group NMVOC to air] | 1.90E+03 | kg | 5.26E-04 |
| C8 Cyclic ketones [Group NMVOC to air] | 1.87E+03 | kg | 5.34E-04 |
| C8 Ketones [Group NMVOC to air] | 1.33E+03 | kg | 7.51E-04 |
| C9 Cyclic ketones [Group NMVOC to air] | 2.08E+03 | kg | 4.80E-04 |
| C9 Ketones [Group NMVOC to air] | 1.68E+03 | kg | 5.97E-04 |
| Carbon monoxide [Inorganic emissions to air] | 7.47E+04 | kg | 1.34E-05 |
| Carbon monoxide (biotic) [Inorganic emissions to air] | 7.47E+04 | kg | 1.34E-05 |
| Chlorobenzene [Halogenated organic emissions to air] | 6.38E+03 | kg | 1.57E-04 |
| cis-2-Butene [Group NMVOC to air] | 3.64E+02 | kg | 2.74E-03 |
| cis-2-Hexene [Group NMVOC to air] | 5.95E+02 | kg | 1.68E-03 |
| cis-2-Pentene [Group NMVOC to air] | 4.74E+02 | kg | 2.11E-03 |
| Crotonaldehyde [Group NMVOC to air] | 4.97E+02 | kg | 2.01E-03 |
| Cumene (isopropylbenzene) [Group NMVOC to air] | 2.03E+03 | kg | 4.93E-04 |
| Cyclobutane [Group NMVOC to air] | 4.06E+03 | kg | 2.46E-04 |
| Cyclohexane (hexahydro benzene) [Group NMVOC to air] | 2.56E+03 | kg | 3.90E-04 |
| Cyclohexanol [Group NMVOC to air] | 1.80E+03 | kg | 5.54E-04 |
| Cyclohexanone [Group NMVOC to air] | 2.91E+03 | kg | 3.43E-04 |
| Cyclohexene [Group NMVOC to air] | 6.42E+02 | kg | 1.56E-03 |
| Cyclopentadiene [Group NMVOC to air] | 8.91E+02 | kg | 1.12E-03 |
| Cyclopentane [Group NMVOC to air] | 1.93E+03 | kg | 5.18E-04 |
| Cyclopentanone [Group NMVOC to air] | 1.65E+03 | kg | 6.05E-04 |
| Cyclopentene [Group NMVOC to air] | 9.19E+02 | kg | 1.09E-03 |
| Cyclopropane [Group NMVOC to air] | 4.48E+04 | kg | 2.23E-05 |
| Decane [Group NMVOC to air] | 5.40E+03 | kg | 1.85E-04 |
| Diacetone alcohol [Group NMVOC to air] | 5.25E+03 | kg | 1.90E-04 |

| | | | |
|---|---|---|---|
| Dibutyl ether [Group NMVOC to air] | 1.46E+03 | kg | 6.86E-04 |
| Dichlorobenzene (p-DCB; 1,4-dichlorobenzene) [Halogenated organic emissions to air] | 1.14E+04 | kg | 8.80E-05 |
| Dichloromethane (methylene chloride) [Halogenated organic emissions to air] | 5.22E+04 | kg | 1.92E-05 |
| Diethyl ether [Group NMVOC to air] | 1.19E+03 | kg | 8.37E-04 |
| Diethylene glycol mono-n-butyl ether [Group NMVOC to air] | 7.50E+02 | kg | 1.33E-03 |
| Diethylketone [Group NMVOC to air] | 3.31E+03 | kg | 3.02E-04 |
| Dimethyl adipate [Group NMVOC to air] | 2.61E+03 | kg | 3.83E-04 |
| Dimethyl ether [Group NMVOC to air] | 4.94E+03 | kg | 2.02E-04 |
| Dimethyl glutarate [Group NMVOC to air] | 8.61E+03 | kg | 1.16E-04 |
| Dimethyl succinate [Group NMVOC to air] | 1.23E+04 | kg | 8.15E-05 |
| Dimethylamine [Group NMVOC to air] | 4.11E+02 | kg | 2.43E-03 |
| d-Limonene [Group NMVOC to air] | 1.09E+03 | kg | 9.14E-04 |
| Dodecane [Group NMVOC to air] | 6.97E+03 | kg | 1.43E-04 |
| Ethane [Group NMVOC to air] | 1.42E+04 | kg | 7.05E-05 |
| Ethanol [Group NMVOC to air] | 2.62E+03 | kg | 3.81E-04 |
| Ethene (ethylene) [Group NMVOC to air] | 5.05E+02 | kg | 1.98E-03 |
| Ethine (acetylene) [Group NMVOC to air] | 4.08E+03 | kg | 2.45E-04 |
| Ethyl acetylen [Group NMVOC to air] | 4.08E+02 | kg | 2.45E-03 |
| Ethyl amine [Group NMVOC to air] | 3.95E+02 | kg | 2.53E-03 |
| Ethyl benzene [Group NMVOC to air] | 1.69E+03 | kg | 5.90E-04 |
| Ethyl butyrate [Group NMVOC to air] | 4.03E+03 | kg | 2.48E-04 |
| Ethyl cyclohexane [Group NMVOC to air] | 2.52E+03 | kg | 3.97E-04 |
| Ethyl cyclopentane [Group NMVOC to air] | 2.17E+03 | kg | 4.61E-04 |
| Ethyl isopropyl ether [Group NMVOC to air] | 1.06E+03 | kg | 9.44E-04 |
| Ethylene acetate (ethyl acetate) [Group NMVOC to air] | 6.29E+03 | kg | 1.59E-04 |
| Ethylene glycol [Group NMVOC to air] | 8.89E+02 | kg | 1.13E-03 |
| Ethylene oxide [Group NMVOC to air] | 5.79E+04 | kg | 1.73E-05 |
| Ethyl-trans-butyl ether [Group NMVOC to air] | 1.78E+03 | kg | 5.63E-04 |
| Formaldehyde (methanal) [Group NMVOC to air] | 5.52E+02 | kg | 1.81E-03 |
| Formic acid (methane acid) [Group NMVOC to air] | 2.78E+04 | kg | 3.59E-05 |
| Furan [Group NMVOC to air] | 3.51E+02 | kg | 2.85E-03 |
| Glyoxal [Group NMVOC to air] | 3.50E+02 | kg | 2.86E-03 |
| Heptane (isomers) [Group NMVOC to air] | 3.51E+03 | kg | 2.85E-04 |
| Hexadecane [Group NMVOC to air] | 9.54E+03 | kg | 1.05E-04 |
| Hexan-2-one [Group NMVOC to air] | 1.35E+03 | kg | 7.39E-04 |
| Hexane (isomers) [Group NMVOC to air] | 2.98E+03 | kg | 3.35E-04 |
| Hexylcyclohexane [Group NMVOC to air] | 5.27E+03 | kg | 1.90E-04 |
| Indan [Group NMVOC to air] | 1.15E+03 | kg | 8.66E-04 |
| iso-Amyl-iso-butyrate [Group NMVOC to air] | 4.73E+03 | kg | 2.11E-04 |
| iso-Butane [Group NMVOC to air] | 3.22E+03 | kg | 3.11E-04 |

| | | | |
|---|---|---|---|
| iso-Butanol [Group NMVOC to air] | 2.04E+03 | kg | 4.91E-04 |
| iso-Butene [Group NMVOC to air] | 7.39E+02 | kg | 1.35E-03 |
| iso-Butyl acetate [Group NMVOC to air] | 4.68E+03 | kg | 2.14E-04 |
| iso-Butyraldehyde [Group NMVOC to air] | 8.09E+02 | kg | 1.24E-03 |
| iso-Pentane [Group NMVOC to air] | 2.60E+03 | kg | 3.84E-04 |
| Isoprene [Group NMVOC to air] | 4.38E+02 | kg | 2.28E-03 |
| iso-Propyl acetate [Group NMVOC to air] | 4.16E+03 | kg | 2.40E-04 |
| Methacrolein [Group NMVOC to air] | 7.78E+02 | kg | 1.29E-03 |
| Methane [Organic emissions to air (group VOC)] | 3.37E+05 | kg | 2.96E-06 |
| Methane (biotic) [Organic emissions to air (group VOC)] | 3.37E+05 | kg | 2.96E-06 |
| Methanol [Group NMVOC to air] | 5.07E+03 | kg | 1.97E-04 |
| Methyl acetate [Group NMVOC to air] | 4.28E+04 | kg | 2.34E-05 |
| Methyl acetylene [Group NMVOC to air] | 3.75E+02 | kg | 2.66E-03 |
| Methyl bromide [Halogenated organic emissions to air] | 2.08E+05 | kg | 4.80E-06 |
| Methyl cyclohexane [Group NMVOC to air] | 2.39E+03 | kg | 4.19E-04 |
| Methyl cyclopentane [Group NMVOC to air] | 2.09E+03 | kg | 4.77E-04 |
| Methyl formate [Group NMVOC to air] | 3.63E+04 | kg | 2.75E-05 |
| Methyl glyoxal [Group NMVOC to air] | 2.90E+02 | kg | 3.45E-03 |
| Methyl isobutyrate [Group NMVOC to air] | 1.19E+04 | kg | 8.44E-05 |
| Methyl propionate [Group NMVOC to air] | 4.18E+03 | kg | 2.39E-04 |
| Methyl propyl Ketone [Group NMVOC to air] | 1.67E+03 | kg | 5.97E-04 |
| Methyl tert-butylether [Group NMVOC to air] | 3.75E+03 | kg | 2.66E-04 |
| Methyl tert-butylketone [Group NMVOC to air] | 4.82E+03 | kg | 2.07E-04 |
| Methylpentanone [Group NMVOC to air] | 1.07E+03 | kg | 9.31E-04 |
| Methylvinyl ketone [Group NMVOC to air] | 5.02E+02 | kg | 1.99E-03 |
| Naphthalene [Group PAH to air] | 1.65E+03 | kg | 6.06E-04 |
| Neopentane [Group NMVOC to air] | 6.34E+03 | kg | 1.58E-04 |
| Nitrobenzene [Group NMVOC to air] | 3.42E+04 | kg | 2.92E-05 |
| Nitrogen oxides [Inorganic emissions to air] | 1.00E+03 | kg | 1.00E-03 |
| Nonane [Group NMVOC to air] | 4.69E+03 | kg | 2.13E-04 |
| Octane [Group NMVOC to air] | 4.05E+03 | kg | 2.47E-04 |
| Octyl cyclohexane [Group NMVOC to air] | 7.08E+03 | kg | 1.41E-04 |
| Pentane (n-pentane) [Group NMVOC to air] | 2.89E+03 | kg | 3.47E-04 |
| Phenol (hydroxy benzene) [Group NMVOC to air] | 1.36E+03 | kg | 7.38E-04 |
| Propane [Group NMVOC to air] | 7.81E+03 | kg | 1.28E-04 |
| Propanol (iso-propanol; isopropanol) [Group NMVOC to air] | 6.20E+03 | kg | 1.61E-04 |
| Propene (propylene) [Group NMVOC to air] | 4.04E+02 | kg | 2.47E-03 |
| Propionic acid (propane acid) [Group NMVOC to air] | 3.67E+03 | kg | 2.73E-04 |
| Propyl acetate [Group NMVOC to air] | 5.16E+03 | kg | 1.94E-04 |
| Propyl cyclopentan [Group NMVOC to air] | 2.47E+03 | kg | 4.05E-04 |
| Propylene carbonate [Group NMVOC to air] | 1.79E+04 | kg | 5.59E-05 |
| Propylene glycol [Group NMVOC to air] | 1.90E+03 | kg | 5.27E-04 |

| | | | |
|---|---|---|---|
| Propylene glycol methyl ether acetate [Group NMVOC to air] | 2.52E+03 | kg | 3.96E-04 |
| Propylene oxide [Group NMVOC to air] | 1.19E+04 | kg | 8.39E-05 |
| Sabinene [Group NMVOC to air] | 6.80E+02 | kg | 1.47E-03 |
| sec-Butanol [Group NMVOC to air] | 2.96E+03 | kg | 3.38E-04 |
| sec-Butyl acetate [Group NMVOC to air] | 2.92E+03 | kg | 3.42E-04 |
| sec-Butyl benzene [Group NMVOC to air] | 2.39E+03 | kg | 4.18E-04 |
| Styrene [Group NMVOC to air] | 2.00E+03 | kg | 5.00E-04 |
| tertiary-Butanol [Group NMVOC to air] | 1.01E+04 | kg | 9.90E-05 |
| tertiary-Butyl acetate [Group NMVOC to air] | 2.44E+04 | kg | 4.10E-05 |
| Tetrachloroethene (perchloroethylene) [Halogenated organic emissions to air] | 4.34E+04 | kg | 2.31E-05 |
| Tetralin [Group NMVOC to air] | 2.58E+03 | kg | 3.87E-04 |
| Tolualdehyde [Group NMVOC to air] | -1.14E+04 | kg | -8.80E-05 |
| Toluene (methyl benzene) [Group NMVOC to air] | 1.20E+03 | kg | 8.32E-04 |
| trans-2-Butene [Group NMVOC to air] | 3.46E+02 | kg | 2.89E-03 |
| trans-2-Hexene [Group NMVOC to air] | 5.95E+02 | kg | 1.68E-03 |
| trans-2-Pentene [Group NMVOC to air] | 4.73E+02 | kg | 2.12E-03 |
| Trichloroethene (isomers) [Halogenated organic emissions to air] | 4.88E+06 | kg | 2.05E-07 |
| Trimethylamine [Group NMVOC to air] | 3.44E+02 | kg | 2.90E-03 |
| Trimethylbenzene [Group NMVOC to air] | 4.54E+02 | kg | 2.20E-03 |
| Valeraldehyde [Group NMVOC to air] | 8.26E+02 | kg | 1.21E-03 |
| Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Group NMVOC to air] | 4.55E+02 | kg | 2.20E-03 |
| Xylene (ortho-Xylene; 1,2-Dimethylbenzene) [Group NMVOC to air] | 6.42E+02 | kg | 1.56E-03 |
| Xylene (para-Xylene; 1,4-Dimethylbenzene) [Group NMVOC to air] | 1.13E+03 | kg | 8.82E-04 |

# ACCEPTANCE LETTER FROM THE CRITICAL REVIEW PANEL

Critical Review of the Life Cycle Assessment Study:

**Life Cycle Assessment of Canada's Polymer Bank Notes and Cotton-Paper Bank Notes**

**Final Report**

Prepared for:

**The Bank of Canada**

May 20, 2011 - **Final Acceptance Letter**

This critical review of the above-noted LCA report provides the comments of the Review Panel composed of the following reviewers:

Wayne Trusty, Past President, Athena Institute (Chair)

Neil Burnham, Senior Technical Advisor, Note Printing Australia

Lindita Bushi, Ph.D Eng., Senior Research Associate, Athena Institute

Nick Pearson, Senior Technical Expert, Bank of England

The review was performed according to Clause 7.3.3 of ISO 14040 (2006) and Clause 6.3 of ISO 14044 (2006) and takes into consideration the ISO 14040 series of standards requirements and recommendations.

The Critical Review Panel finds that the above-noted LCA report is fully in compliance with the ISO 14040 (2006) and 14044 (2006) standards. The Panel commends the Bank of Canada and its consultants for a very thorough and comprehensive study.