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Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)
TRACI version 2.1

User's Guide

SCIENCE

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Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)

USER'S MANUAL

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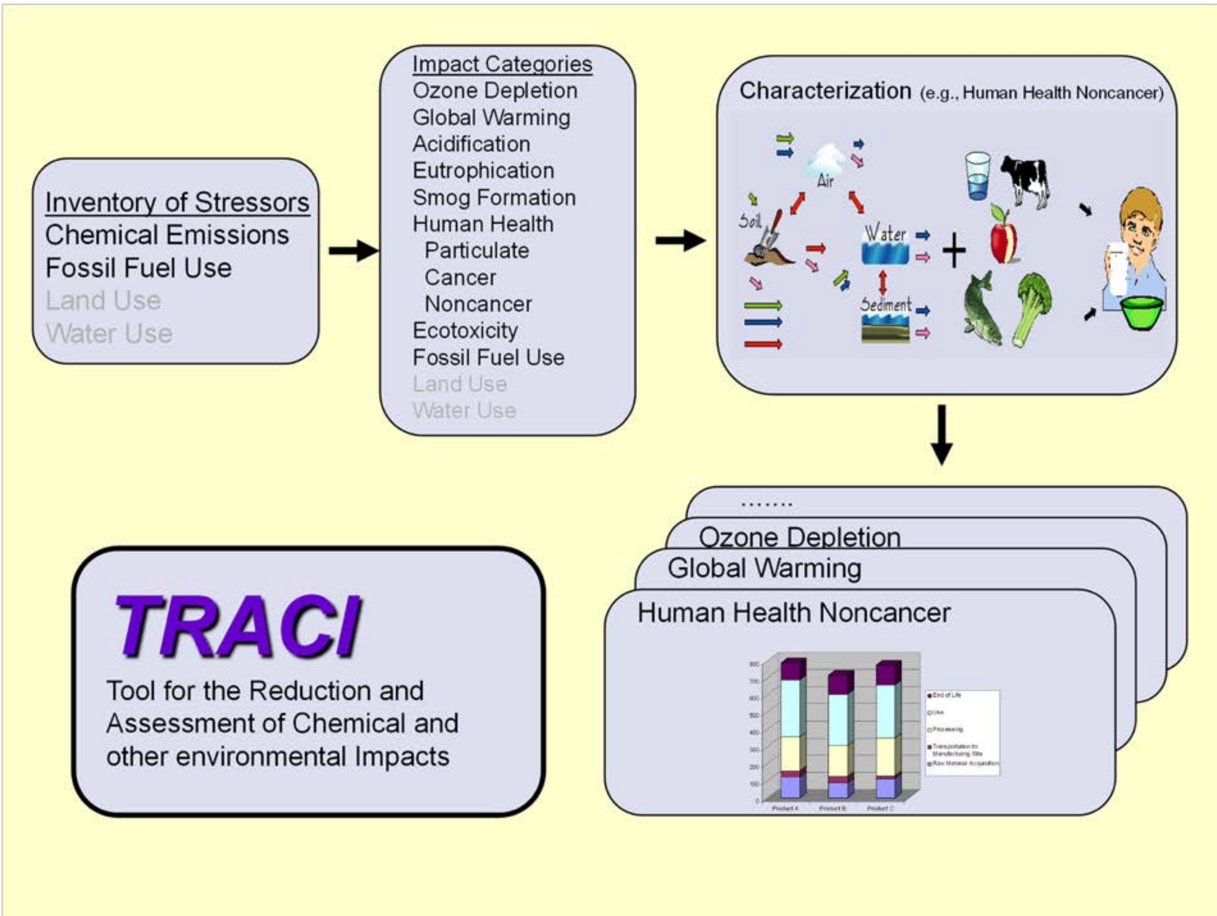
TRACI 2.1

Tool for the Reduction and Assessment of Chemical and other environmental Impacts 2.1



User Manual

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Abbreviations

CTU – Comparative Toxicity Unit

DOE – Department of Energy

EPA – Environmental Protection Agency

GWP – Global Warming Potential

ISO - International Organization of Standardization

LCA – Life Cycle Assessment

LCIA – Life Cycle Impact Assessment

NEI – National Emissions Inventory

NIST – National Institute of Standards and Technology

NRMRL – National Risk Management Research Laboratory

ODP – Ozone Depletion Potential

ORD – Office of Research and Development

PM – Particulate Matter

STD – Sustainable Technology Division

TRACI – Tool for the Reduction and Assessment of Chemical and other environmental Impacts

TRI – Toxics Release Inventory

US – United States

USETOX –model developed under UNEP-SETAC Life Cycle Initiative

Technical Background

Abstract

TRACI 2.1 (the Tool for the Reduction and Assessment of Chemical and other environmental Impacts) has been developed for sustainability metrics, life cycle impact assessment, industrial ecology, and process design impact assessment for developing increasingly sustainable products, processes, facilities, companies, and communities. TRACI 2.1 allows an expanded quantification of stressors that have potential effects, including ozone depletion, global warming, acidification, eutrophication, photochemical smog formation, human health particulate effects, human health cancer, human health noncancer, ecotoxicity, and fossil fuel depletion effects. Research is ongoing to quantify the use of land and water in a future version of TRACI. The original version of TRACI was released in August 2002 (Bare *et al.* 2003) followed by a release of TRACI 2.0 in 2011 (Bare 2011).

Introduction

Impact assessment for environmental decision making in areas such as sustainability metrics, life cycle assessment (LCA), and industrial ecology involve the quantification of a large number of potential impacts. Unfortunately, completing comprehensive assessments for all potential effects at a high level of simulation, sophistication and disaggregation require excessively large amounts of time, data, knowledge, and resources. It therefore follows that every study must be limited in some aspects of sophistication and/or comprehensiveness.

While conducting several LCA case studies, the U.S. Environmental Protection Agency's (US EPA's) National Risk Management Research Laboratory conducted a literature survey of existing methodologies (Heijungs *et al.* 1992a, Heijungs *et al.* 1992b, Guinée *et al.* 2002, Goedkoop *et al.* 2009, Goedkoop & Spriensma 1999, Goedkoop *et al.* 1996, Hauschild & Wenzel 1998a, Hauschild & Wenzel 1998b, Wenzel *et al.* 1997, Wenzel & Hauschild 1997, Jolliet *et al.* 2003). As it was apparent that no tool existed that would allow a level of sophistication, comprehensiveness, and applicability to the United States, the US EPA decided to begin development of a software tool to conduct impact assessment with the best applicable methodologies within each category. This research effort was called TRACI – the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (Bare *et al*. 2003).

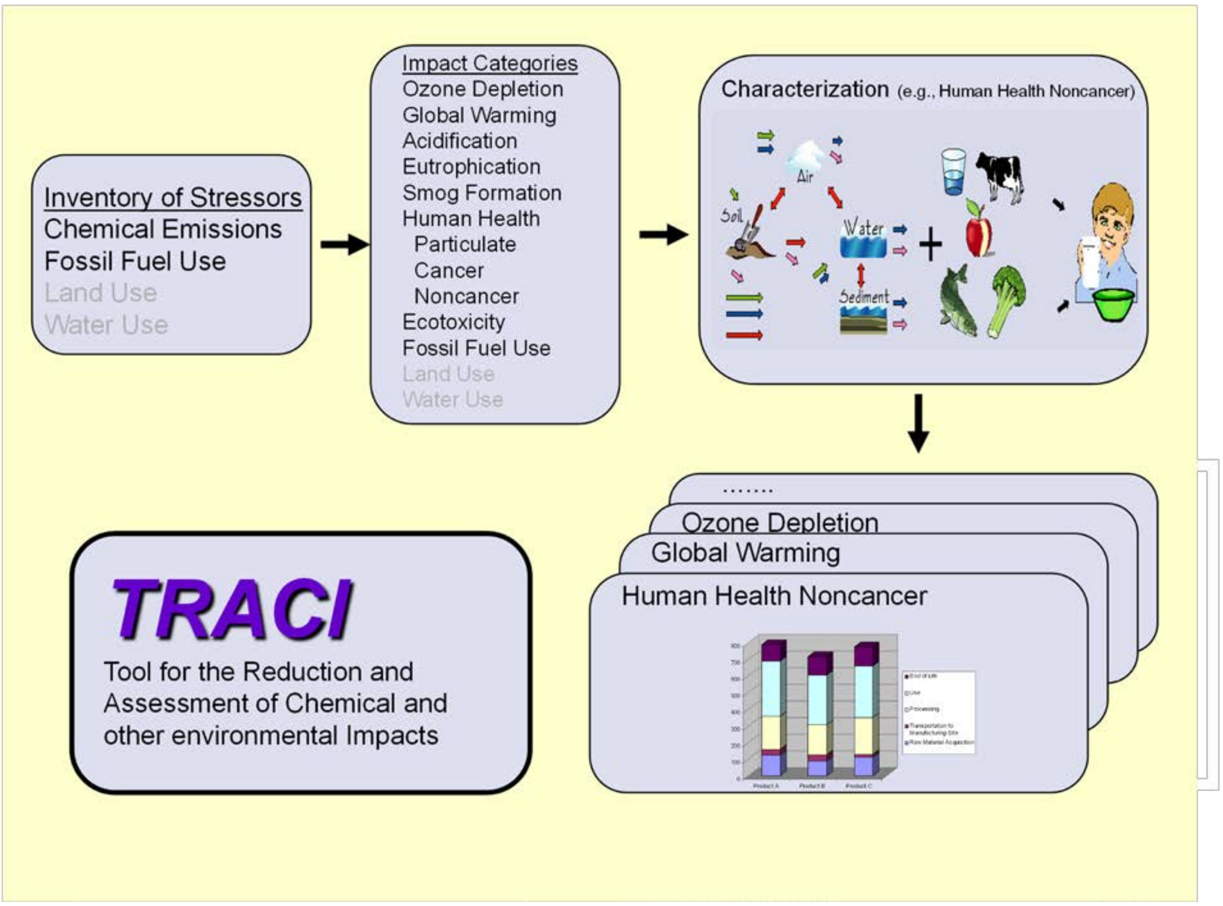
As dictated within the ISO 14042 guidance in this area, an LCA has several steps, some of which may be iterative: inventory, impact assessment, normalization (optional), and either valuation, grouping, or weighting (optional) (International Standards Organization 2000). It is critical to consider the importance of each of these stages (e.g., without a strong inventory possessing high data quality, the results of the impact assessment will be less valuable). In addition, while it is important to show as much comprehensiveness as possible within each study, as was recently demonstrated at an US valuation exercise conducted at NIST, some impact category results may receive much more attention (Gloria *et al.* 2007).

The first step in developing this tool was to select the impact categories for analysis and methodology development. It was soon recognized that the selection of these impact categories is a normative decision depending on what is valued to the individual user. In an attempt to be fully comprehensive in the original selection of impact categories, EPA initiated a taxonomy study of possible impacts (and impact categories) which could be included (Bare & Gloria 2008). From this greater list of impact categories, a smaller more manageable list of impact categories was selected for inclusion into TRACI and subsequently, TRACI 2.1. This "manageable" list was selected for a variety of reasons, including consistency with existing regulations and policies, perceived importance, and ease of modeling.

The traditional pollution categories of ozone depletion, global warming, human health criteria, smog formation, acidification, and eutrophication were included within TRACI due to various programs and regulations within EPA and recognizing the value of minimizing effects from these categories. The category of human health was further subdivided into cancer, noncancer, and criteria pollutants (with an initial focus on particulates) to better reflect the focus of EPA regulations and to allow methodology development consistent with the U.S. regulations, handbooks, and guidelines. Smog formation is recognized as a significant environmental issue within the US and has separate regulations, which address its prevention. Smog formation effects were kept independent and not further aggregated with other human health impacts because environmental effects related to smog formation would have become lost in the process of aggregation. Particulate pollutants within TRACI are various sizes and forms of particulate matter (e.g., PM 2.5 and PM10) and pollutants which lead to respiratory impacts related to particulates (e.g., sulfur oxides and nitrogen oxides). They were maintained as a separate human health impact category allowing a modeling approach that can take advantage of the extensive epidemiological data associated with these well-studied impacts. The resource depletion categories are recognized as significant in the US, especially for fossil fuel use, land use, and water use. Although not included in TRACI 2.1, research is underway to include land use and water use impacts.

The categories within TRACI 2.1 are shown in Figure 1, with land use and water use being listed for future inclusion. It should be noted, however, that this list of impact categories is considered a minimal set that may be expanded in future versions. Further discussion about the history and development of TRACI, including the minimization of assumptions and value choices by the use of midpoint indicators, and a comparison to other methodologies may be found in supplemental documentation (Bare *et al.* 1999, Bare *et al.* 2000, Bare *et al*. 2003, Bare 2006, Bare & Gloria 2008, Bare & Gloria 2006, Hofstetter *et al.* 2002, Pennington & Bare 2001, Pennington *et al.* 2000).

Figure 1. TRACI 2.1 framework



Inventory

The TRACI framework begins with a user provided inventory of stressors. Within a gate-to-gate analysis, inventory data are often available from the facility or facilities. Within an LCA this may be supplemented by inventory data from suppliers, and/or publicly available databases such as those listed below: the 2006 US EPA's Greenhouse Gas Emissions (US Environmental Protection Agency 2008h, US Environmental Protection Agency 2008g, US Environmental Protection Agency 2008f), the 2006 US EPA's National Emissions Inventory (NEI) for Criteria Pollutants (US Environmental Protection Agency 2007b), the 2002 Hazardous Air Pollutants (US Environmental Protection Agency 2002), the 2006 US Department of Agriculture's (USDA's) Simulation of Nutrient Losses (US Department of Agriculture - Natural Resources Conservation Service 2006), the 2005 US Department of Energy's (US DOE's) Energy Consumption Estimates for fossil fuel depletion (US Department of Energy - Energy Information Administration 2008), the 2005 US EPA's Toxics Release Inventory (TRI) (US Environmental

Protection Agency 2005a), and the NREL LCI database (US Department of Energy - National Renewable Energy Laboratory 2008). Data quality and applicability should be considered when including data sources.

Supporting data, such as the TRI database, which were not originally collected or developed for this intention may have some shortcomings. 1) Only exceedance of minimal reporting requirements may be included. 2) Groups of substances may be lumped together (e.g., mercury, mercury compounds, copper, copper compounds, chromium, chromium compounds, lead, and lead compounds). 3) The quality of the data may be uncertain and in many cases hard to predict. TRACI users are encouraged to use the highest quality data whenever possible for minimal data and modeling uncertainty.

Because TRACI is an impact assessment tool, the selection of inventory data source will not be further discussed here. The heart of the TRACI framework is the characterization of each of the impact categories.

Impact Assessment Methodologies

Whether the analysis is being conducted within an LCA, process design, or a sustainability metrics basis, in all impact categories, the underlying methodologies within TRACI utilize the amount of the chemical emission or resource used and the estimated potency of the stressor.

The estimated potency is based on the best available models and data for each impact category. For some impact categories (e.g., ozone depletion potentials, global warming potentials), there is international consensus on the relative potency of the chemicals listed. For other impact categories, the relative potency may be dependent on models related to chemical and physical principles and/or experimental data. Descriptions on individual impact categories are provided below and give greater detail about the modeling underlying each category.

In some impact categories, the location of the emission or resource used is of importance to the potency of the stressor, and the practitioner is encouraged to maintain the location with each stressor. In these cases, the individual stressors do not simply have one potency factor, but a potency factor at each of the locations. The calculations should then be conducted at each location and then summed up to see the total impact for the study overall. As an example, if an impact category (i) has a fate factor (F), and potency factor (P), then the site-specific analysis may be calculated as follows

$$I^i = \sum_s \sum_x \sum_m F^i_{xms} P^i_{xms} M_{xms} \tag{1}$$

Where:

I^i = the potential impact of all chemicals (x) for a specific impact category of concern (i)

F^i_{xms} = the fate of chemical (x) emitted to media (m) at site (s) for impact category (i) the potency of chemical (x) emitted to media (m) at site (s) for impact category (i)

M_{xms} = the mass of chemical (x) emitted to media (m) at site (s)

There are many times when the site-specific location is not utilized. For example, for some individual impact categories, location does not influence the fate, transport, and potency to any great extent, and thus only one characterization factor is presented for global use (e.g., global climate change, stratospheric ozone depletion). At other times, the individual locations of the emissions are not known for a specific study and since all impact categories allow non site-specific characterization, the more site-generic characterization factors may be used. In these situations, the generalized equation without respect to location would be:

$$I^{i} = \sum_{xm} CF^{i}_{xm} * M_{xm} \qquad (2)$$

Where:

I^{i} = the potential impact of all chemicals (x) for a specific impact category of concern (i)

CF^{i}_{xm} = the characterization factor of chemical (x) emitted to media (m) for impact category (i)

M_{xm} = the mass of chemical (x) emitted to media (m)

Although the original version of TRACI was released with site-specificity available for many of the impact categories, the vast majority of TRACI users have not been utilizing the site-specific features. This release of TRACI 2.1, as described below will focus on the US average characterization.

For emission related categories, characterization factors are available for the media listed in Table 1.

Table 1. Characterization Factors are available for the media listed for each impact category.

Impact Category	**Media**
Ozone Depletion	Air
Global Climate	Air
Acidification	Air, Water
Eutrophication	Air, Water
Smog Formation	Air
Human Health Particulate	Air
Human Health Cancer	Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil
Human Health Noncancer	Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil
Ecotoxicity	Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil

Acidification

Acidification is the increasing concentration of hydrogen ion (H+) within a local environment. This can be the result of the addition of acids (e.g., nitric acid and sulfuric acid) into the environment, or by the addition of other substances (e.g., ammonia) which increase the acidity of the environment due to various chemical reactions and/or biological activity, or by natural circumstances such as the change in soil concentrations because of the growth of local plant species.

Acidifying substances are often air emissions, which may travel for hundreds of miles prior to wet deposition as acid rain, fog, or snow or dry deposition as dust or smoke particulate matter on the soil or water. Sulfur dioxide and nitrogen oxides from fossil fuel combustion have been the largest contributors to acid rain (US Environmental Protection Agency 2008q).

Substances, which cause acidification, can cause damage to building materials, paints, and other human-built structures, lakes, streams, rivers, and various plants and animals. The sensitivity of various environments can depend on a number of factors including: the local buffering capacity, the local plant and animal species, and the existing acidity within the environment (US Environmental Protection Agency 2008c).

Consistent with the focus on providing midpoint assessments, TRACI 2.1 uses an acidification model which incorporates the increasing hydrogen ion potential within the environment without incorporation of site-specific characteristics such as the ability for certain environments to provide buffering capability (Wenzel *et al*. 1997, Wenzel & Hauschild 1997).

Eutrophication

Eutrophication is the "enrichment of an aquatic ecosystem with nutrients (nitrates, phosphates) that accelerate biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass" (US Environmental Protection Agency 2008d). Although nitrogen and phosphorus play an important role in the fertilization of agricultural lands and other vegetation, excessive releases of either of these substances may provide undesired effects on the waterways in which they travel and their ultimate destination. While phosphorus usually has a more negative impact on freshwater lakes and streams (U.S. Environmental Protection Agency 2008), nitrogen is often more detrimental to coastal environments (Ecological Society of America 2000).

Some of the major substances which have a role in this impact category are difficult to characterize including emissions from: wastewater treatment plants, decaying plant life pulp and paper mills, food processing plants, and fertilizers used in agricultural, commercial, and individual household locations (US Environmental Protection Agency 1997). For example, the majority of fertilizer (when utilized correctly) provides the benefits for which it was purchased. However, depending on the slope of the fields, the precipitation, and volatilization of the fertilizer, some of this product may go beyond the original intended boundaries and cause unintended consequences downstream. It is these unintended consequences that are considered to be the emission in this case; whereas, the portion of the application that achieved its goal of fertilizing fields was considered to be useful product (US Department of Energy - National Renewable Energy Laboratory 2008).

The original methodology utilized in TRACI allowed site-specific characterization, which is not supported, in the current version. Additional substances, which have the potential to cause eutrophication, have been added to TRACI 2.1.

Global Climate Change

"Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, "global warming" often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities" (US Environmental Protection Agency 2008b). The current trend is to use the phrase 'climate change' instead of global warming to denote the other changes which may occur in addition to temperature change (US Environmental Protection Agency 2008p).

During the last 200 years, the sources of greenhouse gases have increased (mostly caused from the increased combustion of fossil fuels (US Environmental Protection Agency 2008a)), while the sinks have decreased (e.g., deforestation and land use changes). The U.S. is keeping track of the greenhouse gas emissions (US Environmental Protection Agency 2008h, US Environmental Protection Agency 2008g) and has a policy in place for greenhouse gas reductions (US Environmental Protection Agency 2008p).

TRACI 2.1 utilizes global warming potentials (GWPs) for the calculation of the potency of greenhouse gases relative to CO_2 (IPCC (Intergovernmental Panel on Climate Change) 2001). Consistent with the guidance of the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC -The United Nations Framework Convention on Climate Change 2003), the US EPA uses GWPs with 100-year time horizons. TRACI 2.1 expands the list of substances found within the original version of TRACI and utilizes a hierarchy of data sources consistent international acceptance. This hierarchy of sources includes the most current GWPs published by the IPCC (Solomon 2011, Solomon *et al.* 2007, IPCC (Intergovernmental Panel on Climate Change) 2001, IPCC (Intergovernmental Panel on Climate Change) 1996).

Ozone Depletion

Ozone within the stratosphere provides protection from radiation, which can lead to increased frequency of skin cancers and cataracts in the human populations. Additionally, ozone has been documented to have effects on crops, other plants, marine life, and human-built materials. Substances which have been reported and linked to decreasing the stratospheric ozone level are chlorofluorocarbons (CFCs) which are used as refrigerants, foam blowing agents, solvents, and halons which are used as fire extinguishing agents (US Environmental Protection Agency 2008j). Over

20 years ago, the United States signed the Montreal Protocol to reduce CFC production, and later implemented even more stringent reductions, which have led to a complete end of production of CFCs (by 1996) and halons (by 1994). Levels of total inorganic chlorine have been declining since 1998, and recovery of the ozone layer is expected in about 50 years (US Environmental Protection Agency 2008m).

There is international consensus on the use of ozone depletion potentials (ODPs), a metric proposed by the World Meteorological Organization (WMO) (Solomon & Albritton 1992, WMO (World Meteorological Organization) 1999), for calculating the relative importance of substances expected to contribute significantly to the breakdown of the ozone layer. The US EPA maintains websites listing various options for ODPs (US Environmental Protection Agency 2008k, US Environmental Protection Agency 2008l). These options are consistent with the US and WMO documents used internationally (WMO (World Meteorological Organization) 2003, US Environmental Protection Agency 1992, US Environmental Protection Agency 2003, WMO (World Meteorological Organization) 1999, US Environmental Protection Agency 2008l, US Environmental Protection Agency 2008j, US Environmental Protection Agency 2008k). Within TRACI 2.1, the most recent sources of ODPs were used for each substance.

Human Health Particulate

Although this category may be called the human health criteria pollutants category, it deals with a subset of the criteria pollutants, i.e., particulate matter and precursors to particulates. Particulate matter is a collection of small particles in ambient air which have the ability to cause negative human health effects including respiratory illness and death (US Environmental Protection Agency 2008n). Numerous epidemiology studies show an increased mortality rate with elevated levels of ambient particulate matter (US Environmental Protection Agency 2008n). Particulate matter may be emitted as particulates, or may be the product of chemical reactions in the air (secondary particulates). The most common precursors to secondary particulates are sulfur dioxide (SO_2) and nitrogen oxides (NOx). Common sources of primary and secondary particulates are fossil fuel combustion, wood combustion, and dust particles from roads and fields (US Environmental Protection Agency 2008n). Particulate matter is divided into two major groups of concern: “inhalable coarse particles” which are between 2.5 micrometers and 10 micrometers in diameter, like dust from roadways, and “fine particles” which are smaller than or equal to 2.5 micrometers in diameter, and are often the products of combustion (US Environmental Protection Agency 2008o). Sensitive populations such as children, the elderly, and people with asthma are more susceptible to experiencing higher consequences (US Environmental Protection Agency 2008i). Although national US standards have existed since 1971, even more stringent standards were placed in 2006 (US Environmental Protection Agency 2006).

The method for calculation of human health impacts includes the modeling of the fate and exposure into intake fractions (i.e., that portion of the emitted substance, which is expected to be inhaled by a human being). These intake fractions are calculated as a function of the amount of substance emitted into the environment, the resulting increase in air concentration, and the breathing rate of the exposed population. The increasing air concentrations are a function of the location of the release and the accompanying meteorology and the background concentrations of substances, which may influence secondary particle formation. Substances were characterized using PM2.5 as the reference substance (Humbert 2009).

Human health Cancer, Noncancer, and Ecotoxicity

During the development of the original TRACI, human health was represented by three impact categories based on the current structure of the EPA regulations and the chemical and physical behaviors of the pollutants of concern. CalTOX was determined to be the best model for human health cancer and noncancer (McKone 1993), and the input parameters were selected to be consistent with the EPA Risk Assessment Guidelines and the Exposure Factors Handbook (U.S. Environmental Protection Agency 1997, US Environmental Protection Agency 1989a, US Environmental Protection Agency 1989b). Research was conducted to determine the source of the major uncertainties and influence of site-specific parameters on the human toxicity potentials (Hertwich *et al.* 1999). The probabilistic research showed that for the majority of the TRI substances, chemical data (e.g., toxicity and half-life) had the most significant impact on data variability/uncertainty and that site-specific parameters had little effect on the relative human toxicity potentials (Hertwich *et al*. 1999). This research supported later development of global toxicity potentials for human health cancer and noncancer.

Under the Life Cycle Initiative of the United Nations Environment Program (UNEP) / Society of Environmental Toxicology and Chemistry (SETAC) various international multimedia model developers of CalTOX, IMPACT 2002, USES-LCA, BETR, EDIP, WATSON, and EcoSense created a global consensus model known as USEtox (Hauschild *et al.* 2008, Rosenbaum *et al.* 2008, USEtox Team 2010). Over the course of a series of workshops and numerous communications, model results from the original models were compared to determine the most influential parameters and largest sources of differences between the models using 45 organic substances, which were selected for their diversity in environmental partitioning, exposure pathway, persistence, and air transport. The USEtox model adopted many of the best features of the above-named models and was used to develop human health cancer and noncancer toxicity potentials and freshwater ecotoxicity potentials for over 3000 substances including organic and inorganic substances.

This list of 3000 substances goes beyond the list included within the original TRACI, because initially TRACI was focused on covering those chemicals of concern within the US (e.g., TRI chemicals). It has since been recognized that today’s global economy often requires the inclusion of suppliers who are outside of the US within countries who may have their own lists of reportable chemicals. The USEtox expanded set allows this expansion into chemicals of concern globally.

USEtox is developed with two spatial scales: continental and global. The environmental compartments within the continental scale includes: urban air, rural air, agricultural soil, industrial soil, freshwater, and coastal marine water. USEtox includes most of the pathways found in the original EPA Risk Assessment Guidelines, including inhalation, ingestion of drinking water, produce, meat, milk, and freshwater and marine fish.

The USEtox model has been selected to replace the CalTOX model as the basis for the TRACI impact categories of human health cancer, noncancer, and ecotoxicity. It should be noted that some of the characterization factors included within the USEtox model are recommended while others are simply interim and should be used with caution (Rosenbaum *et al*. 2008, Hauschild *et al*. 2008) .

The recommended units for the USEtox human health cancer, noncancer, and ecotoxicity are: CTUcancer, CTUnoncancer, and CTUeco, respectively. Although USEtox guidance allows for the combination of cancerous and noncancerous impacts, users of TRACI are encouraged to maintain these categories independently. Individual emissions to media may be combined to consolidate emissions to these three categories.

Photochemical Smog Formation

Ground level ozone is created by various chemical reactions, which occur between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage. The primary sources of ozone precursors are motor vehicles, electric power utilities and industrial facilities (US Environmental Protection Agency 2008e).

Within the Leiden University's CML 2002 Handbook (Guinée *et al*. 2002) are listed various options for "summer smog" modeling including: 1) Photochemical Ozone Creation Potentials (POCPs) (Derwent *et al.* 1996, Derwent *et al.* 1998, Jenkin & Hayman 1999, Andersson-Skold *et al.* 1992, Derwent 1991), and 2) Maximum Incremental Reactivity (MIR) (Carter 1994, Carter 1997, Carter 2000). More recent work is now available from Carter for MIR values. Some of this work was conducted specifically for TRACI (Carter 2007, Carter 2008).

Carter's MIRs have been selected for use within TRACI 2.1 for the following reasons. 1) It was developed specifically for the US. 2) It is comprehensive in impacts, covering human and environmental effects. 3) It has the most comprehensive substance coverage allowing greater differentiation of effects when available. The full set of POCPs recently available only cover 128 substances and the TRACI 2.1 MIRs cover nearly 1200 substances (Carter 2007, Carter 2008, Carter 2010b, Carter 2012). 4) It is the method that is used and recommended by the US EPA and individual states within the United States for other environmental programs, including cap and trade programs (US Environmental Protection Agency 2007a, US Environmental Protection Agency 2005b, US Environmental Protection Agency).

Many of the methods, including MIRs prior to the TRACI research, did not have a NOx value on the same scale as the VOCs. This was true for MIRs since the MIR reflects the degree of reactivity with NOx, a concept that is not reflective of NOx reactivity with NOx. At the request of this author, Carter was asked to develop and document a proxy NOx value on the same scale as the MIR (Carter 2008, Carter 2010a).

Modifications were made in the development of TRACI 2.1 when compared to the original version of TRACI. First, the MIRs were updated to include the latest work of Carter (Carter 2010b). More chemicals were added and the total number of pollutants now quantified in this category is nearly 1200 substances. Second, to be consistent with the presentation and units of other impact categories a reference substance was adopted. Thirdly, those twelve substances, which have a negative MIR, were set to zero. While it may be true there is a slightly beneficial effect to the reduction of ozone concentrations upon increased concentration of these pollutants, it was decided that providing "credit" for the additional release of pollutants was not generally a good practice. This is consistent with other recommendations in which negative MIRs were not given credits (Carter 2003).

Resource Depletion

Resource depletion is an extremely important issue for the use and development of sustainability metrics and LCA methodologies. Unfortunately, it is one of the most difficult issues to quantify while minimizing value choices and assumptions. Because all of the previously described categories had legislation or international agreements related to their control, it was relatively easy to utilize the models, which were in existence for fate, transport, and potency for each impact category. A parallel track does not exist for these resource depletion categories. Therefore, it is recognized up front the quantification of these impact categories will be the most controversial.

Based on a review performed by the author, a determination was made that the initial resource depletion categories which would be addressed within TRACI would be fossil fuel use, land use, and water use. A non site-specific recommendation for fossil fuel use characterization was included within the original version of TRACI (Bare *et al*. 2003, Goedkoop & Spriensma 1999) and this reference methodology is maintained within this release of TRACI 2.1. Over the next few years, the author will be concentrating research efforts in land and water use and should have additional recommendations. In both cases, land and water use recommendations are expected to be site specific, because of the unique properties of location, meteorology, and existing ecosystems.

Interpretation

Notice that no conclusions can be drawn about the relative importance of the scores when compared across impact categories. Since each impact category has different units it is not appropriate to simply look at the values of each impact category and determine from this point which impact category is of most concern. To look at relative importance would involve normalization and weighting. None of the above impact categories have been aggregated using normalization or weighting. Even the human health impact categories have been maintained independently in these examples.

Whether using TRACI within previously developed software, or using it within an EXCEL spreadsheet, one of the most important phases is a proper interpretation of results. One important component of interpretation is an understanding of the uncertainty involved with various results. Uncertainty in the calculated results can be highly variable depending on the impact category and its underlying methodology. Within the USEtox Manual, for example, they mention that characterization factors associated with USEtox may span three orders of magnitude on the individual factors. Other impact categories such as ozone depletion may be based on chemical data and models with less associated uncertainty for individual substances. These uncertainties can best be understood by consulting the original sources of characterization factors.

Summary

TRACI 2.1 is now available for use in sustainability, life cycle impact assessment, process design, or pollution prevention. All of these applications require quantitative data to guide decision making which impacts the current and future generations. TRACI 2.1 has been updated to include additional substances and updated methodologies. Over the next few years, the US EPA will be continuing to expand research into the areas of land use and water use.

Disclaimer

Use of TRACI, including but not limited to the impact assessment modeling, does not create regulatory or scientific approval by the US EPA on any issues to which it is applied, nor does it release any users from any potential liability, either administratively or judicially, for any damage to human health or the environment. The US EPA does not make any warranty concerning the correctness of the database, any actions taken by third parties as a result of using the model, or the merchantability or fitness for a particular purpose of the model. The EPA does not endorse any products or services.

How to Use TRACI 2.1

The TRACI_2012 spreadsheet includes a number of worksheets. These worksheets and their function are described below.

TRACI 2.1	Provides information concerning the version, source, and disclaimer for using TRACI 2.1.
Fossil Fuels	Provides information specific to the characterization of fossil fuels.
Substances	Includes substances, CAS numbers, and their characterization factors for all of the substance based impact categories.
References	Provides references for all of the characterization factors within TRACI.

Impact Category Headings

CAS # - Chemical Abstract Services Number

Substance Name – Substances Name (may include categories)

Alternate Substance Name – Limited Alternatives are available

Global Warming Air (kg CO2 eq/kg substance) = Global Warming Potentials for Air Emissions

Acidification Air (kg SO2 eq/kg substance) = Acidification Potentials for Air Emissions

Acidification Water (kg SO2 eq/kg substance) = Acidification Potentials for Water Emissions

HH Particulate Air (PM2.5eq/kg substance) = Human Health Particulate (and secondary particulate matter precursors) Potentials for Air Emissions

Eutrophication Air (kg N eq/kg substance) = Eutrophication Potentials for Air Emissions

Eutrophication Water (kg N eq/kg substance) = Eutrophication Potentials for Water Emissions

Ozone Depletion Air (kg CFC-11 eq/kg substance) = Ozone Depletion Potentials for Air Emissions

Smog Air (kg O3 eq/kg substance) = Smog Formation Potentials for Air Emissions

Ecotox CF (CTUeco/kg), Em.airU, freshwater = Freshwater Ecotoxicity Potentials for Urban Air Emissions

Ecotox CF (CTUeco/kg), Em. airC, freshwater = Freshwater Ecotoxicity Potentials for Rural Air Emissions

Ecotox CF (CTUeco/kg), Em. Fr.waterC, freshwater = Freshwater Ecotoxicity Potentials for Freshwater Emissions

Ecotox CF (CTUeco/kg), Em. seawaterC, freshwater = Freshwater Ecotoxicity Potentials for Seawater Emissions

Ecotox CF (CTUeco/kg), Em. Nat.soilC, freshwater = Freshwater Ecotoxicity Potentials for Natural Soil Emissions

Ecotox CF (CTUeco/kg), Em. Agr.soilC, freshwater = Freshwater Ecotoxicity Potentials for Agricultural Soil Emissions

CF Flag Ecotox = Characterization Factor Flag for Ecotoxicity Potentials

Human health CF (CTUcancer/kg), Emission to urban air, cancer = Human health Cancer Potentials for Urban Air Emissions

Human health CF (CTUnoncancer/kg), Emission to urban air, non-canc. = Human health Non-cancer Potentials for Urban Air Emissions

Human health CF (CTUcancer/kg), Emission to cont. rural air, cancer = Human health Cancer Potentials for Rural Air Emissions

Human health CF (CTUnoncancer/kg), Emission to cont. rural air, non-canc. = Human health Non-cancer Potentials for Rural Air Emissions

Human health CF (CTUcancer/kg), Emission to cont. freshwater, cancer = Human health Cancer Potentials for Freshwater Emissions

Human health CF (CTUnoncancer/kg), Emission to cont. freshwater, non-canc. = Human health Non-cancer Potentials for Freshwater Air Emissions

Human health CF (CTUcancer/kg), Emission to cont. sea water, cancer = Human health Cancer Potentials for Sea water Emissions

Human health CF (CTUnoncancer/kg), Emission to cont. sea water, non-canc. = Human health Non-cancer Potentials for Sea water Emissions

Human health CF (CTUcancer/kg), Emission to cont. natural soil, cancer = Human health Cancer Potentials for Natural Soil Emissions

Human health CF (CTUnoncancer/kg), Emission to cont. natural soil, non-canc. = Human health Non-cancer Potentials for Natural Soil Emissions

Human health CF (CTUcancer/kg), Emission to cont. agric. soil, cancer = Human health Cancer Potentials for Agricultural Soil Emissions

Human health CF (CTUnoncancer/kg), Emission to cont. agric. soil, non-canc. = Human health Non-cancer Potentials for Agricultural Soil Emissions

CF Flag HH carcinogenic = Characterization Factor Flag for Human Health Carcinogenic Potentials

CF Flag HH non-carcinogenic = Characterization Factor Flag for Human Health Non-carcinogenic Potentials

Example Case Study Results

To calculate the score for each individual impact category, multiply the mass of the substance (kg) emitted in the given compartment (e.g., urban air, agricultural soil) with the characterization factor for that substance in each impact category.

Example 1

Assume the emissions include the following.

Halon-1301 = 2 kg emissions to air

Which has a GWP for air = 7140,

And an ODP for air = 16.

Would yield the following scores

For GWP = 2 kg * 7140 kg CO2 eq / kg substance = 14,280 kg CO2 eq

For ODP = 2 kg * 16 kg CFC-11 eq / kg substance = 32 kg CFC-11 eq

Example 2

Similarly, the cancer and noncancer categories are treated as independent impact categories and should not be aggregated. The media emissions can be aggregated however.

Assume the emissions include the following.

Benzene = 5 kg emissions to rural air

Which has a Smog Potential for air = 0.72 O3 eq / kg substance,

And an Ecotoxicity Potential for rural air = 0.064 CTUeco / kg substance,

And a Human health Cancer Potential to rural air = 1.2 E-07 CTUcancer / kg substance

And a Human health Noncancer Potential to rural air = 3.0 E-08 CTUnoncancer / kg substance

And Benzene = 10 kg emissions to freshwater

And an Ecotoxicity Potential for freshwater = 66 CTUeco / kg substance,

And a Human health Cancer Potential to freshwater = 2.4 E-07 CTUcancer / kg substance

And a Human health Noncancer Potential to freshwater = 6.1 E-08 CTUnoncancer / kg substance

The above two emissions of benzene would yield the following scores.

For Smog = 5 kg * 0.72 ozone eq / kg substance = 3.6 ozone eq

For Ecotoxicity = (5 kg * 0.064 CTUeco / kg substance) + (10 kg * 66 CTUeco / kg substance) = 660 CTUeco

For Human Health Cancer = (5 kg * 1.2 E-07 CTUcancer / kg substance) + (10 kg * 2.4 E-07 CTUcancer / kg substance) = 3.0 E-06 CTUcancer

For Human Health Noncancer = (5 kg * 3.0 E-08 CTUnoncancer / kg substance) + (10 kg * 6.1 E-08 CTUnoncancer / kg substance) = 7.6 E-7 CTUnoncancer

References

Andersson-Skold, Y., P. Grennfelt & K. Pleijel (1992) Photochemical ozone creation potentials. *Journal of Air and Waste Management,* **42**(9)**,** 1152-1158.

Bare, J. (2011) TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. *Clean Technologies and Environmental Policy,* **13**(5).

Bare, J. C. (2006) Risk assessment and Life-Cycle Impact Assessment (LCIA) for human health cancerous and noncancerous emissions: Integrated and complementary with consistency within the USEPA. *Human and Ecological Risk Assessment,* **12**(3).

Bare, J. C. & T. P. Gloria (2006) Critical analysis of the mathematical relationships and comprehensiveness of life cycle impact assessment approaches. *Environmental Science & Technology,* **40**(4)**,** 1104-1113.

Bare, J. C. & T. P. Gloria (2008) Environmental impact assessment taxonomy providing comprehensive coverage of midpoints, endpoints, damages, and areas of protection. *Journal of Cleaner Production,* **16**(10)**,** 1021-1035

Bare, J. C., P. Hofstetter, D. W. Pennington & H. A. Udo de Haes (2000) Life cycle impact assessment midpoints vs. endpoints – the sacrifices and the benefits. *International Journal of Life Cycle Assessment,* **5**(6)**,** 319-326.

Bare, J. C., G. A. Norris, D. W. Pennington & T. McKone (2003) TRACI – The Tool for the Reduction and Assessment of Chemical and other environmental Impacts. *Journal of Industrial Ecology,* **6**(3)**,** 49-78.

Bare, J. C., H. A. Udo de Haes & D. W. Pennington (1999) Life cycle impact assessment sophistication. *International Journal of Life Cycle Assessment,* **4**(5)**,** 299-306.

Carter, W. (1994) Development of ozone reactivity scales for volatile organic compounds. *Journal of Air and Waste Management Association,* **44,** 881-899.

Carter, W. (1997) Summary of status of VOC reactivity estimates prepared for the California Air Resources Board Consumer Products Working Group Meeting.

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

Carter, W. (2003) Letter to Mr. Richard Corey, Chief, Research and Economics Branch, Research Division, California Air Resources Board, Sacramento, CA, Jan 24.

Carter, W. (2007) Development of the SAPRC-07 Chemical Mechanism and Updated Ozone Reactivity Scales, Final Report. California Air Resources Board.

Carter, W. (2008) Estimation of the Maximum Ozone Impacts of Oxides of Nitrogen.

Carter, W. (2010a) Email to Jane Bare, Feb 3, 2010.

Carter, W. (2010b) SAPRC Atmospheric Chemical Mechanisms and VOC Reactivity Scales.

Carter, W. (2012) SAPRCs Updated [online]. http://www.engr.ucr.edu/~carter/SAPRC/#mec12210 [accessed March 9, 2012

Derwent, R. G., M. E. Jenkin & S. M. Saunders (1996) Photochemical ozone creation potentials for a large number of reactive hydrocarbons under European conditions. *Atmospheric Environment,* **30**(2)**,** 181-199.

Derwent, R. G., M. E. Jenkin, S. M. Saunders & M. J. Pilling (1998) Photochemical ozone creation potentials for organic compounds in Northwest Europe calculated with a master chemical mechanism. *Atmospheric Environment,* **32**(14-15)**,** 2429-2441.

Derwent, R. G., Jenkin, M.E (1991) Hydrocarbons and the Long-Range Transport of Ozone and PAN Across Europe. *Atmospheric Environment,* **25,** 1661-1678.

Ecological Society of America (2000) Nutrient Pollution of Coastal Rivers, Bays, and Seas. *Issues in Ecology,* **7**.

Gloria, T. P., B. C. Lippiatt & J. Cooper (2007) Life cycle impact assessment weights to support environmentally preferable purchasing in the United States. *Environmental Science & Technology,* **41**(21)**,** 7551-7557.

Goedkoop, M., M. Demmers & M. Collignon (1996) The Eco-indicator 95. Pre Consultants.

Goedkoop, M., R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs & R. van Zelm (2009) ReCiPe 2008 - a life cycle impact assessment method which comprises harmonised category indicators at the midpoint and endpoint level - First Edition. Report 1: Characterisation.

Goedkoop, M. & R. Spriensma (1999) The Eco-Indicator 99: A damage orientated method for life cycle impact assessment. the Hague, the Netherlands.

Guinée, J., M. Gorrée, R. Heijungs, G. Huppes, R. Kleijn, A. de Koning, L. van Oers, A. Wegner Sleeswijk, S. Suh, H. Udo de Haes, H. de Bruijn, R. van Duin, M. Huijbregts, E. Lindeijer, A. Roorda, B. van der Ven & B. Weidema (2002) *Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards.* Kluwer Academic Publishers, Dordrecht.

Hauschild, M., M. Huijbregts, O. Jolliet, M. Margni, M. MacLeod, D. van de Meent, R. Rosenbaum & T. McKone (2008) Building a model based on scientific consensus for Life Cycle Impact Assessment of chemicals: The search for harmony and parsimony. *Environmental Science and Technology*, **42**(19)**,** 7032-7036.

Hauschild, M. & H. Wenzel (1998a) *Environmental Assessment of Products.* Chapman & Hall, New York.

Hauschild, M. & H. Wenzel (1998b) *Environmental assessment of products. Volume 2: Scientific background.* London, UK.

Heijungs, R., J. B. Guinée, G. Huppes, R. M. Lankreijer, H. A. Udo De Haes, A. Wegener Sleeswijk, A. M. M. Ansems, P. G. Eggels, R. van Duin & H. P. de Goede (1992a) Environmental life cycle assessment of products: guide and backgrounds (Part 1) CML, Leiden, the Netherlands.

Heijungs, R., J. B. Guinée, G. Huppes, R. M. Lankreijer, H. A. Udo De Haes, A. Wegener Sleeswijk, A. M. M. Ansems, P. G. Eggels, R. van Duin & H. P. de Goede (1992b) Environmental life cycle assessment of products: guide and backgrounds (Part 2) *In* CML (ed.). CML, Leiden, the Netherlands.

Hertwich, E., T. McKone & W. Pease (1999) Parameter uncertainty and variability in evaluative fate and exposure models. *Risk Analysis,* **19,** 1193-1204.

Hofstetter, P., J. C. Bare, J. K. Hammitt, P. A. Murphy & G. E. Rice (2002) Tools for the Comparative Analysis of Alternatives: Competing or Complementary Perspectives? *Risk Analysis,* **22**(5).

Humbert, S. (2009) Geographically Differentiated Life-cycle Impact Assessment of Human Health - A Dissertation. University of California, Berkeley.

International Standards Organization (2000) Environmental management – life cycle assessment – life cycle impact assessment (International Standard ISO14042:2000(E)).

IPCC (Intergovernmental Panel on Climate Change) (1996) Climate Change 1995: The Science of Climate Change. Intergovernmental Panel on Climate Change. *In* J.T. Houghton, L. G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg & K. Maskell (eds.). Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change) (2001) *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, U.K.

Jenkin, M. E. & G. D. Hayman (1999) Photochemical ozone creation potentials for oxygenated volatile organic compounds: sensitivity to variations in kinetic and mechanistic parameters. *Atmospheric Environment,* **33**(8)**,** 1275-1293.

Jolliet, O., M. Margni, R. Charles, S. Humbert, J. Payet, G. Rebitzer & R. Rosenbaum (2003) IMPACT 2002+: A new life cycle impact assessment methodology. *International Journal of Life Cycle Assessment,* **8**(6).

McKone, T. E. (1993) CalTOX, A Multimedia Total Exposure Model for Hazardous-Waste Sites. Lawrence Livermore National Laboratory, Livermore, CA.

Pennington, D. W. & J. C. Bare (2001) Comparison of Chemical Screening and Ranking Approaches: The Waste Minimization Prioritization Tool (WMPT) vs. Toxic Equivalency Potentials (TEPs). *Risk Analysis,* **21**(5).

Pennington, D. W., G. Norris, T. Hoagland & J. C. Bare (2000) Environmental comparison metrics for life cycle impact assessment and process design. *Environmental Progress,* **19**(2).

Rosenbaum, R., T. Bachmann, M. Huijbregts, O. Jolliet, R. Juraske, A. Koehler, H. Larsen, M. MacLeod, M. Margni, T. McKone, J. Payet, M. Schuhmacher, D. van de Meent & M. Hauschild (2008) USEtox - The UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity. *International Journal of Life Cycle Assessment,* **7,** 532-546.

Solomon, S. & D. L. Albritton (1992) Time –dependent ozone depletion potentials for short- and long-term forcast. *Nature 357***,** 33-37.

Solomon, S., D. Qin, M. Manning, R. B. Alley, T. Berntsen, N. L. Bindoff, Z. Chen, A. Chidthaisong, J. M. Gregory, G. C. Hegerl, M. Heimann, B. Hewitson, B. J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J.Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T. F. Stocker, P. Whetton, R. A. Wood & D. Wratt (2007) Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *In* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (ed.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Solomon, S. Q., D.; Manning, M.; Alley, R. B.; Berntsen, T.; Bindoff, N. L.; Chen, Z.; Chidthaisong, A.; Gregory, J. M.; Hegerl, G. C.; Heimann, M.; Hewitson, B.; Hoskins, B. J.; Joos, F.; Jouzel, J.; Kattsov, V.; Lohmann, U.; Matsuno, T.; Molina, M.; Nicholls, N.; J.Overpeck; Raga, G.; Ramaswamy, V.; Ren, J.; Rusticucci, M.; Somerville, R.; Stocker, T. F.; Whetton, P.; Wood, R. A.; Wratt, D., (2011) Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth

Assessment Report of the Intergovernmental Panel on Climate Change. Updated Nov. 17, 2011. *In* Intergovernmental Panel on Climate Change (ed.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

U.S. Environmental Protection Agency (1997) Exposure Factors Handbook. Washington, D.C.

U.S. Environmental Protection Agency (2008) Why is Phosphorus Important? [online]. http://www.epa.gov/owow/monitoring/volunteer/stream/vms56.html [accessed Oct. 30, 2008

UNFCCC -The United Nations Framework Convention on Climate Change (2003) Review of the Implementation of Commitments and of other Provisions of the Convention, National Communications: Greenhouse Gas Inventories from Parties Included in Annex 1 to the Convention, UNFCCC Guidelines on Reporting and Review.

US Department of Agriculture - Natural Resources Conservation Service (2006) Model Simulation of Soil Loss, Nutrient Loss, and Change in Soil Organic Carbon Associated with Crop Production, pp. 114 & 171.

US Department of Energy - Energy Information Administration (2008) Total US Energy Consumption, State Energy Data, Table 7. Energy Consumption Estimates by Source, 1960-2005.

US Department of Energy - National Renewable Energy Laboratory (2008) US Life-Cycle Inventory Database.

US Environmental Protection Agency (1989a) Exposure factors handbook. Office of Health and Environmental Assessment, Washington, D.C.

US Environmental Protection Agency (1989b) Risk assessment guidance for superfund. Volume I. Human health evaluation manual (Part A). Office of Emergency and Remedial Response, Washington, D.C.

(1992) Electronic Code of Federal Regulations, Title 40 -- Protection of Environment, Chapter 1 -- Environmental Protection Agency, Subchapter C -- Air Programs, Part 82 -- Protection of Stratospheric Ozone.

US Environmental Protection Agency (1997) Technical Guidance Manual for Performing Wasteload Allocations, Book II: Streams and Rivers – Part 1: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication.

US Environmental Protection Agency (2002) Custom developed spreadsheet provided by Anne Pope which included all NEI HAP emissions for 2002. Provided in email to Jane Bare on Aug 24, 2007.

(2003) Electronic Code of Federal Regulations, Title 40: Protection of Environment, Part 82 -- Protection of Stratospheric Ozone, Subpart A—Production and Consumption Controls

US Environmental Protection Agency (2005a) 2005 Toxic Release Inventory (TRI): Public Data Release.

US Environmental Protection Agency (2005b) Federal Register, Vol. 70, No. 176, Sept 13, 2005 Rules and Regulations, 53930, 40 CFR Parts 51 and 52. Revisions to the California State Implementation Plan and Revision to the Definition of Volatile Organic Compounds (VOC) – Removal of VOC Exemptions for California's Aerosol Coating Products Reactivity-based Regulation.

US Environmental Protection Agency (2005c) Federal Register: October 5, 2005, Vol. 70, No. 192, Proposed Rules, pages 58138 – 58146. 40 CFR Part 52. Approval and Promulgation of Air Quality Implementation Plans; Texas; Highly Reactive Volatile Organic Compound Emissions Cap and Trade Program for the Houston/Galveston/Brazoria Ozone Nonattainment Area.

US Environmental Protection Agency (2006) Particulate Matter, PM Standards Revision [online]. http://epa.gov/pm/naaqsrev2006.html [accessed June 12, 2008.

(2007a) Federal Register, Vol. 72, No. 135, 38952, July 16, 2007, US EPA, Part IV, 40 CFR Parts 51 and 59, National Volatile Organic Compound Emission Standards for Aerosol Coatings; Proposed Rule.

US Environmental Protection Agency (2007b) National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data and Estimation Procedures, 1970 - 2006 Average Annual Emissions, All Criteria Pollutants in MS EXCEL.

US Environmental Protection Agency (2008a) Climate Change - Greenhouse Gas Emissions - Human-Related Sources and Sinks of Carbon Dioxide [online]. http://www.epa.gov/climatechange/emissions/co2_human.html [accessed Oct 30, 2008

US Environmental Protection Agency (2008b) Climate Change Basic Information [online]. http://epa.gov/climatechange/basicinfo.html [accessed June 9, 2008

US Environmental Protection Agency (2008c) Effects of Acid Rain [online]. http://www.epa.gov/acidrain/effects/index.html [accessed May 30, 2008

US Environmental Protection Agency (2008d) EPA's Report on the Environment, Indicators Presenting Data for EPA Region 5, pp. 51 – 53 [online]. http://www.epa.gov/ncea/roe/pdfs/Region5_Indicators.pdf [accessed June 3, 2008

US Environmental Protection Agency (2008e) Ground-level Ozone, Basic Information [online]. http://www.epa.gov/air/ozonepollution/basic.html [accessed July 10, 2008

US Environmental Protection Agency (2008f) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.

US Environmental Protection Agency (2008g) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006, Annex 6.

US Environmental Protection Agency (2008h) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006, April 15, 2008. Executive Summary: Table ES-1.

US Environmental Protection Agency (2008i) National Ambient Air Quality Standards (NAAQS) [online]. http://www.epa.gov/air/criteria.html [accessed June 12, 2008

US Environmental Protection Agency (2008j) Ozone Layer Depletion - Science [online]. http://www.epa.gov/ozone/science/sc_fact.html [accessed July 10, 2008

US Environmental Protection Agency (2008k) Ozone Layer Depletion - Science, Class I Ozone-depleting Substances [online]. http://www.epa.gov/ozone/science/ods/classone.html [accessed July 10, 2008

US Environmental Protection Agency (2008l) Ozone Layer Depletion - Science, Class II Ozone-depleting Substances [online]. http://www.epa.gov/ozone/science/ods/classtwo.html [accessed July 2, 2008

US Environmental Protection Agency (2008m) Ozone Science: The Facts Behind the Phaseout [online]. http://www.epa.gov/ozone/science/sc_fact.html#fact3 [accessed July 10, 2008

US Environmental Protection Agency (2008n) Particulate Matter Research [online]. http://www.epa.gov/pmresearch/ [accessed June 12, 2008

US Environmental Protection Agency (2008o) Particulate Matter, Basic Information [online]. http://www.epa.gov/air/particlepollution/basic.html [accessed June 12, 2008

US Environmental Protection Agency (2008p) U.S.Climate Policy and Actions [online]. http://epa.gov/climatechange/policy/index.html [accessed June 9, 2008

US Environmental Protection Agency (2008q) What is Acid Rain? [online]. http://www.epa.gov/acidrain/what/index.html [accessed May 30, 2008

USEtox Team (2010) Background of the USEtox Model [online]. http://www.usetox.org/background.aspx

Wenzel, H. & M. Hauschild (1997) *Environmental assessment of products. Volume 2: Scientific backgrounds.* London, UK.

Wenzel, H., M. Z. Hauschild & L. Alting (1997) *Environmental assessment of products. Volume 1. Methodology, tools and case studies in product development.* Chapman and Hall, London.

WMO (World Meteorological Organization) (1999) Scientific Assessment of Ozone Depletion: 1998. Global Ozone Research and Monitoring Project - Report No. 44. Geneva, Switzerland.

WMO (World Meteorological Organization) (2003) Scientific Assessment of Ozone Depletion: 2002, Global Ozone Research and Monitoring Project—Report No. 47. Geneva, Switzerland.