DRAFT APPENDIX

Life Cycle Benefit/Impact Assessment Tool Requirements

Sustainable Products Purchasing Coalition
Pilot Project

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Introduction

Qualifying LCA tools must identify the LCA impacts and impact data in this Appendix, over the life cycle of the specific product. This appendix shows the major assumptions and requirements; they are the ones used by the federal government environmentally preferable purchasing program, and are supported by the Certified Forest Products Council (CFPC), a nonprofit helping specifiers and purchasers use environmentally responsible forest products.[1]

This APPENDIX has been prepared:

- *so the public, including Vendors/manufacturers, better understand why and how LCA impacts are identified and thus the benefits of doing so;*
- *to identify clear and enumerated specifications for impact assessment; and*
- *to allow the City to have a method for sustainable products purchasing consistent with State, federal and international law.*

Impact assessment quantifies the potential contribution of environmental and health impacts of a product over its life cycle. The Classification/Characterization impact assessment approach is used for climate change, acid rain, water pollution, stratospheric ozone depletion, and natural resource depletion because it is supported by a general consensus of LCA practitioners and scientists.[2] This approach is a two step process. First, the releases of pollutants to air, land, and water that cause adverse health and environmental impacts are identified. Second, the potential contribution of these releases to the environmental impacts are characterized by using indices for each impact obtained by weighting each category of pollutant release by its relative contribution to the impact. For example, for identifying climate change impacts, a global warming potential is used expressing each pollutant release in terms of its equivalent amount of carbon dioxide.

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[1] CFPC's environmental partners include Forest Stewardship Council (FSC), National Audubon Society, Natural Resources Defense Council, Rainforest Alliance, The Wilderness Society, World Wildlife Fund, World Resources Institute. CFPC NIST LCA support letter to David Engel, HUD (Oct. 17, 2000).

[2] Society for Environmental Toxicology & Chemistry (SETAC) Europe, *Life Cycle Assessment*, B. DeSmet, et al. (eds. 1992), SETAC, *A Conceptual Framework for Life Cycle Impact Assessment,* J. Fava et al. (eds. 1993), SETAC, *Guidelines for Life Cycle Assessment: A "Code of Practice,"* F. Consoli et al. (eds. 1993), SETAC, *Life Cycle Impact Assessment: The State of the Art,* J. Owens et al. (eds. 1997).

The impact assessment approach used for smog, ecological and human toxicity was suggested by EPA. [3] The Direct Use of Inventories approach is used for solid waste.

Vendors/manufacturers can provide additional data for their individual products in the LCA questionnaire, and are encouraged to submit data showing improved environmental performance. Further detail on assumptions, requirements, and assessment approaches can be obtained by contacting Sustainable Products Corp., 202-338-0313, info@sustainableproducts.com.

Climate Change. The United Nations Intergovernmental Panel on Climate Change[4] projects climate changes in this century leading to "large scale and possible irreversible changes in Earth systems," with "continental and global consequences." The report says that global economic losses in the 1990's from natural catastrophes increased ten times since the 1950's to $400 billion. The work of 700 scientists states that climate change will lead to:

- more "freak" weather conditions like cyclones, floods & droughts
- massive displacement of populations in the worst-affected areas
- potentially enormous loss of life
- greater risk from diseases like malaria as the mosquito widens its reach
- extinction of entire species as their habitat is wiped out

The top 63 chemicals contributing to climate change must be identified as shown below. They have the highest global warming potential (GWP) based on the Intergovernmental Panel on Climate Change best estimates for Global Warming. These GWPs have broad support and are recognized by scientists worldwide.[5]

Greenhouse Gases
Carbon Dioxide (CO2, fossil)
Methane (CH4)
Nitrous Oxide (N2O)
CFC 11 (CFCl3)
CFC 12 (CCl2F2)
CFC 13 (CF3Cl)
CFC 113 (CFCl2CFCl2)
CFC 114 (CF2ClCF2Cl)
CFC 115 (CF3CF2Cl)

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3 U.S. EPA, *Framework for Responsible Environmental Decisionmaking: Using Life Cycle Assessment to Evaluate Preferability of Products,* by Science Applications International Corp., Research Triangle Institute, and EcoSense, Inc. (1999).

4 International Panel on Climate Change (IPCC) *Climate Change 2001: Impacts, Adaption & Vulnerability (Mar. 2001).*

5 IPCC Second Assessment- *Climate Change 1995: A Report of the International Panel on Climate Change* (1996).

HCFC 22 (CHF2Cl)
HCFC 123 (CHCl2CF3)
HCFC 124 (CHClFCF3)
HCFC 141b (CFCl2CH3)
HCFC 142b (CF2ClCH3)
HCFC 225ca (C3HF5Cl2)
HCFC 225cb (C3HF5Cl2)
Carbon Tetrachloride (CCl4)
Methyl Chloroform (CH3CCl3, HC-140a)
Halon 1301 (CF3Br)
HFC 23 (CHF3)
HFC 32 (CH2F2)
HCFC 43-10 mee
HFC 125 (CF3CHF2)
HFC 134 (C2H2F4)
HFC 134a (CF3CH2F)
HFC 152a (CHF2CH3)
HFC 143 (C2H3F3)
HFC 143a (CF3CH3)
HFC 227ea (CF3CF2CHF2)
HFC 236fa (CF3CF2CH2F)
HFC 245ca (CF3CF2CH3)
Chloroform (CHCl3, HC-20)
Methylene Chloride (CH2Cl2, HC-130)
Sulfur Hexafluoride (SF6)
Carbon Tetrafluoride (CF4)
Hexafluoroethane (C2F6, FC116)
Perfluorocyclo-butane (c-C4F8)
Perfluorohexane (C6F14)

An index is used to measure the quantity of carbon dioxide with the same potential for climate change (global warming).

Example Global Warming Potential Equivalency Factors	
Flow	GWP CO_ Equivalents
Carbon Dioxide	1.0
Methane	24.0
Nitrous Oxide	360.0

Acid Rain. Acid rain causes adverse impacts to biota and structures. The following gases must be identified:

Acidification Gases
Sulfur Oxides (Sox as SO2)
Nitrogen Oxides (NOx as NO2)
Ammonia (NH3)
Hydrogen Chloride (HCl)
Hydrogen Fluoride (HF)
Chromic Acid (H2CrO4)
Sulfuric Acid (H2SO4)
Hydrogen Bromide (HBr)
Hydrogen Cyanide (HCN)
Hydrogen Sulphide (H2S)

Potential acid deposition onto the soil and in water uses hydrogen as the reference substance with a single index for potential acidification (in grams of hydrogen per functional unit of product).[6] The following acidification potential equivalence factors are used:

Flow	Hydrogen Ion Equivalents
Sulfur oxides	0.031
Nitrogen oxides	0.022
Ammonia	0.059
Hydrogen Fluoride	0.050
Hydrogen Chloride	0.027

Other Air Emissions. The following air pollutants must be identified:

Other Air Emissions
CO
Particulate Matter
NMHC (total)
Metals (total)

Carbon monoxide is demonstrated as showing adverse impacts to the heart and brain and thus is identified as a criteria pollutant under the Clean Air Act. Particulate matter causes lung cancer and is also a criteria pollutant. Heavy metals are toxic.

[6] CML, Centre of Environmental Science, *Environmental Life Cycle Assessment of Products: Background,* Leiden, The Netherlands (Oct. 1992).

Water Pollution. The following pollutants must be identified:

Eutrophication
Ammonia (NH4+)
Nitrogen (N, total)
Phosphates (PO4 3-)
Phosphorus (P)
COD (Chemical Oxygen Demand)
Nitrogenous Matter (Kjeldhal, as N)
Nitrates (NO3-)
Nitrogenous Matter (unspecified, as N)
Phosphorous Matter (unspecified, as P)
Nitrogen Dioxide (NO2)
Nitrogen Oxide (NO)
Nitrites (NO2-)
Phosphorus Pentoxide (P2O5)

Other Water Effluents
BOD
Suspended Solids
Hydrocarbons (total)
Metals (total)

Eutrophication is used as an impact indicator. It is the unwanted addition of mineral nutrients to the soil or water such as nitrogen and phosphorous which results in undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. In water, it tends to increase algae which leads to reduced dissolved oxygen and therefore death of species like fish.

An index for potential eutrophication is expressed in grams of phosphate ions per functional unit of product and represents the quantity of phosphate ions with the same potential nutrifying effect.[7] The following eutrophication potential equivalency factors are used:

Flow	Phosphate equivalents
Phosphates	1.00
Nitrogen Oxides	0.13
Ammonia	0.42
Nitrogenous Matter	0.42
Nitrates	0.10
Phosphorous	3.06

[7] CML (1992).

Chemical Oxygen Demand	0.02

Natural Resource Depletion. Natural resource depletion is the decreasing availability of natural resources, and for purposes of LCA impact assessment, fossil and mineral resources. This impact addresses only the depletion aspect of resource extraction, not the fact that the extraction may generate impacts. Extraction impacts, such as methane emissions from coal mining, are addressed in other impacts, such as climate change.

Resource depletion is not fully accounted for by price mechanisms to take care of scarcity. Price is influenced by many factors other than resource supply, such as resource demand and non-perfect markets (e.g., monopolies and subsidies). Further, resource depletion is a factor addressed in measuring sustainable products. To assess resource depletion, the amount of reserves of a resource, or resource base, needs to be determined. For mineral resources, the reserve base is defined:

> The reserve base encompasses those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. It includes those resources that are currently economic, marginally economic, and subeconomic.[8]

Reserve base quantities and equivalency factors are derived for each resource that relate its inventory flow with the depletion of the resource. The equivalency factor addresses how long a given resource will continue to be available at current extraction levels, as well as the size of the reserve. The following natural resource depletion equivalency factors are used:

Inventory Flow Kg	Data Source	Annual Production kg/yr	Reserve Base	Equivalency Factor
Oil (in ground)	World Energy Council (WEC) 1995	3.2 E+12	2.4E+14	5.6E-17
Natural Gas (in ground)	WEC 1995	2.0E+12	1.3E+14	1.2E-16
Coal (in ground)	WEC 1995	4.5E+12	3.0E+15	5.0E-19
Bauxite dry	US Bureau of Mines (BOM) 1996	1.1E+11	2.8E+13	1.4E-16
Cadmium Ore	BOM 1996	2.0E+07	9.7E+08	2.1E-11
Copper Ore	BOM 1996	9.8E+09	6.1E+11	2.6E-14
Gold Ore	BOM 1996	2.2E+06	6.1E+07	5.9E-10

8 U.S. Department of Interior, Bureau of Mines, *Mineral Commodity Summary* (1994).

Iron Ore	BOM 1996	4.3E+11	1.2E+11	4.3E-17
Lead Ore	BOM 1996	2.8E+09	1.2E+11	1.9E-13
Manganese Ore	BOM 1996	7.3E+09	5.0E+12	2.9E-16
Mercury Ore	BOM 1996	3.1E+06	2.4E+08	5.4E-11
Nickel Ore	BOM 1996	9.2E+08	1.1E+11	7.6E-14
Phosphate (in Ground)	BOM 1996	1.4E+11	3.4E+13	1.2E-16
Potash (in Ground)	BOM 1996	2.6E+10	1.7E+13	9.1E-17
Silver Ore	BOM 1996	1.4E+07	4.2E+08	7.9E-11
Tin Ore	BOM 1996	1.8E+08	1.0E+10	1.8E-12
Uranium Ore	WEC 1995	3.3E+07	1.3E+10	1.8E-13
Zinc Ore	BOM 1996	7.1E+09	3.3E+11	6.5E-14

Due to abundant resources, the depletion index has been set to zero for the following resources: Clay (in ground), Dolomite (in ground), Feldspar ore, Gypsum ore, Kaolin ore, Limestone (in ground), Sand (in ground), Sodium Chloride (in ground or sea). Note that local shortages of these resources may exist. Local shortages are translated into higher transportation distances and therefore higher emissions, but have no impact on the depletion factor.

Solid Waste. The weight of non-recyclable solid waste is tracked for the product over a 50 year use period. The volume of solid waste represents the solid waste impact and is derived by dividing the total weight, by the density of the product. Solid waste, including hazardous waste, contaminates soil and groundwater and contains powerful solvents and carcinogens as products of decomposition. When incinerated, solid waste can generate highly toxic mercury emissions.

Indoor Air Quality for Building Products. Extended human exposure periods exist for indoor air pollutants especially where fresh air circulation is limited. Volatile organic compounds emanating from products cause adverse health effects.

Equivalency factors are not used because there is little scientific consensus about the relative contributions of pollutants to indoor air performance. In the absence of equivalency factors, a product's total volatile organic compound (VOC) emissions are used as a measure of indoor air performance.

For Floor Coverings, ceramic tile, composite marble tile, and terrazzo are inert and emit no VOCs.[9] The following VOC emissions are used for other flooring products, unless the manufacturer of the product demonstrates that the product does not release VOCs.

Floor Covering	Total VOCs (mg/m_/h at 24h)
Linoleum ①	1.667
Vinyl Composition Tile ①②	0.115

[9] American Institute of Architects, *Environmental Resource Guide,* Ceramic Tile Material Report at 1, and Terrazzo Material Report at 1 (1996).

Carpet ③	0.500

① Averages for three linoleum and two vinyl composition tile emissions tests conducted in a test chamber designed in accordance with ASM D5116-90 at Air Quality Sciences Laboratory, Atlanta, GA (1991-2).
② Note that vinyl composition tile has substantially lower polyvinylchloride and plasticizer content than vinyl sheet flooring and thus emits lower levels of VOCs. Some vinyl sheet flooring may emit higher levles of VOCs than linoleum.
③ Carpet & Rug Institute emissions standard for green labeling. Seventy-five percent of carpets tested meet these standards.

Floor coverings also emit VOCs from their adhesives. Linoleum, vinyl composition tile, and carpets installed with traditional synthetic adhesives are assumed to be installed using a styrene-butadiene adhesive, and ceramic tile with recycled glass and composite marble tile using a styrene-butadiene cement mortar. Carpets installed with a low VOC styrene-butadiene adhesive are assumed to have 17% the emissions of an equivalent quantity of traditional styrene-butadiene adhesive.[10] Assuming indoor air impacts are proportional to the amount of styrene-butadiene used per functional unit, styrene-butadiene usage may be used as a proxy for indoor air performance of adhesives as follows:

- linoleum: 0.00878 kg/m_ (0.00079 kg/ft_)
- vinyl composition tile: 0.00878 kg/m_ (0.00079 kg/ft_)
- ceramic tile with recycled windshield glass: 0.00311 kg/m_ (0.00028 kg/ft_)
- composite marble tile: 0.00311 kg/m_ (0.00028 kg/ft_)
- terrazzo: no installation adhesives
- wool broadloom carpet: 1.30932 kg/m_ (0.12164 kg/ft_) traditional/ 0.22260 kg/m_ (0.02068 kg/ft_) low VOC
- nylon broadloom carpet: 3.27320 kg/m_ (0.30409 kg/ft_) traditional/ 0.55650 kg/m_ (0.05170 kg/ft_) low VOC
- PET broadloom carpet: 3.27320 kg/m_ (0.30409 kg/ft_) traditional/ 0.55650 kg/m_ (0.05170 kg/ft_) low VOC
- wool carpet tile: 0.24779 kg/m_ (0.02302 kg/ft_) traditional/ 0.4209 kg/m_ (0.00391 kg/ft_) low VOC
- nylon carpet tile: 0.61946 kg/m_ (0.05755 kg/ft_) traditional/ 0.10527 kg/m_ (0.00978 kg/ft_) low VOC
- PET carpet tile: 0.61946 kg/m_ (0.05755 kg/ft_) traditional/ 0.10527 kg/m_ (0.00978 kg/ft_) low VOC

To assess overall indoor air performance for floor coverings, each product's performance data for product emissions and installation adhesives are normalized by dividing by the corresponding performance value for the worst performing product, then averaged across

[10] Based on data reported in *Environmental Building News,* Vol. 3, No. 6 at 4 (Nov./Dec. 1994).

performance categories as shown in the table below. By taking the simple average, each performance category is weighted equally.

Floor Covering	Product Emissions	Installation Adhesives	Average
Ceramic tile w/glass	0	0.09	0.05
Linoleum	100.0	0.26	50.13
Vinyl Comp. Tile	15.94	0.26	8.10
Comp. Marble Tile	0	0.09	0.05
Terrazzo	0	0	0
Wool Broadloom	44.52	40.00	42.26
Wool Broadloom & Low VOC	44.52	6.80	25.66
Nylon Broadloom	44.52	100.00	72.26
Nylon Broadloom & Low VOC	44.52	17.00	30.76
PET Broadloom	44.52	100.00	72.26
PET Broadloom & Low VOC	44.52	17.00	30.76
Wool Tile	44.52	7.57	26.05
Wool Tile & Low VOC	44.52	1.29	22.91
Nylon Tile	44.52	18.92	31.72
Nylon Tile & Low VOC	44.52	3.22	23.87
PET Tile	44.52	18.92	31.72
PET Tile/Low VOC	44.52	3.22	23.87

For Interior Wall Finishes, indoor air performance is based on total VOC emissions. Total VOCs for virgin latex paint are estimated to be 100 g/L, and for recycled latex paint 125 g/L.[11] Both paints are initially applied by priming followed by two coats of paint. For both, one coat is reapplied every 4 years over the 50 year use phase. Based on these figures, virgin latex paint emits 13.46 g of VOCs per 0.09 m_ (1 ft_) over 50 years of use, and recycled latex paint 16.58 g of VOCs per 0.09 m_ (1 ft_) over 50 years. These flows are directly used to assess indoor air performance for the two interior wall finishes.

For Wall & Roof Sheathing, emissions arise from formaldehyde emissions in wood products. Formaldehyde affects health, especially for chemically sensitive individuals. Composite wood products using urea-formaldehyde adhesives have higher formaldehyde emissions than those using phenol-formaldehyde adhesives, and different composite wood products have different levels of emissions. Composite wood products include

[11] Based on data reported in *Environmental Building News,* Vol. 8, No. 2 at 12.18 (Feb. 1999).

particleboard, insulation board, medium density fiberboard (MDF), oriented strand board (OSB), hardwood, and softwood and hardwood plywood.

It is assumed that formaldehyde emissions are the only significant indoor air concern for wood products. Two composite wood products – OSB and softwood plywood – are evaluated. Most OSB is now made using a methylene diphenylisocyante (MDI) binder, which is the binder used in modeling OSB performance. OSB using an MDI binder emits no formaldehyde other than the insignificant amount naturally occurring in the wood itself.[12] Softwood plywood also has extremely low formaldehyde emissions because it uses phenol-formaldehyde binders and because it is used primarily on the exterior shell of buildings.[13] Thus, neither of the two composite wood products are thought to significantly affect indoor air quality.

For Wall and Ceiling Insulation, indoor air impacts are primarily health impacts of fibers, hazardous chemicals, and particles released from some insulation products. These are the only releases addressed for insulation.

Fiberglass products are required to have cancer warning labels as a result of their listing by the International Agency for Research on Cancer as a "possible carcinogen." The fiberglass industry has responded by developing fiberglass products reducing the amount of loose fibers escaping to the air. For cellulose products, there are claims that fire retardant chemicals and respirable particles are hazardous to human health. Mineral wool is sometimes claimed to emit fibers and chemicals that could be health irritants. For all of these products, however, there should be little or no health risks to building occupants if they are installed in accordance with the manufacturers recommendations. Assuming proper installation, then, none of these products are thought to significantly affect indoor air quality.[14]

Stratospheric Ozone Depletion. The Montreal Protocol is an international treaty ratified by the US requiring reductions and phase out of pollutants decreasing the stratospheric ozone layer. This layer protects biota by filtering harmful shortwave ultraviolet light while allowing longer wavelengths to pass through. The thinning of the ozone layer also may adversely affect agricultural productivity and climate. Effects on man can include increased skin cancer rates (particularly fatal melanomas) and eye cataracts, as well as suppression of the immune system. Since the 1970's, each Spring, the Antarctic ozone layer is reduced by 80%-98%.

The following pollutants must be identified:

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[12] Alex Wilson & Nadav Malin, "The IAQ Challenge: Protecting the Indoor Environment," Environmental Building News, Vol. 5, No.3 at 15 (May/June 1996).

[13] American Institute of Architects, *Environmental Resource Guide*, Plywood Material Report (May 1996).

[14] Alex Wilson, "Insulation Materials: Environmental Comparisons," *Environmental Building News*, Vol. 4, No. 1 at 15-16 (1995).

Ozone Depletion
CFC 11 ($CFCl_3$)
CFC 12 (CCl_2F_2)
CFC 113 ($CFCl_2CFCl_2$)
CFC 114 (CF_2ClCF_2Cl)
CFC 115 (CF_3CF_2Cl)
HCFC 22 (CHF_2Cl)
HCFC 123 ($CHCl_2CF_3$)
HCFC 124 ($CHClFCF_3$)
HCFC 141b ($CFCl_2CH_3$)
HCFC 142b (CF_2ClCH_3)
HCFC 225ca ($C_3HF_5Cl_2$)
HCFC 225cb ($C_3HF_5Cl_2$)
Carbon Tetrachloride (CCl_4)
Methyl Chloroform (CH_3CCl_3, HC-140a)
Halon 1301 (CF_3Br)
Halon 1211 (CF_2ClBr)
Halon 1202 (CF_2Br_2)
Halon 2402 (CF_2ClBr)
Halon 1201 (CHF_2Br)
Halon 2401 (CHF_2CF_2Br)
Halon 2311 ($CF_3CHBrCl$)
Bromomethane (CH_3Br)

A single index, expressed in grams of CFC-11 per functional unit of product, measures the quantity of CFC-11 with the same potential ozone depleting effect or ozone depletion potential (ODP):[15]

Flow/Pollutant	CFC-11 Equivalents ODP
Methyl Bromide	0.37
Carbon Tetrachloride	1.2
CFC-11	1.0
CFC 113	0.9
CFC-114	0.85
CFC-115	0.4
CFC-12	0.82
Halon 1201	1.4

[15] World Meteorological Organization (WHO), *Scientific Assessment of Ozone Depletion* (1991) and its Update, Report 44 (Global Ozone Research & Monitoring Project (1998).

Halon 1202	1.25
Halon 1211	5.1
Halon 1301	12.0
Halon 2311	0.14
Halon 2401	0.25
Halon 2402	7.0
HCFC 123	0.012
HCFC 124	0.026
HCFC 141b	0.086
HCFC 142b	0.043
HCFC 22	0.034
HCFC 225ca	0.017
HCFC 225cb	0.017
Methyl Chloroform HC-140a	0.11

<u>Limitations</u>

1. ODPs upon which the assessment method is based are subject to considerable uncertainty and regular modification.
2. Greenhouse gases can affect the level of ozone directly through chemical reactions or indirectly by contributing to climate change. At present, the influence of this factor is not incorporated due to the complex nature of the reactions involved.
3. Concentrations of trace gases such as nitrogen oxides affect atmospheric levels of the hydroxyl radical (OH), which in turn can affect the atmospheric lifetime of hydrogenated halocarbons. This process can influence future ozone depletion rates. Thus, ozone depletion rates may vary with time.
4. ODPs are defined at steady state, and therefore do not represent transient effects. In reality, shorter-lived halocarbons will reach a "steady state" ability to destroy ozone before longer-lived compounds. ODPs are based on annually averaged global changes in ozone, which do not take into account the chemical reactions involving a change in state which occur specifically at the Poles. *Consequently, ODP-derived concentrations tend to understate the damage to the ozone caused by the presence of chlorine and bromine in the atmosphere.*

Smog. Under certain climatic and weather conditions, air emissions from industry and transportation can be trapped at ground level, where they react with sunlight to produce photochemical smog which causes adverse health impacts. A major component of smog is ozone, which is not emitted directly, but rather produced through the interactions of volatile organic compounds (VOCs) and oxides of nitrogen (NOx).

While NOx availability ultimately limits the production of ozone, the reactivity of the VOC determines the rate at which ozone is produced. Thus, when attempting to quantify smog potential, not only must the reactivity of the VOC be considered, but also the environmental conditions (e.g., NOx concentration). The method generally accepted by government bodies including EPA and the States is quantification of ozone production potentials of various VOCs based on the incremental reactivity (IR) scale identified through smog chamber testing.[16] EPA has ranked VOCs based on their reactivity for regulating smog.

The following smog generating pollutants must be identified:

Smog (MIR index)
Acetaldehyde (CH3CHO)
Carbon Monoxide (CO)
Methane (CH4)
Ethane (C2H6)
Propane (C3H8)
Butane (n-C4H10)
Pentane (n-C5H12)
Hexane (n-C6H14)
Heptane (C7H16)
Octane (C8H18)
Nonane (n-C9H20)
Butyraldehyde (CH3CH2CH2CHO)
Butyraldehyde (i-CH3CH2CH2CHO)
Dimethylbutane (2,2-C6H14)
Dimethylbutane (2,3-C6H14)
Duodecane (n-C12H26)
Ethyltoluene (m-C6H4CH3C2H5)
Ethyltoluene (o-C6H4CH3C2H5)
Ethyltoluene (p-C6H4CH3C2H5)
Cyclopentane (C5H10)
Cyclohexane (C6H12)
Hexene (1-C6H12)
Heptene (1-C7H14)
Octene (1-C8H16)
Nonene (1-C9H18)
Cyclopentadiene (C5H6)
Pinene (a-C10H16)
Pinene (b-C10H16)
Propylbenzene (n-C6H5C3H7)
Indan (C9H10)
Tetralin (C10H12)
Methyl Acrylate (C4H6O2)
Furan (C4H4O)
Crotonaldehyde (C4H6O)
Tolualdehyde (C8H8O)
Ethylamine (C2H5NH2)
Trimethylamine (CH3)3N)

[16] William P. Carter, "Development of Ozone Reactivity Scales for Volatile Organic Compounds", *Journal of the Air & Waste Management Association,* Vol. 44, at 881-99 (July 1994).

Decane (n-C10H22)
Undecane (n-C11H24)
Ethylene (C2H4)
Propylene (CH2CHCH3)
Butene (1-CH3CH2CHCH2)
3-Methyl-1-Butene (C5H10)
Pentene (1-CH3(CH2)2CHCH3)
Isobutene (CH2C(CH3)2)
2-Methyl-1-Butene (C5H10)
2-Methyl-2-Butene (C5H10)
Pentene (2-CH3CH2(CH)2CH3)
Benzene (C6H6)
Toluene (C6H5CH3)
Ethylbenzene (C8H10)
Xylene (o-C6H4(CH3)2)
Xylene (p-C6H4(CH3)2)
Xylene (m-C6H4(CH3)2)
Naphthalene (C10H8)
Styrene (C6H5CHCH2)
Acetylene (C2H2)
Methanol (CH3OH)
Ethanol (C2H5OH)
Isopropyl Alcohol (CH3CHOHCH3)
Ethylene Glycol (HOCH2CH2OH)
Propylene Glycol (CH3CHOHCH2OH)
Methyl Acetate (CH3COOCH3)
Vinyl Acetate (C4H6O2)
Ethyl Acetate (CH3COOC2H5)
Propyl Acetate (i-CH3COO(CH2)2CH3)
Butyl Acetate (n-CH3COO(CH2)3CH3)
Ethylene Oxide (C2H4O)
Propylene Oxide (C3H6O)
Formaldehyde (CH2O)
Acrolein (CH2CHCHO)
Acetone (CH3COCH3)
Benzaldehyde (C6H5CHO)
Phenol (C6H5OH)
Acrylonitrile (CH2CHCN)
Methyl Chloride (CH3Cl)
Methyl Bromide (CH3Br)
Vinylchloride (CH2CHCl)
Trichloroethylene (C2HCl3)
Tetrachloroethylene (C2Cl4)
Chlorobenzene (C6H5Cl)
Butane (i-C4H10)
Pentane (i-C5H12)
Methylpentane (2-C6H14)

Methylpentane (3-C6H14)
Methylhexane (3-C7H16)
Methylhexane (2-C7H16)
Methylheptane (2-C8H18)
Diethyl Ether
Neopentane (C5H12)
Nitrobenzene (C6H5NO2)
Methylene Chloride (CH2Cl2, HC-130)
Methylene Bromide (CH2Br2)
Ethyl Chloride (C2H5Cl)
Ethylene Dichloride (C2H4Cl2)
Methyl Chloroform (CH3CCl3, HC-140a)
Methyl Ethyl Ketone (MEK, C5H10O)
Methylnonane (2-C10H22)
Methyloctane (2-C9H20)
Propionaldehyde (CH3CH2CHO)
Propylbenzene (n-C6H5C3H7)
Trimethylbenzene (1,2,3-C6H3(CH3)3)
Trimethylbenzene (1,2,4-C6H3(CH3)3)
Trimethylbenzene (1,3,5-C6H3(CH3)3)
Valeraldehyde (CH3(CH2)3CHO)
Butyl Acetate (i-CH3COO(CH2)3CH3)

The Maximum Incremental Reactivity (MIR) Index measures smog formation for 53 pollutants as follows:

Maximum Incremental Reactivity Equivalency Factors	
1-Butanol	3.324
2-Methyl 1-Butene	5.543
Acetaldehyde	6.322
Benzene	0.601
Methyl Bromide	0.015
1-Butene	10.68
Carbon Monoxide	0.061
Cyclopentadiene	12.51
Dibutyl Ether	2.809
1.3-Dimethyl Cyclohexane	2.586
Ethane	0.299
Ethyl Acetylene	11.08
Formaldehyde	7.009
Glyoxal	2.209
Heptane	1.045

Isobutyl Alcohol	2.332
Methane	0.016
Methyl Cyclopentane	3.444
Methyl Goyoxal	14.32
1-Nonene	3.06
3-Octene	7.528
2-Pentene	11.79
Styrene	2.28
Toluene	3.154
Trimethyl Amine	6.699
n-Undecane	0.619
Vinyl Acetate	6.96
m-Xylene	8.82

Ecological Toxicity. In the LCA context, EPA has developed several approaches for ranking chemicals for relative ecological hazard in support of pollution prevention[17] and the Clean Air Act.[18] Research Triangle Institute (RTI), one of the authors of these approaches, developed the method used here after reviewing all of the above sources. This method measures relative hazard (toxicity factors or benchmarks), environmental fate and transport (persistence and biomagnification factors), and involves the following steps:

1. Screen inventory or pollutant release data by identifying chemical specific inventory flows or general inventory flows that can be represented by a chemical-specific surrogate, and eliminate those that are within 15% of each other.
2. Identify aquatic and terrestrial benchmarks for both acute and chronic toxicity.
3. Assign chemicals a default benchmark if data are missing. The geometric mean of the available benchmarks is used as the default.
4. Normalize benchmarks within each category based on the geometric mean.
5. Select the maximum normalized benchmark as the toxicity factor.
6. Identify persistence factors for pertinent environmental media (air, land & water).
7. Identify biomagnification factors.
8. Multiply toxicity, persistence, and biomagnification (TPB) factors for each inventory flow within each environmental medium for the TPB score.

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[17] U.S. EPA, *Waste Minimization Prioritization Tool, Beta Test Version 1.0: User's Guide and System Documentation,* Draft, EPA 530-R-97-019, Office of Pollution Prevention and Toxics (1997); U.S. EPA, *Chemical Hazard Evaluation for Management Strategies, A Method for ranking and Scoring Chemicals by Potential Human Health and Environmental Impacts*, EPA/600/R-94/177, Office of Research & Development (1994); Research Triangle Institute, *A Multimedia Waste Reduction Management System for the State of North Carolina*, Final Report, Prepared for the North Carolina Department of Health, Environment & Natural Resources, Pollution Prevention Program (1993).

[18] U. S. EPA, *Technical Background Document to Support Rulemaking Pursuant to the Clean Air Act – Section 112(g), Ranking of Pollutants with Respect to Hazard to Human Health,* EPA-450/3-92-010, Office of Air Quality Planning & Standards, Research Triangle Park, NC (1994).

9. Multiply TPB scores by the inventory mass per functional unit.
10. Sum factors to derive the total terrestrial and aquatic ecological toxicity imdicator (ETI).
11. Determine the percentage of each ETI relative to the total ETI and select inventory flows (pollutant releases) contributing 0.1% or more.
12. Compare inventory impacts to total US emissions to determine relative significance.

Examples of the 152 RTI ecological toxicity potential equivalency factors used are:

Sampling of Ecological Toxicity Potential Equivalency Factors	
Flow	Ecotoxicity (grams equivalent toxicity)
Hydrocarbons	21.90
Nitrogen Oxides	7.30
Carbon Monoxide	7.30
Dioxins	20.2×10^{8}
Hydrogen Chloride	10.95

Human Toxicity. The approach used to indicate human toxicity is EPA's LCA method for evaluating environmentally preferable products [19] as used by Environmental Defense's Scorecard and developed with the University of California at Berkeley. Industrial pollutant releases cause toxic effects to humans when there is exposure to the toxic pollutant, assimilation by any mode (e.g., oral, dermal or inhalation), and the received dose to the individual exceeds the body's ability to detoxify it. It is difficult to identify and estimate these effects, however, human toxicity to pollutants is important and regulated for a very large number of identified chemicals by the:

- Clean Water Act
- Clean Air Act
- Safe Drinking Water Act
- Toxic Substances Control Act
- Resource Conservation & Recovery Act (Solid Waste Act)
- Comprehensive Environmental Response Compensation & Liability Act (Superfund)

The method required uses toxicity indicators based on pollutant doses that were low enough to cause no or minimal effect to ensure a safety margin because the pollutants can

[19] U.S. EPA, *Framework for Responsible Environmental Decisionmaking (FRED): Using Life Cycle Assessment to Evaluate Preferability of Products,* Draft Report, by Science Applications International Corporation, Research Triangle Institute and Ecosense (1999).

cause permanent disability and death. Two measures are used, one for carcinogenic and the other for noncarcinogenic effects. Toxicity Equivalency Potentials for some 174 inventory or pollutant flows are established. The following table shows a sampling:

Sampling of Human Toxicity Equivalency Potential (TEPS) Factors		
Flow to Air	TEP (carcinogens) Weight Benzene/ Weight substance	TEP (non-carcinogens) weight Toluene weight substance
Ammonia	0	3.2
Benzene	1.0	17.0
Formaldehyde	0.003	7.0
Lead	15.0	1,300,000.0
Phenolics	0	0.045
Flow to Water	TEP (carcinogens) Weight Benzene/ Weight substance	TEP (non-carcinogens) weight Toluene Weight substance
Ammonia	0	0.041
Benzene	0.99	11.0
Phenols	0	0.0038

The following is a sampling of 1316 pollutants that must be identified; they are regulated by the six statutes above because they cause ecological and human toxicity:

Human and Ecological Health
1-(3-Chloroallyl)-3,5,7-triaza-1-azoniaadamantane chloride
1,1,1,2-Tetrachloro-2-fluoroethane (HCFC-121a)
1,1,1,2-Tetrachloroethane
1,1,1-Trichloroethane (Methyl chlorform)
1,1,2,2-Tetrachloro-1-fluoroethane (HCFC-121)
1,1,2,2-Tetrachloroethane
1,1,2-Trichloroethane
1,1-Dichloro-1,2,2,3,3-pentafluoropropane (HCFC-225cc)
1,1-Dichloro-1,2,2-trifluoroethane (HCFC-123b)
1,1-Dichloro-1,2,3,3,3-pentafluoropropane (HCFC-225eb)
1,1-Dichloro-1-fluoroethane (HCFC-141b)
1,1-Dimethyl hydrazine
1,1-Methylene bis(4-isocyanatocyclohexane)

1,2,3-Trichloropropane
1,2,4-Trichlorobenzene
1,2,4-Trimethylbenzene
1,2-Butylene oxide
1,2-Dibromo-3-chloropropane (DBCP)
1,2-Dibromoethane (Ethylene dibromide)
1,2-Dichloro-1,1,2,3,3-pentafluoropropane (HCFC-225bb)
1,2-Dichloro-1,1,2-trifluoroethane (HCFC-123a)
1,2-Dichloro-1,1,3,3,3-pentafluoropropane (HCFC-225da)
1,2-Dichloro-1,1-difluoroethane (HCFC-132b)
1,2-Dichlorobenzene
1,2-Dichloroethane (Ethylene dichloride)
1,2-Dichloroethylene
1,2-Dichloropropane
1,2-Diphenylhydrazine (Hydrazobenzene)
1,2-Phenylenediamine
1,2-Phenylenediamine dihydrochloride
1,3-Bis(methylisocyanate)cyclohexane
1,3-Butadiene
1,3-Dichloro-1,1,2,2,3-pentafluoropropane (HCFC-225cb)
1,3-Dichloro-1,1,2,3,3-pentafluoropropane (HCFC-225ea)
1,3-Dichlorobenzene
1,3-Dichloropropylene
1,3-Phenylene diisocyanate
1,3-Phenylenediamine
1,4-Bis(methylisocyanate)cyclohexane
1,4-Dichloro-2-butene
1,4-Dichlorobenzene
1,4-Dioxane
1,4-Phenylene diisocyanate
1,4-Phenylenediamine dihydrochloride
1,5-Naphthalene diisocyanate
1-Amino-2-methylanthraquinone
1-Bromo-1-(bromomethyl)-1,3-propanedicarbonitrile
1-Chloro-1,1,2,2-tetrafluoroethane (HCFC-124a)
1-Chloro-1,1-difluoroethane (HCFC-142b)
1-Nitropyrene
2,2,4-Trimethylhexamethylene diisocyanate
2,2-Dibromo-3-nitrilopropionamide
2,2-Dichloro-1,1,1,3,3-pentafluoropropane (HCFC-225aa)
2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123)
2,3,5-Trimethylphenyl methylcarbamate

2,3-Dichloro-1,1,1,2,3-pentafluoropropane (HCFC-225ba)
2,3-Dichloropropene
2,4,4-Trimethylhexamethylene diisocyanate
2,4,5-Trichlorophenol
2,4,6-Trichlorophenol
2,4-D [Acetic acid,(2,4-dichlorophenoxy)-1]
2,4-D 2-ethyl-4-methylpentyl ester
2,4-D 2-ethylhexyl ester
2,4-D butoxyethyl ester
2,4-D butyl ester
2,4-D chlorocroctyl ester
2,4-D isopropyl ester
2,4-D propylene glycol butyl ether ester
2,4-D sodium salt
2,4-DB
2,4-Diaminoanisole
2,4-Diaminoanisole sulfate
2,4-Diaminotoluene
2,4-Dichlorophenol
2,4-Dimethyphenol
2,4-Dinitrophenol
2,4-Dinitrotoluene
2,4-Dithiobiuret
2,4-DP
2,6-Dimethylphenol
2,6-Dinitrotoluene
2,6-Xylidine
2-Acetylaminofluorene
2-Aminoanthraquinone
2-Bromo-2-nitropropane-1,3-diol (Bronopol)
2-Chloro-1,1,1,2-tetrafluoroethane (HCFC-124)
2-Chloro-1,1,1-trifluoroethane (HCFC-133a)
2-Chloroacetophenone
2-Ethoxyethanol
2-Mercaptobenzothiazole (MBT)
2-Methoxyethanol
2-Methyllactonitrile
2-Methylpyridine
2-Nitrophenol
2-Nitropropane
2-Phenylphenol
3,3-Dichloro-1,1,1,2,2-pentafluoropropane (HCFC-225ca)
3,3'-Dichlorobenzidine
3,3'-Dichlorobenzidine dihydrochloride
3,3'-Dichlorobenzidine sulfate

3,3'-Dimethoxybenzidine
3,3'-Dimethoxybenzidine-4,4'-diisocyanate
3,3'-Dimethoxybenzidine dihydrochloride (o-Dianisidine dihydrochloride)
3,3'-Dimethyl-4,4'-diphenylene diisocyanate
3,3'-Dimethylbenzidine (o-Tolidine)
3,3'-Dimethylbenzidine dihydrochloride (o-Tolidine dihydrochloride
3,3'-Dimethylbenzidine dihydrofluoride (o-Tolidine dihydrofluoride)
3,3'-Dimethyldiphenylmethane-4,4'-diisocyanate
3,3'-Dimethyloxybenzidine dihydrochloride (o-Dianisidine dihydrochloride)
3-Chloro-1,1,1-trifluoropropane (HCFC-253fb)
3-Chloro-2-methyl-1-propene
3-Chloropropionitrile
3-Iodo-2-propynyl butylcarbamate
4,4'-Diaminodiphenyl ether
4,4'-Isopropylidenediphenol
4,4'-Methylenebis(2-chloroaniline) (MBOCA)
4,4'-Methylenebis(N,N-dimethyl)benzenamine
4,4'-Methylenedianiline
4,4'-Thiodianiline
4,6-Dinitro-o-cresol
4-Aminoazobenzene
4-Aminobiphenyl
4-Cyclohexane diisocyanate
4'-Diisocyanatodiphenyl ether
4'-Diisocyanatodiphenyl sulfide
4-Dimethylaminoazobenzene
4-Methyldiphenylmethane-3,4-diisocyanate
4-Nitrobiphenyl
4-Nitrophenol
5-Methylchrysene
5-Nitro-o-anisidine
5-NItro-o-toluidine
7,12-Dimethylbenz(a)anthracene
7H-Dibenzo(c,g)carbazole
Abamectin [Avermectin B1]
Acephate (Acetylphosphoramidothioic acid O,S-dimethyl ester)
Acetaldehyde
Acetamide
Acetonitrile
Acetophenone

Acifluorfen, sodium salt [5-(2-Chloro-4-(trifluoromethyl)phenoxy)-2-nitro-benzoic acid, sodium salt]
Acrolein
Acrylamide
Acrylic acid
Acrylonitrile
Alachlor
Aldicarb
Aldrin [1,4:5,8-Dimethanonaphthalene,1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-(1.alpha.,4.alpha.,4a.beta.,5.alpha.,8.alpha.,8a.beta.)-]
Allyl alcohol
Allyl chloride
Allylamine
alpha-Hexachlorocyclohexane
alpha-Naphthylamine
Aluminum (fume or dust)
Aluminum oxide (fibrous forms)
Aluminum phosphide
Ametryn (N-Ethyl-N'-(1-methylethyl)-6-(methylthio)-1,3,5,-triazine-2,4-diamine)
Amitraz
Amitrole
Ammonia (includes anhydrous ammonia and aqueous ammonia from water dissociable ammonium slats and other sources; 10 percent of total aqueous ammonia is reportable under this listing)
Anilazine [4,6-Dichloro-N-(2-chlorophenyl)-1,3,5-triazin-2-amine]
Aniline
Anthracene
Antimony
Antimony Compounds
Arsenic
Arsenic Compounds
Asbestos (friable)
Atrazine (6-Chloro-N-ethyl-N'-(1-methylethyl)1,3,5-triazine-2,4-diamine)
Barium
Barium Compounds
Bendiocarb [2,2-Dimethyl-1,3-benzodioxol-4-ol methylcarbamate]
Benfluralin (N-Butyl-N-ethyl-2,6-dinitro-4-(trifluoromethyl) benzenamine)
Benomyl

Benz(a)anthracene
Benzal chloride
Benzamide
Benzene
Benzidine
Benzo(a)phenanthrene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(j)fluoranthene
Benzo(k)fluoranthene
Benzo(rst)pentaphene
Benzoic trichloride (Benzotrichloride)
Benzoyl chloride
Benzoyl peroxide
Benzyl chloride
Beryllium
Beryllium Compounds
beta-Naphthylamine
beta-Propiolactone

Inflows & Outflows. The following inflows and outflows are identified:

Inflows	
Raw Materials:	Water
	Others (please specify)

Purchased Energy:	Electricity
	Steam
	Compressed Air
	Others (please specify)

Purchased Fuels:	Coal

	Coke
	Natural Gas
	Fuel Oil
	Diesel Oil
	Gasoline
	Others (please specify)

Outflows	
Products:	Product (please specify)
	Co-products (please specify)

Pollutants:	*Pollutant Flows*
	Flue Gas
	Wastewater

Solid Waste:	*Total Solid Waste*
	Solid Waste

Recovered Matter:	*Recovered Matter (please specify)*

<u>Use Phase</u>. The following use phase data must be identified:

		Data Quality

	Units	Quantity	Source	Type	Year
Useful Life of the Product:					
Weight of the Product (per functional unit):					
Density of the Product:					
Is the Product Recyclable (y/n):	N/A				
If (yes) What Percent is Currently Recycled:					
Avg. Distance Final Product is Transported:					
Mode of Transport for Final Product:					
Load Weight of Product Transported:					
Maximum Load Weight of Vehicle:					
Manufacturer's Suggested Retail Price:					

Habitat Alteration. This impact assessment category is under development and expected to be completed by 2002. Comments or suggestions are welcomed: info@sustainableproducts.com.