# Chapter 11. Evaluating the Environmental Performance of a Flowsheet

*by*

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After the process flowsheet has been established and energy and mass efficiency measures have been applied (Chapter 10), it is appropriate for a detailed environmental impact evaluation to be performed. The end result of the impact evaluation will be a set of environmental metrics (indices), which represent the major environmental impacts, or risks of the entire process. A number of indexes are needed to account for potential damage to human health and to several important environmental media. The indexes can be used to determine the potential impact to human health and the environment. The indices can be used in several important engineering applications during process design, including the ranking of technology selection, the optimizing of in-process waste recycle/recovery processes, and the evaluation of the modes of reactor operation.

In a quantitative risk assessment, it is shown that impacts are a function of dose that dose is a function of concentration, and that concentration is a function of emission rate. Therefore, emissions from a process design flowsheet are the primary piece of information required for impact assessment. The concentrations in the relevant compartments of the environment (air, water, and soil) are dependent upon the emissions and the location and chemical and physical properties of the pollutants. A suitable fate and transport model can transform the emissions into environmental concentrations. Finally, information regarding toxicity or inherent impact is required to convert the concentration-dependant doses into probabilities or harm (risk). Based on this understanding of risk assessment, the steps for environmental impact assessment are grouped into three categories, a) estimates of the rates of release for all chemicals in the process, b) calculation of environmental fate and transport and environmental concentrations, and c) the accounting for multiple measures of risk using toxicology and inherent environmental impact information.

Ideally, one would prefer to conduct a *quantitative risk assessment* when comparing environmental performance of chemical process designs. Although this approach is preferred when the source and receptor are well defined and localized, it is not well suited for industrial releases that often affect not only local, but also regional and global environments. Also, the computing resources needed to perform a quantitative risk assessment for all release sources and receptors would tax the abilities of even the largest chemical manufacturer. A more achievable approach is to abandon quantitative risk assessment in preference to the assessment of potential environmental and health risks. The establishment of the potential impacts of chemical releases is sufficient for comparing the environmental risks of chemical process designs. In this chapter, material is presented which establish methodologies for assessing the potential for environmental impacts of chemical processes and their designs.

In this development, we will utilize the concept of *benchmarking*. First introduced for the assessment of global warming and ozone depletion potentials of refrigerants in the early 1990's, benchmarking takes the ratio of the environmental impact of a chemical's release to the impact of the identical release of a well-studied compound. A value greater than 1 for this dimensionless quantity indicates that the chemical has a greater potential for environmental impact than the benchmark compound. The product of the benchmarked environmental impact potential with the process emission rate results in the equivalent emission of the benchmark compound in terms of environmental impact. In this text, we adopt the benchmarking concept when assessing the environmental and toxicological impact potentials of releases from chemical processes. (Heijungs et. al. 1992)

Section 11.2 is a description of a multimedia compartment model approach for determining fate and transport of chemical releases into the environment. This model predicts the long-time and large-spatial scale distribution of chemicals using multiple compartments as the physical structure for the environment. Section 11.3 is a presentation of a Tier 3 environmental assessment (Tier 1 and Tier 2 assessments are discussed in Chapter 8) consistent with the goal of efficiently comparing chemical process designs.

## Chapter 11 Example Problem

Example Problem 11.2 Global Warming Index for Air Emissions of 1,1,1-Trichloroethane from a Production Process

1,1,1-Trichloroethane (TCA) is used as an industrial solvent for metal cleaning, as a reaction intermediate, and for other uses (U.S. EPA, 1979-1991)). A major processing route for TCA is by hydrochlorination of vinyl chloride in the presence of a $FeCl_3$ catalyst to produce11,1-dichloroethane, followed by chlorination of this intermediate. Sources for air emissions include distillation condenser vents, storage tanks, handling and transfer operations, fugitive sources, and secondary emissions from wastewater treatment. We wish to estimate the global warming impact of the air emissions from this process. Include direct impacts to the environment (from 1,1,1-TCA) and indirect impacts from energy usage ($CO_2$ and NOx release) in your analysis. Data below show the major chemicals which impact global warming when emitted from the process.

Determine the global warming index for the process and the percentage contribution for each chemical.

Data: Air Emissions (15,500 kg 1,1,1-TCA/hr Process)

| Chemical | $m_i$ (kg/hr) | GWP |
|---|---|---|
| TCA | 40.5 | 100 |
| $CO_2$ | 7,760 | 1 |
| NOx | 93 | 40 |

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TCA emission rate estimated using EPA factors (U.S. EPA, 1979-1991). $CO_2$ and NOx emission rates estimated from a Life Cycle Assessment of Ethylene Production (Allen and Rosselot, 1997; Boustead, 1993).

<u>Solution</u>:
Using equation (11.3-4), the process global warming index is

$$
\begin{aligned}
I_{GW} &= (40.5 \text{ kg/hr})(100) + (7{,}760 \text{ kg/hr})(1) + (93 \text{ kg/hr})(40) \\
&= 4{,}050 + 7{,}760 + 3{,}720
\end{aligned}
$$

$$\boxed{= 15{,}530 \text{ kg/hr}}$$

The percent of the process $I_{GW}$ for each chemical is;
1,1,1-TCA ; (4,050/15,530)x100 = 26.08%
$CO_2$ ; (7,760/15,530)x100 = 49.97%
NOx ; (3,720/15,530)x100 = 23.95%

<u>Discussion</u>: This case study demonstrates that the majority of the global warming impact from the production of 1,1,1-TCA is from the energy requirement of the process and not from the emission of the chemical with the highest global warming potential. This analysis assumes that fossil fuels were used to satisfy the energy requirements of the process. If renewable resources were used (biomass based fuels), the impact of $CO_2$ to the global warming would be significantly reduced. The majority of the global warming impact of 1,1,1-TCA will likely be felt during the usage stage of its life cycle, not the production stage. A complete Life Cycle Assessment of 1,1,1-TCA will be necessary to demonstrate this.

## Chapter 11 Sample Homework Problem

**1.** As a requirement of the 1990 Clean Air Act Amendments, automobile fuels sold in urban areas must be reformulated gasoline, also known as RFG. RFG must contain a certain level of oxygenates (such as MTBE, ETBE, TAME, or ethanol). The maximum incremental reactivities (MIR) values for ethanol and other potential octane boosters are provided below.

| | |
|---|---|
| Ethanol | 1.34 |
| Toluene | 2.70 |
| Xylenes | 7.10 |
| Base Fuel | 1.5 |

Calculate by what percentage the ozone producing potential of an ethanol fuel blend (10% ethanol, 90% base fuel) is reduced compared to a fuel blend containing 10% of toluene and 90% base fuel and another blend containing 10% xylenes and 90% base fuel, respectively. Use the provided MIR values for this calculation.