LCA FOR THE EVALUATION AND DESIGN OF INDUSTRIAL ECOSYSTEM

A.Singh, H. H. Lou, C. L. Yaws, and J. R. Hopper
Department of Chemical Engineering
Lamar University, Beaumont, TX-77710

R. W. Pike
Department of Chemical Engineering
Louisiana State University, Baton Rouge, LA - 70803

Prepared for Presentation at
AIChE Annual National Meeting
Session [T1006] - Industrial Ecology & Life Cycle Assessment
of Sustainable Designs
Austin, TX
November 6-12, 2004

(Phone: 409-880-8207; Fax: 409-880-2197; E-mail: louhh@hal.lamar.edu).

Abstract

Life Cycle Assessment (LCA) is widely used for assessing the environmental impacts of a product, process or service during each phase of the entire life cycle, i.e., from cradle-to-grave. It analyzes all the inputs and outputs of a product or service to assess the related wastes, human health as well as ecological burdens. For their sustainable development, industries need guidance for efficient use of resources, creating new businesses and infrastructure to strengthen the economy while preserving the environment. Industrial ecosystem is an important approach for sustainable development where a group of industries are inter-connected through mass and energy exchanges for mutual benefits exploring the opportunities for internal recycle of waste as well as external use/reuse of waste, products and by-products.

An industrial complex in the Lower Mississippi River Corridor with over fourteen chemical and petrochemical industries is one example of industrial ecosystem. In this paper, an LCA of various design schemes for this complex is conducted. The LCA results provide a better insight about various environmental impacts of the products from the member industries and can be effectively used to evaluate and analyze the industrial complex in order to enhance its sustainability.

Introduction

Development of industrial ecosystems is one of the most popular method being implemented in industrial world for achieving sustainable development. In an industrial ecosystem several industries are interconnected with mass and energy streams for mutual benefit. It converts the industrial process from a linear process to a cyclic process where the waste generated by one industry can be used as a resource by another industry. There are several such industrial ecosystems developed around the world like Industrial Complex at Kalundborg, Denmark[1], Industrial Complex in the Lower Mississippi River Corridor, etc.

Life Cycle Analysis is a procedure to evaluate and analyze the environmental impacts of a product or service by using the complete input and output data for material and energy used for the product or service, starting from the stage of collecting raw material from earth and ending at the stage when all this material is returned back to earth.

In this paper, a Life Cycle Analysis has been conducted for the Agricultural Chemical Production Complex in the Lower Mississippi River Corridor which has about fourteen industries along with the power, steam and cooling water and facilities for waste treatment. This constitutes the Base Case. Another LCA is conducted for a New Design Scheme for this industrial complex developed to minimize the carbon dioxide release into the environment[2]. This New Scheme has about eighteen plants. The LCA for these two design schemes has been conducted by using TRACI, a tool developed by the USEPA.

Life Cycle Analysis (LCA)

Life Cycle Assessment (LCA) is a methodology used for assessing the environmental impacts of any product or service. It takes a cradle–to-grave approach[3,4]. This assessment begins with the stage of gathering raw materials from earth to create a product and ends at the point when all the materials are returned back to earth. It evaluates all the stages of a product's life cycle from the perspective that they are interdependent, meaning that one operation leads to the next. LCA provides an estimation of cumulative environmental impacts resulting from all the stages in the life cycle of a product or service. It accomplishes these goals by first compiling an inventory of relevant energy and material inputs and environmental releases, then evaluating their potential environmental impacts and finally interpreting these results for more informed decision making. The LCA has following four stages as described in Fig. 1.

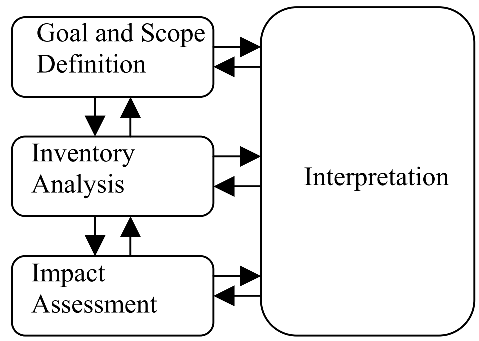

Figure 1. Life Cycle Analysis Methodology (Bare *et al.*, 2002)

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

The software namely, Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) is a tool developed by USEPA to conduct an LCIA. TRACI facilitates environmental comparison of product and process alternatives for environmental decision-making [4,6]. It also characterizes various stressors that may have potential effect on the environment. The first stage in TRACI is project description in which all the relevant details of the project are documented. After that, a list of products to be analyzed is entered and the input and output data of various phases of the life cycle of these products/services is entered into TRACI using its database. Various resources/releases can also be added using their CAS Numbers, depending upon the requirement. Once the inventory data is entered, TRACI can perform a Life Cycle Impact Assessment. During this phase, TRACI first classifies the resources and releases into various impact categories and then characterizes them based on the impact categories, their characterization value. The characterization value quantifies the extent of harm that a stressor can cause in a particular impact category[6]. The impact assessment methodologies in TRACI are based on "mid-point" characterization approach. Using this, the impact assessment models reflect the relative potential of the stressor at a common mid-point within the cause-effect chain. In TRACI, each impact assessment methodology is selected or developed to reflect the current state-of-the-art for each impact category, with a particular emphasis on methodologies that are relevant for the U.S. TRACI characterizes various stressors into the following impact categories:

1. Ozone Depletion
2. Global Warming
3. Acidification
4. Eutrophication
5. Photochemical Smog
6. Human Health Cancer and Non Cancer
7. Human Health Criteria
8. Eco-Toxicity
9. Fossil Fuel Use
10. Land Use
11. Water Use

LCA Analysis of an Industrial Ecosystem

Consider the Agricultural Chemical Production Complex situated in the Lower Mississippi River Basin. Figure 2 presents the "Base Case" for this agricultural complex that has been used for the current case study. There are thirteen production units in this complex along with associated utilities for power, steam and cooling water and facilities for waste treatment. Each plant contains more than one production unit. There is tremendous release of carbon dioxide in this complex primarily due to the Ammonia plant. This contributes largely to global warming along with other emissions.

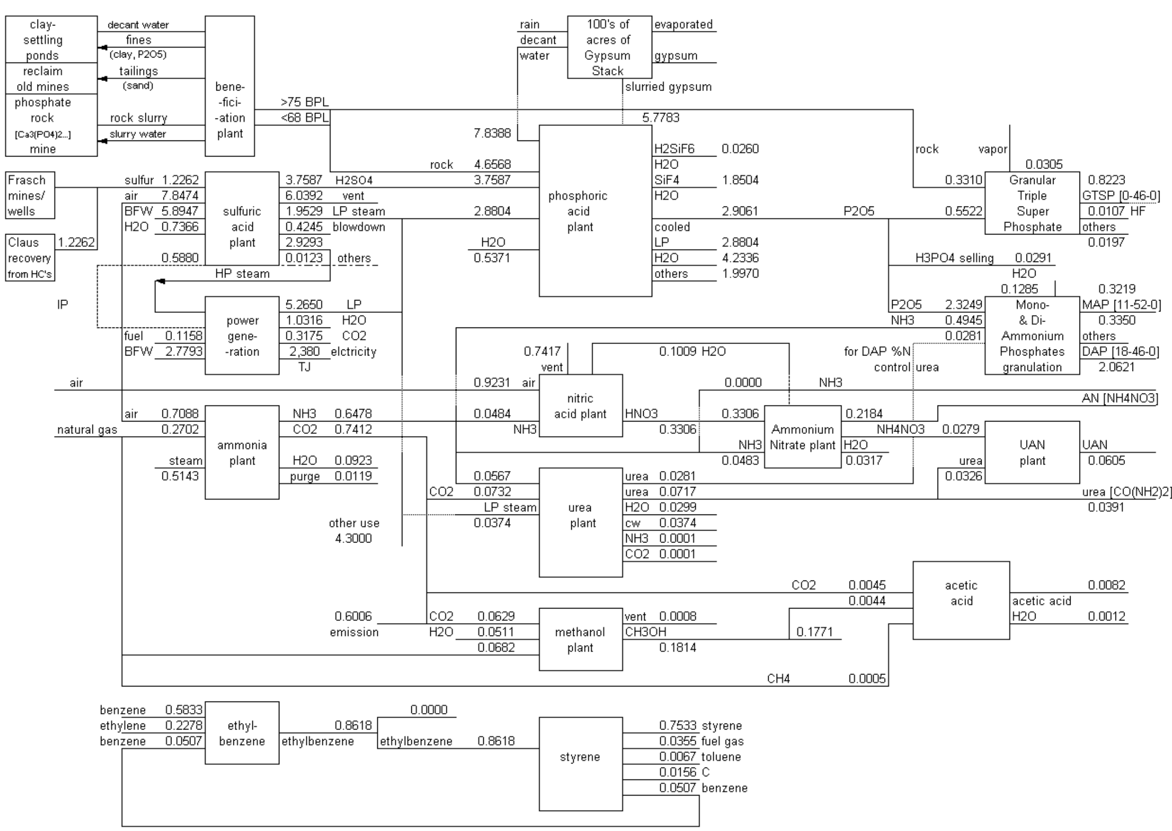

Figure 2. Base Case for Industrial Complex in Lower Mississippi River Corridor[2]

A new design has been proposed[2] in order to minimize the carbon dioxide emission in this complex. This new strategy proposes to use pure carbon dioxide released from all the sources in this complex as a raw material for manufacturing commercially useful products. It is proposed to expand the existing complex to form a new superstructure by using some of the eighteen new manufacturing processes.

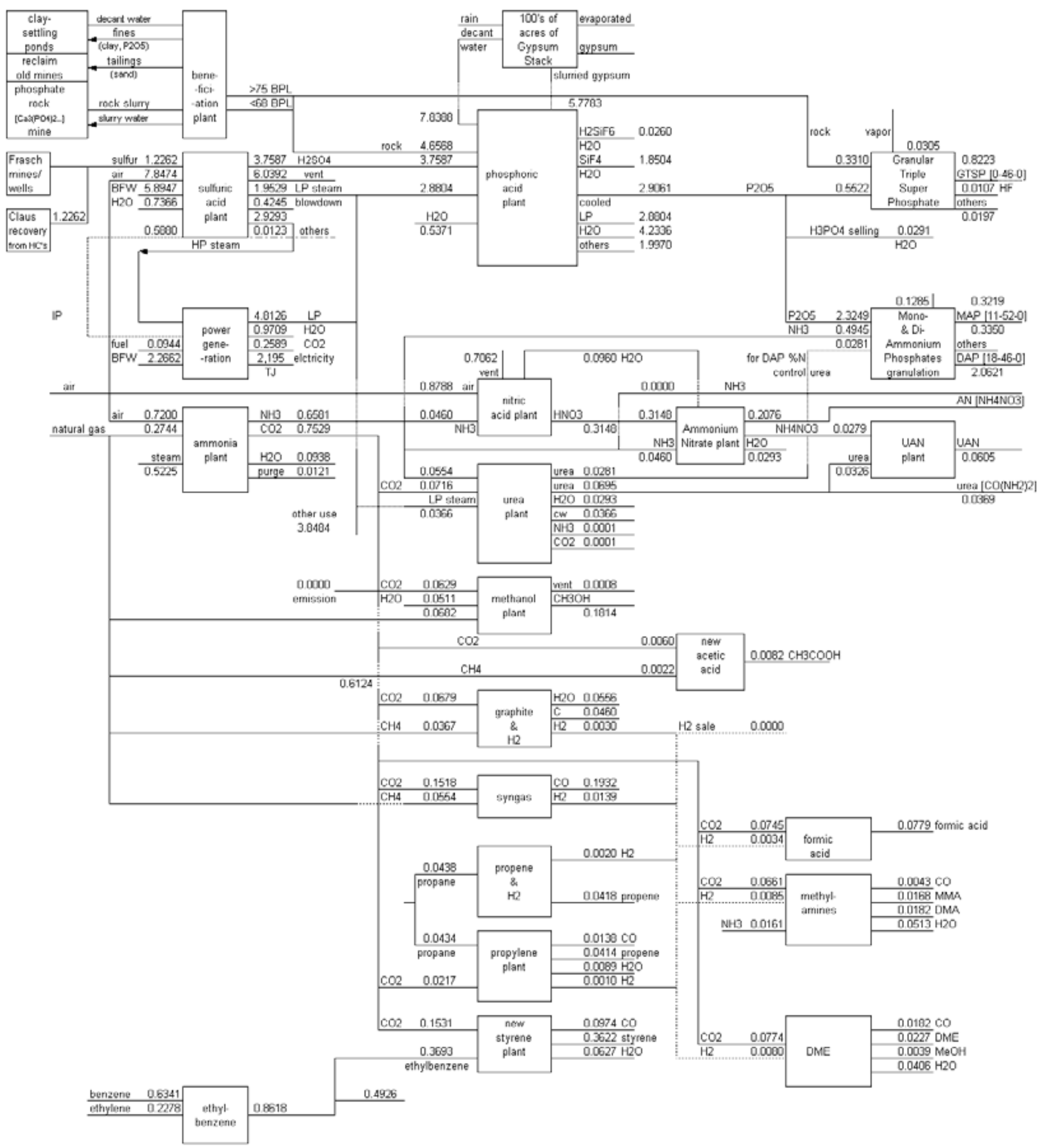

Figure 3. A New Design Scheme for the Industrial Complex in Lower Mississippi River Corridor[2]

These units consist of new manufacturing processes, which are selected on the basis of their operating conditions (temperature and pressure requirements), reactant conversion, product selectivity, cost of raw materials, thermodynamic feasibility and economic benefits. These new plants largely consume pure carbon dioxide as a raw material to produce useful products like propylene, styrene etc. using new manufacturing processes. This helps in reducing the carbon dioxide emission in the atmosphere, hence reducing its contribution to global warming. These eighteen potentially new processes include four processes for methanol production, two processes for propylene, and one process each for ethanol, Di Methyl Ether (DME), formic acid, acetic acid, styrene, methylamines, graphite and synthesis gas, two processes for phosphoric acid production and two processes for recovering sulfer and sulfer dioxide. This superstructure was optimized for getting an optimum configuration of all the plants for consuming all of the carbon dioxide from the ammonia plant operating at full production capacity. This new design is shown in Fig. 3. In this design, best suited processes are selected from the pool of eighteen new processes for the superstructure to consume all the carbon dioxide, giving maximum economic benefits with high environmental sustainability. The nine new processes included in this new design are: Formic Acid, Acetic Acid (new method), Methyl Amines, Graphite, Hydrogen/Synthesis Gas, Propylene from carbon dioxide, Propylene from Propane dehydrogenation, Styrene (new method) and DME Plant.

Next, A TRACI analysis was conducted for Base Case and the New Design Scheme in order to study the improvement the environmental performance of the Agricultural Complex after implementing new processes. The results are calculated using the input material and waste output data for each plant in the Base Case and the New Design Scheme.

A comparative analysis of the contribution of the agricultural complex in various impact categories for Base Case and the New Design Scheme is given in Fig. 4. As can be seen from the results, the environmental performance of the agricultural complex has been improved manifold in terms of global warming and water usage, but on the contrary, its performance has deteriorated in terms of some other impact categories like Fossil Usage and Human Health. A comparative analysis of the results of TRACI for Base Case and the New Design Scheme in each impact category is discussed in the following section.

1. **Acidification:** In the Base Case, the contribution towards acidification is 920.168 and in the New Design Scheme it is 919.210. Hence, the contribution of the industrial complex in the acidification category decreases marginally, as shown in Fig. 4.
2. **Fossil Fuel Usage:** The fossil fuel usage in the New Design Scheme (22547.161) has increased to 175% more than what was consumed in the Base Case (12819.976), as shown in Fig.4. The reason for this increase is the addition of new plants in the industrial complex in order to minimize the emission of carbon dioxide.
3. **Global Warming:** The contribution to this category is reduced by 66% from Base Case (1671.96) to the New Design Scheme (581.4). The ammonia plant in the Base Case was a major contributor to the Global Warming. As can be seen from Fig.4, the carbon dioxide emission decreases largely in the optimal case.
4. **Water Usage:** The water usage reduces by 40% from the Base Case (4126.328) to the New Design Scheme (2511.932). This occurs due to the change in the manufacturing methodology of Phosphoric acid and switching from wet process to a HCL Process for manufacturing Phosphoric Acid. As seen in Fig.4 the water requirement for the Power Generation facility in the New Design Scheme is higher than that in the Base Case, still the reduction in water usage of phosphoric acid plant compensates for this increase.
5. **Eutrophication:** Similar to Acidification, the contribution of the industrial complex in eutrophication reduces marginally, from the Base Case, 0.04856, to the New Design Scheme, 0.04749, as shown in Fig.4.

6. **Human Health Non-Cancer:** The contribution to this environmental impact category increases by 90% from the Base Case (0.7144) to the New Design Scheme (1.359) because of the Propylene Plant which has been added in the New Design Scheme, as shown in Fig. 4. This happens because of the residual Propene released in the atmosphere.
7. **Photochemical Smog:** The contribution of the agricultural complex increases manifold (6.22 E+06%) from the Base Case (0.0045) to the New Design Scheme (279.926). Again, the release of Propene is responsible for this drastic increase in this impact category.
8. **Human Health Criteria:** The contribution of the agricultural complex to this category remains same for both the Base Case as Well as the New Design Scheme.

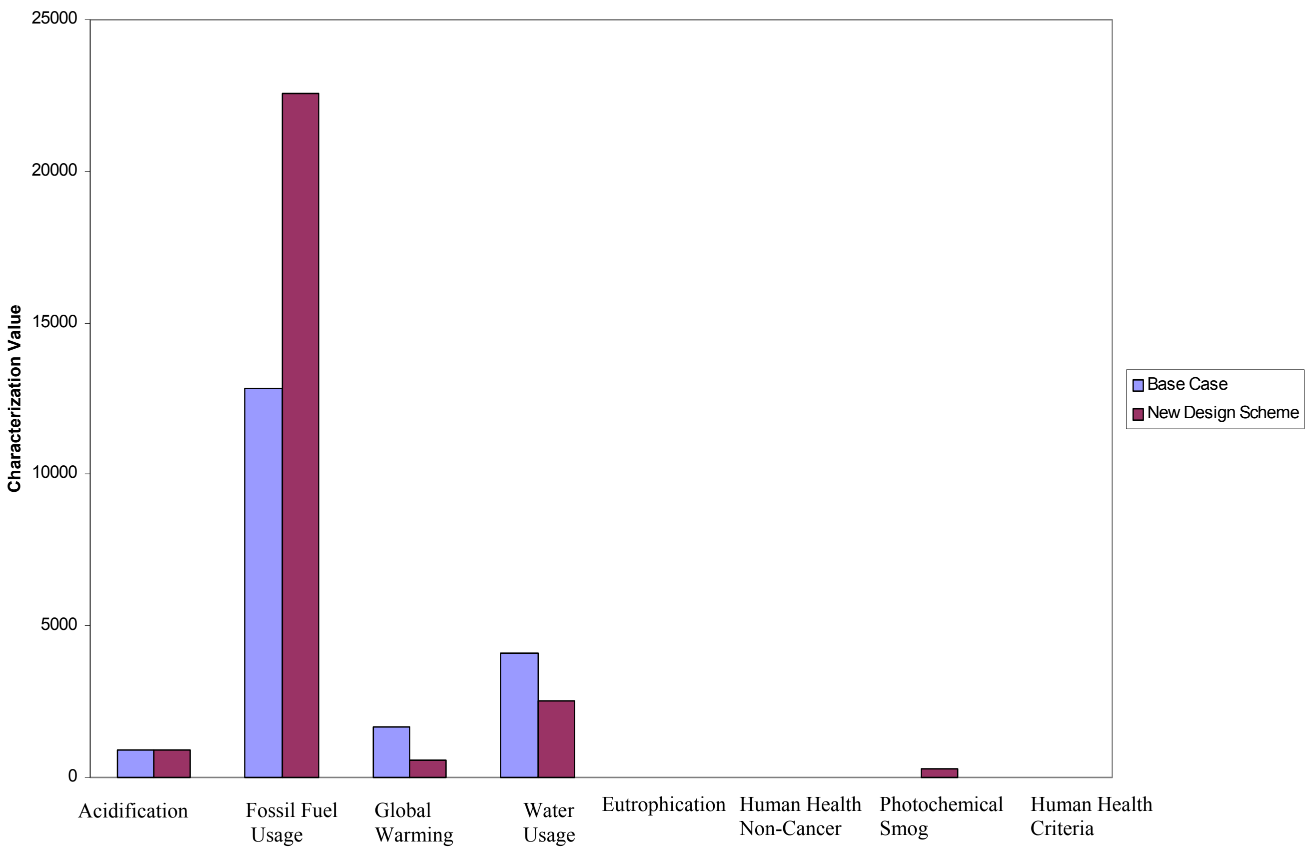

Figure 4. Contribution of Base case and New Design Scheme in various impact categories

By comparison, in the new design, the Propene plant adds to two critical impact categories, Photochemical Smog and Human health Non-Cancer. If Propene Plant is removed from the complex and the operating capacity of the other carbon dioxide consuming plants is increased to compensate for propene plant, the environmental performance of this industrial complex will improve manifold. Moreover, the fossil fuel usage will also be reduced.

Conclusion and Discussion

Development of industrial ecosystems is one of the most promising methods available for sustainable development of industrial systems. While developing such a symbiosis of industries, it is vital to evaluate the environmental impacts of this symbiosis beforehand. This would provide allowance for improving the design and establishing a more efficient industrial symbiosis. TRACI can be used successfully to analyze the environmental impacts of an industrial ecosystem as can be seen from the results of the case study.

References

1. The Kalundborg Centre for Industrial Symbiosis, *Industrial symbiosis*, 2003. www.symbiosis.dk
2. Indala, S., *Development and Integration of New Processes Consuming Carbon Dioxide in Multi-Plant Chemical Production Complexes,* Graduate These, Louisiana State University, LA, 2004.
3. Pre Consultants, *SimaPro 5.1 LCA Software: User Manual*, Netherlands.
4. Bare, J. C., Norris, G. A., Pennington, D. W., and T. McKone, "TRACI: The Tool for Reduction and Assessment of Other Environmental Impacts," *Journal of Industrial Ecology,* **6**(3-4), 49-78, 2002.
5. Christen, P. and N. Caspersen, *Handbook on Environmental Assessment of Products,* Danish EPA, 2001. http://www.pre.nl/simapro/simapro_lca_software.htm
6. USEPA, "Sustainable Technology Systems Analysis, TRACI - Tool for Reduction and Assessment of Other Environmental Impacts," Environmental Protection Agency, National Risk Management Research Laboratory, Ohio, USA. http://epa.gov/ORD/NRMRL/std/sab/iam_traci.htm