Keynote Lecture delivered as Distinguished Speaker at International Conference on LIFE CYCLE ASSESSMENT & LIFE CYCLE MANAGEMENT METHODOLOGIES held during December 4-5, 2006 at The Boulevard Hotel, Kuala Lumpur, Malaysia organized by COMFORI SDN BHD, Malaysia

Life Cycle Inventory Analysis

Dr B V Babu
Dean – Educational Hardware Division (EHD) &
Professor of Chemical Engineering
Birla Institute of Technology and Science (BITS)
PILANI – 333 031 (Rajasthan) India
E-mail: bvbabu@bits-pilani.ac.in
Homepage: http://discovery.bits-pilani.ac.in/discipline/chemical/BVb/

INTRODUCTION

The industrial development with its associated technology has enabled the transformation of the environment in different ways. It has changed the nature and extent of the environmental impacts of industrial activities. Depletion of resources and pollution of air, water and land, are examples of the environmental problems that have emerged as a result of intensified human interventions into the environment. The chemical and process industries find themselves constantly under the scrutiny of various pressure groups demanding more environmentally acceptable processes, products and practices through the ideas of `waste minimization', `zero emission', `producer responsibility', etc. One of the potential dangers of this is that the companies exposed to environmental pressures may simply respond to satisfy a particular group. However, this short-term approach may lead to costly long term mistakes with little environmental improvement and no net business benefit. To avoid this, environmental issues must be assessed in a holistic way using systems approach along with financial, technical and other criteria (Azapagic, 1999).

A product's life cycle starts when raw materials are extracted from the earth, followed by manufacturing, transport and use, and ends with waste management including recycling and final disposal. At every stage of the life cycle there are emissions and consumption of resources. The environmental impacts from the entire life cycle of products and services need to be addressed. To do this, life cycle thinking is required.

Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. The assessment begins with the raw materials input, proceeds through the manufacturing processes, energy use, maintenance, and transportation. It considers use, reuse, and recycling, and concludes with waste management, the environmental impact of packaging, and ultimate disposal of the product (Azapagic, 1996). LCA provides an adequate instrument for environmental decision support. Life cycle assessment has proven to be a valuable tool to document the environmental considerations that need to be part of decision-making towards sustainability. A reliable LCA performance is crucial to achieve a life-cycle economy.

The Fig. 1 shows the interactions of various stages of LCA (Susan, 1995). The key elements of LCA are given below:

1. Identifies and quantifies the environmental loads involved; e.g. the energy and raw materials consumed, the emissions and wastes generated (Life Cycle Inventory Analysis).
2. Evaluates the potential environmental impacts of these loads (Life Cycle Impact Assessment).
3. Assesses the options available for reducing these environmental impacts (Interpretation of Life Cycle Inventory analysis and Impact Assessment).

In the present study the main focus is on Life Cycle Inventory analysis (LCIA)

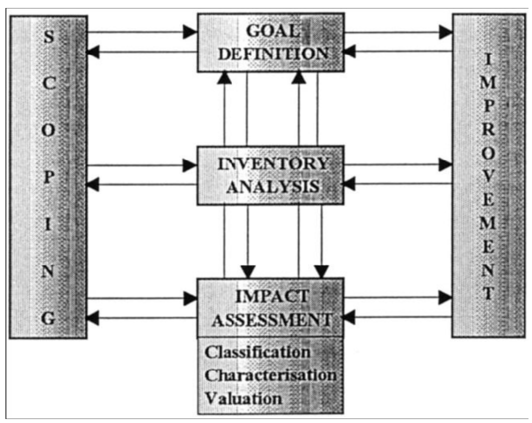

Fig. 1. Interaction between LCA stages

In the second, Inventory Analysis stage, material and energy balances are performed and the environmental burdens are quantified. The burdens are defined by resource consumption and emissions to air, water and solid waste. Aggregation of the burdens into a smaller number of impact categories (Classification) is done in the Inventory Analysis stage. In the present study mainly focus on Life Cycle Inventory analysis (LCIA).

LIFE CYCLE INVENTORY ANALYSIS (LCIA)

Life Cycle Inventory Analysis (LCIA) is a part of the Life Cycle Assessment (LCA), a thorough procedure accounting for the environmental loads during the product's life cycle (Babu and Ramkrishna, 2003). Inventory Analysis is a systematic, objective, stepwise procedure for quantifying energy and raw materials requirement, atmospheric emissions, water borne emissions, solid wastes, and other releases for the entire life cycle of a product, package process, material or activity (Manjare and Babu, 2005). LCIA is a process of data collection and calculations intended to quantify the inputs and outputs of a product system. These inputs and outputs may include resources used, as well as release to air, water, or land (SAIC, 2006).

An inventory may be conducted to aid in decision making by enabling companies or organizations to:

- Develop a baseline for a system's overall resource requirements for benchmarking efforts.
- Identify components of the process that are good targets for resource-reduction efforts
- Aid in the development of new products or processes that will reduce resource requirements or emissions.
- Compare alternative materials, products, processes, or activities within the organization.
- Compare internal inventory information to that of other manufacturers.

Managers using LCA to aid decision-making can improve the validity of the results and keep the analysis focused by precisely defining the scope of the "system" to be analyzed, considering practical constraints such as time and money. This step builds the foundation for the analysis that follows and should be understood and agreed upon by those responsible for commissioning the study. A system refers to a collection of operations that together perform some defined function. The system begins with all the raw materials taken from the environment and ends with the outputs released back to the environment as shown in Fig. 2 (Susan, 1995).

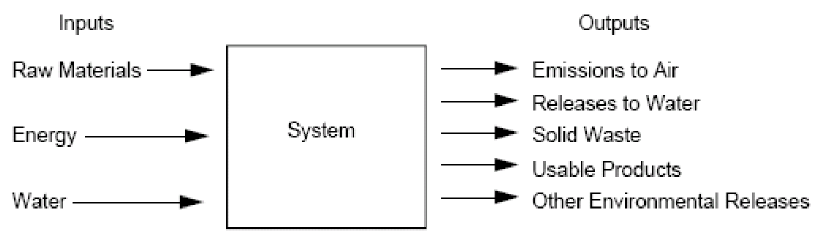

Fig.2. Input and output of a system.

Within most systems, three main groups of operations may be defined:

1. Operations for the production, use, transportation, and disposal of the product.
2. Operations for the production of ancillary materials such as packaging
3. The energy production needed to power the system.

A clearly defined scope will improve the results of subsequent steps when the total process is divided into subsystems. An example of typical subsystem categories is shown in Fig. 3 (Susan, 1995).

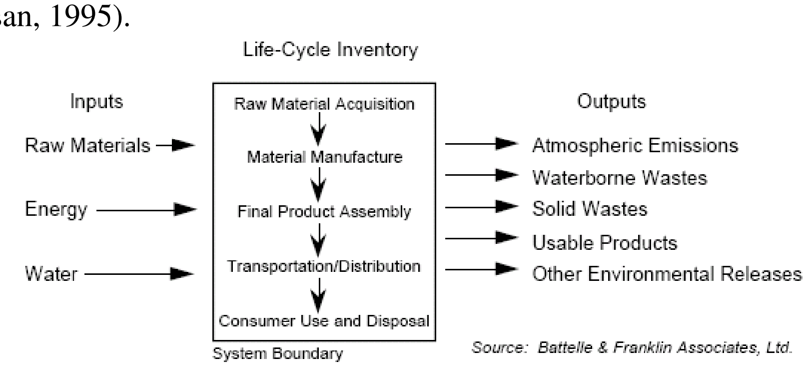

Fig. 3. Defining System Boundaries.

The linkages between subsystems make the process of collecting consistent measurements complex. For example, subsystems must be defined so that they are large enough to provide sufficient data for analysis but not so large that data is aggregated at a level that precludes detailed analysis. In addition, subsystems should be linked by a standard basis of comparison such as equivalent usage ratios.

A thorough understanding of how an inventory analysis is conducted, and the limitations and assumptions inherent in the various stages is critical to effective use of LCA in decision making. The following are the various subsystems analyzed in an inventory analysis: raw materials acquisition, manufacture and fabrication, transportation /distribution, consumer use/disposal, and recycling. The key Steps involved in LCIA are: development of a flow diagram, development of an LCI data collection plan (this step includes defining data quality goals, identifying data quality indicators, identifying data sources and types, developing a data collection spreadsheet), collection of data (inputs in the product LCIA include energy, energy sources, water; and outputs of the Product LCIA include atmospheric emissions, waterborne wastes, solid waste, products, transportation, co-product allocation, industrial scrap, data-time period, specific data versus composite data, geographic specificity, routine/fugitive/accidental releases, special case boundary issues; economic input-output approach to LCIA), evaluating and documenting the LCI Results, and interpretation of Data.

Three case studies are discussed incorporating the above aspects:
Case Study – 1: Environmental Impact Minimization Issues in Batch / Semi-Continuous Plants (Stefanis et al., 1997).
Case Study – 2: Life Cycle Inventory Analysis of Hard Coal Based Electricity Generation (Laura et al., 2005)
Case Study – 3: Comparison of End-of-Life Tyre Treatment Technologies: Life Cycle Inventory Analysis (Silvestravičiūtė and Karaliūnaitė, 2006).

CONCLUSIONS

The following conclusions are drawn from the present study.

- Life Cycle Inventory Analysis is an important component in Life Cycle Assessment.
- Inventory analysis required the thorough understanding of subsystems.
- Flow diagrams are used to model and compare all alternatives under consideration.
- Data collection step is very important in LCIA to determine how much of the energy and material requirements and the environmental releases associated with the process.
- The economic input-output approach quickly covers an entire economy, including all the material and energy inputs.
- The results from the inventory can be presented most comprehensively in tabular form or graphical form.
- The identification of significant issues is possible by interpreting the inventory results.
- A process systems methodology for incorporating environmental concerns in the optimal scheduling and design of batch processes has been presented.

- The proposed methodology identifies waste generation sources within a batch plant and after establishing relationships to link output to input waste generation transforms it into an aggregated over time and species environmental impact vector.
- The heavy metal emissions to the atmosphere occur mainly at the power plant.
- It produces 57-95% of total heavy metal emissions except for Hg, the share of which was 11%.
- Approximately 95% of all the CO2 emissions of the whole system originate from the power plant.
- Transportation of the hard coal from the mines to the power plant induces a great deal of NOX emissions - 30% of the total emissions.
- The baro-destructive method of used tyre recycling requires the highest amount of electric power (522 kWh per 1 tonne of scrap tyres to be recovered).
- While the highest amount of heat energy is generated during direct tyre co-incineration in a cement kiln (energy recovery of 1 tonne of scrap tyres equals to 9304 kWh).

REFERENCES

Azapagic, A. (1999). "Life cycle assessment and its application to process selection, design and optimisation – Review article". *Chemical Engineering Journal*, **73**, pp. 1-21.

Azapagic, A. (1996). "Environmental system analysis: The application of linear programming to life cycle assessment," *Ph.D dissertation*, University of Surrey.

Babu, B.V. and Ramakrishna, V. (2003). "Life Cycle Inventory Analysis in Adsorbent Preparation for Waste Management: A Case Study", *Proceedings of International Conference on Energy and Environmental Technologies for Sustainable Development (ICEET-2003)*, Jaipur, October 8-10, 2003 (Eds. Upendra Pandel & M.P.Poonia), pp. 79-84.

Laura, S., Sirkka, K. and Jyri, S. (2005). "Life cycle inventory analysis of hard coal based electricity generation," *The Finish Environment*, 797.

Manjare, S.D. and Babu, B.V. (2005). *Environmental Management Systems*, Educational Development Division, BITS-Pilani.

Susan, S. (1995). "Note on Life Cycle Analysis", *Pollution Prevention and Corporate Strategy*, National Pollution Prevention Center for Higher Education, Ann Arbor, pp. 1-9.

SAIC (Scientific Applications International Corporation) (2006). *Life Cycle Assessment: Principles and Practice*, EPA/600/R-06/060, May, 2006.

Stefanis, S. K., Livingston, A. G. and Pistikopoulos, E. N. (1997). "Environmental impact considerations in the optimal design and scheduling of batch processes," *Computers & Chemical Engineering*, **10**, pp. 1073-1094.

Silvestravičiūtė I. and Šleinotaitė-Budrienė L. (2002). "Possibility to use scrap tyres as an alternative fuel in cement industry," *Environmental Research, Engineering and Management*, **3**, pp. 38–48.