THE APPLICATION OF LIFE CYCLE ASSESSMENTS (LCA's) IN THE CHEMICAL INDUSTRY

by

Janette van der Walt

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EXECUTIVE SUMMARY

The Life Cycle Assessment (LCA) methodology can be applied in various stages – especially conceptual design and ISO 14001 Environmental Management System (EMS) implementation – in order to add value and incorporate environmental concerns in the chemical industry to improve the overall environmental performance. The LCA methodology was successful in identifying the environmental issues of the conceptual design case study for future environmental focus in the conceptual project, taking into account the limited detail data available so early in the project life cycle. The LCA was even more successful in identifying the major environmental impacts and aspects of different process units relative to each other in the implementation of an ISO 14001 Environmental Management System due to the availability of more detail data from actual analyses and measurements. Only environmental problem identification, focus and priorities are given by the LCA, while the severity of the potential impacts is not determined.

Die Lewens Siklus Analise (LSA) metode kan toegepas word in verskeie stadiums – veral in die konseptuele ontwerp en inbedryf stelling van ISO 14001 Omgewingsbestuur stelsels (OBS) – om waarde toe te voeg en sake rakende die omgewing in die chemiese industrie te inkorposeer en sodoende die algehele omgewings prestasie te verbeter. Die LSA metode het die omgewings vraagstukke suksesvol geidentifiseer in die konseptuele projek, as die beperkinge van die beskikbare data in ag geneem word so vroeg in 'n projek se lewens siklus. Die LSA was selfs meer suksessvol in die identifiseering van die belangrikste omgewingsimpakte en aspekte van die veskillende proses eenhede relatief tot mekaar vir die inbedryfstelling van 'n ISO 14001 OBS. Dit is hoofsaklik as gevolg van die beskikbaarheid van meer detail data vanaf werklike analises en meetings. Slegs omgewingsproblem identifiseering, fokus en prioritiete word deur die LSA aangewys, terwyl die ernstigheid van die moontlike impakte nie aangedui word nie.

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1. LIST OF ABREVIATIONS / TERMS OF REFERENCE

1. **ADI** = Acceptable Daily Intake
2. **Allocation** = Partisioning the input or output flows of a unit process to the product system under study [SABS/ISO 14040:1-3]
3. **AP** = Acidification Potential
4. **CML** = Center for Environmental Science
5. **Comparative assertion** = An environmental claim regarding the superiority or equivalence of one product versus a competing product which performs the same function [SABS/ISO 14040:1-3]
6. **Continuous improvement** = the process of enhancing environmental management to achieve improvements in the overall environmental performance in line with the organisation's environmental policy [SABS/ISO 14001:1-2]
7. **DMK** = Di-methyl ketone (Acetone)
8. **EIA** = Environmental Impact Assessment
9. **ELU** = Environmental Load Units
10. **EMS** = Environmental Management System
11. **End-of-pipe** =Measures taken at the end of a process, just before the material (emission, effluent or waste) is dumped on the environment, to ensure compliance to regulations. Upstream process improvements are not being considered.
12. **Environment** = is the surroundings in which an organisation operates, including air, water, land, natural resources, flora, fauna, humans and their interrelation [SABS/ISO 14001:1-2]
13. **Environmental aspect** = Is an element of an organisation's activities, products or services, which can interact with the environment [SABS/ISO 14001:1-2]
14. **Environmental impact** = Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's activities, products or services [SABS/ISO 14001:1-2]
15. **Environmental Management System (EMS)** = is the part of the overall management system that includes organisational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving reviewing and maintaining the environmental policy [SABS/ISO 14001:1-2]
16. **Environmental objective** = The overall environmental goal, arising from the environmental policy, that the organisation sets itself to achieve and which is quantified where practical [SABS/ISO 14001:1-2]
17. **Environmental performance** = is the measurable results of environmental management related to an organisation's control of its environmental aspects, based on its environmental policy [SABS/ISO 14001:1-2]
18. **Environmental target** = The numerical goal that measures the success of the objective and are therefore detail performance requirements [SABS/ISO 14001:1-2]
19. **eq** = equivalents
20. **F-T** = Fisher Tropsch

21. **Functional unit** = Quantified performance of a product system for use a reference unit in a LCA study [SABS/ISO 14040:1-3]
22. **GJ** = Giga Joule
23. **GWP** = Global Warming Potential
24. **HCA, HCW, HCS** = Human toxicology classification factor for air, water and soil
25. **HxCy** = General Hydrocarbon compounds
26. **ICC** = International Chamber of Commerce
27. **Input** = Material or energy which enters a unit process [SABS/ISO 14040:1-3]
28. **IPCC** = International Panel on Climate Change
29. **ISO** = International Standard Organisation
30. **LCA** = Life Cycle Assessment
31. **LCI** = Life Cycle Inventory
32. **Lean natural gas** = Refined natural gas as most of the sulfur and acid components were removed in or for example a Rectisol or Claus process unit
33. **Life cycle** = Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal. [SABS/ISO 14040:1-3]
34. **Life cycle assessment** = A compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system through out its life cycle [SABS/ISO 14040:1-3]
35. **Life cycle impact assessment** = Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system [SABS/ISO 14040:1-3]
36. **Life cycle inventory** = Phase of life cycle assessment involving the compilation and qualification of inputs and outputs, given product system throughout its life cycle [SABS/ISO 14040:1-3]
37. **LPG** = Liquified Petroleum Gas
38. **Material** = Includes raw materials, intermediate products, products, emissions, effluents and waste [SABS/ISO 14040:1-3]
39. **MIBK** = Methyl iso Butyl Ketone
40. **MP** = Mild pressure
41. **MSDS** = Material Safety and Data Sheet
42. **MTC** = Maximum Tolerable Concentration
43. **NG** = Natural Gas
44. **NP** = Nutrification Potential
45. **OOM** = Order of Magnitude
46. **OSH-act** = Occupational Safety and Health Act
47. **OTV** = Odour Threshold value
48. **Output** = Material or energy which leaves a unit process [SABS/ISO 14040:1-3]
49. **POCP** = Photochemical Ozone Creation Potential
50. **Point sources** = The source of emission and environmental problems at the point of entrance to the environment. For example: the point where the effluent is pumped into the river.
51. **ppb** = Parts per billion
52. **ppm** = Parts per million

53. **Prevention of pollution** = the use of processes, practices, materials or product that avoid, reduce or control pollution, which may include recycling, treatment, process changes, control mechanisms, efficient use of resources and material substitution [SABS/ISO 14001:1-2]
54. **Product system** = The collection of materially and energetically connected unit process which performs one or more defined functions [SABS/ISO 14040:1-3]
55. **R&D** = Research and Development
56. **Raw natural gas** = Unrefined natural gas as extracted from the earth
57. **Red flag analysis** = The identification of key issues on an acceptable or agreed upon set of criteria
58. **ROM** = Rough Order of Magnitude
59. **RSA** = Republic of South Africa
60. **Sasol SPD** = Sasol Slurry Phase Distillate Process
61. **SDE** = Semi Definitive Estimate
62. **System boundary** = The interface between a product system and the environment or other product systems
63. **TCL** = Tolerable Concentration in air
64. **TDI** = Tolerable Daily Intake
65. **TEAM™** = Tools for Environmental Analysis and Management
66. **Unit process** = The smallest portion of a product system for which data are collected when performing a life cycle assessment [SABS/ISO 14040:1-3]
67. **USES** = Uniform System for the Evaluation of Substances
68. **VROM** = Very Rough Order of Magnitude
69. **Waste** = Any output from the product system which is disposed of [SABS/ISO 14040:1-3]

2. INTRODUCTION

2.1 GENERAL INTRODUCTION

Environmental protection has become a strategic issue of increasing importance for industry both in the citing of plants and in the technical performance of processes and products. As environmental issues become more focused with regard to public concern, market pressure and trade aspects, industry must adopt a new approach to its future activities.

It is increasingly accepted that industry will need to pursue three linked environmental goals: responsibility, accountability and sustainability. Among the initiatives designed to achieve these goals are the Business Charter for Sustainable Development launched in 1991 by the International Chamber of Commerce (ICC), Chemical industry initiatives such as Responsible Care and the ISO 14000 standards. Implicit in these documents is the idea that industry will need to accept life cycle responsibility for its project, processes, services and products. [SPOLD, 1993]

This is a challenge for industry to meet, yet environmental criteria are often not considered at the beginning of the design of a product or process when it is the easiest to avoid adverse impacts. Until recently, most environmental impacts were reduced through "end-of-pipe" controls, which are a reactive approach to environment management. As a result, many companies spend too much time and money fixing problems instead of preventing them. But, after the plant was built, it is also important to identify the existing problem areas on which time and effort should be focussed.

Effort is, however, needed to develop a suitable and acceptable approach for the incorporation of environmental considerations into the various stages of industrial activities:

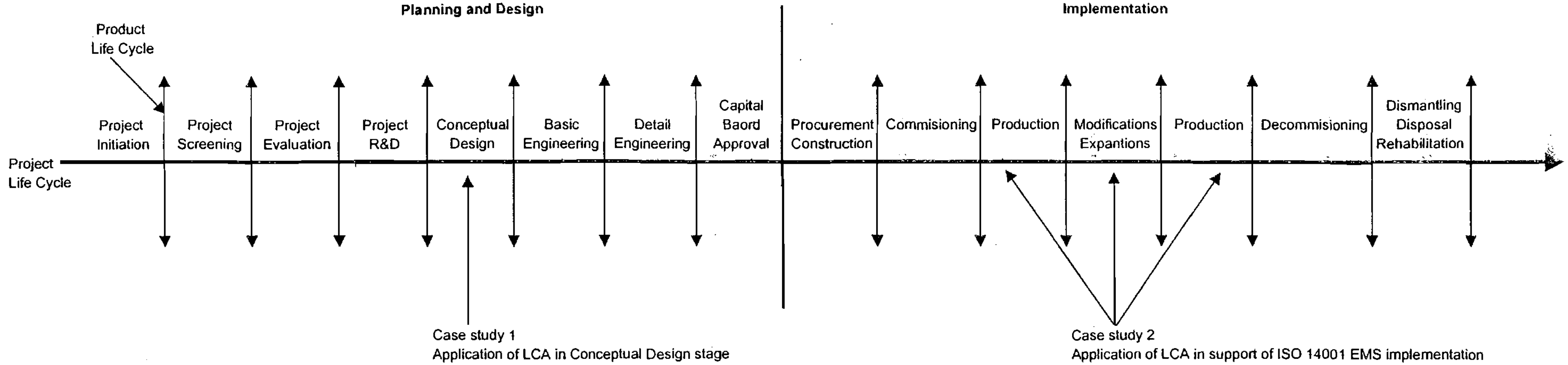
- from raw material acquisition and manufacturing to product use and final disposal (Product Life Cycle) and
- from project initiation to final decommissioning and rehabilitation (Project Life Cycle).

Life Cycle Assessments (LCA's) have evolved from an energy analysis and early life cycle inventories through to proposals for a much more rigorous analysis. There are currently a number of attempts to develop a more "holistic" LCA methodology, covering economic, technical and environmental concerns [SPOLD, 1993]. LCA's have the potential to adhere to this challenge seeing that it speaks the "language" understood by environmentalists, scientists, engineers, marketers, economic evaluators and administrative and government agencies.

The Life-Cycle concept is therefore gradually becoming a more important method for industry to understand, manage and reduce the environmental, health and resource consumption impacts associated with its processes, products and activities [Lindfors et al, 1995:10].

It is in this regard that two case studies were performed to test the application of LCA's in the chemical industry to obtain a better understanding of the environmental issues that should be focussed on. The two case studies performed are on the opposite ends of the project life cycle as illustrated in the next diagram – Figure 1.

FIGURE 1: Position of LCA case studies in the project life cycle



2.2 BASIC HYPOTHESIS / CENTRAL THEORETICAL ARGUMENT

That the Life Cycle Assessment (here after LCA) methodology can be applied at various stages – conceptual design and ISO 14001 implementation - in order to add value and incorporate environmental concerns in the chemical industry.

2.3 OBJECTIVES

1. To investigate the LCA methodology and the application of LCA's in two stages of the project life cycle. Therefore the application of LCA's in the conceptual design of a chemical engineering project to identify the environmental concern areas and as a tool for the identification of environmental impacts and aspects in the implementation of an ISO 14001 Environmental Management System (EMS)

2. Conceptual design :
   - To determine the requirements for the application of LCA's in the conceptual design and engineering phase. Therefore the LCA method must be able to:
     - use readily available information,
     - assist the chemical engineer in identifying critical environmental issues
     - assist the chemical engineer in identifying probable solutions or areas of improvement
     - assist the chemical engineer in evaluating proposed options not only in terms of their technological and economical feasibility but also in terms of its environmental feasibility.

   - To conduct an LCA case study to illustrate the application potential and contributions made by the LCA methodology to the initial engineering stages of a project.

3. ISO 14001 Environmental Management System (EMS)
   - To determine the support an LCA can give an ISO 14001 EMS in the:

  - Evaluation of the application of LCA's as an information source to ISO 14001 implementation.
  - Development of an environmental profile of a chemical division to determine its current environmental status, its environmental impacts and aspects, as well as their root causes.
- To establish an environmental performance baseline for future mitigation measures' environmental effect and emission reduction as well as to provide a baseline for proving continuous improvement.
- To provide a base and criteria for improvement of the data quality and level of detail of future measurements and analysis requirements.

3. LCA MOTIVATION AND METHODOLOGY

3.1 WHY SHOULD AN LCA BE DONE?

The work on the reduction of air, water and solid waste emissions from point sources started many years ago. The "point-source" pollution problem which was intended to be solved through legislation and "end-of-pipe"-solutions has in many cases been brought under control at a price [Lindfors et al, 1995: 9]. These reactive solutions (bio-works, flares, scrubbers, incinerators, electrostatic precipitators etc.) are usually expensive and often an extra unforeseen burden to the company. Solving, or at least reducing, these problems through a proactive approach by increased efficiency (do more with less) and clean technology (less waste generation), is future industrial perspectives.

Despite reduced emissions from point sources, environmental problems are felt to be increasing in complexity. The character of the environmental problems has undergone a significant change and much more emphasis is now placed on sustainable development rather than just pollution prevention or control (section 24 Constitution of the Republic of South Africa 108 of 1996). In many cases, major progress has been made in this environmental protection area through:

- Administrative controls - Effluent permits, Hazardous waste permits.
- Legislation - Atmospheric Pollution Prevention Act 45 of 1965, National Water Act 36 of 1998, Environmental Conservation Act 73 of 1989, National Environmental Management Act 107 of 1998.
- Industrial commitments - Company Mission statement, Company Environmental Policy, Responsible Care, ISO 14000 series.
- Authorities - Department of Water Affairs, Department of Environmental Affairs and Tourism, USA Environmental Protection Agency (EPA).
- Market and Public pressure - Competitive advantage, Eco-labeling, Media and public opinion.

It is therefore believed that the above mentioned measures will play a central role in making industry aware of the need - and demand - for cleaner and environmentally friendlier products and processes. To be able to act more effectively and conclusively to combat further environmental damage, a life-cycle approach to many of the remaining environmental problems is necessary.

Sustained confidence in the claims of manufacturers on the environmental performance of their products and processes is essential for the future long-term existence of these companies. This confidence was considerably shaken by inaccurate or exaggerated claims made by some companies in their enthusiasm for 'green marketing' [SPOLD,1993]. As a result there is a growing interest in LCA methods which offer an improved understanding of the quantitative and qualitative 'cradle to grave' impacts of products, projects, services or processes. A so-called "green" product can have severe adverse environmental impacts in its raw material consumption and manufacturing stages, which are usually not acknowledged. Companies must therefore take life cycle responsibility for their products, projects, services and processes.

3.2 WHAT IS AN LCA?

3.2.1 History of the LCA methodology

[Curran, 1996: 3]

LCA literature has shown an exponential increase in the 1990's. This is clear from any literature search done on the subject, though the first attempts on LCA's were as early as the 1960's. This work was focussed on the "fuel cycle" and energy requirements with limited estimates of environmental releases as done mainly by the US Department of Energy.

In the 1970's LCA's reemerged in studies which focussed on environmental issues as performed by Arthur D. Little and Midwest Research Institute. In Europe the focus of similar studies in this time period were mainly on packaging systems.

In the 1980's the Green Movement in Europe brought new attention to LCA's with relation to recycle and product comparisons. Consumer interest groups wanted to use LCA's to compare products, in order to prove which were the more "environmentally friendly" ones.

The 1990's retained some of the product comparison drive in eco-labeling. However, the main driving force is now to identify opportunities to improve the overall environmental profile of the product, process, service and project.

3.2.2 The goal and objective of an LCA

The main goal of an LCA is to ensure that the time, money and effort spent on environmental protection results in real environmental improvements [SPOLD, 1993].

The LCA process is in this context understood or defined as follows by Lindfors et al [1995:12]:

> *"A process to evaluate the environmental burdens associated with a product system, or activity by identifying and quantitatively or qualitatively describing the energy and materials used, and wastes releases to the environment and to assess the stressors which leads to environmental impacts. The assessment includes the entire life cycle of the product or activity, encompassing extracting and processing raw materials, manufacturing, distribution, use, re-use, maintenance, recycling and final disposal, and all transportation involved. LCA addresses these environmental stressors in the areas of resource depletion, pollution and damage to the landscape, the ecosystem and human beings. Socio-economic effects are not addressed by an LCA study."*

Another description by Cahan & Schweiger (1993: 46), which gives a different perspective, is:

"...identifying and focussing on each individual stage in the life of any product, such as concept formulation, product design and development, manufacturing strategies, manufacturing and production, marketing, distribution and sales and product disposal"

LCA's in general should therefore be looked upon as a design, marketing and decision making tool to be applied at different levels of complexity and scope, depending on the objective of the study, to minimize environmental impacts. The underlying objective of most LCA's is therefore to ensure that decisions are taken on the basis of a better understanding of a wider range of potential environmental consequences.

More specifically, the objectives of LCA studies are the following:

- <u>Conceptually</u> [Lindfors et al, 1993: 10; Fava et al, 1996: 2]

  - ◆ To ensure a "green" paradigm shift in the thought and decision making process in the chemical industry.
    - To be used as an additional criteria to:
      - guide the selection of options during: strategic planning, design, resource allocation and product and process development [Lindfors et al, 1993: 10, Fava et al, 1996: 2].
      - evaluate process, product and project alternatives as well as performance improvement and optimization measures
      - Conserve resources, minimise depletion and use sustainable practices [Keoleian, 1996: 7]

- <u>Qualitatively</u> [Lindfors et al, 1993: 10; Fava et al, 1996: 2]

  - ◆ To assess key environmental burdens or releases [Lindfors et al, 1993: 10] through a so-called "red flag" analysis at all stages in the life cycle of a product or process.
  - ◆ To determine focus or problem areas for research and development.

- To consider alternatives through comparison to improve the overall environmental performance [Curran, 1996: 5].

- Quantitatively [Fava et al, 1996: 2]

    - To develop an inventory of environmental burdens [Lindfors et al, 1993: 10].
    - To identify and evaluate the potential pollution contribution or impacts on the environment and consider alternatives to improve the environmental performance [Fava et al, 1996: 2].

- Strategically

    - To prove through the environmental profile and performance of a product, process or project, the company's commitment to find the best environmental, technical and economic options. This is seen as essential for a company's long term survival.
    - To provide information for strategic decisions [Lindfors et al, 1992: 21].

- Informatively

    - To identify areas lacking in:
        - knowledge and set research priorities,
        - information or data detail, accuracy and adequacy.
    - To supply information needed for legislation, regulatory or public purposes [Lindfors et al, 1992: 21].
    - To provide information to consumers about the characteristics of products, processes and resource consumption through eco-labling for example [Lindfors et al, 1992: 21].

- Marketing

    - To ensure the customers and consumers of the products' or processes' enhanced performance. This can be done through eco-labeling, benchmarking with other products, processes or standards [Foust et al, 1996: 2].

- Technologically

    - To provide criteria for the development and improvement of clean technologies.
    - This can be done through the interaction of
        - environmental studies,
        - economic evaluations,
        - and innovative engineering and research

      from the early stages of the project development cycle.

3.2.3 Issues not included in an LCA

According to Lindfors [1993: 51 – 53] the following issues are not quantified by an LCA:

- Infrastructure
- Accidental spills
- Impacts caused by personnel
- Human resources

Others that can be added to the list are:

- Social issues
- Severity of proposed impact categories
- Specification of site location [Van den Berg et al, 1996: 4]

3.3 LCA METHODOLOGY

Fundamentally an LCA involves looking at what goes into a process (raw materials, energy, water etc.) and what comes out (products, by-products, waste etc.). A critical element is the definition of the system boundary or scope. Beyond the boundary the environment acts both as a source of raw material and energy and as the ultimate sink or receptor of emissions and wastes.

In short the LCA methodology consists of four basic steps: [SABS/ISO 14040: 4; Lindfors, 1993: 21; Curran, 1996: 3-4; Boguski et al, 1996: 1-2; Fava et al, 1996: 3; Heijungs, Guide, 1992: 10]. The fifth step is only added by a few authors [SABS/ISO 14040: 4; Lindfors, 1993: 25,26-28]

1. Determining the scope and objective of the LCA study.
2. The Life Cycle Inventory (LCI).
3. The Life Cycle Impact Assessment or Classification and Valuation step.
4. The Improvement Analysis step or Interpretation.
5 Critical Review or Validation

3.3.1 Determining the scope and objective of the LCA study

Determining the scope and objective of the LCA study is the most critical step in the process and therefore determines to a large extent the success and results of the LCA as well as its application [Lindfors, 1993: 25]. The aim or objective, system boundaries, target audience, process or product alternatives, functional unit, assumptions, study limitations, allocation, data requirement and data quality must be determined in this step [Lindfors, 1993: 25; Boguski et al, 1996: 1; Heijungs et al, Guide, 1992: 17].

- The objective of the study will determine the purpose, depth, audience, alternatives, system boundaries and data requirement of the particular LCA

[Lindfors, 1993: 25, 33; Boguski et al, 1996: 1; Heijungs et al, Guide, 1992: 17]. Objectives can be:

- The comparison of two raw materials, two products or two processes to determine the environmentally preferred option. Environmental standards can also be used as a comparison medium to ensure compliance.
- Minimization of environmental risk and liability by compliance to regulations, laws and permit requirements.
- Product and/or process optimization through design improvements.

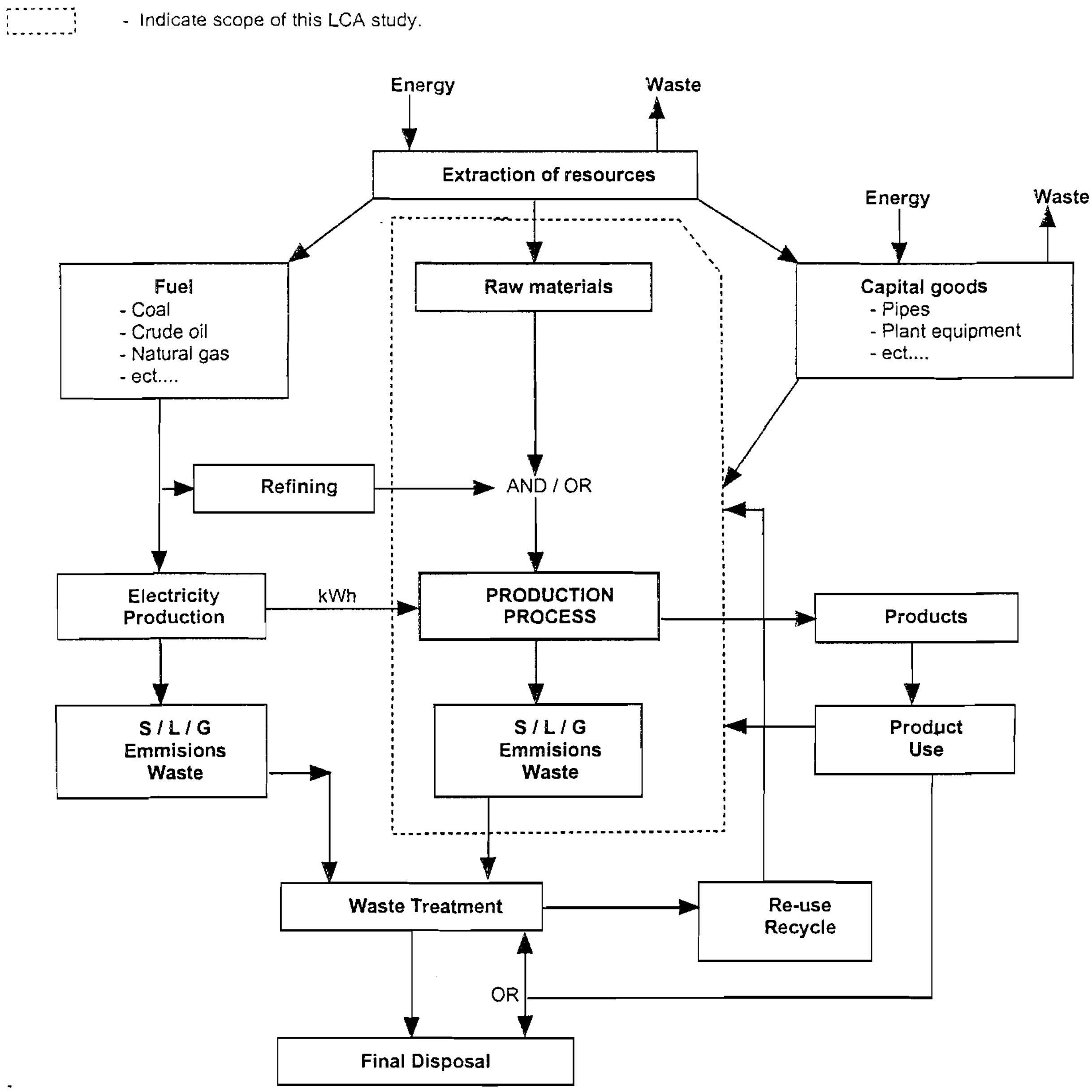
- The system boundary determines the extent of the life cycle under investigation. It gives boundaries to distinguish between what is included in the LCA and what is excluded. Figure 2 illustrates this principle diagrammatically with a defined scope as an example.

The environment is therefore taken as the surroundings of the system. Inputs to the system are natural resources, including energy resources and outputs from the system are a collection of releases to the air, water or land environment. All operations that contribute to the life cycle under investigation falls within the boundaries of the system. Excluding steps from the system boundaries (outside) can only be done with caution and doing so will not change the conclusion of the study seen its scope and aim. [Boguski et al, 1996: 4-7]

Some of the questions to be answered are therefore:

- Will the production of electricity with its associated waste and energy consumption be included or just stated as kilowatts consumed?
- Will the actual mining of the raw material with its associated waste and energy consumption be included?
- Will the product's final use and disposal or recycle be included?
- Will all process units be included?

FIGURE 2 Life cycle procedural diagram



- The functional unit is a relevant, well-defined and measurable function and forms the basis of the analysis. All the inventory data will therefore be related to this unit. This can be a key issue since it will have a strong influence on the results. [Lindfors, 1993: 31-32]

  According to Heijungs et al [Background, 1992: 17] the functional unit should describe a use-function, which is an independent function either for a consumer or for a process.

  The functional unit can be for example: per ton of product, per years the coating will last, per GJ product or per milk carton, depending on the objective and scope of each individual study.

- Allocation is a method for dealing with streams/products that does not form part of the system (not inside system boundaries) under investigation. Traditionally allocation problems are associated with [Lindfors, 1993: 58; Heijungs, Background, 1992: 22; Heijungs, Guide, 1992: 35]:
  - Multi-output or –input processes
  - Open or closed loop recycling
  - Embodied energy [Boguski et al, 1996: 24]

  These problems can be solved by way of transparent allocation strategies such as:
  - Expanding the system boundaries to include these sections [Lindfors, 1993: 59].
  - Using a physical parameter (mass, volume, allocated percentage etc.) to allocate partial responsibility of the environmental impacts to different input or output (product) streams [Lindfors, 1993: 61; Heigjungs, Background, 1992: 24-25]
  - Using only output streams with a positive economic value to allocate the environmental burndens to [Heijung, Guide, 1992: 36].

- The study limitations can be prescribed by the time, money, knowledge and data availability or by technical constraints.

3.3.2 The Life Cycle Inventory (LCI)

Essentially this stage involves the drawing of the life cycle tree or diagram (Figure 3) and the compilation of a mass and energy balance for each single step over the entire life of the product, service or process. LCI is the heart of any LCA study [Van den Berg et al, 1996: 8] and will consume most of the time taken by an LCA study. It entails therefore the identification and quantification of energy and materials used, effluents, emissions and wastes released to the environment and resources extracted from the environment in terms of the functional unit. In this sense Lindfors [1992, 14] gave a "tentative" definition of the LCI step as:

> *"The process of compiling the amounts of natural resources and energy taken in by the system and the amount of wastes irretrievably discharged to the environment from the system per functional unit"*

An example of a typical LCI inscription is (burden / functional unit):

0.2 tons NOx emissions to the atmosphere / ton of product

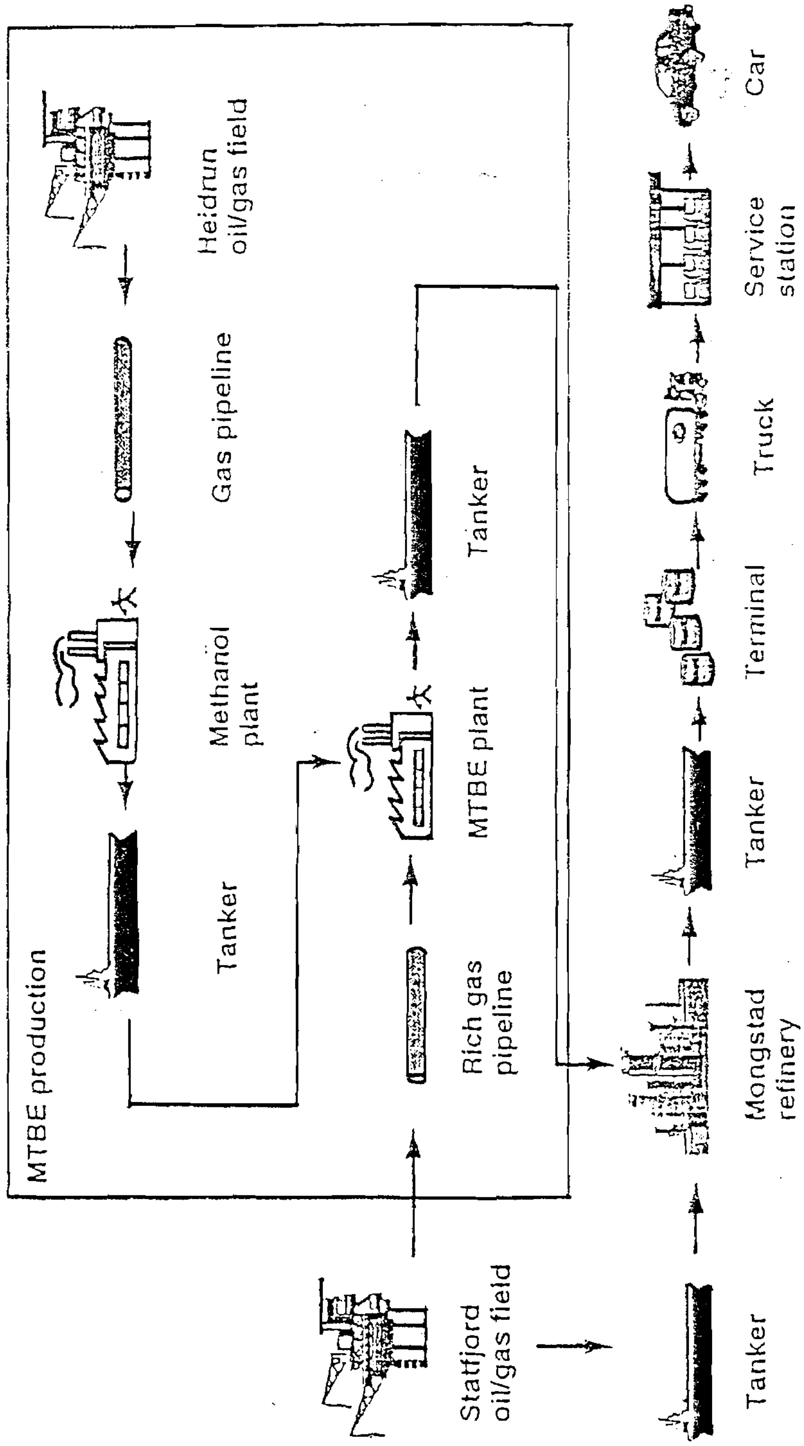
Even compounds present in streams at ppm and ppb levels must be considered. Lack of sufficient detail in the data and information used in an LCA can result in an inaccurate conclusion. Toxic compounds and potential polluters do not have to be present in large quantities to cause environmental and health problems.

For example:

- 1mg of Phenol can potentially make 6 m^3 of water aquatically polluted [Heijung, Guide, 1992: 77].
- 1mg H_2S can potentially make 2326 m^3 of air malodorous [Heijung, Guide, 1992: 77].

FIGURE 3: Life cycle tree diagram

[Furuholt, 1995:253]



3.3.3 The Life Cycle Impact Assessment or Classification and Valuation step

In some references [Vigon et al, 1994: 6] this third step is referred to as an impact assessment. Others [Heijung, Guide, 1992: 10; Heijung, Background, 1992: 5, Ryding, 1992: 436] divide it into two to three separate stages consisting of a classification, valuation and evaluation steps. Some refer to it as both (as in this thesis), thus that the impact assessment step consists of three phases - Classification, Characterisation and Valuation [Lindfors, 1993: 21; Boguski, 1996: 28; Postlethwaite, 1996: 9-10]. In principle it boils down to the use of models or weights to interpret the inventory data to indicate how it will contribute to potential environmental effects, impacts or problems. It is important to note that "potential effects rather that actual effects will be considered" [Lindfors, Background, 1992: 8].

According to Lindfors [1993,72-73] and Van den Berg [1996: 25] the two components – classification and characterisation - have not been separated historically. In characterisation, the relative contribution of each input and output to its assigned impact category is assessed and then aggregated within the impact category to obtain a single value for the potential contribution of the system to a specific impact category. Lindfors (1992: 16) also state that the classification step "aims at translating emission data to effect orientated data".

The results of the classification step are sometimes referred to as an environmental profile [Heijung, Guide, 1992: 12] and usually lists the following widely recognized environmental categories [Heijung, Guide, 1992: 42; Van den Berg, 1996: 32]:

- Depletion of
    - Abiotic resources – the extraction of non renewable raw material such as ores [Van den Berg,1996: 32]
    - Biotic resources – the use of biotic resources as raw material such as animals for example the black rhino or the blue whale [Heijung, Guide, 1992: 66].

- Pollution
  - Greenhouse effect – the increasing amount of CO_2 in the earth's atmosphere leads to an increased absorption of radiation energy and consequently to an increase in temperature [Van den Berg,1996: 32].
  - Ozone layer depletion – leads to an increase in the amount of UV light reaching the earth's surface [Van den Berg,1996: 32].
  - Human toxicity – the exposure of humans to toxic substances causes then health problems. Exposure can take place through air, water and soil [Van den Berg,1996: 32].
  - Eco-toxicity – the exposure of fauna and flora to toxic substances causes health problems [Van den Berg,1996: 32].
  - Photochemical oxidant formation – reactions of NOx with VOC's lead, under the influence of UV light, to photochemical ozone creation which causes smog [Van den Berg,1996: 32].
  - Acidification – the acid deposition onto soil and into water may lead, depending on the local situation, to changes in the degree of acidity [Van den Berg,1996: 32].
  - Nutrification / Eutrophication – the addition of nutrients to water or soil will increase the production of biomass [Van den Berg,1996: 32].
  - Waste heat – the excess heat not used in the process that goes into the environment.
  - Odour
  - Noise

- Damage
  - To ecosystems and landscapes
  - In terms of accident victims

The valuation step that follows after the classification step is still being developed. In this stage the relevant importance of different environmental effects is to be subjectively weighed against each other. Some countries developed their own valuation methods by allocating weights to pollution chemicals depending on their perceived importance. [Lindfors,1993: 135;]

For example:

Switzerland gave NOx a weight of 42.3 while Sweden gave it only 4.74. [Lindfors, 1995: 197]

This system allows for integration across all impact categories. When this assessment is completed, the overall complete impact of a system can be compare with its alternatives on a single score basis. There is no scientific method for accurately completing the allocation of assigning weight factor to various potential impacts, it is highly subjectively done. [Boguski, 1996: 2]

South Africa or the chemical industry will have to decide on, or develop, their own valuation system with relevant criteria based on either local or international standards and issues. It is however debatable if the new ISO 14040 LCA standard will address this issue as valuation systems are usually developed for specific regions and based upon subjective criteria such as public perception, political and social issues as well as science.

3.3.4 The Improvement Analysis step

Van den Berg [1996: 38] sums up the aim of the improvement analysis step as:

> *"LCA does not cure environmental problems, but acts as a decision support in identifying those areas which have the highest improvement potential"*

An improvement analysis is usually carried out only if product or process innovation is the aim of the study [Heijung, Background, 1992: 115]. However comparisons with other products or processes can also lead to improvement, especially if the company's product or process was the less environmentally friendly option.

In this step, potential process or product modifications aimed at reducing the load on the environment, are listed. The information from the LCA is used to make recommendations for the redesign of a product or a process [Curran, 1996: 4]. Therefore a sensitivity assessment should be done in order to find out how sensitive the results are to the most important methodological choices and assumptions made and the gaps and uncertainties in the data used. These proposed recommendations and design variations can then be evaluated after a comprehensive assessment of the project's technical, financial and environmental feasibility.

The development of the Improvement Analysis step is still in its infancy and as a result the strengths or weaknesses of the techniques have yet to be proven and standardized. The iterative/interactive use of an LCA is particularly suitable for the improvement of products' and processes' overall performance. Technical, economical and environmental aspects must be simultaneously evaluated through an analysis method to determine the best available option. According to Foust et al [1996: 11] a technique called multi-criteria decision analysis provides decision-makers with an analytical and systematic tool to evaluate alternatives based on user-defined criteria.

Therefore, the research and development challenge lies mainly in this area. The development will progress with the continuous improvement of the methodology as it is applied in more countries and for more diverse purposes.

3.3.5 Critical review or Validation

Validation or a critical review by an external independent party is essential if the LCA results are to be used outside of the company in marketing, benchmarking, product comparisons, environmental reports or any other external communication. Though SABS/ISO 14040 [1997:10] does make provision for an internal critical review or a review by interested parties.

According to SABS/ISO 14040 [1997: 9] and Lindfors [1993: 27], the critical review process shall ensure that:

- The methods used were consistent with the standard
- The methods used were scientifically and technically valid
- The objective, scope, boundaries assumptions and data collection process were valid
- The data used were appropriate, reasonable and in relation to the objective and scope of the study
- Confidential data or assumptions (not reported) are validated
- The conclusions were credible
- The interpretation of the results reflex the limitations of the study
- The report is transparent and consistent

3.4 CURRENT LCA STATUS AND FUTERE DEVELOPMENT

3.4.1 Current LCA status

As LCA's are a new and developing tool it still has quite a few problems that must be resolved. Hopefully the draft ISO 14040 series (the International Standards Organisation's LCA standard) will provide the solution to some of these current problem/development areas. To a large extent the inventory and scoping criteria have been developed and standardized. Some problem/development areas that still exist are:

- Impact assessment methodology
    - Though most of the categories have been standarised and accepted there is still a concern on the validity of their being generic and not site specific.
    - This concern is focussed mainly on the Human and Eco-toxicity categories.

- The interpretation of LCA results.

- The results from an LCA will depend on the system boundaries, methodology choices, functional unit, detail data and assumptions used in the study.
- Therefore it is not surprising that different LCA studies on the same process/product can give different results [Heijung, Background, 1992: 3].

- The lack of a single standard LCA method and the diversity in its terminology
  - Sometimes variations between independent LCA studies are such that different product alternatives can be identified as the best environmental options [Heijung, Background, 1992: 3].
  - The early architects of LCA have often given more or less the same tools or terms different names.

    For example:

    a) "cradle-to-grave" analysis, eco-balances, life cycle assessment (LCA), product line analysis [SPOLD, 1993]

    b) environmental impacts, -burdens, -loads, -stressors [SPOLD, 1993]

- Current status of ISO 14040 International LCA standards

  In 1997 the draft copy of the ISO 14040 "Environmental management – Life cycle assessment – Principles and framework" document was published. Other LCA standards under development are [SABS/ISO 14040, 1997: 12]
  - ISO 14042 - "Environmental management – Life cycle assessment –Life cycle impact assessment"
  - ISO 14043 – "Environmental management – Life cycle assessment – Life cycle interpretation

3.4.2 Future Development

The development of an analysis method and criteria for decision making is one of the major new developing areas in LCA's. Faust [1996: 10] states that as a future perspective, LCA's can address some elements of environmental risk and will therefore play an important role in environmental management and the decision making process within an organisation. Furthermore he and Heijung [Background, 1992: 105] agrees that the use of LCA in the technique "multi criteria decision analysis" (be it quantitative or qualitative) will provide decision-makers with an analytical and systematic tool to evaluate alternatives that have different scores in different impact categories. The "multi criteria decision analysis" tool must therefore help decision-makers to relate the impact categories with each other in order to make an informed decision based on a defined set of objectives, characteristics and weights.

Furthermore, the life cycle concept contains two aspects:

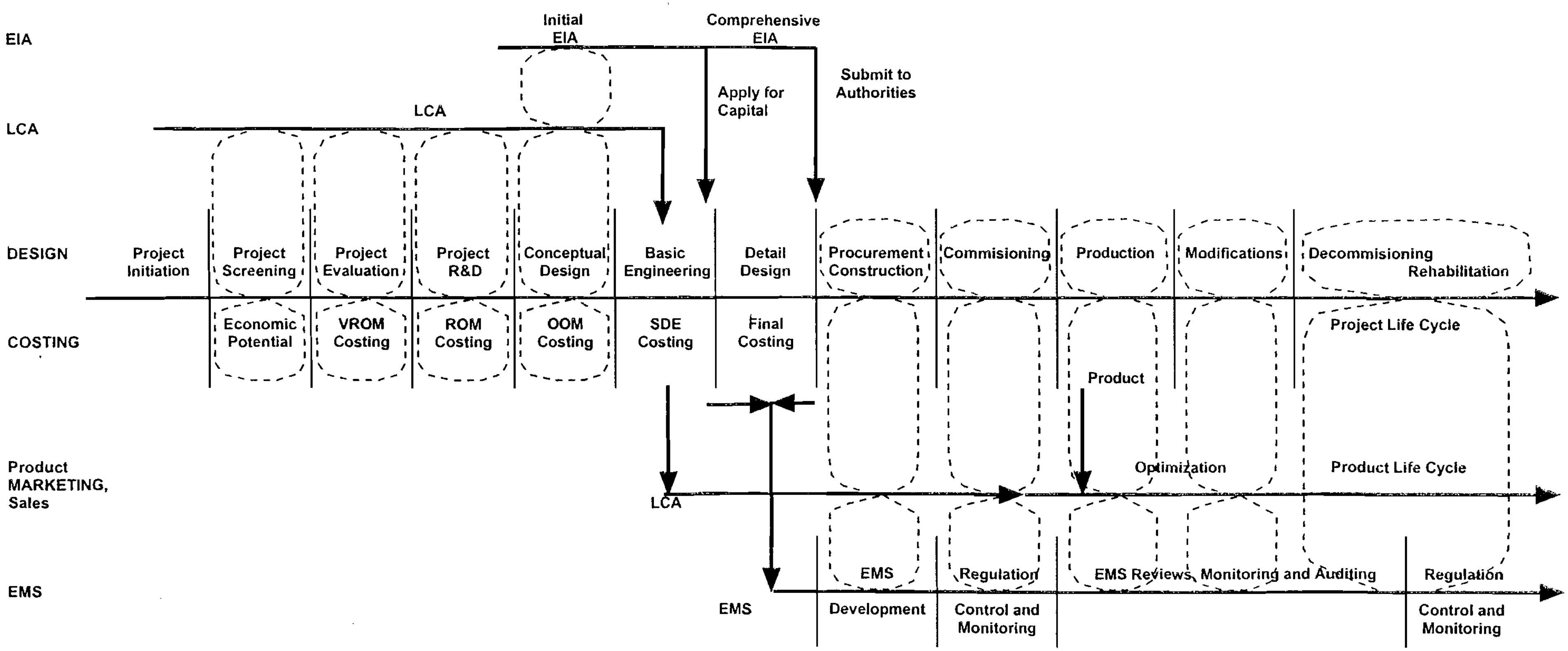
- The Product Life Cycle (LCA) - from raw material acquisition and manufacture to product use and final disposal and the
- Project Life Cycle - from project initiation to final decommissioning and rehabilitation.

In addition to LCA studies, other systems and procedures were developed internationally to enhance the environmental performance of companies like:

- Environmental Impact Assessment (EIA)
- Environmental Management System (EMS)
- Responsible care and product stewardship
- The ISO 14000 series.

Interaction/communication of the LCA procedure with these environmental systems, especially ISO 14001, and the "multi criteria decision analysis" tool as well as process design and costing are proposed to ensure that environmental issues are incorporated in their management strategy. See Figure 4. This will be an iterative process that will grow with a project as it follows the project life cycle. It is also perceived as an environmental tool, suitable for integration with normal engineering practices and ISO 14001 EMS implementation.

FIGURE 4: Iterative and Interactive Spiral Concept Diagram



LCA = Product Life Cycle from Raw material extraction to product use and final disposal

[dashed box] = LCA "Multi-criteria improvement and decision analysis" spiral

3.5 DISCUSSION ON LCA MOTIVATION AND METHODOLOGY

The global environmental perspective is currently towards sustainable development. The so-called engineering definition of sustainable development is to "do more with less". This means a minimization of resource depletion and development of highly efficient processes which consume less energy, produce more and better products and generate less waste. The latest environmental developments were given momentum by initiatives such as Responsible Care, the ISO 14000 series, stringent permit requirements, new legislation and market as well as public pressure.

Claims of a "green" product or technology have to be backed by quantitative information over the entire life cycle of the product or process. For these new environmental strategies to work and offer a genuinely improved environmental performance - the product or process must be technically efficient, economically feasible and competitive on the market.

To supply this information, the LCA methodology is currently being developed as it has the potential to describe and investigate a project, process or product in a "language" understood by

- environmental interested and affected parties,
- the public and government agencies,
- environmental systems (ISO 14000 series)
- engineers and scientists,
- marketing and business sector.

An LCA is based on the material and energy consumption, emission inventory and the potential environmental effects of the product or process over its entire life cycle. Attention - and therefore focus - is placed on what the environmental problems or advantages are, as well as where they originate from. This can therefore disclose opportunities to improve the overall performance of the product or process and enhance competitive advantages on the global market.

The potential contribution of applying the LCA process in the chemical industry was evaluated. There exist several opportunities where an LCA can add value a project other than the more traditional product comparisons for eco-labeling. Some of these contributions are:

- Project screening for the best environmental technology, resource allocation and product/services environmentally preferred.
- Early qualitative and quantitative identification of environmental problem areas,
- As a source of information for EIA's, environmental reports etc.
- The use of decision analysis to ensure the interactive/iterative development and research of the best technical, economical and environmental projects which comply to all permit, standard and legal requirements.
- For impact and aspect identification in ISO 14001 EMS implementation.
- For prioritising waste minimisation options.

In the end this can provide the Chemical industry with a marketing and negotiating advantage over their competitors to ensure long term growth.

With all the potential the LCA methodology shows, the question to be answered still remains – does it actually work in practice? Does it add value to a project in the chemical industry? For this reason, two case studies were conducted as described in detail in the next two chapters.

4. CONCEPTUAL DESIGN LCA CASE STUDY

4.1 INTRODUCTION

The use of LCA's in the design phase of a project is a subject that is found increasingly in the literature. Usually this application of LCA's is referred to as Eco-design, design for the environment or Life Cycle Design. These terms can be defined as:

Life Cycle design [Keoleian, 1996: 2]:

> *"A system-orientated approach for designing more ecologically and economically suitable product systems. It couples the product development cycle used in business with the physical life cycle of a product. Life cycle design integrates environmental requirements into the earliest stages of design so total impacts caused by product systems can be reduced."*

Design for the environment [Keoleian, 1996: 2]:

> *"...a practice by which environmental considerations are integrated into product and process engineering design procedures..."*

As discussed, the Life-Cycle concept is gradually becoming a more important method for industry to understand, manage and reduce the environmental, health and resource consumption impacts associated with its processes, products and activities. [Lindfors, 1993: 10] The main goal of LCA's is that the time, money and effort spent on environmental protection should result in real environmental benefits.

Keoleian [1996: 7] states as a principle of sustainable development that "addressing environmental issues in the design stage is one of the most effective approaches to pollution prevention."

It is in this context that a conceptual design case study was undertaken to:

- increase SASOL's knowledge and understanding of the LCA process,
- to obtain an understanding of the potential environmental impacts of the process and
- to evaluate the value added to this SASOL Technology R&D Division's project by the LCA process.

The SASOL SPD process will play an important role in the SASOL globalization strategy and it was therefore selected as the case study to perform an internal LCA on for internal use in SASOL.

4.2 THE LCA CASE STUDY METHODOLOGY

As the general methodology and problems of an LCA were discussed previously, (Chapter 3) emphasis will only be placed on the actual procedure followed, the assumptions made and the problems experienced in the execution of the case study.

4.2.1 The objective and scope

4.2.1.1 The objective of the LCA case study

The objective of this case study was to determine what is involved to perform an LCA and most importantly what contribution it can make to a project and therefore to SASOL. For the Qatar SPD project the objective was to:

- Construct the Life Cycle Inventory (LCI) and Environmental Profile,
- Identify the SPD processes' environmental impacts,
- Benchmark the SPD process against European Refineries
- Evaluate the impacts against:

i. The Qatar General Petroleum Corporations Health, Safety & Environmental Conservation Policy (which included water and air quality standards).
ii. The RSA water quality standard
iii. The World Bank water quality standard

Note that air quality standards were not considered as the available data are in terms of flow rate from the point source. Air quality standards on the other hand are in concentration limits. There is therefore no common basis for comparisons.

- Evaluate the LCA contributions made.

4.2.1.2 The scope of the LCA case study

In the scoping exercise done for this study the following decisions and assumptions were made:

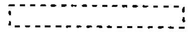
4.2.1.2.1 System boundaries

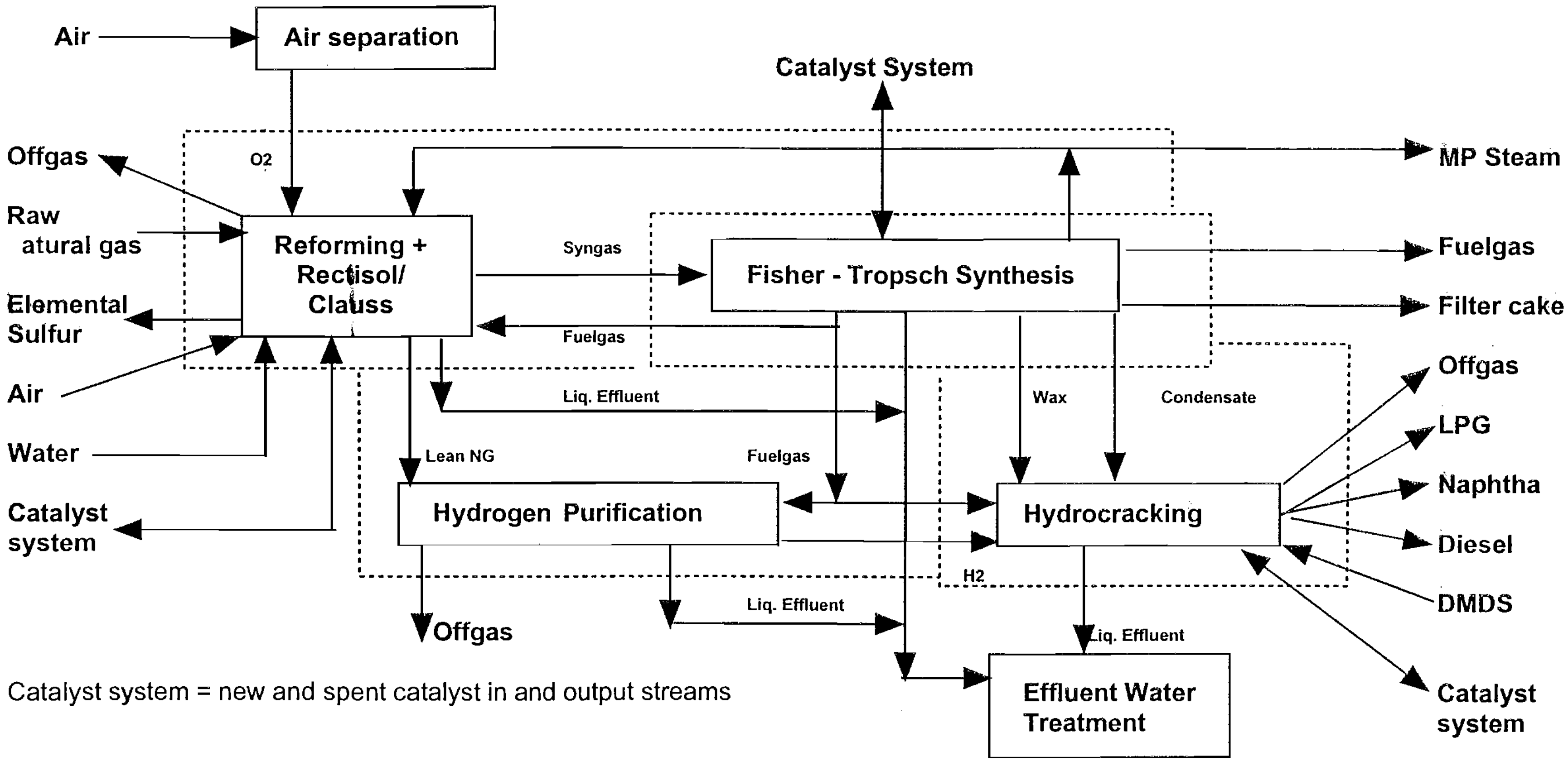
The system boundary of the case study is illustrated in Figure 5.

The following sections were included in the scope of the LCA process

i. Rectisol/Claus, Natural Gas Reforming, Hydrogen Purification, Fischer-Tropsch process and Hydrocracking.
ii. The final products were taken as Elemental Sulfur, Diesel, LPG, Naphtha and Fuel gas.
iii. Only utility consumption was included and not the utility recycle loops. Utilities considered were - steam, cooling water, electricity and air

FIGURE 5: **SPD production process system boundaries**





Catalyst system = new and spent catalyst in and output streams

The following sections were scoped out to simplify the LCA process and in most cases also due to the information not being available.

i. The generation of electricity.
ii. The extraction, transport and storage of the raw material - be it crude oil or natural gas.
iii. The final product's transport, storage, use and disposal or recycle.
iv. The manufacture of fresh catalyst, disposal of spent catalyst and pollution of effluent streams due to catalyst usage.
v. The effluent water treatment facility.
vi. The utility process loops. For example the cooling water cycle including the cooling towers etc.
vii. The Fischer -Tropsch solid waste composition and amount.

4.2.1.2.2 Functional unit

A functional unit of per ton of product was used in the case study.

4.2.1.2.3 Allocation

The total product summarised of each process unit was taken as the final product. Therefore no direct allocation strategy/rules were applied.

4.2.1.2.4 Critical review

As this is a study for internal use in Sasol only – no critical review was required.

4.2.1.2.5 Study limitations

The unavailability or quality of data limited the scope and detail of the study to some extent. This must therefore be regarded as a provisional LCA. Therefore it is the step of the ladder of the interactive/iterative spiral as were proposed in chapter 3.

4.2.1.2.6 Data quality and availability

As the SPD project is still in its conceptual stage, plant data is not available. Simulation results were therefore used for this first LCA. Not all the potential pollutants/by-products could be determined, because during these simulations compounds present in small quantities are not considered (such as metals from the catalyst).

To provide sufficient information for the LCA to be conducted, several assumptions had to be made. Detail of these assumptions and the information used for each process step is discussed below.

The assumptions made for each process unit were:

- Rectisol/Claus process unit
  - The raw and lean natural gas compositions were taken from the Qatar General Petroleum information document.
  - The compositional difference between the raw and lean natural gas composition was taken as the Rectisol off gas to the Claus unit where 95% of the sulfur was recovered as elemental sulfur.
  - The rest of the Rectisol off gas was combusted in oxygen to CO_2, SO_2, NOx and water.

TABLE 1: Natural and Offgas composition

Components Mass %	Raw Natural Gas	Lean Natural Gas	Rectisol Offgas	Claus Offgas
N_2	5.652	6.706	0.622	0.470
CO_2	2.301	2.226	1.325	99.183
H_2S	1.378	0.001	3.524	0.000
SO_2	0.000	0.000	0.002	0.348
COS	0.001	0.000	0.008	0.000
Mercaptans	0.045	0.001	0.100	0.000
C1	71.949	84.743	10.292	0.000
C2	8.597	5.593	70.439	0.000
C3	4.671	0.660	3.846	0.000
iC4	1.289	0.035	1.729	0.000
nC4	2.154	0.035	4.125	0.000
iC5	0.696	0.000	1.424	0.000
nC5	0.602	0.000	1.242	0.000
C6	0.405	0.000	0.843	0.000
C7+	0.262	0.000	0.482	0.000

Raw natural gas contain 190 - 220 ng/m^3 Mercury

- Natural gas reformer unit
  - The Pro II output data, from the simulation of the process in the Pro II software system, was used. This indicated the effluent as clean water.
  - But, independent data received from analysis of the pilot plant effluent indicated 200ppm Ammonia, 10ppm Cyanide and soot in the effluent water. These values were incorporated in the LCA.

- Fischer-Tropsch process units
  - The Pro II data was used.
  - No spent catalyst and other solid wastes generated were included.

As the spent catalyst will be recycled and therefore not impact directly on the environment, the exclusion should not make a significant difference to the LCA results.

- Hydrogen purification unit (PSA)
  - The Pro II data was used which indicated the only effluent as clean water. As the hydrogen is produced from air, contamination of the water effluent should be insignificant.

- Hydrocracking process unit
  - The Pro II data was used.
  - The Di-methyl di-Sulfur compound (DMDS) added to the hydrotreater and Hydrocracking reactors were assumed to be hydrogenated to H_2S and CH_4.
    - Of this H_2S - 200ppm was assumed (based on a paraffin hydrotreating water sample analysis) to be soluble in the water effluent
      - The rest of the H_2S was combusted as an offgas in the flare to SO_2 and H_2O.
    - All the CH_4 was combusted as an offgas in the flare to CO_2 and H_2O.

- Offgas and Fuelgas combustion
  - All gaseous emissions were assumed to be totally (100%) combusted to CO_2, SO_2, NOx and H_2O.
  - The nitrogen in the air used in the combustion of the offgas and fuelgas, was assumed not to be oxidized to NOx.

4.2.2 The Life Cycle Inventory (LCI)

Mass and energy balances were compiled as well as the LCI of the process units under consideration.

4.2.2.1 Mass and Energy Balance

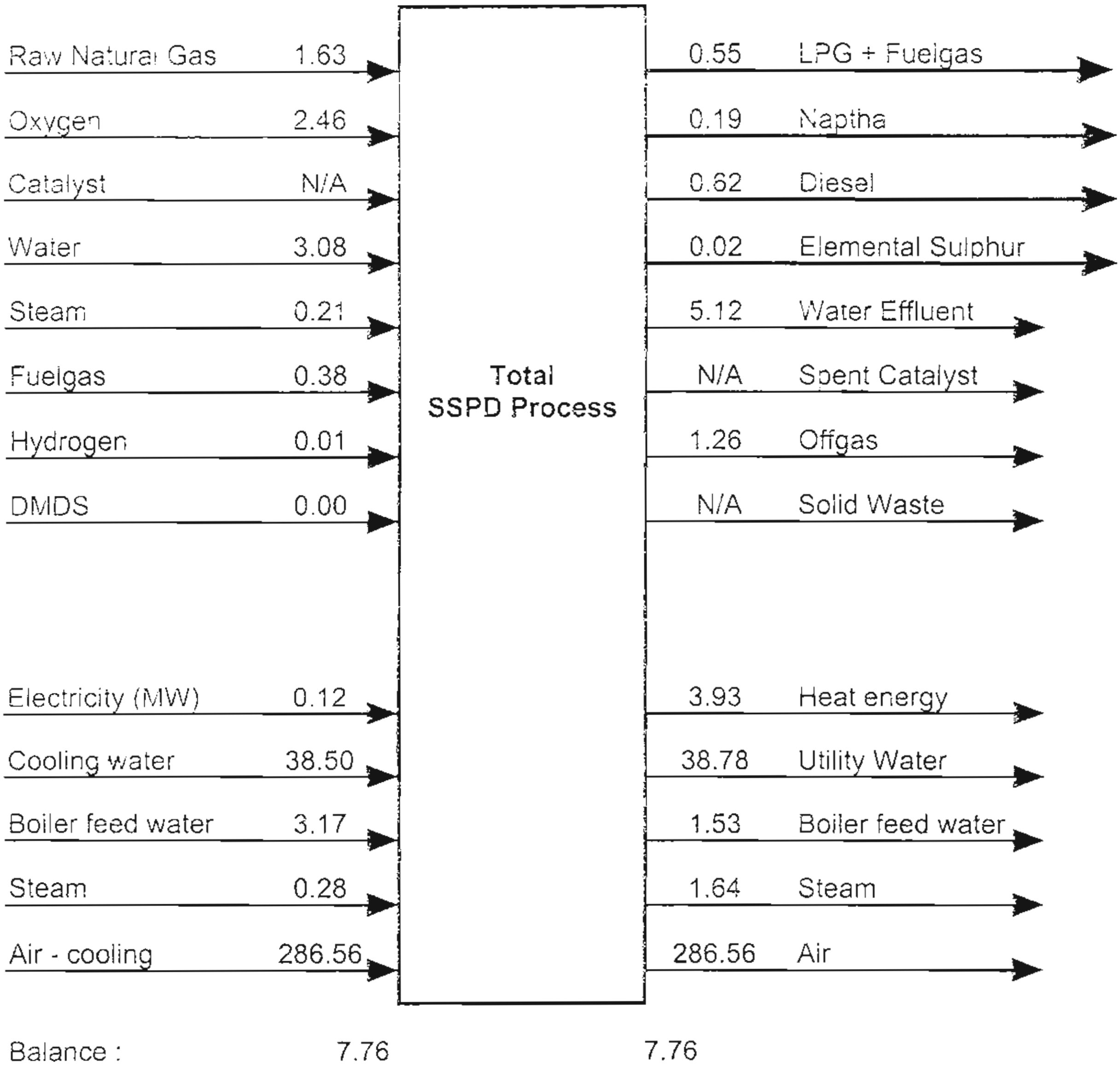
The overall mass and energy balance for the SPD Qatar project is given Figure 6.

The large volumes of air and cooling water needed for product cooling purposes, indicate a waste of energy to the environment. This is supported by the 4 MW energy loss (heat energy output) to the cooling mediums (water and air) used in the heat exchange systems. This energy loss to the environment is distributed as follows:

TABLE 2: Percentage energy loss to the environment

Energy Loss	% of Total Energy Loss
NG Reformer	60
F-T Process	32
Hydrocracking	8

FIGURE 6 Total Mass Balance - ton / ton of Final product



4.2.2.2 Life Cycle Inventory per ton of final product

The emissions, effluent and waste stream composition balance was compiled for the inventory analysis.

The total SPD Qatar Project's LCI is given in Table 3A in the appendix.

Not only a mass balance was performed, but also a component balance, which indicated the following losses of Carbon, Nitrogen and Sulfur to the environment:

TABLE 3: Elemental losses to the environment

Element	% Loss of total quantity to the Environment
C	34
N	74
S	9

- Carbon:
  - 34% of the raw natural gas Carbon (C) is lost to the environment due to CO_2 emissions, which is the main contributor to the greenhouse effect.
  - The C loss is due to the combustion of carbon compounds to CO_2. The raw natural gas contain only 1mole % CO_2.
  - The combustion of the Rectisol tailgas (59% of the 34% C loss) in the Claus unit and the Fuelgas combustion in the NG Reformer furnaces (28% of the 34% C loss) are the main sources of the carbon loss as CO_2.

- Nitrogen:
  - 74% of the inert (N_2) gases entering the process in the raw natural gas, end up as NOx in the environment through the combustion of N_2 to NOx.
  - This is mainly due to the combustion of the Fuelgas in the NG Reformer furnaces (82% of the 74% N loss).

- Sulfur:
  - Only 9% of the sulfur entering the system in the raw natural gas and DMDS process feed- streams, end in the environment as SO_2.
  - But, this result is based on the following two assumptions:
    - 95% of the H_2S in the Rectisol offgas is recovered as elemental sulfur in the Claus unit. The balance of the H_2S is combusted to SO_2 and water (78% of the 9% S loss).
    - The DMDS is hydrogenated to H_2S and CH_4 in the Hydrocracking process. Except for 200ppm H_2S, all these gases are combusted in the flare system to SO_2, CO_2 and water (22% of the 9% S loss).

4.2.3 The Life Cycle Impact Assessment

From the LCI data the potential pollution impact of each process unit and the total process can be calculated by using weight factors (Valuation [Lindfors, 1993: 165-201]) and potential pollution parameters (Classification [Heijung, Guide, 1992: 65-89]). In this way the contributing pollutants and their process unit source can be identified to focus research and mitigation efforts.

4.2.3.1 Classification or environmental profile

The potential pollution parameters and their definitions [Heijung, Background, 1992: 43, 69-79, Heijung, Guide, 1992: 4-6, 42-46] are described in the following table:

TABLE 4 : Description of Classification category parameters

Classification	Environmental Effect *	Factor	Unit	Definition of classification factors
Depletion	Abiotic Resources	1 / Reserves	Kg / kg	Comparing the netto quantity used, with the reserves of raw material available
Pollution	Greenhouse Effect	GWP	kg CO_2 equivalents/ kg	Global warming potential (GWP) is the ratio between the contribution to the heat radiation and absorption resulting from the release of 1kg greenhouse gas and an equal emission of CO_2 integrated over time. (20, 100, 500 year)
	Human Toxicity	HCA / HCW / HCS	kg Bodyweight/ kg	These factors are calculated for air, water and solid waste releases using - ADI (acceptable daily intake), TDI (tolerable daily intake). Maximum tolerable risk levels are used for carcinogenic substances.
	Acidification	AP	kg SO_2 equivalent / kg	Acidification potential (AP) is based on the potential amount of H^+ per mass unit relative to the same parameter for SO_2

Classification	Environmental Effect	Factor	Unit	Definition of classification factors
	Nutrification	NP	kg Phosphate equiv. / kg	Nutrification potential (NP) is based on the average composition of biomass relative to phosphate.
	Odour	1/OTV	m^3 air polluted / mg	The odour threshold value (OTV) is used to assess the odours by calculating the volume of air polluted to the odour threshold.

* Environmental Effect = SUM [Factor(i) * Emission(i) in kg or mg]

The total SASOL SPD Qatar project's contribution to pollution, as per process unit, is illustrated in Table 5 and Figure 7. The two process units, contributing to most of the pollution problems, are the Rectisol/Claus and NG Reformer units.

- Greenhouse effect
    - CO_2 is seen as the cause of the greenhouse effect. There is a lot of controversy surrounding the actual impact of CO_2 on the environment. Some experts see it as a positive plant food source through photosynthesis while others see it as a negative contributor to global warming.
    - The combustion of the Rectisol offgas in the Claus unit (62%) and the combustion of fuelgas in the NG Reformer furnaces (29%) are the main contributors to the greenhouse effect for the SPD process.

- Human toxicity, Acidification and Nitrification
    - The main component contributors in this case study to these potential pollution categories are: NOx, NH_3, HCN, SO_2, Hg, and hydrocarbons (HxCy)

- The NG reformer process unit contributes 80% of the total Human toxicity, Acidification and Nitrification pollution scores due to the combustion of fuelgas (NOx and CO_2) and the NH_4 and HCN in its effluent water.

- Odour
    - The component contributors to the odour problem are: SO_2 and H_2S.
    - The main process unit contributors are :
        - Rectisol/Claus (78%) - from the combustion of the 5% H_2S left in the Rectisol offgas. The other 95% H_2S was recovered as elemental sulfur.
        - Hydrocracking (22%) - from the hydrogenation of the make-up DMDS to H_2S and CH_4.

TABLE 5 : Classification results

Effect Score / ton of final product

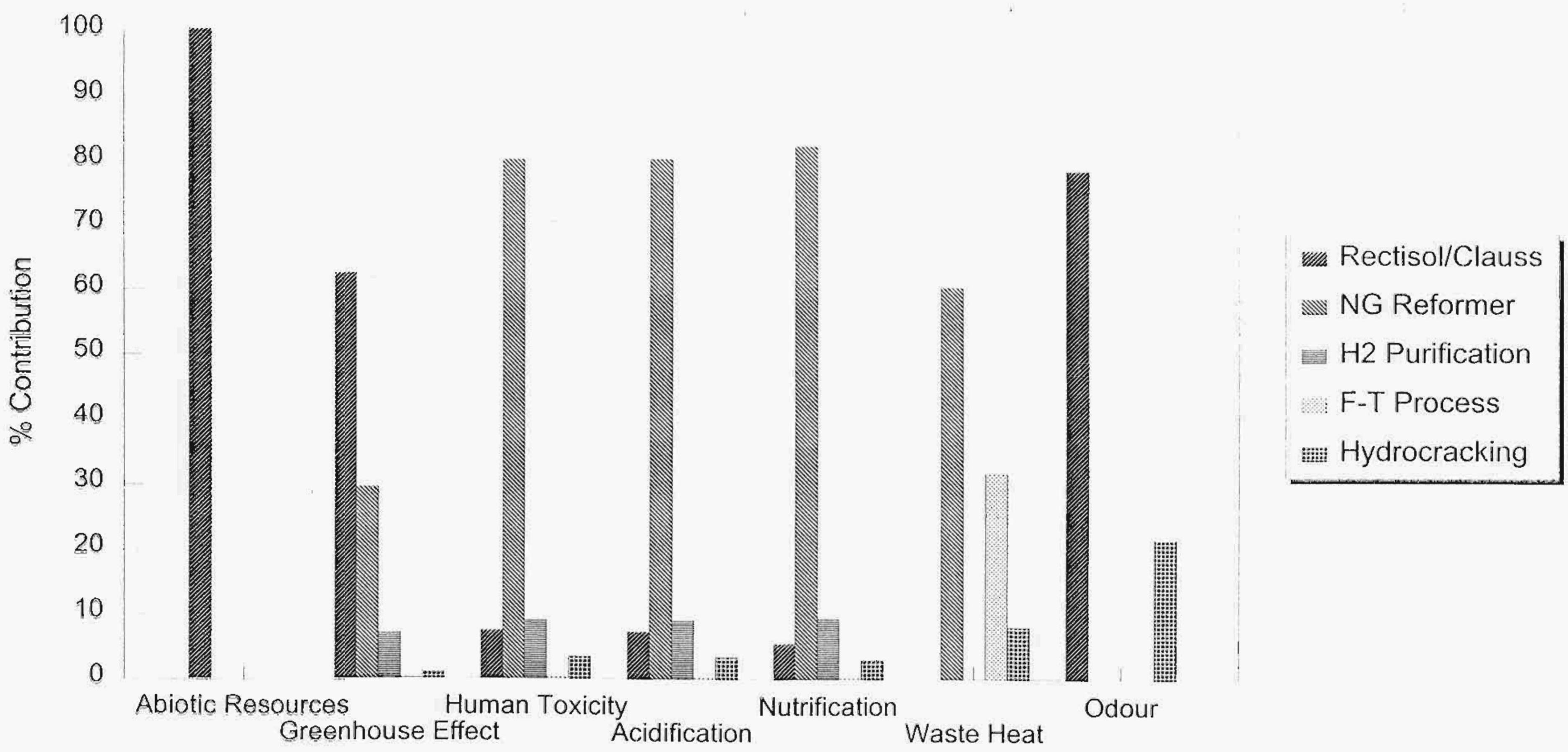
(% Contribution in brackets)

Environmental effect	**Effect Unit**	**Rectisol / Claus**	**NG Reformer**	**H2 Purification**	**F-T Process**	**Hydro - cracking**	**Total SPD process**
Abiotic resources	Factor of resources consumed	1.49E-11 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1.49E-11 (100%)
Greenhouse effect	kg CO_2 equivalent	837.42 (62.33%)	395.84 (29.46%)	94.54 (7.04%)	0.92 (0.07%)	14.92 (1.11%)	1343.64 (100%)
Human Toxicity	kg Bodyweight at toxic level	14.01 (7.34%)	152.59 (80.00%)	17.25 (9.04%)	0.35 (0.18%)	6.55 (3.44%)	190.74 (100%)
Acidification	kg SO_2 equivalent	12.32 (7.21%)	136.93 (80.14%)	15.48 (9.06%)	0.31 (0.18%)	5.81 (3.40%)	170.85 (100%)
Nutrification	kg Phosphate equivalent	5.47 (5.46%)	82.26 (82.12%)	9.29 (9.27%)	0.20 (0.2%)	2.96 (2.95%)	100.17 (100%)
Waste Heat	MW	0 (0%)	2.37 (60.28%)	0 (0%)	1.25 (31.74%)	0.31 (7.98%)	3.93 (100%)
Odour	m^3 air polluted	7.46E+09 (78.39)	0 (0%)	0 (0%)	0 (0%)	2.06E+09 (21.61%)	9.52E+09 (100%)

The component effect scores and environmental effect determination for the total SASOL SPD Process is given in the appendix in Table 5A

SPD process's contribution to pollution

Figure 7



4.2.3.2 *Valuation*

Through the valuation step the relevant importance of different environmental effects are subjectively weighed against each other with the aid of predetermined weight factors [Lindfors, 1993: 135].

The valuation weight factors used in the evaluation of the SPD project were done according to the methods described by the Nordic Guidelines for Life-Cycle Assessment . The following four methods were used:

- Eco-scarcity method which calculate the systems eco-points as derived for [Lindfors, 1993: 138,197; Postlethwaite, 1996: 11; Giegrich, 1996: 4]:
  - Switzerland
  - Netherlands
  - Norway
  - Sweden

- EPS Method which calculate the systems Environmental Load Unit (ELU) [Lindfors, 1993: 140,167,199; Postlethwaite, 1996: 11].
- Effect Category Method which calculate the systems long and short term environmental goals [Lindfors, 1993: 140,198].
- Tellus method, which calculate the systems Pollutant cost in Dollars (S) [Lindfors, 1993: 141,177,200].

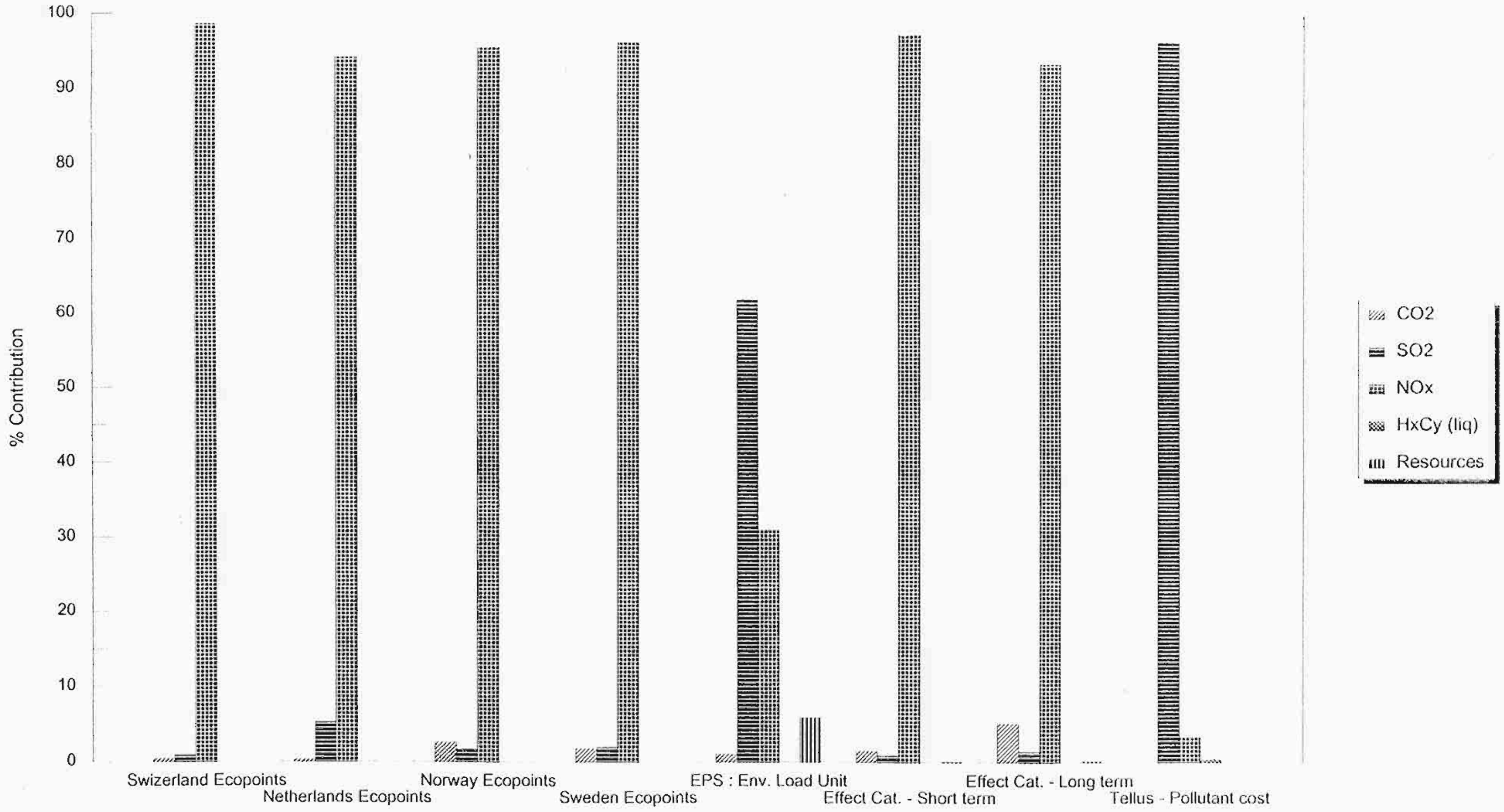
The weighing factors and subsequent valuation values for the four Valuation methods used are available in Table 6A in the Appendix.

Valuation results for the total SPD Qatar Project are illustrated in Figure 8

The Valuation methods support the Classification results, as SO_2 and NOx were identified as the most important pollution compounds.

Valuation results of the SPD process

Figure 8



4.2.4 The Improvement Analysis step

Although product or process innovation/optimization was not the main aim of this LCA case study, the following results and possible suggestions for investigation. came out as a consequence of this study. It must also be remembered that no emission, effluent and waste treatment facilities were included. It can therefore be seen as a worst case scenario.

Through the Life Cycle Inventory and Impact Assessment steps, certain environmental problem areas were identified. To determine the seriousness of these problems identified, the SASOL SPD process was compared with:

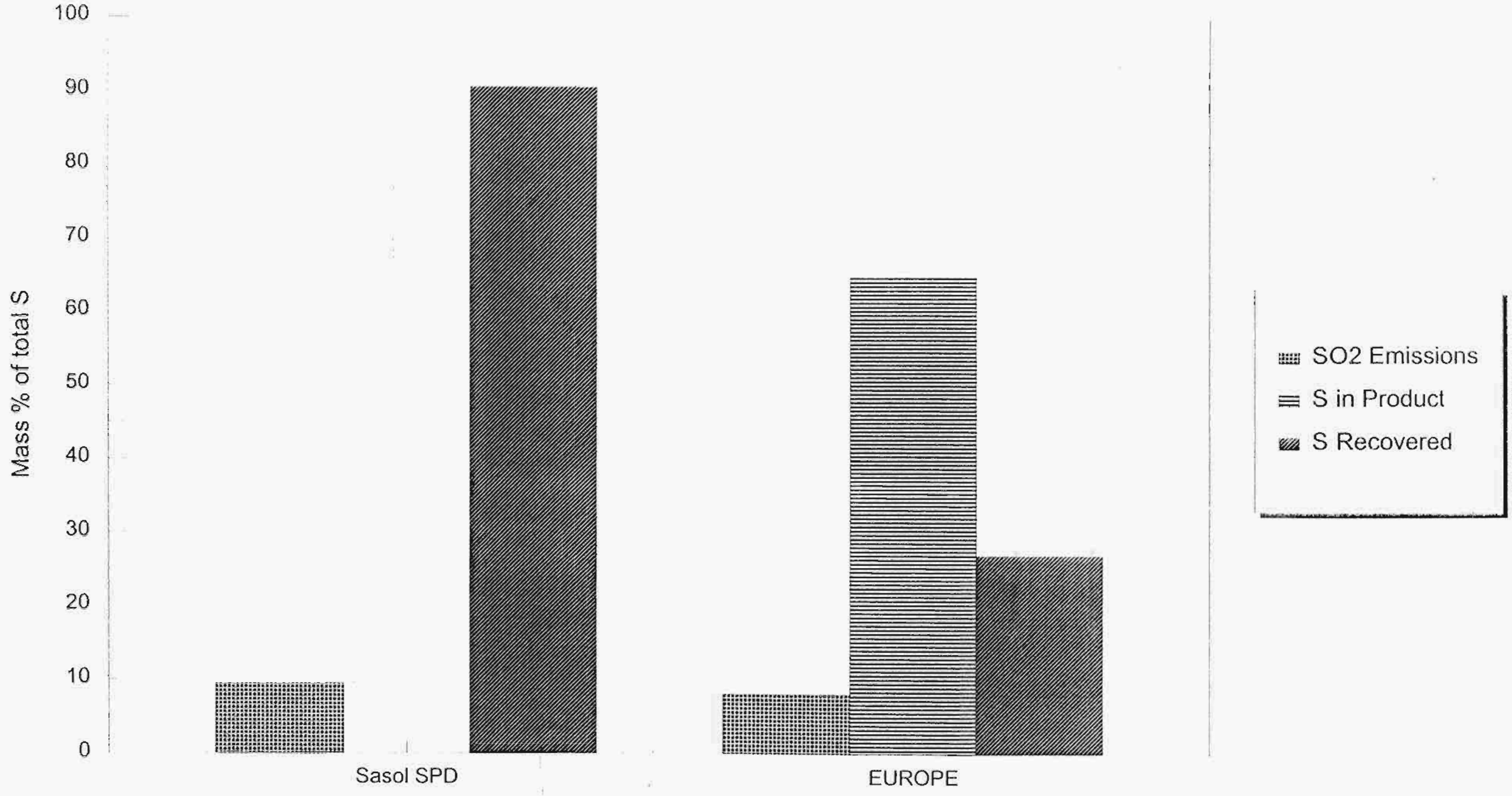
- European Refineries [Concawe] which uses an alternative raw material (Crude oil) and
- with water quality standards (Qatar, RSA and World Bank) to determine compliance requirements.

4.2.4.1 Comparison with European Refineries

- Sulfur Balance Comparison
  - As the product is a fuel, its combustion will set the product sulfur content free to the environment as SO_2 emissions. Therefore the total percentage sulfur to the environment is equal to the plant SO_2 emissions plus the sulfur content in the final product.
  - The sulfur balance comparison (Figure 9) to Europe [Concawe] give a qualitative indication of the SPD processes sulfur recovery advantage (91%) above the European refineries (27%).
  - This very advantageous result is based on an assumption (95% conversion of SO_2 to elemental sulphur) that must still be validated with more detail data and information.
  - If the assumption is proven accurate, this result can be used by technology and product marketers to the advantage of SASOL.

Sulfur Balance Comparison

Figure 9



4.2.4.2 Compliance to water quality standards

The Total SPD project's UNTREATED liquid effluent was compared to the following standards to determine compliance and mitigation requirements:

1. Qatar water quality standard
2. RSA water quality standard
3. World Bank water quality standard

TABLE 6: Water quality comparison

		Water Quality Standard			
Parameter	**Unit**	**Qatar**	**RSA**	**World Bank**	**SPD Project**
Ammonia	mg/l	< 3	< 10		63
Total Nitrogen	mg/l	< 10	< 5		5
Sulfides	mg/l	< 0.1	< 1	< 1	4
Cyanide	mg/l	< 0.1	< 0.5	< 0.2	6
Mercury	mg/l	< 0.005	< 0.02	< 0.001	0.078
Total Organic Carbon	mg/l	< 150			6744

More detail is needed, especially on the metal content of the effluent from the SPD process, to obtain a better assessment of the compliance of the process to the water quality standards and its contribution to potential impact categories. Only a limited number of the standard and impact category components listed were included in the study due to the lack of detail information on composition. On the other hand it must be remembered that this is a conceptual design where only limited information is available.

The reason for not including air quality standards, is the lack of dispersion and air emission concentration data. The data available is limited to the amount released into the atmosphere per time unit. This therefore does not take into account the dispersion of the pollutant into the air by wind and other atmospheric conditions. Air quality standards are available only in terms of atmospheric concentration.

4.2.4.3 Improvement analysis and recommendations

The environmental impact of the SASOL SPD process can be improved if the following aspects are addressed:

- Alternative energy sources to fuel gas combustion must be investigated - heat integration or an alternative use of the fuel gas must be found.
- The latter point are supported by the loss of energy to the environment (air and water cooling) which can be used as an alternative energy source through heat integration.
- Utilization of the Claus offgas as an energy-source.
- The use of alternative reforming technologies (NG Reformer process unit) should be evaluated to eliminate the use of fuelgas as a source of energy.
- The LCI, Classification and Valuation steps indicated NOx, CO_2 and SO_2 as major environmental concerns for the SPD process. To mitigate this problem the following suggestions can be made:
  - The alternative uses of fuelgas and the utilization of the Claus offgas as an alternative energy source
  - Low NOx burners or a DENOx unit for the offgas systems.
  - Higher efficiency recovery of the sulfur from all the gaseous emission streams should be investigated to further enhance the sulfur recovery advantage. (Super Claus, etc)
- Possible liquid effluent treatment options are:
  - biological waste water treatment facilities
  - dilution into other existing effluent streams going to existing treatment facilities and
  - diversion of specific contaminated streams. For example the small

water knockout stream in the Rectisol/Claus process unit, which contains Hg, should not be mixed with the other effluent streams. Small toxic streams can be treated more efficiently or alternatively it can be concentrated and handled or disposed as hazardous waste.

4.3 CONTRIBUTIONS AND LIMITATIONS OF THE LCA TO THE CASE STUDY

4.3.1 Contributions of the LCA

In the evaluation of the LCA's application and contribution to the Qatar SPD project - the general objectives of LCA studies stated in chapter 1 were used as a guideline.

Conceptually

- The execution of the LCA increased the understanding of the LCA procedure, as well as the local and international environmental driving forces and requirements.

Qualitatively

- Before doing any calculations, problem areas can be identified for research and development focus.
- Recovery of elemental Sulfur a definite requirement.
- Hydrocarbons (HxCy) combustion and metals (Hg) in the effluent will cause environmental problems.

Quantitatively

From the LCA, quantitative data was developed to assess the potential pollution problems of the SPD process. The LCI identifies the components present in the untreated emission, effluent and waste streams as well as the elemental losses to the environment.

In the classification stage the potential contribution to pollution was quantified:

TABLE 7: Potential pollution quantification

Potential Pollution	**Contribution / ton final product**
Greenhouse effect	837 kg equivalent CO_2
Human toxicity	14 kg Bodyweight at tolerable risk level
Acidification	12 kg equivalent SO_2 with H^+ potential
Nitrification	5 kg equivalent PO_4^{3+}
Odour	7.5E+09 m^3 air polluted

Process unit contributions were also quantified to focus the attention on the unit that is the source of the pollution problem.

For example: NG Reformer unit contributed:

- 30% of the total Greenhouse effect
- 80% of the total Human toxicity, Acidification and Nutrification pollution scores respectively
- 35% of the total Waste Heat effect

Important environmental issues identified in the classification, valuation and comparison to the standards, concern the following compounds:

- N^- : Ammonia, cyanide, NOx and their contribution to pollution
- S^- : SO_2, H_2S and the need for elemental sulfur recovery
- C^- : CO_2, HxCy and the subsequent energy and product losses
- M^-: Metals and their high pollution and toxicity potential.

Technologically

Problems identified in the construction of the environmental profile can now be focused on for the improvement of the overall performance of the project:

- Alternative reformer technology to the currently used POX reformers which uses fuelgas combustion as its source of heat energy.
- Increase in heat integration to reduce the loss of energy to the

environment through the water and air cooling systems.

- Utilization of the Claus offgas as an energy-source through combustion, or as an alternative fuelgas product.
- To mitigate the NOx and SO_2 emission problems the use of Superclaus as well as DENOx burners can be investigated for the process offgas system.

Informatively, Marketing and Strategically.

- To illustrate to the Qatar Petroleum Company and the consumers of diesel, with quantitative life cycle information, the diesel product and SPD process's true enhanced technical, economic and environmental performance.
- Information such as the sulfur balance (Figure 6) can if externally validated provide SASOL with a competitive advantage.

4.3.2 Limitations of the LCA

The following limitations of the LCA application in conceptual design studies must be taken note of when interpreting the results of the LCA.

- Lack of detail data at such an early stage of a project is an inherent problem as efforts are centred round the production of the desired product.
- As the conceptual project develops in its life cycle the opportunities to make changes to the process becomes less.
- Impacts are only shown in comparison of the unit operations against each other and not the severity.
- Conceptual design case studies must preferably be done in comparison of alternative options and not in a single mode.

4.4 CONCLUSION AND RECOMMENDATIONS

The LCA methodology can be applied in the conceptual design stage of a chemical engineering project to identify environmental concern areas. Taking into account the major concern area – lack of detail data on composition and quantity of air emissions, water effluents and solid waste – the LCA does indicate the major environmental issues related to the available data.

The case study conducted on the Qatar SPD project generated the following main results seen the objectives of this study:

1. Using data that are conceptually known to the chemical engineer
   - The LCA used a mass and energy balance as its basis, which forms the basis of any chemical engineering project. The required data are therefore readily available, but lack detail on the composition and quantity of air emissions, water effluents and solid waste.
   - By making the engineers aware of this problem, they can incorporate the generation of data on the composition and quantity of air emissions, water effluents and solid waste.

2. Identification of the environmental issues for future research and development focus
   - Fuelgas and offgas combustion are the main sources of potential pollution

     Problem pollution components are:

     NOx, CO_2 and SO_2 air emissions

     HCN, Ammonia and Hg in the liquid effluent
   - Process units with the most potential pollution problems are the Rectisol/Claus and Natural gas (NG) Reformer units.
   - Waste of energy in the process suggests the need for better or alternative energy utilization.
   - Benchmarking with the Qatar, RSA and World Bank environmental standards provided the criteria for treatment and mitigation measures to

ensure compliance.

- Benchmarking with European Refineries proved useful. The Sulfur balance is a good example of the LCA's potential contributions to a project.

3. Improvement analysis and future development recommendations.
   - Alternative energy sources to fuelgas combustion and/or better utilization of existing energy sources should be investigated.
   - The reduction of NOx, CO_2 and SO_2 emissions through the reduction of offgas and fuelgas combustion.
   - The investigation of alternative reformer technology.
   - The validation of the Rectisol/Claus unit assumptions and therefore of the sulfur balance results.
   - Effluent treatment systems must be investigated in a revision of the LCA study.
   - Metals in the effluent and solid waste data must be obtained and be included in the next LCA revision.

These alternatives can be evaluated through a revised LCA study to ensure an interactive and iterative LCA process. The scope of the LCA study must also be broadened, as more information becomes available.

5. ISO 14001 EMS SUPPORT CASE STUDY

5.1 INTRODUCTION

ISO 14000 is a series of voluntary standards developed by the International Organisation for Standards (ISO) that provide guidance for developing an integrated approach to environmental management. The standard covers a wide range of subjects, including environmental management systems, environmental auditing, environmental labelling and life cycle assessments. The keystone of the program is ISO 14001, the Environmental Management System (EMS) standard.

The ISO 14001 EMS standard brings environmental concerns into the mainstream of business operation by providing a framework for balancing and integrating environmental, legal and socio-economic interests. It does not, however, state in itself the specific environmental criteria to be considered, but enable a company to formulate a policy as well as objectives and targets. In the planning phase of an ISO 14001 EMS, the significant impact and aspects must be identified of all the activities, products and services. From these impacts and aspects the objectives and targets are then set to help translate the purpose of the EMS into actions. [SABS/ISO 14001, 1996: 1; Schiffman, 1997: 41]

There are a number of approaches available to impact and aspect analysis. One is a regulated approach which identifies those aspects (not impacts) that are regulatory in nature and relies on information derived from documents such as permits, monitoring data, Acts, regulatory checklists and MSDSs [Schiffman, 1997, 45]. A second method is the one proposed in Government Gazette 15529 of 4 March 1994, Government Notice 171 of 1994 for the preparation of environmental impact reports. In this notice it was proposed to identify potential impacts in terms of their nature, extent, duration, intensity, probability and significance. How to determine these terms, was not defined. (Government Notice 171 was used as it is regarded as good environmental practice – after completion of this study Government Notice 1883 of 5 September 1997 was published in Government Gazette 18261.)

A third method is the input/output analysis. This is basically a mass and energy balance of a process seen as a black box. In Life Cycle Assessment (LCA) terms this is a life cycle inventory (LCI) which can be extended to include an impact assessment, to add further value to the aspect and included impact analysis. In order to prove this application of LCA's and the value it can add to an ISO 14001 EMS implementation system, this case study was initiated. [Schiffman, 1997: 45]

The ISO 14001 EMS standard requires that an organisation develops an EMS program that describes all its environmental objectives and targets and how each will be achieved. The underlying premise of ISO14001 is improvement of environmental performance through self-regulation and market-driven pressure. Business can systematically examine all their processes, services and activities for their potential impacts on the environment. An EMS is a continual cycle of planning, reviewing and improving the actions that an organisation takes to meet its environmental obligations. The organisation must therefore keep the information and system up to date. Implementation of EMS enables a company to plan for environmental issues – to get out of the 'reactive mode' where it is constantly responding to regulatory "fires" and into the 'proactive mode' [Schiffman, 1997: 42]

On the other hand, the main goal of an LCA is to ensure that the time, money and effort spent on environmental protection results in real environmental improvements [SPOLD, 1993]. Therefore, LCA principles have a wide range of application in that it can be a valuable source of environmental information to engineers, environmental managers, marketers, economic evaluators, and administrative and governmental agencies.

For this case study the application of LCA principles in the implementation of ISO 14001 EMS standard, in the chemical industry, is being investigated. As Solvents division in Sasolburg are currently implementing their ISO 14001 EMS system, this was seen as an ideal opportunity to test the application of LCA based environmental profile analysis as a tool to determine the required environmental aspects and impacts for their ISO 14001 system.

5.2 ISO 14001 ENVIRONMENTAL MANAGEMENT SYSTEM (EMS)

The model for an ISO 14001 EMS is based on the following five major steps [ISO 14001,1996: 2-5, Schiffman, 1997: 42]:

1. Commitment and Policy (by top management)
2. Planning (The phase where LCA can contribute)
   Clause 4.3 of the ISO 14001 EMS standard spells out four basic steps in planning the EMS:
   1. Identify environmental aspects of the organisation's activities that can be controlled and influenced to determine which are associated with significant environmental impacts.
   2. Identify and maintain access to legal and other requirements.
   3. Set environmental objectives and targets.
   4. Establish the EMS by designating responsibilities and the means and time frame for achieving them.
3. Implementation of the EMS program
4. Measurement and Evaluation
5. Review and Improvement (Environmental Audits)

Therefore, a cross-functional team has to be selected, which will identify all significant environmental impacts of the activities, products and services, along with the legal and other standard requirements. The next step is to define the current status of the organisation – which is to answer the question: "Where are we now?"

The current position of an organisation with regard to the environment can be evaluated by means of an initial environmental review. The review should address the full range of operation conditions – normal as well as abnormal operations, including potential emergencies. The EMS's success may actually depend on the thoroughness, accuracy and integrity of the initial review. [SABS/ISO 14001, 1996: 3; Schiffman, 1997: 43-44]

This requires that data regarding processes, systems and materials be readily accessible and easy to interpret. The environmental profile generated by an LCA through its assessment categories facilitates this requirement as a large amount of raw data is processed (consolidated) to applicable impact categories such as acidification, greenhouse effect, human and eco-toxicity etc. The planning phase on the EMS therefore requires a good understanding of all facility operations and, as with all models, the accuracy of the output is determined by the quality and quantity of the input.

An organisation's policy, objectives and targets should be based on knowledge about the environmental aspects and significant environmental impacts associated with its activities, products and services as well as legal and other requirements, technological options, financial and operational requirements and the views of interested parties [SABS/ISO 1996: 3]. Clause 4.3.1 of the ISO 14001 EMS standard requires the organisation to establish and maintain an up-to-date procedure (in this case an LCA) to identify its significant environmental aspects. It must then make sure that the aspects related to these significant impacts are addressed when setting its environmental objectives and targets. [SABS/ISO 1996: 3,7; Schiffman, 1997: 45] This report will be used as a reference in the initial review where the initial objectives and targets are stated.

Clause 4.3.3 of the ISO 14001 EMS standard requires the organisation to establish and maintain documented environmental objectives and targets at each relevant function and level within the organisation. Environmental objectives and targets are not one-size-fits-all. They are unique to each organisation and should reflect what the organisation does and what it wants to achieve. Objectives and targets must support legislative compliance, impact mitigation, business requirements and reasonable views of interested parties. Environmental targets can then be set to achieve these objectives. Targets should be in line with objectives, cover a defined time period, be measurable and have clear accountability for action. It should not be a "wish list ", as an EMS will be evaluated based on the organisation's ability to achieve its objectives and targets. It is therefore imperative that they are realistic, that the resources are available, that they have the ability to control them and the ability to measure their performance. [SABS/ISO 1996: 3,7; Schiffman, 1997: 47]

Effective environmental management means setting specific performance goals and then taking actions to achieve these goals.

5.3 THE SASOLBURG SOLVENTS DIVISION'S LIFE CYCLE ASSESSMENT

An LCA consists of five basic steps as were discussed in detail in chapter 3. These basic steps are:

1. The objective and scope of the LCA
2. The Life Cycle Inventory (LCI)
3. The Life Cycle Impact Assessment
4. Improvement Analysis
5. Critical review

The fifth step added by ISO 14040 LCA standard is a requirement for LCA's if the results are used externally, especially for marketing and commercial purposes. Since the LCA for the Sasolburg Solvents division are for internal use only, the LCA case study will therefore be discussed in terms of the first four basic steps.

5.3.1 Objective and Scope of the LCA

5.3.1.1 The objective of the LCA

The first objective of the study is to evaluate the application of LCA's as an information source to ISO 14001 EMS implementation.

The second objective is to develop an environmental profile of Solvents division and to determine its current environmental status, the environmental impacts and aspects as well as their root causes as a requirement for their ISO 14001 EMS standard. This forms part of the planning phase of an EMS where the determination of the environmental aspects of the division's operation, along with a strategy outlining the significant aspects in the EMS. This will then be translated into the identification of specific measurable goals/targets and objectives [Diller, 1997: 36].

The third objective is to generate a baseline profile to evaluate future mitigation measures' environmental effect and emission reduction.

The fourth objective is to provide a base and criteria for continuous improvement on the level of detail of the measurements and analysis performed to generate the division's mass and energy balance, as well as their inventory.

5.3.1.2 The scope of the LCA

5.3.1.2.1 System boundaries

The scope used for the LCA was the same scope identified for the ISO 14001 EMS for the Sasolburg Solvents division. This means that it was not the traditional LCA scope of "cradle-to-grave" that was followed for each of the Solvents products, but more a "gate-to-gate" scope concentrating on the manufacturing processes and excluding raw material acquisition, transportation and logistics as well as product use and final disposal. Therefore, the scope included the following plants or plant sections under the Solvents divisions' control:

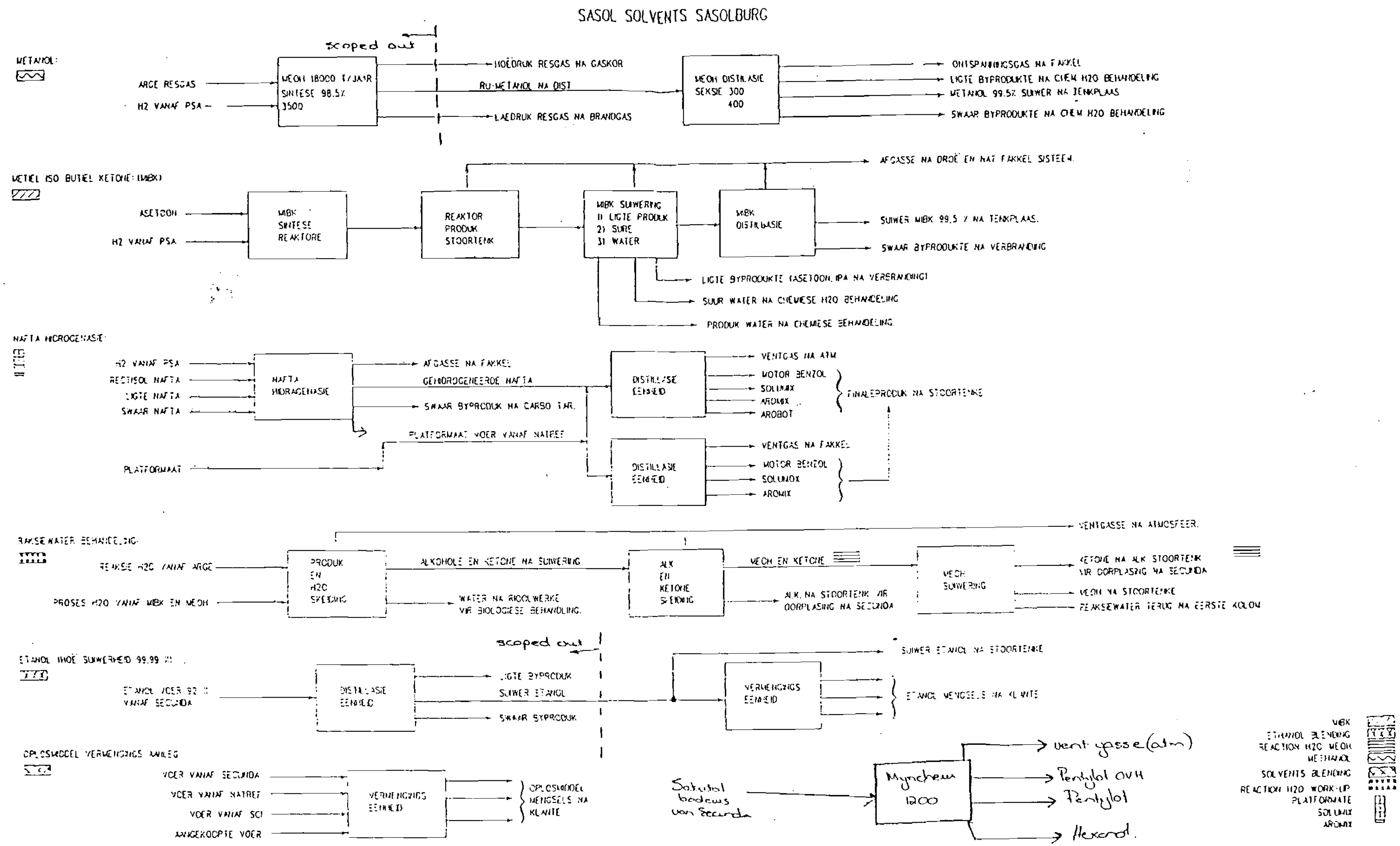
1. Methyl Iso Butyl Ketone (MIBK) plant
2. Naphtha Hydrogenation plant
3. Chemical Water Treatment plant
4. Methanol Distillation section
5. Heavy Alcohol distillation section
6. Ethanol Blending section
7. Solvents Blending plant

Also excluded from the LCA scope was the generation of the utilities used in each of these plants. Therefore only utility consumption is stated in the report and not the impacts from its generation. As the catalysts used in the reactors are being recycled their impact on the environment were excluded from the LCA scope. The same applies to the water effluents to the sewers, which are handled in the Sasol Water System Division, which is ISO 14001 certified. Included in the scope are the production facilities, relevant storage tanks, the flare for Solvent off-gases and the incinerator for the Solvents by-products.

A flow diagram of these plants, with the in and output streams, is illustrated in Figure 10. More detailed diagrams of the mass and utility consumption balances for each of these seven plants are included in the appendix.

5.3.1.2.2 Functional unit

The traditional functional unit for an LCA is per ton of final product. But, due to the relative production rates between the different plants, a functional unit of emission rate per day was used. Comparing the results of the different environmental profiles tested this difference in functional unit. The only significant difference observed was in the percentage distribution of the unit contribution to photochemical oxidant formation impact category.



This Drawing is the Property of SASOL. Copyright, Patents and all Industrial Property Rights Reserved.						SASOL SASOLBURG SITE	Size A2
No.	Description of Revisions	Drawn	Checked	Approved	Date	PROCESS DIAGRAMS FIGURE 10	
Drawn: ELLEN	Date 28/02/98	Checked:	Date	Reviewed:	Date	RNE ENGINEERING (PTY) LTD. P.O. BOX 1490 SASOLBURG TEL :- (016) 960-2494 FAX :- (016) 960-2478	
Approved:	Date	Engineer/Designer:	Date	Scales:		Dwg No. A0138.ORH-1000-A3-DIAGRAM	Sht. / Rev. 0
CAD Ref No. DIAGRAM	Charge No.	Dimensions in mm unless otherwise stated					

5.3.1.2.3 Allocation

No direct allocation rules or strategies were followed as the final products of each process unit were summarised to be the actual final product.

5.3.1.2.4 Data quality and availability

The data needed for the assessment of Solvents division's environmental concerns can be divided into four areas:

- Process data

  The data used in the LCA was obtained from laboratory analyses (GC) of the streams identified as in or output streams for the Solvents division. Some problems were experienced in determining the flow rates of especially vent and other atmospheric gas release streams, as they are not measured. Basic assumptions were made on the flow rates to enable the inclusion of these streams in the environmental assessment. The determination of the flow rates and the assumptions made are listed in the appendix.

- Process and storage tanks data

  To determine the emissions from the blending and storage tanks the computer program TANKS 2.0 was used. The American Petroleum Institute (API) developed TANKS 2.0 and the calculations done in the program are performed according to the EPA's AP-42 system. As most of the components – especially the heavy aromatics are not in the TANKS program database, these heavy aromatic components were included using benzene as model component. The same procedure was followed with the heavy paraffins and heavy alcohols being represented by decane and hexanol. Unknown component fractions were left out of consideration and will be set as an objective for the LCA revision to include more detailed analysis data.

- Assessment data

  The TEAM™ LCA software package from Ecobilan was used. It is an internationally accepted LCA software package. It was one of three software packages indicated as the best packages available by Environment Canada's [1996] and Roland Clift's [1997: 53-57] published reports on their evaluation of available software packages.

  The same problem was experienced, as above, in the LCA TEAM™ assessment database – TEAM-plus. Not all the components present in the release streams to the atmosphere are present in the assessment database. These components were handled in the broad categories of

  - Alkanes (unspecified)
  - Alkenes (unspecified)
  - Alcohols (unspecified)
  - Hydrocarbons (except methane, unspecified)

- Flare and Incineration

  Streams going to the flare or incineration systems were analysed and their combustion off-gas was simulated using the basic assumption of ideal and complete combustion of hydrocarbons to CO_2 and H_2O. The N_2 in the air is not oxidised to NOx, only organic nitrogen was considered to form NOx on combustion.

5.3.2 The Life Cycle Inventory (LCI)

5.3.2.1 Mass and Energy balances

5.3.2.1.1 Mass balance

For each of the seven plants being considered in the Solvents LCA, a mass and utility balance was compiled from the production data. Figure 11 illustrates a combined mass and utility balance for the total Solvents division, as defined in the ISO 14001 EMS scope.

As the plants do not have a common product (each unit produces its own final product as a stand-alone process), a balance per final combined product was done.

5.3.2.1.2 Utility balance

The utility balance profile (Figure 12), compiled from production data, indicates that MIBK is the major air, nitrogen, process- and cooling water consumer. Naphtha Hydrogenation and Chemical water treatment consume the most steam and electricity.

5.3.2.2 Life Cycle Inventories

The data from all the units mass and energy balances with the detail composition of the emissions to the environment and the TANKS 2.0 results on the tank emissions were processed in the acquired TEAM™ software package from Ecobilan to generate the Life Cycle Inventories (LCI).

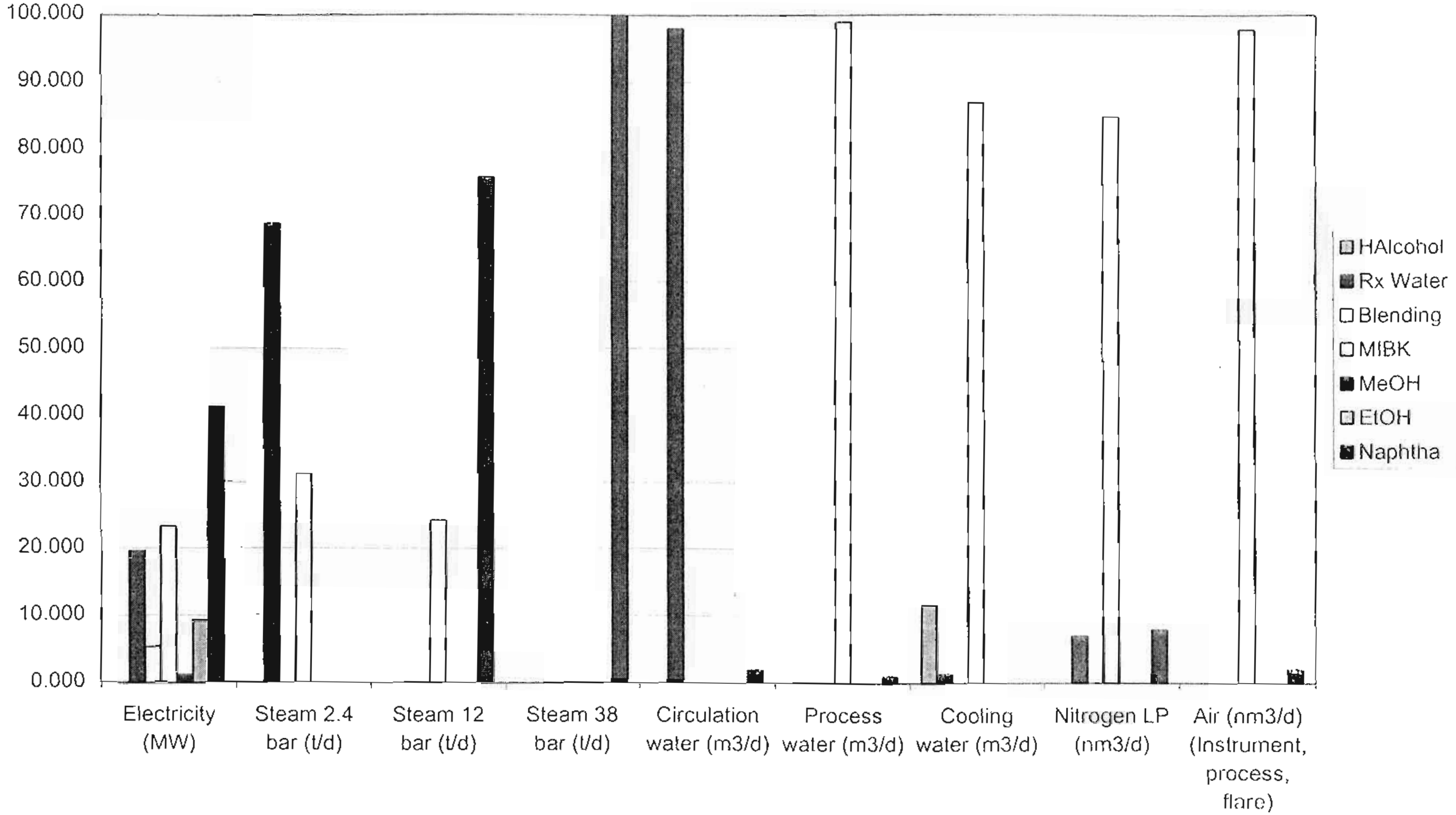
FIGURE 11: Mass and Energy Balance

Process : Total Sasolburg Sovents Division
ton / ton total product

0.088	Acetone (F1152)	Sasolburg Solvents Division's Total Processes	Offgas - Flare	0.014
0.004	Hydrogen (nm3/d)		Offgas - Atm Vent	0.00014
0.066	Wash Water (BFW)		Storage tanks - atm vent	0.00007
0.067	Rectisol Naphtha		Blending tanks - atm vent	0.00008
0.014	Light Naphtha		Catalyst burnoff - to atm.	0.000002
0.006	Heavy Naphtha			
0.034	Platformate		Acid/Seal/Process Water - Rx water	0.102
0.143	Blends Additives		Ammonia-Water - Phenolic sewer	0.014
0.598	Raw Methanol - S3500		Water effluent - WW	1.095
0.024	Sabutol Bottoms (F5168)			
1.024	Arge Reaction water (F519)		Heavy Naphtha By-product - Carbo Tar	0.002
			MIBK By-product - Incinerator	0.014
			MIBK - Product	0.063
			Motor Benzol - Product	0.061
			Solumix - Product	0.041
			Aromix - Product	0.005
			Arobot - Product	0.004
			EtOH Blends	0.027
			Methanol - Product	0.571
			Pentylol OVH - Product	0.013
			Pentylol - Product	0.002
			Hexylol - Product	0.007
			Alcohols - Sucunda	0.039
			Ketones - Secunda	0.026
			Solvent Blends	0.143
			Total	1.000
0.00001	Co-Mo Catalyst (4-5yr life)		Spent Co-Mo catalyst	0.00001
0.00003	Pd/resin cat. (1 yr life)		Pd/resin spent cat. (recycled)	0.00003
0.232	Electricity (MW)	Utilities	Condensate	0.936
0.515	Steam 2.4 bar (t/d)		Steam 2.4 bar	0.013
1.574	Steam 12 bar (t/d)			
3.265	Steam 38 bar (t/d)			
1.686	Circulation water (m3/d)			
321.796	Process water (m3/d)			
33.340	Cooling water (m3/d)			
0.024	Nitrogen LP (nm3/d)			
0.129	Air (Flare and Incineration)			

Note : Gases in nm3/d

% Contribution to Overall Consumption per Utility
FIGURE 12



5.3.2.2.1 Overall Solvents Division

The contribution of each process unit to different component or component group emissions, is illustrated in Figure 13 relative to the contribution of the other process units. This means that the units are being compared to each other and not to an external cut-off point such as governmental regulations.

5.3.2.2.2 Methyl iso Butyl Ketone (MIBK)

MIBK is the major contributor (99%) to CO_2 emissions due to the flaring of the off-gas streams and the incineration of Technical DMK, heavy and light by-products.

TABLE 8: MIBK CO_2 emission sources

CO2 emission source	%
Off-gas to flare	0.2
Technical DMK	24.9
Light By-product	19.1
Heavy By-product	55.9

As none of the MIBK raw material or product storage tanks are inside the ISO14001 EMS scope – no tank emissions were calculated for these tanks.

5.3.2.2.3 Naphtha Hydrogenation

Naphtha hydrogenation is one of the plants that are a major source of gaseous emissions to the atmosphere, especially in the compound groups alkane, aromatics and methane. The concern with these emissions is not only their quantity but also their toxicity and the carcinogenic potential of the aromatics. This will be assessed in the Life Cycle Impact Assessment (Section 5.3.3).

Of the total emissions to the atmosphere of the Naphtha hydrogenation plant, the tank emissions are the main concern. The distribution of the tank emissions is:

Contribution to compound emissions
FIGURE 13

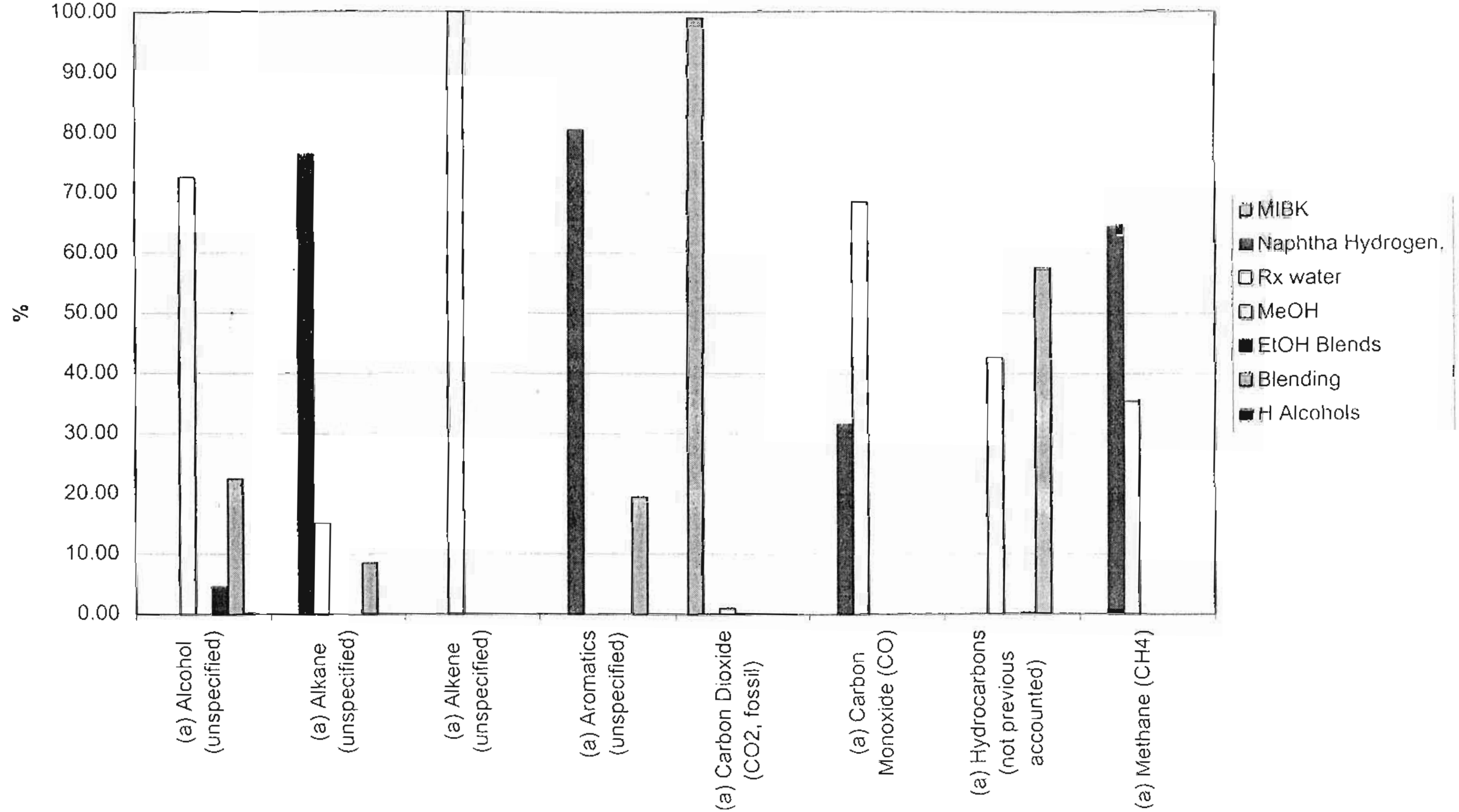


TABLE 9: Naphtha Hydrogenation tank emission distribution

Tank product	Tank number	%
Naphtha Feed Mix	F3801/26	29.8
Platformate	F3812	0.2
Solumix	F3814/15	7.9
Aromix	F3816 A/B	3.2
Arobot	F1224/8	2.2
Rectisol Naphtha	F3825 A/B	56.7

TANK 10: Naphtha Hydrogenation storage tank emission distribution

Tank product	Tank number	%
Raw Material Storage	F3801/26/12/25	87
Product Storage	F3814/15/16, F1224/8	13

5.3.2.2.4 Chemical Water Treatment

This plant contributes to most of the alcohol, alkene and CO emissions due to atmospheric vents on the process plant. Two feed and by-product storage tanks (F530, F519) are part of this process unit. The emissions from the by-product storage tank F530 were calculated in Tanks 2.0. The feed storage tank (F519) is too big to be simulated with the Tanks 2.0 program. The tank height and diameter of 90ft and 71ft is outside the maximum limit in the program of 75ft and 65ft. As the composition of the feed consist of 95.5% water and 4.5 % alcohols, the emissions from this tank were not considered in the LCA.

TABLE 11: Chemical water treatment air emission distribution

Air emissions	%
Production plant	98
Storage tanks	2

5.3.2.2.5 Methanol Distillation

The methanol plant is not a major contributor to any of the component groups. As none of the Methanol raw material or product storage tanks are inside the ISO14001 EMS scope, no tank emissions were calculated.

5.3.2.2.6 Heavy Alcohol Distillation

The Heavy alcohol distillation plant is not a major contributor to the defined compound groups. The product storage tank emissions were also calculated with the Tanks 2.0 program. Several of the alcohols and water did not form part of the program's database. These components were added to the database using vapour pressure information from "*Phase Equilibria in Chemical Engineering*" by Stanley M. Walas [1985: 577-595].

TABLE 12: Heavy alcohol distillation air emission distribution

Air emissions	%
Pentanol Overheads	22
Pentanol	78

5.3.2.2.7 Ethanol Blends

The Ethanol blending section is not a major contributor to the defined compound groups. This plant consists of only blending tanks in which the different ethanol blends are made for tankage/drumming and dispatch to the different customers. To determine the emissions from the different blends, which turnover is dependent on market requests, a yearly average figure was used. The total blend composition, derived from the average raw material intake, was used in stead of determining the emissions of each blend separately. The reason for this is the fluctuation in quantity and frequency in which these blends are made.

5.3.2.2.8 Solvent Blends

The Solvents blending plant is a major contributor to the hydrocarbon group and the second largest contributor to the aromatics group. The same strategy, as above, was followed with regard to the blending and storage tanks. The total composite yearly average composition was used in determining the emissions from the blending tanks. The raw material storage tanks were handled separately. The contributions of the storage and blending tanks to the total tank emissions for this plant are given below:

TABLE 13: Solvents blends' tank emission distribution

	Tank number	**% Contribution**
Raw material storage	F5043 A-M	10
Blending tanks	F5044 A-C	90

5.3.3 The Environmental Assessment of the Life Cycle Inventory

5.3.3.1 Overall Solvents Division

Using the LCA methodology and the TEAM™ software package and its assessment database – TEAM-plus, all seven plants that form part of the Solvents division were assessed. The assessment categories in the TEAM-plus database are the internationally accepted categories used in LCA's. They include the major international environmental issues and are scientifically based. Each of these categories and the source of the assessment factors will be discussed later in this section. The assessment categories were:

- Human toxicity
- Eco-toxicity – aquatic and terrestrial
- Greenhouse effect
- Photochemical oxidant formation (smog)

- Odour
- Acidification
- Eutrophication

The result of this assessment will also be discussed in the following paragraphs and can be seen in Figure 14. The assessment was based on a functional unit of emission per day.

5.3.3.1.1 Human Toxicity

Human toxicity is assessed by relating the emissions to the tolerable daily intake (TDI), the acceptable daily intake (ADI), the tolerable concentration in air (TCL), the air quality guidelines, the maximum tolerable risk level or the C-value for soil based human toxicology considerations. The data is from toxicology experiments about the maximum daily intake or concentration, which is considered acceptable for use in the assessment of human toxicity. [Heijung, Guide,1992: 44]

There are two ways to assess Human toxicity in TEAM-plus, depending on the source of the assessment factors. The CML Human toxicity factors were developed by the Centre of Environmental Science (CML), and are expressed in kg of body weight of a person contaminated to the toxicologically acceptable limit. The other method USES (Uniform System for the Evaluation of Substances), was developed by J. Guinee et al (CML), and is expressed in equivalent grams of 1,4-dichlorobenzene. [TEAM-plus helpfile]

For both assessment routes the Naphtha hydrogenation plant was identified as the major contributor (>80%) to this impact category. The Solvents blending plant contributed the balance 20%. In Figure 15 the Naphtha hydrogenation raw material storage tanks and the Solvents blending plant's blending tank are the main sources of the toxic emissions. Both cases indicate benzene as the toxic component.

% Contribution to Impact Category
FIGURE 14

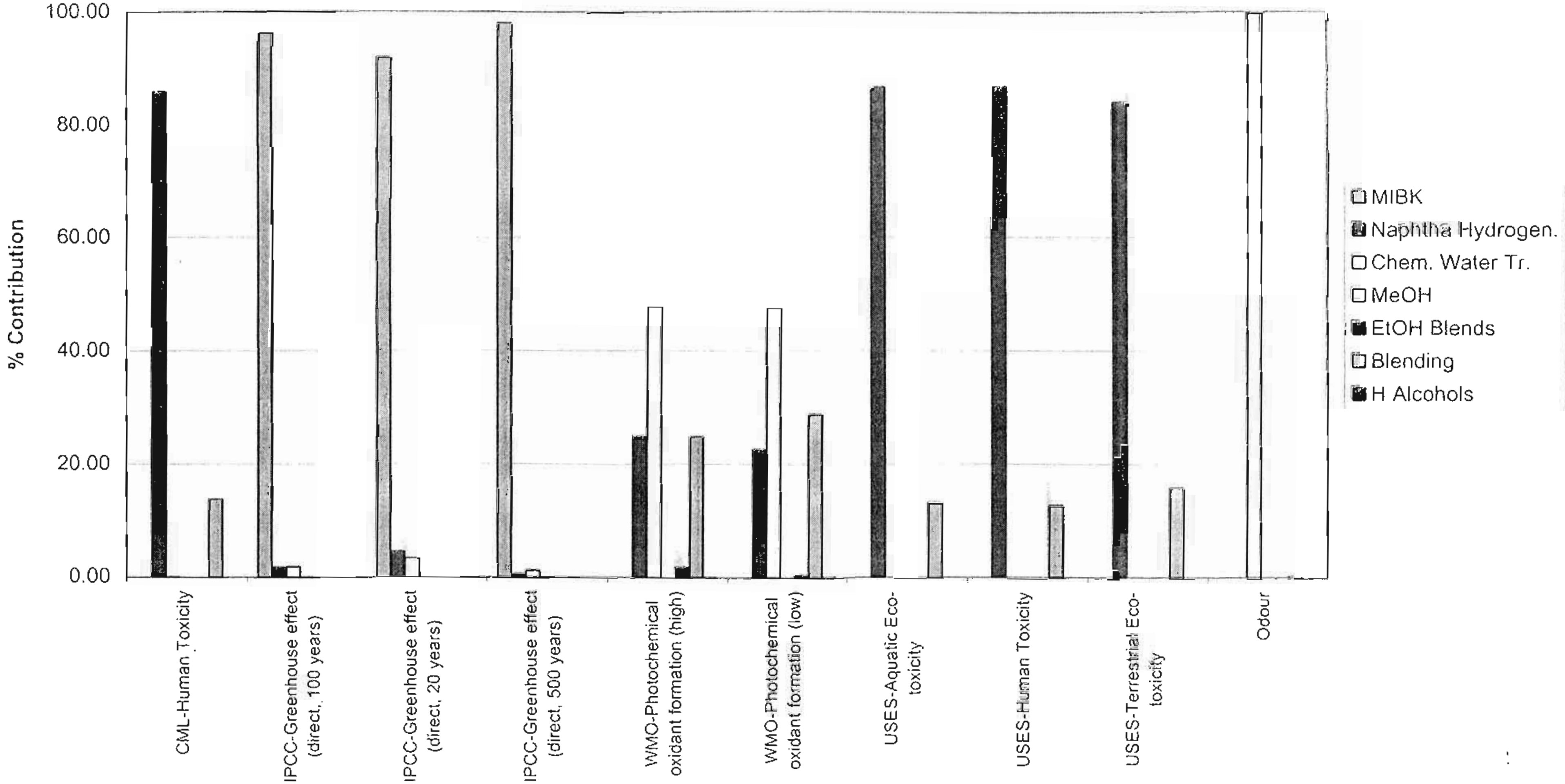
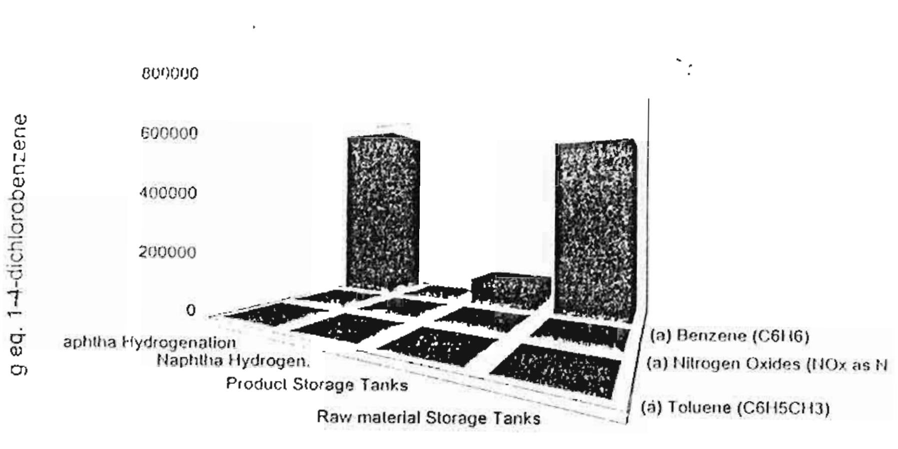
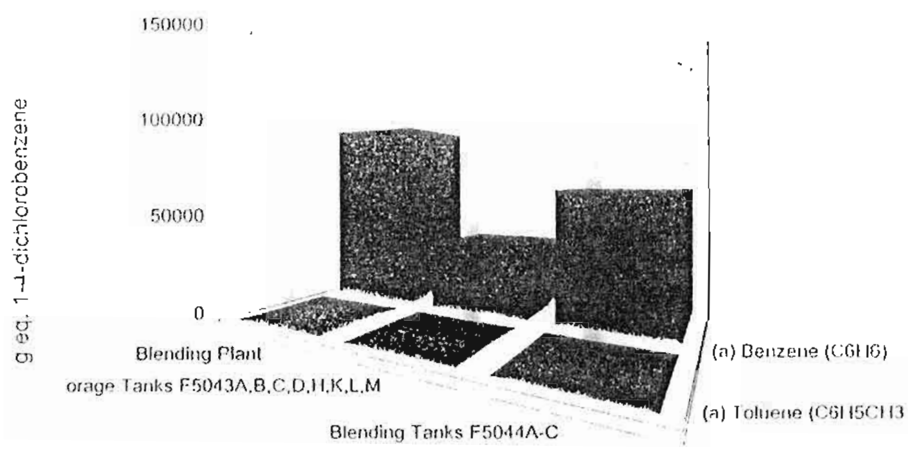


FIGURE 15

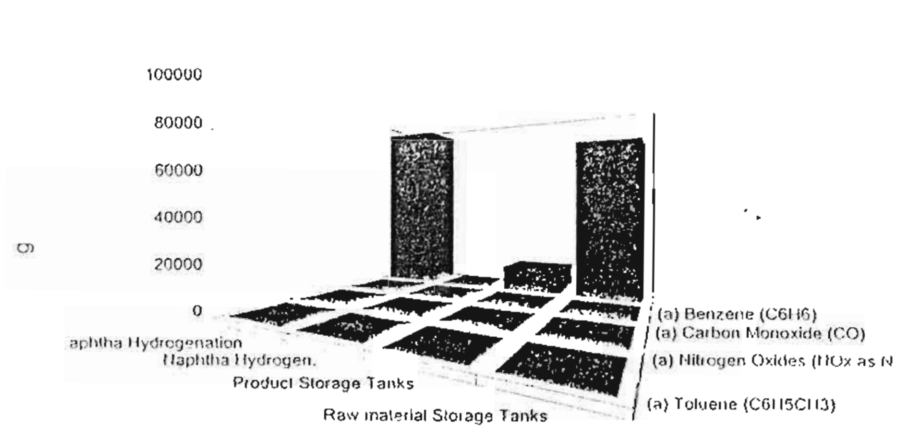
System: Naphtha Hydrogenation - USES-Human Toxicity



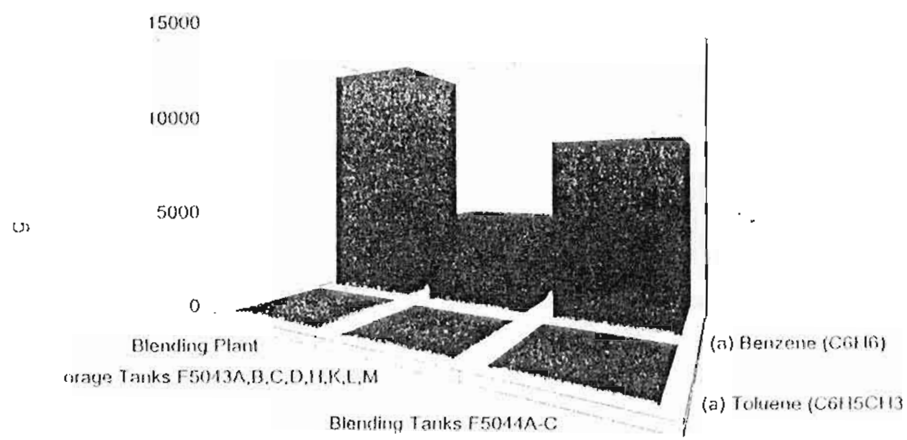
System: Blending Plant - USES-Human Toxicity



System: Naphtha Hydrogenation - CML-Human Toxicity



System: Blending Plant - CML-Human Toxicity



5.3.3.1.2 Eco-toxicity

During the classification of eco-toxic emissions a distinction is made between toxicity to aquatic ecosystems and toxicity to terrestrial ecosystems. The assessment of substances with an effect on species in the ecosystem is based on the maximum tolerable concentration (MTC's) determined according to the EPA method. The method described by J. Guinee et al (CML), was used and the aquatic and terrestrial impacts are expressed in equivalent grams of 1,4-dichlorobenzene. [TEAM-plus helpfile]

Both the aquatic and terrestrial toxicity results are the same to those found for the Human toxicity category, namely that the Naphtha Hydrogenation plant is the main contributor followed by the Solvents Blending plant. The contributing plants and compounds are also the same, except that toluene plays a much larger role in eco-toxicity than in human toxicity. Figure 16.

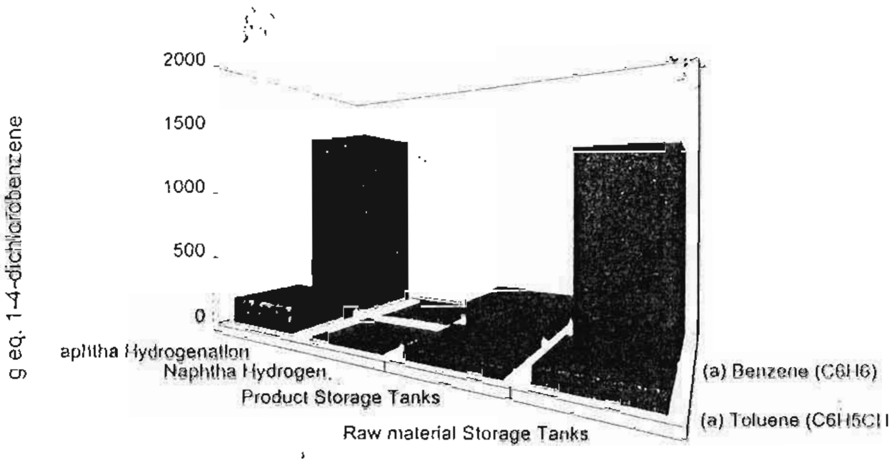
5.3.3.1.3 Photochemical oxidant formation - smog

Under certain climatic conditions, air emissions from industry can be trapped at ground level, where they react with sunlight to produce photochemical smog. Photochemical smog is also called Tropospheric ozone creation or photochemical oxidant formation and is an indication of the volatile organic compounds (VOC's) emitted into the air or smog formation potential. The factors used, Photochemical ozone creation potential (POCP), are expressed as grams equivalents ethylene and were developed by the United Nations. [TEAM-plus helpfile]

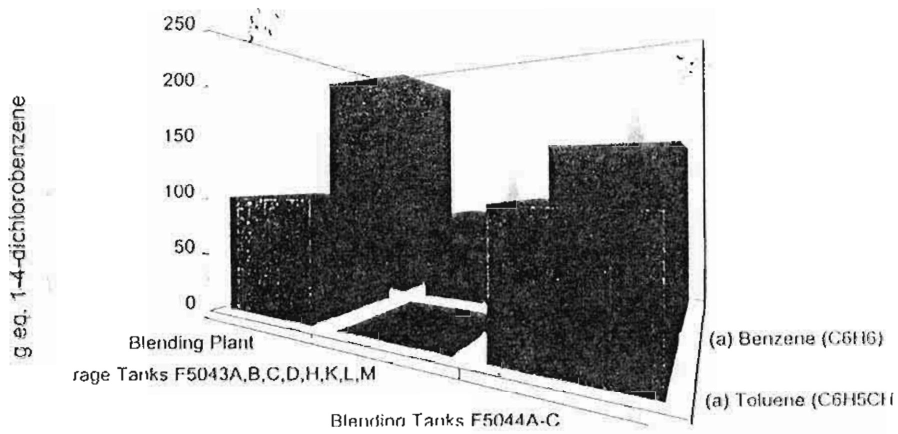
Three plants contribute to this impact category – Naphtha hydrogenation (25%) mainly from the raw material storage tanks, Chemical water treatment (48%) mainly from the atmospheric vents on the distillation plant and Solvents blending plant (25%) mainly from the blending tanks.

FIGURE 16

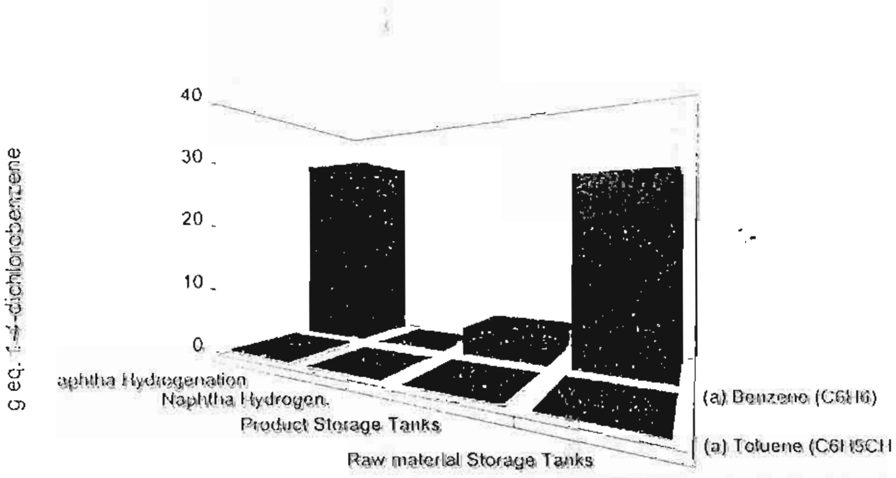
System: Naphtha Hydrogenation - USES-Terrestrial Eco-toxicity



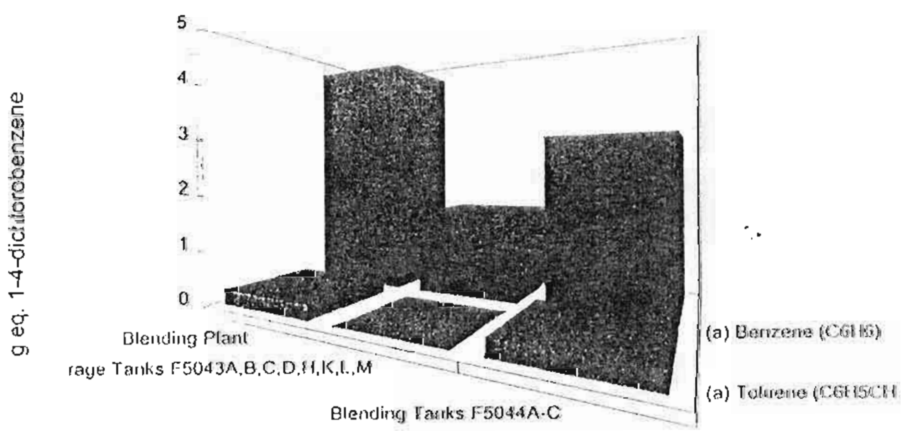
System: Blending Plant - USES-Terrestrial Eco-toxicity



System: Naphtha Hydrogenation - USES-Aquatic Eco-toxicity



System: Blending Plant - USES-Aquatic Eco-toxicity



5.3.3.1.4 Odour

The odour threshold values (OTV) in air, which have been determined for the most important substances, were used to assess the compound's potential contribution to malodorous air. Atmospheric emissions are converted to the volume of air polluted up to the odour threshold. This method was developed by the Center of Environmental Science (CML) [Heijung, Guide, 1992: 45,87-89], and the results are expressed in m^3 malodorous air.

Odour is usually a major strategic concern for industrial divisions due to complaints from the public. In assessing the odour potential the chemical water treatment unit was indicated as the source of 99.8% of the malodorous air potential. This is mainly due to the acetaldehyde and propionaldehyde in the off-gas vent streams to the atmosphere from the distillation plant.

5.3.3.1.5 Green house effect

The earth absorbs radiation from the sun and this energy is then redistributed by the atmosphere and re-radiated to space. The so-called greenhouse gases in the atmosphere absorb some of this thermal radiation, which re-radiate the absorbed energy in all directions. The result is that the surface looses less heat to space than it would do in the absence of these gases. Consequently the earth's temperature can increase resulting in altered atmospheric and oceanic temperatures. The factors (Global warming potential (GWP)) used to calculate the potential contribution to the greenhouse effect are expressed in terms of g equivalent CO_2 and were developed by the International Panel on Climate Change (IPCC). The greenhouse effect is also calculated in three future time horizons of 20, 100 and 500 years. [TEAM-plus helpfile]

92% of the greenhouse effect is from the MIBK plant due to the incineration of their by-products – technical DMK, light by-product and heavy by-product - and the flaring of the process off-gases.

5.3.3.1.6 Acidification and Eutrophication

Acidification is the effect when the buffer capacity of the environment becomes too low and the pH declines. This then leads to biological damage, the release of previously contained toxins and the inability of organisms to assimilate calcium. Acidification is based on those compounds, which are potentially transformed into acid compounds through reactions with atmospheric elements. The results are therefore expressed in grams equivalents H^+.

Eutrophication is the enrichment in nutritive elements of water and soil when referring to human intervention. This enrichment can lead to a shift in the ecosystem composition. The results are therefore expressed in grams equivalents PO^{4-}.

Both the Acidification and Eutrophication factors were developed by the Center of Environmental Science (CML). [TEAM-plus helpfile]

As no ammonia, SO_2 and NOx were indicated in the analysis of the off-gases, the contribution to these categories are zero. This is an area for future improvement in the detail of the analysis available for the next revision of this study.

5.3.4 Improvement Analysis

5.3.4.1 Determination of aspect and impact significance

Once an organisation has identified its environmental aspects and impacts, it must determine whether they are significant or not. It is the significant impacts and aspects that will be considered in setting the environmental objectives and targets.
As ISO 14001 EMS standard requires that the significant aspects and impacts should be addressed [SABS/ISO 14001, 1996: 7], the percentage contribution to the impact categories of each plant relative to the other plants were used as criteria to

determine the relative significant issues. ISO 14001 EMS standard does not define significance or the criteria to determine it and the significance of the same impact can be different for different organisations. Significance can therefore be unique to each division as long as the criteria and methodology is consistent and applicable [Schiffman, 1997: 46].

For the Solvents division using the LCA methodology there was not a single cut-off point to classify the significance, above which a plants performance was "bad" or beneath which it was "good". The plants relative performance with regard to other processes were taken as guideline to determine the significance aspects and impacts. The most significant aspect contributing to a specific impact category was then evaluated to determine the source of the environmental concern. Once the latter is identified – mitigation measures can be determined and further investigated to reduce the source of the specific environmental impact category.

For example: Naphtha Hydrogenation contributes 86% of the division's contribution to Human toxicity impact relative to the other plants. Therefore, the emissions of benzene and other carcinogenic aromatics from this plant, which are the main contributors to the human toxicity category, can be defined as a significant aspect. Alternatively, the Naphtha storage tanks are the major contributor to the human toxicity impact for the Naphtha hydrogenation plant, with the Rectisol naphtha storage tank the major source (57%) of the emissions. Mitigation measures can now be investigated to reduce the atmospheric emissions from this storage tank.

Realising that most organisations work within a budget, not all the impacts can be addressed at once, they must be prioritised. Those causing obvious damage to the environment or human health should be the first priority, as should those costing the organisation money in terms of liabilities, accidents and complaints [Schiffman, 1997: 46].

The criteria used to determine the priority of the impact categories were therefore:

1. Damage to human health
2. Damage to ecosystems
3. Socio-economic factors in terms of liabilities and complaints

The impact categories were ranked in order of priority, relative to each other as:

1. Human toxicity
2. Eco-toxicity
3. Photochemical Oxidant Formation – Smog
4. Odour
5. Greenhouse gasses
   - as developing country we still have exemption from the Kioyto convention.
6. Acidification - no impact registered for this case study
7. Eutrophication - no impact registered for this case study

5.3.4.2 *Significant impacts and aspects*

The following significant impacts and aspects were identified in the LCA study in order of priority:

1. Human and Eco-toxicity

   Plant(s): Naphtha Hydrogenation, Blending tanks

   Source:

   - Naphtha hydrogenation storage tanks – specifically the Rectisol naphtha storage tank and the naphtha feed mix tanks
   - Solvent blending plant's blending tanks

   Priority: 1. Rectisol naphtha tank emissions (F3825 A/B)

2. Blending tanks emissions (F5044 A-C)
3. Naphtha feed mix storage tanks (F3801/26)

2. Photochemical Oxidant Formation – Smog and Odour

Plant(s): Chemical water treatment

Source: Distillation plant vents to atmosphere

Priority: Atmospheric vents

3. Greenhouse gases

Plant(s): MIBK

Source: Off-gas flare and by-product incineration

Priority:
1. Heavy by-product incineration
2. Technical DMK by-product incineration
3. Light by-product incineration
4. Off-gas flare

The actual impacts and aspects identified should also be further assessed to determine their severity in terms of a specific standard or regulation value. This is critical due to the lack of South African air quality standards on hydrocarbon emissions. It is therefore recommended to conduct an ambient monitoring study to measure the actual concentrations of the critical compounds, say benzene, and then evaluate the emissions against the OSH-act TWA values. The results of this ambient study will also influence the mitigation options to investigate.

5.3.4.3 Mitigation recommendations

If ambient monitoring results indicate mitigation procedures are required, the following recommendations can be made:

1. The installation of air emission scrubbers (through liquid extraction or adsorption) to extract the aromatic and carcinogenic compounds. A liquid extraction system using a suitable solvent for recycle to the process or storage tank should be the best solution.
2. The installation of vacuum blowers and refrigeration units to condense the aromatics in the off-gas streams. This will be a very expensive option.
3. The installation and use of nitrogen pressure on the tanks to limit the formation of off-gases. For this option the maximum pressure the storage tanks can handle must first be determined.
4. The control of the tanks at a constant level to reduce the working loss emissions due to the fluctuation of the lank level. This option might work with feed tanks but will be totally unpractical to do on product tanks from a continuous operated plant.
5. Conservation valves – already installed on all the tanks
6. To flare all the off-gas streams. This option is unpractical for most of the off-gas streams are at a lower pressure (atmospheric pressure) than the flare system (80 kPa gauge).
7. Find markets or alternative uses for MIBK by-product streams.

Of all these recommendations – options 1 and 3 seams to be the most practicable and should therefore be further investigated to determine the cost implication and percentage reduction in emissions that can be achieved.

5.4 APPLICATION OF LCA's IN ISO 14001 EMS AND ITS LIMITATIONS

The traditional LCA from "cradle-to-grave" was not followed in this application for ISO 14001 EMS. According to the LCA standard ISO 14040, an LCA is defined as:

> *"A compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle."*
> [SABS/ISO14040: 1997: 2]

Only the methodology was followed to a more restricted scope. If this scope is extended to include from raw material acquisition, product use to final disposal – the percentage contribution of the organisation, under investigation, of the overall environmental burden can be identified. Therefore what percentage of the overall environmental burden is generated outside the "gates" and what inside the "gates" of the organisation. This was not a practical option for the solvents division due to the wide range of products produced inside the divisions' boundaries. For this application the scope was therefore restricted to the manufacturing process only.

Some of the deliverables of such an LCA, in its application in an ISO 14001 EMS is as follows:

- It can describe the current environmental status of a company through the LCA generated environmental profile.
- This environmental profile can then be used as the baseline for the evaluation of mitigation measures, to determine their contribution to the reduction of emissions and its associated impacts.
- The baseline can also be used in future environmental audits to prove continuous improvement by comparing the baseline to the future case.
- It can identify the significant environmental impacts and aspects of the process units, relative to each other. Future investigations and external studies can then focus on the more important ones.
- It can also assist in prioritising the impacts and aspects from which the objectives and targets are derived for the ISO 14001 EMS implementation report and system.
- It can be applied to complex chemical plant systems, as the Solvents division proved.
- It is a consistent, objective and scientifically based method and approach to identify the environmental impacts and aspects and generate the environmental profile of a division.

On the other hand it has the following limitations in its application:

- There is not a single cut-off point, to determine the significance, above which a plant's performance is "bad" or beneath which it is "good".
- Due to the lack of air quality standards and regulations – especially on hydrocarbon emissions – the severity of the identified potential environmental impacts and aspects can not be determined. This will require additional studies, such as ambient monitoring of the identified issues and compounds.
- LCA's depend on the quality, completeness and accuracy of the data used in the model.
- The application of LCA's works for chemical systems and could therefore not be applied to more mechanical systems such as construction. If an action is not presented as part of the systems flow diagram, the LCA method would not address it. An example of such a "mechanical" action is construction of a physical structure.
- The current assessment database is restricted in its list of included components, it should be extended to include a more comprehensive component list.

5.5 CONCLUSION AND RECOMMENDATIONS

ISO 14001 Environmental Management Systems (EMS) is one of the standards that form part of the ISO 14000 series of voluntary environmental standards. An Environmental Management System (EMS) enables a company to manage their environmental performance issues through identification of environmental issues, setting of objectives and targets, scheduling actions and through continuous improvement. One of the starting points of the implementation process is the identification of the organisation's current environmental status and the environmental impacts and aspects that should be addressed.

A Life Cycle Assessment (LCA) case study was compiled for the Sasolburg Solvents division to assist with their ISO 14001 EMS implementation strategy. The objectives of, as well as the contributions made by the study, are summarised below:

Objective 1: To evaluate the application of the LCA methodology during ISO 14001 EMS implementation.

- LCA proved to be suitable to compile information for complex chemical plant systems, like the Solvents division, as required for the implementation of an ISO 14001 Environmental Management System.
- It is a consistent, objective and scientifically based method to identify the environmental impacts and aspects and to compile an environmental profile.
- The significant environmental impacts and aspects of the process units, relative to each other, were identified with this approach. From these impacts and aspects, mitigation measures and objectives and targets can be proposed for the ISO 14001 EMS initial review report and system.
- The severity of the potential environmental impacts and aspects can not be determined with the LCA methodology. The LCA methodology identifies what the environmental problem is, but not how "bad" it is. This is due to the lack of guidelines/criteria according to which the impacts or aspects can be quantitatively evaluated and then classified as a major, intermediate or minor environmental issue. To determine the severity of the impacts or aspects will require additional studies, such as ambient monitoring and a risk/health assessment of the monitoring results. Such a study was initiated and confirmed the LCA findings.

Objective 2: To develop an environmental profile of the Solvents division and to determine its current environmental status, the environmental impacts and aspects as well as its root causes as a requirement for their ISO 14001 EMS standard

- The environmental profile was generated, giving an indication of the division's current contribution, per process unit, to the different impact categories. A category contribution was compiled for each process unit relative to each other. Some of these impact categories are: acidification, eutrophication, human toxicity, aquatic and terrestrial eco-toxicity, greenhouse effect and photochemical oxidant formation (smog).
- From this profile the significant impacts and aspects were derived, in order of priority, they are:
  1. Human and Eco-toxicity impact – from the Naphtha Hydrogenation and Solvents Blending tanks. The major source of the emissions were from the atmospheric vents on the Rectisol Naphtha and Naphtha feed mixture storage tanks as well as from the three blending tanks at the Blending plant.
  2. Photochemical Oxidant Formation (smog) and Odour – from the Chemical water treatment plant. The source of the emissions is the production plant vents emitting directly into the atmosphere.
  3. Greenhouse gases – from the MIBK by-product incineration. Three by-products produced in the plant (technical DMK, light by-product and heavy by-product), are incinerated as a fuel additive at the Thermal Oxidation plant.

<u>Objective 3:</u> To generate a baseline profile to evaluate the effectiveness of future mitigation measures and their emission reduction potential.

- To reduce the above mentioned impacts and aspects, the following mitigation measures were recommended for further investigation:
  - The installation of nitrogen pressure on the storage and blending tanks
  - or alternatively, the installation of air emission scrubbers on the storage and blending tanks to reduce or eliminate the emission of toxic or nuisance components.
  - Finding alternative markets for MIBK by-products in order to eliminate their incineration.

- The contribution of these mitigation measures, if proven necessary, can be environmentally evaluated by using the generated profile as a baseline for comparison of the measures' impact and emission reduction potential for decision making. After implementation, the mitigation effect can also be illustrated by using the generated profile as a baseline.
- For the next ISO 14001 EMS audit, the baseline profile can also be used to prove continuous improvement in their environmental performance. This is a critical requirement for continuous ISO 14001 certification.

Objective 4: To identify areas where improvement is needed in terms of the level of detail of the data, the following gaps in the current data matrix were identified and should be included in the program requirements for future improvement.

- Inclusion of H_2S, SO_2, HCN in off-gas analysis.
- More accurate determination of off-gas flow rates.
- Extension of the component lists in the databases of the software packages used.

The LCA was therefore a successful tool to compile environmental information in the implementation process of an ISO 14001 Environmental Management System at the Sasolburg Solvents division.

6. CONCLUSION AND RECOMMENDATIONS

The Life Cycle Assessment (LCA) methodology can be applied in various stages – especially conceptual design and ISO 14001 Environmental Management System (EMS) implementation – in order to add value and incorporate environmental concerns in the chemical industry.

The LCA methodology was successful in identifying the environmental issues of the conceptual design case study for future environmental focus in the SPD project. Some of these issues are:

- The combustion of fuel and off gases in the Rectisol/Clauss and Natural Gas Reformer process units
- Loss of energy to the environment that can be better utilised.

These issues identified must be interpreted with the limitation of the lack of detail data so early in a chemical engineering project. Changes in the data quality and quantity can change the resulting environmental profile of the project. Still with the available data, based on readily available mass and energy balances, several environmental concern areas were identified for further investigation in terms of their economic, technical and environmental feasibility following the proposed iterative/interactive spiral concept or multi criteria decision making philosophy.

The LCA was more successful in identifying the major environmental impacts and aspects of different process units relative to each other in the implementation of an ISO 14001 Environmental Management System due to the availability of more detail data from actual analyses and measurements. The case study was excepted by the ISO 14001 audit team as a novel approach for impact and aspect identification. These impacts and aspects identified were, in order of priority:

1. Human and Eco-toxicity – from the Naphtha Hydrogenation and Solvents Blending tanks
2. Photochemical Oxidant Formation (smog) and Odour – from the Chemical water treatment plant
3. Greenhouse gases – from MIBK by-product incineration

The LCA does not determine the severity of these impacts as well as the significance thereof in term of the required high, medium or low significance rating. As the environmental issues were identified, mitigation proposals were made for further investigation in terms of their technical and economic feasibility as well as emission reduction potential.

The LCA was also a successful tool in compiling the baseline for future comparisons of mitigation improvements and as a reference for future conceptual design studies on the SPD process and future ISO 14001 EMS audits, to prove continuous improvement. Part of the continuous improvement will be in the level of detail and accuracy of the data used in the LCA studies as they proceed on the interactive/iterative spiral of the project life cycle.

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