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THESIS

LIFE CYCLE ENVIRONMENTAL ASSESSMENT OF SPENT SOLVENT MANAGEMENT BY TYPICAL TREATMENT AND RECYCLING

THIPPAWAN SMITTHINAN

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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This study focuses on the LCA of spent solvents recycling with its functional unit as 200 kilograms before recycling and evaluates the environmental impacts of which by SimaPro software with Eco-indicator 99 and Environmental Design of Industrial Product (EDIP) methods. The result is compared with environmental impacts of solvent incineration as typical treatment. The research is based on 70% and 90% recovery of spent solvent. The results show that, by using Eco-Indicator 99 method, the single score of environmental impacts for solvent recycling are -42.5314 Pt. and -43.8900 Pt. for 70% and 90% recovery efficiency, less than 4.6440 Pt. for solvent incineration. The global warming impacts are -1.76 kg CO_2 equivalent per 1 kg of solvent recycling management at 70% efficiency, -1.81 kg CO_2 equivalent per 1 kg of solvent recycling management at 90% efficiency, comparing with 1.345 kg CO_2 equivalent per 1 kg of solvent incineration. The highest environmental impact for solvent recycling is from the use of electricity, followed by the use of heavy oil as boiler fuel and diesel for transportation, respectively. This could be useful for improving the recycling process to be more environmental friendly.

Thippawan S.

Student's signature

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17 / Mar / 2006

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Thippawan Smitthinan
January 2006

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INTRODUCTION

Environmental problem and resource depletion are widely spread in the world owing to the expansion of economics, industry and populations including developments in various fields in order to supply infinite demand of human. Society has become concerned about the issues of such problems, especially natural resource depletion and environmental degradation. Regulations, guidelines and environmental management tools, such as environmental management system known as ISO 14001, for industries to operate with the least environmental effect, have been issued by the organizations dealing with environmental problems. Several assessment tools e.g. an environmental impact assessment (EIA), a risk assessment, a waste minimization strategy, are also available to handle environmental problems. After realization and as environmental awareness increases, organizations, industries and businesses have started to assess how their activities affect the environment. The environmental performance of products, services and processes has become a key issue, which is why some companies are investigating ways to minimize their effects on environment. Many companies have found it advantageous to explore ways of moving beyond compliance using pollution prevention strategies and environmental management systems to improve their environmental performance. In the past, enterprises have primarily focused on environmental improvements to the production processes within the enterprise's own perimeter fence. Besides, in many cases, the results do not truly reflect the environmental impact. Therefore LCA (life cycle assessment) was proposed to solve this problem and establish a link between the environmental impacts, operation and economics of a process. Life cycle based environmental initiatives focus on improvements to the product in all phases, from raw material extraction and transport, to production and consumption, to re-use or disposal.

LCA is an environmental management tool which identifies all resources used and wastes generated to all environmental compartments (air, waste and soil) over the whole life cycle (cradle-to-grave) of a specific good or service. It has two specific strengths: firstly, because of its comprehensive character, it helps to avoid ‘problem shifting’, where a solution to a particular environmental problem causes a deterioration in another part of the life-cycle or another environmental compartment. Secondly, it accounts for all resources used and wastes generated per unit of ‘value’ to the customer, thereby permitting a value:impact assessment.

Life cycle assessment is a "cradle-to-grave" approach for assessing industrial systems. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product selection. The LCA process is a systematic, phased approach and consists of four components: goal definition and scoping, inventory analysis, impact assessment and interpretation.

The second step in LCA, the life cycle inventory (LCI) analysis, involves identifying and quantifying all of the inputs into the system under study (traced back to resources extracted from the natural environment) and all of the outputs from the system (traced forward to waste material released into the natural environment). It often needs to include data from many different countries, collected from very diverse data sources (industry, national statistics, engineering handbooks, etc.), sometimes with different accuracies. These data are then aggregated over all sites in the lifecycle and over time to obtain the final LCI results. This macro approach provides very useful information to avoid problem shifting and to help overall strategy development, but can not provide all the detail, particularly on the local characteristics of sites where specific parts of the life cycle take place, or on the time distribution of extractions from or releases to the natural environment.

Life Cycle Impact Assessment (LCIA) models are being developed to interpret LCI data in terms of their effects on the environment. Because of the lack of temporal and spatial detail in the LCI data, 'actual' impacts can not at present be assessed using LCA, only 'potential' impacts.

As a result of industry and population growth, the amount of waste has been increasing nowadays, especially for hazardous waste. Figure 1 illustrates the imported and produced amount of chemicals in Thailand during year 1993 to 2002. In 2002, the imported amount of organic and inorganic hazardous chemicals is 6 million tons while domestically produced amount of which equals 43 million tons. Increasing rate of those, based on the amount in year 2001, is approximately 65%, due to the growth after the economics crisis.

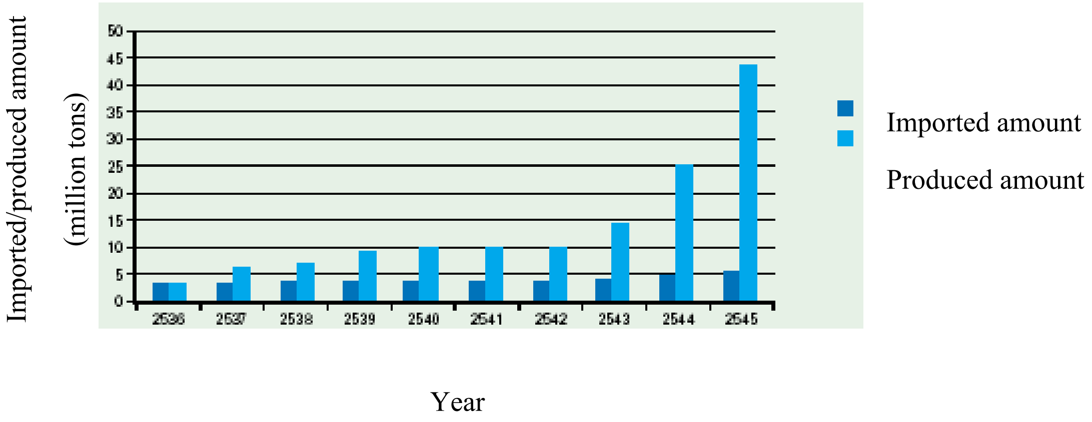

Figure 1 The amount of imported and produced chemicals in Thailand during B.E. 2536-2545

Pollution Control Department estimated that the amount of hazardous waste in year 2002 will increase 3-5% from the amount of that in year 2001 (1.31 million tons). Regarding waste solvent, the quantity is getting larger as 19,760 tons in year 1986, 36,163 tons in year 1991, 66,532 tons in year 1996 and 124,306 tons in year 2001. After use, certainly such chemicals need to be appropriately disposed of otherwise they would be harmful to human health and environment. The waste management policy and strategies have been established and promoted as well as regulations and legislations enacted by the government and relevant organisations to minimise such an environmental problem. Many methods of managing spent solvent have been encouraged e.g. proper disposal by approved service providers, source reduction techniques, minimising the generation of spent solvent at the source as well as pollution prevention (P2) where toxic solvents are replaced with new non-toxic solvents. Among those, recycling is one of the suitable ways to handle spent solvents, with considering of cost effectiveness and reduction of natural resource depletion for the virgin solvent.

This research focuses on the life cycle impact assessment of the spent solvent management by comparing between incineration, a typical spent solvent management and recycling, a new alternative. The objectives of this research are:

1. To determine the life cycle environmental impact of spent solvent management

2. To compare the life cycle environmental impact of 2 alternative spent solvent management methods: typical treatment (incineration) and recycling

3. To propose methods for improving environmental performance of spent solvent management

LITERATURE REVIEW

1. Sustainable development – origin and meaning

Before the widespread use of the term sustainable industries, the terms *sustainable economy* and *sustainable development* were prevalent. Their popularisation started with the United Nations Conference for Environment and Development; the Earth Summit in 1992. The conference was prompted by the report; World Commission on Environment and Development 1987, also known as the Brundtland Commission, which called for strategies to strengthen efforts to promote sustainable and environmentally sound development. After the chairwoman, Dr. Gro Harlem Brundtland, agreed a definition of sustainable development which is now generally recognised as the standard. A series of seven UN conferences followed on environment and development. They coined the most widely used definition of sustainable development as, development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It means that we seek ways of living, working and being that enable all people of the world to lead healthy, fulfilling, and economically secure lives without destroying the environment and without endangering the future welfare of people and the planet. Future generations should have the same right to a healthy environment as we ourselves. But sustainable development means more than conservation. A healthy economy is just as essential in satisfying our material and non-material needs as preserving the natural foundations of life. And only a society that displays a degree of solidarity is able to distribute its goods and opportunities fairly, preserve that society's values and efficiently and effectively organise the use of natural resources. Sustainable development therefore relates equally to the three domains of economy, environment and society.

2. Life cycle assessment (LCA)

Sustainable development is now on the political and business agendas. In Germany, Professor Schmidt Bleek if the Wuppertal Institue expressed forceful views about the significance of LCA in sustainable development, He argued that LCA would be essential in the transition to more sustainable lifestyles and products and noted ‘’ forms that are not well on the way to developing and selling sustainable products will be cut out of the market over the next 10 to 20 years”.

To look at life cycle aspects of products and materials, the first study begins from the late sixties and early seventies. At the end of 1960s and the beginning of the 1970s in the USA, the environmental assessment of products on packaging was conducted and published. They were called “Resource and Environmental Profile Analyses” (REPAs). The energy consumption, resource consumption and generation of waste, in accordance with the focus in the environmental debate of the time, were mainly focal points. It also focused on issues such as energy efficiency, the consumption of raw materials and to some extent, waste disposal. In 1969, for instance, the Coca Cola company funded a study to compare resource consumption and environmental releases associated with beverage containers. At the same time, in Europe, a similar inventory approach was being developed, later known as the ‘Ecobalance’. In 1972, in the UK, Ian Boustead calculated the total energy used in the production of various types of beverage containers, including glass, plastic, steel and aluminium. Over the next few years, Boustead consolidated his methodology to make it applicable to variety of materials and in 1979, published the Handbook of Industrial Energy Analysis. At the beginning, energy use was considered a higher priority than waste and outputs, due to this, there was little distinction, at the time, between inventory development; resources going into a product, and the interpretation of total associated impacts. But after the oil crisis subsided, energy issues declined in prominence. While interest in LCA continued, thinking progressed a bit more slowly. It was not until the mid eighties and early nineties that a real wave of interest in LCA swept over a much broader range of industries, design establishments and retailers taking many of them by surprise. Interest in the environmental assessment of products grew in connection with discussions on environmental impacts from various forms of packaging at the beginning of the 1980s, and LCAs were used in several European countries to compare different beverage packagings.

Despite almost three decades of development, LCA did not grow so much. The rapid surge of interest in ‘cradle to grave’ assessments of materials and products through the late 1980s and early 1990s meant that by the 1992 UN Earth summit there was a ground-swell of opinion that life cycle assessment methodologies were among the most promising new tools for a wide range of environmental management tasks. From the end of the 1980s to now, interest in life cycle assessment has grown very strongly and a growing number of different and increasingly complex products and systems have been assessed. The most comprehensive international survey of LCA activity to date, The LCA Sourcebook, was published in 1993. At the time, LCA was of limited interest, "outside a very small community of scientists, mostly based in Europe or North America". But then, "the Sourcebook noted, "their work escaped from the laboratory and into the real world". Some countries took an early lead. In the UK, said David Cockburn of PIRA, "it has been surprisingly fast. Ten years ago there was only one main practitioner in the UK, Ian Boustead. Now there are many more academics, consultancies and companies with an in-house capability." While the field continues to progress, the pace has been sporadic. In the past couple of years, however, there has been a growing confidence in the LCA community. For instance, Procter & Gamble's Peter Hindle sees "enormous progress" and is optimistic about the future for life-cycle inventories (LCIs) and about the take-up of life-cycle thinking by management generally that the emerging tools have a real future. Others take a very different view. "LCA is a million miles away from the man in the street," said Dr Mike Jeffs of ICI Polyurethanes. Part of the difficulty in making the technique more accessible comes down to the competing needs of simplicity (or at least clarity) to aid practitioners and credibility, to enable decision-makers to have faith in the robustness of the results. As Mariance Hounum of the Dannish Environmental Protection Agency put it: "We need to find a simple way of communicating the results of LCA, because most people have neither the time nor the interest to read entire documents. But if the answers are simple, then again the question of credibility arises – because there is no way for [stakeholders] to check the validity of the results."

More attention has been paid to the development of a methodological basis for life cycle assessment. The international scientific society of environmental chemists, SETAC (Society of Environmental Toxicology and Chemistry) started work on life cycle assessments in 1990 and within a few years it became the international forum for discussion of the methodological basis of the LCA. Many important international conferences and workshops have been held since 1990 with life cycle assessment as their theme. SETAC has played dominant role. The objective of the SETEC workshop in 1993 in Sesimbra, Portugal was to attempt to set common guidelines for the carrying out of an LCA, and the report from this workshop, "Guidelines for Life-Cycle Assessment: A Code of Practice", has gained the status of a common reference for life cycle assessment.

A series of issues in 1995 and 1996, most particularly the controversy surrounding the planned disposal of the Brent Spar oil buoy and the massive economic and social dislocations caused by public reactions to 'mad cow' disease or BES, helped to re-ignite interest in life-cycle thinking, if not necessarily always in LCA methodologies proper. The Brent Spar debate highlighted the need to use LCA not only to fast moving consumer goods like detergents, or consumer durables like washing machines but also to major structures and installations. Although Shell has conducted work on the 'shadow pricing' of the disposal options, many observers wondered why life cycle thinking had not been built into the design and operation at a much earlier stage. The BSE controversy, in turn, raised the life-cycle issue for a wide range of industries and for consumers, by illustrating how vulnerable agricultural and food chains are to new forms of contamination.

Definition of Life cycle assessment

The definition of life cycle assessment has been given by several organisations as some quoted below.

By SETAC: during the work funded by the Nordic Council of Ministers to prepare a Nordic guideline for life cycle assessment, the SETAC definition of LCA was modified "A process to evaluate the environmental burdens associated with a product system, or activity by identifying and quantitatively describing the energy and materials used and wastes released to the environment, and to assess the impacts of those energy and material uses and releases to the environment. 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 environmental impacts of the system under study in the areas of ecological systems, human health and resource depletion. It does not address economic or social effects."

By www.uneptie.org: Life cycle assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. LCA provides an adequate instrument for environmental decision support. Reliable LCA performance is crucial to achieve a life-cycle economy. The International Organisation for Standardisation (ISO), a world-wide federation of national standards bodies, has standardised this framework within the series ISO 14040 on LCA.

By EPA: Life cycle assessment is a "cradle-to-grave" approach for assessing industrial systems. "Cradle-to-grave" begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product selection.

Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential environmental impacts associated with identified inputs and releases;
- Interpreting the results to help you make a more informed decision.

LCA is a technique for assessing all the inputs and outputs of a product, process, or service (Life Cycle Inventory); assessing the associated wastes, human health and ecological burdens (Impact Assessment); and interpreting and communicating the results of the assessment (Life Cycle Interpretation) throughout the life cycle of the products or processes under review. The term "life cycle" refers to the major activities in the course of the product's life-span from its manufacture, use, maintenance, and final disposal; including the raw material acquisition required to manufacture the product.

By UNEP: Life cycle assessment (LCA) is an environmental assessment tool for evaluation of impacts that a product (or service) has on the environment over the entire period of its life – from the extraction of the raw materials from which it is made, through the manufacturing, packaging and marketing processes, and the use, reuse and maintenance of the product, and on to its eventual recycling or disposal as waste at the end of its useful life.

The ISO/FDIS standard in life cycle assessment (1997a) gives the following definition: LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by

- Compiling an inventory of relevant inputs and outputs of a system;
- Evaluation the potential environmental impacts associated with those inputs and outputs;
- Interpreting the results of the inventory and impact phases in relation to the objectives of the study

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences.

Life cycle assessment

The LCA process is a systematic, phased approach and consists of four components; goal definition and scoping, inventory analysis, impact assessment and interpretation as illustrated in figure 2:

The double arrows between the phases indicate the interactive nature of LCA as illustrated by the following example: when doing the impact assessment it can become clear that the certain information is missing which means that the inventory analysis must be improved, or the interpretation of the results might be insufficient to fulfill the needs required by the actual application which means that the goal and scope definition must be revised.

The brief explanation for each for steps is as follows.

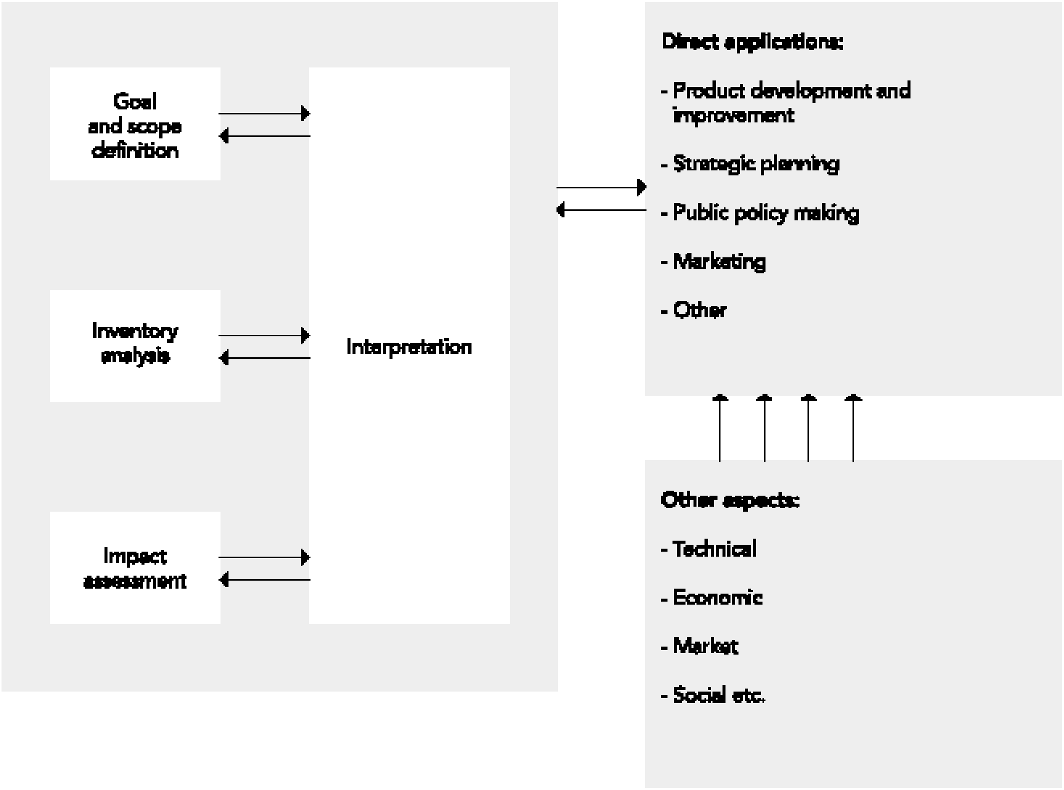

Figure 2 Life cycle assessment framework - phases of an LCA (Source: ISO 1997)

1. Goal definition and scoping – define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment. The products or services to be assessed are defined, a functional basis for comparison is chosen and the required level of detail is defined.

2. Inventory analysis – identify and quantify energy, water and materials usage and environmental releases (e.g. air emissions, solid waste disposal, wastewater discharge). Inventory analysis of extractions and emissions, the energy and raw materials used and emissions to the atmosphere, water and land, are quantified for each process, then combined in the process flow chart and related to the functional basis.

3. Impact assessment – assess the human and ecological effects of energy, water and material usage and the environmental releases identified in the inventory analysis. The effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighed for importance.

4. Interpretation – evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results. The results are reported in the most informative way possible and the need and opportunities to reduce the impact of the products or services on the environment are systematically evaluated.

Life cycle assessment is unique because it encompasses all processes and environmental releases beginning with the extraction of raw materials and the production of energy used to create the product through the use and final disposition of the product. When deciding between two alternatives, LCA can help decision-makers compare all major environmental impacts caused by both products, processes, or services.

The principles, procedure and methods of LCA are presented based on the terminology and structure of the ISO Environmental Management Systems, tools and standards on LCA:

- FDIS/ISO 14040: Environmental management – Life cycle assessment – Principles and framework ISO (1997a).
- DIS/ISO 14041.2: Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis. ISO (1997b).
- CD/ISO 14042.1: Environmental management – Life cycle assessment – Life cycle impact assessment. ISO (1997c).
- CD/ISO 14043.1B: Environmental management – Life cycle assessment – Life cycle interpretation. ISO (1997d).

Selected parts of the standard have been included where appropriated. Please note that the standards on impact assessment and interpretation are still under development and discussion i.e. the quotations shall be regarded as preliminary statements as consensus in ISO has not been reached yet. The quotations from the standards are supplemented by other literature references on LCA, such as:

- Nordic guidelines on life-cycle assessment and technical reports (Lindfors et.al., 1995a;b;c);
- Report from Hanko, Norway on LCA in Strategic management, Product development and improvement, Marketing and Ecolabelling, and Government Policies (Christiansen et. al., 1995);
- SETAC working group reports 1996-97: Simplifying LCA, enhancing inventory methodology, impact assessment, case studies, and conceptually related programmes;
- LCANET workshop background and summary papers 1996 on: Positioning and application of LCA, Goal and scope definition and inventory analysis, impact assessment and interpretation, and Databases and software.

Below a methodological framework for a detailed life cycle assessment is present. This can be considered as a tool box from which individual components can be selected, depending on the particular application.

In summary, there is no one way to life cycle assessment. The technique can be applied with different levels of sophistication, as long as the life cycle approach to assessing choices is retained. Life cycle thinking is the key issue. Irrespective the chosen level of sophistication there is some basic requirements to the LCA i.e. clear and explicit statement of study purpose and goal, reference to the methodology used (e.g. definition of the functional unit, the system boundaries, and the allocation criteria etc.). These requirements can be summarized as a need or transparency in the study i.e. the above mentioned conditions shall be clear to the readers of the LCA report.

Over the past 20-30 years, life cycle assessment has been used by many organizations and companies throughout the last 20-30 years either for internal and external use. For the most part, however, the lack of international consensus or standards on environmental assessment or life cycle assessment, has rendered the results non-comparable and variable. Beginning in 1990, several organizations – including SETAC (Society of Environmental Toxicology and Chemistry) and from 1993 ISO (International Standards Organisation) – began striving to develop consistency in approach to the emerging field. These efforts produced a number of guidelines and draft standards on different aspects of life cycle assessment, with varying degrees of success. The development of LCA methodology in Europe has been further promoted and supported by among others, SPOLD (Society for the Promotion of LCA Development).

Figure 3 illustrates the technical framework for life cycle assessment developed by SETAC in 1993 (Consil et. al., 1993). This terminology presented has been developed further since then, as reflected in the ist of definitions given below and throughout the following text.

The details of each step are described as follows;

<u>Goal and scope definition</u>

Goal and scope definition is the first phase in a life cycle assessment containing the following main issues:

- Goal
- Scope
- Functional unit
- System boundaries
- Data quality
- Critical review process

The definition of the goal and scope is the critical parts of an LCA sue to the strong influence on the result of the LCA. In the Nordic guidelines on life cycle assessment the following minimum decisions and definitions that need to be made are listed (Lindors et. al., 1995c):

- The purpose and intended application
- The function of the studied systems and a defined functional unit
- The studied product group and chosen alternatives, if relevant
- The system boundaries applied
- The data quality needed
- The validation or critical review process needed

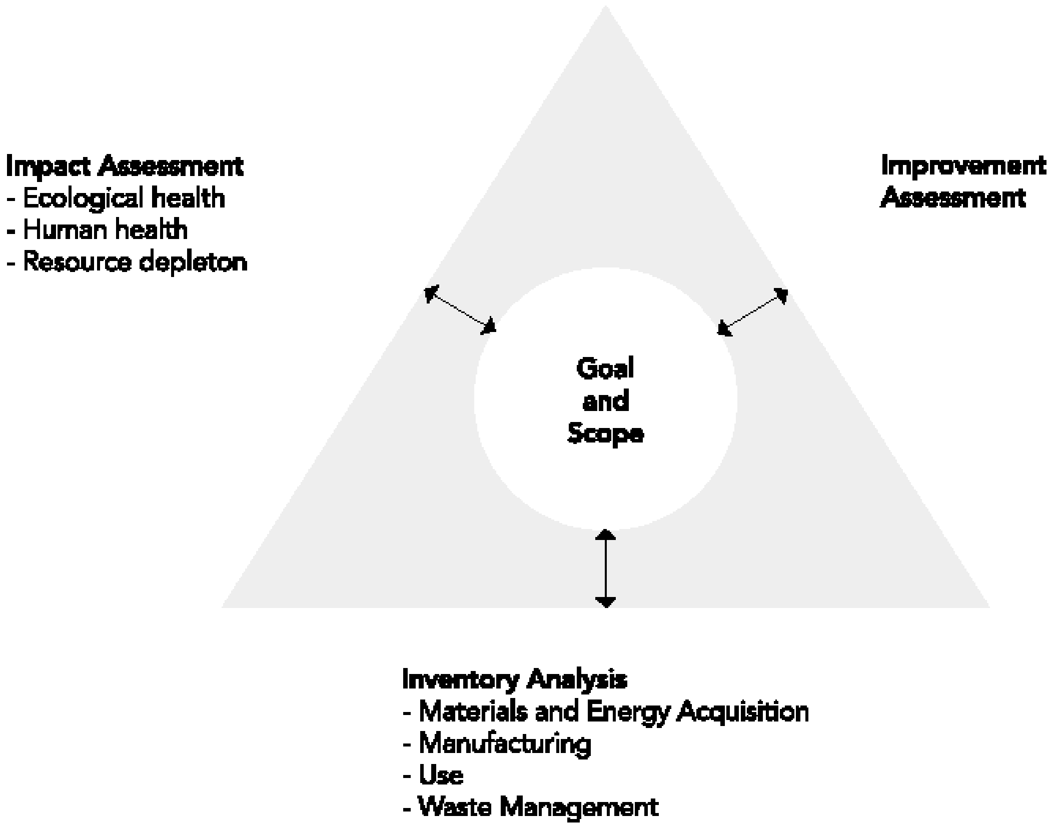

Figure 3 Technical framework for life cycle assessment (Consoli et. al., 1993)

The different needs are described in detail below.

Goal

The definition of the purpose of the life cycle assessment is an important part of the goal definition.

The goal of an LCA study shall unambiguously state the intended application, including the reasons for carrying out the study and the intended audience, i.r. to whom the results of the study are intended to be communicated.

The goal definition also has to define the intended use of the results and users of the result. The practitioner, who has to reach the goal, needs to understand the detailed purpose of the study in order to make proper decisions throughout the study. Examples of goals of a life cycle assessment are:

- To compare two or more different products fulfilling the same function with the purpose of using the information in marketing of the products or regulating the use of the products.
- To identify improvement possibilities in further development of existing products or in innovation and design of new products.
- To identify areas, steps etc. in the life cycle of a product where criteria can be set up as part of the ecolabelling criteria to be used by e.g. the ecolabelling board.

The goal definition determine the level of sophistication of the study and the requirements to reporting. Transparency is essential for all kind of LCA studies. The target group of the LCA study is also important to have in mind in the choice of reporting method.

The goal can be redefined as a result of the findings throughout the study e.g. as a part of the interpretation.

Scope

The definition of the scope of the life cycle assessment sets the borders of the assessment – what is included in the system and what detailed assessment methods are to be used.

In defining the scope of an LCA study, the following items shall be considered and clearly described:

- The functions of the system, or in the case of comparative studies, systems:
- The functional unit:
- The system to be studied:
- The system boundaries:

- Allocation procedures:
- The types of impact and the methodology of impact assessment and subsequent interpretation to be used:
- Data requirement:
- Assumptions:
- Limitations:
- The initial data quality requirements:
- The type of critical review, if any:
- The type and format of the report required for the study

The scope should be sufficient well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the started goal.

LCA is an iterative technique. Therefore, the scope of the study may need to be modified while the study is being conducted as additional information is collected.

Lindfors et. al. (1995c) summaries the single points mentioned in the ISO standard in the following issues to be used in the scoping procedure:

- Product group
- Studied alternatives
- System boundaries
- Impact assessment boundaries
- Data quality goals

The product or product group in focus has to be described in detail in order to identify alternatives to be included in the study. The alternative product or product groups have to be described in detail too, in order to be able to define the system(s) boundaries. The definition of the system(s) boundaries are important in the data collection phase because the system(s) boundaries determine the amount of the work to be done. Impact assessment include a number of different impact categories and impact assessment methods. The impact categories have to be chosen from a default list of categories described. The impact assessment boundaries limit the number of impact categories to be considered. If necessary, the scope can be revised during the study to include new or exclude some of the already chosen impact categories. The data quality goals depend on the overall goal of the study, and include assessment of the level of:

- Accuracy, precision and representativeness of individual data sets (e.g. site – specific or average, measured or estimated data, acceptable age of data etc.)
- Specific data dependent on the included impact categories

The data quality goals can be changed during the study e.g. in the interpretation phase.

Functional unit

Definition of the functional unit or performance characteristics is the foundation of an LCA because the functional unit sets the scale for comparison of two or more productions including improvement to one product (system). All data collected in the inventory phase will be related to the functional unit. When comparing different products fulfilling the same function, definition of the functional unit is of particular importance.

One of the main purposes for a functional units is to provide a reference to which the input and output data are normalized. A functional unit of the system shall be clearly defined and measurable. The results of the measurement of the performance, is the reference flow.

Comparisons between system shall be done on the basis of the same function, measured by the same functional unit in the form of equivalent reference flows.

Three aspects have to be taken into account when defining the functional unit (Linfors et. al., 1995c):

- The efficiency of the product
- The durability of the product
- The performance quality standard

When performing an assessment of more complicated system e.g. multi-functional systems special attention has to be paid to be by-products.

If additional functions of one or other of the systems are not taken into account in the comparison of functional units then these omissions shall be documented. Fro example, system A and B perform function x and y which are represented by the selected functional unit, but system A also performs function z which is not represented in the functional unit. As an alternative, systems associated with the delivery of function z may be added to the boundary of system B to make the systems more comparable. In these cases, the selected processes shall be documented and justified.

System boundaries

The system boundaries define the processes/operations (e.g. manufacturing, transport, and waste management processes), and the inputs and outputs to be taken into account in the LCA. The input can be the overall input to a production as well as input to a single process – and the same is true for the output. The definition of system boundaries is a quite subjective operation and includes the following boundaries (Lindfors et. al., 1995c): geographical boundaries, life cycle boundaries (i.e. limitations in the life cycle) and boundaries between the technosphere and biosphere. Due to the subjectivity of definition of system boundaries, transparency of the defining process and the assumptions are extremely important.

The initial system boundary defines the unit processes which will be included in the system to be modeled. Ideally, the product system should be modeled in such a manner that the manner that the inputs and outputs at its boundary are elementary flows. However, as a practical matter, there typically will not be sufficient time, data, or resources to conduct such a comprehensive study. Decisions must be made regarding which unit processes will be modeled by the study and the level of detail to which these unit processes will be studied. Resources need not be expended on the quantification of minor or negligible inputs and outputs that will not significantly change the overall conclusions of the study. Decisions must also be made regarding which releases to the environment will be evaluated and the level of detail of this evaluation. The decision rules used to assist in the choice of inputs and outputs should be clearly understood and described.

Any omission of life cycle stages, processes or data needs should be clearly started and justified. Ultimately, the sole criterion used in setting the system boundaries is the degree of confidence that the results of the study have not been compromised and that the goal of a given study has been met.

Data quality

The quality of the data used in the life cycle inventory is naturally reflected in the quality of the final LCA. The data quality can be described and assessed in different ways. It is important that the data quality is described and assessed in a systematic way that allows others to understand and control for the actual data quality.

Initial data quality requirements shall be established which define the following parameters:

- Time-related coverage: the described age (e.g. within last 5 years) and the minimum length of time (e.g. annual).
- Geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study (e.g. local, regional, national, continental, global).
- Technology coverage: nature of the technology mix (e.g. weighted average of the actual process mix, best available technology or worst operating unit).

Further descriptions which defined the nature of the data collected form specific sites versus data from published sources, and whether the data should be measured, calculated or estimated shall also be considered.

Data from specific sites should be used for those unit processes that contribute the majority of the mass and energy flows in the systems being studied as determined in the sensitivity analysis. Data from specific sites should also be used for unit processes that are considered to have environmentally relevant emissions.

In all studies, the following additional data quality indicators shall be taken into consideration in a level of detail depending on goal and scope definition:

- Precision: measure of the variability of the data values for each data category expresses (e.g. variance).
- Completeness: percentage of locations reporting primary data from the potential number in existence for each data category in a unit process.
- Representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographic and time period and technology coverage).
- Consistency: qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis.
- Reproducibility: qualitative assessment of the extent to which information about the methodology and data values allows an independent practitioner to reproduce the results reported in the study.

Where a study is used to support a comparative assertion that is disclosed to the public, the above mentioned data quality indicators shall be included.

The data quality can be described systematically by using data quality indicators. Each data quality indicator can be assessed by using a scale from e.g. 1-5, where 1 denotes the best quality (Weidema, 1994b). An example of a data quality index for a data-set can be (1,3,2,1,1) indicating that precision is high, the completeness is medium etc.

The methodology to describe data quality systematically is still quite new. The methodology is still being developed in order to make it more applicable to describe the different environmental data used in a life cycle assessment.

Critical review process

In other uses of environmental standards, certification of a system or product or accreditation of the measuring laboratory is applied. In LCA it is not yet clear what to certify: The study, the individual practitioner or the company of the practitioner. Therefore, a variation of the peer review set-up used in scientific journals is used as described below.

The purpose of the critical review process is to ensure the quality of the life cycle assessment. The review can be either internal, external or involve interested parties as defined within the goal and scoping definition.

The critical review process shall ensure that:

- The methods used to carry out the LCA are consistent with the international standard;
- The methods used to carry out the LCA are scientifically and technically valid;
- The data used are appropriate and reason able in relation to the goal of the study;
- The interpretations reflect the limitations identified and the goal of the study;
- The study report is transparent and consistent.

If an LCA study is to be critically reviewed, the scope of the critical review should be defined during the goal and scope definition phase of the study. The scope should identify why the critical review is being undertaken, what will be covered and to what level of detail, and who needs to be involved in the process.

Internal review

A critical review may be carried out internally. In such case, it shall be performed by an internal expert independent of the LCA study.

Expert review

A critical review may be carried out externally. In such a case, it shall be performed by an external expert, independent of the LCA study.

Review by interested parties

An external, independent expert is selected by the original study commissioner to act as chair person of a review panel. Based on the goal, scope and budget available for the review, the chair person selects other independent qualified reviewers.

“Interested parties” also included stakeholders. The review process can be undertaken in parallel to the LCA study and corrections can be made continuously (in-process critical review). Otherwise the critical review can be made on the final draft with the possibility to make corrections before finishing the report (end-of-process critical review). In some cases it may be relevant to publish the critical review report along with the LCA study.

Inventory analysis

Inventory analysis is the second phase in a life cycle containing the following main issues:

- Data collection
- Refining system boundaries
- Calculation
- Validation of data
- Relating data to the specific system
- Allocation

The different issues will be described in detail below. The description will be based in the terminology defined by ISO. This section includes a short presentation of software tools that can be a useful help in structuring and calculating the inventory data. The inventory analysis and the tasks to be fulfilled can obviously be supported by a flow sheet for the considered product; an example of a flow sheet can be seen in figure 4. Each of the different phases can be mage up from different single processes e.g. production of different kinds of raw material to be combined in the material production phase. The different phases are often connected by transport-processes. Reuse do often involve a cleaning process.

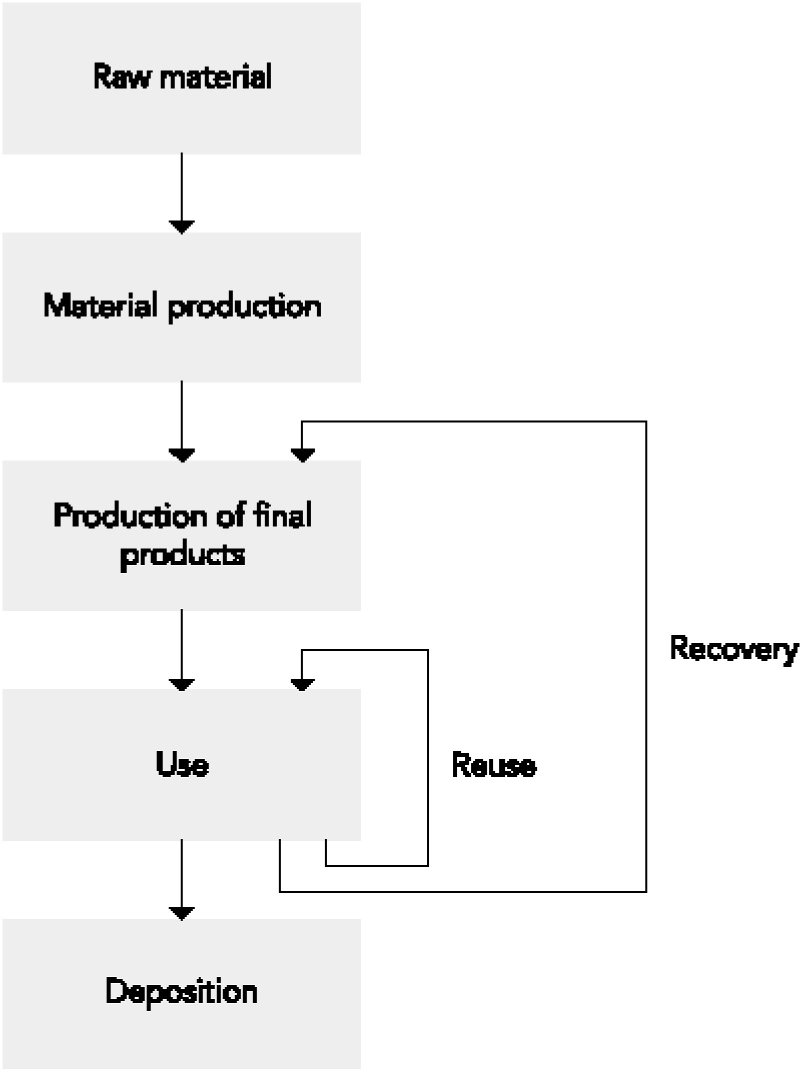

Figure 4 Example of a simple flow sheet to be used as support in the data collection

Compilation of a proper process diagram is crucial to succeed the LCA study i.e. to be sure to include all relevant processes etc. The process diagram do also have a function in the reporting of the LCA while it improve the transparency of the study.

Data collection

The inventory analysis includes collection and treatment of data to be used in preparation of a material consumption, waste and emission profile for all the phases in the life cycle, but also for the whole life cycle. The data can be site specific e.g. from specific companies, specific areas and from specific countries but also more general e.g. data from more general sources e.g. trade organizations, public survey etc. The data have to be collected from all single processes in the life cycle. These data can be quantitative or qualitative. The quantitative data are important in comparisons of processes or materials, but often the quantitative data are missing or the quality is poor (too old or not technologically representative etc.). The more descriptive qualitative data can be used for environmental aspects or single steps in the life cycle that cannot be quantified, or if the goal and scope definition allow a non-quantitative description of the conditions.

Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and releases to air, water and land associated with the system. Interpretation may be drawn from these data, depending on the goals and scope of the LCA. These data also constitute the input to the life cycle impact assessment.

The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data-collection procedures so that the goals of the study will still be met. Sometimes, issues may be identified that require revisions to the goal or scope of the study.

The qualitative and quantitative data for inclusion in the inventory shall be collected for each unit process that is included within the system boundaries. The procedures used for data collection may vary depending on the scope, unit process or intended application of the study. Data collection can be a resource intensive process. Practical constraints in data collection should be considered in the scope and documented in the report.

Some significant calculation considerations are outlined in the following:

- Allocation procedures are needed when dealing with systems involving multiple products (e.g. multiple products from petroleum refining). The materials and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly stated procedures, which shall be documented and justified.
- The calculation of energy flow should take into account the different fuels and electricity sources used, the efficiency of conversion and distribution of energy flow as well as the inputs and outputs associated with the generation and use of that energy flow.

Data collection is often the most work intensive part of a life cycle assessment, especially of site specific data are required for all the single processes in the life cycle. In many cases average data from the literature (often previous investigations of the same or similar products or materials) or data from trade organizations are used. A number of European trade organizations have published or plan to publish “cradle-to-grave” data that include information on inputs and outputs for materials through production of semi-manufactures product to final products.

The average data can be used in the conceptual or simplified LCA to get a first impression of the potential inputs and outputs from producing specific materials. When doing a detailed LCA site specific data must be preferred. Average data are often some years old and therefore do not represent the latest in technological development.

The result of the data collection can be presented in an inventory table as shown in table 1 with an example from the material data published by the Association of Plastic Manufacturers of Europe (APME).

When making a detailed LCA the inventory tables are invariable detailed, intricate and complex whereas the inventory tables required in a streamlined LCA may be more simple if stated in the goal and scope definition i.e. focus on selected emissions as e.g. carbon dioxide, sulfur dioxides and nitrogen oxides.

The applicability of data-sets for specific products i.e. site specific data in life cycle assessment depend on the format of the data. In order to ensure that applicability of industrial data SPOLD has initiated a project with the aim to develop a standard format for data sets to be used in LCA and with the second aim to ensure consistency in registration of data in a data base. The structure of the extensive SPOLD data format consists of five parts (SPOLD, 1996):

A	Data identification; data sources and treatment
B	System model (sub systems; cut-off rules; co-products and allocation rules; energy models; transport models; waste models; other assumptions; other information)
C	System structure
D1	Data 1: inputs (known inputs from technosphere; known inputs from nature)
D2	Data 2: outputs (known outputs to technosphere; known outputs to nature)
D3	Data 3: other
D4	Data 4: balances
E	List of reference

The SPOLD data format will be available by downloading from WWW
(http://ipt.dtu.dk/~ap/icc/).

Refining system boundaries

The system boundaries are defined as a part of the scope definition procedure. After the initial data collection, the system boundaries can be refined e.g. as a result of decisions of exclusion life stages or sub-systems, exclusion of material flows or inclusion of new unit processes shown to be significant according to the sensitivity analysis.

Reflecting the iterative nature of LCA, decisions regarding the data to be included shall be based on a sensitivity analysis to determine their significance, thereby verifying the initial analysis. The initial product system boundary shall be revised in accordance with the cut-off criteria established in the scope definition. The sensitivity analysis may result in:

- The exclusion of life cycle stages or sub-systems when lack of significance can be shown by the sensitivity analysis
- The exclusion of material flows which lack significance to the outcome of the results of the study
- The inclusion of new unit processes that are shown to be significant in the sensitivity analysis

Table 1 Inventory table presenting "Gross inputs and outputs associated with the production of 1 kg of PVC averaged over all the polymerization processes" (Boustead, 1994).

		Unit	Average*
Fuels	Coal	MJ	6.96
	Oil	MJ	6.04
	Gas	MJ	15.41
	Hydro	MJ	0.84
	Nuclear	MJ	7.87
	Other	MJ	0.13
	Total fuels	MJ	37.24
Feedstock	Oil	MJ	16.85
	Gas	MJ	12.71
	Total feedstock	MJ	29.56
Total fuel plus feedstock		MJ	66.80 (48-89)
Raw material	Iron ore	mg	400
	Limestone	mg	1600
	Water	mg	1900000

Table 1 (Cont'd)

		Unit	Average*
	Bauxite	mg	220
	Sodium chloride	mg	690000
	Sand	mg	1200
Air emissions	Dust	mg	3900
	Carbon monoxide	mg	2700
	Carbon dioxide	mg	1944000
	Sulfur oxides	mg	13000
	Nitrogen oxides	mg	16000
	Chlorine	mg	2
	Hydrogen chloride	mg	230
	Hydrocarbons	mg	20000
	Metals	mg	3
	Chlorinated organics	mg	720
Water emissions	COD	mg	1100
	BOD	mg	80
	Acid as H+	mg	110
	Metals	mg	200
	Chloride ions	mg	40000
	Dissolved organics	mg	1000
	Suspended solids	mg	2400
	Oil	mg	50
	Dissolved solids	mg	500
	Other nitrogen	mg	3
	Chlorinated organics	mg	10
	Sulfate ions	mg	4300
	Sodium ions	mg	2300

Table 1 (Cont’d)

		Unit	Average*
Solid waste	Industrial waste	mg	1800
	Mineral waste	mg	66000
	Slags and ash	mg	47000
	Inert chemicals	mg	14000
	Regulated chemicals	mg	1200

* The average values cover a broad spectrum different values representing different technologies. In many cases the actual range of e.g. emissions is more applicable when comparing site specific data with “average” data.

The results of this refining process and the sensitivity analysis shall be documented. This analysis serves to limit the subsequent data handling to those input and output data which are determined to be significant to the goal of the LCA study.

Calculation procedures

No formal demands exist for calculation on life cycle assessment except the described demands for allocation procedures. Due to the amount of data it is recommended as a minimum to develop a spreadsheet for the specific purpose. A number of general PC-programs/software for calculation are available e.g. spreadsheets/spreadsheet applications (EXCEL/Lotus etc.), together with many software programs developed specially for life cycle assessment. The appropriate program can be chosen depending on the kind and amount of data to be handled.

Validation of data

The validation of data has to be conducted during the data collection process in order to improve the overall data quality. Systematic data validation may point out areas where data quality must be improved or data must be found in similar processes or unit processes.

During the process of data collection, a permanent and iterative check on data validity should be conducted. Validation may involve establishing, for example, mass balance, energy balances and/or comparative analysis of emission factors. Obvious anomalies in the data appearing from such validation procedures shall result in (alternative) data values complying with the data quality requirements as established.

For each data category and for each reporting location where missing data are identified, the treatment of the missing data should result in:

- An acceptable reported data value;
- A "zero" data value if justified; or
- A calculated value based on the reported valued from unit processes employing similar technology.

Data from similar processes or unit process do often have a lower overall data quality. This can be reflected in the data quality index for the specific data-set.

Relating data

The fundamental input and output data are often delivered from industry in arbitrary unit e.g. energy consumption as MJ/machine/week or emissions to the sewage system as mg metals/litre wastewater. The specific machine or wastewater stream is rarely connected to the production of the considered product alone but often to a number of similar products or perhaps to the whole production activity.

For each unit process, an appropriate reference flow shall be determined (e.g. one kilogram of material or one megajoule for energy). The quantitative input and output data of the unit process shall be calculated in relation to this reference flow.

Based on the refined flow chart and systems boundary, unit processes are interconnected to allow calculation of the complete system. This is accomplished by normalizing the inputs and outputs of a unit process in the system to the functional unit and then normalizing all upstream and downstream unit processes accordingly. The calculation should result in all system input and output data being referenced to the functional unit. Care should be taken when aggregating the inputs and outputs in the product system. The level of aggregation should be sufficient to satisfy the goal of the study.

Data categories should only be aggregated if they are related to equivalent substances and to similar environmental impacts. If more detailed aggregation rules are required, they should be justified in the goal and scope definition phase of the study or this should be left to a subsequent impact assessment phase.

The reference flow or functional unit shall be defined in order to describe and cover the actual production/function of the considered product e.g. by number of hours the actual machinery is in action per week or the actual emission of wastewater from the process. It this is not the case it will not be possible to relate data to the actual product.

Allocation and recycling

When performing a life cycle assessment of a complex system, it may be possible to handle all the impacts and outputs inside the system boundaries. This problem cab be solved either by:

1. expanding the system boundaries to include all the inputs and outputs or by

2. allocating the relevant environmental impacts to the studied system

When avoiding allocation by e.g. expanding the system boundaries there is a risk of making the system too complex. The data collection, impact assessment and interpretation can then become too expensive and unrealistic in time and money. Allocation may be a better alternative, if an appropriate method can be found for solving the actual problem.

Since the inventory is intrinsically based on material balances between inputs and outputs, allocation procedures should approximate as much as possible such fundamental input-output relationships and characteristics. Some principles should be kept in mind when allocating loadings. They are general and thorough enough to be applicable to co-products, internal energy allocation, services (e.g. transport, waste treatment), and to recycling, either open or closed-loop:

- The product system under consideration seldom exists in isolation; it generally included unit processes which may be shared with other product systems. The study should identify these unit processes and deal with them according to the procedures presented below.
- The inputs and outputs of the unallocated system shall equal the sum of the corresponding inputs and outputs of the allocated system. Any deviation from mass and energy balance shall be reported and explained.
- Whenever several alternative allocation procedure seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach.

Allocation can be necessary when dealing with:

- Multi-output “black box” processes, i.e. when more than one product is produced and some of these product flows are crossing the system boundaries.
- Multi-input processes, such as waste treatment, where a strict quantitative causality between inputs and emissions etc. seldom exists.

- Open-loop recycling, where a waste material leaving the system boundaries is used as a raw material by another system, outside the boundaries of the studied system.

On the basis of the principle presented above, the following descending order of allocation procedures is recommended:

1. Whenever possible, allocation should be avoided or minimized. This may be achieved by subdividing the unit process into two or more sub-processes, some of which can be excluded from the system under study. Transport and materials handling are examples of processes which can sometimes be partitioned in this way. For systems which deliver more than one product or function, or involve recycle streams, allocation may be avoided or reduced by including further unit processes thereby expanding the system boundaries so that inputs, outputs or recycles remain within the system.

2. Where allocation cannot be avoided, the system inputs and outputs should be partitioned between its different products or functions in a way which reflects the underlying physical relationships between them; i.e. they must reflect the way on which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system. These ”causal relationships” between flows into and out of the system may be represented by a process model, which can also represent the economic relationship of the system. The resulting allocation will not necessarily be in proportion to any simple measure such as mass or molar flows of co-products.

3. where physical relationship cannot be established or used as the basis for allocation the inputs should be allocated between the products and functions in a way which reflects economic relationships between them. For example, burdens might be allocated between co-products in proportion to the economic value of the products.

Any deviation from these procedures shall be documented and justified.

Some inputs may be partly co-products and partly waste. In such a case, it is necessary to identify the ratio between co-products and waste since burdens shall/are to be allocated to the co-product only.

There shall be uniform application of allocation procedures to similar inputs and outputs of the systems under consideration. For example if allocation is made to useable products (e.g. intermediate or discarded products) leaving the systems, the allocation procedure shall be similar to the allocation method used for such products entering the systems. The allocation procedure may vary the allocation factor from 0% to 100%.

Lindfors et. al. (1995c) suggest allocations should be based on the following guiding principle mentioned in descending order:

- Natural causality or an adequate approximation
- Economic/social causality e.g. expected gain or gross sales value
- Physical parameters as allocation parameter e.g. mass of outputs, energy content of the output, exergy content of output, area of output, volume of output, molar content of output or arbitrary numbers (100/0% or 50/50%)

The 50/50% allocation method is recommended for simplified LCA because the method ensure that information on “key issues” is not lost. This method can be used in allocation of environmental loadings caused by primary production, waste management and recycling processes.

Recycling of products implies that the environmental inputs and outputs associated with the manufacturing of a product and its recycling are to be shared by more than one product system.

Any system in which recycling occurs, can usually be described as one of three different models:

A. If sufficient information is available as to the proportion of recycled product that is used in another product system (the export ratio), an open-loop recycling approach can be chosen. Open-loop recycling is actually a special case of allocation.

B. If sufficient information is available on the proportion of recycled product that is used in the same product system, a closed-loop recycling approach can be chosen. The recycled product replaces an amount of the virgin product.

C. If sufficient information is available about hw many times the same material is recycled (whether or not within the same product system), the "virgin" environmental inputs and outputs of each product cycle may be divided by the number of cycles which these material will undergo. The result will be added to the other environmental inputs and outputs of each single product cycle ("cascade recycling"). This model would comprise a sequence of models A and / or B.

D.

Claims regarding recycling shall be documented and justified and be based on actual practice rather than theoretical possibilities.

The detail and complexity of the allocation procedures to be used depend on the level of sophistication of the actual life cycle assessment.

The other point of view for the key steps of a life cycle inventory has been cited as follows:

In 1993, EPA published a guidance document entitled *Life-Cycle Assessment: Inventory Guidelines and Principles.* In 1995, EPA published *Guidelines for Assessing the Quality of Life-Cycle Inventory Analysis*. The combination of these two guidance documents provides the framework for performing an inventory analysis and assessing the quality of the data used and the results. The two documents define the following steps of a life cycle inventory:

- develop a flow diagram of the processes being evaluated
- develop a data collection plan
- collect data
- evaluate and report results

Each step is summarized below.

Step 1: Develop a Flow Diagram

A flow diagram is a tool to map the inputs and outputs to a process or system. The "system" or "system boundary" varies for every LCA project. The goal definition and scoping phase establishes initial boundaries that define what is to be included in a particular LCA; these are used as the system boundary for the flow diagram. Unit processes inside of the system boundary link together to form a complete life cycle picture of the required inputs and outputs (material and energy) to the system. Figure 5 illustrates the components of a generic unit process within a flow diagram for a given system boundary.

The more complex the flow diagram, the greater the accuracy and utility of the results. Unfortunately, increased complexity also means more time and resources must be devoted to this step, as well as the data collecting and analyzing steps.

Flow diagrams are used to model all alternatives under consideration (e.g., both a baseline system and alternative systems). For a comparative study, it is important that both the baseline and alternatives use the same system boundary and are modelled to the same level of detail. If not, the accuracy of the results may be skewed.

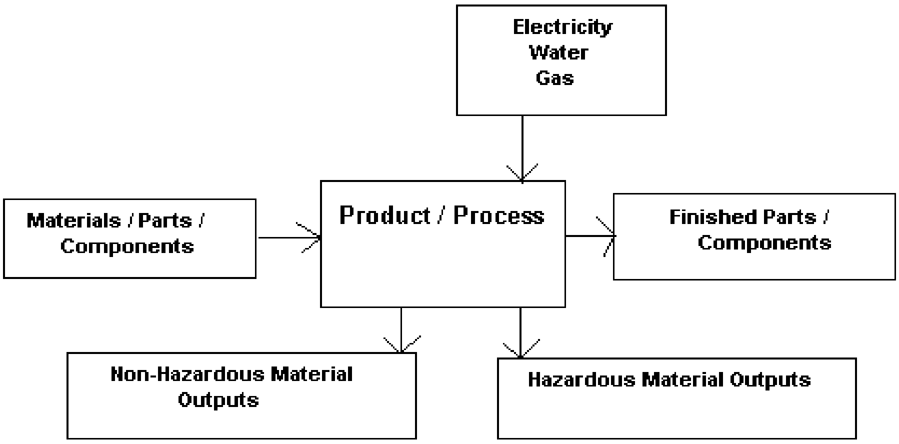

Figure 5 Unit Process Input/Output Template

Step 2: Develop an LCI Data Collection Plan

As part of the goal definition and scoping phase, the required accuracy of data was determined. When selecting sources for data to complete the life cycle inventory, an LCI data collection plan ensures that the quality and accuracy of data meet the expectations of the decision-makers.

Key elements of a data collection plan include the following:

- Defining data quality goals,
- Identifying data sources and types,
- Identifying data quality indicators, and
- Developing a data collection worksheet and checklist.

Each element is described below.

Define Data Quality Goals - Data quality goals provide a framework for balancing available time and resources against the quality of the data required to make a decision regarding overall environmental or human health impact (EPA 1986). Data quality goals are closely linked to overall study goals and serve two primary purposes:

- Aid LCA practitioners in structuring an approach to data collection based on the data quality needed for the analysis; and
- Serve as data quality performance criteria.

No pre-defined list of data quality goals exists for all LCA projects. The number and nature of data quality goals necessarily depends on the level of accuracy required to inform the decision-makers involved in the process.

The following is a sample list of hypothetical data quality goals:

- Site-specific data are required for raw materials and energy inputs, water consumption, air emissions, water effluents, and solid waste generation.
- Approximate data values are adequate for the energy data category.
- Air emission data should be representative of similar sites in the U.S.

- A minimum of 95% of the material and energy inputs should be accounted for in the LCI.

Identify Data Quality Indicators - Data quality indicators are benchmarks to which the collected data can be measured to determine if data quality requirements have been met. Similar to data quality goals, there is no pre-defined list of data quality indicators for all LCIs. The selection of data quality indicators depends upon which ones are most appropriate and applicable to the specific data sources being evaluated. Examples of data quality indicators are precision, completeness, representativeness, consistency, and reproducibility.

Identify Data Sources and Types - For each life cycle stage, unit process, or type of environmental release, specify the necessary data source and/or type required to provide sufficient accuracy and quality to meet the study's goals. Defining the required data sources and types prior to data collection helps to reduce costs and the time required to collect the data.

Examples of data sources include the following:

- meter readings from equipment

- equipment operating logs/journals
- industry data reports, databases, or consultants
- laboratory test results
- government documents, reports, databases, and clearinghouses
- other publicly available databases or clearinghouses
- journals, papers, books, and patents
- reference books
- trade associations
- related/previous life cycle inventory studies
- equipment and process specifications
- best engineering judgement.

Examples of data types include:

- measured
- modeled
- sampled
- non-site specific (i.e., surrogate data)
- non-LCI data (i.e., data not intended for the purpose of use in a LCI)
- vendor data.

The required level of aggregated data should also be specified. For example, whether data are representative of one process or several processes.

Develop a Data Collection Worksheet and Checklist - The next step is to develop a life cycle inventory checklist that covers most of the decision areas in the performance of an inventory. A checklist can be prepared to guide data collection and validation and to enable construction of a database to store collected data electronically. The following eight general decision areas should be addressed on the inventory checklist:

- purpose of the inventory
- system boundaries

- geographic scope
- types of data used
- data collection procedures
- data quality measures
- computational model construction
- presentation of results.

An accompanying data worksheet should be used to record the inputs and outputs for each process modelled in the flow diagram.

The checklist and worksheet are valuable tools for ensuring completeness, accuracy, and consistency. They are especially important for large projects when several people collect data from multiple sources. The checklist and worksheet should be tailored to meet the needs of a specific LCI.

Step 3: Collect Data

The flow diagram(s) developed in Step 1 provides the road map for data to be collected. Step 2 specifies the required data sources, types, quality, accuracy, and collection methods. Step 3 consists of finding and filling in the flow diagram and worksheets with numerical data. This may not be a simple task. Some data may be difficult or impossible to obtain, and the available data may be difficult to convert to the functional unit needed. Therefore, the system boundaries or data quality goals of the study may have to be refined based on data availability. This iterative process is common for most LCAs.

Data collection efforts involve a combination of research, site-visits and direct contact with experts which generate large quantities of data. An electronic database or spreadsheet can be useful to hold and manipulate the data. As an alternative to developing a computer model from scratch, it may be more cost effective to buy a commercially available LCA software package. Prior to purchasing an LCA software package, the decision-makers or LCA practitioner should insure that it will provide the level of data analysis required.

A second method to reduce data collection time and resources is to obtain non-site specific inventory data. Several organizations have developed databases specifically for LCA that contain some of the basic data commonly needed in constructing a life cycle inventory. Some of the databases are sold in conjunction with LCI data collection software; others are stand-alone resources. Many companies with proprietary software also offer consulting services for LCA design.

Step 4: Evaluate and Document the LCI Results

Now that the data has been collected and organized into one format or another, the accuracy of the results must be verified. The accuracy must be sufficient to support the purposes for performing the LCA as defined in the goal and scope.

Steps 1 and 2 of Chapter 5, Life Cycle Interpretation, describe how to efficiently assess the accuracy of the LCI results. As illustrated in Exhibit 1-2, Phases of an LCA, in Chapter 1, LCA is an iterative process. Determining the sensitivity of the LCI data collection efforts in regards to data accuracy prior to conducting the life cycle impact assessment (LCIA) saves time and resources. Otherwise, the LCIA effort may have to be repeated if it is later determined that the accuracy of the data is insufficient to draw conclusions.

When documenting the results of the life cycle inventory, it is important to thoroughly describe the methodology used in the analysis, define the systems analyzed and the boundaries that were set, and all assumptions made in performing the inventory analysis. Use of the checklist and worksheet (see Step 2) supports a clear process for documenting this information.

The outcome of the inventory analysis is a list containing the quantities of pollutants released to the environment and the amount of energy and materials consumed. The information can be organized by life cycle stage, by media (air, water, land), by specific process, or any combination thereof that is consistent with the ground rules defined, Goal Definition and Scoping, for reporting requirements.

Impact assessment

Impact assessment is the third phase in a life cycle assessment containing the following main issues:

- Selection and definition of impact categories – identifying relevant environmental impact categories (e.g. global warming, acidification, terrestrial toxicity).
- Classification – assigning impact results to the impact categories (e.g. classifying CO2 emissions to global warming).
- Characterization – modeling impact within impact categories using science-based conversion factors (e.g. modeling the potential impact of CO2 and methane on global warming).
- Normalization – expressing potential impacts in ways that can be compared (e.g. comparing the global warming impact of CO2 and methane for the two options).
- Grouping – sorting or ranking the indicators (e.g. sorting the indicators by location: local, regional and global).
- Weighing – emphasizing the most important potential impacts
- Evaluating and reporting LCIA results – gaining a better understanding of the reliability of the LCIA results

The elements are explained in relation to the draft ISO standard CD 14042.1 (ISO, 1997c). The different impact categories are described briefly with reference to detailed descriptions of the methodologies. Weighting or equivalent factors are also presented where found appropriate.

The impact assessment can be expressed as a “quantitative and/or qualitative process to characterize and assess the efforts of the environmental interventions identified in the inventory table” (Heijungs & Hofstetter, 1996). According to these authors, “the impact assessment component consists in principle of the following three or four elements: classification, characterization, (normalization,) and valuation are sometimes merged. Valuation is proposed changed to weighting by ISO (ISO 1997c) and this terminology has been adapted by the SETAC-Europe working group (Udo de Haes, 1996a).

The framework for life cycle impact assessment is defined as follows (ISO 1997c):

The life cycle impact assessment framework and its procedure should be transparent and provide the flexibility and practicality for this wide range of application. A large range in the levels of effort and intensity of the analysis are possible with life cycle assessment for different applications. In addition, impact assessment should be effective in terms of cost and resources used.

Life cycle impact assessment is composed of several individual elements. These are category definition, classification, characterization and weighting.

The distinction into different elements is necessary for several reasons:

- Each element represents a different specific procedure;
- All elements are not required for all applications;
- Methods, assumptions and value-choices can be made more transparent and can be documented and reviewed;
- The effects of methods, assumptions and value-choices on the results can be demonstrated.

Depending on the goal and scope of the study and on the application of the study all or parts of the elements can be used.

Selection and definition of impact categories

The life cycle impact assessment involves as a first element the definition of the impact categories to be considered (ISO, 1997c). This is a follow-up of the decisions made in the goal and scoping phase. Based on the type of information collected in the inventory phase the boundaries defined in the goal and scoping may be redefined.

The aim of this section is to provide guidance for selecting and defining the environmental categories.

Numerous environmental categories have been proposed for life cycle impact assessment. Most studies will select from these previous efforts and will not define their own categories. The selection of categories should be consistent with the goal and scope of the study. This selection should not be used to avoid or disguise environmental issues or concerns. The completeness and extent of the survey of categories is goal and scope dependent.

The impact categories are selected in order to describe the impacts caused by the considered products or product systems. A number of questions have to be considered when selecting impact categories (Lindfors et.al., 1995):

- Completeness – all environmental problems of relevance should be covered by the list
- Practicality – the list should not contain too many categories
- Independence – double counting should be avoided by choosing mutually independent impact categories
- Relation to the characterization step – the chosen impact categories should be related to available characterization methods

The first step in an LCIA is to select the impact categories that will be considered as part of the overall LCA. This step should be completed as part of the initial goal and scope definition phase to guide the LCI data collection process and required reconsideration following the data collection phase. The items identified in the LCI have potential human health and environmental impacts. For instance, an environmental release identified in the LCI may harm human health by causing cancer or sterility, or affect workplace safety. Likewise, a release identified in the LCI could also affect the environment by causing acid rain, global warming, or fishkills in a local lake. For an LCIA, impacts are defined as the consequences caused by the input and output streams of a system on human health, plants and animals, or the future availability of natural resources. Typically LCIAs focus on the potential impacts to three main categories: human health, ecological health, and resource depletion. Table 2 shows some of the more commonly used impact categories.

The impact categories considered are:

- Abiotic resources
- Biotic resources
- Land use
- Global warming
- Stratospheric ozone depletion
- Ecotoxicologial impacts
- Human toxicological impacts
- Photochemical oxidant formation acidification
- Eutrophication
- Work environment

Table 2 Commonly used life cycle impact categories

Impact category	Scale	Relevant LCI data (classification)	Common characterization factor	Description of characterization factor
Global warming	Global	Carbon dioxide (CO_2) Nitrogen dioxide (NO_2) Methane (CH_4) Chloroflurocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl bromide (CH_3Br)	Global warming potential	Converts LCI data to carbon-dioxide (CO_2) equivalents Notes: Global warming potentials can be 50, 100, or 500 year potentials
Stratosheric ozone depletion	Global	Chloroflurocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons Methyl bromide (CH_3Br)	Ozone depleting potentail	Converts LCI data to trichlorofluoro-methane (CFC-11) equivalents
Acidification	Regional Local	Sulphur oxides (SO_x) Nitrogen oxides (NO_x) Hydrochloric acid (HCl) Hydrofluoric acid (HF) Ammonia (NH_4)	Acidification potential	Converts LCI data to hydrogen (H+) ion equivalents

Table 2 (Cont'd)

Impact category	Scale	Relevant LCI data (classification)	Common characterization factor	Description of characterization factor
Eutrophication	Local	Phosphate (PO_4) Nitrogen oxide (NO) Nitrogen dioxide (NO_2) Nitrates Ammonia (NH_4)	Eutrophication Potential	Converts LCI data to Phosphate (PO4) equivalents
Photochemical smog	Local	Non-methane hydrocarbon (NMHC)	Photochemical oxidant creation potential	Converts LCI data to ethane (C_2H_6) equivalents
Terrestrial toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC50	Converts LC50 data to equivalents
Resource depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used	Resource depletion potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve
Land use	Global Regional Local	Quantity disposed of in a landfill	Solid waste	Converts mass pf solid waste into volume using an estimated density

The impact categories are described in details as follows;

Global warming

Global warming – or the ‘greenhouse effect’ – is the effect of increasing temperature in the lower atmosphere. The lower atmosphere is normally heated by incoming radiation from the outer atmosphere (from the sun). A part of the radiation is normally reflected by the soil surface but the content of carbon dioxide and other ‘greenhouse’ gases (e.g. methane, nitrogen dioxide, chlorofluorocarbons) in the atmosphere reflects the infrared (IR)-radiation resulting in the greenhouse effect i.e. an increase of temperature in the lower atmosphere to a level above normal. The possible consequences of the greenhouse effect include an increase of the temperature level leading to melting of the polar ice caps, resulting in elevated sea levels. The increasing temperature level may also result in regional climate changes.

The potential global warming or greenhouse effect is normally quantified by using global warming potential (GWP) for substances having the same effect as CO_2 in reflection of heat radiation. GWP for greenhouse gases are expressed as CO_2 –equivalent i.e. their effect are expressed relatively to the effect of CO_2 . Global warming potentials are developed by the “Intergovernmental Panel on Climatic Change” (IPCC) for a number of substances. GWPs are normally based on modeling and are quantified for time horizons of 20, 100 or 500 years for a number of known greenhouse gases (e.g. CO_2 ,CH_4 , N_2O, CFCs, HCFCs, HFCs and several halogenated hydrocarbons etc.)

Hauschild & Wenzel suggest modeling and quantification of GWP for indirect effects of e.g. VOCs of petrochemical origin by using their photochemical ozone creation potential (POCP) as shown in the following formula:

$$GWP(O_3)_{gas\ (i)} = GWP(O_3)_{CO} \frac{POCP_{gas\ (i)}}{POCP_{CO}}$$

Where $GWP(O_3)_{gas\ (i)}$ express the GWP of troposheric oxidation of gas i, $GWP(O_3)_{CO}$ express GWP of CO, $POCP_{gas\ (i)}$ express the total photochemical formation of ozone by oxidation of gas I, and $POCP_{CO}$ express the formation of ozone by oxidation of CO.

The potential greenhouse effect of a process can be estimated by calculating the product of the amount of emitted greenhouse gas per kg produced material and the potential for greenhouse effect given in kg CO_2 – equivalents per kg for each gas. Finally, the contribution to the potential greenhouse effect from each gas has to be summarized. This calculation procedure can be expressed mathematically as:

Potential greenhouse effect (kg CO_2 – eq.) = $\Sigma_i\ GWP_i \times m_i$

If a specific time horizon cannot be chosen and justified in the goal definition it is suggested to estimate the greenhouse effect based on GWPs for 20, 100 as well as 500 years (Lindfors et. al., 1995c)

Stratospheric ozone depletion

Decomposition of the stratospheric ozone layer will cause increased incoming UV-radiation leading to impacts on humans such as increased levels of e.g. skin cancer, cataracts and decreased immune defense, but also impacts on natural organisms and ecosystems e.g. plankton in the south pole region, where the decomposition of the ozone layer is already significant.

The stratospheric ozone layer occurs at an altitude from 10-4- km, with maximum concentration from 15-25 km. the maximal generation of stratospheric ozone (O_3) occur in the top of the stratosphere at the altitude of 40 km as a result of a reaction of molecular oxygen (O_2) and atomic oxygen (O). The reaction depends on the UV-radiation used in the decomposition of oxygen and the availability of other molecules used in the absorption of excess energy from the decomposition process.

The decomposition of ozone is enhanced by the stratospheric input of anthropogenic halogenated compounds (e.g. CFCs, HCFCs, halons etc.). Ozone depletion potentials (ODP) have been presented by the World Meteorological Organisation (WMO) for a number of halogenated compounds (Solomon & Wuebbles, 1995; Pyle et al., 1991). The ODPs are given as CFC-11 equivalents i.e.:

$$ODP_i = \frac{\text{modeled stratospheric ozone depletion due to compound i}}{\text{modeled stratospheric ozone depletion due to same quantity of CFC-11}}$$

ODPs are presented in table 3 for CFCs, HCFCs and halons

Table 3 Ozone depletion potentials (OPD) given in kg CFC-11 equivalents/kg gas (Solomon & Wuebbles, 1995; Pyle et al., 1991; Solomon & Albritton, 1992)

Substance	Formula	Life time years	Total ODP	5 years	10 years	15 years	20 years	30 years	40 years	100 years	500 years
CFC-11	CFCl3	50±5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CFC-12	CF2Cl2	102	0.82	-	-	-	-	-	-	-	-
CFC-113 C	CF2ClCFCl2	85	0.90	0.55	0.56	0.58	0.59	0.62	0.64	0.78	1.09
FC-114	CF2ClCF2Cl	300	0.85	-	-	-	-	-	-	-	-
CFC-115	CF2ClCF3	1,700	0.40	-	-	-	-	-	-	-	-
Tetrachloro-methane	CCl4	42	1.20	1.26	1.25	1.24	1.23	1.22	1.20	1.14	1.08
HCFC-22	CHF2Cl	13.3	0.04	0.19	0.17	0.15	0.14	0.12	0.10	0.07	0.05
HCFC-123	CF3CHCl2	1.4	0.014	0.51	0.19	0.11	0.08	0.06	0.04	0.03	0.02
HCFC-124	CF3CHFCl	5.9	0.03	0.17	0.12	0.10	0.08	0.06	0.05	0.03	0.02
HCFC-141 b	CFCl2CH3	9.4	0.10	0.54	0.45	0.38	0.33	0.26	0.22	0.13	0.11
HCFC-142 b	CF2ClCH3	19.5	0.05	0.17	0.16	0.15	0.14	0.13	0.12	0.08	0.07
HCFC-225ca	C3F5HCl2	2.5	0.02	0.42	0.21	0.14	0.10	0.07	0.05	0.03	0.02
HCFC-225cb	C3F5HCl2	6.6	0.02	0.21	0.17	0.14	0.11	0.09	0.07	0.04	0.03
1,1,1-Trichlorethan	CH3CCl3	5.4±0.4	0.12	1.03	0.75	0.57	0.45	0.32	0.26	0.15	0.12
Halon 1301	CF3Br	65	12	10.3	10.4	10.5	10.5	10.7	10.8	11.5	12.5
Halon 1211	CF2ClBr	20	5.1	11.3	10.5	9.7	9.0	8.0	7.1	4.9	4.1
Halon 1202	CF2Br2		~1.25	12.8	12.2	11.6	11.0	10.1	9.4	7.0	5.9
Halon 2401	CF2BrCF2Br	25	~7	-	-	-	-	-	-	-	-
HBFC 1201	CF2HBr		~1.4	-	-	-	-	-	-	-	-
HBFC 2401	CF3CHFBr		~0.25	-	-	-	-	-	-	-	-
HBFC 2311	CF3CHClBr		~0.14	-	-	-	-	-	-	-	-
Methylbromid	CH3Br	1.3	0.64	15.3	5.4	3.1	2.3	1.5	1.2	0.69	0.57

The potential depletion of stratospheric ozone as an effect of certain process can be estimated by summarizing the ODPs:

Stratospheric ozone depletion potential (kg CF-11 equivalents) = $S_i \, ODP_i \, m_i$

Ecotoxicological impacts

Ecotoxicological impacts depend on exposures to and effects of chemical and biological substances. The potential effects on ecosystems depend on the actual emission and fate of the specific substances emitted to the environment. An effect factor is proposed in the following formula for effect scores (S).

$$S_i^{nm} = E_i^{m} F_i^{nm} M_i^{n}$$

M is the emission of a substance i to an initial medium n (air, water or soil), E is effect factor for a substance i in the medium m (air, water, soil or food chain), and F is fate and exposure factor for a substance i emitted to an initial medium n and transferred to compartment m.

The fate of chemical substances depend on:

- Degradation rate (aerobic/anaerobic hydrolytic/photolytic)
- Bioaccumulation
- Evaporation
- Deposition

The degradation rate will affect both the possibility of the substance to reacting the target organism and the kind of toxic effect. Readily degradable substances can show acute toxic effects depending on the degradation type and rate in the actual medium, whereas substances which are not readily degradable can bioaccumulate in the environment and/or show chronic toxic effects. The rates of evaporation/deposition will affect the transfer of substances between the different mediums (e.g. air, water, soil or food chains), e.g. in aeration of leads to evaporation of volatile substances form the water, and thereby protecting the biological processes in the wastewater treatment plant against potential toxic or inhibitory effects but also burdening the surroundings.

One way of assessing the potential ecotoxicological effects of chemical substances is to use the criteria for classification of substances as “Dangerous for the environment” (indicated by the symbol N) (EEC 1993):

- Biodegradation
- Bioaccumulation
- Aquatic toxicity (acute/chronic)
- Terrestrial toxicity

Criteria already exist for assessing biodegradation, bioaccumulation and aquatic effects whereas no formalized criteria have been developed for terrestrial toxicity. Guidance to the actual assessment procedure can be found in Pedersen et al. (1995).

A number of different methods addressing chemical fate, route of exposure and toxicological effect into account have been developed:

- Quantitative approach with partial fate analysis (Lindfors et al., 1995: Finnveden et al., 1992)
- MUP-method (Jensen et al., 1994)
- EDIP-method (Hauschiled et al., 1997a)
- The “ecotoxicity potential approach” (Guinee & Heijungs, 1993; Guinee et al., 1996)
- The “provisional method” (Heijungs et al., 1992)

International consensus on specific methods for assessing ecotoxicological impacts has not yet been reached and development of some the methods is still in progress. It is therefore recommended to use different methods when assessing potential ecotoxicological impacts for a specific data-set.

Photochemical oxidant formulation (smog)

Photochemical ozone formulation is caused by degradation of organic compounds (VOC) in the presence of light and nitrogen oxide (NO_x) ("smog" as a local impact and "troposheric ozone" as a regional impact). The biological effects of photochemical ozone can be attributed to biochemical effects of reactive ozone compounds. Exposure of plants to ozone may results in damage of the leaf surface, leading to damage of the photosynthetic function, discolouring of the leaves, dieback of leaves and finally the whole plant. Exposure of humans to ozone may result in eye irritation, respiratory problems, and chronic damage of the respiratory system.

The reaction can be described in a simplified way in terms of four steps (Nichols et al., 1996; Hauschild & Wenzel, 1997c):

- Reaction between organic compounds (VOC) and hydroxyl radicals (OH) to form organic peroxy radicals
- The peroxy radicals react with nitrogen oxide (NO) to form nitrogen dioxide (NO_2)
- Nitrogen dioxide react in the presence of sunlight to form nitrogent oxide (NO) and oxygen atoms
- Atomic oxygen reacts with oxygen (O_2) to form ozone (O_3)

The photochemical ozone formation can be quantified by using photochemical ozone creation potentials (POCP) for organic compounds. POCPs for organic compounds are expressed as ethylene (C_2H_4) equivalents i.e. their impacts are expressed relative to the effect of C_2H_4.POCP-values can be calculated in different ways as proposed by Anderson-Skold et al. (1992). Anderson-Skold et al. (1992) give the POCPs for three different acenarios:

- Maximum differences in concentration
- Ordinary Swedish background during 0-4 days
- High NO_x background during 0-4 days

Heijungs et al. (1992) provide POCPs calculated as the contribution to ozone formation at peak ozone formation based on average of data from three different locations in Europe.

The photochemical ozone creation potential of certain processes can be estimated by summarising the POCPs for the VOCs:

POCP (kg ethylene equivalents) = S_i $POCP_i$ m_i

A method considering only POCPs for VOCs is not sufficient to describe the impact category. A possible approach can be to divide the category in two subcategories: one category for nitrogen oxides (aggregated as NO_x) and one category for VOC (aggregated with POCP as weighting factor using an appropriate scenario or all the four above mentioned scenarios) as proposed by Lidfors et al. (1995a; 1995c) in the Nordic guideline for life cycle assessment. If the inventory data do not make it possible calculating total POCP based on weighting factors due to lack of information on the composition of the VOCs, it is suggested that the data be aggregated in the following subcategories:

- Nitrogen oxides NO_x
- Hydrocarbons (HC) or volatile organic compounds (VOCs)
- Carbon monoxide (CO)
- Methane (CH_4)

Acidification

Acidification is caused by releases of protons in the terrestrial or aquatic ecosystems. In the terrestrial ecosystem the effects are seen softwood forests (e.g. spruce) as inefficient growth and as a final consequence dieback of the forest. These effects are mainly seen in Scandinavia and in the middle/eastern part of Europe. In the aquatic ecosystem the effects are seen as (clear), acid lakes without any wildlife. These effects are mainly seen Scandinavia. Buildings, constructions, sculptures and other objects worthy of preservation are also damaged by e.g. acid rain.

Substances are considered to have an acidification effect if they results in:

- Supply or release of hydrogen ions (H+) in the environment
- Leaching of the corresponding anions from the concerned system

The potential effects are strongly dependent on the nature of the receiving ecosystem e.g. nitrogen oxides (NO_x) can be fixed in the ecosystem due to uptake in plants. This problem can be managed by using two scenarios as suggested by Lidfors et al. (1995a) recommended the following substances should be considered: SO_2, NO_x, NH_3 and HCl but also other substances having a proton releasing effect have to be considered (i.e. other sulphur compounds and other acids). The acidification potential (AP) can be estimated as SO_2 equivalents or as mole hydrogen (H^+).

The potential acidification effect of a given process can be estimated by summarising the acidification potentials for the actual substances:

Acidification potential (SO_2 – equivalents) = Σ_i AP_i x m_i

Eutrophication

Eutrophication (or nutrient enrichment) of aquatic and terrestrial ecosystems can be caused by surplus nitrogen, phosphorus and degradable organic substances. Eutrophication can be defined as: enrichment of aquatic ecosystems with nutrients leading to increased production of plankton algae and higher aquatic plants leading to a deterioration of the water quality and a reduction in the value of the utilisation of the aquatic ecosystem.

The primary effect of surplus nitrogen and phosphorus in aquatic ecosystems is growth of algae. The secondary effect is decomposition of dead organic material (e.g. algae) and anthropogenic organic substances. The decomposition of organic material is an oxygen consuming process leading to decreasing oxygen saturation and sometimes anaerobic conditions. The anaerobic conditions in the sediment at the bottom of lakes or other inland waters may furthermore result in production of hydrogen sulphide (H_2S) which may lead to "bottom up" incidents and liberation of toxic hydrogen sulphide to the surrounding water. The possible effects of the emissions leading to eutrophication depend on the receiving waters i.e. some recipients are sensitive to nutrient supply while others are not.

The effects of eutrophication of terrestrial ecosystem are seen on changes in function and diversity of species in nutrient poor ecosystems as heaths, dune heaths, raised bogs etc. and they are caused by atmospheric deposition of nitrogent compounds.

Lidfors et al. (1995c) present two methods to calculate the eutrophication potential: 1) a separate segregation method and 2) a scenario-based approach. The separate aggregation method divides the loadings in four subcategories to be calculated separately:

1. Organic material to water measured as BOD5
2. Total-N to water as kg N
3. Total-P to water as kg P
4. Total-N to air as kg N

In the scenario-based approach the eutrophication category is suggested to be divided into two subcategory considering aquatic ecosystems and terrestrial ecosystems, respectively. The reason for using the scenario-based approach is to take the conditions of the receiving ecosystems into account, because P is the limiting factor in some circumstances and N is the limiting factor in other. It is assumed that only the limiting factor contributes to the eutrophication and therefore, the aggregation can be done in the following subcategories:

1. Total-N to air (terrestrial effects)
2. Total-P emissions and emission of organic material to water
3. Total-N emissions and emission of organic material into water
4. Total-N emissions and emission of organic material into water and N emissions to air
5. Total-P and -N emissions to air and water and also emission of organic material into water (assuming that both N, P and organic material contribute)

The eutrophication potential (EP) can be expressed as O_2 – or PO_4 – equivalents and its presented in table 3 for a number of substances. Hauschild & Wenzel (1997e) have calculated EP as total-N, total-P and NO_3 – equivalents; table 4.

Table 4 Eutrophication potential (EP) as total-N, total-P or NO_3 –equivalents (Hauschild & Wenzel, 1997e)

Substance	M_w g/mole	EP(N) kg N/kg	EP(P) kg P/kg	EP kg NO_3/kg
NO_3^-	62	0.23	0	1
NO_2	46	0.30	0	1.35
NO_2^-	46	0.30	0	1.35
NO	30	0.47	0	2.07
NH_3	17	0.82	0	3.64
CN^-	26	0.54	0	2.38
Total-N	14	1	0	4.43
PO_4^{3-}	95	0	0.33	10.45
$P_2O_7^{2-}$	174	0	0.35	11.41
Total-P	31	0	1	32.03

The eutrophication potential of a certain process can be estimated by summarising the eutrophication factors for the organic material, P- and N-containing substances:

$$\text{Eutrophication potential (O2-equivalents)} = \Sigma_i \text{ eutrophication potential}_i \times m_i$$

The eutrophication can also be expressed as PO_4^{3-} -equivalents. In this approach, no differentiation is made between ecosystems limited by different nutrients (Lindfors et al., 1995c).

Classification

The life cycle impact assessment includes as a second element classification of the inventory input and output data (ISO, 1997c).

The classification element aims to assign inventory input and output data to categories.

The purpose of classification is to organise and possible combine the LCI results into impact categories. For LCI items that contribute to only one impact category, the procedure is a straightforward assignment. For example: Carbon dioxide (CO_2) emissions can be classified into the global warming category.

For LCI items that contribute to two or more different impact categories, a rule must be established for classification. There are two ways of assigning LCI results to multiple impact categories (ISO 1998):

- Allocate a representative portion of the LCI results to the impact categories to which they contribute. This is typically allowed in cases when the effects are dependent on each other.
- Assign all LCI results to all impact categories to which they contribute. This is typically allowed when the effects are independent of each other.

For instance, since one SO_2 molecules could stay at ground level or travel up into the atmosphere, it can affect either human health or acidification but not both at the same time. Therefore, SO_2 emissions would typically be divided between those two impact categories e.g. 50% allocated to human health and 50% allocated to acidification. On the other hand, since nitrogen dioxide (NO_2) could potentially affect both ground level ozone formation and acidification at the same time, the entire quantity of NO_2 would be allocated to both impact categories e.g. 100% to ground level ozone and 100% to acidification. The allocation procedure must be clearly documented.

The assignment of inventory data is the simples or minimum level of life cycle impact assessment. This can be used to identify and flag issues associated with inventory input and output data. At this stage, there is an implicit assumption of ‘less is better’ and excludes several important considerations such as differences in potency or environmental persistence.

Classification is a qualitative step based on scientific analysis of relevant environmental processes. The classification has to assign the inventory input and output data to potential environmental impacts i.e. impact categories. Some outputs contribute to different impact categories and therefore, they have to be mentioned twice. The resulting double counting is acceptable if the effects are independent of each other whereas double counting of different effects in the same effect chain (e.g. stratospheric ozone depletion and human toxicological effects as e.g. skin cancer) is not allowed.

The impact categories can be placed on a scale dividing the categories into three (four) different space groups: global impacts, (continental impacts,) regional impacts and local impacts. The grouping is not unequivocal for all the impact categories exemplified by e.g. environmental toxicity which can be global, continental, regional as well as local. The impact categories is often related directly to exposure i.e. global exposure is leading to global impacts, continental exposure is leading to continental impacts. Some of the impact categories are strongly correlated with continental, regional or local conditions i.e. some localities are more predisposed to certain impacts that other localities. Certain lakes in Scandinavia can be mentioned as examples of localities that are more predisposed to acidification than lakes in other parts of Europe. The time aspect is also important when considering certain impact categories e.g. global warming and stratospheric ozone depletion with time horizons on 20 to 500 years.

To date, consensus has not been reached for one single default list of impact categories. Therefore, the relevant impact categories may be selected from a preliminary list of examples. A number of suggestions for lists of impact categories with reference to the scale in which they are valid are shown in table 5. Consensus about handling the impact categories has mainly been obtained for the global impacts. Development of methodologies for the other categories is still being discussed in different expert groups e.g. within the framework of SETAC.

Characterization

The life cycle impact assessment includes, as a third element, characterization of the inventory data (ISO, 1997c).

The characterization of characterization is to model categories in terms of indicators, and, if possible, to provide a basis for the aggregation of the inventory input and output within the category. This is also done in terms of the indicator to represent an overall change or loading to that category. The result of characterization is that the combination of category indicators represents initial loading and resource depletion profile.

Each category should have a specific model for the relationship between the input and output data and the indicator. The model should be based on scientific knowledge, where possible, but may have simplifying assumptions and value-choices. The representativeness and accuracy of each model depends on several factors, such as spatial

Table 5 Selected lists of impact categories; references are given in the list

The "leiden list" SETAC-europe (1992)	SETAC "default list" Udo de Haes (1996b)	"Nordic list" Lindfors et. al. (1995c)	ISO preliminary list ISO (1997c)	Scale/comments
Non-renewable	Abiotic resources	Energy and material	Abiotic resources	Global
Scarce, renewable	Biotic resources		Biotic resources	Global
		Water		
	Land	Land	Land use	Local
Global warming	Global warming	Global warming	Global warming/ Climate change	Global
	Depletion of stratospheric ozone	Depletion of stratospheric ozone	Stratospheric ozone depletion	Global
Human toxicity	Human toxicological impact	Human health, toxicological excl. work environment	Human toxicity	Global, continental, regional, local
		Human health, non-		

Table 5 (Cont'd)

The "leiden list" SETAC-europe (1992)	SETAC "default list" Udo de Haes (1996b)	"Nordic list" Lindfors et. al. (1995c)	ISO preliminary list ISO (1997c)	Scale/comments
		toxicological excl. work environment		
Occupational safety		Human health impacts in work environment		Local
Environmental toxicity	Ecotoxicological impacts	Ecotoxicological impacts	Ecotoxicity	Global, continental, regional, local
Photo-oxidant formation	Photo-oxidant formation	Photo-oxidant formation	Photochemical oxidant formation (smog)	Continental, regional. local
acidification	acidification	acidification	acidification	Continental, regional, local
Futrophication	Entrophication (incl. BOD and heat)	Futrophication	Futrophication	Continental, regional, local
COD (chemical oxygen demand) discharge				Local
Effects of waste heat on water				Local
Nuisance (smell, noise)	Odour			Local
	Noise			Local
	Radiation			Local, regional
Space requirement				Local
Final solid waste (hazardous)				Regional, local
Final solid waste (non-hazardous)				Regional, local
	casualties			Local
		Habitat alterations and impacts on biological diversity		Local

*The SETAC “default list” also mention some “flows not followed up to system boundary: input related (energy, materials, plantation woods etc.) and output related (solid waste etc.)”

and temporal compatibility of the category, with the inventory. The relationship between the inventory input and output data and the category indicator is normally strong (or within reach). The relationship between the indicator and the endpoint(s) is usually weaker and may be mainly quantitative.

Impact characterisation uses science-based conversion factors, called characterisation factors, to convert and combine the LCI results into representative indicators of impacts to human and ecological health. Characterisation factors also are commonly referred to as equivalency factors. Characterisation provided a way to directly compare the LCI results within each impact category. In other words, characterisation factors translate different inventory inputs into directly comparable impact indicators. For example, characterisation would provide an estimate of the relative terrestrial toxicity between lead, chromium and zinc.

Impact categories

The following is a list of several impact categories and endpoints that identify the impacts.

Global impacts

- Global warming – polar melt, soil moisture loss, longer seasons, forest loss/change, and change in wind and ocean patterns.
- Ozone depletion – increased ultraviolet radiation.
- Resource depletion – decreased resources for future generations.

Regional impacts

- Photochemical smog – ''smog'' decreased visibility, eye irritation, respiratory tract and lung irritation and vegetation damage.
- Acidification – building corrosion, water body acidification, vegetation effects and soil effects.

Local impacts

- Human health – increased morbidity and mortality.
- Terrestrial toxicity – decreased production and biodiversity and decreased wildlife for hunting or viewing.
- Aquatic toxicity – decreased aquatic plant and insect production and biodiversity and decreased commercial or recreational fishing.
- Land use - loss of terrestrial habitat for wildlife and decreased landfill space.

Impact indicators are typically characterised using the following equation:

Inventory Data x Characterisation factor = impact indicators

Σ impact potentials = Σ Quantity of substance x substance's impact potential

$EP(j)_i = Q_i \times EF(j)_i$

$EP(j) = \Sigma\, EP(j)_i = \Sigma\, (Q_i \times EF(j)_i)$

Where

EP are environmental impacts' potentials

Q are quantities of substances

EF are substances' equivalency factors

j are environmental impact categories

i are emissions of the substances

For example, all greenhouse gases can be expressed in terms of carbondioxide (CO_2) equivalents by multiplying the relevant LCI results by a characterisation factor and then combining the resulting impact indicators to provide an overall indictor of global warming potential.

Characterisation of global warming impacts

Chloroform GWP factor value* = 9
Quantity = 20 pounds
Methane GWP factor value* = 21
Quantity = 10 pounds

Chloroform GWP impact = 20 pounds x 9 = 180
Methane GWP impact = 10 pounds x 21 = 210

GWP = Global warming potential
*Intergovernmental panel on climate change (IPCC) model

Characterisation can out these different quantities of chemicals on an equal scale to determine the amount of impact each one has on global warming. The calculations show that 10 pounds of methane have a larger impact on global warming than 20 pounds of chloroform.

The key to impact characterisation is using the appropriate characterisation factor. For some impact categories, such as global warming and ozone depletion, there is a consensus on acceptable characterisation factors. For other impact categories, such as resource depletion, a consensus is still being developed.

A properly referenced LCIA will document the source of each characterisation factor to ensure that they are relevant to the goal and scope of the study. For instance, many characterisation factors are based on studies conducted in Europe. Therefore, the relevancy of the

European characterisation factors must be investigated before they can be applied to American data.

Characterization is mainly a quantitative step based on scientific analysis of the relevant environmental processes. The characterization has to assign the relative contribution of each input and output to the selected impact categories. The potential contribution of each input and output to the environmental impacts has to be estimated. For some of the environmental impact categories there is consensus about equivalency factors to be used in the estimation of the total impact (e.g. global warming potentials, ozone depletion potentials etc.) whereas equivalence factors for other environmental impacts are not available at consensus level (e.g. biotic resources, land use etc.).

Normalisation

Normalisation is an LCIA tool used to express impact indicator data in a way that can be compared among impact categories. This procedure normalises the indicator results by dividing by a selected reference value.

There are numerous methods of selecting a reference value, including:

- The total emissions or resource use for a given area that may be global, regional or local.
- The total emissions or resource use for a give area on a per capita basis.
- The ratio of one alternative to another (i.e. the baseline)
- The highest value among all options

The goal and scope of the LCA may influence the choice of an appropriate reference value. Note that normalised data can only be compared within an impact category. For example, the effects of acidification cannot be directly compared with those of aquatic toxicity because the characterisation factors were calculated using different scientific methods.

In normalisation, the impact potential or resource consumption (P(j)) are divided by the corresponding normalisation references. The normalisation reference are calculated on the basis of an inventory of all of society's activities over a period of time which must be the same as the duration of the product's services, as defined in the functional unit. If the functional unit defines the duration of the service as T years, the normalisation reference is therefore expressed as T*R(j), where R(j) denoted the normalisation reference for 1 year. The normalised impact potentials and resource consumptions, NP(j), are calculated as follows:

$$NP\ (j) = P(j)\ x \quad [\ 1\ /T\ x\ R(j)]$$

Normalisation references

Region specific considerations

It is important for the subsequent weighting that the normalisation reference correspond to an impact for which the magnitude and contribution to effects in the environment and the working environment and to depletion of reserves are known.

It is important that the impacts are summarised for the area which actually contributes to the current condition of the environment as it is experienced.

For the global impacts it makes no difference where the environment exchanges occur. But for regional and local impacts, only the exchanges occurring within the regions or local areas in question contribute to the current and future condition of the environment there. Emission of greenhouse gases thus contribute to global warming, irrespective of where in the world they occur. But the Far Eastern and North American emissions of substances which can contribute to acidification have no influence on the degree of acidification of forests and lakes observable in Europe today.

On this basis, the normalisation and the subsequent weighting should ideally be carried out with normalisation references and weighting factors which, for each individual emission, are representative of the region where the emission is occurring.

Time dependence

The impact of society's activities changes with time, for example as a consequence of changes in consumption and living standard and as a consequence of targeted initiatives against the worst impacts. It is necessary to choose one and the same reference year for all impact categories with in each of the main groups environment, to ensure that the scale is indeed common for all impact categories.

The person equivalent

Normalisation reference = (impact potential or resource consumption for the area in question in the reference year) / (Population of the inventorised area in the reference year)

When the impact potentials are normalised, they are expressed in person-equivalents (PE) i.e. fractions of the contribution to the impact deriving from the average person

Grouping

Grouping assigns impact categories into one or more sets to better facilitate the interpretation of the results into specific areas of concern. Typically grouping involves sorting or ranking indicators. The following are two possible ways to group LCIA data (ISO 1998):

- Sort indicators by characteristics such as emissions (e.g. are and water emissions) or location (e.g. local, regional, or global).

- Sort indicators by a ranking system, such as high, low, or medium priority. Ranking is based in value choices.

Weighting

The previous element, characterization, results in a quantitative statement on different impact categories e.g. global warming, stratospheric ozone depletion and ecotoxicological effects. Comparison of these categories is not immediately possible. Therefore, the life cycle impact assessment includes as a fourth element a valuation/weighting of the impact categories against each other (ISO, 1997c)

The weighting step (also referred to as valuation) of an LCIA assigns weights or relative values to the different impact categories based on in their perceived importance or relevance. Weighting is important because the impact categories should also reflect study goals and stakeholder values. As stated earlier, harmful air emissions could be of relatively higher concern in an air non attainment zone than the same emission level in an area with better air quality. Because weighting is not a scientific process, it is vital that the weighting methodology is clearly explained and documented.

Weighting aims to rank, weight, or, possible, aggregate the results of different life cycle impact assessment categories in order to arrive at the relative importance of these different results. The weighting process is not technical, scientific, or objective as these various life cycle impact assessment results e.g., indicators for greenhouse gases or resource depletion, are not directly comparable. However, weighting may be assisted by applying scientifically-based analytical technique. Weighting may be considered to address three basic aspects:

- To express the relative preference of an organization or group of stakeholders based on policies, goals or aims, and personal or group opinions or beliefs common to the group;
- To ensure that process is visible, documentable, and reportable, and

- To establish the relative importance of the results is based on the state of knowledge about these issues.

Although weighting is widely used in LCAs, the weighting stage is the least developed of the impact assessment steps and also is the one most likely to be challenged for integrity. In general, weighting includes the following activities:

- Identifying the underlying values of stakeholders
- Determining weights to place on impacts
- Applying weights to impact indicators

Weighted data could possible be combined across impact categories but the weighting procedure must be explicitly documented. The un-weighted data should be shown together with the weighted results to ensure a clear understanding of the assigned weights.

Note that in some cases, the presentation of the impact assessment results alone often provides sufficient information for decision-making, particularly when the results are straight forward or obvious. For example, when the best-performing alternative is significantly and meaningfully better than the others in at least one impact category and equal to the alternatives in the remaining impact categories, then one alternative is clearly better. Therefore, any relative weighting of the impact assessment results would not change its rank as first preference. The decision can be made without the weighting step.

Several issues exit that make weighting a challenge. The first issue is subjectivity. According to ISO 14042, any judgement of preferability is a subjective judgement regarding the relative importance of one impact category over another. Additionally, these value judgements may change with location of time of year. For, example, someone located in Los Angles, CA, may place more importance on the values for photochemical smog than a person located in Cheyenne, WY. The second issue is derived from the first: how should users fairly and consistently make decisions based on environmental preferability, given the subjective nature of weighting

Developing a truly objective (or universally agreeable) set of weights or weighting methods is not feasible. However, several approaches to weighting do exist and are used successfully for decision-making, such as the Analytical Hierarchy Process (AHP), the Modified Delphi Technique and Decision Analysis Using Multi-Attribute Theory (MAUT).

Weighting is qualitative or quantitative step not necessarily based on natural science but often on political or ethical values. Weighting has previously been referred to as valuation. Weighting methods have been developed by different institutions based on different principles (Lindeijer, 1996):

- "Proxy approach"
- "Technology abatement approach"
- "Monetarisation"
- "Authorized goals or standards" ("Distance to target")
- "Authoritative panels" ("Societal approach")

Proxy approach

In this approach one or several quantitative measures are stated to be indicative for the total environmental impact. Energy consumption, material displacement and space consumption are examples on using this approach.

Technology abatement approach

The possibility of reducing environmental burdens by using different technological abatement methods can be used to set a value on the specific environmental burden. This approach can be applied to inventory data as well as impact scores.

Monetarisation

This approach can be described with the following premises:

- Utilitarianism (values are measured by the aggregation of human preferences)
- Willingness to pay/accept is an adequate measure of preferences
- Values of environmental quality can be substituted by other commodities

This approach can be applied to inventory data as well as impact scores.

Authorized goals or standards

Environmental standards and quality targets as well as political reduction targets can be used to calculate critical volumes for emissions to air, water, soil or work environment. The targets of standards can be formulated by national or local authorities, within a company etc.

Authoritative panels

The authoritative panel can be made up pf lay people, of societal group panels, of scientific experts, of governments or international bodies. The credibility of a panel, according to Volkvein et. al. (1996), can be improved by using:

1. LCA-experts from different societal groups as panellists.
2. Peer reviewed sets of valuation criteria, rules for their application, a transparent ranking technique.
3. Documentation of the arguments leading to the final valuation.

The present methods – with some still under development “as a method” – are described briefly in table 6.

Table 6 Different methods for weighting different impact categories (adapted from Lindeijer, 1996)

Method	Methodology	Characteristics / comments	Reference
Energy requirement	Equal energy requirement	Proxy	Franklin
MIPS	Equal material displacement	Proxy	Schmidt-Bleek (1994)
SPI	Equal space consumption	Proxy, technology	
Abatement energy	Equal space consumption including energy fro abatement of environmental burden	Technology	Cramer et. al. (1993)
Abatement costs	Equal modeled costs for abating emissions according to national goals	Technology, monetarisation, authorized targets	Kroon et. al. (1994)
Abatement costs/the Tellus system	Equal costs for abating emissions, most human toxic emissions abatement costs extrapolated from characterization factors via lead (combining carcinogenic and non carcinogenic substances via PEL values)	Monetarisation, authorized standards	Tellus institute (1992)
DESC	Equal projected generic costs for abatement of Technology, monetarisation, burden according to national goals derived per impact category	Technology, monetarisation, authorized targets	Krozer (1992)
The EPS system	The EPS system is based on "willingness to pay" to restore the concerned effect to their normal status. The concerned effects are biodiversity, production, human health, resources and aesthetic values.	Monetarisation, technology, the willingness to pay/the weighing will be different from country to country	Steen & Ryding (1992); Bostrom & Steen (1994)
The "Molar" method	Equal critical volume scores, the volume of each medium weighted according to their mole density	Authorized standards	Schaltegger & Sturm (1991)

Table 6 (Cont'd)

Method	Methodology	Characteristics / comments	Reference
The "Critical volume" method	Equal critical volume scores weighted subjectly	Authorized standards	Kohlert & Thalmann (1992)
The "Critical surface time" method	Equal critical immission volumes weighted subjectively	Authorized standards	Jolliet (1994a)
The "Ecoscarcity" approach	Equal scores over proportional distances to political targets	Authorized standards	Ahbe et. al. (1990)
The "Effect category" method			Baumann et. al. (1993)
Distance to target	Equal scores of distances to political targets optionally additionally weighted subjectively	Authorized targets	Corten et. al. (1994)
NSAEL	Equal scores of overshoots of sustainable targets optionally weighted subjectively	Authorized targets	Kortman et. al. (1994)
The "Eco-indicator 95" method	Equal scores of distances to science-political targets contributing to the equally weighted safeguard subjects 1 on a million human lives, 95% of ecosystems and human health complaints due to smog	Authorized targets	Goedkoop (1995)
Iso-utility functions	Equal panel scores on relative (negative) utilities of actual impact scores	Panel	Tukker (1994)
Iso-preference approach	Equal panel preferences for elasticities in relative impact scenarios	Panel	Heijungs (1994)
Delphi technique	Equal expert panel scores on actual impacts	Panel	Wilson & Jones (1994)
Questionnaire	Equal industry/science panel scores on impact categories	Panel	Nagata et. al. (1995)

Table 6 (Cont'd)

Method	Methodology	Characteristics / comments	Reference
Panel questionnaire	Equal societal group panel scores on impact categories	Panel	Kortman et. al. (1994)
Structured dialogue	Panel agreement on weights based on argumentation	Panel	Weidema (1994a)
Argumentative evaluation	Societal group consensus on the interpretation of product systems comparison with inputs form normalization, environmental problem weights by a political panel and a sensitivity analysis	Panel	Schmitz et. al. (1994)
Export panel prioritisation	Equal interpretation of product systems comparison using a qualitative valuation of normalization data and expert panel scores on the criteria time, space and hazard	Panel	Volkwein et. al. (1996)

The different methods focus on different impacts as can be illustrated by case studies in which the different methods have been tested.

Evaluate and document the LCIA results

Now that the impact potential for each selected category has been calculated, the accuracy of the results must be verified. The accuracy must be sufficient to support the purposes for performing the LCA as defined in the goal and scope. When documenting the results of the life cycle impact assessment, thoroughly describe the methodology used in the analysis, define the systems analysed and the boundaries that were set and all assumptions made in performing the inventory analysis. When documenting the results of life cycle impact assessment, thoroughly describe the methodology used in the analysis and all assumptions made in performing the LCIA.

The LCIA, like all other assessment tools, ahs inherent limitations. Although the LCIA process follows a systematic procedure, there are many underlying assumptions and simplifications, as well subjective value choices.

Some of the key limitation include:

- Lack of spatial resolution – e.g. a 4,000 gallon ammonia release is worse in a small stream than in a large river.
- Lack of temporal resolution – e.g. a 5 tone release of particulate matter during a one month period is worse than the same released spread through the whole year.
- Inventory speciation – e.g. broad inventory listing such as ''VOC'' or ''metals'' do not provide enough information to accurately assess environmental impacts.
- Threshold and non-threshold impact – e.g. ten tone of contamination is not necessarily ten times worse than one tone of contamination.

The selection of more complex or site-specific impact models can help reduce the limitations of the impact assessment's accuracy. It is important to document these limitations and to include a comprehensive description of the LCIA methodology, as well as, a discussion of the underlying assumptions, value choices, and known uncertainties in the impact models with the numerical results of LCIA to be used in interpreting the results of the LCA.

Interpretation

Life cycle interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the life cycle inventory (LCI) and the life cycle impact assessment (LCIA), and communicate them effectively. Life cycle interpretation is the last phase of the LCA process.

The International Organization for Standardization (ISO) has defined the following two objectives of life cycle interpretation:

1. Analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA and to report the results of the life cycle interpretation in a transparent manner.
2. Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study. (ISO 1998b)

Interpreting the results of an LCA is not as simple as 2 is better then 3, therefore Alternative A is the best choice! While conducting the LCI and LCIA it is necessary to make assumptions, engineering estimates, and decisions based on your values and the values of involved stakeholders. Each of these decisions must be included and communicated within the final results to clearly and comprehensively explain conclusions drawn from the data. In some cases, it may not be possible to state that one alternative is better than the others because of the uncertainty in the final results. This does not imply that efforts have been wasted. The LCA process will still provide decision-makers with a better understanding of the environmental and health impacts associated with each alternative, where they occur (locally, regionally, or globally), and the relative magnitude of each type of impact in comparison to each of the proposed alternatives included in the study. This information more fully reveals the pros and cons of each alternative.

The purpose of conducting an LCA is to better inform decision-makers by providing a particular type of information (often unconsidered), with a life cycle perspective of environmental and human health impacts associated with each product or process. However, LCA does not take into account technical performance, cost, or political and social acceptance. Therefore, it is recommended that LCA be used in conjunction with these other parameters.

The guidance provided here is a summary of the information provided on life cycle interpretation from the ISO's draft standard entitled "*Environmental Management - Life Cycle Assessment - Life Cycle Interpretation*," ISO/DIS 14043 (ISO 1998b). Within the ISO draft standard the following steps to conducting a life cycle interpretation are identified and discussed:

- Identify Significant Issues
- Evaluate the Completeness, Sensitivity, and Consistency of the Data
- Draw Conclusions and Recommendations

Interpretation is the forth phase in life cycle assessment containing the following main issues (ISO, 1997d):

- Identification of significant environmental issues
- Evaluation
- Conclusions and recommendations

The different elements are explained in relation to the ISO standard. The ISO standard on interpretation is the least developed part of the standard and therefore the description below is expected to be revised when the standard is finally approved.

Life cycle assessment interpretation is a systematic procedure to identify, qualify, check, and evaluate information from the conclusions of the inventory analysis and/or impact assessment of a system, and present them in order to meet the requirements of the application as described in the goal and scope of the study.

Life cycle interpretation is also a process of communication designed to give credibility to the results of the more technical phases of LCA, namely the inventory analysis and the impact assessment, in a form which is both comprehensible and useful to the decision maker.

Interpretation is performed in interaction with the three other phases of the life cycle assessment. If the results of the inventory analysis or the impact assessment, is found not to fulfill the requirements defined in the goal and scoping phase, the inventory analysis must be improved by e.g. revising the system boundaries, further data collection etc. followed by an improved impact assessment. This iterative process must be repeated until the requirements in the goal and scoping phase are fulfilled as can be described by the following steps:

1. Identify the significant environmental issues
2. Evaluate the methodology and results for completeness, sensitivity and consistency
3. check that conclusions are consistent with the requirements of the goal and scope of the study, including, the particular, data quality requirements, predefined assumptions and values, and application oriented requirements.
4. If so, report as final conclusions. If not, return to step 1 or 2

This procedure has to be repeated until 3 is fulfilled.

The aim of interpretation is to reduce the number of quantified data and / or statements of the inventory analysis and / or a impact assessment to the key results to facilitate a decision making process based on, among other inputs, the LCA study. This reduction should be robust to uncertainties in data and methodologies applied and give an acceptable coverage and representation of the preceding phases.

Figure 6 illustrates the steps of the life cycle interpretation process in relation to the other phases of the LCA process. Each step is summarised below.

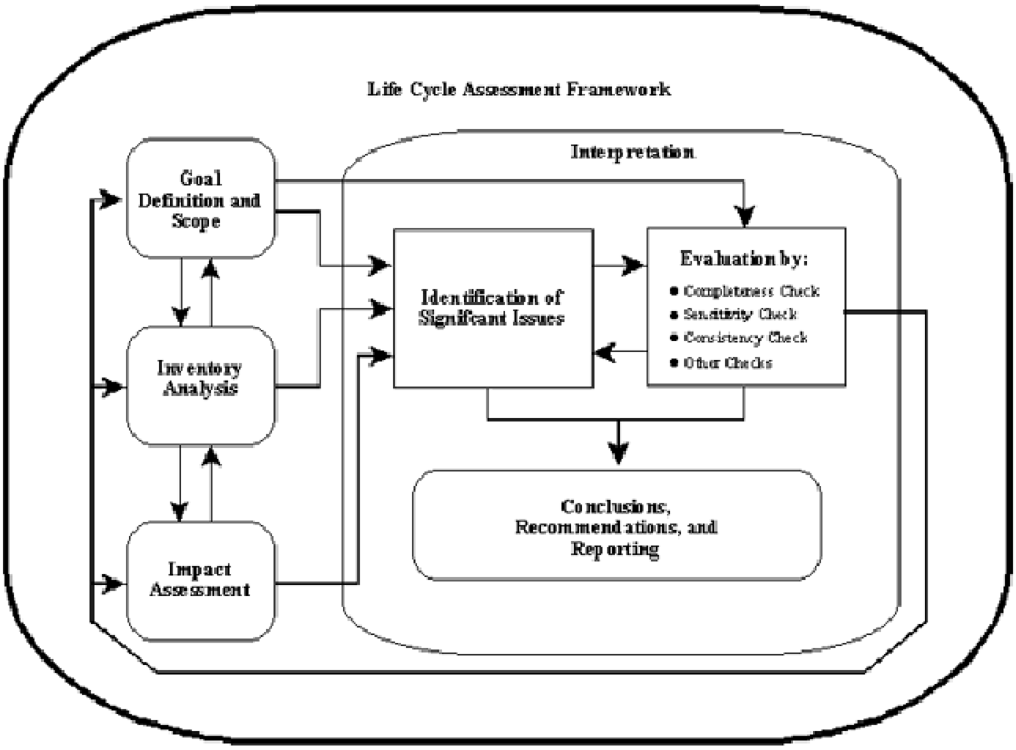

Figure 6 Relationship of interpretation steps with other phases of LCA (source: ISO, 1998b)

Identification of significant environmental issues

The first step in the identification is the selection of key results on a prudent and justifiable manner.

The objective of this step is to structure the information form the inventory analysis and if additionally conducted – from the life cycle impact assessment phase in order to determine the significant environmental issues in accordance with the goal and scope definition.

Environmental issues are inputs and outputs i.e. results of the inventory phase and environmental indicators i.e. the results of the life cycle impact assessment phase if LCIA is conducted

Significant environmental issues are found to represent the most important results of the study in accordance with the goal and scope definition.

The identification step include structuring and presentation of relevant information:

- Results from the different phases i.e. presentation of e.g. data from inventory analysis in tables, figures or diagrams etc. or presentation of results of the impact assessment
- Methodological choices
- Valuation methods used
- Role and responsibility of different interested parties

Depending on the complexity of the LCA study the significant environmental issues of the considered system can be e.g. CO_2, NO_x, and SO_2 or they can be e.g. global warming, stratospheric ozone depletion, ecotoxicological and human toxicological impacts etc.

Review the information collected and the presentations of results developed to determine if the goal and scope of the LCA study have been met. If they have, the significance of the results can then be determined.

Determining significant issues of a product system may be simple or complex. For assistance in identifying environmental issues and determining their significance, the following approaches are recommended:

- *Contribution Analysis* - the contribution of the life cycle stages or groups of processes are compared to the total result and examined for relevance.
- *Dominance Analysis* - statistical tools or other techniques, such as quantitative or qualitative ranking (e.g., ABC Analysis), are used to identify significant contributions to be examined for relevance.
- *Anomaly Assessment* - based on previous experience, unusual or surprising deviations from expected or normal results are observed and examined for relevance.

Significant issues can include:

- inventory parameters like energy use, emissions, waste, etc.
- impact category indicators like resource use, emissions, waste, etc.
- essential contributions for life cycle stages to LCI or LCIA results such as individual unit processes or groups of processes (e.g., transportation, energy production).

Evaluation

The second step, involving three elements, is firstly to conduct a qualitative check of the selection of data, processes etc. e.g. to discuss the possible consequences of leaving out information, secondly to apply a systematic qualitative or quantitative analysis of any implications of changes in the input data (directly as data uncertainty and indirectly caused by methodological or epistemological uncertainties), and thirdly to discuss the variations identified in the frame of the goal and scope, e.g. the data quality goals of the study.

The objective of this step is to establish confidence in the results of the study, based on the preceding LCA phases, and on the significant environmental issues identified in the first step of the interpretation. The results should be presented in such a form as to give the commissioner or any interested party a clear and understandable view of the outcome of the study.

The evaluation shall be undertaken in accordance with the goal and scope, and should take into account the final use of the study.

The interpretation made at this stage shall be reinforced by the facts and calculations brought forward in at least the three following elements:

1. Completeness check
2. Sensitivity check
3. Consistency check

And supplemented by results of:

- Uncertainty analysis and
- Data quality assessment

The methodology for the above mentioned elements in the evaluation step is only developed to a limited degree. Below completeness, sensitivity and consistency check are described briefly.

Completeness check

Completeness check is a qualitative procedure.

The objective of this first element in the evaluation step is to ensure that the significant environmental issues previously identified adequately represent the information from the different LCA phases (inventory analysis, impact assessment) in accordance with the goal and scope defined.

The procedure focus on the information collection in the inventory phase. In many LCA studies there will be some data sets that are unavailable or incomplete i.e. there will be a data gab unless necessary resources are used to improve the data set. The completeness check has to decide whether it is necessary to complete the data set. If the data set is important according to the defined environmental issues, the data collection can be improved or the goal and scope definition can be revised.

Sensitivity check

Sensitivity check involves a systematic procedure for estimating the effects of variations in parameters to the outcome of the study with the aim to establish a required degree of confidence in the results of the study relative to its overall goal.

The objective of this step is:

- To review the results of the sensitivity analyses and uncertainty analyses that were performed in the different phases (inventory analysis, impact assessment), and
- To assess if the significant environmental issues, previously identified as the most important ones, are found to exceed the acceptable variations stated in the goal and the scope of the study.

By conducting a sensitivity analysis, the stability of those parameters are checked.

A sensitivity check can be performed on the significant issues using the following three common techniques for data quality analysis:

- Gravity Analysis - Identifies the data that has the greatest contribution on the impact indicator results.
- Uncertainty Analysis - Describes the variability of the LCIA data to determine the significance of the impact indicator results.
- Sensitivity Analysis - Measures the extent that changes in the LCI results and characterization models affect the impact indicator results.

Additional guidance on how to conduct a gravity, uncertainty, or sensitivity analysis can be found in the EPA document entitled "Guidelines for Assessing the Quality of Life Cycle Inventory Analysis," April 1995, EPA 530-R-95-010. As part of the LCI and LCIA phases, a sensitivity, uncertainty, and/or gravity analysis may have been conducted. These results can be used as the sensitivity check. As part of the goal, scope, and definition phase of the LCA process, the data quality and accuracy goals were defined. Verify that these goals have been met with the sensitivity check. If deficiencies exist, then the accuracy of the results may not be sufficient to support the decisions to be made and additional efforts are required to improve the accuracy of the LCI data collected and/or impact models used in the LCIA. In some cases, better data or impact models may not be available. Under these circumstances report the deficiencies for each relevant significant issue and estimate the impact to the comparison either quantitatively (percent uncertainty) or qualitatively (Alternative A's reported result may be higher or lower because the uncertainty in "X" is greater than recommended in the goal and scope of the study).

The sensitivity analysis can be done by making a kind of “what if” scenario, where the value of different input parameters are changes systematically. A more proper way to do sensitivity analysis is to change the input parameters systematically by using simulations (e.g. Monte Carlo simulations).

Consistency check

Consistency check is also a qualitative procedure.

The objectives of this element of the evaluation step is to conduct a thorough check in the consistency of methods, procedures and treatment of data used throughout the study.

The procedure has to test whether methods etc. have been used consistently and especially within comparative studies. The following items are subjects for consistence check:

- Regional and/or temporal differentiations
- System boundaries
- Allocation methods
- Differentiation between foreground and background processes
- Valuation/weighting methods

The completeness, sensitivity and consistency check can be supplemented by the results of uncertainty analysis and data quality assessment. Both are performed throughout the study as they are closely related to the individual data and calculations. The conclusions of the uncertainty analysis and data quality assessment are important in the process of interpretation of the data and the results of the calculations.

A formal checklist should be developed to communicate the results of the consistency check. Table 7 provides examples of the types of information to be included in the checklist. The goal and scope of the LCA determines which categories should be used.

Table 7 Examples of checklist categories and potential inconsistencies

Category	Example of inconsistency
Data source	Alternative a is based on literature and alternative B is based on measured data
Data accuracy	For Alternative A, a detailed process flow diagram is used to develop the LCI data. For Alternative B, limited process information was available and the LCI data developed was for a process that was not described or analyzed in detail.
Data age	Alternative A uses 1980's era raw materials manufacturing data. Alternative B used a one year old study.
Technological representation	Alternative A is bench scale laboratory model. Alternative B is a full-scale production plant operation.
Temporal representation	Data for Alternative A describe a recently developed technology. Alternate B describes a technology mix, including recently built and old plants.
Geographical representation	Data for Alternative A were data from technology employed under European environmental standards. Alternative B uses the data from technology employed under U.S. environmental standards.
System boundaries, assumptions & models	Alternative A uses a Global Warming Potential model based on 500 year potential. Alternative B uses a Global Warming Potential model based on 100 year potential.

Conclusions and recommendations

The final step of the interpretation is more or less similar to the traditional concluding and recommending part of a scientific and technical assessment, investigation or alike.

The aim of this third step of the interpretation is to reach conclusions and recommendations for the report of the LCA study or life cycle inventory study.

This step is important to improve the reporting and the transparency of the study. Both are essential for the readers of the LCA report.

The results of the critical review of the study shall be included when presenting the conclusions and recommendations.

Depending upon the scope of the LCA, the results of the impact assessment will return either a list of un-normalized and un-weighted impact indicators for each impact category for the alternatives, or it will return a single grouped, normalized, and weighted score for each alternative.

In the latter case, the recommendation may simply be to accept the product/process with the lowest score. However, do not forget the underlying assumptions that went into the analysis.

If an LCIA stops at the characterization stage, the LCIA interpretation is less clear-cut. The conclusions and recommendations rest on balancing the potential human health and environmental impacts in the light of study goals and stakeholder concerns.

A few words of caution should be noted. It is important to draw conclusions and provide recommendations based only on the facts. Understanding and communicating the uncertainties and limitations in the results is equally as important as the final recommendations. In some instances, it may not be clear which product or process is better because of the underlying uncertainties and limitations in the methods used to conduct the LCA or the availability of good data, time, or resources. In this situation, the results of the LCA are still valuable. They can be used to help inform decision-makers about the human health and environmental pros and cons, understanding the significant impacts of each, where they are occurring (locally, regionally, globally), and the relative magnitude of each type of impact in comparison to each of the proposed alternatives included in the study.

Reporting the Results

Now that the LCA has been completed, the materials must be assembled into a comprehensive report documenting the study in a clear and organized manner. This will help communicate the results of the assessment fairly, completely, and accurately to others interested in the results. The report presents the results, data, methods, assumptions and limitations in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA study.

If the results will be reported to someone who was not involved in the LCA study, i.e., third-party, stakeholders, this report will serve as a reference document and should be provided to them to help prevent any misrepresentation of the results.

The reference document should consist of the following elements (ISO 1997):

- Administrative Information

    - Name and Address of LCA Practitioner (who conducted the LCA study)
    - Date of Report
    - Other Contact Information or Release Information

- Definition of Goal and Scope
- Life Cycle Inventory Analysis (data collection and calculation procedures)
- Life Cycle Impact Assessment (methodology and results of the impact assessment that was performed)

- Life Cycle Interpretation
    - Results
    - Assumptions and Limitations
    - Data Quality Assessment
- Critical Review (internal and external)
    - Name and Affiliation of Reviewers
    - Critical Review Reports
    - Responses to Recommendations

3. Hazardous waste management in Thailand

Thailand's high economic growth since the late 1980s has mostly been due to the country's rapid industrialization. The main target of industrial output has changed from domestic consumption to export. While an industry-driven economy creates higher income opportunities for some people, it also has an undeniable impact on the country's environment and on its natural resources. Industrialization has introduced to Thailand, as it has elsewhere, the use of hazardous substances as raw materials and the production of hazardous wastes. The hazardous waste problem in Thailand has dramatically worsened in recent years.

A study commissioned by the Office of the National Environment Board in 1986 to formulate a hazardous waste management plan for Thailand estimates that heavy metal sludge and solids form the largest quantity of hazardous waste generated by Thai industries. Of the total 1,160,780 tons of hazardous waste generated in 1986, heavy metal sludge and solids accounted for 832,870 tons, or 71.75 percent. Since this study used the United States' waste generation rate for its estimates, the Department of Pollution Control (DPC) of the Ministry of Science, Technology and Environment requested the Department of Industrial Works of the Ministry of Industry to revise the national inventory. The revised quantities turned out to be lower than the earlier study; the total amount of waste generated in 1986, for example, dropped from 1,160,780 tons to 531,154 tons. Even after the revision, however, heavy metal sludge and solids still top the list, although their proportion has reduced from 71.75 percent to 56.92 percent. The revision estimated that by the year 2001, Thailand will produce 2.8 million tons of hazardous waste per year.

A 1990 study co-sponsored by the United States Agency for International Development (USAID) and the United States Environmental Protection Agency (USEPA) identified three categories of environmental health risks in Bangkok:

- The high risk category includes: 1) particulate matter, 2) lead and 3) microbiological diseases;
- The medium risk category includes: 1) carbon monoxide and 2) other metals;
- The low risk category includes: 1) toxic air pollution, 2) other air pollutants (SO2, NOx, and O3), 3) surface water contamination, 4) ground water contamination, 5) food contamination and 6) solid and hazardous waste disposal.

Hazardous wastes are known to be potentially carcinogenic. Arsenic tops the list of hazardous wastes listed by WHO, and is of particular concern to the environmental regulatory institutions of industrialized nations. Arsenic poisoning is readily visible. By contrast, heavy metal poisoning, often a health hazard of chronic or long-term nature, is very difficult to identify.

The Environmental Quality Standards Division, Office of the National Environment Board, used to provide a definition of hazardous wastes as "substances or materials which are not used or cannot be used, which contain or are contaminated with combustible substances, corrosive substances, highly active substances, explosives, toxic substances, soluble substances, radio-active substances, and/or disease producing organisms which are produced by various industrial, community, agricultural activities." This definition follows the United States concept. Thailand does not have an integrated legislative structure for the control and management of hazardous waste. Legislation is fragmented and the jurisdiction and authority to implement these laws is spread out in several ministries, viz., the Ministry of Industry, the Ministry of Science, Technology and Environment (MOSTE), the Ministry of Public Health, and the Ministry of

Agriculture and Cooperatives, in the past. Currently regulations and legislations are almost from Ministry of Industry.

In 1983, the Canadian International Development Agency (CIDA) funded a pre-feasibility study for the construction of a plant for the treatment of industrial hazardous waste in Bangkok and its vicinity. The estimated annual volume of waste from 682 factories out of 862 possible waste generators, it can be seen that the electroplating industry and the textile industry are the biggest polluters, generating, respectively, about 84,000 tons of waste water and 38,300 tons of sludge each year.

In 1986, the Asian Development Bank sponsored a pre-feasibility study of a combined industrial wastewater and hazardous waste treatment facility in Samutprakarn province, which has the largest number of industrial establishments in Thailand. As the estimates of hazardous waste generated by various industrial sectors, a good deal of hazardous waste in Samutprakarn is generated by the tanning and chemical industries.

On the basis of these pre-feasibility studies and the aforementioned estimates for hazardous waste inventories, the Division of Industry Work (DIW) built in 1988 a pilot-scale industrial hazardous waste treatment center at Samae Dam, Bang Khun Tian district, in a western suburb of Bangkok. The center comprises: (a) a chemical treatment plant for treating electroplating waste-water on a batch basis, with a capacity of 200-cmd (cubic metres per day); (b) an 800-cmd-capacity continuous chemical treatment plant for textile dyeing wastewater; and (c) a 100-ton solidification facility for hazardous sludge or solid waste. The government has spent 31.5 million baht on the center and has leased it out to a private company to operate. The 80 hectare disposal landfill site is in Ratchaburi province, about 100 km southwest of Bangkok.

The Samae Dam center's capacity is, however, insufficient for the whole country. As of 1992-1993, the amount of waste treated by the plant represents approximately 10 percent of the estimated 0.9 million tons of waste generated each year. Therefore, the DIW plans to have four more hazardous waste treatment centers at Chonburi, Rayong, Ratchaburi and Saraburi to serve the industries in and around Bangkok. The Ratchaburi center will be the extension of the Samae Dam center, and will have an incinerator of 15,000 tons/year capacity, with a secure landfill of

10,000 tons/year. The government has provided the budget for land acquisition and development to do this. The Chonburi center will have a capacity of 70,000 tons/year for the physico-chemical treatment of heavy metals, 15,000 tons/year for incineration, 100,000 tons/year for solidification treatment and 7,200 tons/year for distillation treatment. The Saraburi center will process 70,000 tons/year in physico-chemical treatment, 15,000 tons/year for incineration and 100,000 tons/year for secure landfill. The Rayong center will process 100,000 tons/year for secure landfill. The construction of the Chonburi and Rayong centers has been delayed because of opposition from local communities.

As of February 8, 1994, DIW had a memorandum of understanding with GCN Holding Co. Ltd. for the latter to be a private partner in the development of the hazardous waste treatment centers. GCN holds 75 percent while the Government holds 25 percent of the primary registered capital of 600 million baht. The capital investment for the project is about 2,370 million baht.

The complexity of hazardous waste problems demands a multidisciplinary approach to its control, calling for expertise in science, engineering, public health, medicine, and economics.

Pollution Control Department has conducted the report B.E. 2545 to conclude pollution situation in Thailand as shown in table 8.

Table 8 Quantity of hazardous waste categorized by sources and areas B.E. 2545 (unit: million tons)

Areas/Regions	Sources		
	Industries	Communities	% By total
Bangkok and adjacent areas	0.925	0.156	60.7
Middle region	0.078	0.037	6.4
Eastern region	0.094	0.022	6.5
North-eastern region	0.043	0.077	6.7
Northern region	0.146	0.05	11
Southern region	0.114	0.042	8.7
Total	1.4	0.38	100

Data of waste management in paint industry in B.E. 2545 surveyed by JICA are demonstrated in the table 9 to 12. The results in the tables are collected by 2 Japanese experts during visiting 11 factories who are members of TPMA (large size = 5 factories, medium and small size = 6 factories).

Table 9 Waste from 11 surveyed factories

Wastes	Amounts from 11 factories (ton/year)
Others	914
Waste metals	884
Waste paint	756
Waste solvent	604
Sludge	359
Waste paper	85
Dust	76
Waste wood	46
Waste plastics	5
Cotton wastes	2
Total	3,732

Table 10 Amount of total waste from the paint industry in the study area

Wastes	Amount of wastes (ton/year)
Others	4,048
Waste metals	3,915
Waste paint	3,350
Waste solvent	2,677
Sludge	1,592
Waste paper	376
Dust	338
Waste wood	205
Waste plastics	23
Cotton wastes	7
Total	16,531

Table 11 Amount of off-site waste disposal from the paint industry in the study area

Wastes	Amount of wastes (ton/year)
Waste metals	3,915 (100%)
Waste solvent	2,375 (89%)
Sludge	1,592 (100%)
Waste paint	982 (29%)
Others	854 (21%)
Dust	336 (99%)
Waste paper	376 (100%)
Waste wood	203 (99%)
Waste plastics	23 (100%)
Cotton wastes	7 (100%)
Total	10,646 (64%)

Note: The figure in the parentheses shows the proportion of off-site disposal amount of total amount.

Table 12 Amount of off-site disposal to be paid for treatment/final disposal

Wastes	Amount of wastes (ton/year)
Sludge	1,592
Waste paint	982
Others	854
Dust	336
Waste metals	176
Waste paper	21
Cotton wastes	7
Waste plastics	0.44
Total	3,968.44

From above data, the conclusion by JICA is as follows;

1. Thai paint manufacturers are more enthusiasm than Japanese ones are, in term of waste improvement in order to reuse or recycle in lower grade of paint.
2. The amount of waste from production in Thailand, are higher than that in Japan.
3. Wastes needed treatment, are gelled paints and sludge because those can not be reused or recycled. Treatment is done by service provider, viz. GENCO. Price is expensive but service is weak.
4. Survey team found that, besides the wastes mentioned in item 3 above, the other type of wastes are well managed.
5. Service providers for waste disposal in Thailand are not only insufficient but also lack of potentiality e.g. inappropriate incinerator

which is the reason why cooperation from cement manufacturer is required.

6. Incinerating of paint waste composed of chlorine and heavy metal may affect to cement quality. Therefore analysis of waste composition is necessary.

Details of chemical solvents

Trichloroethylene

Trichloroethylene is believed to have been discovered in 1864 and was first commercially produced in Germany in the early 1900s. It has been commonly used for cleaning of metals and other parts since the introduction of the vapor degreasing process in the early 1930s and continues to be the standard by which other cleaning processes are compared. Today, its primary uses are as an intermediate in the production of hydrofluorocarbon refrigerants and as a cleaning agent.

The health effects of trichloroethylene have been studied extensively. The most significant findings to come out of the many long-term animal studies of the chemical are that it has caused liver and lung tumors in mice. The significance of these tumors to human health is unclear due to species differences in both trichloroethylene metabolism and reaction to the metabolites. This is supported by epidemiology studies of workers exposed to trichloroethylene that generally indicate no overall increase in cancer risk. Although recent studies of a small population of exposed workers in Germany appear to show an increase in kidney cancer, these studies suffer from major design flaws and are inconsistent with the results of larger, better conducted studies.

The International Agency for Research on Cancer (IARC) currently considers trichloroethylene to be "probably carcinogenic to humans" (Group 2A), based on its conclusions that there is "limited" evidence of carcinogenicity in humans. The epidemiological data base for trichloroethylene is considered by the American Conference of Governmental Industrial Hygienists (ACGIH), however, to support classification in Group A5 (Not Suspected as a Human

Carcinogen) "since the substance has been demonstrated by well controlled epidemiological studies not to be associated with any increased risk of cancer in exposed humans." The U.S. Environmental Protection Agency currently is conducting a reassessment of the carcinogenic potential of trichloroethylene.

Trichloroethylene is used widely by industry as a metal degreaser. It is especially valuable because of its cleaning properties, low flammability, and lack of a measurable flashpoint. Trichloroethylene also is used as a chemical process intermediate in fluorochemical and polyvinyl chloride (PVC) production. It has been used worldwide for more than 70 years.

Trichloroethylene, a colorless, volatile liquid, is an unsaturated aliphatic halogenated hydrocarbon. In the United States, it is produced by The Dow Chemical Company and PPG Industries, Inc. In 1998, U.S. demand was about 171 million pounds (77,700 metric tons) of which about 15 million pounds (6,800 metric tons) were imported. About 84 million pounds (38,000 metric tons) were exported.

Chemical Intermediate

High-purity grades of trichloroethylene are used as a feedstock in the synthesis of the refrigerant hydrofluorocarbon 134a. In this process, the trichloroethylene molecule is destroyed to form the new fluorinated compound. It also is used in the production of such chlorinated end products as polychlorinated aliphatics and flame-retardant chemicals. In polyvinyl chloride (PVC) manufacture, trichloroethylene is used as a molecular-weight control agent.

Metal Cleaning/Degreasing

Among the properties that have contributed to trichloroethylene's wide acceptance as a metal cleaner and degreaser are the following:

- low flammability (no flash point)
- high solvency
- non-corrosiveness
- high stability

- low specific heat
- low boiling point
- low latent heat of vaporization

Trichloroethylene’s advantages for metal cleaning include the ability to degrease more thoroughly and several times faster than alkaline cleaners, and its compatibility with smaller equipment that consumes less energy. Trichloroethylene is an important solvent for degreasing aluminum and for cleaning sheet and strip steel prior to galvanizing. Trichloroethylene also is used for cleaning liquid oxygen and hydrogen tanks.

Commercial trichloroethylene formulations include a stabilizer system to help prevent solvent breakdown caused by contaminants such as acids, metal chips and fines, and exposure to oxygen, light, and heat.

Miscellaneous

Trichloroethylene is used as a solvent in some nonflammable adhesive and aerosol formulations, and as a low temperature heat-transfer medium. Other applications of trichloroethylene include its use as a solvent in the metal processing, electronics, printing, pulp and paper, and textile industries.

HEALTH EFFECTS

General

Acute (short-term) overexposure to trichloroethylene vapor can cause central nervous system effects (e.g., light-headedness, drowsiness, headache, giddiness) which may lead to unconsciousness or prove fatal in extreme circumstances. Also, at very high exposure levels, trichloroethylene can sensitize the heart to the effects of adrenaline and similar agents, which may lead to sudden cardiac arrest. In addition, trichloroethylene may irritate the respiratory tract at high vapor concentrations. Repeated or lengthy contact with the chemical in liquid form can cause irritation of the skin and eyes.

Chronic (repeated) overexposure, well in excess of recommended occupational limits, has been associated with damage to the liver and kidneys, although this is less well documented in humans than in animals.

Genotoxicity

Trichloroethylene has been tested for its mutagenicity (genotoxicity) in a number of assays in bacterial and mammalian systems, both in vivo (animal experiments) and in vitro (test tube experiments). Several of these assays have been complicated by the presence of stabilizers that are known to cause positive responses. Overall, these studies indicate that pure trichloroethylene either has no mutagenic activity or only weak activity under certain conditions. Binding of trichloroethylene, or its metabolites, to protein, RNA, and DNA has been shown in vitro. Extremely low or no binding to DNA has been reported in vivo. Hence, trichloroethylene does not show significant evidence of genotoxicity in these test systems.

Carcinogenicity

The carcinogenic potential of trichloroethylene in laboratory animals and in humans (through epidemiology studies) has been well studied. It has been shown to cause an increased incidence of liver and lung tumors in certain laboratory mice, and small increases in kidney tumors in male rats in some studies. Because of species differences in metabolism of trichloroethylene, the relevance of these results to humans is uncertain

Laboratory Animal Studies

There have been a number of studies of the carcinogenic potential of trichloroethylene in mice, rats, and hamsters, providing both positive and negative results. Interpretation of these conflicting results requires careful examination of a number of factors, including variations in the purity of the test substances and difficulties in establishing the maximum tolerated dose.

Gavage (feeding-tube) studies by the National Cancer Institute (NCI) and the National Toxicology Program (NTP) showed an increased incidence of liver tumors in B6C3F1 mice. The doses in these two studies ranged up to 2,339 milligrams per kilogram (mg/kg) per day and 1,000 mg/kg/day, respectively. A gavage study by Henschler in Swiss mice (2,400 mg/kg/day to males, 1,800 mg/kg/day to females), on the other hand, showed no significant increase in tumors, and led the researchers to conclude that the study did not support the conclusion that pure trichloroethylene is carcinogenic under realistic exposure conditions.

A gavage study by NCI in Osborne-Mendel rats (1,097 mg/kg/day) showed no significant increase in tumors. Additional gavage studies in Fischer 344 rats and four other rat strains were judged inadequate by NTP to evaluate the presence or absence of a carcinogenic response.

An inhalation study by Henschler in NMRI mice exposed to up to 500 parts per million (ppm) of trichloroethylene showed no increase in tumors in males. An increase in lymphoma incidence was observed in females, but the authors did not attribute the effect to trichloroethylene exposure. An inhalation study by Fukuda in female ICR mice (up to 450 ppm) showed an increase in lung cancer at higher doses, but the incidence of total lung tumors (benign and malignant) was not significantly increased.

Inhalation studies by Henschler in Wistar rats and Syrian hamsters (up to 500 ppm) showed no increased incidence of cancer. Additional inhalation studies by Fukuda in female Sprague-Dawley rats (up to 450 ppm) also showed no increase in cancer incidence.

Finally, several studies of trichloroethylene exposure have been conducted by Maltoni in Swiss mice, B6C3F1 mice, and Sprague-Dawley rats. These studies showed a variety of responses, including an increased trend, or incidence, of kidney and Leydig cell tumors in male rats and lung tumors in mice. The Science Advisory Board of the U.S. Environmental Protection Agency (EPA) has indicated, however, that the Maltoni studies are of questionable value because of inadequacies in methodology and in the collection and reporting of the data.

Significance of the Animal Data

Extensive research into the induction of mouse liver tumors has shown that the presence of one or more metabolites of trichloroethylene increases the number of certain intracellular organelles (peroxisomes) in the mouse liver with an associated increase in cell division. Such a cancer mechanism may be "promotional" in nature — that is, trichloroethylene would not contribute to induction of tumors unless they had been initiated by other processes unrelated to exposure to the solvent.

In rats, the liver does not show peroxisome proliferation or other evidence of promotional activity following trichloroethylene exposure. This observation is consistent with the absence of liver tumor induction in long-term toxicity tests in rats. Human liver cells, similarly, do not show increases in peroxisomes in response to treatment with trichloroethylene or its metabolites. Consequently, it appears that the mechanism leading to an increase in mouse liver tumors is unlikely to occur in humans.

Laboratory research indicates that the probable mechanism underlying the increase in mouse lung tumors observed in some inhalation studies also may not be relevant to humans. A specific cell type, the Clara cell, in the mouse lung shows a dramatic cytotoxic response to the substance chloral which is formed in these cells by the metabolism of trichloroethylene by the cytochrome P450 pathway. The formation of mouse lung tumors is believed to result from the repeated cycle of damage and repair in the Clara cell which occurs during the dosing regimen of the cancer study. Human lungs, in contrast, have far fewer Clara cells and exhibit little or no P450 activity. Thus, chloral is not expected to accumulate in human Clara cells.

A marginal increase in kidney tumor incidence was seen in rats in certain experiments. Hypotheses concerning the response of the rat kidney to trichloroethylene administration are being explored experimentally. As discussed below, large, well-conducted epidemiology studies of U.S. workers show no association between trichloroethylene and kidney cancer.

The species-, sex-, and strain-specific patterns of tumor induction have led to investigations of trichloroethylene metabolism and mechanisms of action. The availability of this new information has prompted the U.S. Environmental Protection Agency (EPA) to initiate a reassessment of the carcinogenic risk associated with exposure to trichloroethylene.

Epidemiology Studies

Studies of U.S. workers exposed to trichloroethylene have consistently indicated no overall increase in cancer risk. A retrospective study of over 7,000 U.S. aircraft maintenance workers followed for an average 25 years failed to demonstrate any significant association between exposure to trichloroethylene and an excess rate of cancer. Two similar studies of 4,700 and 2,300 exposed workers, respectively, found no significant increase in cancer mortality despite additional potential exposure through contaminated groundwater in one of the studies. These and other epidemiology studies on trichloroethylene provide support for the conclusion that trichloroethylene does not pose a risk of cancer, including kidney cancer, under normal conditions of occupational exposure and when products are used in accordance with manufacturers' instructions.

A recent study of a small number of employees in a German cardboard factory reported a substantial increase in the risk of kidney cancer which appeared to be associated with trichloroethylene exposure. Reviewers of this study have criticized its conclusions because the existence of a cluster of cases was recognizable before the study began. As a result, they note that the study cannot be used as an independent test of an association. A small, case-control study by the same group also appeared to support a link between trichloroethylene exposure and kidney cancer. However, the design of this study also has been heavily criticized, particularly with respect to the selection of control subjects. The results of these studies are not consistent with other larger, well conducted epidemiology studies, none of which has associated trichloroethylene exposure with an increased risk of kidney cancer.

Impairment of the function of the von Hippel-Lindau (VHL) tumor suppressor gene is known to be involved in most cases of human kidney cell cancer. Recently, a German group of researchers has reported a possible association between trichloroethylene exposure and multiple mutations of the VHL gene among kidney cancer patients, including a high proportion of subjects showing a specific "hot spot" mutation. Induction of multiple mutations in a single gene, however, is believed by experts to be highly unlikely to lead to development of a tumor. While experts in the VHL research field believe that a specific "hot spot" mutation could be highly significant, further testing has failed to confirm the original observation.

Cancer Classification

The International Agency for Research on Cancer (IARC) currently classifies trichloroethylene in Group 2A, as a substance considered "probably carcinogenic" to humans. IARC, following its own restrictive classification scheme, concluded that the combination of the results from some of the epidemiology studies provided "limited" evidence of carcinogenicity in humans. The American Conference of Governmental Industrial Hygienists (ACGIH) has classified trichloroethylene in Group A5 (Not Suspected as a Human Carcinogen), however, "since the substance has been demonstrated by well controlled epidemiological studies not to be associated with any increased risk of cancer in exposed humans."

The National Toxicology Program (NTP) classified trichloroethylene as "reasonably anticipated to be a human carcinogen" in the Ninth Report on Carcinogens. NTP proposed to classify it as a "known human carcinogen" in the Tenth Report on Carcinogens. In December 2000, however, a subcommittee of NTP's Board of Scientific Counselors rejected this proposal and voted 9-to-1 to retain the classification of "reasonably anticipated."

EPA’s Science Advisory Board has stated that the weight of the evidence for trichloroethylene does not support classification as a probable human carcinogen (category B2) under the Agency's 1986 guidelines for carcinogen risk assessment, and that the uncertainties and moderate nature of the responses should be emphasized. The solvent currently is being reassessed under revised guidelines proposed in April 1996. The revised guidelines provide for greater use of mechanistic data to account for differences in response between test animals and humans observed after exposure to substances like trichloroethylene.

Reproductive and Developmental Toxicity

There have been a number of inconclusive reports of developmental toxicity in populations exposed to trichloroethylene and other chemicals in their drinking water. In an attempt to understand more fully the developmental toxicity of trichloroethylene, HSIA recently sponsored a study designed in conjunction with the federal Agency for Toxic Substances and Disease Registry following EPA guidelines. Pregnant rats were exposed to up to 600 ppm trichloroethylene for 6 hours per day, 7 days per week during gestation. The top dose of 600 ppm was chosen because it is known to result in some toxicity in pregnant rats. No maternal toxicity was observed in the lower doses (50 and 150 ppm) and no evidence of developmental toxicity was observed in the fetuses at any dose.

Several earlier studies evaluated the ability of trichloroethylene to affect the reproductive or developmental process in animals. Inhalation studies in rats, mice, and rabbits at concentrations ranging from 300 ppm to 1,800 ppm showed no significant developmental effects. At 300 ppm, no significant maternal toxicity, embryotoxicity, or fetotoxicity was seen in Sprague-Dawley rats or Swiss-Webster mice. No significant effects were observed in Sprague-Dawley rats exposed to 500 ppm. A nonsignificant increased incidence of hydrocephalus (brain swelling) was seen in

New Zealand rabbits exposed to 500 ppm. This effect is now recognized as an artifact of the techniques employed, however, and unrelated to solvent exposure. Slight fetoxicity and growth depression were seen in Long-Evans rat offspring at 1,800 ppm. A dominant lethal study in mice suggests the absence of any adverse effect on the male reproductive system.

This spectrum of negative animal data indicates that trichloroethylene is unlikely to have an adverse effect on human reproduction or development when handled in accordance with manufacturers' instructions.

REGULATION

A number of federal and state requirements control the use and disposal of trichloroethylene. Some of these requirements are summarized below.

Air

The Clean Air Act Amendments of 1990 significantly revised the provisions of Section 112 relating to the regulation of emissions of hazardous air pollutants. Under the new law, EPA is required to develop national emission standards based on maximum achievable control technology, or MACT, for sources of trichloroethylene and 188 other substances within 10 years. The revised Section 112 also requires EPA to review the need for additional control of regulated sources within 8 years of the implementation of the MACT standard. Trichloroethylene also is regulated as an air toxic in most states.

A standard for halogenated solvent cleaning (degreasing) with trichloroethylene and the other chlorinated solvents was promulgated in December 1994 and became effective for existing sources in December 1997. As a result, all degreasing sources using trichloroethylene will be required to obtain an operating permit from the state regulatory agency. Permitting for small degreasing sources may be deferred until 2004.

EPA has determined that trichloroethylene is an acceptable alternative in many applications for methyl chloroform and chlorofluorocarbon (CFC) 113, solvents whose production has been phased out because of their potential to deplete stratospheric ozone.

Trichloroethylene is controlled as a volatile organic compound (VOC) under state regulations implementing the national ambient air quality standard for ozone (smog). The available information suggests, however, that trichloroethylene exhibits relatively low photochemical reactivity when compared to many other hydrocarbon solvents.

Water

EPA has established national drinking water regulations setting a maximum contaminant level of 5 micrograms per liter (ug/l), equal to 5 parts per billion (ppb), for trichloroethylene. The maximum contaminant level goal (MCLG) for trichloroethylene is zero. EPA has indicated that "[t]he establishment of an MCLG at zero does not imply that actual harm necessarily occurs to humans at a level somewhat above zero, but rather that zero is an aspirational goal, which includes a margin of safety, within the context of the Safe Drinking Water Act." Various states also may have drinking water regulations that apply to trichloroethylene.

For various industry categories, EPA has established effluent limitation guidelines, which may contain effluent limitations for trichloroethylene. EPA also has published ambient water quality criteria for trichloroethylene for use by states in developing water quality standards.

Waste

Trichloroethylene waste is considered hazardous under the federal Resource Conservation and Recovery Act (RCRA) and many state laws. The waste must be stored, transported, and disposed of in accordance with applicable RCRA and state requirements.

The reportable quantity (RQ) for releases of trichloroethylene under the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) is 100 pounds. It is one of several hundred chemicals subject to material safety data sheet (MSDS), inventory, and release reporting under the Emergency Planning and Community Right-to-Know Act (Title III of the 1986 Superfund Amendments and Reauthorization Act, or SARA).

Occupational Exposure

In 1989, the U.S. Occupational Safety and Health Administration (OSHA) lowered the permissible exposure limit (PEL) for trichloroethylene from 100 ppm to 50 ppm for an 8-hour time-weighted-average (TWA). OSHA also established a short-term (15-minute) exposure limit, or STEL, of 200 ppm. These actions were overturned by a federal court in 1993, and the PELs reverted to the former limits of 100 ppm (8-hour TWA), 200 ppm (ceiling), and 300 ppm (peak). Several states that adopted the lower 1989 limits, however, have not adopted the higher limit.

ACGIH currently recommends threshold limit values (TLVs) of 50 ppm for an 8-hour TWA and 100 ppm for a 15-minute STEL.

Trichloroethylene is subject to the OSHA Hazard Communication Standard, which imposes labeling, material safety data sheet (MSDS), and other requirements on employers and their suppliers.

Beyond Compliance

HSIA does not recommend the use of trichloroethylene in any application, including cold cleaning, unless all applicable workplace, disposal, and other environmental regulatory requirements are met. In addition to complying with these various regulatory requirements, many prudent operators of degreasing and other equipment have elected to adopt practices and standards for the use, management, and disposal of trichloroethylene and trichloroethylene-containing wastes that go beyond the strict legal requirements. These operators recognize that environmental protection is their responsibility. They also understand that they are potentially liable for environmental contamination that can be traced to their solvent wastes, whether at their own plant or elsewhere, regardless of the fact that they may have complied with the letter of the law. These operators recognize that additional measures that go "Beyond Compliance" make good business sense because they minimize the risks of liability that arise when trichloroethylene is released to the environment.

Table 13 Regulatory (Federal) and Other Information for Trichloroethylene

Chemical Formula	C_2HCl_3
Molecular Weight	131.4
CAS Number	79 01-6
Boiling Point	189°F (87°C)
Weight per Gallon (@77°F)	12.11 pounds
Flash Point	none
Flammable Limits @77°F (% solvent in air, by volume)	
Lower Limit	8.0
Upper Limit	9.2 (vapor saturation point)
Flammable Limits @212°F (% solvent in air, by volume)	
Lower Limit	8.0
Upper Limit	44.8
Solubility @77°F (grams/100 grams)	
Trichloroethylene in water	0.10

Table 13 (Cont'd)

Water in trichloroethylene	0.04
OSHA PEL (see discussion in text)	
8 hr TWA	100 ppm
Ceiling	200 ppm
Peak	300 ppm
ACGIH TLV	
8 hr TWA	50 ppm
15 min STEL	100 ppm
Cancer Classification	
ACGIH	A5
IARC	2A
NTP	"reasonably anticipated "
CERCLA Reportable Quantity (RQ)	100 pounds
Maximum Contaminant Level (MCL)	5 ppb (5 micrograms/liter)
RCRA Hazardous Waste No.	U 228
Department of Transportation	
Hazard Classification	6.1 (packing group III)
ID Number	UN 1710

Toluene

Toluene is a clear, colorless liquid with a distinctive smell. Toluene occurs naturally in crude oil. It is also produced in the process of making gasoline and other fuels from crude oil and making coke from coal. Toluene is used in making paints, paint thinners, fingernail polish, lacquers, adhesives, and rubber and in some printing and leather tanning processes. Exposure to toluene occurs from breathing contaminated workplace air, in automobile exhaust, some consumer products paints, paint thinners, fingernail polish, lacquers, and adhesives. Toluene affects the nervous system. Toluene has been found at 959 of the 1,591 Superfund sites.

What happens to toluene when it enters the environment

Toluene enters the environment when you use materials that contain it. It can also enter surface water and groundwater from spills of solvents and petrolium products as well as from leaking underground storage tanks at gasoline stations and other facilities. When toluene-containing products are placed in landfills or waste disposal sites, the toluene can enter the soil or water near the waste site. Toluene does not usually stay in the environment long. Toluene does not concentrate or buildup to high levels in animals. Toluene may affect the nervous system. Low to moderate levles can cause tiredness, confusion, weakness, drunken-type actions, memory loss, nausea, loss of appetite, and hearing and color vision loss. These symptoms usually disappear when exposure is stopped.

Inhaling High levels of toluene in a short time can make you feel light-headed, dizzy, or sleepy. It can also cause unconsciousness, and even death.

Some studies in animals suggest that babies may be more sensitive than adults.

Breathing very high levels of toluene during pregnancy can result in children with birth defects and retard mental abilities, and growth. We do not know if toluene harms the unborn child if the mother is exposed to low levels of toluene during pregnancy.

Is there a medical test to show whether I've been exposed to toluene

There are tests to measure the level of toluene or its breakdown products in exhaled air, urine, and blood. To determine if you have been exposed to toluene, your urine or blood must be checked within 12 hours of exposure. Several other chemicals are also changed into the same breakdown products as toluene, so some of these tests are not specific for toluene.

What happens with toluene waste

According to the 2000 Toxics Release Inventory, industry managed appoximately 2 billion pounds of toluene waste of which 81 million pounds were released by stationary sources into the air. 339 million pounds were treated and 214 million pounds were used as an energy source.

How is toluene disposed

Despite the risk, toluene is not a toxicity characteristic chemical. Therefore, some toluene waste, depending on its use, is not required to follow the federal solid waste law rules for hazardous waste.

Generally, it is used as a waste fuel or burned in incinerators.

Hazardous waste according to EPA law (USA) : Under the law, hazardous waste must be handled more carefully (treated or stabilized and put in properly managed double-lined landfills) than common household garbage. Hazardous waste can be a liquid, solid or sludge that is a by-product of a manufacturing process. It can also be a commercial product like battery acid or industrial solvents that are discarded. Under the law, a waste is hazardous and must be treated specially if the Environmental Protection Agency lists the chemical as being toxic or if the waste demonstrates that is has any of the following characteristics:

Ignitable: A waste that is flammable (has a flash point under 140 degrees Fahrenheit) such as solvents, points or cleaning products.

Corrosive:wastes that are acids or alkaline that can burn human tissue or corrode metal.

Reactive:A broad range of wastes that are unstable, explosive or can create toxic fumes. Of the thousands of toxic chemicals in commerce, EPA has listed only 40 as having toxic characteristics.

However, according to a study by EPA, the tests to determine whether a chemical meets the characteristic tests for hazardousness have serious flaws. Because of the weaknesses in the tests, many hazardous wastes are unregulated.

Thinner

The direct heating of used thinner is dangerous when thinner is recovered by distillation because the flash point of used thinner is low and the impurity is included in it. In addition, there happens a problem in the equipment maintenance. The problem mentioned above can be avoided by using the proper system. The thinnner is heated and vaporized by blowing the steam into the used thinner. The vaporized thinner and steam by heating are distilled and condensed and both components are separated. By this method, however, a water-soluble solvent dissolves into the water of heating source and a higher-boiling product than water is not collected easily. The thinner thus recovered is unsuitable for the finishing of products because some amount of water is contained.

4. Solvent recycling process

Waste solvents are organic dissolving agents that are contaminated with suspended and dissolved solids, organics, waters, other solvents, or any other substance not added to the solvent during its manufacture. Recycling is the process of restoring waste solvent to a condition that permits its reuse, either for its original purpose or for other industrial needs. Not all waste solvents generated by industry are recycled because the costs of reclamation may exceed the value of the recycled solvent, it is not always technically feasible to do so.

Industries that product waste solvents include solvent refining, polymerisation processes, vegetable oil extraction, metallurgical operations, surface coating and cleaning operations. The amount of solvent recovered from the waste varies from about 40 to 99 percent, depending on the extent and characterisation of the contamination and on the recovery process employed.

Design parameters and economic factors determine whether solvent reclamation is accomplished as a main process by a private contractor, as an intergral part of a main process (such as solvent refining), or as an added process (as in the surface coating and cleaning industries). Most contract solvent reprocessing operations recover halogenated hydrocarbons, such as dichloromethane and trichloroethylene, from degreasing, and/or aliphatic, aromatic, and naphthenic solvents such as those used in paint, ink and coating industries. They may also reclaim small quantities of numerous specialty solvents, such as phenols, nitriles, and oils.

A solvent recycling process is illustrated by figure 7. Industrial operations may not incorporate all of these steps. For example, initial treatment is necessary only when liquid waste solvents contain dissolved contaminations.

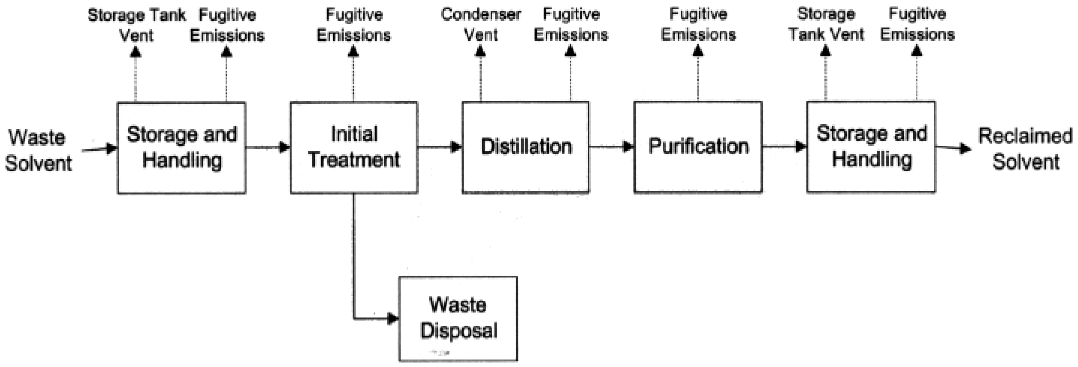

Figure 7 General processes in solvent recycling operations

Solvents are stored before and after recycling in containers ranging from 0.2 m^3 (44 gallon drums) to tanks with capacities of 75 m^3 or more. Various types and sizes of tanks are used for storage. Most of these tanks have a fixed-roof design.

Solvent handling includes loading waste solvent into process equipment and filling drums and tanks prior to transport and storage. The filling is most often done through submerged or bottom loading.

Waste solvents are initially treated by vapor recovery, or mechanical separation. Vapor recovery entails removal of solvent vapors from a gas stream in preparation for further reclaiming operations. In mechanical separation undissolved solid contaminants are removed from liquid solvents. Vapor recovery or collection methods employed include condensation, adsorption, and absorption. Technical feasibility of the method chosen depends on the solvent's miscibility, vapor composition and concentration, boiling point, reactivity, and solubility, as well as several other factors.

Condensation of solvent vapors is accomplished by water-cooled condensers and refrigeration units. For adequate recovery, a solvent vapor concentration well above 20 mg/m^3 is required. To avoid explosive mixtures of a flammable solvent and air in the process gas stream, air is replaced with an inert gas, such as nitrogen. Solvent vapors that escape condensation are recycled through the main process stream or recovered by adsorption or absorption.

After initial treatment, waste solvents are distilled to remove dissolved impurities and to separate solvent mixtures. Separation of dissolved impurities is accomplished by simple batch, simple continuous, or steam distillation. Mixed solvents are separated by multiple simple distillation methods, such as batch or continuous rectification. These processes are shown in figure 8.

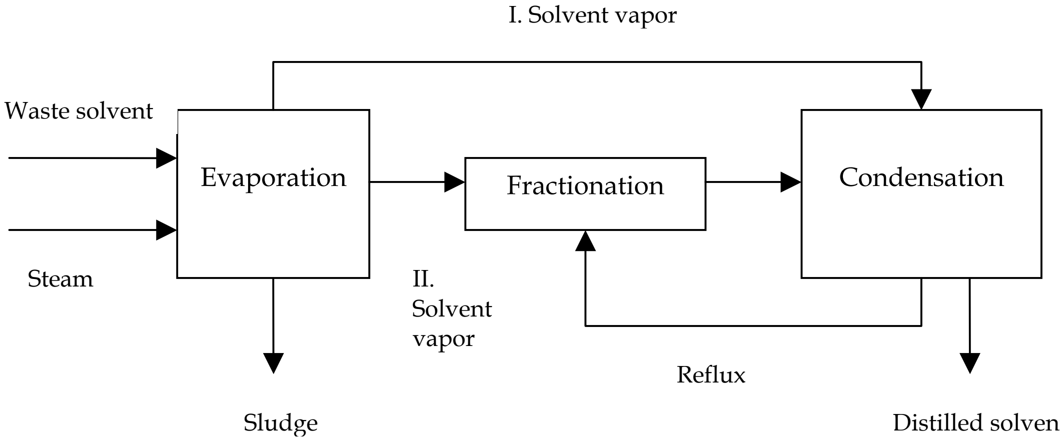

Figure 8 Distillation process for solvent recycling

In simple distillation, waste solvent is charged to an evaporator. Vapors are tehn continuously removed and condensed, and the resulting sludge or still bottoms are drawn off. In steam distillation, solvents are vaporized by direct contact with steam, which is injected into the evaporator. In contrary, in hot oil distillation, solvent do not directly contact with heat carrier. Simple batch, continuous, and steam distillations follow path I in figure 8.

The separation of mixed solvents requires multiple simple distillation or rectification. Batch and continuous rectification are represented by path II in figure 8. In batch rectification, solvent vapors pass through a fractionating column, where they contact condensed solvent (reflux) entering at the top of the column. Solvent not returned as reflux is drawn off as overhead product. In continuous rectification, the waste solvent feed enters continuously at an intermediate point in the column. The more volatile solvents are drawn off at the top, while those with higher boiling points collect at the bottom.

Design criteria for evaporating vessels, depends on the composition of the waste solvent. Scraped surface stills or agitated thin film evaporators are the most suitable for heat sensitive or viscous materials. Condensation is accomplished by barometric, or shell and tube, condensers. Azeotropic solvent mixtures are separated by the addition of a third solvent component, while solvents with higher boiler points (those in the range of hogh-flash naphthas at 155 ºC), are most effectively distilled under vacuum. The level of purity required in the reclaimed solvent determines the number of distillations, reflux ratios, and the processing time needed.

After distillation, water is removed from the solvent by decanting or salting. Decanting is accomplished with immiscible solvent and water which, when condensed, form separate liquid layers, one or the other of which can be drawn off mechanically. Additional cooling of the solvent/water mix before decanting increases the separation of the two components by reducing their solubility. In salting, solvent is passed through a calcium chloride bed, and water is removed by absorption.

During purification, reclaimed solvents are stabilized, if necessary. Buffers are added to virgin solvents to virgin solvents to ensure that pH level is kept constant during use. To renew it, special additives are added during purification.

History of Recycle Engineering Co., Ltd.

Since the start of business activities in 1998, Recycle Engineering Co., Ltd has developed and improved its own regulations and activities for the effective and safe recycling of chemical solvents. They achieved full support from the Thai Board of Investments (BOI) and successfully carried out an environmental impact assessment in accordance with the requirements of the Ministry of Industry. They obtained the Factory certificate No. 101 for the recycling of used chemicals and chemical waste.

The recycling business for chemicals is a very new field of business in Thailand. For this reason, there is a need to promote public awareness and responsibility for the appropriate treatment of chemical solvent. Thus Recycling Engineering established TCDEPR to be a center of environmental knowledge exchange in Thailand. Industrial companies and the respective authorities need to know about the possibilities to recycle and safely dispose chemical waste material without any negative environmental side effects.

Recycling Engineering has committed itself to contribute to the reduction of both environmental problems and the danger for workers and other people in Thailand caused by the improper handling and disposal of hazardous waste and used chemicals. They pay thire highest attention towards environmental and human protection and to ensure a high quality level of our recycled products.

Recycle Engineering aims to become a center of competence for environmental technology. The emphasis is laid on technology which is highly effective and affordable for companies in Thailand.

To achieve this target, Recycle Engineering co-operates closely with the relevant Thai government authorities, leading universities as well as international agencies and companies from different countries which provide superior environmental technology.

To ensure a further positive development of their company, they put a great emphasis on the training and development of their highly motivated staff. Recycle Engineering is proud to provide in increasing number of jobs in a safe working environment.

Hierarchy of proper waste management

- Step 1 Avoidance by using clean technologies to minimize waste
- Step 2 Collect and recycle all waste materials for reuse
- Step 3 Convert all non-recyclable materials into energy for high temperature incineration (sufficient air washing system to be ensured, i.e. cement kiln).
- Step 4 Bring non-recyclable and non-combustible materials for concrete mixing and landfill while applying standard procedures to ensure environmental protection.

Type of waste for recycling

- Group 1 Chemical solvents; NMP, acetone, MEK, MIBK, methanol, ethanol, IPA, butyl cellosolve, butyl acetate, ethyl acetate, ethylene glycol, etc.
- Group 2 Hydrocarbon solvent, mixed solvent; thinner, toluene, xylene, hydrocarbon mixture, light oil, NS clean, daphne, etc.
- Group 3 Halogenated solvents; 1,1,2 trichloroethylene, methylene chloride, perchloroethylene, 1-bromopropane, halogenated hydrocarbon, etc.
- Group 4 Refrigerants; HCFC 141 B, decafluropentane (vertrel), Dichloro – Pentafluoroproapane (AK-225)
- Group 5 Monomer, polymer; styrene monomer, silicone, polyurethane, polycarbonate, etc.

Recycle process and procedures

They use the recycle technology and equipment from Germany, such as vacuum-distillation, molecular distillation, evaporisation, filtration, extraction, neutralization, dehydration and others in a most effective way. All these processes are suitable for the recycling chemical solvents and petrochemicals which have a boiling point ranging from 10 °C -300 °C.

MATERIAL EQUIPMENT AND RESEARCH METHODOLOGY

Material and Eauipement

1. Personnel/laptop computer (MS, window 2000 with Pentium 3)	1
2. LCA software programme; SimaPro version 5.1	1
3. LCA software programme; SimaPro version 6.0	1

Research Methodology

The methodology of life cycle assessment according to Wenzel et al. (1997) method from ISO14000 by using SimaPro 5.1 Program is used in this research. The 4 steps were followed as below;

1. Goal and scope definition

1.1 Goal

In order to assess the environmental impacts or burdens of spent solvent management, the impact-results from solvent recycling are compared with ones from typical treatment, incineration.

1.2 Functional Unit

The research defines functional unit as 200 kilograms (1 drum) of spent solvent (solvent before treatment).

1.3 Scope and System boundary

The system boundary of this study is demonstrated in the figure 9.

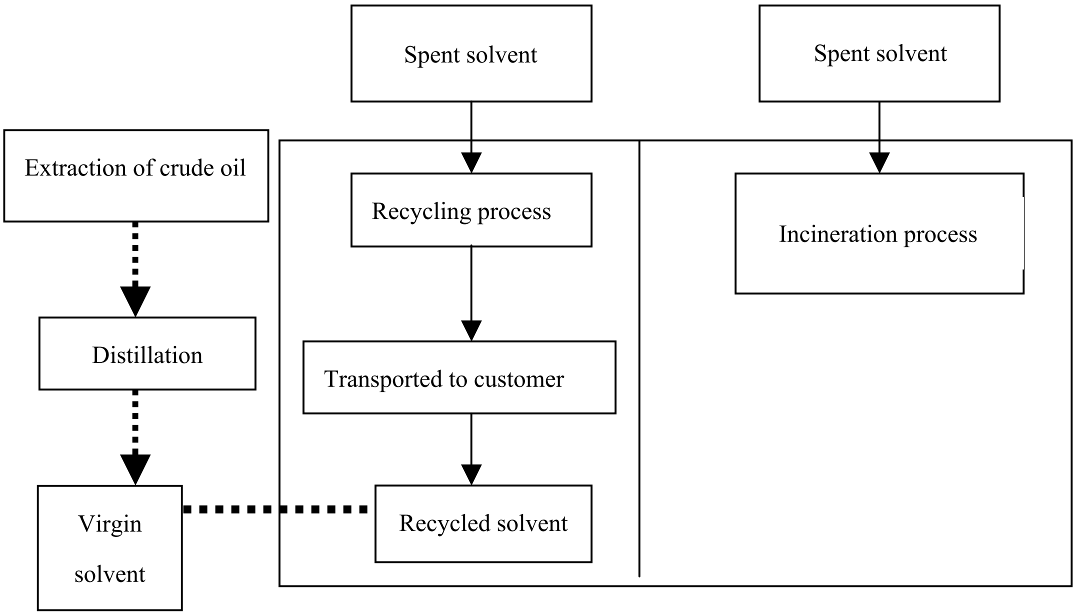

Figure 9 scope and boundary

1.4 Limitation and Assumption

Life cycle assessment in Thailand is at the beginning stage of study so LCA database is quite limited and not systematic. Therefore Thai and international databases are used during the research. Water and electricity data are from Thai database while the rest are from SimaPro database. Transportation data after recycling process, is collected from the amount of gasoline actually used to deliver treated solvent (recycled solvent) to user's premise but the gasoline database is from SimaPro. The efficiency of recycling process is depending on impurity of spent solvent. Therefore the efficiency is approximately in the range from 70% (high impurity) to 90% (low impurity). For metal drum as packaging, it can be used at least 2 times as minimum.

The recycling data, from the middle of year 2004 to the middle of year 2005, are collected and used for this research. The measurement results (e.g. characteristics of air emission, quality of wastewater) are tested by third party laboratory that is registered with Department of Industrial Work.

Due to the limitation of database in SimaPro 5.1, Ecoinvent database in SimaPro 6.0 is additionally used in order to obtain the LCA results for incineration of spent solvent and LCA results for virgin solvent (solvent from manufacturing process).

2. Inventory analysis

After goal and scope is defined, the next step is life cycle inventory (LCI) which is collected and calculated from processes. Input and output of processes are considered by resources, energy, emissions to air, water and waste.

3. Impact assessment

SimaPro 5.1 and 6.0 are used during the research. Environmental Design of Industrial Product (EDIP) and Eco-Indicator 99 methods are used as tools for analysis and impact assessment because EDIP is quite simple and easy to understand. However resource use is not considered in normalization and weighting steps of EDIP as normalization factor and weighting factor are equal to zero. So EDIP is used only in characterization step and Eco-Indicator 99 is used in normalization and weighting steps in order to obtain single score. Resource use is taken into account by Eco-Indicator 99.

Environmental indexes considered in the research are categorized into 15 groups as below;

1. Global warming
2. Ozone depletion
3. Acidification
4. Eutrophication

5. Photochemical smog
6. Ecotoxicity water chronic
7. Ecotoxicity water acute
8. Ecotoxicity soil chronic
9. Human toxicity air
10. Human toxicity water
11. Human toxicity soil
12. Bulk waste
13. Hazardous waste
14. Slag/ashes
15. Resources

4. Life Cycle Interpretation

The step of life cycle interpretation indicates possibility or chance to reduce environmental effects by comparing between solvent recycling and solvent incineration (typical treatment). Besides, it also can point out, which emission or resource use during recycling processes significantly affects to environment which should be considered or improved to be more environmental friendly.

Place and duration

1. Place

The place where data are collected, is “Recycle Engineering Co., Ltd.”, a solvent recycle factory in Chonburi province. Their staff are very helpful and cooperative to provide information.

2. Duration

Plan and timeframe are shown in table 14

Table 14 Plan and timeframe

Items	**2004**					**2005**											
(month)	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Step 1: Literature review																	
Collect relevant researches	■	■															
Survey			■	■													
Study of SimaPro5.1 program				■	■												
Step 2: Goal and boundary defined					■												
Step 3: Analysis and inventory																	
Collect data						■	■	■	■	■	■	■	■	■	■		
Step 4: Impact assessment											■	■	■	■	■		
Step 5: Interpretation															■	■	
Step 6: Conclusion and paper work																■	■

RESULT AND DISCUSSION

The data with in the system boundary, were collected from recycling plant and calculated on the basis of its functional unit as 200 kilograms of spent solvent (solvent before treatment) at the minimum and maximum efficiency as 70% and 90% respectively. The different efficiency is depending on impurity of spent solvent. If impurity is lower, the efficiency of recycling process is higher. The details of emission and resource use, are shown in the table 15.

Table 15 Emission/resource used per functional unit as 200 kilograms of spent solvent (solvent before treatment)

Emission/resource use		With 70% efficiency	With 90% efficiency
Air emission	TSP (mg)	26974.84	20980.43
	CO (mg)	667.48	519.14
	NOx (mg)	26033.68	20248.42
	SOx (mg)	26701.16	20767.57
Wastewater discharge	SS (mg)	6864.52	5339.07
	BOD (mg)	6604.84	5137.10
	COD (mg)	24834.19	19315.48
Toxic waste	Toxic waste (ton)	0.043	0.03
Water use	Water (cubic meter)	0.29	0.23
Electricity use	Electricity (kWh)	38.75	30.14
Packaging	Metal drum (kg)	6.92	8.90
Fuel for boiler	Heavy oil (kg)	6.83	5.32
Fuel for transportation	Diesel (kg)	2.80	3.60

In consequence, the above data were analyzed by using SimaPro 5.1 in order to obtain life cycle assessment inventory and life cycle impacts of recycled solvent. In the meanwhile, the life cycle assessment inventory and life cycle impacts of incinerated solvent and virgin solvent are acquired by using SimaPro 6.0 with Ecoinvent database. Due to the limitation of database in SimaPro 5.1, the different version of SimaPro is needed.

As aforementioned in the above paragraph and as mentioned in the previous chapter in the part of research methodology, SimaPro 5.1 and 6.0 are used during the research. In both versions, the two analysis methods are Environmental Design of Industrial Product (EDIP) and Eco-Indicator 99. Environmental Design of Industrial Product (EDIP) and Eco-Indicator 99 methods are used as tools for analysis and impact assessment because EDIP is quite simple and easy to understand. However resource use is not considered in normalization and weighting steps of EDIP as normalization factor and weighting factor are equal to zero. So EDIP is used only in characterization step and Eco-Indicator 99 is used in normalization and weighting steps in order to obtain single score. Global warming is taken into account by Eco-Indicator 99 method.

The LCA results for solvent recycling management at 70% and 90% efficiency compared with those for solvent incineration as typical treatment, are demonstrated in the table 16 and table 17.

Table 16 Single score and environmental impacts from Eco-Indicator 99 method (Unit : Pt) for solvent recycling management with 70% and 90% efficiency and solvent incineration

Impact	Solvent recycling management with 70% efficiency	Solvent recycling management with 90% efficiency	Solvent Incineration
Single score	-42.5314	-43.8900	4.6440
Carcinogens	-0.2685	-0.2745	0.15642
Resp. organics	-0.0169	-0.0180	0.0006588
Resp. inorganics	-6.5931	-6.7940	1.4292
Climate change	-1.8784	-1.9295	1.323
Radiation	-0.0134	-0.0136	0.005202
Ozone layer	-0.0576	-0.0581	0.0001305
Ecotoxicity	-0.1934	-0.1985	0.04932
Acidification/Eutrophication	-0.6215	-0.6487	0.07596
Land use	-0.0542	-0.0560	0.03258
Minerals	-0.1014	-0.1017	0.017694
Fossil fuels	-32.7214	-33.7900	1.5570

By using Eco-Indicator 99 method, the single score and environmental impacts of solvent recycling management with 70% and 90% efficiency and of solvent incineration, are illustrated in the table 16.

From table 16, it is shown that the single score of solvent incineration is higher than those of solvent recycling at both 70% and 90% efficiency. The score of solvent incineration is equal to 4.6440, comparing with -42.5314 and -43.8900 for solvent recycling management at 70% and 90% efficiency, respectively. This indicates that, by average, the environmental impacts of solvent recycling management are lower than those of solvent incineration as typical treatment.

Besides, the solvent recycling management could also reduce environmental impacts as minus values obtained.

When comparing environmental impacts obtained by using Eco-Indicator 99, it is observed that all environmental impacts of solvent incineration, are higher than those from solvent recycling management at both 70% and 90% efficiency. Thus, this could support in the same way as single score result that the solvent recycling management generates less environmental impacts than solvent incineration does. Due to environmental impacts from EDIP method more understandable than those from Eco-Indicator 99 method, the details of environmental impacts are discussed later in the part of table 17 for EDIP method.

Refer to Life Cycle and Matrix Analyses for Re-refined Oil in Japan by Chie Nakaniwa and Thomas E. Graedel, the goal of this paper is to evaluate the use of re-refined oil as a fuel as opposed to the option of using virgin heavy oil as fuel and disposing of waste oil without re-refining. The results of such research demonstrates that disposing of waste oil without re-refining have higher environmental impacts than re-refined oil. It is similar to spent solvent case which solvent incineration has higher environmental impacts than solvent recycling does.

As observed in the table 16, single score and all environmental impacts of solvent recycling management with 70% efficiency are higher than those with 90% efficiency. This is because there are more impurities in recycled solvent with 70% efficiency than those with 90% efficiency. During recycling process, more impurities in recycled solvent with 70% efficiency, consumes more energy (e.g. electricity, fuel for boiler) and also generates more toxic waste than, less impurities in recycled solvent with 90% efficiency does. So the impurity in spent solvent is one parameter effecting environmental impacts.

The environmental impacts of solvent recycling management at 70% and 90% efficiency and of solvent incineration, obtained by using EDIP method are shown in the table 17.

Table 17 Environmental impacts from EDIP method at characterization step

Impact	Unit	Solvent recycling management with 70% efficiency	Solvent recycling management with 90% efficiency	Solvent incineration
Global warming (GWP 100)	g CO_2	-3.52E+05	-3.62E+05	2.42E+05
Ozone depleting	g CFC_{11}	-2.11E+00	-2.13E+00	3.23E-03
Acidification	g SO_2	-1.92E+03	-2.00E+03	1.83E+02
Eutrophication	g NO_3	-1.86E+03	-1.94E+03	1.73E+03
Photochemical smog	g ethene	-1.09E+02	-1.10E+02	2.71E+00
Ecotoxicity water chronic	m^3/g	-4.57E+04	-5.69E+04	4.88E+04
Ecotoxicity water acute	m^3/g	-4.64E+03	-5.75E+03	5.77E+03
Ecotoxicity soil chronic	m^3/g	-5.69E+03	-5.70E+03	7.43E+02
Human toxicity air	m^3/g	-1.92E+09	-1.92E+09	1.23E+07
Human toxicity water	m^3/g	-8.35E+03	-8.36E+03	1.94E+03
Human toxicity soil	m^3/g	-3.06E+03	-3.06E+03	1.58E+02
Bulk waste	kg	7.44E-02	7.26E-02	0
Hazardous waste	kg	5.53E+01	3.30E+01	0
Radioactive waste	kg	0	0	0
Slags/ashes	kg	9.18E-03	9.11E-03	0
Resources (all)	kg	-2.55E-02	-2.60E-02	3.14E-03

According to the data in table 17, when comparing environmental impacts obtained by using EDIP, it is observed that three environmental impacts; bulk waste, hazardous waste and slags/ashes of solvent recycling management, are higher than those of solvent incineration. The twelve of the rest impacts from solvent incineration are higher than those from solvent recycling management. No radioactive waste from both solvent recycling management and solvent incineration. The details of comparison are described below.

For global warming (GWP 100), environmental impact is in the unit of g CO_2. The impact from solvent incineration; 2.42E+05, is higher than those from solvent recycling management; -3.52E+05 for recycled solvent with 70% efficiency and -3.62E+05 for recycled solvent with 90% efficiency.

For ozone depleting, environmental impact is in the unit of g CFC_{11}. The impact from solvent incineration; 3.23E-03, is higher than those from solvent recycling management; -2.11E+00 for recycled solvent with 70% efficiency and -2.13E+00 for recycled solvent with 90% efficiency.

For acidification, environmental impact is in the unit of g SO_2. The impact from solvent incineration; 1.83E+02, is higher than those from solvent recycling management; -1.92E+03 for recycled solvent with 70% efficiency and -2.00E+03 for recycled solvent with 90% efficiency.

For eutrophication, environmental impact is in the unit of g NO_3. The impact from solvent incineration; 1.73E+03, is higher than those from solvent recycling management; -1.86E+03 for recycled solvent with 70% efficiency and -1.94E+03 for recycled solvent with 90% efficiency.

For photochemical smog, environmental impact is in the unit of g ethane. The impact from solvent incineration; 2.71E+00, is higher than those from solvent recycling management; -1.09E+02 for recycled solvent with 70% efficiency and -1.10E+02 for recycled solvent with 90% efficiency.

For Ecotoxicity water chronic, environmental impact is in the unit of m^3/g. The impact from solvent incineration; 4.88E+04, is higher than those from solvent recycling management; -4.57E+04 for recycled solvent with 70% efficiency and -5.69E+04 for recycled solvent with 90% efficiency.

For Ecotoxicity water acute, environmental impact is in the unit of m^3/g. The impact from solvent incineration; 5.77E+03, is higher than that from solvent recycling management; -4.64E+03 for recycled solvent with 70% efficiency and -5.75E+03 for recycled solvent with 90% efficiency.

For Ecotoxicity soil chronic, environmental impact is in the unit of m^3/g. The impact from solvent incineration; 7.43E+02, is higher than those from solvent recycling management; -5.69E+03 for recycled solvent with 70% efficiency and -5.70E+03 for recycled solvent with 90% efficiency.

For human toxicity air, environmental impact is in the unit of m^3/g. The impact from solvent incineration; 1.23E+07, is higher than those from solvent recycling management; -1.92E+09 for recycled solvent with 70% efficiency and -1.92E+09 for recycled solvent with 90% efficiency.

For human toxicity water, environmental impact is in the unit of m^3/g. The impact from solvent incineration; 1.94E+03, is higher than those from solvent recycling management; -8.35E+03 for recycled solvent with 70% efficiency and -8.36E+03 for recycled solvent with 90% efficiency.

For human toxicity soil, environmental impact is in the unit of m^3/g. The impact from solvent incineration; 1.58E+02, is higher than those from solvent recycling management; -3.06E+03 for recycled solvent with 70% efficiency and -3.06E+03 for recycled solvent with 90% efficiency.

For bulk waste, environmental impact is in the unit of kg. No such impact is from solvent incineration while the impacts from solvent recycling management are 7.44E-02 for recycled solvent with 70% efficiency and 7.26E-02 for recycled solvent with 90% efficiency. This is because the packaging as metal drum of recycled solvent, becomes bulk waste after use for two times. The environmental impact for bulk waste could be reduced if packaging would be used more than two times in order to improve the recycled solvent to be more environmental friendly.

For hazardous waste, environmental impact is in the unit of kg. No such impact is from solvent incineration whereas the impacts from solvent recycling management are 5.53+01 for recycled solvent with 70% efficiency and 3.30E+01 for recycled solvent with 90% efficiency. During recycling process, hazardous waste is mainly generated from impurities in spent solvent. Adversely, for incineration, all in spent solvent is burnt then no hazardous waste is produced.

For radioactive waste, environmental impact is in the unit of kg. However, no such impact from both solvent recycling management and solvent incineration as the value of this impact is equal to zero.

For slags/ashes, environmental impact is in the unit of kg. No such impact is from solvent incineration while the impact from solvent recycling management; 9.18E-03 for recycled solvent with 70% efficiency and 9.11E-03 for recycled solvent with 90% efficiency. For recycled solvent, the slags/ashes comes from use of diesel, electricity and water whereas no such is used for solvent incineration.

For resources (all), environmental impact is in the unit of kg. The impact from solvent incineration; 3.14E-03, is higher than that from solvent recycling management; 2.55E-02 for recycled solvent with 70% efficiency and -2.60E-02 for recycled solvent with 90% efficiency.

Regard to efficiency of solvent recycling, all environmental impacts of recycled solvent with 70% efficiency are higher than those with 90% efficiency from table 17. This is because there are more impurities in recycled solvent with 70% efficiency than those with 90% efficiency. During recycling process, more impurities in recycled solvent with 70% efficiency, consumes more energy (e.g. electricity, fuel for boiler) and also generates more toxic waste than, less impurities in recycled solvent with 90% efficiency does. So the impurity in spent solvent is one parameter effecting environmental impacts.

In figure 10, by using Eco-Indicator 99 method, the single score of recycled solvent (virgin solvent), solvent recycling with 70% efficiency, solvent recycling with 90% efficiency and incineration have been obtained in graph. With considering of negative impacts from recycled solvent (virgin solvent), the single scores of recycling process and transportation in figure 10 are calculated and demonstrated in figure 11. It is seen that solvent recycling management (combine virgin solvent and recycling process and transportation) could reduce environmental impacts as the negative values indicated. The single score of solvent recycling management with 70% efficiency is -42.5314 while that with 90% efficiency is -43.8900, comparing with single score of incineration equal to 4.6440.

The single scores of environmental impacts of virgin solvent, solvent recycling (recycling process and transportation) with 70% efficiency, solvent recycling with 90% efficiency and incineration, are illustrated in figure 12. After calculation of single scores from figure 12 with consideration of negative impacts from virgin solvent, the graph in figure 13 is obtained for solvent recycling management. Noted that the negative value, indicates reduction on environmental impacts (save environment). From the figure 13, it is indicated that the solvent recycling management could mainly save fossil fuels (e.g. extraction of raw material from underground) which is used for manufacturing of virgin solvent.

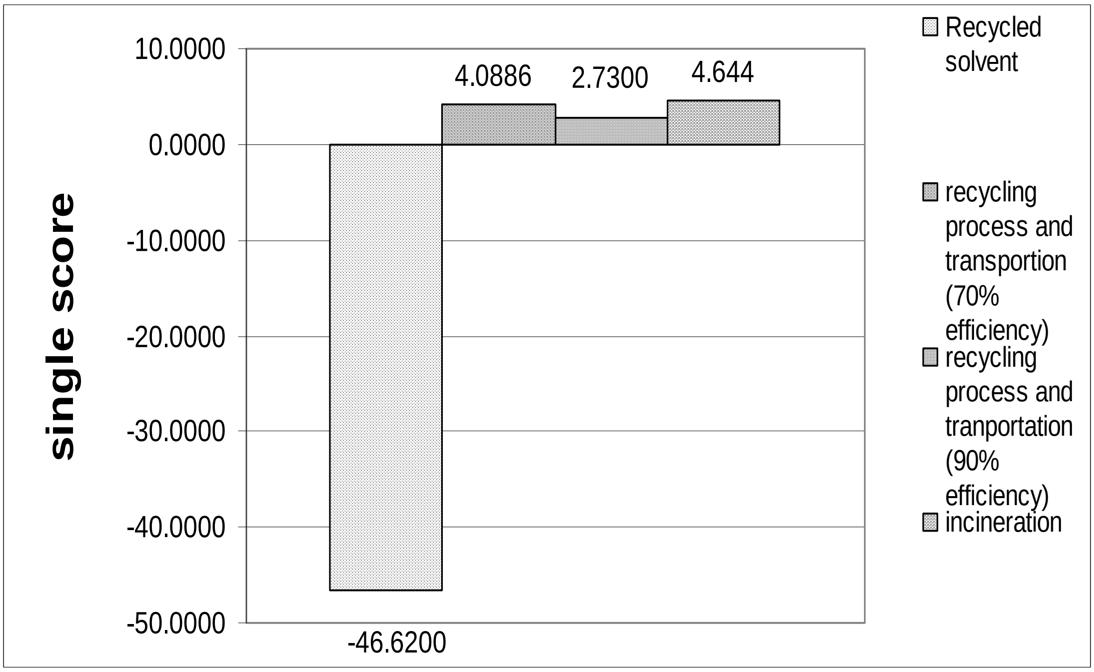

Figure 10 Comparing single score of recycled solvent, solvent recycling with 70% efficiency, solvent recycling with 90% efficiency and incineration by using Eco-Indicator 99 method

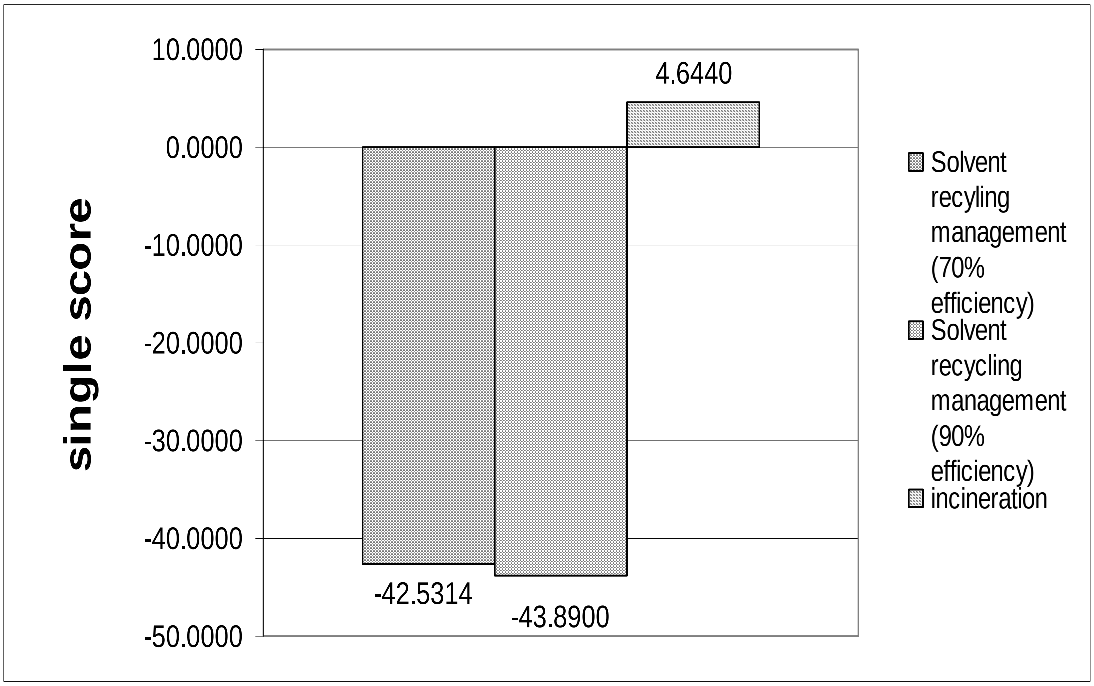

Figure 11 By using Eco-Indicator 99 method, comparing single score of solvent recycling management with 70% efficiency, solvent recycling management with 90% efficiency and incineration with considering negative impacts from virgin solvent

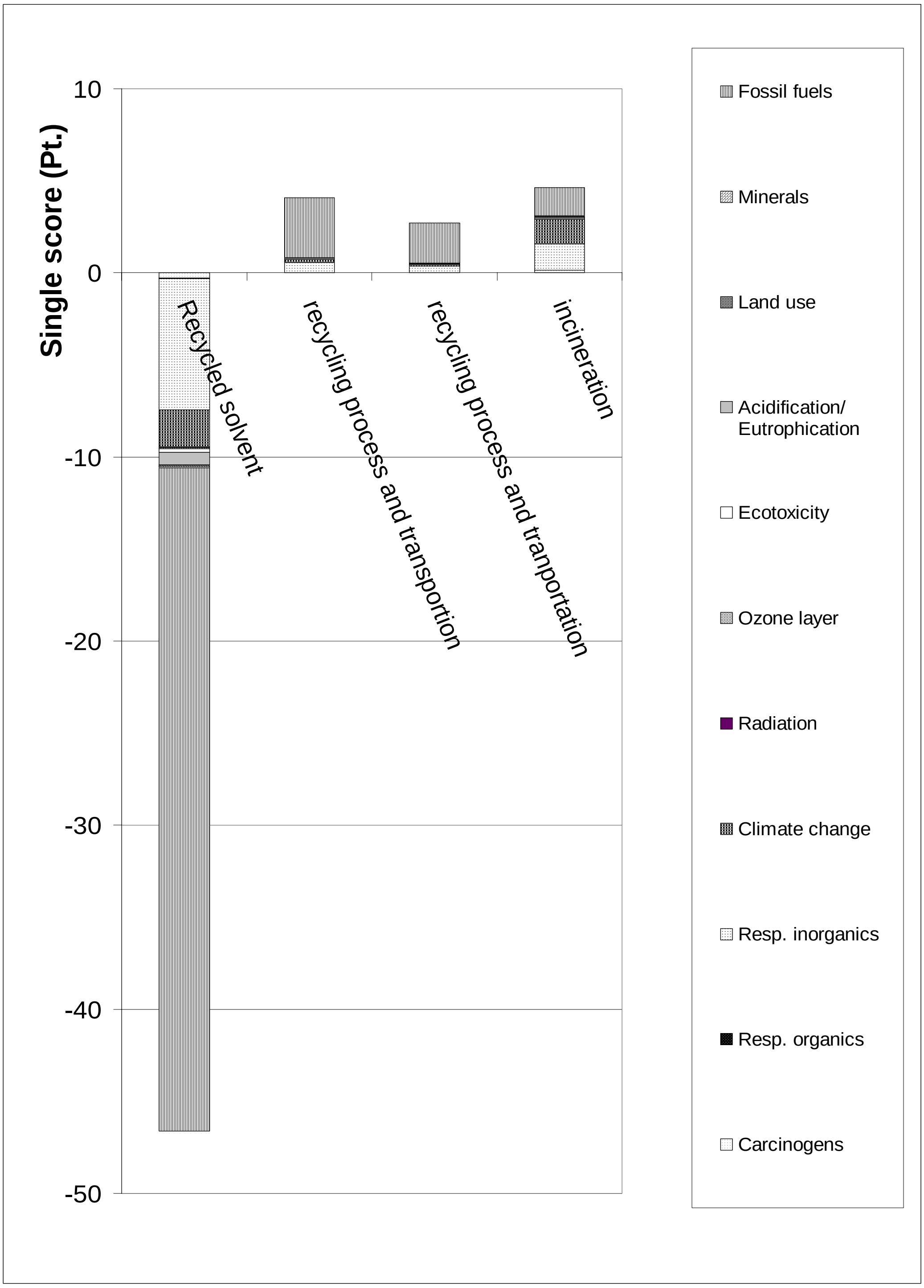

Figure 12 Comparing single score environmental impacts of recycled solvent, solvent recycling with 70% efficiency, solvent recycling with 90% efficiency and incineration by using Eco-Indicator 99 method

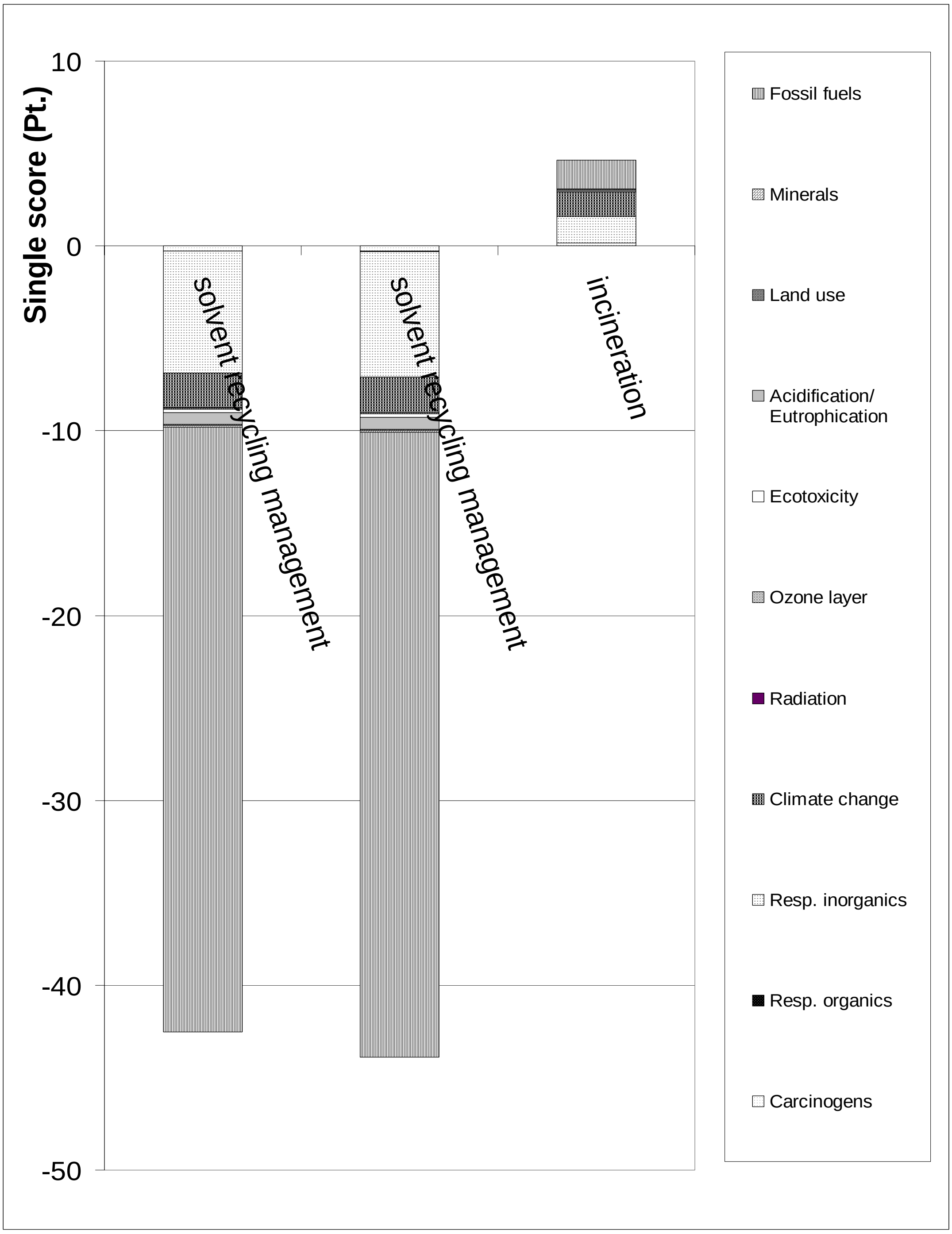

Figure 13 By using Eco-Indicator 99 method, comparing single score environmental impacts of solvent recycling management with 70% efficiency, solvent recycling management with 90% efficiency and incineration with considering negative impacts from virgin solvent

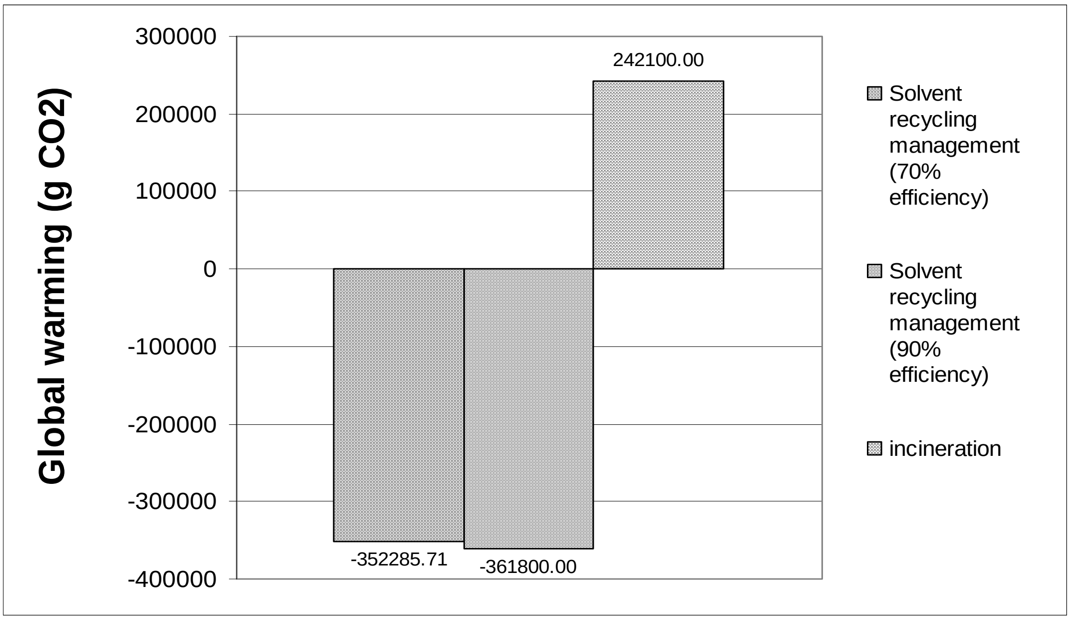

Figure 14 By using EDIP, comparing environmental impact of global warming for solvent recycling management with 70% efficiency, solvent recycling management with 90% efficiency and incineration with considering negative impacts from virgin solvent

The further investigation is done by focusing on global warming as carbon dioxide emission by using EDIP method. The result is illustrated in figure 14. The negative impacts are also taken into account for this calculation due to environmental saving, when comparing with virgin solvent. The global warming could be decreased as -352285.71 for solvent recycling management with 70% efficiency whereas that is -361800.00 for solvent recycling management with 90% efficiency, comparing to 242100.00 as global warming generated from incineration. In the other words, solvent recycling management could help for reduction of global warming impact.

Refer to Life Cycle and Matrix Analyses for Re-refined Oil in Japan by Chie Nakaniwa and Thomas E. Graedel, it demonstrates that, by using a streamlined LCA matrix, re-refining waste oil can reduce environmental impacts compared with the case in which virgin oil is chosen.

The trend from the aforementioned research is the same as the trend obtained from this research. Recycling one produces less environmental impacts than virgin one.

When conducting an analysis by type of emission and resource for solvent recycling, the figure 15, 16, 17, 18 and the table 18, 19 are presented. The Eco-Indicator 99 method is used to compare the environmental impacts for emission and resource required in solvent recycling. From the figure 13, 14, 15, 16 and the table 18, 19, the following are observed.

The single scores of electricity are 1.29 (equal to 41%) and 1.01 (equal to 37%) for 70% and 90% efficiency, respectively while that of boiler fuel (heavy oil) are 1.27 (equal to 40%) and 0.99 (equal to 36%) for 70% and 90% efficiency, respectively. If considering the use of diesel for transportation, the single scores are 0.48 (equal to 15%) and 0.617 (equal to 23%) for 70% and 90% efficiency, respectively.

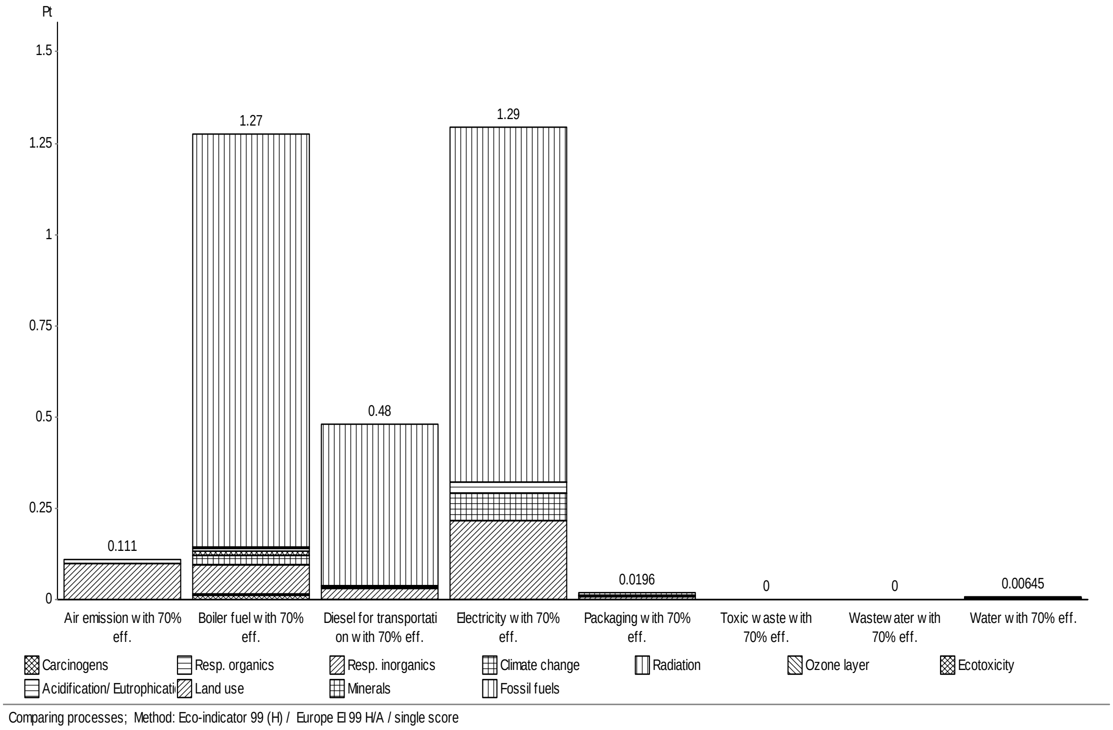

Figure 15 Comparing single score of emission and resource for solvent recyling with 70% efficiency by using Eco-Indicator 99 method

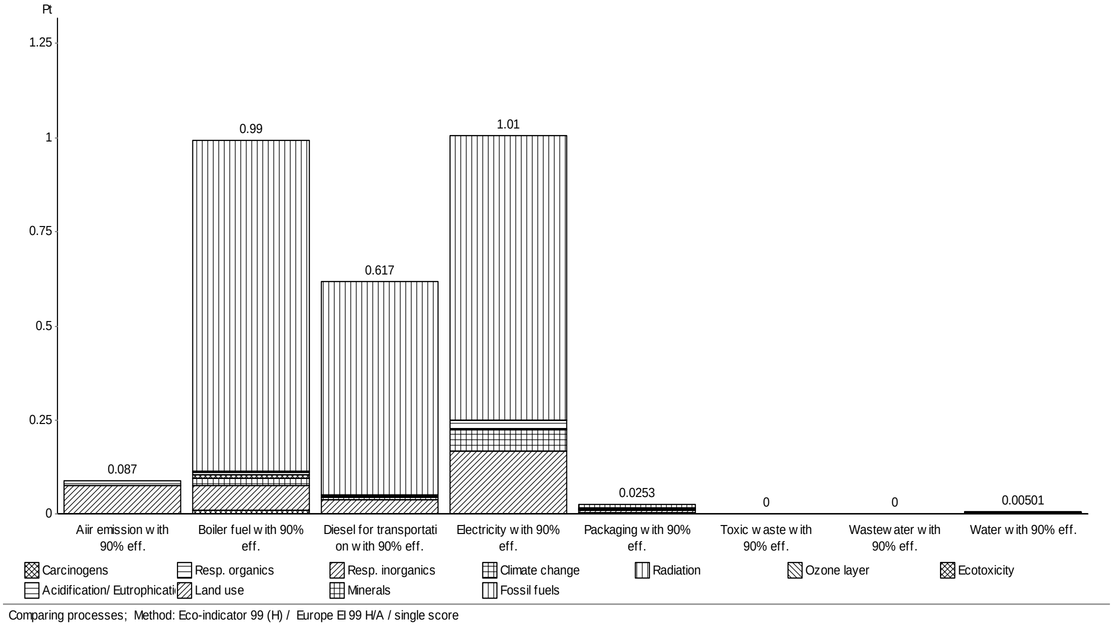

Figure 16 Comparing single score of emission and resource for solvent recycling with 90% efficiency by using Eco-Indicator 99 method

It is indicated that environmental impact of solvent recycling is mainly from use of electricity (around 37-41%), following by use of boiler fuel (heavy oil) (36-40%) and diesel for transportation (15-23%). The most significance of environmental impact comes from electricity use. The second one is boiler fuel (heavy oil) and the third one is diesel for transportation. Therefore the reduction on those threes should firstly be considered when improving the solvent recycling process in order to have less impacts to environment.

Table 18 Comparing the data of single score of emission and resource for solvent recycling with 70% efficiency by using Eco-Indicator 99 method

Impact	Air emission	Boiler	Diesel for transportation	Electricity	Packaging	Toxic waste	Waste-water	Water
Total	1.11E-01	1.27	4.80E-01	1.29	1.96E-02	0	0	6.45E-03
Carcinogens	0	1.16E-02	6.63E-05	3.78E-04	1.75E-03	0	0	4.39E-05
Resp. organics	0	2.01E-03	2.70E-04	1.64E-04	8.29E-06	0	0	9.06E-05
Resp. inorganics	9.72E-02	8.16E-02	2.86E-02	2.15E-01	5.47E-03	0	0	1.51E-03
Climate change	0	2.56E-02	4.35E-03	7.35E-02	2.64E-03	0	0	6.16E-04
Radiation	0	3.64E-04	0	0	0	0	0	6.91E-06
Ozone layer	0	9.86E-04	0	5.10E-09	2.17E-06	0	0	3.27E-07
Ecotoxicity	0	9.68E-03	5.61E-05	4.33E-04	4.15E-04	0	0	1.18E-05
Acidification/ Eutrophication	1.37E-02	8.79E-03	4.02E-03	3.11E-02	6.17E-04	0	0	1.51E-04
Land use	0	3.25E-03	1.13E-03	3.97E-04	1.36E-03	0	0	3.98E-05
Minerals	0	3.93E-04	1.09E-05	2.23E-04	1.07E-04	0	0	8.07E-05
Fossil fuels	0	1.13	4.41E-01	9.71E-01	7.27E-03	0	0	3.91E-03

Table 19 Comparing the data of single score of emission and resource for solvent recycling with 90% efficiency by using Eco-Indicator 99 method

Impact	Air emission	Boiler	Diesel for transportation	Electricity	Packaging	Toxic waste	Waste--water	Water
Total	8.70E-02	9.90E-01	6.17E-01	1.01	2.53E-02	0	0	5.01E-03
Carcinogens	0	9.00E-03	8.54E-05	2.94E-04	2.25E-03	0	0	3.40E-05
Resp. organics	0	1.56E-03	3.48E-04	1.28E-04	1.07E-05	0	0	7.03E-05
Resp. inorganics	7.63E-02	6.35E-02	3.68E-02	1.68E-01	7.03E-03	0	0	1.17E-03
Climate change	0	1.99E-02	5.59E-03	5.72E-02	3.40E-03	0	0	4.77E-04
Radiation	0	2.83E-04	0	0	0	0	0	5.36E-06
Ozone layer	0	7.67E-04	0	3.97E-09	2.79E-06	0	0	2.53E-07
Ecotoxicity	0	7.53E-03	7.22E-05	3.37E-04	5.33E-04	0	0	9.13E-06
Acidification/ Eutrophication	1.07E-02	6.84E-03	5.18E-03	2.42E-02	7.94E-04	0	0	1.17E-04
Land use	0	2.52E-03	1.46E-03	3.09E-04	1.75E-03	0	0	3.09E-05
Minerals	0	3.06E-04	1.41E-05	1.73E-04	1.38E-04	0	0	6.26E-05
Fossil fuels	0	8.78E-01	5.67E-01	7.55E-01	9.36E-03	0	0	3.03E03

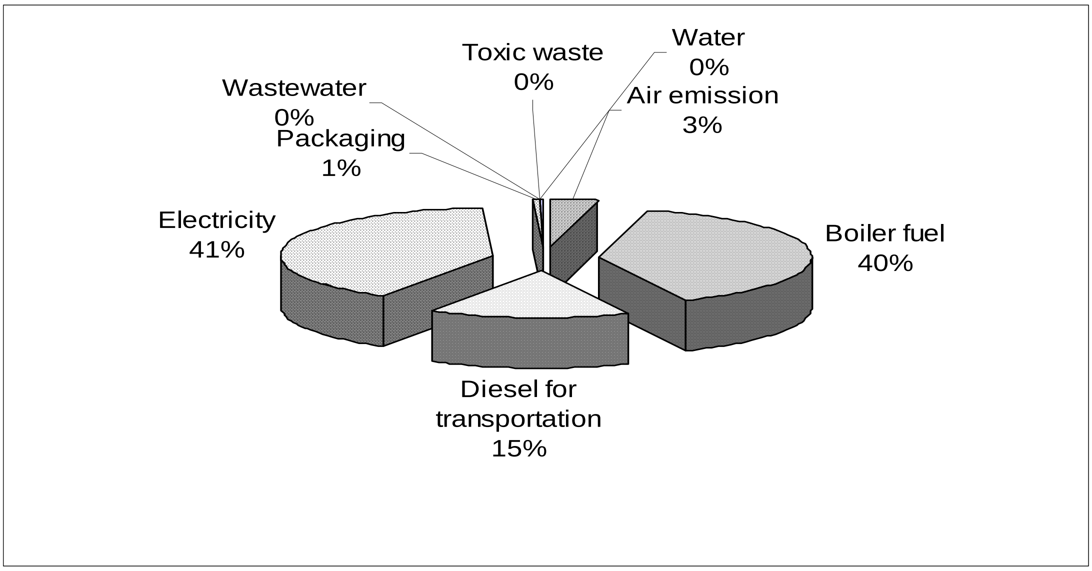

Figure 17 Pie chart comparing percentage of environmental impacts from emission and resource for solvent recycling with 70% efficiency by using Eco-Indicator 99 method

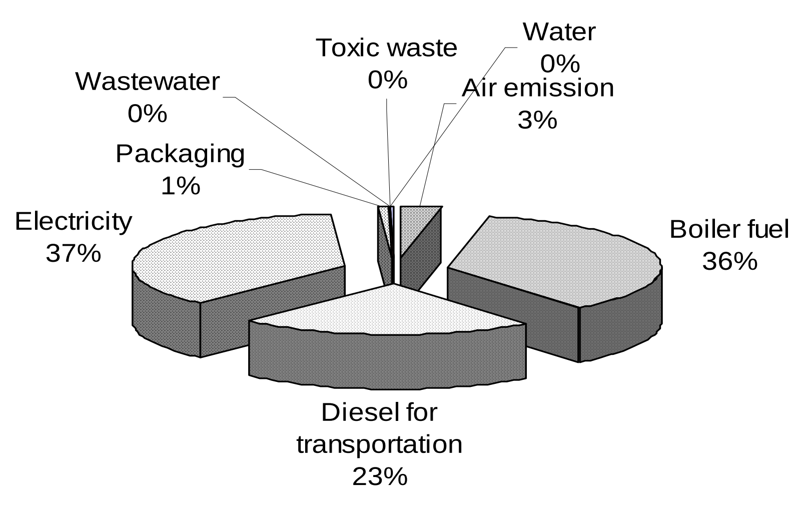

Figure 18 Pie chart comparing percentage of environmental impacts from emission and resource for solvent recycling with 90% efficiency by using Eco-Indicator 99 method

For improvement on recycling process, it is suggested that the energy conservation project should be considered e.g. reduction on electricity consumption, selection of energy-saving equipment, reduction on heavy oil consumption by adjustment of boiler efficiency. Those could help to reduce environmental impacts of recycling process.

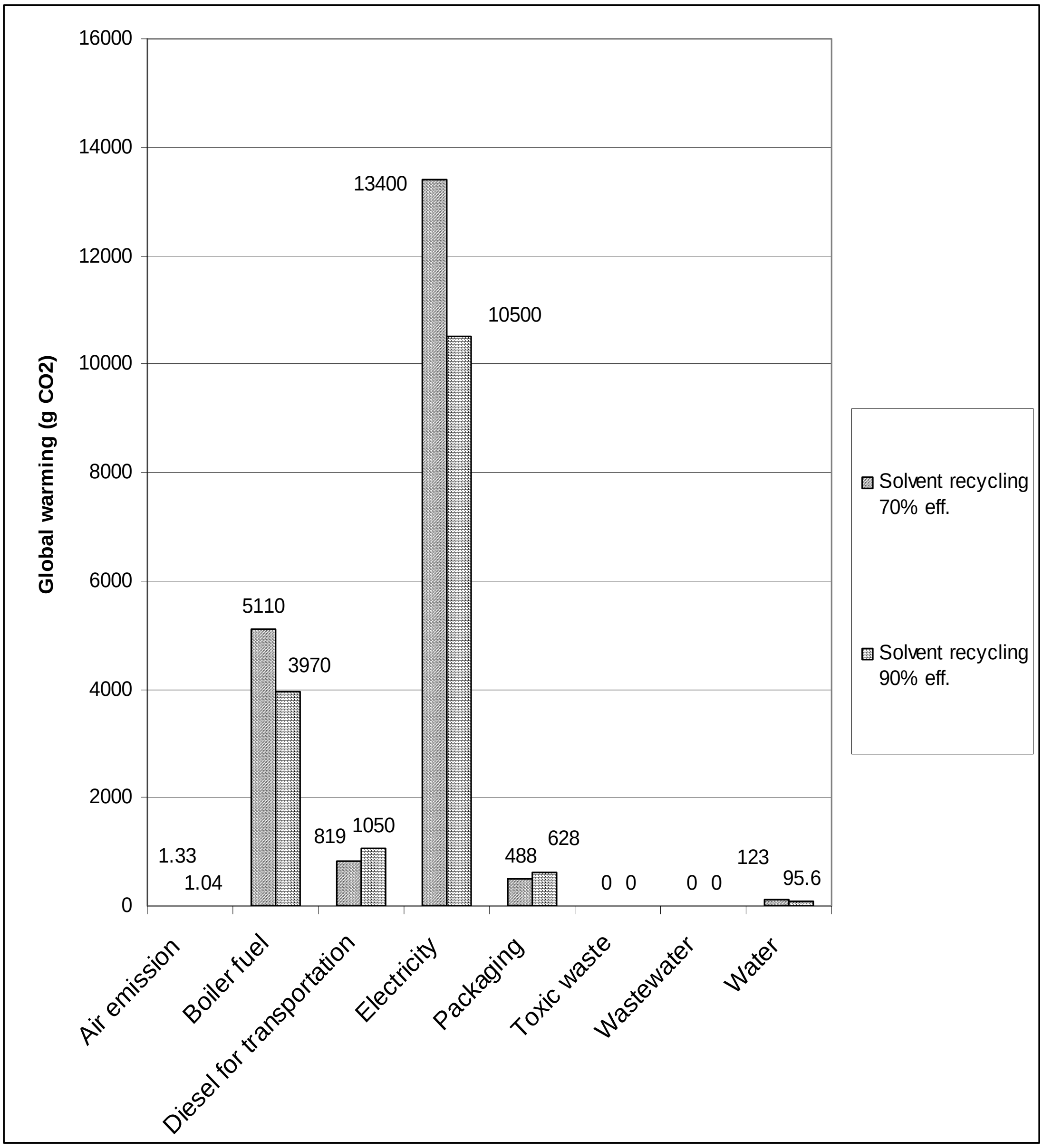

Figure 19 Comparing global warming of emission and resources used for recycling process

From figure 19, it is indicated that global warming impact of recycling process is mainly from use of electricity, following by use of boiler fuel (heavy oil) and diesel for transportation, respectively. Thus the reduction of global warming impact should be dine by reduction on electricity, heavy oil and diesel.

CONCLUSION

The research is related to life cycle assessment of the solvent recyling by using Sima Pro 5.1 with Eco-Indicator and EDIP method and comparing the result with solvent incineration which is obtained by using Sima Pro 6.0. The functional unit is 200 kilograms of spent solvent. For recycled solvent, 2 efficiency which are 70% (minimum) and 90% (maximum) for recovering spent solvent, has been selected for this research. The results can be concluded as follows;

1. The single score of environmental impact assessment for solvent recycling management by using Eco-Indicator 99 are -42.5314 Pt. and -43.8900 Pt. for 70% and 90% efficiency, respectively. Those are found lower than 4.6440 Pt. of solvent incineration. When comparing between 70% and 90% recovery efficiency, environmental impacts of 70% are higher than those of 90%.

2. By using EDIP method, the environmental impacts are as below;

Impact	Unit	Solvent recycling management with 70% efficiency	Solvent recycling management with 90% efficiency	Solvent Incineration
Global warming (GWP 100)	g CO_2	-3.52E+05	-3.62E+05	2.42E+05
Ozone depleting	g CFC_{11}	-2.11E+00	-2.13E+00	3.23E-03
Acidification	g SO_2	-1.92E+03	-2.00E+03	1.83E+02
Eutrophication	g NO_3	-1.86E+03	-1.94E+03	1.73E+03
Photochemical smog	g ethene	-1.09E+02	-1.10E+02	2.71E+00
Ecotoxicity water chronic	m^3/g	-4.57E+04	-5.69E+04	4.88E+04
Ecotoxicity water acute	m^3/g	-4.64E+03	-5.75E+03	5.77E+03
Ecotoxicity soil chronic	m^3/g	-5.69E+03	-5.70E+03	7.43E+02
Human toxicity air	m^3/g	-1.92E+09	-1.92E+09	1.23E+07
Human toxicity water	m^3/g	-8.35E+03	-8.36E+03	1.94E+03

Impact	Unit	Solvent recycling management with 70% efficiency	Solvent recycling management with 90% efficiency	Solvent Incineration
Human toxicity soil	m^3/g	-3.06E+03	-3.06E+03	1.58E+02
Bulk waste	kg	7.44E-02	7.26E-02	0
Hazardous waste	kg	5.53E+01	3.30E+01	0
Radioactive waste	kg	0	0	0
Slags/ashes	kg	9.18E-03	9.11E-03	0
Resources (all)	kg	-2.55E-02	-2.60E-02	3.14E-03

1. Regarding global warming, it is concluded that -1.76 kg CO_2 equivalent per 1 kg of solvent recycling management at 70% efficiency, -1.81 kg CO_2 equivalent per 1 kg of solvent recycling management at 90% efficiency, comparing with 1.345 kg CO_2 equivalent per 1 kg of solvent incineration.

2. For both 70% and 90% efficiency, global warming impact is firstly from electricity, secondly from boiler fuel (heavy oil) and thirdly by diesel for transportation.

3. At both 70% and 90% recovery efficiency, the environmental impact is mainly from use of electricity, following by use of boiler fuel (heavy oil) and diesel for transportation. Thus, in order to reduce environmental impact, the reduction on use of electricity, boiler fuel (heavy oil) and diesel should be considered, respectively.

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APPENDIX

APPENDIX A

LCI result of spent solvent at 70% efficiency
by Eco-indicator 99 method

No	Substance	Compartment	Unit	Total	Distillation Solvent	Fuel oil lowS 2000 refinery CH S	Diesel I	Cold transforming steel	Elec Thai	Water Thai
1	additions	Raw	g	3.32	x	x	x	x	2.43	0.893
2	air	Raw	g	2.35	x	x	x	x	x	2.35
3	aluminium (in ore)	Raw	µg	210	x	x	x	x	210	0.208
4	baryte	Raw	g	33.9	x	33.7	x	0.168	0.00099	0.00396
5	bauxite	Raw	mg	2320	x	378	895	314	723	6.22
6	bentonite	Raw	g	2.86	x	2.68	x	0.178	0.00028	0.00346
7	chromium (in ore)	Raw	g	1.54	x	0.0376	x	0.00833	1.49	0.00168
8	clay	Raw	g	5.8	x	5.8	x	x	x	0.00469
9	coal	Raw	g	182	x	x	14.3	x	15.5	153
10	coal ETH	Raw	g	245	x	129	x	112	0.845	2.74
11	cobalt (in ore)	Raw	µg	22.4	x	22.4	x	0.00422	1.92E-05	0.000151
12	copper (in ore)	Raw	mg	267	x	152	x	110	2.23	1.93
13	crude oil	Raw	mg	813	x	x	x	x	792	21.5
14	crude oil ETH	Raw	oz	273	x	272	x	0.977	0.0023	0.0377
15	crude oil IDEMAT	Raw	oz	167	x	x	102	x	65	0.0678
16	energy (undef.)	Raw	MJ	9.34	x	x	x	x	9.33	0.00923

17	energy from hydro power	Raw	kJ	670	x	x	x	648	18.4	3.35
18	energy from uranium	Raw	kJ	12.2	x	x	x	x	12.2	0.0129
19	gas from oil production	Raw	cu.in	82.8	x	x	x	82.2	0.193	0.442
20	gravel	Raw	g	97.6	x	54.9	x	x	41.7	1.07
21	gypsum	Raw	mg	965	x	x	x	x	705	259
22	iron (in ore)	Raw	g	62.7	x	36.8	x	1.43	24.3	0.0944
23	iron (ore)	Raw	g	114	x	x	0.392	x	0.0077	114
24	lead (in ore)	Raw	mg	30.5	x	22.6	x	7.63	0.000616	0.199
25	lignite	Raw	oz	300	x	x	x	x	300	0.296
26	lignite ETH	Raw	g	269	x	118	x	148	0.0121	3.27
27	limestone	Raw	g	14.8	x	x	0.392	x	4.05	10.4
28	manganese (in ore)	Raw	mg	93.1	x	10.1	x	1.53	81.1	0.352
29	marl	Raw	g	61.2	x	30.8	x	4.61	18.8	6.98
30	methane (kg)	Raw	mg	810	x	x	x	799	5.96	4.79
31	methane (kg) ETH	Raw	mg	943	x	929	x	x	x	13.8
32	molybdene (in ore)	Raw	µg	41.6	x	41.6	x	0.00179	7.57E-06	0.000116
33	natural gas	Raw	oz	235	x	x	6.1	x	228	0.239
34	natural gas (vol)	Raw	cu.in	809	x	x	x	x	x	809
35	natural gas ETH	Raw	l	40.5	x	16.9	x	22.5	0.453	0.593

36	nickel (in ore)	Raw	mg	295	x	24	x	5.86	264	0.405
37	palladium (in ore)	Raw	µg	1.26	x	1.26	x	0.0001	8.25E-07	0.000109
38	petroleum gas ETH	Raw	l	527	x	527	x	x	x	0.037
39	platinum (in ore)	Raw	µg	1.44	x	1.44	x	0.000198	1.61E-06	0.000126
40	potential energy water ETH	Raw	kJ	756	x	745	x	x	x	11.1
41	reservoir content ETH	Raw	m3y	0.0169	x	0.0167	x	x	x	0.000242
42	rhenium (in ore)	Raw	µg	1.38	x	1.38	x	0.0000565	4.7E-07	0.000108
43	rhodium (in ore)	Raw	µg	1.34	x	1.34	x	0.0000847	7.04E-07	0.000116
44	rock salt	Raw	g	8.82	x	1.1	x	0.101	0.000422	7.62
45	sand	Raw	g	45.4	x	12.2	x	x	32.6	0.623
46	silicon (in SiO2)	Raw	mg	74.5	x	x	x	x	74.3	0.189
47	silver	Raw	µg	82.3	x	x	x	81.7	0.193	0.44
48	silver (in ore)	Raw	mg	24.3	x	24.3	x	x	x	0.0017
49	tin (in ore)	Raw	mg	13.5	x	13.5	x	0.0454	0.000107	0.00119
50	turbine water ETH	Raw	gal*	996	x	980	x	x	x	15.4
51	unspecified energy	Raw	kJ	312	x	x	x	x	x	312
52	uranium (in ore)	Raw	mg	10.1	x	x	x	10	0.0055	0.0522
53	uranium (in ore) ETH	Raw	mg	9.05	x	8.88	x	x	x	0.17
54	uranium (ore)	Raw	ng	105	x	x	x	x	105	0.104

55	water	Raw	lb	152	x	101	1.3	47.1	0.467	1.92
56	wood	Raw	g	2.05	x	x	x	2.03	0.00893	0.00722
57	wood (dry matter) ETH	Raw	g	1.69	x	1.66	x	x	x	0.0253
58	zeolite	Raw	mg	1.88	x	x	x	1.86	0.00364	0.00995
59	zinc (in ore)	Raw	mg	2.14	x	2.08	x	0.0572	0.000316	0.00273
60	1,2-dichloroethane	Air	µg	9.91	x	x	x	9.89	0.00898	0.0135
61	acetaldehyde	Air	µg	688	x	462	x	221	0.394	5.19
62	acetic acid	Air	mg	2.97	x	1.93	x	1.01	0.00417	0.0239
63	acetone	Air	µg	687	x	462	x	220	0.373	5.16
64	acrolein	Air	ng	287	x	230	x	56.6	0.225	0.351
65	Al	Air	mg	13.9	x	6.65	x	7	0.0758	0.182
66	aldehydes	Air	mg	86.2	x	0.00711	x	0.00801	85.1	1.14
67	alkanes	Air	mg	186	x	184	x	2.05	0.00543	0.0494
68	alkenes	Air	µg	1350	x	637	x	691	2.83	16.3
69	ammonia	Air	mg	3.71	x	1.69	x	1.33	0.00766	0.676
70	As	Air	µg	285	x	257	x	26	2.11	0.708
71	B	Air	mg	9.97	x	4.52	x	5.31	0.00401	0.125
72	Ba	Air	µg	199	x	100	x	95.3	0.534	2.79
73	Be	Air	µg	2.07	x	1.08	x	0.953	0.00545	0.0306

74	benzaldehyde	Air	ng	98.2	x	78.6	x	19.4	0.0771	0.12
75	benzene	Air	mg	73.9	x	72.9	x	0.651	0.0382	0.293
76	benzo(a)pyrene	Air	µg	13.5	x	4.1	x	0.203	4.5	4.72
77	Br	Air	µg	821	x	466	x	342	1.68	12
78	butane	Air	mg	714	x	711	x	2.97	0.0235	0.0793
79	butene	Air	mg	17.4	x	17.4	x	0.0473	0.000112	0.00233
80	Ca	Air	mg	14.9	x	10.2	x	4.48	0.00676	0.173
81	carbon black	Air	mg	25.4	x	x	x	x	x	25.4
82	Cd	Air	µg	364	x	348	x	9.7	6.26	0.325
83	CFC-11	Air	µg	2.83	x	2.77	x	x	x	0.0539
84	CFC-114	Air	µg	75.9	x	74.5	x	x	x	1.42
85	CFC-116	Air	µg	17.3	x	4.11	x	13.1	0.0112	0.0933
86	CFC-12	Air	ng	608	x	596	x	x	x	11.6
87	CFC-13	Air	ng	382	x	375	x	x	x	7.27
88	CFC-14	Air	µg	143	x	37	x	105	0.0895	0.795
89	Cl2	Air	mg	18	x	x	x	x	18	0.0442
90	CO	Air	g	7.99	0.667	4.42	0.224	0.0888	1.21	1.38
91	CO2	Air	oz	655	x	145	28	16	463	3.45
92	cobalt	Air	µg	512	x	457	x	53.5	0.103	1.36

93	Cr	Air	µg	337	x		281	x			51.7		2.77	1.16
94	Cu	Air	µg	962	x		793	x			128		37.9	3.15
95	CxHy	Air	g	15.6	x	x			8.11		4.58E-08		4.74	2.71
96	CxHy aromatic	Air	µg	1010	x		360	x			10.7		0.0205	637
97	cyanides	Air	µg	11.5	x		11.2	x			0.271		0.00486	0.0196
98	dichloroethane	Air	µg	12.5	x		12.4	x		x		x		0.155
99	dichloromethane	Air	µg	39.2	x		0.61	x		x		x		38.6
100	dioxin (TEQ)	Air	ng	2.66	x		0.143	x			0.0151		2.5	0.00679
101	dust	Air	mg	496	x	x		x		x			495	0.489
102	dust (coarse)	Air	mg	1470	x	x		x			731		3.02	738
103	dust (coarse) process	Air	mg	571	x		567	x		x		x		3.85
104	dust (PM10) mobile	Air	mg	133	x		133	x		x		x		0.0846
105	dust (PM10) stationary	Air	g	1.52	x		1.52	x		x		x		0.00205
106	dust (SPM)	Air	g	7.3	x	x			0.951	x			6.22	0.127
107	ethane	Air	mg	183	x		178	x			4.67		0.083	0.123
108	ethanol	Air	µg	1380	x		924	x			441		0.745	10.4
109	ethene	Air	mg	43.1	x		42.7	x			0.264		0.00304	0.0466
110	ethylbenzene	Air	mg	18.3	x		17.6	x			0.687		0.00542	0.0155
111	ethyne	Air	µg	35.9	x		26.6	x			8.2		0.111	0.967
112	F2	Air	µg	362	x	x		x		x			212	150

113	Fe	Air	mg	13.2	x		9.38	x			3.73	0.0189	0.114
114	fluoranthene	Air	µg	60.6	x	x		x		x		13.5	47.1
115	formaldehyde	Air	mg	3.86	x		2.1	x			1.7	0.0237	0.0382
116	H2S	Air	mg	34.2	x		2.23	x			0.518	2.41	29
117	HALON-1301	Air	mg	3.01	x		3	x			0.00662	1.55E-05	0.000246
118	HCFC-21	Air	µg	124	x		69	x		x		x	55.1
119	HCFC-22	Air	ng	670	x		657	x		x		x	12.7
120	HCl	Air	mg	182	x		91.4		14		74.3	0.637	2.02
121	He	Air	mg	531	x		531	x		x		x	0.0373
122	heptane	Air	mg	171	x		171	x			0.473	0.00112	0.0123
123	hexachlorobenzene	Air	pg	530	x		521	x		x		x	8.49
124	hexane	Air	mg	357	x		356	x			0.997	0.00236	0.0258
125	HF	Air	mg	20.4	x		11.5	x			7.88	0.0384	1.04
126	HFC-134a	Air	pg	0.00000718	x		0.00000718	x		x		x	x
127	Hg	Air	µg	85.6	x		65.2	x			12.2	1.8	6.32
128	I	Air	µg	382	x		210	x			165	0.565	5.42
129	K	Air	mg	7.99	x		7.1	x			0.857	0.00525	0.028
130	La	Air	µg	5.77	x		2.93	x			2.74	0.0158	0.0799
131	metals	Air	mg	20.5	x	x			2.8	x		17.7	0.0175
132	methane	Air	g	32.1	x		30.9	x			1.03	0.152	0.0222
133	methanol	Air	mg	1.78	x		1.33	x			0.442	0.000751	0.0108

134	Mg	Air	mg	4.9	x	2.31	x	2.51	0.014	0.0647
135	Mn	Air	mg	1.8	x	1.75	x	0.047	0.000213	0.00229
136	Mo	Air	µg	259	x	243	x	15.6	0.0381	0.467
137	MTBE	Air	µg	4.03	x	4.03	x	x	x	0.00607
138	N2	Air	mg	4.98	x	4.87	x	x	x	0.117
139	N2O	Air	mg	1110	x	79.2	x	20.9	970	43.5
140	Na	Air	mg	14.9	x	13.7	x	1.19	0.00404	0.0319
141	naphthalene	Air	ng	458	x	x	x	x	457	1.14
142	Ni	Air	mg	10.8	x	10.3	x	0.502	0.00146	0.0117
143	NO2	Air	mg	59.7	x	x	x	x	56.4	3.3
144	non methane VOC	Air	g	58	x	57.7	x	0.218	0.000684	0.00573
145	NOx	Air	g	72.8	x	x	8.11	0.967	63.5	0.256
146	NOx (as NO2)	Air	g	42.2	26	16.1	x	x	x	0.0152
147	P	Air	µg	83	x	x	x	82	0.483	0.477
148	P-tot	Air	µg	312	x	310	x	x	x	1.95
149	PAH's	Air	µg	52.1	x	37	x	14.5	0.199	0.392
150	particulates (unspecified)	Air	g	27	27	x	x	x	x	x
151	Pb	Air	mg	1.94	x	1.6	x	0.117	0.225	0.0037
152	pentachlorobenzene	Air	ng	1.42	x	1.39	x	x	x	0.0226
153	pentachlorophenol	Air	pg	229	x	225	x	x	x	3.67
154	pentane	Air	mg	901	x	897	x	3.94	0.0369	0.105

155	phenol	Air	µg	2.43	x	1.7	x	0.704	0.00841	0.0162
156	propane	Air	mg	715	x	711	x	3.45	0.0318	0.0913
157	propene	Air	mg	34.5	x	34.3	x	0.155	0.000618	0.00474
158	propionic acid	Air	µg	29.5	x	11.7	x	17	0.344	0.426
159	Pt	Air	ng	234	x	234	x	0.00996	8.11E-05	0.344
160	Sb	Air	µg	9.65	x	5.71	x	3.79	0.0103	0.143
161	Sc	Air	µg	2.05	x	0.981	x	1.04	0.00676	0.0274
162	Se	Air	µg	418	x	353	x	62.8	0.205	1.66
163	Si	Air	mg	23	x	22.6	x	x	x	0.485
164	silicates	Air	mg	18	x	x	x	17.8	0.0666	0.0991
165	Sn	Air	µg	4.58	x	2.11	x	2.39	0.0147	0.0584
166	SO2	Air	g	37	x	x	x	2.27	34.5	0.29
167	soot	Air	mg	14	x	x	x	x	14	0.0462
168	SOx	Air	g	5.34	x	x	5.04	x	0.298	0.00179
169	SOx (as SO2)	Air	g	46	26.1	19.9	x	x	x	0.0509
170	Sr	Air	µg	218	x	100	x	114	0.657	2.99
171	tetrachloromethane	Air	µg	9.45	x	3.01	x	x	x	6.44
172	Th	Air	µg	8.28	x	1.86	x	6.31	0.038	0.0779
173	Ti	Air	µg	596	x	277	x	309	2.04	8.03
174	Tl	Air	ng	983	x	708	x	255	1.78	17.5
175	toluene	Air	mg	107	x	106	x	0.793	0.0781	0.223

176	trichloromethane	Air	ng	331	x		327	x	x		x	4.1
177	U	Air	µg	4.9	x		2.06	x		2.76	0.0171	0.0619
178	unspecified emission	Air	mg	20.4	x	x		x	x		x	20.4
179	V	Air	mg	35.7	x		33.8	x		1.86	0.00484	0.0412
180	vinyl chloride	Air	µg	7.7	x		2.02	x		5.65	0.00513	0.033
181	VOC	Air	mg	194	x	x		x	x		193	0.195
182	xylene	Air	mg	74.4	x		71.2	x		2.94	0.0119	0.287
183	Zn	Air	mg	2.54	x		2.25	x		0.172	0.11	0.00732
184	Zr	Air	ng	709	x		548	x		155	2.77	3.26
185	1,1,1-trichloroethane	Water	ng	18.2	x		18.1	x	x		x	0.0814
186	acenaphthylene	Water	µg	39.4	x		38.7	x	x		x	0.745
187	Acid as H+	Water	µg	39.6	x	x		x		38.7	0.694	0.277
188	acids (unspecified)	Water	µg	149	x		148	x	x		x	0.76
189	Ag	Water	µg	219	x		218	x		0.87	0.00197	0.0235
190	Al	Water	mg	424	x		236	x		182	1.35	4.5
191	alkanes	Water	mg	46.8	x		46.6	x		0.184	0.000504	0.00458
192	alkenes	Water	mg	4.32	x		4.3	x		0.0167	4.57E-05	0.000422
193	AOX	Water	mg	1.11	x		1.1	x		0.00481	1.14E-05	0.000126
194	As	Water	µg	1050	x		673	x		365	2.72	8.91
195	B	Water	mg	9.93	x		9.61	x		0.309	0.00193	0.00771
196	Ba	Water	mg	947	x		929	x		17.8	0.116	0.437

197	baryte	Water	g	6.12	x	6.08	x	0.0328	0.000205	0.000786
198	Be	Water	ng	437	x	303	x	128	0.0698	6.72
199	benzene	Water	mg	46.8	x	46.6	x	0.185	0.000506	0.0046
200	BOD	Water	g	6.66	6.6	0.0443	0.014	0.000144	0.000275	9.43E-06
201	calcium compounds	Water	mg	205	x	x	x	203	1.25	1.18
202	calcium ions	Water	g	13.9	x	13.9	x	x	x	0.00446
203	Cd	Water	µg	382	x	370	x	11.6	0.248	0.362
204	chlorinated solvents (unspec.)	Water	µg	4.08	x	4.08	x	x	x	0.00315
205	chlorobenzenes	Water	pg	75.8	x	73.8	x	1.66	0.0155	0.343
206	Cl-	Water	g	195	x	193	0.028	1.91	0.0285	0.0483
207	Co	Water	µg	783	x	414	x	358	2.69	8.75
208	COD	Water	g	26	24.8	1.1	0.028	0.00194	0.00232	8.72E-05
209	Cr	Water	mg	1.85	x	x	x	1.82	0.0161	0.0109
210	Cr (III)	Water	mg	5.3	x	5.27	x	x	x	0.0336
211	Cr (VI)	Water	ng	794	x	313	x	468	3.24	9.88
212	crude oil	Water	mg	62.3	x	x	x	0.148	61.7	0.514
213	Cs	Water	µg	360	x	359	x	1.39	0.00325	0.0351
214	Cu	Water	mg	2.61	x	1.67	x	0.902	0.0108	0.0246
215	CxHy	Water	mg	127	x	0.108	56	33.8	36.4	0.613
216	CxHy aromatic	Water	mg	215	x	214	x	0.868	0.00263	0.0215
217	CxHy chloro	Water	µg	3.37	x	x	x	3.36	0.0039	0.00537

218	cyanide	Water	mg	1.29	x		1.27	x			0.0198		0.000188	0.00044
219	di(2-ethylhexyl)phthalate	Water	pg	705	x		697	x		x		x		7.68
220	dibutyl p-phthalate	Water	ng	3.99	x		3.92	x		x		x		0.0754
221	dichloroethane	Water	µg	11.4	x		6.36	x			4.95		0.00449	0.0866
222	dichloromethane	Water	mg	3.3	x		3.29	x			0.00169		9.83E-06	0.00028
223	dimethyl p-phthalate	Water	ng	25.1	x		24.7	x		x		x		0.475
224	dissolved organics	Water	µg	341	x	x		x			332		6.66	2.46
225	dissolved substances	Water	mg	172	x		86.6	x			76.8		0.573	8.42
226	DOC	Water	µg	256	x		249	x		x		x		6.28
227	ethyl benzene	Water	mg	8.65	x		8.62	x			0.0333		7.81E-05	0.000829
228	F2	Water	mg	11.8	x	x		x		x		x		11.8
229	fats/oils	Water	g	6.98	x		6.98	x		x		x		0.000508
230	fatty acids as C	Water	g	1.82	x		1.82	x		x		x		0.000139
231	Fe	Water	mg	708	x		409	x			292		0.426	6.61
232	fluoride ions	Water	mg	52	x		51.4	x			0.559		0.00339	0.0185
233	formaldehyde	Water	ng	71.6	x		59.2	x			11.7		0.14	0.504
234	glutaraldehyde	Water	µg	756	x		752	x			4.04		0.0252	0.097
235	H2	Water	mg	139	x	x			83.9	x			54.5	0.0543
236	H2S	Water	µg	58.1	x		50.1	x			7.73		0.139	0.18
237	hexachloroethane	Water	pg	143	x		141	x		x		x		1.78
238	Hg	Water	µg	6.71	x		5.39	x			0.33		0.153	0.845

239	HOCL	Water	mg	3.01	x		1.3	x			1.66		0.00534	0.0368
240	I	Water	mg	36	x		35.9	x			0.139		0.000325	0.00345
241	inorganic general	Water	mg	5.97	x	x		x		x			5.97	0.00589
242	K	Water	g	1.84	x		1.78	x			0.0604		0.00042	0.00149
243	Kjeldahl-N	Water	mg	6.78	x	x		x		x			6.76	0.0166
244	metallic ions	Water	mg	23.1	x	x			14	x			9.08	0.00905
245	Mg	Water	mg	797	x		638	x			154		1.14	3.73
246	Mn	Water	mg	29	x		24.5	x			4.34		0.0281	0.106
247	Mo	Water	µg	1550	x		937	x			593		3.6	15.8
248	MTBE	Water	ng	330	x		329	x		x		x		0.504
249	N-tot	Water	mg	629	x		622		2.8		4.05		0.0642	0.133
250	N organically bound	Water	mg	100	x		100	x		x		x		0.00335
251	Na	Water	g	116	x		115	x			0.629		0.00225	0.0164
252	NH3 (as N)	Water	mg	469	x		469	x		x		x		0.0581
253	Ni	Water	mg	2.99	x		2.04	x			0.914		0.00683	0.0223
254	nitrate	Water	mg	206	x		200	x			5.12		0.0301	0.115
255	nitrite	Water	µg	381	x		375	x		x		x		6.69
256	OCl-	Water	mg	1.33	x		1.3	x		x		x		0.029
257	oil	Water	µg	11.2	x	x		x		x			11.2	0.0275
258	P-compounds	Water	µg	200	x		200	x		x		x		0.0227
259	P-tot	Water	ng	338	x	x		x			335		0.361	1.76

260	PAH's	Water	mg	4.68	x	4.66	x	0.0181	4.34E-05	0.00126
261	Pb	Water	mg	3.38	x	2.24	x	1.1	0.012	0.0344
262	phenol	Water	µg	215	x	x	x	214	0.599	1.16
263	phenols	Water	mg	42.9	x	42.9	x	x	x	0.00384
264	phosphate	Water	mg	27.3	x	16.2	x	10.8	0.0809	0.264
265	Ru	Water	mg	3.59	x	3.59	x	x	x	0.000275
266	S	Water	µg	43.2	x	x	x	42.9	0.1	0.231
267	salt	Water	mg	524	x	x	x	521	0.0926	2.68
268	salts	Water	mg	431	x	422	x	x	x	8.82
269	Sb	Water	µg	7.33	x	4.33	x	2.91	0.0199	0.0692
270	Se	Water	mg	2.23	x	1.29	x	0.913	0.00675	0.0225
271	Si	Water	mg	3.68	x	3.68	x	0.000781	4.87E-06	0.00145
272	Sn	Water	µg	4.11	x	1.56	x	2.48	0.0166	0.0476
273	SO3	Water	µg	280	x	195	x	80.9	0.553	3.54
274	Sr	Water	g	2.18	x	2.17	x	0.0105	3.58E-05	0.000262
275	sulphate	Water	g	7.91	x	7.87	x	x	x	0.0339
276	sulphates	Water	g	2.04	x	x	x	2.02	0.00653	0.0111
277	sulphide	Water	mg	8.89	x	8.88	x	x	x	0.000899
278	suspended solids	Water	g	6.86	6.86	x	x	x	x	x
279	suspended substances	Water	mg	211	x	x	x	130	0.661	80
280	tetrachloroethene	Water	ng	17	x	16.8	x	x	x	0.21

281	tetrachloromethane	Water	ng	25.9	x	25.6	x	x	x	0.322
282	Ti	Water	mg	23.5	x	12.4	x	10.7	0.0808	0.263
283	TOC	Water	g	5.57	x	5.54	x	0.033	0.000474	0.00102
284	toluene	Water	mg	38.9	x	38.7	x	0.167	0.000458	0.0039
285	tributyltin	Water	µg	315	x	310	x	5.69	0.0305	0.118
286	trichloroethene	Water	µg	1.92	x	1.06	x	0.847	0.000768	0.0145
287	trichloromethane	Water	µg	3.94	x	3.89	x	x	x	0.0487
288	triethylene glycol	Water	µg	256	x	249	x	x	x	6.28
289	undissolved substances	Water	g	18.9	x	18.9	x	x	x	0.00228
290	V	Water	mg	2.33	x	1.33	x	0.974	0.00681	0.0237
291	vinyl chloride	Water	ng	4.82	x	4.76	x	x	x	0.0598
292	VOC as C	Water	mg	125	x	125	x	x	x	0.00947
293	W	Water	µg	9.38	x	7.24	x	1.95	0.0135	0.175
294	waste water (vol)	Water	cm3	3.76	x	x	x	x	x	3.76
295	xylene	Water	mg	33.8	x	33.7	x	0.133	0.000365	0.00332
296	Zn	Water	mg	13.2	x	11.2	x	1.84	0.0411	0.0517
297	dust - not specified	Solid	mg	7.55	x	x	x	x	7.53	0.0185
298	final waste (inert)	Solid	g	55	x	x	6.16	48.2	0.442	0.281
299	high active nuclear waste	Solid	mm3	1.71	x	x	x	1.7	0.000934	0.00884
300	inorganic general	Solid	mg	362	x	x	x	x	361	0.472
301	low,med. act. nucl. waste	Solid	mm3	110	x	x	x	110	0.21	0.542

302	mineral waste	Solid	g	2.47	x	x	x	x	2.47	0.00247
303	mineral waste (mining)	Solid	mg	1.72	x	x	x	x	x	1.72
304	oil	Solid	mg	26.5	x	x	x	x	26.5	0.0651
305	produc. waste (not inert)	Solid	g	103	x	x	x	14	28.1	60.9
306	slag	Solid	g	7.14	x	x	7	x	0.141	0.00017
307	soot	Solid	ng	610	x	x	x	x	609	0.602
308	toxic waste	Solid	kg	43	43	x	x	x	x	x
309	Al (ind.)	Soil	mg	474	x	474	x	x	x	0.0389
310	As (ind.)	Soil	µg	190	x	190	x	x	x	0.0155
311	C (ind.)	Soil	g	1.47	x	1.47	x	x	x	0.00012
312	Ca (ind.)	Soil	g	1.9	x	1.9	x	x	x	0.000155
313	Cd (ind.)	Soil	µg	7.11	x	7.11	x	x	x	0.000683
314	Co (ind.)	Soil	µg	9.84	x	9.84	x	x	x	0.000735
315	Cr (ind.)	Soil	mg	2.37	x	2.37	x	x	x	0.000195
316	Cu (ind.)	Soil	µg	49.2	x	49.2	x	x	x	0.00368
317	Fe (ind.)	Soil	mg	950	x	950	x	x	x	0.0779
318	Hg (ind.)	Soil	µg	1.35	x	1.35	x	x	x	0.000109
319	Mn (ind.)	Soil	mg	19	x	19	x	x	x	0.00155
320	N	Soil	µg	381	x	381	x	x	x	0.0346
321	Ni (ind.)	Soil	µg	73.8	x	73.8	x	x	x	0.00551
322	oil (ind.)	Soil	mg	318	x	318	x	x	x	0.024

323	oil biodegradable	Soil	µg	26.5	x	26.1	x	x	x	0.398
324	Pb (ind.)	Soil	µg	224	x	224	x	x	x	0.0168
325	phosphor (ind.)	Soil	mg	24.2	x	24.2	x	x	x	0.00201
326	S (ind.)	Soil	mg	285	x	285	x	x	x	0.0234
327	Zn (ind.)	Soil	mg	7.59	x	7.59	x	x	x	0.00062
328	Ag110m to air	Non mat.	µBq	3.43	x	3.36	x	x	x	0.0704
329	Ag110m to water	Non mat.	mBq	23.4	x	23	x	x	x	0.479
330	alpha radiation (unspecified) to water	Non mat.	µBq	2.74	x	2.69	x	x	x	0.0569
331	Am241 to air	Non mat.	µBq	70.3	x	69	x	x	x	1.31
332	Am241 to water	Non mat.	mBq	9.19	x	9.02	x	x	x	0.173
333	Ar41 to air	Non mat.	Bq	7.4	x	7.24	x	x	x	0.152
334	Ba140 to air	Non mat.	µBq	20.2	x	19.9	x	x	x	0.274
335	Ba140 to water	Non mat.	µBq	158	x	157	x	x	x	0.859
336	beta radiation (unspecified) to air	Non mat.	µBq	1.31	x	1.31	x	x	x	0.0088
337	C14 to air	Non mat.	Bq	5.91	x	5.81	x	x	x	0.106
338	C14 to water	Non mat.	mBq	467	x	458	x	x	x	8.72
339	Cd109 to water	Non mat.	nBq	914	x	909	x	x	x	4.97
340	Ce141 to air	Non mat.	nBq	325	x	318	x	x	x	6.53

341	Ce141 to water	Non mat.	µBq	23.6	x	23.5	x	x	x	0.129
342	Ce144 to air	Non mat.	µBq	745	x	731	x	x	x	13.9
343	Ce144 to water	Non mat.	mBq	211	x	207	x	x	x	3.95
344	Cm (alpha) to air	Non mat.	µBq	111	x	109	x	x	x	2.08
345	Cm (alpha) to water	Non mat.	mBq	12.2	x	12	x	x	x	0.228
346	Cm242 to air	Non mat.	nBq	0.333	x	0.326	x	x	x	0.0069
347	Cm244 to air	Non mat.	nBq	3.02	x	2.96	x	x	x	0.0628
348	Co57 to air	Non mat.	nBq	5.81	x	5.69	x	x	x	0.121
349	Co57 to water	Non mat.	µBq	162	x	161	x	x	x	0.881
350	Co58 to air	Non mat.	µBq	96.3	x	94.3	x	x	x	2
351	Co58 to water	Non mat.	mBq	78.7	x	77.9	x	x	x	0.747
352	Co60 to air	Non mat.	µBq	153	x	150	x	x	x	2.98
353	Co60 to water	Non mat.	Bq	2.1	x	2.07	x	x	x	0.0381
354	Conv. to continuous urban land	Non mat.	mm2	4.3	x	x	x	x	4.29	0.01
355	Conv. to industrial area	Non mat.	mm2	142	x	x	57.6	x	83.9	0.851
356	Cr51 to air	Non mat.	µBq	12.9	x	12.6	x	x	x	0.247
357	Cr51 to water	Non mat.	mBq	3.48	x	3.46	x	x	x	0.0189
358	Cs134 to air	Non mat.	mBq	2.65	x	2.6	x	x	x	0.0498
359	Cs134 to water	Non mat.	mBq	472	x	464	x	x	x	8.82
360	Cs136 to water	Non mat.	nBq	845	x	841	x	x	x	4.61

361	Cs137 to air	Non mat.	mBq	5.13	x		5.03	x	x		x		0.096
362	Cs137 to water	Non mat.	Bq	4.35	x		4.27	x	x		x		0.0813
363	Fe59 to air	Non mat.	nBq	132	x		129	x	x		x		2.73
364	Fe59 to water	Non mat.	µBq	2.8	x		2.78	x	x		x		0.0152
365	Fission and activation products (RA) to water	Non mat.	mBq	24.9	x		24.4	x	x		x		0.517
366	H3 to air	Non mat.	Bq	54.5	x		53.4	x	x		x		1.09
367	H3 to water	Non mat.	Bq	13800	x		13500	x	x		x		258
368	heat losses to air	Non mat.	MJ	6.33	x	x		x		6.27		0.0251	0.0349
369	heat losses to soil	Non mat.	kJ	269	x	x		x		269		0.00983	0.0318
370	heat losses to water	Non mat.	kJ	128	x	x		x		125		1.93	0.863
371	I129 to air	Non mat.	mBq	20	x		19.6	x	x		x		0.374
372	I129 to water	Non mat.	Bq	1.33	x		1.31	x	x		x		0.0249
373	I131 to air	Non mat.	mBq	4.06	x		4.02	x	x		x		0.0415
374	I131 to water	Non mat.	mBq	1.28	x		1.26	x	x		x		0.0166
375	I133 to air	Non mat.	mBq	1.14	x		1.12	x	x		x		0.0233
376	I133 to water	Non mat.	µBq	721	x		718	x	x		x		3.93
377	I135 to air	Non mat.	mBq	1.69	x		1.65	x	x		x		0.0348
378	K40 to air	Non mat.	mBq	9.65	x		9.43	x	x		x		0.216
379	K40 to water	Non mat.	mBq	30.3	x		29.7	x	x		x		0.627
380	Kr85 to air	Non mat.	kBq	345	x		338	x	x		x		6.44

381	Kr85m to air	Non mat.	Bq	1.02	x		1.01	x	x		x		0.00761
382	Kr87 to air	Non mat.	mBq	358	x		355	x	x		x		3.4
383	Kr88 to air	Non mat.	Bq	14.9	x		14.6	x	x		x		0.304
384	Kr89 to air	Non mat.	mBq	321	x		318	x	x		x		2.39
385	La140 to air	Non mat.	µBq	9.54	x		9.36	x	x		x		0.174
386	La140 to water	Non mat.	µBq	32.8	x		32.6	x	x		x		0.178
387	land use (sea floor) II-III	Non mat.	m2a	0.488	x		0.488	x	x		x		4.77E-05
388	land use (sea floor) II-IV	Non mat.	cm2a	504	x		504	x	x		x		0.0492
389	land use II-III	Non mat.	cm2a	732	x		404	x		321	x		8
390	land use II-IV	Non mat.	cm2a	129	x		121	x		7.53	x		0.152
391	land use III-IV	Non mat.	cm2a	100	x		96.4	x		3.81	x		0.138
392	land use IV-IV	Non mat.	mm2a	138	x		137	x		1.45	x		0.175
393	Mn54 to air	Non mat.	µBq	3.55	x		3.48	x	x		x		0.0714
394	Mn54 to water	Non mat.	mBq	315	x		309	x	x		x		5.85
395	Mo99 to water	Non mat.	µBq	11.1	x		11	x	x		x		0.0601
396	Na24 to water	Non mat.	mBq	4.87	x		4.85	x	x		x		0.0265
397	Nb95 to air	Non mat.	nBq	638	x		625	x	x		x		12.6
398	Nb95 to water	Non mat.	µBq	90	x		89.5	x	x		x		0.488
399	Np237 to air	Non mat.	nBq	3.66	x		3.59	x	x		x		0.0685
400	Np237 to water	Non mat.	µBq	589	x		578	x	x		x		11
401	Occup. as contin. urban land	Non mat.	mm2a	304	x	x		x	x			303	1.12

402	Occup. as convent. arable land	Non mat.	mm2a	45.4	x	x	x	x	40.7	4.68
403	Occup. as forest land	Non mat.	mm2a	0.00524	x	x	x	x	0.0047	0.000541
404	Occup. as industrial area	Non mat.	cm2a	184	x	x	156	x	27.6	0.547
405	Occup. as rail/road area	Non mat.	mm2a	147	x	x	x	x	147	0.332
406	Pa234m to air	Non mat.	mBq	2.22	x	2.18	x	x	x	0.0416
407	Pa234m to water	Non mat.	mBq	41.1	x	40.3	x	x	x	0.77
408	Pb210 to air	Non mat.	mBq	58.6	x	57.3	x	x	x	1.22
409	Pb210 to water	Non mat.	mBq	24.1	x	23.6	x	x	x	0.499
410	Pm147 to air	Non mat.	mBq	1.89	x	1.85	x	x	x	0.0353
411	Po210 to air	Non mat.	mBq	86.6	x	84.7	x	x	x	1.85
412	Po210 to water	Non mat.	mBq	24.1	x	23.6	x	x	x	0.499
413	Pu alpha to air	Non mat.	µBq	222	x	218	x	x	x	4.15
414	Pu alpha to water	Non mat.	mBq	36.6	x	35.9	x	x	x	0.685
415	Pu238 to air	Non mat.	nBq	7.54	x	7.38	x	x	x	0.156
416	Pu241 Beta to air	Non mat.	mBq	6.11	x	5.99	x	x	x	0.115
417	Pu241 beta to water	Non mat.	mBq	912	x	895	x	x	x	17.1
418	Ra224 to water	Non mat.	Bq	17.9	x	17.9	x	x	x	0.00136
419	Ra226 to air	Non mat.	mBq	78.3	x	76.8	x	x	x	1.5
420	Ra226 to water	Non mat.	Bq	205	x	202	x	x	x	3.18
421	Ra228 to air	Non mat.	mBq	4.74	x	4.63	x	x	x	0.107
422	Ra228 to water	Non mat.	Bq	35.9	x	35.9	x	x	x	0.00271

423	radio active noble gases to air	Non mat.	Bq	1.67	x	1.66	x	x	x	0.00909
424	radioactive substance to air	Non mat.	Bq	879000	x	x	x	874000	479	4530
425	radioactive substance to water	Non mat.	Bq	8100	x	x	x	8060	4.4	41.8
426	radionuclides (mixed) to water	Non mat.	µBq	22.3	x	21.9	x	x	x	0.373
427	Rn220 to air	Non mat.	mBq	443	x	433	x	x	x	9.42
428	Rn222 (long term) to air	Non mat.	kBq	494	x	485	x	x	x	9.25
429	Rn222 to air	Non mat.	Bq	5420	x	5320	x	x	x	101
430	Ru103 to air	Non mat.	nBq	44.7	x	43.9	x	x	x	0.713
431	Ru103 to water	Non mat.	µBq	53	x	52.7	x	x	x	0.288
432	Ru106 to air	Non mat.	mBq	22.2	x	21.8	x	x	x	0.415
433	Ru106 to water	Non mat.	Bq	2.22	x	2.18	x	x	x	0.0415
434	Sb122 to water	Non mat.	µBq	158	x	157	x	x	x	0.859
435	Sb124 to air	Non mat.	nBq	976	x	957	x	x	x	19.3
436	Sb124 to water	Non mat.	mBq	7.64	x	7.52	x	x	x	0.124
437	Sb125 to air	Non mat.	nBq	277	x	275	x	x	x	2.45
438	Sb125 to water	Non mat.	mBq	1.29	x	1.28	x	x	x	0.00701
439	Sr89 to air	Non mat.	µBq	6.25	x	6.13	x	x	x	0.125
440	Sr89 to water	Non mat.	µBq	357	x	355	x	x	x	1.94
441	Sr90 to air	Non mat.	mBq	3.67	x	3.6	x	x	x	0.0685
442	Sr90 to water	Non mat.	mBq	444	x	436	x	x	x	8.31
443	Tc99 to air	Non mat.	nBq	155	x	152	x	x	x	2.9

444	Tc99 to water	Non mat.	mBq	233	x	229	x	x	x	4.37
445	Tc99m to water	Non mat.	µBq	74.2	x	73.8	x	x	x	0.405
446	Te123m to air	Non mat.	µBq	15.1	x	14.8	x	x	x	0.314
447	Te123m to water	Non mat.	µBq	6.67	x	6.64	x	x	x	0.0363
448	Te132 to water	Non mat.	µBq	2.73	x	2.72	x	x	x	0.0148
449	Th228 to air	Non mat.	mBq	4.01	x	3.92	x	x	x	0.0901
450	Th228 to water	Non mat.	Bq	71.7	x	71.7	x	x	x	0.00541
451	Th230 to air	Non mat.	mBq	24.7	x	24.2	x	x	x	0.463
452	Th230 to water	Non mat.	Bq	6.42	x	6.3	x	x	x	0.121
453	Th232 to air	Non mat.	mBq	2.54	x	2.49	x	x	x	0.0572
454	Th232 to water	Non mat.	mBq	5.65	x	5.53	x	x	x	0.117
455	Th234 to air	Non mat.	mBq	2.22	x	2.18	x	x	x	0.0416
456	Th234 to water	Non mat.	mBq	41.4	x	40.7	x	x	x	0.777
457	U alpha to air	Non mat.	mBq	79.4	x	77.9	x	x	x	1.49
458	U alpha to water	Non mat.	Bq	2.68	x	2.63	x	x	x	0.0503
459	U234 to air	Non mat.	mBq	26.6	x	26.1	x	x	x	0.499
460	U234 to water	Non mat.	mBq	54.9	x	53.9	x	x	x	1.03
461	U235 to air	Non mat.	mBq	1.29	x	1.26	x	x	x	0.0242
462	U235 to water	Non mat.	mBq	81.5	x	80	x	x	x	1.53
463	U238 to air	Non mat.	mBq	33.5	x	32.8	x	x	x	0.655
464	U238 to water	Non mat.	mBq	138	x	135	x	x	x	2.61

465	waste heat to air	Non mat.	MJ	63.8	x	63.6	x	x	x	0.169
466	waste heat to soil	Non mat.	kJ	28.4	x	28	x	x	x	0.461
467	waste heat to water	Non mat.	MJ	7.81	x	7.81	x	x	x	0.00182
468	Xe131m to air	Non mat.	Bq	1.65	x	1.63	x	x	x	0.0157
469	Xe133 to air	Non mat.	Bq	243	x	239	x	x	x	4.63
470	Xe133m to air	Non mat.	mBq	112	x	110	x	x	x	2.33
471	Xe135 to air	Non mat.	Bq	51.5	x	50.7	x	x	x	0.789
472	Xe135m to air	Non mat.	Bq	9.78	x	9.7	x	x	x	0.0778
473	Xe137 to air	Non mat.	mBq	217	x	215	x	x	x	1.93
474	Xe138 to air	Non mat.	Bq	2.7	x	2.68	x	x	x	0.021
475	Y90 to water	Non mat.	µBq	18.3	x	18.2	x	x	x	0.0993
476	Zn65 to air	Non mat.	µBq	18.1	x	17.8	x	x	x	0.307
477	Zn65 to water	Non mat.	mBq	10.3	x	10.3	x	x	x	0.0558
478	Zr95 to air	Non mat.	nBq	221	x	216	x	x	x	4.57
479	Zr95 to water	Non mat.	mBq	18.9	x	18.5	x	x	x	0.353

APPENDIX B

LCIA profile of spent solvent at 70% efficiency by Eco-indicator 99 method

Impact category	Unit	Total	Distillation Solvent	Fuel oil lowS 2000 refinery CH S	Diesel I	Cold transforming steel	Elec Thai	Water Thai
Total	Pt	3.18	0.111	1.27	0.48	0.0196	1.29	0.00645
Carcinogens	Pt	0.0138	x	0.0116	0.0000663	0.00175	0.000378	4.39E-05
Resp. organics	Pt	0.00254	x	0.00201	0.00027	0.00000829	0.000164	9.06E-05
Resp. inorganics	Pt	0.43	0.0972	0.0816	0.0286	0.00547	0.215	0.00151
Climate change	Pt	0.107	x	0.0256	0.00435	0.00264	0.0735	0.000616
Radiation	Pt	0.00037	x	0.000364	x	x	x	6.91E-06
Ozone layer	Pt	0.000989	x	0.000986	x	0.00000217	5.1E-09	3.27E-07
Ecotoxicity	Pt	0.0106	x	0.00968	0.0000561	0.000415	0.000433	1.18E-05
Acidification/ Eutrophication	Pt	0.0584	0.0137	0.00879	0.00402	0.000617	0.0311	0.000151
Land use	Pt	0.00618	x	0.00325	0.00113	0.00136	0.000397	3.98E-05
Minerals	Pt	0.000815	x	0.000393	0.0000109	0.000107	0.000223	8.07E-05
Fossil fuels	Pt	2.55	x	1.13	0.441	0.00727	0.971	0.00391

APPENDIX C

LCI results of spent solvent at 90% efficiency by Eco-indicator 99 method

No	Substance	Compartment	Unit	Total	Distillation Solvent 90%	Fuel oil lowS 2000 refinery CH S	Diesel I	Cold transforming steel	Elec Thai	Water Thai
1	additions	Raw	g	2.58	x	x	x	x	1.89	0.693
2	air	Raw	g	1.83	x	x	x	x	x	1.83
3	aluminium (in ore)	Raw	µg	164	x	x	x	x	163	0.161
4	baryte	Raw	g	26.4	x	26.2	x	0.216	0.00077	0.00307
5	bauxite	Raw	g	2.42	x	0.294	1.15	0.404	0.562	0.00483
6	bentonite	Raw	g	2.31	x	2.08	x	0.228	0.000217	0.00268
7	chromium (in ore)	Raw	g	1.2	x	0.0292	x	0.0107	1.16	0.0013
8	clay	Raw	g	4.51	x	4.51	x	x	x	0.00364
9	coal	Raw	g	149	x	x	18.4	x	12.1	118
10	coal ETH	Raw	g	248	x	100	x	144	0.657	2.13
11	cobalt (in ore)	Raw	µg	17.4	x	17.4	x	0.00543	1.49E-05	0.000117
12	copper (in ore)	Raw	mg	264	x	119	x	142	1.73	1.5
13	crude oil	Raw	mg	633	x	x	x	x	616	16.7
14	crude oil ETH	Raw	oz	213	x	212	x	1.26	0.00179	0.0293
15	crude oil IDEMAT	Raw	oz	182	x	x	131	x	50.6	0.0526
16	energy (undef.)	Raw	MJ	7.27	x	x	x	x	7.26	0.00716
17	energy from hydro power	Raw	kJ	850	x	x	x	834	14.3	2.6
18	energy from uranium	Raw	kJ	9.5	x	x	x	x	9.49	0.00997

19	gas from oil production	Raw	cu.in	106	x	x	x	106	0.15	0.343
20	gravel	Raw	g	75.9	x	42.7	x	x	32.4	0.828
21	gypsum	Raw	mg	750	x	x	x	x	549	201
22	iron (in ore)	Raw	g	49.5	x	28.6	x	1.84	18.9	0.0732
23	iron (ore)	Raw	g	88.7	x	x	0.504	x	0.00599	88.2
24	lead (in ore)	Raw	mg	27.6	x	17.6	x	9.82	0.000479	0.155
25	lignite	Raw	oz	234	x	x	x	x	233	0.23
26	lignite ETH	Raw	g	284	x	91.9	x	190	0.0094	2.53
27	limestone	Raw	g	11.7	x	x	0.504	x	3.15	8.05
28	manganese (in ore)	Raw	mg	73.2	x	7.87	x	1.97	63.1	0.273
29	marl	Raw	g	49.9	x	23.9	x	5.93	14.6	5.41
30	methane (kg)	Raw	g	1.04	x	x	x	1.03	0.00463	0.00371
31	methane (kg) ETH	Raw	mg	734	x	723	x	x	x	10.7
32	molybdene (in ore)	Raw	µg	32.3	x	32.3	x	0.00231	5.89E-06	9.03E-05
33	natural gas	Raw	oz	186	x	x	7.85	x	178	0.186
34	natural gas (vol)	Raw	cu.in	627	x	x	x	x	x	627
35	natural gas ETH	Raw	l	42.9	x	13.1	x	29	0.352	0.46
36	nickel (in ore)	Raw	mg	232	x	18.7	x	7.53	206	0.314
37	palladium (in ore)	Raw	ng	983	x	983	x	0.129	0.000641	0.0846

38	petroleum gas ETH	Raw	l	410	x	410	x	x	x	0.0287
39	platinum (in ore)	Raw	µg	1.12	x	1.12	x	0.000255	1.25E-06	9.77E-05
40	potential energy water ETH	Raw	kJ	588	x	579	x	x	x	8.58
41	reservoir content ETH	Raw	m3y	0.0132	x	0.013	x	x	x	0.000187
42	rhenium (in ore)	Raw	µg	1.07	x	1.07	x	0.0000726	3.65E-07	8.37E-05
43	rhodium (in ore)	Raw	µg	1.04	x	1.04	x	0.000109	5.48E-07	9.01E-05
44	rock salt	Raw	g	6.89	x	0.856	x	0.13	0.000328	5.91
45	sand	Raw	g	35.3	x	9.46	x	x	25.4	0.483
46	silicon (in SiO2)	Raw	mg	57.9	x	x	x	x	57.8	0.147
47	silver	Raw	µg	106	x	x	x	105	0.15	0.341
48	silver (in ore)	Raw	mg	18.9	x	18.9	x	x	x	0.00132
49	tin (in ore)	Raw	mg	10.5	x	10.5	x	0.0585	8.35E-05	0.000921
50	turbine water ETH	Raw	gal*	774	x	762	x	x	x	12
51	unspecified energy	Raw	kJ	242	x	x	x	x	x	242
52	uranium (in ore)	Raw	mg	13	x	x	x	12.9	0.00428	0.0404
53	uranium (in ore) ETH	Raw	mg	7.04	x	6.91	x	x	x	0.132
54	uranium (ore)	Raw	ng	81.8	x	x	x	x	81.7	0.0805
55	water	Raw	lb	143	x	78.6	1.67	60.6	0.363	1.49
56	wood	Raw	g	2.62	x	x	x	2.61	0.00695	0.0056
57	wood (dry matter) ETH	Raw	g	1.31	x	1.29	x	x	x	0.0196

58	zeolite	Raw	mg	2.41	x	x		x	2.39	0.00283	0.00772
59	zinc (in ore)	Raw	mg	1.69	x		1.62	x	0.0735	0.000246	0.00212
60	1,2-dichloroethane	Air	µg	12.7	x	x		x	12.7	0.00699	0.0105
61	acetaldehyde	Air	µg	648	x		359	x	284	0.306	4.02
62	acetic acid	Air	mg	2.83	x		1.5	x	1.3	0.00325	0.0186
63	acetone	Air	µg	646	x		359	x	283	0.29	4
64	acrolein	Air	ng	252	x		179	x	72.8	0.175	0.272
65	Al	Air	mg	14.4	x		5.17	x	9	0.059	0.141
66	aldehydes	Air	mg	67.1	x		0.00553	x	0.0103	66.2	0.886
67	alkanes	Air	mg	146	x		143	x	2.63	0.00422	0.0383
68	alkenes	Air	µg	1400	x		496	x	889	2.2	12.6
69	ammonia	Air	mg	3.56	x		1.32	x	1.72	0.00596	0.524
70	As	Air	µg	235	x		200	x	33.4	1.64	0.549
71	B	Air	mg	10.5	x		3.52	x	6.84	0.00312	0.0969
72	Ba	Air	µg	203	x		77.8	x	123	0.416	2.17
73	Be	Air	µg	2.09	x		0.841	x	1.23	0.00424	0.0237
74	benzaldehyde	Air	ng	86.3	x		61.1	x	25	0.06	0.0933
75	benzene	Air	mg	57.8	x		56.7	x	0.837	0.0297	0.227
76	benzo(a)pyrene	Air	µg	10.6	x		3.19	x	0.261	3.5	3.66
77	Br	Air	µg	813	x		362	x	440	1.31	9.34

78	butane	Air	mg	557	x	553	x	3.82	0.0182	0.0615
79	butene	Air	mg	13.6	x	13.5	x	0.0609	8.73E-05	0.0018
80	Ca	Air	mg	13.8	x	7.93	x	5.76	0.00525	0.134
81	carbon black	Air	mg	19.7	x	x	x	x	x	19.7
82	Cd	Air	µg	288	x	270	x	12.5	4.87	0.252
83	CFC-11	Air	µg	2.2	x	2.16	x	x	x	0.0418
84	CFC-114	Air	µg	59	x	57.9	x	x	x	1.1
85	CFC-116	Air	µg	20.2	x	3.19	x	16.9	0.0087	0.0724
86	CFC-12	Air	ng	472	x	463	x	x	x	8.98
87	CFC-13	Air	ng	297	x	291	x	x	x	5.64
88	CFC-14	Air	µg	164	x	28.8	x	135	0.0696	0.616
89	Cl2	Air	mg	14	x	x	x	x	14	0.0343
90	CO	Air	g	6.37	0.519	3.44	0.288	0.114	0.937	1.07
91	CO2	Air	oz	532	x	113	36.1	20.6	360	2.68
92	cobalt	Air	µg	426	x	356	x	68.8	0.0804	1.06
93	Cr	Air	µg	288	x	219	x	66.4	2.15	0.897
94	Cu	Air	µg	813	x	617	x	165	29.5	2.44
95	CxHy	Air	g	16.2	x	x	10.4	0.000000059	3.69	2.1
96	CxHy aromatic	Air	µg	788	x	280	x	13.8	0.016	494
97	cyanides	Air	µg	9.08	x	8.72	x	0.348	0.00378	0.0152

98	dichloroethane	Air	µg	9.74	x	9.62	x	x	x	0.12
99	dichloromethane	Air	µg	30.4	x	0.475	x	x	x	29.9
100	dioxin (TEQ)	Air	ng	2.08	x	0.111	x	0.0194	1.94	0.00526
101	dust	Air	mg	386	x	x	x	x	385	0.379
102	dust (coarse)	Air	mg	1510	x	x	x	940	2.35	573
103	dust (coarse) process	Air	mg	444	x	441	x	x	x	2.98
104	dust (PM10) mobile	Air	mg	103	x	103	x	x	x	0.0656
105	dust (PM10) stationary	Air	g	1.18	x	1.18	x	x	x	0.00159
106	dust (SPM)	Air	g	6.16	x	x	1.22	x	4.84	0.0982
107	ethane	Air	mg	145	x	138	x	6.01	0.0646	0.0956
108	ethanol	Air	µg	1290	x	719	x	567	0.58	8.04
109	ethene	Air	mg	33.6	x	33.2	x	0.339	0.00237	0.0362
110	ethylbenzene	Air	mg	14.6	x	13.7	x	0.883	0.00421	0.012
111	ethyne	Air	µg	32.1	x	20.7	x	10.6	0.0865	0.75
112	F2	Air	µg	281	x	x	x	x	165	116
113	Fe	Air	mg	12.2	x	7.29	x	4.8	0.0147	0.0887
114	fluoranthene	Air	µg	47	x	x	x	x	10.5	36.5
115	formaldehyde	Air	mg	3.87	x	1.63	x	2.19	0.0184	0.0296
116	H2S	Air	mg	26.8	x	1.74	x	0.666	1.87	22.5
117	HALON-1301	Air	mg	2.34	x	2.33	x	0.00851	1.21E-05	0.000191

118	HCFC-21	Air	µg	96.4	x	53.7	x	x	x	42.8
119	HCFC-22	Air	ng	521	x	511	x	x	x	9.84
120	HCl	Air	mg	187	x	71	18	95.5	0.495	1.56
121	He	Air	mg	413	x	413	x	x	x	0.0289
122	heptane	Air	mg	133	x	133	x	0.609	0.000873	0.00951
123	hexachlorobenzene	Air	pg	412	x	406	x	x	x	6.58
124	hexane	Air	mg	278	x	277	x	1.28	0.00184	0.02
125	HF	Air	mg	19.9	x	8.93	x	10.1	0.0299	0.807
126	HFC-134a	Air	pg	5.58E-06	x	0.00000558	x	x	x	x
127	Hg	Air	µg	72.7	x	50.7	x	15.7	1.4	4.9
128	I	Air	µg	381	x	164	x	213	0.439	4.21
129	K	Air	mg	6.65	x	5.52	x	1.1	0.00409	0.0217
130	La	Air	µg	5.88	x	2.28	x	3.53	0.0123	0.062
131	metals	Air	mg	17.4	x	x	3.6	x	13.7	0.0136
132	methane	Air	g	25.5	x	24	x	1.33	0.119	0.0172
133	methanol	Air	mg	1.61	x	1.03	x	0.568	0.000584	0.00839
134	Mg	Air	mg	5.09	x	1.8	x	3.23	0.0109	0.0502
135	Mn	Air	mg	1.42	x	1.36	x	0.0605	0.000165	0.00178
136	Mo	Air	µg	210	x	189	x	20.1	0.0296	0.362
137	MTBE	Air	µg	3.14	x	3.13	x	x	x	0.00471

138	N2	Air	mg	3.87	x	3.78	x	x	x	0.0906
139	N2O	Air	mg	877	x	61.6	x	26.9	755	33.8
140	Na	Air	mg	12.2	x	10.6	x	1.53	0.00315	0.0247
141	naphthalene	Air	ng	356	x	x	x	x	355	0.887
142	Ni	Air	mg	8.64	x	7.99	x	0.646	0.00114	0.00906
143	NO2	Air	mg	46.4	x	x	x	x	43.9	2.56
144	non methane VOC	Air	g	45.2	x	44.9	x	0.281	0.000532	0.00444
145	NOx	Air	g	61.3	x	x	10.4	1.24	49.4	0.199
146	NOx (as NO2)	Air	g	32.8	20.2	12.5	x	x	x	0.0118
147	P	Air	µg	106	x	x	x	106	0.376	0.37
148	P-tot	Air	µg	243	x	241	x	x	x	1.52
149	PAH's	Air	µg	47.8	x	28.8	x	18.6	0.155	0.304
150	particulates (unspecified)	Air	g	21	21	x	x	x	x	x
151	Pb	Air	mg	1.57	x	1.24	x	0.151	0.175	0.00287
152	pentachlorobenzene	Air	ng	1.1	x	1.08	x	x	x	0.0176
153	pentachlorophenol	Air	pg	178	x	175	x	x	x	2.84
154	pentane	Air	mg	702	x	697	x	5.07	0.0287	0.0813
155	phenol	Air	µg	2.25	x	1.32	x	0.906	0.00654	0.0125
156	propane	Air	mg	558	x	553	x	4.43	0.0247	0.0708
157	propene	Air	mg	26.9	x	26.7	x	0.199	0.000481	0.00368

158	propionic acid	Air	µg	31.6	x		9.09	x	21.9	0.268	0.331
159	Pt	Air	ng	182	x		182	x	0.0128	6.31E-05	0.267
160	Sb	Air	µg	9.43	x		4.44	x	4.87	0.00802	0.111
161	Sc	Air	µg	2.12	x		0.763	x	1.33	0.00526	0.0212
162	Se	Air	µg	357	x		274	x	80.7	0.159	1.29
163	Si	Air	mg	17.9	x		17.5	x	x	x	0.376
164	silicates	Air	mg	23	x	x		x	22.9	0.0518	0.0768
165	Sn	Air	µg	4.78	x		1.64	x	3.08	0.0114	0.0453
166	SO2	Air	g	30	x	x		x	2.93	26.8	0.225
167	soot	Air	mg	10.9	x	x		x	x	10.9	0.0359
168	SOx	Air	g	6.71	x	x		6.48	x	0.232	0.00139
169	SOx (as SO2)	Air	g	36.3	20.8		15.5	x	x	x	0.0395
170	Sr	Air	µg	227	x		77.8	x	147	0.511	2.32
171	tetrachloromethane	Air	µg	7.34	x		2.34	x	x	x	4.99
172	Th	Air	µg	9.65	x		1.44	x	8.12	0.0295	0.0604
173	Ti	Air	µg	621	x		216	x	397	1.58	6.23
174	Tl	Air	ng	894	x		551	x	329	1.39	13.6
175	toluene	Air	mg	83.5	x		82.2	x	1.02	0.0607	0.173
176	trichloromethane	Air	ng	257	x		254	x	x	x	3.18
177	U	Air	µg	5.21	x		1.6	x	3.55	0.0133	0.048

178	unspecified emission	Air	mg	15.8	x	x	x	x	x	15.8
179	V	Air	mg	28.7	x	26.2	x	2.4	0.00377	0.0319
180	vinyl chloride	Air	µg	8.86	x	1.57	x	7.27	0.00399	0.0256
181	VOC	Air	mg	151	x	x	x	x	150	0.151
182	xylene	Air	mg	59.4	x	55.3	x	3.78	0.00925	0.222
183	Zn	Air	mg	2.06	x	1.75	x	0.221	0.0859	0.00567
184	Zr	Air	ng	630	x	426	x	199	2.16	2.53
185	1,1,1-trichloroethane	Water	ng	14.1	x	14.1	x	x	x	0.0632
186	acenaphthylene	Water	µg	30.7	x	30.1	x	x	x	0.578
187	Acid as H+	Water	µg	50.5	x	x	x	49.7	0.54	0.214
188	acids (unspecified)	Water	µg	116	x	115	x	x	x	0.589
189	Ag	Water	µg	171	x	169	x	1.12	0.00153	0.0183
190	Al	Water	mg	422	x	184	x	234	1.05	3.49
191	alkanes	Water	mg	36.5	x	36.2	x	0.237	0.000392	0.00355
192	alkenes	Water	mg	3.37	x	3.34	x	0.0215	3.56E-05	0.000327
193	AOX	Water	µg	863	x	856	x	6.18	0.00886	0.0978
194	As	Water	µg	1000	x	524	x	469	2.12	6.91
195	B	Water	mg	7.88	x	7.47	x	0.397	0.0015	0.00598
196	Ba	Water	mg	746	x	722	x	22.9	0.0901	0.339
197	baryte	Water	g	4.77	x	4.73	x	0.0421	0.000159	0.00061

198	Be	Water	ng	405	x	235	x	164	0.0543	5.21
199	benzene	Water	mg	36.5	x	36.3	x	0.237	0.000393	0.00357
200	BOD	Water	g	5.19	5.14	0.0344	0.018	0.000186	0.000214	7.31E-06
201	calcium compounds	Water	mg	263	x	x	x	261	0.975	0.919
202	calcium ions	Water	g	10.8	x	10.8	x	x	x	0.00346
203	Cd	Water	µg	303	x	288	x	14.9	0.193	0.281
204	chlorinated solvents (unspec.)	Water	µg	3.18	x	3.17	x	x	x	0.00244
205	chlorobenzenes	Water	pg	59.8	x	57.4	x	2.14	0.0121	0.266
206	Cl-	Water	g	152	x	150	0.036	2.45	0.0221	0.0375
207	Co	Water	µg	791	x	322	x	460	2.1	6.78
208	COD	Water	g	20.2	19.3	0.856	0.036	0.0025	0.0018	6.77E-05
209	Cr	Water	mg	2.36	x	x	x	2.34	0.0125	0.00845
210	Cr (III)	Water	mg	4.12	x	4.1	x	x	x	0.0261
211	Cr (VI)	Water	ng	856	x	243	x	602	2.52	7.66
212	crude oil	Water	mg	48.6	x	x	x	0.19	48	0.398
213	Cs	Water	µg	281	x	279	x	1.78	0.00253	0.0272
214	Cu	Water	mg	2.49	x	1.3	x	1.16	0.00836	0.019
215	CxHy	Water	mg	144	x	0.084	72	43.4	28.3	0.475
216	CxHy aromatic	Water	mg	168	x	166	x	1.12	0.00205	0.0167
217	CxHy chloro	Water	µg	4.33	x	x	x	4.32	0.00303	0.00416

218	cyanide	Water	µg	1010	x	985	x	25.4	0.146	0.341
219	di(2-ethylhexyl)phthalate	Water	pg	548	x	542	x	x	x	5.95
220	dibutyl p-phthalate	Water	ng	3.1	x	3.05	x	x	x	0.0585
221	dichloroethane	Water	µg	11.4	x	4.95	x	6.36	0.00349	0.0671
222	dichloromethane	Water	mg	2.56	x	2.56	x	0.00217	7.65E-06	0.000217
223	dimethyl p-phthalate	Water	ng	19.6	x	19.2	x	x	x	0.369
224	dissolved organics	Water	µg	434	x	x	x	427	5.18	1.91
225	dissolved substances	Water	mg	173	x	67.3	x	98.8	0.446	6.53
226	DOC	Water	µg	199	x	194	x	x	x	4.87
227	ethyl benzene	Water	mg	6.75	x	6.7	x	0.0428	6.08E-05	0.000643
228	F2	Water	mg	9.13	x	x	x	x	x	9.13
229	fats/oils	Water	g	5.43	x	5.43	x	x	x	0.000394
230	fatty acids as C	Water	g	1.41	x	1.41	x	x	x	0.000107
231	Fe	Water	mg	699	x	318	x	375	0.331	5.12
232	fluoride ions	Water	mg	40.7	x	40	x	0.719	0.00264	0.0144
233	formaldehyde	Water	ng	61.6	x	46	x	15.1	0.109	0.391
234	glutaraldehyde	Water	µg	590	x	585	x	5.2	0.0196	0.0752
235	H2	Water	mg	150	x	x	108	x	42.4	0.0421
236	H2S	Water	µg	49.2	x	39	x	9.95	0.108	0.14
237	hexachloroethane	Water	pg	111	x	110	x	x	x	1.38

238	Hg	Water	µg	5.39	x		4.19	x			0.425		0.119	0.655
239	HOCL	Water	mg	3.18	x		1.01	x			2.14		0.00415	0.0285
240	I	Water	mg	28.1	x		27.9	x			0.178		0.000253	0.00268
241	inorganic general	Water	mg	4.64	x	x		x		x			4.64	0.00457
242	K	Water	g	1.46	x		1.38	x			0.0777		0.000327	0.00115
243	Kjeldahl-N	Water	mg	5.27	x	x		x		x			5.26	0.0129
244	metallic ions	Water	mg	25.1	x	x			18	x			7.07	0.00702
245	Mg	Water	mg	698	x		496	x			198		0.885	2.89
246	Mn	Water	mg	24.8	x		19.1	x			5.59		0.0218	0.0822
247	Mo	Water	µg	1510	x		729	x			763		2.8	12.2
248	MTBE	Water	ng	257	x		256	x		x		x		0.391
249	N-tot	Water	mg	493	x		484		3.6		5.21		0.0499	0.103
250	N organically bound	Water	mg	78.1	x		78.1	x		x		x		0.0026
251	Na	Water	g	90.4	x		89.6	x			0.809		0.00175	0.0127
252	NH3 (as N)	Water	mg	365	x		365	x		x		x		0.0451
253	Ni	Water	mg	2.79	x		1.59	x			1.18		0.00531	0.0173
254	nitrate	Water	mg	162	x		156	x			6.58		0.0234	0.0889
255	nitrite	Water	µg	296	x		291	x		x		x		5.19
256	OCl-	Water	mg	1.03	x		1.01	x		x		x		0.0225
257	oil	Water	µg	8.7	x	x		x		x			8.68	0.0213

258	P-compounds	Water	µg	155	x		155	x	x		x	0.0176
259	P-tot	Water	ng	433	x	x		x		431	0.28	1.37
260	PAH's	Water	mg	3.65	x		3.63	x		0.0232	3.37E-05	0.000976
261	Pb	Water	mg	3.19	x		1.74	x		1.41	0.00933	0.0267
262	phenol	Water	µg	276	x	x		x		275	0.466	0.9
263	phenols	Water	mg	33.4	x		33.4	x	x		x	0.00298
264	phosphate	Water	mg	26.7	x		12.6	x		13.8	0.0629	0.204
265	Ru	Water	mg	2.79	x		2.79	x	x		x	0.000213
266	S	Water	µg	55.5	x	x		x		55.2	0.0779	0.179
267	salt	Water	mg	672	x	x		x		670	0.072	2.08
268	salts	Water	mg	335	x		328	x	x		x	6.84
269	Sb	Water	µg	7.18	x		3.36	x		3.75	0.0154	0.0537
270	Se	Water	mg	2.2	x		1	x		1.17	0.00525	0.0175
271	Si	Water	mg	2.86	x		2.86	x		0.001	3.79E-06	0.00112
272	Sn	Water	µg	4.46	x		1.22	x		3.19	0.0129	0.0369
273	SO3	Water	µg	259	x		152	x		104	0.43	2.74
274	Sr	Water	g	1.7	x		1.69	x		0.0135	2.78E-05	0.000203
275	sulphate	Water	g	6.15	x		6.12	x	x		x	0.0263
276	sulphates	Water	g	2.61	x	x		x		2.6	0.00508	0.00862
277	sulphide	Water	mg	6.91	x		6.91	x	x		x	0.000697

278	suspended solids	Water	g	5.34	5.34	x	x	x	x	x
279	suspended substances	Water	mg	230	x	x	x	167	0.514	62
280	tetrachloroethene	Water	ng	13.2	x	13.1	x	x	x	0.163
281	tetrachloromethane	Water	ng	20.2	x	19.9	x	x	x	0.25
282	Ti	Water	mg	23.8	x	9.67	x	13.8	0.0628	0.204
283	TOC	Water	g	4.35	x	4.31	x	0.0425	0.000369	0.000789
284	toluene	Water	mg	30.3	x	30.1	x	0.215	0.000356	0.00303
285	tributyltin	Water	µg	248	x	241	x	7.32	0.0237	0.0914
286	trichloroethene	Water	µg	1.92	x	0.824	x	1.09	0.000598	0.0112
287	trichloromethane	Water	µg	3.06	x	3.02	x	x	x	0.0378
288	triethylene glycol	Water	µg	199	x	194	x	x	x	4.87
289	undissolved substances	Water	g	14.7	x	14.7	x	x	x	0.00176
290	V	Water	mg	2.31	x	1.03	x	1.25	0.0053	0.0183
291	vinyl chloride	Water	ng	3.75	x	3.7	x	x	x	0.0464
292	VOC as C	Water	mg	97.5	x	97.5	x	x	x	0.00735
293	W	Water	µg	8.29	x	5.63	x	2.51	0.0105	0.136
294	waste water (vol)	Water	cm3	2.92	x	x	x	x	x	2.92
295	xylene	Water	mg	26.4	x	26.2	x	0.171	0.000284	0.00258
296	Zn	Water	mg	11.2	x	8.72	x	2.37	0.032	0.0401
297	dust - not specified	Solid	mg	5.87	x	x	x	x	5.85	0.0143

298	final waste (inert)	Solid	g	70.4	x	x	7.92	61.9	0.344	0.218
299	high active nuclear waste	Solid	mm3	2.2	x	x	x	2.19	0.000726	0.00686
300	inorganic general	Solid	mg	281	x	x	x	x	281	0.366
301	low,med. act. nucl. waste	Solid	mm3	142	x	x	x	141	0.164	0.42
302	mineral waste	Solid	g	1.92	x	x	x	x	1.92	0.00191
303	mineral waste (mining)	Solid	mg	1.33	x	x	x	x	x	1.33
304	oil	Solid	mg	20.6	x	x	x	x	20.6	0.0505
305	produc. waste (not inert)	Solid	g	87	x	x	x	17.9	21.8	47.2
306	slag	Solid	g	9.11	x	x	9	x	0.11	0.000132
307	soot	Solid	ng	474	x	x	x	x	474	0.467
308	toxic waste	Solid	kg	33	33	x	x	x	x	x
309	Al (ind.)	Soil	mg	369	x	369	x	x	x	0.0302
310	As (ind.)	Soil	µg	148	x	148	x	x	x	0.012
311	C (ind.)	Soil	g	1.14	x	1.14	x	x	x	9.29E-05
312	Ca (ind.)	Soil	g	1.48	x	1.48	x	x	x	0.00012
313	Cd (ind.)	Soil	µg	5.53	x	5.53	x	x	x	0.00053
314	Co (ind.)	Soil	µg	7.65	x	7.65	x	x	x	0.00057
315	Cr (ind.)	Soil	mg	1.84	x	1.84	x	x	x	0.000151
316	Cu (ind.)	Soil	µg	38.3	x	38.3	x	x	x	0.00285
317	Fe (ind.)	Soil	mg	739	x	739	x	x	x	0.0604

318	Hg (ind.)	Soil	µg	1.05	x	1.05	x	x	x	8.43E-05
319	Mn (ind.)	Soil	mg	14.8	x	14.8	x	x	x	0.0012
320	N	Soil	µg	296	x	296	x	x	x	0.0269
321	Ni (ind.)	Soil	µg	57.4	x	57.4	x	x	x	0.00428
322	oil (ind.)	Soil	mg	247	x	247	x	x	x	0.0186
323	oil biodegradable	Soil	µg	20.6	x	20.3	x	x	x	0.309
324	Pb (ind.)	Soil	µg	174	x	174	x	x	x	0.013
325	phosphor (ind.)	Soil	mg	18.8	x	18.8	x	x	x	0.00156
326	S (ind.)	Soil	mg	222	x	222	x	x	x	0.0181
327	Zn (ind.)	Soil	mg	5.9	x	5.9	x	x	x	0.000481
328	Ag110m to air	Non mat.	µBq	2.67	x	2.61	x	x	x	0.0546
329	Ag110m to water	Non mat.	mBq	18.2	x	17.9	x	x	x	0.372
330	alpha radiation (unspecified) to water	Non mat.	µBq	2.13	x	2.09	x	x	x	0.0441
331	Am241 to air	Non mat.	µBq	54.7	x	53.7	x	x	x	1.02
332	Am241 to water	Non mat.	mBq	7.15	x	7.02	x	x	x	0.134
333	Ar41 to air	Non mat.	Bq	5.75	x	5.63	x	x	x	0.118
334	Ba140 to air	Non mat.	µBq	15.7	x	15.5	x	x	x	0.213
335	Ba140 to water	Non mat.	µBq	123	x	122	x	x	x	0.666
336	beta radiation (unspecified) to air	Non mat.	µBq	1.02	x	1.02	x	x	x	0.00683

337	C14 to air	Non mat.	Bq	4.6	x	4.52	x	x	x	0.0819
338	C14 to water	Non mat.	mBq	363	x	356	x	x	x	6.76
339	Cd109 to water	Non mat.	nBq	711	x	707	x	x	x	3.85
340	Ce141 to air	Non mat.	nBq	253	x	248	x	x	x	5.06
341	Ce141 to water	Non mat.	µBq	18.4	x	18.3	x	x	x	0.1
342	Ce144 to air	Non mat.	µBq	579	x	569	x	x	x	10.8
343	Ce144 to water	Non mat.	mBq	164	x	161	x	x	x	3.06
344	Cm (alpha) to air	Non mat.	µBq	86.7	x	85	x	x	x	1.61
345	Cm (alpha) to water	Non mat.	mBq	9.48	x	9.3	x	x	x	0.177
346	Cm242 to air	Non mat.	nBq	0.259	x	0.254	x	x	x	0.00535
347	Cm244 to air	Non mat.	nBq	2.35	x	2.3	x	x	x	0.0487
348	Co57 to air	Non mat.	nBq	4.52	x	4.43	x	x	x	0.0937
349	Co57 to water	Non mat.	µBq	126	x	125	x	x	x	0.684
350	Co58 to air	Non mat.	µBq	74.9	x	73.3	x	x	x	1.55
351	Co58 to water	Non mat.	mBq	61.2	x	60.6	x	x	x	0.58
352	Co60 to air	Non mat.	µBq	119	x	117	x	x	x	2.31
353	Co60 to water	Non mat.	Bq	1.64	x	1.61	x	x	x	0.0296
354	Conv. to continuous urban land	Non mat.	mm2	3.34	x	x	x	x	3.33	0.00778
355	Conv. to industrial area	Non mat.	mm2	140	x	x	74.2	x	65.2	0.66
356	Cr51 to air	Non mat.	µBq	10	x	9.83	x	x	x	0.191

357	Cr51 to water	Non mat.	mBq	2.7	x		2.69	x	x		x		0.0146
358	Cs134 to air	Non mat.	mBq	2.06	x		2.03	x	x		x		0.0386
359	Cs134 to water	Non mat.	mBq	367	x		361	x	x		x		6.84
360	Cs136 to water	Non mat.	nBq	657	x		654	x	x		x		3.58
361	Cs137 to air	Non mat.	mBq	3.99	x		3.91	x	x		x		0.0744
362	Cs137 to water	Non mat.	Bq	3.39	x		3.32	x	x		x		0.063
363	Fe59 to air	Non mat.	nBq	103	x		100	x	x		x		2.12
364	Fe59 to water	Non mat.	µBq	2.18	x		2.16	x	x		x		0.0118
365	Fission and activation products (RA) to water	Non mat.	mBq	19.4	x		19	x	x		x		0.401
366	H3 to air	Non mat.	Bq	42.4	x		41.5	x	x		x		0.843
367	H3 to water	Non mat.	Bq	10700	x		10500	x	x		x		200
368	heat losses to air	Non mat.	MJ	8.11	x	x		x		8.07		0.0195	0.0271
369	heat losses to soil	Non mat.	kJ	345	x	x		x		345		0.00765	0.0246
370	heat losses to water	Non mat.	kJ	163	x	x		x		161		1.5	0.669
371	I129 to air	Non mat.	mBq	15.5	x		15.3	x	x		x		0.29
372	I129 to water	Non mat.	Bq	1.03	x		1.02	x	x		x		0.0193
373	I131 to air	Non mat.	mBq	3.16	x		3.13	x	x		x		0.0322
374	I131 to water	Non mat.	µBq	996	x		983	x	x		x		12.8
375	I133 to air	Non mat.	µBq	890	x		872	x	x		x		18

376	I133 to water	Non mat.	µBq	561	x	558	x	x		x	3.05
377	I135 to air	Non mat.	mBq	1.31	x	1.29	x	x		x	0.027
378	K40 to air	Non mat.	mBq	7.5	x	7.33	x	x		x	0.168
379	K40 to water	Non mat.	mBq	23.6	x	23.1	x	x		x	0.486
380	Kr85 to air	Non mat.	kBq	268	x	263	x	x		x	4.99
381	Kr85m to air	Non mat.	mBq	793	x	787	x	x		x	5.9
382	Kr87 to air	Non mat.	mBq	278	x	276	x	x		x	2.64
383	Kr88 to air	Non mat.	Bq	11.6	x	11.4	x	x		x	0.235
384	Kr89 to air	Non mat.	mBq	250	x	248	x	x		x	1.85
385	La140 to air	Non mat.	µBq	7.42	x	7.28	x	x		x	0.135
386	La140 to water	Non mat.	µBq	25.5	x	25.4	x	x		x	0.138
387	land use (sea floor) II-III	Non mat.	m2a	0.38	x	0.379	x	x		x	0.000037
388	land use (sea floor) II-IV	Non mat.	cm2a	392	x	392	x	x		x	0.0382
389	land use II-III	Non mat.	cm2a	733	x	314	x		412	x	6.2
390	land use II-IV	Non mat.	cm2a	104	x	94.1	x		9.68	x	0.118
391	land use III-IV	Non mat.	cm2a	80	x	74.9	x		4.9	x	0.107
392	land use IV-IV	Non mat.	mm2a	108	x	106	x		1.86	x	0.136
393	Mn54 to air	Non mat.	µBq	2.76	x	2.71	x	x		x	0.0554
394	Mn54 to water	Non mat.	mBq	245	x	241	x	x		x	4.54
395	Mo99 to water	Non mat.	µBq	8.6	x	8.56	x	x		x	0.0466

396	Na24 to water	Non mat.	mBq	3.79	x		3.77	x	x	x		0.0206
397	Nb95 to air	Non mat.	nBq	496	x		486	x	x	x		9.76
398	Nb95 to water	Non mat.	µBq	70	x		69.6	x	x	x		0.379
399	Np237 to air	Non mat.	nBq	2.85	x		2.8	x	x	x		0.0532
400	Np237 to water	Non mat.	µBq	458	x		450	x	x	x		8.5
401	Occup. as contin. urban land	Non mat.	mm2a	236	x	x		x	x		236	0.869
402	Occup. as convent. arable land	Non mat.	mm2a	35.3	x	x		x	x		31.7	3.63
403	Occup. as forest land	Non mat.	mm2a	0.00407	x	x		x	x		0.00365	0.000419
404	Occup. as industrial area	Non mat.	cm2a	222	x	x		201	x		21.5	0.424
405	Occup. as rail/road area	Non mat.	mm2a	115	x	x		x	x		114	0.258
406	Pa234m to air	Non mat.	mBq	1.73	x		1.7	x	x	x		0.0323
407	Pa234m to water	Non mat.	mBq	32	x		31.4	x	x	x		0.597
408	Pb210 to air	Non mat.	mBq	45.5	x		44.6	x	x	x		0.95
409	Pb210 to water	Non mat.	mBq	18.7	x		18.3	x	x	x		0.387
410	Pm147 to air	Non mat.	mBq	1.47	x		1.44	x	x	x		0.0274
411	Po210 to air	Non mat.	mBq	67.3	x		65.9	x	x	x		1.44
412	Po210 to water	Non mat.	mBq	18.7	x		18.3	x	x	x		0.387
413	Pu alpha to air	Non mat.	µBq	173	x		170	x	x	x		3.22
414	Pu alpha to water	Non mat.	mBq	28.5	x		28	x	x	x		0.532
415	Pu238 to air	Non mat.	nBq	5.86	x		5.74	x	x	x		0.121

416	Pu241 Beta to air	Non mat.	mBq	4.75	x	4.66	x	x	x	0.089
417	Pu241 beta to water	Non mat.	mBq	709	x	696	x	x	x	13.2
418	Ra224 to water	Non mat.	Bq	14	x	14	x	x	x	0.00105
419	Ra226 to air	Non mat.	mBq	60.9	x	59.7	x	x	x	1.16
420	Ra226 to water	Non mat.	Bq	160	x	157	x	x	x	2.47
421	Ra228 to air	Non mat.	mBq	3.69	x	3.6	x	x	x	0.0827
422	Ra228 to water	Non mat.	Bq	27.9	x	27.9	x	x	x	0.0021
423	radio active noble gases to air	Non mat.	Bq	1.3	x	1.29	x	x	x	0.00705
424	radioactive substance to air	Non mat.	Bq	1130000	x	x	x	1120000	373	3510
425	radioactive substance to water	Non mat.	Bq	10400	x	x	x	10400	3.43	32.4
426	radionuclides (mixed) to water	Non mat.	µBq	17.4	x	17.1	x	x	x	0.289
427	Rn220 to air	Non mat.	mBq	344	x	337	x	x	x	7.31
428	Rn222 (long term) to air	Non mat.	kBq	384	x	377	x	x	x	7.17
429	Rn222 to air	Non mat.	Bq	4210	x	4130	x	x	x	78
430	Ru103 to air	Non mat.	nBq	34.7	x	34.2	x	x	x	0.553
431	Ru103 to water	Non mat.	µBq	41.2	x	41	x	x	x	0.224
432	Ru106 to air	Non mat.	mBq	17.3	x	17	x	x	x	0.322
433	Ru106 to water	Non mat.	Bq	1.73	x	1.7	x	x	x	0.0322
434	Sb122 to water	Non mat.	µBq	123	x	122	x	x	x	0.666
435	Sb124 to air	Non mat.	nBq	759	x	744	x	x	x	15

436	Sb124 to water	Non mat.	mBq	5.94	x	5.85	x	x	x	0.0961
437	Sb125 to air	Non mat.	nBq	216	x	214	x	x	x	1.9
438	Sb125 to water	Non mat.	µBq	1000	x	999	x	x	x	5.43
439	Sr89 to air	Non mat.	µBq	4.86	x	4.77	x	x	x	0.0969
440	Sr89 to water	Non mat.	µBq	278	x	276	x	x	x	1.5
441	Sr90 to air	Non mat.	mBq	2.85	x	2.8	x	x	x	0.0532
442	Sr90 to water	Non mat.	mBq	346	x	339	x	x	x	6.44
443	Tc99 to air	Non mat.	nBq	121	x	119	x	x	x	2.25
444	Tc99 to water	Non mat.	mBq	181	x	178	x	x	x	3.39
445	Tc99m to water	Non mat.	µBq	57.7	x	57.4	x	x	x	0.314
446	Te123m to air	Non mat.	µBq	11.8	x	11.5	x	x	x	0.243
447	Te123m to water	Non mat.	µBq	5.19	x	5.16	x	x	x	0.0281
448	Te132 to water	Non mat.	µBq	2.13	x	2.12	x	x	x	0.0115
449	Th228 to air	Non mat.	mBq	3.12	x	3.05	x	x	x	0.0698
450	Th228 to water	Non mat.	Bq	55.8	x	55.8	x	x	x	0.0042
451	Th230 to air	Non mat.	mBq	19.2	x	18.8	x	x	x	0.359
452	Th230 to water	Non mat.	Bq	4.99	x	4.9	x	x	x	0.0937
453	Th232 to air	Non mat.	mBq	1.98	x	1.93	x	x	x	0.0443
454	Th232 to water	Non mat.	mBq	4.39	x	4.3	x	x	x	0.0906
455	Th234 to air	Non mat.	mBq	1.73	x	1.7	x	x	x	0.0323

456	Th234 to water	Non mat.	mBq	32.2	x	31.6	x	x	x	0.602
457	U alpha to air	Non mat.	mBq	61.7	x	60.6	x	x	x	1.16
458	U alpha to water	Non mat.	Bq	2.09	x	2.05	x	x	x	0.039
459	U234 to air	Non mat.	mBq	20.7	x	20.3	x	x	x	0.387
460	U234 to water	Non mat.	mBq	42.7	x	41.9	x	x	x	0.795
461	U235 to air	Non mat.	µBq	1000	x	983	x	x	x	18.7
462	U235 to water	Non mat.	mBq	63.4	x	62.2	x	x	x	1.19
463	U238 to air	Non mat.	mBq	26	x	25.5	x	x	x	0.508
464	U238 to water	Non mat.	mBq	107	x	105	x	x	x	2.02
465	waste heat to air	Non mat.	MJ	49.6	x	49.5	x	x	x	0.131
466	waste heat to soil	Non mat.	kJ	22.1	x	21.7	x	x	x	0.358
467	waste heat to water	Non mat.	MJ	6.07	x	6.07	x	x	x	0.00141
468	Xe131m to air	Non mat.	Bq	1.28	x	1.27	x	x	x	0.0122
469	Xe133 to air	Non mat.	Bq	189	x	185	x	x	x	3.59
470	Xe133m to air	Non mat.	mBq	87.4	x	85.6	x	x	x	1.8
471	Xe135 to air	Non mat.	Bq	40	x	39.4	x	x	x	0.612
472	Xe135m to air	Non mat.	Bq	7.61	x	7.55	x	x	x	0.0603
473	Xe137 to air	Non mat.	mBq	168	x	167	x	x	x	1.5
474	Xe138 to air	Non mat.	Bq	2.1	x	2.08	x	x	x	0.0163
475	Y90 to water	Non mat.	µBq	14.2	x	14.1	x	x	x	0.077

476	Zn65 to air	Non mat.	µBq	14.1	x	13.9	x	x	x	0.238
477	Zn65 to water	Non mat.	mBq	8.02	x	7.97	x	x	x	0.0433
478	Zr95 to air	Non mat.	nBq	171	x	168	x	x	x	3.54
479	Zr95 to water	Non mat.	mBq	14.7	x	14.4	x	x	x	0.274

APPENDIX D

LCIA profile of spent solvent at 90% efficiency by Eco-indicator 99 method

Impact category	Unit	Total	Distillation Solvent 90%	Fuel oil lowS 2000 refinery CH S	Diesel I	Cold transforming steel	Elec Thai	Water Thai
Total	Pt	2.73	0.087	0.99	0.617	0.0253	1.01	0.00501
Carcinogens	Pt	0.0117	x	0.009	0.0000854	0.00225	0.000294	0.000034
Resp. organics	Pt	0.00212	x	0.00156	0.000348	0.0000107	0.000128	7.03E-05
Resp. inorganics	Pt	0.352	0.0763	0.0635	0.0368	0.00703	0.168	0.00117
Climate change	Pt	0.0865	x	0.0199	0.00559	0.0034	0.0572	0.000477
Radiation	Pt	0.000288	x	0.000283	x	x	x	5.36E-06
Ozone layer	Pt	0.00077	x	0.000767	x	0.00000279	3.97E-09	2.53E-07
Ecotoxicity	Pt	0.00848	x	0.00753	0.0000722	0.000533	0.000337	9.13E-06
Acidification/ Eutrophication	Pt	0.0479	0.0107	0.00684	0.00518	0.000794	0.0242	0.000117
Land use	Pt	0.00607	x	0.00252	0.00146	0.00175	0.000309	3.09E-05
Minerals	Pt	0.000694	x	0.000306	0.0000141	0.000138	0.000173	6.26E-05
Fossil fuels	Pt	2.21	x	0.878	0.567	0.00936	0.755	0.00303

APPENDIX E

LCI result of spent solvent at 70% efficiency by using EDIP method (Characterization step)

No	Substance	Compartment	Unit	Total	Distillation Solvent	Fuel oil lowS 2000 refinery CH S	Diesel I	Cold transforming steel	Elec Thai	Water Thai
1	additions	Raw	g	3.32	x	x	x	x	2.43	0.893
2	air	Raw	g	2.35	x	x	x	x	x	2.35
3	aluminium (in ore)	Raw	µg	210	x	x	x	x	210	0.208
4	baryte	Raw	g	33.9	x	33.7	x	0.168	0.00099	0.00396
5	bauxite	Raw	mg	2320	x	378	895	314	723	6.22
6	bentonite	Raw	g	2.86	x	2.68	x	0.178	0.00028	0.00346
7	chromium (in ore)	Raw	g	1.54	x	0.0376	x	0.00833	1.49	0.00168
8	clay	Raw	g	5.8	x	5.8	x	x	x	0.00469
9	coal	Raw	g	182	x	x	14.3	x	15.5	153
10	coal ETH	Raw	g	245	x	129	x	112	0.845	2.74
11	cobalt (in ore)	Raw	µg	22.4	x	22.4	x	0.00422	1.92E-05	0.000151
12	copper (in ore)	Raw	mg	267	x	152	x	110	2.23	1.93
13	crude oil	Raw	mg	813	x	x	x	x	792	21.5
14	crude oil ETH	Raw	oz	273	x	272	x	0.977	0.0023	0.0377
15	crude oil IDEMAT	Raw	oz	167	x	x	102	x	65	0.0678
16	energy (undef.)	Raw	MJ	9.34	x	x	x	x	9.33	0.00923

17	energy from hydro power	Raw	kJ	670	x	x	x	648	18.4	3.35
18	energy from uranium	Raw	kJ	12.2	x	x	x	x	12.2	0.0129
19	gas from oil production	Raw	cu.in	82.8	x	x	x	82.2	0.193	0.442
20	gravel	Raw	g	97.6	x	54.9	x	x	41.7	1.07
21	gypsum	Raw	mg	965	x	x	x	x	705	259
22	iron (in ore)	Raw	g	62.7	x	36.8	x	1.43	24.3	0.0944
23	iron (ore)	Raw	g	114	x	x	0.392	x	0.0077	114
24	lead (in ore)	Raw	mg	30.5	x	22.6	x	7.63	0.000616	0.199
25	lignite	Raw	oz	300	x	x	x	x	300	0.296
26	lignite ETH	Raw	g	269	x	118	x	148	0.0121	3.27
27	limestone	Raw	g	14.8	x	x	0.392	x	4.05	10.4
28	manganese (in ore)	Raw	mg	93.1	x	10.1	x	1.53	81.1	0.352
29	marl	Raw	g	61.2	x	30.8	x	4.61	18.8	6.98
30	methane (kg)	Raw	mg	810	x	x	x	799	5.96	4.79
31	methane (kg) ETH	Raw	mg	943	x	929	x	x	x	13.8
32	molybdene (in ore)	Raw	µg	41.6	x	41.6	x	0.00179	7.57E-06	0.000116
33	natural gas	Raw	oz	235	x	x	6.1	x	228	0.239
34	natural gas (vol)	Raw	cu.in	809	x	x	x	x	x	809
35	natural gas ETH	Raw	l	40.5	x	16.9	x	22.5	0.453	0.593
36	nickel (in ore)	Raw	mg	295	x	24	x	5.86	264	0.405

37	palladium (in ore)	Raw	µg	1.26	x	1.26	x	0.0001	8.25E-07	0.000109
38	petroleum gas ETH	Raw	l	527	x	527	x	x	x	0.037
39	platinum (in ore)	Raw	µg	1.44	x	1.44	x	0.000198	1.61E-06	0.000126
40	potential energy water ETH	Raw	kJ	756	x	745	x	x	x	11.1
41	reservoir content ETH	Raw	m3y	0.0169	x	0.0167	x	x	x	0.000242
42	rhenium (in ore)	Raw	µg	1.38	x	1.38	x	0.0000565	4.7E-07	0.000108
43	rhodium (in ore)	Raw	µg	1.34	x	1.34	x	0.0000847	7.04E-07	0.000116
44	rock salt	Raw	g	8.82	x	1.1	x	0.101	0.000422	7.62
45	sand	Raw	g	45.4	x	12.2	x	x	32.6	0.623
46	silicon (in SiO2)	Raw	mg	74.5	x	x	x	x	74.3	0.189
47	silver	Raw	µg	82.3	x	x	x	81.7	0.193	0.44
48	silver (in ore)	Raw	mg	24.3	x	24.3	x	x	x	0.0017
49	tin (in ore)	Raw	mg	13.5	x	13.5	x	0.0454	0.000107	0.00119
50	turbine water ETH	Raw	gal*	996	x	980	x	x	x	15.4
51	unspecified energy	Raw	kJ	312	x	x	x	x	x	312
52	uranium (in ore)	Raw	mg	10.1	x	x	x	10	0.0055	0.0522
53	uranium (in ore) ETH	Raw	mg	9.05	x	8.88	x	x	x	0.17
54	uranium (ore)	Raw	ng	105	x	x	x	x	105	0.104
55	water	Raw	lb	152	x	101	1.3	47.1	0.467	1.92

56	wood	Raw	g	2.05	x	x	x	2.03	0.00893	0.00722
57	wood (dry matter) ETH	Raw	g	1.69	x	1.66	x	x	x	0.0253
58	zeolite	Raw	mg	1.88	x	x	x	1.86	0.00364	0.00995
59	zinc (in ore)	Raw	mg	2.14	x	2.08	x	0.0572	0.000316	0.00273
60	1,2-dichloroethane	Air	µg	9.91	x	x	x	9.89	0.00898	0.0135
61	acetaldehyde	Air	µg	688	x	462	x	221	0.394	5.19
62	acetic acid	Air	mg	2.97	x	1.93	x	1.01	0.00417	0.0239
63	acetone	Air	µg	687	x	462	x	220	0.373	5.16
64	acrolein	Air	ng	287	x	230	x	56.6	0.225	0.351
65	Al	Air	mg	13.9	x	6.65	x	7	0.0758	0.182
66	aldehydes	Air	mg	86.2	x	0.00711	x	0.00801	85.1	1.14
67	alkanes	Air	mg	186	x	184	x	2.05	0.00543	0.0494
68	alkenes	Air	µg	1350	x	637	x	691	2.83	16.3
69	ammonia	Air	mg	3.71	x	1.69	x	1.33	0.00766	0.676
70	As	Air	µg	285	x	257	x	26	2.11	0.708
71	B	Air	mg	9.97	x	4.52	x	5.31	0.00401	0.125
72	Ba	Air	µg	199	x	100	x	95.3	0.534	2.79
73	Be	Air	µg	2.07	x	1.08	x	0.953	0.00545	0.0306
74	benzaldehyde	Air	ng	98.2	x	78.6	x	19.4	0.0771	0.12

75	benzene	Air	mg	73.9	x	72.9	x	0.651	0.0382	0.293
76	benzo(a)pyrene	Air	µg	13.5	x	4.1	x	0.203	4.5	4.72
77	Br	Air	µg	821	x	466	x	342	1.68	12
78	butane	Air	mg	714	x	711	x	2.97	0.0235	0.0793
79	butene	Air	mg	17.4	x	17.4	x	0.0473	0.000112	0.00233
80	Ca	Air	mg	14.9	x	10.2	x	4.48	0.00676	0.173
81	carbon black	Air	mg	25.4	x	x	x	x	x	25.4
82	Cd	Air	µg	364	x	348	x	9.7	6.26	0.325
83	CFC-11	Air	µg	2.83	x	2.77	x	x	x	0.0539
84	CFC-114	Air	µg	75.9	x	74.5	x	x	x	1.42
85	CFC-116	Air	µg	17.3	x	4.11	x	13.1	0.0112	0.0933
86	CFC-12	Air	ng	608	x	596	x	x	x	11.6
87	CFC-13	Air	ng	382	x	375	x	x	x	7.27
88	CFC-14	Air	µg	143	x	37	x	105	0.0895	0.795
89	Cl2	Air	mg	18	x	x	x	x	18	0.0442
90	CO	Air	g	7.99	0.667	4.42	0.224	0.0888	1.21	1.38
91	CO2	Air	oz	655	x	145	28	16	463	3.45
92	cobalt	Air	µg	512	x	457	x	53.5	0.103	1.36
93	Cr	Air	µg	337	x	281	x	51.7	2.77	1.16

94	Cu	Air	µg	962	x	793	x	128	37.9	3.15
95	CxHy	Air	g	15.6	x	x	8.11	4.58E-08	4.74	2.71
96	CxHy aromatic	Air	µg	1010	x	360	x	10.7	0.0205	637
97	cyanides	Air	µg	11.5	x	11.2	x	0.271	0.00486	0.0196
98	dichloroethane	Air	µg	12.5	x	12.4	x	x	x	0.155
99	dichloromethane	Air	µg	39.2	x	0.61	x	x	x	38.6
100	dioxin (TEQ)	Air	ng	2.66	x	0.143	x	0.0151	2.5	0.00679
101	dust	Air	mg	496	x	x	x	x	495	0.489
102	dust (coarse)	Air	mg	1470	x	x	x	731	3.02	738
103	dust (coarse) process	Air	mg	571	x	567	x	x	x	3.85
104	dust (PM10) mobile	Air	mg	133	x	133	x	x	x	0.0846
105	dust (PM10) stationary	Air	g	1.52	x	1.52	x	x	x	0.00205
106	dust (SPM)	Air	g	7.3	x	x	0.951	x	6.22	0.127
107	ethane	Air	mg	183	x	178	x	4.67	0.083	0.123
108	ethanol	Air	µg	1380	x	924	x	441	0.745	10.4
109	ethene	Air	mg	43.1	x	42.7	x	0.264	0.00304	0.0466
110	ethylbenzene	Air	mg	18.3	x	17.6	x	0.687	0.00542	0.0155
111	ethyne	Air	µg	35.9	x	26.6	x	8.2	0.111	0.967
112	F2	Air	µg	362	x	x	x	x	212	150
113	Fe	Air	mg	13.2	x	9.38	x	3.73	0.0189	0.114

114	fluoranthene	Air	µg	60.6	x	x	x	x	13.5	47.1
115	formaldehyde	Air	mg	3.86	x	2.1	x	1.7	0.0237	0.0382
116	H2S	Air	mg	34.2	x	2.23	x	0.518	2.41	29
117	HALON-1301	Air	mg	3.01	x	3	x	0.00662	1.55E-05	0.000246
118	HCFC-21	Air	µg	124	x	69	x	x	x	55.1
119	HCFC-22	Air	ng	670	x	657	x	x	x	12.7
120	HCl	Air	mg	182	x	91.4	14	74.3	0.637	2.02
121	He	Air	mg	531	x	531	x	x	x	0.0373
122	heptane	Air	mg	171	x	171	x	0.473	0.00112	0.0123
123	hexachlorobenzene	Air	pg	530	x	521	x	x	x	8.49
124	hexane	Air	mg	357	x	356	x	0.997	0.00236	0.0258
125	HF	Air	mg	20.4	x	11.5	x	7.88	0.0384	1.04
126	HFC-134a	Air	pg	7.18E-06	x	0.00000718	x	x	x	x
127	Hg	Air	µg	85.6	x	65.2	x	12.2	1.8	6.32
128	I	Air	µg	382	x	210	x	165	0.565	5.42
129	K	Air	mg	7.99	x	7.1	x	0.857	0.00525	0.028
130	La	Air	µg	5.77	x	2.93	x	2.74	0.0158	0.0799
131	metals	Air	mg	20.5	x	x	2.8	x	17.7	0.0175
132	methane	Air	g	32.1	x	30.9	x	1.03	0.152	0.0222

133	methanol	Air	mg	1.78	x			1.33	x			0.442		0.000751		0.0108
134	Mg	Air	mg	4.9	x			2.31	x			2.51		0.014		0.0647
135	Mn	Air	mg	1.8	x			1.75	x			0.047		0.000213		0.00229
136	Mo	Air	µg	259	x			243	x			15.6		0.0381		0.467
137	MTBE	Air	µg	4.03	x			4.03	x		x		x			0.00607
138	N2	Air	mg	4.98	x			4.87	x		x		x			0.117
139	N2O	Air	mg	1110	x			79.2	x			20.9		970		43.5
140	Na	Air	mg	14.9	x			13.7	x			1.19		0.00404		0.0319
141	naphthalene	Air	ng	458	x		x		x		x			457		1.14
142	Ni	Air	mg	10.8	x			10.3	x			0.502		0.00146		0.0117
143	NO2	Air	mg	59.7	x		x		x		x			56.4		3.3
144	non methane VOC	Air	g	58	x			57.7	x			0.218		0.000684		0.00573
145	NOx	Air	g	72.8	x		x			8.11		0.967		63.5		0.256
146	NOx (as NO2)	Air	g	42.2		26		16.1	x		x		x			0.0152
147	P	Air	µg	83	x		x		x			82		0.483		0.477
148	P-tot	Air	µg	312	x			310	x		x		x			1.95
149	PAH's	Air	µg	52.1	x			37	x			14.5		0.199		0.392
150	particulates (unspecified)	Air	g	27		27	x		x		x		x		x	
151	Pb	Air	mg	1.94	x			1.6	x			0.117		0.225		0.0037

152	pentachlorobenzene	Air	ng	1.42	x			1.39	x		x		x		0.0226
153	pentachlorophenol	Air	pg	229	x			225	x		x		x		3.67
154	pentane	Air	mg	901	x			897	x			3.94		0.0369	0.105
155	phenol	Air	µg	2.43	x			1.7	x			0.704		0.00841	0.0162
156	propane	Air	mg	715	x			711	x			3.45		0.0318	0.0913
157	propene	Air	mg	34.5	x			34.3	x			0.155		0.000618	0.00474
158	propionic acid	Air	µg	29.5	x			11.7	x			17		0.344	0.426
159	Pt	Air	ng	234	x			234	x			0.00996		8.11E-05	0.344
160	Sb	Air	µg	9.65	x			5.71	x			3.79		0.0103	0.143
161	Sc	Air	µg	2.05	x			0.981	x			1.04		0.00676	0.0274
162	Se	Air	µg	418	x			353	x			62.8		0.205	1.66
163	Si	Air	mg	23	x			22.6	x		x		x		0.485
164	silicates	Air	mg	18	x		x		x			17.8		0.0666	0.0991
165	Sn	Air	µg	4.58	x			2.11	x			2.39		0.0147	0.0584
166	SO2	Air	g	37	x		x		x			2.27		34.5	0.29
167	soot	Air	mg	14	x		x		x		x			14	0.0462
168	SOx	Air	g	5.34	x		x			5.04	x			0.298	0.00179
169	SOx (as SO2)	Air	g	46		26.1		19.9	x		x		x		0.0509
170	Sr	Air	µg	218	x			100	x			114		0.657	2.99

171	tetrachloromethane	Air	µg	9.45	x	3.01	x	x	x	6.44
172	Th	Air	µg	8.28	x	1.86	x	6.31	0.038	0.0779
173	Ti	Air	µg	596	x	277	x	309	2.04	8.03
174	Tl	Air	ng	983	x	708	x	255	1.78	17.5
175	toluene	Air	mg	107	x	106	x	0.793	0.0781	0.223
176	trichloromethane	Air	ng	331	x	327	x	x	x	4.1
177	U	Air	µg	4.9	x	2.06	x	2.76	0.0171	0.0619
178	unspecified emission	Air	mg	20.4	x	x	x	x	x	20.4
179	V	Air	mg	35.7	x	33.8	x	1.86	0.00484	0.0412
180	vinyl chloride	Air	µg	7.7	x	2.02	x	5.65	0.00513	0.033
181	VOC	Air	mg	194	x	x	x	x	193	0.195
182	xylene	Air	mg	74.4	x	71.2	x	2.94	0.0119	0.287
183	Zn	Air	mg	2.54	x	2.25	x	0.172	0.11	0.00732
184	Zr	Air	ng	709	x	548	x	155	2.77	3.26
185	1,1,1-trichloroethane	Water	ng	18.2	x	18.1	x	x	x	0.0814
186	acenaphthylene	Water	µg	39.4	x	38.7	x	x	x	0.745
187	Acid as H+	Water	µg	39.6	x	x	x	38.7	0.694	0.277
188	acids (unspecified)	Water	µg	149	x	148	x	x	x	0.76
189	Ag	Water	µg	219	x	218	x	0.87	0.00197	0.0235

190	Al	Water	mg	424	x	236	x	182	1.35	4.5
191	alkanes	Water	mg	46.8	x	46.6	x	0.184	0.000504	0.00458
192	alkenes	Water	mg	4.32	x	4.3	x	0.0167	4.57E-05	0.000422
193	AOX	Water	mg	1.11	x	1.1	x	0.00481	1.14E-05	0.000126
194	As	Water	µg	1050	x	673	x	365	2.72	8.91
195	B	Water	mg	9.93	x	9.61	x	0.309	0.00193	0.00771
196	Ba	Water	mg	947	x	929	x	17.8	0.116	0.437
197	baryte	Water	g	6.12	x	6.08	x	0.0328	0.000205	0.000786
198	Be	Water	ng	437	x	303	x	128	0.0698	6.72
199	benzene	Water	mg	46.8	x	46.6	x	0.185	0.000506	0.0046
200	BOD	Water	g	6.66	6.6	0.0443	0.014	0.000144	0.000275	9.43E-06
201	calcium compounds	Water	mg	205	x	x	x	203	1.25	1.18
202	calcium ions	Water	g	13.9	x	13.9	x	x	x	0.00446
203	Cd	Water	µg	382	x	370	x	11.6	0.248	0.362
204	chlorinated solvents (unspec.)	Water	µg	4.08	x	4.08	x	x	x	0.00315
205	chlorobenzenes	Water	pg	75.8	x	73.8	x	1.66	0.0155	0.343
206	Cl-	Water	g	195	x	193	0.028	1.91	0.0285	0.0483
207	Co	Water	µg	783	x	414	x	358	2.69	8.75
208	COD	Water	g	26	24.8	1.1	0.028	0.00194	0.00232	8.72E-05
209	Cr	Water	mg	1.85	x	x	x	1.82	0.0161	0.0109

210	Cr (III)	Water	mg	5.3	x	5.27	x	x	x	0.0336
211	Cr (VI)	Water	ng	794	x	313	x	468	3.24	9.88
212	crude oil	Water	mg	62.3	x	x	x	0.148	61.7	0.514
213	Cs	Water	µg	360	x	359	x	1.39	0.00325	0.0351
214	Cu	Water	mg	2.61	x	1.67	x	0.902	0.0108	0.0246
215	CxHy	Water	mg	127	x	0.108	56	33.8	36.4	0.613
216	CxHy aromatic	Water	mg	215	x	214	x	0.868	0.00263	0.0215
217	CxHy chloro	Water	µg	3.37	x	x	x	3.36	0.0039	0.00537
218	cyanide	Water	mg	1.29	x	1.27	x	0.0198	0.000188	0.00044
219	di(2-ethylhexyl)phthalate	Water	pg	705	x	697	x	x	x	7.68
220	dibutyl p-phthalate	Water	ng	3.99	x	3.92	x	x	x	0.0754
221	dichloroethane	Water	µg	11.4	x	6.36	x	4.95	0.00449	0.0866
222	dichloromethane	Water	mg	3.3	x	3.29	x	0.00169	9.83E-06	0.00028
223	dimethyl p-phthalate	Water	ng	25.1	x	24.7	x	x	x	0.475
224	dissolved organics	Water	µg	341	x	x	x	332	6.66	2.46
225	dissolved substances	Water	mg	172	x	86.6	x	76.8	0.573	8.42
226	DOC	Water	µg	256	x	249	x	x	x	6.28
227	ethyl benzene	Water	mg	8.65	x	8.62	x	0.0333	7.81E-05	0.000829
228	F2	Water	mg	11.8	x	x	x	x	x	11.8

229	fats/oils	Water	g	6.98	x		6.98	x	x		x		0.000508
230	fatty acids as C	Water	g	1.82	x		1.82	x	x		x		0.000139
231	Fe	Water	mg	708	x		409	x		292		0.426	6.61
232	fluoride ions	Water	mg	52	x		51.4	x		0.559		0.00339	0.0185
233	formaldehyde	Water	ng	71.6	x		59.2	x		11.7		0.14	0.504
234	glutaraldehyde	Water	µg	756	x		752	x		4.04		0.0252	0.097
235	H2	Water	mg	139	x	x		83.9	x			54.5	0.0543
236	H2S	Water	µg	58.1	x		50.1	x		7.73		0.139	0.18
237	hexachloroethane	Water	pg	143	x		141	x	x		x		1.78
238	Hg	Water	µg	6.71	x		5.39	x		0.33		0.153	0.845
239	HOCL	Water	mg	3.01	x		1.3	x		1.66		0.00534	0.0368
240	I	Water	mg	36	x		35.9	x		0.139		0.000325	0.00345
241	inorganic general	Water	mg	5.97	x	x		x	x			5.97	0.00589
242	K	Water	g	1.84	x		1.78	x		0.0604		0.00042	0.00149
243	Kjeldahl-N	Water	mg	6.78	x	x		x	x			6.76	0.0166
244	metallic ions	Water	mg	23.1	x	x		14	x			9.08	0.00905
245	Mg	Water	mg	797	x		638	x		154		1.14	3.73
246	Mn	Water	mg	29	x		24.5	x		4.34		0.0281	0.106
247	Mo	Water	µg	1550	x		937	x		593		3.6	15.8

248	MTBE	Water	ng	330	x		329	x	x		x	0.504
249	N-tot	Water	mg	629	x		622		2.8	4.05	0.0642	0.133
250	N organically bound	Water	mg	100	x		100	x	x		x	0.00335
251	Na	Water	g	116	x		115	x		0.629	0.00225	0.0164
252	NH3 (as N)	Water	mg	469	x		469	x	x		x	0.0581
253	Ni	Water	mg	2.99	x		2.04	x		0.914	0.00683	0.0223
254	nitrate	Water	mg	206	x		200	x		5.12	0.0301	0.115
255	nitrite	Water	µg	381	x		375	x	x		x	6.69
256	OCl-	Water	mg	1.33	x		1.3	x	x		x	0.029
257	oil	Water	µg	11.2	x	x		x	x		11.2	0.0275
258	P-compounds	Water	µg	200	x		200	x	x		x	0.0227
259	P-tot	Water	ng	338	x	x		x		335	0.361	1.76
260	PAH's	Water	mg	4.68	x		4.66	x		0.0181	4.34E-05	0.00126
261	Pb	Water	mg	3.38	x		2.24	x		1.1	0.012	0.0344
262	phenol	Water	µg	215	x	x		x		214	0.599	1.16
263	phenols	Water	mg	42.9	x		42.9	x	x		x	0.00384
264	phosphate	Water	mg	27.3	x		16.2	x		10.8	0.0809	0.264
265	Ru	Water	mg	3.59	x		3.59	x	x		x	0.000275
266	S	Water	µg	43.2	x	x		x		42.9	0.1	0.231
267	salt	Water	mg	524	x	x		x		521	0.0926	2.68

268	salts	Water	mg	431	x	422	x	x	x	8.82
269	Sb	Water	µg	7.33	x	4.33	x	2.91	0.0199	0.0692
270	Se	Water	mg	2.23	x	1.29	x	0.913	0.00675	0.0225
271	Si	Water	mg	3.68	x	3.68	x	0.000781	4.87E-06	0.00145
272	Sn	Water	µg	4.11	x	1.56	x	2.48	0.0166	0.0476
273	SO3	Water	µg	280	x	195	x	80.9	0.553	3.54
274	Sr	Water	g	2.18	x	2.17	x	0.0105	3.58E-05	0.000262
275	sulphate	Water	g	7.91	x	7.87	x	x	x	0.0339
276	sulphates	Water	g	2.04	x	x	x	2.02	0.00653	0.0111
277	sulphide	Water	mg	8.89	x	8.88	x	x	x	0.000899
278	suspended solids	Water	g	6.86	6.86	x	x	x	x	x
279	suspended substances	Water	mg	211	x	x	x	130	0.661	80
280	tetrachloroethene	Water	ng	17	x	16.8	x	x	x	0.21
281	tetrachloromethane	Water	ng	25.9	x	25.6	x	x	x	0.322
282	Ti	Water	mg	23.5	x	12.4	x	10.7	0.0808	0.263
283	TOC	Water	g	5.57	x	5.54	x	0.033	0.000474	0.00102
284	toluene	Water	mg	38.9	x	38.7	x	0.167	0.000458	0.0039
285	tributyltin	Water	µg	315	x	310	x	5.69	0.0305	0.118
286	trichloroethene	Water	µg	1.92	x	1.06	x	0.847	0.000768	0.0145

287	trichloromethane	Water	µg	3.94	x	3.89	x	x	x	0.0487
288	triethylene glycol	Water	µg	256	x	249	x	x	x	6.28
289	undissolved substances	Water	g	18.9	x	18.9	x	x	x	0.00228
290	V	Water	mg	2.33	x	1.33	x	0.974	0.00681	0.0237
291	vinyl chloride	Water	ng	4.82	x	4.76	x	x	x	0.0598
292	VOC as C	Water	mg	125	x	125	x	x	x	0.00947
293	W	Water	µg	9.38	x	7.24	x	1.95	0.0135	0.175
294	waste water (vol)	Water	cm3	3.76	x	x	x	x	x	3.76
295	xylene	Water	mg	33.8	x	33.7	x	0.133	0.000365	0.00332
296	Zn	Water	mg	13.2	x	11.2	x	1.84	0.0411	0.0517
297	dust - not specified	Solid	mg	7.55	x	x	x	x	7.53	0.0185
298	final waste (inert)	Solid	g	55	x	x	6.16	48.2	0.442	0.281
299	high active nuclear waste	Solid	mm3	1.71	x	x	x	1.7	0.000934	0.00884
300	inorganic general	Solid	mg	362	x	x	x	x	361	0.472
301	low,med. act. nucl. waste	Solid	mm3	110	x	x	x	110	0.21	0.542
302	mineral waste	Solid	g	2.47	x	x	x	x	2.47	0.00247
303	mineral waste (mining)	Solid	mg	1.72	x	x	x	x	x	1.72
304	oil	Solid	mg	26.5	x	x	x	x	26.5	0.0651
305	produc. waste (not inert)	Solid	g	103	x	x	x	14	28.1	60.9

306	slag	Solid	g	7.14	x		x			7	x		0.141		0.00017
307	soot	Solid	ng	610	x		x		x		x		609		0.602
308	toxic waste	Solid	kg	43		43	x		x		x	x		x	
309	Al (ind.)	Soil	mg	474	x			474	x		x	x			0.0389
310	As (ind.)	Soil	µg	190	x			190	x		x	x			0.0155
311	C (ind.)	Soil	g	1.47	x			1.47	x		x	x			0.00012
312	Ca (ind.)	Soil	g	1.9	x			1.9	x		x	x			0.000155
313	Cd (ind.)	Soil	µg	7.11	x			7.11	x		x	x			0.000683
314	Co (ind.)	Soil	µg	9.84	x			9.84	x		x	x			0.000735
315	Cr (ind.)	Soil	mg	2.37	x			2.37	x		x	x			0.000195
316	Cu (ind.)	Soil	µg	49.2	x			49.2	x		x	x			0.00368
317	Fe (ind.)	Soil	mg	950	x			950	x		x	x			0.0779
318	Hg (ind.)	Soil	µg	1.35	x			1.35	x		x	x			0.000109
319	Mn (ind.)	Soil	mg	19	x			19	x		x	x			0.00155
320	N	Soil	µg	381	x			381	x		x	x			0.0346
321	Ni (ind.)	Soil	µg	73.8	x			73.8	x		x	x			0.00551
322	oil (ind.)	Soil	mg	318	x			318	x		x	x			0.024
323	oil biodegradable	Soil	µg	26.5	x			26.1	x		x	x			0.398
324	Pb (ind.)	Soil	µg	224	x			224	x		x	x			0.0168

325	phosphor (ind.)	Soil	mg	24.2	x	24.2	x	x	x	0.00201
326	S (ind.)	Soil	mg	285	x	285	x	x	x	0.0234
327	Zn (ind.)	Soil	mg	7.59	x	7.59	x	x	x	0.00062
328	Ag110m to air	Non mat.	µBq	3.43	x	3.36	x	x	x	0.0704
329	Ag110m to water	Non mat.	mBq	23.4	x	23	x	x	x	0.479
330	alpha radiation (unspecified) to water	Non mat.	µBq	2.74	x	2.69	x	x	x	0.0569
331	Am241 to air	Non mat.	µBq	70.3	x	69	x	x	x	1.31
332	Am241 to water	Non mat.	mBq	9.19	x	9.02	x	x	x	0.173
333	Ar41 to air	Non mat.	Bq	7.4	x	7.24	x	x	x	0.152
334	Ba140 to air	Non mat.	µBq	20.2	x	19.9	x	x	x	0.274
335	Ba140 to water	Non mat.	µBq	158	x	157	x	x	x	0.859
336	beta radiation (unspecified) to air	Non mat.	µBq	1.31	x	1.31	x	x	x	0.0088
337	C14 to air	Non mat.	Bq	5.91	x	5.81	x	x	x	0.106
338	C14 to water	Non mat.	mBq	467	x	458	x	x	x	8.72
339	Cd109 to water	Non mat.	nBq	914	x	909	x	x	x	4.97
340	Ce141 to air	Non mat.	nBq	325	x	318	x	x	x	6.53
341	Ce141 to water	Non mat.	µBq	23.6	x	23.5	x	x	x	0.129
342	Ce144 to air	Non mat.	µBq	745	x	731	x	x	x	13.9

343	Ce144 to water	Non mat.	mBq	211	x		207	x		x	x		3.95
344	Cm (alpha) to air	Non mat.	µBq	111	x		109	x		x	x		2.08
345	Cm (alpha) to water	Non mat.	mBq	12.2	x		12	x		x	x		0.228
346	Cm242 to air	Non mat.	nBq	0.333	x		0.326	x		x	x		0.0069
347	Cm244 to air	Non mat.	nBq	3.02	x		2.96	x		x	x		0.0628
348	Co57 to air	Non mat.	nBq	5.81	x		5.69	x		x	x		0.121
349	Co57 to water	Non mat.	µBq	162	x		161	x		x	x		0.881
350	Co58 to air	Non mat.	µBq	96.3	x		94.3	x		x	x		2
351	Co58 to water	Non mat.	mBq	78.7	x		77.9	x		x	x		0.747
352	Co60 to air	Non mat.	µBq	153	x		150	x		x	x		2.98
353	Co60 to water	Non mat.	Bq	2.1	x		2.07	x		x	x		0.0381
354	Conv. to continuous urban land	Non mat.	mm2	4.3	x	x		x		x		4.29	0.01
355	Conv. to industrial area	Non mat.	mm2	142	x	x			57.6	x		83.9	0.851
356	Cr51 to air	Non mat.	µBq	12.9	x		12.6	x		x	x		0.247
357	Cr51 to water	Non mat.	mBq	3.48	x		3.46	x		x	x		0.0189
358	Cs134 to air	Non mat.	mBq	2.65	x		2.6	x		x	x		0.0498
359	Cs134 to water	Non mat.	mBq	472	x		464	x		x	x		8.82
360	Cs136 to water	Non mat.	nBq	845	x		841	x		x	x		4.61

361	Cs137 to air	Non mat.	mBq	5.13	x		5.03	x	x		x		0.096
362	Cs137 to water	Non mat.	Bq	4.35	x		4.27	x	x		x		0.0813
363	Fe59 to air	Non mat.	nBq	132	x		129	x	x		x		2.73
364	Fe59 to water	Non mat.	µBq	2.8	x		2.78	x	x		x		0.0152
365	Fission and activation products (RA) to water	Non mat.	mBq	24.9	x		24.4	x	x		x		0.517
366	H3 to air	Non mat.	Bq	54.5	x		53.4	x	x		x		1.09
367	H3 to water	Non mat.	Bq	13800	x		13500	x	x		x		258
368	heat losses to air	Non mat.	MJ	6.33	x	x		x		6.27		0.0251	0.0349
369	heat losses to soil	Non mat.	kJ	269	x	x		x		269		0.00983	0.0318
370	heat losses to water	Non mat.	kJ	128	x	x		x		125		1.93	0.863
371	I129 to air	Non mat.	mBq	20	x		19.6	x	x		x		0.374
372	I129 to water	Non mat.	Bq	1.33	x		1.31	x	x		x		0.0249
373	I131 to air	Non mat.	mBq	4.06	x		4.02	x	x		x		0.0415
374	I131 to water	Non mat.	mBq	1.28	x		1.26	x	x		x		0.0166
375	I133 to air	Non mat.	mBq	1.14	x		1.12	x	x		x		0.0233
376	I133 to water	Non mat.	µBq	721	x		718	x	x		x		3.93
377	I135 to air	Non mat.	mBq	1.69	x		1.65	x	x		x		0.0348
378	K40 to air	Non mat.	mBq	9.65	x		9.43	x	x		x		0.216

379	K40 to water	Non mat.	mBq	30.3	x	29.7	x	x	x	0.627
380	Kr85 to air	Non mat.	kBq	345	x	338	x	x	x	6.44
381	Kr85m to air	Non mat.	Bq	1.02	x	1.01	x	x	x	0.00761
382	Kr87 to air	Non mat.	mBq	358	x	355	x	x	x	3.4
383	Kr88 to air	Non mat.	Bq	14.9	x	14.6	x	x	x	0.304
384	Kr89 to air	Non mat.	mBq	321	x	318	x	x	x	2.39
385	La140 to air	Non mat.	µBq	9.54	x	9.36	x	x	x	0.174
386	La140 to water	Non mat.	µBq	32.8	x	32.6	x	x	x	0.178
387	land use (sea floor) II-III	Non mat.	m2a	0.488	x	0.488	x	x	x	4.77E-05
388	land use (sea floor) II-IV	Non mat.	cm2a	504	x	504	x	x	x	0.0492
389	land use II-III	Non mat.	cm2a	732	x	404	x	321	x	8
390	land use II-IV	Non mat.	cm2a	129	x	121	x	7.53	x	0.152
391	land use III-IV	Non mat.	cm2a	100	x	96.4	x	3.81	x	0.138
392	land use IV-IV	Non mat.	mm2a	138	x	137	x	1.45	x	0.175
393	Mn54 to air	Non mat.	µBq	3.55	x	3.48	x	x	x	0.0714
394	Mn54 to water	Non mat.	mBq	315	x	309	x	x	x	5.85
395	Mo99 to water	Non mat.	µBq	11.1	x	11	x	x	x	0.0601
396	Na24 to water	Non mat.	mBq	4.87	x	4.85	x	x	x	0.0265
397	Nb95 to air	Non mat.	nBq	638	x	625	x	x	x	12.6

398	Nb95 to water	Non mat.	µBq	90	x	89.5	x	x	x	0.488
399	Np237 to air	Non mat.	nBq	3.66	x	3.59	x	x	x	0.0685
400	Np237 to water	Non mat.	µBq	589	x	578	x	x	x	11
401	Occup. as contin. urban land	Non mat.	mm2a	304	x	x	x	x	303	1.12
402	Occup. as convent. arable land	Non mat.	mm2a	45.4	x	x	x	x	40.7	4.68
403	Occup. as forest land	Non mat.	mm2a	0.00524	x	x	x	x	0.0047	0.000541
404	Occup. as industrial area	Non mat.	cm2a	184	x	x	156	x	27.6	0.547
405	Occup. as rail/road area	Non mat.	mm2a	147	x	x	x	x	147	0.332
406	Pa234m to air	Non mat.	mBq	2.22	x	2.18	x	x	x	0.0416
407	Pa234m to water	Non mat.	mBq	41.1	x	40.3	x	x	x	0.77
408	Pb210 to air	Non mat.	mBq	58.6	x	57.3	x	x	x	1.22
409	Pb210 to water	Non mat.	mBq	24.1	x	23.6	x	x	x	0.499
410	Pm147 to air	Non mat.	mBq	1.89	x	1.85	x	x	x	0.0353
411	Po210 to air	Non mat.	mBq	86.6	x	84.7	x	x	x	1.85
412	Po210 to water	Non mat.	mBq	24.1	x	23.6	x	x	x	0.499
413	Pu alpha to air	Non mat.	µBq	222	x	218	x	x	x	4.15
414	Pu alpha to water	Non mat.	mBq	36.6	x	35.9	x	x	x	0.685
415	Pu238 to air	Non mat.	nBq	7.54	x	7.38	x	x	x	0.156
416	Pu241 Beta to air	Non mat.	mBq	6.11	x	5.99	x	x	x	0.115
417	Pu241 beta to water	Non mat.	mBq	912	x	895	x	x	x	17.1

418	Ra224 to water	Non mat.	Bq	17.9	x		17.9	x	x		x	0.00136
419	Ra226 to air	Non mat.	mBq	78.3	x		76.8	x	x		x	1.5
420	Ra226 to water	Non mat.	Bq	205	x		202	x	x		x	3.18
421	Ra228 to air	Non mat.	mBq	4.74	x		4.63	x	x		x	0.107
422	Ra228 to water	Non mat.	Bq	35.9	x		35.9	x	x		x	0.00271
423	radio active noble gases to air	Non mat.	Bq	1.67	x		1.66	x	x		x	0.00909
424	radioactive substance to air	Non mat.	Bq	879000	x	x		x		874000	479	4530
425	radioactive substance to water	Non mat.	Bq	8100	x	x		x		8060	4.4	41.8
426	radionuclides (mixed) to water	Non mat.	µBq	22.3	x		21.9	x	x		x	0.373
427	Rn220 to air	Non mat.	mBq	443	x		433	x	x		x	9.42
428	Rn222 (long term) to air	Non mat.	kBq	494	x		485	x	x		x	9.25
429	Rn222 to air	Non mat.	Bq	5420	x		5320	x	x		x	101
430	Ru103 to air	Non mat.	nBq	44.7	x		43.9	x	x		x	0.713
431	Ru103 to water	Non mat.	µBq	53	x		52.7	x	x		x	0.288
432	Ru106 to air	Non mat.	mBq	22.2	x		21.8	x	x		x	0.415
433	Ru106 to water	Non mat.	Bq	2.22	x		2.18	x	x		x	0.0415
434	Sb122 to water	Non mat.	µBq	158	x		157	x	x		x	0.859
435	Sb124 to air	Non mat.	nBq	976	x		957	x	x		x	19.3
436	Sb124 to water	Non mat.	mBq	7.64	x		7.52	x	x		x	0.124
437	Sb125 to air	Non mat.	nBq	277	x		275	x	x		x	2.45

438	Sb125 to water	Non mat.	mBq	1.29	x	1.28	x	x	x	0.00701
439	Sr89 to air	Non mat.	µBq	6.25	x	6.13	x	x	x	0.125
440	Sr89 to water	Non mat.	µBq	357	x	355	x	x	x	1.94
441	Sr90 to air	Non mat.	mBq	3.67	x	3.6	x	x	x	0.0685
442	Sr90 to water	Non mat.	mBq	444	x	436	x	x	x	8.31
443	Tc99 to air	Non mat.	nBq	155	x	152	x	x	x	2.9
444	Tc99 to water	Non mat.	mBq	233	x	229	x	x	x	4.37
445	Tc99m to water	Non mat.	µBq	74.2	x	73.8	x	x	x	0.405
446	Te123m to air	Non mat.	µBq	15.1	x	14.8	x	x	x	0.314
447	Te123m to water	Non mat.	µBq	6.67	x	6.64	x	x	x	0.0363
448	Te132 to water	Non mat.	µBq	2.73	x	2.72	x	x	x	0.0148
449	Th228 to air	Non mat.	mBq	4.01	x	3.92	x	x	x	0.0901
450	Th228 to water	Non mat.	Bq	71.7	x	71.7	x	x	x	0.00541
451	Th230 to air	Non mat.	mBq	24.7	x	24.2	x	x	x	0.463
452	Th230 to water	Non mat.	Bq	6.42	x	6.3	x	x	x	0.121
453	Th232 to air	Non mat.	mBq	2.54	x	2.49	x	x	x	0.0572
454	Th232 to water	Non mat.	mBq	5.65	x	5.53	x	x	x	0.117
455	Th234 to air	Non mat.	mBq	2.22	x	2.18	x	x	x	0.0416
456	Th234 to water	Non mat.	mBq	41.4	x	40.7	x	x	x	0.777
457	U alpha to air	Non mat.	mBq	79.4	x	77.9	x	x	x	1.49
458	U alpha to water	Non mat.	Bq	2.68	x	2.63	x	x	x	0.0503

459	U234 to air	Non mat.	mBq	26.6	x	26.1	x	x	x	0.499
460	U234 to water	Non mat.	mBq	54.9	x	53.9	x	x	x	1.03
461	U235 to air	Non mat.	mBq	1.29	x	1.26	x	x	x	0.0242
462	U235 to water	Non mat.	mBq	81.5	x	80	x	x	x	1.53
463	U238 to air	Non mat.	mBq	33.5	x	32.8	x	x	x	0.655
464	U238 to water	Non mat.	mBq	138	x	135	x	x	x	2.61
465	waste heat to air	Non mat.	MJ	63.8	x	63.6	x	x	x	0.169
466	waste heat to soil	Non mat.	kJ	28.4	x	28	x	x	x	0.461
467	waste heat to water	Non mat.	MJ	7.81	x	7.81	x	x	x	0.00182
468	Xe131m to air	Non mat.	Bq	1.65	x	1.63	x	x	x	0.0157
469	Xe133 to air	Non mat.	Bq	243	x	239	x	x	x	4.63
470	Xe133m to air	Non mat.	mBq	112	x	110	x	x	x	2.33
471	Xe135 to air	Non mat.	Bq	51.5	x	50.7	x	x	x	0.789
472	Xe135m to air	Non mat.	Bq	9.78	x	9.7	x	x	x	0.0778
473	Xe137 to air	Non mat.	mBq	217	x	215	x	x	x	1.93
474	Xe138 to air	Non mat.	Bq	2.7	x	2.68	x	x	x	0.021
475	Y90 to water	Non mat.	µBq	18.3	x	18.2	x	x	x	0.0993
476	Zn65 to air	Non mat.	µBq	18.1	x	17.8	x	x	x	0.307
477	Zn65 to water	Non mat.	mBq	10.3	x	10.3	x	x	x	0.0558
478	Zr95 to air	Non mat.	nBq	221	x	216	x	x	x	4.57
479	Zr95 to water	Non mat.	mBq	18.9	x	18.5	x	x	x	0.353

APPENDIX F

LCI result of spent solvent at 90% efficiency by using EDIP method
(Characterization step)

No	Substance	Compartment	Unit	Total	Distillation Solvent 90%	Fuel oil lowS 2000 refinery CH S	Diesel I	Cold transforming steel	Elec Thai	Water Thai
1	additions	Raw	g	2.58	x	x	x	x	1.89	0.693
2	air	Raw	g	1.83	x	x	x	x	x	1.83
3	aluminium (in ore)	Raw	µg	164	x	x	x	x	163	0.161
4	baryte	Raw	g	26.4	x	26.2	x	0.216	0.00077	0.00307
5	bauxite	Raw	g	2.42	x	0.294	1.15	0.404	0.562	0.00483
6	bentonite	Raw	g	2.31	x	2.08	x	0.228	0.000217	0.00268
7	chromium (in ore)	Raw	g	1.2	x	0.0292	x	0.0107	1.16	0.0013
8	clay	Raw	g	4.51	x	4.51	x	x	x	0.00364
9	coal	Raw	g	149	x	x	18.4	x	12.1	118
10	coal ETH	Raw	g	248	x	100	x	144	0.657	2.13
11	cobalt (in ore)	Raw	µg	17.4	x	17.4	x	0.00543	1.49E-05	0.000117
12	copper (in ore)	Raw	mg	264	x	119	x	142	1.73	1.5
13	crude oil	Raw	mg	633	x	x	x	x	616	16.7
14	crude oil ETH	Raw	oz	213	x	212	x	1.26	0.00179	0.0293
15	crude oil IDEMAT	Raw	oz	182	x	x	131	x	50.6	0.0526
16	energy (undef.)	Raw	MJ	7.27	x	x	x	x	7.26	0.00716
17	energy from hydro power	Raw	kJ	850	x	x	x	834	14.3	2.6

18	energy from uranium	Raw	kJ	9.5	x	x	x	x	9.49	0.00997
19	gas from oil production	Raw	cu.in	106	x	x	x	106	0.15	0.343
20	gravel	Raw	g	75.9	x	42.7	x	x	32.4	0.828
21	gypsum	Raw	mg	750	x	x	x	x	549	201
22	iron (in ore)	Raw	g	49.5	x	28.6	x	1.84	18.9	0.0732
23	iron (ore)	Raw	g	88.7	x	x	0.504	x	0.00599	88.2
24	lead (in ore)	Raw	mg	27.6	x	17.6	x	9.82	0.000479	0.155
25	lignite	Raw	oz	234	x	x	x	x	233	0.23
26	lignite ETH	Raw	g	284	x	91.9	x	190	0.0094	2.53
27	limestone	Raw	g	11.7	x	x	0.504	x	3.15	8.05
28	manganese (in ore)	Raw	mg	73.2	x	7.87	x	1.97	63.1	0.273
29	marl	Raw	g	49.9	x	23.9	x	5.93	14.6	5.41
30	methane (kg)	Raw	g	1.04	x	x	x	1.03	0.00463	0.00371
31	methane (kg) ETH	Raw	mg	734	x	723	x	x	x	10.7
32	molybdene (in ore)	Raw	µg	32.3	x	32.3	x	0.00231	5.89E-06	9.03E-05
33	natural gas	Raw	oz	186	x	x	7.85	x	178	0.186
34	natural gas (vol)	Raw	cu.in	627	x	x	x	x	x	627
35	natural gas ETH	Raw	l	42.9	x	13.1	x	29	0.352	0.46
36	nickel (in ore)	Raw	mg	232	x	18.7	x	7.53	206	0.314
37	palladium (in ore)	Raw	ng	983	x	983	x	0.129	0.000641	0.0846

38	petroleum gas ETH	Raw	l	410	x		410	x	x		x	0.0287
39	platinum (in ore)	Raw	µg	1.12	x		1.12	x		0.000255	1.25E-06	9.77E-05
40	potential energy water ETH	Raw	kJ	588	x		579	x	x		x	8.58
41	reservoir content ETH	Raw	m3y	0.0132	x		0.013	x	x		x	0.000187
42	rhenium (in ore)	Raw	µg	1.07	x		1.07	x		0.0000726	3.65E-07	8.37E-05
43	rhodium (in ore)	Raw	µg	1.04	x		1.04	x		0.000109	5.48E-07	9.01E-05
44	rock salt	Raw	g	6.89	x		0.856	x		0.13	0.000328	5.91
45	sand	Raw	g	35.3	x		9.46	x	x		25.4	0.483
46	silicon (in SiO2)	Raw	mg	57.9	x	x		x	x		57.8	0.147
47	silver	Raw	µg	106	x	x		x		105	0.15	0.341
48	silver (in ore)	Raw	mg	18.9	x		18.9	x	x		x	0.00132
49	tin (in ore)	Raw	mg	10.5	x		10.5	x		0.0585	8.35E-05	0.000921
50	turbine water ETH	Raw	gal*	774	x		762	x	x		x	12
51	unspecified energy	Raw	kJ	242	x	x		x	x		x	242
52	uranium (in ore)	Raw	mg	13	x	x		x		12.9	0.00428	0.0404
53	uranium (in ore) ETH	Raw	mg	7.04	x		6.91	x	x		x	0.132
54	uranium (ore)	Raw	ng	81.8	x	x		x	x		81.7	0.0805
55	water	Raw	lb	143	x		78.6	1.67		60.6	0.363	1.49
56	wood	Raw	g	2.62	x	x		x		2.61	0.00695	0.0056
57	wood (dry matter) ETH	Raw	g	1.31	x		1.29	x	x		x	0.0196

58	zeolite	Raw	mg	2.41	x	x	x	2.39	0.00283	0.00772
59	zinc (in ore)	Raw	mg	1.69	x	1.62	x	0.0735	0.000246	0.00212
60	1,2-dichloroethane	Air	µg	12.7	x	x	x	12.7	0.00699	0.0105
61	acetaldehyde	Air	µg	648	x	359	x	284	0.306	4.02
62	acetic acid	Air	mg	2.83	x	1.5	x	1.3	0.00325	0.0186
63	acetone	Air	µg	646	x	359	x	283	0.29	4
64	acrolein	Air	ng	252	x	179	x	72.8	0.175	0.272
65	Al	Air	mg	14.4	x	5.17	x	9	0.059	0.141
66	aldehydes	Air	mg	67.1	x	0.00553	x	0.0103	66.2	0.886
67	alkanes	Air	mg	146	x	143	x	2.63	0.00422	0.0383
68	alkenes	Air	µg	1400	x	496	x	889	2.2	12.6
69	ammonia	Air	mg	3.56	x	1.32	x	1.72	0.00596	0.524
70	As	Air	µg	235	x	200	x	33.4	1.64	0.549
71	B	Air	mg	10.5	x	3.52	x	6.84	0.00312	0.0969
72	Ba	Air	µg	203	x	77.8	x	123	0.416	2.17
73	Be	Air	µg	2.09	x	0.841	x	1.23	0.00424	0.0237
74	benzaldehyde	Air	ng	86.3	x	61.1	x	25	0.06	0.0933
75	benzene	Air	mg	57.8	x	56.7	x	0.837	0.0297	0.227
76	benzo(a)pyrene	Air	µg	10.6	x	3.19	x	0.261	3.5	3.66
77	Br	Air	µg	813	x	362	x	440	1.31	9.34

78	butane	Air	mg	557	x	553	x	3.82	0.0182	0.0615
79	butene	Air	mg	13.6	x	13.5	x	0.0609	8.73E-05	0.0018
80	Ca	Air	mg	13.8	x	7.93	x	5.76	0.00525	0.134
81	carbon black	Air	mg	19.7	x	x	x	x	x	19.7
82	Cd	Air	µg	288	x	270	x	12.5	4.87	0.252
83	CFC-11	Air	µg	2.2	x	2.16	x	x	x	0.0418
84	CFC-114	Air	µg	59	x	57.9	x	x	x	1.1
85	CFC-116	Air	µg	20.2	x	3.19	x	16.9	0.0087	0.0724
86	CFC-12	Air	ng	472	x	463	x	x	x	8.98
87	CFC-13	Air	ng	297	x	291	x	x	x	5.64
88	CFC-14	Air	µg	164	x	28.8	x	135	0.0696	0.616
89	Cl2	Air	mg	14	x	x	x	x	14	0.0343
90	CO	Air	g	6.37	0.519	3.44	0.288	0.114	0.937	1.07
91	CO2	Air	oz	532	x	113	36.1	20.6	360	2.68
92	cobalt	Air	µg	426	x	356	x	68.8	0.0804	1.06
93	Cr	Air	µg	288	x	219	x	66.4	2.15	0.897
94	Cu	Air	µg	813	x	617	x	165	29.5	2.44
95	CxHy	Air	g	16.2	x	x	10.4	0.000000059	3.69	2.1
96	CxHy aromatic	Air	µg	788	x	280	x	13.8	0.016	494
97	cyanides	Air	µg	9.08	x	8.72	x	0.348	0.00378	0.0152

98	dichloroethane	Air	µg	9.74	x	9.62	x	x	x	0.12
99	dichloromethane	Air	µg	30.4	x	0.475	x	x	x	29.9
100	dioxin (TEQ)	Air	ng	2.08	x	0.111	x	0.0194	1.94	0.00526
101	dust	Air	mg	386	x	x	x	x	385	0.379
102	dust (coarse)	Air	mg	1510	x	x	x	940	2.35	573
103	dust (coarse) process	Air	mg	444	x	441	x	x	x	2.98
104	dust (PM10) mobile	Air	mg	103	x	103	x	x	x	0.0656
105	dust (PM10) stationary	Air	g	1.18	x	1.18	x	x	x	0.00159
106	dust (SPM)	Air	g	6.16	x	x	1.22	x	4.84	0.0982
107	ethane	Air	mg	145	x	138	x	6.01	0.0646	0.0956
108	ethanol	Air	µg	1290	x	719	x	567	0.58	8.04
109	ethene	Air	mg	33.6	x	33.2	x	0.339	0.00237	0.0362
110	ethylbenzene	Air	mg	14.6	x	13.7	x	0.883	0.00421	0.012
111	ethyne	Air	µg	32.1	x	20.7	x	10.6	0.0865	0.75
112	F2	Air	µg	281	x	x	x	x	165	116
113	Fe	Air	mg	12.2	x	7.29	x	4.8	0.0147	0.0887
114	fluoranthene	Air	µg	47	x	x	x	x	10.5	36.5
115	formaldehyde	Air	mg	3.87	x	1.63	x	2.19	0.0184	0.0296
116	H2S	Air	mg	26.8	x	1.74	x	0.666	1.87	22.5
117	HALON-1301	Air	mg	2.34	x	2.33	x	0.00851	1.21E-05	0.000191

118	HCFC-21	Air	µg	96.4	x	53.7	x	x	x	42.8
119	HCFC-22	Air	ng	521	x	511	x	x	x	9.84
120	HCl	Air	mg	187	x	71	18	95.5	0.495	1.56
121	He	Air	mg	413	x	413	x	x	x	0.0289
122	heptane	Air	mg	133	x	133	x	0.609	0.000873	0.00951
123	hexachlorobenzene	Air	pg	412	x	406	x	x	x	6.58
124	hexane	Air	mg	278	x	277	x	1.28	0.00184	0.02
125	HF	Air	mg	19.9	x	8.93	x	10.1	0.0299	0.807
126	HFC-134a	Air	pg	5.58E-06	x	0.00000558	x	x	x	x
127	Hg	Air	µg	72.7	x	50.7	x	15.7	1.4	4.9
128	I	Air	µg	381	x	164	x	213	0.439	4.21
129	K	Air	mg	6.65	x	5.52	x	1.1	0.00409	0.0217
130	La	Air	µg	5.88	x	2.28	x	3.53	0.0123	0.062
131	metals	Air	mg	17.4	x	x	3.6	x	13.7	0.0136
132	methane	Air	g	25.5	x	24	x	1.33	0.119	0.0172
133	methanol	Air	mg	1.61	x	1.03	x	0.568	0.000584	0.00839
134	Mg	Air	mg	5.09	x	1.8	x	3.23	0.0109	0.0502
135	Mn	Air	mg	1.42	x	1.36	x	0.0605	0.000165	0.00178
136	Mo	Air	µg	210	x	189	x	20.1	0.0296	0.362
137	MTBE	Air	µg	3.14	x	3.13	x	x	x	0.00471

138	N2	Air	mg	3.87	x	3.78	x	x	x	0.0906
139	N2O	Air	mg	877	x	61.6	x	26.9	755	33.8
140	Na	Air	mg	12.2	x	10.6	x	1.53	0.00315	0.0247
141	naphthalene	Air	ng	356	x	x	x	x	355	0.887
142	Ni	Air	mg	8.64	x	7.99	x	0.646	0.00114	0.00906
143	NO2	Air	mg	46.4	x	x	x	x	43.9	2.56
144	non methane VOC	Air	g	45.2	x	44.9	x	0.281	0.000532	0.00444
145	NOx	Air	g	61.3	x	x	10.4	1.24	49.4	0.199
146	NOx (as NO2)	Air	g	32.8	20.2	12.5	x	x	x	0.0118
147	P	Air	µg	106	x	x	x	106	0.376	0.37
148	P-tot	Air	µg	243	x	241	x	x	x	1.52
149	PAH's	Air	µg	47.8	x	28.8	x	18.6	0.155	0.304
150	particulates (unspecified)	Air	g	21	21	x	x	x	x	x
151	Pb	Air	mg	1.57	x	1.24	x	0.151	0.175	0.00287
152	pentachlorobenzene	Air	ng	1.1	x	1.08	x	x	x	0.0176
153	pentachlorophenol	Air	pg	178	x	175	x	x	x	2.84
154	pentane	Air	mg	702	x	697	x	5.07	0.0287	0.0813
155	phenol	Air	µg	2.25	x	1.32	x	0.906	0.00654	0.0125
156	propane	Air	mg	558	x	553	x	4.43	0.0247	0.0708
157	propene	Air	mg	26.9	x	26.7	x	0.199	0.000481	0.00368

158	propionic acid	Air	µg	31.6	x	9.09	x	21.9	0.268	0.331
159	Pt	Air	ng	182	x	182	x	0.0128	6.31E-05	0.267
160	Sb	Air	µg	9.43	x	4.44	x	4.87	0.00802	0.111
161	Sc	Air	µg	2.12	x	0.763	x	1.33	0.00526	0.0212
162	Se	Air	µg	357	x	274	x	80.7	0.159	1.29
163	Si	Air	mg	17.9	x	17.5	x	x	x	0.376
164	silicates	Air	mg	23	x	x	x	22.9	0.0518	0.0768
165	Sn	Air	µg	4.78	x	1.64	x	3.08	0.0114	0.0453
166	SO2	Air	g	30	x	x	x	2.93	26.8	0.225
167	soot	Air	mg	10.9	x	x	x	x	10.9	0.0359
168	SOx	Air	g	6.71	x	x	6.48	x	0.232	0.00139
169	SOx (as SO2)	Air	g	36.3	20.8	15.5	x	x	x	0.0395
170	Sr	Air	µg	227	x	77.8	x	147	0.511	2.32
171	tetrachloromethane	Air	µg	7.34	x	2.34	x	x	x	4.99
172	Th	Air	µg	9.65	x	1.44	x	8.12	0.0295	0.0604
173	Ti	Air	µg	621	x	216	x	397	1.58	6.23
174	Tl	Air	ng	894	x	551	x	329	1.39	13.6
175	toluene	Air	mg	83.5	x	82.2	x	1.02	0.0607	0.173
176	trichloromethane	Air	ng	257	x	254	x	x	x	3.18
177	U	Air	µg	5.21	x	1.6	x	3.55	0.0133	0.048

178	unspecified emission	Air	mg	15.8	x	x	x	x	x	15.8
179	V	Air	mg	28.7	x	26.2	x	2.4	0.00377	0.0319
180	vinyl chloride	Air	µg	8.86	x	1.57	x	7.27	0.00399	0.0256
181	VOC	Air	mg	151	x	x	x	x	150	0.151
182	xylene	Air	mg	59.4	x	55.3	x	3.78	0.00925	0.222
183	Zn	Air	mg	2.06	x	1.75	x	0.221	0.0859	0.00567
184	Zr	Air	ng	630	x	426	x	199	2.16	2.53
185	1,1,1-trichloroethane	Water	ng	14.1	x	14.1	x	x	x	0.0632
186	acenaphthylene	Water	µg	30.7	x	30.1	x	x	x	0.578
187	Acid as H+	Water	µg	50.5	x	x	x	49.7	0.54	0.214
188	acids (unspecified)	Water	µg	116	x	115	x	x	x	0.589
189	Ag	Water	µg	171	x	169	x	1.12	0.00153	0.0183
190	Al	Water	mg	422	x	184	x	234	1.05	3.49
191	alkanes	Water	mg	36.5	x	36.2	x	0.237	0.000392	0.00355
192	alkenes	Water	mg	3.37	x	3.34	x	0.0215	3.56E-05	0.000327
193	AOX	Water	µg	863	x	856	x	6.18	0.00886	0.0978
194	As	Water	µg	1000	x	524	x	469	2.12	6.91
195	B	Water	mg	7.88	x	7.47	x	0.397	0.0015	0.00598
196	Ba	Water	mg	746	x	722	x	22.9	0.0901	0.339
197	baryte	Water	g	4.77	x	4.73	x	0.0421	0.000159	0.00061

198	Be	Water	ng	405	x	235	x	164	0.0543	5.21
199	benzene	Water	mg	36.5	x	36.3	x	0.237	0.000393	0.00357
200	BOD	Water	g	5.19	5.14	0.0344	0.018	0.000186	0.000214	7.31E-06
201	calcium compounds	Water	mg	263	x	x	x	261	0.975	0.919
202	calcium ions	Water	g	10.8	x	10.8	x	x	x	0.00346
203	Cd	Water	µg	303	x	288	x	14.9	0.193	0.281
204	chlorinated solvents (unspec.)	Water	µg	3.18	x	3.17	x	x	x	0.00244
205	chlorobenzenes	Water	pg	59.8	x	57.4	x	2.14	0.0121	0.266
206	Cl-	Water	g	152	x	150	0.036	2.45	0.0221	0.0375
207	Co	Water	µg	791	x	322	x	460	2.1	6.78
208	COD	Water	g	20.2	19.3	0.856	0.036	0.0025	0.0018	6.77E-05
209	Cr	Water	mg	2.36	x	x	x	2.34	0.0125	0.00845
210	Cr (III)	Water	mg	4.12	x	4.1	x	x	x	0.0261
211	Cr (VI)	Water	ng	856	x	243	x	602	2.52	7.66
212	crude oil	Water	mg	48.6	x	x	x	0.19	48	0.398
213	Cs	Water	µg	281	x	279	x	1.78	0.00253	0.0272
214	Cu	Water	mg	2.49	x	1.3	x	1.16	0.00836	0.019
215	CxHy	Water	mg	144	x	0.084	72	43.4	28.3	0.475
216	CxHy aromatic	Water	mg	168	x	166	x	1.12	0.00205	0.0167

217	CxHy chloro	Water	µg	4.33	x	x	x	4.32	0.00303	0.00416
218	cyanide	Water	µg	1010	x	985	x	25.4	0.146	0.341
219	di(2-ethylhexyl)phthalate	Water	pg	548	x	542	x	x	x	5.95
220	dibutyl p-phthalate	Water	ng	3.1	x	3.05	x	x	x	0.0585
221	dichloroethane	Water	µg	11.4	x	4.95	x	6.36	0.00349	0.0671
222	dichloromethane	Water	mg	2.56	x	2.56	x	0.00217	7.65E-06	0.000217
223	dimethyl p-phthalate	Water	ng	19.6	x	19.2	x	x	x	0.369
224	dissolved organics	Water	µg	434	x	x	x	427	5.18	1.91
225	dissolved substances	Water	mg	173	x	67.3	x	98.8	0.446	6.53
226	DOC	Water	µg	199	x	194	x	x	x	4.87
227	ethyl benzene	Water	mg	6.75	x	6.7	x	0.0428	6.08E-05	0.000643
228	F2	Water	mg	9.13	x	x	x	x	x	9.13
229	fats/oils	Water	g	5.43	x	5.43	x	x	x	0.000394
230	fatty acids as C	Water	g	1.41	x	1.41	x	x	x	0.000107
231	Fe	Water	mg	699	x	318	x	375	0.331	5.12
232	fluoride ions	Water	mg	40.7	x	40	x	0.719	0.00264	0.0144
233	formaldehyde	Water	ng	61.6	x	46	x	15.1	0.109	0.391
234	glutaraldehyde	Water	µg	590	x	585	x	5.2	0.0196	0.0752
235	H2	Water	mg	150	x	x	108	x	42.4	0.0421
236	H2S	Water	µg	49.2	x	39	x	9.95	0.108	0.14

237	hexachloroethane	Water	pg	111	x	110	x	x	x	1.38
238	Hg	Water	µg	5.39	x	4.19	x	0.425	0.119	0.655
239	HOCL	Water	mg	3.18	x	1.01	x	2.14	0.00415	0.0285
240	I	Water	mg	28.1	x	27.9	x	0.178	0.000253	0.00268
241	inorganic general	Water	mg	4.64	x	x	x	x	4.64	0.00457
242	K	Water	g	1.46	x	1.38	x	0.0777	0.000327	0.00115
243	Kjeldahl-N	Water	mg	5.27	x	x	x	x	5.26	0.0129
244	metallic ions	Water	mg	25.1	x	x	18	x	7.07	0.00702
245	Mg	Water	mg	698	x	496	x	198	0.885	2.89
246	Mn	Water	mg	24.8	x	19.1	x	5.59	0.0218	0.0822
247	Mo	Water	µg	1510	x	729	x	763	2.8	12.2
248	MTBE	Water	ng	257	x	256	x	x	x	0.391
249	N-tot	Water	mg	493	x	484	3.6	5.21	0.0499	0.103
250	N organically bound	Water	mg	78.1	x	78.1	x	x	x	0.0026
251	Na	Water	g	90.4	x	89.6	x	0.809	0.00175	0.0127
252	NH3 (as N)	Water	mg	365	x	365	x	x	x	0.0451
253	Ni	Water	mg	2.79	x	1.59	x	1.18	0.00531	0.0173
254	nitrate	Water	mg	162	x	156	x	6.58	0.0234	0.0889
255	nitrite	Water	µg	296	x	291	x	x	x	5.19
256	OCl-	Water	mg	1.03	x	1.01	x	x	x	0.0225

257	oil	Water	µg	8.7	x	x	x	x	8.68	0.0213
258	P-compounds	Water	µg	155	x	155	x	x	x	0.0176
259	P-tot	Water	ng	433	x	x	x	431	0.28	1.37
260	PAH's	Water	mg	3.65	x	3.63	x	0.0232	3.37E-05	0.000976
261	Pb	Water	mg	3.19	x	1.74	x	1.41	0.00933	0.0267
262	phenol	Water	µg	276	x	x	x	275	0.466	0.9
263	phenols	Water	mg	33.4	x	33.4	x	x	x	0.00298
264	phosphate	Water	mg	26.7	x	12.6	x	13.8	0.0629	0.204
265	Ru	Water	mg	2.79	x	2.79	x	x	x	0.000213
266	S	Water	µg	55.5	x	x	x	55.2	0.0779	0.179
267	salt	Water	mg	672	x	x	x	670	0.072	2.08
268	salts	Water	mg	335	x	328	x	x	x	6.84
269	Sb	Water	µg	7.18	x	3.36	x	3.75	0.0154	0.0537
270	Se	Water	mg	2.2	x	1	x	1.17	0.00525	0.0175
271	Si	Water	mg	2.86	x	2.86	x	0.001	3.79E-06	0.00112
272	Sn	Water	µg	4.46	x	1.22	x	3.19	0.0129	0.0369
273	SO3	Water	µg	259	x	152	x	104	0.43	2.74
274	Sr	Water	g	1.7	x	1.69	x	0.0135	2.78E-05	0.000203
275	sulphate	Water	g	6.15	x	6.12	x	x	x	0.0263
276	sulphates	Water	g	2.61	x	x	x	2.6	0.00508	0.00862

277	sulphide	Water	mg	6.91	x			6.91	x	x		x	0.000697
278	suspended solids	Water	g	5.34		5.34	x		x	x		x	x
279	suspended substances	Water	mg	230	x		x		x		167	0.514	62
280	tetrachloroethene	Water	ng	13.2	x			13.1	x	x		x	0.163
281	tetrachloromethane	Water	ng	20.2	x			19.9	x	x		x	0.25
282	Ti	Water	mg	23.8	x			9.67	x		13.8	0.0628	0.204
283	TOC	Water	g	4.35	x			4.31	x		0.0425	0.000369	0.000789
284	toluene	Water	mg	30.3	x			30.1	x		0.215	0.000356	0.00303
285	tributyltin	Water	µg	248	x			241	x		7.32	0.0237	0.0914
286	trichloroethene	Water	µg	1.92	x			0.824	x		1.09	0.000598	0.0112
287	trichloromethane	Water	µg	3.06	x			3.02	x	x		x	0.0378
288	triethylene glycol	Water	µg	199	x			194	x	x		x	4.87
289	undissolved substances	Water	g	14.7	x			14.7	x	x		x	0.00176
290	V	Water	mg	2.31	x			1.03	x		1.25	0.0053	0.0183
291	vinyl chloride	Water	ng	3.75	x			3.7	x	x		x	0.0464
292	VOC as C	Water	mg	97.5	x			97.5	x	x		x	0.00735
293	W	Water	µg	8.29	x			5.63	x		2.51	0.0105	0.136
294	waste water (vol)	Water	cm3	2.92	x		x		x	x		x	2.92
295	xylene	Water	mg	26.4	x			26.2	x		0.171	0.000284	0.00258
296	Zn	Water	mg	11.2	x			8.72	x		2.37	0.032	0.0401

297	dust - not specified	Solid	mg	5.87	x	x	x	x	5.85	0.0143
298	final waste (inert)	Solid	g	70.4	x	x	7.92	61.9	0.344	0.218
299	high active nuclear waste	Solid	mm3	2.2	x	x	x	2.19	0.000726	0.00686
300	inorganic general	Solid	mg	281	x	x	x	x	281	0.366
301	low,med. act. nucl. waste	Solid	mm3	142	x	x	x	141	0.164	0.42
302	mineral waste	Solid	g	1.92	x	x	x	x	1.92	0.00191
303	mineral waste (mining)	Solid	mg	1.33	x	x	x	x	x	1.33
304	oil	Solid	mg	20.6	x	x	x	x	20.6	0.0505
305	produc. waste (not inert)	Solid	g	87	x	x	x	17.9	21.8	47.2
306	slag	Solid	g	9.11	x	x	9	x	0.11	0.000132
307	soot	Solid	ng	474	x	x	x	x	474	0.467
308	toxic waste	Solid	kg	33	33	x	x	x	x	x
309	Al (ind.)	Soil	mg	369	x	369	x	x	x	0.0302
310	As (ind.)	Soil	µg	148	x	148	x	x	x	0.012
311	C (ind.)	Soil	g	1.14	x	1.14	x	x	x	9.29E-05
312	Ca (ind.)	Soil	g	1.48	x	1.48	x	x	x	0.00012
313	Cd (ind.)	Soil	µg	5.53	x	5.53	x	x	x	0.00053
314	Co (ind.)	Soil	µg	7.65	x	7.65	x	x	x	0.00057
315	Cr (ind.)	Soil	mg	1.84	x	1.84	x	x	x	0.000151
316	Cu (ind.)	Soil	µg	38.3	x	38.3	x	x	x	0.00285

317	Fe (ind.)	Soil	mg	739	x	739	x	x	x	0.0604
318	Hg (ind.)	Soil	µg	1.05	x	1.05	x	x	x	8.43E-05
319	Mn (ind.)	Soil	mg	14.8	x	14.8	x	x	x	0.0012
320	N	Soil	µg	296	x	296	x	x	x	0.0269
321	Ni (ind.)	Soil	µg	57.4	x	57.4	x	x	x	0.00428
322	oil (ind.)	Soil	mg	247	x	247	x	x	x	0.0186
323	oil biodegradable	Soil	µg	20.6	x	20.3	x	x	x	0.309
324	Pb (ind.)	Soil	µg	174	x	174	x	x	x	0.013
325	phosphor (ind.)	Soil	mg	18.8	x	18.8	x	x	x	0.00156
326	S (ind.)	Soil	mg	222	x	222	x	x	x	0.0181
327	Zn (ind.)	Soil	mg	5.9	x	5.9	x	x	x	0.000481
328	Ag110m to air	Non mat.	µBq	2.67	x	2.61	x	x	x	0.0546
329	Ag110m to water	Non mat.	mBq	18.2	x	17.9	x	x	x	0.372
330	alpha radiation (unspecified) to water	Non mat.	µBq	2.13	x	2.09	x	x	x	0.0441
331	Am241 to air	Non mat.	µBq	54.7	x	53.7	x	x	x	1.02
332	Am241 to water	Non mat.	mBq	7.15	x	7.02	x	x	x	0.134
333	Ar41 to air	Non mat.	Bq	5.75	x	5.63	x	x	x	0.118
334	Ba140 to air	Non mat.	µBq	15.7	x	15.5	x	x	x	0.213
335	Ba140 to water	Non mat.	µBq	123	x	122	x	x	x	0.666

336	beta radiation (unspecified) to air	Non mat.	µBq	1.02	x		1.02	x	x	x		0.00683
337	C14 to air	Non mat.	Bq	4.6	x		4.52	x	x	x		0.0819
338	C14 to water	Non mat.	mBq	363	x		356	x	x	x		6.76
339	Cd109 to water	Non mat.	nBq	711	x		707	x	x	x		3.85
340	Ce141 to air	Non mat.	nBq	253	x		248	x	x	x		5.06
341	Ce141 to water	Non mat.	µBq	18.4	x		18.3	x	x	x		0.1
342	Ce144 to air	Non mat.	µBq	579	x		569	x	x	x		10.8
343	Ce144 to water	Non mat.	mBq	164	x		161	x	x	x		3.06
344	Cm (alpha) to air	Non mat.	µBq	86.7	x		85	x	x	x		1.61
345	Cm (alpha) to water	Non mat.	mBq	9.48	x		9.3	x	x	x		0.177
346	Cm242 to air	Non mat.	nBq	0.259	x		0.254	x	x	x		0.00535
347	Cm244 to air	Non mat.	nBq	2.35	x		2.3	x	x	x		0.0487
348	Co57 to air	Non mat.	nBq	4.52	x		4.43	x	x	x		0.0937
349	Co57 to water	Non mat.	µBq	126	x		125	x	x	x		0.684
350	Co58 to air	Non mat.	µBq	74.9	x		73.3	x	x	x		1.55
351	Co58 to water	Non mat.	mBq	61.2	x		60.6	x	x	x		0.58
352	Co60 to air	Non mat.	µBq	119	x		117	x	x	x		2.31
353	Co60 to water	Non mat.	Bq	1.64	x		1.61	x	x	x		0.0296
354	Conv. to continuous urban land	Non mat.	mm2	3.34	x	x		x	x		3.33	0.00778

355	Conv. to industrial area	Non mat.	mm2	140	x	x	74.2	x	65.2	0.66
356	Cr51 to air	Non mat.	µBq	10	x	9.83	x	x	x	0.191
357	Cr51 to water	Non mat.	mBq	2.7	x	2.69	x	x	x	0.0146
358	Cs134 to air	Non mat.	mBq	2.06	x	2.03	x	x	x	0.0386
359	Cs134 to water	Non mat.	mBq	367	x	361	x	x	x	6.84
360	Cs136 to water	Non mat.	nBq	657	x	654	x	x	x	3.58
361	Cs137 to air	Non mat.	mBq	3.99	x	3.91	x	x	x	0.0744
362	Cs137 to water	Non mat.	Bq	3.39	x	3.32	x	x	x	0.063
363	Fe59 to air	Non mat.	nBq	103	x	100	x	x	x	2.12
364	Fe59 to water	Non mat.	µBq	2.18	x	2.16	x	x	x	0.0118
365	Fission and activation products (RA) to water	Non mat.	mBq	19.4	x	19	x	x	x	0.401
366	H3 to air	Non mat.	Bq	42.4	x	41.5	x	x	x	0.843
367	H3 to water	Non mat.	Bq	10700	x	10500	x	x	x	200
368	heat losses to air	Non mat.	MJ	8.11	x	x	x	8.07	0.0195	0.0271
369	heat losses to soil	Non mat.	kJ	345	x	x	x	345	0.00765	0.0246
370	heat losses to water	Non mat.	kJ	163	x	x	x	161	1.5	0.669
371	I129 to air	Non mat.	mBq	15.5	x	15.3	x	x	x	0.29
372	I129 to water	Non mat.	Bq	1.03	x	1.02	x	x	x	0.0193
373	I131 to air	Non mat.	mBq	3.16	x	3.13	x	x	x	0.0322

374	I131 to water	Non mat.	µBq	996	x	983	x	x		x	12.8
375	I133 to air	Non mat.	µBq	890	x	872	x	x		x	18
376	I133 to water	Non mat.	µBq	561	x	558	x	x		x	3.05
377	I135 to air	Non mat.	mBq	1.31	x	1.29	x	x		x	0.027
378	K40 to air	Non mat.	mBq	7.5	x	7.33	x	x		x	0.168
379	K40 to water	Non mat.	mBq	23.6	x	23.1	x	x		x	0.486
380	Kr85 to air	Non mat.	kBq	268	x	263	x	x		x	4.99
381	Kr85m to air	Non mat.	mBq	793	x	787	x	x		x	5.9
382	Kr87 to air	Non mat.	mBq	278	x	276	x	x		x	2.64
383	Kr88 to air	Non mat.	Bq	11.6	x	11.4	x	x		x	0.235
384	Kr89 to air	Non mat.	mBq	250	x	248	x	x		x	1.85
385	La140 to air	Non mat.	µBq	7.42	x	7.28	x	x		x	0.135
386	La140 to water	Non mat.	µBq	25.5	x	25.4	x	x		x	0.138
387	land use (sea floor) II-III	Non mat.	m2a	0.38	x	0.379	x	x		x	0.000037
388	land use (sea floor) II-IV	Non mat.	cm2a	392	x	392	x	x		x	0.0382
389	land use II-III	Non mat.	cm2a	733	x	314	x		412	x	6.2
390	land use II-IV	Non mat.	cm2a	104	x	94.1	x		9.68	x	0.118
391	land use III-IV	Non mat.	cm2a	80	x	74.9	x		4.9	x	0.107
392	land use IV-IV	Non mat.	mm2a	108	x	106	x		1.86	x	0.136
393	Mn54 to air	Non mat.	µBq	2.76	x	2.71	x	x		x	0.0554

394	Mn54 to water	Non mat.	mBq	245	x	241	x	x	x	4.54
395	Mo99 to water	Non mat.	µBq	8.6	x	8.56	x	x	x	0.0466
396	Na24 to water	Non mat.	mBq	3.79	x	3.77	x	x	x	0.0206
397	Nb95 to air	Non mat.	nBq	496	x	486	x	x	x	9.76
398	Nb95 to water	Non mat.	µBq	70	x	69.6	x	x	x	0.379
399	Np237 to air	Non mat.	nBq	2.85	x	2.8	x	x	x	0.0532
400	Np237 to water	Non mat.	µBq	458	x	450	x	x	x	8.5
401	Occup. as contin. urban land	Non mat.	mm2a	236	x	x	x	x	236	0.869
402	Occup. as convent. arable land	Non mat.	mm2a	35.3	x	x	x	x	31.7	3.63
403	Occup. as forest land	Non mat.	mm2a	0.00407	x	x	x	x	0.00365	0.000419
404	Occup. as industrial area	Non mat.	cm2a	222	x	x	201	x	21.5	0.424
405	Occup. as rail/road area	Non mat.	mm2a	115	x	x	x	x	114	0.258
406	Pa234m to air	Non mat.	mBq	1.73	x	1.7	x	x	x	0.0323
407	Pa234m to water	Non mat.	mBq	32	x	31.4	x	x	x	0.597
408	Pb210 to air	Non mat.	mBq	45.5	x	44.6	x	x	x	0.95
409	Pb210 to water	Non mat.	mBq	18.7	x	18.3	x	x	x	0.387
410	Pm147 to air	Non mat.	mBq	1.47	x	1.44	x	x	x	0.0274
411	Po210 to air	Non mat.	mBq	67.3	x	65.9	x	x	x	1.44

412	Po210 to water	Non mat.	mBq	18.7	x	18.3	x	x	x	0.387
413	Pu alpha to air	Non mat.	µBq	173	x	170	x	x	x	3.22
414	Pu alpha to water	Non mat.	mBq	28.5	x	28	x	x	x	0.532
415	Pu238 to air	Non mat.	nBq	5.86	x	5.74	x	x	x	0.121
416	Pu241 Beta to air	Non mat.	mBq	4.75	x	4.66	x	x	x	0.089
417	Pu241 beta to water	Non mat.	mBq	709	x	696	x	x	x	13.2
418	Ra224 to water	Non mat.	Bq	14	x	14	x	x	x	0.00105
419	Ra226 to air	Non mat.	mBq	60.9	x	59.7	x	x	x	1.16
420	Ra226 to water	Non mat.	Bq	160	x	157	x	x	x	2.47
421	Ra228 to air	Non mat.	mBq	3.69	x	3.6	x	x	x	0.0827
422	Ra228 to water	Non mat.	Bq	27.9	x	27.9	x	x	x	0.0021
423	radio active noble gases to air	Non mat.	Bq	1.3	x	1.29	x	x	x	0.00705
424	radioactive substance to air	Non mat.	Bq	1130000	x	x	x	1120000	373	3510
425	radioactive substance to water	Non mat.	Bq	10400	x	x	x	10400	3.43	32.4
426	radionuclides (mixed) to water	Non mat.	µBq	17.4	x	17.1	x	x	x	0.289
427	Rn220 to air	Non mat.	mBq	344	x	337	x	x	x	7.31
428	Rn222 (long term) to air	Non mat.	kBq	384	x	377	x	x	x	7.17

429	Rn222 to air	Non mat.	Bq	4210	x	4130	x	x	x	78
430	Ru103 to air	Non mat.	nBq	34.7	x	34.2	x	x	x	0.553
431	Ru103 to water	Non mat.	µBq	41.2	x	41	x	x	x	0.224
432	Ru106 to air	Non mat.	mBq	17.3	x	17	x	x	x	0.322
433	Ru106 to water	Non mat.	Bq	1.73	x	1.7	x	x	x	0.0322
434	Sb122 to water	Non mat.	µBq	123	x	122	x	x	x	0.666
435	Sb124 to air	Non mat.	nBq	759	x	744	x	x	x	15
436	Sb124 to water	Non mat.	mBq	5.94	x	5.85	x	x	x	0.0961
437	Sb125 to air	Non mat.	nBq	216	x	214	x	x	x	1.9
438	Sb125 to water	Non mat.	µBq	1000	x	999	x	x	x	5.43
439	Sr89 to air	Non mat.	µBq	4.86	x	4.77	x	x	x	0.0969
440	Sr89 to water	Non mat.	µBq	278	x	276	x	x	x	1.5
441	Sr90 to air	Non mat.	mBq	2.85	x	2.8	x	x	x	0.0532
442	Sr90 to water	Non mat.	mBq	346	x	339	x	x	x	6.44
443	Tc99 to air	Non mat.	nBq	121	x	119	x	x	x	2.25
444	Tc99 to water	Non mat.	mBq	181	x	178	x	x	x	3.39
445	Tc99m to water	Non mat.	µBq	57.7	x	57.4	x	x	x	0.314
446	Te123m to air	Non mat.	µBq	11.8	x	11.5	x	x	x	0.243
447	Te123m to water	Non mat.	µBq	5.19	x	5.16	x	x	x	0.0281
448	Te132 to water	Non mat.	µBq	2.13	x	2.12	x	x	x	0.0115

449	Th228 to air	Non mat.	mBq	3.12	x	3.05	x	x	x	0.0698
450	Th228 to water	Non mat.	Bq	55.8	x	55.8	x	x	x	0.0042
451	Th230 to air	Non mat.	mBq	19.2	x	18.8	x	x	x	0.359
452	Th230 to water	Non mat.	Bq	4.99	x	4.9	x	x	x	0.0937
453	Th232 to air	Non mat.	mBq	1.98	x	1.93	x	x	x	0.0443
454	Th232 to water	Non mat.	mBq	4.39	x	4.3	x	x	x	0.0906
455	Th234 to air	Non mat.	mBq	1.73	x	1.7	x	x	x	0.0323
456	Th234 to water	Non mat.	mBq	32.2	x	31.6	x	x	x	0.602
457	U alpha to air	Non mat.	mBq	61.7	x	60.6	x	x	x	1.16
458	U alpha to water	Non mat.	Bq	2.09	x	2.05	x	x	x	0.039
459	U234 to air	Non mat.	mBq	20.7	x	20.3	x	x	x	0.387
460	U234 to water	Non mat.	mBq	42.7	x	41.9	x	x	x	0.795
461	U235 to air	Non mat.	µBq	1000	x	983	x	x	x	18.7
462	U235 to water	Non mat.	mBq	63.4	x	62.2	x	x	x	1.19
463	U238 to air	Non mat.	mBq	26	x	25.5	x	x	x	0.508
464	U238 to water	Non mat.	mBq	107	x	105	x	x	x	2.02
465	waste heat to air	Non mat.	MJ	49.6	x	49.5	x	x	x	0.131
466	waste heat to soil	Non mat.	kJ	22.1	x	21.7	x	x	x	0.358
467	waste heat to water	Non mat.	MJ	6.07	x	6.07	x	x	x	0.00141
468	Xe131m to air	Non mat.	Bq	1.28	x	1.27	x	x	x	0.0122

469	Xe133 to air	Non mat.	Bq	189	x	185	x	x	x	3.59
470	Xe133m to air	Non mat.	mBq	87.4	x	85.6	x	x	x	1.8
471	Xe135 to air	Non mat.	Bq	40	x	39.4	x	x	x	0.612
472	Xe135m to air	Non mat.	Bq	7.61	x	7.55	x	x	x	0.0603
473	Xe137 to air	Non mat.	mBq	168	x	167	x	x	x	1.5
474	Xe138 to air	Non mat.	Bq	2.1	x	2.08	x	x	x	0.0163
475	Y90 to water	Non mat.	µBq	14.2	x	14.1	x	x	x	0.077
476	Zn65 to air	Non mat.	µBq	14.1	x	13.9	x	x	x	0.238
477	Zn65 to water	Non mat.	mBq	8.02	x	7.97	x	x	x	0.0433
478	Zr95 to air	Non mat.	nBq	171	x	168	x	x	x	3.54
479	Zr95 to water	Non mat.	mBq	14.7	x	14.4	x	x	x	0.274

APPENDIX G

Raw data

Emission/resource use per month		
Air emission	TSP (mg/m3)	99.33
	CO (ppm)	2
	NOx (ppm)	78
	SOx (ppm)	80
Wastewater discharge	SS (mg/L)	3-23
	BOD (mg/L)	6-9
	COD (mg/L)	23-71
	FOG (mg/L)	Not detectable
Toxic waste	Toxic waste (ton)	95
Water use	Water (cubic meter)	650
Electricity use	Electricity (kWh)	85800
Fuel for boiler	Heavy oil (litre)	17000
Fuel for transportation	Diesel (litre)	7000

The inventory analysis is done by calculation of the above impact on the basis of functional unit by using conversion factor and density. Thus the input and output to SimaPro 5.1 are shown in table 15.