UNIT 3 LIFE CYCLE ASSESSMENT

Structure

3.0 INTRODUCTION

The Life Cycle Assessment (LCA) is an environmental management technique to assess the potential adverse effects and impacts of any product or procedure or service. It assemble an inventory for a product with regard to energy, materials inputs in the process and environmental discharges.LCA examines the all possible impacts related to the identified discharges while compilation. It elucidates the outcome to assist in making a decision about the environmental and human health.

LCA can be done on many products and processes along with computers, jet engines, trash disposal etc. For any conventional product, LCA takes into consideration about the supply of starting raw materials, intermediate compounds formed during manufacturing and after manufacturing the desired product, its packaging, transportation of raw materials, intermediates, during the product usage and till dumping the product after use. This sequence of events is known as "Cradle to Grave" assessment. If any product that generates no waste which means that all materials during and after manufacturing are either recyclable or can be converted into biodegradable nutrients. This type of assessment is known as "Cradle to Cradle".

3.1 OBJECTIVES

After studying this Unit, you should be able to:

- define Life Cycle Assessment (LCA);

- explain the concept of LCA as an environmental management tool;
- identify possible environmental impacts of LCA of a product;
- discuss the basic steps involved in LCA process; and
- explain the measurement techniques of LCA.

3.2 LIFE CYCLE ASSESSMENT(LCA)

Definition: According to International Organization for Standardization (ISO), the ISO 14040 and ISO 14044 standards for Life cycle assessment, it is defined as "the compiling and evaluation of the inputs and outputs and the potential environmental impacts of a product system during a product's lifetime". LCA is also known as life cycle analysis or Ecobalance.

LCA can also be defined as a process to examine the stress on the environmental which are related with a product system. The product development procedure involves the usage of energy and materials. The LCA identify quantitatively the amount of energy and materials used in the product development, wastes released, and its adverse impacts on the environment. It includes the whole life cycle of the product generation process, from extracting and processing raw materials to use and disposal of the product.

Life cycle management (LCM) is one of the new concepts in LCA, which is an integrated path to diminishing environmental concerns throughout the period of existence of a product, system or service. It examine the product generation process qualitatively and quantitatively to evaluate the environmental impacts. The LCA uses modeling technique, which is a complex technical system that provides a flow sheet or process tree from the development, transport and use to dispose of a product.

3.2.1 Stages in LCA

The LCA consists of four steps.

Step 1: **The goal and scope** aims at serving the end system assessment. The goal states the proposed application that includes various reasons for perform the study and the proposed audience, whom the results of the study are expected to be communicated. Where as the scope establish the borders of the assessment. It makes sure the comprehensiveness and the available data of the study are suitable and sufficient to address the defined goal.

Step 2- Inventory analysis describes about material and energy flows with in the product system and its interaction with natural environment, raw material consumption, and emissions. It includes-data collection, defining system boundaries, calculation of energy flow and materials used, validation of collected data, relating data to the specific system and finally allocation of the impacts to the system.

Inventory analysis procedure comprises of data collection and calculation procedures to measure suitable inputs and outputs of a product system. The inputs and outputs may encompass the utilization of resources and releases in to atmosphere, water and soil related to the system. Explanation may be drawn from these data, on the basis of goals and scope of the LCA. This data also establish the input to the life cycle impact assessment. The operative LCA process of 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. Often, issues may be found that require revisions to the defined goal or scope of the study.

Step 3- Impact Assessment can be done on the basis of the details available from inventory analysis. The results from different indicators under all impact categories are described in this step. Impact assessment consists of defining categories, classification; characterization and valuation or weighing. The importance of every impact category is assessed by normalization and eventually also by weighting by ISO.

Step 4- Interpretation of a life cycle consists of identification of potential environmental issues, critical review, evaluation methods and conclusions & recommendations. According to ISO, "Life Cycle Interpretation Assessment Interpretation is a systematic procedure to identify, qualify, check, and evaluate information from the of the inventory analysis and/or impact assessment of a system, and present them in order to meet the requirements of the application as explained 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, like inventory analysis and the impact assessment, in a form which is both comprehensible and useful to the decision maker".

Check Your Progress 1

1. Explain briefly about the following.

   a. LCA b. Goal and Scope c. Inventory analysis

3.2.2 Triple Bottom-line Approach

The TBL concept was introduced in 1994 and came into practice in 1997 by John Elkington. Triple bottom line is also known as TBL or 3BL,which is an economical framework with three dimensions- social, environmental (or ecological) and financial. Integration of social, environmental (ecological) and economic dimensions in to LCA is to signifies the benefits of input and output modeling of a product on quantifying sustainable effects. ecological) and financial. Many organizations have adopted the

In general and broader perspective TBL framework is used to evaluate the performance in a business to create a greater value. In conventional business accounting, the "bottom line" applied to either the "profit" or "loss", on a statement of revenue and expenses. From the past 50yrs environmentalists and "social justice" advocates, define bottom line by introducing full cost accounting. If we consider a case of an industry that shows a fiscal profit, but their asbestos mine causes thousands of deaths from asbestosis disease, where as copper mine pollutes a water body, and the government turn out to be spending taxpayers' money on health care and river clean-up, a full societal cost benefit analysis will not be possible to perform. This situation cause's a basis to add two more "bottom lines"- social and environmental (ecological) concerns to have TBL. In 2007, United Nations ratified TBL standard for urban and community accounting and became an assertive approach in full cost accounting to public and private sectors. The three facets of TBL are "people, planet, and profit". It is a coordinated effort to incorporate economic, environmental and social considerations into an industrial evaluation and decision making processes. TBL is a tool for LCA, to evaluate the positive and negative effects of industrial or business activities on the economic line, social equity line and the environment.

Economic Line

The economic line of TBL framework refers to the impact of the industrial business practices on the growth, efficiency and optimum use of resources. The economic dimension is a subsystem of sustainable development where it is in agreement from a resource transition to an economy that relies on natural resources and safeguard ecosystem capital from exhaustion, and the economic value provided by the organization to the surrounding system in a way that prospers it and promotes for its capability in order to support future generations.

The Social line

The Social line of TBL accounts for regulating useful and equitable business practices to the labor, human capital, and the society. The main focus is that these practices extend value to the society and "refund" to the community by considering equity, empowerment, social cohesion and cultural identity. These practices help in providing equitable wages and health care coverage. The social performance of the business focuses mainly on the interaction between the society and the organization and addresses issues related to community involvement, employee relations, and fair wages.

Environmental Line

The environmental line of TBL accounts for implementing practices that do not compromise the environmental resources for future generations. According to Bruntland Report 1987 Sustainable development is "considered the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs". This concept is developed in the context of conflicts between environment and developmental concerns. It discourse the use of energy recourses efficiently, safeguard vital life-support ecosystems and reducing emission of greenhouse gases. The integrative theme of environmental sustainability focused on ecosystem capital where natural and controlled ecosystems which provide essential goods and services to human pursuit.

Advantages of Triple Bottom Line

TBL is a socioecological agreement between the community and businesses.

- It provides increased transparency to mitigate concerns of stakeholders on hidden information.
- TBL reporting demonstrates to stakeholders that the business is taking accountability to a higher level.
- It maintains and raises expectations of companies and improves "global clout"
- It provides evidences to the consumers about diminishing natural resources and made them aware of the impact businesses on the world.
- It provides the knowledge of the company and expands their relationships with other stakeholders in the company.

- It builds a sustainable environment on how the business world can lend a helping hand in protecting the natural resources that are quickly evaporating.
- By uniting the business employees toward a common set of goals, especially ones that have a broader impact than just efficiency and profit, could outweigh the risks of additional public scrutiny and substantial policy adjustment.

3.2.3 Design for Environment (DfE)

Design for the environment is a term applied for many industrial methods for incorporating environmental factors into the design process of any product that can use to reduce the adverse environmental impact of designs throughout their life cycles. The concept of DfE has been developed for industrial designing process that should be ecologically viable, socially desirable, and economically feasible, comprehensive and radical.

The principles of DfE may vary from industry to industry but World Industry Council for the Environment (WICE, 1994) developed common themes for all industries. The objectives of DfE are to optimize the environmental efficiency of a product throughout its life cycle by integrating the concepts of preventing pollution in the manufacturing process and show concerns about energy efficiency of products. Conceptually LCA and DfE address the same problem areas.

Any product development, 70-80% of costs, manufacture and use are decided in early stages of designing process. It is also clear that the decisions that affect future environmental impacts are made at the design stage. Designers of the industry necessarily think for functionality and performance of a proposed product, its manufacturability, logistics, reliability, safety, cost, market feasibility.

There are many sets of principles are being developed for manufacturing products by specific regions and industries. For example, the Restriction of Hazardous Substances (ROHS) and Waste Electrical and Electronic Equipment (WEEE) directives are two sets of rules widely accepted for prohibited materials in electronics. The European Eco-Label provides a few product specific guidelines and requires a full life-cycle assessment. The McDonough, Braungart and Anastas et al provide abstract principles like “it is better to prevent waste than to treat or clean up waste after it is formed” for the product design. All DfE principles and procedures should follow the following criteria to achieve environmental sustainability.

1. **Designer-oriented**: The principles must be within the scope of a product designer. The decision should be made for overall layout, form and types of components, selection of materials, and communication with the user or manufacturer.

2. **Actionable:** These criteria must propose an avenue for the design improvement. It should ensure that technical life should be met by aesthetic life and plan for efficiency refinement.

3. **General:** The principle should be applicable to a large range of products

4. **Positive Imperative:** It helps to projecting designer focus on positive possibilities, including redesign of process. The principle should focus on developing the best possible solution

Do You Know?

Levels of DfEz

Design for Manufacturability **(DfM):** To enable pollution prevention during manufacturing For less material For fewer different materials For safer materials and processes ,Design for Energy Efficiency **(DfEE)**: For reduced energy demand during use,flexible energy use, for use with renewable energy, for Zero Emission, Design for Carbon Neutrality, Design for Zero Toxics **(DfZT),** Design for Dematerialization (**DfD**), Design for Packaging (**DfP**): Minimize packaging and Rethink selling method, Design for Logistics (**DfL**): Use of local materials – Less Transportation Arrange outsourcing to minimize transportation, Design for Longevity (**DfL**): Design for Modularity Design for Serviceability Delay replacement, Design for Modularity (**DfMo**): To ease upgrading To ease serviceability and, later, disassembly longer life, Design for Serviceability (**DfS**):For ease of repairs, For recapture of used/broken parts, Design for use of recycled materials **(DfRM)**, Design for reduced material variety (**DfRMV**),Design for healthy materials (**DfHM**) Design for Disassembly **(DfD**)To promote re-use of components For quicker and cheaper disassembly For more complete disassembly For dismantling by simple tools ,Design for Recycling (**DfR**) For greater materials recovery Use of materials that can be locally recycled For easier materials identification For safer disposal of non-recyclables, Design for Economic Recycling (**DfER**)To promote recycling,Design for Compostability (**DfC**),Design for Energy Recovery (**DfER**) For safe incineration of residues For composting of residues,Design for Compliance (**DfC**) To meet regulations more easily To prepare for future regulations

3.2.4 Role of LCA

The following are some of the roles of LCA.

i. Supporting decision-making, highlighting efficiency opportunities along a value chain.

ii. Understanding the industrial systems involved in manufacturing products and delivering services to end-users.

iii. Optimizing industrial systems by identifying operations within a market chain that have the greatest opportunity for improvement, often known as “hot spots.”

iv. Ensuring that changes made to improve one part of an industrial system do not “shift the burden,” by moving a problem, or creating a new issue in another part of the chain.

v. Communicating decision makers about the trade-offs that a decision will have on the balance of impacts across the environmental impact categories, such as, implementing a particular technology to reduce GHG emissions that may result in increased water consumption.

vi. Comparing two systems that deliver the same service or product as defined by the functional unit. It is to be noted that differences of less than approximately 10 percent are within the typical error of good quality LCAs; meaningful differences must be much larger. ƒ LCAs can only meaningfully compare products or services that deliver the same functional unit.

vii. Indicating whether an improvement investment at one part of a market chain will have any significant improvement effect over the whole life cycle of a particular product.

viii. Benchmarking one industrial process against an industry average of similar processes to identify refinement possibilities.

ix. Providing foot printing data, such as carbon footprints, water foot prints.

3.2.5 Product Stewardship

Product Stewardship is defined as "the accountable and ethical management of any product during its development from process initiation to final use and beyond". Product Stewardship is an approach to managing the adverse impacts of different products and materials used. It believes that those involved in the production, selling, using and disposing of products have mutual responsibility to ensure that those products or materials are managed responsibly so that it reduces their impact, throughout their lifecycle, on the environment, human health and safety as well. The purpose of Product Stewardship is to make accountable for health, safety and environmental protection as an integral part of designing, manufacturing, marketing, distributing, using, recycling and disposing of products. This concept was developed initially by the chemical industry in 1987 in order to minimize the hazards associated with chemical products at all stages of the life cycle. Now the Product Stewardship is applied to all complex products and services. A major difference between LCA and the Product Stewardship lies in the environmental impacts are not cumulated over the whole life cycle.

The product stewardship aim at encouraging manufacturers and retailers to take responsibility to minimize the total life-cycle impacts of a product including consumption of energy and materials, its packaging, emissions in to air and water, toxicity of the product, worker safety, and waste disposal in product design and after use. Product stewardship is one of the key strategies to reduce greenhouse gas emissions and to address climate change issues.

The following are some of the Principles of Product Stewardship helps in promoting product stewardship by developing agreements with industry and the community to mitigate the health and environmental impacts from consumer products.

1. **Responsibility:** This principle is to fix up the responsibility for reducing product adverse impacts by sharing them among industry, government, and consumers. The greater the ability of an entity to minimize the impacts of a product in entire life-cycle, the greater would be the responsibility for addressing those impacts. All product manufacturers are more responsible in reducing the adverse impacts of a product.

2. **Internalize Costs:** The entire lifecycle of a product cost, from raw materials, to mitigate environmental and health impacts during the whole of the production process, to managing products at the end-of-life – should be incorporated in the total product cost. The proposed environmental costs of product manufacture, use, and disposal after use should be minimized, to the possible extent, for local and state governments, and ultimately shifted to the manufacturers and consumers of products. Manufacturers thus have a direct financial incentive to redesign their products to reduce these costs.

3. **Incentives for Cleaner Products and Sustainable Management Practices:** Policies that encourage and implement product stewardship principles should create incentives for the manufacturer cleaner technology. These policies should also extend to provide incentives for the development of a sustainable and environmentally sound system to recycle and reuse the products till the end of their life.

4. **Flexible Management Strategies**: The eco-friendly manufacturers' are responsible for mitigating adverse environmental and health impacts of products should possess flexible management strategies in determining and addressing those impacts efficiently.

5. **Roles and Relationships**: The industry and the Government will need to have leadership in realizing these principles and the practices of product stewardship through procurement, technical assistance, program evaluation, education and awareness, development of market, agency coordination, and by addressing regulatory barriers. Industry and the government should provide information required to make responsible environmental purchasing, reuse, recycling, and disposal measures to the consumers.

Check Your Progress 2

Note: a) Write your answer in about 50 words.

b) Check your progress with possible answers given at the end of the unit.

1. Explain how life cycle thinking and life cycle assessment should lead to selection and design of more sustainable process and products?

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2. Considering LCA, discuss how the burdens associated with raw materials, manufacturing and waste allotted in recycling process?

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3. What is the role of LCA?

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4. What is 3BL and mention any two advantages?

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3.3 MEASUREMENT TECHNIQUES

Life Cycle Impact Assessment (LCIA) is a measurement technique based on quantitative and qualitative methods for characterization of environmental impacts of a specific system. In this phase, quantified mass and energy balances of a particular system in Life Cycle Inventory (LCI) phase are combined in to specified environmental effects. The LCIA consists of the following four steps.

i. Classification

ii. Characterization

iii. Normalization

iv. Valuation

Classification: It is a qualitative technique where the environmental burdens are compiled to categorize in to various impacts to specify adverse effects on depletion of natural resources, environmental and human health. The compilation can be done based on the adverse impacts of the burdens to identify a similar burden which is common to a number of impacts.

Ex: Volatile Organic Compounds are responsible for global warming and ozone depletion.

Problem-oriented approach is the method used to classify the potential impacts. The following impacts which are considered for LCA are

i. Abiotic Resource Depletion(ADP)

ii. Global warming(GWP)

iii. Ozone depletion(ODP)

iv. Acidification (AP)

v. Eutrophication(EP)

vi. Photochemical oxidant formation(POCP)

vii. Human toxicity(HTP) and

viii. Eco toxicity(ETP)

ix. Land Use(LU)

Characterization: It is a quantitative step to measure total impacts of the environmental burdens predicted in LCI analysis. Since this phase of analysis is quantitative in nature and could be based on the scientific findings on the predicted environmental impacts in the inventory analysis. In the problem-oriented methodology, the effects are measured relative to a reference. For example for determination of the global warming potential of gases like CH_4 & VOCs carbon-di-oxide is a reference gas. The overall impact can be calculated by the following equation.

$$E_k = \sum_{j=1}^{j} ec_{k,j} B_j \qquad \text{———— (i)}$$

Where $ec_{k,j}$ =relative contribution of burden (bj)

E_k = impact

The LCIA method are not well established and it is reorganized that there is comparatively huge uncertainty in impact categorization, environmental burdens, parameters for modeling and the type of model each used for impact category. So far USES-LCA (Uniform System for the Evaluation of Substances) is one such model is in practice.

Normalization: This can be carried out to compare the data to the correct magnitude of adverse effects in a given system. This can be performed on the total emissions in a specific area over a given a period of time. For example entire emissions of global warming gases and natural resources depletion can be measured relatively. Whereas impacts like acidification, human toxicity are difficult to major at the global level hence normalization methods may not be a reliable processor for comparing the adverse effects of a system.

Valuation: Valuation is the final and most subjective step of impact assessment, in which the relative significance of different impacts is weighted so that they can be compared among themselves. As a result, different environmental impacts are reduced to a single environmental impact function, EI, as a measure of environmental performance. This can be represented by Equation.

$$E_k = \sum_{k=1}^{k} WkEk \qquad \text{———— (ii)}$$

Where W_k is the relative importance of impact E_k.

There are other techniques for valuation process which are based on expressing preferences by decisions makers or by experts or by the public. Multi attribute utility theory, analytical hierarchy process, impact analysis matrix cost-benefit analysis and contingent valuation are some other methods for valuation process.

3.4 REPORTING : GENERAL REQUIREMENTS AND CONSIDERATIONS

The type and format of the report shall be defined in the scope phase of the study.

According to ISO 14044:2006(E) the Reporting procedures is as follows.

"The results and conclusions of the LCA shall be completely and accurately reported without bias to the intended audience. The results, data, methods, assumptions and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA. The report shall also allow the results and interpretation to be used in a manner consistent with the goals of the study

The following items/points should be considered when preparing third-party reports

a) Modifications to the initial scope together with their justification;

b) System boundary, including ¯# type of inputs and outputs of the system as elementary flows,decision criteria;

c) Description of the unit processes, including ¯# decision about allocation;

d) Data, including- decision about data, details about individual data, and data quality requirements;

e) Choice of impact categories and category indicators.

A graphical presentation of LCI results and LCIA results as part of the report may be useful, but it should be considered that this invites implicit comparisons and conclusions.

Additional requirements and guidance for third-party reports

When results of the LCA are to be communicated to any third party, regardless of the form of communication, a third-party report shall be prepared. The third-party report can be based on study documentation that contains confidential information that may not be included in the third-party report. The third-party report constitutes a reference document, and shall be made available to any third party to whom the communication is made. The third-party report shall cover the following aspects.

a) **General aspects**:

1) LCA commissioner, practitioner of LCA (internal or external);

2) date of report;

3) Statement that the study has been conducted according to the requirements of this International Standard.

b) **Goal of the study**:

1) Reasons for carrying out the study;

2) Its intended applications;

3) The target audiences;

4) Statement as to whether the study intends to support comparative assertions intended to be disclosed to the public.

c) **Scope of the study**:

1) **Function, including**

i) Statement of performance characteristics, and

ii) Any omission of additional functions in comparisons;

2) **Functional unit, including**

i) Consistency with goal and scope,

ii) Definition,

iii) Result of performance measurement;

3) **System boundary, including**

i) Omissions of life cycle stages, processes or data needs,

ii) Quantification of energy and material inputs and outputs, and

iii) Assumptions about electricity production;

4) **Cut-off criteria for initial inclusion of inputs and output, including**

i) Description of cut-off criteria and assumptions,

ii) Effect of selection on results,

iii) Inclusion of mass, energy and environmental cut-off criteria.

d) **Life cycle inventory analysis**:

1) Data collection procedures;
2) Qualitative and quantitative description of unit processes;
3) Sources of published literature;
4) Calculation procedures;
5) Validation of data, including
    i) Data quality assessment, and
    ii) Treatment of missing data;
6) Sensitivity analysis for refining the system boundary;
7) Allocation principles and procedures, including
    i) Documentation and justification of allocation procedures, and
    ii) Uniform application of allocation procedures.

e) **Life cycle impact assessment**, where applicable:

1) The LCIA procedures, calculations and results of the study;
2) Limitations of the LCIA results relative to the defined goal and scope of the LCA;
3) The relationship of LCIA results to the defined goal and scope,
4) The relationship of the LCIA results to the LCI results,
5) Impact categories and category indicators considered, including a rationale for their selection and a reference to their source;
6) Descriptions of or reference to all characterization models, characterization factors and methods used, including all assumptions and limitations;
7) descriptions of or reference to all value-choices used in relation to impact categories, characterization models, characterization factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence on the results, conclusions and recommendations;
8) A statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks and, when included as a part of the LCA, also
    i) a description and justification of the definition and description of any new impact categories, category indicators or characterization models used for the LCIA,
    ii) a statement and justification of any grouping of the impact categories,
    iii) any further procedures that transform the indicator results and a justification of the selected references, weighting factors, etc.,
    iv) any analysis of the indicator results, for example sensitivity and uncertainty analysis or the use of environmental data, including any implication for the results, and

v) Data and indicator results reached prior to any normalization, grouping or weighting shall be made available together with the normalized, grouped or weighted results.

f) **Life cycle interpretation**:

1) The results;

2) Assumptions and limitations associated with the interpretation of results, both methodology and data related;

3) Data quality assessment;

4) Full transparency in terms of value-choices, rationales and expert judgments.

g) **Critical review**, where applicable:

1) Name and affiliation of reviewers;

2) Critical review reports;

3) Responses to recommendations.

Further reporting requirements for comparative assertion intended to be disclosed to the public

For LCA studies supporting comparative assertions intended to be disclosed to the public, the

Following issues shall also be addressed by the report

a) Analysis of material and energy flows to justify their inclusion or exclusion;

b) Assessment of the precision, completeness and representativeness of data used;

c) Description of the equivalence of the systems being compared

d) Description of the critical review process;

e) An evaluation of the completeness of the LCIA;

f) A statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use;

g) An explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study;

h) The results of the uncertainty and sensitivity analyses;

i) Evaluation of the significance of the differences found.

If grouping is included in the LCA, the following should be added.

a) The procedures and results used for grouping;

b) A statement that conclusions and recommendations derived from grouping are based on value-choices;

c) A justification of the criteria used for normalization and grouping (these can be personal, organizational or national value-choices);

d) The statement that "ISO 14044 does not specify any specific methodology or support the underlying value choices used to group the impact categories";

e) The statement that "The value-choices and judgments within the grouping procedures are the sole responsibilities of the commissioner of the study

3.5 CRITICAL REVIEW

General

The critical review process shall ensure that the methods used to carry out the LCA are consistent with this International Standard, the methods used to carry out the LCA are scientifically and technically valid, the data used are appropriate and reasonable in relation to the goal of the study, the interpretations reflect the limitations identified and the goal of the study, and the study report is transparent and consistent.

The scope and type of critical review desired shall be defined in the scope phase of an LCA, and the decision on the type of critical review shall be recorded.

In order to decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties shall conduct critical reviews on LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public.

3.5.1 Critical Review by Internal or External Expert

A critical review may be carried out by an internal or external expert. In such a case, an expert independent of the LCA shall perform the review. The review statement, comments of the practitioner and any response to recommendations made by the reviewer shall be included in the LCA report.

3.5.2 Critical Review by Panel of Interested Parties

A critical review may be carried out as a review by interested parties. In such a case, an external independent expert should be selected by the original study commissioner to act as chairperson of a review panel of at least three members. Based on the goal and scope of the study, the chairperson should select other independent qualified reviewers. This panel may include other interested parties affected by the conclusions drawn from the LCA, such as government agencies, non-governmental groups, competitors and affected industries. For LCIA, the expertise of reviewers in the scientific disciplines relevant to the important impact categories of the study, in addition to other expertise and interest, shall be considered.

The review statement and review panel report, as well as comments of the expert and any responses to recommendations made by the reviewer or by the panel, shall be included in the LCA report".

3.6 LET US SUM UP

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 make a more informed decision about the human health and environmental impacts of products, processes, and activities. The proposing activity can be explore the possibilities from 'cradle to grave' to 'cradle to cradle' approach in their activity by following ISO standards. This unit provided information about whole process of LCA with suitable examples.

3.7 KEY WORDS

Activity input : Exchange entering an activity from another activity or from the Environment. Also land transformation, land occupation, and working hours are exchanges from (services provided by) the Environment. Also inputs of primary production factors of the economy (labor costs, net taxes, net operation surplus, and rent) are exchanges from the environment even when measured as the economic costs of these inputs.

Activity output : Exchange from an activity to another activity or to the Environment. Not to be confused with Gross or Net (economic) output.

Attribution : A system modeling approach in which Exchanges are attributed to the Functional unit of a Product system by linking and/or partitioning the Unit process of the system according to a normative rule

Benefit : Value (utility) obtained from an Activity (related to a specified time period or Product). Divided in Revenue (income) and external benefits (positive Externalities), the sum of which is the Social benefit.

By-product : Product output from an Activity, that is not a Determining product. Product outputs that can displace determining products from other activities are always by-products. Materials for treatment can classified as either by-products or Wastes, but the distinction has no practical implications. (Synonym: dependent Co-product).

Characterization : The use of characterization factors to calculate the amount of an Impact category indicator that corresponds to a Functional unit.

Contingent valuation : Stated preference valuation method where the marginal value of a Non-market product is identified from the stated Willingness to pay or accept compensation for a specified change in the availability of the non-market product.

Cost-Benefit Assessment (CBA) : Life Cycle Sustainability Assessment with monetary valuation of the externalities

Eco-efficiency : The ratio between the Values added of an Activity or Product and one or more of its Externalities. When applied to a product, it is the ratio of LCC/LCIA results. The concept may be applied to any physical measure of environmental Impact, and may then be used to identify hotspots in a Product system with high environmental impacts relative to the value added (low eco-efficiency). While relevant as a tool to increase value added, it is less relevant to support overall cost reductions, since it simply provides an incentive to increase private (internal) costs and reduce external costs. This becomes obvious when expressing environmental Costs (and Benefits) in monetary units: the relevant measure to minimize is not internal/external costs but internal external costs, i.e. total costs. Thus, when it is possible to express environmental costs (and benefits) in monetary units, eco-efficiency simply measures the level of Internalization of costs, and loses its relevance as a tool to compare systems. Sometimes the term eco-efficiency is used for the inverse ratio, i.e. the ratio between the environmental impacts and the value added, which implies – somewhat illogically – that a low eco-efficiency would be desirable. This use is dissuaded.

Functional Unit : Quantified performance of a Product system for use as a reference unit (Source: ISO 14040).

Impact (noun) : Causal, directional relationship between an Activity and an environmental issue of concern, typically involving a significant Externality.

Impact Assessment : Calculation of the amount of one or more impact category indicators to express the potential environmental impacts of an Activity or a group of activities.

Life Cycle Assessment Result : Elementary exchanges and potential environmental Impacts of a Product system, i.e., the LCI result and LCIA result presented together.(Synonym: Accumulated system result).

Life Cycle Costing (LCC) : Assessment of all Costs associated with the life cycle of a product, sometimes restricted to the cost perspective of the end user of the Product. See also Environmental Life Cycle Costing.

Life Cycle Impact Assessment (LCIA) : Phase of Life Cycle Assessment aimed at understanding and evaluating the magnitude and

		significance of the potential environmental Impacts for a Product system throughout the life cycle of the Produc t(Source: ISO 14040 clause 3.4).
Life cycle impact Assessment Result (LCIA result)	:	Potential environmental Impacts of a Product system expressed in amounts of one or more Impact category indicators (synonym: Product footprint; Environmental profile; Eco-balance).
Life Cycle Inventory Analysis (LCI)	:	Phase of Life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (Source: ISO 14040 clause 3.3).
Normalization Factor	:	Factor applied to an amount of an Impact category indicator to express the amount relative to a normalization reference.
Normalization Reference	:	Amount of an Impact category indicator for a specific Activity or group of activities (typically the aggregated per capita production or consumption for a geographical area) for use as a reference to which a Life cycle impact assessment result can be compared.
Product Life Cycle	:	The production, use and final disposal of a product. In marketing, the term is used with a different meaning (introduction, growth, maturity, decline). (Synonym: Product chain).
Product System	:	System of consecutive and interlinked Unit processes which models a product life cycle (disentangled from the circular definitions of "Product system" and "life cycle" in ISO 14040, section 3.1 and 3.34).
System Model	:	A conceptual model describing a procedure for linking Activity datasets to form Product systems, or more generally for transforming a Supply-use table to a Direct requirements table. (Synonyms used in input-output economics: technology model/ assumption/construct).
System Boundaries	:	The denominations of which entities are inside the system and which are outside.
Weighting Factor	:	Characterization factor based solely on value choices describing the relative contribution to an Impact category endpoint from other (intermediate) impact category endpoints.

3.8 REFERENCES AND SUGGESTED FURTHER READINGS

EPA 2006: Scientific Applications International Corporation (SAIC): Life Cycle Assessment: Principles and Practice. U.S. EPA, Systems Analysis Branch, National Risk Management Research Laboratory. Cincinnati, Ohio.

Green Chemistry Metrics: Measuring and Monitoring Sustainable Process-edited by Alexei Lapkin,Centre for Sustainable Chemical Technologies, University of Bath,UK & Glaxosmithkline,USA,Wliey publication 2008

Hand book of Green Chemistry and Technology, Edited by James Clark and Duncan Macquarrie, Wiley publication, 2014

3.9 ANSWERS TO CHECK YOUR PROGRESS

Your answers should include the following points:

Answers to Check your Progress 1

1 a. **The Life Cycle Assessment (LCA)** measure and evaluate all the consumptions and emissions of a product throughout is life cycle from manufacture through use to disposal ("from cradle to grave"). It is expressed in terms of potential environmental impacts. The LCA methodology (ISO 14040, 1977) is based on four stages: goal and scope definition, inventory analysis, impact assessment, interpretation.

b. **Goal and scope definition**: the purpose of the study and its intended use, definition of the system boundaries, definition of the functional unit, data quality, assumptions and limitations of study. The functional unit is a quantitative measure of the output of products or service which the system delivers. It is a reference for normalization of input and output data.

C. **Inventory analysis**: identify and quantify the environmental burdens in the life cycle of a product. It is a kind of mass balance where the quantities are the environmental impacts. The burdens are defined by the material and energy used in the system and emissions to air, liquid effluent, and solid waste. It is expressed in terms of the environmental effect. The system is defined as the collection of materially and energetically connected operations which performs some defined function.

Answers to Check your Progress 2

Explain how life cycle thinking and life cycle assessment should lead to selection and design of more sustainable process and products?

1. The life cycle assessment measure and evaluate all the consumption and emission of a product throughout its life cycle, from manufacture through use to disposal. It is expressed in terms of the environmental impacts.

   On the impact assessment stage, the third of four stages, it is possible to quantify each emission (or row material consumption) in quantities that reflect the problem caused, which can be exemplified in eight categories, which are: non-renewable resource depletion, global warming, ozone depletion, acidification, eutrophication, photochemical oxidant formation, human toxicity and eco toxicity.

This scenario favors the selection and design of more sustainable process and products, forcing the producers to design products that are easy to reuse, repair or recycle, and as result, there will be less demand to use natural resources, the linear use (extraction, production, use disposal) represents a drop in quality of the materials and has been substituted by the cyclic hierarchy model. This one which promotes the use of sustainable materials reduces environmental impacts, add economic benefits and maximise quality through life of material. The aim is to slow the flow of material resources through society, maximizing their value to society from source to reintegration into natural processes.

Then, the researches have been increased on the field to use less materials or less energy to produce products that can be reused or easily recycled, ease of disassembly (means lower costs), substitute materials to others less harmful, less scarce and lighter ones, increase the composting by investing on biodegradable products, and avoiding landfill and incineration, because they are the lowest-value option.

2. Considering LCA, discuss how the burdens associated with raw materials, manufacturing and waste allotted in recycling process?

There are three common ways of looking at the End of Life (EoL) of products: the cycle, the chain and the cascade.

The recycle chain is an idealist way of how it should be, when 100% of the products and /or materials are recycled, and all the problems of materials depletion and landfill are resolved.

Modeling the End of Life as one single loop, however, one most cope with two important aspects of reality:

I. The second law of thermodynamics, requiring and upgrading activity to cope with degradation, contamination and dilution of materials within the loop;

II. The many lives of recycled materials do not stay in one product loop, but switch to other product loops

Recycling system normally combines many chains, and we have to deal with question like: is it wiser to recycle a certain type of plastic, or burn it?

So, analyzing the End of Life product/material as a cascade would be more suitable to optimize the use of resources.

3. TBL is a socioecological agreement between the community and businesses.

- It provides increased transparency to mitigate concerns of stakeholders on hidden information.
- TBL reporting demonstrates to stakeholders that the business is taking accountability to a higher level.
- It maintains and raises expectations of companies and improves “global clout”
- It provides evidences to the consumers about diminishing natural resources and made them aware of the impact businesses on the world.