CHAPTER II
LITERATURE SURVEY

2.1 Background

The use of plastic has increased continuously and this has led to an increase in the amount of plastic waste. Disposal of plastic, especially in packaging materials, is becoming a serious problem. Conventional techniques for minimizing disposal problem of plastic waste are recycling, incineration and landfill, but they have serious limitation. Recycling is viable for high cost and low volume specialty plastics. For incineration, not only corrosive and toxic gases are produced but also high energy is required. Due to the low weight-to-volume ratio, plastics tend to occupy more space than other materials in landfill. Moreover, most plastics can not be degraded even after a period of two decades due to its high molecular weight. For this reasons, conventional methods of waste disposal are not so attractive.

In response to this concern, an interest in environmentally degradable plastics has increased. The synthesis of biodegradable polymers was developed to replace non-biodegradable polymers.

2.2 Plastics

2.2.1 Definition

Plastics are polymers which are defined as long chain, high molecular weight chemical materials. A polymer formed into a shape by molding, extrusion, foaming, etc. is called plastic (Witcoff, 1996). Plastics provide the most important application for polymers, particularly, packaging. The molecules resulting from a chemical reaction, which leads to polymers, can be many types such as linear, branched, and crosslinked as shown in Figure 2.1.

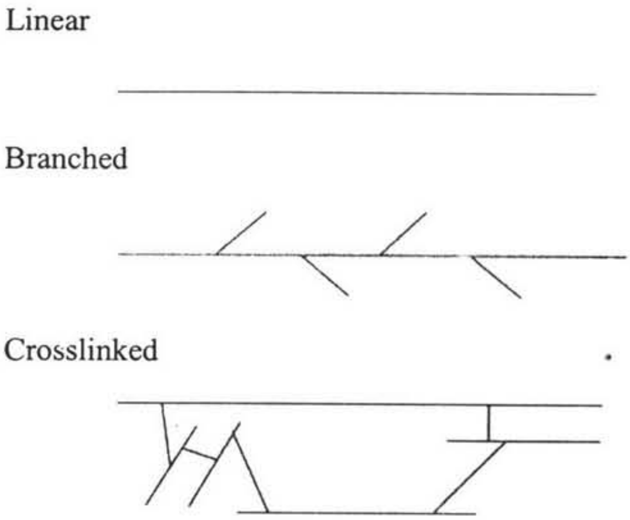

Figure 2.1 Molecular forms of polymers.

2.2.2 Classification

The classification is very important regarding the chemistry and the scientific research of polymers. From the technical point of view and more related to the applications, it is necessary to divide the polymer materials in the way given in the following list in Table 2.1.

From Table 2.1, there are two classifications of polymer:

1. Thermoplastic

These polymer molecules consist of long chains which have only weak bonds between the chains. The bonds between the chains are so weak that they can be broken when the plastic is heated. The chains can then move around to form a different shape. The weak bonds reform when it is cooled and the thermoplastic material keeps its new shape.

2. Thermosetting

These polymer molecules consist of long chains which have many strong chemical bonds between the chains. The bonds between the chains are so strong that they cannot be broken when the plastic is heated. This means that the thermosetting material always keeps its shape.

Table 2.1 Classification and properties of plastics (Taksina, 2003)

Class	Structure	Physical Appearance	Behavior on Heating	Behavior on Solvent Treatment
Thermo plastics	linear or branched macromolecules	partially crystalline: flexible to horn-like; hazy, milky or opaque; only thin films transparent	material softens, fuses and becomes clear on melting; often fibers can be drawn from melt; heat sealable	may swell; difficult to dissolve in cold solvents, but readily dissolved on heating in solvent
		amorphous: clear and transparent without additives (except heterophasic systems); hard to rubbery	material softens, fuses and becomes clear on melting; often fibers can be drawn from melt; heat sealable	soluble in certain organic solvents, after initial swelling
Thermosets (after processing)	densely crosslinked macromolecules	amorphous; hard; opaque with fillers; transparent without fillers	remain hard, almost dimensionally stable until chemical decomposition sets in	insoluble, do not swell or only slightly

2.2.3 Application

Plastics are used in such a wide range of applications because they are uniquely capable of offering many different properties that offer consumer benefits unsurpassed by other materials. From daily tasks to our most unusual needs, polyethylene has increasingly provided the performance characteristics that fulfill consumer needs at all levels. They are also unique in that their properties may be customized for each individual application as shown in Table 2.2.

Table 2.2 Plastics Applications (Chem Systems, 1987)

Polymer Type	Application
High density polyethylene (HDPE)	Bottles for milk and washing-up liquids, dustbins, bottles, pipes.
Low density polyethylene (LDPE)	Carrier bags and sacks, bin liners, squeezable detergent bottles, wire and cable applications, and film applications.
Polypropylene (PP)	Margarine tubs, microwaveable meal trays, ketchup bottles, yogurt containers, medicine bottles, pancake syrup bottles, and automobile battery casings.
Polystyrene (PS)	Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys, household chemicals, computers, video and audio cassettes.
Polyvinyl Chloride (PVC)	Blood bags, credit cards, pipe and fittings, siding, carpet backing and windows, wire and cable sheathing, insulation, film and sheet, floor coverings, synthetic leather products, coatings, and medical tubing.

Polyethylene Terephthalate (PET)	Electrical/electronic components, automotive electrical components, consumer products, office furniture components, fizzy drink bottles, oven-proof trays, and anorak and duvet filling.
Polyurethane	Upholstery, sports shoe soles, roller skate wheel, and electrical/electronic components.
Polyacrylate	Glazing, electrical/electronic components, automotive fog lamps, and microwave oven components.
Nylon	Wire and cable, barrier packaging film, electrical connectors, windshield wiper parts, radiator and tanks, brake fluid reservoirs, gears, impellers, and house wares.
Polycarbonates	Electrical/electronic components, housings, switches, aerodynamically styled headlights, glazing, appliances, medical apparatus, compact (audio) discs, baby bottles, car headlights, and firemen's helmets.
Other Plastics	Any other plastics that do not fall into any of the above categories. An example is melamine, which is often used in plastic plates and cups

2.3 Polyethylene

2.3.1 Definition

Polyethylene or polyethene (PE) is one of the simplest and most inexpensive polymers. It is a waxy, chemically inert plastic. It is named thus because it is obtained by the polymerization of ethylene as shown in Figure 2.2. It can be produced through radical polymerization, anionic polymerization, and cationic polymerization. This is because ethane does not have any substituent groups which influence stability of the propagation head of the polymer. Each of these methods results in a different type of polyethylene. Polyethylene (HDPE, LDPE and LLDPE) are the most common resins in plastic bag production, especially, blown film extrusion process.

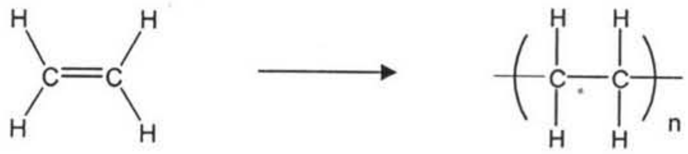

Figure 2.2 The structure of polyethylene.

Polyethylene is a suitable material for blending since it is widely used as packaging plastics. It is one of the largest commodity plastics, manufactured by ethylene polymerization. The characteristic of polyethylene which lead to its widespread uses are low cost, easy to process, excellent moisture barrier properties, and good chemical resistance. Polyethylene films are a rapidly growing application, replacing paper and glass. Polyethylene bags are popular in fast-food outlets, supermarkets, and department stores. However, its degradability is very low because of its high molecular weight, water resistance and low surface area to volume ratio.

Physical properties of polyethylene depending on the crystallinity and molecular weight, a melting point and glass transition may or may not be observable. The temperature at which these occur varies strongly with the type of PE.

2.3.2 Classification of Polyethylene

Polyethylene is classified into several different categories based mostly on its mechanical properties. The mechanical properties of PE depend significantly on variables such as the extent and type of branching, the crystal structure, and the molecular weight.

- UHMWPE (ultra high molecular weight PE)
- HDPE (high density PE)
- LDPE (low density PE)
- LLDPE (linear low density PE, sometimes referred to as Medium Density PE, MDPE)

UHMWPE is polyethylene with a molecular weight numbering in the millions, usually between 3.1 and 5.67 million. The high molecular weight results in a very good packing of the chains into the crystal structure. This results in a very tough material. UHMWPE is made through metallocene catalysis polymerization.

HDPE has a low degree of branching and thus stronger intermolecular forces and tensile strength. The lack of branching is ensured by an appropriate choice of catalyst (e.g. Ziegler-Natta catalysts) and reaction conditions.

LDPE has a high degree of branching, which means that the chains do pack into the crystal structure as well. It has therefore less strong intermolecular forces as the instantaneous-dipole induced-dipole attraction is less. This results in a lower tensile strength and increased ductility. LDPE is created by free radical polymerization.

LLDPE is a substantially linear polymer, with significant numbers of short branches, commonly made by copolymerization of ethylene with longer-chain olefins.

UHMWPE is used in high modulus fibers and in bulletproof vests. The most common household use of HDPE is in containers for milk, liquid laundry detergent, etc; the most common household use of LDPE is in plastic bags. LLDPE is used primarily in flexible tubing.

Recently, much research activity has focused on *Long Chain Branched* polyethylene. This is essentially HDPE, but has a small amount (perhaps 1 in 100 or 1000 branches per backbone carbon) of very long branches. These materials combine the strength of HDPE with the processability of LDPE.

2.4 Plastic Bag Production

To manufacture shopping bags, industry usually uses a process known as Blown Film Extrusion. This process is used to manufacture not only shopping bags but also many items such as; vapor barrier, bread bags, grocery bags, zip bags and garbage bags.

The process involves extrusion of a plastic through a circular die, followed by "bubble-like" expansion. The principal advantages of manufacturing film by this process include the ability to produce tubing (both flat and gusseted) in a single operation, to regulate the film width and thickness by control of the volume of air in the bubble, the output of extruder and the speed of the haul-off, to eliminate end effects such as edge bead trim and non uniform temperature that can result from flat die film extrusion, and capability of biaxial orientation (allowing uniformity of mechanical properties).

Blown Film Extrusion can be used for the manufacture of co-extruded, multilayer films for high barrier applications such as food packaging. The process can be described as follows.

The plastic is fed in pellet form into the machines hopper (this machine is known as an Extruder); the plastic is conveyed forward by a rotating screw inside a heated barrel and softened by both friction and heat. The softened plastic is then forced upwards through a circular die in a shape of a hollow tube.

Plastic melt is extruded through an annular slit die, usually vertically, to form a thin walled tube. This is a continuous process where the tube is expanded with air above the die, and collapsed by the take-off or nip rollers, the volume of air inside the bubble, the speed of the nip rollers and the extruders output rate all play a role in determining the thickness and size of the film. Air is introduced via a hole in the centre of the die to blow up the tube like a balloon.

The tube or "web" of film is then continuously rolled up by take-off rollers, or the web of film may be fed directly into a bag-machine in an in-line process. Mounted on top of the die, a high-speed air ring blows onto the hot film to cool it. The tube of film then continues upwards, continually cooling, until it passes through nip rolls where the tube is flattened to create what is known as a "lay-flat" tube of film. This lay-flat or collapsed tube is then taken back down the extrusion "tower" via more rollers. On higher output lines, the air inside the bubble is also exchanged. This is known as Internal Bubble Cooling (IBS). The lay-flat film is then cither kept as such or the edges of the lay-flat are slit off to produce two flat film sheets and wound up onto reels. If kept as lay-flat, the tube of film is made into bags by sealing across the width of film and cutting or perforating to make each bag. This is done either in line with the blown film process or at a later stage.

Typically, the expansion ratio between die and blown tube of film would be 1.5 to 4 times the die diameter. The drawdown between the melt wall thickness and the cooled film thickness occurs in both radial and longitudinal directions and is easily controlled by changing the volume of air inside the bubble and by altering the haul off speed. This gives blown film a better balance of properties than traditional cast or extruded film which is drawn down along the extrusion direction only as shown in Figure 2.3.

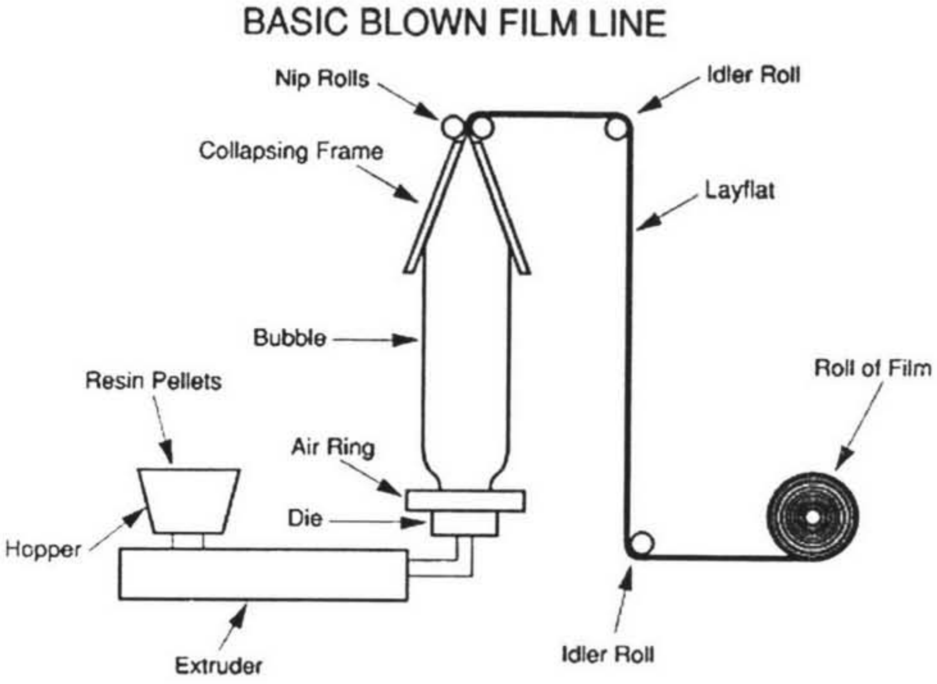

Figure 2.3 A typical blown film line.

2.5 Life Cycle Assessment (LCA)

2.5.1 History

LCA first took off in 1990, although the first LCA was carried out in the late 1960's on a Coke Cola can. Originally these were called REPA studies. Resource and Environmental Profile Analysis looked at resource use and environmental releases of a product. In the late 80's a few were carried out, by 1993 this had risen to 180 studies carried out by 16 research groups. A typical analysis takes about 4-5 man months, mainly due to lack of availability of basic input data, (rather a case of reinventing the wheel).

The Society of Environmental Toxicology and Chemistry (SETAC) works to develop broad consensus on the conduct of LCA which was initiated in 1990. A Society for the Promotion of Life Cycle Development (SPOLD) has been set up, SPOLD-members include Dow Chemical, Norsk Hydro, Proctor and Gamble and Unilever. It aims to promote the development of LCA as a scientific tool and to use the results for inputs into discussions concerning legislation such as eco-labeling.

2.5.2 Definition

LCA is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements (SETAC, 1990).

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. Figure 2.4 illustrates the possible life cycle stages that can be considered in an LCA and the typical inputs/outputs measured.

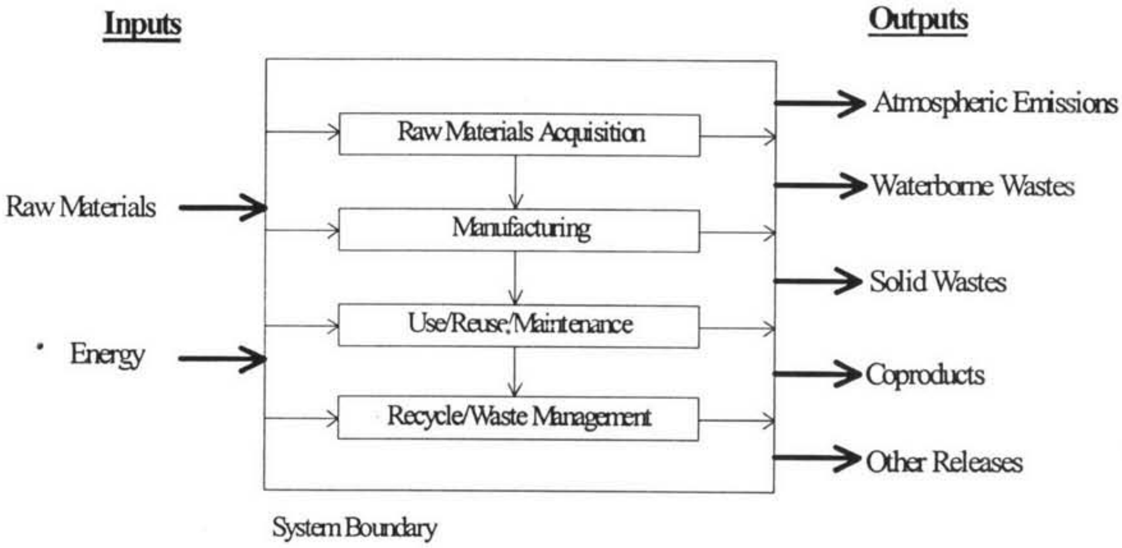

Figure 2.4 LCA Frameworks (US. EPA, 1993).

2.5.3 Method

The method of LCA is now being standardized as ISO 140040 series. According to ISO 14040, LCA framework consists of 4 elements: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation as illustrated in Figure 2.5.

The LCA method is an environmental assessment method, which focuses on the entire life cycle of a product from raw material acquisition to final product disposal. According to ISO 14040 an LCA study must consists of four parts: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation as illustrated in Figure 2.5.

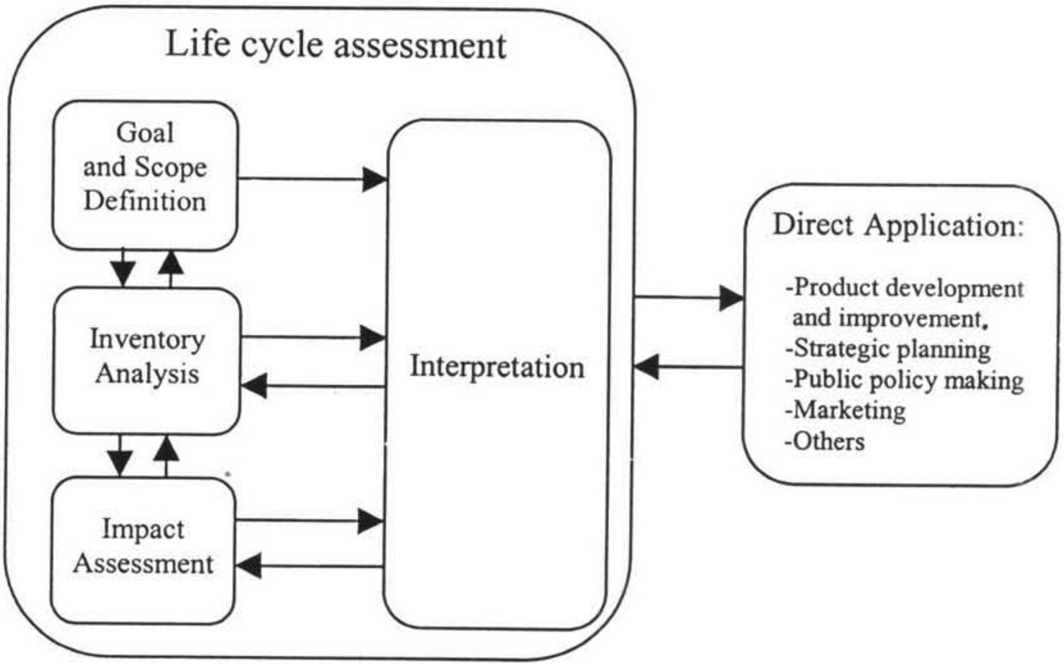

Figure 2.5 Phases of LCA (ISO, 1997).

2.5.3.1 Goal and Scope Definition

The goal will state the intended application, the reason for carrying out the study and the target audience. The scope describes the breadth, the depth and the detail of the study. It is important to define a functional unit and the system boundaries. The data quality requirements should be carefully specified.

-Function, functional unit and reference flow

A particularly important issue in product is comparison in the functional unit or comparison basis. In many cases, one cannot simply compare product A and B, as they may have different performance characteristics. For example, a milk carton can be used only once, while a returnable milk bottle can be used ten or more times. If the purpose of the LCA is to compare milk-packaging systems, one cannot compare one milk carton with one bottle. A much better approach is to compare two ways of packaging and delivering 1000 liters of milk.

-Initial System Boundaries

It is clear that one cannot trace all inputs and outputs to a product systems, and that one has to define boundaries around the system. It is so clear that by excluding certain parts as they are outside the system boundaries, the results can be distorted.

-Data Quality Requirement

It is important to determine in advance what type of data we are looking for. In some studies we would like to get an average of all steel producers in the whole world. In other studies we would like to have only data from a single steel producer or from a group of Electro steel producers in Germany. Likewise, we should determine if we want data on average, modern, or worst case technology.

2.5.3.2 Life Cycle Inventory Analysis (ISO 14041)

Inventory analysis aims at determining flows of material and energy between the technical product system and the environmental. It involves data collection and calculation procedures for the technical process. Input data could be resources such as raw materials, energy or land and output data could be emissions to air, water or land. The inventory datasheet usually depends on the typical overall scheme of product's life cycle as shown in figure 2.6 and defined scope of the study.

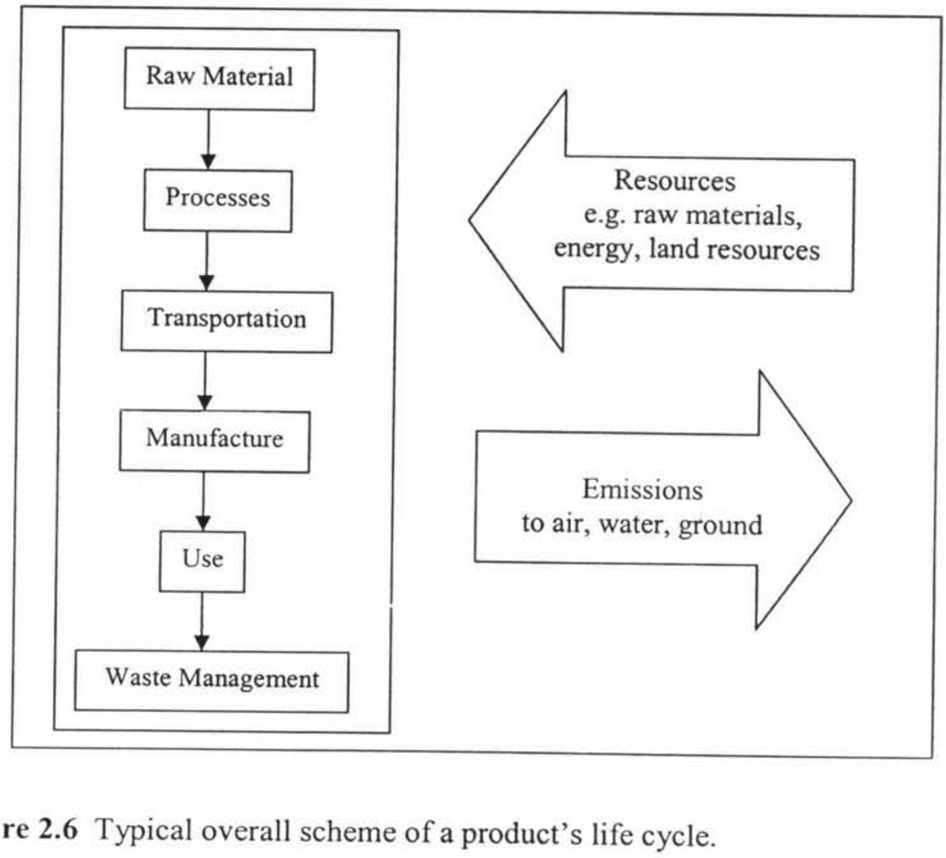

Figure 2.6 Typical overall scheme of a product's life cycle.

2.5.3.3 Life Cycle Impact Assessment (ISO 14042)

Life Cycle Impact Assessment, LCIA aims at evaluating the significance of potentially environmental impact based on the result of the life cycle inventory analysis (LCA result). Impact assessment includes:

-Definition of impact categories and category indicators.

An important step is the selection of the appropriate impact categories. The choice is guided by the goal of the study.

Common impact categories (and indicators) are:

- Climate change (CO_2 equivalents)
- Acidification (SO_2 equivalents)
- Eutrophication of waters (PO_4 equivalents)
- Photo-oxidant creation potential (Ethylene equivalents)
- Stratospheric ozone depletion (CFC-11 equivalents)

- Classification

The inventory result of an LCA usually contains hundreds of different emissions and resource extraction parameters. Once the relevant impact categories and determined, these LCI results must be assigned to these impact categories. For example CO_2 and CH_4 are both assigned to the impact category "Global Warming", while SO_2 and NH_3 are both assigned to an impact category acidification. It is possible to assign emission to more than one impact category at the same time; for example SO_2, may also be assigned to an impact category like human health, or respiratory diseases.

-Characterization

Once the impact categories are defined and the LCI results are assigned to these impact categories, it is necessary to define characterization factors. These factors should reflect the relative contribution of an LCI result to the impact category indicator result. For example, on a time scale of 100 years the contribution of 1 kg CH_4 to global warming is 42 times as high as the emission of 1 kg CO_2. This means that if the characterization factor of CO_2 is 1, the characterization factor of CH_4 is 42.

Thus, the impact category indicator result for global warming can be calculated by multiplying the LCI result with the characterization factor.

After characterization comes an optional step called weighting (ready-made LCIAs) (ISO 14042). It is used when there is a need to compare the relative important of various impact categories. If the environmental burdens are summarized, a single value is obtained that can be used for comparing different products, process or services.

2.5.3.4 Interpretation (ISO 14043)

Interpretation step means that conclusions are drawn and that recommendations can be given.

-Uncertainty

All data in life cycle models have some uncertainty. One can distinguish three main types:

- Data uncertainties
- Uncertainties on the correctness (representatively) of the model

It refers to the fact that there is not only way to make a model of reality. In each LCA, one will have to make more or less subjective choices in order to make a model. Some examples are data from other sources, choice of functional unit. These factors can have very significant impacts on the results. The only way to deal with them is in the sensitivity analysis.

- Uncertainties caused by incompleteness of the model

It refers to the unavoidable data gaps. Important issues are system boundaries, incomplete data sheets, mismatch between inventory and impact assessment.

-Sensitivity analysis

In order to see the influence of the most important assumptions, it is strongly recommended to perform a sensitivity analysis during and at the end of the LCA. The principle is simple. Change the assumption and the recalculation the LCA. With this type of analysis we will get a better understanding of the magnitude of the effect of the assumption we make. We will find the outcome of the LCA can be quite heavily depends on some of the assumptions. This does not need to be a problem as long as the conclusions of our LCA are stable. However, if we find that less than one assumption product A has a higher load than B, and under a different assumption product B has a higher load, we carefully need to explain under which assumptions our conclusions are valid. We may also conclude that there is no single answer, as everything depends on the assumptions.

2.6 Plastic Disposal

Currently 80% of post-consumer plastic waste is sent to landfill, 8% is incinerated and only 7% is recycled (Wastewatch, 2003). There are 6 ways to disposal plastics:

2.6.1 Landfill

The primary purpose of solid waste management processes is to remove wastes from living and work areas in ways that protect human health and the environment. Fortunately, new landfill technologies, stabilization techniques and site-monitoring systems are ensuring the protection of our present and future environment. Many landfills include thick plastic liners, required by the EPA, that help protect groundwater from contamination as well as several foot-thick linings of clay and an imperious synthetic fabric to prevent rain and other liquids from draining into the ground. Pipes collect water that accumulates above the liner and it is pumped into holding tanks for treatment. Systems are also in place to monitors methane gas, a volatile byproduct of rotting garbage.

2.6.2 Incineration

In many countries, incineration is a traditional and available method in reducing the different plastic wastes. In view of both reduction and destruction, incineration is a valuable means of waste disposal with the advantage of being highly effective in reducing the volume of waste. Thus, the method or technology regarding incineration is becoming a more widespread concern. During the incineration process, air pollutants such as CO, NOx, SOx, particles, and polycyclic aromatic hydrocarbons (PAHs) are exhausted. Understanding the characteristics of both formation and emission of PAHs is necessary because it is proved that some PAHs are carcinogenic. PAHs and their derivatives are widespread harmful compounds generated by incomplete combustion of organic material arising, in part, from natural combustion such as forest fires and volcanic eruptions, but for the most important part, from human activities, such as industrial production, transportation, waste incineration, and so on.

2.6.3 Energy Production

Plastics have high calorific value which often equal to heating oil – generates valuable energy for heat and electricity. A number of countries already make use of this. For example, Sweden recovers energy from around half of its domestic waste to meet the needs of approximately 15 per cent of its district heating. Fuel pellets produced from mixed plastics and plastics/paper fractions separated from household waste can be used as a fuel replacing coal. There are many such power stations across Europe using large amounts of pulverized coal that has the potential to be substituted by fuels based on pre-treated mixed plastics waste.

2.6.4 Biodegradation

Biodegradation is the decomposition of organic material by microorganisms such as bacteria, fungi and yeasts. The microbial organisms transform the contaminants through metabolic or enzymatic processes. Certain chemical structures are more susceptible to microbial breakdown than others; vegetable oils, for example, will biodegrade more rapidly than petroleum oils. Most petroleum products typically will completely biodegrade in the environment within two months to two years. The final product of the degradation frequently is carbon dioxide or methane. It is often used in relation to sewage treatment, environmental remediation (bioremediation) and to plastic materials although biodegradation is perhaps better regarded as the closing of the loop commencing with photosynthesis.

There are two types of biodegradation. The first one is aerobic biodegradation which is the breakdown of organic contaminants by microorganisms when oxygen is present. Aerobic bacteria use oxygen as an electron acceptor, and break down organic chemicals into smaller organic compounds, often producing carbon dioxide and water as the final product. The second is anerobic biodegradation which is the breakdown of organic contaminants by microorganisms when oxygen is not present. Some anaerobic bacteria use nitrate, sulfate, iron, manganese, and carbon dioxide as their electron acceptors, and break down organic chemicals into smaller compounds, often producing carbon dioxide and methane as the final products.

In some areas of the country, alternate disposal methods such as composting are available as a solid waste disposal option for readily degradable materials. But it is important to remember that compost facilities and landfills are very different things. Modern landfills are designed to limit degradation, so degradable materials of any type are not likely to affect the amount of landfill space available. Most people do not realize that plastics act similarly to other materials in a modern landfill, since the conditions necessary for rapid degradation are not present - or even desirable.

2.6.5 Photodegradation

Photodegradation is the chemical transformation of a compound into smaller compounds caused by the absorption of ultraviolet, visible, or infrared radiation from light of the sun. However, other forms of electromagnetic radiation can cause photodegradation such as light from xenon lamp. In many cases photodegradation is an oxidation process. Most plastics tend to absorb high-energy radiation in the ultraviolet portion of the spectrum, which activates their electrons to higher reactivity and causes oxidation, cleavage, and other degradation.

2.6.6 Recycling and Reuse

The most important strategy for environmental protection in the plastics products industry is the use of recycled and recyclable plastic. Many kinds of plastic are easily recycled within the production process, so there is very little scrap. Most of the environmental concerns in such companies are about air emissions. Changes in plastic formulation and improvements in air emissions controls are the main environmental protection solutions for air pollution. Energy efficiency is particularly important for this sector because almost all processing use heat. When scrap plastic cannot be recycled within the production process, it often can be ground up and used as filler in other products.

Reusing plastic is preferable to recycling as it uses less energy and fewer resources. Long life, multi-trip plastics packaging has become more widespread in recent years, replacing less durable and single-trip alternatives, so reducing waste.

2.7 Environmental Impacts of Plastics in Life Cycle Concept

The production and use of plastics has a range of environmental impacts. Firstly, plastics production requires significant quantities of resources, primarily fossil fuels, both as a raw material and to deliver energy for the manufacturing process. In addition, plastics manufacture requires other resources such as land and water and produces waste and emissions. The overall environmental impact varies according to the type of plastic and the production method employed.

Plastics production also involves the use of potentially harmful chemicals, which are added as stabilizers or colorants. Many of these have not undergone environmental risk assessment and their impact on human health and the environment is currently uncertain.

The disposal of plastics products also contributes significantly to their environmental impact. Because most plastics are non-degradable, they take a long time to break down, often several hundred years, when they are landfilled. With more and more plastics products, particularly plastics packaging, being disposed of soon after their purchase, the landfill space required by plastics waste is a growing concern.

2.8 Literature Review

The disposal of plastics in an ecologically sound manner has resulted in the evolution of two newly growth industries, recyclable plastics and biodegradable plastics (Narayan, 1993). Biodegradable plastic is targeted towards single use, disposable packaging, consumer goods, disposable nonwovens, coatings for paper and paperboard and some non-packaging markets. The growth of composting as an ecologically sound waste management approach supports the need for biodegradable plastics in the market place. Polyesters such as poly(caprolactone), poly(lactic acid), poly(hydroxybutyrate-co-hydroxyvalerate), thermoplastic starch and modified starch formulations, poly(vinyl alcohol), protein polymers, are examples of biodegradable polymeric materials being introduced into the market place. ASTM subcommittee D20.96 has developed standards in the area of biodegradable plastics.

There are two types of biodegradable polymer (Scott, 1999). The first type, of which cellulose, starch and aliphatic polyesters are typical, is rapidly converted to carbon dioxide and water in compost, in landfill and on the surface of the soil by a process of hydro-biodegradation. The second type is the oxo-biodegradable polymers, which includes naturally occurring polymers such as natural rubber and lingo-cellulose. The latter, in the form of wood, twigs, peat, straw, etc. is the most abundant polymer on the earth and in some cases, for example in the oak or the sequoia trees it may take many hundreds of years for the lingo-cellulose to be returned to the environment as CO_2, even straw takes up to ten years to be fully converted to carbon dioxide in biologically active soil. Oxo-biodegradable polymers, unlike cellulose and starch, do not hydrolyze rapidly and they are protected from oxidation in the environment by antioxidants present as natural components of their structure.

ASTM has provided the mechanism by which industry, government, and academia come together to develop consensus standards (Narayan and Pettigrew, 1999). Through these standards, industry and governments (and their regulatory agencies) can operate in a clear, safe, and effective manner for the benefit of the general public. ASTM standards played in helping define and grow a new biodegradable plastics industry. The standards helped overcome the confusion and misunderstandings in this new area. They provided a level, well-defined field whereby companies could introduce new degradable products, governmental agencies could monitor and confirm degradability claims, and consumers could safely use and dispose of the products with a clear understanding of the environmental benefits of degradable products. This paper also demonstrates the synergistic value and utility of ASTM's Institute for Standards Research (ISR) in helping perform the necessary R&D to write standards in emerging technology areas such as degradable plastics.

Blending starch with a biodegradable polymer is one method to produce a bioplastic. Due to the high cost of biopolymers, techniques have been developed to enable a high concentration of starch in the blend. The study was conducted in order to determine the effect of particle size (9 to 15 μm) of cassava starch on the physical and biodegradable properties of polycaprolactone (PCL)/cassava starch blend (Petnamsin *et al.*, 2000). It was found that particles of cassava starch, after ball milling (0, 60, 90 and 120 minutes), lost their crystallinity as observed by DSC and birefringency. With less crystallinity, particles observed by SEM easily formed clumps during the blending process. The tensile strength and %elongation decreased from 12.21 MPa and 302.89 of PCL/native starch to 4.48 MPa and 25.63 for the 120 minutes ball milled starch/PCL blend (15: 85 w/w). Addition of glycerol (25%w/w) into the blend could support only %elongation but not tensile strength. Excellent susceptibility to α-amylase and glucoamylase hydrolysis was evident when small particles were incorporated in the blend, compared to native starch. Blends with 60, 90, 120 minutes ball milled (both with and without addition of glycerol) showed very high biodegradability as determined by total organic carbon (TOC) released after subject to amylase digestion.

Applications of the life cycle assessment to Naturework$^{\mathrm{Tm}}$ polylactide (PLA) production was studied by Vink *et al.*, (2003). They explained including the role of life cycle assessment (LCA), a tool used for measuring environmental sustainability and identifying environmental performance-improvement objectives. An overview of applications of LCA to PLA production was give and insight into how they were utilized was provided. The first application reviewed the contributions to the gross fossil energy requirement for PLA (54 MJ/Kg) and the second one PLA was compared with petrochemical-based polymers using fossil energy use, global warming and water use as the three impact indicators. The last application gave more details about the potential reductions in energy use and greenhouse gasses. They concluded that polymers from renewable resources can be significantly lower in greenhouse gas emissions and fossil energy use today as compared with conventional petrochemical-based polymers. Over the longer term, LCA demonstrates that PLA production processes can become both fossil-energy free and a source of carbon credits.

James and Grant (2003) presented background information on the types of degradable polymers and results from a streamlined life cycle assessment that compared degradable polymers and alternative materials such as HDPE, LDPE, PP, Kraft paper and calico. The paper concludes with a checklist for use in selecting degradable polymers. Polymer based reusable bags have lower environmental impacts than all of the single-use bags. Degradable bags have similar greenhouse and eutrophication impacts to conventional HDPE bags. If the degradable material can be kept out of landfill, and managed through composting the greenhouse impacts will be reduced, but not eliminated. The synthetic polymer bags have higher impacts on resource impacts (abiotic depletion). The study developed indicators for litter which attempt to represent some of the damage effects caused by litter. Litter impact are lowest for the reusables, but of all the single use bags, the biodegradable generally have lower emissions, although in the marine environment it is the density of the bridgeable material which matters and not its degradability.

Ross and Evans (2003) presented the findings of a life-cycle assessment (LCA) that examined whether a re-use and recycle strategy for a plastic-based packaging that substantially reduces the quantity of waste to landfill would also reduce the overall environmental burden. The resources and environmental effects assessed over the life of each of the packagings included fossil fuel consumption, greenhouse gas emissions and photochemical oxidant precursors. The results demonstrate that recycle and reuse strategies for plastic-based products can yield significant environmental benefits. The study also includes some interesting findings regarding the relative contributions of transportation and construction energy, and the potential benefits of adjusting the impact assessment results to take into account the spatial variation in the significance of some environmental effects.

SRI Consulting's Process Economics Program (PEP) was commissioned by its clients to undertake a life cycle assessment (LCA) for the purpose of comparing a biodegradable polymer with a conventional commodity polymer in packaging applications (Bohlmann, 2004). Biodegradable polymers offer the potential of addressing a wide range of environmental concerns associated with conventional polymers such as greenhouse gas emissions and sustainability. LCA is a tool specifically developed for assessing the overall environmental burden of a product including the system used for manufacturing it and its end-of-life treatment. This paper provides a cradle-to-grave LCA of two polymers that may be used in food packaging applications: polylactide (PLA), which is a biodegradable polymer derived from corn; and polypropylene (PP). An inventory analysis of the PLA and PP systems is presented. An impact assessment focused on global warming is also provided.

A degradation of compost bags strips made of supposedly degradable polyethylene and nondegradable low density and high density polyethylene were evaluated in soil mixed with 50% (w/w) mature municipal solid waste compost supplied from municipal refuse (Orhan *et al.*, 2004). Plastic films were buried during 15 months at room temperature in 2 L desiccator jars containing soil adjusted to 40% of maximum water holding capacity. Degradation of plastic was determined by the weight loss of sample, tensile strength, carbon dioxide production, chemical changes measured in infrared spectrum and bacterial activity in soil. The examined films can be ranges in order of decreasing susceptibility to degradation: degradable polyethylene is very much more than low density polyethylene and high density polyethylene.

The most fundamental aspect in the ISO 14001 standard environmental management systems-specification with guidance for use was to find out ways by which an organization influenced environment to a significant degree. Zackrisson (2004) examined environmental data from companies manufacturing products mainly from metals and/or polymers. The data were collected in a uniform way by use of special guidelines. Weighting and valuation methods often used in the life cycle assessment were used to quantitatively compare and rank environmental aspects. The study results suggested that, in general, the largest environmental impact in the investigated manufacturing sub-vector could be associated with product use and/or disposal phases. This in turn showed a need for more attention on environmental work on the design for environment than what the ISO 14001 standard required. It was further suggested that weighting or valuation methods could aid in determining the significance of environmental impacts and aspects in the context of ISO 14001.