1997

A study of the life cycle assessment of multilayer plastic fuel tank.

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A STUDY OF THE LIFE CYCLE ASSESSMENT OF MULTILAYER PLASTIC FUEL TANK

By

Dan Albu

A Thesis Submitted to the
Faculty of Graduate Studies and Research through the
Department of Industrial and Manufacturing Systems Engineering
in Partial Fulfillment of the Requirements for the
Degree of Master of Applied Science at the
University of Windsor

Windsor, Ontario, Canada

1997

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ABSTRACT

One of the objectives of the Life Cycle Assessment (LCA) is to evaluate environmental burdens associated with a product, process or activity by quantifying energy and materials used and wastes released to the environment. The assessment includes the entire life cycle of the product encompassing raw material processing, manufacturing, transportation, use, recycling and disposal. This paper analyzes the multilayer plastic fuel tank from the LCA perspective, determines the main environmental burdens and expands the analysis on the improvement areas of the product for the purpose of lowering the environmental burdens.

Many companies in the private sector are beginning to see the advantages of life cycle thinking in product management. As evidence of its importance, industry itself is tacking significant steps to guide the use of life cycle thinking through its involvement in the development of international standards. Life cycle assessment allows these companies to make effective trade-offs between suppliers of key product inputs or between a number of ways of designing and manufacturing the products themselves. Life cycle assessment helps companies to keep a step ahead of rapidly changing regulatory requirements on solid waste, persistent toxic chemicals, emissions, and effluent discharges. In addition, life cycle strategies for pollution prevention and minimizing energy costs are beginning to reveal economic benefits in terms of more efficient production, improved product quality and minimization of down the road environmental risks.

DEDICATION

To

My Son

ACKNOWLEDGMENTS

I would like to express my appreciation to my supervisor Dr. S. M. Taboun, for his advice, patience and moral support which were instrumental in completing the program requirements, while working full time.

I also wish to express my gratitude to Dr. S. M. Taboun and Dr. M. Wang for offering interesting and challenging topics with direct industrial application, and for their dedication to making the courses accessible to part time students.

Much of the plastic fuel tank engineering knowledge I have acquired during my nine years experience is due to my colleagues at Kautex Corp., and Walbro Corp. and specially Mr. H. Schwochert, VP Walbro Corp. which I would like to tank.

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CHAPTER I

INTRODUCTION

1.1 OVERVIEW

In the automotive industry, the environmental impact of items such as engines, paints, and the fuel system has long been a matter of concern.

In US, the Clean Air Act of 1970 gave EPA broad authority to regulate motor vehicle pollution, and the Agency's emission control policies have become progressively more stringent since the early 1970's, Figure 1.1.

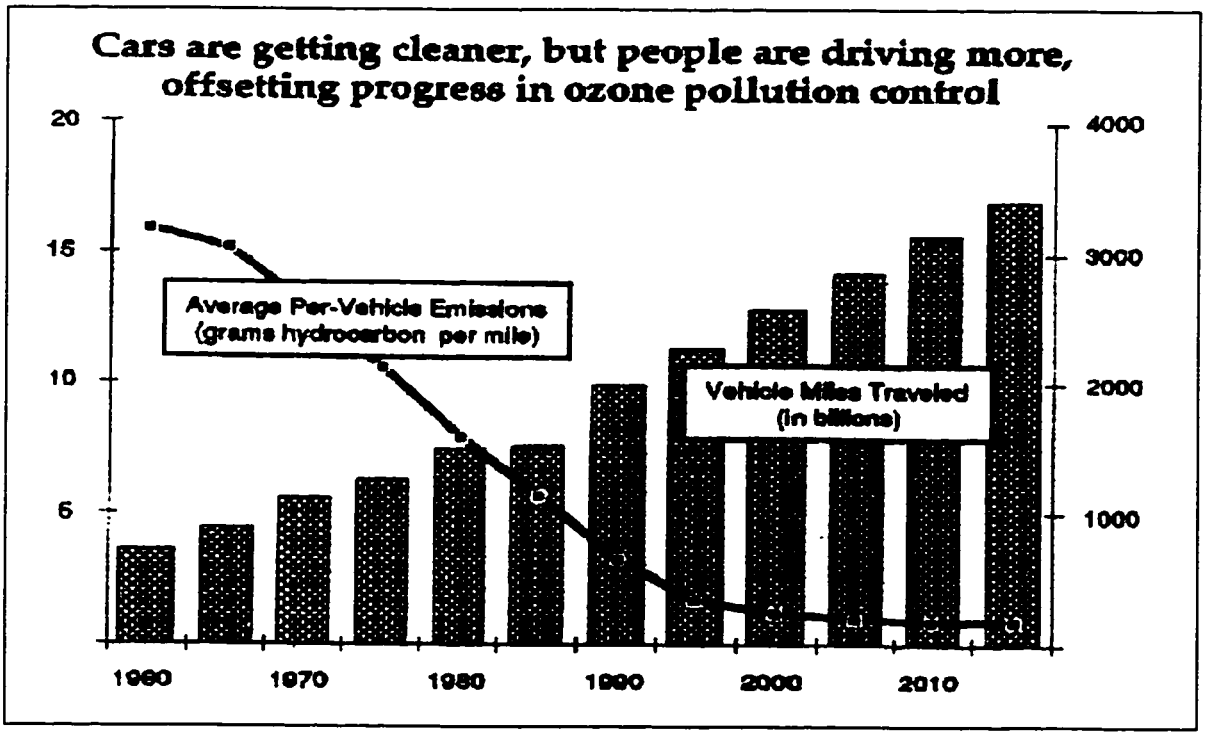

Figure 1.1 Average Per-Vehicle HC emission [EPA].

Vehicle emissions are being further reduced by provisions of the 1990 Clean Air Act. Mobile source provisions include even tighter tailpipe standards, increased durability, improved control of evaporative emissions, and computerized diagnostic systems that identify malfunctioning emission controls.

One of the components of a car emissions is the hydrocarbons emission. The HC can be emitted due to incomplete burning of fuel (tailpipe), hydrocarbon pollutants also escape into the air through fuel evaporation, refueling and due to permeation through the fuel system components including the fuel storage system.

Hydrocarbons react in the presence of nitrogen oxides and sunlight to form ground-level ozone, a major component of smog. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems. It is our most widespread and intractable urban air pollution problem Figure 1.2.

Estimates put the fuel savings due to the 2.7 kg mass reduction from replacing steel fenders with plastic ones at 24 liters of gasoline over the car's 150,000 km lifetime. The SPI estimates that vehicles produced in 1988 will save 118 trillion Kj over their lifetime, equivalent to 21 million barrels of oil, due to weight savings using plastics (5-10% fuel savings). In the last decade a 5-10% fuel savings has been achieved by replacement of ferrous components with plastic ones [Automotive Eng./ Aug.1994].

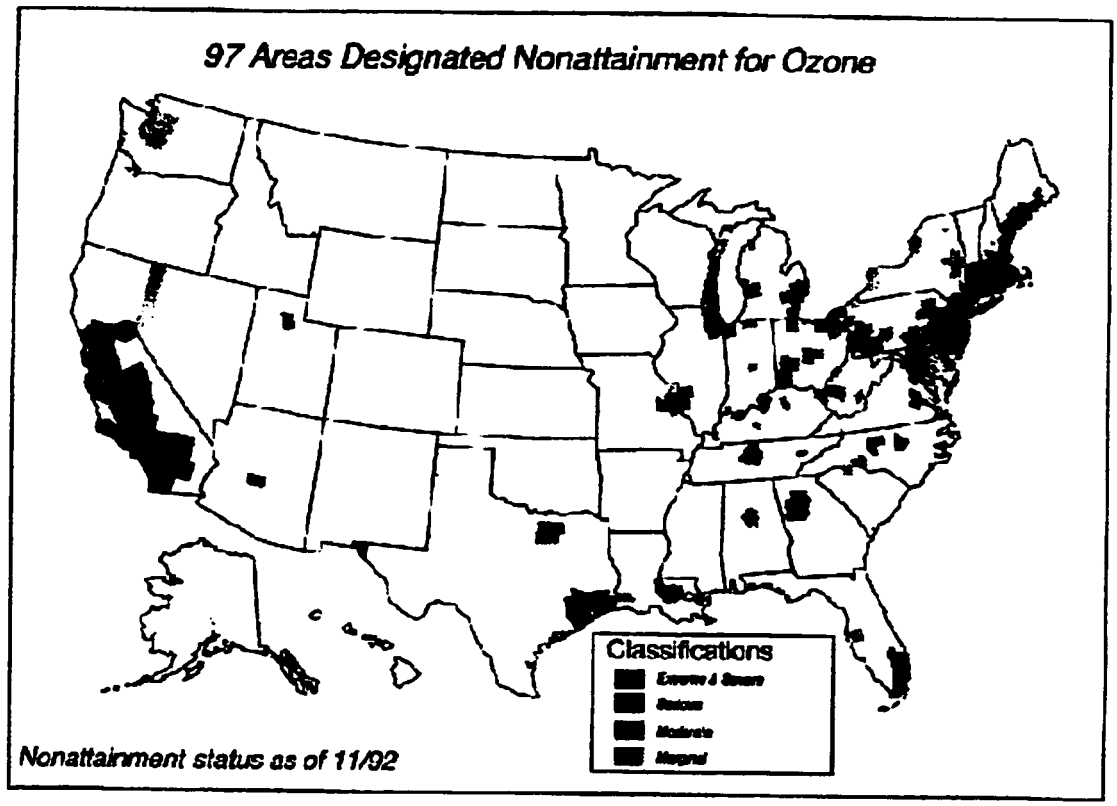

Figure 1.2. 1997 Areas Designated Nonattainment for Ozone [EPA].

One of the vehicle metal component that has been replaced with plastic is the fuel tank. Currently 35% of the North American car market utilizes PFT and it is estimated that will reach 65% before the end of the century, the European automotive industry has a 70% utilization of plastic fuel tanks Figure 1.3. The benefits of the Plastic Fuel Tank (PFT) have been long acknowledged by the automotive industry Table 1.1.

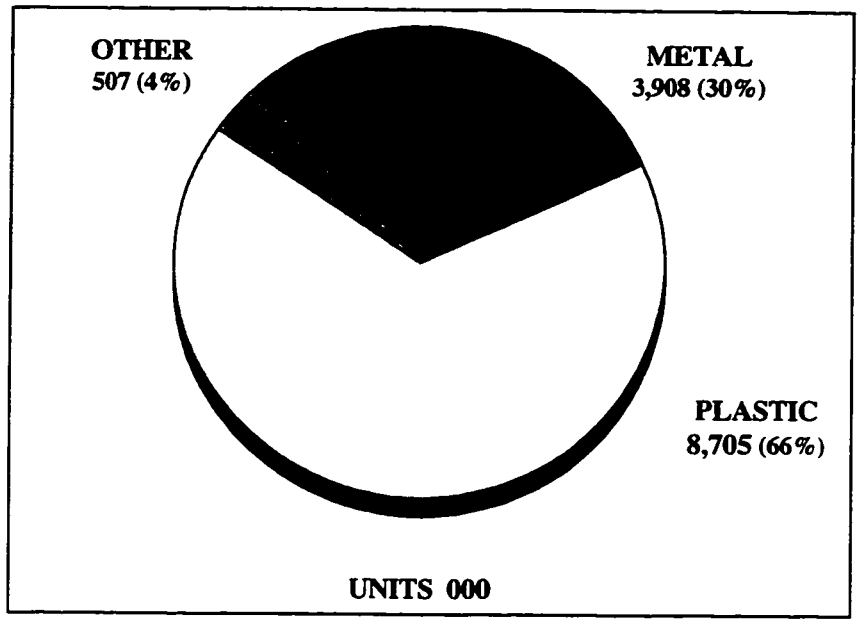

Figure 1.3. Technology in Europe 1995.

Table 1.1 Comparison of Steel vs. Plastic Fuel Tanks.

	STEEL	PLASTIC	
		ALTERNATE BARRIERS	COEX TECHNOLOGY
Design Flexibility		X	X
Weight Saving		X	X
Crash Behaviour		X	X
Thermal Dismensional Stability	X		
Resistance to Hot Exhaust Gases	X		
Fire Safety		X	X
Gasoline Permeation	X		X
Gasoline & Alcohol Resistance		X	X
Environmental Corrosion Resistance		X	X
Gravel Chip Resistance		X	X
Cost Effectiveness		X	X
Capacity		X	X
Thermal Conductivity	X		
Integrated Design		X	X
Acoustic Attenuation		X	X
Long Term Durability		X	X
Recyclability	X	X	X

The life-cycle analysis of plastic fuel tank shows that most serious environmental loads are imposed at the phase of raw materials (HDPE) production.

In order to enhance the plastic fuel tank recycling objectives emphasis should be placed on part design, rather than material composition. Examples of problem designs for recycling are plastic fuel tanks with encapsulated metal components, or welded plastic/metal assemblies.

The proposed method for performing the Life Cycle Assessment of the multilayer plastic fuel tank, is to take into account the weight of the emissions and their toxicity viewed through a Pareto approach. This paper assesses the environmental burdens of the multilayer plastic fuel tank using a cradle-to-grave approach, emphasis being placed on the most damaging emissions of hydrocarbons (HC) and SO2, and the solid waste generation..

1.2 MOTIVATION

I have selected this subject in order to evaluate from the environmental perspective the performance of the MFPT and contribute to the continuous improvement of this product. My work has also been encouraged by GM's interest in this area and their current project "GM Fuel Tank Life Cycle Assessment", as well as the fact that my current employer will produce more than two million PFT per year by the year 2000.

"The goal of GM's project on life cycle assessment (LCA) of fuel tanks is to gather an objective and quantitative database of environmental, energy and cost impacts covering the entire life cycle of a plastic and steel fuel tank. This cradle-to-grave approach will allow us to fully assess the benefits and corresponding needs and responsibilities of selecting one fuel system over another." [GM Fuel Tank Life Cycle Assessment, 1996].

1.3 OBJECTIVE

The multilayer plastic fuel tank (MPFT) is a new technology, which has been introduced in 1993 concurrently by Ford Motor Co. and Walbro Automotive Corp.

After a few years of strong resistance from the two established North American PFT manufacturers, the technology has been accepted and currently all North American manufacturers are offering the MPFT.

The objective of this Life-Cycle Assessment (LCA) study is:

1. to define the environmental burden of the MPFT;
2. to point out ways to reduce the environmental burden of the MPFT.

Ultimately this study is intended to help Walbro Automotive Corp. expand the already established leading position in the MPFT manufacturing, by addressing some of the product improvement opportunities, seen from the environmental view point.

CHAPTER II

LITERATURE REVIEW

2.1 WHAT IS LIFE CYCLE ASSESSMENT ?

Life cycle assessment is a method by which the environmental interventions related to product/processes can be quantitatively analyzed and evaluated [Environmental Management, 1993]..

Studies that identify life-cycle characteristics of a product have been conducted in the United States and Europe over the past 25 years and a multitude of terms have been used simultaneously to denote these studies.

Historically, the first studies consisted primarily of an inventory of energy consumption and releases to the atmosphere, to water or to land. The process of quantifying the resource use and environmental releases became known as Resource and Environmental Profile Analysis (REPA). These early studies became the blueprint for development of modern LCA. The need to move beyond the inventory stage and add an evaluation of the impact of the resource requirements and environmental consequences gave impetus to increased research activity. The name of the methodology was changed from life cycle analysis to life cycle assessment in order to convey the message that the inventory has to be followed by an impact assessment.

In the "A Technical Framework for Life-Cycle Assessment", The life-cycle assessment is defined as an objective process to evaluate the environmental burdens associated with product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements.

Life-cycle assessment have the potential to becoming a powerful tool for helping to reduce the environmental burdens associated with a product, process, or activity. Life-cycle assessment should be composed of three separate but interrelated components.

Life-Cycle Inventory-An objective data-based process of quantifying energy and raw material requirements, air emissions, waterborne effluents, solid waste, and other environmental releases throughout the life cycle of a product, process, or activity.

Life-Cycle Impact Analysis-A technical, quantitative, and/or qualitative process to characterize and assess the effects of the environmental loading identified in the inventory component. The assessment should address both ecological and human health considerations, as well as such other effects as habitat modification and noise pollution.

Life-Cycle Improvement Analysis-A systematic evaluation of the needs and opportunities to reduce the environmental burden associated with energy and raw materials use and environmental releases throughout the whole life cycle of the product, process, or activity. This analysis may include both quantitative and qualitative measures of improvements, such as charges in product, process, and activity design; raw material use; industrial processing; consumer use; and waste management.

The life-cycle assessment process is not necessarily a linear or stepwise process. Environmental benefits can be realized at each step. For example, the inventory alone may be used to identify opportunities for reducing environmental releases, energy, and material use.

The objectives of the inventory and its application :

- To establish a comprehensive baseline of information on a system's overall resource requirements, energy consumption, and emission loading for further analysis.
- To identify points within the life cycle as a whole, or within a given process, where the greatest reduction in resource requirements and emissions might be achieved.
- To compare the system inputs and outputs associated with alternative products, processes, or activities.
- To help guide the development of new products, processes, or activities toward a net reduction of resource requirements and emissions.
- To help identify needs for the life-cycle impact analysis.
- To provide the information needed to conduct an improvement analysis.

The criteria to be met by Life-cycle inventories :

- Scientifically Based - Only scientifically based analysis is used to distinguish between products or to ascertain product life-cycle improvements.

- Quantitative - All energy and material uses are quantified and documented using current databases or measurements with suitable quality control. Uncertainties and assumptions in data and methodology are specified.
- Appropriate Detail - The inventory is carried out to a level of detail commensurate with the purpose of the study, with the availability of data, and with the projected effect of a given parameter on the study conclusions.
- Replicable - The data sources and methodology are sufficiently described or referenced that comparable results would be obtained from a skilled replication or evidence would exist to explain any deviation.
- Comprehensive - All significant raw material and energy uses and environmental releases are included, or any elements missing because of data availability or cost and time constraints are clearly documented.
- Broadly Applicable - The analysis is sufficiently broad in model conception that the results can be applied to the range of situations expected.
- Consistent - The findings are consistent with those of prior studies, or the reasons for inconsistencies are specified; format is consistent with worldwide practice.
- Peer Reviewed - If the results are to be released to the public or used in a public manner, the report should be peer reviewed, using an accepted protocol.
- Useful - The users of the document can make appropriate decisions concerning the area listed; any limitations to the utility of the report should be clearly listed; and presentations should be clear and understandable.

In "Guidelines for Life-Cycle Assessment: A "Code of Practice", it is highlited that LCAs are composed of several interrelated components: goal definition and scoping, inventory analysis, impact assessment, and improvement assessment.

Goal Definition and Scoping;

This component consists of defining the study purpose and its scope, establishing the functional unit, and establishing a procedure for quality assurance of the study.

Inventory Analysis;

Any product or service needs to be represented as a system in the inventory analysis methodology. A system is defined as a collection of materially and energetically connected operations.

Impact Assessment;

Impact Assessment in LCA is a technical, quantitative, and/or qualitative process to characterize and assess the effects of the environmental burdens identified in the Inventory component.

The Impact Assessment component consists of the following three steps:

- classification,

(data from inventory analysis are grouped together into a number of impact categories)

- characterization,

(the analysis/quantification, and aggregation of the impacts within the given impact categories take place)

- valuation.

(The contributions from the different specific impact categories are weighed so that they can be compared among themselves).

Improvement Assessment

Is the component of LCA in which options for reducing the environmental impacts or burdens of the system under the study are identified and evaluated.

Improvement assessment deals with the identification, evaluation, and selection of options for environmental improvements in products or processes.

The relationship among the Impact Assessment phases and the LCA technical framework is presented in Figure 2.1 [A Conceptual Framework for Life-Cycle Impact Assessment].

The Impact Assessment Component can be further defined in three phases :

1. Classification - The process of assignment and initial aggregation of data from inventory studies to relatively homogenous stressor categories (e.g. greenhouse gases or ozone depletion compounds) within the larger impact categories (i.e., human and ecological health, and resource depletion).

2. Characterization - The analysis and estimation of the magnitude of impacts on the ecological health, human health, or resource depletion for each of the stressor categories, derived through application of specific impact assessment tools.

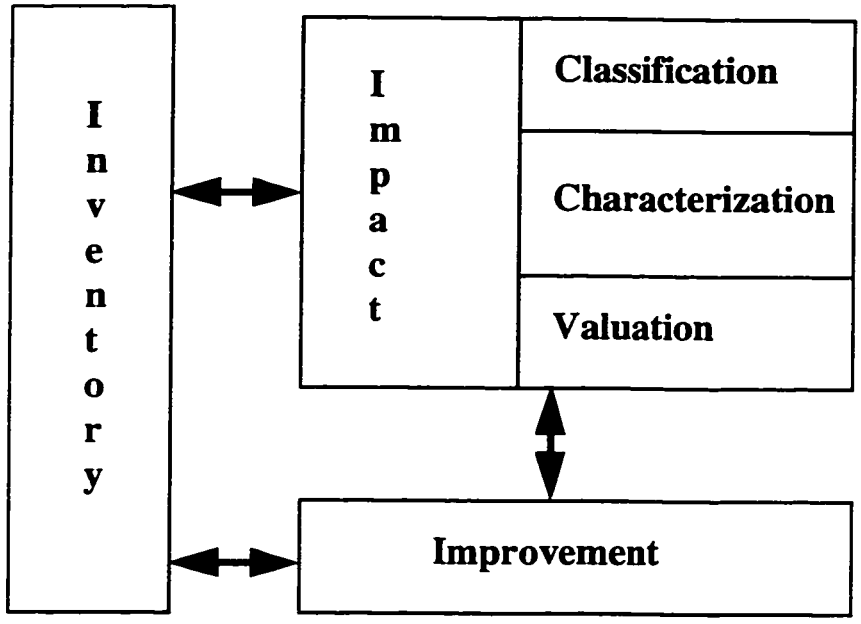

Figure 2.1 Impact Assessment Phases.

3. Valuation - The assignment of relative values or weights to different impacts and their integration across impact categories to allow decisionmakers to assimilate and consider the full range of relevant impacts across impact categories. Use of formal valuation methods should make this process explicit and collective, rather than one based on implicit, individual value judgments.

The Expanded Technical Framework for Life-Cycle Assessment discussed during SETAC-Europe workshop held in Leiden, Netherlands, in December 1991 points out the importance of including goal definition and scoping Figure 2.2.

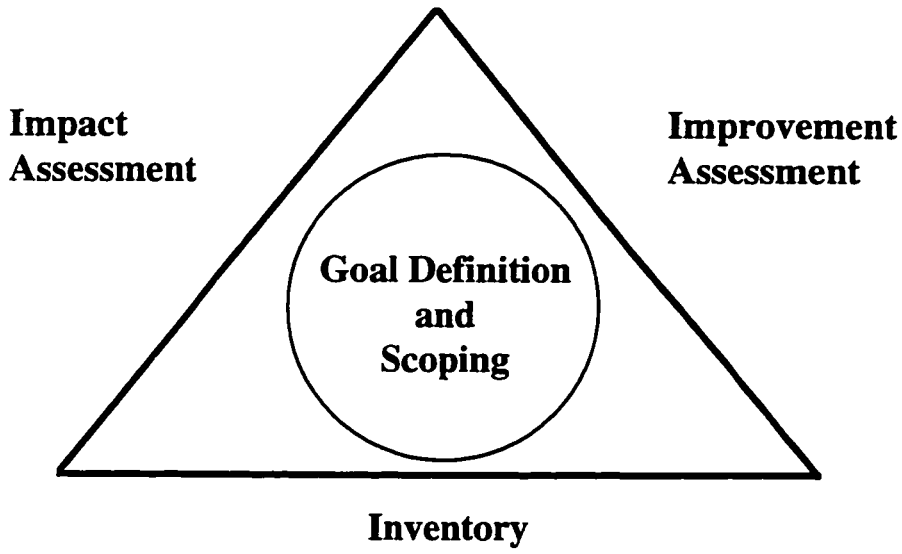

Figure2.2. Incorporation of Goal Definition and Scoping into LCA.

Scoping should be attempted before any LCA is conducted to ensure that:

- The breadth and depth of analysis are compatible with and sufficient to address the goal of the LCA.
- All boundaries, methodologies, data categories, and assumptions are clearly stated, comprehensible, and visible.

The life-cycle assessment is an objective 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 materials uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process, or activity, encompassing extraction and

processing of raw materials, manufacturing, transportation and distribution, use / re-use / maintenance, recycling, and final disposal [SETAC, 1990].

Life cycle assessment is a decision support tool supplying information on the environmental effects of products [UNEP, 1995]. The technique differs from other environmental tools in a number of significant ways:

- it can be used to study the environmental impact of either a product or a function a product is designed to perform;
- it provides objective data which are not dependent on any ideology;

it is much more complex than other environmental tools.

Some of the main applications of LCA are in :

- communications about the environmental aspects of products;
- product and process improvement;
- product and process design;
- development of business strategies; including investment plans;
- setting ecolabelling criteria;
- developing product policies;
- developing policy strategy;
- purchasing decisions; and
- development of life styles.

There are three main reasons for using LCA;

- because it is product oriented;
- because it is integrative; and

- because it is scientific and quantitative.

ISO 14000 defines life cycle analysis as "a systematic tool of assessing the environmental impacts associated with a product or service system to build an inventory of inputs and outputs, make a qualitative and quantitative evaluation of these inputs and outputs, and identify the most significant aspects of the system relative to the objective of the study",

CHAPTER III

METHODOLOGY

An approach implemented by progressive and competitive corporations on the global level is the Life Cycle Assessment (LCA) approach. In LCA, tracking starts at the time materials leave the location at which they naturally occur, and ends when they are returned to their natural state. For example, LCA would begin when oil is extracted and would not end until product disposal, perhaps years later. In life cycle management (LCM) tracking the material starts when it enters the plant and ends when the product leaves the plant. Common to both approaches is the division of all problems into three stages: inventory, impact, and assessment and improvement.

The methodology used for the LCA comparison includes:

- Inventory analysis - the quantification of energy and raw material requirements, emissions and waste for the entire life cycle of the products.
- Impact analysis - the quantitative and qualitative characterization and assessment of the effects of the environmental loading.
- Improvement analysis - an evaluation of the needs and opportunities to reduce the environmental burden associated with energy and raw material use and waste emissions throughout the life cycle of the products.

3.1 LIFE CYCLE INVENTORY

In the inventory stage, the corporation attempts to define all aspects of the materials and manufacturing processes. Steps in the manufacturing process are followed, and individual processes are evaluated, to determine the materials used, costs, emissions, and existing controls.

Simultaneously, the design and selection of materials are evaluated to determine whether acceptable alternatives exist that could fulfill the desired function without the loss of quality or a compromise in the components function.

The environmental profile of raw materials, manufacturing processes, use of the product (consumer stage), recycling and disposal have been collected from various sources, the following Life Cycle Stages were being considered :

1. Raw material stage.

- The raw material for the manufacturing of plastic fuel tanks (PFT) is HDPE. all environmental burden generated by the manufacturing and transportation of HDPE were considered

2. Manufacturing stage.

- The blow molding processes - used for manufacturing of PFT.

3. Use stage (consumer).

- The environmental impact of the multilayer plastic fuel tank (MPFT) has been analyzed considering a 10 years and 200,000 km life of the vehicle.

4. Recycling / Waste management stage.

- Disposal to landfill and energy recovery through 100% waste incineration of the MPFT material were calculated.

3.2 IMPACT ASSESSMENT

Based on the inventory information, the required environmental and occupational health and safety impacts are assessed. Additionally, the effect and extent of recycling is determined. The energy demands for the process are then added. In the LCM approach, the total cost of materials, processes, and disposal/liability must be included.

3.3 IMPROVEMENT ANALYSIS

Assessments of all impacts are made for each material or process as are comparisons between alternative courses of action.

The alternative that provides some improvements over existing materials or processes at the lowest cost is selected.

Improvements is defined as compliance with reduced costs while increasing performance and quality.

An advantage that LCM has over LCA is that a decision hierarchy exists to assign a priority of actions that also includes costs. This hierarchy includes the following general areas, in order of importance: elimination, substitution, and reduction.

3.4 ASSUMPTIONS

The following assumptions have been made :

- All the calculations have been made for a (Probe) multilayer plastic fuel tank of 120L, and 12kg/PFT weight.
- The total production volume of the Probe fuel tank is 20,000 / year.
- During one batch there are 2,500 MPFT produced.
- There are 8 batches per year.
- The environmental effects of HDPE, LDPE, Adhesive, EVOH are considered to be identical.
- All raw material, transportation and energy recovery from incineration as per [Packaging and the Environment] and [WAC].
- The MPFT has 75% the weight of a metal fuel tank. It is estimated that using the Probe MPFT (12kg) results in 4 kg weight savings compared to the metal fuel tank.
- The emissions generated by the fuel consumed for transporting the weight of the fuel tank during the life of the vehicle were neglected.
- The emissions generated by the molding and welding operation of the MPFT are considered negligible.

3.5 LIFE CYCLE ASSESSMENT BOUNDARY

The boundary of the system span from the extraction of the crude oil to the disposition of used MPFT at the end of their life cycle.

From material production, to manufacturing, testing, transportation, use and disposal, including landfill and incineration of the MPFT material have been considered.

Special emphasis has been placed on the manufacturing improvement side regarding both product improvement and process improvement.

CHAPTER IV

LIFE CYCLE INVENTORY

4.1 HDPE PRODUCTION (Raw materials stage)

Polyethylene may be produced by radical polymerization of ethylene at high pressures (1500-3000 bar) or by coordination polymerization with the aid of catalysts at low pressures. Depending on the polymerization conditions, polymers of various densities (0.9-0.97 g/cm3) and various molecular weights are produced.

According to Plastics Industry Information Council about 300,000 tones/year of polyethylene are used by the packaging industry. The HDPE fraction is about 109,000 tones/year.

Usually, polyethylene is characterized by its density and melt flow index. The HDPE grades are very important for blow molding applications. This applies in particular to the high-molecular weight granular grades. Polyethylene is a semi-crystalline plastic. Depending on the polymerization conditions, polyethylene with various degrees of branching are produced. The less branched the macro-molecules the higher the crystalline proportion and thus also the density.

Alongside the degree of branching of the polymer chains, an important parameter for characterizing the properties of polyethylene is the length of the chains and thus the average molecular weight. Differences in the molecular weight usually result in

differences in the melt viscosity. This has an influence on processibility and flow of the products.

As a rule, molding compounds of relatively high molecular weight have a relatively high melt viscosity and relatively low flow. One measurable variable which is an indication of this is the melt flow index. High numerical values correspond to low viscosity, in other words low molecular weights, and vice versa. As density increases, cristallinity becomes greater, the yield stress also increases.

In the case of HDPE, the influence of the melt flow index dominates. Polyethylene is, to a certain extent, permeable to gases, vapors and liquids. The permeability decreases with increasing crystallinity and density.

4.1.1 PRODUCTION EMISSIONS

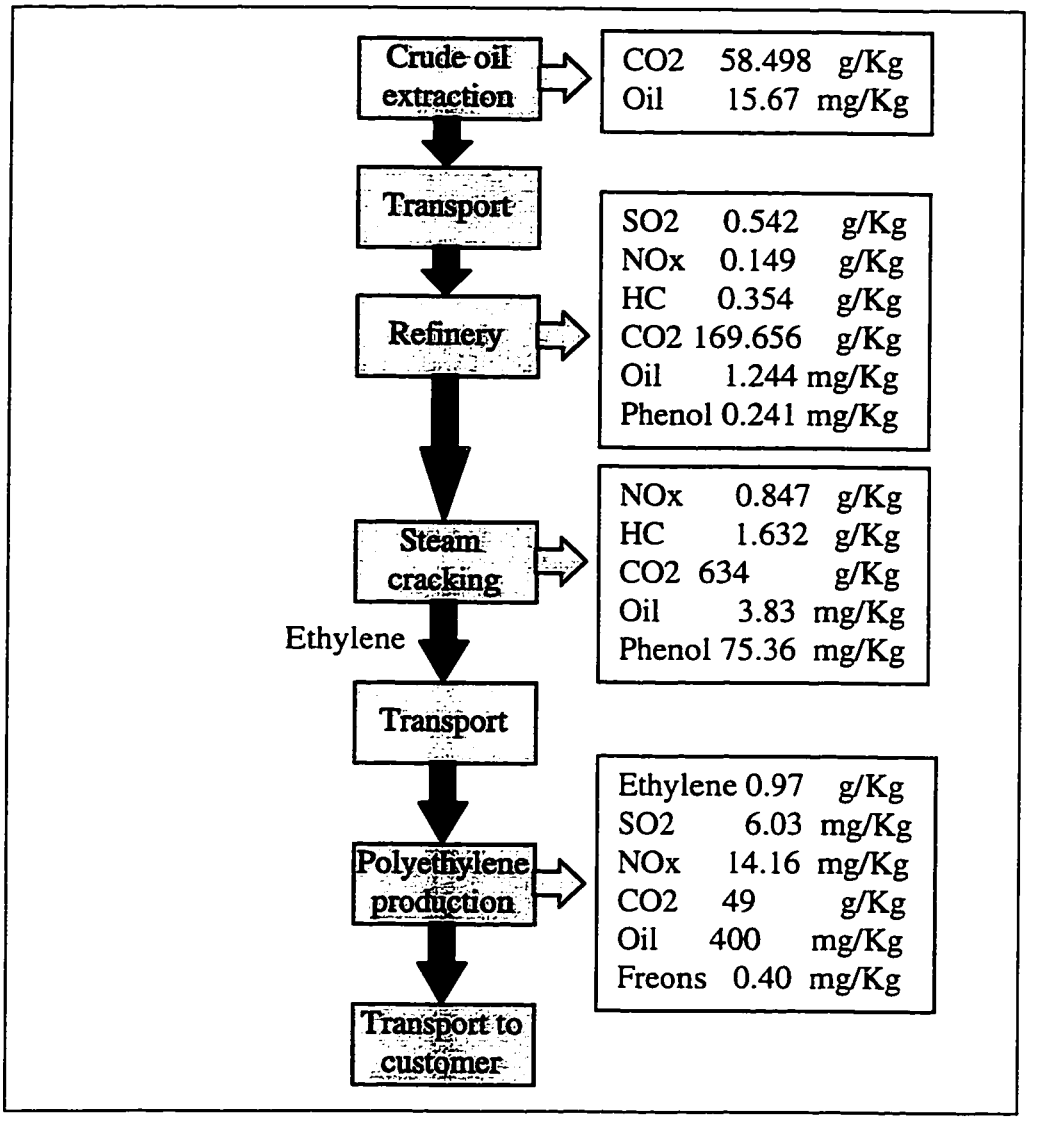

Figure 4.1 Process flow chart - HDPE manufacturing emissions..

The raw material consists of oil which is refined to make naphtha and propane, among other compounds. The next step is to break these down by heating in the steam cracking process. In this form of cracking steam is added, hence its name. The main

products are ethylene and propylene. Others are burning gas, which is used internally as fuel, cracked gasoline and heavy unsaturated hydrocarbons. The various products are separated after the cracking furnaces by distillation, compression and cooling.

The manufacture of HDPE takes place in a low-pressure process. HDPE is polymerized in a fluidised bed of catalytic sand at a maximum of 21 bar and 110 C. The polymerization catalyst of metal compounds precipitated in extremely fine quartz sand. The base resin is removed from the reactor in the form of a powder and is transferred to an extruder where pelletisation of the base resin takes place.

4.1.2 PRODUCTION ENERGY REQUIREMENTS

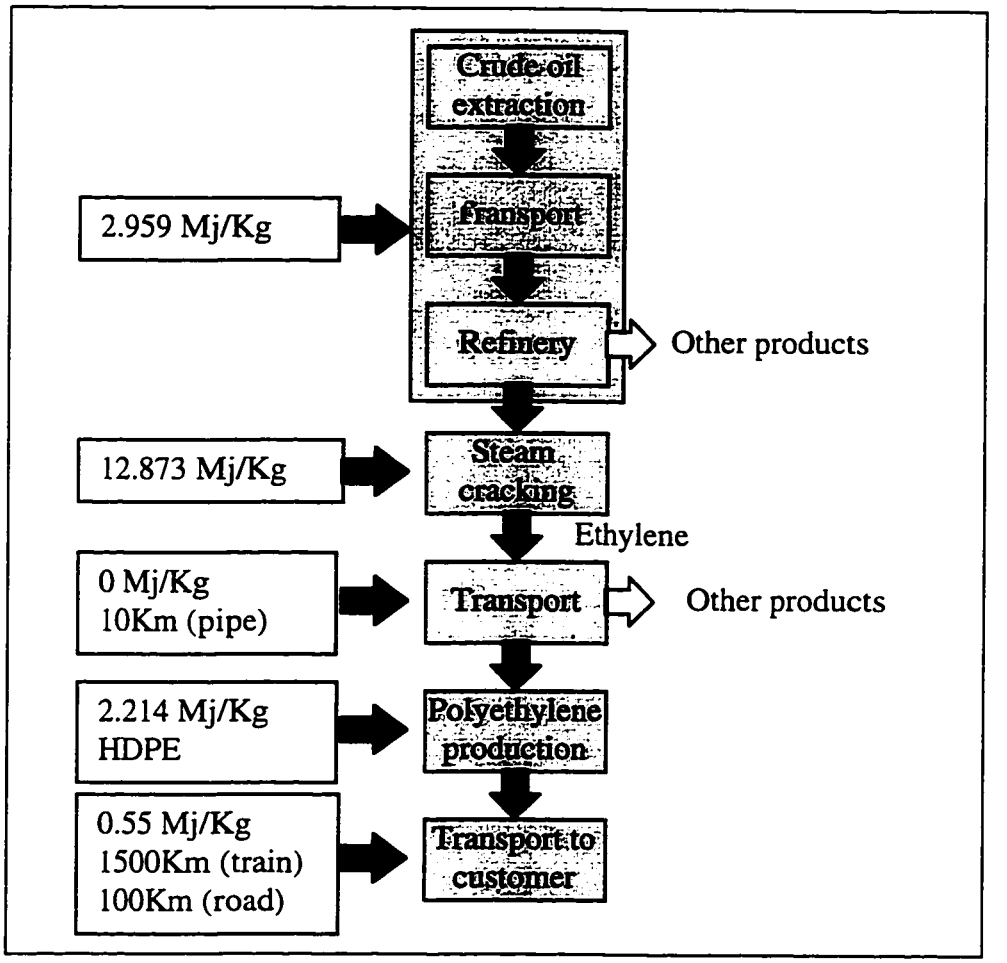

Figure 4.2 Process flow chart - HDPE manufacturing energy.

Table 4.1 Environmental profile - HDPE.

(Waste to Landfill)

PROCESS: HDPE Production DATA SOURCE: Packaging and the Environment 1992.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per kg of virgin HDPE.	**OUTPUTS**	Per kg of virgin HDPE.
RAW MATERIAL	Extract from the environment crude oil.	**MAIN PRODUCT**	1 kg HDPE
ENERGY	65.47 MJ/kg. Electric and Thermal (Includes end of life disposal transportation energy.)	**SOLID WASTE**	1.0004 kg/kg
TRANSPORT	0.85 MJ/kg 1500 km / Rail 400 km / Road	**EMISSIONS**	HC 3.161 g/kg SO2 0.849 g/kg NOx 1.728 g/kg CO2 94.6 g/kg

CALCULATIONS :
1500 [km] (Rail), 400 [km] (Road). The transportation of MPFT to the Landfill, at the end of the life cycle is neglected.

TRANSPORT:
0.0003 [MJ/kgkm] X 1500 [km] + 0.001[MJ /kgkm] X 400 [km] = 0.85 [MJ / kg]

Table 4.2 Environmental profile - HDPE.

(Waste Incinerated)

PROCESS: HDPE Production DATA SOURCE: Packaging and the Environment 1992.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per kg of virgin HDPE.	**OUTPUTS**	Per kg of virgin HDPE.
RAW MATERIAL	Extract from the environment crude oil.	**MAIN PRODUCT**	1 kg HDPE
ENERGY	26.74 MJ/kg. Electric and Thermal (Includes end of life disposal transportation energy.)	**SOLID WASTE**	0.0004 kg/kg
TRANSPORT	0.85 MJ/kg 1500 km / Rail 400 km / Road	**EMISSIONS**	HC 2.441 g/kg SO2 -14.0 g/kg NOx 2.605 g/kg CO2 98.5 g/kg

CALCULATIONS :

1500 [km] (Rail), 400 [km] (Road). The transportation of MPFT to the Incinerator, at the end of the life cycle is neglected.

TRANSPORT:

0.0003 [MJ/kgkm] X 1500 [km] + 0.001[MJ /kgkm] X 400 [km] = 0.85 [MJ / kg]

4.2 PLASTIC FUEL TANK (Product manufacturing stage).

The base material for the manufacturing of plastic fuel tank (PFT) is the high density polyethylene (HDPE) which represents more than 90% of it's total weight. The HDPE is a thermoplastic with good processibility, is a fusible material and has mechanical properties that makes it the most suitable material for the manufacture of PFT.

The extrusion blow molding process is the primary method applied for the manufacturing of PFT. In the past mostly accumulator head extrusion machines were used, but with the introduction of strict emission requirements, the multilayer technology expanded into the PFT manufacturing Figure 4.3.

Effective barrier plastics such as ethylenevinil alcohol (EVOH) can only be joined by bonding agents to body materials such as polyethylene. If the barrier itself has to be protected against attack from certain substances in order to retain its effectiveness, at least five layers have to be extruded simultaneously.

The EVOH barrier is an excellent oxygen and hydrocarbon barrier but it is sensitive to water, and as a result it has to be incorporated between two water-resistant barriers like HDPE. This requirement can only be met with five layers, and if the flash is also to be used as regrind, six layers have to be extruded.

ɪtrusion blow molding machine.

The extrusion blow molding process consist in the following operations :

- Material system feeds the granulated material (HDPE, Adhesive, Barrier, Regrind) to the individual extruders.
- The friction generated by the extruder screw pushing material through the extruder, combined with additional electrical heating of different zones of the extruder casing melts the material.
- The melted material is continuously pushed into the extrusion head. For the first portion of the extrusion head, each material follows an individual path covering the entire perimeter of the head. In the second phase the individual material channels converge into one common channel and all the individual material layers merge into a compounded layer.
- The compounded layer is extruded through the mouth piece of the head, which consist into a core and die. The control of the wall thickness is done automatically following a pre set profile. The wall thickness of the extruded tube (parison) can be computer controlled both longitudinal and radial.
- The open mold is shuttled under the extrusion head and the parison is clamped.
- Air is blown into the parison while the mold Figure 4.4, is still open during the pre blow phase.
- The mold closes and the hot, molten parison is then blown like a balloon and forced against the walls of the mold to form the desired shape.

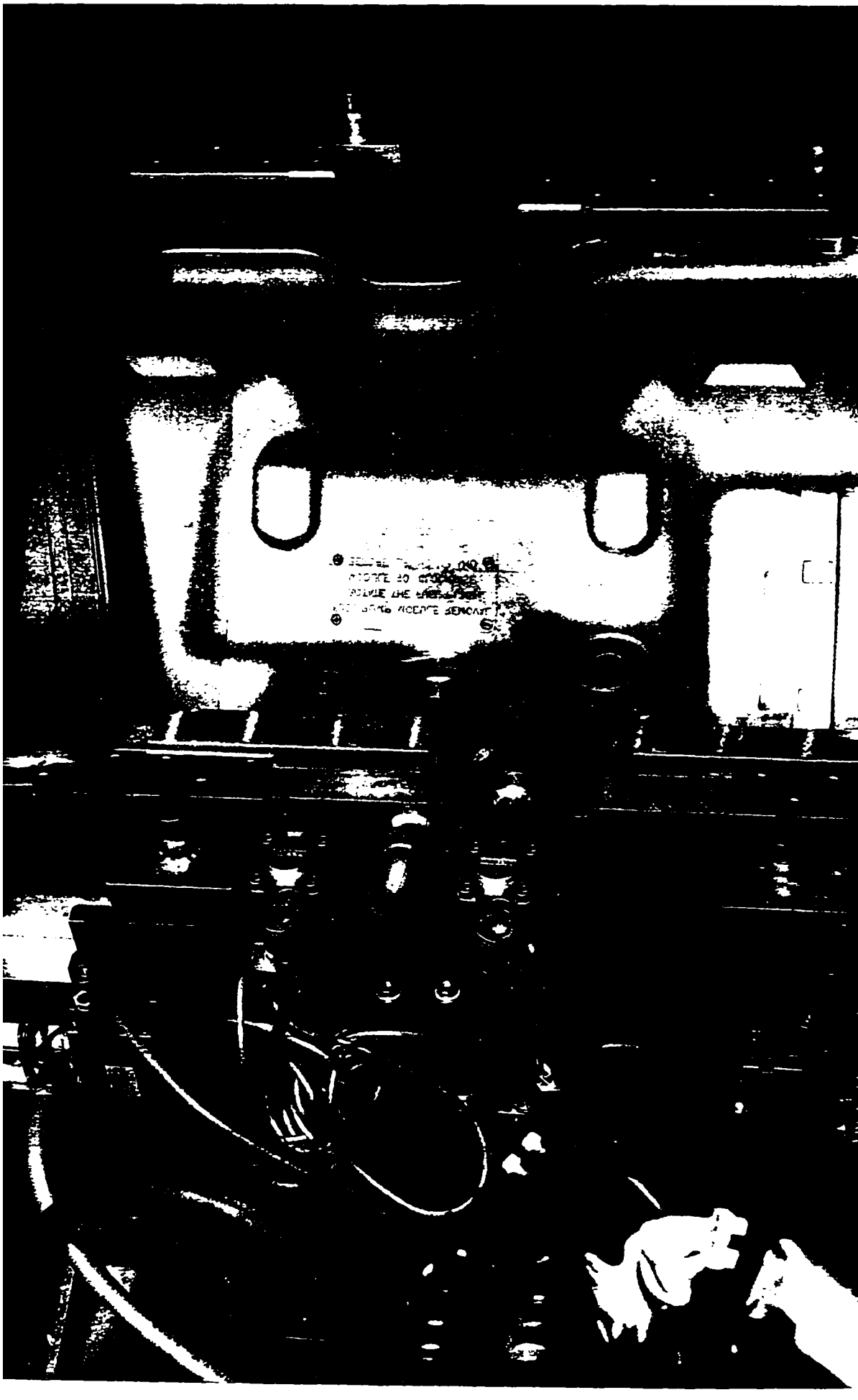

Figure 4.4. Plastic fuel tank mold.

- The last step before part removal is the cooling process in which the material of the formed product releases most of the heat into the cooled mold and the material hardens.
- All the materials (granules) are feed to the BM machine by blowers. The materials carried by air from the material bins/silos accumulate into a hopper in top of each individual extruders. From the hopper the material is weighed and then transferred to the extruder intake zone. The amount of material of all the six layers is computer controlled and the proportion is kept constant tacking into account changes in material density, and throughput.

As opposed to the surface treatment of PFT employing the use of very reactive substances like F2 or SO3, or coating of sheet metal used for metal fuel tanks, the multilayer technology has a substantially reduced impact on the environment by using only inert solid materials.

After molding, the tank shell is transferred to the machining and welding stations Figure4.5 , were a number of components are welded using ultrasonic or hot plate methods. Those methods use substantially less energy compared to welding of metal fuel tanks (melt point of HDPE 190 C, iron 1570 C).

Most of the new machines are using continuous extrusion process and most common the multilayer plastic fuel tank is composed of six layers as per Figure 4.6 and Table 4.1.

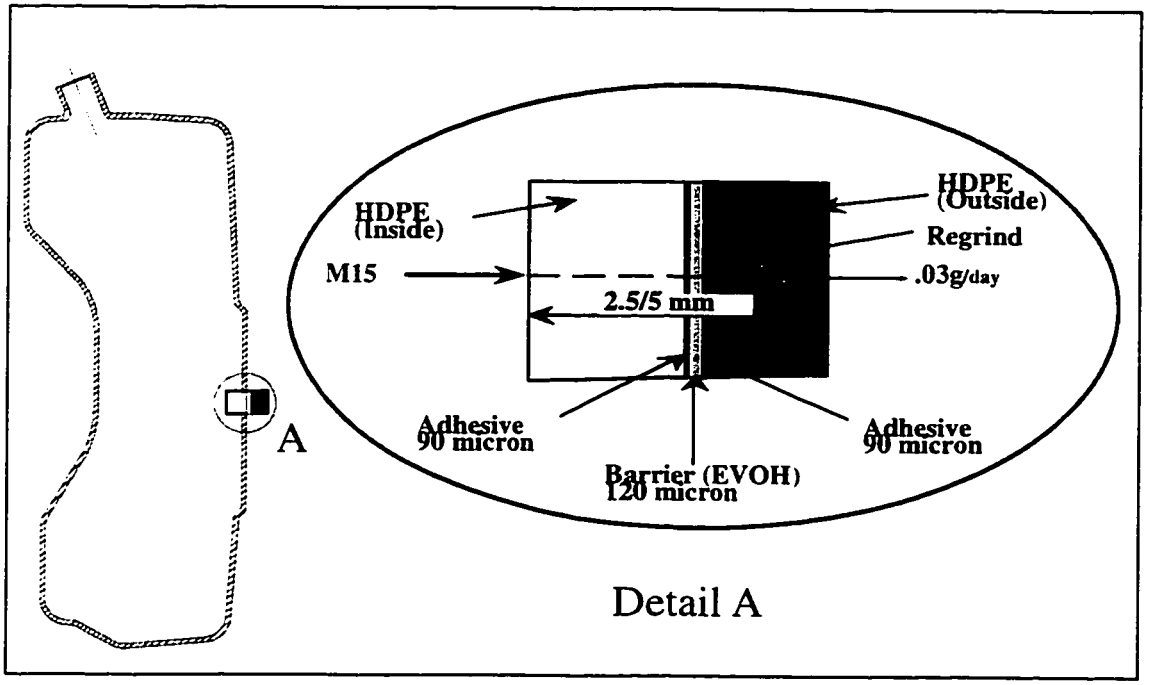

Figure 4.6 Multilayer plastic fuel tank structure [WAC].

Table 4.3 Multilayer plastic fuel tank composition.

Layer	Description	%
1	Outer HDPE (virgin HDPE + PolyBlack)	12%
2	Regrind	40%
3	Outer Adhesive	2.5%
4	Barrier (EVOH)	3%
5	Inner Adhesive	2.5%
6	Inner HDPE (virgin HDPE)	40%

Due to the process characteristics, extrusion blow-molded articles still have parts of the preform attached to them, known as flash, which has to be trimmed. The flash material is then ground and reused as part of the regrind layer.

4.2.1 MANUFACTURING EMISSIONS

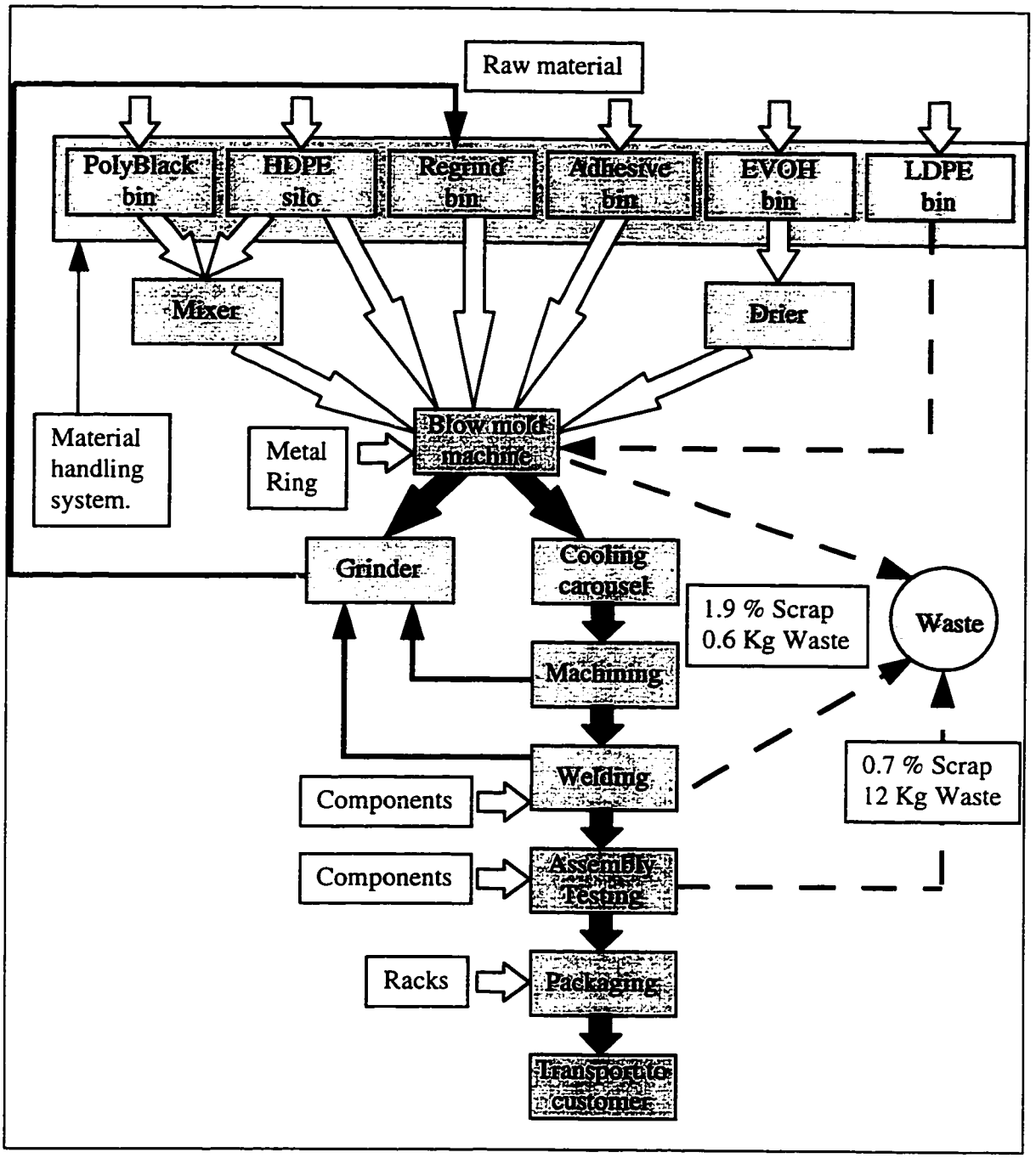

Figure 4.7 Process flow chart - MPFT manufacturing material and emissions.

4.2.2 MANUFACTURING ENERGY REQUIREMENTS

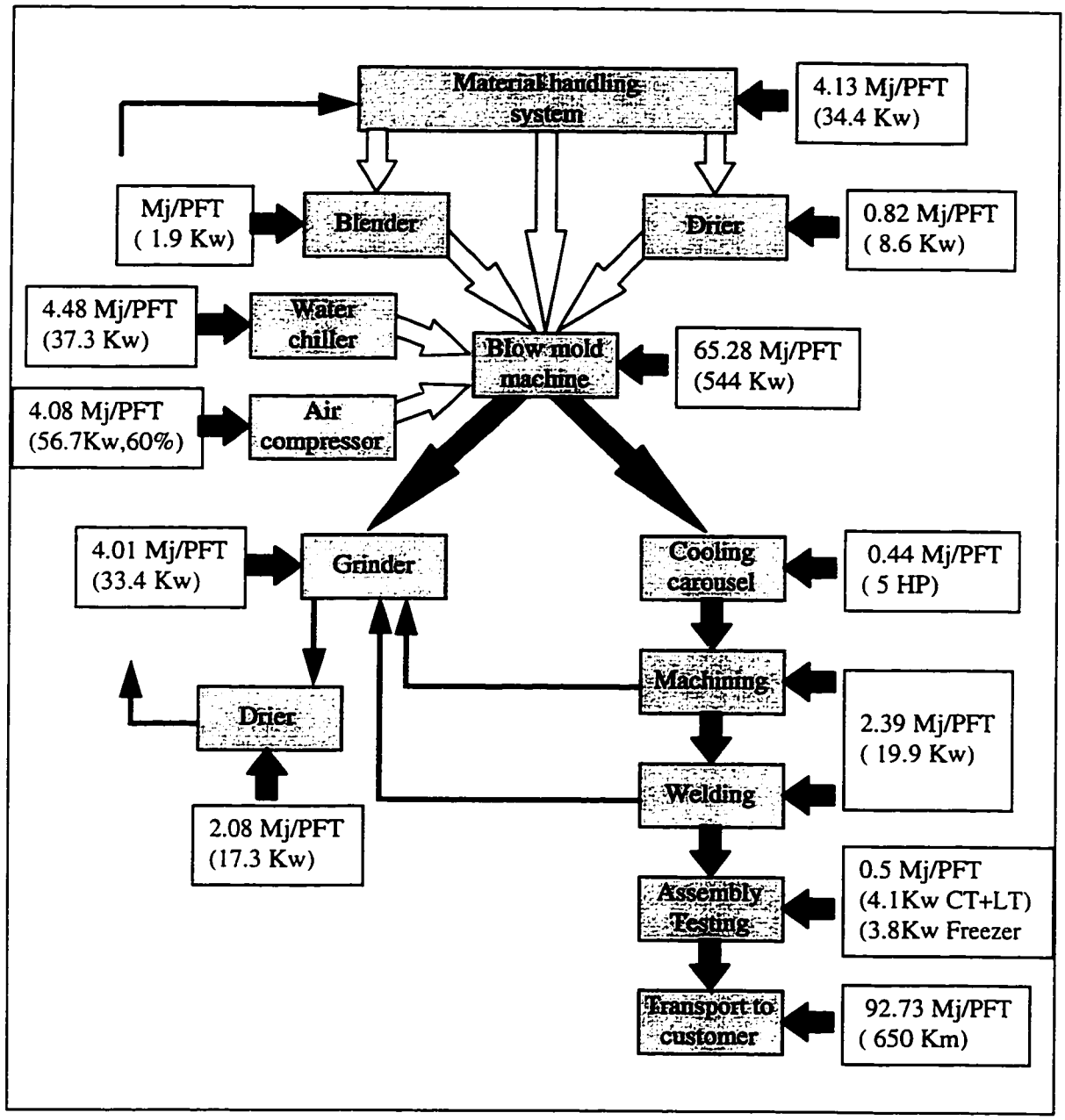

Figure 4.8 Process flow chart - MPFT manufacturing energy input.

Table 4.4 Production data.

Shift	Production	Destructive test (DT)	Total scrap including (DT)
1	222	1	5
2	221	2	11
3	224	1	2
4	226	1	5
5	223	3	6
6	93	1	2
Total	1209	9	31
%	100	0.7	2.6

Table 4.5 Environmental profile - MPFT manufacturing Material Handling System.

PROCESS: HDPE Manufacturing (MH) DATA SOURCE: WAC.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
RAW MATERIAL	15 kg HDPE	**MAIN PRODUCT**	1 MPFT
ENERGY	4.13 MJ / MPFT Electric.	**SOLID WASTE**	0.0 kg / MPFT
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
34.4 [Kw], 30 [MPFT / hr], 12 [kg/MPFT], 3 [kg} (Flash).

ENERGY :
34.4 [KWh] / 30 [MPFT / hr] = 1.147 [KWh / MPFT]
1.147 [KWh / MPFT] X 3.6 [MJ / KWh] = 4.13 [MJ / MPFT]

Table 4.6 Environmental profile - MPFT manufacturing Water Chiller.

PROCESS: HDPE Manufacturing (CH) DATA SOURCE: WAC.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
RAW MATERIAL	WATER Water recirculated in a closed loop system.	**MAIN PRODUCT**	1 MPFT
ENERGY	4.48 MJ / MPFT Electric.	**SOLID WASTE**	0.0 kg / MPFT
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
37.3 [Kw], 30 [MPFT / hr]

ENERGY :
37.3 [KWh] / 30 [MPFT / hr] = 1.243 [KWh / MPFT]
1.243 [KWh / MPFT] X 3.6 [MJ / KWh] = 4.48 [MJ / MPFT]

Table 4.7 Environmental profile - MPFT manufacturing (100 HP) Compressor.

PROCESS: HDPE Manufacturing (CP) DATA SOURCE: WAC.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
RAW MATERIAL	COMPRESSED AIR Compressor 60% ON.	**MAIN PRODUCT**	1 MPFT.
ENERGY	4.08 MJ / MPFT Electric.	**SOLID WASTE**	0.0 kg / MPFT
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
56.7 [Kw], 30 [MPFT / hr], 60% ON.

ENERGY :
56.7 [KWh] / 30 [MPFT / hr] = 1.89 [KWh / MPFT]
1.89 [KWh / MPFT] X 3.6 [MJ / KWh] = 6.80 [MJ / MPFT]
0.6 X 6.80 = 4.08 [MJ / MPFT]

Table 4.8 Environmental profile - MPFT manufacturing Blow Molding # 1.

(1.9% scrap and 0.6kg waste/MPFT)

PROCESS: HDPE Manufacturing (BM) DATA SOURCE: WAC.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
RAW MATERIAL	12. 010 HDPE 1 (0.1 kg) Metal Ring Assume all layers HDPE.	**MAIN PRODUCT**	1 Probe MPFT.
ENERGY	65.28 MJ / MPFT Electric.	**SOLID WASTE**	0.011 kg / MPFT
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
1.9% (SCRAP), 0.6 [kg] (METAL RING CUT OUT) @ 0.1 [kg] (Metal Ring),
544 [Kw] (BM #1), 30 [MPFT / hr] (Production)

WASTE :
1.9% (SCRAP MPFT) X 0.5 [kg/MPFT] = 0.010 [kg / MPFT] (HDPE)
1.9% (SCRAP MPFT) X 0.1 [kg/MPFT] = 0.001 [kg / MPFT] (Metal)
0.010 [kg/MPFT] + 0.001 [kg/MPFT] = 0.011 [kg/MPFT] (Total Waste)

ENERGY :
544 [KWh] / 30 [MPFT / hr] = 18.133 [KWh / MPFT] (Includes melting of Flash)
18.133 [KWh / MPFT] X 3.6 [MJ / KWh] = 65.28 [MJ / MPFT]

Table 4.9 Environmental profile - MPFT manufacturing / Purging.

PROCESS: HDPE Manufacturing (PU) (Startup / Shut Down Purge) DATA SOURCE: WAC		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
NOTE : Applicable to small batches when the BM machine is not dedicated to one project. For this specific case : 8 Start-ups / year, 680 kg Waste / (Start-up&Shut-down) and 2500 MPFT Produced / Start-up, BM #1 Throughput = 360 kg/hr.			
RAW MATERIAL	0.272 kg HDPE Assume all layers HDPE.	**MAIN PRODUCT**	1 Probe MPFT.
ENERGY	1.48 MJ / MPFT Electric.	**SOLID WASTE**	0.272 kg / MPFT
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
680 [kg/Batch] (HDPE Wasted), 2500 [MPFT / Batch] (Necessary for : Purging the Barrier extruder with LDPE for Shut-down and reintroducing EVOH for Start-up.
5.43 [MJ / kg HDPE] (BM #1 Energy consumption).

WASTE :
680 [kg] / 2500 [MPFT / Batch] = 0.272 [kg / MPFT] (Wasted)

ENERGY :
5.43 [MJ / kg] X 0.272 [kg / MPFT] = 1.48 [MJ / MPFT]

Table 4.10 Environmental profile - MPFT manufacturing Grinder # 1.

PROCESS: HDPE Manufacturing (GR) DATA SOURCE: WAC.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
RAW MATERIAL	1.MPFT	**MAIN PRODUCT**	1 Probe MPFT Finished.
ENERGY	4.01 MJ / MPFT Electric.	**SOLID WASTE**	0.0 kg / MPFT
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
33.4 [Kw], 30 [MPFT / hr]

ENERGY :
33.4 [KWh] / 30 [MPFT / hr] = 1.113 [KWh / MPFT]
1.113 [KWh / MPFT] X 3.6 [MJ / KWh] = 4.01 [MJ / MPFT]

Table 4.11 Environmental profile - MPFT manufacturing Cooling Carousel.

PROCESS: HDPE Manufacturing (CC) DATA SOURCE: WAC.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
RAW MATERIAL	1.MPFT	**MAIN PRODUCT**	1 Probe MPFT Finished.
ENERGY	0.44 MJ / MPFT Electric.	**SOLID WASTE**	0.0 kg / MPFT
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
3.7 [KWh] (5 HP), 30 [MPFT / hr]

ENERGY :
3.7 [KWh] / 30 [MPFT / hr] = 0.123 [KWh / MPFT]
0.123 [KWh / MPFT] X 3.6 [MJ / KWh] = 0.44 [MJ / MPFT]

Table 4.12 Environmental profile - MPFT manufacturing Machining / Welding.

PROCESS: HDPE Manufacturing (MW) DATA SOURCE: WAC.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
RAW MATERIAL	1.MPFT 7 Components Welded.	**MAIN PRODUCT**	1 MPFT
ENERGY	2.4 MJ / MPFT Electric.	**SOLID WASTE**	0.0 kg / MPFT All waste already accounted on molding.
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
19.9 [Kw], 30[MPFT/hr]

ENERGY :
19.9 [KWh] / 30 [MPFT / hr] = 0.66 [KWh / MPFT]
0.66 [KWh / MPFT] X 3.6 [MJ / KWh] = 2.4 [MJ / MPFT]

4.2.3 TESTING - EMISSIONS AND ENERGY

Table 4.13 Environmental profile - MPFT manufacturing / Testing.

PROCESS: HDPE Manufacturing (TE). DATA SOURCE: WAC		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT..
NOTE : During production, 2 MPFT / 8 hr are used for destructive testing.			
RAW MATERIAL	2 MPFT 1 [MPFT/Shift] Drop Test 1 [MPFT/Shift] Layer Tk.	**MAIN PRODUCT**	1 Shift - required test.
ENERGY	0.52 MJ / MPFT Electric.	**SOLID WASTE**	0.1 kg / MPFT (HDPE)
TRANSPORT	0.0 MJ / MPFT	**EMISSIONS**	Glycol 0.006 L /MPFT HC 0.0 g / MPFT SO2 0.0 g / MPFT NOx 0.0 g / MPFT CO2 0.0 g / MPFT

CALCULATIONS :
2 [MPFT / Shift], 12 [kg / MPFT], 240 [MPFT / Shift], 2500 [MPFT / Week]
Energy for Freezer 3.8Kw, (3 MPFT / Shift on Freezer), Amount of Glycol 15 [l/week].
0.83 [Kw] (Continuity tester), 3.3 [Kw] (Leak tester)

WASTE :
2 [MPFT/Shift] X 12 [kg/MPFT] / 240 [MPFT / Shift] = 0.1 [kg / MPFT]
15 [L] / 2500 [MPFT] = 0.006 [l/MPFT]

ENERGY :
3.8 [KWh] / 3 [MPFT/Shift] X 3.6 [MJ/KWh] / 240 [MPFT/Shift] = 0.02 [MJ / MPFT]
(0.83 [KWh] + 3.3 [KWh]) X 3.6 [MJ/KWh] / 30 [MPFT/hr] = 0.5 [MJ/MPFT]

4.2.4 TRANSPORTATION - EMISSIONS AND ENERGY

Table 4.14 Environmental profile - MPFT Transportation

(650 km distance to customer)

PROCESS: MPFT Transport DATA SOURCE: Packaging and the Environment 1992 & WAC		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT.
RAW MATERIAL	1 MPFT 1/12 METAL RACK	**MAIN PRODUCT**	1 MPFT at the Customer site.
ENERGY	0.0 MJ/MPFT	**SOLID WASTE**	0.0 kg/MPFT
TRANSPORT	92.8 MJ/MPFT 650 km / Road	**EMISSIONS**	HC 0.0 g/MPFT SO2 0.0 g/MPFT NOx 0.0 g/MPFT CO2 0.0 g/MPFT

CALCULATIONS :
12 [MPFT / RACK], 12 [kg / MPFT], 784 [kg / Rack], 650 [km], ROAD TRANSPORT

TRANSPORT :
12 X 12 [kg / RACK] + 784 [kg / RACK] = 928 [kg] (Rack with 12 MPFT)
928 [kg] / 12 (MPFT) X 0.001 [MJ/kgkm] X 650 [km] = 50.3 [MJ/ MPFT] Full Rack
784 [kg] / 12 (MPFT) X 0.001 [MJ/kg km] X 650 [km] = 42.5 [MJ/ MPFT] EmptyRack
50.3 [MJ/MPFT] + 42.5 [MJ/MPFT] = 92.8 [MJ/MPFT] (During Life-Cycle)

Table 4.15 Transportation Energy [Packaging and the Environment 1992].

#	Type of transport	MJ / tone-km
1	Road, long-distance	1.0
2	Road, short-distance	2.7
3	Rail	0.3 (elec. energy)

4.3 USE - EMISSIONS AND ENERGY REQUIREMENTS

Table 4.16 Environmental profile - MPFT Use.

PROCESS: MPFT Use DATA SOURCE: Packaging and the Environment 1992 & WAC		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT.
RAW MATERIAL	1 MPFT	**MAIN PRODUCT**	1 MPFT in Use.
ENERGY	0 MJ/MPFT	**SOLID WASTE**	0 kg/MPFT
TRANSPORT	2,400 MJ/MPFT 200,000 km / Road	**EMISSIONS**	HC 959.0 g/MPFT SO2 0.0 g/MPFT NOx 0.0 g/MPFT CO2 0.0 g/MPFT

CALCULATIONS :
12 [kg/MPFT], 0.263 [g/24 hr] assembly permeation, 10 years life, 200,000 [km/Life], 0.001 [MJ/kgkm] (Road)

TRANSPORT :
12 [kg] X 200,000 [km/Life] X 0.001 [MJ/kgkm] = 2,400 [MJ/MPFT]

EMISSIONS:
0.263 [g/day] X 3650 [days/MPFT] = 960.0 [g/MPFT]

4.4 EQUIPMENT MAINTENANCE - EMISSIONS AND ENERGY

Table 4.17 Environmental profile - Equipment Maintenance

(Solid Waste to Landfill, Oil Recycled)

PROCESS: MPFT End of Life DATA SOURCE: Packaging and the Environment 1992 & WAC		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT.
RAW MATERIAL	1700L Hydraulic Oil 3 Heater Bands 4 Welding Plates	**MAIN PRODUCT**	1 MPFT
ENERGY	0.0 MJ/MPFT	**SOLID WASTE**	0.0007 kg/MPFT
TRANSPORT	0.0 MJ/MPFT	**EMISSIONS**	HC 0.0 g/MPFT SO2 0.0 g/MPFT NOx 0.0 g/MPFT CO2 0.0 g/MPFT Oil 0.014 l/MPFT (The OIL is Recycled)

CALCULATIONS :
1700 [l/Year] (Hydraulic Oil), 120,000 [MPFT/BMmachineYear] (The Oil is Recycled)
20 [kg] (Heater band), 5 [kg] (Welding plate).
NOTE : The Energy required for - Installing and removing the Down Line (8 times / year)- is unknown and will be neglected.

WASTE :
1700 / 120,000 [MPFT/Year] = 0.014 [l/MPFT]
3 X 20 [kg/Heater band] + 4 X 5 [kg/Welding plate] = 80 [kg/Year]
80 [kg/Year] / 120,000 [MPFT/BMachine Year] = 0.7 [g/MPFT]

4.5 RESULTS - MPFT EMISSIONS AND ENERGY REQUIREMENT

Table 4.18 Environmental profile - MPFT Entire Life Cycle

(Waste to landfill)

PROCESS: MPFT End of Life DATA SOURCE: Table 4.1,5,6,7,8,9,10, 11,12,13,14,16,17.		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT.
RAW MATERIAL	12.382 kg HDPE 0.001 kg Metal Ring 0.0007 kg Metal parts	**MAIN PRODUCT**	1 MPFT Life Cycle.
ENERGY	891 MJ/MPFT (Includes end of life disposal transportation energy.)	**SOLID WASTE**	12.384 kg/MPFT
TRANSPORT	2503.3 MJ/MPFT (Does not include end of life disposal transportation energy.)	**EMISSIONS**	HC 998.1 g/MPFT SO2 10.5 g/MPFT NOx 21.4 g/MPFT CO2 1171.3 g/MPFT

CALCULATIONS :

12.382 [kg / MPFT] (HDPE), 0.85 [MJ/kg] (Transport HDPE), 2492.8 [MJ/MPFT] (Transport MPFT), 86.82 [MJ/MPFT] (Mfg + Use], 65.47 [MJ/kg] (HDPE production), 3.161 [g/kg] (HC Emission -HDPE), 959 [g/MPFT] (Emission from permeation), 0.849 [g/kg] (SO2 Emission -HDPE), 1.728 [g/kg] (Nox Emission -HDPE), 94.6 [g/kg] (CO2 Emission -HDPE),

TRANSPORT :

0.85 [MJ/kg] X 12.382 [kg/MPFT] + 2492.8 [MJ/MPFT] = 2503.3 [MJ / MPFT]

ENERGY:

86.82 [MJ/MPFT] + 65.47 [MJ/kg] X 12.382 [kg/MPFT] = 891 [MJ / MPFT]

SOLID WASTE:
12.382 [kg/MPFT] + 0.0.002 [kg/MPFT] = 12.384 [kg/MPFT]

EMISSIONS :
(HC)
3.161 [g/kg] X 12.382 [kg / MPFT] (HDPE) = 39.14 [g / MPFT] (Production of HDPE)
959 [g/MPFT] + 39.14 [g/MPFT] = 998.1 [g / MPFT]

(SO2)
0.849 [g/kg] X 12.382 [kg/MPFT] = 10.5 [g / MPFT] (Production of HDPE)

(NOx)
1.728 [g/kg] X 12.382 [kg/MPFT] = 21.4 [g / MPFT] (Production of HDPE)

(CO2)
94.6 [g/kg] X 12.382 [kg/MPFT] = 1171.3 [g / MPFT] (Production of HDPE)

Table 4.19 Environmental profile - MPFT Entire Life Cycle

(Waste Incinerated)

PROCESS: MPFT End of Life DATA SOURCE: Packaging and the Environment 1992 & WAC		ENVIRONMENTAL DATA SHEET Date: Nov. 22, 1996	
INPUTS	Per Probe MPFT.	**OUTPUTS**	Per Probe MPFT.
RAW MATERIAL	12.382 kg HDPE 0.001 kg Metal Ring 0.0007 kg Metal parts	**MAIN PRODUCT**	1 MPFT End of Life
ENERGY	417.9 MJ/MPFT (Includes end of life disposal transportation energy.)	**SOLID WASTE**	12.384 kg/MPFT
TRANSPORT	2503.3 MJ/MPFT (Does not include end of life disposal transportation energy.)	**EMISSIONS**	HC 989.2 g/MPFT SO2 -173.3 g/MPFT NOx 32.3 g/MPFT CO2 1219.6 g/MPFT

CALCULATIONS :
12.382 [kg / MPFT] (HDPE), 0.85 [MJ/kg] (Transport HDPE), 2492.8 [MJ/MPFT] (Transport MPFT), 86.82 [MJ/MPFT] (Mfg + Use], 26.74 [MJ/kg] (HDPE production), 2.441 [g/kg] (HC Emission -HDPE), 959 [g/MPFT] (Emission from permeation), -14.0 [g/kg] (SO2 Emission -HDPE), 2.605 [g/kg] (Nox Emission -HDPE), 98.5 [g/kg] (CO2 Emission -HDPE),

TRANSPORT :
0.85 [MJ/kg] X 12.382 [kg/MPFT] + 2492.8 [MJ/MPFT] = 2503.3 [MJ / MPFT]

ENERGY:
86.82 [MJ/MPFT] + 26.74 [MJ/kg] X 12.382 [kg/MPFT] = 417.9 [MJ / MPFT]

SOLID WASTE:

12.382 [kg/MPFT] + 0.0.002 [kg/MPFT] = 12.384 [kg/MPFT]

EMISSIONS :
(HC)
2.441 [g/kg] X 12.382 [kg / MPFT] (HDPE) = 30.22 [g / MPFT] (Production of HDPE)
959 [g/MPFT] + 30.22 [g/MPFT] = 989.2 [g / MPFT] (Total HC Emissions)

(SO2)
-14.0 [g/kg] X 12.382 [kg/MPFT] = -173.3 [g / MPFT] (Production of HDPE)

(NOx)
2.605 [g/kg] X 12.382 [kg/MPFT] = 32.3 [g / MPFT] (Production of HDPE)

(CO2)
98.5 [g/kg] X 12.382 [kg/MPFT] = 1219.6 [g / MPFT] (Production of HDPE)

CHAPTER V

IMPACT ASSESSMENT

5.1 GASOLINE PERMEABILITY AND REDUCTION IN PERMEATION

High density, high molecular weight polyethylene has been a material in demand for fuel tanks for almost 15 years. The freedom in choice of shape, the weight saving compared to sheet steel tanks of the same capacity, simple fabrication by extrusion blow molding and simple assembly in the vehicle are features, offered to make mass production more cost-effective. Compared with steel, polyethylene is not fully impermeable to gasoline, but it can never rust. Processes which are used in the present are fluorination, sulphonation, cellar, and coextrusion of multilayer tanks (EVOH - barrier layer).

The motor vehicle-related air toxics study is the result of the first directive of Section 202 (1) of the Clean Air Act, which directed EPA to complete a study by May 15, 1992 of the need for, and feasibility of, controlling emissions of the toxic air pollutants which are unregulated under this Act and associated with motor vehicles and motor vehicle fuels. Specific pollutants or pollutant categories discussed in this report include benzene, formaldehyde, 1,3-butadiene, acetaldehyde, diesel particulate, gasoline particulate, gasoline vapors as well as selected metals.

5.1.1 GASOLINE VAPORS

Unleaded gasoline is a refined product of crude oil (petroleum) composed of a complex mixture of hydrocarbons, additives, and blending agents. This mixture of hydrocarbons that distills within the range of 100 to 400°F is comprised of paraffins (alkanes), olefins (alkenes), and aromatics. Compounds containing sulfur, nitrogen, and oxygen are also present in the gasoline refinery streams.

Gasoline exists in two phases, liquid and vapor, with the hydrocarbon compositions being different. Liquid gasoline consists principally of 66 to 69 percent paraffins (alkanes), 24 to 27 percent aromatics, and 6 to 8 percent olefins (alkenes) (Battelle, 1985). Gasoline vapors consist mainly of short-chained and iso-alkanes.

Gasoline vapors are also released from the vehicle itself through evaporative and tailpipe emissions. Vapors released into the atmosphere are subject to the processes of transport, dilution, and dispersion, thus, spreading the vapor over a wide area. Due to the differences in the partial pressure of various hydrocarbons, gasoline vapors emitted in the manner described above, consist of relatively more of the lighter compounds (e.g., alkanes) and less of the heavier ones (e.g., branched alkanes) than liquid fuel.

The effect of gasoline vapors has been divided in carcinogenic and non-carcinogenic effects. The carcinogenic effects are summarized from NESCAUM (1989) in Table 5.1.

Table 5.1. Summary of Ambient Concentrations and Exposure Doses Associated with Exposure to Gasoline and Benzene (NESCAUM, 1989).

{PRIVATE }Scenario	Ambient Concentrations (mg/m^3)		Estimated Exposure Doses based on alveolar ventilation (mg/kg/day)	
	Mean	Maximum	Mean	Maximum
Scenario 1: Self-service customer at gas station exposed via inhalation.				
Gasoline	369.8	1882.3	9.4×10^{-3}	1.0×10^{-1}
Benzene	2.9	13.4	7.3×10^{-5}	7.2×10^{-4}
Scenario 2: Gas station attendant exposed via inhalation.				
Gasoline	54.6	-	1.8	-
Benzene	0.6	4.1	$21.\times10^{-2}$	1.4×10^{-1}
Scenario 3: Resident living downwind of gas station exposed via inhalation.				
Gasoline	1.5×10^{-2}	7.7×10^{-2}	3.1×10^{-3}	1.6×10^{-2}
Benzene	1.3×10^{-4}	5.1×10^{-4}	2.6×10^{-5}	1.1×10^{-4}

5.1.2 NON-CARCINOGENIC EFFECTS

Exposure to gasoline vapors through inhalation at low concentrations and/or acute exposure may cause a variety of symptoms including respiratory tract irritation and burning with cough and sore throat, and central nervous system depression with headache, nausea, and mental confusion.

5.1.3 LOW LEVEL OZONE

Hydrocarbons react in the presence of nitrogen oxides and sunlight to form ground-level ozone, a major component of smog. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems. It is our most widespread and intractable urban air pollution problem Figure 1.2.

5.2 BENZENE

The Benzene molecule C_6H_6 is the cornerstone for aromatic compounds, most of which contain one or more benzene rings. Benzene is a clear, colorless, aromatic hydrocarbon which has a characteristic sickly, sweet odor.

Benzene is present in both exhaust and evaporative emissions. Data show the benzene level of gasoline to be about 1.5%. The fraction of benzene in the evaporative emissions also depends on the fuel composition and other factors and is generally about 1%. Approximately 60% of total benzene emissions can be attributed to on road motor vehicles, and this is split between exhaust and evaporative benzene emissions at about 80% exhaust and 20% evaporative. Thus the overall benzene fraction was estimated to be 3.89% of exhaust hydrocarbon and 1.04% of evaporative hydrocarbon emissions.

Benzene is minimally reactive in the atmosphere, this gives benzene long-term stability in the atmosphere.

The total amount of benzene released through evaporation from the MPFT assembly during the life-cycle of the MPFT is about 10 g [Table 4.18].

5.2.1 CARCINOGENICITY OF BENZENE

The weight-of-evidence indicates that benzene is a Group A, known human carcinogen. This is based on sufficient human epidemiologic evidence [Rinsky et al. 1981; Ott et al. 1978; Wong et al. 1983].

5.3 CARBON DIOXIDE CO2

Carbon dioxide emissions from fossil fuel combustion have been growing (except WWar I, and WWar II)at the rate of 4.3% per year since 1960. The global warming effects can be attributed in part to this increase of CO2 in the atmosphere. EPA states that the limits on vehicle-generated carbon dioxide may become important in the future

5.4 SULFUR DIOXIDE SO2

The SO2 released produces acid rain which in turn affects the acidification of lakes and changes of the ecosystem. The effect of Incineration versus landfill disposal has a great impact on the amount of SO2 released into the atmosphere. Table 4.1 and Table 4.2 comparison shows a 15 times lower SO2 emissions if the HDPE is incinerated (compared to burning of oil).

CHAPTER VI

IMPROVEMENT ANALYSIS

Since 1971, fuel tanks on cars have been designed as a closed system in which vapors that evaporate from gasoline in the tank are not released into the atmosphere. The system is sealed and under pressure so that excess vapors are shunted to a canister filled with charcoal known as the evaporative canister.

Some of the improvements specially concerning the design of the MPFT can further decrease the environmental burden specific to this product.

6.1 PRODUCT IMPROVEMENT

It is recommended the use of molded thread for the fuel sender unit module, Figure 6.1, as opposed to encapsulated metal ring Figure 6.2 or a plastic/metal ring assembly Figure 6.3. These improvements would considerably decrease the amount of waste generated during manufacturing. In the case of metal fuel sender unit (FSU) ring, the plastic material in the FSU ring area can not be recycled due to the difficulty of separating the encapsulated metal component. Scrapping one probe MPFT will generate approximately 0.6 kg of solid waste. The design / selection of components as Roll Over Valve (ROV), Fill Limit Vent Valve (FLVV), Check Valve (CV) etc is another factor in improving the disassembly of the PFT.

Some of these items which are welded on the PFT use metal components which require cutting the adjacent area of the fuel tank in order to remove these contaminating materials, and consequently increase the amount of solid waste.

The integration of the fill neck into the design of the PFT and the elimination of the fill pipe gasket interface which has higher permeability of HC than the multilayer material, would also improve the environmental performance of the PFT.

Figure 6.1 Fuel sender unit assembly using molded thread.

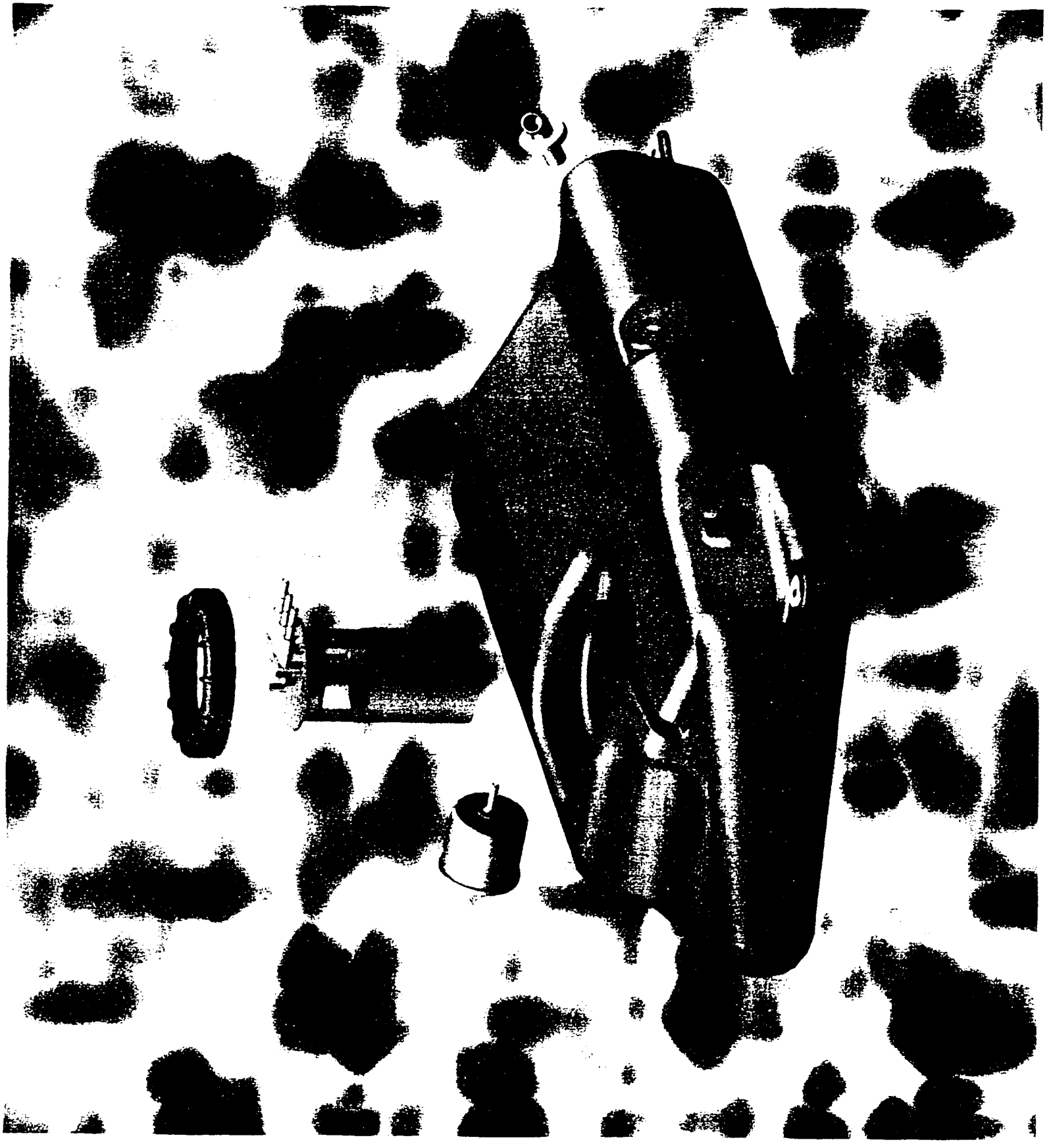

Figure 6.2 Fuel sender unit (exploded view) using molded thread.

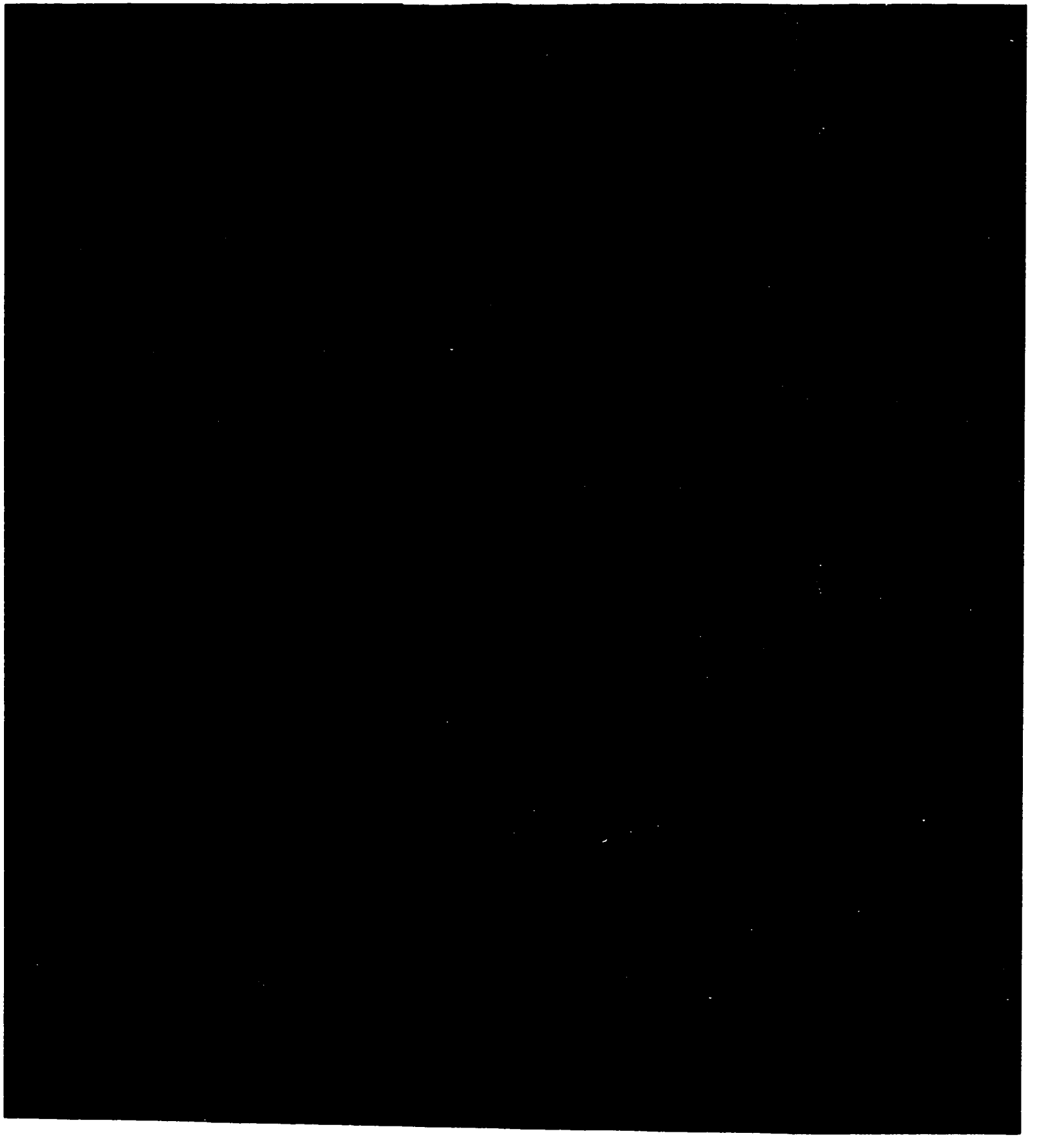

Figure 6.4 Fuel sender unit assembly using welded ring assembly.

6.2 PROCESS IMPROVEMENT

Process improvements include the minimization of preblow variation, and careful use of die profiling, for reducing the amount of flash material. Even though all the flash material is recycled, energy savings (used for grinding and melting) can be achieved by the minimization of flash. Significant energy conservation (without requiring additional equipment) can also be achieved by recuperating of heat generated by the water chilling equipment, which can be then used for heating the plant area during the cold season.

6.3 EMISSION REDUCTION

A significant amount of work has been done over the last twenty years on reducing the HC emissions of the PFT assembly.

The time / emission analysis of a car performance, Figure 6.5 shows a significant increase of HC emissions over time [EPA, 1996]. The parallel investigation of the time / emission performance regarding the multylayer fuel storage systems Figure 6.6 shows a consistent HC barrier performance over time, well below the required OEM standards.

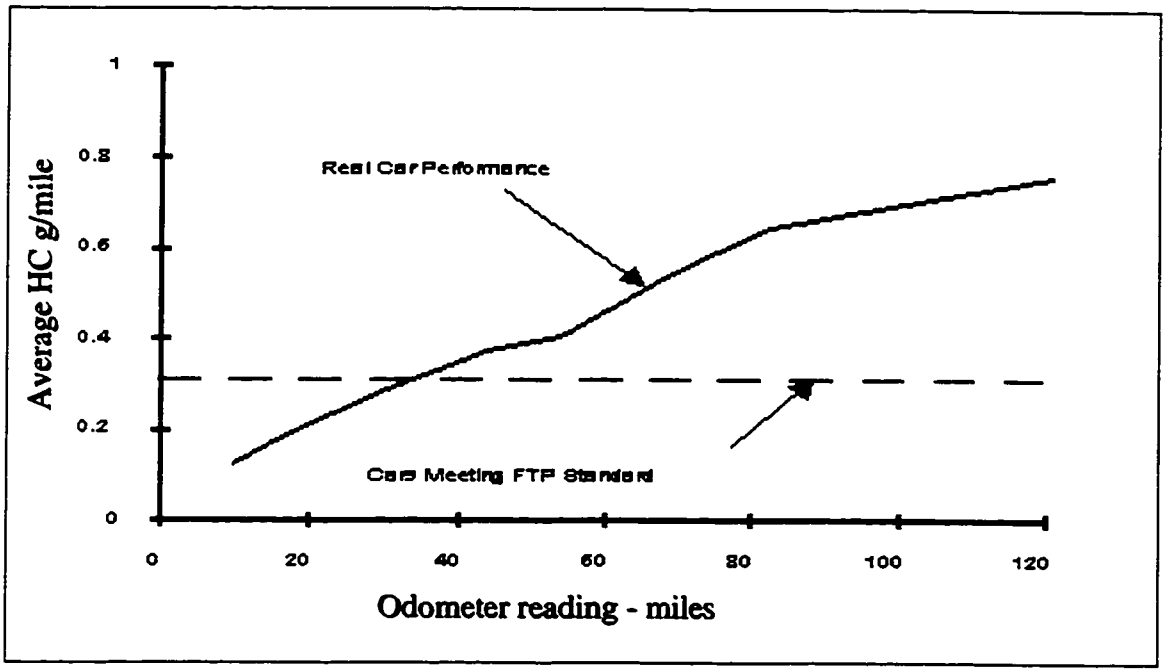

Figure 6.5 Vehicle HC emissions vs. Time [EPA].

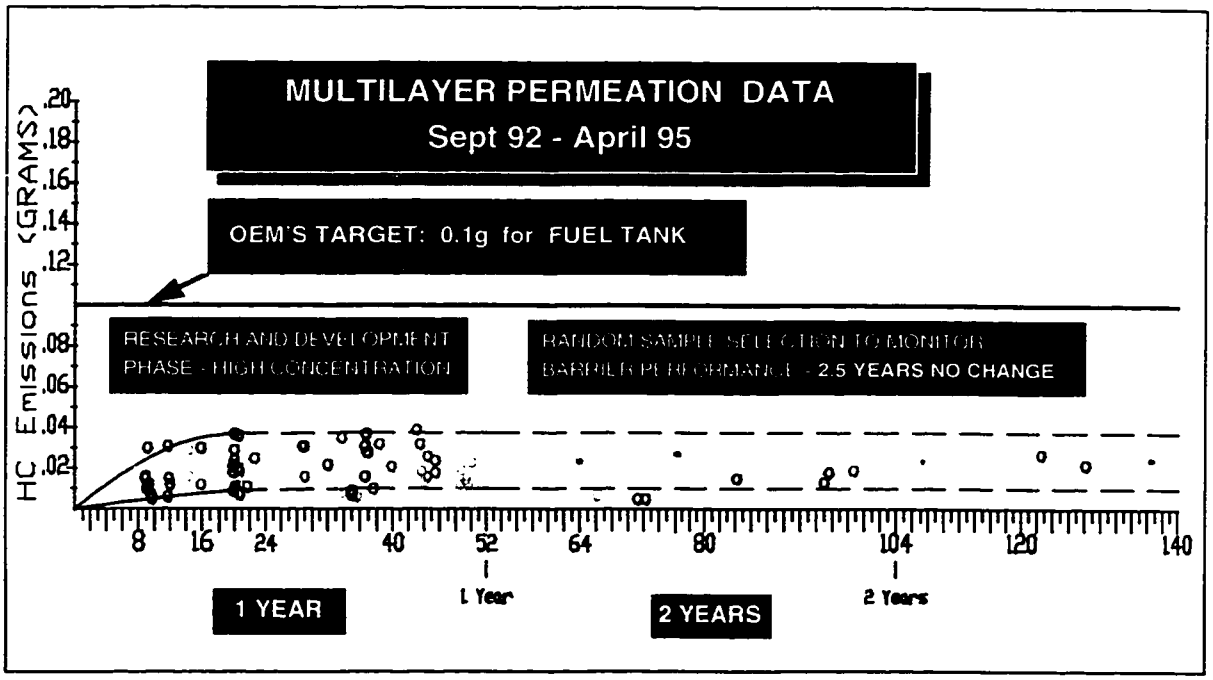

Figure 6.6 Multilayer plastic fuel tank - Permeation Data [WAC].

The corrosion of the metal fuel tank (alcohol fuels) specially in the weld area where the protective coating is removed, and the degradation of the surface barrier layer of the surface treated PFT's due to slosh, results in increased HC permeation rate over the life of the vehicle. The MPFT avoids all of these effects by using a barrier layer (EVOH), which is protected by HDPE layers on each side.

The use of alcohol fuels is made possible by the plastic fuel tank, this results in a further reduction of the total amount of emissions of the vehicle. Hydrocarbon permeation data for different test fuels (oxygenated fuels or fuel blends with lower vapor pressure) also shows a consistent barrier performance of the multilayer plastic fuel tank over time. In order to reduce the amount of harmful emissions, the OEM's investigated a number of alternate fuels. Fuel blends with up to 80% ethanol are considered by the OEM's, which would require the use of Stainless Steel for corrosion protection, or the use of plastic fuel tanks. The use of Stainless Steel would greatly increase the price of the fuel storage system.

The performance of the fuel storage systems related to alternate fuels Figure 6.7 and Figure 6.8, shows that the multylayer technology can perform significantly better than surface treatment methods (using F2 or SO3).

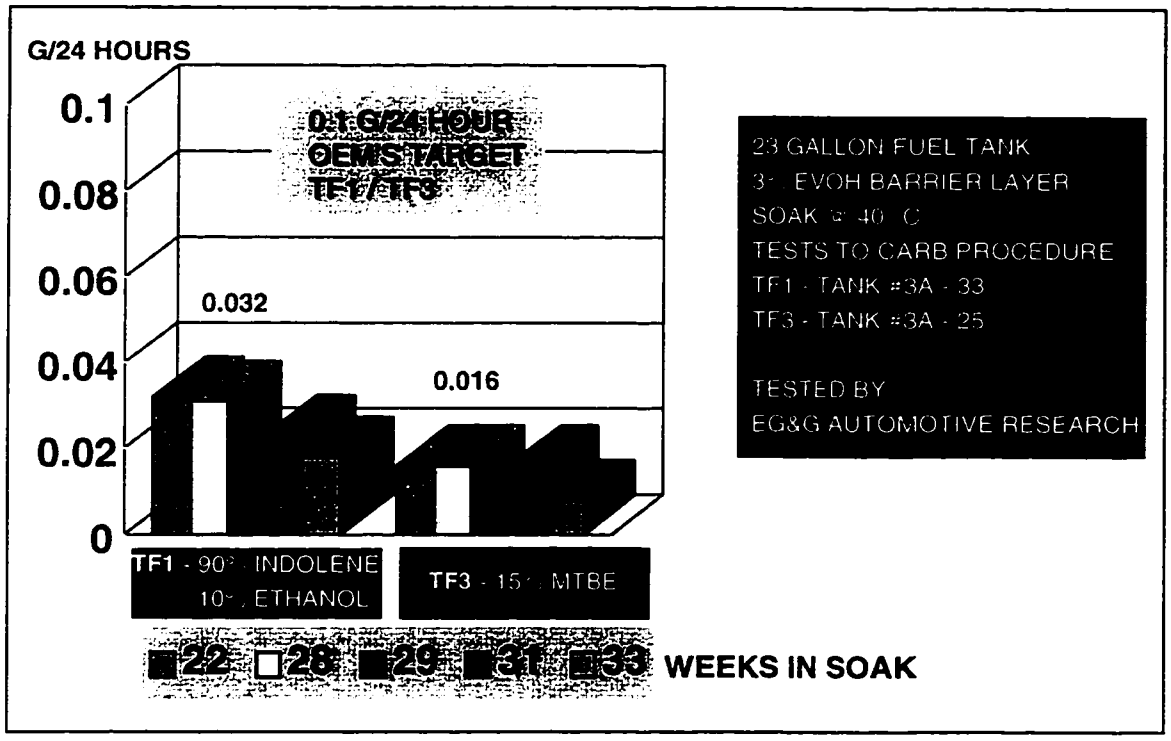

Figure 6.7 Multilayer plastic fuel tank - TF1 and TF3 Fuel Testing Results [WAC].

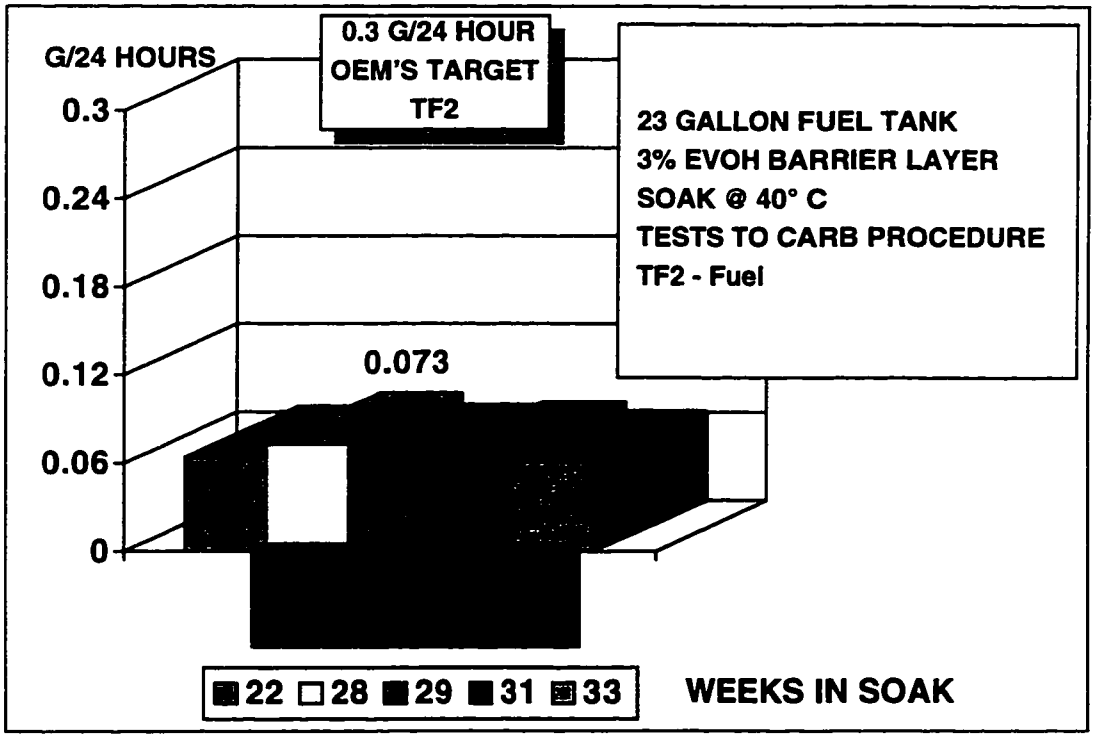

Figure 6.8 Multilayer plastic fuel tank - TF2 Fuel Testing Results [WAC].

Tests show that total aggregate toxics were 9-32% lower with reformulated gasoline C2 than with Fuel A in all the older and current cars.

- Fuel A is the historic baseline for fuel-effects testing.

- Fuel C2 was blended from refinery streams available prior to 1996, contain MTBE (the oxygenate used at 11%).

The emission levels of Nonmethane hydrocarbon (NMHC), CO, and NOx emissions were lower on all cars. Formaldehyde and benzene are the predominant species, Acetaldehyde and 1,3 butadiene, were present in lesser amounts.

Reactivity weighted emissions were significantly lower with reformulated gasoline C2 than with gasoline A. Decreases in RWE ranged from 16% in the Older fleet to 30% in the current cars.

Considerable improvements on HC emission reduction continue to be made especially in the interface areas by eliminating the grommet / gasket interfaces, with the weldment of these components directly on the fuel tank surface Figure 6.9 and Table 6.1.

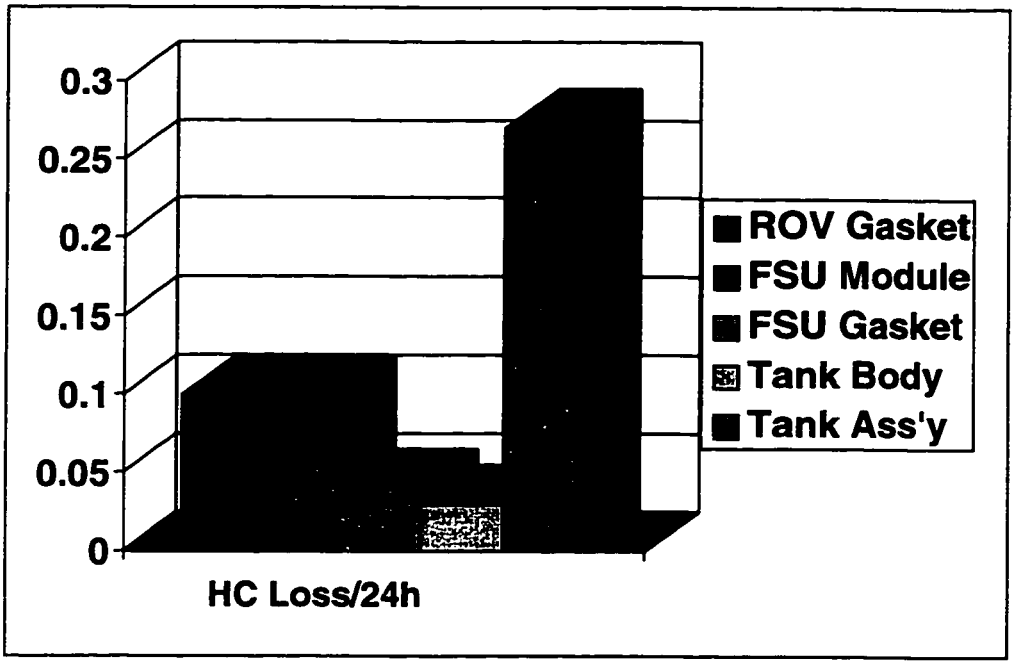

Figure 6.9 HC loss (g/24h) / component (PFT tank body) [WAC].

Table 6.1. Fuel Tank Assembly - Permeation Contribution [WAC].

DESCRIPTION	WEEKS SOAK	TANK #C3.21 GRAMS/24 HOURS	TANK #C3.56 GRAMS/24 HOURS
STATIC SOAK @ 40°C FULL TANK ASSEMBLY	8		
1,000,000 SLOSH CYCLES @ 40°C PERMEATION TEST TANK ASSEMBLY	16	0.261	.0.217
STATIC SOAK @ 40°C PERMEATION TEST TANK ASSEMBLY	69	0.287	0.239
ASSEMBLY MINUS ROV/GROMMET	69.25	0.188 (0.099)	0.214 (0.025)
ASSEMBLY W/O ROV/GROMMET MINUS FILL/VENT HOSES	69.5	0.184 (0.004)	0.209 (0.005)
ASSEMBLY W/O ROV/GROMMET, FILL/VENT HOSES MINUS FSU MODULE	69.75	0.082 (0.102)	0.075 (0.134)
FSU MODULE GASKET	70	0.046	0.041
TANK BODY CONTRIBUTION	70	0.036	0.034

TANK CAPACITY - 23 GALLONS UTILIZING 3% EVOH
CUSTOM REFERENCE 'C' FUEL - 24 HOUR CARB PROCEDURE
(REF 'C' FUEL - 47.5% ISO-OCTANE, 47.5% TOLUENE, 5% ISO-BUTANE)

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONTINUOUS IMPROVEMENT

With ozone continuing to present a persistent urban air pollution problem, future vehicle emission control programs will emphasize hydrocarbon and nitrogen oxide reductions Figure 7.1. Carbon monoxide control will remain critical in many cities, and limits on vehicle-generated carbon dioxide may become important in the future.

A large influence regarding hydrocarbons emission lies with the type of fuel used (some are corrosive making them unsuitable to metal fuel tanks) and it's vapor pressure. The vehicle exhaust emissions are also influenced by the type of fuel used (alcohol fuels). The utilization of multilayer plastic fuel tank greatly increases the number of options of using alternate fuels and indirectly decrease the amount of emissions generated by the vehicle.

Extensive testing has been performed for developing a technology that will ensure both a good barrier performance Figure 7.2, combined with the ability to integrate different components like filler neck, and weld components to fuel tank, significantly reducing the hydrocarbon emission compared to other technologies including metal fuel tanks.

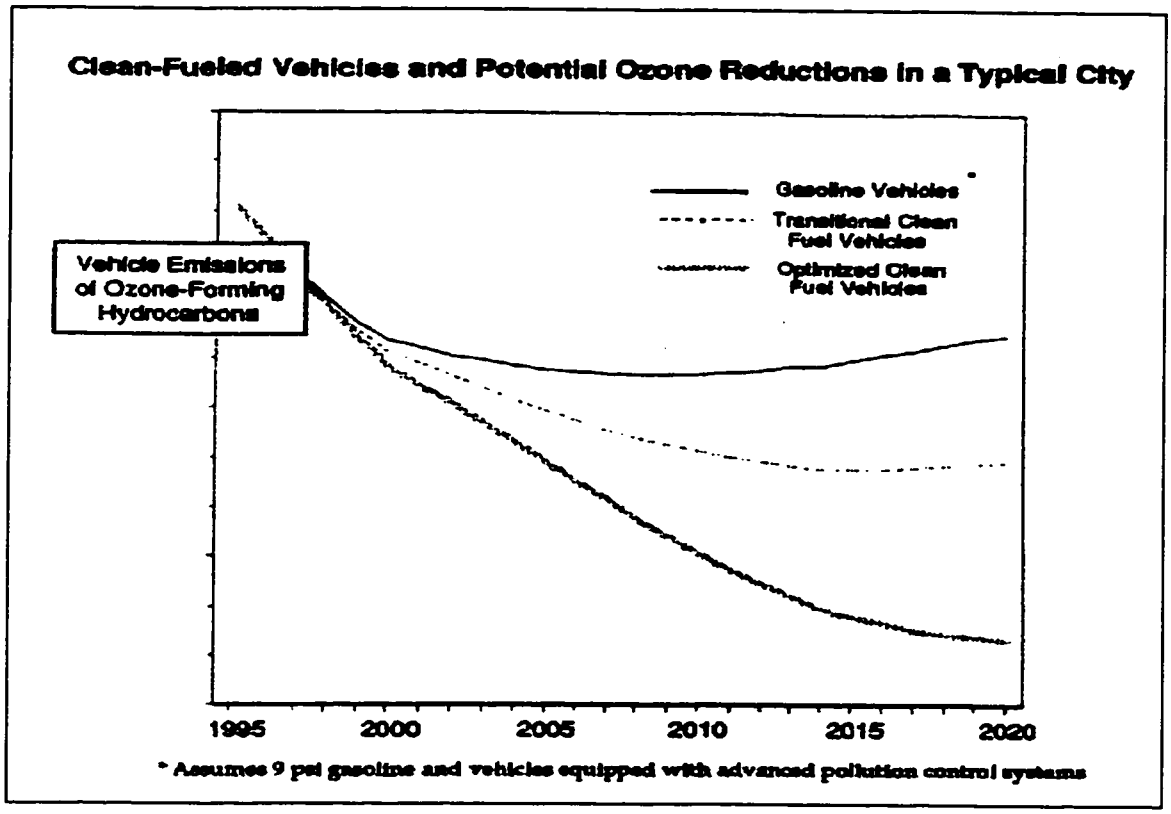

Figure 7.1. Hydrocarbon emission vs. alternate fuels [EPA].

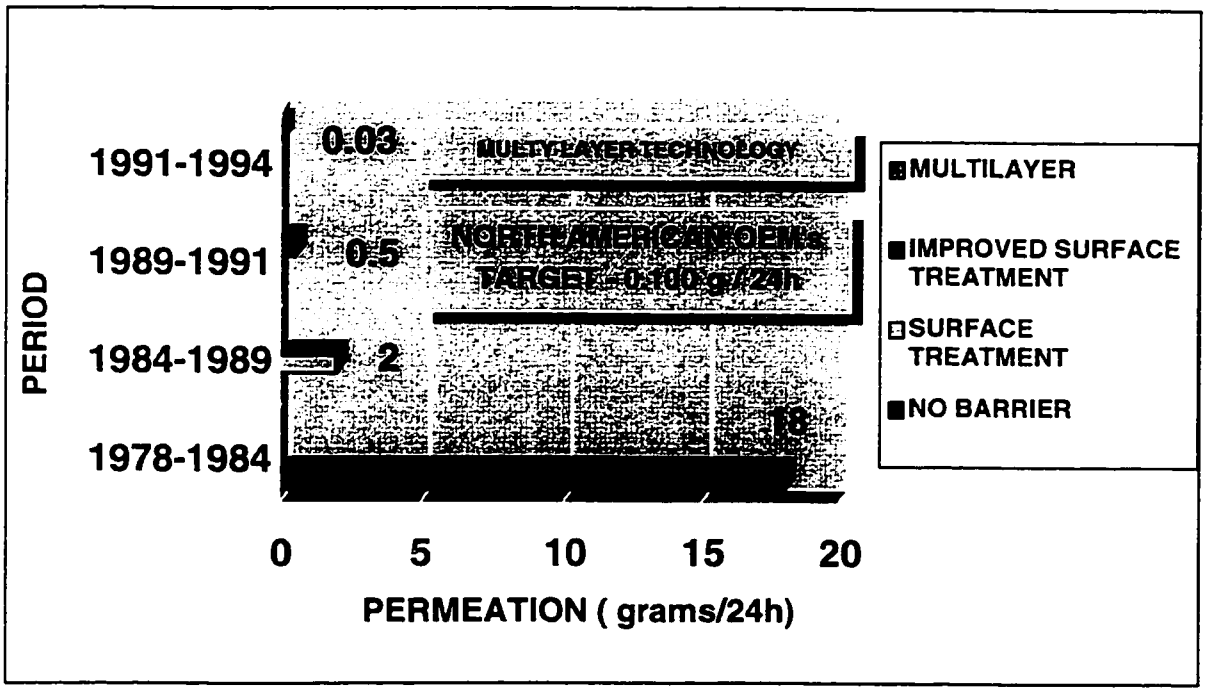

Figure 7.2. Barrier improvement history [WAC].

The plastic fuel tank has the advantage that some of the high permeation interfaces (vent nipples or filler neck for example) can be eliminated as compared to a metal fuel tank by welding of the plastic components directly on the plastic tank or integrating the fill pipe together with the plastic tank. It also reduces gas consumption by approximately 25% compared to a similar volume metal fuel tank due to the reduced weight (approximately 75% of a metal fuel tank), also uses all generated process materials like flash and most of the scrap in a closed loop system thus minimizing the environmental impact.

As opposed to surface treatment technologies (F2 or SO3), the multilayer plastic fuel tank does not require any highly reactive substances and consequently additional environmental loading, in order to generate the HC barrier.

From the life cycle inventory, we can conclude that a significant (15 g/kg) reduction in SO2 generation can be achieved if the material of the PFT is incinerated instead of landfilled. Approximately 65 % of the energy put into the material (HDPE) can be recovered by incineration.

The amount of scrapped materials can be divided in :

1. process scrap,
2. destructive testing.

While the process scrap is primarily a function of the equipment capability and technical knowledge and experience of the production technicians, the destructive testing of the MPFT can be significantly reduced by applying non destructive techniques as ultrasonic layer distribution measurements instead of microtome analysis.

7.2 THE RECYCLING OPTION

A number of tests have been performed since 1990 in order to investigate alternate methods to landfill disposal and incineration of plastic fuel tanks. The [Plastics Week, 1/23/95], discusses this issue in the article "Is it practical to recycle plastics gas tanks?", and exposes the opinion of Mr. Mark Ellis of Nissan's European Technology Center. Mr. Ellis's opinion is that the in-plant scrap should be recycled, but rejects the closed-loop recycling of post-consumer HDPE tanks.

BASF in Europe and PAXON Polymer Co. (producers of HDPE) in US have investigated the option of recycling the HDPE material of the plastic fuel tanks, and the feasibility of using this recycled material for the manufacture of less demanding products.

In the US, the plastic gas tanks are not recycled, they are removed from cars in junk yards and find their way into landfills along with other automotive plastics.

In 1994 PAXON and Ford Motor Co. have agreed "to find a way to see that at the end of their lives, the plastic gas tanks used on their (Ford) vehicles are disposed of in an environmentally acceptable manner."

Two procedures were identified to prove viable - Mechanical Recycling and Advanced Feedstock Recycling.

7.2.1 PYROLYSIS

Another approach involves pyrolysis of MPFT to recover chemical feedstock. Pyrolysis is an ideal means of dealing with the complex, heterogeneous mixture of polymeric materials.

- Pyrolysis offers several advantages such as :
- Large volume reduction.
- Reduced potential air pollution problems over incineration.
- Production of salable products.
- Energy production.

Pyrolysis experiments were performed by PAXON and Conrad Industries of Chehalis Washington. Pieces of shredded gas tanks are heated in the absence of air to 1000 - 1400 F and the gaseous and liquid products are collected for use as chemical feedstocks.

The experimental results are as follow [Conrad Industries, of Chehalis Washington] :

The results at low temperature (1100 F) :

Liquid product - 70 % (by weight charge)

Composition : 92% aliphatic

: 4% aromatic

: 4% unidentified

Carbon number range C6 through C50

Gaseous product - 29 % (by weight charge)

Composition : C1 through C5

Residue - 1% (by weight charge) carbonaceous.

The results at high temperature (1400 F) :

Liquid product - C6 through C50

Composition : 85 % aliphatic

: 13% aromatic

: 2% unidentified

Gaseous product - C1 through C5

A number of 'Pros' and 'Cons' were pointed out by PAXON and Conrad Industries, some of them are:

Pros :

- Gas tanks represent a clean consistent feedstock
- Pyrolysis products :

  consistent composition

  wholly hydrocarbon

  possibly easy to use as chemical feedstocks
- Procedure proved commercially viable in Europe.

Cons :

- Need collection and transport to Advanced Recycling (AR)
- Represent trivial amounts of feedstock to petrochemical plants
- Low value products

Requires capital investment to set up AR plants.

7.2.2 MECHANICAL RECYCLING

The closed-loop recycling of post-consumer gas tanks is more complex. The difficulties are cause by the fuel absorbed into the plastic and the cost of the safety procedures this requires. Nissan found it necessary to grind the used HDPE tanks in an inert atmosphere, due to the low flash point of gasoline absorbed into the plastic. The ground material must then be washed and vacuum dried to remove residual gasoline. Impact resistance of material recovered in this way is only 70% that of virgin HDPE. The high cost of this processing, combined with the reduced impact strength, makes this material impractical for the production of new gas tanks.

Similar tests were performed during 1995 - 1996 by PAXON and K.W. Plastics of Troy Alabama. According to K.W. Plastics the fully soaked fuel tanks can be safely shredded and granulated. The regrind was processed through the wash system, dried, and repelletized. The initial tests show that the wash system does not remove enough hydrocarbons. The total hydrocarbons were measured by Headspace GC (C6 and lower) and GC/MS (octane, toluene and aromatics, C8 and higher), Table 7.1.

Table 7.1 Plastic Fuel Tank - Mechanical Recycling results [K.W. Plastics].

Regrind	C6 and lower	Octane	Toluene	Aromatics	Total HC %
no wash	7380	19300	3740	644	3.1
1 wash	6610	15200	3010	633	2.5
2 wash	5950	13200	1680	772	2.2
3 drying	2550	16000	1250	450	2.0
2 purge	83	2150	423	190	0.28
4 purge	246	944	426	283	0.19

7.3 FUTURE DIRECTIONS

The PFT project considered for this Life-Cycle Assessment study is far from having a typical yearly production volume. This significantly increases the amount of solid waste generated per MPFT. The sample MPFT in this study has 20,000 MPFT/year production volume, and it is currently run in 8 batches during the year. Start-up and shut-down of each batch results in about 680 kg of wasted HDPE (purging), which means about 5.5 ton of solid waste generated during one year. While this represents the worst case scenario with regards to solid waste generated, a more realistic scenario would be to consider an average PFT production volume (of about 100,000 to 150,000 PFT/year). This would significantly reduces the amount of solid waste / MPFT from purging and would represent a more realistic LCA for the average MPFT.

While the life-cycle inventory data has been collected from the PFT production facility, the data used for the Life-cycle inventory of HDPE is specific for Sweden. A more accurate MPFT LCA could be obtained if data specific for the North American HDPE production would be used.

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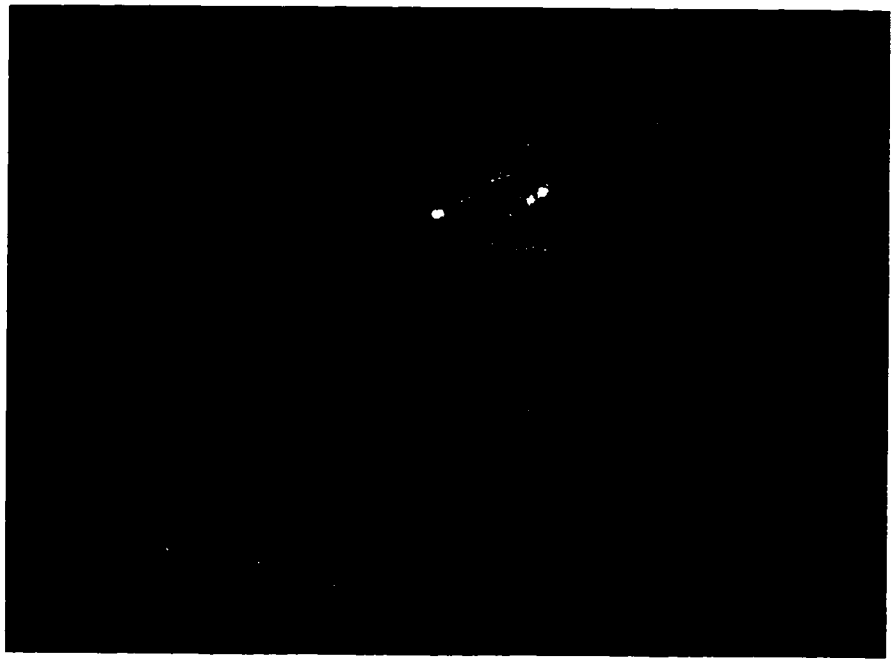
VITA AUCTORIS



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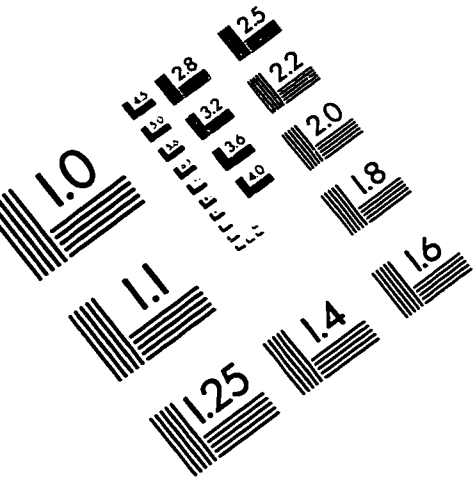
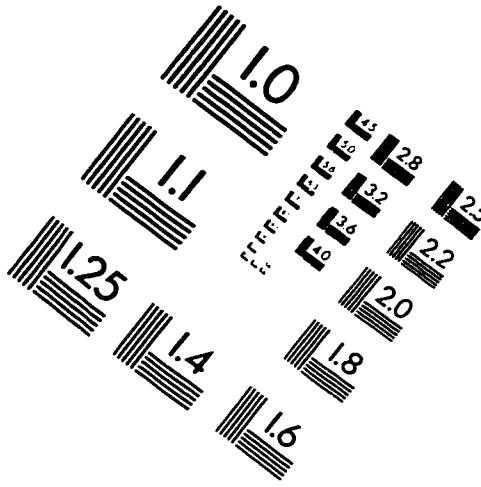
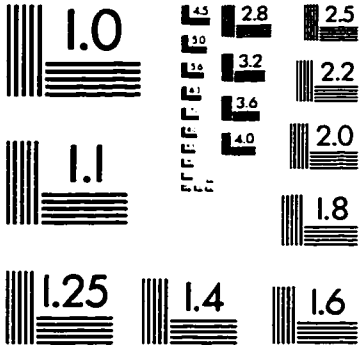
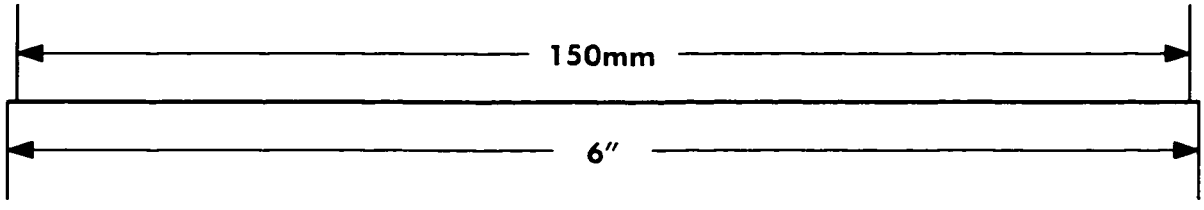
He obtained a B.A.Sc in Mechanical Engineering from the University of Windsor, and studied towards a M.A.Sc. in Industrial and Manufacturing Systems Engineering at the University of Windsor since 1993.

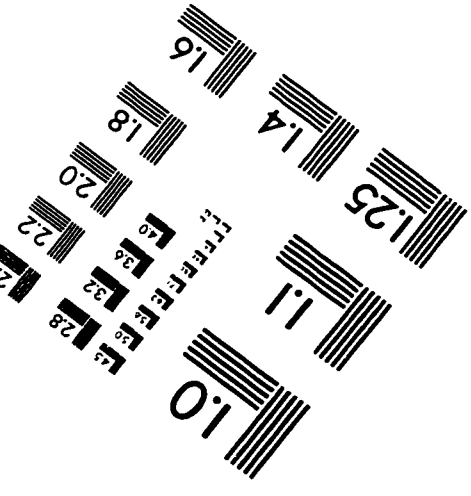
IMAGE EVALUATION
TEST TARGET (QA-3)

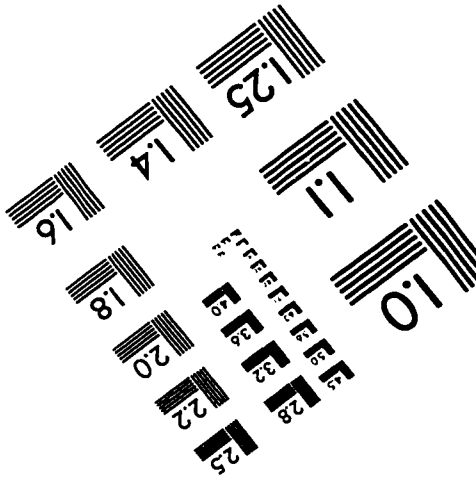












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