United States
Environmental Protection
Agency

National Risk Management
Research Laboratory
Cincinnati, OH 45268

Research and Development
EPA/600/SR-97/118
December 1997

Project Summary

Life Cycle Design of a Fuel Tank System

Gregory A. Keoleian, Sabrina Spatari, and Robb Beal

This life cycle design (LCD) project was a collaborative effort between the National Pollution Prevention Center at the University of Michigan, General Motors (GM), and the U.S. Environmental Protection Agency (EPA). The primary objective of this project was to apply life cycle design tools to guide the improvement of fuel tank systems. Two alternative fuel tank systems used in a 1996 GM vehicle line were investigated: a multi-layer high density polyethylene (HDPE) tank system, and a steel tank system. The design analysis included a life cycle inventory (LCI) analysis, performance analysis and preliminary life cycle cost analysis. The scope of the LCI study encompassed materials production, the manufacturing processes for each tank system, the contribution of each tank system to the use phase burdens of the vehicle, and the end-of-life management processes based on the current vehicle retirement infrastructure.

The LCI analysis indicated lower energy burdens for the HDPE tank system and comparable solid waste burdens for both systems. Based on the results of the LCI, streamlined environmental metrics were proposed. While both systems meet basic performance requirements, the HDPE system offers design flexibility in meeting capacity requirements, and also provided a fuel cost savings. The life cycle design framework was useful in evaluating environmental, performance, and cost trade-offs among and between both fuel tank systems.

This Project Summary was developed by the National Risk Management Research Laboratory's Sustainable Technology Division, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Integration of environmental considerations into the design process represents a complex challenge to designers, managers and environmental professionals. A logical framework including definitions, objectives, principles and tools is essential to guide the development of more ecologically and economically sustainable product systems. In 1991, the US Environmental Protection Agency (EPA) collaborated with the University of Michigan to develop the life cycle design (LCD) framework. This framework is documented in two publications: *Life Cycle Design Guidance Manual* and the *Life Cycle Design Framework and Demonstration Projects*.

Project Description

This pilot project with General Motors (GM) Corporation applied the LCD framework and tools to the design of fuel handling and storage systems used in the 1996 GMT600 vehicle line. A key component of this project was the evaluation of environmental burdens along with the life cycle costs and performance of two fuel tank designs. A cross-functional core team from GM, Delphi Automotive Systems, a GM subsidiary, and Walbro Automotive

Corporation, a GM supplier, participated with University of Michigan project team members.

Objectives

The overall purpose of this project was to apply LCD tools to better integrate environmental considerations into product system design and management. The project focused on material selection analysis and decision-making for the design of fuel tanks. The project identified specific tools and developed environmental metrics to be used in the GM product development process. The scope of the study is to perform a comparative evaluation of the high density polyethylene (HDPE) and steel fuel tanks used on the 1996 GMT600 cutaway van and passenger van. Specific objectives included:

- Compare steel and multi-layer HDPE fuel tanks and auxiliary components that were not common between the two systems using multicriteria matrices, LCI analysis, and life cycle cost analysis
- Evaluate key criteria and develop environmental metrics for material selection
- Facilitate cross-functional team interaction and networking to effectively use GM's internal resources
- Demonstrate the value and barriers associated with the use of LCD as an engineering design method to management

Methodology

Product Composition

Figure 1 shows the product composition by mass for each tank system. The total weight of the steel and HDPE tank systems (including shield and straps) are 21.92 kg and 14.07 kg, respectively. Each fuel tank system consists of three components: the tank which contains the fuel, straps which secure the tank to the frame, and a shield which has a unique function for each fuel tank system. The steel tank is made of plain carbon steel (1008-1010), with a nickel-zinc coating and an aluminum epoxy paint coat. The straps are made of hot dipped galvanized steel with a painted finish. The tank shield is made of HDPE. The HDPE tank is a six-layer plastic structure which consists primarily of HDPE. The six layers of the plastic tank, from outer to inner layer, include : virgin HDPE mixed with carbon black, a regrind layer which incorporates flash and scrapped tanks, an adhesive layer, an ethyl vinyl alcohol (EVOH) copolymer permeation barrier, an adhesive layer, and finally a virgin HDPE inner layer. The straps for this tank system are also hot-dipped galvanized steel with a PVC coating. The tank shield is plain carbon steel.

The steel fuel tank has a volume of 31 gallons while the volume of the HDPE tank is 34.5 gallons. The HDPE tank weight was normalized to 31 gallons so that the two tanks delivered equivalent functionality.

Life Cycle Inventory Analysis

A LCI analysis was conducted following US EPA and SETAC guidelines. The boundaries and major assumptions for this study are given in Table 1. A life cycle cost analysis was conducted following conventional practices. This analysis did not include external costs that are not reflected in market prices.

Environmental data evaluated were material and energy consumption, solid waste generation, and air and water pollutant releases. Environmental data in the material production stage were obtained from published sources. Material production energy data and emissions factors were used to evaluate the environmental burdens for the steel and HDPE tank systems. Environmental data in the manufacturing stage were obtained from GM facilities and supplemented with external and published sources. In the use phase, fuel efficiency data was provided by GM and emissions standards for light duty trucks were obtained from the US EPA and supplemented with off-cycle emissions data from Ross. In the retirement phase, shredding data was also obtained from published results.

Emissions and wastes for different life cycle stages were obtained as the sum of process and fuel-related emissions and wastes.

Transport distance data for the linkages between manufacturing operations were obtained from the GM project team, while transport distance estimates for end-of-life management were obtained from the American Plastics Council.

Cost data evaluated include material cost, aftermarket replacement cost, use cost, and retirement cost. The cost of materials were evaluated from unit cost data from published sources. A cost assessment for the manufacturing of each fuel tank was excluded from the study because such information is proprietary, and hence data was not available for publishing. However, aftermarket costs were obtained from a GMC Truck dealership in Saginaw, MI. The aftermarket price of each fuel tank system was used to determine a rough estimate of manufacturing costs. Use phase costs were calculated from the

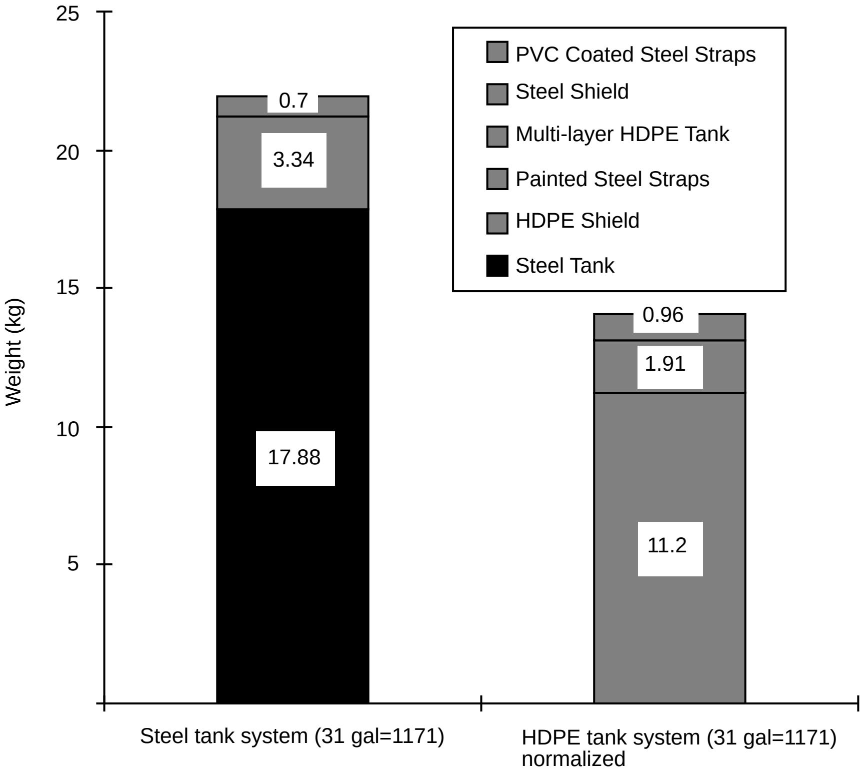

Figure 1. Composition of fuel tank systems.

Table 1. Boundaries and Major Assumptions for Fuel Tank Systems

LC Stage	Steel Tank	HDPE Tank
Material Production	The paint applied to the steel straps was modeled as steel because of the lack of data on the amount of paint applied.	HDPE was substituted for the following components of the multi-layer tank: Carbon Black PE-based Adhesive EVOH PVC applied to straps was assumed to be emulsion PVC.
Manufacturing	None of life cycle burdens of process materials were inventoried due to data availability. Scrap rate of 2% was estimated for HDPE injection molding process based on generic scrap rate data. No scrap was considered to be generated in steel strap fabrication. Zinc-Nickel coating and soap lubrication were not included due to data availability. Copper is used as a process material in steel tank fabrication. Copper recycling was not inventoried due to data availability. Foam pads used for tank distribution were excluded based on mass.	None of life cycle burdens of process materials were inventoried due to data availability. No scrap was considered to be generated in steel strap fabrication. The energy consumption for tank blow molding was based on generic blow molding/injection molding energy data.
Use	Contribution of tank system weight to use phase energy consumption is calculated by assuming that weight is linearly proportional to fuel consumption. No secondary weight savings were estimated. Vehicle use phase emissions are the sum of US EPA in-use emission standards for light trucks plus off-cycle emissions. Tank system contribution to vehicle emissions is obtained by assuming that emissions are proportional to total vehicle fuel consumption allocated to the fuel tank system; the allocation rule is accurate for CO_2 but for other gases the relationship is non-linear.	
End of Life	All components are considered to be shredded. Shredding fuel requirements were considered independent of the type of material shredded or shape of the part. Steel is assumed to be recovered at 100% within each system. All HDPE is assumed to be landfilled. Preliminary analysis indicated that steel recovered at end of life generated (at least) the amount of scrap steel needed for steel making. No credit was given to the system for any steel recovered in excess of the amount needed for steel making.	

price of consumed fuel over the useful life of the vehicle, but this cost was not corrected for potential inflation. Finally, retirement costs were evaluated using techniques from Kar and Keoleian (1996) which incorporate a retirement spreadsheet model of the American Plastics Council (APC). Transportation and disposal costs were calculated using data from Franklin Associates and the National Solid Waste Management Association (NSWMA) (1995).

A performance analysis was conducted which took into consideration the in-use engineering performance parameters of the two fuel tank designs, and manufacturing and assembly and end of life management performance criteria.

Results and Discussion

The LCI analysis and the life cycle cost analysis provide comprehensive environmental and cost data for evaluating the steel and HDPE fuel tank designs. The results are based on functionally equivalent fuel tank systems. The LCI analysis also serves to guide the development of environmental metrics.

Life Cycle Energy

The life cycle energy profile for each fuel tank based on a vehicle life of 110,000 miles is shown in Figure 2. (The primary energy consumed for each stage of life cycle is indicated in units of GJ/tank.) For both tank systems, the use phase accounts for the majority of the energy consumed. Over the 110,000 miles traveled, the steel and HDPE tanks (including shield and straps) are responsible for the consumption of 88.2 and 56.6 liters of gasoline, respectively. For comparison, the G passenger van consumes 25,390 liters when equipped with a steel fuel tank system; whereas when equipped with an HDPE fuel tank system, it consumes 25,359 liters.

For the steel tank design, the use phase constitutes 76% of the total life cycle energy. For the HDPE tank, it is responsible for 66% of the total energy. Although less HDPE material is used in the fabrication of one tank relative to steel, the higher specific energy for HDPE (81 MJ/kg) compared to steel (33.5 MJ/kg) yields comparable total material production energies for each system. The manufacturing for the HDPE tank system requires 85% more energy than for steel which is a consequence of greater energy input for blow molding of HDPE compared to steel stamping. End-of-life management energy is relatively negligible. The current practice of landfill disposition for the HDPE tank, however, results in a significant loss

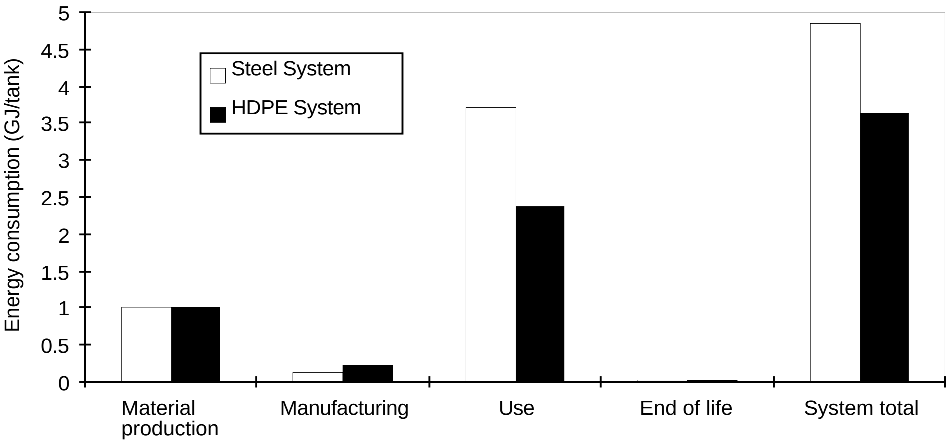

Figure 2. Life cycle energy consumption for HDPE and steel tank systems.

of energy in the form of the embodied energy of the material.

Life Cycle Solid Waste

The solid waste generated across each stage of the fuel tank life cycle is shown in Figure 3. The material production and end-of-life management stages indicate opposite trends for the two systems. The relatively high solid waste from the production of steel is associated with precombustion processes (e.g. coal mining) and slag, whereas the high solid waste from the plastic system results from end-of-life management.

A significant fraction of the slag from steel production is reused in applications such as road construction, and was not inventoried as waste. Solid waste from the end-of-life management stage was evaluated using a model describing current practices. It is recognized that the infrastructure may change over the next decade when a majority of these tanks will be retired. Scenarios involving HDPE recycling, energy recovery, and tank reuse could significantly impact the results.

Proposed Environmental Metrics

A primary objective of this project was to develop metrics to guide the environmental improvement of automotive parts and components. These environmental metrics complement the existing set of metrics and criteria that support design analysis and decision making. The LCI of the fuel tank can be used as a basis to propose a set of generic metrics for product design, although the distribution and magnitude of environmental burdens and impacts will vary according to the automotive part/component under development. Three factors influence the selection of metrics: reliability and accuracy in representing environmental burdens and impacts, ease of measurement and evaluation, and their applicability to a wide range of automotive parts and components. Based on these preconditions the project team decided to make recommendations for the following cases.

Case 1. A comprehensive set of metrics applicable to all automotive applications; unrestricted by data availability (i.e., the ideal case).

Case 2. Metrics that are specific to fuel tank design.

Case 3. A subset of the metrics defined in Case 1 but restricted by data availability.

Specific metrics for each case are provided in the project report.

Conclusions and Recommendations

Several differences between environmental profiles appear to be significant. The total life cycle energy consumption for the steel and HDPE tank systems was 4.9 GJ and 3.6 GJ per tank, respectively. A majority of this energy was consumed during the use phase. Conversely, the solid waste burdens associated with the fuel tank systems were concentrated in the material production and end-of-life management phases. The steel tank system generated approximately 14 kg of total solid waste per tank while the HDPE system generated approximately 13 kg. These differences are not significant within the expected uncertainty of this analysis. The analysis indicates that most of the solid waste associated with steel is generated in the material production phase whereas the HDPE solid waste is concentrated in vehicle end-of-life management.

The lighter weight of the HDPE results in significant savings in use phase energy relative to the steel for this particular application. This contributes to an overall lower life cycle energy requirement for the HDPE tank system. The life cycle solid waste generation for both systems is comparable. Currently, the HDPE tank is not recyclable in the end-of-life management stage. On the other hand, in the material production phase, the steel tank system results in significantly more solid waste compared to the HDPE system according to the published data sources available for this study. Air and water release data is much less reliable, but in several pollutant categories, the use phase burdens associated with the full gasoline fuel cycle dominate. In these instances, the HDPE tank system has lower burdens.

A performance analysis addressing manufacturability and use phase performance requirements was conducted along with a life cycle cost analysis of manufacturing, gasoline costs, and end-of-life processing costs. Both tanks meet basic performance requirements. Evaporative emissions testing showed that the HDPE multilayer design, with an EVOH layer, served effectively as a permeation barrier to VOCs in gasoline. The major performance requirement that distinguished the two tank designs was design flexibility in meeting capacity requirements within defined spatial constraints.

The difference in use phase costs between the two tank systems is significant—with the HDPE tank system providing a $10 fuel cost savings to consumers over 110,000 vehicle miles traveled. Although the savings related to the fuel tank may appear small, successful application of LCD to other vehicle components can result in a much greater total savings to the consumer. In the waste management stage, the scrap value associated with the steel tank system more than offsets the end-of-life management costs; whereas, the current scrap value for the plastic fuel tank system is not significant enough to cover the end-of-life management costs, resulting in a net cost for this life cycle phase.

Environmental metrics for LCD design were proposed based on the results of the LCI analysis. LCI metrics were developed in three categories: life cycle energy, materials and wastes. A critical need for implementing LCD is accurate sets of air emission factors (g of pollutant emissions/kg of product material), waste generation factors (g of solid waste/kg of product material), and energy factors (MJ of

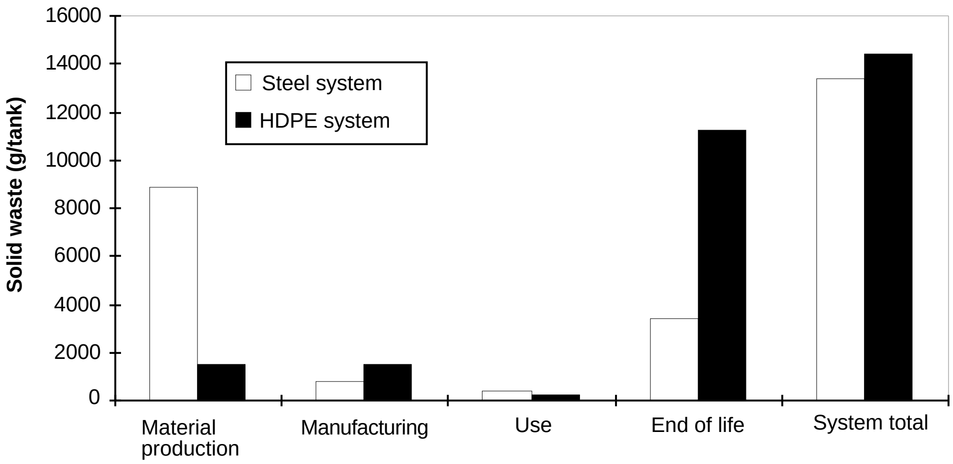

Figure 3. Life cycle solid waste generation for HDPE and steel tank systems.

energy/kg of product material). These parameters were compiled for the fuel tank system from either primary plant data or previously published data. The inventory analysis also served to identify metrics that are associated with a majority of the environmental burden across the life cycle.

GM recognized the importance of LCD and management as evidenced by their corporate environmental principle, which states: “We are committed to reducing waste and pollutants, conserving resources and recycling materials at every stage of the product life cycle”. This demonstration project represents one initiative to implement this policy at an operational level within the company. Further refinement in the valuation component of life cycle impact assessment is required to guide decision makers in the interpretation of inventory data. Significant trade-offs can exist within and between inventory categories. Integration of the full set of performance, cost, environmental, and regulatory requirements becomes even more complex. Policies and guidelines are in place that address vehicle recyclability, however, issues such as material production energy and waste are not specifically addressed. Design decisions are made in the context of internal and external policies. External policies and regulation do not treat environmental burdens consistently across the life cycle, which makes design analysis and decision making by OEMs more difficult. Inventory interpretation and impact assessment represents a logical extension of this project and another area for further research.

Gregory A. Keoleian, Sabrina Spatari, and Robb Beal are with the University of Michigan, School of Natural Resources & Environment, Ann Arbor, MI 48109-1115.
***Kenneth R. Stone** is the EPA Project Officer (see below).*

The complete report, entitled "Life Cycle Design of a Fuel Tank System," (Order No. PB98-117856; Cost: $25.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Sustainable Technology Division
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

Official Business
Penalty for Private Use $300

EPA/600/SR-97/118