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Center for Sustainable Systems
University of Michigan

Ultra Light Steel Auto Body - Advanced Vehicle Concepts (ULSAB-AVC)

Life Cycle Inventory Study

Final Report

Commissioned by the International Iron and Steel Institute

Vanessa M. Smith, David L. Gard and Gregory A. Keoleian

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ULTRA LIGHT STEEL AUTO BODY ADVANCED VEHICLE CONCEPTS (ULSAB-AVC) LIFE CYCLE INVENTORY STUDY
FINAL REPORT
Vanessa M. Smith, David L. Gard and Gregory A. Keoleian
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EXECUTIVE SUMMARY

Background

ULSAB-AVC (Ultra Light Steel Auto Body - Advanced Vehicle Concepts) is the most recent addition to the global steel industry's series of initiatives offering steel solutions to the challenges facing automakers around the world today. These are, the need to increase vehicle fuel efficiency while improving safety and maintaining affordability. ULSAB-AVC concepts dramatically change the kinds of steels normally applied to vehicle architectures, as well as demonstrate cutting edge steel vehicle design. This vehicle concepts initiative, engineered by Porsche Engineering Services, Inc., Troy, Michigan, USA, brings the potential for safe, affordable, fuel efficient vehicles, which are environmentally responsible, to near-term reality.

The ULSAB-AVC program presents advanced vehicle concepts that help automakers use steel more efficiently and provide a structural platform for achieving:

- anticipated crash safety requirements for 2004,
- significantly improve fuel economy,
- optimised environmental performance regarding emissions, source reduction and recycling, and
- high volume manufacturability at affordable costs.

Porsche Engineering Services, Inc. was contracted to develop concepts with a common platform approach for the popular European C-Class (so-called Golf class) and the North American midsize-class, which is the target for the PNGV (Partnership for a New Generation of Vehicles) program (referred to as the PNGV-class vehicle). The ULSAB-AVC PNGV-class vehicle is shown in Figure ES-1.

A life cycle inventory (LCI) study was completed to evaluate the inputs and outputs of the ULSAB-AVC vehicles product system over its life cycle. That is, resource and energy consumption, emissions to air, water, and ground, and vehicle function were studied, from extraction of resources through vehicle manufacturing, operation and maintenance, and disposition.

A life cycle inventory approach was used as it provides a holistic and comprehensive view of the vehicle product system. With such an approach, it can be determined which aspects of vehicle manufacturing, operation, maintenance and disposition are most environmentally significant and how changes to the product system affect the outcome. Thus, it is possible to characterise environmental performance and identify those aspects of benefit and greatest priority for improvements.

Figure ES-1. ULSAB-AVC PNGV-class Vehicle.

The International Iron and Steel Institute commissioned the Center for Sustainable Systems at the University of Michigan (USA) to complete the LCI study. The Center for Sustainable Systems has extensive experience in life cycle modelling of vehicles and particular experience with the groundbreaking vehicle LCI study conducted by the United States Automotive Materials Partnership (USAMP). The study was completed in cooperation with life cycle inventory and automotive experts in the steel and automotive industries.

The study was undertaken to provide quantitative measures of the environmental performance of ULSAB-AVC vehicles. This information will be used to communicate with automobile companies and their suppliers in support of the ULSAB-AVC program. Secondly, the study will be communicated to the public to illustrate the world steel industry's commitment to improving environmental performance in the use of its products. Thirdly, the study will set a baseline for evaluating future developments in optimising steel vehicles.

Life Cycle Inventory

The ULSAB-AVC life cycle inventory study is largely based on the methodology, modelling and data utilised in an earlier study by the United States Automotive Materials Partnership (USAMP), a consortium within the United States Council for Automotive Research. This approach was taken to utilise currently available research as much as possible, thereby reducing the expense and time needed to complete the study. As a result, the study could focus primarily on new research presented by the ULSAB-AVC automobile program.

The function of the product system under study is to provide a mode of personal transportation with the characteristics of a mid-sized vehicle[1]. In any life cycle study, inputs and outputs to the system are evaluated based on a unit of the system's function. In this study, the functional unit is defined as one complete service lifetime of the automobile, taken as 193,000 km (120,000 miles).

The life cycle stages specific to the automobile are shown in Figure ES-2 and are representative of a cradle-to-grave analysis. They include extraction and processing of raw materials from the earth; material production; subassembly manufacture; auto assembly; vehicle use and maintenance; and material recovery, recycling and disposal. Balanced material flows link the subsystems and individual processes within the system.

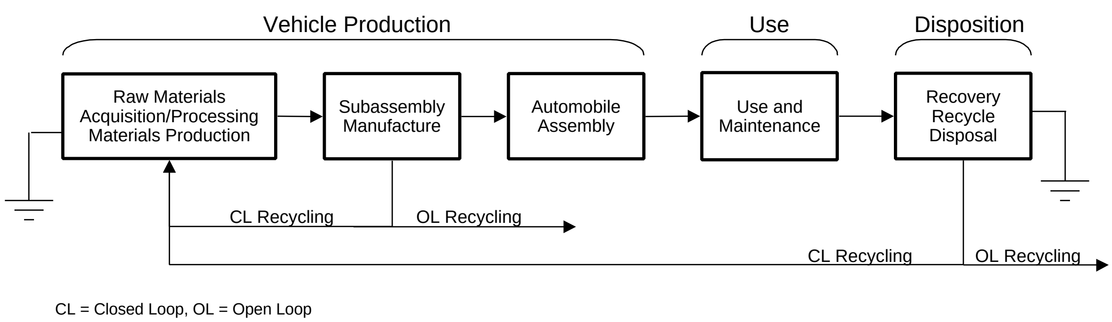

Figure ES-2. Major life cycle stages for the ULSAB-AVC automobile.

Throughout the ULSAB-AVC study, the life cycle stages are grouped into three phases: Vehicle production, Use and Disposition (see Figure ES-2). The first three life cycle stages are grouped and referred to collectively as the Vehicle Production phase. The Use phase includes operations, maintenance and repair and the Disposition phase includes material recovery, recycling and disposal.

[1] The EPA characterizes a vehicle by its passenger and cargo volume and defines that of a mid-size vehicle to be 110 to 119 cubic feet [EPA and DOE (2002). Economy guide, Model year 2002**:** p.3].

Consideration is not given to the deployment and maintenance of transportation infrastructure (e.g. roads, bridges, buildings) and support of people (e.g. food production, commuting to work). These potential aspects of the system boundary were deemed beyond the scope of the study given time and cost constraints and the expected negligible effect on the functional unit calculations.

The PNGV design includes two variants: gasoline and diesel. In order to keep the project scope manageable, only the gasoline variant was fully evaluated in this study. Using USAMP results as a guide, the majority of impact from the ULSAB-AVC vehicle was predicted to occur in the Use Phase. Therefore, only this phase was analysed for the diesel variant. This eliminated duplication of the significant modelling effort associated with upstream production activities.

The material composition of the ULSAB-AVC PNGV-gas engine vehicle was estimated using the PNGV-gas engine vehicle parts list (provided by Porsche Engineering Services, Inc.) and USAMP data. The general material distribution of the ULSAB-AVC PNGV-gas engine vehicle is shown in Figure ES-3.

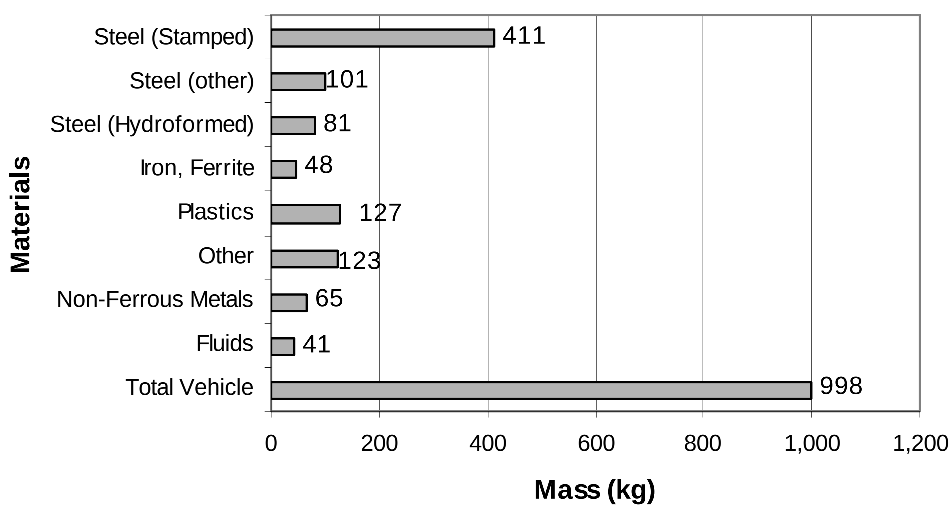

Figure ES-3. Material Distribution for the ULSAB-AVC PNGV-Gas Engine Vehicle.

Results and Interpretation

The ULSAB-AVC LCI model was based on methodology from the original USAMP LCI study and hence, adopted many of the same system boundary assumptions and input data. However, there are some significant methodological differences. For example, while USAMP included operational testing data from actual vehicles, no ULSAB-AVC prototype was available to generate such hard data. Instead, EU4 emissions standards were defined as the upper limit to the possible range of emissions. Results for this study were generated using TEAM™ software[2].

Total life cycle inventory results for the ULSAB-AVC study encompasses the results from each of the three major life cycle phases including Vehicle Production, Use and Disposition. These results are presented by life cycle phase in Table ES-1 for the PNGV-Gas engine variant.

[2] Tools for Environmental Analysis and Management, Ecobalance, copyright 1992, 1993.

Table ES-1. ULSAB-AVC Total Life Cycle Inventory Results

	ULSAB-AVC					
	PNGV Gas Engine Vehicle					
Category	**Environmental Flow****	**Units**	**Vehicle Production Phase**	**Use Phase**	**Disposition Phase**	**Vehicle Life Cycle Total**
Resource Use	(r) Bauxite (Al2O3, ore)	kg	108	0.01		108
	(r) Coal (in ground)	kg	1,556	414	7.1	1,977
	(r) Ilmenite (FeO.TiO2, ore)	kg	1	0		1
	(r) Iron (Fe, ore)	kg	1,496	0.37	0.03	1,496
	(r) Lead (Pb, ore)	kg	9.6	15		25
	(r) Limestone (CaCO3, in ground)	kg	163	80	1.4	244
	(r) Natural Gas (in ground)	kg	532	518	1.8	1,052
	(r) Oil (in ground)	kg	336	7,162	35	7,532
	(r) Perlite (SiO2, ore)	kg	0.74	0		0.74
	(r) Pyrite (FeS2, ore)	kg	1.7	0.00003		1.7
	(r) Sulfur (S)	kg	0.08	0.00003		0.08
	(r) Tungsten (W, ore)	kg	0.0005	0.0007		0.001
	(r) Uranium (U, ore)	kg	0.01	0.009	0.0002	0.02
	(r) Zinc (Zn, ore)	kg	34	6.9		41
	Iron Scrap	kg	65	26		91
	Natural Rubber	kg	5.3	10		15
	Raw Materials (unspecified)	kg	12	0.24		12
	Water Used (total)	liter	41,149	4,411	3.9	45,563
Air Emissions	(a) Carbon Dioxide (CO2, fossil)	kg	6,088	22,449	131	28,668
	(a) Carbon Monoxide (CO)	g	57,235	222,391*	677	280,303
	(a) HC (except methane)	g	10,228	30,138*	167	40,534
	(a) Hydrogen Chloride (HCl)	g	207	206	3.8	417
	(a) Hydrogen Fluoride (HF)	g	21	24	0.48	46
	(a) Lead (Pb)	g	36	50	0.01	86
	(a) Methane (CH4)	g	11,647	22,492	118	34,257
	(a) Nitrogen Oxides (NOx as NO2)	g	16,995	32,983*	763	50,741
	(a) Particulates (unspecified)	g	12,402	8,682*	190	21,274
	(a) Sulfur Oxides (SOx as SO2)	g	21,987	40,418	250	62,655
Water Emissions	(w) Ammonia (as N)	g	222	1,008	1.9	1,231
	(w) Dissolved Matter (unspecified)	g	3,390	1,079	11	4,480
	(w) Heavy Metals (total)	g	26	2	0.0009	28
	(w) Oils (unspecified)	g	581	3,155	7.3	3,743
	(w) Phosphates (as P)	g	9.3	0.10	0.00001	9.4
	(w) Suspended Matter (unspecified)	g	3,396	31,324	58	34,778
Solid Waste	Waste (municipal and industrial)	kg	76	32	200	307
	Waste (total)	kg	796	574	230	1,600
Energy Consumption	E Total Primary Energy	MJ	100,521	383,286	1,971	485,778

* Vehicle emissions for ULSAB-AVC PNGV-gas variant are based on EU4 Regulations and represent an upper limit.

** (r): Raw material in ground, (a): Airborne emissions, (w): Waterborne emissions

The ULSAB-AVC PNGV-Gas Engine vehicle consumes 486 GJ throughout its life cycle. The major contributor to this total is the Use phase, in which 79% of the total energy is consumed as shown in Figure ES-4 below. This portion is overwhelmingly attributed to the fuel consumed during vehicle operation.

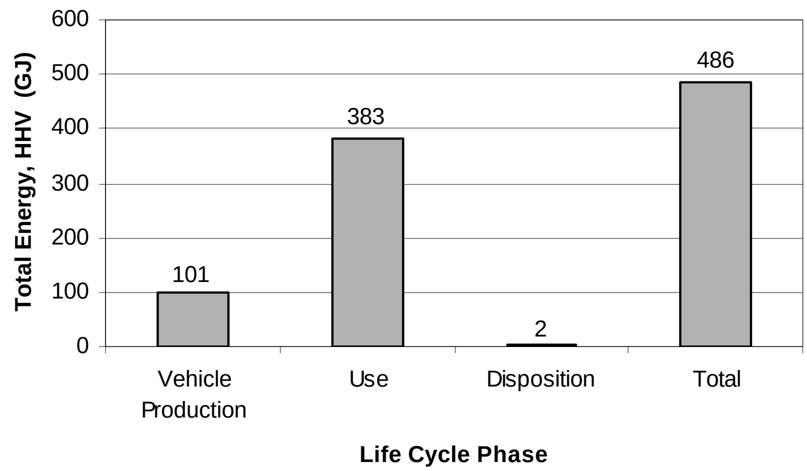

Figure ES-4. Total Life Cycle Energy Consumption for the ULSAB-AVC PNGV-Gas Engine Vehicle.

Total life cycle CO_2 air emissions for the ULSAB-AVC PNGV-gas engine vehicle follow a similar trend to total energy consumption, with 78% of the emissions attributed primarily to fuel consumption during the use phase, as shown in Figure ES-5 below.

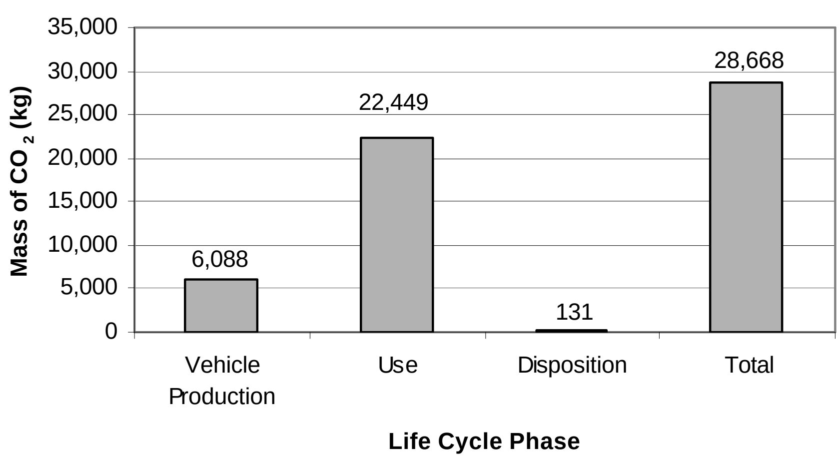

Figure ES-5. Total Life Cycle Carbon Dioxide Emissions for the ULSAB-AVC PNGV-Gas Engine Vehicle.

The Use phase dominated energy consumption and air emissions. As a result, focusing attention on vehicle operation represents the best opportunity for achieving further reduction in these impact categories.

Air emission results should be considered the upper bound to performance because the emissions factors used in the TEAM™ model were taken directly from EU4 standards, not from actual vehicle test data. Therefore, results for an actual ULSAB-AVC vehicle would probably be lower than the results stated here.

The superior performance over existing vehicles is due to some combination of mass reduction and improved powertrain technology. It was beyond the scope of this study to determine the specific contributions of these two factors. There are interactive effects between these two factors that increase the complexity of this issue even further. No simple ratio exists between vehicle mass and energy/emissions performance for the Use phase. Furthermore, there are additional secondary, non-linear effects related to other components such as brakes that have not been evaluated. Consequently, results from this study should not be used to support specific claims about the relative merits of weight reduction vs. powertrain improvements.

Solid waste and water consumption were highest in the Vehicle Production phase. Therefore, efforts to reduce either of these burden categories should be focused on upstream production activities.

The upstream process of hydroforming, which would be applied to 8% of the vehicle (PNGV-gas) by mass, must still be evaluated. Although hydroforming was part of the initial ULSAB-AVC design, modelling data for this process was not available for inclusion in this LCI study. When it is eventually incorporated into the model, it is expected that material production burdens – energy, emissions and resource requirements – will decrease. This is due to expectations that the scrap rate would be significantly lower than 1.68, which is the scrap rate of stamping, the process that would be partially displaced by hydroforming. This would result in less material required to provide the same components, fewer parts in some cases.

Other Full Vehicle LCI Studies

In order to provide some context for the ULSAB-AVC study results, USAMP study results are cited and a review published in 2002 of nine full vehicle LCIs is also discussed.

The model developed for the ULSAB-AVC life cycle inventory was based on that created for the USAMP study, hence, major similarities exist between the two, such as definition of functional unit (193,000 km) and system boundaries. The ULSAB-AVC database is also directly interrelated with the USAMP database. In addition to similarities, there are important distinctions between the two studies that must be kept in mind. These include: methodological differences, the age of relevant data and vehicle characteristics. The differences between the two studies are far from trivial. Consequently, it is not valid to make a comparison of the USAMP and ULSAB-AVC vehicles; rather, USAMP results are referenced in discussing ULSAB-AVC results.

Figure ES-6 shows the total life cycle energy consumption for the ULSAB-AVC vehicle next to that of the USAMP generic vehicle for reference.

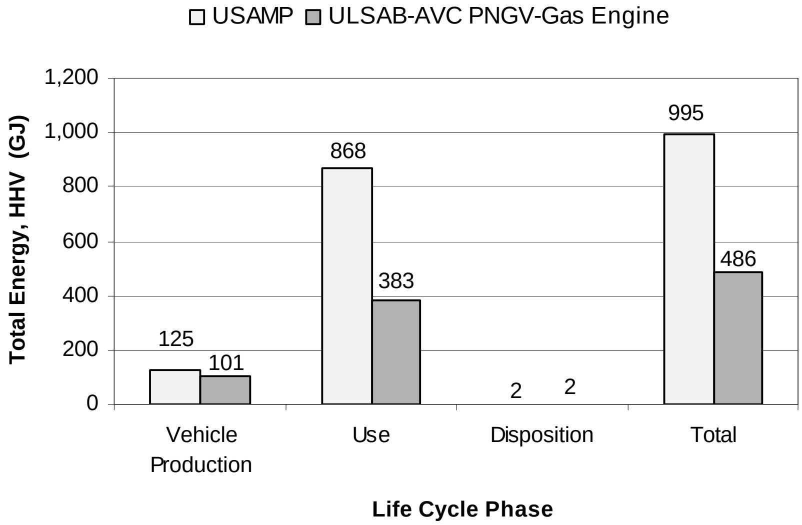

Figure ES-6. Total Life Cycle Energy Consumption for ULSAB-AVC with USAMP presented for reference.

Clearly, the PNGV-gas engine vehicle consumes less than half of the energy scored in USAMP. Most of this improvement can be seen in the Use phase. In particular:

- PNGV-gas consumes **51%** less energy over the total life cycle.
- PNGV-gas consumes **20%** less energy in the Vehicle Production phase.
- PNGV-gas consumes **56%** less energy in the Use phase.
- PNGV-diesel consumes **64%** less energy in the Use phase.
- PNGV-gas consumes **9%** less energy in the Disposition phase.

Reductions in energy consumption seen in the Use phase are attributed to a combination of two factors. These are (1) Mass reduction/light-weighting effects, with the ULSAB-AVC saving nearly 500 kg; and (2) Powertrain improvement effects, primarily fuel economy (USAMP 10.3 L/100km (22.8 mpg), ULSAB-AVC PNGV-gas 4.5 L/100km (52.4 mpg), ULSAB-AVC PNGV-diesel 3.4 L/100km (68 mpg)).

Sullivan and Cobas-Flores published a review on nine select full vehicle LCI studies in 2002. The level of completeness varied among the studies, as did the application of life cycle boundaries (e.g. at times data categories were not consistently applied to all life cycle stages for a certain study). However, all of the selected studies included results for the vehicle production, use and disposition phases and did not include infrastructure burdens.

It was found that regardless of vehicle size, powertrain or service life distance, the use phase of the vehicle life cycle is the major contributor of life cycle burdens, with 66 to 91% of the total energy and 60% or more of the carbon dioxide and hydrocarbon burdens attributed to this phase. The same trends are seen for the ULSAB-AVC PNGV-gas vehicle which attributed 79% of total energy consumption, 78% of carbon dioxide emissions, 65 to 79% of CO, NO_X, SO_X and HC emissions to the use phase.

In the review, 60-80% of total solid waste production was attributed to the material production stage. With the exception of solid waste burdens, to which it contributes 7 to 11 percent, disposition activities made only small contributions to total vehicle life cycle burdens. Similarly, solid waste production for the ULSAB-AVC PNGV-gas vehicle LCI was highest for the vehicle production phase with 50% of total solid waste produced during this phase, 36% in the use phase and 14% in the disposition phase. Overall, the disposition phase was of negligible impact on total life cycle burdens for the ULSAB-AVC PNGV-gas vehicle with the exception of solid waste.

Recommendations

Communication of Results

The stated goal of this project was to complete a life cycle inventory of an ULSAB-AVC vehicle. It was intended to establish a baseline for measuring the environmental life cycle performance of future steel automobiles and to support communication efforts aimed at vehicle manufacturers and their suppliers, including members of the worldwide steel industry who play a role in providing steel to the automotive industry. These purposes have been achieved. Results from this study can be used to support public statements on the environmental performance of ULSAB-AVC automobiles. Additionally, they can be made available to vehicle manufacturers as input to the design and development of new cars with improved environmental performance.

However, while preliminary results do suggest environmental benefits of the ULSAB-AVC design, they are based on a significant number of assumptions and data from previous research. Public statements based on these results should therefore not be definitive, but rather suggestive of potential benefits. Limitations of the study should be clearly and openly acknowledged.

Vehicle Design and Development

As demonstrated in previous automotive LCI studies, the ULSAB-AVC model predicts the greatest environmental impact from the Use phase. Therefore, design activities to improve environmental performance should be focused on vehicle operation; specifically, actions that would deliver higher fuel economy. These would include:

- Further reducing total vehicle mass through selection of materials and design of components and systems.
- Development of more efficient powerplants. Incidentally, mass reduction produces the secondary benefit of requiring smaller, less powerful engines that use less energy overall.

It should be stressed that consumers, and therefore manufacturers, will demand that any improvement in environmental performance not degrade performance in other categories such as safety, reliability, handling, comfort and cabin noise. To the extent that the ULSAB-AVC auto body can deliver this performance mix at a competitive cost, it will be successful in the marketplace.

Future Research

Results from this LCI study suggest the value of pursuing future research in the following areas:

- Incorporate hydroforming data into the TEAM™ model when it becomes available. Evaluate results to determine the effect of this manufacturing process on environmental performance of the total vehicle life cycle.

- The material composition of ULSAB-AVC was not specified in detail on the parts list provided by Porsche; therefore, material composition was estimated using USAMP data. Consequently, a more accurate life cycle model could be developed as materials for the ULSAB-AVC vehicle are further specified.

- Differentiate the relative contributions of mass reduction and powertrain contributions to overall environmental performance. Use results of this analysis to guide further improvements in body structure design and powertrain technology.

- Future research activities would be enhanced by the development and manufacturing of an ULSAB-AVC prototype vehicle. This would be useful not only for collecting operational test data, but also for learning valuable lessons about designing manufacturing processes that could be applied to mass producing an ULSAB-AVC vehicle.

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ABBREVIATIONS AND ACRONYMS

AA	Aluminium Association
APC	American Plastics Council
DEAM™	Database for Environmental Analysis and Management
EPA	Environmental Protection Agency
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
OEM	Original Equipment Manufacturer
TEAM™	Tools for Environmental Analysis and Management
ULSAB-AVC	Ultra Light Steel Auto Body - Advanced Vehicle Concepts
USAMP	United States Automotive Materials Partnership

1 UltraLight Steel

The world steel industry has completed a series of environmentally-focussed initiatives to assist their automotive customers with viable lightweighting solutions. Four consortia of steel producers, representing all parts of the world, commissioned the projects known as ULSAB, ULSAC, ULSAS, and ULSAB-AVC.

The most recent programme, ULSAB-AVC, published its results in 2002. It is this programme that is the subject of this report; a life cycle inventory study of the resultant PNGV-class vehicle designs.

1.1 UltraLight Steel Auto Body (ULSAB)

www.ulsab.org

ULSAB was a $22 million phased project: The first phase was a concept CAE study; the second was a validation phase. Crucial to this project's success were an holistic approach to design, the optimisation of the inherent engineering properties of steel, the use of state-of-the-art manufacturing processes, and simultaneous engineering among manufacturing partners and steel manufacturers. This programme was an initiative of the ULSAB consortium, a grouping of 35 steel producers from 18 countries.

The ULSAB structure weighs merely 203 kg, 25 percent less than the average benchmarked in the concept phase of the study. Physical tests of the structure reveal similar remarkable results: torsion and bending tests showed improvements over benchmark of 80 percent and 52 percent, respectively, and 1st body structure mode indicates a 58 percent improvement. Analyses also show ULSAB satisfies mandated crash requirements, even at speeds exceeding the requirements. In addition to reduced weight and superior performance, ULSAB costs no more to build than typical auto body structures in its class and can even yield potential cost savings, according to economic analysis.

1.2 UltraLight Steel Auto Closures (ULSAC)

www.ulsac.org

The UltraLight Steel Auto Closure Program was a study undertaken by global steel producers to demonstrate the effective use of steel in producing lightweight, structurally sound steel automotive closures that are manufacturable and affordable.

ULSAC began as a concept development program, producing lightweight concept designs for doors, hoods, decklids and hatches. The program continued to the manufacture of steel frameless door demonstration hardware that is 42% lighter than the average of benchmarked frameless doors. ULSAC meets or exceeds stringent safety and structural performance targets and can be manufactured at affordable costs.

1.3 UltraLight Steel Auto Suspensions (ULSAS)

www.ulsas.org

The UltraLight Steel Auto Suspension (ULSAS) project was undertaken by the global steel industry to demonstrate the effective use of steel in producing lightweight, structurally sound steel automotive suspensions that are manufacturable and affordable. Through the intelligent application of steel and the use of near-reach materials and technologies, the five ULSAS suspension design concepts achieved up to 34 percent mass reductions over conventional steel systems, up to 30 percent cost advantages over a benchmarked aluminium system, and equal or better performance results.

1.4 UltraLight Steel Auto Body – Advanced Vehicle Concepts (ULSAB-AVC)

www.ulsab-avc.org

The ULSAB-AVC (Advanced Vehicle Concepts) Program is a design effort to offer steel solutions to meet society's demands for a safe, affordable, environmentally responsible range of vehicles for the 21st Century.

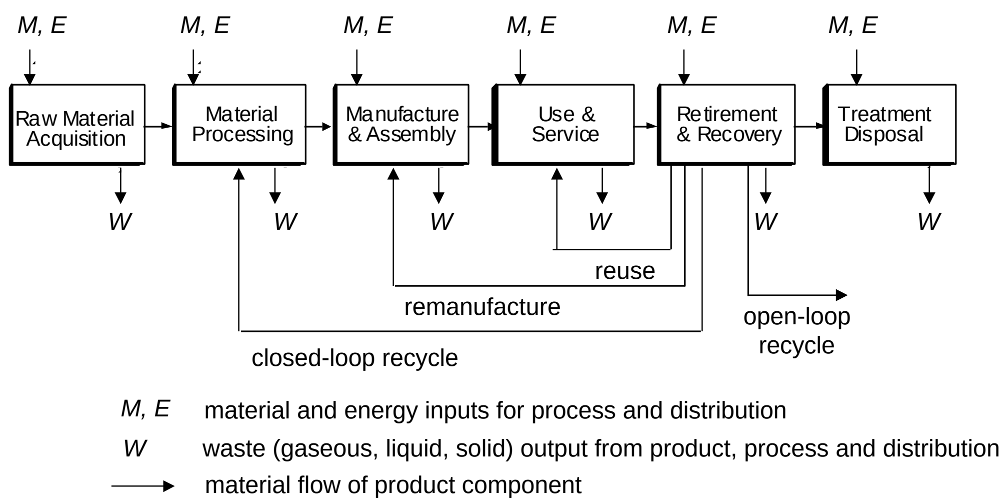
ULSAB-AVC, the latest in a series of environmentally-centred initiatives by an international consortium of sheet steel producers, offers the promise that steel is the most environmentally optimal and affordable material for future generations of vehicles. The program supports this offer by demonstrating the application of new steels, advanced manufacturing processes, and innovative design concepts.

This vehicle concepts initiative, engineered by Porsche Engineering Services, Inc., Troy, Michigan, USA, brings the potential for safe, affordable, fuel-efficient vehicles, which are environmentally responsible, to near-term reality, achieving anticipated crash safety requirements for 2004, significantly improved fuel efficiency and recycling, and high volume manufacturability at affordable costs.

2 ABOUT LIFE CYCLE INVENTORY (LCI)

Life Cycle Assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a product [ISO_14040 1999]. LCA studies consist of four phases: goal and scope definition, inventory analysis, impact assessment and interpretation of results [ISO_14041 1998]. A life cycle inventory (LCI) study is one that does not include the impact assessment phase of a LCA study. It focuses strictly on the compilation of life cycle inventory results, or the inputs and outputs of material and energy for a given product system.

A LCI study considers various stages throughout a product's life cycle from upstream production activities, through use, to final disposition. Each life cycle stage is shown in Figure 1 for a generic product system with corresponding material and energy input flows and waste output flows for each stage.



Source: [Keoleian, Koch et al. 1995]

Figure 1. Generic Product System Life Cycle Stages.

This report on the current LCI study describes goal and scope definition, methods used to conduct the study, results and interpretation of these results.

3 GOAL DEFINITION

3.1 Goal of the Study

The goal of the study is to complete a life cycle inventory (LCI) of an Ultra-Light Steel Auto Body – Advanced Vehicle Concepts (ULSAB-AVC) automobile.

Results from the study are intended to validate public statements on the environmental performance of ULSAB-AVC automobiles. Additionally, it is intended to make the study available to automobile manufacturers to assist them with the development of new cars with improved environmental performance.

The project team assembled to carry out the ULSAB-AVC life cycle inventory study consisted of one to three members from each of the following organisations: Center for Sustainable Systems at the University of Michigan (CSS), International Iron and Steel Institute (IISI), American Iron and Steel

Institute (AISI), ULSAB-AVC Consortium, and General Motors' Chemical and Environmental Sciences Lab (GM).

3.2 Intended Applications

The study is intended to be used as a baseline for measuring the life cycle performance of future steel automobiles and to support communication efforts of the ULSAB-AVC program.

3.3 Target Audiences

The intended audience for this study is, primarily, automobile manufacturers and their suppliers who influence the design of automobiles and selection of materials. Secondarily, the intended audience includes members of the worldwide steel industry who play a role in providing steel to the automotive industry, such as market development engineers, sales and marketing professionals, laboratory researchers and environmental policy analysts.

4 SCOPE DEFINITION

The ULSAB-AVC life cycle inventory study is largely based on the methodology, modelling and data utilised in an earlier study by the United States Automotive Materials Partnership (USAMP), a consortium within the United States Council for Automotive Research [Keoleian, Lewis et al. 1998]. This approach was taken to utilise currently available research as much as possible, thereby reducing the expense and time needed to complete the study. As a result, the study could focus primarily on new research presented by the ULSAB-AVC automobile program.

4.1 Vehicle Function and Characteristics

4.1.1 Function and Functional Unit

The function of the product system under study is to provide a mode of personal transportation with the characteristics of a mid-sized vehicle[3].

In any life cycle study, inputs and outputs to the system are evaluated on the basis of a unit of the system's function. In this study, the functional unit is defined as one complete service lifetime of the vehicle, taken as 193,000 km (120,000 miles). The characteristics of the vehicle are described in the following section.

4.1.1.1 Vehicle Characteristics

The purpose of the USAMP baseline study was to identify a suitable set of metrics to benchmark the environmental performance of a "generic vehicle," namely, a synthesis of the 1995 Chrysler Intrepid, GM Lumina and Ford Taurus [Keoleian, Lewis et al. 1998]. In order to accomplish this goal, the USAMP research team initiated the development of a life cycle inventory of a six-passenger vehicle with an average mass of approximately 1,500 kg. USAMP generic vehicle characteristics are listed in Appendix G.

The ULSAB-AVC consortium, with its contractor Porsche Engineering Services, designed two ULSAB-AVC concept vehicles: PNGV and C-Class. Both classes are based on Porsche parts lists that were developed using both measured and estimated parts mass values. Estimated values were used for parts that were not yet designed [Porsche Engineering Services 2001]. Of these two vehicles, only the PNGV vehicle was evaluated in the current LCI study. See Table 1 for a list of PNGV and C-Class vehicle characteristics. Characteristics of the C-Class are provided for informational purposes only.

The PNGV design includes two variants: gasoline and diesel. In order to keep the project scope manageable, only the gasoline variant was fully evaluated in this study. Using USAMP results as a

[3] The EPA characterizes a vehicle by its passenger and cargo volume and defines that of a mid-size vehicle to be 110 to 119 cubic feet [EPA and DOE (2002)].

guide, the majority of impact from the ULSAB-AVC vehicle was predicted to occur in the Use Phase. Therefore, only this phase was analysed for the diesel variant. In addition, the differences between the gas and diesel variants are small, apart from fuel consumption. As Table 1 shows, the difference in mass between the PNGV-gas and PNGV-diesel vehicles is only 33 kg. This suggests that any disparity in their material and production burdens would not be significant.

Table 1. ULSAB-AVC automobile characteristics and performance.

General Characteristics and Functions	**PNGV-Class (Gas)**	**PNGV-Class (Diesel)**	**C-Class (Gas)**	**C-Class (Diesel)**
Vehicle Curb Weight (kg)	998	1031	933	966
Body Structure Mass (kg)	218	218	202	202
Fuel Type	Gasoline	Diesel	Gasoline	Diesel
Fuel Efficiency European Driving Cycle (L/100 km) (U.S. Driving Cycle (mpg))	4.5 (52.4)	3.4 (68)	4.4 (53)	3.2 (73)
Vehicle Service Life (km)	193,000	193,000	193,000	193,000
Engine Power (kW)	61 @ 6000 rpm	54 @ 4000 rpm	61 @ 6000 rpm	54 @ 4000 rpm
Engine Torque (Nm)	108 @ 4000 rpm	167 @ 1800 rpm	108 @ 4000 rpm	167 @ 1800 rpm
Engine Displacement (L)	1.2	1.2	1.2	1.2
Number of Passengers	5	5	5	5
Number of Doors	4	4	3	3
Luggage Volume (m^3)	0.57	0.57	0.30/1.19*	0.30/1.19*
Acceleration Time, 0 to 100 km/h (s)	13.9	13.9	13.5	13.4
Top Speed (km/h)	193	184	194	184
Airbags	4	4	4	4
Antilock Brake System (ABS)	Yes	Yes	Yes	Yes
Length (mm)	4744	4744	4179	4179
Width (mm)	1765	1765	1766	1766
Height (mm)	1455	1455	1455	1455

* unfolded/folded rear seat

4.2 System Boundaries

The life cycle stages specific to the automobile are shown in Figure 2 and are representative of a cradle-to-grave analysis. They include extraction and processing of raw materials from the earth; material production; subassembly manufacture; auto assembly; vehicle use and maintenance; and material recovery, recycling and disposal. Balanced material flows link the subsystems and individual processes within the system.

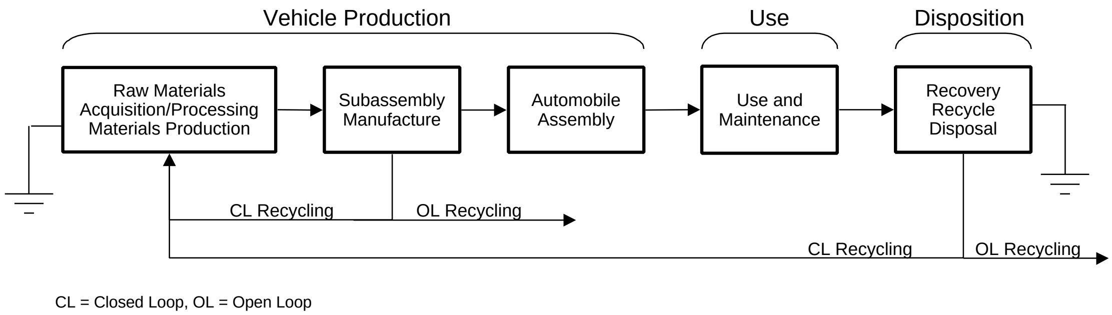


Figure 2. Major life cycle stages for the ULSAB-AVC automobile.

Throughout the ULSAB-AVC study, the life cycle stages are grouped into three phases: Vehicle production, Use and Disposition (see Figure 2). The first three life cycle stages are grouped and referred to collectively as the Vehicle Production phase. The Use phase includes operations, maintenance and repair and the Disposition phase includes material recovery, recycling and disposal.

Consideration is not given to the deployment and maintenance of transportation infrastructure (e.g. roads, bridges, buildings) and support of people (e.g. food production, commuting to work). These potential aspects of the system boundary were deemed beyond the scope of the study given time and cost constraints and the expected negligible effect on the functional unit calculations.

4.2.1 Vehicle Production

The Vehicle production phase encompasses the acquisition and processing of raw materials, material production, part and subassembly manufacturing and assembly of the vehicle. For the ULSAB-AVC study the vehicle production phase is modelled based on the PNGV-gas engine variant only. The diesel engine variant was not considered (see Section 4.1.2). Most data used for the ULSAB-AVC study were sourced from the previous USAMP study.

4.2.1.1 Raw Materials Acquisition and Materials Production

Materials production encompasses the acquisition of raw materials from the earth and their processing into engineered materials such as rolled steel, cast aluminium and plastic resin. Life cycle inventory (LCI) data for the production of steel were sourced from the International Iron and Steel Institute [IISI 2002]. Other data for materials production were sourced from the database created for the USAMP LCI study. From that earlier study, primary data for the production of aluminium and plastics materials were provided while secondary data sources were used for other materials such as glass and rubber. Data sources and coverage (temporal and geographic) for each of these materials are listed in Appendix A.

4.2.1.2 Manufacturing and Assembly

The boundaries of this stage encompass everything between engineered materials (e.g., rolled steel, wrought aluminium, PVC resin) and the assembled vehicle. Many tiers of supplier plants and Original Equipment Manufacturer (OEM) plants make up the supply chain from the materials industry to the OEM final vehicle assembly plants. In the USAMP study, it was not feasible to collect data for each manufacturing process associated with the 20,000+ parts comprising the vehicle. Therefore, a practical modelling approach was followed which utilised primary and secondary data collection for the key manufacturing processes. These processes were classified into three types: part fabrication, subassembly manufacturing and vehicle assembly. Part fabrication represents the primary transformation of engineered materials including stamping, casting, moulding, and forging. In addition to these processes, the current study also includes hydroforming, though hydroforming data has not yet been incorporated. Stamping is used as a substitute, albeit higher scraprates are associated with stamping (see Section 4.2.4 Key Assumptions and Exclusions).

Discrete parts often require many other processing steps such as machining, surface treatment, welding, fastening, etc. Subassembly manufacturing involves further processing and assembly of parts into higher level components such as the engine, transmission, seats, instrument panels, etc. Final vehicle assembly integrates all parts, subassemblies, and fluids together into the final vehicle and includes exterior painting.

For process materials and energy consumed during the manufacturing of the vehicle's parts and components, plant data were collected by the OEMs for the USAMP study. The plants, indicated in Table 2 below, included three final assembly plants and ten other plants involving either major vehicle components manufacturing (e.g., engine, transmission) or key automotive fabrication processes (e.g., stamping)[4].

Table 2. OEM Plants Inventoried.

Type	Plant Function
Vehicle Assembly	Assembly (1)
Vehicle Assembly	Assembly (2)
Vehicle Assembly	Assembly (3)
Component Manufacturing	Alternator
Component Manufacturing	Brake
Component Manufacturing	Electronics
Component Manufacturing	Engine
Component Manufacturing	Transmission
Fabrication Process	Forging
Fabrication Process	Glass
Fabrication Process	Iron Casting
Fabrication Process	Plastic Moulding
Fabrication Process	Stamping

[4] The OEM plants inventoried were all based in North America. Primary plant data was generally based on the 1995 model production year. Water emissions inventory for the forging plant is based on data from 1996. The plastics molding plant includes energy data, nitrogen oxides data, and some water emissions data from 1996. The air emissions data from the glass plant was for 1993 and the water emissions inventory is based on permit data for 1994-1997.

4.2.2 Vehicle Use

Use Phase activities were organised into two broad categories: (1) Vehicle Operation, and (2) Maintenance and Repair. This section describes the area of scope for both of these.

4.2.2.1 Vehicle Operation

This part of the Use Phase encompasses driving the vehicle a total distance of 193,000 km, after which it is retired. The relevant scope of analysis includes energy consumption and emissions related to fuel combustion in the engine, and upstream production and delivery of the fuel. Both PNGV variants – gas and diesel – were considered.

Assuming hybrid and fuel cell manufacturing technologies would not be affordable by 2004, an internal combustion power plant was specified for the ULSAB-AVC [Porsche Engineering Services 2001]. Because no prototype vehicle existed on which to collect test data, engine performance was based on knowledge of currently available technology.

Target emissions for carbon dioxide provided a basis for estimating vehicle fuel efficiency. For other select vehicle air emissions (carbon monoxide, non-methane hydrocarbons, oxides of nitrogen, and particulate matter), EU4 standards (2005) were adopted as emissions factors (g/km). While EU4 standards cannot be met using current engine technology, vehicle manufacturers believe that they will be achieved for gasoline engines by 2005. Diesel technology will meet EU4 standards only if low-sulphur fuel is used and if catalytic converter and particulate filter technologies progress as expected.

Whereas the original USAMP study considered both on-cycle emissions (normal operation) and off-cycle emissions (resulting from vehicle ageing and powertrain malfunctions), the current LCI study was limited to on-cycle emissions only for both the USAMP and ULSAB-AVC systems. Again, lack of an ULSAB-AVC prototype vehicle precluded analysis of actual deterioration and malfunction effects.

4.2.2.2 Maintenance and Repair

Scope for these activities includes material production and manufacturing of replacement parts consumed during routine service and maintenance, as well as unscheduled parts replacement.

In the USAMP study, a parts replacement schedule was developed to estimate the required parts and part quantities for these activities. This schedule was adopted with minor adjustments for use in the current LCI. Maintenance also includes periodic washing of the vehicle. Repair service for accidents was not considered due to uncertainty about the relationship between design parameters and accident rates.

For the average car, most replacement parts such as filters and oil are used for regular maintenance rather than replacement of major structural or mechanical components. Therefore, replacement parts are assumed to originate in vehicle manufacturing plants, not remanufacturing or dismantling facilities. The same OEM plants used to model the vehicle production phase were used to model the production of replacement parts in the Use Phase (see Table 3, Section 5.2.1.2).

4.2.3 Vehicle Disposition

Vehicle Disposition encompasses transportation of the used car to a dismantling facility, dismantling and shredding activities, and disposal of shredder residue. It is assumed that the vehicle is retired at the end of its useful life, 193,000 km, and then transported 100 km by truck to the dismantling facility. Open and closed loop recycling of scrap are both considered. For the ULSAB-AVC study, only the PNGV-gas variant was modelled for the disposition phase.

4.2.4 Key Assumptions and Exclusions

In defining the scope of the ULSAB-AVC life cycle inventory study, it is important to note the key assumptions and exclusions that are described in the following sections.

4.2.4.1 Vehicle Production

4.2.4.1.1 Raw Material Acquisition

- The ULSAB model used updated steel LCI data from IISI [IISI 2002]. The steel data used for the USAMP model remained 1995 data.
- Capital assets (plant and equipment), transportation infrastructure (roads, streetlights, service stations), and human activity (food and transport) associated with the production of materials are excluded from both the ULSAB-AVC and USAMP studies because the relative contribution to the product system for the functional unit being considered would be minor.
- Materials that were not modelled in this study are specified in Appendix B. The total mass of the materials not modelled is 2.7 kg for the ULSAB-AVC PNGV-gas vehicle (0.270% of its total mass) and 4.9 kg for the USAMP generic vehicle (0.315% of its total mass).
- The mass of "Paint and PVC" from the ULSAB-AVC PNGV-gas engine vehicle parts list (20 kg) is excluded from the material production model because it is accounted for as part of the assembly plant burdens (as it is in the USAMP study).

4.2.4.1.2 Manufacturing and Assembly

- Hydroforming is not yet incorporated in the ULSAB-AVC model[5]. In the meantime, stamping has been used as a substitute. With its lower scrap rate compared with stamping, hydroforming is expected to improve environmental performance of the ULSAB-AVC vehicle in the vehicle production phase. The production of tubes for hydroforming is included although the tube bending process is excluded.
- Capital equipment, human activities and some generic fabrication processes were excluded from both the USAMP and ULSAB-AVC studies. The generic fabrication processes that were excluded are listed in Appendix B.
- A scrap rate of 3% is assumed for the vehicle assembly stage in the USAMP study and is applied in the ULSAB-AVC study.

4.2.4.2 Use

- The PNGV-diesel engine variant is modelled in addition to the PNGV-gas engine variant for the ULSAB-AVC study. Only on-cycle emissions were considered (for both USAMP and ULSAB-AVC).

- Diesel fuel production data was the same as that used for diesel fuel production in the USAMP study. The gasoline distribution module was adopted as the diesel distribution module, for which data were not available.

4.2.4.3 Disposition

- Energy and process wastes associated with vehicle dismantling were neglected, as they are expected to be minor. Modelling of the reuse, material and/or energy recovery potentials of dismantled parts is outside the boundaries of the vehicle system being considered.

- The model assumes that all fluids are completely drained and available for recovery. The shredder model functions as a three-way material separator (into ferrous, non-ferrous and automotive shredder residue (ASR)). It assumes perfect material recovery rates.

- The USAMP model contains the following error: it used 0.097 MJ as shredder electricity when it is actually primary energy. This resulted in primary energy being divided by the conversion efficiency, so USAMP disposition results are overstated. To maintain an accurate comparison, we accepted the same relationship without revision for ULSAB-AVC. The total result for this element was already small; it is even less significant in the current results.

[5] 8% of the total PNGV-gas engine vehicle mass is hydroformed steel.

4.3 Data Categories

The data categories tracked for the ULSAB-AVC LCI study are shown in Table 3 and presented in the Results section of this report (Section 6). The highlighted categories in the table are presented in detail in the Results section: Total Primary Energy, Carbon Dioxide, Carbon Monoxide, Nitrogen Oxides, Non-methane Hydrocarbons, Particulate Matter, Sulphur Oxides and Solid Waste (total). An exhaustive set of data categories is available in the ULSAB-AVC TEAM™ model (see Section 5.1 for TEAM™ model details).

Energy is generally expressed as low heating value (LHV) or high heating value (HHV). Throughout this study, Total Primary Energy is expressed as HHV except for the IISI steel data sets, which express total primary energy as LHV.

It should be noted that the IISI steel life cycle data includes non-methane hydrocarbon air emissions as part of the volatile organic compounds (VOC) data category in their report [IISI 2002]. However, to stay consistent with the modelling methods used in the USAMP study, the non-methane hydrocarbons category was maintained for the current study. VOC burdens from steel production were tracked as non-methane hydrocarbon, as most VOCs in the steel manufacturing process are attributed to non-methane hydrocarbons. Therefore, non-methane hydrocarbon emissions are slightly overestimated.

The steel modules provided by IISI exclude all input and output data categories of less than 2% by mass from the inventory. Natural resources used in the production of crude steel in very small amounts include the following ores (mass expressed in parentheses in kg/kg Hot Rolled Coil BF route): bauxite ore (0.00617), chromium ore (0.000682), ilmenite ore (0.000298), manganese ore (0.009878) and uranium ore (1.8E-06) [IISI 2002]. These data are available upon request from IISI.

Table 3. List of Data Categories.

Data Category	Environmental Flow
Resource Use	(r) Bauxite (Al2O3, ore) (r) Coal (in ground) (r) Ilmenite (FeO.TiO2, ore) (r) Iron (Fe, ore) (r) Lead (Pb, ore) (r) Limestone (CaCO3, in ground) (r) Natural Gas (in ground) (r) Oil (in ground) (r) Perlite (SiO2, ore) (r) Pyrite (FeS2, ore) (r) Sulfur (S) (r) Tungsten (W, ore) (r) Uranium (U, ore) (r) Zinc (Zn, ore) Iron Scrap Natural Rubber Raw Materials (unspecified) Water Used (total)
Air Emissions	**(a) Carbon Dioxide (CO2, fossil)** **(a) Carbon Monoxide (CO)** **(a) Hydrocarbons (except methane)** (a) Hydrogen Chloride (HCl) (a) Hydrogen Fluoride (HF) (a) Lead (Pb) (a) Methane (CH4) **(a) Nitrogen Oxides (NOx as NO2)** **(a) Particulates (unspecified)** **(a) Sulfur Oxides (SOx as SO2)**
Water Emissions	(w) Ammonia (as N) (w) Dissolved Matter (unspecified) (w) Heavy Metals (total) (w) Oils (unspecified) (w) Phosphates (as P) (w) Suspended Matter (unspecified)
Solid Waste	Waste (municipal and industrial) **Waste (total)**
Energy Consumption	**E Total Primary Energy**

4.4 Criteria for Inclusion of Inputs and Outputs

Because the ULSAB-AVC study was primarily based on the methodology, modelling and data from the USAMP study the criteria for input and output flows are determined by the USAMP study. Decision rules were established by the USAMP/LCA partners to ensure that ancillary material flows modelled in the inventory were consistently identified. These rules are listed in Appendix C.

4.5 Data Quality

Data quality for the ULSAB-AVC life cycle inventory study was dictated primarily by the USAMP study because it is largely based on the methodology, modelling and data utilised for the USAMP study. The USAMP/LCA partners made every effort to collect high quality primary data. Secondary or surrogate data were employed where primary data were not available.

Data quality indicators were used to report data quality for each process and for data subsets within a process. These data quality indicators included precision, completeness, representativeness and consistency.

4.6 Comparisons Between Systems

This study does not include a comparison between product systems.

4.7 Critical Review Considerations

In accordance with the international standard ISO 14040:1997(E), section 7.3, a critical review was undertaken for this study. Internal experts, per section 7.3.1 of the standard, undertook the critical review. The reviewers consisted of experts with knowledge of the steel, automotive, and life cycle assessment fields.

The purpose of the critical review was to facilitate understanding, improve the quality of the study and enhance the credibility of the study among the target audience.

A review statement is attached to this report.

5 DATA COLLECTION AND CALCULATION PROCEDURES

The purpose of this section is to describe the modelling methods used to carry out the ULSAB-AVC life cycle inventory study. The methods describe how each vehicle life cycle phase was modelled including Vehicle Production, Vehicle Use and Vehicle Disposition. A description of the TEAM™ software tool, used to compile the inventory results, is also included. The modelling methods generally mirror those used for the USAMP study. Modelling tasks and challenges specific to the ULSAB-AVC study are discussed in each section below.

For the ULSAB-AVC study, the Vehicle Production and Vehicle Disposition phases were modelled based on the ULSAB-AVC PNGV-gas engine variant. The Vehicle Use phase encompassed both the PNGV-gas and diesel engine variants.

5.1 Developing the TEAM model

A life cycle inventory software model was built, using TEAM™ software[6], to compile and compute the life cycle inventory of the generic vehicle for the USAMP study. It was organised according to the USAMP organisational code and hierarchy (see Section 5.2.1). The same software model formed the basis of the ULSAB-AVC LCI. The model was modified to represent the ULSAB-AVC PNGV-gas vehicle for each life cycle phase and also included the PNGV-diesel engine variant as a use phase

[6] Tools for Environmental Analysis and Management, Ecobalance, copyright 1992, 1993.

option so that the use phase burdens could be calculated for either the gas engine or diesel engine PNGV variant. These modifications are detailed in the following sections.

5.2 Modelling the Vehicle Production Phase

The purpose of the Vehicle Production phase model was to determine the life cycle environmental burdens associated with raw material acquisition, material production, manufacturing and vehicle assembly.

In order to calculate burdens associated with raw material acquisition, material production and manufacturing for the ULSAB-AVC system the material composition of the vehicle was needed with material type and processing specified. The ULSAB-AVC PNGV-gas engine vehicle parts list included measured or estimated mass and quantity data for 497 parts components and subsystems, all together summing to the total PNGV-gas engine vehicle mass of 998 kg [Porsche Engineering Services 2001]. These parts were described by the 17 general ULSAB-AVC material categories shown in Table 4. Casting is the only process step specified.

Table 4. ULSAB-AVC Material Categories

ULSAB-AVC Material Categories
Cast Iron/Cast Aluminium
Fluids
Glass
Light Alloy
Magnesium
Other - Adhesives
Other - Bitumen
Other - Fibre Composite
Other - Unspecified
Other - Plastic
Plastic
Plastic - Composite
Plastic - Nylon Hybrid
Rubber
Steel
Steel/Aluminium - Combo
Steel/Other - Combo

The material categories specified by the parts list did not provide sufficient detail for the TEAM™ software model, which required specific material and process data. Because obtaining further material composition detail for each part or subassembly would have required an ULSAB-AVC prototype vehicle to be built, instead, USAMP material and process data was used to further specify the ULSAB-AVC system material composition. Each part in the USAMP system was described by one of approximately 140 material/process combinations modelled in the USAMP system.

The first step in the material composition detailing process was to map the ULSAB-AVC parts, components and subsystems according to the USAMP organisational code. This is described in the next section. The second step was to establish a material mapping procedure to apply to the ULSAB-AVC parts list consistently to estimate the material composition of each ULSAB-AVC part/subassembly. These procedures are explained in the decision tree in figure E-1 in Appendix E and the results of the material mapping are shown in Table E-1, the ULSAB-AVC PNGV-gas engine vehicle parts list.

5.2.1 Parts Mapping

The USAMP team developed their own organisational code and hierarchy for classifying a generic vehicle into subsystems, components and parts. This was done as a result of significant differences and varying levels of detail between each OEM parts code and in the interest of keeping the OEM's individual parts codes confidential. The resulting USAMP organisational code consists of 19 subsystems (see Appendix D for complete code description) which are organised into the following seven vehicle systems:

- Fluids
- Heating, Ventilation and Air Conditioning (HVAC)
- Interior
- Suspension
- Electrical
- Powertrain
- Body

The ULSAB-AVC PNGV-gas engine vehicle parts, components and subsystem were originally categorised according to the German GADH hierarchical standards[7] and had to be translated to the USAMP organisational code. Although an initial side-by-side comparison of the two lists showed that some of the parts could be easily translated, it was not always possible to map down to the part level because there was a difference in detail between the two systems[8]. As a result, it was not feasible to map the ULSAB-AVC system part-by-part according to the USAMP code. The project team decided that mapping the ULSAB-AVC system to the subsystem level would be sufficient detail for the purposes of the current life cycle study and that attempting to make a more detailed map (to the part level) would be beyond the scope of the project.

Each part or subassembly on the ULSAB-AVC list was categorised according to the USAMP vehicle subsystem to which it belonged[9] based on CSS knowledge of automotive systems and technical information received from AISI, IISI and ULSAB-AVC consortium members. Results of the subsystem mapping process are shown in Table E-1 in Appendix E.

[7] See Appendix 5 of ULSAB-AVC Engineering Report for GADH details Porsche Engineering Services, I. (2001). ULSAB-AVC Engineering Report, ULSAB-AVC, Porsche..

[8] The ULSAB-AVC vehicle parts list often gave detail only to the sub-subsystem level. For example, the mass of the engine (subsystem of the Powertrain subsystem or sub-subsystem of the Vehicle) was listed, but the mass of the crankshaft, an engine component, was not listed separately because it was included in the mass of the engine.

[9] For example, the engine was categorized under the Powertrain subsystem, and the front and rear bumpers were categorized under the Body subsystem.

5.2.2 Material Distribution

The specific material distribution resulting from further material composition detailing of the ULSAB-AVC PNGV-gas engine vehicle is shown in Appendix F. The general material distribution by material category of the ULSAB-AVC PNGV-gas engine vehicle is shown in Figure 3.

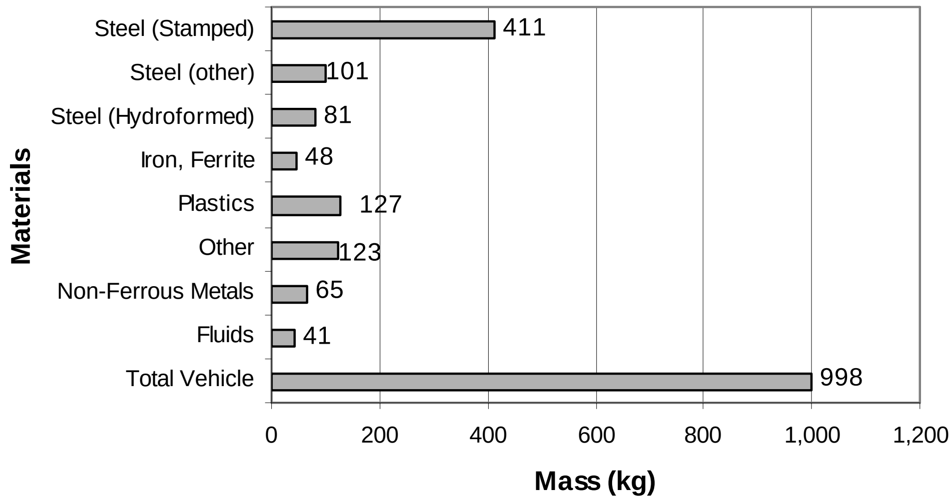


Figure 3. Material Distribution for the ULSAB-AVC PNGV-Gas Engine Vehicle.

In addition to the steel part fabrication processes (including extruding, stamping and forging) already in the USAMP model, the ULSAB-AVC PNGV vehicle also applies the hydroforming process[10] as shown in Figure 3 above. Primary plant data for this process was being collected in conjunction with the current study, but was not available for inclusion in the model as of the writing of this report; hence, stamping was applied as a substitute for the mass of hydroformed material (see Section 4.2.4.1.2). The hydroforming process is expected to result in a significantly lower scrap rate and lower energy consumption than the stamping process; therefore, when the hydroforming module is applied in the future, an additional reduction of environmental burdens is expected for the ULSAB-AVC vehicle.

5.2.3 Plant Burdens Allocation Procedure

Two different approaches were used to allocate environmental burdens from the OEM plants listed in Table 3 (Section 4.2.1.2). Environmental burdens from parts fabrication plants with multiple product outputs were allocated on a product mass basis. This allocation procedure was more accurate for some processes than others. Burdens from component and subassembly plants (such as the alternator, electronic components, and engine and transmission plants) were allocated on a unit product output basis. Although different types of engine and transmission models are manufactured at the OEM plants, burdens were allocated by total numbers of each type produced. This approach was less accurate for electronic components, which vary significantly in composition.

5.3 Modelling the Use Phase

The TEAM model that was developed for the ULSAB-AVC Use Phase was based on previous USAMP modelling efforts. This section includes a summary comparison of the ULSAB-AVC and USAMP models, followed by detailed modelling descriptions for Vehicle Operation and Vehicle Maintenance and Repair.

[10] 8% of the total PNGV-gas engine vehicle mass is hydroformed steel.

5.3.1 Summary of USAMP and ULSAB-AVC Modelling

In the USAMP study, fuel consumption for three mid-sized automobiles was directly measured using federal testing procedures for city and highway driving. This data was averaged to form a composite vehicle profile based on the U.S. EPA fuel economy formula of 45% highway mileage and 55% city mileage, yielding 10.3 L/100km (22.8 mi/gallon). Emissions of carbon monoxide, non-methane hydrocarbons, oxides of nitrogen, and particulate matter were directly measured from the three vehicles to yield average emission factors in grams/kilometre (grams/mile). Carbon dioxide emissions were estimated using a mass balance equation that considered the carbon content of fuel. Therefore, CO_2 was actually derived from USAMP fuel efficiency data.

In the current study, collection of test data from an actual vehicle was not possible. Instead, U.S. combined city/highway fuel economy data for the PNGV program were adopted. CO_2 emissions were again calculated using the USAMP carbon content mass balance formula.

For all other vehicle emissions in the ULSAB-AVC model, EU4 standards (2005) were adopted as emissions factors (g/km). It should be emphasised that both gas and diesel variants were evaluated for the ULSAB-AVC, while the USAMP study considered only a gasoline-powered vehicle.

With regard to Maintenance and Repair, the USAMP replacement parts schedule was adopted for use in the ULSAB-AVC model with the exception of fluid volumes, which were recalculated (see Section 5.3.3).

5.3.2 Vehicle Operation

This subsection includes two separate modelling descriptions for energy and CO_2 emissions, and other select vehicle emissions.

5.3.2.1 Modelling of Energy and CO_2 Emissions

Table 5 shows U.S. combined cycle CO_2 emissions and fuel consumption for the PNGV research program.

Table 5. PNGV CO_2 Emissions and Fuel Consumption (U.S. combined)

	Gas	Diesel
CO_2 emissions (g/km)	108	92
Fuel economy (L/100km)	4.5	3.4

Source: Table 15.5-2, ULSAB-AVC Engineering Report, [Porsche Engineering Services 2001]

These fuel economy values were adopted for the ULSAB-AVC model and were directly applied to the functional unit (193,000 km) to yield total fuel consumption over the vehicle's useful life. Energy consumption was then calculated by applying factors for fuel energy content.

The CO_2 values from Table 6 were not adopted for this study. Instead, the USAMP mass balance formula for carbon content was used. According to the GREET 1.5 transportation spreadsheet model published by the University of Chicago, conventional gasoline's carbon content is 85.5% by mass and its density is 10,565 grams/litre (2,791 grams/gallon). For conventional and reformulated low-sulphur diesel fuel, the carbon content is 87% and its density is 12,265 grams/litre (3240 grams/gallon). These diesel factors were added to the model for the ULSAB-AVC analysis.

5.3.2.2 Modelling of Other Select Vehicle Emissions

EU4 standards, which are provided below in Table 6, were adopted as emissions factors for carbon monoxide, non-methane hydrocarbons, oxides of nitrogen, and particulate matter.

Table 6. EU4 Emissions Standards.

EU4 (g/km)	CO	HC	NOx	HC + NOx	PM
Gas	1.0	0.1	0.08	---	---
Diesel	0.5	---	0.25	0.3	0.025

Source: Table 2.7-1, ULSAB-AVC Engineering Report, [Porsche Engineering Services 2001]

These EU4-based emissions factors were used to calculate pollutant emission results for the PNGV-gas and diesel engine variants. EU4 emissions standards are maximum allowable legal limits of emissions in the European Union beginning in 2005. Therefore, they represent an upper bound for potential ULSAB-AVC emissions. The validity of this approach can be tested by comparing USAMP emissions results, based on actual vehicle tests, to contemporary U.S. EPA standards from 1995. Table 7 shows the headroom or gap between USAMP and U.S. EPA data from 1995. At 100,000 km, which is below the functional unit in this study 193,000 km, USAMP emissions were clearly below established standards at the time. Therefore, it can be reasonably assumed that the EU4 upper bound approach for determining ULSAB-AVC emissions is valid.

Table 7. USAMP Generic Vehicle on-cycle emissions based on the average of US EPA certification test results g/km (g/mi) for the Taurus, Lumina and Intrepid.

(Standard Deviations are indicated as +/- values. Compared with 1995 US EPA Federal Certification Exhaust Emissions Standards for Light-Duty Vehicles (Passenger Cars)[11].)

Pollutant Species	Unit km (mi)	USAMP Emissions Test Rating 193 K (120 K)	1995 U.S. EPA Standard*** Tier 0 80K (50K)	1995 U.S. EPA Standard*** Tier 0 161K (100K)	1995 U.S. EPA Standard*** Tier 1 80K (50K)	1995 U.S. EPA Standard*** Tier 1 161K (100K)
CO	g/km (g/mi)	0.80 +/- 0.33 (1.29 +/- 0.53)	2.11 (3.40)	n/a (n/a)	2.11 (3.40)	2.6 (4.2)
NOX	g/km (g/mi)	0.33 +/- 0.14 (0.53 +/- 0.23)	0.62 (1.0)	n/a (n/a)	0.25 (0.4)	0.37 (0.6)
HC*	g/km (g/mi)	0.35 +/- 0.21 (0.56 +/- 0.34)	0.21** (0.34**)	(n/a) (n/a)	0.16** (0.25**)	(0.19**) (0.31**)

*HC = total of methane and non-methane hydrocarbons (NMHC).
**Non-methane hydrocarbons (NMHC) value only. Methane not included.
***Source: [EPA February 2000]

Finally, the original USAMP model incorporated off-cycle factors to describe effects of normal vehicle wear and malfunction on emissions. This additional complexity was not expected to contribute much to the value of the ULSAB-AVC model and it was excluded from the analysis. To provide a valid literature reference for the ULSAB-AVC study, the off-cycle option was disabled when generating results from the USAMP model.

[11] EPA 1995 Emissions schedule required at least 80% of vehicles to comply with Tier 1, 20% Tier 0 allowed.

5.3.3 Maintenance and Repair

Maintenance and Repair encompasses burdens due to replacement parts consumed during routine service and maintenance, as well as unscheduled parts replacement.

The USAMP project team compiled a list of replacement parts and fluids from various sources and estimated the average quantity consumed over the lifetime of a car. This replacement schedule was adopted for the PNGV-gas model, except that new fluid volumes were calculated.[12] Table 8 shows the list of replacement parts for both vehicles.

Table 8. Replacement items used during automobile lifetime.

General Characteristics and Functions			
Item	**Unit**	**USAMP**	**PNGV-gas**
Brake fluid	Litre	3	1.4
Engine coolant fluid	Litre	22.2	8.9
Engine oil	Litre	78.1	101.1
Transaxle fluid	Litre	28	4.6
Windshield cleaner	Litre	44	27.5
Air filter	Quantity	4.3	4.3
Battery	Quantity	1.7	1.7
Brake pads front	Quantity	4	4
Brake pads rear	Quantity	4	4
Drive belt	Quantity	2	2
Lamp Bulbs	Quantity	3.5	3.5
Muffler, exhaust pipe	Quantity	1	1
Oil filter	Quantity	15.7	15.7
PCV-valve	Quantity	2	2
Shock absorbers	Quantity	4	4
Spark plugs	Quantity	16	16
Tires	Quantity	8	8
Transaxle fluid filter	Quantity	1	1
Windshield	Quantity	1	1
Windshield wiper blades	Quantity	18.7	18.7

[12] Using USAMP data, refill frequencies were calculated. These were then multiplied by ULSAB-AVC tank capacities.

Replacement part burdens were determined using existing TEAM™ modules for vehicle manufacturing; no separate modules were developed for the remanufacturing of replacement parts. The following rules were applied in this process:

- If the mass of a part is less than 1% of total ULSAB-AVC vehicle mass, then assume USAMP mass and material composition for that part.
- If the mass of a part is greater than 1% of total ULSAB-AVC vehicle mass, then refer to material mapping procedures in Figure E-1 in Appendix E.

Assuming that burdens for manufacturing are higher than those for remanufacturing, environmental impacts associated with maintenance and replacement parts have probably been overstated in the ULSAB-AVC model. In addition, error in quantifying material waste has been reduced in that outgoing large parts were considered to be recycled rather than disposed of as waste. They have been recorded as “used parts” outflows in the inventory when they leave the system (e.g. “Bumper (used)”).

Finally, USAMP data on vehicle washing were adopted for the current LCI. CSS previously collected inventory data from a car wash facility in Ann Arbor, Michigan. Environmental burdens included consumption of 284 litres of water and 3.5 kWh of electricity per wash. USAMP wash frequency was assumed for ULSAB-AVC.

5.4 Modelling the Disposition Phase

After the vehicle reaches its 193,000 km service life, it is managed through a series of four major disposition activities, which mirror those identified in the USAMP study:

- Transportation to the dismantling facility
- Dismantling
- Shredding
- Disposal of shredder residue

Scrap recycling is also accounted for. The TEAM™ model was modified by scaling down the mass of parts according to the PNGV-gas variant parts list for the ULSAB-AVC study.

5.4.1 Transportation

It was assumed that the retired vehicle is transported a distance of 100 km to the dismantling facility and that this freight linkage involves only trucks.

5.4.2 Dismantling

Actual burdens from dismantling operations and dismantled parts were excluded from the analysis. It is expected that these are quite small by comparison. Nevertheless, it was assumed that fluids and other high-value components (e.g. catalytic converter, tires, battery etc.) are removed for recycling and reuse markets. While practices for draining fluids vary considerably, it was assumed that all fluids were drained completely and made available for full recovery. The tires are either recycled, combusted for energy recovery, or treated as waste. The post-dismantling vehicle hulk is then sent to the shredder [Keoleian, Lewis et al. 1998].

5.4.3 Shredding
The shredder model functions as a material separator which perfectly divides the vehicle into ferrous, non-ferrous and automotive shredder residue (ASR) fractions without any losses or contamination. The shredder model does not account for any burdens other than energy requirements, which are estimated. Allocation of shredder energy use is handled on a mass basis. Energy consumed by the shredder was estimated to be 0.097 MJ/kg of shredder material. The average U.S. energy grid was assumed for electricity consumption.

5.4.4 Disposal and Recycling
Landfill burdens include construction, operation (placement of waste and daily cover), closure and post-closure activities at the landfill. They are allocated on a mass basis. Ancillary materials including on-site capital equipment were quantified using the same database as the generic vehicle model. The average U.S. energy grid was assumed for electricity consumption.

Open-loop and closed-loop recycling of scrap is also considered. Scrap, such as recycled steel and aluminium, that is used in production of the generic vehicle is modelled in a consistent manner. The only burdens associated with scrap inputs to the generic vehicle system accrue from recycling processes and transportation. This applies to both scrap recycling from another product system as well as to closed-loop recycling. The scrap that leaves the system (open-loop recycling) is treated neither as waste nor co-product. This approach places all burdens associated with vehicle parts production within the generic vehicle life cycle boundary, even though some of the material is recycled. For instance, a 3 kg steel part requiring 5 kg of steel to produce is attributed 5 kg worth of steel manufacturing burdens and not 3 kg worth, even though 2 kg are recycled.

5.4.5 Disposition Emissions and Waste
Disposition air emissions are due to transportation emissions, shredder energy use and landfilled ASR. In particular, emissions for ASR stem from landfill equipment upstream capital equipment. It is assumed that the ASR does not decompose and produce any landfill gas.

Water effluents associated with the disposition are due to energy precombustion and landfill leachate from ASR. The leachate produced from ASR is based on the average leachate in municipal solid waste scaled up to reflect the increased metal content of ASR.

Solid waste in this part of the model comes from the portion of the vehicle that can not be recovered after shredding (ASR). It is assumed to be landfilled.

6 LIFE CYCLE INVENTORY RESULTS
The life cycle inventory results for the ULSAB-AVC PNGV-gas and diesel engine variants are given in the following four sections. Total life cycle results are presented in the first section. In the proceeding three sections, results are broken down by individual life cycle phase: Vehicle Production, Vehicle Use and Vehicle Disposition.

6.1 Total Life Cycle Inventory Results
Total life cycle inventory results for the ULSAB-AVC study encompasses the results from each of the three major life cycle phases including Vehicle Production, Use and Disposition. These results are presented by life cycle phase in Table 9 for the PNGV-Gas engine variant. Use phase burdens for the PNGV-Diesel engine variant are shown in Table 10. This section highlights the total life cycle energy consumption, CO_2 emissions, other select air emissions and solid waste production for the ULSAB-AVC PNGV-Gas engine variant.

Table 9. ULSAB-AVC Total Life Cycle Inventory results for PNGV-gas engine variant.

	ULSAB-AVC					
	PNGV Gas Engine Vehicle					
Category	**Environmental Flow****	**Units**	**Vehicle Production Phase**	**Use Phase**	**Disposition Phase**	**Vehicle Life Cycle Total**
Resource Use	(r) Bauxite (Al2O3, ore)	kg	108	0.01		108
	(r) Coal (in ground)	kg	1,556	414	7.1	1,977
	(r) Ilmenite (FeO.TiO2, ore)	kg	1	0		1
	(r) Iron (Fe, ore)	kg	1,496	0.37	0.03	1,496
	(r) Lead (Pb, ore)	kg	9.6	15		25
	(r) Limestone (CaCO3, in ground)	kg	163	80	1.4	244
	(r) Natural Gas (in ground)	kg	532	518	1.8	1,052
	(r) Oil (in ground)	kg	336	7,162	35	7,532
	(r) Perlite (SiO2, ore)	kg	0.74	0		0.74
	(r) Pyrite (FeS2, ore)	kg	1.7	0.00003		1.7
	(r) Sulfur (S)	kg	0.08	0.00003		0.08
	(r) Tungsten (W, ore)	kg	0.0005	0.0007		0.001
	(r) Uranium (U, ore)	kg	0.01	0.009	0.0002	0.02
	(r) Zinc (Zn, ore)	kg	34	6.9		41
	Iron Scrap	kg	65	26		91
	Natural Rubber	kg	5.3	10		15
	Raw Materials (unspecified)	kg	12	0.24		12
	Water Used (total)	liter	41,149	4,411	3.9	45,563
Air Emissions	(a) Carbon Dioxide (CO2, fossil)	kg	6,088	22,449	131	28,668
	(a) Carbon Monoxide (CO)	g	57,235	222,391*	677	280,303
	(a) HC (except methane)	g	10,228	30,138*	167	40,534
	(a) Hydrogen Chloride (HCl)	g	207	206	3.8	417
	(a) Hydrogen Fluoride (HF)	g	21	24	0.48	46
	(a) Lead (Pb)	g	36	50	0.01	86
	(a) Methane (CH4)	g	11,647	22,492	118	34,257
	(a) Nitrogen Oxides (NOx as NO2)	g	16,995	32,983*	763	50,741
	(a) Particulates (unspecified)	g	12,402	8,682*	190	21,274
	(a) Sulfur Oxides (SOx as SO2)	g	21,987	40,418	250	62,655
Water Emissions	(w) Ammonia (as N)	g	222	1,008	1.9	1,231
	(w) Dissolved Matter (unspecified)	g	3,390	1,079	11	4,480
	(w) Heavy Metals (total)	g	26	2	0.0009	28
	(w) Oils (unspecified)	g	581	3,155	7.3	3,743
	(w) Phosphates (as P)	g	9.3	0.10	0.00001	9.4
	(w) Suspended Matter (unspecified)	g	3,396	31,324	58	34,778
Solid Waste	Waste (municipal and industrial)	kg	76	32	200	307
	Waste (total)	kg	796	574	230	1,600
Energy Consumption	E Total Primary Energy	MJ	100,521	383,286	1,971	485,778

* Vehicle emissions for ULSAB-AVC PNGV-gas variant are based on EU4 Regulations and represent an upper limit.

** (r): Raw material in ground, (a): Airborne emissions, (w): Waterborne emissions

Table 10. ULSAB-AVC Use Phase Life Cycle Inventory results for PNGV-diesel engine variant.

	ULSAB-AVC		
	PNGV Diesel Engine Vehicle		
Category	**Environmental Flow****	**Units**	**Use Phase**
Resource Use	(r) Bauxite (Al2O3, ore)	kg	0.01
	(r) Coal (in ground)	kg	298
	(r) Ilmenite (FeO.TiO2, ore)	kg	0
	(r) Iron (Fe, ore)	kg	0.37
	(r) Lead (Pb, ore)	kg	15
	(r) Limestone (CaCO3, in ground)	kg	58
	(r) Natural Gas (in ground)	kg	262
	(r) Oil (in ground)	kg	6,272
	(r) Perlite (SiO2, ore)	kg	0
	(r) Pyrite (FeS2, ore)	kg	0.00003
	(r) Sulfur (S)	kg	0.00003
	(r) Tungsten (W, ore)	kg	0.0007
	(r) Uranium (U, ore)	kg	0.007
	(r) Zinc (Zn, ore)	kg	6.9
	Iron Scrap	kg	26
	Natural Rubber	kg	10
	Raw Materials (unspecified)	kg	0.24
	Water Used (total)	liter	4181
Air Emissions	(a) Carbon Dioxide (CO2, fossil)	kg	17,657
	(a) Carbon Monoxide (CO)	g	123,869*
	(a) HC (except methane)	g	16,334*
	(a) Hydrogen Chloride (HCl)	g	143
	(a) Hydrogen Fluoride (HF)	g	16
	(a) Lead (Pb)	g	50
	(a) Methane (CH4)	g	15,586
	(a) Nitrogen Oxides (NOx as NO2)	g	58,653*
	(a) Particulates (unspecified)	g	10,165*
	(a) Sulfur Oxides (SOx as SO2)	g	22,814
Water Emissions	(w) Ammonia (as N)	g	347
	(w) Dissolved Matter (unspecified)	g	1,023
	(w) Heavy Metals (total)	g	2.4
	(w) Oils (unspecified)	g	1,352
	(w) Phosphates (as P)	g	0.10
	(w) Suspended Matter (unspecified)	g	10,805
Solid Waste	Waste (municipal and industrial)	kg	32
	Waste (total)	kg	280
Energy Consumption	E Total Primary Energy	MJ	309,866

* Vehicle emissions for ULSAB-AVC PNGV-diesel variant are based on EU4 Regulations and represent an upper limit.
** (r): Raw material in ground, (a): Airborne emissions, (w): Waterborne

The ULSAB-AVC PNGV-Gas Engine vehicle consumes a total of 486 GJ throughout its life cycle. The major contributor to this total is the Use phase, in which 79% of the total energy is consumed as shown in Figure 4 below. This portion is overwhelmingly attributed to the fuel consumed during vehicle operation.

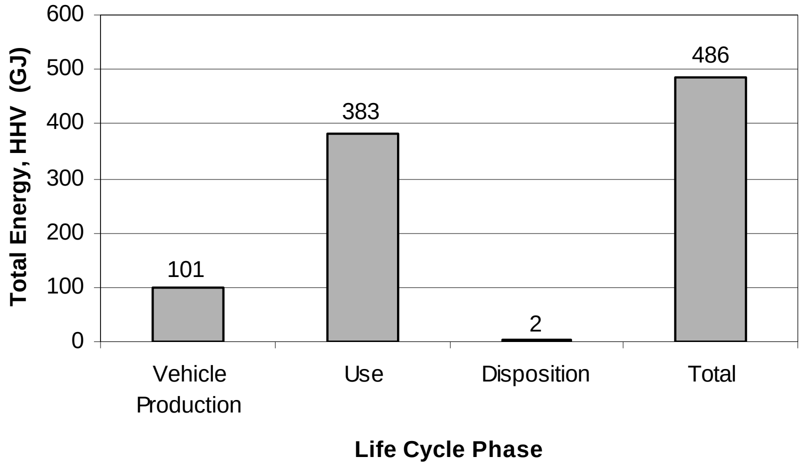


Figure 4. Total Life Cycle Energy Consumption for the ULSAB-AVC PNGV-Gas Engine Vehicle.

Total life cycle CO_2 air emissions for the ULSAB-AVC PNGV-gas engine vehicle follow a similar trend to total energy consumption, with 78% of the emissions attributed primarily to fuel consumption during the use phase, as shown in Figure 5 below.

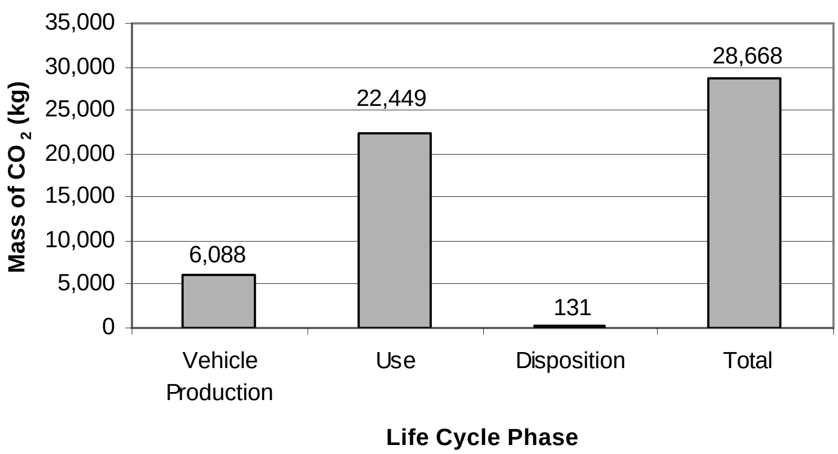


Figure 5. Life Cycle Carbon Dioxide Emissions for the ULSAB-AVC PNGV-Gas Engine Vehicle.

Total life cycle air emissions of select air pollutants for the ULSAB-AVC PNGV-gas engine vehicle are presented in Figure 6 below. Air emissions are broken down by phase in Table 10 above. Of the total CO, NO_X, SO_X and HC (non-methane) emissions, 79%, 65%, 65% and 74%, respectively, are emitted during the vehicle's Use phase. Again, this is primarily due to fuel combustion during vehicle operation. For particulate matter, approximately 58% are emitted during the vehicle production phase, 41% during the Use phase and 1% during the Disposition phase. Particulates are therefore the only major air pollutant that occurs predominantly outside of the use phase.

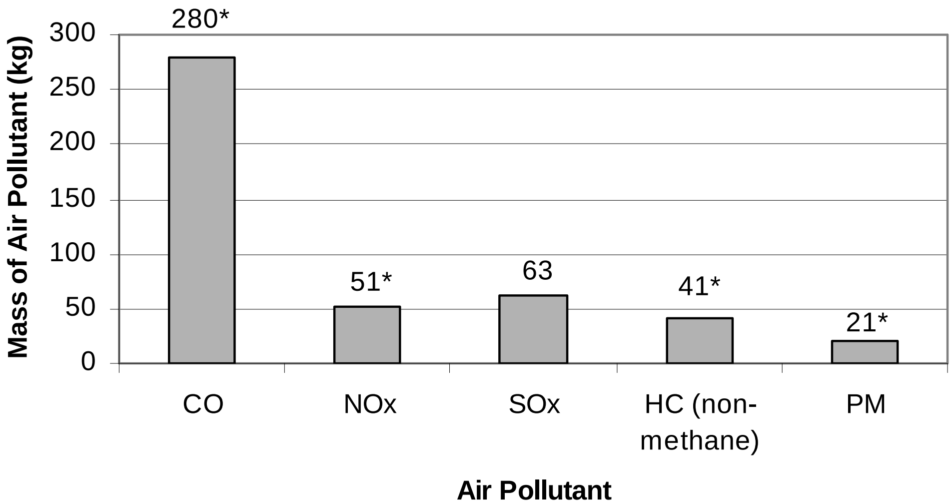


Figure 6. Total Life Cycle Emissions of Select Air Pollutants for the ULSAB-AVC PNGV-Gas Engine Vehicle (*Vehicle emissions are based on EU4 Regulations & represent an upper limit).

Half of all life cycle solid waste is produced during the vehicle production phase of the ULSAB-AVC PNGV-gas engine vehicle. This is primarily attributed to material production. Of the total solid waste produced, 36% occurs during the Use phase and 14% occurs during the Disposition phase, as shown in Figure 7 below.

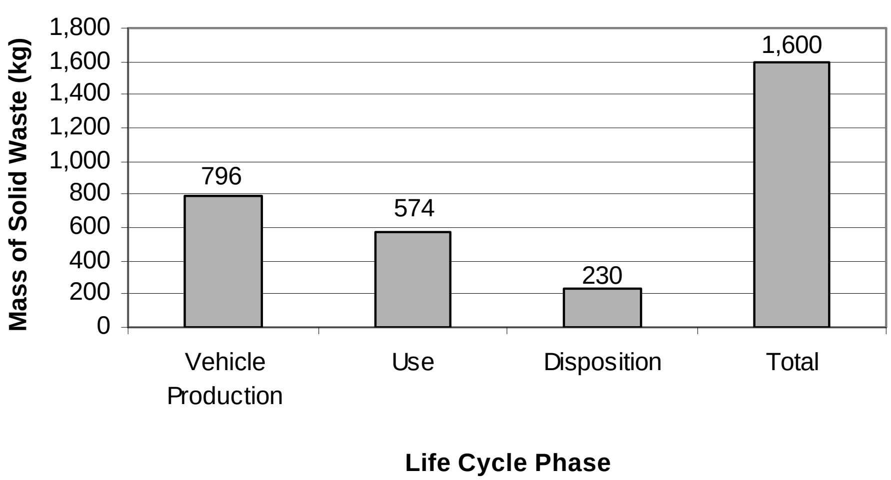


Figure 7. Total Life Cycle Solid Waste Production for the ULSAB-AVC PNGV-Gas Engine Vehicle.

6.2 Vehicle Production

Life cycle inventory results for the Vehicle Production phase cover raw material acquisition, material production, manufacturing, vehicle assembly and the transport between these stages. This section highlights the energy consumption associated with the vehicle production phase for the ULSAB-AVC PNGV-Gas engine vehicle. A detailed list of total environmental burdens associated with Vehicle Production is shown in Table 10 in Section 6.1.

Energy consumption associated with the total Vehicle Production phase is broken down in Figure 8 by subsystem, assembly and transport for the ULSAB-AVC PNGV-Gas engine vehicle. Production consumes a total of 101 GJ of energy. The greatest amount, approximately 34%, is attributed to the body subsystem.

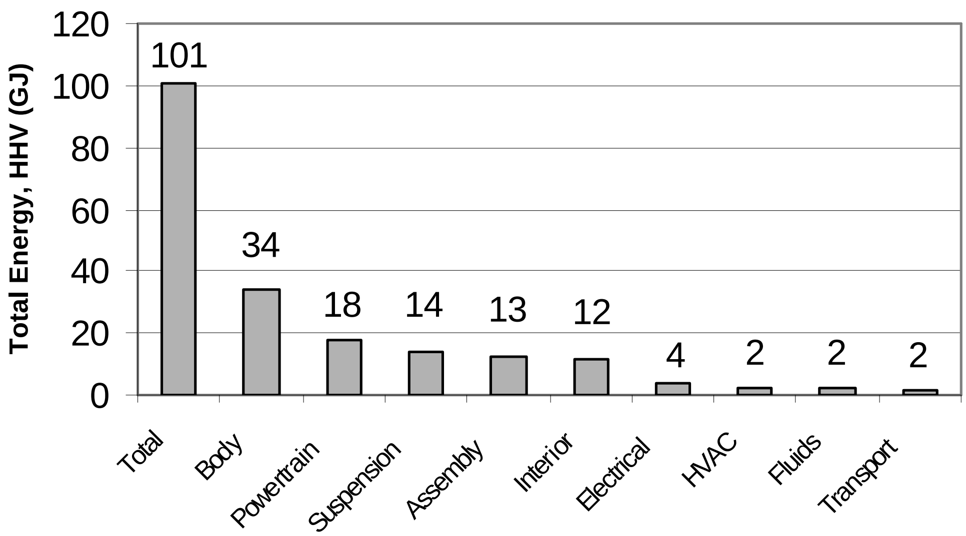


Figure 8. ULSAB-AVC PNGV-Gas Engine Vehicle Production Energy by Subsystem, Assembly and Transport.

6.3 Vehicle Use

Life cycle inventory results for the Vehicle Use phase were compiled for both the ULSAB-AVC PNGV-gas and diesel engine variants. The Use phase includes Vehicle Operation (covering total fuel cycle[13]), Maintenance and Repair stages. It covers the vehicle's 193,000 km (120,000 mile) service life. This section highlights Use phase energy and the select air emissions for the gas and diesel variants. Detailed lists of environmental burdens associated with the Use phase for each variant are presented in Tables 10 and 11 in Section 6.1.

As shown in Figure 9 the use phase energy consumption for the diesel engine variant is 19% lower than that for the gas engine variant. This is attributed to the fact that the PNGV-diesel engine variant at 3.4 L/100km (68 mpg) is more fuel efficient than then PNGV-Gas engine variant at 4.5 L/100km (52.4 mpg).

[13] The total fuel cycle includes production and delivery of fuels in addition to consumption.

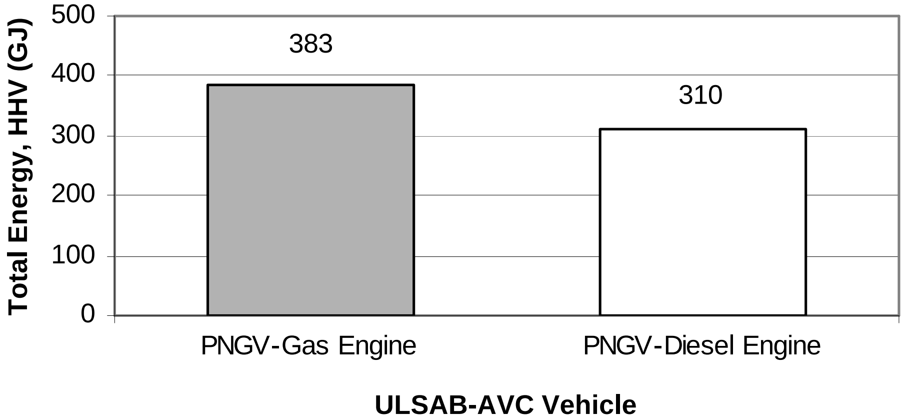


Figure 9. ULSAB-AVC PNGV-Gas and Diesel Engine Use Phase Energy Consumption.

Figure 10 shows the HC and NO_X emissions for the PNGV-Gas and Diesel engine variants. These vehicle emissions (one component of the total use phase emissions) are based on EU4 regulations because it was not possible to obtain actual test data from prototype vehicles. In effect, these EU4-based emissions represent upper limits for the vehicle emissions of both variants. Actual emissions are expected to be lower than these values. Note that the EU4 standards for the Diesel engine variant are given only for NO_X and combined HC + NO_X emissions. The HC + NO_X emissions category for the Gas variant is shown for reference and is the sum of the individual HC and NO_X emissions.

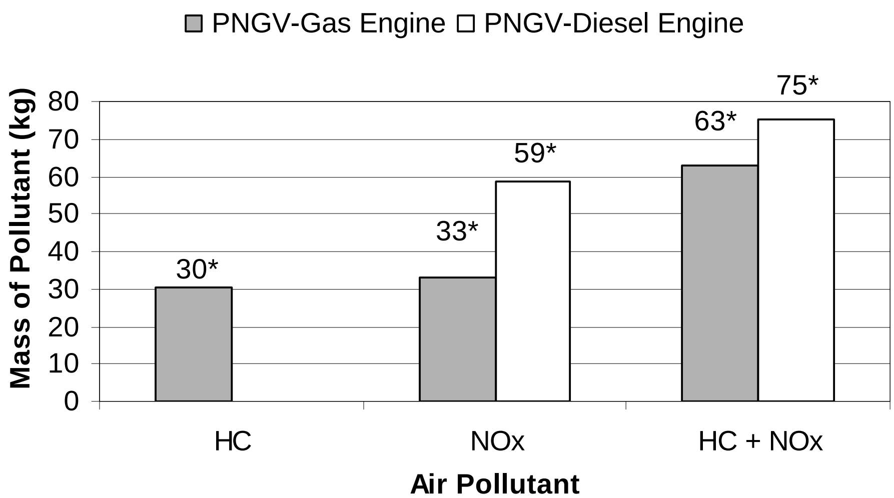


Figure 10. ULSAB-AVC PNGV-Gas and Diesel Engine Use Phase Air Emissions (*Vehicle emissions are based on EU4 Regulations and represent an upper limit).

6.4 Vehicle Disposition

Vehicle Disposition encompasses transportation of the used car to a dismantling facility, dismantling, shredding and disposal of the shredder residue. It is assumed that the vehicle is retired at the end of its useful life, 193,000 km, and then transported 100 km by truck to the dismantling facility. For the ULSAB-AVC study, only the PNGV-gas variant was considered for the disposition phase. At 0.41%, the Disposition phase is a minor contributor to the total vehicle lifecycle energy consumption, therefore, a separate graph of these results is omitted. This trend of negligible impact from disposition follows for all of the environmental burdens compiled for the life cycle inventory except for the Municipal and Industrial Solid Waste category, as shown in Table 10 in Section 6.1.

7 INTERPRETATION

7.1 Other Full Vehicle LCI Studies in the Literature

The following sections present a brief overview of other previously conducted full vehicle LCI studies from the Literature. The results of these studies are referenced to provide some context in discussing the results of the current ULSAB-AVC study.

7.1.1 Original USAMP Study

7.1.1.1 Similarities and Differences Between USAMP and ULSAB-AVC

The model developed for the ULSAB-AVC life cycle inventory was based on that created for USAMP. Major similarities exist between the two, such as definition of functional unit (193,000 km) and system boundaries. The ULSAB-AVC database is also directly interrelated with the USAMP database. In addition to similarities, there are important distinctions between the two studies that must be kept in mind. These include:

- Methodological differences. Alternate methods for collecting steel data for ULSAB-AVC has resulted in steel modules that are not identical. For example, in the USAMP steel module zinc flow reflects resource consumption, while the updated steel module used in the ULSAB-AVC model assigns a resource credit for zinc. Beyond this, the overall level of detail of USAMP data was greater due to the ability to measure the parameters of actual vehicles. Much of the ULSAB-AVC data were based on Porsche design estimates (e.g., powerplant performance).
- Age of relevant data. The USAMP study is based on data that originated in 1995. Due to ULSAB-AVC limitations, much of the USAMP data had to be adopted without modification. In reality using current data for parameters such as production plant burdens would lead to somewhat different results for the ULSAB-AVC system.
- Vehicle characteristics. While the vehicles from the two studies are similar in functional performance, the USAMP automobile was defined as a 6-passenger vehicle, while the ULSAB-AVC car – based on PNGV – is considered to be a 5-passenger vehicle. This is an important distinction to remember when referencing USAMP results. A full list of USAMP characteristics is shown in Appendix G and the USAMP generic vehicle material distribution is shown in Appendix H.

The differences between the two studies are far from trivial. As a result, it is not valid to make a comparison of the USAMP and ULSAB-AVC vehicles; rather, USAMP results are referenced in discussing ULSAB-AVC results.

7.1.1.2 Results of Original USAMP Study

Appendix I provides a summary of life cycle inventory results for the USAMP generic vehicle (as Table 10 does for the ULSAB-AVC PNGV-Gas engine vehicle). Referring to the ULSAB-AVC results presented in Section 6, an initial observation can be made: the PNGV-gas engine vehicle embodies significant overall reductions in both energy consumption and air emissions relative to the USAMP vehicle. Specific observations are highlighted in Figures 11 through 14 below.

Figure 11 shows the total life cycle energy consumption for the ULSAB-AVC vehicle next to that of the USAMP vehicle for reference.

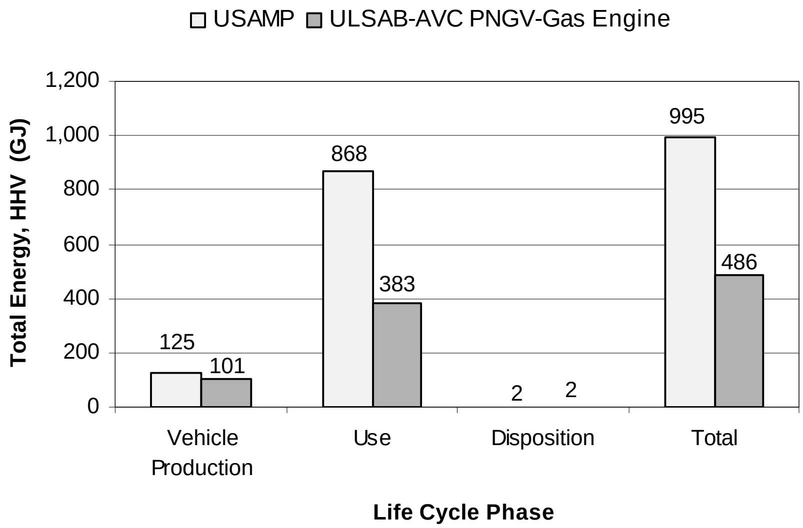


Figure 11. Total Life Cycle Energy Consumption for ULSAB-AVC with USAMP presented for reference.

Clearly, the PNGV-gas engine vehicle consumes less than half of the energy scored in USAMP. Most of this improvement can be seen in the Use phase. In particular:

- PNGV-gas consumes **51%** less energy over the total life cycle.
- PNGV-gas consumes **20%** less energy in the Vehicle Production phase.
- PNGV-gas consumes **56%** less energy in the Use phase.
- PNGV-diesel consumes **64%** less energy in the Use phase.
- PNGV-gas consumes **9%** less energy in the Disposition phase.

Reductions in energy consumption seen in the Use phase are attributed to a combination of two factors. These are (1) Mass reduction/light-weighting effects, with the ULSAB-AVC saving nearly 500 kg; and (2) Powertrain improvement effects, primarily fuel economy (USAMP 10.3 L/100km (22.8 mpg), ULSAB-AVC PNGV-gas 4.5 L/100km (52.4 mpg), ULSAB-AVC PNGV-diesel 3.4 L/100km (68 mpg)). These two factors are not independent of each other.

Energy savings can also be attributed to the Vehicle Production phase. In particular, the reduced mass of the ULSAB-AVC vehicle translates to a lower material processing burden. Table 11 presents vehicle production energy consumption and mass distribution by subsystem, vehicle assembly and transport for ULSAB-AVC and USAMP; it also includes relative % change from USAMP to ULSAB-AVC. Refer to Appendix H for the complete USAMP Generic Vehicle Material Distribution.

Table 11. Vehicle Production Phase Energy Consumption (by Subsystem, Vehicle Assembly and Transport) and Mass Distribution by Subsystem for ULSAB-AVC with USAMP presented for reference (with % change before rounding for significant figures).

	Vehicle Production Total Energy (GJ)			Mass (kg)		
	USAMP	ULSAB-AVC PNGV-gas	% Change	USAMP	ULSAB-AVC PNGV-gas	% Change
Body	39	34	**-12%**	559	403	**-28%**
Electrical	7	4	**-44%**	70	34	**-52%**
Fluids	5	2	**-57%**	91	41	**-55%**
HVAC	5	2	**-60%**	45	17	**-63%**
Interior	12	12	**2%**	139	139	**0%**
Powertrain	29	18	**-37%**	352	161	**-54%**
Suspension	14	14	**-5%**	297	183	**-38%**
Assembly	13	13	**0%**	n/a	n/a	n/a
Transport	2	2	**0%**	n/a	n/a	n/a
Total Vehicle	**125**	**101**	**-20%**	**1,554**	**998***	**-36%**

* Total Mass includes 20 kg mass of "Paint and PVC" which is not listed here. This mass is assumed to be added during the vehicle assembly process.

Figure 12 shows the life cycle CO_2 emissions for the USAMP and ULSAB-AVC PNGV-gas vehicles.

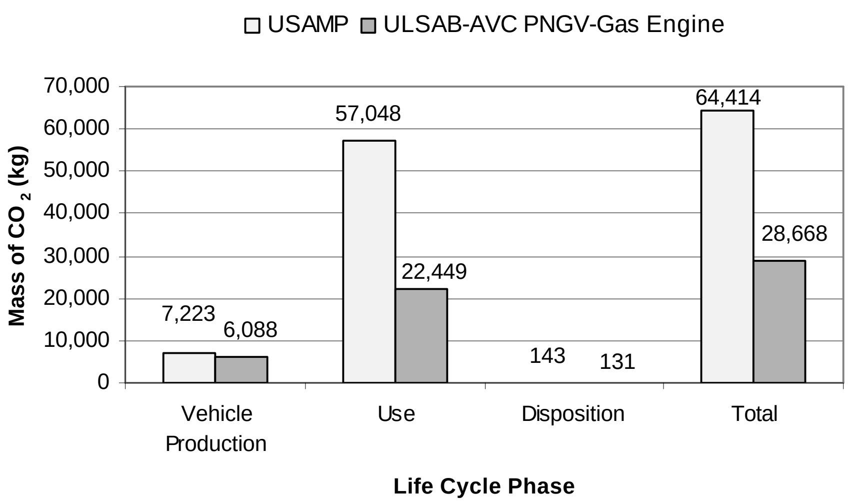


Figure 12. Total Life Cycle CO_2 Emissions for ULSAB-AVC with USAMP presented for reference.

In both models, CO_2 emissions in the Use phase were calculated directly from the fuel economy parameter. Therefore, results for CO_2 in Figure 12 mirror results for energy consumption in Figure 11.

Figure 13 shows the life cycle emissions of select air pollutants for the USAMP and ULSAB-AVC PNGV-gas engine vehicles. It is important to note that vehicle emissions for the ULSAB-AVC PNGV-gas variant are based on EU4 Regulations and represent an upper limit where as the USAMP emissions are based on actual U.S. EPA certification tests for the generic vehicle (see Table 8, Section 5.3.2.2).

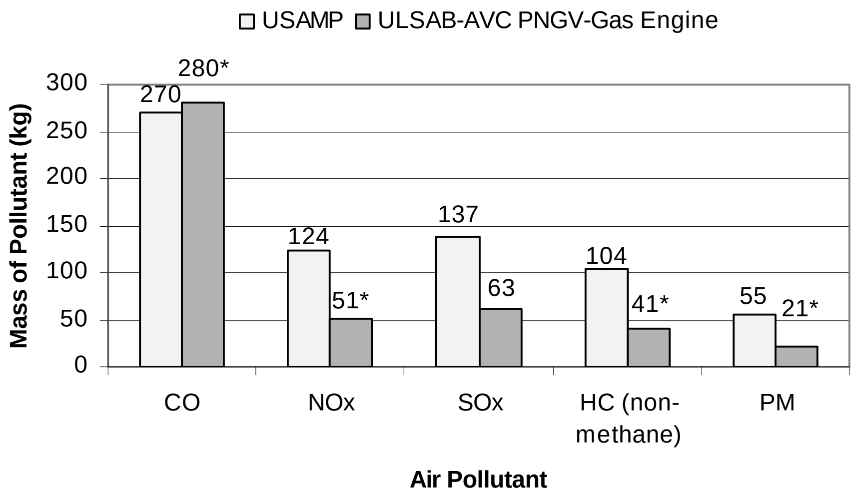


Figure 13. Total Life Cycle Emissions of Select Air Pollutants for ULSAB-AVC with USAMP presented for reference (*Vehicle emissions for ULSAB-AVC PNGV-gas variant are based on EU4 Regulations & represent an upper limit).

The ULSAB-AVC PNGV-gas vehicle demonstrates significant improvements over USAMP for all pollutants in Figure 3 (except carbon monoxide (CO)) even though the emissions shown for ULSAB-AVC are based on upper limits. The only exception, overall CO emissions for USAMP, are 4% less than that for ULSAB-AVC (due to the use phase CO gap of 9%). This is explained as follows:

- The EU4 standard for CO that was adopted as the ULSAB-AVC vehicle emission factor is 1.0 g/km (1.6 g/mile).
- The USAMP composite performance for CO vehicle emissions is equivalent to 1.29 g/mile (see Table 8 in Section 5.3.2.2).
- The EU4 standard for 2005 happens to be above what the USAMP car already achieved in 1995. Consequently, the ULSAB-AVC vehicle would be expected to underperform the USAMP vehicle because its theoretical CO emission level is EU4-based.
- However, it is important to bear in mind that the ULSAB-AVC emission factor for CO represents an upper bound. It is quite probable that an actual vehicle designed to meet the EU4 standard would deliver CO emissions safely below the 1.6 g/mile limit. Incidentally, the USAMP vehicle's CO performance of 1.29 g/mi is well below the contemporary U.S. EPA standard of 3.4 g/mile.

Figure 14 shows the life cycle solid waste production for the USAMP and ULSAB-AVC vehicles.

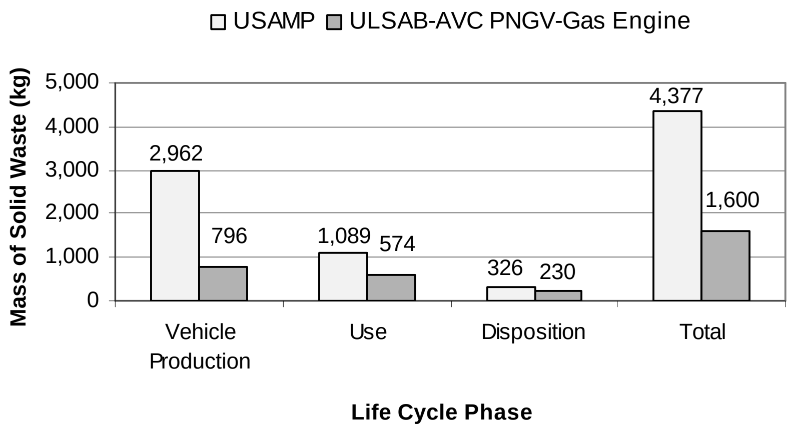


Figure 14. Total Life Cycle Solid Waste Production for ULSAB-AVC with USAMP presented for reference.

The ULSAB-AVC design delivers a significant reduction in solid waste over the USAMP vehicle. Figure 14 shows improvements in all three phases, but primarily in the Vehicle Production phase. This is due primarily to the significant reduction from the USAMP vehicle to the ULSAB-AVC PNGV-gas vehicle in total vehicle mass, approximately 500 kg, resulting in major material production related solid waste reductions. In addition, further reduction in solid waste production is expected for the ULSAB-AVC vehicle when the hydroforming module is incorporated in the model, as hydroforming results in lower scrap rates than stamping does. Improvement in the Use phase for ULSAB-AVC is attributed to consuming less fuel, which reduces upstream fuel production burdens. Reduced solid waste generated in the Disposition phase is primarily explained by the lower mass of the ULSAB-AVC vehicle. There is simply less material to be transported, disassembled, shredded, landfilled, etc.

7.1.2 Other Literature References

To date, many full vehicle life cycle inventory studies have been conducted. Sullivan and Cobas-Flores published a review on 9 select full vehicle LCI studies in 2002 [Sullivan and Cobas-Flores 2002]. The level of completeness varied among the studies, as did the application of life cycle boundaries (e.g. at times data categories were not consistently applied to all life cycle stages for a certain study). However, all of the selected studies included results for the vehicle production, use and disposition phases and did not include infrastructure burdens. As it is not possible to make direct comparisons with the current LCI study, LCI results and consumption trends from the review are cited for reference.

The nine studies encompassed a total of 14 automobiles, ten of which were spark ignited, three compression ignited and one was an electric vehicle. The service life, mass and fuel economy ranges for the vehicles included in the review are as follows:

- Service life distance range: 120,000 to 230,000 km (74,600 to 143,000 miles)
- Mass of vehicles range: 650 kg to 2000 kg
- Fuel economy range: 16.6 to 3.5 L/100km (14.2 to 68.1 mpg)

It was found that regardless of vehicle size, powertrain or service life distance, the use phase of the vehicle life cycle is the major contributor of life cycle burdens, with 66 to 91% of the total energy and 60% or more of the carbon dioxide and hydrocarbon burdens attributed to this phase. The same trends are seen for the ULSAB-AVC PNGV-gas vehicle which attributed 79% of total energy consumption, 78% of carbon dioxide emissions, 65 to 79% of CO, NO_X, SO_X and HC emissions to the use phase.

In the review, 60-80% of total solid waste production was attributed to the material production stage. With the exception of solid waste burdens, to which it contributes 7 to 11 percent, disposition activities made only small contributions to total vehicle life cycle burdens. Similarly, solid waste production for the ULSAB-AVC PNGV-gas vehicle LCI was highest for the vehicle production phase with 50% of total solid waste produced during this phase, 36% in the use phase and 14% in the disposition phase. Overall the disposition phase was of negligible impact on total life cycle burdens for the ULSAB-AVC PNGV-gas vehicle with the exception of solid waste.

7.2 Evaluation of Results

7.2.1 Consistency and Completeness

The ULSAB-AVC modelling methods were generally based on those used for the USAMP study. These methods have been consistently applied in the ULSAB-AVC modelling unless otherwise specified. Original data collection for this study consisted of parts and materials data from the ULSAB-AVC Porsche Engineering Report [Porsche Engineering Services 2001]. Because no ULSAB-AVC prototype has actually been built, this data did not provide sufficient detail for the life cycle modelling of the vehicle consistently with USAMP; therefore, the decision tree shown in figure E-1 in Appendix E was utilised to further detail the material composition of the ULSAB-AVC PNGV-gas engine vehicle in a consistent manner (results of the detailing are shown in Table E-1). Because the vehicle is not yet in production, regulatory values were used to represent upper limits for vehicle emissions. This has probably caused Use phase results to be overstated, although it is not possible to measure this gap until more design detail is specified for the vehicle's powertrain system.

7.2.2 Sensitivity

A sensitivity analysis was conducted in order to assess how the ULSAB-AVC life cycle inventory results would be affected by changes in two major parameters: vehicle service life and fuel economy. Both of these parameters focus on the Use phase, during which the most significant energy consumption and air and water emission burdens occur.

The ULSAB-AVC TEAM™ model was used to generate results for the following difference in fuel economy: 3.8 and 5.5 L/100 km fuel economy for the PNGV-gas variant and 3.0 and 4.1 L/100 km for the PNGV-diesel variant (10-mpg increase and decrease in fuel economy for each variant). It was also used to generate results for two varying vehicle service life distances 160,935 km (100,000 miles) and 289,680 km (180,000 miles) for both the PNGV-gas and diesel variants. The results of this analysis are presented in tables J-1 and J-2 in Appendix J.

These results show that as service life increases, vehicle production energy becomes less significant on a per-mile basis and the use phase energy tends to dominate. However, the model only takes scheduled repairs into account, therefore, energy associated with unscheduled repairs (which are expected to increase with vehicle age) is not accounted for in the analysis.

Because use phase energy consumption is directly related to fuel consumption, the use phase results are very sensitive to changes in fuel economy, as expected.

7.3 Significant Issues

Analysis of results from this ULSAB-AVC life cycle inventory identified a number of relevant issues. Of particular importance are the following four issues:

1. **Energy consumption and CO_2 emissions.** It is interesting to focus on the ULSAB-AVC performance regarding these two burden categories because of growing concerns about global warming, global economic interdependence and energy security. In addition, results for energy and CO_2 are useful proxies for a host of other environmental burdens including air emissions, water effluent and solid waste.

2. **Use phase dominance.** Clearly, most of the environmental impact from the ULSAB-AVC vehicle occurs within the Use phase. For example, 79% of total energy consumption across all phases is directly attributed to fuel combustion during vehicle operation. In terms of identifying effective strategies for improving environmental performance, it would be reasonable to focus attention on activities within the Use phase.

3. **Driving distance.** Given the dominant influence of Use phase activities, driving distance is a critical parameter in determining environmental performance. Use phase results are calculated on a per mile basis; therefore, total burden for Use phase is directly proportional to distance driven. The functional unit of analysis in this LCI study was defined as 193,000 km (120,000 miles) per vehicle. Clearly, as this parameter changes, the ratio of Use phase results to production and disposition effects will shift.

4. **Lightweighting vs. powertrain efficiency.** The ULSAB-AVC LCI model adopted the fuel economy estimates from the program engineering report [Porsche Engineering Services 2001]. These data suggest performance that is superior to typical vehicles currently on the market. The resulting gap represents a combination of improvement due to lighter vehicle mass, which requires less power to move, and better powertrain technology. However, results from this study cannot be used to determine the relative influence of these two factors, as they are not independent of each other.

7.4 Conclusions

The ULSAB-AVC LCI model was based on methodology from the original USAMP LCI study and hence, adopted many of the same system boundary assumptions and input data. However, there are some significant methodological differences. For example, while USAMP included operational testing data from actual vehicles, no ULSAB-AVC prototype was available to generate such hard data. Instead, EU4 emissions standards were defined as the upper limit to the possible range of emissions. Results for this study were generated using TEAM™ software. The following sections summarise the results and significant issues that were identified.

7.4.1 Influence of Use Phase

The Use phase dominated energy consumption and air emissions. As a result, focusing attention on vehicle operation represents the best opportunity for achieving further reduction in these impact categories. Table 12 shows the breakdown of energy consumption by life cycle phase.

Table 12. Energy Consumption by Life Cycle Phase for ULSAB-AVC PNGV-Gas Variant

Production Phase		Use Phase		Disposition Phase	
GJ	Portion of Total	GJ	Portion of Total	GJ	Portion of Total
101	21%	383	79%	2	0.41%

Table 13 shows the breakdown of air emissions by life cycle phase.

Table 13. Air Emissions by Life Cycle Phase for ULSAB-AVC PNGV-Gas Variant

	Production Phase		Use Phase		Disposition Phase	
Emission Type	Mass (g)	Portion of Total	Mass (g)	Portion of Total	Mass (g)	Portion of Total
CO_2	6,088**	21%	22,449**	78%	131**	0.5%
CO	57,235	20%	222,391*	79%	677	0.2%
HC	10,228	25%	30,138*	74%	167	0.4%
NO_X	16,995	33%	32,983*	65%	763	1.5%
PM	12,402	58%	8,682*	41%	190	0.9%

*Vehicle emissions for ULSAB-AVC PNGV-gas variant are based on EU4 Regulations and represent an upper limit.

**NOTE: CO_2 amounts are presented in kilograms (kg).

Use phase air emission results should be considered the upper bound to performance because the emissions factors used in the TEAM™ model were taken directly from EU4 standards, not from actual vehicle test data. Therefore, results for an actual ULSAB-AVC vehicle would probably be lower than the results stated here.

The superior performance over existing vehicles is due to some combination of mass reduction and improved powertrain technology. It was beyond the scope of this study to determine the specific contributions of these two factors. There are interactive effects between these two factors that increase the complexity of this issue even further. No simple ratio exists between vehicle mass and energy/emissions performance for the Use phase. Furthermore, there are additional secondary, non-linear effects related to other components such as brakes that have not been evaluated. Consequently, results from this study should not be used to support specific claims about the relative merits of weight reduction vs. powertrain improvements.

7.4.2 Influence of Production Phase

Solid waste and water consumption are highest in the Vehicle Production phase due primarily to the material production stage. Therefore, efforts to reduce either of these burden categories should be focused on upstream production activities.

The upstream process of hydroforming, which would be applied to 8% of the vehicle (PNGV-gas) by mass, must still be evaluated. Although hydroforming was part of the initial ULSAB-AVC design, modelling data for this process was not available for inclusion in this LCI study. When it is eventually incorporated into the model, it is expected that material production burdens – energy, emissions and resource requirements – will decrease. This is due to expectations that the scrap rate would be significantly lower than 1.68, which is the scrap rate of stamping, the process that would be partially displaced by hydroforming. This would result in less material required to provide the same components, fewer parts in some cases.

7.4.3 Reference to Other Full Vehicle LCI Results

With this ULSAB-AVC life cycle inventory completed, it is possible to reference results from previously published full vehicle LCI studies. Total energy consumption provides a useful point of departure and will be discussed here.

The present study drew heavily on modelling efforts developed by the USAMP team. For reference, USAMP energy results compare to ULSAB-AVC results as follows:

- **Total life cycle.** The ULSAB-AVC vehicle consumes 51% less energy overall.
- **Production phase.** The ULSAB-AVC vehicle consumes 20% less energy in upstream processing and manufacturing. Much of this gap can be explained by a 36% mass reduction over the USAMP composite vehicle. Lower mass leads directly to reduced material processing burdens.
- **Use phase.** The ULSAB-AVC gasoline vehicle consumes 56% less energy during operation, clearly demonstrating the heavy influence of fuel economy performance on overall life cycle results. The ULSAB-AVC diesel vehicle performs even better by comparison, achieving a 64% energy reduction over the USAMP vehicle in the Use phase.
- **Disposition phase.** The ULSAB-AVC vehicle consumes 9% less energy in downstream activities. This primarily reflects the fact that a lighter vehicle would require management of less material at disposition.

Sullivan and Cobas-Flores evaluated nine vehicle LCI studies that considered 14 different vehicle models [Sullivan and Cobas-Flores 2002]. These varied widely in terms of service life distance, vehicle mass and fuel economy. Energy consumption for the Use phase ranged between 66 and 91%. This interval is similar to findings for the ULSAB-AVC vehicle, which consumed 79% of total life cycle energy in the Use phase.

7.5 Recommendations

7.5.1 Communication of Results

The stated goal of this project was to complete a life cycle inventory of an ULSAB-AVC vehicle. It was intended to establish a baseline for measuring the environmental life cycle performance of future steel automobiles and to support communication efforts aimed at vehicle manufacturers and their suppliers, including members of the worldwide steel industry who play a role in providing steel to the automotive industry. These purposes have been achieved. Results from this study can be used to support public statements on the environmental performance of ULSAB-AVC automobiles. Additionally, they can be made available to vehicle manufacturers as input to the design and development of new cars with improved environmental performance.

However, while preliminary results do suggest environmental benefits of the ULSAB-AVC design, they are based on a significant number of assumptions and data from previous research. Public statements based on these results should therefore not be definitive, but rather suggestive of potential benefits. Limitations of the study should be clearly and openly acknowledged.

7.5.2 Vehicle Design and Development

As demonstrated in previous automotive LCI studies, the ULSAB-AVC model predicts the greatest environmental impact from the Use phase. Therefore, design activities to improve environmental performance should be focused on vehicle operation; specifically, actions that would deliver higher fuel economy. These would include:

- Further reducing total vehicle mass through selection of materials and design of components and systems.
- Development of more efficient powerplants. Incidentally, mass reduction produces the secondary benefit of requiring smaller, less powerful engines that use less energy overall.

It should be stressed that consumers, and therefore manufacturers, will demand that any improvement in environmental performance not degrade performance in other categories such as safety, reliability, handling, comfort and cabin noise. To the extent that the ULSAB-AVC auto body can deliver this performance mix at a competitive cost, it will be successful in the marketplace.

7.5.3 Future research

Results from this LCI study suggest the value of pursuing future research in the following areas:

- Incorporate hydroforming data into the TEAM^{TM} model when it becomes available. Evaluate results to determine the effect of this manufacturing process on environmental performance of the total vehicle life cycle.

- The material composition of ULSAB-AVC was not specified in detail on the parts list provided by Porsche; therefore, material composition was estimated using USAMP data. Consequently, a more accurate life cycle model could be developed as materials for the ULSAB-AVC vehicle are further specified.

- Differentiate the relative contributions of mass reduction and powertrain contributions to overall environmental performance. Use results of this analysis to guide further improvements in body structure design and powertrain technology.

- Future research activities would be enhanced by the development and manufacturing of an ULSAB-AVC prototype vehicle. This would be useful not only for collecting operational test data, but also for learning valuable lessons about designing manufacturing processes that could be applied to mass producing an ULSAB-AVC vehicle.

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APPENDIX A: LIST OF THE UNIT PROCESSES AND ELECTRICITY GRID INCLUDED IN THE SYSTEM BOUNDARY

Unit Process	Data Source	Data Quality	
		Temporal*	Geographical
Hot Rolled Steel	IISI	1994/95 (USAMP) and 1999/00 (ULSAB-AVC)	International
Cold Rolled Steel	IISI	1994/95 (USAMP) and 1999/00 (ULSAB-AVC)	International
Galvanised Steel	IISI	1994/95 (USAMP) and 1999/00 (ULSAB-AVC)	International
EAF Steel	IISI	1994/95 (USAMP) and 1999/00 (ULSAB-AVC)	International
Cold Rolled Aluminium	AA	1992, 1995/96	North America
Hot Rolled Aluminium	AA	1992, 1995/96	North America
Extruded Aluminium	AA	1992, 1995/96	North America
Cast Aluminium	AA	1992, 1995/96	North America
Polyethylene	APC	1991	North America
Polypropylene	APC	1991	North America
Polyethylene Terephthalate	APC	1991	North America
PVC	APC	1991	North America
Polyurethane	APC	1993	USA
Electricity	DEAM™ Database	1996**	USA

*Temporal Information applies to both the USAMP and ULSAB-AVC models unless otherwise specified in parentheses.

**U.S. Grid Fuel Mix for 1996: Coal (56.6%), Natural Gas (8.6%), Heavy Fuel Oil (2.2%), Nuclear (22%), Hydroelectricity (10.6%)

APPENDIX B: MATERIAL AND GENERIC PROCESS EXCLUSIONS[14]

The following materials were not modelled for the ULSAB-AVC model:

- Acrylonitrile Styrene Acrylate (ASA, moulded)
- Adhesive Agent
- Aluminium Oxide (Al2O3)
- Asbestos
- Bromine (Br)
- Ceramic (fired)
- Charcoal
- Cordierite (honeycomb structured)
- Desiccant Agent
- Glycol Ether (Brake Fluid)
- Graphite
- Thermoplastic Elastomeric Olefin (TEO, injection moulded)
- Windshield Cleaning Additives

The generic fabrication processes excluded from the ULSAB-AVC model are listed here:

- Acetal – Moulding
- Acrylic Resin – Moulding
- Acrylonitrile Butadiene Styrene (ABS) – Extrusion and moulding
- Acrylonitrile Styrene Acrylate (ASA) – moulding
- Brass – Casting, rolling and stamping
- Ceramic – Fired
- Cordierite – Honeycomb structure
- Ethylene Propylene Diene Monomer (EPDM) – Extruding and moulding
- Glass – Blowing
- Lead – Casting
- Polyamide (PA 6) – Moulding
- Polyamide (PA 66) – Moulding
- Polybutylene Terephthalate (PBT) – Moulding
- Polycarbonate (PC) – Injection moulding
- Polyester Resin – Extruding, weaving and gluing
- Polyethylene (PE) – Injection moulding
- Polyethylene Terephthalate (PET) – Injection Moulding
- Polypropylene (PP) – Moulding
- Polyurethane (PUR) – Moulding
- Polyvinyl Chloride (PVC) – Moulding
- PP-EPDM (Polypropylene Ethylene Propylene Diene Monomer Blend) – Injection moulding
- PPO-PC (Polyphenylene Oxide Polycarbonate Blend) – Injection moulding
- PPO-PS (Polyphenylene Oxide Polystyrene Blend) – Injection moulding
- Recycled Textile Fibres – Compression
- Rubber – Calendering and moulding

[14] These materials and processes were not modeled in the original USAMP study.

APPENDIX C: USAMP DECISION RULES FOR ANCILLARY MATERIAL FLOW INCLUSION

In order to establish the consistent identification of ancillary material flows that will be modelled in the inventory, the USAMP/LCA partners agreed that best efforts will be made to apply the following decisions rules:

- First, the identification of all potential ancillary material flows for a unit process is established by listing all ancillary materials that are greater than 1% by mass of the output for the unit process. Once the ancillaries have been identified, a mass balance for the subsystems being analysed is performed and normalised to the output from the subsystem.
- Ancillary materials that will be included in the scope of the analysis are then classified as primary, secondary, or negligible ancillaries on the basis of an analysis of their contribution to the total mass of the system, total energy of the system and their environmental relevance.
- All ancillary materials of a ranked ancillary list that have a cumulative mass contribution of up to 90% of the system are considered as primary ancillaries and will require primary data sources within the data collection activities. The additional ancillary materials that bring the total cumulative mass of the system to at least 95% of the total would be considered as secondary ancillaries for which secondary data sources may be used to quantify their life cycle contribution.
- A further decision rule is used to classify energy contribution. All ancillary materials that have a cumulative contribution of 95% of the total system energy are considered primary ancillaries, regardless of their mass ranking. The additional ancillary materials that bring the cumulative systems energy to at least 99% are considered as secondary ancillaries.
- In addition, any input, regardless of mass or energy contribution, is considered as a primary ancillary if any of the environmental releases during its extraction, manufacturing or use contributes more that 15% to an environmental release data category.
- All remaining ancillary materials should be considered negligible and need not be included in the scope of the study. Each of the USAMP/LCA partners shall prepare the listings of primary, secondary, and negligible ancillaries for their respective subsystems. Each USAMP/LCA partner shall identify and justify all deviations from the decisions rules outlined above to the other partners and such deviations shall be noted in the final report.

APPENDIX D: USAMP GENERIC VEHICLE PARTS ORGANISATIONAL CODE

A. Powertrain

01. Engine
    - 1.1 Cylinder Head
    - 1.2 Engine Block
    - 1.3 Fuel Injection
    - 1.4 Engine Air System
    - 1.5 Ignition System
    - 1.6 Starter System
    - 1.7 Generator
    - 1.8 Lubrication System
    - 1.9 Miscellaneous Engine Parts

02. Engine Cooling
    - 2.1 Water Pump
    - 2.2 Radiator
    - 2.3 Fan
    - 2.4 Miscellaneous Engine Cooling Parts

03. Fuel Supply System
    - 3.1 Fuel Tank
    - 3.2 Tank Straps
    - 3.3 Insulation
    - 3.4 Filling and Sending Piping
    - 3.5 Miscellaneous Fuel Supply Parts

04. Air Cleaner System
    - 4.1 Air Filter
    - 4.2 Miscellaneous Air Cleaner Parts

05. Exhaust System
    - 5.1 Catalytic Converter
    - 5.2 Heat Shields
    - 5.3 Muffler
    - 5.4 Exhaust Piping
    - 5.5 Miscellaneous Exhaust Parts

07. Transmission
    - 7.1 Transmission
    - 7.2 Torque Converter
    - 7.3 Miscellaneous Transmission Parts

B. Suspension

08. Suspension System
    - 8.1 Front Suspension
    - 8.2 Rear Suspension

09. Tires and Wheels
    - 9.1 Tires
    - 9.2 Wheels
    - 9.3 Spare Tire
    - 9.4 Miscellaneous Tire Parts

10. Brakes
    - 10.1 Pedal Assembly
    - 10.2 Front Braking System
    - 10.3 Rear Braking System
    - 10.4 Parking Brake System
    - 10.5 Miscellaneous Brake Parts

16. Control Systems
    - 16.2 Steering Systems
    - 16.3 Miscellaneous Control Parts

C. HVAC

11. Climate Control System
    - 11.1 Air Flow System
    - 11.2 Heating Systems
    - 11.3 Air Conditioning Systems

D. Electrical

6. Automotive Battery
    - 6.1 Battery
    - 6.2 Miscellaneous Battery Parts

14. Electrical Systems
    - 14.1 Engine Compartment Electronics
    - 14.2 IP Electronics
    - 14.3 Body Electronics
    - 14.4 Switches
    - 14.5 Lamps
    - 14.6 Miscellaneous Electrical Parts

E. Body

13. Mirrors
    - 13.1 Inside Rearview
    - 13.2 Outside Side view

15. Windshield Cleaning
    - 15.1 Wiper
    - 15.2 Washer

17. Body System
    - 17.1 Doors
    - 17.2 Structural Parts
    - 17.3 Vehicle Tools
    - 17.4 Bumper, Fascia and Panels
    - 17.5 Exterior Ornamentation
    - 17.6 Hood
    - 17.7 Frame and Engine Support
    - 17.8 Sealant and Paint
    - 17.9 Miscellaneous Body Parts

19. Glass System
    - 19.1 Windshield
    - 19.2 Rear Window
    - 19.3 Side Windows

F. Interior

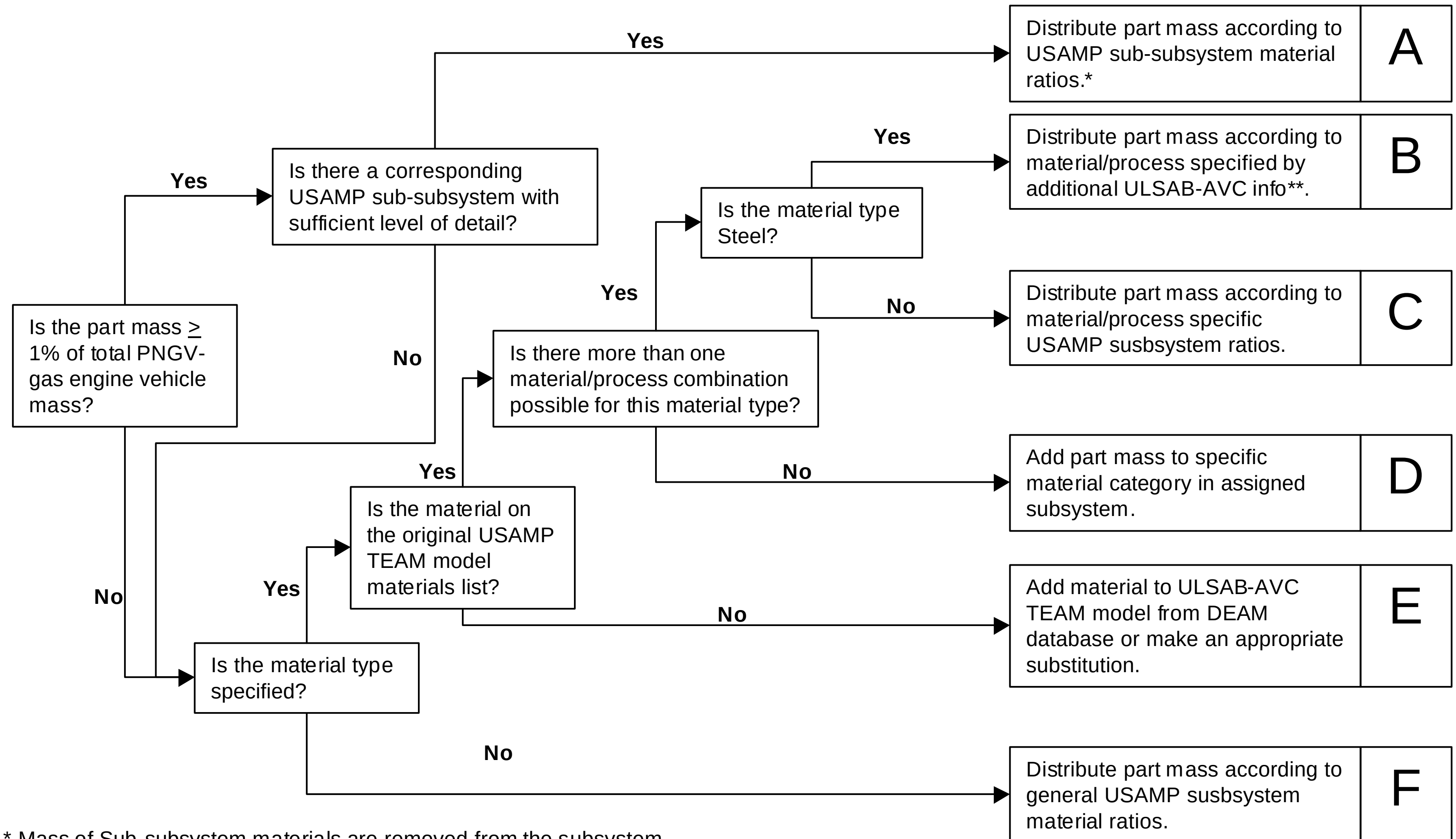
12. Built in Safety Systems
    - 12.1 Air Bag System
    - 12.2 Seat Belts
    - 12.3 Miscellaneous Safety Parts

18. Interior System
    - 18.1 Console
    - 18.2 Seats
    - 18.3 Interior Trim (except Door Trim)
    - 18.4 Carpet and Acoustic Treatments
    - 18.5 Instrument Panel (IP)
    - 18.6 Miscellaneous Interior Parts

APPENDIX E: ULSAB-AVC PNGV-GAS ENGINE VEHICLE PARTS LIST AND MAPPING PROCEDURE

A mapping procedure, based on USAMP data, was followed because materials were not specified in detail on the ULSAB-AVC PNGV-gas engine vehicle parts list. The decision tree shown in Figure E-1 was used to estimate the material composition of each ULSAB-AVC part. Following the decision tree results in five mapping procedures A, B, C, D and E. Table E-1 ("ULSAB-AVC PNGV-Gas Engine Parts List") following the decision tree includes the mapping procedure that was used for each part (A, B, C, D or E), the subsystem to which the part was assigned, the sub-subsystem to which it belongs (if applicable) and the estimated material composition of the part. The "Estimated Material Composition" column specifies how the part's material was added to its corresponding subsystem.

Figure E-1. Decision Tree for Estimating Material Composition of ULSAB-AVC Parts.



* Mass of Sub-subsystem materials are removed from the subsystem material list so that they are not included in the general subsystem material ratios.
**Additional steel information was provided by the ULSAB-AVC consortium (from Porsche Engineering Report and Personal Communications, 6/2002)

Table E-1. ULSAB-AVC PNGV-Gas Engine Vehicle Parts List and Mapping Procedure

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
Gasoline engine complete	1000	1	83,000	83,000	Cast Iron/Alum	A	Powertrain	Engine	Used USAMP Powertrain_Engine material ratios to distribute the 83 kg.
Sub-Total - Cast Iron / Cast Aluminum				**83,000**					
*Climatic fluid	8039	1	350	350	Fluid - Climatic fluid	D	Fluid		Refrigerant
Cooling water	1949	1	5,000	5,000	Fluid - Cooling water	D	Fluid		Engine coolant
Engine oil	1729	1	5,000	5,000	Fluid - Engine oil	D	Fluid		Engine Oil (SAE 10w-30)
Fuel	2019	1	27,000	27,000	Fluid - Fuel	D	Fluid		Gasoline
Gear oil	3219	1	1,400	1,400	Fluid - Gear oil	D	Fluid		Automatic Transmission Fluid
Washing water	9239	1	1,500	1,500	Fluid - Water	C	Fluid		Windshield cleaner fluid: 20% Windshield Cleaning Additives, 80% Water.
Sub-Total - Fluids				**40,250**					
Door Glass	6420	2	2,847	5,694	Glass	A	Body	Glass System	Took sum of all Body glass (sum of all glass is > 1%) and allocated as 99.98% pressed, 0.02% Acetal (inj. Molded) - according to USAMP Body_glass system ratios.
Door Glass	6420	2	2,882	5,764	Glass	A	Body	Glass System	
Rear-window incl. bracket	6430	1	5,298	5,298	Glass	A	Body	Glass System	
Windshield incl. Bracket and trim strip	6410	1	9,695	9,695	Glass	A	Body	Glass System	
Sub-Total - Glass				**26,451**					
*Climate cooler	8030	1	2,500	2,500	Light alloy	C	HVAC		Sum of HVAC Light alloy parts (7.6 kg) - added according to Al ratio in HVAC (30.2% cast, 66.7% extruded, 3.1% rolled, stamped).
*Climatic line cooler-heating	8030	1	600	600	Light alloy	C	HVAC		
*Dryer incl. Line	8030	1	1,800	1,800	Light alloy	C	HVAC		
*Heat exchanger	8010	1	1,100	1,100	Light alloy	C	HVAC		
*Vaporizer	8030	1	1,600	1,600	Light alloy	C	HVAC		

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
*Airbag control unit incl. Bracket	6840	1	300	300	Light alloy	C	Interior		Added according to Al ratio in Interior (100% Aluminum (automotive, extruded))
*Heat shield tunnel incl. bracket	2695	1	2,890	2,890	Light alloy	A	Powertrain	Exhaust System	Treated together with Exhaust System (GADH no. 2610), sum is distributed according to Powertrain_Exhaust System Ratios.
Water cooling system	1940	1	2,100	2,100	Light alloy	C	Powertrain		Added according to Al ratios in Powertrain (77.6% Al(automotive, cast) 22.4% Al(automotive, extruded))
Steering wheel incl. Bracket	4820	1	2,450	2,450	Light alloy	C	Suspension		Added according to Al ratio in Suspension (100% Al(automotive, cast))
Base Plate	4310	1	2,479	2,479	Magnesium	E	Suspension		Magnesium added to TEAM model materials list from DEAM database. Added to Suspension subsystem.
Sub-Total - Light Alloy & Magnesium				**17,819**					
*Window seal Adhesive Windshield	6410	1	350	350	Other - Adhesive	D	Body		Allocate as "Adhesive agent." 0.35 kg - Body subsystem.
Anti Noise Foil	6815	1	2,600	2,600	Other - Bitumen	E	Interior		No Bitumen model in DEAM database. Substituted with asphalt from DEAM database.
Upper Guide	4310	1	215	215	Other - Fiber composite	C	Suspension		Sum of "Other - Fiber composite" (0.295 kg) allocated according to PA6 and PA66 ratios in Suspension (100% PA 66, injection molded).
Lower Guide	4310	2	40	80	Other - Fiber composite	C	Suspension		
*Camera incl. Wire loom	6610	2	100	200	Other - Unspecified	F	Body		Sum (by subsystem) of "Other - Unspecified" allocated according to subsystem ratios (unless specified otherwise). Mass of "Other - Unspecified": Body = 21.3 kg (not incl. Paint and PVC), Powertrain = 5.15 kg, Suspension = 2.3 kg, Interior = 26.52 kg, HVAC = 0.260 kg, Electrical = 1.35 kg.
*Impact Protection	5220	1	900	900	Other - Unspecified	F	Body		
*Operating Mechanism for lock	5515	1	200	200	Other - Unspecified	F	Body		

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
Brackets and Underfloor Cover				20,000	Other - Unspecified	F	Body		> 1% of total mass but no corresponding USAMP category.
*Battery	9910	1	12,300	12,300	Other - Unspecified	A	Electrical	Automotive Battery	Distribute mass according to Automotive Battery Material ratios.
*Rain Sensor	9210	1	50	50	Other - Unspecified	F	Electrical		
Radio	9110	1	1,300	1,300	Other - Unspecified	F	Electrical		
*Brake Fluid	4639		500	500	Other - Unspecified	D	Fluids	Brake Fluid	Allocate as Brake Fluid
*Seal heat exchanger-front wall	8010	1	60	60	Other - Unspecified	F	HVAC		
*Seal heating slot	8020	1	10	10	Other - Unspecified	F	HVAC		
*Seal pollen filter	8020	2	60	120	Other - Unspecified	F	HVAC		
*Seat vaporizer-front wall	8030	1	70	70	Other - Unspecified	F	HVAC		
Attachment Bolts and brackets	7250	6	34	200	Other - Unspecified	F	Interior		
Bolster head rest incl. Frame	7225	2	580	1,160	Other - Unspecified	F	Interior		
Floor carpet incl. damping	6815	1	16,000	16,000	Other - Unspecified	A	Interior	Interior System --> 18.4 Carpet and acoustic treatments	Treated together with "Floor carpet incl. Damping Trunk" and "Sound Insulation Front Wall." Distributed using Interior_Carpet and acoustic treatments ratios. Total mass = 25.3 kg.
Floor carpet incl. Damping Trunk	6825	1	4,000	4,000	Other - Unspecified	A	Interior	Interior System --> 18.4 Carpet and acoustic treatments	
Head rest	7250	3	1,000	3,000	Other - Unspecified	F	Interior		
Insulation Tunnel	6815	1	6,100	6,100	Other - Unspecified	F	Interior		
Other Covers and Isolations	6815	1	5,740	5,740	Other - Unspecified	F	Interior		

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
Seat back bolster	7225	2	1,000	2,000	Other - Unspecified	F	Interior		
Seat back bolster trim	7225	2	750	1,500	Other - Unspecified	F	Interior		
Seat back trim	7250	1	600	600	Other - Unspecified	F	Interior		
Seat bolster	7225	2	1,050	2,100	Other - Unspecified	F	Interior		
Seat Bolster Trim	7250	2	420	840	Other - Unspecified	F	Interior		
Seat Bolster upper and lower	7250	1	2,400	2,400	Other - Unspecified	F	Interior		
Seat Trim	7250	1	660	660	Other - Unspecified	F	Interior		
Sound Insulation Front Wall	6910	1	5,300	5,300	Other - Unspecified	A	Interior	Interior System --> 18.4 Carpet and acoustic treatments	
Trim Headrest	7225	2	110	220	Other - Unspecified	F	Interior		
*Air-filter insert	2410	1	150	150	Other - Unspecified	F	Powertrain		
Electric shift actuator	3200	1	5,000	5,000	Other - Unspecified	F	Powertrain		
EPB Unit	4350	1	1,300	1,300	Other - Unspecified	F	Suspension		
Tire fit	4420	1	1,000	1,000	Other - Unspecified	F	Suspension		
Paint and PVC	5000		20,000	20,000	Other - Unspecified				Paint burdens are included as part of the Assembly plant burdens, therefore, do not include in TEAM model material inventory.
Sub-Total - Other & Unspecified Materials				**118,225**					

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
*Camera Case	6610	2	150	300	Plastic	C	Body		Sum (by subsystem) of "Plastics" allocated according to subsystem ratios (plastics ratios only).
*Pump with rubber seal	9230	1	90	90	Plastic	C	Body		Body = 17.386 kg
*Rear Console for License Plate Illumination	6610	1	250	250	Plastic	C	Body		Electrical = 17.606 kg
*Spraying nozzle	9230	2	20	40	Plastic	C	Body		HVAC = 5.45 kg
*Wheel-house liner back	5925	2	550	1,100	Plastic	C	Body		Interior = 32.982 kg
Apliquet Roof Side incl. Clips	6610	2	1,430	2,860	Plastic	C	Body		Powertrain = 4.615 kg
B-Pillar Cover and Seal	6610	2	750	1,500	Plastic	C	Body		Suspension = 0.686 kg
Cover	6610	1	440	440	Plastic	C	Body		
Fascia Front	5210	1	4,290	4,290	Plastic	C	Body		
Fascia rear	5220	1	4,867	4,867	Plastic	C	Body		
Radiator Air Intake	5210	1	649	649	Plastic	C	Body		
Service Box	5210	1	600	600	Plastic	C	Body		
Washer tank incl. Bracket	9230	1	400	400	Plastic	C	Body		
*Battery box incl. Cover	9920	1	946	946	Plastic	C	Electrical		
*Bracket battery	9920	1	90	90	Plastic	C	Electrical		
*Fuse Box	9720	1	1,000	1,000	Plastic	C	Electrical		
*Holder fro control unit	2750	1	150	150	Plastic	C	Electrical		
*Instrument cluster incl. Bracket	9010	1	600	600	Plastic	C	Electrical		
*LCD Displays Rear View	9010	3	400	1,200	Plastic	C	Electrical		
3.Stop light incl. Bracket and nozzle	9420	1	110	110	Plastic	C	Electrical		
Antenna base	9110	1	130	130	Plastic	C	Electrical		
Antenna rod	9110	1	40	40	Plastic	C	Electrical		
Interior lamp incl. Bracket	9430	1	170	170	Plastic	C	Electrical		
Main headlamp incl. Flasher	9410	2	1,500	3,000	Plastic	C	Electrical		
Tail lamp incl. Bracket	9420	2	1,100	2,200	Plastic	C	Electrical		
Wiring loom	9720	1	7,970	7,970	Plastic	C	Electrical		
*Air channel incl. Bracket	8020	2	90	180	Plastic	C	HVAC		
*Air distributor	8020	1	370	370	Plastic	C	HVAC		
*Air guide left incl. Bracket	8020	1	80	80	Plastic	C	HVAC		
*Air guide left incl. Bracket	8020	1	220	220	Plastic	C	HVAC		
*Air guide on the tunnel	8020	1	300	300	Plastic	C	HVAC		

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
*Air guide right incl. Bracket	8020	1	60	60	Plastic	C	HVAC		
*Air guide right incl. Bracket	8020	1	140	140	Plastic	C	HVAC		
*Air outlet nozzle center	8020	2	115	230	Plastic	C	HVAC		
*Air outlet nozzle exterior	8020	2	130	260	Plastic	C	HVAC		
*Cover center, ashtray and heater circuit	8020	1	850	850	Plastic	C	HVAC		
*Heat case incl. Vertical mot. and bracket	8020	1	2,300	2,300	Plastic	C	HVAC		
*Mounting heat exchanger	8010	1	10	10	Plastic	C	HVAC		
*Pollen filter	8020	1	450	450	Plastic	C	HVAC		
*Control panel incl. Bracket	6830	1	6,300	6,300	Plastic	C	Interior		
*Cover Deck Lid	6825	1	1,000	1,000	Plastic	C	Interior		
*Cover Instrument Steering console incl. Bracket	6830	1	300	300	Plastic	C	Interior		
*Cover rear side Luggage compartment	6825	1	150	150	Plastic	C	Interior		
*Cover rear side Luggage compartment	6825	2	150	300	Plastic	C	Interior		
*Covers left and right incl. bracket	6820	2	200	400	Plastic	C	Interior		
*Steering Column Cover	6830	1	600	600	Plastic	C	Interior		
Airbag Module	6840	1	1,050	1,050	Plastic	C	Interior		
Airbag Module incl. Bracket	6840	2	680	1,360	Plastic	C	Interior		
A-pillar covering bottom incl. bracket	6820	2	300	600	Plastic	C	Interior		
A-pillar covering incl. bracket	6820	2	380	760	Plastic	C	Interior		
B-pillar covering incl. bracket	6820	2	340	680	Plastic	C	Interior		
B-Pillar lower Covering	6820	2	680	1,360	Plastic	C	Interior		
Center console incl. Bracket and Cupholder	6830	1	1,500	1,500	Plastic	C	Interior		
Cover back incl. Bracket	7250	1	600	600	Plastic	C	Interior		
Cover Rocker Inner	6820	4	175	700	Plastic	C	Interior		

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
C-pillar covering incl. bracket	6820	2	595	1,190	Plastic	C	Interior		
Door Bracket Trim Attachment	6820	4	4	16	Plastic	C	Interior		
Door Bracket Trim Attachment	6820	4	4	16	Plastic	C	Interior		
Door Mirror Flag Cover	6820	2	30	60	Plastic	C	Interior		
Door Switch Assembly	6820	2	40	80	Plastic	C	Interior		
Door Switch Assembly	6820	2	40	80	Plastic	C	Interior		
Door Vapor Barrier	6820	2	150	300	Plastic	C	Interior		
Door Vapor Barrier	6820	2	150	300	Plastic	C	Interior		
Entrance strip incl. bracket	6820	4	140	560	Plastic	C	Interior		
Inner Belt Seal	6820	2	270	540	Plastic	C	Interior		
Inside Remote Handle	6820	2	80	160	Plastic	C	Interior		
Inside Remote Handle	6820	2	80	160	Plastic	C	Interior		
Rear deck	6820	1	1,200	1,200	Plastic	C	Interior		
Roofliner incl. bracket	6820	1	1,600	1,600	Plastic	C	Interior		
Seat back bolster	7250	1	2,400	2,400	Plastic	C	Interior		
Sun vizor incl. Bracket	6850	2	330	660	Plastic	C	Interior		
Trim Panel Assembly	6820	2	3,000	6,000	Plastic	C	Interior		
*Air routing	1940	1	300	300	Plastic	C	Powertrain		
*Bracket for water hose	1940	1	5	5	Plastic	C	Powertrain		
*Fuel pump incl. cover	2020	1	815	815	Plastic	C	Powertrain		
*Fuel valve incl. bracket	2030	1	225	225	Plastic	C	Powertrain		
*Roll-over valve incl. line	2020	1	110	110	Plastic	C	Powertrain		
*Ventilation hose	2020	1	60	60	Plastic	C	Powertrain		
*Volume air-flow meter incl. bracket	2430	1	220	220	Plastic	C	Powertrain		
Activated carbon filter	2030	1	700	700	Plastic	C	Powertrain		
Air-filter box with bearing rubber	2410	1	500	500	Plastic	C	Powertrain		
Cooling-water tank	1940	1	550	550	Plastic	C	Powertrain		
cover incl. bracket	2410	1	550	550	Plastic	C	Powertrain		
Filler cap	2010	1	100	100	Plastic	C	Powertrain		
Fuel Filler door incl. Bracket	2010	1	130	130	Plastic	C	Powertrain		

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
Intake hose incl. bracket	2430	1	350	350	Plastic	C	Powertrain		
*Cover	4310	1	268	268	Plastic	C	Suspension		
Gaspedal	4320	1	215	215	Plastic	C	Suspension		
Hand brake lever incl. Bracket	4350	1	203	203	Plastic	C	Suspension		
Leaf Spring with support rubber	4020	1	2,300	2,300	Plastic - Composite	C	Suspension		Used USAMP plastics and non-tire rubber ratios. 16.35% ABS-PC (inj. Molded), 1.2% Acetal (inj. Molded), 11.78% ABS (extruded), 4.24% Epoxy resin, 5.39% PA66 (inj. Molded), 10.27% Rubber (extruded), 50.78% Rubber (inj. Molded). 2.3 kg total.
Wheelhouse Liner/Radiator Frame	5210	1	8,340	8,340	Plastic - Nylon hybrid	C	Body		USAMP ratios of PA 6 and PA 66 in Body sub-system (27.1% PA 6 (inj. Molded), 24.1% PA 66 (inj. Molded) 48.9% PA 66, molded) applied to total sum of these two Plastic-Nylon Hybrid and added to Body subsystem. 17.264 kg total mass.
Engine cover	5210	1	8,924	8,924	Plastic - Nylon hybrid	C	Body		
Sub-Total - Plastic & Plastic Composites				**98,289**					
*Door Sealing (cop Ford Focus)	5715	2	1,052	2,104	Rubber	C	Body		Sum (by subsystem) of "Rubber" allocated according to subsystem ratios (rubber ratios only).
*Door Sealing (cop Ford Focus)	5725	2	952	1,904	Rubber	C	Body		Body = 6.246 kg
*Lid rear Sealing	5525	1	408	408	Rubber	C	Body		Electrical = 0 kg
*Rear Window Seal	5525	1	320	320	Rubber	C	Body		HVAC = 0 kg
*Sealing Rubber	6610	1	480	480	Rubber	C	Body		Interior = 6.58 kg
*Splash hose front incl. Bracket	9230	1	50	50	Rubber	C	Body		Powertrain = 1.695 kg
Door Boot Harness	5715	2	40	80	Rubber	C	Body		Suspension = 0.706 kg
Door Boot Harness	5725	2	40	80	Rubber	C	Body		Suspension (tire) = 26 kg
Door Mirror Flag Seal	5715	2	140	280	Rubber	C	Body		
Door Outer Belt Seal	5715	2	130	260	Rubber	C	Body		

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
Door Outer Belt Seal	5725	2	140	280	Rubber	C	Body		
Inner Belt Seal	6820	2	290	580	Rubber	C	Interior		
Trim Panel Assembly	6820	2	3,000	6,000	Rubber	C	Interior		
*Air-filter hose	2410	1	620	620	Rubber	C	Powertrain		
*Exhaust rubber mean and end muffler	2615	3	85	255	Rubber	C	Powertrain		
*Exhaust rubber of catalyst	2615	2	65	130	Rubber	C	Powertrain		
*Line	2020	2	25	50	Rubber	C	Powertrain		
*Rubber grip	1940	4	45	180	Rubber	C	Powertrain		
*Rubber seal	2020	1	40	40	Rubber	C	Powertrain		
*Ventilation hose incl. Bracket	2020	1	110	110	Rubber	C	Powertrain		
Water hose incl. bracket	1940	1	210	210	Rubber	C	Powertrain		
Water hose incl. bracket	1940	1	100	100	Rubber	C	Powertrain		
Rubber bushing	4210	2	343	706	Rubber	C	Suspension		
Tires 17/65R 14	4420	4	6,500	26,000	Rubber	C	Suspension		
Sub-Total - Rubber				**41,227**					
Body structure	5000	1	218,124	218,124	Steel	A	Body	Body System --> 17.2 Structural Parts	Use ULSAB-AVC ratios for structural steel parts - based on ULSAB-AVC Porsche Engineering Report: 77.5% Steel (galvanized, stamped) 22.5% Steel (tube, hydroforming). Kept non-steel ratios for non-steel parts in USAMP "Body System."
Deck lid	5520	1	10,270	10,270	Steel	A	Body	Body System --> 17.6 Hood	See Hood (GADH no. 5510).
Hood	5510	1	9,534	9,534	Steel	A	Body	Body System --> 17.6 Hood	Use USAMP ratios for Hood. Treat together with "Deck Lid." Total mass = 19.804. Use USAMP Ratios for Body_Hood.
Exhaust system	2610	1	14,150	14,150	Steel	A	Powertrain	Exhaust System	Treated together with Heat Shield (GADH no. 2695), sum is distributed according to Powertrain_Exhaust System Ratios.
Electrical Powered Assisted Steering Gear	4810	1	14,150	14,150	Steel	A	Suspension	Control Systems	Use USAMP ratios for Control Systems (includes Steering Systems and misc. control parts). Treat together with "Steering column incl. Vertical adj. And bracket." Total mass = 19.65.
Steering column incl. Vertical adj. And bracket	4820	1	5,500	5,500	Steel	A	Suspension	Control Systems	

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
Bumper Beam Front Inner	5210	1	1,940	1,940	Steel	B	Body		Steel (cold rolled, stamped)
Bumper Beam Rear Inner	5220	1	2,336	2,336	Steel	B	Body		Steel (cold rolled, stamped)
*Bolts assy Crash Box	5210	8	40	320	Steel	B	Body		Steel (EAF, forged, machined)
*Bolts assy Crash Box	5220	8	40	320	Steel	B	Body		Steel (EAF, forged, machined)
Assy Crash Box Bumper Fror	5210	2	704	1,408	Steel	B	Body		Steel (galvanized, stamped)
Bumper Beam Front Outer	5210	1	2,640	2,640	Steel	B	Body		Steel (galvanized, stamped)
Assy Crash Box Bumper Rea	5220	2	460	920	Steel	B	Body		Steel (galvanized, stamped)
Bumper Beam Rear Outer	5220	1	1,536	1,536	Steel	B	Body		Steel (galvanized, stamped)
*Fixing Rail Rear end	5220	1	600	600	Steel	B	Body		Steel (galvanized, stamped)
Service Modul Door Incl. Brac	5510	1	548	548	Steel	B	Body		Steel (galvanized, stamped)
*Engine hood mounting incl. E	5515	2	340	680	Steel	B	Body		Steel (galvanized, stamped)
*Engine hood lock incl. Brack	5515	1	270	270	Steel	B	Body		Steel (galvanized, stamped)
*Gas spring incl. bracket	5525	2	350	700	Steel	B	Body		Steel (galvanized, stamped)
*Hinge lid rear	5525	2	550	1,100	Steel	B	Body		Steel (galvanized, stamped)
Hinges incl. Bolts and Bracke	5715	2	739	1,478	Steel	B	Body		Steel (galvanized, stamped)
Door Check Strap	5715	2	410	820	Steel	B	Body		Steel (galvanized, stamped)
Door Check Strap	5725	2	410	820	Steel	B	Body		Steel (galvanized, stamped)
Hinges incl. Bolts and Bracke	5725	2	739	1,478	Steel	B	Body		Steel (galvanized, stamped)
*Wiper leaf incl. Bracket front	9210	2	170	340	Steel	B	Body		Steel (galvanized, stamped)
*Wiper arm incl. Bracket front	9210	2	330	660	Steel	B	Body		Steel (galvanized, stamped)
Wiper linkage incl. Engine an	9210	1	2,780	2,780	Steel	B	Body		Steel (galvanized, stamped)
Fender	5025	2	1,608	3,216	Steel	B	Body		Steel (galvanized, stamped)
Door structure	5710	2	9,593	19,186	Steel	B	Body		Steel (galvanized, stamped)
Door structure	5720	2	9,278	18,556	Steel	B	Body		Steel (galvanized, stamped)
*Engine controller	2750	1	700	700	Steel	B	Electrical		Steel (galvanized, stamped)
*Bracket for horn	9050	1	80	80	Steel	B	Electrical		Steel (galvanized, stamped)
*Horn	9050	1	346	346	Steel	B	Electrical		Steel (galvanized, stamped)
*Bracket for cable loom	9720	1	300	300	Steel	B	Electrical		Steel (galvanized, stamped)
Ventilator incl.bracket	1930	1	1,400	1,400	Steel	B	HVAC		Steel (galvanized, stamped)
*Additional resistor incl. brack	1930	1	70	70	Steel	B	HVAC		Steel (galvanized, stamped)
*Heater fan	8020	1	1,500	1,500	Steel	B	HVAC		Steel (galvanized, stamped)
*Bracket heater case	8020	4	25	100	Steel	B	HVAC		Steel (galvanized, stamped)
*Mounting climatic line	8030	10	15	150	Steel	B	HVAC		Steel (galvanized, stamped)
*Bracket for dryer incl. Mount	8030	1	300	300	Steel	B	HVAC		Steel (galvanized, stamped)
*Airbag module incl. Cover ar	6840	1	4,300	4,300	Steel	B	Interior		Steel (galvanized, stamped)
*Belt set back incl. Bracket ar	6840	2	1,650	1,650	Steel	B	Interior		Steel (galvanized, stamped)

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
*Belt set front incl. Bracket	6840	2	1,750	1,750	Steel	B	Interior		Steel (galvanized, stamped)
*Belt Lock Front incl. Bracket	6840	2	175	350	Steel	B	Interior		Steel (galvanized, stamped)
									>1 % but no corresponding USAMP category.
FRONT Seat LH/RH Module	7210	1	19,364	19,364	Steel	B	Interior		Steel (galvanized, stamped)
Bracket seat bolster	7225	30	1	30	Steel	B	Interior		Steel (galvanized, stamped)
									>1 % but no corresponding USAMP category.
Rear Seat Frame incl. Bracke	7240	1	10,151	10,151	Steel	B	Interior		Steel (galvanized, stamped)
Mounting seat back trim	7250	35	1	35	Steel	B	Interior		Steel (galvanized, stamped)
Crossmember Instrument Par	6830	1	6,315	6,315	Steel	B	Interior		Steel (tube for hydroforming, hydroforming)
Lock Nut	3410	2	53	107	Steel	B	Powertrain		Steel (EAF, forged, machined)
Dry Sump Oil Reservoir	1730	1	1,750	1,750	Steel	B	Powertrain		Steel (galvanized, stamped)
Cooling Frame incl. Bracket	1940	1	1,200	1,200	Steel	B	Powertrain		Steel (galvanized, stamped)
Fuel tank	2010	1	4,456	4,456	Steel	B	Powertrain		Steel (galvanized, stamped)
Tank band incl. bracket	2010	1	500	500	Steel	B	Powertrain		Steel (galvanized, stamped)
*Tube set incl. bracket	2020	3	380	1,140	Steel	B	Powertrain		Steel (galvanized, stamped)
*Bracket for fuel filter	2020	1	80	80	Steel	B	Powertrain		Steel (galvanized, stamped)
*Fuel filter	2020	1	150	150	Steel	B	Powertrain		Steel (galvanized, stamped)
*Seal	2615	1	25	25	Steel	B	Powertrain		Steel (galvanized, stamped)
Drive Shaft left	3410	1	3,454	3,454	Steel	B	Powertrain		Steel (hot rolled, forged, machined)
Drive Shaft right	3410	1	3,503	3,503	Steel	B	Powertrain		Steel (hot rolled, forged, machined)
									>1 % but no corresponding USAMP category. Use ULSAB-AVC ratios for structural steel parts - based on ULSAB-AVC Porsche Engineering Report: 77.5% Steel (galvanized, stamped)
Subframe	4010	1	17,112	17,112	Steel	B	Suspension		22.5% Steel (tube, hydroforming).
Wheel bearing	4210	2	825	1,650	Steel	B	Suspension		Steel (EAF, forged, machined)
Nuts	4210		506	506	Steel	B	Suspension		Steel (EAF, forged, machined)
Bolts	4410	16	83	1,328	Steel	B	Suspension		Steel (EAF, forged, machined)
Brake Disk	4610	2	3,750	7,500	Steel	B	Suspension		Steel (EAF, forged, machined)
Brake Caliper	4610	2	4,414	8,829	Steel	B	Suspension		Steel (EAF, forged, machined)
Brake Disk	4620	2	3,300	6,600	Steel	B	Suspension		Steel (EAF, forged, machined)
Brake Caliper	4620	2	2,918	5,836	Steel	B	Suspension		Steel (EAF, forged, machined)
Hand brake control cable incl.	4350	1	610	610	Steel	B	Suspension		Steel (galvanized, extruded)
Upper Wishbone Assembly	4010	2	1,678	3,356	Steel	B	Suspension		Steel (galvanized, stamped)
Lower Wishbone Assembly	4010	2	4,258	8,516	Steel	B	Suspension		Steel (galvanized, stamped)
Steering knuckle complete	4010	2	5,166	10,332	Steel	B	Suspension		Steel (galvanized, stamped)
Engine Mounting Brackets	4010	1	2,569	2,569	Steel	B	Suspension		Steel (galvanized, stamped)

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
Damper incl Brackets	4020	2	1,310	2,620	Steel	B	Suspension		Steel (galvanized, stamped)
*Bracket for hitch line	4310	1	50	50	Steel	B	Suspension		Steel (galvanized, stamped)
Connection Base Plate	4310	1	428	428	Steel	B	Suspension		Steel (galvanized, stamped)
Upper Rail	4310	1	230	230	Steel	B	Suspension		Steel (galvanized, stamped)
Lower Rail	4310	2	120	240	Steel	B	Suspension		Steel (galvanized, stamped)
Connection Platform	4310	1	165	165	Steel	B	Suspension		Steel (galvanized, stamped)
Connection IP-Structure	4310	1	558	558	Steel	B	Suspension		Steel (galvanized, stamped)
Brakepedal	4340	1	415	415	Steel	B	Suspension		Steel (galvanized, stamped)
Spring	4220	2	1,505	3,010	Steel	B	Suspension		Steel (hot rolled, forged, machined)
Steel rims	4410	4	3,720	14,880	Steel	B	Suspension		Steel (hot rolled, stamped) >1 % but no corresponding USAMP category.
Twist-beam rear axle	4210	1	17,221	17,221	Steel	B	Suspension		Steel (tube for hydroforming, hydroforming)
Shock absorber	4220	2	1,334	2,668	Steel	B	Suspension		Steel (tube for hydroforming, hydroforming)
*Brake Tubes	4630		2,500	2,500	Steel	B	Suspension		Steel (tube for hydroforming, hydroforming)
Sub-Total - Steel				**521,365**					
Gear box complete	3200	1	31,000	31,000	Steel/Alum - Combo	C	Powertrain		>1 % but no corresponding USAMP category. Used USAMP "Powertrain" ratios of Al and steel only.
Door Window Regulator Assembly	5718	2	1,910	3,820	Steel/Alum - Combo	C	Body		Used USAMP "Body" ratios of al and steel only. Total mass Al/steel = 7.64 kg
Door Window Regulator Assembly	5728	2	1,910	3,820	Steel/Alum - Combo	C	Body		
Door Speaker	9110	2	560	1,120	Steel/Other - Combo	F	Electrical		
Gas Pressure Spring	4310	1	1,227	1,227	Steel/Plastic - Combo	C	Suspension		Used USAMP ratios of Steel and plastic for each of the subsystems in this mat'l category.
*Attachments	4310	1	200	200	Steel/Plastic - Combo	C	Suspension		Suspension = 6.527 kg
EHB-Unit	4630	1	5,100	5,100	Steel/Plastic - Combo	C	Suspension		Body = 3.92 kg
*Lock incl. Control	5525	1	560	560	Steel/Plastic - Combo	C	Body		Interior = 0.76 kg

Part	GADH No.	No. Pcs.	Single Mass (g)	Total Mass (g)	ULSAB-AVC Material Category	Mapping Procedure	USAMP Subsystem	Sub-subsystem	Estimated Material Composition
Door latch assembly	5715	2	370	740	Steel/Plastic - Combo	C	Body		
Door Outside Remote Handle	5715	2	470	940	Steel/Plastic - Combo	C	Body		
Door latch assembly	5725	2	370	740	Steel/Plastic - Combo	C	Body		
Door Outside Remote Handle	5725	2	470	940	Steel/Plastic - Combo	C	Body		
*Lap Belt Rear	6840	1	265	265	Steel/Plastic - Combo	C	Interior		
*Belt Lock Rear incl. Bracket	6840	3	165	495	Steel/Plastic - Combo	C	Interior		
Sub-Total - Steel/Alum & Steel/Plastic Combinations				**50,967**					
Total Vehicle Weight				**997,593**					

* = Parts not designed and/or the weight is estimated

APPENDIX F: ULSAB-AVC PNGV-GAS ENGINE VEHICLE MATERIAL DISTRIBUTION

Fluids

Material	*Mass*	*Mass (%)*
Automatic Transmission Fluid	1.4	0.140%
Engine Coolant	5	0.501%
Engine Oil (SAE 10w-30)	5	0.501%
Gasoline	27	2.706%
Glycol Ether (Brake Fluid)*	0.5	0.050%
Refrigerant	0.35	0.035%
Water: Unspecified Origin	1.2	0.120%
Windshield Cleaning Additives*	0.3	0.030%
Total Fluids:	40.75	4.085%

Metals (Ferrous)

Material	*Mass (kg)*	*Mass (%)*
Ferrite (Fe)	0.068	0.007%
Iron (Fe, cast, heat treated)	2.53	0.254%
Iron (Fe, cast, machined)	34.9	3.501%
Iron (Fe, forged, machined)	10.4	1.039%
Steel (cold rolled, extruded)	2.25	0.226%
Steel (cold rolled, extruded, machined)	1.01	0.101%
Steel (cold rolled, extruded, machined, welded)	0.375	0.038%
Steel (cold rolled, machined)	7.408	0.743%
Steel (cold rolled, machined, plated)	0.041	0.004%
Steel (cold rolled, machined, welded)	0.061	0.006%
Steel (cold rolled, plated)	0.004	0.0004%
Steel (cold rolled, stamped)	15	1.507%
Steel (cold rolled, stamped, machined)	4.80	0.481%
Steel (EAF, extruded)	1.98	0.199%
Steel (EAF, extruded, machined)	1.03	0.103%
Steel (EAF, forged, machined)	36.0	3.611%
Steel (EAF, machined)	35.4	3.551%
Steel (EAF, machined, heat treated)	0.658	0.066%
Steel (EAF, machined, plated)	0.007	0.001%
Steel (galvanized, extruded)	4.21	0.422%
Steel (galvanized, stamped)	356	35.685%
Steel (galvanized, stamped, machined)	0.027	0.003%
Steel (hot rolled, extruded)	0.091	0.009%
Steel (hot rolled, forged)	0.443	0.044%
Steel (hot rolled, forged, machined)	10.0	1.007%
Steel (hot rolled, forged, welded)	0.282	0.028%
Steel (hot rolled, stamped)	23.3	2.334%
Steel (hot rolled, stamped, machined)	1.55	0.156%
Steel (stainless)	0.028	0.003%
Steel (stainless, extruded)	0.00007	0.000%
Steel (stainless, stamped)	10.7	1.073%
Steel (tube for hydroforming, hydroforming)	81.5	8.169%
Total Metals (Ferrous):	642.159	64.370%

Metals (Non-Ferrous)

Material	*Mass*	*Mass (%)*
Aluminum (automotive, cast)	37.2	3.733%
Aluminum (automotive, extruded)	10.9	1.098%
Aluminum (automotive, rolled, stamped)	1.66	0.167%
Aluminum Oxide (Al2O3)*	0.164	0.016%
Brass	0.264	0.026%
Brass (cast)**	0.011	0.001%
Brass (rolled, stamped)**	0.002	0.000%
Chromium (Cr)	0.073	0.007%
Copper (Cu)	0.112	0.011%
Copper (Cu, extruded)	2.66	0.266%
Lead (Pb)	9.03	0.905%
Lead (Pb, cast)**	0.062	0.006%
Magnesium	2.48	0.248%
Platinum (Pt)	0.001	0.000%
Rhodium (Rh)	0.0002	0.000%
Silver (Ag)	0.0002	0.000%
Tin (Sn, coated)	0.029	0.003%
Tin (Sn, extruded)	0.0002	0.000%
Tungsten (W)	0.0005	0.000%
Zinc (Zn)	0.026	0.003%
Total Metals (Non-Ferrous):	64.767	6.492%

Other Materials

Material	*Mass*	*Mass (%)*
Adhesive Agent*	0.469	0.047%
Asbestos*	0.014	0.001%
Asphalt	2.60	0.261%
Bromine (Br)*	0.010	0.001%
Carpeting (compressed)	6.895	0.691%
Ceramic (fired)*	0.011	0.001%
Charcoal*	0.132	0.013%
Cordierite (honeycomb structured)*	0.744	0.075%
Desiccant Agent*	0.0001	0.000%
Fiberglass (extruded)	0.020	0.002%
Fiberglass (pressed)	2.33	0.234%
Glass (blown)**	0.045	0.005%
Glass (pressed)	26.5	2.655%
Glass (pressed, plated)	0.010	0.001%
Graphite*	0.0008	0.000%
Paint and PVC***	20	2.005%
Paper	0.034	0.003%
Recycled Textile Fibers (compressed)**	6.96	0.698%
Rubber (except tire)	13.2	1.327%
Rubber (calendered)**	0.173	0.017%
Rubber (extruded)	12.6	1.259%
Rubber (injection molded)**	2.28	0.228%
Sulfuric Acid (H2SO4, 100%)	1.69	0.169%
Tire	26.4	2.645%
Wood	0.176	0.018%
Wood (coated)	0.100	0.010%
Total Other Materials:	123.373	12.367%

Plastics

Material	*Mass*	*Mass (%)*
ABS-PC (Acrylonitrile Butadiene Styrene Polycarbonate blend, injection molded)	1.11	0.111%
Acetal	0.075	0.007%
Acetal (injection molded)	2.90	0.290%
Acetal (molded)**	0.208	0.021%
Acrylic Resin (injection molded)	1.65	0.166%
Acrylic Resin (molded)**	0.208	0.021%
Acrylonitrile Butadiene Styrene (ABS, extruded)**	0.553	0.055%
Acrylonitrile Butadiene Styrene (ABS, injection molded)**	4.03	0.403%
Acrylonitrile Butadiene Styrene (ABS, molded)	1.74	0.174%
Acrylonitrile Styrene Acrylate (ASA, molded)*	0.129	0.013%
Epoxy Resin	0.262	0.026%
Ethylene Propylene Diene Monomer (EPDM, extruded)**	1.81	0.182%
Ethylene Propylene Diene Monomer (EPDM, injection molded)	0.913	0.091%
Ethylene Propylene Diene Monomer (EPDM, molded)**	2.70	0.271%
PA 6-PC (Polyamide Polycarbonate blend, injection molded)	0.366	0.037%
Phenolic Resin	0.250	0.025%
Phenolic Resin (injection molded)	0.615	0.062%
Polyamide (PA 6, blow molded)	0.222	0.022%
Polyamide (PA 6, injection molded)	4.81	0.482%
Polyamide (PA 6, molded)**	0.691	0.069%
Polyamide (PA 66, extruded)	2.69	0.270%
Polyamide (PA 66, injection molded)	6.84	0.686%
Polyamide (PA 66, molded)**	10.5	1.055%
Polybutylene Terephthalate (PBT, injection molded)	0.100	0.010%
Polybutylene Terephthalate (PBT, molded)**	0.182	0.018%
Polycarbonate (PC, injection molded)**	2.23	0.223%
Polycarbonate (PC, molded)	0.589	0.059%
Polyester Resin (extruded, woven)**	4.85	0.486%
Polyester Resin (glued)**	4.83	0.485%
Polyester Resin (woven)**	0.219	0.022%
Polyethylene (PE, extruded)	0.537	0.054%
Polyethylene (PE, injection molded)	2.91	0.292%
Polyethylene (PE, molded)**	1.11	0.112%
Polyethylene Terephthalate (PET, compression molded)	0.439	0.044%
Polyethylene Terephthalate (PET, fibers, compressed)	0.496	0.050%
Polyethylene Terephthalate (PET, injection molded)**	0.766	0.077%
Polypropylene (PP, blow molded)	0.839	0.084%
Polypropylene (PP, compression molded)	2.27	0.228%
Polypropylene (PP, extruded)	0.439	0.044%
Polypropylene (PP, foam, injection molded)	1.23	0.123%
Polypropylene (PP, injection molded)	13.0	1.305%
Polypropylene (PP, molded)**	0.392	0.039%
Polystyrene (PS, molded)	0.005	0.001%
Polyurethane (PUR, blow molded)	0.254	0.025%
Polyurethane (PUR, foam, injection molded)	14.8	1.484%
Polyurethane (PUR, injection molded)	1.66	0.166%
Polyurethane (PUR, molded)**	0.129	0.013%
Polyurethane (PUR, reaction injection molded, RIM)	9.39	0.941%

Polyvinyl Chloride (PVC, extruded)	7.81	0.783%
Polyvinyl Chloride (PVC, injection molded)	4.64	0.465%
Polyvinyl Chloride (PVC, molded)**	0.255	0.026%
PP-EPDM (Polypropylene Ethylene Propylene Diene Monomer blend, injection molded)**	0.073	0.007%
PPO-PC (Polyphenylene Oxide Polycarbonate blend, injection molded)**	0.019	0.002%
PPO-PS (Polyphenylene Oxide Polystyrene blend, injection molded)**	1.64	0.165%
Thermoplastic Elastomeric Olefin (TEO, injection molded)*	0.218	0.022%
Total Plastics:	126.555	12.686%
TOTAL Mass of ULSAB- AVC PNGV-gas engine Vehicle:	997.604	100%

* Material (and corresponding process) not modeled. See Appendix C: Material and Generic Process Exclusions.
**Process not modeled. See Appendix C: Material and Generic Process Exclusions.
***Paint and PVC were classified under "Other Materials" because only one mass was provided so these materials could not be disaggregated.

APPENDIX G: USAMP GENERIC VEHICLE CHARACTERISTICS

Source: [USAMP, Ecobalance et al. 1999]

General Characteristics and Functions	USAMP (Gas)
Vehicle Curb Weight (kg)	1554
Body Structure (kg)	229
Fuel	Gasoline
Fuel Efficiency U.S. Driving Cycle, L/100km (mpg)	10.3 (22.8)
Vehicle Service Life (km)	193,000
Engine Power (kW)	140 @ 4800 rpm
Engine Torque (Nm)	N/A
Engine Displacement (L)	3.0
Passengers	6
Doors	4
Luggage Volume (m^3)	0.48
Acceleration, 0 to 60 mph (s)	10.7
Top Speed (km/h)	N/A
Airbags	N.S.
Antilock Brake System (ABS)	Yes
Length (mm)	N.S.
Width (mm)	N.S.
Height (mm)	N.S.

N.S. Not Specified in USAMP study.

APPENDIX H: USAMP GENERIC VEHICLE MATERIAL DISTRIBUTION

Fluids		
Material	*Mass*	*Mass (%)*
Automatic Transmission Fluid	6.69	0.430%
Engine Coolant	12.4	0.798%
Engine Oil (SAE 10w-30)	3.46	0.223%
Gasoline	64.4	4.147%
Glycol Ether (Brake Fluid)*	1.05	0.068%
Refrigerant	0.910	0.059%
Water: Unspecified Origin	1.92	0.124%
Windshield Cleaning Additives*	0.480	0.031%
Total Fluids:	91.34	5.879%

Metals (Ferrous)		
Material	*Mass (kg)*	*Mass (%)*
Ferrite (Fe)	1.48	0.096%
Iron (Fe, cast, heat treated)	5.53	0.356%
Iron (Fe, cast, machined)	126	8.115%
Iron (Fe, forged, machined)	22.6	1.455%
Steel (cold rolled, extruded)	9.02	0.580%
Steel (cold rolled, extruded, machined)	4.76	0.307%
Steel (cold rolled, extruded, machined, welded)	0.817	0.053%
Steel (cold rolled, machined)	27.1	1.744%
Steel (cold rolled, machined, plated)	0.338	0.022%
Steel (cold rolled, machined, welded)	1.25	0.081%
Steel (cold rolled, plated)	0.082	0.005%
Steel (cold rolled, stamped)	43.3	2.790%
Steel (cold rolled, stamped, machined)	32.2	2.071%
Steel (EAF, extruded)	4.74	0.305%
Steel (EAF, extruded, machined)	2.40	0.154%
Steel (EAF, forged, machined)	13.8	0.885%
Steel (EAF, machined)	195	12.560%
Steel (EAF, machined, heat treated)	1.44	0.092%
Steel (EAF, machined, plated)	0.151	0.010%
Steel (galvanized, extruded)	7.80	0.502%
Steel (galvanized, stamped)	349	22.431%
Steel (galvanized, stamped, machined)	0.588	0.038%
Steel (hot rolled, extruded)	8.77	0.565%
Steel (hot rolled, forged)	9.75	0.628%
Steel (hot rolled, forged, machined)	0.636	0.041%
Steel (hot rolled, forged, welded)	6.15	0.396%
Steel (hot rolled, stamped)	95.6	6.156%
Steel (hot rolled, stamped, machined)	5.29	0.341%
Steel (stainless)	0.227	0.015%
Steel (stainless, extruded)	0.011	0.001%
Steel (stainless, stamped)	18.5	1.194%
Total Metals (Ferrous):	994.126	63.985%

Metals (Non-Ferrous)

Material	*Mass*	*Mass (%)*
Aluminum (automotive, cast)	71.4	4.598%
Aluminum (automotive, extruded)	22.0	1.418%
Aluminum (automotive, rolled, stamped)	3.30	0.213%
Aluminum Oxide (Al2O3)*	0.273	0.018%
Brass	7.20	0.464%
Brass (cast)**	1.24	0.080%
Brass (rolled, stamped)**	0.045	0.003%
Chromium (Cr)	0.912	0.059%
Copper (Cu)	0.145	0.009%
Copper (Cu, extruded)	17.5	1.124%
Lead (Pb)	12.1	0.781%
Lead (Pb, cast)**	0.922	0.059%
Platinum (Pt)	0.001	0.000%
Rhodium (Rh)	0.0003	0.000%
Silver (Ag)	0.003	0.000%
Tin (Sn, coated)	0.063	0.004%
Tin (Sn, extruded)	0.005	0.000%
Tungsten (W)	0.011	0.001%
Zinc (Zn)	0.321	0.021%
Total Metals (Non-Ferrous):	137.519	8.851%

Other Materials

Material	*Mass*	*Mass (%)*
Adhesive Agent*	0.167	0.011%
Asbestos*	0.399	0.026%
Bromine (Br)*	0.229	0.015%
Carpeting (compressed)	11.2	0.722%
Ceramic (fired)*	0.248	0.016%
Charcoal*	0.220	0.014%
Cordierite (honeycomb structured)*	1.24	0.080%
Desiccant Agent*	0.023	0.001%
Fiberglass (extruded)	0.433	0.028%
Fiberglass (pressed)	3.34	0.215%
Glass (blown)**	0.985	0.063%
Glass (pressed)	41.2	2.653%
Glass (pressed, plated)	0.127	0.008%
Graphite*	0.092	0.006%
Paper	0.204	0.013%
Recycled Textile Fibers (compressed)**	12.0	0.773%
Rubber (except tire)	11.3	0.727%
Rubber (calendered)**	0.560	0.036%
Rubber (extruded)	35.9	2.308%
Rubber (injection molded)**	10.9	0.704%
Sulfuric Acid (H2SO4, 100%)	2.18	0.140%
Tire	45.4	2.923%
Wood	1.91	0.123%
Wood (coated)	0.378	0.024%
Total Other Materials:	180.682	11.629%

Plastics

Material	*Mass*	*Mass (%)*
ABS-PC (Acrylonitrile Butadiene Styrene Polycarbonate blend, injection molded)	2.81	0.181%
Acetal	0.100	0.006%
Acetal (injection molded)	4.03	0.259%
Acetal (molded)**	0.279	0.018%
Acrylic Resin (injection molded)	2.21	0.142%
Acrylic Resin (molded)**	0.279	0.018%
Acrylonitrile Butadiene Styrene (ABS, extruded)**	1.74	0.112%
Acrylonitrile Butadiene Styrene (ABS, injection molded)**	5.67	0.365%
Acrylonitrile Butadiene Styrene (ABS, molded)	2.33	0.150%
Acrylonitrile Styrene Acrylate (ASA, molded)*	0.180	0.012%
Epoxy Resin	0.766	0.049%
Ethylene Propylene Diene Monomer (EPDM, extruded)**	2.83	0.182%
Ethylene Propylene Diene Monomer (EPDM, injection molded)	1.36	0.088%
Ethylene Propylene Diene Monomer (EPDM, molded)**	3.42	0.220%
PA 6-PC (Polyamide Polycarbonate blend, injection molded)	0.454	0.029%
Phenolic Resin	0.394	0.025%
Phenolic Resin (injection molded)	0.706	0.045%
Polyamide (PA 6, blow molded)	0.591	0.038%
Polyamide (PA 6, injection molded)	0.281	0.018%
Polyamide (PA 6, molded)**	0.811	0.052%
Polyamide (PA 66, extruded)	3.09	0.199%
Polyamide (PA 66, injection molded)	3.66	0.236%
Polyamide (PA 66, molded)**	3.52	0.227%
Polybutylene Terephthalate (PBT, injection molded)	0.134	0.009%
Polybutylene Terephthalate (PBT, molded)**	0.238	0.015%
Polycarbonate (PC, injection molded)**	2.97	0.191%
Polycarbonate (PC, molded)	0.788	0.051%
Polyester Resin (extruded, woven)**	5.57	0.359%
Polyester Resin (glued)**	5.55	0.357%
Polyester Resin (woven)**	0.345	0.022%
Polyethylene (PE, extruded)	0.617	0.040%
Polyethylene (PE, injection molded)	4.08	0.263%
Polyethylene (PE, molded)**	1.49	0.096%
Polyethylene Terephthalate (PET, compression molded)	0.504	0.032%
Polyethylene Terephthalate (PET, fibers, compressed)	0.569	0.037%
Polyethylene Terephthalate (PET, injection molded)**	1.13	0.073%
Polypropylene (PP, blow molded)	2.24	0.144%
Polypropylene (PP, compression molded)	3.19	0.205%
Polypropylene (PP, extruded)	0.504	0.032%
Polypropylene (PP, foam, injection molded)	1.73	0.111%
Polypropylene (PP, injection molded)	18.3	1.180%
Polypropylene (PP, molded)**	0.553	0.036%
Polystyrene (PS, molded)	0.007	0.000%
Polyurethane (PUR, blow molded)	0.676	0.043%
Polyurethane (PUR, foam, injection molded)	17.0	1.094%
Polyurethane (PUR, injection molded)	3.91	0.252%
Polyurethane (PUR, molded)**	0.180	0.012%
Polyurethane (PUR, reaction injection molded, RIM)	13.1	0.846%

Polyvinyl Chloride (PVC, calendered)	3.64	0.234%
Polyvinyl Chloride (PVC, extruded)	10.5	0.674%
Polyvinyl Chloride (PVC, injection molded)	5.97	0.384%
Polyvinyl Chloride (PVC, molded)**	0.339	0.022%
PP-EPDM (Polypropylene Ethylene Propylene Diene Monomer blend, injection molded)**	0.103	0.007%
PPO-PC (Polyphenylene Oxide Polycarbonate blend, injection molded)**	0.026	0.002%
PPO-PS (Polyphenylene Oxide Polystyrene blend, injection molded)**	2.20	0.141%
Thermoplastic Elastomeric Olefin (TEO, injection molded)*	0.307	0.020%
Total Plastics:	150.022	9.656%
TOTAL Mass of ULSAB- AVC PNGV-gas engine Vehicle:	1553.690	100%

* Material (and corresponding process) not modeled. See Appendix C: Material and
**Process not modeled. See Appendix C: Material and Generic Process Exclusions.

APPENDIX I: USAMP GENERIC VEHICLE LIFE CYCLE INVENTORY RESULTS

			USAMP Generic Vehicle			
Category	**Environmental Flow**	**Units**	**Vehicle Production Phase**	**Use Phase**	**Disposition Phase**	**Vehicle Life Cycle Total**
Resource Use	(r) Bauxite (Al2O3, ore)	kg	233	0.28		233
	(r) Coal (in ground)	kg	1,668	876	11	2,554
	(r) Ilmenite (FeO.TiO2, ore)	kg	0.98	0.0001		0.98
	(r) Iron (Fe, ore)	kg	1,483	3.0	0.04	1,486
	(r) Lead (Pb, ore)	kg	14	20		33
	(r) Limestone (CaCO3, in ground)	kg	285	168	2.0	454
	(r) Natural Gas (in ground)	kg	688	1,136	2.2	1,827
	(r) Oil (in ground)	kg	505	16,303	35	16,843
	(r) Perlite (SiO2, ore)	kg	2.5	0		2.5
	(r) Pyrite (FeS2, ore)	kg	13	0.00004		13
	(r) Sulfur (S)	kg	0.10	0.00004		0.10
	(r) Tungsten (W, ore)	kg	0.01	0.0007		0.01
	(r) Uranium (U, ore)	kg	0.02	0.02	0.0003	0.04
	(r) Zinc (Zn, ore)	kg	29	11		40
	Iron Scrap	kg	206	43		249
	Natural Rubber	kg	9.1	16		25
	Raw Materials (unspecified)	kg	16	0.32		16
	Water Used (total)	liter	72,877	7,662	4.0	80,543
Air Emissions	(a) Carbon Dioxide (CO2, fossil)	kg	7,223	57,048	143	64,414
	(a) Carbon Monoxide (CO)	g	64,715	204,199	683	269,596
	(a) Hydrocarbons (except methane)	g	13,222	90,858	170	104,251
	(a) Hydrogen Chloride (HCl)	g	297	446	5.7	749
	(a) Hydrogen Fluoride (HF)	g	62	54	0.71	117
	(a) Lead (Pb)	g	52	65	0.02	117
	(a) Methane (CH4)	g	19,469	49,968	144	69,581
	(a) Nitrogen Oxides (NOx as NO2)	g	21,412	101,494	806	123,712
	(a) Particulates (unspecified)	g	35,846	19,193	247	55,286
	(a) Sulfur Oxides (SOx as SO2)	g	46,414	90,671	315	137,400
Water Emissions	(w) Ammonia (as N)	g	132	2,301	1.9	2,435
	(w) Dissolved Matter (unspecified)	g	5,838	2,063	17	7,918
	(w) Heavy Metals (total)	g	37	3.1	0.001	40
	(w) Oils (unspecified)	g	645	7,211	7.4	7,864
	(w) Phosphates (as P)	g	15	0.42	0.00002	16
	(w) Suspended Matter (unspecified)	g	4,505	71,555	58	76,118
Solid Waste	Waste (municipal and industrial)	kg	93	41	296	430
	Waste (total)	kg	2,962	1,089	326	4,377
Energy Consumption	E (HHV) Total Energy	MJ	125,383	867,616	2,164	995,163

APPENDIX J: ULSAB-AVC SENSITIVITY ANALYSIS

Table J-1: ULSAB-AVC PNGV Sensitivity Analysis on Vehicle Fuel Economy

			PNGV-Gas Engine Vehicle Use Phase					PNGV-Diesel Engine Vehicle Use Phase				
			Fuel Economy L/100km (mpg)					Fuel Economy L/100km (mpg)				
Category	Environmental Flow*	Units	**4.5 (52.4)**	5.5 (42.4)	% Change	3.8 (62.4)	% Change	**3.4 (68)**	4.1 (58)	% Change	3.0 (78)	% Change
Resource Use	(r) Bauxite (Al2O3, ore)	kg	0.01	0.01	0%	0.01	0%	0.01	0.01	0%	0.01	0%
	(r) Coal (in ground)	kg	414	494	19%	360	-13%	298	336	13%	269	-9%
	(r) Ilmenite (FeO.TiO2, ore)	kg	0	0		0		0	0		0	
	(r) Iron (Fe, ore)	kg	0.37	0.37	0%	0.37	0%	0.37	0.37	0%	0.37	0%
	(r) Lead (Pb, ore)	kg	15	15	0%	15	0%	15	15	0%	15	0%
	(r) Limestone (CaCO3, in ground)	kg	80	95	19%	70	-13%	58	65	13%	52	-9%
	(r) Natural Gas (in ground)	kg	518	627	21%	444	-14%	262	298	14%	235	-10%
	(r) Oil (in ground)	kg	7,162	8,816	23%	6,037	-16%	6,272	7,328	17%	5,486	-13%
	(r) Perlite (SiO2, ore)	kg	0	0		0		0	0		0	
	(r) Pyrite (FeS2, ore)	kg	0.00003	0.00003	0%	0.00003	0%	0.00003	0.00003	0%	0.00003	0%
	(r) Sulfur (S)	kg	0.00003	0.00003	0%	0.00003	0%	0.00003	0.00003	0%	0.00003	0%
	(r) Tungsten (W, ore)	kg	0.0007	0.0007	0%	0.0007	0%	0.0007	0.0007	0%	0.0007	0%
	(r) Uranium (U, ore)	kg	0.009	0.011	20%	0.008	-14%	0.007	0.008	14%	0.006	-10%
	(r) Zinc (Zn, ore)	kg	6.9	6.9	0%	6.9	0%	6.9	6.9	0%	6.9	0%
	Iron Scrap	kg	26	26	0%	26	0%	26	26	0%	26	0%
	Natural Rubber	kg	10	10	0%	10	0%	10	10	0%	10	0%
	Raw Materials (unspecified)	kg	0.24	0.24	0%	0.24	0%	0.24	0.24	0%	0.24	0%
	Water Used (total)	liter	4,411	4,624	5%	4,266	-3%	4,181	4,298	3%	4,095	-2%
Air Emissions	(a) Carbon Dioxide (CO2, fossil)	kg	22,449	27,728	24%	18,861	-16%	17,657	20,659	17%	15,424	-13%
	(a) Carbon Monoxide (CO)	g	222,391	223,493	0%	221,641	0%	123,869	124,323	0%	123,531	0%
	(a) HC (except methane)	g	30,134	32,419	8%	28,588	-5%	16,329	17,276	6%	15,633	-4%
	(a) Hydrogen Chloride (HCl)	g	206	249	21%	177	-14%	143	164	14%	128	-11%
	(a) Hydrogen Fluoride (HF)	g	24	30	22%	21	-15%	16	19	16%	14	-12%
	(a) Lead (Pb)	g	50	50	0%	50	0%	50	50	0%	50	0%
	(a) Methane (CH4)	g	22,492	27,224	21%	19,277	-14%	15,586	17,854	15%	13,899	-11%
	(a) Nitrogen Oxides (NOx as NO2)	g	32,983	36,685	11%	30,468	-8%	58,653	60,137	3%	57,550	-2%
	(a) Particulates (unspecified)	g	8,682	10,439	20%	7,488	-14%	10,165	10,878	7%	9,635	-5%
	(a) Sulfur Oxides (SOx as SO2)	g	40,418	49,263	22%	34,408	-15%	22,814	26,244	15%	20,263	-11%
Water Emissions	(w) Ammonia (as N)	g	1,008	1,243	23%	848	-16%	347	405	17%	304	-12%
	(w) Dissolved Matter (unspecified)	g	1,079	1,183	10%	1,008	-7%	1,023	1,090	7%	974	-5%
	(w) Heavy Metals (total)	g	2.4	2.4	0%	2.4	0%	2.4	2.4	0%	2.4	0%
	(w) Oils (unspecified)	g	3,155	3,890	23%	2,655	-16%	1,352	1,579	17%	1,183	-12%
	(w) Phosphates (as P)	g	0.10	0.10	0%	0.10	0%	0.10	0.10	0%	0.10	0%
	(w) Suspended Matter (unspecified)	g	31,324	38,610	23%	26,373	-16%	10,805	12,593	17%	9,475	-12%
Solid Waste	Waste (municipal and industrial)	kg	32	32	0%	32	0%	32	32	0%	32	0%
	Waste (total)	kg	574	657	15%	517	-10%	280	290	4%	272	-3%
Energy Consumption	Total Primary Energy	MJ	383,286	470,579	23%	323,972	-15%	309,866	361,021	17%	271,828	-12%

* (r): Raw material in ground, (a): Airborne emissions, (w): Waterborne emissions

Table J-2: ULSAB-AVC PNGV Sensitivity Analysis on Vehicle Service Life

			PNGV-Gas Engine Vehicle Use Phase					PNGV-Diesel Engine Vehicle Use Phase				
			Vehicle Service Life km (miles)					Vehicle Service Life km (miles)				
Category	**Environmental Flow***	**Units**	**193,120 km (120,000 mi)**	160,935 km (100,000 mi)	% Change	289,680 km (180,000 mi)	% Change	**193,120 km (120,000 mi)**	160,935 km (100,000 mi)	% Change	289,680 km (180,000 mi)	% Change
Resource Use	(r) Bauxite (Al2O3, ore)	kg	0.01	0.01	-17%	0.02	50%	0.01	0.01	-17%	0.02	50%
	(r) Coal (in ground)	kg	414	349	-16%	611	47%	298	252	-15%	436	46%
	(r) Ilmenite (FeO.TiO2, ore)	kg	0	0		0		0	0		0	
	(r) Iron (Fe, ore)	kg	0.37	0.31	-17%	0.55	50%	0.37	0.31	-17%	0.55	50%
	(r) Lead (Pb, ore)	kg	15	13	-17%	23	50%	15	13	-17%	23	50%
	(r) Limestone (CaCO3, in ground)	kg	80	67	-16%	118	47%	58	49	-16%	85	47%
	(r) Natural Gas (in ground)	kg	518	432	-17%	776	50%	262	219	-17%	392	50%
	(r) Oil (in ground)	kg	7,162	5,968	-17%	10,742	50%	6,272	5,227	-17%	9,407	50%
	(r) Perlite (SiO2, ore)	kg	0	0		0		0	0		0	
	(r) Pyrite (FeS2, ore)	kg	0.00003	0.00002	-17%	0.00004	50%	0.00003	0.00002	-17%	0.00004	50%
	(r) Sulfur (S)	kg	0.00003	0.00002	-17%	0.00004	50%	0.00003	0.00002	-17%	0.00004	50%
	(r) Tungsten (W, ore)	kg	0.0007	0.0006	-17%	0.001	50%	0.0007	0.0006	-17%	0.001	50%
	(r) Uranium (U, ore)	kg	0.009	0.008	-16%	0.01	47%	0.007	0.006	-15%	0.01	46%
	(r) Zinc (Zn, ore)	kg	6.9	5.8	-17%	10	50%	6.9	5.8	-17%	10	50%
	Iron Scrap	kg	26	22	-17%	39	50%	26	22	-17%	39	50%
	Natural Rubber	kg	10	8.4	-17%	15	50%	10	8	-17%	15	50%
	Raw Materials (unspecified)	kg	0.24	0.20	-17%	0.36	50%	0.24	0.20	-17%	0.36	50%
	Water Used (total)	liter	4,411	3,676	-17%	6,616	50%	4,181	3,484	-17%	6,271	50%
Air Emissions	(a) Carbon Dioxide (CO2, fossil)	kg	22,449	18,718	-17%	33,640	50%	17,657	14,725	-17%	26,452	50%
	(a) Carbon Monoxide (CO)	g	222,391	185,328	-17%	333,579	50%	123,869	103,226	-17%	185,796	50%
	(a) HC (except methane)	g	30,134	25,115	-17%	45,206	50%	16,329	13,612	-17%	24,500	50%
	(a) Hydrogen Chloride (HCl)	g	206	174	-16%	303	47%	143	121	-15%	210	46%
	(a) Hydrogen Fluoride (HF)	g	24	20	-16%	36	47%	16	14	-15%	24	46%
	(a) Lead (Pb)	g	50	41	-17%	75	50%	50	41	-17%	74	50%
	(a) Methane (CH4)	g	22,492	18,770	-17%	33,659	50%	15,586	13,015	-16%	23,300	49%
	(a) Nitrogen Oxides (NOx as NO2)	g	32,983	27,520	-17%	49,374	50%	58,653	48,911	-17%	87,879	50%
	(a) Particulates (unspecified)	g	8,682	7,284	-16%	12,876	48%	10,165	8,520	-16%	15,100	49%
	(a) Sulfur Oxides (SOx as SO2)	g	40,418	33,744	-17%	60,442	50%	22,814	19,073	-16%	34,035	49%
Water Emissions	(w) Ammonia (as N)	g	1,008	840	-17%	1,512	50%	347	289	-17%	521	50%
	(w) Dissolved Matter (unspecified)	g	1,079	904	-16%	1,602	49%	1,023	858	-16%	1,519	48%
	(w) Heavy Metals (total)	g	2.4	2.0	-17%	3.6	50%	2.4	2.0	-17%	3.6	50%
	(w) Oils (unspecified)	g	3,155	2,629	-17%	4,732	50%	1,352	1,127	-17%	2,028	50%
	(w) Phosphates (as P)	g	0.10	0.09	-17%	0.16	50%	0.10	0.09	-17%	0.16	50%
	(w) Suspended Matter (unspecified)	g	31,324	26,104	-17%	46,986	50%	10,805	9,004	-17%	16,206	50%
Solid Waste	Waste (municipal and industrial)	kg	32	27	-17%	48	50%	32	27	-17%	48	50%
	Waste (total)	kg	574	480	-16%	856	49%	280	235	-16%	415	48%
Energy Consumption	Total Primary Energy	MJ	383,286	319,582	-17%	574,400	50%	309,866	258,398	-17%	464,270	50%

* (r): Raw material in ground, (a): Airborne emissions, (w): Waterborne emissions