ULSAB-AVC (Advanced Vehicle Concepts): A Solution for Today (Engineering, Life Cycle Inventory, and Cost Analyses)

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ABSTRACT

Historically, the demand for automobiles that reduce environmental impacts and the demands for improved vehicle safety and cost effectiveness have been in conflict. However, results of the ULSAB-AVC (Advanced Vehicle Concepts) program, the most recent global steel industry initiative, show that all of these challenging demands can be met simultaneously. The goal of the program was to reduce the weight of auto body structures and to improve fuel economy, while maintaining vehicle performance, safety, reliability, and affordability.

The ULSAB-AVC project creates a complete conceptual design for a steel-intensive, energy-efficient, safe and affordable mid-size sedan. Gasoline and diesel powered models were designed to achieve fuel efficiencies of 52 mpg and 68 mpg, respectively, for the U.S. driving cycle. The mid-size sedan concept met stringent 2004 crash safety requirements in simulated crash tests, with the potential to achieve a quadruple "Five-Star" crash safety rating, the highest rating possible in North America and Europe. This was accomplished using existing off-the-shelf technology augmented with innovative designs, advanced steels, and manufacturing techniques. With high-volume manufacturing of 225,000 units per year, the ULSAB-AVC automobile would cost no more to manufacture than comparable family sedans.

The ULSAB-AVC automobile offers an environmentally responsible automotive design solution that can be implemented using currently available technology and existing infrastructure. This paper highlights results of the concept engineering, life cycle inventory, and cost analyses.

Introduction

Automotive manufacturers are faced with the challenge to reduce the environmental impact of the automobile while meeting increasingly stringent crash safety requirements and maintaining affordability. Significant environmental improvements can only be achieved by implementation of an environmentally responsible solution across a large sector of the automotive fleet and therefore, must meet the safety, reliability, and affordability requirements expected by consumers.

Design solutions proposed to date (such as vehicles designed in the US PNGV Program) have achieved impressive fuel economies but have not fully addressed high volume manufacturability, reliability, affordability and crash safety. These solutions incorporate far-reaching technologies still in their infancy. Implementation of these solutions, on a scale necessary to achieve significant environmental improvements, requires revolutionary developments to meet the affordability and reliability requirements combined with daunting capital investments to develop the infrastructure necessary to support vehicle production, operation, and disposition. Consequently, many of these solutions are long-term propositions, at best.

The ULSAB-AVC program is the most recent global steel industry initiative to provide steel-based solutions to the challenges of reducing the environmental impact of automobiles while improving safety and maintaining affordability. Two concept vehicles were designed and engineered by the ULSAB-AVC consortium with their contractor, Porsche Engineering Services, Inc. of Troy MI USA: a North American mid-size vehicle which referenced the PNGV (Partnership for a New Generation of Vehicles) program targets (shown in Figure 1), and a European C-class vehicle which referenced the EUCAR (European CO_2 reduction program) requirements. Both vehicles rely on existing technology and infrastructure for automotive production, operation, and recycling, and could be implemented within the normal product development time frame of a new vehicle. This paper presents the engineering, cost and life cycle inventory analyses of the ULSAB-AVC PNGV-class vehicle.

Figure 1. ULSAB-AVC PNGV-Class Mid-Size Sedan

Source: Porsche Engineering Services, Inc. [1]

Engineering Analysis

The targets of the PNGV program included the development of a five passenger sedan with a high manufacturing volume that achieves up to three times current vehicle fuel economy, meets 2004 crash safety requirements, at no additional cost compared to current mid-size sedans. All PNGV program concept vehicles developed relied on steel alternative materials for the major structural components and a diesel/electric hybrid power train. Although the PNGV program was cancelled at the end of 2001, in part due to projected vehicle costs exceeding the target by over 100%, the program goals are still relevant today. The steel industry felt it necessary to demonstrate a steel based solution to this challenge to maintain the long-term viability of steel in automotive design.

The ULSAB-AVC program met the PNGV targets by providing a concept design of a steel intensive five-passenger sedan that achieves 52 mpg with the gasoline-engine variant and 68 mpg with the diesel-engine variant, capable of meeting stringent 2004 crash requirements at no additional cost compared to current vehicles in production. The design utilizes standard safety equipment of front and rear air bags, safety belts for all passengers and ABS braking, as well as features generally expected by consumers such as air-conditioning, power locks and windows, radio and folding back seat. The ULSAB-AVC program engineering report [1] provides complete concept design details including body structure and chassis design, crash analysis, powertrain, aerodynamics, NVH, performance, packaging, and vehicle styling. The findings of three prior steel industry initiatives were incorporated into the ULSAB-AVC automobile design, which demonstrated a 25%, 42% and 34% mass savings for the Body [5,6], Closures [7,8] and Suspension [9] systems, respectively, over conventional systems, at no additional cost. The mass savings of these programs, as well as the current ULSAB-AVC program were accomplished utilizing high strength steels, advanced manufacturing, and innovative design. As will be discussed, mass reduction is a factor influencing the environmental impact with regard to source reduction, fuel economy, and disposition.

The use (or driving) phase is the major contributor of environmental impact during the vehicle service life (see Figure 9 in the Life Cycle Inventory section) and is closely related to fuel efficiency, which is a function of rolling resistance, climbing resistance, acceleration resistance, aerodynamic drag, powertrain efficiency and vehicle mass. For the purposes of the ULSAB-AVC program and the calculated fuel efficiency, the rolling resistance, climbing resistance, and acceleration resistance are considered to be conventional values of current production vehicles.

A vehicle's aerodynamic drag has a significant influence on its fuel consumption and CO_2 emissions. Aerodynamic drag is a function of the frontal area of the vehicle and the drag coefficient. The frontal area of the ULSAB-AVC automobile is dictated by the packaging study, which considers the requirements of seating two 95th percentile sized passengers in the front and three 95th percentile passengers in the rear. Using computer modeling, Porsche Engineering Services predicts a drag coefficient that meets the target of 0.25 and uses it in fuel economy calculations. In designing a vehicle, significant improvements are made using wind tunnel developments. Figure 2 compares the ULSAB-AVC target to current production comparison vehicles as well as the PNGV concept vehicle, which demonstrates that a drag coefficient of 0.25 is a conservative number of what can be achieved in a detailed test program.

Figure 2. Drag Coefficient Benchmark

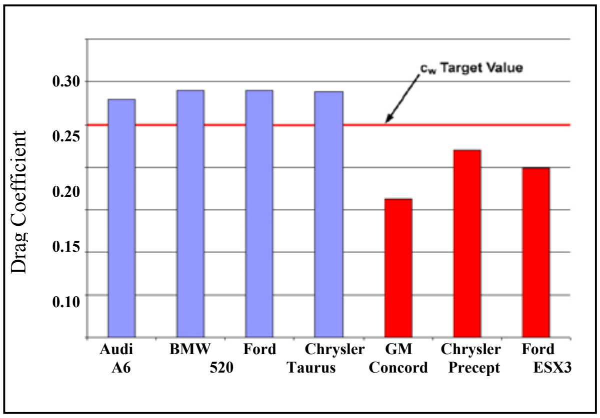
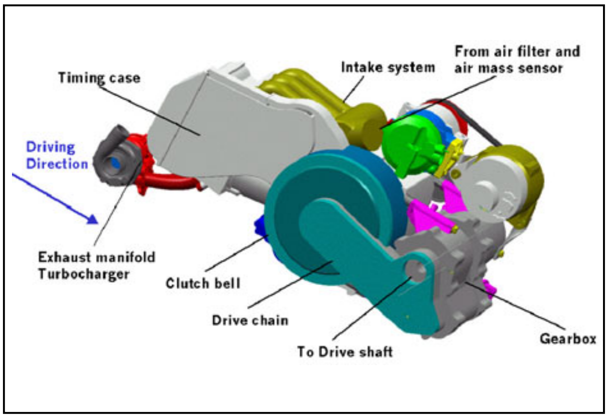


Figure 3. Diesel Powertrain & Auxiliaries



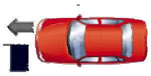
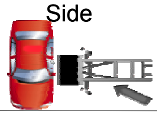
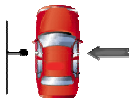
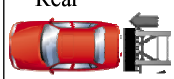
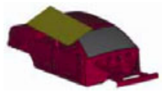
Source: ULSAB-AVC Engineering Report (Porsche Engineering Services) [1]

One of the most important contributors to fuel economy is the powertrain. The affordability target of the program eliminated the consideration of hybrid systems, such as internal combustion engines or fuel cells combined with an electric motor. The system had to meet the requirements of package space, affordability, torque and power, CO_2, and mass. Calculations predicted that a conventional 1.2L gasoline or diesel engine combined with a manual transmission would meet fuel consumption, CO_2 emission, and acceleration requirements. A VR-3 (three cylinder) engine layout was selected to meet the packaging constraints. The chain driven manual transmission selected is augmented with an electronic shifter allowing the efficiencies of a manual transmission as well as the convenience of automatic shifting. Although the specific powertrain, as shown in Figure 3, is not in production today, the VR engine, chain drive transmission, and electronic shift are all represented in current production vehicles. Again, the concepts are off-the-shelf and could be implemented in a new engine and vehicle program.

Another important factor in fuel economy is vehicle mass. The steel body, closures, and chassis comprise 50% of vehicle mass. Hence, any discussion of vehicle mass must start here. The body has several functions in the performance of a vehicle. It is the structure to which every other component attaches. The stiffness of the body in bending and torsion is a key feature of a vehicle's ride and handling characteristics. In crash safety the body is the first and last line of defense, absorbing the energy of a crash event in controlled collapse of the structure while maintaining the integrity of the passenger compartment. Government regulation, industry insurance groups as well as internal marketing strategies are increasing the expectation for improved crash safety, placing greater demand on the body structure. Figure 4 compares the crash targets of the year 2000 to those anticipated for 2004 and indicates the relative increased severity of crash events. Today, designers are focused on the challenge of meeting stringent crash safety requirements while avoiding significant increases in cost and mass of the vehicle structure. ULSAB-AVC provides a solution to this with the utilization of Advanced High Strength Steels (AHSS), which absorb more crash energy than conventional materials and, combined with innovative design, enable a designer to meet future crash requirements without increasing vehicle mass or costs.

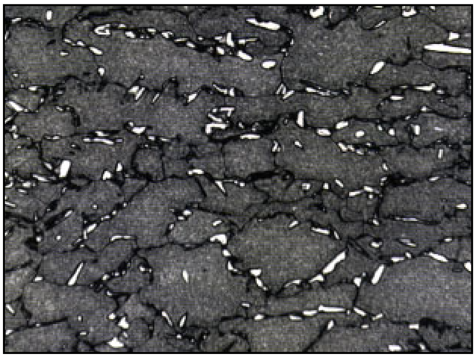
Over the past decade in an effort to reduce vehicle mass, designers have been substituting mild steel with High Strength Steels (HSS) as an affordable means of achieving mass reduction and crash safety improvements. However, conventional HSS, comprised of a single phase of the iron lattice, increases its strength at the expense of ductility. This restricts the complexity of the part that can be stamped and therefore inhibits full utilization of HSS in automotive applications. Advanced High Strength Steels are a completely new material. The new

Figure 4. Increasing Crash Safety Requirements

Crash	Crash 2000	Crash 2004	Relative Severity of Crash Event
Full Frontal 	USNCAP 35 mph Full Frontal Pass Test Criteria	USNCAP 35 mph Full Frontal 5-Star	* **Same Energy** * **5 star Criteria**
Offset 	AMS 34 mph 50% Offset Intrusion < 150mm	Euro NCAP 40 mph 40% Offset Intrusion < 150 mm	* **38% More Energy** * **Same Intrusion**
Side 	EEVC Side 31 mph 950 kg trolley Intrusion <8m/sec	SINCAP 38.5 mph 1370 kg trolley Intrusion < 7m/sec	* **122% More Energy** * **Reduced Intrusion**
Side 	Event Not Considered	Side Pole 20 mph Intrusion < 8m/sec	**No Equivalent Event**
Rear 	US FMVSS 301 35 mph 4000 lbs trolley Intrusion < 120mm	US FMVSS 301 35 mph 4000 lbs trolley Intrusion< 50mm	* **Same Energy** * **60% less intrusion**
Roof Crush 	FMVSS 216 (Rollover) 1.5 x Veh. Wt. Intrusion <127mm	Roof Crush (Roll Over) 2.5 x Veh. Wt. Intrusion < 127mm	* **66% More Energy** * **Same Intrusion**

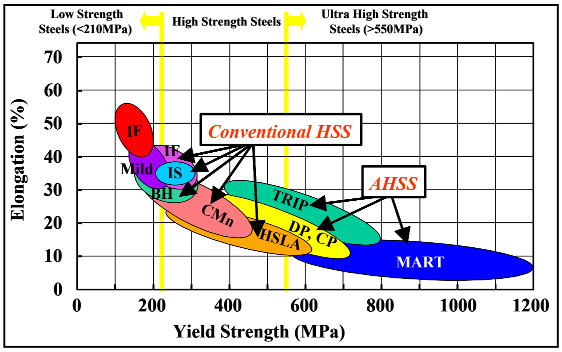
Source: SAE2002-01-0044 ULSAB-AVC Materials [3] steels are composed of several phases: ferrite, martensite, austenite and bainite. These phases are unique materials in their own right with vastly different material properties, and when combined together in AHSS, as shown in Figure 5, they create a composite material, where the synergistic interaction of the phases creates mechanical behavior that exceeds the performance of conventional steel grades. Figure 6 presents the properties most important to automotive steels: strength and ductility. The commodity grades of sheet steel, to the left, have excellent ductility, and have defined vehicle architecture for several decades. However, these grades lack the strength required to improve structural efficiency. The conventional high strength steels, in the center, can be used to improve crash energy management and structural performance, but lack the ductility to produce the complex geometries required for vehicle design. Advanced High Strength Steels are engineered products that provide a wide range of strength levels with significantly improved ductility.

Figure 5. Composite Steel Microstructure



Source: SAE Paper 2001-01-3041 [10]

Figure 6. Steel Grade Elongation vs. Strength



Source: SAE Paper 2001-01-3041 [10]

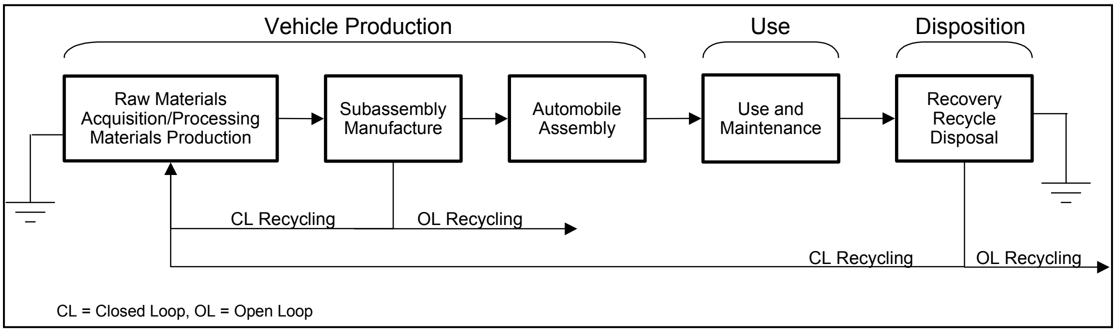
The utilization of AHSS in the ULSAB-AVC automobile provides a body structure and closures that meet the 2004 crash requirements at no additional cost relative to conventional body structures while achieving a 20% mass reduction compared to comparable production bench mark vehicles. The mass reduction of the body translates into mass reduction of additional vehicle systems and an overall reduction in vehicle mass. The ULSAB-AVC PNGV-gas engine vehicle weighs only 998 kg and the diesel engine variant weighs 1031 kg, which is 34% and 31% lighter, respectively, than the USAMP equivalent size current production vehicles discussed in the LCI portion of this paper and slightly less in mass relative to the PNGV solutions that incorporated alternative materials as documented in industry trade journals. These comparison vehicle are not designed with structures capable of meeting the 2004 crash requirements

The concepts presented by the ULSAB-AVC automobile design can be achieved using conventional off-the-shelf technology and, consequently, fit into the existing manufacturing infrastructure currently in place to support the high volume production of automobiles. The powertrain, interior, electrical, and fuel systems all draw upon existing technology in vehicles produced today. Advanced High Strength Steels are currently used in many high volume manufactured vehicles, with increasing amounts being utilized in each new vehicle launched in North America.

Life Cycle Inventory Analysis

A life cycle inventory (LCI) analysis was conducted to evaluate the environmental performance of the ULSAB-AVC PNGV-class automobile. The inventory quantifies the inputs and outputs of each life cycle stage specific to the automobile, as shown in Figure 7. They include material production (resource extraction and processing); subassembly manufacture; auto assembly; vehicle use and maintenance; and material recovery, recycling and disposal. Throughout the analysis, the life cycle stages are grouped into three phases: Vehicle production (the first three life cycle stages); Use (operations, maintenance and repair); and Disposition (material recovery, recycling and disposal). The LCI is based on a 193,000 km (120,000 miles) service life. The data categories measured for each life cycle phase include resource consumption (e.g., coal, iron, natural gas), energy consumption (e.g., fossil, process etc.), air pollutant emissions (e.g., CO_2, NO_X, PM etc.), water pollutant emissions (e.g., dissolved matter, heavy metals, oils etc.), and solid waste production.

Figure 7. Major Life Cycle Stages for the ULSAB-AVC Automobile



Source: Center for Sustainable Systems [4]

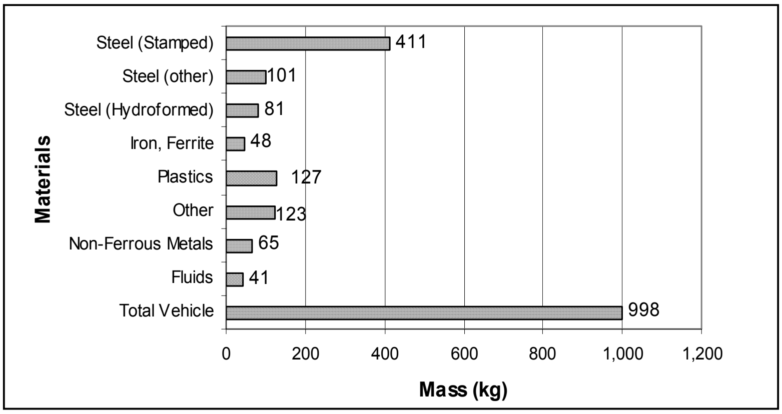
The ULSAB-AVC LCI analysis is based on the methods, model and data from the 1999 study by the United States Automotive Materials Partnership (USAMP), a consortium within the United States Council for Automotive Research (Keoleian et al. 1998; Sullivan et al. 1998). The USAMP research team developed a LCI of a six-passenger generic vehicle (1500 kg), namely, a synthesis of the 1995 Chrysler Intrepid, GM Lumina and Ford Taurus. A LCI software model was developed, using TEAM™ software[1], to compile and compute the LCI of the generic vehicle for the USAMP study. This model was modified to represent the ULSAB-AVC PNGV-gas engine vehicle (998 kg) for each life cycle phase and also modeled the use phase of the PNGV-diesel engine variant (1031 kg). The modifications included the use of the Porsche parts list for material and mass allocation, incorporation of updated steel LCI data from the International Iron and Steel Institute (IISI), and the use of EU4 standards (2005) for vehicle emissions. The material composition of the ULSAB-AVC PNGV-gas engine vehicle is shown in Figure 8.

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, modeling 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

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

production burdens – energy, emissions and resource requirements – will decrease. This is due to expectations that the scrap rate would be significantly lower than 40%, which is the scrap rate of stamping, the process that would be partially displaced by hydroforming. This would result in less material required to manufacture the same components, and in some cases, fewer parts.

Figure 8. Material Distribution for the ULSAB-AVC PNGV-Gas Engine Vehicle



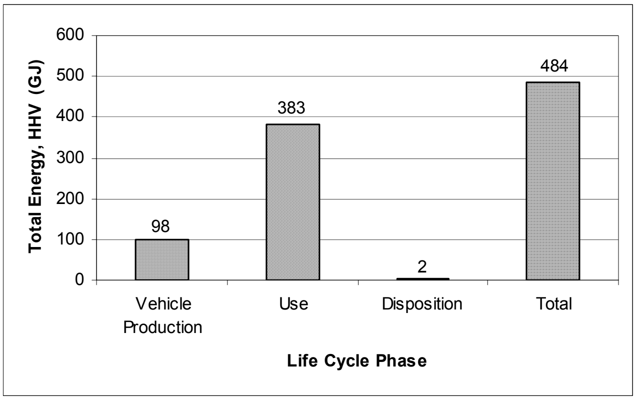
Source: Center for Sustainable Systems [4]

Select life cycle inventory results are presented here. A more extensive set of results will be reported in forthcoming publications (JSAE IBEC 2003). The ULSAB-AVC PNGV-Gas Engine vehicle consumes 484 GJ of primary energy 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 9. This portion is overwhelmingly attributed to the fuel consumed during vehicle operation. Total life cycle CO_2 air emissions for the ULSAB-AVC PNGV-gas engine vehicle follow a similar trend to total energy consumption.

Although the USAMP generic vehicle is not functionally equivalent to the ULSAB-AVC vehicle, both are mid-sized sedans which can be referenced with the PNGV program goals. The USAMP generic vehicle energy consumption results are cited for reference. The USAMP vehicle consumes a total of 995 GJ of energy throughout its life cycle. Most of the improvement in energy efficiency for the ULSAB-AVC PNGV vehicle is seen in the Use phase. In particular:

- PNGV-gas consumes **51%** less energy over the total life cycle.
- PNGV-gas consumes **22%** 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.

Figure 9. Total Life Cycle Energy Consumption for the ULSAB-AVC PNGV-Gas Engine Vehicle



Source: Center for Sustainable Systems [4]

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

Affordability – Manufacturing

Porsche Engineering Services, Massachusetts Institute of Technologies and the steel producers conducted a detailed manufacturing cost assessment for the ULSAB-AVC program as detailed in SAE 2002-01-0361 [3]**.** In this paper affordability measures are divided into three categories: manufacturing (vehicle production), use and end-of-life (disposition).

Thorough knowledge of the manufacturing cost position of the ULSAB-AVC design was necessary to evaluate the implication of changes throughout the vehicle. To understand the elemental costs involved in the production of a modern vehicle is an enormous undertaking, requiring explicit vehicle design details and a clear understanding of manufacturer-supplier relationships. Being a concept vehicle, this information was unavailable to the ULSAB-AVC design team. Hence, the cost assessment could only be as detailed as the design information provided. Many subsystems of the vehicle, notably the vehicle body structure and closures, were designed in great detail to fully demonstrate the feasibility of the approach. Cost assessment of these subsystems involved modeling component fabrication and assembly costs. Other subsystem costs, considered largely unchanged from today's standard vehicles, were estimated using industry cost data. Analysis of the body structure and closures relied on the modeling approach to derive fabrication and assembly costs for each component. The remaining vehicle component costs were estimated using generic industry data, supplier quotes, and automaker estimates for individual components and vehicle subsystems. Finally, the cost of vehicle paint and general assembly (trim line) processes were estimated, using technical cost modeling principles, assuming industry average data for these activities.

Table 1 compares specific body structure costs and attributes for the ULSAB-AVC body to a conventional body structure. The structural crash targets of ULSAB-AVC require the use of advanced high strength grades and, therefore, more expensive sheet steel. This may lead to an initial assumption that the ULSAB-AVC automobile material costs will be greater than for its predecessor. However, the ULSAB-AVC design applies advanced steel processing techniques, such as laser welded blanks and tubular hydroforming, allowing for part consolidation, as shown in the part count. For example, a conventional vehicle body is comprised of 135 to 200 components while ULSAB-AVC has only 81 components requiring fewer stamping dies, less stamping press time, fewer parts to inventory and assemble into the body structure, all of which contributes to offsetting the increased cost of materials for the structural system. It is this approach that allows for the structural system to meet future crash criteria, while reducing mass, at no extra cost.

Table 1. Comparison of a Conventional Body and the ULSAB-AVC Body

	Conventional Body	ULSAB-AVC Body
Material -%		
Mild Steel	80%	0%
High Strength	20%	20%
Advanced High	0%	80%
Processing - %		
Conventional	95%	43%
Laser Welded	5%	41%
Tubular	0%	16%
$ Material	$369	$468
$ Forming	$282	$213
$ Assembly	$328	$291
$ Total Body	$979	$972
Major Body	135	81
Body	270 Kg	218 Kg
Crash	Yr 2000	Yr 2004

Source: SAE Paper 2002-01-0361 [3]

Table 2. ULSAV-AVC Automobile Manufacturing Costs

ULSAB-AVC Cost	Gas	Diesel
Assembled Body Strucuture	$972	$972
Assembled Closures	$383	$383
Paint	$580	$580
Chassis	$1,760	$1,760
Power Train	$2,241	$2,941
Electrical	$1,288	$1,288
Body(Purchased Parts)	$1,944	$1,944
Assembly	$370	$370
Total Vehicle Cost	**$9,538**	**$10,238**

Source: Porsche Engineering Services, Inc. [1]

Table 2 provides the cost breakdown of the major vehicle subsystems, which were obtained from global tier one suppliers. The cost of the fully assembled ULSAB-AVC automobile ranges from $9,538 for the gas variant to $10,238 for the diesel variant, not more than the cost for vehicles of equivalent sizes on the road today [1]. Affordability is attributed to the use of technology that is currently available and in use.

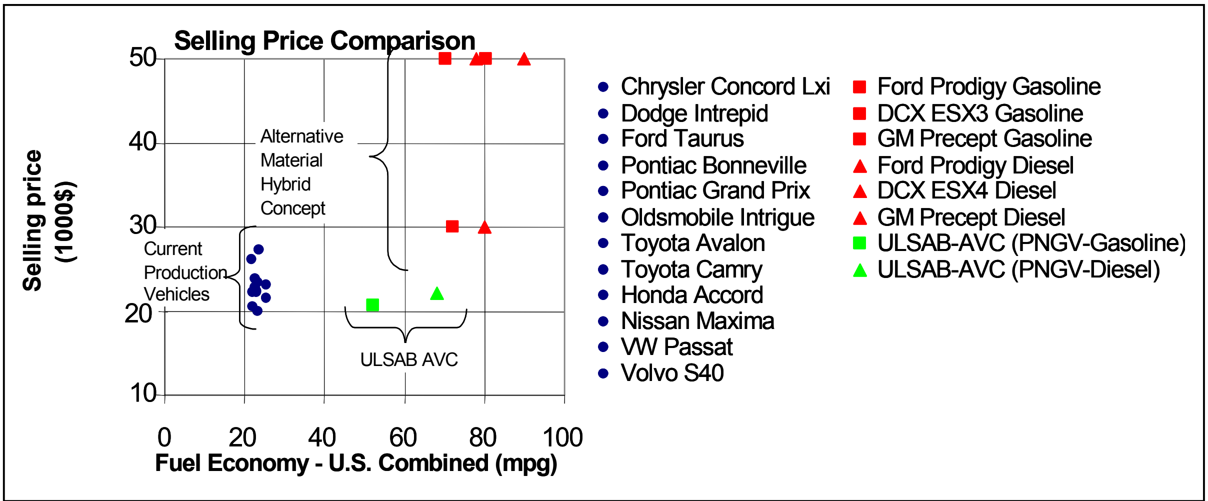
It is difficult to demonstrate the affordability of these manufacturing costs. Manufacturing costs of automakers are closely guarded; hence, data are not available for comparison in the public domain. The approach used to demonstrate affordability by the ULSAB-AVC program is to perform a selling price comparison of the ULSAB-AVC against similarly sized and equipped vehicles. This is accomplished by obtaining an MSRP for ten current production mid-size five-passenger sedans. In addition, estimates of the predicted selling price of three PNGV vehicles are obtained from figures reported in the press. Details of this study are provided in the appendix of the ULSAB-AVC Engineering Report [1].

The selling price of the ULSAB-AVC is then estimated. The retail price accounts for costs attributed to manufacturing logistics, engineering and development, warranty, marketing and sales, automaker overhead and profit, and dealer overhead and profit. Logistics costs are estimated to be between 6 and 8% more than manufacturing costs. Several estimates of the relationship between manufacturing costs and retail price are provided in reports by Argonne National Laboratory, OTA (Office of Technology Assessment) and Borroni-Bird [2]. Because automakers have different overhead cost structures and different strategies for pricing, it was expected that overhead estimates would range and indeed, the reference data indicates that overhead is in the range of 50% to 100% of the manufacturing and logistics costs.

Based on the information available, a conservative estimate for the selling price is based on 8% logistics costs and a conservative 100% overhead. This calculation provides a conservatively high selling price of \$20,500 for the ULSAB-AVC gasoline variant and \$22,000 for the diesel variant. Figure 10 compares the estimated selling price of the comparison vehicles with the fuel economy. It is noted that ULSAB-AVC utilizes more conventional technology such as steel manufacturing and internal combustion engines. The three PNGV solutions utilize alternative material manufacturing and hybrid powertrains and result in the vehicles being more expensive than current production vehicles of the same class.

Manufacturing affordability is important to auto manufacturers around the world. It is also of utmost importance that eco-efficient vehicles be affordable to the consumer in order to break the current paradigm attached to the traditional automotive market.

Figure 10. Estimated Selling Price Comparison



Source: SAE Paper 2002-01-0361 [3]

Affordability – In Use

Affordability comes to the consumer in many ways. The first way is through the purchase price, or monthly payment, that a consumer incurs as they determine whether or not an eco-efficient vehicle meets their needs. The second way is through affordability of insurance. Consumers are aware that some of the exotic materials being suggested in order to produce an eco-efficient vehicle will dramatically increase their insurance premiums to compensate for the higher cost of repairs. Finally, it comes through affordability of fuel necessary to operate the vehicle.

Over the past 25 years, consumers have become less concerned about total vehicle cost, otherwise known as the selling price, and much more concerned with the monthly payment. As most consumers have monthly household budgets, they can manipulate the timeframe of a car loan to reduce the monthly cost of repayment. It is important to remember, however, that financial institutions need to recover their capital outlay in a reasonable period of time. Typically, in the case of an automobile, this reasonable period of time ranges between 36 and 48 months and can be extended to 60 months.

In today's automotive scheme of low interest rate availability, a $20,000 car with a $4,000 down payment, as compared to a $40,000 with an $8,000 down payment, can burden a family's monthly cash flow rather dramatically at a very economical 4% interest rate as shown in Table 3 below.

Table 3. Monthly Payment Calculations

Loan Period	Loan Value $16,000	Loan Value $32,000
36 months	$472.32	$944.64
48 months	$361.28	$722.56
60 months	$294.72	$589.44

Source: Mathematical Equation Based on Interest Rates (TheSteelAlliance)

As can be seen in Table 3, an eco-efficient vehicle costing $40,000, even with 20% down, will put the average family in North America under tremendous financial pressure if they choose to be environmentally responsible. On the other hand, if all cars in the future are priced at this exorbitant rate, more and more families will choose to remain in their current less efficient vehicles.

This is why the ULSAB-AVC is so revolutionary. Not only does the ULSAB-AVC PNGV-gas engine vehicle deliver the fuel consumption savings of 52 mpg, almost double that of the current comparable vehicles (Lumina, Concorde, Taurus), but it can also be manufactured at an equivalent manufacturing cost of $9,500. With this in mind, consumers will be able to afford to purchase this vehicle. As more and more consumers move from their cars of the 20th century into their cars of the 21st century, dramatic savings will materialize for the environment without penalizing the economy and most importantly, consumers' budgets.

The cost of insurance reflects the cost of repairs, and it is important to point out that the cost of repairs reflects the labor necessary to replace or repair the damaged part. Currently, the infrastructure for repairing slight dents or damage from minor collisions utilizes a well-known infrastructure made up of new and repaired parts. As a result of steel's maturity, virtually all body shops are quite familiar with the techniques needed to repair steel bumpers and doors, to name just a few, and because of steel's cost effectiveness, these new or repaired bumpers and doors can be rejuvenated in a very cost effective manner.

As can be seen with some luxury vehicles, such as the Corvette, repair costs and insurance costs are dramatically higher, as the steel body on this vehicle has been replaced with various other materials. If one were to extrapolate these exotic materials on the over 16 million cars sold in the United States each year, consumers would see dramatic increases in insurance premiums for decades until the infrastructure was in place to supply new and repaired parts for these slight dents or damage from minor collisions. With the above in mind, one can easily see that consumers will choose the vehicle that delivers the most value to their lives, including both the monthly payment as well as the quarterly insurance expense.

Finally, use phase affordability for consumers depends on the cost of fuel. Vehicles in the same class average 27.5 mpg, while the comparable ULSAB-AVC PNGV gas-engine vehicle is projected to achieve 52 mpg. As can be seen in Table 4, this also has a dramatic impact on a family's annual budget.

Table 4. Current vs. ULSAB-AVC Fuel Calculations

Model **Type**	Miles Per **Gallon**	Miles Per **Year**	Cost Per **Gallon**	Total Cost Per Year
Current	27.5	12,000	$1.50	$654.55
AVC	52.0	12,000	$1.50	$346.15
Difference	+24.5	0	0	$-308.40

Source: Mathematical Equation Based on Interest Rates (TheSteelAlliance)

It is important to point out that these savings would only help this family to pay approximately $25 more per month of a monthly car payment. This will not be necessary for the AVC vehicle, and these savings can be spent on other family needs. Just as importantly, over the course of one year (12,000 miles), 205.6 gallons of gasoline are saved on each Advanced Vehicle Concept vehicle put on the road. Therefore, if 100% of the approximately 16 million vehicles purchased each year move to the Advanced Vehicle Concept, the United States would save almost 3.3 billion gallons of gasoline, resulting in a decrease of 32 million tons of CO_2.

Affordability – End-of-Life

Environmental effects do not stop with the use of a vehicle; it is important to consider what will happen to the vehicle once it reaches the end of its useful life. The Steel Recycling Institute has done an in-depth analysis of the recyclability of automobiles in North America. Currently, as can be seen in Table 5, 80% of the curb weight of vehicles is recycled (including tire derived fuel), with steel as the primary driver.

Table 5. End-of-Life Recycling Rate

Material	Pounds Per Vehicle	Recycling Rate %
Steel	2,324.00	99.90
Rubber	133.74	90.00
Aluminum	144.25	73.75
Copper and Brass	41.75	49.75
Powder Metal Parts	20.50	25.00
Zinc Die Castings	19.25	25.00
Lubricants and Fluids	180.00	10.00
Other Materials	89.00	15.00
Plastic	212.00	0.00
Glass	85.00	0.00
TOTAL	3,251.75	80.30

Source: American Metal Market

The infrastructure in place to recycle end-of-life vehicles is mature and primarily made up of auto dismantlers and auto shredders. This existing infrastructure understands that recycling does not happen unless someone is there to buy the products that are produced during the recycling process. As can be seen in Table 5, this combined industry has developed techniques, such as magnetic separation, to ensure that virtually 100% of the steel is recycled. This is important, as the steel industry's number one raw material is old steel. In addition, the end-of-life infrastructure system for some of the materials currently being considered as a replacement for steel have a long way to go in order to reach the efficiency of the steel end-of-life infrastructure system. In summary, the automobile is the most recycled product in the world today, primarily due to the highly developed end-of-life steel infrastructure system.

Conclusion

The ULSAB-AVC automobile was created as a complete conceptual design. Results of simulations confirmed that this approach led to steel-intensive, energy-efficient, safe and affordable mid-size sedan. Gasoline and diesel powered models were designed to achieve fuel efficiencies of 52 mpg and 68 mpg, respectively, for the U.S. driving cycle. The mid-size sedan concept would also meet stringent 2004 crash safety requirements, with potential to achieve a quadruple "Five-Star" crash safety rating, the highest rating possible in North America and Europe. The design utilizes standard safety equipment of front and rear air bags, safety belts for all passengers and ABS braking, as well as features generally expected by consumers such as air-conditioning, power locks and windows, radio and folding back seat.

The demands for improved vehicle safety and cost effectiveness, and the demand for eco-efficient automobiles have been thought to be conflicting in nature. However, results of the ULSAB-AVC program, the most recent global steel industry initiative, show that all of these challenging demands can be met simultaneously. This has been accomplished using existing off-the-shelf technology augmented with innovative design and advanced steels and manufacturing techniques. With high-volume manufacturing of 225,000 units per year, the ULSAB-AVC automobile would not cost more to manufacture than comparable family sedans. The ULSAB-AVC automobile concepts offer an environmentally responsible automotive design solution for today that can be implemented using currently available technology and existing infrastructure while improving safety and maintaining affordability.

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