A special supplement produced by the Aluminum Association's Auto and Light Truck Group

Aluminum in Autos

Driving Toward a Sustainable Environment

Energy and the environment are dominant concerns today. Growing concentrations of carbon in the atmosphere and diminishing petroleum stocks have focused efforts on policy and technological solutions.

The automotive fleet represents a significant source of carbon. As such, reducing vehicles' fuel consumption and emissions are essential to combat climate change and reduce our dependence on foreign oil.

Enter aluminum.

Aluminum: Sustainable Solution for Today

Since the onset of the first "oil crisis" in the early 1970s, high-strength, low-weight aluminum technologies have been used increasingly by automakers to reduce fuel consumption and, by extension, exhaust emissions. For the past 33 years, North American automakers have increased their usage of aluminum every single year—a remarkable record and a testament to aluminum's versatility across a range of automotive applications.

By 2000, aluminum had passed plastic as an automotive material in use worldwide (as measured by average weight per vehicle) and, in 2006, it overtook iron. Aluminum's continued momentum in market penetration is projected to continue for the foreseeable future.

Perhaps someday technology such as electric, hybrid-electric, or hydrogen-powered fuel cell vehicles will provide a clean, low-cost, energy-efficient mode of transport. If and when that happens, aluminum will, without a doubt, play a strong role in the design of these vehicles. That's because aluminum can be used to offset the added weight of the powertrains and battery packs that these vehicles carry. In the meantime, aluminum has an invaluable role to play in the design of lighter, conventionally powered vehicles that minimize both the consumption of petroleum-based products and the emissions associated with their use.

Photo: Audi

Volkswagen AG Chairman Ferdinand Piech first came up with the idea for an aluminum-bodied Audi after noticing environmental degradation while driving through Germany's Black Forest. Studies showed auto emissions to be part of the cause.

As noted in a new study produced by the International Aluminium Institute (IAI), in cooperation with the Aluminum Association and the European Aluminium Association, *Improving Sustainability in the Transport Sector Through Weight Reduction and the Application of Aluminum*, the use of aluminum in reduced-weight vehicles offers significant environmental benefits not only during the vehicle's operational stage, but also at the end of its useful life. Aluminum's ability to be recycled with great efficiency—during which it uses only 5 percent of the energy required by primary aluminum production—provides "cradle to cradle" benefits, rather than merely "cradle to grave."

Audi, Aluminum, and Sustainability

It was on a drive through southwest Germany's fabled Black Forest when Ferdinand Piech first had his vision for aluminum-intensive vehicles. The region, famous for its cuckoo clocks, wines, and schnapps, had suffered serious environmental deterioration, which studies showed was the result of auto emissions and industrial pollution.

Piech, the chairman of Volkswagen AG as well as Volkswagen's Audi unit, would see his vision come to fruition in 1994 with the introduction of the world's first mass-produced all-aluminum car, the Audi A8. The company has now sold roughly 300,000 all-aluminum cars.

The A8's structural foundation is an aluminum spaceframe that is 40 percent lighter than a comparable steel frame. Integrated into the spaceframe are aluminum body panels. Adding to the A8's revolutionary advances in aluminum construction are suspension components that further improve response, ride quality, and handling performance.

The study quantifies both the primary energy and greenhouse gas savings realized from lightweighting specific vehicle components based on a life-cycle assessment methodology. Although the report tabulates these savings for passenger vehicles and light trucks, it notes that the model is also applicable to light-duty trucks, commercial road vehicles, buses, ships, and trains.

The study's conclusions? The application of aluminum in passenger vehicles and light trucks manufactured in 2006 will lead to potential savings of approximately 154 million tons of carbon-dioxide equivalent emissions—and energy savings equivalent to roughly 16 billion gallons of crude oil over the life cycle of these vehicles.

IAI's study uses real cases where aluminum and an alternative material could be used in the design of a new vehicle. In each case study, the vehicle manufacturer supplied the respective weights of the component when designed by both materials. Sets of bumper beams, front hoods, engine blocks, and bodies-in-white were all run through this comparison.

The study found that use of an aluminum bumper beam on a European compact vehicle saved 7 lbs. over a high-strength steel beam. Over a 120,000-mile driving cycle, the bumper will reduce greenhouse gas emissions by 19 lbs. per pound of aluminum—or 134 lbs. for the bumper.

Use of an aluminum hood on a U.S. family sedan registered a 52 percent weight reduction (counting both direct and indirect weight savings) over high-strength steel. Over a 120,000-mile driving cycle, the hood will reduce the carbon-dioxide equivalent emissions by 354 lbs.

The study also revealed that each ton of aluminum replacing iron in engine blocks has the potential to save the energy equivalent of over 2,100 gallons of crude oil over the vehicle's life cycle. According to a study released by Ducker Worldwide in 2006, an average of 99 lbs. of aluminum was put into each car and light truck in the form of engine blocks in 2006, resulting in energy savings equivalent to 99 gallons of crude oil per vehicle for this application alone.

IAI notes that, in addition to the direct weight reductions made possible by substituting aluminum for heavier materials, there are additional possibilities for lightweighting. Aluminum-specific fabrication techniques, such as thin-walled, high-strength vacuum die casting and multi-hollow extrusions, can yield design solutions that further reduce a component's weight.

What's more, the reduction of a vehicle's overall weight offers the potential for significant "secondary" weight savings. IAI notes that, when Audi designed its first-generation A8 model, it ultimately chose an all-aluminum body-in-white weighing 543 lbs. over a steel alternative weighing 970 lbs. As a result of its choice, it then could also realize additional weight savings by reducing the size of the engine, fuel tank, etc.

Audi is reported to have realized a further 99 lbs. of such "secondary" weight savings—or 23 percent of the direct weight savings of 427 lbs. As a result of the aluminum design chosen, the overall weight savings compared with the steel design was 526 lbs.

Aluminum's Environmental Advantage

- Each pound of aluminum replacing two pounds of iron or steel in a car can save a net 20 pounds of CO2 emissions over the lifetime of a typical vehicle.
- A 6 to 8 percent fuel savings can be realized for every 10 percent weight reduction by substituting aluminum for heavier steel through appropriate design, resulting in fewer greenhouse gas emissions.
- According to the Environmental Protection Agency, nearly 90 percent of automotive aluminum is recovered and recycled.
- According to Ducker Worldwide, in 2006 about 57 percent of the aluminum content in North America was sourced from recycled (secondary) aluminum, compared with 50 percent in Europe and 63 percent in Japan.

Photo: Jaguar

Bigger + Lighter = Safer

When corporate average fuel economy (CAFE) standards first came into place in the U.S. in the 1970s, the most expedient way to meet the heightened fuel standards was to downsize vehicles. Unsurprisingly, the fatality rate among occupants of these smaller vehicles rose.

In the decades since, aluminum use in vehicles has more than tripled—allowing automakers to reduce weight (or keep it neutral) while adding heavier safety and consumer devices, increasing the size and safety of their vehicles, and improving gas mileage. It has been a successful strategy. For two years running, the nation's fatality rate has been the lowest since the National Highway Traffic Safety Administration (NHTSA) began keeping such records more than 30 years ago.

This points up the difference between "lightweighting" and "downsizing." Viewed another way, this "smart weighting" is crucial to understanding why aluminum vehicles can be engineered to be safer than competing designs. Simply put, a vehicle's size—not its weight—is the better determinant of vehicle safety.

To demonstrate this point, the Aluminum Association commissioned Dynamic Research Inc. to carry out modeling studies to predict crashworthiness and crash compatibility of differently designed SUVs involved in single-car crashes and crashes with other vehicles. A numerical modeling approach was used sampling 499 crashes over six years (1997-2002) that were taken from NHTSA's National Automotive Sampling System Crashworthiness Data System.

Jaguar XK: Sporty *and* Safe

The new aluminum-bodied Jaguar XK makes significant use of castings and extrusions to eliminate the need for many of the joints that would have been used to hold stamped pieces together. The result is a strong, rigid body—31 percent stiffer than the previous steel-bodied XK, according to Jaguar—for improved handling and safety.

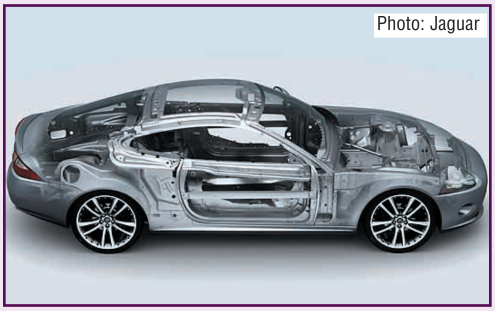


Photo: Jaguar

Adding to the safety of the XK convertible is its state-of-the-art rollover protection. It consists of two aluminum arches recessed behind the rear passenger seats. A solid-state gyro sensor system monitors the vehicle and, in the event of a rollover, deploys the arches above the heads of the rear passengers.

In the front end of the XK, the windshield pillars are supported at the instrument panel with a strong aluminum casting and reinforced with a thick-wall aluminum extrusion in the center. With the hoops in the rear and a reinforced windshield structure in the front, a rollover "cage" is created to protect the heads of passengers wearing seat belts.

One part of the study tested the crashworthiness of an SUV whose weight was cut by 20 percent, via the use of an aluminum-intensive structure and closure panels, but which remained the same size. Another part increased the SUV in size by four and a half inches without changing its weight.

Modeling the crash behavior of each of the vehicles, and the injury potential to the vehicles' occupants in a variety of hypothetical crashes (rollovers, hitting a fixed object, hitting another SUV, and hitting a car), the study determined:

- When the SUV is lightened without extending its front and end crash zones, overall injuries are reduced about 15 percent—with a very significant safety improvement to the other driver, whose injuries are reduced by over half; and
- Slightly increasing the size of the SUV, without changing its weight, has a very significant impact, reducing overall injuries by 26 percent.

The conclusions drawn from these results are that varying both the weight and the size of a vehicle provides societal benefits in terms of reducing energy, injury, and making roads a safer place. Aluminum is a readily available technology that can help automakers produce bigger cars and trucks that consumers demand, without adding weight and without compromising fuel economy or safety.

NHTSA affirmed this size-based approach when it issued its new CAFE standards for light trucks (SUVs, vans, minivans, and pickups) last year. The agency based its new fuel economy standards on a measure of vehicle size called the "footprint," which is achieved by multiplying a vehicle's wheelbase by its track width.

The Performance Edge

Ferrari. Jaguar. Audi. Lotus. All are known for their high performance standards. It's no coincidence they are all high-aluminum-content vehicles. All other factors equal, vehicles made lighter with aluminum accelerate more quickly and require shorter stopping distances than heavier vehicles.

Overall, lightweighting with aluminum increases the vehicle's performance and driving satisfaction and—best of all—maintains or even improves the vehicle's safety and fuel efficiency. Bottom line: aluminum builds a better car.

Photo: Lotus Cars

Lotus' operating philosophy is "performance through light weight." Its Elise model helped to pioneer the use of an ultra-lightweight (150-lb.) epoxy-bonded aluminum tub/chassis.

"Performance Through Light Weight"

Lotus Cars has taken this notion to heart with the announced philosophy of its founder, Colin Chapman: "Performance Through Light Weight." This objective was most clearly realized with the development of its aluminum-chassised Lotus Elise.

During the early days of the original Elise development program, Lotus searched for an appropriate and available chassis technology for its new lightweight sports car. Lotus engineers ultimately settled on a system of aluminum extrusions and modern aerospace bonding techniques to produce a lightweight and extremely rigid structure.

Unveiled in 1995, the groundbreaking epoxy-bonded aluminum tub/chassis represented a breakthrough in sportscar technology.

The structure is an assembly of individually extruded lengths bonded together by epoxy resin adhesive. The adhesive used to bond the chassis achieves exceptional strength with the ability to absorb extreme loads, pressures, and forces that it may encounter under demanding driving conditions.

The bonding of lap joints provides a superior joint to traditionally welded butted joints (with bonded joints, there is no distortion of the material's integrity at the join). Self-pierce rivets further increase the structural integrity through reducing material "peel" in severe impacts.

The resulting vehicle—with its 150-lb. aluminum tub/chassis—weighed in at half the mass of an average family sedan. This reduced weight bestowed the car with an extremely high power-to-weight ratio, allowing it to accelerate from zero to 60 mph in roughly 5.8 seconds.

Ten years later, the Lotus Exige uses the same aluminum chassis technology to keep its overall weight to one ton. Outfitted with a mere 1.8-liter engine, the car's reduced weight nonetheless gives it a power-to-weight ratio of approximately 190 horsepower per ton and acceleration from 0 to 60 miles per hour in 4.9 seconds.

Aluminum Performance Data

Aluminum provides significant performance advantages compared with steel. Among them:

- Aluminum is up to 50 percent lighter than steel, and is proven to be very stiff and safe. Additionally, aluminum cars may have an extended life, given their excellent corrosion resistance.
- Vehicles made lighter and with higher structural stiffness with aluminum accelerate more quickly, provide better stability and response, and require shorter stopping distances than heavier vehicles.
- The design flexibility of aluminum allows automakers to engineer optimum shape and performance for each application.

Aluminum: A Cost-Effective Solution

Cost is an issue in every material decision made on an automobile. When making a material substitution, cost can be viewed as a simple part-by-part substitution, as a manufacturing and product system cost, and/or increasingly as a life-cycle cost.

As original equipment manufacturers (OEMs) apply aluminum to lightweight their vehicles, the focus is increasingly directed toward the system cost and life-cycle cost, since improved driving performance or reduced fuel consumption/emissions is the desired outcome. More and more, OEMs are considering how to fully exploit the weight reduction in one or more parts, thus allowing these weight reductions to create the opportunity for further weight or cost savings in other vehicle components.

Photo: courtesy of www.freeimages.co.uk

Aluminum vs. Steel: A Life-Cycle Comparison

With this in mind, the Aluminum Association sought to conduct an objective analysis of the overall cost of an aluminum-intensive, four-door passenger car versus a conventional steel car, taking into consideration the total manufacturing and operational expenses of both vehicles. The vehicles used conventional internal-combustion-engine powertrain components and were matched in size and performance (i.e., acceleration and driving range).

The Association commissioned IBIS Associates, an independent consulting firm specializing in technical and economic analysis of materials in manufacturing technology, to provide a cost-benefit analysis of material choices in high-volume vehicles and the economics of vehicle design in a future state.

IBIS set out to analyze vehicle costs assuming a high-volume manufacturing system, optimized in terms of manufacturing equipment for both vehicles. Additional costs for manufacturing the aluminum were included in recognition of its forming and joining disadvantages. The aluminum vehicle has more stampings and joints and includes some steel components where particularly beneficial. The powertrain was resized to match the performance requirement, with the cost determined by reviewing a large number of powertrain components of various power or torque outputs.

In practice, due to the common approach of "carrying over" components from model to model, not all sizes might be readily available, but were considered available in the high-production end-state approach.

IBIS Study Findings

The table below shows that the mass on the baseline steel car, 3,441 lbs., would slim down to 2,834 lbs. in an aluminum-intensive car—for a 607-lb. curb weight saving, or about 17.6 percent.

Baseline Steel		Baseline Aluminum	
Mass (lb.)	Cost ($)	Mass (lb.)	Cost ($)
3,441	$14,871	2,834	$14,974

The primary weight savings—including the parts that would actually change to aluminum in this analysis such as body-in-white, the cradle, and aluminum wheels—amount to 359 lbs. However, when this weight is taken out of the structure, there are also secondary weight savings achievable by downsizing other components. For every pound taken out of the structure, another 0.68 lbs. in secondary weight savings can be taken out as well—or a further 244 lbs.

A cost premium of $630 is incurred when manufacturing the aluminum structure and closure panels. However, this cost penalty can be partially offset by secondary cost savings of $527 if the smaller driveline components are chosen.

	Baseline Steel	Baseline Aluminum
Avg. mpg	21.7	25.1
Fuel Net Present Value (NPV) Cost	$9,342	$8,071

This savings in mass and powertrain resizing translates to more than a 15 percent increase in average mileage per gallon. (For a 10 percent mass reduction, the fuel mileage was improved by 9 percent.) The estimated mileage of the vehicle jumps from 21.7 miles per gallon to 25.1 miles per gallon.

Net present value of the fuel was determined by assuming fuel cost at $2.50 per gallon on a vehicle traveling 10,000 miles per year over a 12-year period, resulting in approximately $1,300 in fuel savings over the life of the vehicle.

Considering only the cost to substitute aluminum for steel, with no offsetting considerations, results in a $1.60-per-pound cost premium.

Considering the weight savings of the engine and other components, but not considering any cost savings, results in a $0.92-per-pound cost premium.

Finally, if both the weight and cost savings of the engine and other components are considered, the cost premium comes all the way down to $0.17 per pound for an aluminum-intensive vehicle. This brings the cost to improve the car 1 mpg down to $30.

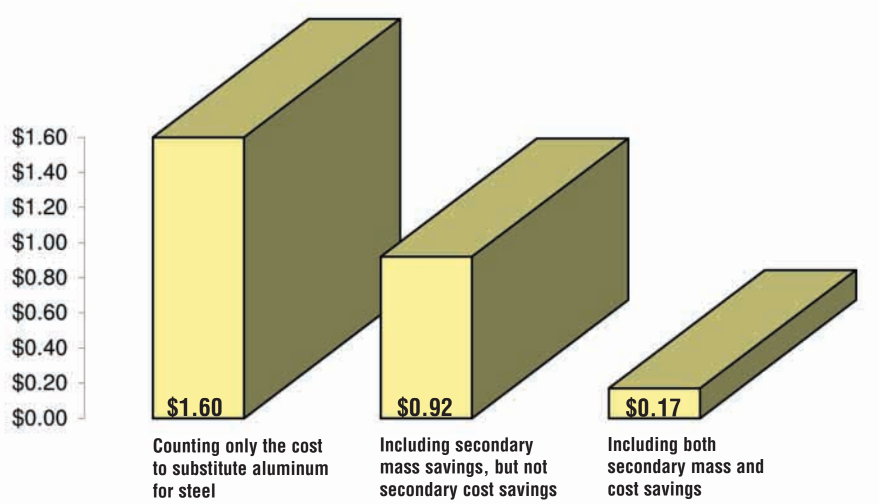
Study Methodologies and Assumptions

The IBIS study was based on an average, mid-sized family sedan that was designed to be an aluminum-intensive, safe, and highly fuel-efficient automobile. It was a component of a new generation vehicle program, in partnership with the Department of Energy. The model car is a real vehicle, not something that was designed specifically for this study.

The stamping and assembly challenges associated with aluminum were not ignored; they were considered a part of the future cost analysis. The capital required to build this type of vehicle was also taken into account. All of the economics associated with the fuel economy were discounted at a 7 percent rate to determine a net-present-value figure for fuel economy. Fuel consumption was calculated on an equivalent acceleration and size basis, so only the mass and the powertrain change with the use of aluminum.

The cost used for aluminum in the study was $1.50 per pound, which was taken directly from the midpoint of the project in order to avoid any future cost assumptions. The cost used for the steel comparison was $0.35 to $0.37 per pound, which was a mid-range price from the time the study began—therefore using neither a peak nor a low value.

Cost Premium (per lb.) of Replacing Steel with Aluminum



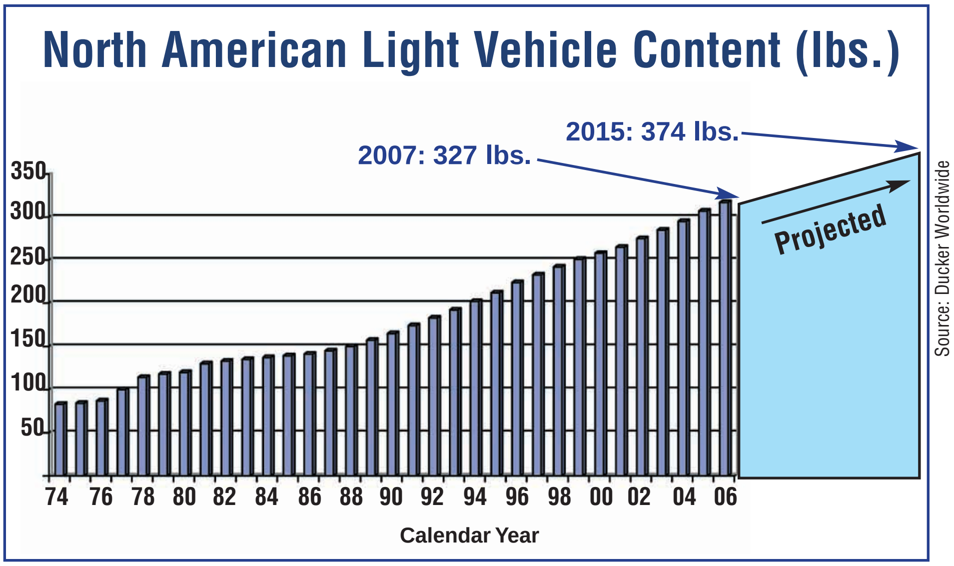
Conclusion

The study demonstrates that cost-effective solutions exist with aluminum-intensive cars and trucks. Under the right conditions, these vehicles can be mass-produced economically. Further, the fuel savings can be significant and a real benefit to the consumer.

As OEMs look for cost-effective solutions to reduce the fuel consumption of their vehicles, lightweight aluminum vehicles with appropriately sized powertrains are a very attractive option.

Auto Aluminum: 30 Years of Continuous Growth

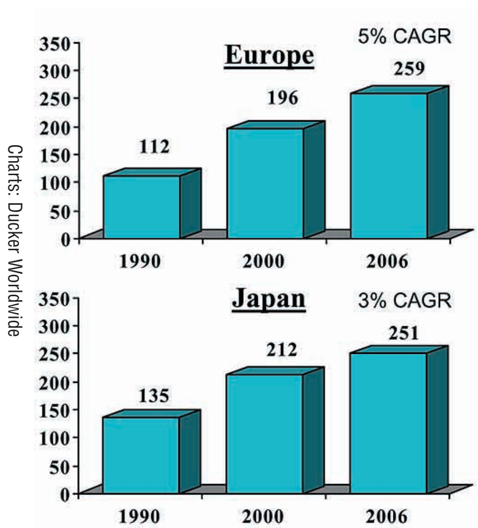
Automotive aluminum is sometimes thought of as a material for use in high-performance vehicles. However, the latest Ducker Worldwide growth report confirms that aluminum is in no way just for high-end cars. Aluminum is now used in today's family cars and trucks at a significant level—from the hoods of the top-selling truck in North America (Ford's F150) to the tailgates of familiar family SUVs. This increased use is a direct result of the safety, environmental, fuel-efficiency, and performance benefits that aluminum offers.



Global Auto Aluminum Use Continues to Spiral

The Ducker study demonstrated that in 2006, for the first time, aluminum eclipsed iron in vehicle content worldwide. In addition, current data shows that aluminum content for autos and light trucks is projected to continue its uninterrupted growth, just as it has year-over-year for the last 33 years. Current projections are that this growth will continue at a rate of approximately 8 to 10 lbs. per vehicle annually, or roughly 3 percent, for the foreseeable future.

Growth in Aluminum Content in European and Japanese Light Vehicles



The Ducker study also found that regardless of the market (North America, Europe, Japan), light-vehicle aluminum content has essentially doubled between 1990 and 2006.

In North America, automakers have reduced vehicle weight by adding aluminum content to the powertrain, whereas in Europe, with the prevalence of diesel engines and manual transmissions, the focus has been on adoption of aluminum in bodies-in-white, closures, instrument panels, and heat shields.

Aluminum is increasingly the material of choice for automakers when substituting for steel, and forecasts predict that this will continue. In 2006, the use of aluminum in light vehicles amounted to 12 billion lbs.—or over 25 percent more aluminum than was used in the year 2000. Also of note: the over 580 million lbs. of aluminum sheet incorporated into closures, instrument panels, structures, and body components represents a 100 percent increase over the aluminum requirement in 2002.

In 2006 there were over 100,000 vehicles built with complete aluminum bodies. The study also demonstrated that the amount of aluminum in vehicles is not only increasing, but also spreading across market segments.

Ducker Survey Method

The data was collected on an OEM, platform-by-platform, and product-by-product basis. Ducker conducted direct interviews with the purchasing and engineering personnel at the OEMs, tier suppliers, and aluminum companies directly involved in making decisions to utilize aluminum for each component. Nearly 100 components, 20 countries, and 40 OEMs were studied for this project.