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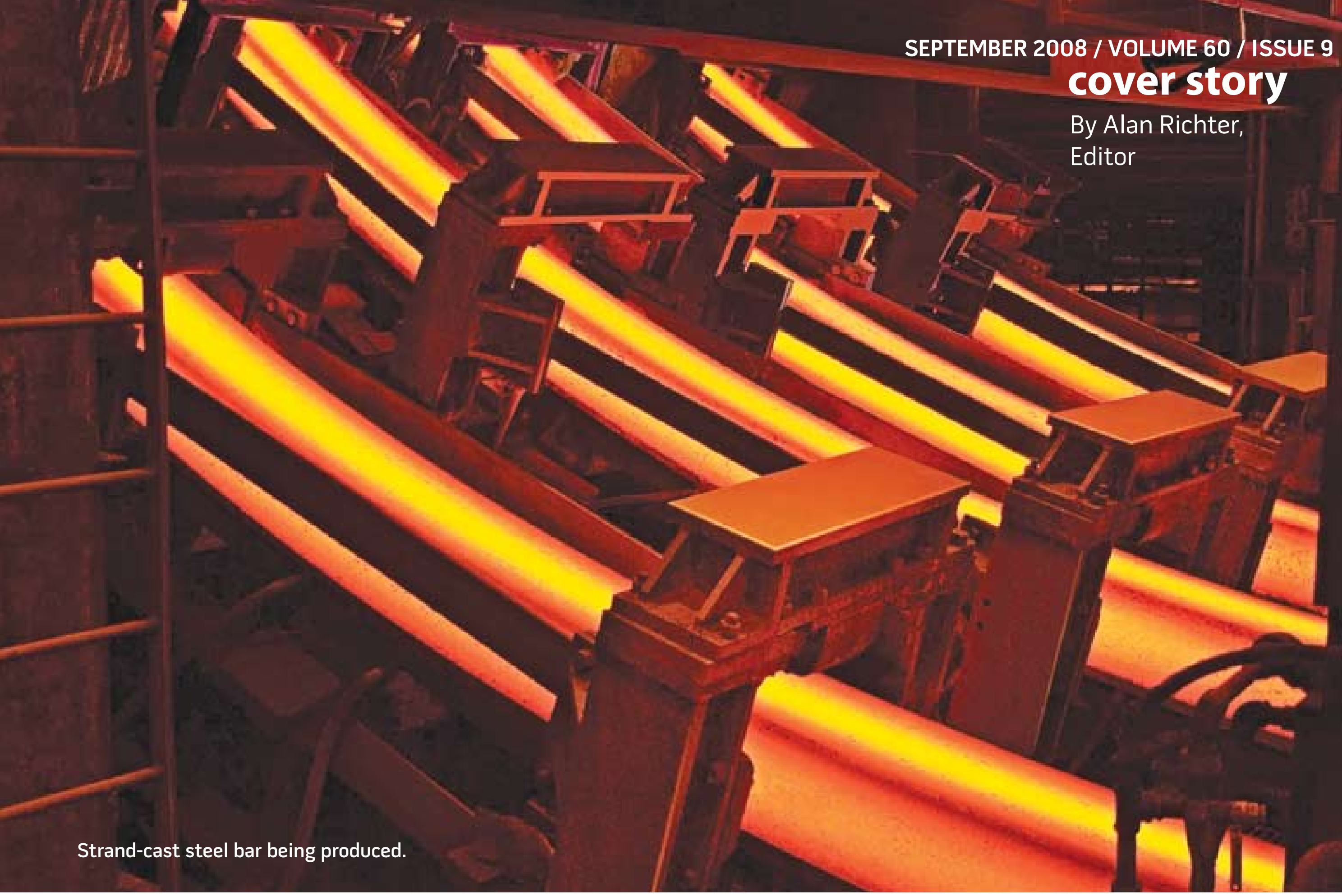
cover story

By Alan Richter, Editor



Strand-cast steel bar being produced.

American Iron and Steel Institute

'Smart Weighting'

Auto manufacturers are 'lightweighting' vehicles by incorporating more aluminum and microalloy steel components.

With gasoline prices near record highs, U.S. consumers are fleeing heavy vehicles faster than automakers can increase production of smaller cars, as witnessed by sales for June down 18 percent year-to-date—the industry's worst June in 17 years. Of course, a sluggish economy doesn't help.

Solutions exist, though, to increasing fuel economy without necessarily reducing vehicle size. One such solution is "lightweighting" vehicles by switching from mild steel and iron to components made of lower weight materials. This article focuses on incorporating parts machined from aluminum and advanced high-strength steels, specifically microalloy steels, including those cut from solid workpieces and near-net shapes.

Slimming the U.S. vehicle fleet's weight previously occurred as a result of the Arab oil embargo of 1973-'74 and the CAFE (corporate average fuel economy) requirements initially enacted in 1975—but similar to what many dieters experience, the pounds eventually returned (Table 1).

"After the CAFE requirements had been satisfied, the passenger car and truck fleets basically plateaued in terms of fuel economy," said Doug Richman, vice president of engineering and technology for Kaiser Aluminum Corp., Foothill Ranch, Calif., a producer of fabricated aluminum products. "Over the next 20-year period, vehicles got about 1,000 lbs. heavier, performance improved by over 10 percent on average for zero to 60 mph acceleration, and they maintained the same fuel economy."

In addition to average vehicle size

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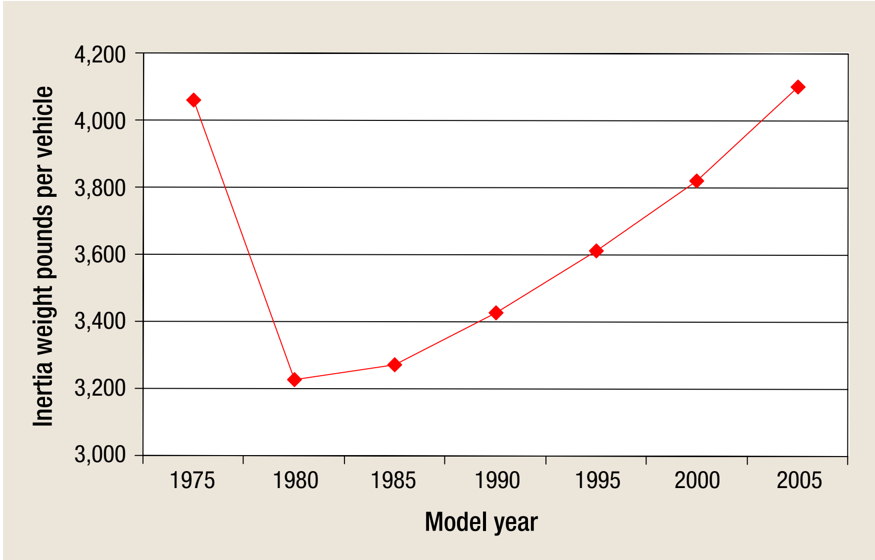
increasing with the rise in popularity of pickups and SUVs, Richman added that the weight increase came from adding on-board safety and telemetry equipment, more cup holders and providing more comfort and convenience in general. "Now, with high fuel prices, the voice of the customer has very quickly focused less on DVD players and more on fuel economy improvement," Richman said.

Aluminum Content

On average, Richman said switching to aluminum from steel and iron reduces component weight by 50 percent. "For 100 lbs. of aluminum on a vehicle, that vehicle has saved 100 lbs. overall in total weight," he said, noting that a 2006 vehicle contained, on average, 327 lbs. of aluminum based on the most recent data. "That's almost 10 percent of the total vehicle [by weight]."

That amount is expected to increase to 374 lbs. per vehicle in 2015, according to a presentation at the American Iron and Steel Institute's 2007 Great Designs in Steel seminar by Dick Schultz, project consultant for Ducker Worldwide, Troy, Mich. Of that amount, power train applications will represent more than 55 percent of the aluminum content in 2015, and chassis, steering and suspension components will comprise 10 percent of the aluminum content—75 percent more than 2007. In addition, wheels will represent 14.7 percent, HVAC parts 8.5 percent, brake components 6.0 percent and body, bumper and closures 5.5 percent.

Richman said large castings represent about 80 percent of the automotive



Source: EPA

Table 1: U.S. light vehicle average inertia weight.

applications for aluminum, including cylinder heads, engine blocks, transmission cases, master cylinders, wheel cylinders and brake calipers. Over the past couple decades, the auto industry has converted most of the castings that can be aluminum to that material, with, for example, 60 percent of the cylinder blocks and more than 90 percent of the cylinder heads in North America being aluminum. "As engines are redesigned and new model engines come out, they come out with aluminum blocks," Richman said. "We're nearing saturation on aluminum blocks and heads."

Although automakers have made efforts to replace aluminum engine blocks with magnesium and even plastic, the alternatives failed to make it to production. "Nobody has been able to displace aluminum castings in any significant effort," Richman said. "Aluminum [still] is the global standard for engine blocks and large castings."

'As engines are redesigned and new model engines come out, they come out with aluminum blocks.'

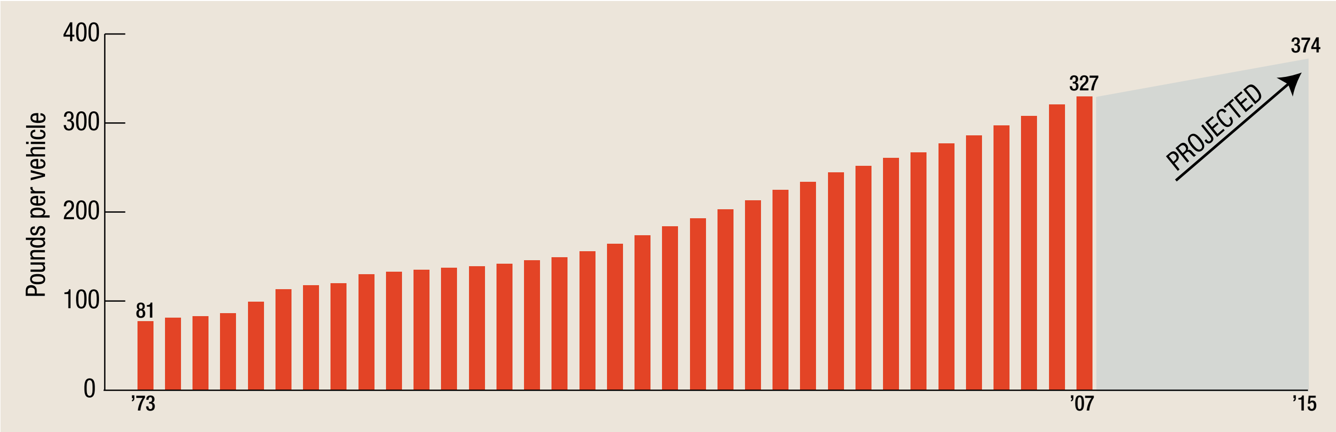
In addition to large castings, aluminum suspension component castings require machining and are continuing to make inroads in automotive as they are converted from iron. Richman estimated that a third of the control arms and about half of the steering knuckles in North America are cast aluminum.

Alloy Types

Aluminum castings for manifolds and other components that aren't exposed to high thermal cycle stress are typically made from 319 alloy, as well as 356 or 357 alloys, with the latter being a slightly higher-strength version but not a difficult-to-machine material. "The casting alloys machine pretty darn well," Richman said.

Traditionally, wrought alloys for automotive applications were 2011, 6061, 6082 and 6262. Richman indicated that the main machining issue for wrought alloys is controlling chip formation to avoid creating a bird's nest. To aid chip formation, soft constituents such as lead or tin typically with bismuth are added to the material's matrix to function as a chipbreaker when machining aluminum. Depending on the alloy, the amount of lead or tin generally ranges from 0.4 to 0.9 percent. Bismuth content is also typically from 0.4 to 0.9 percent. "Most machine houses find 2011 machines like free-machining brass," Richman said. "The chips come off like grains of rice, but it has a high lead content."

The lead improves machinability but poses environmental problems. Similar to what occurred with leaded gasoline, efforts are underway to minimize the amount of lead in automotive components, such as the standard for recycling end-of-life vehicles (ELV) in the European Union. The interim standard mandates no more than 0.4 percent lead in aluminum products, but the expectation is that the standard will be tightened to



Ducker Worldwide

Table 2: Aluminum content growth in North American light vehicles.

'Smart Weighting' *(continued)*

allow no more than 0.1 percent. And with globalization, what's required in one region is desired in all. "For automotive, we're talking no lead because I have not encountered an automotive customer that was interested in one of the low-lead alternatives," Richman said.

That means increasing the tin and/or bismuth content and keeping the lead out. Alloys developed in the last few years to achieve that include 6020 and 6040. They are derivatives of 6061, the lowest-cost and most common alloy for the automotive industry, but one with machinability issues because it doesn't contain soft constituents. "The only machine shops that have been able to handle 6061 are the folks who are really good at chip breakage, either with tool design or coolant jets," Richman said. "We have a few high-volume screw machine houses that do a wonderful job on 6061, but for most customers chip formation is just too much of a problem." He noted that 6020 and 6040 provide about 85 to 90 percent of the chip forming capabilities as the alloys they replace.

As previously noted, the amount of aluminum content in light vehicles is expected to increase, but Richman indicated that the following factors limit more components from being converted.

keywords

ALUMINUM ALLOYS: Aluminum containing specified quantities of alloying elements added to obtain the necessary mechanical and physical properties. Aluminum alloys are divided into two categories: wrought compositions and casting compositions. Some compositions may contain up to 10 alloying elements, but only one or two are main alloying elements, such as copper, manganese, silicon, magnesium, zinc or tin.

STEEL: Basically, iron in combination with carbon and other elements. There are five major groups of steels: carbon steel, alloy steel, stainless steel, tool steel and maraging steel.

STEEL-SPECIFICATION NUMBER: System of numbers developed by the American Iron and Steel Institute and Society of Automotive Engineers to identify steel. The first two digits in the code indicate the family and basic alloying elements. The final two digits indicate the approximate carbon content in hundredths of a percent. For steels with a carbon content above 1.00 percent, five digits are used. Numbers with L or S added indicate alloys incorporating lead or sulfur for improved machinability. A number of steels and alloys are identified under different codes, including tool steel, carbon tool steel, high-speed steel, die steel, stainless steel, strain-hardenable or workhardening steel and nickel-base superalloys.

—CTE Metalworking Glossary

Although aluminum hasn't recently seen as large a percentage increase in cost as some other metals, such as magnesium, copper and steel, it still costs more per pound than steel and iron. Copper, stainless steel and some other metals are poised to cost less in 2009 after price spikes over the last 2 years, according to a forecast from *The Kiplinger Letter*, Washington, but production downturns in Australia, China and South Africa spell a 10 percent increase for aluminum.

Another factor is parts makers may need to make a capital investment to switch equipment to machine a different metal. "If you've already got the process validated, it costs money to switch," Richman said. "I've never seen anybody competitively process aluminum on machines designed to process steel, because the machines for steel run too slow. Aluminum doesn't like to be machined slow, and machinists don't like to machine anything slow."

American Iron and Steel Institute

According to a University of Toledo study, the redesigned forged steel crankshaft (left) weighs 18 percent less than the cast iron crankshaft and showed no degradation in performance.

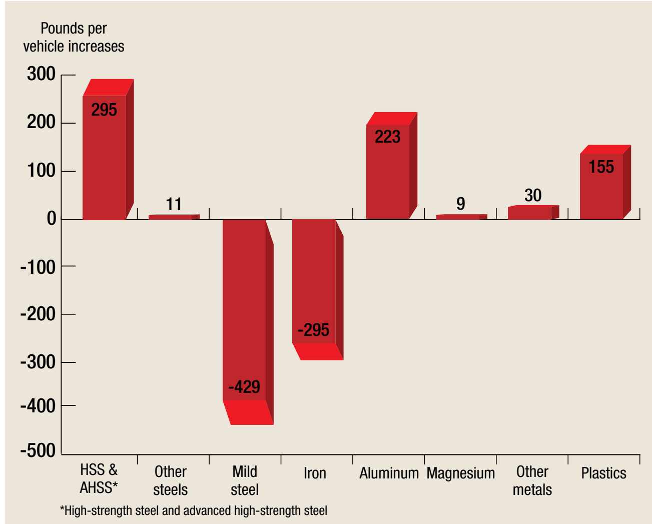
Nonetheless, lightweighting of vehicles continues. "Most everyone in the industry is expecting that lightweight materials will experience a significant growth [in percentage of vehicle weight], including high-strength steel," Richman said. "That's one of the materials that will see more use."

Steel on Wheels

Use of advanced high-strength steels will grow at a 14 percent compound annual growth rate starting in 2007 and reach more than 400 lbs. per vehicle by 2015, according to Ducker's Schultz. During the same time, he expects the total amount of steel content per light vehicle to decline from 2,300 lbs. to 2,100 lbs., as advanced high-strength steels replace other steels to save weight and improve acceleration. (A light vehicle is generally one with a gross vehicle weight of 8,500 lbs. or less.)

Schultz stated that vehicle weights are likely to decrease by 4 percent by 2015 from 2007 with no significant change in interior space or average footprint over the next 8 years. Various technologies, including lightweighting, are likely to improve fuel economy by at least 12 percent by 2015 from 2007 while maintaining or improving vehicle performance. Changes in the material mix will be used primarily to improve vehicle performance with material substitution contributing less than 2 percent of the fuel savings.

When component manufacturers talk about using advanced high-strength steels, they usually mean microalloy steels. That type of steel has 0.015 to



Ducker Worldwide

Table 3: Changes in North American light vehicle material content from 1975 to 2005.

'Smart Weighting' *(continued)*

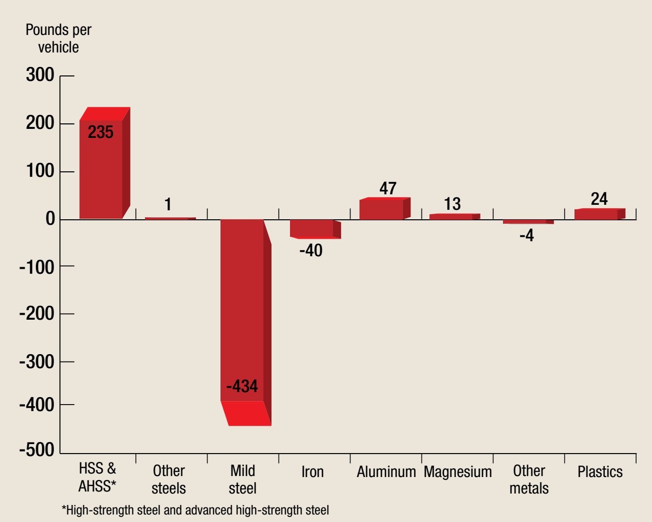
0.030 percent columbium and 0.05 to 0.15 percent vanadium to strengthen the metal's microstructure, and most are precipitation hardening, said David W. Anderson, director, Long Products Market Development for the American Iron and Steel Institute (AISI). "Steel makers improved the formation of fine grain structures, which increases the hardness levels without requiring heat treatment," he said. "With the microalloy steels, we can show complex phases right after forging and controlled cooling operations, so you get a bainite, ferrite and martensitic microstructure or a martensitic and ferrite microstructure."

By eliminating the need to heat treat workpieces before finish machining and/or grinding them, auto parts manufacturers reduce their manufacturing costs and production time. "The part arrives at the shop at the strength level it needs to be, and there all the parts maker does is machine it into the final shape," said Roger Joseph, project manager of AISI's machinability subcommittee of the Bar Applications Group.

Because microalloy steels are harder and stronger than the steel products they replace that require heat treating, microalloy steels are slightly more difficult to machine, but the difference isn't daunting. "A knowledgeable machinist or engineer should fairly easily make any adjustments in setting up their machines, parameters and tooling," Joseph said. "It's not vastly different."

To help automotive engineers calculate machining productivity when cutting steel, AISI developed its Bar Steel Machinability Estimator, which is available online at www.autosteel.org/barsteelmachinability. Users can input a steel composition and receive a relative machinability number or an estimated cutting speed in sfm for 30 minutes of tool life.

The machinability estimator builds on the bar steel machinability database, a record of bar steel machinability for automotive applications conducted via single-point turning using uncoated grade VC-5 carbide tools from Valenite. Machinability tests were conducted on more than 30 carbon, alloy, resulfurized and microalloyed steel grades. "Tests are



Ducker Worldwide

Table 4: Changes in North American light vehicle material content from 2007 to 2015. According to Ducker Worldwide, 319 lbs. of advanced and high-strength steels, aluminum, magnesium and plastics will replace 478 lbs. of mild steel, iron and other metals for a 33 percent metallic material weight savings during the 8-year period.

underway using coated carbide tools, and those test results will be incorporated into the machinability estimator upon completion," Joseph said.

Lightweighting by Redesign

By doing a "smart redesign" of a component, lightweighting can be maximized when converting the component to steel. Part designers look at the component's stress and strain concentration points for static and dynamic situations when doing the redesign, Anderson noted. "They eliminate material where there isn't a high-stress concentration, and in some cases add a little material where there is a high-stress concentration," he said.

AISI conducted a study with the University of Toledo and the Forging Industry Educational and Research Foundation to compare forged steel crankshafts with cast iron ones. A forged steel crankshaft was redesigned to change the crank webs' dimensions and geometry, yet it maintained the original part's dynamic balance. The redesign reduced weight 18 percent, which improved fuel efficiency with no degradation in performance, according to AISI.

The original forged steel and cast iron crankshafts were from one-cylinder, four-stroke engines, typical of those used in riding lawnmowers, and were similar in weight and design. Researchers concluded that the test results are applicable to automotive crankshaft design because the critical performance parameters are similar to those in automobile crankshafts.

Another AISI redesign project involved changing from a cast iron to a forged microalloy steel transmission drive shaft flange for the Ford 250/350 pickup truck. According to Anderson, substituting a higher strength, more formable material permitted reducing the flange diameter by 2.5mm, increasing the fillet to 6mm, reducing the thickness to 10mm and creating lobes instead of a constant diameter. The cast iron material had a tensile strength of 100 ksi, a yield strength of 70 ksi and an elongation of 3 percent compared to the microalloy’s 130-ksi tensile strength, 110-ksi yield strength and 20 percent elongation.

The switch from a casting to a forging eliminated a significant amount of machining. The casting was machined 100 percent, while the forging technology for microalloy steel resulted in a near-net-shape part that only required machining of end faces, the mounting hole and the spline shaft. Through the material saving and reduced machining, the new design cost less to produce. “We do not recommend redesign for mass reduction on a part-by-part basis,” Anderson said. “Instead, we firmly believe in the clean-sheet design approach.” With that approach, the total vehicle is redesigned instead of one component at a time.

Redesigning the flange reduced its stationary mass by 2.18 lbs., or 34 percent, while rotating mass (inertia) went from 21.49 in.^{2}-lbs. to 9.47 in.^{2}-lbs.—a 56 percent reduction. “By reducing the rotational weight of an engine component, you get almost twice the benefit of just reducing a static weight, like a sheet product,” Anderson said. “Rotational weight improvements are more desirable.”

American Iron and Steel Institute

By redesigning a cast iron transmission output hub (left) to be forged as a near-net shape from microalloy steel (right), the part’s weight was reduced by 2.18 lbs., or 34 percent, while the part’s rotating mass was reduced 56 percent, from 21.49 in.^{2}-lbs. to 9.47 in.^{2}-lbs.

Of course, automakers don’t want to redesign anything unless there’s a compelling reason. The *Chicago Tribune* reported that when Robert Lutz, vice president of product development for General Motors, was recently asked why GM postponed the redesign of its large pickups and SUVs, he responded: “Redesigning full-size trucks creates an enormous bubble in engineering expense and the capital needed for plants. The last one was almost $2.7 billion. Now that big trucks are no longer purchased as fashion accessories and it’s down to those who really need them, there is very little need to reengineer or redesign those vehicles.”

Other types of vehicles, however, can be appropriate for redesign and

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A. Richter

A selection of aluminum auto parts from Kaiser Aluminum.

material substitution. Consumers could save fuel and reduce carbon emissions through greater use of aluminum in hybrid- and diesel-powered vehicles, according to The Aluminum Association Inc.'s study titled, "Benefit Analysis: Use of Aluminum Structures in Conjunction with Alternative Powertrain Technologies in Automobiles." The study reported fuel economy gains of 46 percent in diesel-powered vehicles and 51 percent in hybrid vehicles complemented by aluminum structures when compared to existing gasoline-powered vehicles.

"With sky-high fuel costs expected over the long term and intense consumer pressure demanding long-term solutions, the time has come to rethink the basics of vehicle design," said Steve Larkin, president of the association. "If automakers opt to reduce the weight of vehicles with next-generation hybrids and diesels through greater use of aluminum, consumers will be 'paid back' faster at the gas pump compared to the payback time associated with the added costs of today's heavier hybrids and diesels."

Technologies are available to improve fuel economy, but lightweighting through material substitution will continue to be needed regardless of the fuel being consumed. In response to the U.S. Department of Transportation's proposed new fuel economy standards, Buddy Stemple, chair of the Aluminum Association's Auto and Light Truck Group, said: "For automakers to meet the U.S. DOT's proposed fuel economy standards of 35-mpg average by 2020, power train advances alone won't get the job done and cutting weight must be part of the solution. The status quo in the industry is dead and the days of heavy, standard gasoline-burning vehicles are numbered. Automakers are moving quickly on hybrids, clean diesels, ethanol and even fuel cells—and reducing vehicle weight with high-strength, low-weight materials like aluminum is vital to making each of those options even more efficient." CTE

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