Automotive Technology: Greener Products, Changing Skills

Lightweight Materials & Forming Report

CAR
CENTER FOR AUTOMOTIVE RESEARCH

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LIGHTWEIGHT MATERIALS & FORMING REPORT

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DRIVING CHANGE
Greening the Automotive Workforce

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1. Introduction

Making lightweight vehicles is not a new concept. In fact, the use of lighter materials and reduction of parts is a concept that has existed since the inception of the automobile, yet much of the change that has existed over the last 50 years has been incremental. Existing infrastructure and familiarity with physical characteristics of certain materials has limited the range of materials and designs for automotive components. Today, changes in powertrain strategies and emphasis on fuel economy are forcing automakers to make significant changes in material selection and possibly vehicle design methodology.

Recent changes to the Corporate Average Fuel Economy (CAFE) are driving automakers to seek more aggressive methods for fuel consumption reductions. Lightweighting of vehicles will be a factor in meeting these requirements due to the inherent relationship between mass and fuel consumption. In addition, lightweighting may benefit other advanced fuel-saving but load constrained technologies, such as battery-powered vehicles.

The ability to introduce new lightweight materials into vehicles is not a trivial matter. Many see a new concept, or limited production, vehicle introduced to the market with lightweight "space-aged" materials and feel that adoption by mass produced vehicles is a simple matter of "remove and replace." However, this is not the case; factors such as existing infrastructure, material cost, and high volume capacity become of great importance for mass production vehicles. In addition, many of the low production vehicles incorporate these lightweight materials as a method for gaining experience on their performance. Without significant data to support durability, the risk-averse automotive culture will not adopt new materials. Therefore it often takes many years to implement lightweight technology in mainstream production vehicles.

As new materials are introduced and adopted, the workforce will need to adjust to accommodate the following changes in the industry:

- Greater focus on systems approach to vehicle design
- Greater emphasis on characterization of material properties
- Interaction of a mix of materials (aluminum–steel, steel–composite, aluminum–magnesium, etc.)
- Wider variety of manufacturing processes
- Greater use of computer-aided engineering

1.1 Methodology

Researchers at the Center for Automotive Research (CAR) investigated the general market for lightweight vehicle technology—collected and reviewed articles, reports, and other documents on the current state of the technology, the market, and what future trends may be.

To supplement this information, researchers spoke with people representing the public, private, and nonprofit sectors. These experts have significant knowledge of manufacturing and materials, and provided substantial insight into the future trends, technological applications, and expectations for labor skills needed. The following organizations were represented in our discussion:

- American Iron and Steel Institute
- Automotive Aluminum Association
- American Chemistry Council
- Ford
- General Motors
- Chrysler
- ArcelorMittal
- Kaiser Aluminum
- Oak Ridge National Laboratory
- Lotus Engineering
- Multimatic
- BASF
- Custom Design

1.2 Automotive Lightweighting

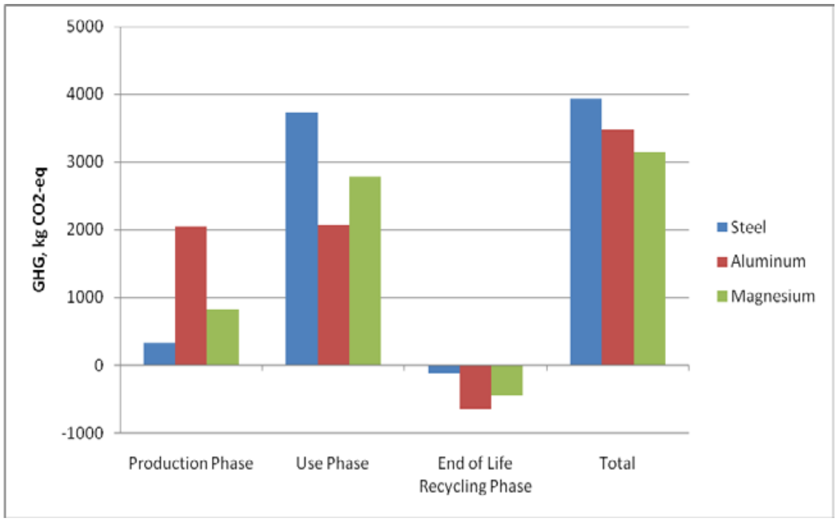
There are numerous benefits through automotive lightweighting. As a result, lightweighting is not only popular because of its positive impact on fuel economy, but also because of the many additional benefits lightweighting creates. Indeed, lightweighting is a perennial objective of the automotive industry.

The most obvious benefit is the impact it has on fuel consumption. In fact, it is estimated that a 10 percent reduction in mass will result in a 3 to 7 percent reduction in fuel consumption.[1] The reasoning behind this is simple; it takes less work to accelerate and move a lighter object.

In terms of lifecycle management, the use cycle of the vehicle typically dominates the overall CO2 emissions generation of the vehicle (see Figure 1). Lighter weight materials have the advantage of providing sustained greenhouse gas emission reductions over the use cycle of the vehicle.

[1] Ashley, S. (2010, April 6). Shedding pounds on a magnesium diet. Automotive Engineering International, pp. 34-36.

Figure 1: Total Greenhouse Gas Emissions during Various Phases of the Vehicle Lifecycle



Source: Dubreuil, A. et al (2010) A Comparative Life Cycle Assessment of Magnesium Front End Autoparts, SAE 2010-01-0275

Lightweight materials may also improve vehicle performance such as acceleration or ride and handling. A reduction in mass within the unsprung weight (area not supported by the suspension) can significantly improve the noise, vibration, and handling characteristics of the vehicle. As a result, a great deal of attention is given to weight reductions of unsprung mass. Reducing weight near the top of the vehicle has advantages, as well, by lowering the center of gravity and reducing the risk of rollover. Improved performance provides a marketing point beyond fuel economy improvements.

Another major benefit of weight reduction is the ability to introduce new content into the vehicle. As consumer preference shifts toward electrification of the vehicle, additional components such as batteries may increase the weight and thereby reduce vehicle performance. By lightweighting the entire vehicle, these technologies may be introduced with limited or no degradation in performance. In the case of electric vehicles, the introduction of more expensive lightweight materials may be justified by the ability to reduce the size (and cost) of the battery. In other words, vehicle lightweighting makes it possible to introduce other technologies such as battery electric vehicles with limited cost and vehicle performance issues.

2. Lightweight Vehicle Techniques

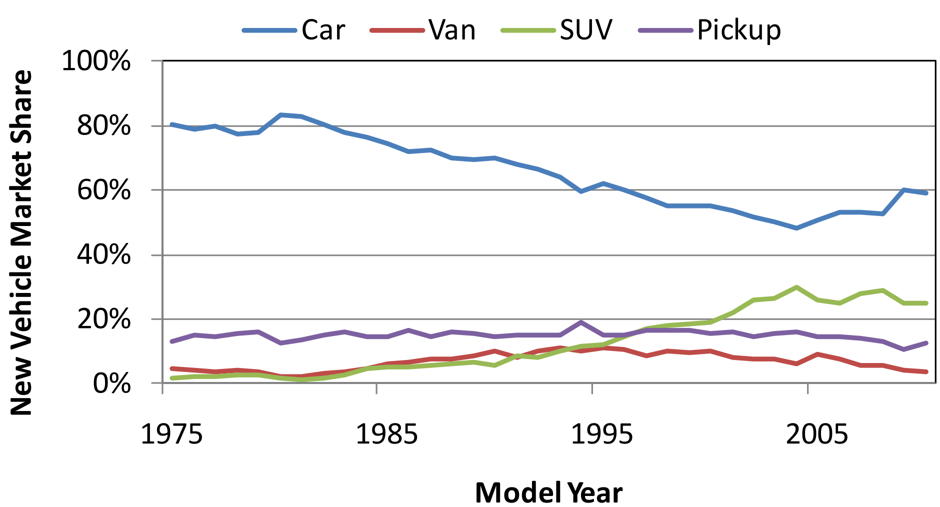
The quest to lighten the weight of vehicles is not a new field. As far back as the days of Henry Ford, vehicle design and manufacturing has strived to achieve the most cost-effective lightweight vehicle possible: “Excess weight kills any self-propelled vehicle. There are a lot of fool ideas about weight … Whenever anyone suggests to me that I might increase weight or add a part, I look into decreasing weight and eliminating a part!”[2] It is safe to say that lightweighting of vehicles is an evolving field of materials and manufacturing technology that offers a robust vehicle design.

2.1 Vehicle Size

Reducing overall vehicle size is the simplest way to reduce vehicle mass. However, this would run counter to the overall market trend of new vehicles sold in the United States. As seen in Figure 2a, there is a steady decline in car market share as larger vehicles such as SUVs have grown in market share. In reality, the average vehicle weight has increased since the early 1980s due to larger vehicles and increases in in-vehicle technology (see Figure 2b). These trends are expected to continue making it unlikely that lightweighting can be achieved through a simple reduction in fleet vehicle size.

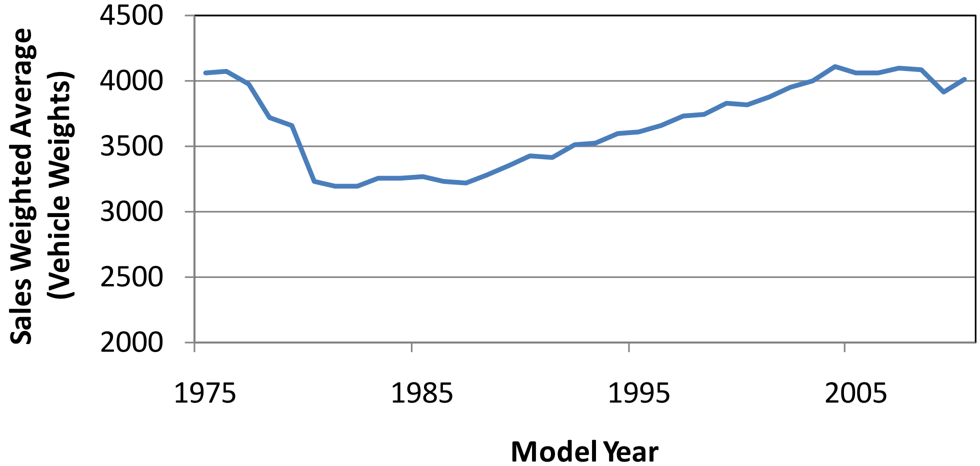
Figure 2: Impact of Market on Vehicle Weight

a)



[2] Ford, H. (2009). My Life and Work. CreateSpace.

b)



Source: U.S. EPA (2009). Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2009

2.2 Vehicle Redesign and Content Reduction

Another method used to reduce vehicle mass is through a complete vehicle redesign. Examples of redesign may be a switch from body-on-frame to unibody construction or reducing non-structural elements of vehicles. However, in many instances this is not possible. For example, changing the body construction affects the overall volume of vehicles produced and may increase cost due to complex assembly techniques. Reducing content is also a difficult option to carry out and it is likely that consumers will demand more content—not less—in the future. With a desire to buy and sell large vehicles at comparable cost and increased functionality, automakers must use advanced materials to mitigate increased weight, meet increased fuel economy standards and improve crash performance.

2.3 Material Selection

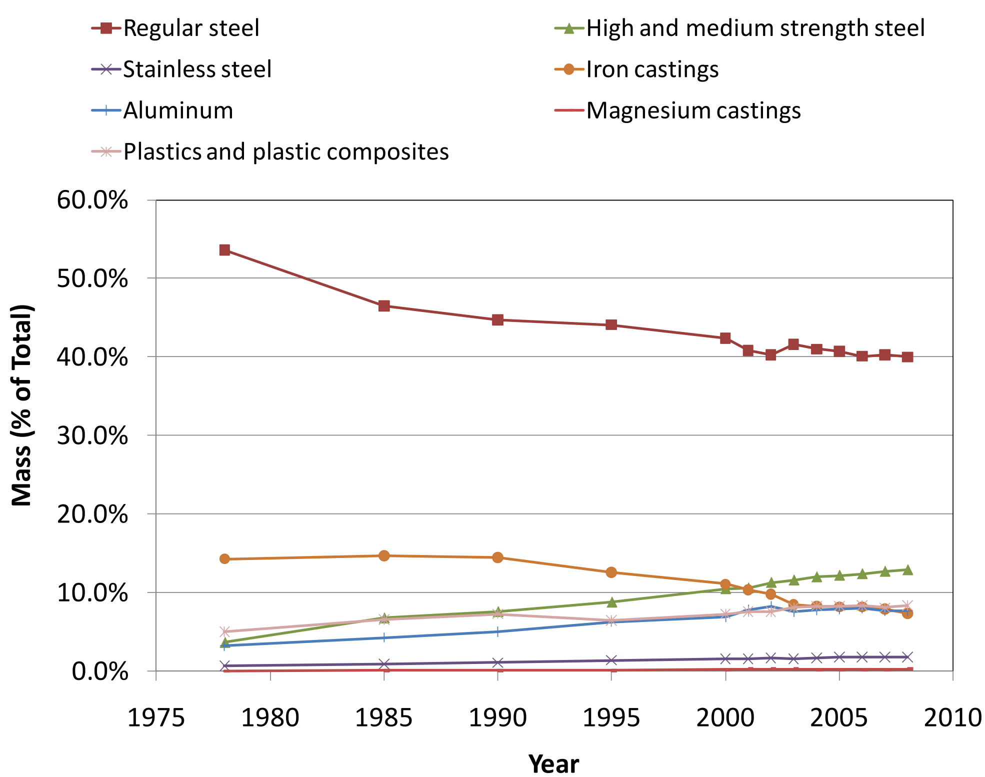
Unlike vehicle size and content reductions, advanced lightweight materials may be introduced into the vehicle with little or no impact on the consumer. In fact, lightweighting while maintaining vehicle size may actually increase the performance of a comparable vehicle. Steel has been a dominant force in the material selection of automotive parts. A combination of high-strength, low cost and capacity to be produced in high volumes has made mild steel a very attractive material in automotive applications. However, as technology changes and fuel economy increases in importance, other materials are gaining acceptance in the automotive industry. In addition, as these new materials are used in the industry, engineers and scientists have the opportunity to learn new applications for them, further increasing their utilization.

3. Automotive Lightweight Material Overview

3.1 Materials

Materials such as high-strength steel, aluminum, composites, and to a much lesser extent magnesium have increased their overall utilization over the past 30 years, while mild steels have seen a steady decline (see Figure 3). At the same time, regular steel and iron castings have also seen a steady decline. The following section will review a few of the popular material choices, risks associated with lightweight materials, and research in the field of automotive lightweighting through material technology.

Figure 3: Vehicle Material Composition by Percent Mass



Source: Ward's, Motor Vehicle Facts and Figures, 2010, 2008, 2006, 2004, 2002, 2000 and 1995

3.1.1 High-Strength Steel

The use of high-strength steel has seen a steady growth over the past 30 years. A combination of existing infrastructure and familiarity with the physical behavior of steel makes it a material of choice for many engineers. Popular high-strength steels in use today include dual-phase, martinsitic and boron steel. With both-dual phase and martinsitic steels, the general forming methodologies are fundamentally similar to those of milder steels. With boron steels, the process is drastically different, as the sheet of metal is first heated then stamped and cooled giving it its high-strength capability. Boron steels are able to be formed into very complex shapes as the high temperature blank is very malleable. Typical applications for high-strength steels include front end structures, chassis components, rails, and body panels.[3]

3.1.2 **Aluminum**

Aluminum is particularly strong in areas that require cast parts such as engines blocks, transmission casings and wheels. Today, over 50 percent of all cylinder blocks are made from aluminum. Some aluminum-intensive vehicles are on the market today (e.g., the Jaguar XJ and BMW 5 series). However, costs associated with aluminum material, existing steel infrastructure and formability difficulties prevent aluminum from dominating the automotive market.[4]

3.1.3 **Magnesium**

Magnesium is the least dense of mainstream metal options within the automotive industry— 30 percent less dense than aluminum and 75 percent less dense than steel.[5] Magnesium has its greatest use in thin-wall die castings. Instrument panels and cross car beams make up 40 percent of the total magnesium content in vehicles. Another promising area for magnesium appears to be in closures where a magnesium inner structure is paired with an aluminum outer structure. For example, the liftgate of the Lincoln MKT features a magnesium inner structure with a total mass reduction of 22 pounds.[6] Magnesium has seen limited introduction in vehicles— driven partly by material cost, durability concerns (such as high temperature creep or distortion), corrosion, and limited availability of stock material sheet and extruded forms.[7]

3.1.4 **Composites**

Composites currently represent 50 percent of the total vehicle by volume.[8] There are many applications for composites today; however, they typically involve components that are more for cosmetic purposes rather than structural performance. Glass fiber reinforced plastics make up the majority of applications available today but have limitations in terms of strength. Recent activity indicates that there is much more interest today in composites (particularly carbon fiber) that provide additional structural performance.[9,10,11] The recently announced BMW

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[3] Lutsey, N. (2010), Review of technical literature and trends related to automobile mass-reduction technology, University of California, Davis, 2010

[4] Bandivadekar, A., Bodek, K., Cheah, L., Evans, C., Groode, T., Heywood, J., et al. (2008). On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions. Massachusetts Institute of Technology.

[5] Ibid.

[6] Ashley, S. (2010, April 6). Shedding pounds on a magnesium diet. Automotive Engineering International, pp. 34-36.

[7] Bandivadekar, A., Bodek, K., Cheah, L., Evans, C., Groode, T., Heywood, J., et al. (2008). On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions. Massachusetts Institute of Technology.

[8] Ibid.

[9] Brooke, L. (2009, May). A Featherweight Future. Automotive Engineering International , pp. 24-26.

[10] http://blogs.edmunds.com/greencaradvisor/2010/04/daimler-to-develop-fuel-saving-carbon-fiber-car-parts-with-japanese-textile-maker.html

Megacity electric vehicle is reported to rely heavily on carbon fiber components for structural elements. According to BMW, the choice of carbon fiber over other materials was driven by a reduction in battery storage, thereby reducing cost in the battery despite increasing cost in the body components.[12] The use of structural composites will benefit those industries that specialize in these fields. Already, BMW and Daimler have developed working relationships with material providers to jointly develop processes and techniques to bring carbon fiber vehicles to the market and create jobs.[13,14,15] The main issues with composites are the overall material cost, limited quantities of available material, and recycling of material.

3.2 Research Activity

Recent research activity between the automotive industry and various institutions has shown that a mix of materials will be needed to provide an optimal lightweight vehicle. Designs ranging from steel, aluminum, and carbon fiber-intensive designs to multi-material designs have been studied. Table 1 demonstrates potential optimized designs using different material strategies. Steel-intensive designs typically involve the addition of higher strength steels and consolidation of parts. In addition to their low density, aluminum and carbon fiber designs often revolve around the elimination of parts, as hinges and other features can be built into the main component. The multi-material designs take advantage of the best properties of all materials. Multi-material designs take a whole systems approach to design to reach an optimal design at minimal cost.

Table 1: Mass Reduction Potential of Various Vehicle Material Design Strategies

Design Strategy	Mass Reduction
Steel-Intensive	15 – 40%
Aluminum-Intensive	30 – 45%
Carbon Fiber-Intensive	40 – 60%
Multi-Material	30 - 60%

Source: Lutsey, N. (2010). Survey of Vehicle Mass-Reduction Technology Trends and Prospects, 2010

A few examples of mass reduction strategies include:

Magnesium Front End Research and Development – The project's goal was to develop "an automotive unibody 'front-end' structure realizing a 50 percent weight savings relative to present steel technology, meeting all expected vehicle attributes at an affordable cost to the manufacturer."[16] Collaboration between industry, academia, and government included USCAR,

[11] Birch, S. (2009, Nov.). Coming Out Party, Automotive Engineering International

[12] http://green.autoblog.com/2010/04/28/bmw-has-big-plans-for-carbon-fiber-that-go-beyond-megacity-high/

[13] http://green.autoblog.com/2010/04/07/bmw-megacity-ev-makes-carbon-fiber-jobs-in-america/

[14] http://blogs.edmunds.com/greencaradvisor/2010/04/daimler-to-develop-fuel-saving-carbon-fiber-car-parts-with-japanese-textile-maker.html

[15] http://www.bmwblog.com/2010/06/16/bmw-megacity-vehicle-is-creating-600-jobs-in-germany/

[16] Magnesium Front End Research and Development Project AMD604. (2009). DOE Merit Review Presentation.

Meridian Magnesium, various universities, and the governments of Canada, the United States, and China.

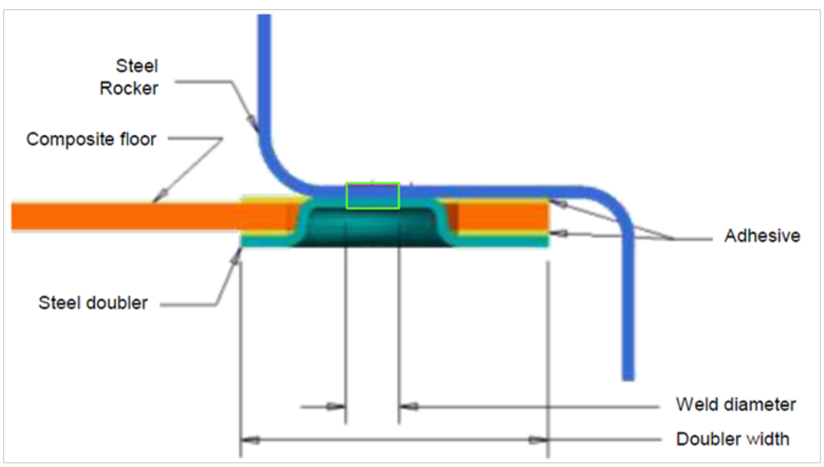
Included among the accomplishments of the group were:

- Warm-forming of magnesium sheet material
- First "super vacuum die cast" magnesium components
- Assessment of pretreatment effect on adhesive bonding and loss of adhesive strength in corrosion undercutting

Composite Underbody Focal Project #4 – The purpose of the project was to develop a structural composite underbody. This objective was reached with the outcomes of a 2 ½ minute cycle time and methods for joining and assembling the underbody. Collaboration between USCAR, Multimatic, and Polywheels enabled the design and analysis of such an assembly.

As part of the research, a new weld bonding technique joining a steel rail to the composite underbody was developed to increase stiffness, reduce mass, and improve durability of the assembly. The technique incorporates both application of an adhesive and a spot weld (see Figure 4).

Figure 4: Composite to Steel Joint Design



Source: Berger, L. et al. (2009). Development of a Structural Composite Underbody, SPE Automotive Composites Conference.

SuperLight Car – The main objective of the SuperLight Car project was to develop an innovative multi-material lightweight design for vehicle structures achieving:

- 30 percent weight-reduced vehicle structure body-in-white (BIW)
- Cost-reduced multi-material manufacturability
- High volume capability
- Benchmark performance (C-class segment)
- Recyclability/ Sustainability

The partnership was divided among many sectors and consisted of a team of seven vehicle manufacturers (including: Volkswagen, Volvo, and Opel), 10 R&D companies, 10 suppliers, and seven universities.

The end product was a mixed material vehicle featuring a wide range of materials and joining technology (see Figure 5).

Figure 5: Results from the SuperLight Car Project

Source: Goede, Martin. "SuperLIGHT-Car project - An integrated research approach for lightweight car body innovations." Innovative Developments for Lightweight Vehicle Structures. Wolfsburg: Volkswagen, 2009. 30.

3.3 Risks to Adoption of New Materials

The automotive industry as a whole tends to have a very risk-averse culture. As a result, the introduction of new materials is often met with trepidation. Existing infrastructure, material cost, crashworthiness, and durability are among the concerns automakers have for the introduction of new materials.

3.3.1 Infrastructure

Capital costs such as manufacturing and assembly equipment are averaged over the life of that equipment. Therefore, incumbent materials using existing equipment have a distinct advantage over any new material that will require new equipment and new capital cost. This fact has been pointed out in several discussions with industry representatives. It is important to note that lightweight material studies often focus on a “clean sheet” approach to vehicle design and therefore underestimate the infrastructure cost of alternative lightweight materials.

Steel, with its strong position within the automotive industry, has an inherent advantage in this area. In general, the equipment and processes to manufacture and join new advanced and ultra high-strength steels are fundamentally unchanged. As a result, steel is often a manufacturer’s first choice when seeking to lighten the weight of vehicles.

Other materials must look to new and niche vehicles to gain acceptance. With new vehicles, there is a greater chance for investment in new capital equipment. Niche vehicles also pose an opportunity, as typical mass production processes are too expensive to justify on such low volumes. Materials such as aluminum, magnesium, and composites tend to have an advantage in these vehicles as capital costs are typically lower than steel.

3.3.2 Material Cost

At high volumes, material cost becomes a major issue. Again, steel typically has an advantage in this area as it is the cheapest material per pound of those considered for structural components (see Table 3). Based on discussions with industry representatives, cost is the primary factor limiting the adoption of materials. This fact is particularly pronounced with carbon fiber where a 50 to 60 percent reduction in weight results in a cost of two to 10 times that of a comparable steel design.[17] Similar to the infrastructure issues, materials with high cost will be limited to niche vehicles.

3.3.3 Supply Chain Volatility

Raw materials for use within automotive applications are often mined. As a result, the raw material supply chain is driven primarily by the location of raw materials. The volatility of a particular region can affect the supply and cost of a particular material. For example, China—a major supplier of many raw materials—has, in some instances, withheld raw materials from other countries with little notice.[18] In addition, in the case of magnesium, antidumping laws in the United States prevent U.S. companies from purchasing raw magnesium in China.[19] As a result, automotive manufacturers must consider the stability of their material supply chain for any material decisions.

3.3.4 Crashworthiness and Durability

The structural and long-term capability of any new material must meet the demands of the rigorous automotive environment. A significant amount of testing must be conducted before any new material would be considered usable in a mass production vehicle. This exemplifies the need for education within the automotive industry on the properties of new materials. For example, BMW recently announced that it had developed a prototype X5 carbon fiber vehicle in 2003, for durability and life cycle testing.[20] The vehicle went through over 40,000 km of testing to determine how carbon fiber would behave in the real world. BMW's full scale development testing of carbon fiber composite structures has taken at least 10 years and exemplifies the time required to justify new materials in terms of performance characteristics.

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[17] Ashley, S. (2009, August). Lightweighting gives composites new life, Automotive Engineering International

[18] http://www.bloomberg.com/news/2010-06-01/wto-questions-rationale-of-chinese-restrictions-on-raw-material-exports.html

[19] http://www.stlbeacon.org/issues-politics/280-washington/107945-companies-lawmakers-battle-qantidumpingq-tariffs-on-magnesium

[20] http://www.bmwblog.com/2010/07/06/exclusive-bmw-x5-with-carbon-fiber-unibody/ (accessed 7/6/2010)

3.4 Automotive Lightweight Materials Forecast

Trends and various studies on lightweight design indicate a tendency toward a greater mix of materials.[21,22,23] Table 2 shows the projected change in vehicle content of various materials. These new materials will be added at the expense of mild strength steels. Steel will continue to be a factor as new advanced and ultra-high-strength steels allow automakers to reduce the thickness (and weight) of components while maintaining the required level of strength. Aluminum, magnesium, and composites also appear poised to gain a stronger footing in the market as fuel economy legislation pushes automakers to consider more aggressive weight reduction strategies.

Table 2: Increase in Material Content from 2009 to 2020

Material	Change in Vehicle Content by 2020 (lbs. increase)
Advanced and Ultra High-Strength Steel	350
Aluminum	31 to 70
Magnesium	10 (130 to 350 possible)[24]
Plastics and Composites	25

Source: Schultz, R. et al (2009), Metallic Material Trends for North American Light Vehicles

[21] Lutsey, N. (2010), Review of technical literature and trends related to automobile mass-reduction technology, University of California, Davis, 2010

[22] Lotus Engineering. (2010). *An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program.*

[23] VolksWagen (2009). *Innovation Developments for Lightweight Vehicle Structures.*

[24] Lutsey, N. (2010), Review of technical literature and trends related to automobile mass-reduction technology, University of California, Davis, 2010

3.5 Automotive Lightweight Materials - Summary

A summary of the material options is provided in Table 3. High-strength steels and aluminum figure to increase in overall utilization as they provide very cost-competitive options. Magnesium is expected to see some growth, particularly in closures where consolidation of parts and reduction in mass are critical for fuel economy improvements. Composites are already a major part of vehicle design; however, due to cost constraints, composite structured components will see slow growth.

Table 3: Comparison of Lightweight Automotive Materials

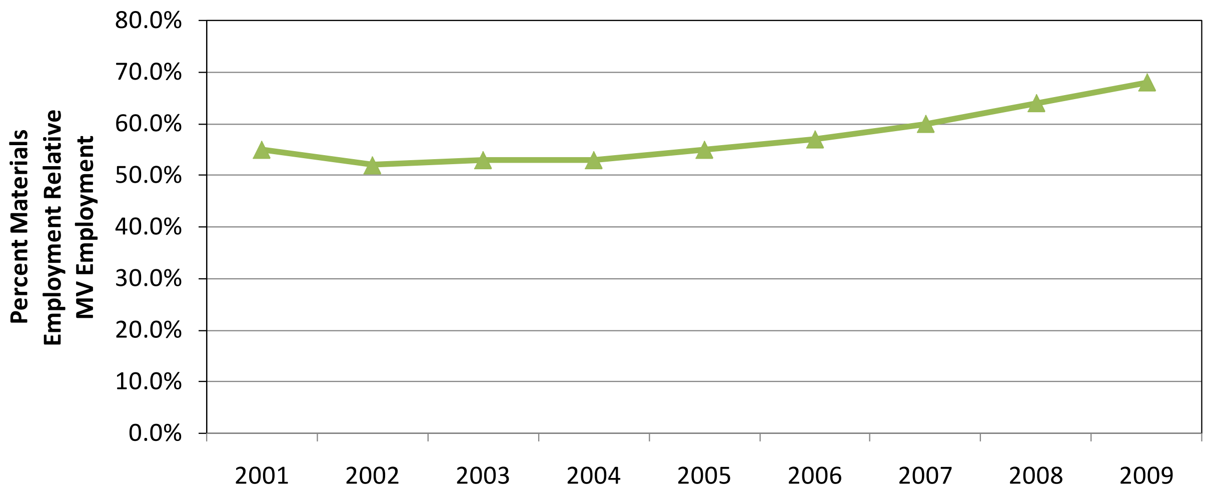
Material	Benefits	Constraints	Cost (per lb.)
Aluminum	• Recyclable • Casting technology is well established • Consolidation of parts	• Corrosion • Difficult to form • Bonding is more challenging than steel	$0.90 – $1.00
High-Strength Steel	• Infrastructure is well established • Good working relationship with automotive • Material properties are well known	• Lower strength to weight ratio than other alternatives • Reducing thickness reduces material stiffness	$0.35 – $0.40
Magnesium	• Low density • Consolidation of parts • Highly recyclable	• Limited production of stock material for manufacturing • High cost • Limited familiarity within the industry	$1.70 – $2.00
Glass Fiber-Reinforced Plastic	• Consolidation of parts • Handles harsh chemical environments • Excellent damping capabilities • Accommodates complex designs	• Slow cycle times • Not recyclable • Limited strength	$0.50 - $5.00
Carbon Fiber-Reinforced Plastic	• Highest strength to weight ratio of all materials • Greatest potential for weight reduction	• Slow cycle times • High cost • Limited familiarity within the industry	$6.00 - $10.00

Source: Bandivadekar et al. (2008); Ashley, S. (2010, April 6)

4. Automotive Lightweight Materials Workforce Outlook

The evolution of lightweight materials for automotive applications will bring about several changes to the industry, and the incumbent workforce and future employees must adapt to these changes. The concentration of jobs related specifically to materials, as opposed to motor vehicle parts, indicates that the automotive industry values the knowledge and skills of those who work directly with materials. The decrease in automotive jobs related to materials was far less severe than those related to manufactured parts, as shown in Figure 6.

Figure 6: Automotive Materials-Related Jobs Relative to Automotive Parts Manufacturing Jobs



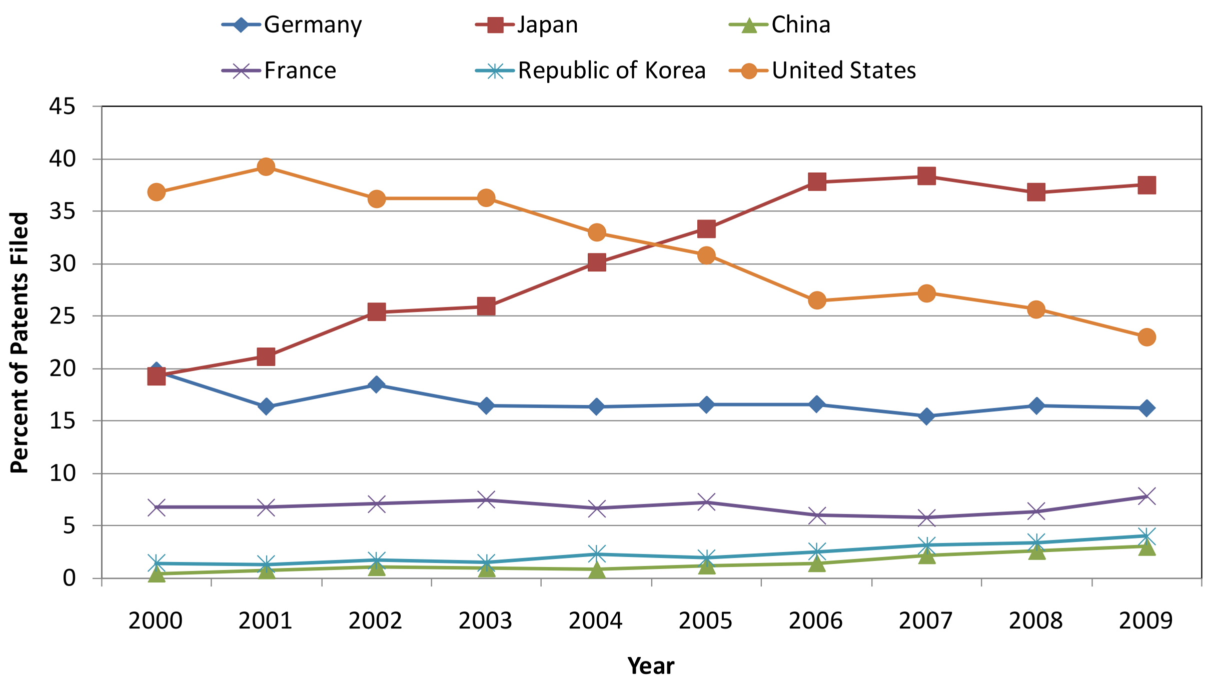
Note: Motor vehicles employment includes NAICS 3363 and 3361; Automotive materials-related employment includes NAICS 325211, 335991, 331522, 331528, 333514, 333515, 331312, 331315, 331316, 331319, 325991, 331210, 331221, 331111, 336211, 336370, 333511, 33351 and 333513.
Source: *BLS-QCEW, U.S. Census Bureau-County Business Patterns*

The following section outlines the material design changes and identifies areas in which the workforce must adapt.

4.1 Metallurgy and Fundamental Composites Research

Fundamental research of composites and metals (metallurgy) will take on greater significance as materials reach the limitations of their ability. Understanding the behavior of materials opens the door for a wide variety of skills that would promote the use of lightweight materials. Through fundamental research, engineers will be able to understand limitations of current materials, opportunities to create specialized alloys for automotive applications and real world material behaviors for simulation modeling. This particular skill set was identified by several respondents as lacking in the industry. The United States appears to be losing ground (particularly in metallurgy) in this area to other countries (see Figure 7). Other countries have seen the importance of such research and have taken significant steps to improve research in those areas. The U.S. automotive industry faces an additional challenge in this area (as identified by respondents) as highly qualified graduates often choose other industries such as aerospace and durable goods which are more accustomed to working with advanced materials.

Figure 7: Materials, Metallurgy Patent Filing Market Share by Country



Source: Data Source: World Intellectual Property Organization

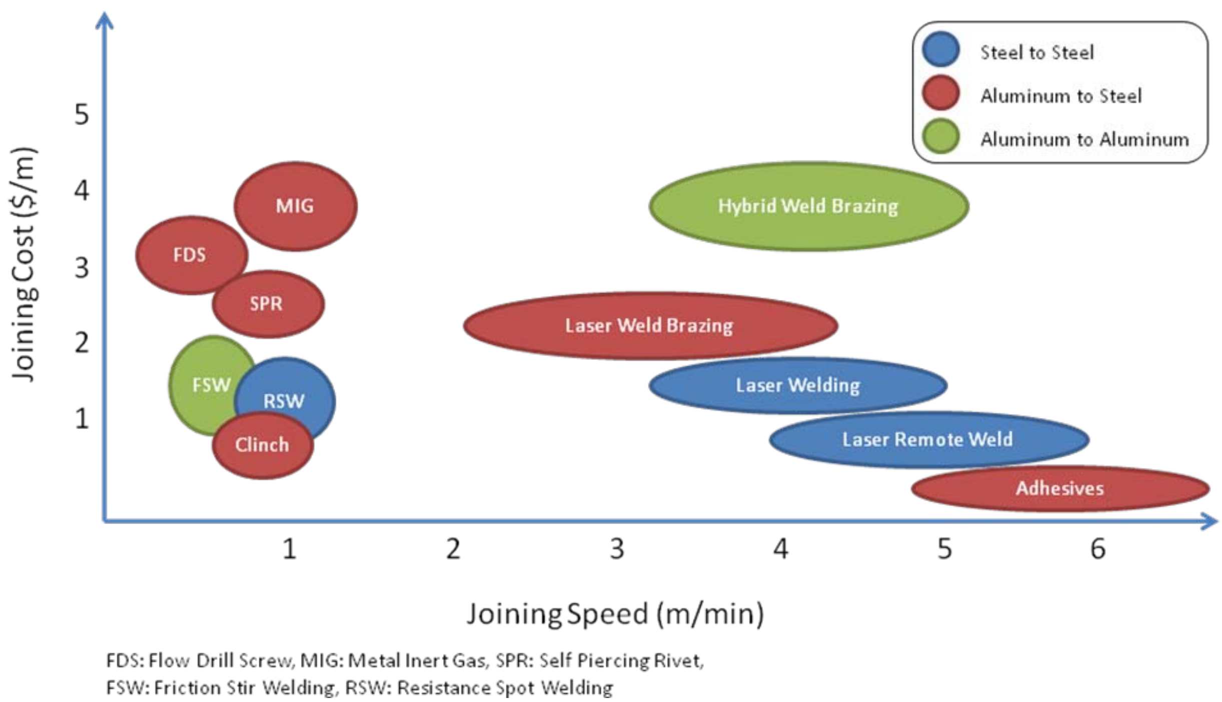
4.2 Joining and Interfacing

As automotive material choices become more diverse, the likelihood of differing materials coming into contact with each other will be much greater than they are today. As a result, joining issues that do not currently exist will become a major challenge in the future. Traditional methods for joining include mechanical fastening such as rivets, spot welding, and brazing. As materials interface more often, these traditional joining techniques will no longer suffice; seldom used or new joining technologies will be necessary. Greater use of adhesives is expected to provide the bond strength required and the corrosion barrier between dissimilar materials. In instances where the stiffness of new materials is an issue, bonding through adhesives may improve noise, vibration and harshness (NVH) and crash performance through a more complete bonding surface of materials.[25] Another example is self-piercing rivets which lend themselves better to the joining of aluminum sheet metal.

Corrosion is another major issue between dissimilar materials. As a result, coatings will be necessary to prevent corrosion of parts in the areas at which they interface. Such coatings will be dependent on the two materials that are in contact. Use of magnesium inners with aluminum outers on vehicle closures is one example of such an interaction. Magnesium is very susceptible to corrosion and must be coated before being introduced to aluminum.[26] In addition, the adhesive used between the two materials must provide some level of corrosion protection.[27]

Factors such as speed, cost, surface quality and reliability will need to be considered to determine the most applicable materials selection and joining technology for a particular vehicle. Engineers who are accustomed to traditional joining methods must become familiar with the tradeoffs and benefits of new joining methods required for mixed materials. An example of these tradeoffs in terms of joining cost and speed is shown in Figure 8.

Figure 8: Cost and Speed of Joining Technology with Consideration to Bonded Materials



Source: Dr.-Ing. Bernard Criqui, "Robust joining processes for series production today and tomorrow." Innovative Developments for Lightweight Vehicle Structures. Wolfsburg: Volkswagen, 2009. 190.

[25] http://www.thefabricator.com/article/laserwelding/laser-welding-structural-adhesive-bonding-for-body-in-white-assembly

[26] Ashley, S. (2010, April 6). Shedding pounds on a magnesium diet. Automotive Engineering International, pp. 34-36.

[27] SAE 2009-01-0037, Effect of Surface Pretreatments on Adhesive Bonding and Corrosion Resistance of AM60B, AZ31-H24, and AM30 Magnesium

4.3 Systems Level Engineering

Traditional methods to reduce vehicle weight revolve around material substitution, where one material is replaced by another. In material substitution, very little consideration is given to the effect a substituted part has on adjacent parts or other performance criteria of the vehicle beyond its primary function. As a result, material substitution has limited usefulness; risks evolve from making poor choices in new designs or materials. The alternative is to take a complete systems approach to vehicle design and material selection. Given the need for new lightweight materials, a systems approach will become critical to the implementation and development of new materials. There have been several research projects indicating that a systems approach will be necessary to maximize weight reduction while maintaining performance and cost.[28,29]

Engineers will need to understand and use systems analysis techniques to develop the next generation of lightweight vehicles. A cross-disciplinary education in manufacturing processes, material science, chemical engineering, and mechanical engineering will be needed to provide the level of knowledge required for proper analysis, design and engineering.

4.4 Computer-Aided Engineering

Steel has been a dominant material for the automobile, almost from the beginning of mass production. As such, there is a solid understanding of the mechanics and performance of the material, under a wide variety of conditions. This understanding has allowed for the creation of simulation models that accurately imitate real world data for areas such as formability and crashworthiness.

The manufacturing and performance characteristics of new lightweight materials and the joining processes are not as well understood. The introduction of new materials will require new simulation modeling techniques to capture the behavioral characteristics of those materials. In addition, close coordination of physical testing with simulation modeling will be needed to improve modeling for future use. All areas of modeling will need to be considered: forming, joining and assembly, static and dynamic vehicle performance, and crashworthiness.

4.5 Durability and Reliability

The introduction of new materials will bring a level of uncertainty to the design of new vehicles that must be tested, similar to computer-aided engineering. Durability and reliability testing will need to be refined to account for the behavior of these new materials. For example, replacing spot welds with adhesives introduces new challenges in terms of durability due to the unknown behavior of some adhesives subjected to fluctuating temperatures. A greater understanding of materials and their behavior in various environments will be needed to justify the inclusion of these materials and their assembly processes in new vehicles. This will be a key

[28] VolksWagen (2009). *Innovation Developments for Lightweight Vehicle Structures.*

[29] Lotus Engineering. (2010). *An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program.*

issue as more testing moves from the road and laboratory to computer-aided testing and analysis.[30,31] As a result, there will be a greater need for engineers who understand material characteristics through standardized testing.

To achieve the level of confidence required for inclusion into new vehicle design, fundamental analysis of new materials and their joining technology will be required. A good example of this kind of work is the Auto/Steel Partnership (A/SP). A/SP is a group of steel providers and automotive manufacturers that study the impact new steel grades have on vehicle manufacturability. The work done through A/SP allows new grades of steel to be utilized in vehicles with assurance that the performance criteria of the materials are well understood.[32] Partnerships like A/SP in other materials sectors will help in the education of automakers and material providers in determining the steps necessary to include new materials in vehicles. This information can then transfer to other industry engineers.

4.6 Manufacturing Processes

While traditional manufacturing techniques will still be a part of the automotive industry, new materials are going to force engineers to adopt new techniques and processes. For example, with the addition of magnesium and aluminum for body components, processes such as casting will become more important. A greater amount of composites, typically formed through a sheet molding compound process, may be used for components such as fenders and doors. Carbon fiber composites require sophisticated curing processes which are typically done in an autoclave.[33] All of these examples will require innovations to deliver parts and components made of these materials in a mass production vehicle. A list of materials and possible processes is provided (see Table 4). Engineers will need to consider a greater variety of manufacturing processes (particularly for composites, magnesium, and aluminum).

Table 4: Manufacturing Process and Material Compatibility

Process	Technique	Materials			
		Al	Steel	Plastic	Mg
Extrusion	Hot	*	*		*
	Cold	*	*		
	Direct	*	*		
	Indirect	*	*		
	Hydrostatic	*			*
Stamping	Progressive Die	*	*		

[30] Vasilash, G. (2009, Sept/Oct) Developing More Faster at Ford, Time Compression

[31] Monaghan, M. (2009, June) Lighter, Smaller, Cheaper…Safer, Automotive Engineering International

[32] Auto/Steel Partnership (2010) Advanced High-Strength Steel Applications Design and Stamping Process Guidelines

[33] http://www.compositesworld.com/articles/automating-and-optimizing-autoclave-cure

Process	Technique	Materials			
		Al	Steel	Plastic	Mg
	Deep Draw Die	*	*		
	Form Die				
	Compound Die				
	Hot				
Forging	Hot	*	*		*
	Cold	*	*		*
	Open-Die	*	*		*
	Closed-Die	*	*		*
	Press	*			*
	Upset	*	*		
	Induction	*	*		
Casting	Investment	*			
	Centrifugal	*			
	Gravity Die				*
	Sand	*			*
	Shell	*			*
	Spin			*	
	T-Mag				*
	Low Pressure Permanent Mold	*			*
	High Pressure Die	*			*
	Thixocasting	*			
	Thixomolding				*
	Squeeze				*
	Vacuum Die	*			*
Other	Powder Metallurgy	*			*
	Bending	*	*		
	Spinning	*	*		
Open Molding	Hand Lay-Up			*	
	Chopped Laminate Process			*	
	Filament Winding			*	
Close Molding	Compression Molding			*	
	Pultrusion			*	
	Reinforced Reaction Injection Molding			*	
	Resin Transfer Molding			*	

Process	Technique	Materials			
		Al	Steel	Plastic	Mg
	Vacuum Bag Molding			*	
	Vacuum Infusion Processing			*	
	Centrifugal Casting			*	
	Continuous Lamination			*	
Forming	Roll Forming	*	*		
	Cold Forming				
	Vacuum Forming				
	Thermoforming				
	Super Plastic Forming				
	Quick Plastic Forming	*			
	Hydro Forming	*			

Source: CAR Research

5. Workforce Skills and Development

The changing environment of automotive materials is going to require a new set of skills—from the fundamental study of material properties, all the way to impact on vehicle performance. This section will outline several job functions throughout the supply chain and how they will evolve.

5.1 Manufacturing Process and Material Research

Research into materials and manufacturing processes will require both evolving and additive skills. In many ways this has been an ongoing process since the first mass produced vehicle rolled off the assembly line. However, greater use of mixed materials and a reduction in mild steels will require greater focus on joining technology, as well as the impact joining of mixed materials has on long-term durability.

5.2 Engineering Design and Development

Design and development will continue to evolve as new materials are introduced into products. Greater emphasis will be placed on computer-aided engineering at all stages of design and development. In some cases, this will require new methods and approaches as new materials will demand new modeling techniques. In addition, design and manufacturing engineers are likely to merge skills to create one engineering profession. Design engineers will be asked to understand the manufacturing processes behind their parts and manufacturing engineers will be asked to understand the behavior of parts within the vehicle.[34]

Engineers will need to take a systems approach to vehicle and part design. With a mix of materials, simple material substitution will not work. Joining and other interactions between parts will require engineers to consider adjacent parts (at the very least) and in some cases, the entire vehicle, as it may impact total vehicle performance. The ability to take a systems-level view of vehicle design will be necessary for material optimization to succeed.

5.3 Tooling

Tool making will rely more heavily on computer-aided engineering. In the past, tool makers relied on a tryout period in which parts were made and measured to determine necessary modifications to the tool. To produce a suitable part, experienced tool makers would typically make changes based on their prior knowledge. With new materials that behave much differently than traditional materials, this is not possible. In addition, a reduction (or in some cases, elimination) of tool tryout is expected in the current environment. To achieve acceptable tool

[34] Interview with Custom Design

design, tool makers will need to have a greater understanding of material properties and the ability to develop tooling models to reduce tryout time.

5.4 Part Fabrication

Manufacturing process engineers will have to evolve to learn a greater variety of manufacturing processes. While traditional sheet stamping will continue to be a major process in automotive bodies, there are several niche manufacturing processes that will make their way into part production. A few examples of these new processes include: sheet hydroforming, hot stamping, cast aluminum and magnesium, sheet molded compound, and autoclaving. Closer relations between material providers and automotive manufacturers may be needed to provide the correct level of experience.

5.5 Assembly

The joining required between dissimilar materials is a major issue in mixed material vehicles. Assembly engineers will need to enhance their skills to understand and utilize new joining processes. These processes may mean a modification of existing ones (such as in the Lincoln MKT liftgate) or they may be entirely new processes (such as the steel doubler of the Composite Underbody Focal Project).[35,36]

Another unique characteristic of mixed material joining is the corrosion that can occur between the two different materials. Coating during the assembly process and the impact certain processes have on the selected coatings may require greater focus than it has in the past.

5.6 Vehicle Repair and Service

Repair and service technicians will need to evolve their skills to address the unique requirements of new automotive materials. For example, in the past, steel body structures could be heated, reformed, and cooled to provide parts that were close to their original shape and strength. Today's steel structures fatigue under heat and once heated do not regain their strength, making them unsuitable for use.[37] Consideration of the materials used in each part will be of greater importance as a greater variety of materials are introduced to the vehicle.

[35] Ashley, S. (2010, April 6). Shedding pounds on a magnesium diet. Automotive Engineering International, pp. 34-36.

[36] Berger, Libby, Hannes Fuchs, Erik Banks, and Ronald Wlosinski. "Development of a Structural Composite Unerbody." *Automotive Composites Conference and Exposition.* Troy, 2009.

[37] American Iron and Steel Institute. Advanced High-Strength Steel Repairabillity Phase I & II.

5.7 Vehicle Recycling

Over 95 percent of end-of-life vehicles are recycled—84 percent of the total weight of the vehicle.[38] With new materials, recyclers will need to develop new ways to identify and sort materials for reprocessing. In addition, recyclers must have a market for the recycled product. In some cases, recycling of new automotive materials will require new techniques. Most of the work involved in recycling will be in the upfront process planning. Recyclers who are able to develop techniques and create a secondary market may benefit from the introduction of new automotive materials.

5.8 Job Skills and Employment Trend

Table 5 shows the SOC codes for jobs most likely to be impacted by the use of advanced lightweight materials. The chart outlines the type of impact that will be experienced, as well as the importance of each position in the future.

Table 5: Lightweight Automotive Materials' Skill Impact on Workforce, and Expected Trends

			Skill Impact on Workforce			Expected Trend
Job Function	**Associated SOC Codes**	**Description**	**Evolving**	**Additive**	**New**	
Production	49-9044	Millwrights	X			Neutral
	51-2041	Structural Metal Fabricators & Fitters	X			Increasing
	51-2091	Fiberglass Laminators & Fabricators	X			Neutral
	51-4011	Computer-controlled Machine Tool Operators, metal & plastic	X			Increasing
	51-4021	Extruding & Drawing Machine Setters, Operators, & Tenders, metal & plastic	X			Increasing
	51-4022	Forging Machine Setters, Operators, & Tenders, metal & plastic	X			Increasing
	51-4023	Rolling Machine Setters, Operators, & Tenders, metal &	X			Increasing

[38] Vehicle Recycling Partnership. (n.d.). Retrieved from USCAR: http://www.uscar.org/guest/view_team.php?teams_id=16

Job Function	Associated SOC Codes	Description	Skill Impact on Workforce			Expected Trend
			Evolving	Additive	New	
		plastic				
	51-4031	Cutting, Punching, & Press Machine Setters, Operators, & Tenders, metal & plastic	X			Increasing
	51-4041	Machinists	X			Increasing
	51-4061	Model Makers, metal & plastic	X			Neutral
	51-4062	Patternmakers, metal & plastic	X			Neutral
	51-4071	Foundry Mold & Coremakers	X			Neutral
	51-4072	Molding, Coremaking, & Casting Machine Setters, Operators, & Tenders, metal & plastic	X			Neutral
	51-4111	Tool & Die Makers	X			Neutral
	51-4199	Other Metal Workers & Plastic Workers	X			Increasing
	15-1031	Computer Software Engineers, applications	X			Increasing
	51-4121	Welders, Cutters, Solderers, & Braziers	X			Increasing
	51-4122	Welding, Soldering, & Brazing Machine Setters, Operators, & Tenders	X			Increasing
	51-4191	Heat Treating Equipment Setters, Operators, & Tenders, metal & plastic	X			Neutral
	51-4193	Plating & Coating Machine Setters, Operators, & Tenders, metal & plastic	X	X		Neutral
Mfg Eng.	17-2081	Environmental Engineers	X			Increasing
	17-2111	Health & Safety	X			Increasing

Job Function	Associated SOC Codes	Description	Skill Impact on Workforce			Expected Trend
			Evolving	Additive	New	
		Engineers				
	17-2112	Industrial Engineers	X			Increasing
	19-4031	Chemical Technicians	X	X		Increasing
R&D Product Engineering	15-1031	Computer Software Engineers, applications	X	X		Increasing
	17-2041	Chemical Engineers		X	X	Neutral
	17-2081	Environmental Engineers	X			Neutral
	17-2131	Materials Engineers		X	X	Neutral/Decreasing
	17-2141	Mechanical Engineers	X	X		Neutral/Decreasing
	17-2199	Other Engineers	X			Neutral/Decreasing
	19-2031	Chemists		X	X	Increasing
	19-2032	Material Scientists		X	X	Increasing
	27-1021	Commercial & Industrial Designers	X	X		Increasing

Source: CAR Research

6. Conclusions

There is no doubt that lightweight material usage will increase in the years ahead. Due to cost constraints, high-strength steels will continue to be the biggest contributor to lightweighting. Other materials will begin to see a greater role when high-strength steels are pushed to the limit of their capabilities (e.g., stiffness). Materials such as aluminum, composites and magnesium will then be adopted more readily. It is likely that these materials will require a more systems approach to design and manufacturing, as they will need to interact with each other.

There were several skills identified during the study. Fundamentals of material properties, systems engineering, computer-aided engineering and manufacturing systems were all identified as skills needed for the adoption of new lightweight materials. Knowledge on the fundamentals of material properties may lead to the creation of new alloys and composites. Understanding fundamental properties will also aid in the development of new simulation models—a key barrier to adoption in the industry. The mix of new materials will require a systems approach to material selection. As lightweighting becomes more aggressive, the interaction of a wide variety of materials is likely. An optimized design will most likely require a systems approach of the entire vehicle. Computer-aided engineers will need to work with a new set of tools to accommodate a growing list of materials. In addition, these materials will interact with each other in ways they have not previously. Finally, new manufacturing systems will need to be developed to handle the mass production and joining of dissimilar materials.

Many engineers and technicians have a basic skill set in the areas necessary to adjust to new lightweight vehicle designs. The largest training benefit to the workforce would be through certification or lifelong learning programs. These programs could be focused on fundamental material properties, systems engineering and manufacturing processes.