european
aluminium association

ALUMINIUM IN CARS

FOREWORD: POSITION OF THE EUROPEAN ALUMINIUM INDUSTRY ON CO_2 & CARS

The aluminium industry recognises the need for a drastic reduction of the GHG emissions to counter ongoing climate changes and has taken appropriate actions:

In the production of primary aluminium, continuous efforts to reduce specific GHG emissions led to significant savings: -7.7% between 2002 and 2005[1]. Furthermore, the aluminium industry recycles all available scrap, saving 95% of primary energy input and GHG emissions.

Transportation is a significant source of CO_2 emissions with individual transportation (cars) producing a major share of it. Among the many measures to reduce CO_2 emissions from cars, technological ones (i.e. the ones that are intrinsic to the car and do not depend on driver behaviour) are the most reliable. Light-weighting is one of the most effective and directly impacts CO_2 emissions, as **100kg saved on the mass of a car is equivalent to a reduction of 9 grams of CO_2 per kilometre**.

The European Automotive industry, in close co-operation with the European Aluminium industry, has developed and introduced numerous innovative light-weighting solutions based on aluminium and aluminium alloys. By the intensive use of safe and cost efficient light-weight aluminium concepts which can be applied with little adaptations across all car models, the European producers have taken technological global leadership in the light-weighting of passenger cars.

The aluminium industry supports ambitious CO_2 reduction targets for cars and is prepared to increase joint development efforts with the Automotive industry and expand its European production capacity to cope with increasing market demand.

For car buyers, fuel consumption is seldom the dominant purchasing decision criteria despite its huge impact on operating costs and the well known environmental consequences. Therefore it would be unfair to put car manufacturers under pressure without educating the public, encouraging and stimulating the demand for low CO_2 emitting cars through appropriate incentives.

The aluminium industry welcomes regulatory & fiscal initiatives aimed at stimulating the demand for low CO_2 emitting cars.

[1] EAA report "Sustainability of the European aluminium industry 2006"

CONTENTS

1. REDUCING MASS IS NECESSARY TO REDUCE CO_2 EMISSIONS

1.1. VEHICLE MASS DIRECTLY IMPACTS FUEL CONSUMPTION

Weight reduction directly reduces the energy consumption because the energy required to move a vehicle is, except for aerodynamic resistance, directly proportional to its mass.

On average, 100kg mass reduction achieved on a passenger car saves[b]:

- 0.35 litre of fuel per 100km
- 9 grams of CO_2 per km at the car exhaust pipe

When including emissions for fuel production & supply (well-to-wheel), 100kg mass reduction achieved on a passenger car saves:

- 10 grams of CO_2 per km

$$F = F_W + F_R + F_G + F_A$$

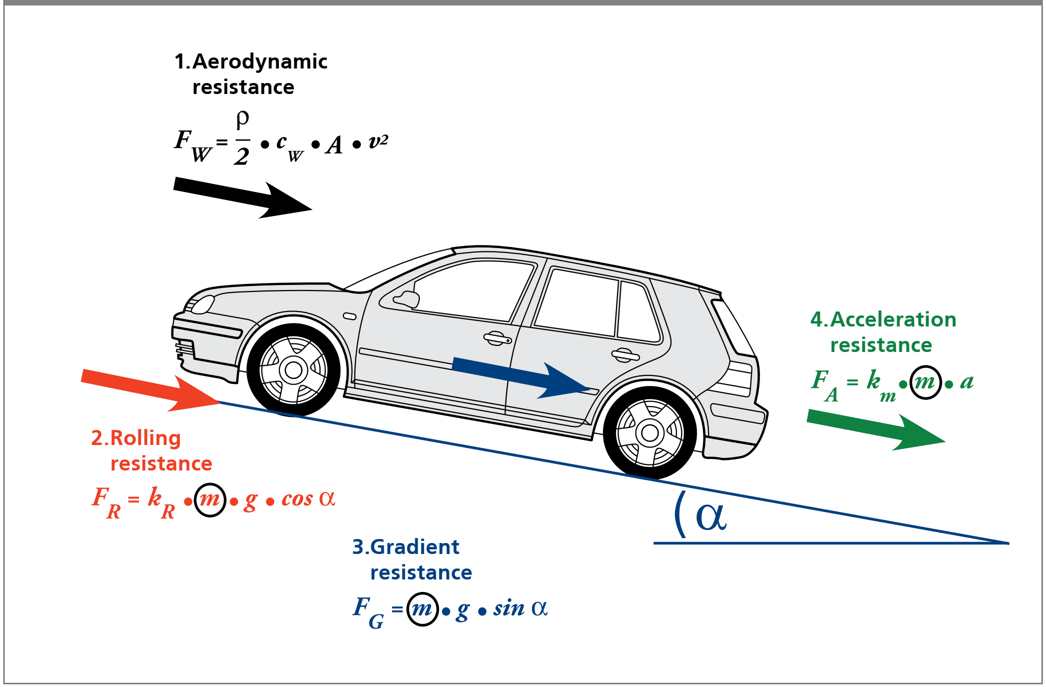

Figure 1: Resisting forces

[b] These figures are material-independent and slightly vary depending on specific factor such as vehicle type, driving cycle, etc.. They assume the following average values for petrol and diesel:
- The combustion of 1 litre of fuel emits 2.5kg of CO_2 at the car exhaust pipe
- 1 litre of fuel represents 2.8kg of CO_2 from well-to-wheel

1.2. EUROPEAN VEHICLES ARE GETTING HEAVIER - THE WEIGHT SPIRAL

Despite its impact on fuel consumption, the average mass of European vehicles has dramatically increased, as illustrated in Figure 2. The weight increase is basically due to more stringent legislative requirements and changing customer demands (growing vehicle size, extra comfort & safety devices, etc) that, in turn, have caused an increase weight of other components (e.g. engines, transmission, brakes) to reach the envisaged performance level. This phenomenon is known as the "weight spiral".

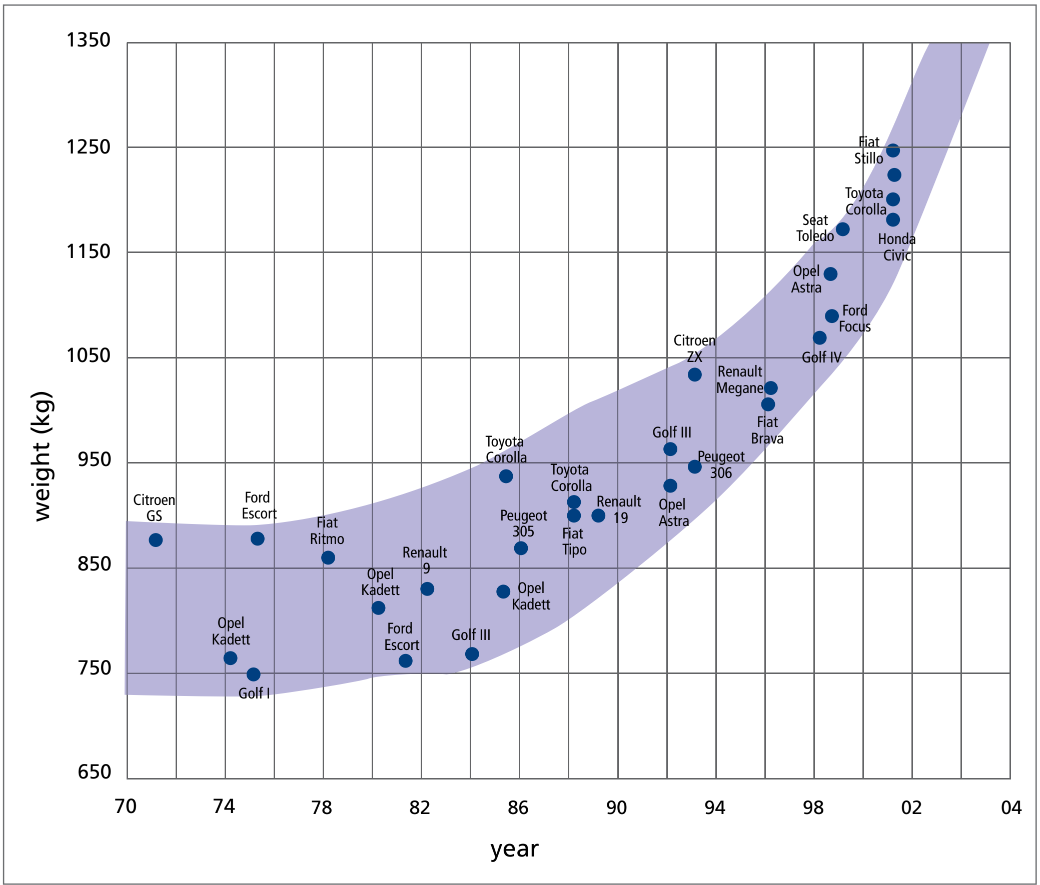

Figure 2: Evolution of weight in the compact class

1.3. VEHICLE MASS REDUCTION POSSIBILITIES

In order to invert this weight spiral, a reduction of the vehicle mass is therefore a necessity. The fuel saving potential through reduced vehicle mass is significant. Weight reduction without any change of the functionality of the car can be realised not only through the substitution of a heavier material by a lighter material, but also by the introduction of new design and manufacturing concepts or, in the ideal case, by a combination of these measures.

2. REDUCING MASS HAS ADDITIONAL BENEFITS

2.1. ACCELERATION

Keeping the car acceleration performance constant, which is generally reflected by the power-to-weight ratio, saving weight allows downsizing of the power train (engine, transmission, axle differential etc…) and thus provides additional weight savings.

Keeping the power train unmodified, reduced weight increases the power-to-weight ratio and therefore improves acceleration.

2.2. BRAKING

Keeping braking power constant, light-weighting shortens braking distance.

Keeping the braking performance constant, light-weighting allows downsizing of the brakes, which offers further weight saving potential.

2.3. HANDLING

Road handling is improved by light-weighting in many different ways:

- Handling of a lighter car is easier in demanding driving situations.
- Reducing body weight lowers the centre of gravity improving the car's stability and reducing the risk of roll-over.
- The optimal weight distribution between front and rear axle being 50:50 and the front axle being usually overloaded, using light-weight aluminium components for the front parts of cars is particularly beneficial.

2.4 DRIVING COMFORT

Saving weight on unsuspended parts like wheels increases driving comfort.

3. ALUMINIUM IS THE IDEAL LIGHT-WEIGHTING MATERIAL

3.1. ALUMINIUM PROPERTIES

With 2,700 kg/m^3, the density of aluminium is one third of that of steel. But such a weight reduction is seldom achieved since for a large number of parts, it is necessary to increase the average thickness of aluminium compared to steel to achieve the same part characteristics.

The most frequently encountered ratio of thickness in structural applications is approx. 1.5, which means for instance that 0.8 mm steel component can be replaced by a 1.2 mm aluminium component: in this case, the weight reduction is still 50%.

However, the relationship between the material properties and the strength, stiffness and weight of a component is very complex and can be strongly influenced by the part geometry so that there is no absolute rule. In practice, it will be necessary to consider each component individually to determine the actual weight reduction potential. The following section further illustrates this fact.

3.2. PRIMARY WEIGHT SAVINGS

Aluminium allows a saving of up to 50% over competing materials in many applications.

Typical relative[c] and average absolute weight savings of today's main aluminium applications in mass-produced cars are given below.

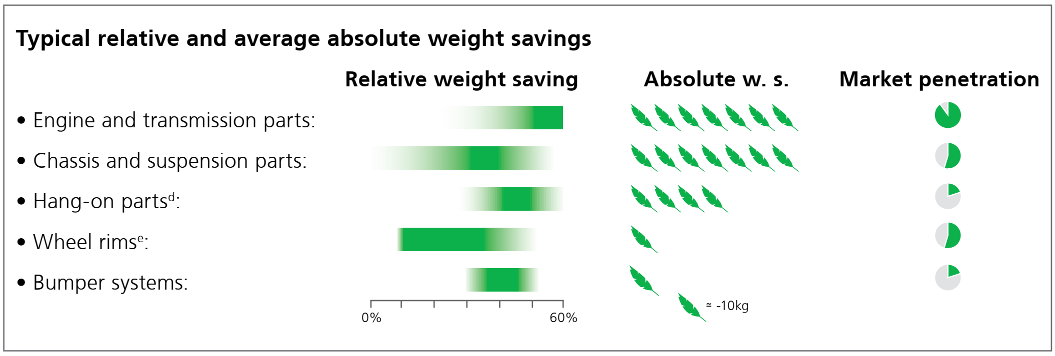

Figure 3

For niche models, full aluminium bodies allow saving 30-40% weight, and between 70 and 140kg, depending on the size of the car.

[c] Relative to the weight of substituted parts
[d] Doors, bonnet, wings, boot
[e] Wheel rims are presently not always weight-optimised. However, 50% weight saving is achievable.

3.3. SECONDARY WEIGHT SAVINGS

Keeping a car's performance constant, primary weight savings allow downsizing of other car parts (powertrain, brakes, fuel tank, crash management systems etc…), leading to so called "secondary weight savings".

In case the primary weight savings achieved on a defined vehicle are small (i.e. when only little aluminium is used) secondary weight savings are not likely to be achieved by car manufacturers.

On the other side, when aluminium is intensively used, secondary weight savings can exceed 50%. For example, in the case of the Audi A2, the intensive use of aluminium allowed direct weight savings of 134kg that allowed 75kg secondary weight savings thanks to drivetrain, motor and chassis downsizing.

3.4. TODAY'S CARS CONTAIN 132KG OF ALUMINIUM

Besides well-known aluminium-intensive cars like the Audi A8, which contains about 520kg of aluminium or the Jaguar XJ, many cars contain significant amounts of light metals.

A recent study by Knibb, Gormezano & Partners (KGP) in cooperation with the European Aluminium Association shows that the amount of aluminium used in new European cars has risen from 50kg in 1990 to 132kg in 2005 and is predicted to grow by another 25kg by 2010.

The study is based on the analysis of car models representing a European production volume of 15 million units in 2005. Key results are summarized in Figure 4.

CAR BODY

- 20 components analysed
- highest alu application
  - bonnets & doors
  - front structure
  - bumper beams
- aluminium content = 26kg

CHASSIS & SUSPENSION

- 17 components analysed
- highest alu application
  - wheels
  - suspension arms
  - steering system
- aluminium content = 37kg

DRIVETRAIN

- 25 components analysed
- highest alu application
  - engine block & cylinder head
  - transmission housings
  - radiators
- aluminium content = 69kg

TOTAL ALUMINIUM CONTENT = 132KG

Figure 4: Results of KGP study for cars produced in 2005

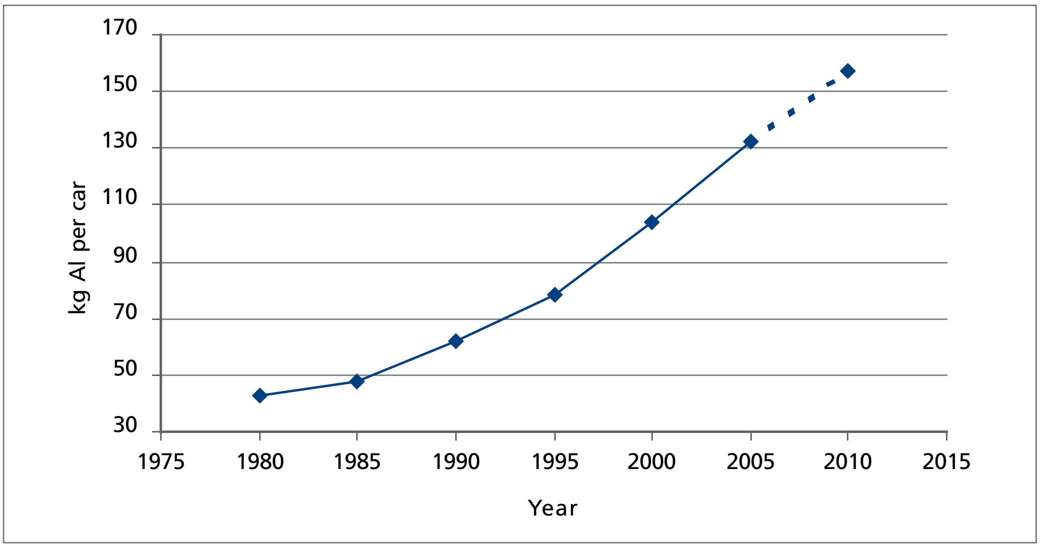

Figure 5: Evolution of aluminium content in European cars

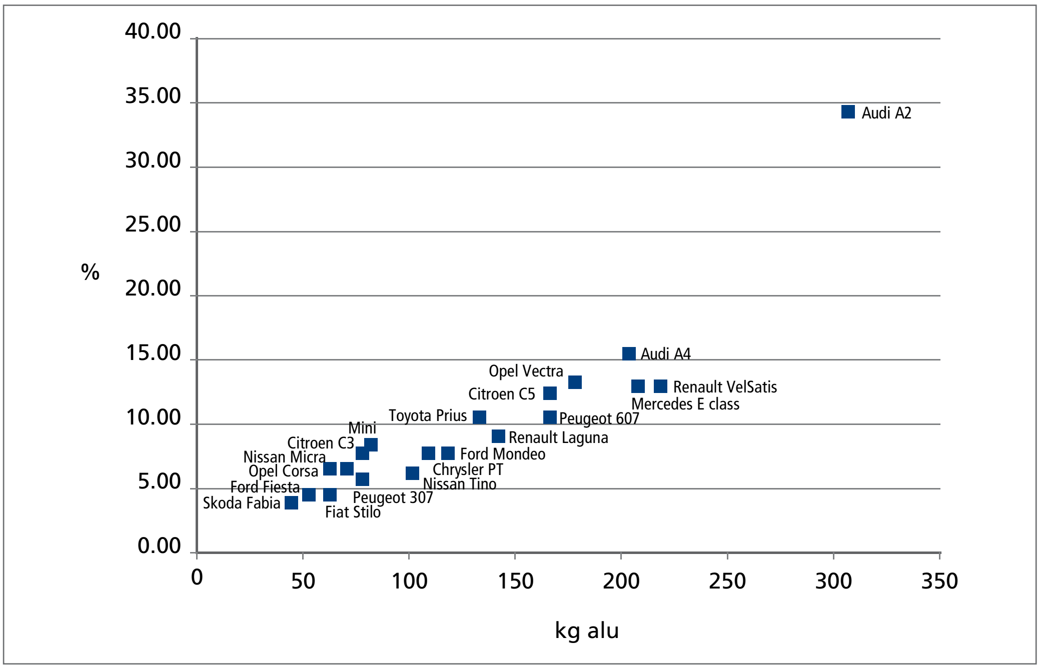

Figure 6: Aluminium content of some European cars

3.5. TOMORROWS CARS COULD EASILY BE 40KG LIGHTER

Innovative, safe and cost efficient light-weight aluminium bonnets, wings, doors and bumpers can be found across all car models today. For these parts, switching to aluminium is relatively easy and does not need full re-engineering of the car. Together, their light-weighting potential exceeds 40kg per car. However, penetration in the market is less than 20%.

In practice, material substitution is generally connected to a model change where extensive re-design takes place anyway. Mixed material design does not present bigger problems provided appropriate design and manufacturing measures are taken. Thus, the weight saving potential could be even significantly greater.

3.6. ALUMINIUM FRONT STRUCTURES IN THE MEDIUM TERM?

Aluminium front structures are already used in sport and executive cars today.

In a recent study from the Institut für Kraftfahrwesen- University of Aachen (IKA), aluminium front sections for medium sized cars were examined. Numerical simulations made on a reference car indicate a minimum weight reduction potential of 35%. In a progressive approach, the design space was expanded as far as possible with respect to the major package components of the reference vehicle to allow more design freedom and encourage innovative ideas. In this case, a weight reduction potential of 41% was achieved, with a significant increase in stiffness plus improved energy absorption in case of a crash. Thus, even if this weight reduction potential cannot be fully realised, aluminium front structures are clearly a most interesting future application for aluminium.

Figure 7: Aluminium front structure

3.7. LONG TERM VISION: INVERTING THE WEIGHT SPIRAL

The Alumaximised Car study was carried out by IKA, University of Aachen, to determine what sort of weight saving is achievable in a car designed to make optimum use of aluminium wherever possible. The results are quite significant; the 'Alumaximised' car is remarkably lighter than the reference model. The reference car, an amalgam of five popular small family cars, weighs 1.229kg without fuel or occupants. The 'Alumaximised' car's final weight, after primary and maximum secondary weight savings, is just 785kg.

It is therefore possible and it is high time to invert the "weight spiral".

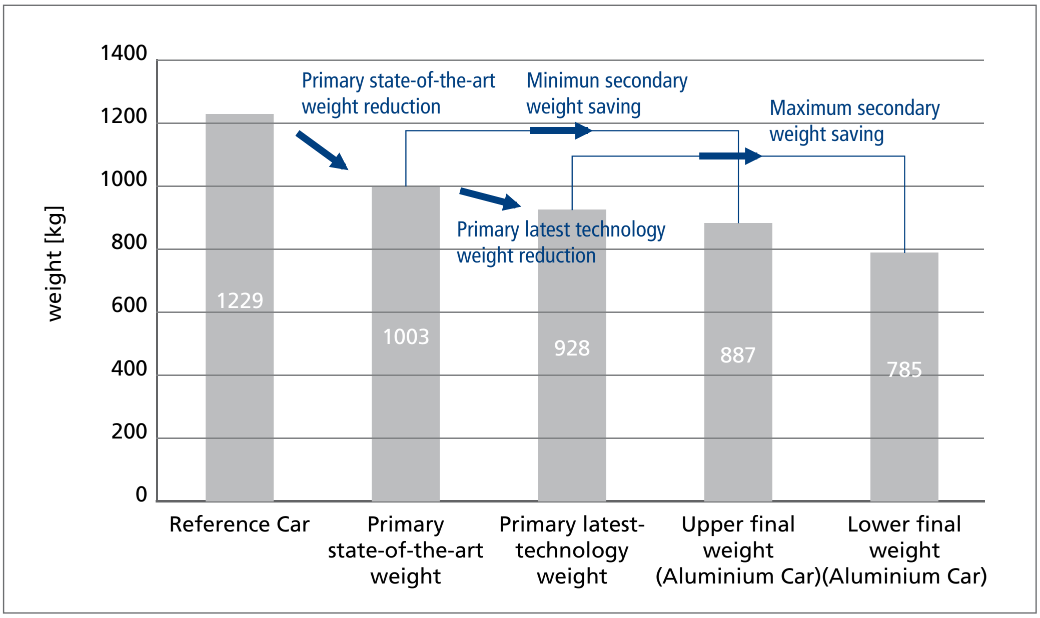

Figure 8

3.8. POTENTIAL OF ALUMINIUM APPLICATIONS IS ENDLESS

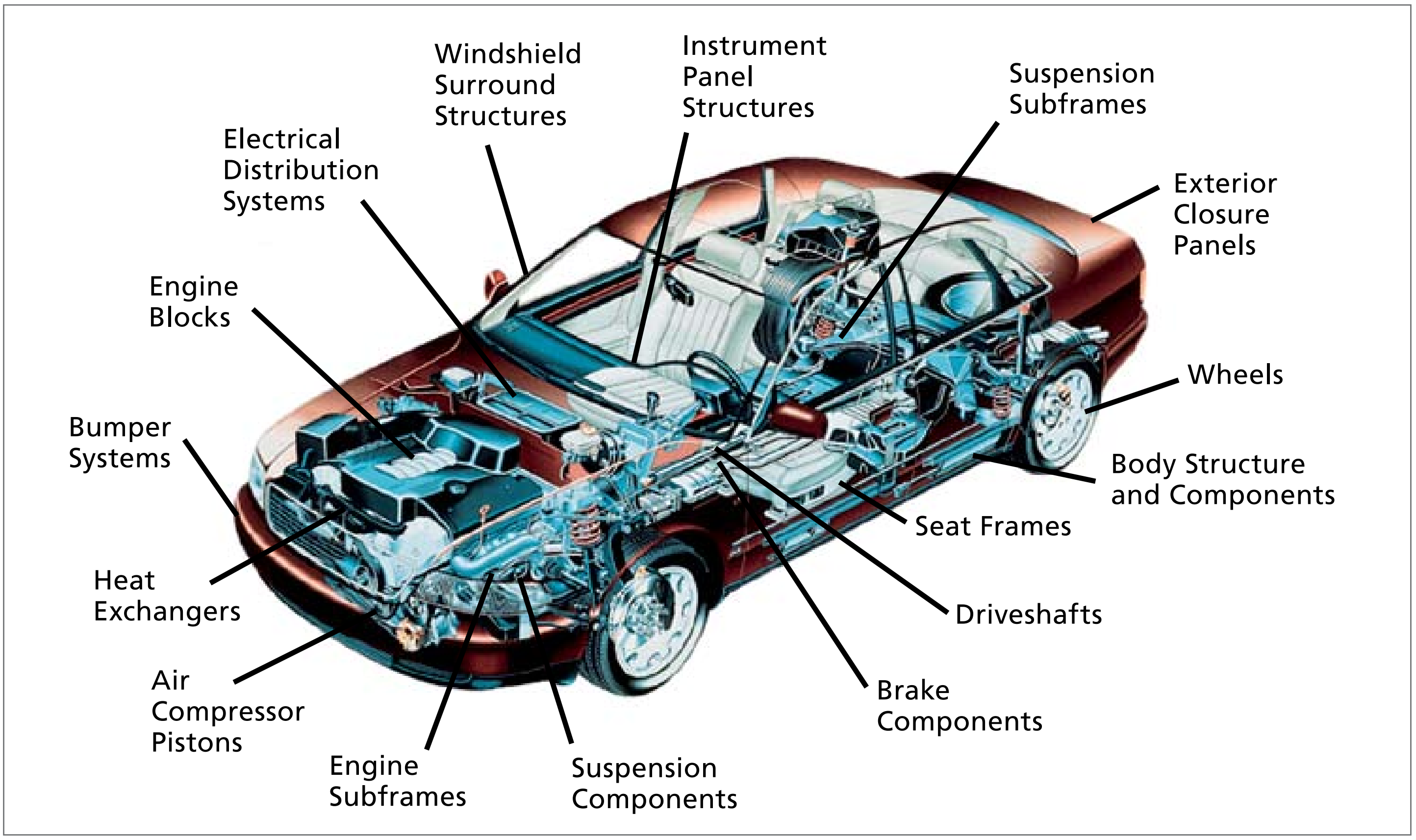

Figure 9: Aluminium applications

4. ALUMINIUM AND SAFETY PERFORMANCE

4.1. CRASH DESIGN IS COMPLEX

Today's vehicles have to fulfil different and more and more stringent crash test requirements (e.g. EuroNCAP, IIHS etc.). Two of the most important vehicle crash tests are the front and the side impact. The front crash load path starts at the bumper and proceeds via the longitudinal beams to the centre area of the vehicle. For a side impact, the load path starts at the doorsill and the B-pillar[f] and proceeds via the crossbeams in the floor and the roof area to the other side of the vehicle. So, in these two examples very different body components are a part of the load paths. This shows the complexity of the crash design for vehicle body structures.

But car safety is not only a question of the applied material; even more important is the design and assembly concept. In the development of the body, it is most important to find a suitable compromise between structural stiffness, crash energy absorption capability and further body requirements (e.g. package, etc.).

4.2. ALUMINIUM IS WELL SUITED FOR CRASH MANAGEMENT SYSTEMS

Aluminium is well suited to solve these often conflicting goals with maximum performance and the lowest possible mass. The mass-specific energy absorption capacity of aluminium is twice that of mild steel and compares also favourably to the newly developed high strength steel grades. Proper alloy selection ensures that the aluminium components deforms heavily before crack formation starts and the part eventually factures.

To increase the chances of survival in an accident, vehicles include a stiff, stable passenger cell to ensure survival space and surrounding deformation zones where the crash energy can be absorbed to a maximum amount. The high rigidity of an aluminium structure compared to a steel design is the result of the higher material thickness (aluminium components are generally about 50% thicker) and in particular the possibility to use closed multi-hole extrusions and high quality die castings of sophisticated design (which also allows the elimination of joints). Depending on the available package space, it is therefore still possible to improve the rigidity of the entire structure while maintaining a weight reduction of up to 40 – 50 %. The same principles also apply to pedestrian protection where properly designed aluminium front end structures and bonnets help to prevent injuries and reduce the risk of fatality.

4.3. VEHICLES COMPATIBILITY

Last but not least, vehicle safety strongly depends on the compatibility between vehicles or obstacles involved in an accident. The first important thing in case of a crash is that the obstacle makes contact with the vehicle at the height of its bumpers. The compatibility of bumper heights of all road users is therefore a key criterion for safety. This is a material independent requirement, but lightweight aluminium designs offer the possibility to improve this aspect. It is important to then consider the respective masses of the different vehicles. The use of a heavier vehicle is generally safer for its occupants, but it is significantly more dangerous for the lighter road users. Light-weighting all vehicles while keeping their size would improve the survival rate for all road users.

[f] I.e. the pillar between the front and rear door connecting the floor structure and the roof .

5. ALUMINIUM IS SUSTAINABLE

5.1. ALUMINIUM IS EASY TO RECYCLE

Aluminium is easy to recycle and saves 95% of the energy necessary to produce primary aluminium.

RWTH-Aachen recently analyzed the aluminium recycling process and concluded that 95% of the aluminium contained in end-of-life vehicles can be recovered by mechanical processing in modern shredder and non ferrous metal recovery plants[g].

The End-of-Life vehicle dismantling and aluminium recycling process[h] is summarised in Figure 10. Aluminium recycling from end-of-life vehicles is an established and profitable business and the proceeds from the recycled aluminium are a most important factor in the economy of the car recycling.

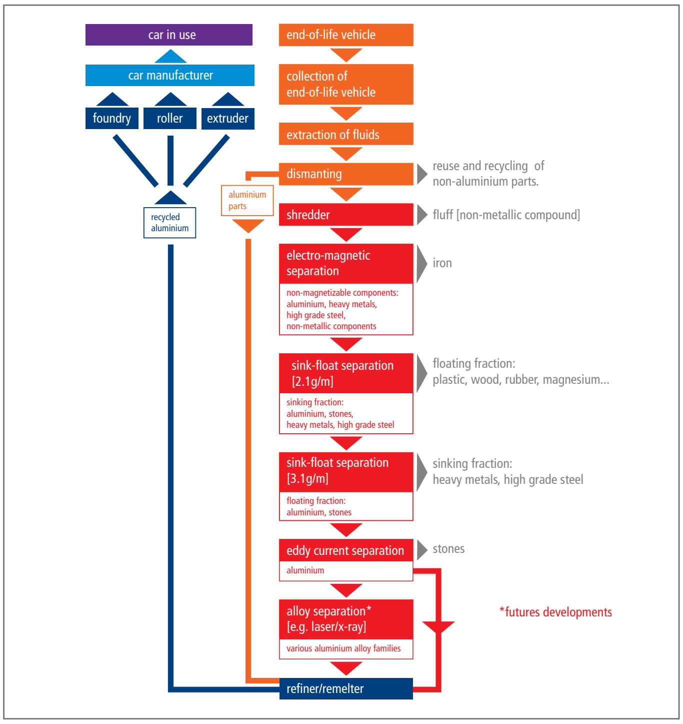

Figure 10: End-of-Life Vehicle Dismantling and Aluminium Recycling Process

5.2. LIFE-CYCLE CO_2 SAVINGS

We assume a driving distance of 200.000km and 20% secondary weight savings.

Based on the 2 million tons of aluminium components put on the road in 2005:

- each kg of aluminium provided an average light-weighting of 1kg.
- 1kg of aluminium in a car reduces CO_2 emissions by 20kg during its use phase.
- 1kg of aluminium in a car reduces CO_2 emissions by 19kg during its whole life-cycle.

Several detailed case studies can be found in the paper "Improving Sustainability in the Transport Sector Through Weight Reduction and the Application of Aluminium" recently published by the International Aluminium Institute and downloadable from www.world-aluminium.org

5.3. COST CONSIDERATIONS

Assuming an average fuel cost of 1.20€ per litre, every kilogram saved on the mass of a European car saves more than 8€ over 200.000km through fuel saving.

However, today's price premium accepted by car manufacturers does in general not exceed 4€ per kg saved on family cars. This is because first car buyers are focused on purchase price and do not care enough about total life cycle cost, fuel consumption and CO_2 emissions.

Regulatory & fiscal initiatives aiming to stimulate the demand for low CO_2 emitting cars are therefore necessary.

Several of today's aluminium applications are already affordable (i.e. between 2 and 4€ per kg light-weighting) and easy to apply (hang-on parts), so that a fast upgrade to aluminium is possible.

The industry is also working on reducing the cost of other aluminium applications presently used in sport and luxury cars, so that they could also find their place in smaller cars.

[g] This figure does not include aluminium losses within smelting and refining processes.
[h] Aluminium Recycling in Europe, the Road to High Quality Products (OEA-EAA 2007)
[i] An end-of-life recycling rate of 95% is assumed for aluminium and competing materials

6. ALUMINIUM AND COMPETITIVENESS OF EUROPEAN INDUSTRY

The European Automotive industry, in close co-operation with the European Aluminium industry, has developed and introduced numerous innovative aluminium light-weighting solutions. A key success factor is the product-specific development and selection of the proper aluminium alloys and the consistent reproduction of the required quality level for the various product forms (sheets, extruded sections, castings, forgings, etc.). Most important is also the full exploitation of aluminium-specific design possibilities and the introduction of manufacturing methods highly suited for forming, machining, assembly and surface finishing of aluminium components. Intensive joint research and development activities have enabled the practical use of safe and cost efficient light-weight aluminium concepts both in high volume production and in the manufacturing of small series and niche vehicles. These solutions can be applied with little adaptation across all car models.

The European producers have taken technological global leadership in the light-weighting of passenger cars with aluminium. Europe is the leader for aluminium body applications, in chassis and suspension, bumper systems, etc., to name just a few. An important element proved to be the joint R&D efforts of both the Automotive and the Aluminium industry, often facilitated by the support of the European Commission.

Figure 11 further illustrates this fact, taking the example of car body applications.

Increasing Complexity ↓

Aluminium Application		Aluminium Share			Main Drivers for Aluminium
		Europe	N.America	Asia	
Bonnets		18%	8%	3%	Weight Reduction Driving Dynamics Pedestrian Safety
Wings		4%	1%	< 1%	Weight Reduction Pedestrian Safety
Doors & Boot lids		2%	1%	< 1%	Weight Reduction Ease of Handling Driving Dynamics
Structure Front structure		2%	0%	2%	Weight Reduction Driving Dynamics Front Axle Load
Roofs (incl. hard tops)		< 1%	0%	< 1%	Weight Reduction Driving Dynamics

Figure 11: Europe leads vehicles light-weighting

Europe should therefore safeguard its competitive advantage and remain the pioneer of vehicle light-weighting.

7. ALUMINIUM SUPPLY

Aluminium supplies will continue to meet the demand because:

- Current reserves of bauxite, used to produce primary aluminium, will last for many generations
- The amount of aluminium available for recycling is constantly increasing
- The production capacity of aluminium (primary, recycling, casting, extrusion and rolling…) is ready to match the automotive industry's increasing demand

8. CONCLUSION

Because the average mass of passenger cars has dramatically increased since the 70's and because vehicle weight directly impacts fuel consumption, light-weighting is necessary more than ever to reduce CO_2 emissions. 100kg mass reduction achieved on a car saves 9 grams of CO_2 per km at the exhaust pipe.

Aluminium is the ideal light-weighting material as it allows a weight saving of up to 50% over competing materials in most applications without compromising safety.

Today's European cars contain an average of 132kg of aluminium components. In the short term, many additional aluminium applications could be realised without significant re-engineering and extensive cost impact (e.g. by the use of more aluminium hang-on parts). This could easily reduce the average weight of the cars produced in Europe by 40kg.

The industry is working on reducing the cost of other aluminium applications, in particular in the body structure and for chassis and suspension parts, presently used in sport and luxury cars, so that they can also find their place in smaller cars.

As a long term vision, an "Alu-maximised" small family car could be 30-35% lighter after primary and maximum secondary weight savings.

Together, the European Automotive and Aluminium industries are worldwide leaders in respect to the development and application of innovative, safe and cost efficient light-weighting aluminium solutions. They should safeguard this competitive advantage and remain the pioneer of vehicle light-weighting.

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