Life Cycle Assessment of Magnesium Components in Vehicle Construction

Executive Summary

DLR

Title	Life Cycle Assessment of Magnesium Components in Vehicle Construction – Executive Summary
Date	May, 8th, 2013
Author	Simone Ehrenberger
With contribution from	Dr. Hajo Dieringa (Helmholtz Centre Geesthacht), Prof. Dr. Horst E. Friedrich

German Aerospace Centre e.V.
Institute of Vehicle Concepts
Prof. Dr.-Ing. H. E. Friedrich
Pfaffenwaldring 38-40
D-70569 Stuttgart, GERMANY

Tel.: +49 (0)711/6862-256
Fax : +49 (0)711/6862-258

Simone Ehrenberger
+49 (0) 711/6862-412
+49 (0) 711/6862-258
simone.ehrenberger@dlr.de

1 The IMA LCA Study

Magnesium has considerable potentials as lightweight material for many applications. It offers valuable advantages in transport. Looking for strategies to lower emissions from the transport sector, we find lightweight design to be one of the key solutions to increase the efficiency of road vehicles, trains or aircrafts. In order to evaluate ecological benefits from lightweight design and to prevent trade-offs between single life stages, potential advantages and disadvantages from such materials have to be weighted for the whole life cycle.

This executive summary presents the main results of the study “Life cycle Assessment (LCA) of Magnesium in Vehicle Construction” which has been initiated by the International Magnesium Association (IMA). The study analyses the entire life cycle of magnesium components for two exemplary transport applications. This includes the production of primary magnesium, alloying, component production, use phase and the end-of-life of magnesium components. For the use phase, examples for vehicle and aircraft components are selected to show benefits compared to aluminium. The results of the study provide up-to-date information about potentials concerning energy and emissions for the use of magnesium. Therefore the study aims to provide valuable information for producers, manufacturers and end-users to design and determine the magnesium process with reliable data. The overall results of the study can be found in a detailed report which includes data for the life cycle inventory as well as results of the impact assessment.

The study follows the standards for life cycle assessment ISO 14040 and 14044. The report includes a critical review by an external reviewer (Dr. Hans-Jörg Althaus, Switzerland) with broad experience in LCA of metals and transport. The critical review report is part of the full report of this study and concludes that the study and its documentation comply with the ISO 14044 standard in all relevant matters.

2 Goal and Scope

The study is divided in four parts (Figure 1): magnesium production, production of two exemplary components, the use of these components in a gasoline passenger vehicle and a mid-haul aircraft and the end-of-life of vehicle components. The life cycle of the magnesium components is compared to the same parts made from aluminium. The models for all life cycle steps include all upstream processes which are needed to provide energy and material inputs for magnesium use. The study intends to provide up-to-date and reliable data and results on magnesium production, processing and the end-of-life of magnesium car components. In general, for the core processes of magnesium production, processing and end-of-life, primary data from various sources has been used. Figures for upstream processes and for data gaps are taken from literature and the ecoinvent database 2.2.

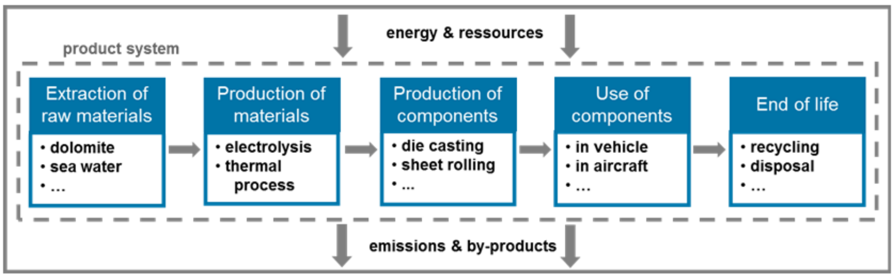

Figure 1: Overview of magnesium life cycle for transport applications

The four life cycle steps of magnesium are analyzed separately. The analysis of the magnesium production is a cradle-to-gate assessment. Assessing these two production routes with up-to-date data, we provide a representative and up-to-date evaluation of present magnesium production. The alloy and component production as well as the end-of-life stage are analyzed gate-to-gate. Two exemplary magnesium applications are analyzed: a steering wheel frame produced via die casting for the use in a passenger car and door parts made via sand casting for the use in an aircraft. The door parts are a gearbox and a seal closer for each of top and bottom of an aircraft door. Both examples represent components that are currently in use in automotive and aviation applications. The alloy production is assessed as separate process step, but in practice the alloys can be created directly at the magnesium production site as last process step of magnesium primary production. The calculation of the use stage of the components presented above is evaluated in terms of greenhouse gas emissions. The entire life cycle of the parts from cradle to grave is evaluated for the steering wheel used in a passenger car. The analysis of the aircraft parts focus on production and the break-even point for the comparison of magnesium and aluminium parts during aircraft operation. The evaluation of the end-of-life of magnesium parts in vehicles and the recycling aims to assess a representative recycling path for magnesium components in vehicles in a gate-to-gate approach. The further use of magnesium as alloying element for aluminium is analyzed as standard path for today's end-of-life of magnesium components. Additionally, we analyze the recovery of primary magnesium as an alternative path.

The impact assessment for magnesium production, processing and end-of-life includes four impact categories. For all impact categories, we use the CML 2001 method. Focus of this study and of the discussion of the results of the impact assessment is the global warming potential. For the impact assessment of greenhouse gas emissions (GHG), all emissions relevant for the greenhouse effect are calculated as kg carbon dioxide equivalents (CO_{2eq}) for a time horizon of 100 years. The overall analysis of the components' life cycles and the comparison with aluminium is restricted to this category. Additionally, we calculate the results for the potentials of acidification (SO_{2eq}) and eutrophication (PO_{4eq}). The fourth category calculated in this study is depletion of abiotic resources (kg Sb_{eq}).

3 Analysis of Primary Magnesium Production

Pidgeon Process

For the magnesium primary production, recent technology developments and alternatives are evaluated. We develop a life cycle inventory for the production via Pidgeon process in China which represents the production in 2011.Coal as energy source is only used for the calcination process. For other process steps, coke oven, semi coke oven, producer or natural gas are used.

The plants running with natural gas use coal powder as energy carrier for the calcination process for economic reasons. For other gas fuels, the use of gas in the calcination furnace can be seen as standard in short-term, because there are no economic reasons for the use of coal. The impacts of this assumption as well as of a variation of other parameters, like gas composition, are subject to a sensitivity analysis.

Figure 2 shows the greenhouse gas emissions of the Pidgeon process. The fuel gas and electricity consumption as well as transports are allocated to the single process steps. Clearly, the production of ferrosilicon (FeSi), the calcination of dolomite and the reduction itself are the most GHG-emission intensive life cycle steps. The weighted result for greenhouse gas emission of the Pidgeon process in 2011 is 25.8 kg CO_{2eq} / kg Mg. The weighting considers the annual production volume of each of the scenarios. Regarding the contribution to the results for acidification, eutrophication and resource depletion, FeSi production is a dominant factor for all categories due to its high energy and material consumption.

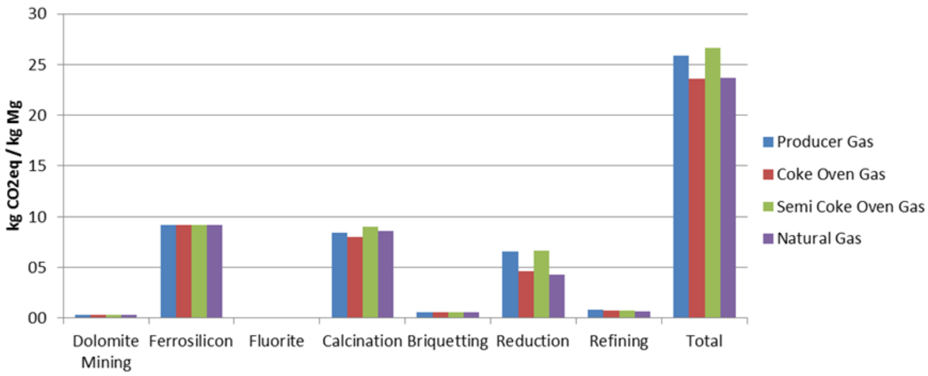

Figure 2: Greenhouse gas emissions of Pidgeon process according to fuel gas used

The calculation of the standard scenario is based on an allocation for the production of coke oven gas and semi coke oven gas according to the energetic contribution of the fuel gases to the entire production from the (semi) coke plant. The emissions are completely accounted to the Pidgeon process. The ISO 14044 standard gives a preference to system expansion or dividing unit processes instead of allocation in case of multifunctional processes. As coke oven and semi coke oven gas are waste from (semi) coke production, the use of such production waste can be credited to the primary magnesium production. Thus, an alternative methodological approach is applied. By applying this approach, the weighted average GHG emissions of the Pidgeon process decreases to 19.9 kg CO_{2eq} / kg Mg.

Electrolysis

In our study, we developed a model for an electrolysis which represents today's conditions. The electrolysis model is site specific for the production of magnesium in Israel. Electrolysis plants in Russia are based on carnallite as well and most of the process steps and parameter are similar to the process evaluated in this study. In the carnallite based electrolysis plant, two by-products are produced: liquefied chlorine (Cl_2) and KCl-rich salt. The first has a wide range of potential uses and the second one can be converted to potassium fertilizer. The production of these by-products is credited as it substitutes the production of the material from other routes.

For all impact categories, the electrolysis step itself is the dominant process followed by the preparation of the raw materials. Main factor for emissions and resource depletion is the consumption of electricity. For the global warming potential, the overall emissions amount to 17.8 kg CO_{2eq} / kg Mg. The substitution of the production of the by-products in other processes can be credited in the impact assessment. In case of GWP the results decrease slightly to 14 kg CO_{2eq} / kg Mg.

4 Analysis of Magnesium Parts Manufacturing

Magnesium Steering Wheel (Die Casting)

The model for manufacturing a steering wheel which is used in a car refers to the steering wheel frame (referred as “steering wheel” in the following). The functional unit of the product systems is the production process of a magnesium steering wheel frame made from AM50 via die casting for the use in a passenger car. To prevent oxidation, the use of a cover gas is necessary. Three different alternative gas types are analyzed in this study: SF_6 / air mixture, SO_2 / air mixture and R134a / CO_2 mixture.

A further input parameter for the die casting process is the share of production scrap. Though data in literature appear to show that aluminium offers lower amounts of production scrap, this does not apply for the comparison of one product made from either magnesium or aluminium. For the evaluation of the production of the steering wheel, a standard scenario for die casting is defined. This scenario includes a rate of production waste of 45 %, the use of electric furnaces for die casting and the use of SO_2 as cover gas for the magnesium part. These parameters are seen as most representative for an exemplary steering wheel production. A second model for the production of a steering wheel made from aluminium has been developed.

The impact assessment of the die casting process shows that in general, the die casting step itself has higher environmental impacts than the further treatment of the parts. In both process steps, the magnesium steering wheel has lower impacts compared to the aluminium part. For the acidification category, the use of SO_2 as cover gas leads to comparatively high emissions. As the functional unit of the models is one steering wheel, the results include that for the magnesium component less material has to be processed. This implies also a lower energy consumption for the process.

Magnesium Aircraft Parts (Sand Casting)

For the magnesium use in aviation, a gearbox and a seal closer for each of top and bottom of an aircraft door serve as example. The parts are produced via sand casting. The functional unit of the models developed for magnesium and aluminium is the production of all three parts together.

Unlike in the die casting process, the moulds have to be formed exclusively for the casting of each part. After the sand casting step itself, the parts have to be cut into shape and powder coated in a further treatment step. A second model for the production of sand casting parts from aluminium has been developed as well.

For the categories climate change and resource depletion, the production of magnesium parts has lower impacts than the production of aluminium parts. The potential impacts on eutrophication are in the same range. In the magnesium model, the production of the sand moulds has considerable influence in all impact categories. In case of the category climate change, the cast process itself is the dominant process due to the consumption of fluxes and energy. For the acidification potential, the use of SO_2 which is filled into the mould plays a major role for the magnesium parts.

5 Analysis of End of Life and Recycling

The processing of end-of-life vehicles consists of several steps. First, the vehicle is drained and specific parts are dismantled. The remaining car body is then shredded. The subsequent processes separate the materials from each other. Ferrous metals are removed by a magnetic separator. The remaining fractions are treated by different processes. The non-ferrous (NF) metals are composed of a mix of aluminium, magnesium and heavy metals (mainly copper). The NF-fraction can be separated in a float-sink plant or via x-ray separation, for instance. As for aluminium, recycling yields of 90 % are reported for automotive components, this rate is applied for the overall light metal fraction in this study. The recycling of magnesium within the aluminium cycle is seen as standard scenario for magnesium end-of-life.

As the energy consumption for the vehicle treatment is much lower than for the aluminium alloy processing, the impact of this process is significantly lower as well. For the global warming potential, the vehicle treatment contributes with 4 % to the overall emissions of 3.8 kg CO_{2eq} / kg material. For other categories, the contribution ranges from 2 to 7 %.

6 Comparison of Magnesium and Aluminium Components

Analysis of the Life Cycle of a Steering Wheel

For the ecological assessment of the use of lightweight materials in transport, the use phase has considerable influence on the overall balance. In the following, the results of the use stage calculations in the context of the overall life cycle balance of greenhouse gas emissions is presented for the component example "steering wheel" made from magnesium. The magnesium part is compared to a steering wheel made from aluminum. Only the differences of absolute emissions for component production, use stage and end-of-life are analyzed. Fuel savings are calculated for a middle class passenger car operated with gasoline for a mileage of 200,000 km. The fuel reduction coefficient is 0.35 l / 100kg*100km. Figure 3 shows the overall balance for component production, use stage and end-of-life. The sum of emissions from production and end-of-life of the magnesium steering wheel are subtracted from the emission of the aluminium component. The results are calculated according to the source of primary magnesium. The average world scenario is based on a combination of GHG emissions from the average Pidgeon process and electrolysis. A share of 83 % Pidgeon process and 17 % electrolysis is assumed. The term "Pidgeon process – average with credits" refers to the Pidgeon process scenario for coke oven and semi coke oven gas in which these gases credited as waste gases. The recovery rates are assumed to be equal for both metals.

For the aluminium reference, a world average is assumed as source of primary metal. The results show a positive net balance of CO_{2eq} emissions for all magnesium production scenarios. The lowest advantage is reached when magnesium from the Pidgeon process based on semi-coke oven gas is used as primary metal. Magnesium from electrolysis leads to the highest savings of CO_{2eq} emissions.

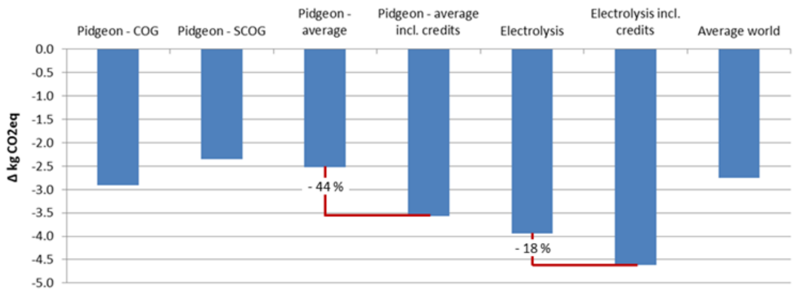

Figure 3: Overall balance for magnesium steering wheel compared to aluminium steering wheel based on a mileage of 200,000 km

Figure 4 reveals the break-even points for the main scenarios of magnesium production from Pidgeon process and electrolysis. Again only the differences of the absolute emissions from both material life cycles are depicted. The break-even point is reached at about 150,000 km for magnesium from a coke oven gas based Pidgeon process. The Pidgeon process using semi-coke oven gas as fuel does not lead to an amortization of emissions during the mileage of 200,000 km. As considerable amounts of magnesium are produced using semi-coke oven gas, the average Pidgeon process also shows a break-even point late in the life cycle of the steering wheel. When the use of coke oven and semi coke oven gas as production waste is credited, a break-even at 46,000 km is reached for the average Pidgeon process. In case of magnesium from electrolysis, the production of the steering wheel already results in lower emissions compared to the aluminium reference.

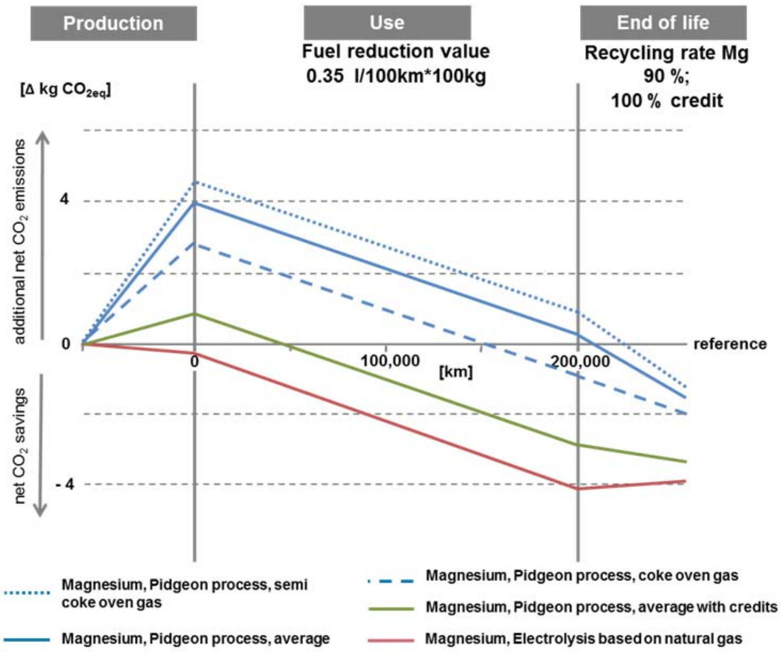

Figure 4: Savings of greenhouse gas emissions during life cycle of a steering wheel for different magnesium scenarios

As the results for the comparison of GHG emissions are sensitive to both the source of primary metal and the vehicle and fuel consumption parameters of the use stage, general conclusions on the comparison of magnesium and aluminium parts cannot be drawn without ambiguity.

Analysis of the Life Cycle of Components for Aircrafts

The use of the aircraft parts is analyzed for application in an A320 aircraft. An exemplary use case representing a flight over a distance of 4,100km has been defined to calculate the emissions during aircraft operation. The relation of aircraft weight and fuel consumption is calculated using the DLR model VAMPzero. The end-of-life of aircraft components is not part of the study as it is not considered to be relevant for the greenhouse gas emissions of this use case.

In case of the comparison between aircraft parts of magnesium and aluminium, only few flights are necessary to reach a break-even point for the amortization of higher emissions during component production (Figure 5).

When magnesium is produced by electrolysis and the by-products are credited, the production of components has already fewer emissions compared to the aluminium reference. For other magnesium scenarios, the break-even point is reached at latest during the ninth flight. Due to high potentials of fuel savings during aircraft operation, the influence of component production and source of primary metal is insignificant.

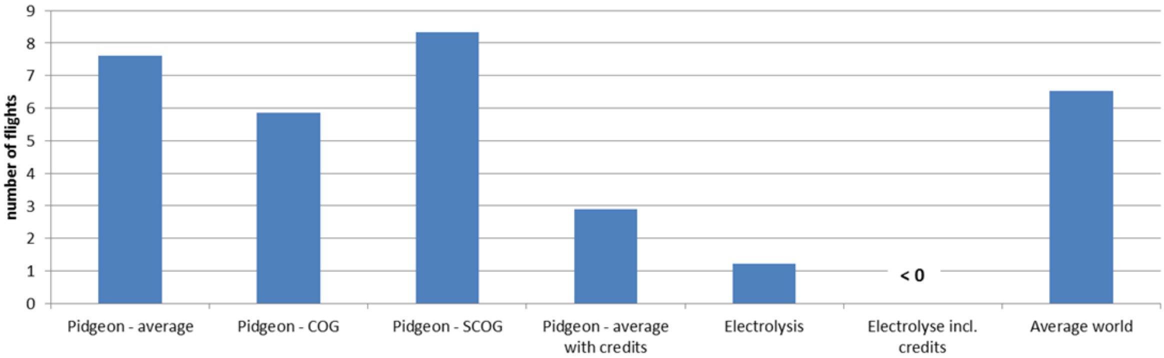

Figure 5: Number of flights for emission amortization for difference magnesium scenarios

The maximum difference to the aluminum reference for component production is 0.18 t CO_{2eq}. In contrast to that, the emission savings during aircraft operation amount to approximately 8 t CO_{2eq} per year. Assuming a life time of 30 years for an aircraft, the reduction potential for magnesium components is about 226 t CO_{2eq}. The following end-of-life of the aircraft does not notably influence the overall emission savings for the magnesium components.

7 Conclusions

- The magnesium production with Pidgeon process shows higher CO_2 emissions than magnesium from electrolysis. Due to improvements in the technical processes, the emissions have dropped significantly in the last few years.
- The recycling process does not contribute significantly to the overall emissions. To credit reuse of magnesium shows an important influence to LCA.
- The calculations on the break even points for the passenger car components are sensitive to the source of primary metal. The uncertainties from the vehicle specific parameters which lead to fuel and emission savings during vehicle operation are higher than the differences between the steering wheel alternatives.
- Already with existing magnesium-productions it is possible to gain advantages over aluminium if the magnesium-components are designed specifically to the magnesium-characteristics.
- In comparison with aluminium magnesium parts in aircrafts show significant benefits in terms of CO_2 emissions. In the use phase of the material high fuel reduction potential of magnesium parts for aircrafts leads to fast amortization of additional emissions from the earlier production stage.