Update of Recycled Content and SF_6 Emissions for Magnesium in the GREET® Model

by
Q. Dai, J. Kelly and A. Elgowainy
Systems Assessment Group
Energy Systems Division
Argonne National Laboratory

September 2016

CONTENTS

TABLES

This page intentionally left blank.

Update of Recycled Content and SF_6 Emissions for Magnesium in GREET

Qiang Dai, Jarod C. Kelly and Amgad Elgowainy

Energy Systems Division
Argonne National Laboratory

September 2016

This memo documents the changes in recycled content and SF_6 emissions associated with magnesium (abbreviated as Mg) in GREET. These changes reflect the current status of magnesium production, and will be incorporated into GREET 2016.

1 RECYCLED CONTENT OF MAGNESIUM USED IN VEHICLES

As the lightest engineering metal, magnesium has gradually increased in vehicle component applications, such as the steering wheel, instrument panel, clutch casing, etc., in accordance with the global trend of vehicle lightweighting strategies (EPA 2015, EPA 2012, NHTSA 2012, Kulekci 2008). Since magnesium scrap can be recycled into secondary magnesium without degradation in its material properties, and the energy demand for secondary magnesium production is less than 5% of that associated with primary magnesium production (Johnson and Sullivan 2014), an up-to-date recycled content of magnesium automotive components is crucial to the evaluation of environmental footprints associated with magnesium use for vehicle lightweighting.

TABLE 1. 2014 U.S. Magnesium Statistics (USGS 2016)

	Primary consumption	Mg metal import	Mg metal export	Secondary production	Primary casting	Secondary casting
Metric ton (t) of Mg	65,700	16,200	6,010	78,600	9,640	10,500

Statistics for U.S. magnesium in 2014 are summarized in Table 1. The U.S. primary magnesium production, although withheld by USGS to protect the proprietary data of the one and only domestic primary magnesium producer, is estimated to be 55,000 t in 2014 by Eq. 1 and statistics listed in Table 1, assuming that imported and exported Mg metal is all primary, and that changes in yearend stocks between 2013 and 2014 are insignificant. Casting products include die castings, permanent mold castings, and sand castings (USGS 2016).

$$Primary\ production = Primary\ consumption + metal\ export - metal\ import \qquad \text{Eq.1}$$

Although secondary magnesium production accounted for 58.6% of total domestic magnesium production in 2014, 86% of the recovered secondary magnesium was used for aluminum alloys (USGS 2016). Therefore, the share of secondary production in the magnesium industry as a whole is not representative of the recycled content of magnesium within automotive applications. Rather, the ratio of secondary magnesium consumption for casting to the total magnesium (i.e., primary and secondary) consumption for casting can serve as a good approximation for the recycled content of magnesium used in vehicles, since magnesium automotive components are mostly die castings (USGS 2016). This ratio is calculated to be 52.1% for 2014 by dividing 10,500 t by the sum of 9,640 t and 10,500 t, and will replace the 33.3% recycled content assumed in GREET 2015.

It should be noted that fundamentally different recycled content for magnesium parts in vehicles has been suggested in literature, as information on vehicle end-of-life handling is still lacking. Ehrenberger and Friedrich claimed that in Europe, obsolete magnesium vehicle components are not separated from aluminum ones in the waste stream and typically end up as an additive for secondary aluminum alloy (Ehrenberger and Friedrich 2013). This translates into a recycled content close to 0%. In contrast, the U.S. International Trade Commission, in their most recent five-year review of the antidumping duty order on magnesium from China and Russia, stated that on the U.S. market, only high quality secondary magnesium alloy, which is recovered from post-consumer automotive scrap, is acceptable for automotive die castings, whereas primary Mg is not used for this purpose (ITC 2011). This indicates a recycled content close to 100%. Due to the discrepancy, the recycled content of magnesium used in vehicles should be re-examined and updated if more detailed information on magnesium use in the automotive industry becomes available.

2 SF_6 EMISSIONS FROM MAGNESIUM

SF_6 is used as a cover gas by the magnesium industry to prevent molten magnesium from oxidation. Processes involving the use of SF_6 include primary magnesium production, magnesium casting, and secondary magnesium production (EPA 2016).

SF_6 is the most potent greenhouse gas, with a global warming potential of 22,800 kg CO_2 eq. /kg SF_6 (EPA 2016). In 1999, a voluntary SF_6 reduction partnership was initiated by the U.S. EPA, the U.S. magnesium industry, and the International Magnesium Association to reduce greenhouse gas emissions by utilizing SF_6 alternatives, such as HFC-134a, Novec™612 and SO_2 (USGS 2016). Under this partnership, U.S. magnesium industry participants, which in 2010 represented 100% of domestic primary and secondary productions, as well as 16% of domestic castings production, reported their annual SF_6 consumptions to EPA from 1999 to 2010 (EPA 2016). Based on the reported SF_6 consumption, and corresponding magnesium production data obtained from USGS, EPA estimated emission factors of the U.S. magnesium industry. The average of the emission factors for 1999 – 2010 are summarized in Table 2. Note that the emission factor for die casting is the average of collected data from 2000 to 2007, during which time participating companies represented 100% of domestic die casters. Between 2008 and 2010, EPA only received limited responses from the die casters. The emission factors of die casting for those years were estimated by applying an emission factor of 3 kg SF_6/t Mg to all the die casters that did not participate. As a result, the die casting emission factor in 2010 was estimated to be 2.94 kg SF_6/t Mg, because participating companies in 2010 only represented 16% of domestic casters (EPA 2016). Since the emission factors of 2008-2010 are not representative of the industry average, the 2000-2007 average emission factor for die casting is chosen to be incorporated into GREET.

TABLE 2. 1999-2010 Average SF_6 Emission Factors for U.S. Magnesium Industry (EPA 2016)

	Primary production	Secondary production	Sand casting	Die casting	Permanent mold	Wrought	Anodes
kg SF_6/t Mg	W	W	W	0.76*	2	1	1

W. Withheld by EPA to protect company data.
** Average of 2000-2007.*

After the partnership ended in 2010, U.S. magnesium producers and processors still reported their cover gas emissions through EPA's Greenhouse Gas Reporting Program (GHGRP), and EPA published industry-wide SF_6 emission for 2011-2014 in their U.S. greenhouse gas inventory report. However, process-specific emission factors for this period were not disclosed. As a result of decreased magnesium production from reporting facilities in recent years, and the ongoing effort of the magnesium industry to reduce SF_6 use, the SF_6 emissions from magnesium production and processing decreased from 2.8 million metric ton (MMt) CO_2 eq. in 2011 to 1.0 MMt CO_2 eq. in 2014. According to EPA, the most significant reduction between 2013 and 2014 was from primary production, because an increasing amount of HFC-134a was used in lieu of SF_6 as the cover gas for primary production during that time. As a result, the emission of HFC-134a from the magnesium industry increased by 0.06 MMt CO_2 eq. (46,000 kg HFC 134-a) in 2014(EPA 2016). Since there is only one primary Mg producer in the

U.S., the significant increase in HFC-134a consumption for primary Mg production suggests that the primary Mg producer has switched to SF_6 alternatives. Assuming that the switch to HFC-134a for primary production accounted for all the increase of HFC-134a emission in 2014, in other words, the primary Mg producer consumed 46,000 kg of HFC-134a to produce 55,000 t of Mg in 2014, the emission factor of primary Mg production is estimated to be 0.84 kg HFC-134a/t Mg.

TABLE 3. 2010 U.S. Magnesium Production with SF_6 Emissions (USGS 2012, EPA 2016)

	Primary production	Secondary production	Sand casting	Die casting	Permanent mold	Wrought	Anode
t Mg	42,800[1]	6,520[2]	424	26,120[3]	163	2,120	709
kg SF_6/t Mg	N/A	N/A	N/A	2.94	2	1	1

1. Estimated by Eq.1
2. Recovered magnesium-based alloy only (for castings)
3. Includes both primary and secondary magnesium

Although the SF_6 emission factor for secondary production was withheld by EPA to protect company data, it can be estimated based on total SF_6 emissions from the U.S. Mg industry, domestic Mg production volumes, and SF_6 emission factors from other Mg production sectors. As mentioned earlier, 2010 is the last year for which process specific SF_6 emission factors were reported by EPA, so 2010 data is used to calculate the emission factor for secondary production. EPA estimated that in 2010, the U.S. magnesium industry emitted 2.1 MMt CO_2 eq. of SF_6, which is equivalent to 92,000 kg of SF_6 (EPA 2016). Since the production steps involving SF_6 use (i.e., magnesium alloy ingot casting) are identical for secondary and primary magnesium (Palmer 2001), it can be assumed that the SF_6 emission factors for primary and secondary magnesium production are the same before the switch to SF_6 alternatives for primary production. Given the total SF_6 emission, as well as 2010 U.S. magnesium production volume and the process specific emissions factors as presented in Table 3, the SF_6 emission factor for primary and secondary production can be estimated by Eq. 2.

$$EF_{production} = \frac{Total\ SF_6\ emission - \sum EF_{i,non-production} \times Volume_{i,non-production}}{Volume_{primary\ production} + Volume_{secondary\ production}} \qquad \text{Eq.2}$$

Where $EF_{production}$ represents the emission factor for both primary production and secondary production, and $EF_{i,\ non\text{-}production}$ represents the emission factor for process *i* that are not pertinent to primary and secondary magnesium production.

Assuming sand casting has the same emission factor as permanent mold casting, the emission factor of primary and secondary magnesium production is calculated to be 0.23 kg SF_6/t Mg for 2010. The calculated emission factor is in good agreement of SF_6 emissions measured at a domestic magnesium alloy ingot casting facility, which are in the range of 0.23-0.37 kg SF_6/t Mg throughput (EPA 2008). Although the calculated emission factor can be an underestimate for primary production, it is realistic for secondary production, because not all U.S. secondary Mg producers use SF_6 as cover gas (Palmer 2001). The emission factor of 0.23 kg SF_6/t Mg, is therefore used in GREET for secondary Mg production.

The existing SF_6 emission factor of 1.65 kg SF_6/t Mg in GREET 2015 is based on a 2010 study, and represents total SF_6 emissions from a generic process for magnesium instrument panel production, which includes magnesium melting, holding and high-pressure die-casting (Tharumarajah and Koltun 2010). Changes made to SF_6 emission factors are summarized in Table 4. The emissions for magnesium from electrolytic production, which represents primary magnesium in the U.S., is changed to 0.84 kg HFC-134a/t Mg (760 g HFC-134a/short ton Mg); the emission for magnesium from thermal production, which represents the Pidgeon process of primary magnesium production in China, is changed to zero, since for cost reasons, Chinese magnesium producers do not use SF_6 as cover gas (Ehrenberger 2013, Palmer 2001); the emission for secondary magnesium production is changed to 0.23 kg SF_6/t Mg; the emission for magnesium casting and molding is changed to 0.76 kg SF_6/t Mg (see Table 2).

TABLE 4. SF_6 Emissions from Mg Production (g SF_6/short ton Mg)

	Mg from electrolytic production	Mg from thermal production	Secondary Mg	Mg casting and molding
GREET2 2015	1,500	1,500	1,500	0
GREET2 2016	0	0	210	690

REFERENCES

Ehrenberger, S. 2013. Life cycle assessment of magnesium components in vehicle construction. http://www.intlmag.org/pdfs/reports/111913_lca_report_public.pdf

Ehrenberger, S. and Friedrich, H. 2013. Life cycle assessment of the recycling of magnesium vehicle components. *JOM-J. Min. Met. Mat. S.*, 65: 1303-1309.

Johnson, M.C. and Sullivan, J.L. 2014. "Lightweight Materials for Automotive Application: An Assessment of Material Production Data for Magnesium and Carbon Fiber." ANL/ESD-14/7

Kulekci, M. 2008. Magnesium and its alloys applications in automotive industry. *Int. J. Adv. Manuf. Technol.*, 39: 851-865.

National Highway Traffic Safety Administration. 2012. "Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025." DOT HS 811 666.

Palmer, B. 2001. "SF_6 Emissions from Magnesium Production". Chapter 3 in *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. http://www.ipcc-nggip.iges.or.jp/public/gp/english/3_Industry.pdf

Tharumarajah, A. and Koltun, P. 2010. Improving environmental performance of magnesium instrument panels. *Resour. Conserv. Recy.*, 54: 1189-1195.

U.S. Environmental Protection Agency. 2016. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." EPA 430-R-16-002

U.S. Environmental Protection Agency. 2015. "Mass Reduction and Cost Analysis— Light-Duty Pickup Truck Model Years 2020-2025." EPA-420-R-15-006.

U.S. Environmental Protection Agency. 2012. "Light-Duty Vehicle Mass Reduction and Cost Analysis — Midsize Crossover Utility Vehicle." EPA-420-R-12-026.

U.S. Environmental Protection Agency. 2008. "Characterization of Cover Gas and Byproduct Emissions from Secondary Magnesium Ingot Casting." EPA-430-R-08-008.

U.S. Geological Survey. 2016. "2014 Mineral Yearbook: Magnesium." http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/myb1-2014-mgmet.pdf

U.S. Geological Survey. 2012. "2011 Mineral Yearbook: Magnesium." http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/myb1-2011-mgmet.pdf

U.S. International Trade Commission. 2011. "Magnesium from China and Russia." Investigation Nos. 731-TA-1071-1072 (Review).