TECHNICAL SUPPORT DOCUMENT FOR PROCESS EMISSIONS FROM MAGNESIUM PRODUCTION AND PROCESSING: PROPOSED RULE FOR MANDATORY REPORTING OF GREENHOUSE GASES

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1. Source Description

Magnesium is a high-strength and light weight metal that is important for the manufacture of a wide range of products and materials, such as electronics, vehicles, and other machinery. The United States accounts for less than 10 percent of world primary magnesium production (USGS 2007), but is a significant importer of magnesium for casting operations. The production and processing of magnesium metal under common practice results in emissions of sulfur hexafluoride (SF_6).

The magnesium metal production (primary and secondary) and casting industry typically uses SF_6 as a cover gas to prevent the rapid oxidation and burning of molten magnesium in the presence of air. A dilute gaseous mixture of SF_6 with dry air and/or CO_2 is blown over molten magnesium metal to induce and stabilize the formation of a protective crust. A small portion of the SF_6 reacts with the magnesium to form a thin molecular film of mostly magnesium oxide and magnesium fluoride. The amount of SF_6 reacting in magnesium production and processing is under study but presently assumed to be negligible. Thus, all SF_6 used is assumed to be emitted into the atmosphere. Cover gas systems are typically used to protect the surface of a crucible of molten magnesium that is the source for a casting operation and to protect the casting operation itself (e.g., ingot casting). Sulfur hexafluoride has been used in this application around the world for the last twenty years. Due to increasing awareness of the global warming potential of SF_6, the magnesium industry has begun exploring climate-friendly alternative melt protection technologies. At this time the leading alternatives are HFC-134a, a fluorinated ketone FK 5-1-12 ($C_3F_7C(O)C_2F_5$), and dilute sulfur dioxide (SO_2). The application of the fluorinated alternatives mentioned here may generate byproduct emissions of concern including perfluorocarbons (PFCs).

a. Total U.S. Emissions

Emissions of SF_6 from magnesium production and processing in the United States were estimated to be 3.2 million metric tons of CO_2 equivalent ($MMTCO_2e$) in 2006 (EPA 2008). There are approximately 10 magnesium die casting facilities in the United States which accounted for 29 percent, or 0.9 $MMTCO_2e$ of total magnesium-related SF_6 emissions. Primary and secondary production activities accounted for 64 percent of total emissions, or 2 $MMTCO_2e$. Other smaller casting activities such as sand and permanent mold accounted for the remaining seven percent of total magnesium-related emissions of SF_6.

2. Options for Reporting Threshold

EPA evaluated a range of threshold options for magnesium production and processing facilities. These included emission-based thresholds of 1,000, 10,000, 25,000 and 100,000 $mtCO_2e$ and capacity-based thresholds equivalent to these. The capacity-based thresholds were based on 100-percent capacity utilization and an SF_6 emission rate of 1.6 kg SF_6/ metric ton of magnesium produced or processed. This emission factor represents the sum of (1) the average of the emission factors reported for secondary production and die casting through EPA's magnesium Partnership (excluding outliers), and (2) the standard deviation of those emission factors. The 1.6 kg-per-ton factor is higher than most, though not all, of the emission factors reported, which ranged from 0.7 to 7 kg/ton Mg in 2006. Thus, it is somewhat conservative, but not unreasonably so.

The numbers of facilities and quantities of emissions covered by each of the thresholds considered are presented in Tables 1 and 2 below.

Table 1. Threshold Analysis for Mg Production Based On Emissions

Threshold Level $mtCO_2e/yr$	Total Nationwide Emissions $mtCO_2e/Yr$	Nationwide Number of Facilities[1]	Emissions Covered		Facilities Covered	
			$mtCO_2e/yr$	Percent	Number of Facilities	Percent
100,000	3,200,000	13	2,872,982	89.8%	9	69%
25,000	3,200,000	13	2,939,741	91.9%	11	85%
10,000	3,200,000	13	2,939,741	91.9%	11	85%
1,000	3,200,000	13	2,954,559	92.3%	13	100%

Table 2. Threshold Analysis for Mg Production Based On Mg Production Capacity

Capacity Threshold Level mt Mg/yr	Total Nationwide Emissions	Nationwide Number of Facilities[1]	GHG Emissions Reported		Affected Facilities	
			$mtCO_2e/yr$	Percent	Number of Facilities	Percent
2,622	3,200,000	13	2,780,717	86.9%	9	69%
656	3,200,000	13	2,949,732	92.2%	12	92%
262	3,200,000	13	2,949,732	92.2%	12	92%
26	3,200,000	13	2,954,559	92.3%	13	100%

As can be seen from the tables, the coverages of the emissions and capacity-based thresholds are similar but not identical, with the 25,000- and 10,000-$mtCO_2e$ thresholds covering one less facility than the 656- and 262-metric-ton-of-magnesium thresholds. The emissions threshold of 25,000 $mtCO_2e$ is estimated to cover all currently operating U.S. primary and secondary magnesium producers and most die casters, accounting for over 99 percent of emissions from these source categories.

A key advantage of the emission-based thresholds is that they take into account the variability in cover gas identities, usage rates, and process conditions. In facilities where SF_6 is used, the usage rate can vary by an order of magnitude depending on the casting process and operating conditions. Alternatives to SF_6 have considerably lower GWPs than SF_6, adding to the potential variability. Because emissions of each cover gas are assumed to equal use, and facilities are expected to track use in the ordinary course of business, facilities would have little difficulty determining whether or not they must report under an emission-based threshold.

Table 3 below presents the amounts of cover gas species that equal a reporting threshold of 25,000 $mtCO_2e$.

Table 3. Threshold Translation to Weight of Gas using 100-year GWP*

25,000 $mtCO_2e$.	is equal to:	1,046 kg SF_6 19,231 kg HFC-134a 25,000,000 kg CO_2 or FK 5-1-12

To determine whether or not they exceeded an emission threshold of 25,000 $mtCO_2e$, magnesium production and processing facilities would multiply the total consumption of each cover or carrier gas by a GWP and unit conversion factor. Facilities would calculate the CO_2 equivalent of their cover gas usage based on the following expression:

$$E_{SF6} + E_{134a} + E_{FK} + E_{CO2} + E_{OG} > 25{,}000 \text{ metric tons of } CO_2 \text{ Eq.}$$

$$E_{SF6} = C_{SF6} \times 23.9$$

$$E_{134a} = C_{134a} \times 1.3$$

$$E_{FK} = C_{FK} \times 0.001$$

$$E_{CO2} = C_{CO2} \times 0.001$$

$$E_{OG} = C_{OG} \times GWP_{OG}/1000$$

[1] This estimate includes all primary and secondary production facilities and most die casting facilities. It excludes a few die casting facilities as well as facilities that perform other types of casting, such as wrought and anode casting. These types of casting generally occur at much lower volumes than die casting.

where,

E_{SF6} is emissions of SF_6 from magnesium production and processing ($mtCO_2e$.)

E_{134a} is emissions of HFC-134a from magnesium production and processing ($mtCO_2e$)

E_{FK} is emissions of FK 5-1-12 from magnesium production and processing ($mtCO_2e$)

E_{CO2} is emissions of CO_2 from magnesium production and processing ($mtCO_2e$)

E_{OG} is emissions of other fluorinated GHGs from magnesium production and processing ($mtCO_2e$.)

C_{SF6} is annual consumption of SF_6 based on facility tracking (kg)

C_{134a} is annual consumption of HFC-134a based on facility tracking (kg)

C_{FK} is annual consumption of FK 5-1-12 based on facility tracking (kg)

C_{CO2} is annual consumption of CO_2 based on facility tracking (kg)

C_{OG} is annual consumption of other fluorinated GHGs based on facility tracking (kg)

GWP_{OG} is the Global Warming Potential of other fluorinated GHGs

The values 23.9, 1.3, and 0.001 are simple factors for converting kg of gas to $mtCO_2e$.

Consumption of cover gases or carrier gases is estimated by monitoring changes in container masses and inventories using a number of different possible methods, as described in Section 3 below

3. Options for Monitoring Methods

EPA reviewed a range of protocols and guidance for this analysis. These protocols included the *2006 IPCC Guidelines*, EPA's SF_6 Emission Reduction Partnership for the Magnesium Industry, the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, the Technical Guidelines for the Voluntary Reporting of Greenhouse Gases (1605(b)) Program, EPA's Climate Leaders Program, and The Climate Registry.

The methods described in these protocols and guidance coalesce around the methods described by the IPCC guidelines and U.S. Inventory methodology. These methods range from a lower tiered (Tier 1) approach based on magnesium metal processed to a higher-tiered (Tier 3) approach based on facility-specific analytic monitoring data.

a. Option 1: Default Emission Factor

Option 1, which is the same as the IPCC Tier 1 approach, equates cover gas emissions to the product of a default emission factor and the quantity of magnesium produced or processed. Though this method is simple, the default emission factor for the SF_6 usage and emissions rate is significantly uncertain due to the variability in production processes and operating conditions. As discussed above, the SF_6 usage rate can vary by an order of magnitude in facilities where SF_6 is used, depending on the casting process and operating conditions. Moreover, alternatives to SF_6 have considerably lower GWPs than SF_6, adding to the potential variability.

b. Option 2: Cover Gas Consumption

Option 2 for monitoring emissions of GHG cover gases is similar to the Tier 2 approach in the 2006 IPCC Guidelines for magnesium production. This approach is based on facility-specific SF_6 tracking information for cover gas consumption. This methodology translates to any cover gas that is a GHG, including CO_2, HFC-134a and FK 5-1-12. It does not account for any destruction of the cover or carrier gas during use.

EPA has analyzed three methods for tracking consumption of cover and carrier gases, as follows:

In the first method, consumption of cover gases or carrier gases is estimated by monitoring changes in container masses and inventories using Equation 1 below:

$$\text{Equation 1)}\quad C = IB - IE + A - D$$

where:

C = Consumption of that cover gas or carrier gas in kg over the period (e.g., 1 year)

IB = Inventory of that cover gas or carrier gas stored in cylinders or other containers at the beginning of the period (e.g., 1 year) including heels in kg.

IE = Inventory of that cover gas or carrier gas stored in cylinders or other containers at the end of the period (e.g., 1 year) including heels in kg.

A = Acquisitions of that cover gas or carrier gas during the period (e.g., year) through purchases or other transactions, including heels in cylinders or other containers returned to the magnesium production or processing facility, in kg.

D = Disbursements of cover gas or carrier gas through sales or other transactions during the period, including heels in cylinders or other containers returned by the magnesium production or processing facility to the gas distributor, in kg.

In the second method, consumption of cover gases or carrier gases is estimated by monitoring changes in the masses of individual containers as their contents are used, using Equation 2:

$$\text{Equation 2)} \quad C_{GHG} = \sum_{p=1}^{n} Q_p$$

where:

C_{GHG} = The consumption of the cover gas over the period (kg)

Qp = The mass of the cover gas used over the period (kg)

N = The number of periods in the year

For purposes of Equation 2, the mass of the cover gas used over the period p is estimated by using Equation 3 below:

$$\text{Equation 3)} \quad Q_P = M_B - M_E$$

where:

Qp = The mass of the cover gas used over the period (kg)

M_B = The mass of the contents of the cylinder at the beginning of period p

M_E = The mass of the contents of the cylinder at the end of period p

In the third method, consumption of cover gases or carrier gases is estimated by using flowmeters in cover gas distribution systems.

Any of these three methods should yield an accurate and precise estimate of cover gas usage and emissions as long as accurate and precise weigh scales and/or flowmeters are used. Thus, a facility's choice of method will probably depend primarily on the current equipment and methods used by that facility.

The cover gas usage rate shall be calculated using Equation 4 below:

$$\text{Equation 4)} \quad R_{GHG} = C_{GHG}/Mg$$

where:

R_{GHG} = The usage rate for a particular cover gas over the period

C_{GHG} = The consumption of that cover gas over the period (kg)

Mg = The magnesium produced or fed into the casting process over the period (metric tons)

c. *Option 3: Facility-specific measurements of emissions*

The Tier 3 methodology of conducting facility-specific measurements of emissions to account for potential cover gas destruction and byproduct formation is the most accurate, but also poses significant operational and economic challenges for implementation because of the cost of direct emission measurements.

4. Procedures for Estimating Missing Data

In general, it is unlikely that cover gas consumption data will be missing. Facilities are expected to know the quantities of cover gas that they consume because facility operations rely on accurate monitoring and tracking of costs. Facilities will possess invoices from gas suppliers during a given year and many facilities track the weight of SF_6 consumed by weighing individual cylinders prior to replacement.

However, where cover gas consumption information is missing, facilities could estimate emissions by multiplying production by the average cover gas usage rate (kg gas per ton of magnesium produced or processed) from the most recent period when operating conditions were similar to those for the period for which the data are missing, i.e., using the same cover gas concentrations and flow rates and, if applicable, casting parts of a similar size.

5. QA/QC Requirements

Options for QA/QC of reporting under the Option 2 monitoring method include the following:

- Calculation of the facility usage rate, comparison with known default values and historical data for the facility, and investigation of any anomalies;
- Ensure that all cylinders returned to the gas supplier are weighed on a scale that is certified to be accurate and precise to within 1%. Facilities would be required either to weigh residual gas (the amount of gas remaining in returned cylinders) themselves or to have the gas supplier weigh it. Gas suppliers can provide detailed monthly spreadsheet with exact residual gas amounts returned.
- All flowmeters, scales, and load cells used to measure quantities shall be calibrated using suitable NIST-traceable standards and suitable methods published by a consensus standards organization (e.g., ASTM, ASME, ASHRAE, or others). Alternatively, calibration procedures specified by the flowmeter, scale, or load cell manufacturer may be used. Calibration shall be performed prior to the first reporting year. After the initial calibration, recalibration shall be performed at least annually or at the minimum frequency specified by the manufacturer, whichever is more frequent.
- Track cylinders leaving and entering storage with check-out sheets and weigh-in procedures before the cylinders are put back into storage.
- Maintain invoices of cover gas purchases, check-out and weigh-in sheets, and scale calibrations.
- Ensure all production lines have provided information to the manager compiling the emissions report (if it is not already handled through an electronic inventory system).

These measures would be useful to verify that the GHG emissions monitoring and calculations were done correctly and accurately.

6. Reporting Procedures

Data that would be important for understanding and verifying emissions estimates would include total facility GHG emissions and emissions by process type (primary production, secondary production, die casting, or other type of casting). For total facility and process emissions, emissions could be reported in metric tons of SF_6, HFC-134a, FK 5-1-12, CO_2 (used as a carrier gas), and other fluorinated GHGs, and in $mtCO_2e$.

Data that would be useful for understanding and verifying emissions estimates would also include the following supplemental data (as well as the supplemental data required in the combustion and calcination sections):

- Total GHG emissions by facility and by gas in kg
- Type of production processes (e.g., primary, secondary, die casting);
- Magnesium production amount in metric tons for each process;
- Cover gas flow rate and composition;
- Amount of CO_2 used as a carrier gas during reporting period;

- If data were missing, the length of time the data were missing, the method used to estimate emissions in their absence, and the quantity of emissions thereby estimated.
- Explanation for any significant deviation in emission rate (e.g., leak discovered in the cover gas delivery system resulted in increased consumption); and
- Data from the prior year for comparison.
- A description of any new melt protection technologies to account for reduced emissions in a given year.

The following records would be important for verifying and documenting emissions estimates:

(1) Records documenting the facility's adherence to the QA/QC requirements outlined above and (2) records verifying the quantities reported above. These records include check-out and weigh-in sheets and procedures for cylinders, residual gas amounts in cylinders sent back to suppliers, and invoices for gas purchases or sales.

These non-emissions data are needed to understand the nature of the facilities and processes for which data are being reported and for verifying the reasonableness of the reported data.

7. References

EPA (2008) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006. U.S. Environmental Protection Agency, Washington, D.C.

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change, H.S. Eggleston, L. Buendia, K. Miwa, T Ngara, and K. Tanabe (eds.). Hayama, Kanagawa, Japan.

USGS (2007) 2006 Minerals Yearbook - Magnesium. U.S. Geological Survey, Reston, VA.