# Draft Concept Paper

# Sulfur Hexafluoride ($SF_6$) use in Non-Utility and Non-Semiconductor Applications

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**This paper provides background for the greenhouse gas mitigation early action to reduce emissions of sulfur hexafluoride ($SF_6$). The information presented includes the different uses, emissions, and emission projections for $SF_6$. It also discusses potential mitigation strategies.**

## Background on Sector

Sulfur hexafluoride ($SF_6$) is a potent greenhouse gas with a global warming potential (GWP) of 23,900, one of the largest GWPs currently identified. $SF_6$ is a versatile gas used in a multitude of sectors including the use by utilities as well as the semiconductor industry, which will be addressed under separate strategies. Therefore, this early action focuses on the non-utility/semiconductor-related emissions of $SF_6$. Specifically, the strategy discussed here will consider a potential ban on the use of $SF_6$ where technologically feasible and cost-effective alternatives are available. The main uses of $SF_6$ in California that are not directly related to utilities or semiconductor manufacturing include:

- Magnesium Casting Operations
- Consumer Products (tennis balls)
- Medical uses (ultrasounds, eye surgery)
- Tracer gas in leak testing (including fume hood testing), research and bioterrorism studies
- Insulator for particle accelerators
- Etchant for flat panel display units
- Other

Some of these uses are closely aligned with other early actions or other regulatory processes and will be addressed in those forums. $SF_6$ usage in flat panel display manufacture is similar to its use in semiconductor applications as an etchant. Similarly, use of $SF_6$ as an insulator for particle accelerators is similar to the use in electric utilities. In both cases, the regulatory approach will mirror findings from those two measures to ensure consistency. These applications will not be discussed further in this white paper.

*Magnesium Casting*

$SF_6$ is used in magnesium die-casting and production. California has no production and only two die-casting facilities. The Unites States Environmental Protection Agency (EPA) has estimated annual emissions of less than 0.1 $MMTCO_2E$ in 2004 from those two facilities (EPA, 2007a). California does not have any magnesium production facilities. In sand and die-casting, $SF_6$ is used as a cover gas to prevent the rapid oxidation of molten magnesium in the presence of air. This is accomplished when a small portion of the $SF_6$ reacts with the magnesium to form a thin molecular film of mostly magnesium oxide and magnesium fluoride (EPA, 2007b). The two identified magnesium casters in California are partners in the U.S. EPA's "Magnesium Industry Partnership". As members, these companies have agreed to voluntarily phase-out the use of $SF_6$ in the magnesium industry by the end of 2010.

*Consumer Products*

$SF_6$ has been used in many products due to its characteristics. $SF_6$ will remain in rubber and plastic insulated products and provide bounce and cushion and rarely leaks out when injected into rubber or plastic insulated products . For these reasons, it has historically been utilized in tennis balls and athletic shoes. $SF_6$ use in tires has occurred in Europe but not in the US. $SF_6$ in consumer products has declined as use in shoes has been discontinued. Further analysis as to the status of $SF_6$ in tennis balls and other products is needed.

*Tracer Gas Uses*

$SF_6$ has proven to be a good tracer gas for several reasons. It is not found naturally in the environment and background levels tend to be close to zero. It should be noted that at least one recent study found that background levels of $SF_6$ were elevated due to nearby electric utilities. In addition to the low background levels, $SF_6$ is measurable at low concentrations. It is also generally considered to be non-toxic and inert and resistant to microbial degradation.

$SF_6$ has been used as a tracer gas in recent bioterrorism studies in other states and countries. ARB is not aware of any studies being planned in California at this time.

Leak testing is a subset of tracer gas use. In particular, fume hood testing is a leak testing use with potentially large emissions. Current state law includes requirements for fume hood testing on newly installed hoods. The law includes voluntary tracer gas tests for all new fume hoods and mandatory tracer gas testing for fume hoods that wish to use a reduced face velocity when hoods are unintended, resulting in a decrease in energy use and a corresponding decrease in carbon dioxide emissions from energy use. The current standards require the use of $SF_6$ as the tracer gas but allow for alternate gases if SF6 is not suitable for the type of fume hood being tested and if the alternative gas meets state criteria, to be discussed in the next section. The test require approximately 1.5 pounds of SF6 use per hood test which corresponds to approximately 16 metric tonnes of $CO_2$-equivalent gas released per hood test.

*Other uses*

Medical uses of $SF_6$ include eye surgery and ultrasound imaging. In eye surgery, $SF_6$ acts as a tamponade gas, for example as a plug for retinal holes in retinal detachment related operations. Additionally, one type of ultrasound imaging utilizes $SF_6$ micro-bubbles as a contrast agent to enhance blood vessel visibility. This technique may be viable for other applications as well. Medical uses of $SF_6$ need to be carefully considered and would be excluded from a ban if it is determined that it is an essential use where a viable alternative is not available.  PFCs have been used in these medical applications; however, PFCs also have high global warming potentials (approximately 6,000-9,000). Emissions from eye surgery should be minimal since the gas acts as a plug and is expected to remain within the body.

Given the wide variety of uses for $SF_6$ there is the potential for uses and emission sources we have not yet identified.  An effective ban would serve as a barrier to new uses.

**Inventory, Projections, and Trends**

Non-electric and non-semiconductor related emissions of $SF_6$ are not well understood in general.  The best estimates exist for the magnesium industry which provides U.S. EPA with confidential data on $SF_6$ use and usage rates at the plant level.  U.S. EPA has provided us with a state level estimate.  Emissions from other uses are estimated based on national information on use of $SF_6$ and assuming use is a robust proxy for emissions although this may not be the case for all uses.

Assuming that California is similar to the rest of the US, approximately five percent of $SF_6$ use can be attributed to these miscellaneous uses.  ARB used two methods to estimate emissions: 1) Scale national level estimate to California based on population, and 2) Assume 5 percent of state $SF_6$ use can be attributed to these sources and estimate based on magnesium, utility and semiconductor estimates.  Using these methods, the emissions estimate ranges from 0.1 to 0.9 $MMTCO_2E$.  Additional information would improve this estimate.  Table 1 provides the summary historical and projected emission estimates.

| Table 1 - $SF_6$ Emissions in California ($MMTCO_2E$) | | |
|---|---|---|
| Use | 2004 | 2020 |
| Magnesium | <0.1 | 0 |
| Other Uses<br>- Tracer<br>- Consumer Products<br>- Medical | 0.1- 0.9 | TBD |

The sub-source estimates are even more difficult to determine.  Consumer product uses are assumed to be minimal since most uses have been discontinued.  Medical uses are likely to be small as well.  $SF_6$ used in eye surgery is expected to stay within the eye as a plug and emissions will be minimal.  It is unclear how much $SF_6$ is used in each ultrasound and how many of these types of ultrasounds are performed each year.  Vent hood and tracer gas studies are likely the largest sources as all the gas used is emitted. Given the large number of universities and laboratories within the state, emissions from vent hood testing could be the largest use in this category.  As mentioned earlier, $SF_6$ tests are only required for hoods to be certified to run at a lower face velocity when not in use, reducing emissions from $CO_2$ due to electricity consumption. The tradeoffs between reduced $SF_6$ emissions and reduced $CO_2$ emissions need to be fully evaluated if an alternate tracer cannot be used for certification.

Although there are no regulatory controls on $SF_6$ use in any sector in the US, the magnesium sector is voluntarily reducing $SF_6$ use with emissions expected to reach zero by 2010. Reductions are expected through efficiency and switching to alternate cover gases.

Consumer product uses are expected to remain at or near zero but other sector emissions are expected to grow slightly over time in a business-as-usual scenario due to population and GDP growth. Quantification of projected 2020 emissions is not feasible at this time.

*International Perspective and Issues*

Europe has banned $SF_6$ use in magnesium die-casting (above 0.75 metric tons of $SF_6$ or almost 18,000 metric tons $CO_2E$ per year per facility) and tires as well as prohibited specified new products and equipment reliant on fluorinated greenhouse gases. A few countries have even more stringent regulations and taxes for $SF_6$ consumption and production.

Denmark has implemented a tax on industrial gases (HFCs, PFCs and $SF_6$) imports and a ban on the import, sale, and use of the substances or new products containing the substances from January 1, 2006 with limited exceptions. Since March 2001, imports of these gases have been subject to a tax beginning at DKK 1/kg and up to DKK 400/kg or between $0.20 - $70 / metric tonne $CO_2$. Denmark estimates that the tax and regulations led to a reduction of 0.05 $MMTCO_2E$ in 2001 with an expected reduction of 0.15 $MMTCO_2E$ in 2005 and .37 $MMTCO_2E$ in 2020. The reduction cost is estimated at DKK 200/tonne $CO_2$ or approximately $35/tonne $CO_2$ (Danish Ministry of Environment, 2005).

Austria has a schedule for phasing out $SF_6$. The phase-out includes tires, windows, magnesium, semiconductors, and a reduction for electric switchgear.

## Alternatives by End-Use Sector

*Magnesium*

As mentioned above, $SF_6$ is used as a cover cast in magnesium die-casting and production. $SO_2$ and fluorinated gases are readily available alternative cover gases. Fluorinated gases available for use as a cover gas are fluorinate ketones and HFC-134a (Mibrath, 2002; Ricketts 2002, Hillis, 2002). These gases have fewer concerns over toxicity, odor, or corrosivity than $SO_2$. Fluorinated ketones do not have a global warming potential; HFC-134a has a global warming potential of 1,300 which is much lower than that for $SF_6$ (23,900). Depending on the alternate cover gas, greenhouse gas emission could be reduced by 95 to 100% (EPA 2006). These alternative gases are suitable at all locations within California. The one-time capital cost will vary but conservatively can be assumed to be similar to the cost for $SO_2$ systems (EPA 2006). Annual costs are likely to be close to $SO_2$ annual costs as well, however, there will be no cost savings from the gas itself as fluorinated cover gases are similar in cost to $SF_6$.

The industry previously used $SO_2$ but concerns over odor, toxicity, and corrosivity resulted in the use of $SF_6$ instead of $SO_2$. Current research aims to improve the process by addressing the aforementioned issues through containment and pollution control systems. $SO_2$ can replace $SF_6$ entirely and is technically feasible at all die casters. Based on Canadian data, the one-time cost for replacement is \$5.73/$MTO_2E$ (metric ton carbon dioxide equivalent). The cost for training per facility is approximately \$50,000. $SO_2$ is significantly cheaper than $SF_6$ and there will be an annual savings that will at least partially offset costs. Based on U.S. EPA analysis, overall mitigation costs will range from \$0.50 to \$1.50/$MTCO_2E$ (EPA 2006). These options should be applicable to the California casters as well. In fact, as noted above, magnesium casters in California are already moving to alternative cover gases.

*Consumer Products*

Consumer product uses of $SF_6$ are non-essential. Previous phase out of $SF_6$ in products such as Nike tennis shoes and European tires shows that low or no GWP alternatives are available for these types of uses at low cost.

*Tracer Gas Uses*

Many gases have been used as tracers with gas choice dependant on use. Propane, nitrous oxide, and carbon dioxide have been used in some settings. Perfluorocarbons and hydroflorourocarbons have been used as tracer gases in situations where $SF_6$ is often used (i.e., airshed simulations). In an internal memo from 2000, U.S. EPA recommends the use of HCFC 123 instead of $SF_6$ but HCFC 123 will be phased out in 2015. HFCs may also be a viable alternative as all but HFC 23 have significantly lower GWPs than both the PFCs and $SF_6$.

A fume hood testing gas should be non-toxic, non-explosive, relatively inexpensive, stable, non-odorous, non-corrosive and approximately the density of ambient laboratory air (LBNL 2007, ASHRAE110 1995). Although $SF_6$ is non toxic, and non-explosive, it is much heavier than air. LBNL provided several potential alternatives including ethylene which is non toxic and the same weight as air. Although it is combustible, concentrations would need to be at much higher levels than necessary for fume hood testing. According to the same LBNL study, costs for measurement devices for the alternative gases are similar or less expensive when compared to the cost for $SF_6$ measurement devices. Additionally, fume hood testing could be modified to reduce the amount of $SF_6$ used.

Use of alternate tracer gases needs to be examined further to consider the safety and effectiveness of alternatives.

*Medical uses*

PFCs have been used in eye surgery and as contrast agents. PFCs have high GWPs from approximately 6,000 to 9,000, which are lower than $SF_6$. $SF_6$ emissions from eye surgeries are expected to be low as the $SF_6$ should stay within the eye. Other contrast agents are available for ultrasounds and other medical uses but $SF_6$ may provide an enhanced contrast.

Potential Strategies being Considered

1. Ban all non-electrical and non-semiconductor uses of SF
    a. Exclusions - may include medical uses, limits on some uses (i.e. x kg per study)
    b. Include reporting for sources that are not banned
    c. Magnesium - Exclude or Phase in ban
    d. Consider waivers and mitigation fees
2. Mitigation Fee on all non-electrical and non-semiconductor uses of $SF_6$

For the potential strategies being considered, reductions would range from 0.1-1 $MMTCO_2E$ with a cost estimate of less than $5/$MMTCO_2E$ where alternatives are available

3. Others? We welcome input from stakeholders on potential reduction strategies

Options to consider include alternative compliance mechanisms such as offsetting the carbon footprint of the operation when no viable alternatives exist.

Costs

Where alternatives exist, costs are expected to be under $5/$MTCO_2E$ with highest costs for the magnesium sector where equipment would need to be replaced or adjusted. Costs for magnesium are estimated at $0.50-1.50 /$MTCO_2E$. In terms of the cost of the gas, alternatives are likely to be less expensive than $SF_6$. The cost is not expected to reach levels for Denmark's legislation since that cost included HFCs and PFCs as well as a tax.

Considerations and Outstanding Questions and Barriers

The largest outstanding issues revolve around a lack of data. It is unclear if all uses of $SF_6$ have been identified and the emissions from each use are uncertain. The reduction potential of this sector and the associated total cost is unknown. The number of entities that will be impacted is also not known. It is difficult to estimate the life cycle impact of alternatives in comparison to $SF_6$ with the current level of information.

Another consideration is the magnesium industry's current voluntary agreement to eliminate $SF_6$ emissions by 2010. The magnesium industry can currently sell credits in voluntary markets but if included under a regulation, voluntary markets may no longer consider this an additional reduction. Additionally, the magnesium industry would need to be considered during formulation of ARB's voluntary early action policy. Stakeholders have already expressed concern over voluntary actions in the magnesium sector in other states as a result of this regulation.

Summary

$SF_6$ uses from non-electrical and non-semiconductor applications are varied with alternatives generally available. Although data is limited, limits on use appear to be viable for most applications. The safety, effectiveness, and cost of the alternatives will be further evaluated in the regulatory process. Additionally, the current voluntary agreements will be considered. Overall it is estimated that at least 1 $MMTCO_2E$ can be reduced at a low cost from this sector.

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