Department of Energy

Fluorinated Greenhouse Gas Fugitive Emission Reduction 2008-2018

Office of Sustainable Environmental Stewardship
Office of Environment, Health, Safety and Security
Executive Summary

The purpose of this report is to present the achievements of the Department of Energy (DOE or Department) in reducing fluorinated greenhouse gas (GHG) fugitive emissions over the period 2008-2018 in support of overall DOE and United States Government GHG reduction efforts.

While there is no specific driver, this report aligns with the Department’s sustainability and GHG reduction efforts and identifies successful and low-cost efforts to drive down releases of high global warming potential (GWP) gases which can help DOE elements identify additional opportunities.

Since the issuance of Executive Order (E.O.) 13514, Leadership in Environmental, Energy, and Economic Performance, dated October 5, 2009, federal agencies have been required to implement comprehensive accounting and emissions reductions measures for GHG based on a baseline of fiscal year (FY) 2008 emission levels. Based on the inventory of 2008 GHG emissions and implementation of reasonable measures, DOE initially established a goal of 28% reduction of all targeted GHG emissions by 2020.

DOE’s FY 2008 emissions inventory indicated that approximately 17% of DOE total GHG emissions were comprised of fugitive emissions (i.e., releases from nonpoint sources such as equipment and seal leaks) of fluorinated GHG identified in the E.O. The majority of DOE fluorinated GHG fugitive emissions were comprised of sulfur hexafluoride, a material that has a global warming potential of over 22,000 times than that of carbon dioxide, used in power distribution and highly specialized scientific equipment.

To implement a strategy for reducing fluorinated GHG fugitive emissions, DOE created the Fugitive Emissions Working Group (FEWG) comprised of representatives throughout the Department. The FEWG serves as an information and collaboration resource for DOE sites to share information and methods to manage fluorinated GHG more effectively with the goal of reducing fugitive emissions of these materials.

From 2008 to 2018, through the efforts of Program Offices and sites, and with the support of the FEWG, DOE has reduced fluorinated GHG fugitive emissions from its operations by approximately 56 percent, double the original Departmental goal. These achievements were accomplished with minimal capital investment demonstrating that GHG emissions can be reduced utilizing cost-effective measures.
Introduction

The purpose of this report is to present the achievements of the Department of Energy (DOE or Department) in reducing fluorinated greenhouse gas (GHG) fugitive emissions over the period 2008-2018 in support of overall DOE and United States Government GHG reduction efforts. DOE intends for this report to foster continued fluorinated GHG emission reductions by sharing this information within DOE and to other agencies, academia, and private enterprises.

While there is no specific driver, this report aligns with the Department’s sustainability and GHG reduction efforts and identifies successful and low-cost efforts to drive down releases of high global warming potential (GWP) gases which can help DOE elements identify additional opportunities.

Background

Executive Order (E.O.) 13514, Leadership in Environmental, Energy, and Economic Performance, dated October 5, 2009, among other things, required federal agencies to implement comprehensive accounting and emissions reductions measures for GHG by 2020 based on a baseline of fiscal year (FY) 2008 emission levels. DOE established a goal of 28% reduction of all targeted GHG emissions by 2020. While E.O. 13514 was subsequently replaced with E.O. 13693, Planning for Federal Sustainability in the Next Decade, March 19, 2015, and then E.O. 13834, Efficient Federal Operations, May 17, 2018, the GHG accounting and reporting requirements were retained.

The GHG targeted for emission reductions in the three E.O.s and their associated GWP are provided in Table 1. GWP, measured in CO₂ equivalent (CO₂e), is the measure of a substance to absorb thermal radiation compared to CO₂.

<table>
<thead>
<tr>
<th>GHG</th>
<th>GWP (CO₂e)</th>
</tr>
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<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>1</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>28-36</td>
</tr>
<tr>
<td>Nitrous oxide (N₂O)</td>
<td>265-298</td>
</tr>
<tr>
<td>Hydrofluorocarbons (HFC)</td>
<td>12-17,700</td>
</tr>
<tr>
<td>Perfluorocarbons (PFC)</td>
<td>12-17,700</td>
</tr>
<tr>
<td>Nitrogen trifluoride (NF₃)</td>
<td>17,200</td>
</tr>
<tr>
<td>Sulfur hexafluoride (SF₆)</td>
<td>22,800</td>
</tr>
</tbody>
</table>

The first three targeted GHG (CO₂, CH₄, and N₂O), which are generally associated with the consumption of fossil fuels, comprise the majority of DOE GHG emissions. However, the DOE GHG inventory also indicated that approximately 17% of DOE emissions were comprised of fugitive emissions (i.e., releases from nonpoint sources such as equipment and seal leaks) of the
targeted fluorinated GHG, i.e., HFC, PFC, NF₃, and SF₆ (see Table 2). Furthermore, approximately 90% of DOE fluorinated GHG fugitive emissions consisted of SF₆, the material with the highest GWP.

Table 2: DOE GHG Emissions by Source

<table>
<thead>
<tr>
<th>Source Category</th>
<th>FY 2008 Emissions</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offsite Energy Generation</td>
<td>2,856,816</td>
<td>59.72%</td>
</tr>
<tr>
<td>Onsite Stationary Sources</td>
<td>979,686</td>
<td>20.48%</td>
</tr>
<tr>
<td>Fugitive Emissions of Fluorinated GHG</td>
<td>798,992</td>
<td>16.70%</td>
</tr>
<tr>
<td>Mobile Sources</td>
<td>120,191</td>
<td>2.51%</td>
</tr>
<tr>
<td>Other Fugitive Sources</td>
<td>28,114</td>
<td>0.59%</td>
</tr>
<tr>
<td>Total GHG</td>
<td>4,783,799</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Specific uses for fluorinated GHG by DOE power administrations, laboratories, and other sites are detailed in Table 3.

Table 3: DOE Uses of Fluorinated GHG

<table>
<thead>
<tr>
<th>GHG</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC and PFC</td>
<td>• Replacement refrigerant for ozone depleting substances</td>
</tr>
<tr>
<td></td>
<td>(chlorofluorocarbons and hydro-chlorofluorocarbons)</td>
</tr>
<tr>
<td></td>
<td>• Foaming agent in polystyrene foams</td>
</tr>
<tr>
<td></td>
<td>• Fire extinguishing agent</td>
</tr>
<tr>
<td></td>
<td>• Aerosol propellants</td>
</tr>
<tr>
<td>PFC and NF₃</td>
<td>• Cleaning agent and plasma etchant in semiconductor manufacturing</td>
</tr>
<tr>
<td></td>
<td>• Used in specialized particle tracking apparatuses</td>
</tr>
<tr>
<td>SF₆</td>
<td>• Dielectric material in high energy applications such as lasers,</td>
</tr>
<tr>
<td></td>
<td>accelerators, electron microscopes, and circuit breakers</td>
</tr>
<tr>
<td></td>
<td>• Insulating agent in electrical equipment, such as accelerators,</td>
</tr>
<tr>
<td></td>
<td>switch gear, and high-voltage power supplies</td>
</tr>
</tbody>
</table>

While the Department implemented measures and achieved reductions of GHG emissions in all source categories, this report focuses on the DOE fluorinated GHG fugitive emission reductions, SF₆ in particular, and highlights site-specific projects, best practices, innovations, and lessons learned.

DOE Fluorinated GHG Fugitive Emissions

As required by E.O. 13514, DOE calculated its baseline GHG emissions inventory across all DOE Program Offices and sites for FY 2008. Forty-eight DOE sites reported having fluorinated GHG
fugitive emissions. However, the following 12 DOE sites represent approximately 93% of DOE’s total fluorinated GHG fugitive emissions.

- Argonne National Laboratory (ANL)
- Bonneville Power Administration (BPA)
- Fermi National Accelerator Laboratory (FNAL)
- Lawrence Livermore National Laboratory (LLNL)
- Los Alamos National Laboratory (LANL)
- Oak Ridge National Laboratory (ORNL)
- Princeton Plasma Physics Laboratory (PPPL)
- Sandia National Laboratories – New Mexico (SNL-NM)
- Stanford National Accelerator Laboratory (SLAC)
- Thomas Jefferson National Accelerator Facility (TJNAF)
- Western Area Power Administration (WAPA)
- Y-12 National Security Complex (Y-12)

Figure 1 illustrates the type and percentage of fluorinated GHG fugitive emissions identified during the emissions inventory conducted throughout the Department for FY 2008. Figure 2 illustrates the distribution of the fluorinated GHG fugitive emissions across the 12 DOE sites.

**Figure 1: DOE FY 2008 Fluorinated GHG Fugitive Emissions by Type**

![Graph showing fluorinated GHG fugitive emissions by type](image-url)
To implement a strategy for reducing fluorinated GHG fugitive emissions, DOE created the Fugitive Emissions Working Group (FEWG) comprised of DOE Headquarters and site personnel from a range of disciplines and functions. The FEWG serves as an information and collaboration resource for DOE sites to share information and methods for the purpose of managing fluorinated GHG more effectively, thereby reducing fugitive emissions of these materials. The FEWG continues to meet routinely to stay abreast of emerging trends and technologies; and to share best practices and lessons learned.

To better understand the process generating fluorinated GHG fugitive emissions, DOE sites identified sources and developed tracking and accounting programs for SF₆, HFC, PFC, and NF₃. Fugitive emissions of fluorinated GHG are measured by each site and recorded each FY in Site Sustainability Reports and the DOE Sustainability Dashboard.

As indicated in Figure 1, SF₆ is the primary contributor to fluorinated GHG fugitive emissions from DOE sites. DOE recognized early on that it could not simply replace SF₆ with other substances, due the complexity and variety of the processes using SF₆, the lack of available substitutes for SF₆, and the hazardous nature of available SF₆ substitutes. Rather, the Department’s efforts focus on improved processes, management controls, capture technologies, and reduced usage of SF₆. These same measures would also be applied to the other fluorinated GHG fugitive emissions.

As illustrated in Figure 3, DOE, through the efforts of the Program Offices and sites has reduced fluorinated GHG fugitive emissions from its operations by approximately 56%, double the
Departmental goal and two years ahead of schedule. These achievements were accomplished with minimal capital investment, making it an exceptionally cost-effective for reducing GHG emissions.

Figure 3: Reduction of DOE Fluorinated GHG Fugitive Emissions from 2008 - 2018

Figure 4 details the GHG emissions associated with fluorinated gases for each of the 12 sites listed above. With the exception of LANL, all sites reduced fugitive GHG emissions for the period 2008 through 2018. The GHG emissions increase at LANL was due to identifying additional sources of fluorinated gas releases and incorporating better accounting protocols, increasing the accuracy of collected data.
DOE Site-Specific Success Stories

DOE sites have undertaken specific actions to reduce releases of SF\textsubscript{6} and other fluorinated GHG fugitive emissions. A few of these actions are presented here in alphabetical order by site as success stories.

**Argonne National Laboratory (ANL)**

ANL adopted an SF\textsubscript{6} management strategy in 2010 that successfully captured large quantities of SF\textsubscript{6} from decommissioning the Argonne Tandem Linac Accelerator System (ATLAS) in the spring of 2014. ANL estimated the amount of SF\textsubscript{6} in the ATLAS equipment to be approximately 4 tons. A contractor was hired to capture and reclaim the SF\textsubscript{6}. After analyzing the purity of the SF\textsubscript{6}, the contractor agreed to pay 50¢ per pound recovered. During the transfer, ANL staff setup a leak detection system and conducted daily leak checks on the temporary evacuation lines and equipment. Over a 15-day period, 7,787 pounds of SF\textsubscript{6} were collected, with only 410 pounds lost to the atmosphere (10 pounds from the evacuation process and 400 pounds that could not be evacuated from the system).
Bonneville Power Administration (BPA)

In 1999, BPA entered into a voluntary partnership with EPA to develop an SF₆ management plan. BPA activities to reduce SF₆ predate the formation of the FEWG and allowed for early adoption of proven SF₆ emissions reduction measures by other sites.

BPA staff use Forward-Looking InfraRed (FLIR) cameras to identify SF₆ emissions from electrical equipment. When leaking equipment is identified, the SF₆ is evacuated into a container for reclamation, instead of being dispersed directly into the atmosphere.

Fermi National Accelerator Laboratory (FNAL)

The Tevatron was the second most powerful particle accelerator in the world at the time of its decommissioning in 2011. Deactivation of the Tevatron removed a source of fugitive emissions of SF₆, and FNAL was able to identify opportunities for reusing SF₆ from the Tevatron.

FNAL has implemented a Refrigerant Management (RM) program to manage over 600 pieces of equipment using various HFC refrigerants. The refrigerant manager is responsible for the RM program, including maintaining a database of refrigerant and equipment, document technician and regulatory compliance, and tracking all refrigerant use. With the RM program, the refrigerant manager is able to identify problem and leaking equipment for more immediate repair, reducing fugitive emissions.

Lawrence Livermore National Laboratory (LLNL)

LLNL developed and implemented a robust SF₆ management and capture plan. The plan includes several features for reducing SF₆ emissions, including: disposition of unneeded SF₆; elimination of SF₆ from certain applications; replacement of electrical equipment containing SF₆ with alternative equipment that does not use SF₆; developing and implementing capture technologies; installing leak detection alarms; and requiring purchases of SF₆ to be reviewed by an air quality specialist.

As part of this program, LLNL obtained a portable reclamation unit for capturing SF₆ and added gas scrubbers to extend the life of SF₆ used in their Flash X-Ray project. These improvements have minimized fugitive emissions of SF₆ and yielded significant cost savings in labor and materials.
Los Alamos National Laboratory (LANL)

In collaboration with Virginia Tech University, LANL redesigned its electric switches to use compressed air or oil instead of SF\(_6\). In 2018, LANL began replacing older switches containing SF\(_6\) with the newer switches in 2018 and has not purchased any additional SF\(_6\) for electrical switches since.

LANL has successfully identified and implemented pollution prevention projects to reduce SF\(_6\) emissions. Funding for pollution prevention projects was used to obtain handheld SF\(_6\) monitors that are used to identify fugitive emissions. In the Dual-Axis Radiographic Hydrodynamic Test facility (DARHT), SF\(_6\) is used as a dielectric insulator for high voltage switches. Using the handheld monitors, LANL was able to identify multiple leaking mechanical joints. These joints were repaired and replaced with welded joints that are less prone to leakage, and DARHT reduced its SF\(_6\) consumption from 22 to 9 cylinders per year.

LANL continues its pollution prevention efforts to identify alternatives to SF\(_6\) and new programs to reduce fugitive SF\(_6\) emissions.

Oak Ridge National Laboratory (ORNL)

ORNL decommissioned the Holifield Radioactive Ion Beam Facility (HRIBF), which used SF\(_6\) as an insulating gas. In 2018, ORNL recovered and transferred 74,000 lbs. of SF\(_6\) from the HRIBF, closely monitoring transfer operations for leaks and fugitive losses.

Princeton Plasma Physics Laboratory (PPPL)

PPPL developed an SF\(_6\) leak detection program that was implemented in February, 2010. As part of this program, PPPL developed an improved inventory management and weighing system. PPPL has identified and repaired leaks during periodic leak checks and vents pressure relief valves to bladders, where the SF\(_6\) is processed with a portable cart. This allows PPPL to reclaim, recover, and store SF\(_6\) for eventual reuse.

Sandia National Laboratories – New Mexico (SNL-NM)

SNL-NM established an SF\(_6\) Working Group in 2010 to facilitate collaboration in identifying SF\(_6\) management solutions and to share successes and lessons learned with other users around the
The Saturn and High-Energy Radiation Megavolt Electron Source (HERMES) III accelerators create X-rays and gamma rays powerful enough to simulate conditions created by nuclear weapons, allowing research of the effects of radiation in a laboratory setting.

To reduce SF₆ emissions, SNL-NM undertook a leak reduction effort that included upgrading valves, replacing tubing, and eliminating and replacing fittings and joints. SNL-NM also increased the accuracy of estimating SF₆ emissions and developed a site-specific SF₆ recovery program using a custom-designed SF₆ recovery cart. Finally, SNL-NM is educating employees and contractors on the environmental impacts of SF₆, to foster further improvements in reducing SF₆ emissions. SNL-NM was awarded the NNSA Sustainability Award in 2013 for these GHG reduction efforts at Saturn/HERMES III.

The Z Machine is another major contributor to SF₆ emissions at SNL-NM and a number of SF₆ gas usage reduction efforts have focused on this source. Efforts include system leak identification and repair, removal of unused systems and components, and effective management of gas usage post shot (faster shut off of SF₆ gas to leaking components). These efforts have resulted in steadily reducing emissions from normal operations.

**Stanford National Accelerator Laboratory (SLAC)**

SLAC has been voluntarily reporting GHG emissions, including fugitive SF₆ emissions, since 2007 to The Climate Registry. SLAC has identified SF₆ use at substations with circuit breakers and switches, research labs, and support facilities. Leak surveys have focused more heavily on older equipment that is prone to leaks.

SLAC has also reduced SF₆ emissions in research projects by incorporating design changes into new and existing equipment. At SLAC, a laboratory experiment that used large quantities of HFC-134a implemented a process change to use a substitute substance; as a result, SLAC HFC-134a emissions decreased by over 4,700 metric tons CO₂e.

**Thomas Jefferson National Accelerator Facility (TJNAF)**

TJNAF spearheaded a novel approach to capturing SF₆ in an inflatable bag during maintenance operations. Afterwards, the SF₆ is pumped from the bag back into the process. This novel approach was immediately considered a best management practice and adopted by other DOE sites after TJNAF shared the concept at a FEWG meeting.

TJNAF has also adopted the use of a FLIR A20M camera to identify leaks in SF₆ equipment and
Western Area Power Administration (WAPA)

In 2000, WAPA entered into a voluntary partnership with EPA to develop an SF₆ management plan. Elements of this plan include leak detection of SF₆ leaks and development of best management practices for the repair of electrical equipment leaking SF₆.

Other best management practices include the recovery of SF₆ from leaking equipment, and requirements to weigh SF₆ bottles before and after use, to better inventory SF₆ emissions from specific equipment.

Thanks to its efforts, WAPA has been able to decrease its overall SF₆ emissions while significantly increasing its nameplate capacity.

Y-12 National Security Complex (Y-12)

At Y-12, a process change was implemented to reduce emissions of HFC-443-10mee. Y-12 implemented a system to reclaim and reuse the HFC-443-10mee from onsite processes. Although this resulted in lower GHG emissions, it proved to be an interim step, as Y-12 also began testing alternatives to the material. Within two years, the site had identified a new material and was able to implement a new cleaning process that eliminated HFC-443-10mee use. Y-12 HFC-443-mee emission reduced by 14,514 metric tons CO₂e from FY 2008 to FY 2018.

Additionally, Y-12 reduced fugitive emissions of SF₆ by upgrading its chiller systems and improving its metal chip cleaning process.

Conclusion

For the period of 2008 through 2018, DOE has reduced fluorinated GHG fugitive emissions by 56%. The reductions to date have been achieved through the dedication and initiative of individual DOE Program Offices and Sites.

The FEWG continues to identify novel approaches to managing fluorinated gases and evaluate the technical and financial feasibility of reduction measures to help DOE sites decrease GHG emissions from fluorinated gases.