World Semiconductor Council

Best Practice Guidance for Semiconductor Process Greenhouse Gases Emission Reductions

In order to effectively and efficiently achieve the World Semiconductor Council (WSC) post-2020 voluntary process greenhouse gases (GHG)emission reduction program, this technical guidance is set as the best practices for WSC members' reference and should not be viewed or applied as a standard. Implementation of identified best practices will vary among members based on availability for specific applications and feasibility. Emissions estimation protocol used will be based on WSC member agreement.

This best practices document covers selected process greenhouse gases as described in the next sections and does not include additional Scope 1 and Scope 2 emissions. The WSC will work to expand this document to cover additional emissions as work progresses.

The elements of the 2030 goal include the following:

- Target of 85% selected process greenhouse gases emissions reduction (kgCO_2e emissions / kgCO_2e Emission amount without reduction) through implementation of best practices in new and existing fabs.

- The inclusion of "Rest of World" fabs (fabs located outside the WSC regions that are operated by a company from a WSC association or not included in that WSC region's inventory) in reporting of emissions and the implementation of best practices for new and existing fabs.

The target applies to the following selected process greenhouse gas emissions: fluorinated greenhouse gases (F-GHG) including perfluorocarbons (e.g., CF_4, C_3F_6 and C_3F_8), hydrofluorocarbons (e.g., CHF_3, CH_3F and CH_2F_2), NF_3 and SF_6.

A verification of the target will be conducted in 2025 and the goal may be adjusted. Adjustments may include:

- Expanding the basket of gases to include N_2O and F-HTF.
- Expanding the goal with additional Scope 1 and Scope 2 emissions.

All semiconductor fabs which break ground and existing fab expansions adding greater or equal to 10% cleanroom space are considered to be new fabs and must employ the WSC best practices.

Best practices will be reviewed and updated as needed by the related technical working group.

1. Emission Estimates
   The WSC goal was established based on the estimation method using “2019 IPCC Refinement of Guidelines for National Greenhouse Gas Inventories, Volume 3, Chapter 6” (IPCC GL), Tier 2c [5.1] and the Fifth Assessment Report (AR5) GWP_{100} values [5.2]. This method is the most accurate and current internationally accepted greenhouse gas emission estimation method for the semiconductor industry.

2. Best practices

   The selection of the best practice for a specific situation will depend on several factors such as viability, efficiency, and other considerations.
   The best practices apply to process greenhouse gas emissions including but not limited to perfluorocarbons (e.g., CF4, C2F6 and C3F8), hydrofluorocarbons (e.g., CHF3, CH3F and CH2F2), NF3 and SF6.

   2.1. Process recipe optimization
   Optimizing processes to consume less greenhouse gases is a fundamental practice to be done for process greenhouse gases emission reduction. Note: See chapter 3.1 and 3.2 for details.

   2.2. Greenhouse gas replacement
   Replacing high global warming potential (GWP) gases with lower GWP or GWP-free gases or using gases more

efficiently in the plasma process are another solution to further reducing net process greenhouse gases emissions. Note: See chapter 3.2 for details.

2.3. Abatement/treatment

An abatement/treatment system is used to reduce selected Process Greenhouse Gases by destroying the process greenhouse gases. Abatement may be capable of treating process greenhouse gases and hazardous gases simultaneously.

Note: See chapter 3.3 for details.

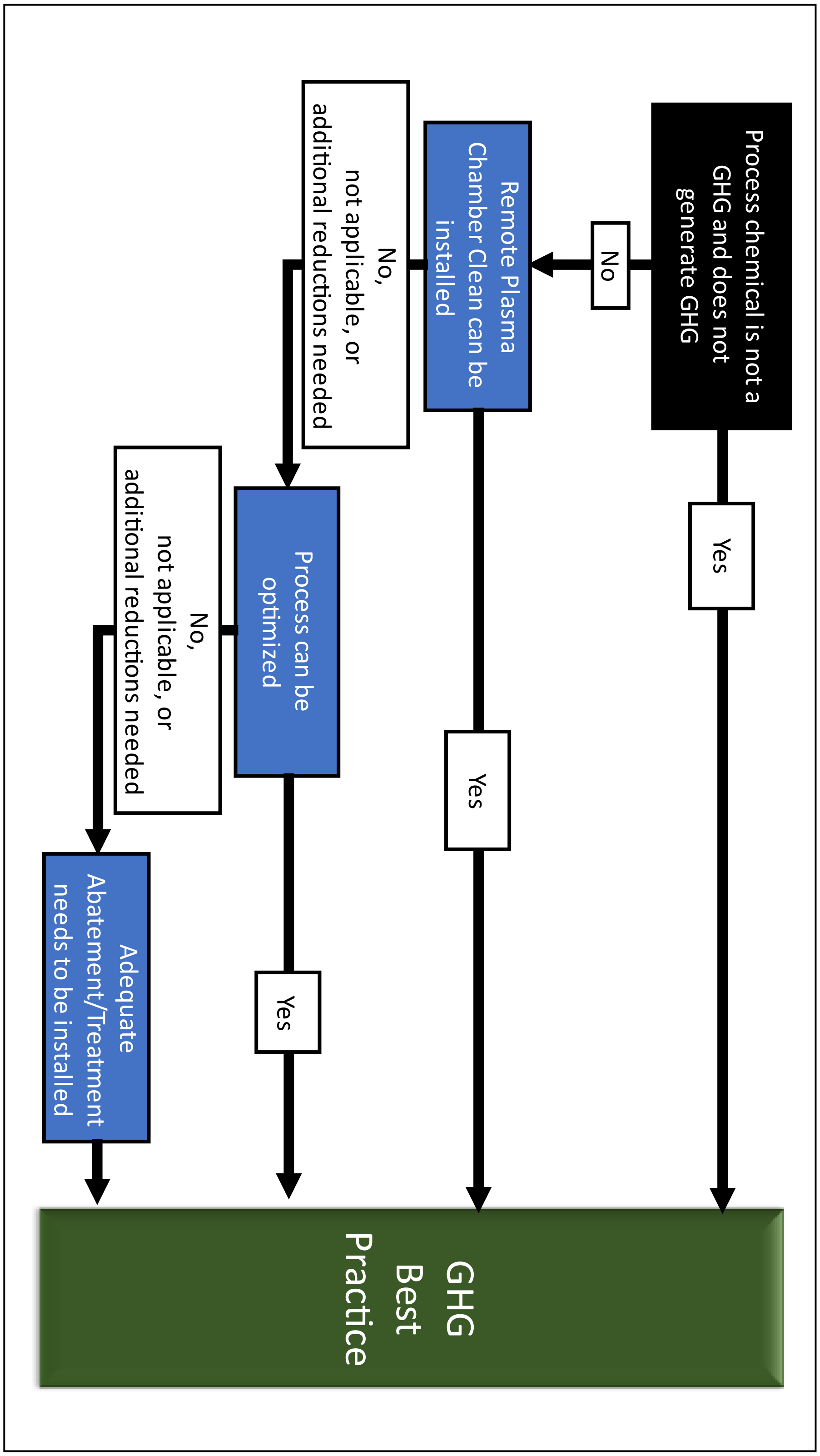
Process greenhouse gas abatement can be applied to:

- All new fabs and expansions of existing fab
- Changes to existing fabs
    - Maintain or replace existing installed abatement capacity
    - Existing tools relocated to different fabs should include abatement where feasible
    - For upgrades to tools at existing fabs, , when installing new tools (as infrastructure and space allow), and during major expansions and retrofits

2.4. Remote Plasma Cleans (RPC)

This is the best way to enhance the NF_3 dissociation rate in Chemical Vapor Deposition (CVD) chamber cleaning. Remote NF_3 plasma clean has the lowest emission profile among the CVD chamber cleaning operations. Note: See chapter 3.4 for details.

2.5. Example of the best practice selection flow



Reduction methodology

3.1 Process recipe optimization

- General technology description

  Process optimization allows emission reduction by adjusting process parameters such as the chamber pressure, temperature, plasma power, cleaning gas flow rates, gas flow time, and gas ratios in the case of mixtures. Process optimization can be applicable to both chamber cleans and etching/wafer cleaning processes.

  Process optimization can sometimes be accomplished by using an endpoint detection system, which uses techniques such as mass spectroscopy (MS), infrared (IR) spectroscopy, optical emission spectroscopy (OES), and radio frequency (RF) impedance monitoring to monitor changes and provide plasma process end-point times. Endpoint detection has been used extensively for CVD chamber cleans, but the technology can also be applied to etch and other process greenhouse gas processes.

- Applicability

  Process optimization is applicable to ≤150 mm, 200 mm, and 300 mm CVD reactors and to other process tools using process greenhouse gases.

3.2 Gas Replacement Chemistry

- General Technology Description

  Alternative chemistry, or chemical substitution, is the use of chemicals with lower global warming potential (GWP_{100}) or GWP_{100}-free as alternatives to process greenhouse gases. Alternative chemistry also includes high GWP_{100} gases that are more efficiently used in plasma processes, resulting in an overall greenhouse gas emissions reduction.

  When considering alternative chemicals, it is essential also to consider their potential safety and health impact to workers, employee protection, and external environmental and community impacts.

- Applicability

The usage of low GWP_{100} Chemicals and

GWP-free chemicals depend on the specific processes (e.g., C_4F_6 for certain etching processes).

In some cases, it is appropriate to use high GWP_{100} gases that are more efficiently used in plasma processes which results in lower emissions (e.g., Nitrogen Trifluoride (NF_3)).

3.3 Abatement and recovery

- General technology Description

  Suppliers have undertaken continued development of process greenhouse gas abatement technologies [5.3]. The industry historically has favored POU over centralized EOP (End of Pipe) abatement for process greenhouse gases, finding that it is typically more effective to abate emissions close to the source before the exhaust stream is further contaminated and diluted.

  Although some countries and industry consortia have developed methods to determine abatement destruction/removal efficiency (DRE) [5.4, 5.5, 5.6], the industry has not universally adopted a standardized method for determining the DRE. Moreover, performance of abatement systems varies greatly depending on a variety of abatement device and process parameters such as temperature, process greenhouse gases inlet concentration, flow rate, pump purge rates, overall inlet stream composition, etc. All measurement methods must account for dilution through the system and other considerations detailed in IPCC 2019

- Applicability
  Technologies should be tested and certified by the Original Equipment Manufacturers (OEM) to meet the default DRE values indicated in Table 6.17 of IPCC 2019 Refinement.

- Capture/recovery technologies (membrane separation, cryogenic recovery, and pressure swing adsorption/desorption) have been evaluated by the industry but have not been proven as viable technology.

- Per IPCC 2019, abatement uptime should be tracked, and average uptime calculated using Equation 6.20, if there is abatement redundancy or process interlock the uptime can be considered 100%
- When NF_3 is used in RPC processes or F_2 is used as an input gas and when hydrocarbon-fuel-based combustion emissions control technology is used, direct reaction with hydrocarbon fuel and F_2 (including F_2 resulting from the decomposition of NF3 in RPC processes) can form CF_4. Refer to IPCC 2019 Fig 6.4 decision tree for process GHG emission control equipment default emission factor.

3.4 Remote Plasma Cleans

- General technology Description
  Remote plasma clean technology was developed as an alternative to in situ CVD chamber cleans to clean the residues left in the chamber after deposition. With remote plasma clean, a plasma-generating unit is mounted on the lid of a CVD chamber. Remote cleans typically react NF3 in a plasma. The fluorine radicals and ions generated in the remote plasma unit are routed to the processing chamber where they chemically react with deposits. The deposition byproducts are then carried away in gaseous form, e.g., SiF_4.
- Applicability
  Technology is commercially available for some <=200 mm and 300 mm CVD chamber cleans. Tool suppliers manufacture or integrate remote plasma systems for retrofits to some existing process tools to replace in situ process greenhouse gas cleans.

3.5 New technologies will continue to be evaluated and shared among the WSC process greenhouse gases WG.

4. Evaluation of new technologies

In case companies want to measure emissions or want to determine the effectiveness of new technologies, reliable measurements protocols must be followed. Examples of such protocols are given in the references (chapter 5).

5. References

5.1. 2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories, V3, Chapter 6,https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/3_Volume3/19R_V3_Ch06_Electronics.pdf .

5.2. Intergovernmental Panel on Climate Change (IPCC), Fifthth Assessment Report (AR5), Working Group 1, Chapter 8, Anthropogenic and Natural Radiative Forcing, Table 8.A.2, pp. 731-738,

https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf.

5.3. “Whitepaper: PFAS-Containing Fluorochemicals used in Semiconductor Manufacturing Plasma-enabled Etch and Deposition”, Semiconductor PFAS Consortium, 2023.

PROCESS GREENHOUSE GASES5.4. “Guideline for Characterization of Semiconductor Process Equipment – Revision 3”, SEMATECH Technology Transfer #06124825C-ENG, http://www.sematech.org/docubase/document/4825ceng.pdf.

5.5. JEITA Guideline for F-GHG Characterization and Management, October, 2011, http://semicon.jeita.or.jp/committee/docs/F-GHG_guideline_20110520_en.pdf.

5.6. US EPA Protocol for Measuring Destruction or Removal Efficiency (DRE) of Fluorinated Greenhouse Gas

Abatement Equipment in Electronics Manufacturing, Version 1, https://www.epa.gov/sites/production/files/2016-02/documents/dre_protocol.pdf.

5.7. US EPA Greenhouse Gas Mandatory Reporting Rule, Subpart I, http://www.ecfr.gov/cgi-bin/text-idx?SID=a8058176db91462ef40c742dd2e236d4&mc=true&node=pt40.23.98&rgn=div5#sp40.23.98.i.

6. Revision History

October 2023