Final Programmatic Environmental Assessment for Modernization and Expansion of Existing Semiconductor Fabrication Facilities under the CHIPS Incentives Program

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FINAL PROGRAMMATIC ENVIRONMENTAL ASSESSMENT FOR MODERNIZATION AND EXPANSION OF EXISTING SEMICONDUCTOR FABRICATION FACILITIES UNDER THE CHIPS INCENTIVES PROGRAM

Designation	**Final Programmatic Environmental Assessment** **NIST-CPO/EA-001**
Lead Agency	**U.S. Department of Commerce, National Institute of Standards and Technology, CHIPS Program Office**
Affected Region	**Nationwide**
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Further Information	**CHIPSNEPA@chips.gov**
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ABSTRACT

The CHIPS Program Office within the National Institute of Standards and Technology, an agency of the U.S. Department of Commerce, has prepared this Final Programmatic Environmental Assessment pursuant to the National Environmental Policy Act, 42 U.S.C. § 4321 *et seq.*, and the Council on Environmental Quality NEPA implementing regulations, 40 C.F.R. Parts 1500-1508.

The CHIPS Program Office is considering the Proposed Action to provide federal financial assistance under the CHIPS Incentives Program for the proposed modernization or expansion of existing current-generation, mature-node, or leading-edge front- or back-end commercial semiconductor fabrication facilities within existing facility footprints.

The purpose of the CHIPS Program Office's Proposed Action is to invest in U.S. production of strategically important semiconductor chips and ensure a sufficient, sustainable, and secure supply of older, current, and next-generation chips for national security purposes and critical manufacturing industries.

This Final Programmatic Environmental Assessment evaluates the potential environmental effects of the Proposed Action and the no action alternative, or not providing federal financial assistance, on the following resource areas: Climate Change and Climate Resilience; Air Quality; Water Quality; Human Health and Safety; Hazardous and Toxic Materials; Hazardous and Solid Waste Management; Utilities; Environmental Justice; and Socioeconomics. The CHIPS Program Office's analysis of the direct, indirect, and cumulative environmental effects of the alternatives will inform its decision making with respect to proposed projects considered under the Final Programmatic Environmental Assessment.

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ACRONYMS AND ABBREVIATIONS

ACGIH	American Council of Governmental Industrial Hygienists
AIM	American Innovation and Manufacturing Act
ArF	argon fluoride
BEI	biological exposure index
BG	block group
BLS	U.S. Bureau of Labor Statistics
BMP	best management practice
BPSG	borophosphosilicate glass
CAA	Clean Air Act
Cal/OSHA	California Division of Occupational Safety and Health
CDC	Centers for Disease Control and Prevention
CDR	Chemical Data Reporting (rule)
CEJST	Climate and Environmental Justice Screening Tool
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	chlorofluorocarbon
CFE	carbon pollution-free electricity
C.F.R.	Code of Federal Regulations
CH_4	methane
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CMP	chemical mechanical polishing
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide-equivalent
COP	coefficient of performance
CPO	CHIPS Program Office
CT	census tract
CVD	chemical vapor deposition
CWA	Clean Water Act
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DRAM	dynamic random-access memory
DUV	deep ultraviolet
EA	environmental assessment
EAC	energy attribute certificate
E&EC	electrical and electronic components
EHS	environmental, health, and safety
EIS	environmental impact assessment
EJ	environmental justice
ELGS	effluent limitations guidelines and standards
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EUV	extreme ultraviolet
FDA	U.S. Food and Drug Administration
F-HTF	fluorinated heat transfer fluid
FLIGHT	Facility Level Information on Greenhouse Gases Tool
FONSI	finding of no significant impact
FOUP	front opening unified pod
FR	Federal Register
GaAs	gallium arsenide
GAC	granular activated carbon
GaN	gallium nitride
GDP	gross domestic product
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GHS	UN Globally Harmonized System of Classification and Labelling of Chemicals
GVA	gross value added
GWP	global warming potential
H_2SO_4	sulfuric acid
HAP	hazardous air pollutant
HCl	hydrochloric acid
HEPA	high-efficiency particulate air (filter)
HF	hydrofluoric acid

HFC	hydrofluorocarbon
HIA	Health Impact Assessment
HVAC	heating, ventilation, and air conditioning
IPCC	Intergovernmental Panel on Climate Change
IR	infrared
ISMI	International Sematech Manufacturing Initiative
ISO	International Organization for Standardization (standard)
L	liter
lb.	pound
LED	light-emitting diode
LEP	limited English proficiency
LEPC	Local Emergency Planning Committee
LQG	large quantity generator
MACT	Maximum Achievable Control Technology
MERV	minimum efficiency reporting value
mm	millimeter
MMT	million metric tons
MW	megawatt
MWh	megawatt-hour
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System (code)
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NF_3	nitrogen trifluoride
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
nm	nanometer
NMHC	non-methane hydrocarbon
NMP	N-Methylpyrrolidone
NNSR	nonattainment new source review
NO_X	nitrogen oxides
NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice of Funding Opportunity
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standards
NSR	New Source Review
NWI	National Wetlands Inventory
O_3	(ground level) ozone
OEL	occupational exposure limit
OSHA	Occupational Safety and Health Administration
PBT	persistent, bio-accumulative, and toxic
PCB	polychlorinated biphenyl
PDD	PEA Decision Document
PEA	Programmatic Environmental Assessment
PEL	permissible exposure limit
PFAS	per- and polyfluoroalkyl substances
PFC	perfluorocarbon
PFPE	perfluoropolyether
PFPMIE	perfluoropolymethylisopropyl-ether
PGMEA	propylene glycol monomethyl ether acetate
PM	particulate matter
POTW	publicly owned treatment works
POU	point of use
PPA	Pollution Prevention Act
PPE	personal protective equipment
PSD	Prevention of Significant Deterioration
PTE	potential to emit
PtSi	platinum silicate
PVD	physical vapor deposition
RCRA	Resource Conservation and Recovery Act
REL	recommended exposure limit

RF	radio frequency
RMM	risk management measure
RMP	risk management plan
ROC	region of comparison
ROI	region of influence
RPC	remote plasma clean
RQ	reportable quantity
RSEI	Risk-Screening Environmental Indicators
RTO	regenerative thermal oxidizer
SCC	Semiconductor Climate Consortium
SCR	selective catalytic reduction
SDS	safety data sheet
SEMI	Semiconductor Equipment and Materials International
SERC	State Emergency Response Commission
SF_6	sulfur hexafluoride
Si_3N_4	silicon nitride
SIA	Semiconductor Industry Association
SiC	silicon carbide
SiCr	sichrome
SiO_2	silicon dioxide
SIP	state implementation plan
SME	semiconductor manufacturing equipment
SO_X	sulfur oxides
SO_2	sulfur dioxide
SoC	system-on-a-chip
SPCC	Spill Prevention, Control, and Countermeasure (Plan)
SQG	small quantity generator
SWPPP	Stormwater Pollution Prevention Plan
TCA	trichloroethane
TCE	trichloroethylene
TEPC	Tribal Emergency Planning Committee
TERC	Tribal Emergency Response Commission
TFD	thin-film deposition
TLV	threshold limit value
TMAH	tetramethylammonium hydroxide
TMDL	total maximum daily load
TO	thermal recuperative oxidizer
tpy	tons per year
TRI	Toxics Release Inventory
TRIR	total recordable incident rate
TSCA	Toxic Substances Control Act
UL	Underwriters Laboratory
ULPA	ultra-low penetration air (filter)
UPS	uninterruptible power supply
UPW	ultra-pure water
USACE	U.S. Army Corps of Engineers
U.S.C.	United States Code
USCB	U.S. Census Bureau
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UV	ultraviolet
VOC	volatile organic compound
VSQG	very small quantity generator
WHO	World Health Organization
WOTUS	Waters of the United States
WQS	water quality standard
WSC	World Semiconductor Council
°C	degrees Celsius
°F	degrees Fahrenheit
µg	microgram

1.0 INTRODUCTION

The Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act in Title XCIX of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 (Pub. L. 116-283), as amended by the CHIPS and Science Act of 2022 (Division A of Pub. L. 117-167) (together, the CHIPS Act or Act), authorized the CHIPS Incentives Program within the U.S. Department of Commerce (Department). The CHIPS Incentives Program aims to boost American semiconductor research, development, and production by investing across the country, including in high-tech production of semiconductors essential to national defense and other critical manufacturing sectors. More specifically, the Act provides $50 billion to the Department to help revitalize the U.S. semiconductor industry, including $39 billion dedicated to semiconductor manufacturing initiatives. The Act will bolster U.S. leadership in semiconductors, promote innovation in American supply chains, and advance technologies of the future. The Department will provide CHIPS financial assistance for American semiconductor research, development, manufacturing, and workforce development.

The CHIPS Incentives Program is administered by the CHIPS Program Office (CPO) within the National Institute of Standards and Technology (NIST), an agency of the Department. CPO published the CHIPS Incentives Program Commercial Fabrication Facilities Notice of Funding Opportunity (NOFO) in February 2023 and amended the NOFO in June 2023. The NOFO solicits applications for: (1) the construction, expansion, or modernization of commercial facilities for the front- and back-end fabrication of leading-edge, current-generation, and mature-node semiconductors; (2) commercial facilities for wafer manufacturing; and (3) commercial facilities for materials used to manufacture semiconductors and semiconductor manufacturing equipment, provided that the capital investment equals or exceeds $300 million. The potential amount available under the NOFO is up to $38.22 billion for direct funding and up to $75 billion in direct loans or loan guarantees.

The National Environmental Policy Act (NEPA), 42 U.S.C. § 4321 *et seq.*, requires federal agencies to analyze the effects of major federal actions on the natural and human environments as part of their planning and decision-making processes. The White House Council on Environmental Quality (CEQ) has promulgated NEPA implementing regulations at 40 C.F.R. Parts 1500-1508. Federal agencies are responsible for complying with NEPA and the NEPA implementing regulations and developing agency NEPA procedures specific to their structure and organization.

Agencies may prepare programmatic environmental documents under NEPA to support decision making for programmatic federal actions, such as the adoption of new agency programs, as well as to support subsequent NEPA reviews of project- or site-specific actions under a broader policy or program. 40 C.F.R. §§ 1501.11 and 1502.4(b). Programmatic NEPA documents are appropriate to support reviews of actions with relevant similarities, such as common timing, impacts, alternatives, methods of implementation, media, or subject matter, or by stage of technological development, *Id.* § 1502.4(b). They should be used to support project-specific actions when they eliminate repetitive discussions of similar issues (such as similar technologies, construction practices, and impacts), focus on issues ripe for the agency's decision making, and exclude discussion of specific issues not yet relevant or ripe at the programmatic level of review. *See id.* § 1501.11.

CPO has prepared this Programmatic Environmental Assessment (PEA) to inform its decision making with respect to providing federal financial assistance for the proposed modernization or expansion of existing current-generation, mature-node, or leading-edge front- or back-end commercial semiconductor fabrication facilities (or "fabs") within existing fab facility footprints (hereinafter referred to as the "Proposed Action"). The Proposed Action does not include: (i) facilities that manufacture equipment used in fabs; (ii) facilities that perform only research and development; (iii) fabless firms (i.e., firms that produce their own designs for semiconductors but do not have their own production facilities); or (iv) facilities that only produce wafers used as inputs or substrates in manufacturing semiconductor chips.

An applicant must be a "covered entity" as defined by the NOFO to be eligible to receive CHIPS financial assistance and must complete a multi-step application process as outlined in the NOFO. One step of the application process is the completion of the Environmental Questionnaire (EQ), which includes 26 questions on the nature of the proposed project, the local environment, the potential for environmental effects, and permits and approvals required for construction of improvements and operation of the facility to be upgraded with CHIPS financial assistance. CPO conducts a merit review of any application that meets the eligibility requirements outlined in the NOFO, including an evaluation of the applicant's responses to the Environmental Questionnaire.

If an applicant proceeds through merit review, the Department will provide the applicant with a Preliminary Memorandum of Terms for review and negotiation prior to or upon entering the due diligence phase for the application. The CPO process for conducting environmental due diligence is discussed in **Appendix A**. CPO is responsible for completing the NEPA process before federal financial assistance can be provided and may require applicants to commit to certain best management practices (BMPs) or other relevant mitigation measures to reduce environmental effects resulting from implementation of modernization and expansion projects. For any proposed project that will incorporate a BMP as part of the project design or rely on a specific BMP as a mitigation measure, CPO will include that BMP as an enforceable condition in the NEPA decision document and the final award document. BMPs that CPO may require to be incorporated in specific projects are listed in **Appendix B**.

1.1 PROGRAMMATIC ENVIRONMENTAL REVIEW

Programmatic environmental review can facilitate a meaningful and efficient NEPA process. Use of a programmatic environmental document is appropriate for analyzing all or some of the environmental effects of a policy, program, plan, or group of related actions. 42 U.S.C. § 4336e(11). This includes proposed agency action (such as providing federal financial assistance) with respect to proposed projects that share common context, timing, impacts, and technology.

CPO recognizes that many semiconductor manufacturers will apply for federal financial assistance under the CHIPS Act solely for the purpose of modernizing or expanding their existing fabs. Based on its understanding of the semiconductor industry, CPO assesses that most projects focused solely on modernizing or expanding existing fabs will use similar technologies and thus will have similar environmental effects. Accordingly, CPO prepared this PEA under NEPA to analyze the typical direct, indirect, and cumulative environmental effects of providing CHIPS financial assistance for modernization and expansion at existing semiconductor fabs.

Based on its analysis of the potential environmental effects of semiconductor fab modernization and expansion projects, CPO has determined that such projects generally will not result in significant adverse environmental effects. Therefore, CPO has issued a finding of no significant impact (FONSI) for the Proposed Action and approves the Final PEA concurrent with the FONSI. CPO anticipates that for many semiconductor fab modernization and expansion projects, CPO will be able to apply the PEA and FONSI and conclude the NEPA process without additional project-specific analysis.

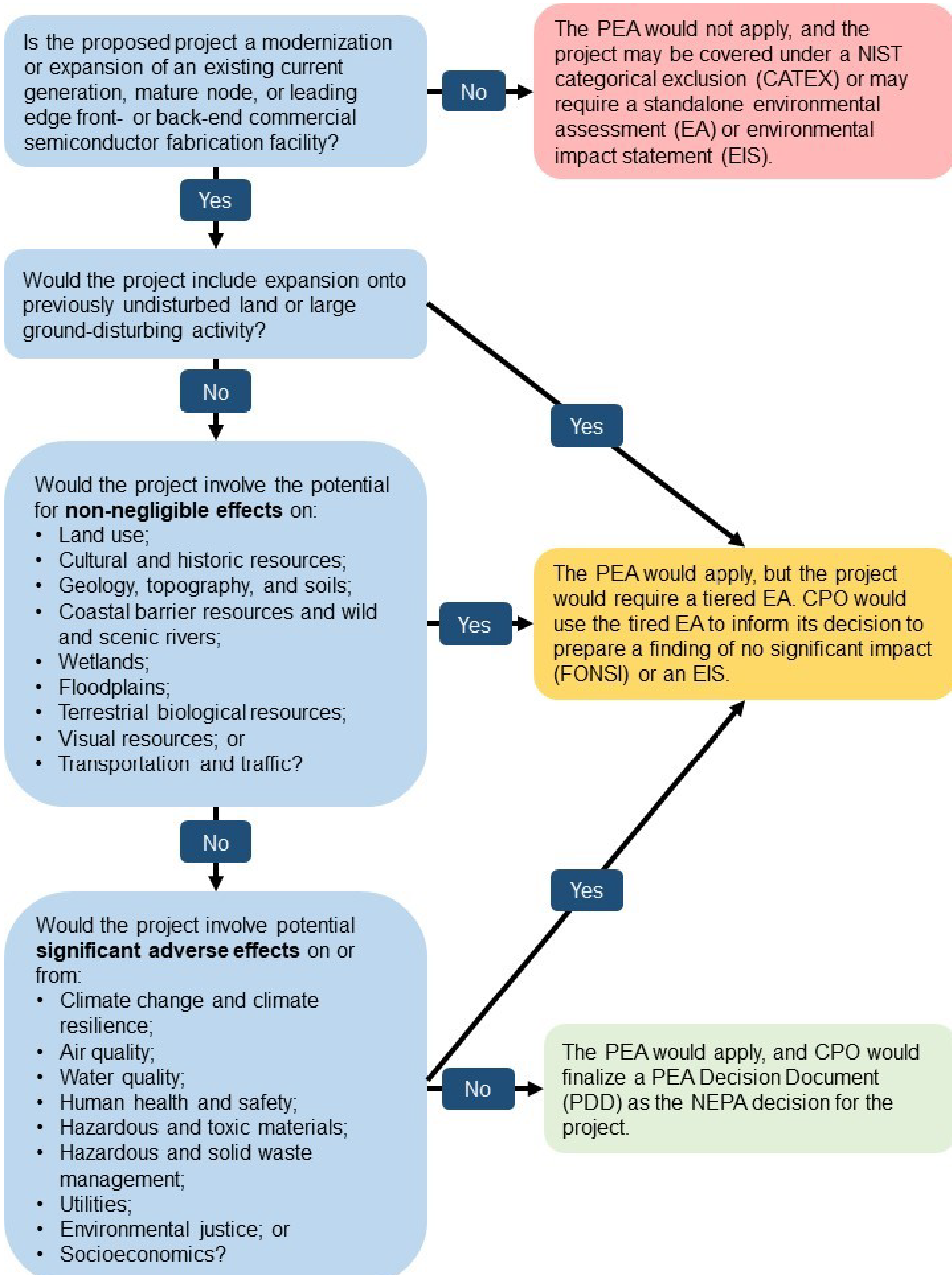
CPO recognizes, however, that environmental effects are caused by site-specific, project-level activities and that a specific project may include activities that the PEA does not account for. Accordingly, CPO will apply this PEA to future project-specific actions only if proposed project activities are within the range of activities being considered as part of the Proposed Action under the PEA. To determine whether the PEA may be applied to an applicant's proposed project, CPO will conduct preliminary environmental due diligence as part of the process outlined in **Appendix A** and will confirm the specific types of activities for which the applicant seeks to use CHIPS financial assistance, which may not be known until the Department signs a Preliminary Memorandum of Terms with the applicant.

If a proposed project's activities fall within the range of activities under the Proposed Action defined in **Section 2.4** of this Final PEA, CPO will apply the PEA to the project using a PEA Decision Document (PDD) and will finalize the PDD as the NEPA decision document for the project. CPO anticipates that for most semiconductor fab modernization and expansion projects, the PDD will be sufficient to document the project's potential environmental effects. CPO may require larger modernization or expansion projects to incorporate established BMPs or mitigation to avoid significant effects. Those requirements will be reflected in the PDD.

In the rare case where CPO finds that a proposed modernization or expansion project could result in potentially significant effects or where the significance of the effects is unknown, and the project cannot rely on established BMPs or mitigation to avoid significant effects, CPO will require the applicant to prepare a tiered environmental assessment (EA). In addition, a tiered EA will be required for any proposed project involving expansion onto previously undisturbed land or involving large ground disturbing activities. If a tiered EA is required, CPO will use the EA to determine whether to prepare a finding of no significant impact (FONSI) or an environmental impact statement (EIS).

Figure 1.1-1 below outlines the CPO decision making process for the PEA.

Figure 1.1-1. PEA Decision Making Process



1.2 PURPOSE AND NEED

The purpose of the CHIPS Incentives Program in this area is to invest in U.S. production of strategically important semiconductors ("chips") and ensure a sufficient, sustainable, and secure supply of older, current, and next generation chips for national security purposes and critical manufacturing industries. As part of this effort, CPO aims to increase semiconductor manufacturing capacity and strengthen the security of the U.S. supply chain via the modernization of semiconductor production at semiconductor fabs. Eligible projects include the replacement or upgrade of existing equipment, the addition of new semiconductor manufacturing equipment, and the expansion of cleanroom space within the existing fab facility footprint.

The need for CPO's action in this area is to fulfill the agency's statutory responsibilities under the CHIPS Act, including the requirements of 15 U.S.C. § 4652 to incentivize investment in facilities and equipment in the United States for the fabrication, assembly, testing, advanced packaging, production, or research and development of semiconductors, materials used to manufacture semiconductors, or semiconductor manufacturing equipment. The CHIPS Incentives Program action is also needed in this area to address decades of decline in the U.S. semiconductor manufacturing sector and to promote the production of a domestic supply of advanced chips, which are critical to U.S. economic and national security. Chips are an integral part of a consumer's everyday life. They are found in household items, such as coffee makers, garage door openers, and refrigerators, as well as in more complex products, such as mobile phones, pacemakers, and automobiles. They are fundamental to the operation of virtually every military system, including communication and navigation systems and complex weapons systems, such as those found in combat aircraft. Advanced semiconductors are key to the technologies of the future, including artificial intelligence and 5G telecommunications. However, the United States no longer produces the world's most advanced semiconductors and has lost the ability to produce key supply chain inputs, such as lithography tools, substrates, and certain specialty chemicals. The United States currently manufactures only 10 percent of global chip capacity and provides only 3 percent of global chip packaging, assembly, and test capacity (DOC, 2022).

1.3 PUBLIC INVOLVEMENT

CPO published a Notice of Availability of the Draft PEA for public comment in the *Federal Register* on December 27, 2023.[1] CPO extended the 30-day public comment period by two weeks from January 25, 2024, to February 9, 2024.[2]

The Department received seven comment submissions on the Draft PEA. Commenters included semiconductor manufacturing companies, industry organizations, and non-governmental organizations. The comments addressed a range of issues including:

- Technical Corrections;
- Due Diligence;
- Application of NEPA;
- Application of the PEA;

[1] "Notice of Availability of Draft Programmatic Environmental Assessment for Modernization and Internal Expansion of Existing Semiconductor Fabrication Facilities Under the CHIPS Incentives Program," 88 Fed. Reg. 89372 (Dec. 27, 2023).

[2] 89 Fed. Reg. 6506 (Feb. 1, 2024).

- Range of Alternatives;
- Climate Change and Climate Resilience;
- Air Quality;
- Water Quality;
- Human Health and Safety;
- Hazardous and Toxic Materials;
- Hazardous and Solid Waste Management;
- Environmental Justice;
- Socioeconomics;
- Mitigation and Monitoring;
- Best Management Practices; and
- Other Topics.

CPO considered the input received and has responded to comments in **Appendix E** of the Final PEA. CPO has made revisions to the PEA in response to comments where appropriate.

2.0 ALTERNATIVES

2.1 RANGE OF ALTERNATIVES

NEPA requires federal agencies to analyze a reasonable range of alternatives to the proposed agency action that are technically and economically feasible and meet the purpose and need for the agency's action in the relevant area. To meet the purpose and need for investment in U.S. production of strategically important chips, particularly those using leading-edge technologies, and to ensure a sufficient, sustainable, and secure supply of older and current generation chips for national security purposes and critical manufacturing industries, CPO determined that a proposed alternative must:

- be technically feasible;
- not violate any federal statute or regulation;
- be consistent with reasonably foreseeable funding levels; and
- meet national, regional, and local needs.

As described in **Section 2.4**, the Proposed Action evaluated in this PEA is for CPO to provide federal financial assistance for the modernization or expansion of existing current-generation, mature-node, or leading-edge front- or back-end commercial semiconductor fabs, within existing fab facility footprints. This could be accomplished by evaluating applications and providing federal financial assistance to certain applicants who propose one or more of the following activities, which are within the scope of this PEA:

- upgrading existing semiconductor manufacturing equipment;
- replacing existing equipment;
- adding new equipment;
- expanding cleanroom space and adding new cleanroom equipment; or
- disposing of equipment that is replaced.

To be covered by the PEA, any of the activities noted above (other than offsite equipment disposal) must occur within the existing fab facility footprint, as described in Section 2.4.

As explained in the NOFO, front-end semiconductor fabrication is the process of forming devices (e.g., transistors) on a wafer of semiconductor material; a more detailed description is provided in **Section 2.2.2**. Back-end fabrication refers to the assembly, testing, or packaging of semiconductors that have completed the front-end fabrication process. This category includes advanced packaging of semiconductors. Advanced packaging is a subset of packaging technologies that uses novel techniques and materials to increase the performance, power, modularity, and/or durability of an integrated circuit.

Current-generation facilities produce semiconductors using up to 28 nanometer (nm) process technologies and include logic, analog, radio frequency, and mixed-signal devices. Mature-node facilities fabricate generations of: (a) logic and analog chips that are not based on fin field-effect transistor (FinFET) architectures, post-FinFET transistor architectures, or any other sub-28 nm transistor architectures; (b) discrete semiconductor devices, such as diodes and transistors; (c) optoelectronics and optical semiconductors; and (d) sensors. Leading-edge facilities refer to facilities that produce logic or memory chips that use the most advanced front-end fabrication processes, which achieve the highest transistor and power performance.[3]

This PEA does not cover proposed projects involving: (i) facilities that manufacture equipment used in fabs; (ii) facilities that perform only research and development; (iii) fabless firms (i.e., firms that produce their own designs for semiconductors but do not have their own production facilities); or (iv) facilities that only produce wafers used as inputs or substrates in manufacturing semiconductor chips. The action area, or geographic scope, of the PEA encompasses U.S. states with existing fabs.

CPO has determined that the Proposed Action is the only alternative that meets the purpose and need. Therefore, the PEA only considers the Proposed Action and the no action alternative. **Section 2.2** provides an overview of semiconductor manufacturing as context for the detailed discussion of the no action alternative in **Section 2.3** and the Proposed Action in **Section 2.4**.

2.2 SEMICONDUCTOR MANUFACTURING OVERVIEW

In this PEA, the terms "semiconductor," "semiconductor chip," or "chip" are used to refer to an integrated electronic device or system, such as analog and digital electronics, power electronics, and photonics, for memory, processing, sensing, actuation, and communications applications. The process of creating a semiconductor chip consists of thousands of steps and can take more than 90 days from design to production. Semiconductor chip fabrication is conducted in cleanrooms to maintain quality and purity.

2.2.1 Cleanrooms

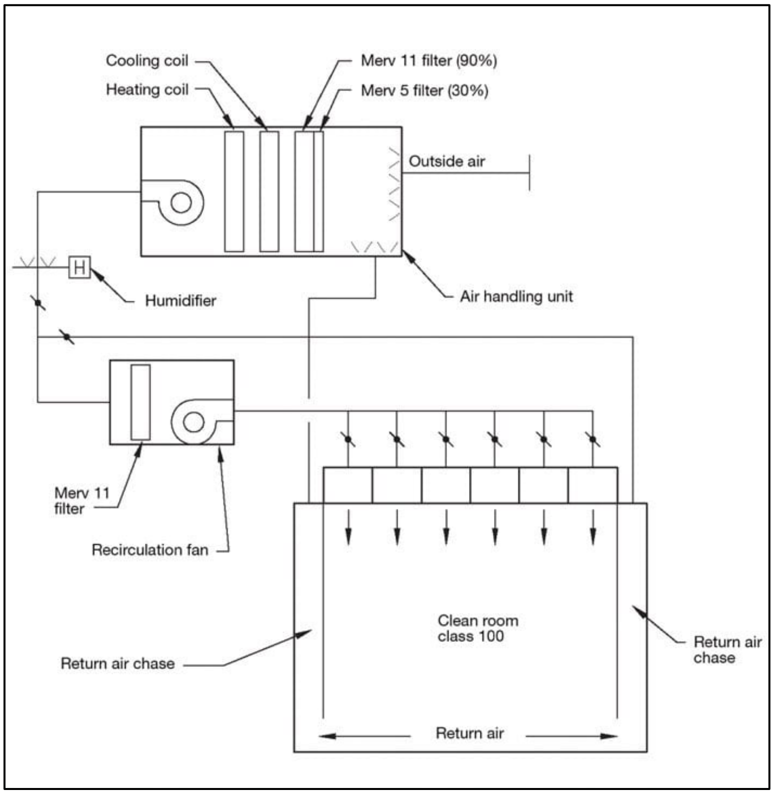
Most semiconductor cleanrooms are designed to comply with International Organization for Standardization (ISO) Standard 14644-1 Cleanroom Classifications, Class 4-6 requirements (Thomas, 2023). These classifications stipulate a maximum allowed particle count between 352-35,200 particles 0.5 micrometers (µm) or smaller. Most semiconductor cleanrooms also must meet the requirements of ISO 14644-2, which imposes a quality control system to maintain these standards. However, not all processes require such stringent controls; for example, the testing of manufactured wafers could be performed in ISO Class 7 or 8 cleanrooms (Thomas, 2023).

Depending on the end use of the manufactured chips, semiconductor cleanrooms also may have to meet industry-specific requirements, such as American Society for Testing and Materials International standards (for automotive applications) and National Aeronautics and Space Administration (NASA) standards (for aerospace applications). These standards ensure that the chips produced are of consistent quality for the intended application.

Powerful heating, ventilation, and air conditioning (HVAC) and filtration systems achieve allowable limits in cleanrooms by utilizing high efficiency particulate air (HEPA) or ultra-low penetration air (ULPA) filters to remove airborne particles. Equipment within the cleanroom also may have its own filtration system to remove particles from exhaust. An example of the airflow system for a cleanroom is shown in **Figure 2.2-1** below.

[3] Leading-edge logic chip facilities produce semiconductors at high volumes using extreme ultraviolet (EUV) lithography tools. Leading-edge memory chip facilities are capable of producing 3D NAND flash chips with 200 or more layers, and/or dynamic random-access memory (DRAM) chips with a half-pitch of 13 nm and below.

Figure 2.2-1. Example Cleanroom Airflow System



Source: Sakraida, 2008. Minimum efficiency reporting value (MERV) is a measure of a filter's ability to capture larger particles between 0.3 and 10 µm.

Semiconductor cleanrooms also must be controlled for other environmental factors that can affect the quality of the final product, such as:

- **Static:** Electrostatic discharge damages the conductive properties of semiconductors. Static dissipative materials for flooring, wall panels, furniture, and more must be used.
- **Humidity:** Uncontrolled humidity in semiconductor cleanrooms can result in inconsistent bake-out times, surface swelling and corrosion, and evaporation of solvents. A consistent relative humidity between 35 and 65 percent is necessary.
- **Out-gassing:** Semiconductor cleanroom equipment can introduce airborne contaminants into the space. This must be controlled with proper equipment cleaning and maintenance, as well as consistent use of air filtration systems.

2.2.2 Manufacturing Processes

The semiconductor chip manufacturing process begins with production of semiconductor-grade polysilicon and compound semiconductor substances, which are purified and crystallized to produce wafers. Wafers are typically greater than 99.999 percent pure silicon, sliced from a cylinder of silicon (known as an ingot) to the appropriate thickness. Wafers also may be created from other materials, such as gallium nitride, gallium arsenide, germanium, or silicon carbide, which may be used for certain high-temperature or high-speed chips (e.g., in defense applications) (Khan et al., 2021). The wafers are then polished to create an extremely smooth surface and are transported to fabs.

Once the wafer is transported to a fab, the semiconductor fabrication process continues. The following steps are an essential part of the typical "front-end" chip manufacturing process using a standard silicon wafer:

- **Oxidation:** After cleaning, the wafer is placed in a high temperature environment, where pure oxygen and/or water vapor is used to form a thin protective film of silicon dioxide on the wafer and impurities and pollutants are removed. Dry or wet oxidation methods can be used.
- **Lithography:** The wafer is then covered with a light-sensitive coating called photoresist, which is comprised of a polymer, a sensitizer, and a solvent. There are two types of photoresist: positive and negative. Positive photoresist becomes more soluble when exposed to ultraviolet (UV) light, so that it can be removed through the etching step. Positive photoresist is used in semiconductor manufacturing because of its higher resolution capability. The coated wafer is inserted into a lithography machine, where it is exposed to deep UV (DUV) or extreme UV (EUV) light. Light is projected onto the wafer through a transparent plate containing a circuit pattern, known as a photomask, to transfer the pattern to the chip. This causes a chemical change and degradation in the photoresist layer using the desired pattern.
- **Etching:** The wafer is baked to harden undissolved photoresist and developed to dissolve portions hit by light so that the photoresist coating is washed away to reveal a three-dimensional pattern. Etching is then performed in places where the photoresist has dissolved to transfer the circuit pattern permanently onto the wafer substrate below. "Dry" or "wet" etching methods can be used; dry methods use gases to expose the pattern, whereas wet methods use chemical baths.
- **Deposition:** Deposition is the process of adding thin layers of material onto the wafer's surface. There are several deposition techniques, such as chemical vapor deposition (CVD) and physical vapor deposition (PVD), which can be used to deposit a wide range of materials, including metals, insulators, and semiconductors. The process creates metal (conducting) layers or dielectric (insulating) layers. Deposition may involve the use of fluorinated gases and/or nitrous oxide (N_2O) (EPA, 2023a; Khan et al., 2021).
- **Ion Implantation:** Once patterns are etched, the wafer is bombarded with positive or negative ions (such as arsenic or phosphorous). These embedded impurities, called dopants, give different parts of the wafer different levels of conductivity to make functional transistors in chips. Heat processing activates the ions.
- **Metallization and Interconnects:** Metal layers are deposited onto the wafer's surface to serve as electrical connections between the various components of the device. These metal layers can be deposited using a variety of techniques, such as sputtering or CVD. The metal layers are then patterned and etched to form the desired interconnect structures.
- **Passivation:** Passivation involves the deposition of a protective layer onto the wafer's surface. This layer serves to protect the delicate underlying structures from damage and contamination during the packaging process and subsequent use. Common passivation materials include silicon dioxide, silicon nitride, and polyimides, which offer good adhesion, low moisture permeability, and compatibility with underlying semiconductor materials.
- **Chemical Mechanical Planarization:** Once one layer is complete, it is flattened and the process is repeated to add a new layer; as a result, at the end of the overall manufacturing process, a single chip may contain dozens of layers.
- **Dicing:** The wafer, which contains dozens of chips in a grid pattern, is sliced into individual chips to remove the chips from the wafer.
- **Testing and Quality Control:** Chips are subjected to various tests, such as temperature, speed, and operation testing, to ensure they perform properly.

The "front-end" manufacturing process encompasses the steps from a blank wafer to a completed wafer and is illustrated in **Figure 2.2-2** below. As a wafer proceeds through the front-end process, hundreds of individual process tools, known as semiconductor manufacturing equipment (SME), are used and require a range of chemicals, water, and energy as inputs. Within each type of SME, a fab will typically have a dozen or more pieces of equipment from different suppliers. **Table 2.2-1** summarizes the types of SME used in each manufacturing step and the general industry trends for SME pollution control and water and energy conservation.

After the front-end manufacturing process is complete, chips undergo "back-end" manufacturing or processing, which refers to chip assembly, testing, and packaging. Some chips undergo advanced packaging, a subset of packaging technologies that uses novel techniques and materials to increase chip performance, power, modularity, and/or durability. Each chip is mounted, interconnected, and encapsulated in a protective metal container or "housing" with a cooling system to ensure the chips do not overheat.

Figure 2.2-2. Front-End Semiconductor Manufacturing Process

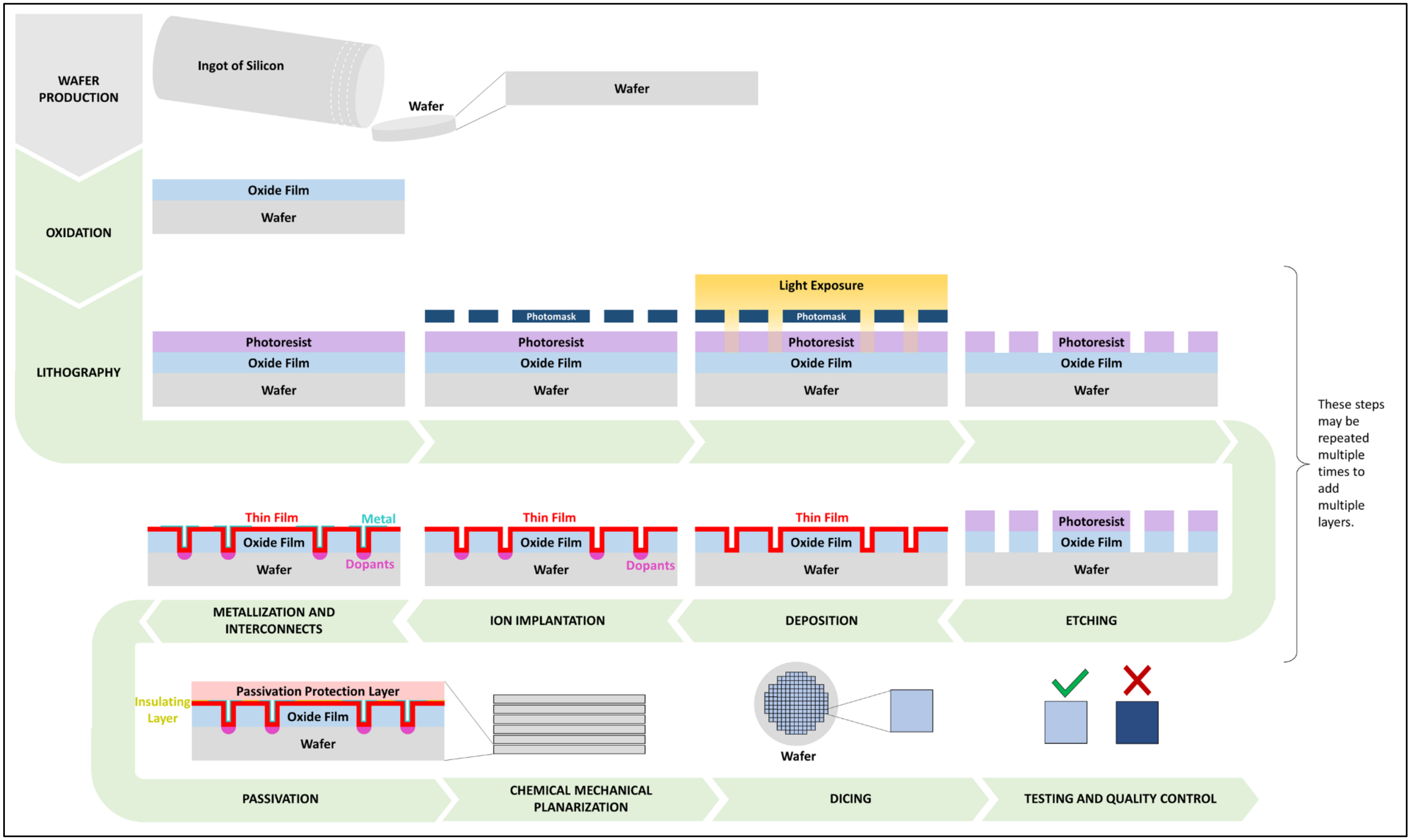


Table 2.2-1. Semiconductor Manufacturing Process and Equipment

Process Step	Semiconductor Manufacturing Equipment (SME)	Pollution Control and Water and Energy Conservation Trends
Oxidation	• Dry or wet thermal oxidation equipment. • Plasma-enhanced CVD equipment. • Electrochemical anodic oxidation equipment. • Diffusion/oxidation furnaces.	Manufacturers are increasingly using single wafer cleaning processes, which increase energy and water consumption per wafer; however, fabs also are increasing process and non-process (cooling and abatement) water reuse to offset this increased water demand.
Lithography	• Wafer and photomask handlers, including front-opening unified pods (FOUPs) and other types of automated wafer handling systems. • Resist processes (tracks) coat photoresists on wafers (typically by spin-coating, which spins the wafer to spread deposited photoresist), develop them (dissolve portions hit by light), and bake them (harden undissolved photoresist to prepare for etching). • Scanners and steppers are used to produce light that passes through the photomask (e.g., EUV scanners, argon fluoride (ArF) scanners, ArF immersion scanners, krypton fluoride steppers, and i-line steppers). • Mask aligners. • Electron-beam lithography (chip- and/or mask-making). • Laser lithography (mask-making). • Ion-beam lithography (mask-making). • Imprint lithography.	Transition to increased use of EUV lithography over DUV lithography may initially greatly increase the energy consumption per mask step; however, EUV reduces process complexity, which, depending on the productivity of the EUV lithography tools, can reduce the consumption of water, chemicals, and energy needed in the process.
Etching	• Dry (gas) etching, which may include equipment for conductor etching, dielectric etching, ion milling, and/or dry stripping. • Dry cleaning equipment.	Currently, per- and polyfluoroalkyl substances (PFAS) are used in lithography and etching. PFAS compounds contain the stable carbon-fluorine bond, making decomposition into smaller, nontoxic molecules difficult.

Process Step	Semiconductor Manufacturing Equipment (SME)	Pollution Control and Water and Energy Conservation Trends
	• Wet etching and wet cleaning equipment.	PFAS compounds are resistant to hydrolytic, photolytic, and oxidative reactions, which limit wastewater treatment technologies to high temperature (high cost) processes or adsorption onto a medium. Adsorption has limitations on the ability to remove small molecules and requires disposal of the medium. To determine the removal efficiency of such technologies, analytical methods for the detection of PFAS compounds in wastewater are needed; however, currently available methods for detection are limited to only a few chemistries. This has posed challenges to permitting and control authorities who have begun to include PFAS monitoring requirements in permits. See **Appendix C** for more detailed information on PFAS use in fabs. Dry etching and thin-film deposition (TFD) chamber cleaning use and emit powerful and long-lived, high global warming potential (GWP) fluorinated greenhouse gases (F-GHGs), including perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), nitrogen trifluoride (NF_3), and hydrofluorocarbons (HFCs). TFD, diffusion, and dry removal of photoresist use and emit nitrous oxide (N_2O). Fabs are reducing these emissions through abatement, alternative chemistries, and process optimization.
Deposition and Passivation	• CVD equipment, including plasma CVD, low pressure CVD, high temperature CVD, and atomic layer deposition equipment. • PVD equipment. • Electrochemical coating. • Spin-coating. • Rapid thermal processing.	Deposition and dry etching use high GWP F-GHGs, including PFCs, HFCs, and N_2O. Fabs are reducing these emissions through abatement, alternative chemistries, and process optimization. Dry etching and TFD chamber cleaning use and emit F-GHGs, including PFCs, SF_6, NF_3, and HFCs. TFD, diffusion, and dry removal of photoresist use and emit N_2O.

Process Step	Semiconductor Manufacturing Equipment (SME)	Pollution Control and Water and Energy Conservation Trends
	• Tube-based diffusion and deposition. • Deposition (non-integrated circuits). • TFD chamber cleaning, which can occur through three different processes: in-situ plasma, in-situ thermal, and remote plasma, with remote plasma becoming the dominant technology.	Fabs are reducing these emissions through abatement, alternative chemistries, and process optimization.
Ion Implantation	• Low to medium current ion implanters. • High current ion implanters. • High voltage ion implanters. • Ultra-high dose doping ion implanters.	There are no notable pollution control or water and energy conservation trends for ion implantation.
Metallization and Interconnects	• Sputtering. • CVD. • Interconnects for silicon-based chips were historically made of aluminum, but now are typically made of copper and cobalt. • Spin-coating is most typically used to deposit insulator layers between metal interconnects.	The number of chip-to-chip interconnects is expected to continue to increase, increasing the demand for materials and the need for PFC abatement. Changes in metallization over time may include new formulations for copper electrochemical deposition, including extending copper plating bath life or recycling for reuse.
Chemical Mechanical Planarization	• Chemical mechanical planarization tools use chemical slurries and polishing pads to press and flatten the wafer.	Fabs are trending toward more three-dimensional structures over the traditional planar structure, requiring more masking, deposition, etching, and polishing steps per wafer to achieve the required transistor density on the device. This requires more tools, cleanroom space, and ultra-pure water (UPW) to support a given number of wafers, which drives greater water, energy, and chemical demand. Specific drivers of increasing fab emissions include: (1) The increasing complexity of devices, reflected in an increasing number of layers per device; and (2) The decreasing linewidths of the devices, which are achieved through multiple patterning and etching steps for

Process Step	Semiconductor Manufacturing Equipment (SME)	Pollution Control and Water and Energy Conservation Trends
		each layer. Each turn or step for each layer requires the use of F-GHGs to etch patterns. Each deposition step increases the need for F-GHGs to clean TFD chambers.
Dicing	• Wafer bonders and aligners are used to join silicon wafers prior to dicing. • Dicing tools.	There are no notable pollution control or water and energy conservation trends for dicing.
Testing and Quality Control	• Memory test. • System-on-a-chip (SoC) test. • Burn-in test. • Linear and discrete test. • Handlers and probers. • Inspection and measuring equipment, including scanning electron microscopes, atomic force microscopes, optical inspection systems, and wafer probes. • Certain metrology and inspection systems.	There are no notable pollution control or water and energy conservation trends for testing and quality control. Fluorinated heat transfer fluids (F-HTFs) are used for temperature control in manufacturing processes, cleaning, soldering, and thermal shock testing. These high-molecular-weight, fully fluorinated compounds are typically liquid at room temperatures and pressures but evaporate during use (which often occurs at high temperatures) to enter the atmosphere. Fluorinated compounds are potent, long-lived GHGs. They include perfluoroamines, perfluoromorpholines, perfluoropolyethers (PFPEs), and long-chain perfluorocarbons. F-HTF abatement methods include monitoring and repairing leaks, and recovery and proper disposal of F-HTFs upon chiller servicing or retirement.

Sources: Bassler, 2022; EPA, 2022a; IEEE, 2015; IEEE, 2016; IEEE, 2023; Khan et al., 2021.

2.2.3 Energy Use in Manufacturing

Semiconductor fabs use varying amounts of energy depending on the fab's size and its energy efficiencies. Of 29 fabs (the largest sample size available), the median energy usage in 2021 was approximately 2.74 million megawatt-hours (MWh) of power (Wang et al., 2023a). SME and supporting equipment, such as vacuum pumps and local exhaust abatement devices, require energy to operate. Lithography, etching, and deposition tend to be the most energy intensive process steps. Energy is required to generate nitrogen, which is used to protect wafers from moisture and oxygen, as described below, and to purify other bulk gases. Cleanrooms require energy for recirculation air flow and temperature and humidity control to meet contamination control requirements.

Reliable power is essential to support the semiconductor manufacturing process. Any electricity supply issue, such as a power outage or voltage sag, can disrupt fab operations and lead to wasted batches of semiconductors. Many fab facilities employ an uninterruptable power supply (UPS), a device that provides backup power to electrical systems during power outages or fluctuations. A UPS senses when the main power is fluctuating or cut. Its internal circuitry is fast enough to assume the power load so that downstream devices are not affected. The UPS then uses the power stored in its batteries to act as a bridge until main power is restored or until gas or diesel generators can be fired up to temporarily support the load.

2.2.4 Water Use in Manufacturing

Water demand at fabs typically falls into five categories: (1) process water (about 48 percent of demand); (2) cooling water (23 percent); (3) abatement technologies to remove hazardous gases from SME (20 percent); (4) UPW treatment losses (9 percent); and (5) non-industrial use (less than 1 percent). Most of the process water used in a fab is purified to provide UPW and for use in various wet-processing SME (IEEE, 2023). In 2021, the median ultra-pure water (UPW) usage among 29 fabs was approximately 4.25 billion gallons (Wang et al., 2023a).

2.2.5 Raw Materials Used in Manufacturing

Semiconductor fabs use large volumes of process gases and raw materials. The most commonly used bulk gases in the manufacturing process are nitrogen, hydrogen, helium, and argon. A modern fab can use up to 50,000 cubic meters of nitrogen per hour for inerting and purging gas to protect wafers from moisture and oxygen. Hydrogen is used for wafer annealing, deposition, and plasma cleaning in lithography. Helium, being a highly thermally conductive and inert gas, is used to protect wafers from thermal damage and chemical reactions. Argon, an inert gas with a low ionization energy, is used as a plasma gas for etching and deposition reactions, as well as in lithography (Air Products PLC, 2022).

In addition, the semiconductor fabrication process uses a wide range of other raw materials. The following is a list of the most frequently used materials and their purposes:

- **Silicon (Si):** Silicon's properties as a semiconductor make it the foundation of the modern semiconductor industry.
- **Alloy 42:** Alloy 42 is an alloy of iron, nickel, manganese, and cobalt used to manufacture lead frames.
- **Aluminum (Al):** Aluminum is used to create the wiring that connects semiconductor components because it adheres well to silicon dioxide.
- **Boron (B):** As a hard semi-metallic element with one less valence electron than silicon, boron is commonly used for doping.

- **Borophosphosilicate glass (BPSG):** BPSG is a compound used to isolate conductive lines and circuit components.
- **Copper (Cu):** As a better conductor than gold, copper is used to create lead frames for plastic packages and is used for metal lines in semiconductor devices (IEEE, 2020).
- **Gallium arsenide (GaAs) and gallium nitride (GaN):** Gallium arsenide and gallium nitride are compound semiconductor materials capable of operating at higher temperatures than silicon; however, use in semiconductor devices is complicated because of the toxicity of these compounds (IEEE, 2020; EPA, 2022a).
- **Germanium (Ge):** Germanium was the first semiconductor material used to create transistors and diodes; however, germanium has largely been replaced by silicon materials.
- **Gold (Au):** As the most malleable metal, gold conducts heat and electricity well and is often used in wire bonding to connect the integrated circuit to its package leads.
- **Kovar:** Kovar is an iron-nickel-manganese-cobalt alloy used to manufacture lead frames.
- **Lead (Pb):** Lead is used to solder the external leads of integrated circuit packages.
- **Phosphorus (P):** Phosphorus is used as a doping agent because it provides a valence electron when it bonds with silicon.
- **Platinum silicate (PtSi):** Platinum silicate is used as a metal coating between a silicon substrate and metal circuit components.
- **Polysilicon:** Polysilicon is a highly pure, polycrystalline form of silicon used as a conductor and resistor.
- **Sichrome (SiCr):** Sichrome, a compound of silicon and chromium, is used as a film resistor (IEEE, 2020).
- **Silicon carbide (SiC):** Silicon carbide is an alternative silicon compound semiconductor material that is more energy efficient and can handle higher voltages, temperatures, and frequencies compared to silicon (Pretz, 2020).
- **Silicon dioxide (SiO_2):** Silicon dioxide is a silicon compound used to isolate layers of an integrated circuit.
- **Silicon nitride (Si_3N_4):** Silicon nitride is a compound often used as the final layer of a circuit due to its ability to protect against moisture, corrosion, and physical damage.
- **Silver (Ag):** Silver, a better conductor than copper and gold, is used to increase thermal and electrical conductivity in circuits while also helping prevent the chemical degradation of die pads and bonding fingers.
- **Spin-on glass:** Spin-on glass is a glass compound used to smooth the surface of semiconductor wafers.
- **Tin (Sn):** Tin, like lead, is used to solder the external leads of integrated circuit packages (IEEE, 2020).

2.3 NO ACTION ALTERNATIVE

Under the no action alternative, CPO would not provide federal financial assistance for proposed semiconductor fab modernization and expansion projects. For purposes of the PEA analysis, the no action alternative assumes that applicants would decide not to undertake or complete proposed modernization and expansion projects at existing fabs, and such fabs would simply continue production at current rates, using existing equipment, within existing fab facility footprints. The no action alternative also assumes that applicants' existing facilities would continue to meet applicable permit conditions and regulatory standards.

2.4 PROPOSED ACTION

Under the Proposed Action, CPO would provide federal financial assistance to applicants for the proposed modernization or expansion of existing current-generation, mature-node, or leading-edge front- or back-end commercial semiconductor fabs within existing fab facility footprints. Specifically, CPO would consider applications that propose any combination of upgrades, replacement, and additions within its existing fab facility footprint. CPO would then provide federal financial assistance to certain applicants whose proposals meet the purpose and need described above. For any given proposal, the resulting modernization and/or expansion of the fab facility could yield combinations of: (1) increased production of current chip products; (2) steady production at current rates of new chip products; or (3) increased production of new chip products. Examples of these project scenarios are described in **Sections 2.4.1 to 2.4.3**. On balance, CPO anticipates that modernization or expansion using CHIPS financial assistance would result in varying degrees of increased chip production capacity.

CPO may provide CHIPS financial assistance under this PEA for supporting infrastructure at the fab facility. This infrastructure could be located within the sub fab (the basement area below the cleanroom where electrical and mechanical systems needed to support the cleanroom are located) or elsewhere within the fab facility footprint (though as stated in **Section 1.1**, projects involving expansions onto previously undisturbed land or involving large ground disturbing activities would require a tiered EA). Such supporting infrastructure could include: replacement of existing gas storage tanks with new gas tanks; installation of new gas storage tanks in previously existing auxiliary spaces; upgrades to water purification systems and wastewater treatment systems; upgrades to electrical connections and wiring; upgrades to hazardous waste storage areas; and installation of new air handler units and replacement or change-out of existing air handler units.

For projects to be considered under the PEA using the PDD (as opposed to requiring a tiered EA), all cleanroom expansions and all improvements to auxiliary process support infrastructure must occur within the existing fab facility footprint, such as on existing concrete pads or in other areas previously modified from the prior natural state (e.g., conversion of a parking lot space into a gas tank storage space) and must not involve large ground disturbing activities.

Proposed project construction activities would involve the use of construction vehicles, equipment, and materials. Temporary onsite equipment and material storage areas also may be needed during construction; however, these staging or laydown areas must be restricted to already disturbed areas. Additionally, construction activities would likely require the temporary storage and use of diesel fuel and other materials, such as welding gases, paint, adhesives, thinners, and solvents. While construction activities are ongoing, the amount of waste the facility would generate would likely increase; such waste may include building debris, cardboard, plastic, aluminum, and other construction material. Construction vehicles and workers entering and leaving the site by automobile may cause a temporary increase in vehicle traffic around the site. This construction-related traffic, in combination with the operation of construction vehicles and equipment, may temporarily contribute to noise and air emissions. CPO would review applicant construction plans to ensure they include relevant health and safety features and follow industry standards. **Appendix B** includes BMPs that could be applied to reduce construction noise and promote safety at construction sites.

As part of the CPO environmental due diligence process described in **Appendix A**, an applicant must demonstrate compliance with all existing facility permits. Upon completing a modernization and/or expansion project, the facility would be required to comply with any additional or amended permit conditions based on any changes to the facility's operations. CPO may require the facility to commit to appropriate BMPs or other mitigation measures to reduce environmental effects resulting from implementation of the modernization and/or expansion project. CPO will use the resource-specific analysis in **Chapter 3** of the PEA to inform decision making with respect to BMP or mitigation commitments as well as agreements to use the best available technologies to address environmental effects of the Proposed Action. BMPs are included in **Appendix B**.

2.4.1 Expansion of Cleanroom Space

Converting a portion of a fab into new cleanroom space could allow a fab to increase production. Spaces that may be converted into new cleanroom spaces include storage space, office space, and obsolete processing spaces. New SME would be added to the new cleanroom space to increase the number and types of semiconductors that could be manufactured at the fab. Sub fab space located below the cleanroom may also need to be expanded to support the new cleanroom areas.

2.4.2 Modernization to Increase Production

Some fabs would not require expanded cleanroom space to increase production volumes but would pursue other modernization activities to boost production. For example, a fab could replace equipment that has reached or exceeded industry lifecycles, has limited remaining capability, or utilizes lagging technology. As noted above, the fab may need to upgrade or refresh its supporting infrastructure to accommodate or support the new equipment. Infrastructure upgrades needed to support increased production could include chilled water, UPW, high temperature water, chemical and gas distribution, process cooling water, high voltage distribution, air emission/scrubber infrastructure, building improvements, and overall facility control systems. The fab refurbishment could also include the purchase and installation of the latest SME, or replacement of tools that are obsolete or less capable. The new equipment that would be installed also would likely be more space efficient, allowing the fab to allocate valuable cleanroom space for additional capacity and capability in the future, increasing the economic competitiveness of the fab.

Upgrades to the fab could also include improvements to environmental, health, and safety systems. This could include removal of equipment and services that do not meet the highest safety standards and/or upgrades to the fire alarm, emergency power, and manufacturing chemical distribution systems equipment. Projects that would abate greenhouse gas (GHG) emissions could include conversions of certain CVD tools to remote nitrogen trifluoride (NF_3) plasma clean sources and installation of combustion abatement units.

2.4.3 Modernization to Produce New Chip Products

Modernization of a fab can lead to a new chip product. For example, until approximately five years ago, gallium nitride semiconductor devices had only been demonstrated in 150-millimeter (mm) or smaller wafer diameter fabs with less advanced processing capabilities and very limited production capacities. Technology advancements now allow gallium nitride devices to be produced at a 200-mm wafer size. Upgrading a fab's equipment and supporting infrastructure to support gallium nitride semiconductor production at the newer 200-mm wafer size would assist in meeting the rapidly increasing demand for gallium nitride semiconductor chips used in electric vehicles and 5G/6G mobile communications.

3.0 AFFECTED ENVIRONMENT AND ENVIRONMENTAL CONSEQUENCES

This chapter discusses the existing conditions for resource areas that may be affected by a project under the Proposed Action and the environmental consequences of a project under the Proposed Action and the no action alternative.

Resource Areas Considered but Not Carried Forward for Full Analysis

All potentially relevant environmental resource areas were considered for analysis in the PEA. To focus the analysis, potential effects to the following resource areas were not analyzed in detail because they are anticipated to be negligible or non-existent for proposed projects reviewed under the PEA. For proposed projects with more than negligible potential effects to these resource areas based on site-specific conditions, CPO will require the preparation of a tiered EA:

- **Land Use:** Under the Proposed Action, equipment modernization and expansion would occur within the existing fab facility footprint and would not alter existing land use. Any associated improvements to fab supporting infrastructure would occur in previously disturbed spaces within the existing fab facility footprint. Temporary storage areas may be needed for construction; however, these staging or laydown areas would be restricted to previously disturbed areas. Accordingly, direct effects to land use are not analyzed. Federal financial assistance for modernization could induce additional private investment to expand semiconductor manufacturing at existing or new locations, which could affect future land use. These potential cumulative effects are discussed in **Chapter 4.0**.
- **Cultural and Historic Resources:** Existing semiconductor fabrication facilities largely consist of newer buildings that likely are not eligible for the National Register of Historic Places. Additionally, because the federal financial assistance under the Proposed Action must be used to modernize equipment and expand production within the existing fab facility footprint, historic properties, properties of religious or cultural significance to Tribal Nations, archaeological sites, and traditional cultural properties are unlikely to be affected.
- **Geology, Topography, and Soil:** Under the Proposed Action, equipment modernization and expansion and other activities would be limited to previously disturbed land within the existing fab facility footprint. Therefore, they would not cause disturbance of geological resources.
- **Coastal Barrier Resources and Wild and Scenic Rivers:** Under the Proposed Action, equipment modernization and expansion and other activities would be limited to previously disturbed land within the existing fab facility footprint. Therefore, they would not cause disturbance to coastal barrier resources or rivers.
- **Wetlands and Floodplains:** Under the Proposed Action, equipment modernization and expansion and other activities would be limited to previously disturbed land within the existing fab facility footprint. Therefore, they would not cause disturbance to wetlands and floodplains.
- **Terrestrial Biological Resources:** As activities under the Proposed Action would occur within the existing fab facility footprint in industrial settings, the action would not modify, physically disturb, or disrupt any terrestrial vegetation, wildlife, or special status species, such as migratory birds. Terrestrial biological resources would not be affected by the Proposed Action.
- **Visual Resources:** As the Proposed Action would occur within the existing fab facility footprint in industrial settings, only negligible changes to visual resources are expected to occur.
- **Transportation and Traffic:** Under the Proposed Action, projects would be anticipated to involve only operational changes in peak and average daily traffic falling below any federal, state, or local

thresholds for conducting a Traffic Impact Analysis or equivalent study. CPO will review project-specific federal, state, or local traffic and transportation studies or plans as part of the due diligence process as described in **Appendix A**.

When evaluating an applicant's proposed project, CPO may determine that the proposed project could result in more than negligible effects to one or more of the above resource areas, involve work in previously undisturbed land, or involve large ground disturbing activities. In such cases, CPO would require preparation of a tiered EA to evaluate the proposed project's potential effects to all resource areas and determine whether additional mitigation measures would be needed, using the process described in **Section 1.1**.

3.1 AFFECTED ENVIRONMENT METHODOLOGY

The affected environment sections describe the existing conditions from a nationwide, programmatic perspective and discuss legal and regulatory requirements relating to the existing conditions where appropriate.

3.2 ENVIRONMENTAL CONSEQUENCES METHODOLOGY

The environmental consequences analysis considers how the condition of a resource may change for a project as a result of implementing the no action alternative or the Proposed Action identified in **Sections 2.3 and 2.4**, respectively, and describes the potential effects in terms of type (i.e., direct, indirect, or cumulative, and beneficial or adverse), duration, and magnitude, which CPO will consider in combination to determine whether effects are significant.

3.2.1 Types of Effects

Pursuant to the NEPA implementing regulations, direct and indirect effects are defined as:

- **Direct effects**: Effects that are caused by the action and occur at the same time and place. 40 C.F.R. § 1508.1(g)(1).
- **Indirect effects**: Effects that are caused by the action and occur later in time or are farther removed in distance but are still reasonably foreseeable. Indirect effects also include "induced changes" in the human and natural environments. 40 C.F.R. § 1508.1(g)(2).

Environmental effects may be either adverse or beneficial, or both. Pursuant to the NEPA regulations, adverse and beneficial effects are not defined, but should be identified and differentiated. Under this PEA, adverse and beneficial effects are defined as:

- **Adverse effects**: Effects that cause or result in a negative or harmful change to a resource, move a resource away from a desired condition, or detract from a resource's appearance or condition.
- **Beneficial effects**: Effects that cause or result in a positive or supportive change to a resource, move a resource toward a desired condition, or augment a resource's appearance or condition.

3.2.2 Significance Criteria

Pursuant to the NEPA regulations, under this PEA, CPO will determine whether effects of proposed project activities are significant by analyzing the potentially affected environment and the degree of effects of the activities. 40 C.F.R. § 1501.3(b). In considering the potentially affected environment of a proposed project, CPO will consider whether effects would be:

- **Local** – Effects to resources in a proposed project's immediate vicinity or surrounding area.
- **Regional** – Effects extending beyond a proposed project's local level to resources in areas broadly defined by natural criteria, such as watersheds and ecosystems, or human activity, such as urban or rural population areas, or at a scale that could have interstate consequences.
- **National** – Effects extending beyond a proposed project's regional level to resources on a nationwide scale or at a scale that could have cross-regional ecosystem, multi-state, or nationwide consequences.

In considering the degree of effects of proposed project activities, CPO will consider their potential duration, magnitude, and repetition, as described below:

- **Temporary –** Effects occurring only during active semiconductor fab modernization, expansion, or equipment installation or replacement.
- **Short-term –** Effects likely to continue beyond the temporary timeframe but not likely to last more than several months.
- **Long-term** – Effects likely to continue beyond the short term, but not indefinitely.
- **Permanent** – Effects likely to last indefinitely or for the life of a semiconductor fabrication facility.

CPO will use four impact descriptors to categorize the potential magnitude of effects:

- **Negligible** – Effects with minimal impact on a resource; any change that might occur would be barely perceptible and would not be easily measurable.
- **Minor –** Effects that would produce a detectable change to a resource but that would be unlikely to substantially alter its appearance or condition.
- **Moderate –** Effects that would produce a noticeable change to a resource and that may substantially alter its appearance or condition, but the integrity of the resource would remain intact.
- **Major** – Effects that would produce a highly noticeable and easily defined substantial impact or change to a resource that would measurably alter its appearance or condition, and potentially threaten the integrity of the resource.

In addition to duration and magnitude, CPO will consider the repetitive nature of effects, meaning whether effects would be continuous (i.e., constant) or intermittent (i.e., recurring, or periodic). Continuous and intermittent effects could occur at any duration or magnitude.

Finally, CPO will consider effects of proposed semiconductor modernization and expansion project activities on public health and safety, as well as whether effects would violate federal, state, tribal, or local laws, regulations, or ordinances to protect the environment.

3.3 RELEVANT ENVIRONMENTAL LAWS AND REGULATIONS

Table 3.3-1 and **Table 3.3-2** below list the relevant laws, regulations, and Executive Orders (EOs) that could apply to modernization and expansion of existing semiconductor fabrication facilities. These laws, regulations, and EOs are referenced throughout the PEA.

Table 3.3-1. Relevant Environmental Laws and Regulations

Environmental Law and Regulations	Responsible Agency	Summary	Site-Specific Requirements
Clean Water Act (CWA), 33 U.S.C. § 1251 *et seq.*	U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (USACE), and State Agencies	The CWA regulates pollutant discharges into the waters of the United States. CWA Section 402, the National Pollutant Discharge Elimination System (NPDES), applies to point source discharges, including stormwater from any construction activities that disturb more than five (5) acres of land. Section 404 regulates discharges of dredged or fill material into waters of the United States, including wetlands.	CWA Section 402 (NPDES) Permit; Section 404 Permit.
Clean Air Act (CAA), 42 U.S.C. § 7401 *et seq.*; 40 C.F.R. Pt. 98	EPA and State and Local Air Pollution Control Agencies	The CAA sets nationwide air quality standards that states must regulate under EPA oversight. The CAA establishes various permitting programs implemented by EPA, states, local agencies, and approved tribes.	Title V Operating Permit, New Source Permit, and reporting to the Greenhouse Gas Reporting Program.
Toxic Substances Control Act (TSCA), 15 U.S.C. § 2601 *et seq.*	EPA	TSCA requires reporting, recordkeeping, and testing, restricts certain chemical substances and mixtures, and regulates use and disposal of specific chemicals, such as polychlorinated biphenyls (PCBs).	TSCA reporting, recordkeeping, and testing.
Emergency Planning and Community Right-to-Know Act (EPCRA), 42 U.S.C. § 1100 *et seq.*	EPA	EPCRA helps communities plan for chemical emergencies by requiring industry and federal facilities to report on the storage, use, and releases of certain chemical substances that, because of their quantity, concentration, or physical, chemical, or toxic characteristics, may present a danger to public health and welfare or the environment if released.	Toxics Release Inventory (TRI) Program and Tier II Reporting.
Occupational Safety and Health Act, 29 U.S.C. § 651 *et seq.*	Occupational Safety and Health Administration (OSHA)	OSHA ensures safe and healthy working conditions by authorizing and enforcing standards for worker health and safety and public safety.	Compliance with OSHA standards.

Environmental Law and Regulations	Responsible Agency	Summary	Site-Specific Requirements
Resource Conservation and Recovery Act (RCRA), 42 U.S.C. § 6901 *et seq.*	EPA	RCRA authorizes EPA to regulate hazardous waste and non-hazardous solid waste. Hazardous waste is regulated from cradle to grave, including generation, transportation, treatment, storage, and disposal.	EPA hazardous waste generator ID number; accumulation time and quantity limits; recordkeeping and reporting requirements.
American Innovation and Manufacturing (AIM) Act, 42 U.S.C. § 7675 *et seq.*	EPA	The AIM Act directs EPA to reduce production and consumption of hydrofluorocarbons (HFCs) in the United States by 85 percent over 15 years, beginning in 2021.	Adherence to HFC production and consumption allowances; recordkeeping and reporting requirements.

In addition to the above laws and regulations, the EOs listed in **Table 3.3-2** could apply to modernization and expansion of existing semiconductor fabrication facilities.

Table 3.3-2. Relevant Executive Orders

Executive Order	Summary	Additional Information
EO 14096, Revitalizing Our Nation's Commitment to Environmental Justice for All and EO 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations	EO 14096 reaffirms the goals of EO 12898, which include advancing environmental justice by directing federal agencies to consider measures to address and prevent disproportionate and adverse environmental and health impacts on communities, including the cumulative impacts of pollution and climate change, and to actively facilitate meaningful public participation and just treatment of all people in agency decision making.	For more information, see Section 3.11, Environmental Justice.
EO 13045, Protection of Children from Environmental Health Risks and Safety Risks	Requires federal agencies to identify and assess environmental, health, and safety risks that may disproportionately affect children and ensure that policies, programs, activities, and standards address disproportionate risks to children.	For more information, see Section 3.11 Environmental Justice.

Executive Order	Summary	Additional Information
EO 13166, Improving Access to Persons with Limited English Proficiency	Requires federal agencies to develop and implement a plan to provide services to limited English proficiency (LEP) individuals to ensure meaningful access to programs and activities conducted by federal agencies.	For more information, see Section 3.11 Environmental Justice.
EO 13693, Planning for Federal Sustainability in the Next Decade	Requires federal agencies to improve environmental and energy efficiency and sustainability, including by reducing greenhouse gas emissions, and increasing fleet performance, energy conservation, solid waste diversion, and pollution prevention.	For more information, see Section 3.4 Climate Change and Climate Resilience.
EO 14008, Tackling the Climate Crisis at Home and Abroad	Builds on the Paris Agreement's three overarching objectives: a safe global temperature, increased climate resilience, and financial flows aligned with a pathway toward low greenhouse gas emissions and climate-resilient development.	For more information, see Section 3.4 Climate Change and Climate Resilience and Chapter 4.0 Cumulative Effects.
EO 13690, Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input	Establishes U.S. policy to improve the resilience of communities and federal assets against the impacts of flooding. Establishes a new Flood Risk Management Standard to ensure that agencies expand management from the current base flood level to a higher vertical elevation and corresponding horizontal floodplain to address current and future flood risk and ensure that projects funded with taxpayer dollars last as long as intended.	Applies to federal investments for new construction and substantial improvement.
EO 13990, Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis	Directs federal agencies to review and, if necessary, revise or suspend regulations and policies that may hinder environmental protection or public health.	Reinstated EO 13653, Preparing the United States for the Impacts of Climate Change.

3.4 CLIMATE CHANGE AND CLIMATE RESILIENCE

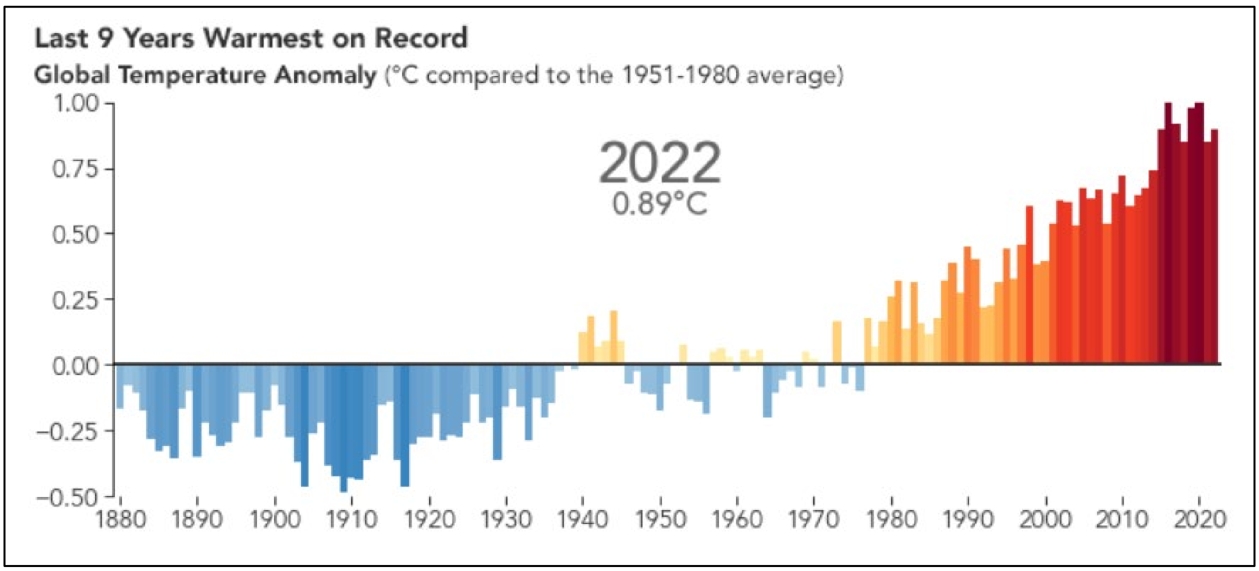
This section analyzes the affected environment and the potential consequences of a project under the Proposed Action and the no action alternative on climate change and climate resilience.

3.4.1 Affected Environment

Climate refers to the predictable average weather, temperature, and precipitation patterns that characterize a region, whereas **climate change** refers to long-term shifts in the climate of a given region or the Earth as a whole. These shifts can be natural, anthropogenic (i.e., caused by human activities), or both (UNFCC, No Date-a). **Climate resilience** refers to "changes in processes, practices and structures to moderate potential damage to or benefit from opportunities associated with climate change" (UNFCC, No Date-b). Climate resilience refers to the capacity of countries and communities to successfully cope with current and future impacts from climate change while working to prevent those impacts from worsening.

Since the Nineteenth Century, increased burning of fossil fuels to provide the energy demanded by a rapid increase in the human population and its economic activities (e.g., production and consumption) has been the major driver of observed climate change (IPCC, 2023). As a result of rising anthropogenic greenhouse gas (GHG) emissions over the past two centuries, and a concomitant increase in GHG concentrations in the atmosphere, the average temperature at the Earth's surface has risen about 1.1°C above its level before the industrial revolution. The planetary surface is now the warmest it has been in the last 100,000 years, and the last decade (2011-2020) is the warmest on record (**Figure 3.4-1**) (NASA Earth Observatory, 2022; WMO, 2021).

Figure 3.4-1. Average Global Surface Temperature Anomalies from 1880 to 2022



Source: NASA Earth Observatory, 2022.

Among the observed present and predicted future consequences of climate change are increasing and more intense droughts, water scarcity, flooding, increasing and more severe wildfires, melting polar ice and glaciers, more catastrophic storms, and declining biodiversity (UN, No Date).

3.4.1.1 Legal and Regulatory Framework

Executive Orders

On February 19, 2021, President Biden signed Executive Order (EO) 13990, *Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis*, and reinstated EO 13653, *Preparing the United States for the Impacts of Climate Change* and CEQ's 2016 *Final Guidance for Federal Departments and Agencies on Consideration of GHG Emissions and the Effects of Climate Change in National Environmental Policy Act (NEPA) Reviews*. The CEQ guidance directs federal agencies to quantify the direct and indirect GHG emissions of a proposed action and weigh climate change impacts in considering alternatives and in evaluating mitigation measures.

In January 2023, CEQ published a notice of interim guidance and request for comments in the *Federal Register* on consideration of GHG emissions and climate change in NEPA documents (CEQ, 2023a). The notice directs federal agencies to quantify reasonably foreseeable GHG emissions whenever possible and place those emissions in the appropriate context when analyzing a proposed action's climate impacts.

Laws and Regulations

In 2021, Congress passed the American Innovation and Manufacturing Act (AIM). It directs EPA to reduce production and consumption of hydrofluorocarbons (HFCs) in the U. S. by 85 percent over the next 15 years. The AIM Act is expected to avoid up to 0.5°C of global warming by 2100 (EPA, 2023b). In September 2021, EPA issued a final rule to implement the AIM Act's requirements, including HFC production and consumption allowance allocations.86 Fed. Reg. 55116 (Oct. 5, 2021). From 2024-2028, these allowances will be capped at 40 percent below their baseline historic levels. 40 C.F.R. Pt. 84; EPA, 2023b).

Subparts C and I of EPA's Greenhouse Gas Reporting Program (GHGRP) include reporting requirements for the Electronics Manufacturing Sector, which encompasses Semiconductors and Related Devices. 40 C.F.R. Pt. 98. Facilities emitting more than 25,000 metric tons of carbon dioxide equivalent (CO_2e) annually are required to report emissions of fluorinated GHGs (F-GHGs) and fluorinated heat transfer fluids (F-HTFs), as well as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) combustion emissions from each stationary combustion unit. Semiconductors and Related Devices, North American Industry Classification System (NAICS) Code 334413, is a free-standing reporting category under the program. This category includes semiconductor fabs, wafer production facilities, and facilities that manufacture other products, including solar cells and other optoelectronic devices. EPA makes reporting information publicly available through the GHGRP and associated databases.

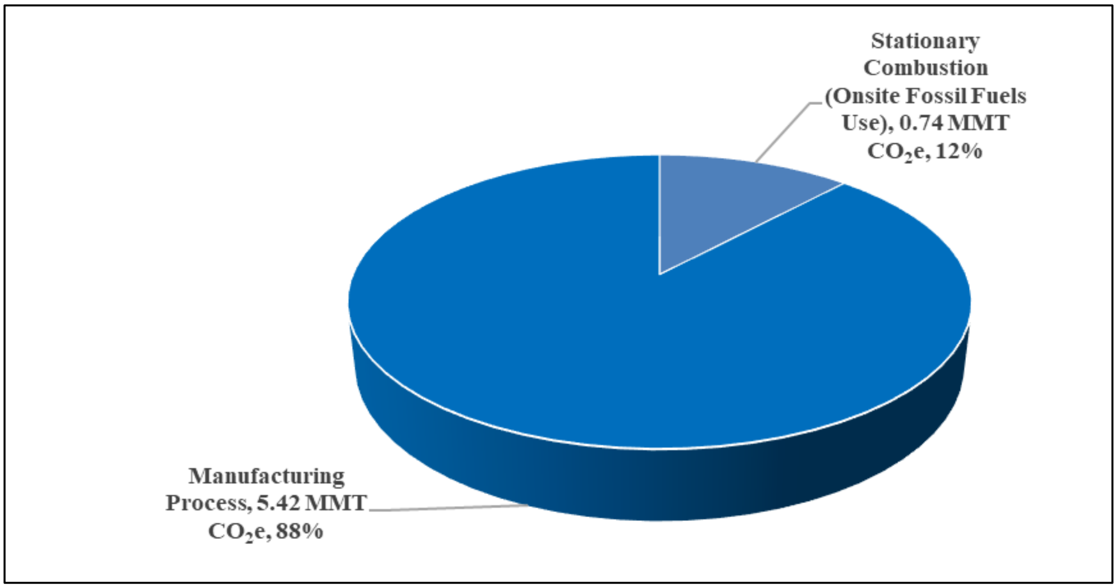
3.4.1.2 GHG Emissions from the Semiconductor Manufacturing Sector

GHG emissions from semiconductor manufacturing include **direct** and **indirect** emissions. Sources of direct GHG emissions include onsite stationary combustion and manufacturing processes. Indirect GHG emissions result from onsite electricity consumption from offsite fossil fuel energy generation (EPA, 2023c). Both direct and indirect GHG emissions must be included for a full accounting of the carbon footprint associated with the semiconductor industry sector.

CPO analyzed data from the GHGRP database for the years 2014-2022 for Semiconductors and Related Devices (NAICS Code 334413). Semiconductor fabs first reported direct emissions under the program in 2014, and the total direct emissions for the category were 6.18 million metric tons (MMT) CO_2e. Direct GHG emissions in 2015-2017 reached a peak of 6.4 MMT CO_2e and a low of 5.9 MMT CO_2e. In 2022, total direct GHG emissions for NAICS Code 334413 were 6.2 MMT CO_2e. On average during the period from 2014-2022, manufacturing processes accounted for 88 percent of direct emissions and onsite stationary combustion sources accounted for 12 percent of direct emissions (**Figure 3.4-2**).

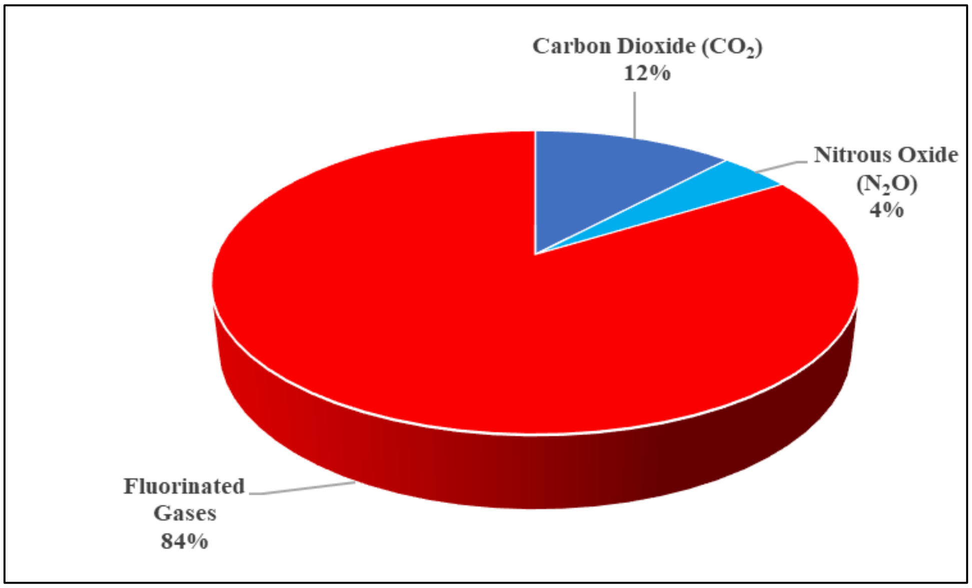
During this period, fluorinated gases contributed 84 percent of the average direct emissions, CO_2 contributed 12 percent, and N_2O contributed 4 percent, as depicted in **Figure 3.4-3**. **Figure 3.4-4** shows the percentage breakdown of average annual direct emissions from 2014-2022 attributable to specific GHG constituents. At 46 percent, perfluorocarbons (PFCs) comprised by far the highest percentage of direct emissions. Sulfur hexafluoride (SF_6) was next at 12 percent of direct emissions, while CO_2 from onsite stationary combustion sources also contributed 12 percent.

Figure 3.4-2. Average Annual Direct GHG Emissions, NAICS Code 334413 Facilities, 2014-2022



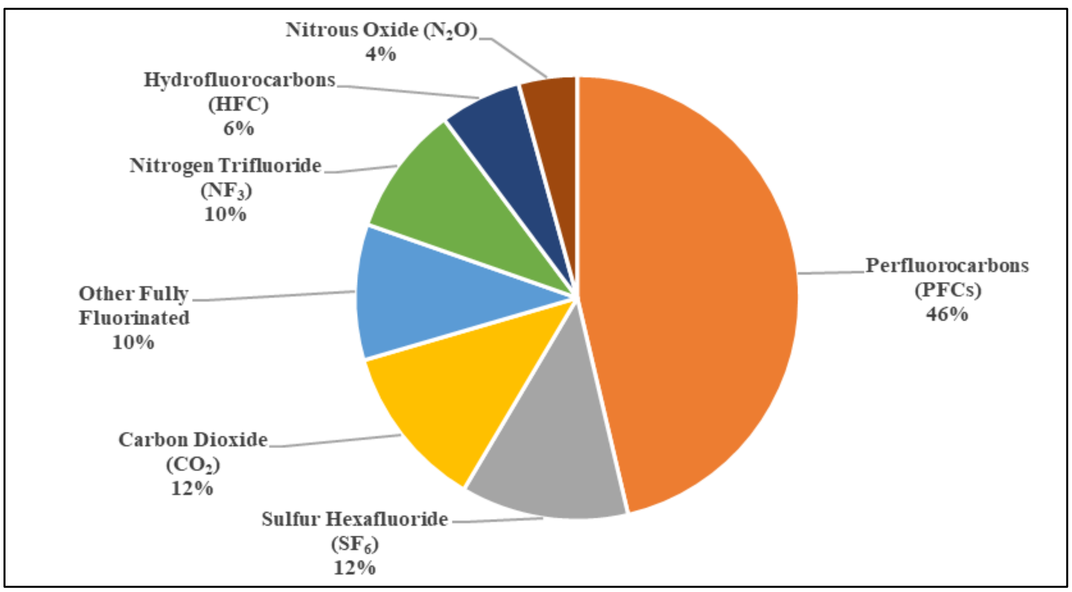
Source: EPA, 2023c.

Figure 3.4-3. Composition of Direct GHG Emissions, NAICS Code 334413 Facilities, 2014-2022



Source: EPA, 2023c.

Figure 3.4-4. Composition of Direct GHG Emissions by Constituent, NAICS Code 334413 Facilities, 2014-2022



Source: EPA, 2023c.

The U.S. Department of Energy's (DOE) Manufacturing Energy and Carbon Footprint summary (last updated in 2021) for the Semiconductor and Related Devices Manufacturing Industry (NAICS Code 334413) estimated 5.3 MMT CO_2e of **indirect** GHG emissions from electricity consumption supplied from offsite fossil fuel generation to support manufacturing (DOE, 2021). Combining the average annual **direct** GHG emissions from 2014-2022 of 6.2 MMT CO_2e with the estimated **indirect** GHG emissions of 5.3 MMT CO_2e sets the best available estimate for the total GHG footprint at approximately 11.5 MMT CO_2e annually. According to EPA's Greenhouse Gas Equivalencies Calculator, this level is equivalent to the annual CO_2e emissions from 2.5 million gasoline-powered cars, the energy use of 1.5 million homes, three coal-fired power plants, or 29 gas-fired power plants. Offsetting and displacing this level of emissions would require 3,198 wind turbines operating for a year (EPA, 2023d).

Fluorinated Gas Emissions

Most of the GHG emissions from semiconductor fabs consist of fluorinated gases, including PFCs, SF_6, nitrogen trifluoride (NF_3), and HFCs. These potent and long-lived GHGs are used to etch circuits onto wafers and clean thin-film deposition (TFD) chambers. Under normal operating conditions, EPA estimates that 2 to 80 percent of these gases pass through the manufacturing process unreacted and, unless abated, are released into the atmosphere. Additional fluorinated gases are generated as byproducts during etching and cleaning processes and are also emitted unless abated. Once released, these compounds generally remain in the atmosphere for thousands of years (EPA, 2023e).

Global warming potential (GWP) is a measure of how much energy the emission of 1 ton of a gas will absorb over a given period (in this case, 100 years), relative to the emission of 1 ton of CO_2 (EPA, 2023f). Ton for ton, the fluorinated gases used in semiconductor manufacturing often trap thousands of times as much heat as CO_2. **Table 3.4-1** shows the 100-year GWPs of select GHGs associated with semiconductor manufacturing from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. The average annual emissions of fluorinated GHGs for the semiconductor sector from 2017 to 2022 were 4.3 MMT CO_2e.

HFCs are widely used in fabs to print circuits on wafers, to clean chemical vapor deposition (CVD) chambers, and as F-HTFs (Ruberti, 2023). F-HTFs, which are used for process cooling, substrate cleaning, soldering, and thermal shock testing, are potent and long-lived GHGs. These high-molecular-weight, fully fluorinated compounds are typically liquid at room temperatures and pressures but evaporate during use (which often occurs at high temperatures) and, unless abated, are released into the atmosphere.

HFCs include perfluoroamines, perfluoromorpholines, perfluoropolyethers (e.g., perfluoropolymethyl-isopropyl-ether (PFPMIE)) and long-chain perfluorocarbons and hydrofluorocarbons. As shown in **Figure 3.4-4**, HFCs represent, on average, 6 percent of the GHG emissions from semiconductor and related device manufacturing facilities. The semiconductor industry initially adopted HFCs as alternatives to ozone-depleting refrigerants (chlorofluorocarbons (CFCs)). However, as noted above, some HFCs have a high GWP which, molecule for molecule, can be up to thousands of times greater than CO_2 (EPA, 2023b). The average annual emissions of HFCs for the semiconductor and related devices sector from 2014 to 2022 was 0.4375 MMT CO_2e (EPA, 2023c).

Table 3.4-1. 100-Year Global Warming Potential of Select Greenhouse Gases

Greenhouse Gas	100-Year GWP
Sulfur Hexafluoride (SF_6)	23,500
Nitrogen Trifluoride (NF_3)	16,100
HFC-23	12,400
Perfluorocyclobutane (PFC)-116	11,100
Perfluoropolyethers (PFPE) (HT-70)	9,710
PFC-318 (C_4F_8)	9,450
PFC-218	8,900
PFC-14	6,630
HFC-32	677
Nitrous Oxide (N_2O)	265
HFC-41	116
Carbon Dioxide (CO_2)	1

Source: IPCC, 2018.

Many semiconductor facilities have identified the means to abate GHG emissions through removal or destruction technologies, source reduction and process improvements, and use of alternative chemicals (EPA, 2023e). EPA's GHGRP database for Semiconductors and Related Devices (NAICS Code 334413) shows that in 2022, 24 semiconductor facilities reported using GHG abatement systems with removal or destruction efficiencies ranging from 1 to 70 percent. EPA requires facilities to account for the effects of abatement systems when reporting GHG emissions estimates to the GHGRP. 40 C.F.R. § 98.93. Another 23 semiconductor facilities reported that they did not use GHG abatement systems (EPA, 2023c).

3.4.2 Environmental Consequences

This section analyzes the potential consequences of a project under the Proposed Action and the no action alternative on climate change and climate resilience.

3.4.2.1 Proposed Action

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of the CHIPS financial assistance, changes to the facility's chip production capacity and manufacturing processes could lead to changes to the type and quantity of its direct and indirect GHG emissions, which would affect climate change and climate resilience.

Overall increased fab production capacity due to modernization or expansion likely would result in increased direct GHG emissions, including increased emissions of CO_2, methane, N_2O, and fluorinated gases, absent additional emission controls. Because crucial fab processes depend heavily on high-GWP fluorinated gases, modernization or expansion may lead to proportional increased use of fluorinated gases and increased levels of high-GWP emissions.

Although fab modernization and expansion could cause direct GHG emissions to increase, modernization of fab equipment and tools or changes to fab manufacturing processes, such as implementation of BMPs or other mitigation measures, could moderate, mitigate, or reduce the potential for increased direct GHG emissions. Examples of methods to abate increased direct GHG emissions, including emissions of N_2O and fluorinated gases, include: (1) chip manufacturing process improvements and source reductions; (2) use of alternative or substitute chemicals; and (3) vapor and process gas destruction technologies. Examples of projects that could abate direct GHG emissions include converting certain CVD tools to NF_3 remote plasma clean (RPC) sources and installing gas abatement units (EPA, 2016a; EPA, 2023b).

Overall increased fab production capacity due to modernization or expansion also likely would result in increased indirect GHG emissions during construction as well as operation, due to increased electricity use necessary for the chip manufacturing process, which could be provided directly or indirectly (i.e., via electricity generation) by fossil fuel sources, such as natural gas- or coal-fired power plants.

Although fab modernization and expansion could cause indirect GHG emissions to increase absent changes to fab energy sources, many semiconductor companies are shifting to electricity generated from renewable energy sources, which could result in substantial reductions in indirect fab GHG emissions. Additional information on semiconductor manufacturing industry energy use and sources can be found in **Section 3.10 (Utilities)**.

Summary of Effects

As discussed in **Section 2.4**, under the Proposed Action, most fab modernization projects would involve expanding fab cleanroom space or upgrading, replacing, or adding new SME. The practical effects of these actions may vary, but CPO generally anticipates that modernization or expansion using CHIPS financial assistance will result in varying degrees of increased chip production capacity.

In general, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in increased direct and indirect GHG emissions, including increased emissions of high-GWP chemicals, such as fluorinated gases. The effects of specific projects may vary depending on the size of the project and the degree to which the project implements BMPs or other mitigation measures, such as installation of abatement systems for fluorinated gases, chip manufacturing process improvements and source reductions, or use of alternative or substitute chemicals. CPO concludes that such modernization and expansion projects likely would have direct, *temporary to permanent*, *minor to moderate*, and ultimately *national* or global effects on climate change and climate resilience. CPO will require larger modernization or expansion projects that could have significant effects to incorporate at least one of those BMPs or mitigation measures, any of which would generally be sufficient to avoid significant effects.

CPO concludes that modernization or expansion projects also likely would have indirect, *temporary to permanent*, *minor to moderate* climate effects primarily due to increased emissions from construction and increased indirect emissions from energy use during operation. The effects of specific projects may vary depending on the degree of shifting electricity use to renewable energy sources, implementation of more energy-efficient processes, and energy conservation measures.

3.4.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur.

GHG emission reductions through improved SME, installation of abatement systems, or increased facility energy efficiency measures would not occur.

Under the no action alternative, there would continue to be *temporary to permanent*, *minor to moderate*, *national* to potentially global effects on climate change and climate resilience. Overall, the climate effects of the no action alternative would represent the business-as-usual scenario for semiconductor facility emissions, with concomitant adverse impacts on climate change and climate resilience given the relatively high level of GHG emissions, including a disproportionately high level of fluorinated gas emissions from this sector.

3.5 AIR QUALITY

This section analyzes the affected environment and the potential consequences of a project under the Proposed Action and the no action alternative on air quality.

3.5.1 Affected Environment

Air quality is the measure of the atmospheric concentration of defined pollutants in a specific area. An air pollutant can be any substance in the air that can cause harm to humans or the environment. Air pollutant sources can be natural, such as smoke from wildfires ignited by lightning, windblown dust, and wind erosion, or human-made, such as emissions from vehicles, industrial facilities, and construction sites. Air quality in a geographic area can be affected by the area's surface topography, air basin size, prevailing meteorological condition, and climate conditions.

Air pollutant emissions from semiconductor fabrication facilities are regulated under federal and state law, and facilities must follow regulatory standards to control their emissions, including from, for example, process equipment vents and storage tanks. Emission limits applicable to facilities are based on factors such as the manufacturing processes the facility performs, the raw materials and chemicals it uses, and local air quality conditions. Semiconductor fabrication facilities also are sources of GHG emissions, as discussed in **Section 3.4**.

3.5.1.1 Regulatory Framework

The Clean Air Act (CAA), 42 U.S.C. § 7401 *et seq.*, is the primary federal law designed to improve air quality to protect human health and the environment. The CAA authorizes EPA to set health based National Ambient Air Quality Standards (NAAQS), *id.* § 7409, as well as stationary source National Emission Standards for Hazardous Air Pollutants (NESHAP), *id.* § 7412. These two types of standards are particularly relevant to semiconductor fab air quality effects and are discussed in further detail below.

The CAA established several permitting programs designed to carry out the goals of the law. EPA is authorized to delegate its CAA permitting authority to states and tribes. Air permits are generally issued by state, tribal, or local air pollution control agencies, although some are issued by EPA regional offices (SMAQMD, 2017). In general, semiconductor fabs are subject to both construction and operation permitting requirements under the CAA. Specific CAA permitting requirements vary by permitting authority and facility, depending on factors such as the air quality designations applicable to the facility's location and the nature of the facility's emissions. Some fabs may be permitted as "minor" sources where they emit pollutants below applicable thresholds, whereas other fabs may be regulated as "major" sources and may be subject to more substantial permitting requirements and controls.

National Ambient Air Quality Standards (NAAQS)

NAAQS are nationwide air quality standards set by EPA using science-based thresholds for emissions of specific air pollutants. To date, EPA has set NAAQS for the following six air pollutants, known as “criteria pollutants”:

1. Sulfur oxides (SOx)
2. Nitrogen oxides (NOx)
3. Carbon monoxide (CO)
4. Ground-level ozone (O_3)
5. Particulate matter (PM)
6. Lead (Pb)

See 40 C.F.R. Part 50. The CAA identifies two types of NAAQS: (1) primary standards, designed to protect public health, including the health of sensitive populations, such as asthmatics, children, and the elderly; and (2) secondary standards, designed to protect public welfare, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. The NAAQS also address potential adverse effects from short-term exposure to higher levels of emissions by providing high and low averaging time standards, with lower averaging times applicable to higher emission levels and higher averaging times applicable to lower emission levels.

Where EPA delegates implementation of the NAAQS to a state, the state must develop a state implementation plan (SIP) for achieving the NAAQS in all geographic areas of the state and must incorporate source-specific emission limitations in the SIP applicable to sources in the state. Each SIP is subject to EPA review and approval. A SIP must designate each geographic area as an “attainment area” or a “nonattainment area.” These designations are criteria pollutant-specific. An area is designated “attainment” when air quality based on emissions of a criteria pollutant within that area meets or is cleaner than the NAAQS for that pollutant, whereas an area is designated “nonattainment” when air quality in that area does not meet the NAAQS for one or more criteria pollutants. The same geographic area can therefore be in attainment for some air pollutants but in nonattainment for others. If there is no air quality data, the area is designated as “unclassifiable” and is treated as in attainment. An area that has had a history of nonattainment but is now meeting and working to maintain the NAAQS is known as a “maintenance” area.

As discussed further below, the CAA requires state and other permitting authorities to conduct pre-construction and pre-operation reviews of new and modified sources of air pollution to regulate the air emissions from such sources based on whether they are in attainment, maintenance, or nonattainment areas, while taking into account existing permitted sources. A permitting authority therefore must consider whether a new or modified source, such as a semiconductor facility expansion, may be permitted consistent with the relevant area’s air quality designations. The permitting authority may require the source to install air pollution abatement and control technology to prevent air quality in an attainment or maintenance area from deteriorating below the applicable NAAQS, or to prevent air quality in a nonattainment area from worsening. Emission control standards applicable to semiconductor fabrication facilities typically are set within SIPs, with the level of emission controls required varying based on whether the facility is within a NAAQS attainment area or nonattainment area and whether the facility is a “minor” or “major” source of criteria pollutants. A facility is a major source if its emissions of a criteria pollutant exceed a defined threshold.

National Emission Standards for Hazardous Air Pollutants (NESHAP)

CAA Section 112(b) establishes national emission standards for hazardous air pollutants (NESHAP), which regulate sources and source categories that emit hazardous air pollutants (HAPs) that pose risks to human health. Under the CAA, EPA has listed 188 HAPs that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. HAPs generally originate from stationary sources, but may also originate from mobile sources (e.g., internal combustion engines) and indoor sources (e.g., certain building materials and industrial cleaning processes).

EPA promulgated NESHAP for semiconductor manufacturing facilities in 2003 and amended the semiconductor NESHAP in 2008. 40 CFR Part 63, Subpart BBBBB. In the amended NESHAP, EPA imposed a new air pollution control technology standard on semiconductor manufacturing facilities, requiring such facilities to install maximum achievable control technology (MACT) for existing and new combined process vent streams containing inorganic and organic HAPs. EPA also clarified the emission control requirements for process vents by adding definitions for organic, inorganic, and combined HAP process vent streams that contain both organic and inorganic HAPs. The regulations also require new, reconstructed, or existing major sources of HAPs at semiconductor fabrication facilities to install emission controls on process vents and storage tanks. The regulations prescribe separate control requirements for process vents containing organic pollutants, such as methanol, and process vents containing inorganic pollutants, such as hydrogen chloride (HCl, or hydrochloric acid) or hydrogen fluoride (HF, or hydrofluoric acid) (EPA, 2003). Facilities must reduce emissions from process vents containing organic air toxics by 98 percent, or to below 20 parts per million (ppm) by volume, and must reduce emissions from process vents containing inorganic pollutants by 95 percent, or to below 0.42 ppm by volume. In addition, facilities must reduce HAP emissions from storage tanks with capacities greater than 1,500 gallons to the same level of control as inorganic process vents (EPA, 2003).

CAA Section 112 defines a “major source” of HAPs as any stationary source or group of stationary sources located within a contiguous area and under common control that “emits or has the potential to, considering controls, in the aggregate, emit 10 tons per year (tpy) of any single [HAP] or 25 tpy of any combination of HAPs.” Sources that emit less than these thresholds are designated as “area sources” of HAPs.

When EPA established the semiconductor NESHAP in 2003, EPA estimated that there were only 20 major semiconductor sources of HAPs that would be subject to the rule; during preparations for a required periodic review of the rule in 2020, EPA determined that there were no major semiconductor sources of HAPs. Given the potential for growth in the semiconductor industry, EPA will have to evaluate whether there are existing or new semiconductor fabs that are major sources of HAPs prior to conducting the next required review of the semiconductor NESHAP. EPA also will have to evaluate whether there are existing or new semiconductor fabrication facilities that operate area sources of HAPs; such sources would have to comply with applicable standards, such as the Area Source Boilers NESHAP and the Stationary Reciprocating Engines NESHAP. However, there is not a NESHAP that applies specifically to semiconductor fabrication operations at area source facilities.

New Source Performance Standards

CAA Section 111(b) authorizes EPA to set new source performance standards (NSPS) for categories of sources that cause or contribute significantly to air pollution that may reasonably be anticipated to endanger public health or welfare. The primary purpose of the NSPS is to ensure that the best demonstrated emission control measures are employed as industrial infrastructure is modernized.

Since 1970, the NSPS have been successful in achieving long-term emissions reductions across numerous industries by assuring cost-effective controls are installed on new, reconstructed, or modified sources (EPA, 2023g). Certain proposed semiconductor fab modernization projects could involve upgrades to SME or other tools subject to NSPS. Most semiconductor facilities also must comply with 40 C.F.R. Subparts 60 Db-Dc (boilers), JJJJ (stationary spark ignition internal combustion engines), and KKKK (generators). Semiconductor facilities must comply with NSPS for both major and minor sources, as applicable.

New Source Review

The New Source Review (NSR) program, commonly referred as the "preconstruction permitting program," is a CAA program that requires industrial facilities to install air pollution control equipment for newly built facilities and existing facilities that are undergoing expansion or renovations that significantly increase emissions. Under the NSR program, the state or local air pollution control agency issues the required permits, if the agency has an EPA-approved program. In the absence of an approved program, EPA regional offices will generally issue the permits, but states may obtain delegated authority to administer the federal program. EPA administers the NSR program in many tribal areas. Some tribes may have agreements with states pursuant to tribal implementation plans, which may affect how the NSR program is administered in tribal areas. In general, there are three types of NSR permitting requirements. An individual source may have to meet one or more of these permitting requirements:

- **Prevention of Significant Deterioration (PSD)** permits are required for new major sources or major sources making a major modification in attainment or unclassifiable areas;
- **Nonattainment NSR (NNSR) permits** are required for new major sources or major sources making a major modification in nonattainment areas; and
- **Minor source permits** are required for new construction and modifications that do not result in emissions increases above major source or modification thresholds. The purpose of minor NNSR permits is to prevent emissions increases that would interfere with attainment or maintenance of a NAAQS or violate the control strategy in nonattainment areas.

Specific types of minor sources that may be subject to minor source permit requirements include:

- **True minor source**: a source that emits, or has the potential to emit (PTE), regulated NSR pollutants in amounts that are less than the major source thresholds, but equal to or greater than the minor NSR thresholds under 40 C.F.R. § 49.153, without the need to take a federally enforceable restriction to reduce its PTE to such levels.
- **Synthetic minor source**: a source that has the potential to emit regulated NSR pollutants in amounts that are at or above the thresholds for major sources, but that has implemented a federally enforceable restriction so that its PTE is less than such amounts for major sources. State minor NSR programs also typically cover these types of sources. Once a permittee has accepted an enforceable emission limitation, it must continue to comply with that limitation to avoid the need to apply for a major source permit. If a facility applies for a synthetic minor source permit (or a synthetic minor HAP source permit), it also must comply with public participation requirements, and the final permit issuance is subject to review under applicable administrative and judicial procedures. *See* 40 C.F.R. §§ 49.157, 49.159, 51.161.
- **Synthetic minor HAP source**: a source that otherwise has the potential to emit HAPs in amounts that are at or above those for major sources of HAPs, but that has implemented a federally enforceable restriction so that its potential to emit HAPs is less than such amounts for major sources.

A source can be designated a synthetic minor source of both regulated NSR pollutants and HAPs.

General Conformity Program

The CAA prohibits federal agencies from supporting or providing financial assistance to any activity that does not conform with the relevant SIP or other implementation plan requirements applicable to that activity. 42 U.S.C. § 7506(c). EPA regulations establish a General Conformity program implementing this prohibition. 40 C.F.R. Pt. 93, Subpart B. The General Conformity regulations prohibit federal agencies from supporting or providing financial assistance to activities that affect NAAQS maintenance or nonattainment areas unless the emissions from the activity will not:

- Cause or contribute to new violations of NAAQS;
- Worsen existing violations of the NAAQS; and/or
- Interfere with attainment or maintenance of the NAAQS.

As part of the environmental due diligence process described in **Appendix A**, CPO will review an applicant's proposed semiconductor modernization or expansion project and determine whether a General Conformity applicability analysis will be required to ensure that CHIPS financial assistance for the project would be in conformity with the applicable SIP or implementation plan. CPO may require the applicant to submit relevant facility air emissions information to support this analysis. In addition, CPO may engage with the responsible state or local air pollution control agency regarding site-specific controls or other requirements applicable to the applicant's project.

3.5.1.2 Air Emissions Sources and Characterization

A variety of air pollutants may be emitted from semiconductor fabrication facilities. These include acid fumes and organic solvent emissions from cleaning, rinsing, resist drying, developing, and resist stripping; HCl emissions from etching; and various other emissions from spent etching solutions, spent acid baths, and spent solvents (EPA, 2001a). Processes related to semiconductor fabrication, such as water purification and industrial wastewater treatment, may also generate air emissions at semiconductor facilities.

In a November 1994 Semiconductor Industry Association (SIA) report to EPA that was ultimately used to develop the NESHAP standards for semiconductor fabrication facilities, the 20 participating facilities were reported to have been using 29 different chemicals listed as HAPs. Ion bed regeneration for deionized water production used the greatest amount of HAP chemicals out of any source in the facilities. Within the semiconductor fabrication process, lithography operations used the most HAP chemicals and wet etching used the second most. The other parts of the semiconductor fabrication process with substantial HAP chemical use were diffusion, crystallization, and some cleaning operations (EPA, 2001a).

SIA reported that five chemicals comprised 95 percent of the total HAP chemical use: HCl, HF, glycol ethers, methanol, and xylene. Of the 95 percent total HAP chemical use, 76 percent were acids (87 percent HCl), 23 percent were organics (32 percent xylene, 29 percent methanol, and 22 percent glycol ethers), and 1 percent were inorganics (metals, hydrides, and chlorine). Inorganics other than acids comprise only a small percentage of HAP chemicals used at semiconductor fabrication facilities. Reported human health effects from exposure to some of these HAPs include respiratory effects, eye irritation, neurological effects, blurred vision, headache, dizziness, central nervous system depression, nausea, cardiopulmonary effects, renal damage, lack of muscle coordination, and unconsciousness (EPA, 2001a). For more information on health effects from exposures, refer to **Section 3.7 (Human Health and Safety)**. Another SIA report showed that 10 chemicals comprised approximately 93.8 percent of all listed HAPs emitted: methanol, ethylbenzene, ethylene glycol, methylene chloride, glycol ethers, perchloroethylene, HCl, HF, trichloroethylene, and xylene. Methanol was emitted in the greatest amounts (EPA, 2001a).

Exhaust systems are designed to remove chemical vapors or gases and heat from manufacturing tool exhausts. For example, PFCs and HFCs are essential for plasma etching, plasma cleaning, and other low-volume applications as their uses balance the process requirement for high chemical and ion reactivity with the need for safe and effective manufacturing (SIA, 2023a). The chemistries used in photolithography have a relatively low vapor pressure, and the industry does not anticipate emissions from photolithography. There are four general categories of exhaust systems (SIA, 2023a):

- General exhaust is a centralized exhaust system consisting of air from exhausted enclosures, typically uncontaminated with hazardous or toxic chemicals and heat exhaust. General exhaust does not require abatement.
- Acid and alkali (corrosive) exhaust, the highest-volume exhaust stream, is primarily generated from the use or generation of acid or alkali gases within etch, deposition, and cleaning processes. Chlorine, fluorine, fluorinated GHG, and hydrides are components of acid exhaust. Alkali exhaust is usually segregated from acid exhaust in order to prevent the clogging and formation of submicron particles and to treat the exhaust more effectively. Acid and alkali exhaust treatments often occur in centralized pH-controlled packed-bed wet scrubbers.
- Organic exhaust is primarily generated from the use or generation of volatile organic compounds (VOCs) within photolithography and organic cleaning processes.
- Organic solvent exhaust typically has a high volume and a low concentration, which often leads to a concentrated exhaust stream before treatment with centralized thermal, catalytic, or plasma oxidizers.

In general, each manufacturing tool has an exhaust system that may include point of use (POU) devices tied to ductwork that is then connected to control equipment. POU control systems are designed for treating air emissions from the outlet of the manufacturing process to remove the compounds of interest and prevent them from entering the main exhaust ductwork (EPA, 2001a). POU abatement systems have evolved over time to meet safety, environmental, and risk-reduction targets (SIA, 2023a). They facilitate effective and safe treatment for pyrophoric, toxic, flammable and corrosive gases.

Researchers, suppliers, and semiconductor manufacturers have undertaken extensive efforts to develop and improve fluorinated GHG abatement technologies over the last 30 years. Abatement technologies including combustion with a wet scrubber, electrical heating with a wet scrubber, chemisorption/adsorber, and plasma have been shown to remove PFCs and other fluorinated GHGs from process exhaust.

Cleanrooms have more stringent air quality requirements than average industrial spaces; therefore, most fabs have a limited number of air exhaust streams. These air exhaust streams are characteristically high-volume, low-velocity streams resulting in dilute pollutant concentrations. In general, the HAP emissions from a fab consist of two different classes: acids and organics. These two classes of emissions are separated at the fab so they can be treated by the appropriate control device. Each fab has an exhaust system which may include POU devices connected to ductwork that directs emissions to the appropriate control equipment, which includes scrubbers and oxidizers (EPA, 2001a).

According to a study on facility-by-facility HAP emissions accounting conducted by the SIA, the industry also has uncontrolled emission points within the semiconductor manufacturing process. Approximately 65.1 megagrams per year (Mg/yr) (71.6 tpy) of uncontrolled emissions were identified by the 11 studied facilities. Of this amount, 54.0 Mg/yr (59.3 tpy) (or about 83 percent of the uncontrolled emissions) were associated with cleaning, photoresist formulation (mixing), ceramic layering activities, and other activities (EPA, 2001a).

Under the EPA GHGRP, owners and operators of electronics manufacturing facilities that emit equal to or greater than 25,000 metric tons of CO_2e per year from fluorinated GHGs and N_2O emissions must report these emissions from all electronics manufacturing processes and any other sources at the facility to EPA. See **Section 3.4** for more information.

To ensure an uninterruptable power supply during electrical grid outages or disruptions, semiconductor fabrication facilities use large-scale backup generators to serve as a critical contingency measure. See **Section 3.10 (Utilities)** for more information on backup generators. Large industrial facilities use internal combustion emergency backup generators (Chen et al., 2013). Internal combustion generators for large facilities are typically Tier 2 and Tier 3 diesel engines, which require routine monthly maintenance and testing of up to 100 hours per year, resulting in air emissions even when no emergency use occurs (NESCAUM, 2012). Tiering for generators was established in EPA's NSPS and depends on the emission rate when in use (EPA, 2008). Generators that are Tier 4-compliant under EPA's current continual operation standard, 40 C.F.R. Pt. 1039, emit 80 percent less PM than comparable Tier 2 generators (EPA, 2016b). Currently, EPA requires backup generators used only during grid outages to be Tier 2-compliant. Emission standards for non-methane hydrocarbons (NMHC), nitrogen oxides (NO_x), PM, and CO are summarized in **Table 3.5-1**.

Table 3.5-1. Emission Rates of NMHC, NO_x, PM, and CO for Tier 1 to 4 Engines

Standard	NMHC Rate (lb./MWh)	NO_x Rate (lb./MWh)	PM Rate (lb./MWh)	CO Rate (lb./MWh)
Tier 1	2.87	20.28	1.18	25.13
Tier 2	-	-	0.44	7.72
Tier 4	0.42	7.72	0.09	7.72

Source: EPA, 2016b.

In comparison to diesel back-up generators, other sources of emergency power have the potential for lower emissions rates per MWh. The emission rates for new natural gas combined cycle facilities are 0.089 lb./MWh for NO_x and 0.0041 lb./MWh for sulfur dioxide (SO_2) compared to all-tier diesel fuel generators, which maintained an SO_2 rate of approximately 0.44 lb./MWh in 2022 (PJM, 2023). Additional costs and benefits of alternative backup energy sources are discussed further in **Section 3.10**.

3.5.1.3 Emissions Control Equipment

To meet air permitting requirements, the semiconductor manufacturing industry uses air pollution control measures that include add-on control devices and preventive measures. Add-on control devices are used to reduce or remove pollutants from air discharge streams and include oxidizers and scrubbers that are described in more detail below. In addition, POU control devices can be used on individual process tools. Preventive measures include product substitution and reformulation, work practice procedures, and equipment modifications.

- A **catalytic oxidizer** is used to convert harmful gases into harmless or less harmful substances. It is a combustion device that controls VOCs, HAPs, and odorous emissions by reacting oxygen with pollutants over a specially designed catalyst and converting the pollutants into CO_2, water/steam, and usable heat. A catalyst is a substance that is used to accelerate the rate of a chemical reaction, allowing the reaction to occur faster and at a lower temperature range. The catalyst may be a precious metal, such as platinum or palladium, or it may be a basic metal, such as metal oxides or metal carboxylates using iron, vanadium, or molybdenum (CP, 2023).

- **Thermal recuperative oxidizers (TOs)** destroy air pollutants emitted from process exhaust streams at temperatures ranging from 760 °C (1,400 °F) to 815 °C (1,500 °F). TOs use a multi-pass shell-and-tube type heat exchanger fabricated of heavy-duty stainless steel. Oxidation is achieved as pollutants pass through the combustion chamber and are mixed and held at elevated temperatures. Thermal oxidation promotes a chemical reaction of the air pollutant with oxygen at elevated temperatures. This reaction destroys the VOC emission in the air stream by converting it to CO_2, water/steam, and heat (CP, 2023; CMM, 2023).
- In a **regenerative thermal oxidizer (RTO)**, process exhaust fumes are forced into a recuperative oxidizer inlet manifold (with a high-pressure supply fan) and directed into the cold side of a high efficiency, stainless steel, multi-pass shell-and-tube type heat exchanger. The pollutant laden air passes through the combustion chamber, is thoroughly mixed for temperature uniformity, and is held at the elevated set-point temperature for a residence time of 0.5 to 1.0 seconds. VOC/HAP emission control takes place within the combustion chamber where auxiliary fuel is introduced if necessary (CMM, 2023).
- **Scrubbers** are used to remove gaseous and particulate contaminants generated during various process steps, such as chemical vapor deposition (CVD) and etching, to ensure that the exhaust gases are clean and safe to release into the environment. Wet scrubbers use a liquid scrubbing solution, such as water, to remove pollutants from the exhaust gases. Dry scrubbers use a solid or gaseous scrubbing medium, such as activated carbon or sorbents, to remove pollutants from the exhaust gases. Hybrid scrubbers are scrubbers that use a combination of liquid and solid or gaseous scrubbing mediums to remove pollutants from the exhaust gases (Abachy, 2022).
- **Ammonia abatement systems** are designed to remove ammonia from a liquid waste stream. Some systems allow for ammonia removal from air streams with a very small percentage of NOx formation. NOx formation is further reduced by the use of secondary catalyst systems without the use of costly reactants and chemicals (CP, 2023). Selective catalytic reduction (SCR) is the secondary catalyst system used to selectively reduce harmful NOx by converting them to nitrogen across a catalyst.
- Onsite back-up generator controls could be implemented with the construction of an emergency power supply to reduce emissions. Reducing emissions from onsite back-up generators could be achieved through implementing: (1) retrofits to install control devices like SCR systems or scrubbers; (2) upgrades that replace older engines with higher tier engines; (3) switching from internal combustion engines entirely to battery back-up systems; (4) fuel-cell microturbines; and (5) clean energy microgrids.

There are several opportunities available to reduce air emissions and move toward net-zero GHG emission status in the semiconductor manufacturing industry. Many manufacturers have already achieved substantial reductions by employing one or more of these pollution abatement technologies.

3.5.2 Environmental Consequences

This section analyzes the potential consequences of a project under the Proposed Action and the no action alternative on air quality.

3.5.2.1 Proposed Action

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of CHIPS financial assistance, changes to the facility's chip production capacity and manufacturing processes could lead to changes to the type and quantity of air pollutants it generates.

Overall increased fab production capacity due to modernization or expansion likely would result in increases in pollutant loads and changes in the types of pollutants emitted to the air, such as increased emissions of criteria pollutants or HAPs, which could affect the fab's air permitting category or regulatory requirements, absent sufficient abatement or other controls. In addition, project activities, such as fab expansion and equipment installation, likely would result in emissions from operation of light duty construction equipment, such as cranes, light trucks, and generators, while the fab modernization is in progress, as well as emissions from supporting infrastructure and ancillary systems during operation.

Although fab modernization and expansion could cause air quality effects to increase, SME upgrades or changes to fab manufacturing processes, such as implementation of BMPs or other mitigation measures, could moderate, mitigate, or reduce the potential for increased criteria pollutant and HAP emissions. Fabs undertaking modernization or expansion projects would still need to comply with all applicable air permit limits. In addition, some fabs may use emissions control technologies such as those discussed in **Section 3.5.1.3** to control emissions of criteria pollutants and HAPs to achieve compliance with applicable air permit limits. Existing fab emissions control technologies may be sufficient to control emissions of some air pollutants, whereas controlling other types of air pollutant emissions may not be achievable without installing new technologies or abatement systems.

Summary of Effects

As discussed in **Section 2.4**, under the Proposed Action, most fab modernization projects would involve expanding fab cleanroom space or upgrading, replacing, or adding new SME. The practical effects of these actions may vary, but CPO generally anticipates that modernization or expansion using CHIPS financial assistance will result in varying degrees of increased chip production capacity. As part of the due diligence process to receive CHIPS Incentives Program funding, an applicant will be required to demonstrate compliance with all existing facility permits, including CAA permits. Upon completing modernization and/or expansion projects, the facility will still be required to comply with permit limits, including any new or revised permit limits triggered by new source requirements.

In general, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in increased emissions of criteria pollutants and HAPs but would still be required to comply with applicable air permit requirements, including applicable emissions limitations, technology control standards, and emissions offset requirements. CPO concludes that such modernization and expansion projects likely would have direct, *temporary to permanent*, *minor*, and *local to regional* effects on air quality. Specific projects that maximize use of abatement technologies to reduce overall air pollutant loads and emissions may have comparatively reduced air quality effects.

3.5.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur. In general, no changes in the amount or pollutant load of air emissions would occur because fabs would continue to use existing equipment and processes in their current configurations.

Under the no action alternative, there would continue to be *temporary to permanent*, *minor*, and *local to regional* effects on air quality. Fabs would continue to be subject to all applicable laws, regulations, and air permitting requirements.

3.6 WATER QUALITY

This section analyzes the affected environment and the potential consequences of a project under the Proposed Action and the no action alternative on water quality.

3.6.1 Affected Environment

Water quality describes the condition of water resources, including their chemical, physical, and biological characteristics. The most common types of standards used to address overall water quality typically involve monitoring and assessing the extent of water pollution, the condition of drinking water sources, human-water contact safety issues, and the health of aquatic ecosystems. Federal water quality standards (WQS) refer to federal, state, territorial, tribal, or local laws or regulations approved by EPA that govern the desired condition of a water body and how that condition will be protected or achieved (EPA, 2022a). States, territories, and tribes may be authorized to establish WQS for U.S. waters to protect human health and aquatic life. WQS form a legal basis for controlling pollutants entering U.S. waters. Both surface water and groundwater resources are susceptible to pollution impacts. Surface water includes oceans, bays, rivers, streams, lakes, and wetlands. Groundwater is subsurface water found beneath the water table in soils and geologic formations. Groundwater is the most prevalent source of available freshwater that supports potable, agricultural, and industrial uses, especially in areas that lack access to surface water resources. Groundwater quality is impacted by interactions with soil, sediments, rocks, surface waters, and the atmosphere. Groundwater quality also may be significantly affected by agricultural, industrial, urban, and other human actions.

3.6.1.1 Regulatory Framework

Water quality is protected by federal, state, and local law. At the federal level, the Clean Water Act (CWA), 33 U.S.C. § 1251 *et seq.*, is the primary federal statute regulating water quality; the goal of the CWA is to restore and maintain the chemical, physical, and biological integrity of U.S. waters (EPA, 2023h). The CWA regulates surface water through various programs, including the following.

- **Section 303(d)** requires states to develop lists of all impaired water bodies and prioritize impaired waters when establishing plans to restore degraded areas. The CWA authorizes EPA to assist states, territories, and authorized tribes in listing water bodies for protection and developing limitations on the maximum amount of pollutants that can be discharged into such waters while continuing to meet water quality standards, known as total maximum daily loads (TMDLs).
- **Section 305(b)** requires states to report on the overall condition of aquatic resources.
- **Section 301** authorizes EPA to develop effluent limitation guidelines and standards (ELGS) for existing sources of water pollution, standards of performance for new sources, and pretreatment standards for new and existing sources. EPA has promulgated ELGS for semiconductor fabrication facilities in the Electrical and Electronic Components (E&EC) source category at 40 C.F.R. Part 469.
- **Section 307** establishes national pretreatment standards to control pollutants that pass through or interfere with wastewater treatment processes at Publicly Owned Treatment Works (POTWs) or that may contaminate sewage sludge. The national pretreatment program is a cooperative effort

among federal, state, and local environmental regulatory agencies established to protect water quality and designed to reduce conventional and toxic pollutant levels discharged by industrial facilities through municipal sewer systems and into the environment. EPA and authorized state pretreatment programs approve local municipalities to perform permitting, administration, and enforcement for discharges to municipal POTWs.

- **Section 402** establishes the National Pollutant Discharge Elimination System (NPDES), a permit program designed to regulate discharges of water pollutants from “point sources” (such as pipes, ditches, or other means of conveyance). A facility or other point source discharging into federal waters must obtain a NPDES permit, which incorporates ELGS applicable to the facility and includes monitoring and reporting requirements and other provisions to ensure that discharges from the source do not degrade water quality or human health. EPA is authorized to delegate NPDES program administration and enforcement to state, tribal, and territorial governments.
- **Section 404** prohibits the discharge of dredged or fill material into federal waters without a permit. The Section 404 program is jointly administered by EPA and the U.S. Army Corps of Engineers (USACE). Modernization and expansion projects under the PEA normally would not be expected to involve this type of discharge, which would require a Section 404 permit from the USACE, but applicants will be required to state whether their projects would involve such discharges.

In a recent report, EPA found that a majority of semiconductor fabrication facilities discharge their wastewater to local or regional POTWs (EPA, 2022a) as opposed to directly discharging their wastewater to surface waters. As indirect dischargers through POTWs, these fabs are subject to the general pretreatment regulations for existing and new sources of pollution at 40 C.F.R. Part 403 and the standards for the E&EC point source category at 40 C.F.R. Part 469. Some semiconductor fabs may generate wastewater from metal finishing and/or electroplating operations as well as E&EC operations; such facilities also may be subject to ELGS for the Electroplating and Metal Finishing point source categories at 40 C.F.R. Parts 413 and 433, respectively.

Pretreatment permits are issued by the POTW if it has a local pretreatment program approved by the state or EPA. Pretreatment standards are pollutant discharge limits that apply to industrial users of the POTW. There are three types of pretreatment standards: (1) general and specific prohibitions; (2) categorical pretreatment standards; and (3) local limits. A pretreatment permit issued to a semiconductor fab may include general prohibitions that forbid the discharge of any pollutant(s) to the POTW that can cause pass through or interference under 40 C.F.R. Part 403, in addition to the specific prohibitions at 40 C.F.R. § 403.5(b). An additional layer of protection is provided by the technology-based pretreatment standards or ELGS for the E&EC point source category at 40 C.F.R. Part 469.

As indirect dischargers, semiconductor fabrication facilities are required to conduct self-monitoring and submit monitoring reports to the pretreatment control authority (POTW, state, or EPA) at least once every six months. 40 C.F.R. § 403.12(h). The monitoring reports generally include a description of the nature and concentration of pollutants with their respective effluent limitations, records of measured or estimated average and maximum daily flows for the reporting period, and pollution prevention documentation.

Any semiconductor fabrication facility that directly discharges pollutants from a point source, e.g., pipe or drain, to U.S. water bodies, e.g., rivers or creeks, is subject to the NPDES permit program. NPDES permits are issued by EPA or authorized states (EPA, 2022b). These permits must include applicable technology based ELGS for the industry pursuant to 40 C.F.R. Part 469, as well as any necessary permit limits and conditions to protect the water quality of the receiving water body. As a result, more stringent water quality-based effluent limitations, limits for additional pollutants, and/or other requirements may be included in the NPDES permit compared to the requirements in the ELGS. Direct dischargers also must submit discharge monitoring reports to the permitting authority in compliance with the NPDES permit.

The method for pretreating industrial wastewater will vary based on whether the discharge is indirect or direct. Indirect discharging semiconductor fabrication facilities pretreat their industrial wastewater through processes such as neutralization or chemical precipitation with clarification prior to discharging to a POTW (EPA, 2022b). Direct discharging facilities use treatment processes such as solvent management, neutralization, chemical precipitation with clarification, filtration, and in-process control for specific pollutants, such as collection of metal-bearing wastes for resale, reuse, or disposal (EPA, 2022b). Most facilities implement a solvent management plan, which is designed to prevent organic contaminants from entering the wastewater. Some facilities even recover organic solvents for reuse or resale.

3.6.1.2 Wastewater Characterization

Wastewater generated from semiconductor fabrication and related facility operations can be treated and reused, treated and discharged, or transported offsite for treatment, disposal, or reuse. Segregation of wastewater flows allows facilities to more cost-effectively treat, dispose, or reclaim wastewater. Facilities maintain wastewater flows with different constituents separated prior to treatment, including separating wastewater flows containing solvents for disposal. Automated wastewater treatment systems are programmed to accept or divert wastewater flows based on input from influent monitoring instrumentation. Diverted flows can then be separately captured, managed, or discharged as needed. Common wastewater streams and handling methods include (IEEE, 2023; ISMI, 2006):

- **Hydrofluoric (HF) acid wastewater** can contain ozone and/or ammonia (these constituents often require additional treatment measures) and can be treated onsite, producing calcium-based solid waste that can be reused elsewhere outside of the semiconductor facility.
- **Ammonium $[NH_4]^+$ wastewater** can contain hydrogen peroxide and can be treated onsite, producing ammonium sulfate solution for offsite recycling and disposal.
- **Solvent wastewater** can contain isopropyl alcohol and other solvent waste (e.g., glycols, ethers, and polar and non-polar photoresist) and can be corrosive and/or contain hydrogen peroxide or PFAS. Solvent collection systems prevent untreated liquid waste from mixing with other wastewater streams. Solvents not treated onsite can be shipped offsite to vendors for reuse after purification or to approved treatment and disposal facilities.
- **Metal wastewater** can contain metals and metallic compounds. Metal collection systems allow for onsite or offsite treatment or recycling (e.g., copper solid produced from concentrated waste by electrowinning).
- **Acidic or caustic wastewater** can contain acidic or caustic solutions from processes or facility maintenance. Wastewater streams from various processes can be combined and neutralized by sulfuric acid or sodium hydroxide before discharging.
- **Concentrated sulfuric acid (H_2SO_4) waste** contains sulfuric acid and can contain impurities. It can be collected in tanks for onsite or offsite reuse in other industries. Onsite reuse typically only occurs in waste treatment unless it is refined to electronic grade for reuse.
- **Wastewater containing suspended solids** (e.g., silicon from backside grinding or silicon dioxide from chemical mechanical polishing (CMP)) can be combined with acid wastewater or sent to a solids removal system with the clarified water sent for reuse.
- **Lithography developer waste (contains tetramethylammonium hydroxide (TMAH))** can be treated on or offsite. Typically, concentrated organic solvents are segregated from other wastewater flows and sent offsite for reuse or disposal. Treatment methods include biological treatment to digest the TMAH, or recovery of the TMAH in a segregated drain and treatment system for reuse offsite.

- **Concentrated phosphoric acid waste** can be collected in tanks for treatment onsite or sent offsite for reuse. Onsite reuse typically only occurs as a nutrient for biological treatment. Onsite treatment may include neutralization to lower pH, precipitation to remove metals, and filtration to remove solids and impurities.

Fabs typically have complex wastewater drain systems that carry process-specific wastewater flows through pre-treatment, equalization, and neutralization steps before merging into a combined facility effluent (SIA, 2023a). Segregated wastewater drain and treatment systems include those for certain metals, fluoride, certain acids, and chemical-mechanical planarization processes but vary according to facility design and applicable federal, state, and local pre-treatment requirements. Typical pre-treatment requirements for the semiconductor industry include the removal of fluoride, ammonia, copper, and other plating metals; solids and dissolved solids removal; and pH adjustments.

Pollutants currently regulated under discharge restrictions for process operations associated with semiconductor manufacturing, 40 C.F.R. Pt. 469, include direct discharges of total toxic organics, arsenic, pH, fluoride, and total suspended solids, and indirect discharges of total toxic organics and arsenic (EPA, 2022b).

The ELGS for total toxic organics are based on the sum of the concentrations for each of the regulated toxic organic compounds that are found in the wastewater discharge at a concentration greater than 10 micrograms/liter (µg/L). The regulated toxic organic compounds are listed under 40 C.F.R. Part 469. The Metal Finishing Category effluent limitations guidelines at 40 C.F.R. Part 433 also apply to semiconductor fabrication facilities that generate electroplating wastewater and include limits for nickel, copper, chromium, and lead.

Since the 1980s, the semiconductor industry has incorporated up to 49 additional chemical elements into semiconductor manufacturing operations (EPA, 2022b). For example, the industry has developed several new process chemistries for photolithography over the past 30 years that use new solvent systems, such as ethyl lactate and propylene glycol monomethyl ether acetate (PGMEA). In addition, some chemically amplified photoresists and antireflective coatings can contain perfluoroalkyl substances (PFAS). While most photolithography waste is handled as solvent and incinerated, most semiconductor facilities send 100 percent of waste antireflective coating (containing PFAS) to industrial wastewater drains, unless segregated in a separate drain and collection system for disposal. For more information about the use of PFAS in semiconductor fabrication facilities and emerging PFAS standards, see **Appendix C**. In addition, some facilities may be discharging more substantial quantities of certain previously listed or regulated pollutants, including copper and fluoride, due to manufacturing process changes, while phasing out the use of other pollutants, such as organic chemicals.

The fate of PFAS-containing materials depends on the material type and the treatment processes used on PFAS-containing wastewater. Removal of PFAS-containing materials from facility wastewater flows is generally more effective when wastewater flows are intercepted and/or treated close to their source, where the effluent flows are typically lower and concentrations higher. Typical fab effluents can be on the order of 12,000 m^3/day to 23,000 m^3/day. Removing low concentrations of PFAS-containing materials from a final effluent discharge point source that operates at a high flow can be very expensive and, in some cases, infeasible (SIA, 2023a).

There are two types of treatment process technologies for removing PFAS-containing materials: technologies that remove or separate PFAS constituents from wastewater, and technologies that destroy the PFAS-containing material (SIA, 2023a). Treatment processes, such as granular activated carbon (GAC), can remove PFAS-containing materials from wastewater, but following the completion of the sorption cycle, the used GAC itself becomes waste.

A recent EPA report confirmed that updated semiconductor manufacturing industry processes are introducing pollutants previously not commonly observed in fab wastewater flows due to new materials, lithography process chemistries, and advanced tools required for fabs to keep pace with rapidly changing technology demands (EPA, 2022b). Most noteworthy of the pollutants observed in new fab processes are PFAS and elements such as germanium and gallium, which are toxic, persistent, and can bioaccumulate. EPA's review shows that the industry continues to rely on traditional technologies for wastewater treatment; however, the industry is actively evaluating new technologies (e.g., biological ion exchange, reverse osmosis, electrowinning) and wastewater management practices (e.g., rinse recycle, reverse osmosis reject recycle) aimed at treating some of the newer pollutants. EPA concluded that the existing ELGS are sufficient to prevent interference or upset at POTWs and protect water quality of receiving waters, but additional study will be required to identify any new pollutants of concern as new technologies are developed and new chemicals are used in semiconductor fabrication.

According to the EPA's Effluent Guidelines Program Plan 15, which was released in 2023, the agency intends to continue to monitor discharges of PFAS from E&EC facilities through the POTW Influent Study, updated Toxics Release Inventory (TRI) reporting requirements for PFAS, and NPDES permit monitoring requirements for federally issued permits and state permits as more states include monitoring for PFAS in permits. These data will help EPA identify any significant sources of these chemicals in future reviews. EPA will conduct rulemaking to consider revising the ELGS for the Electroplating and Metal Finishing Point Source Categories at 40 C.F.R. Parts 413 and 433 to address wastewater discharges of PFAS from chromium finishing operations (EPA, 2023i).

3.6.2 Environmental Consequences

This section analyzes the potential consequences of a project under the Proposed Action and the no action alternative on water quality.

3.6.2.1 Proposed Action

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of the CHIPS financial assistance, changes to the facility's chip production capacity and manufacturing processes could lead to changes to the type and quantity of discharges of pollutants, including changes in discharge volumes and wastewater pollutant loads. Project activities such as fab expansion and equipment installation would not be expected to generate more than minimal effects on water quality, as water would only be used for such activities as part of dust abatement and cleaning and would be handled properly via internal plumbing or drains.

Wastewater from semiconductor fabrication may contain a variety of pollutants, including organic compounds, heavy metals, nitrogen, and phosphorus. Semiconductor fabrication facilities have the potential to cause large effects on water quality and are subject to strict environmental regulations and permitting as discussed in **Section 3.6.1.1**. To satisfy national, state, and local regulations, fab wastewater must be properly treated prior to discharge.

Most semiconductor fabs use a range of management practices to control toxic compounds in fab wastewater flows, such as developing solvent management plans, segregating wastewater flows, and employing wastewater disposal alternatives, such as water recycling or reuse. Segregation of wastewater flows allows facilities to treat, dispose, or reclaim wastewater while keeping different pollutants separate prior to treatment or disposal. With new and modernized equipment, effective effluent segregation could include (IEEE, 2023):

- Segregation of highly concentrated wastes with subsequent disposal (or ideally reuse) to reduce contamination and complexity of the facility's wastewater treatment and reclamation system.
- Segregation of higher purity wastewater streams to allow for greater water recycling within the manufacturing process or reuse within the facility.
- Segregation of wastewater streams with specific contaminants of concern for environmental regulatory compliance or that are relatively easier to treat (e.g., N-Methylpyrrolidone (NMP)), or difficult to treat (e.g., TMAH), to achieve targeted wastewater management solutions.

Heavy metals are among the most harmful water pollutants due to their non-degradable properties. Although World Health Organization (WHO) and EPA standards state that heavy metal concentrations in drinking water should remain subject to very low maximum concentration thresholds, heavy metals nevertheless can accumulate in the ecosystem and enter the human body through food. Heavy metals present in wastewater, such as cadmium, chromium, arsenic, lead, zinc, copper, and mercury, are highly toxic to human health even at trace levels (Vidu et al., 2020). In concentrations higher than a few µg/L, heavy metals affect the normal development and function of organs, poisoning the body and damaging internal organs and tissues by various mechanisms, such as enzyme denaturation, ion replacement, and protein inactivation.

Removing heavy metals from wastewater flows is a technically challenging process that requires constant attention and monitoring. Modernized, onsite equipment has the potential to remove heavy metal ions from wastewater using methods such as adsorption treatments (using different adsorbents, i.e., carbon-based, carbon-composites, minerals, magnetic, and biosorbents), membrane treatments (i.e., nanofiltration, microfiltration, reverse osmosis, forward osmosis, and electrodialysis), chemical treatments (i.e., chemical precipitation, coagulation-flocculation, and flotation), electric treatments (i.e., electrochemical reduction, advanced oxidation, and ion exchange), and photocatalysis.

For example, chemical mechanical polishing (CMP) uses a large amount of water and accounts for approximately 40 percent of water consumption in the semiconductor industry (Lee et al., 2022). After the CMP process in a fab is run, the process wastewater, which contains various chemicals and slurry particles, is treated through electrodecantation and electrocoagulation to remove the particles, and the treated wastewater is disposed. The CMP process can generate 30-50 liters (L) of chemical waste slurry for every 200 mm wafer. CMP wastewater produced during CMP and post-CMP wafer cleaning processes contains abrasive particles and chemicals, such as silica, alumina, magnesia, ceria, and zirconia. Chemical agents such as surfactants, buffing agents, complexing (or chelating) agents, and corrosion inhibitors are also present in the wastewater. Onsite industrial treatments via pretreatment systems include precipitation of metals or sorption of pollutants onto the precipitated materials. Precipitated materials are gravitationally settled, separated, and disposed of in landfills. The waste materials that are not removed are discharged into municipal sewer systems, and they enter municipal wastewater treatment plants that often use biological treatments designed to remove the nutrients (e.g., carbon, nitrogen, and phosphorous), but are also capable of removing the nanomaterials.

EPA has found that most water pollutants are detected in screening data used for semiconductor facility permit development and are observed at concentrations that do not pose a threat to cause interference or upset at the POTW or occur at concentrations lower than local water quality standard thresholds (EPA, 2022b). The semiconductor industry continues to rapidly change as new technologies are developed and new chemicals are used in the manufacturing process. A few semiconductor manufacturing facilities are beginning to track and monitor potential emerging pollutants (e.g., PFAS and gallium) to the extent that they are able, but to date EPA has not identified any new industry-wide potential parameters of concern for wastewater discharges (EPA, 2022b).

Summary of Effects

As discussed in **Section 2.4**, under the Proposed Action, most fab modernization projects would involve expanding fab cleanroom space or upgrading, replacing, or adding new SME. The practical effects of these actions may vary, but CPO generally anticipates that modernization or expansion using CHIPS financial assistance will result in varying degrees of increased chip production capacity and could require the treatment of new chemicals. As part of the due diligence process to receive CHIPS Incentives Program funding, an applicant will be required to demonstrate compliance with all existing facility permits, including CWA Section 402 permits, which include ELGS for heavy metals. Upon completing modernization and/or expansion projects, the facility will still be required to comply with permit limits, including any new or revised permit limits triggered by increased wastewater flows or pollutant loads. CPO notes that EPA has determined NPDES and related permit violations at existing direct and indirect discharging semiconductor manufacturing facilities to be rare, isolated exceedances that do not represent consistent issues at any specific facility or across the semiconductor industry (EPA, 2022b). CPO will review an applicant's compliance history during the due diligence process as described in **Appendix A**, including to determine whether the applicant's fab presents any ongoing, systemic water quality issues.

In general, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in increased wastewater volumes but would still be required to comply with existing or revised permit requirements, including semiconductor-specific ELGS, discharge reporting, and compliance monitoring. CPO concludes that such modernization and expansion projects likely would have *temporary to permanent*, *minor,* and direct *local* effects on water quality (for direct dischargers) and *regional* effects (for indirect dischargers). Specific projects that maximize use of pretreatment technologies, solvent management plans, segregation of wastewater flows, and wastewater recycling or reuse may have comparatively reduced water quality effects.

3.6.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur. In general, no changes in the amount or pollutant load of wastewater would occur because fabs would continue to use existing equipment and processes in their current configurations.

Under the no action alternative, there would continue to be *temporary to permanent*, *minor*, and *local* or *regional* effects on water quality, depending on the discharger. Fabs would continue to be subject to all applicable laws, regulations, and water permitting requirements.

3.7 HUMAN HEALTH AND SAFETY

This section analyzes the affected environment and the potential consequences of a project under the Proposed Action and the no action alternative on human health and safety, with a particular focus on occupational health and safety issues for semiconductor fab workers.

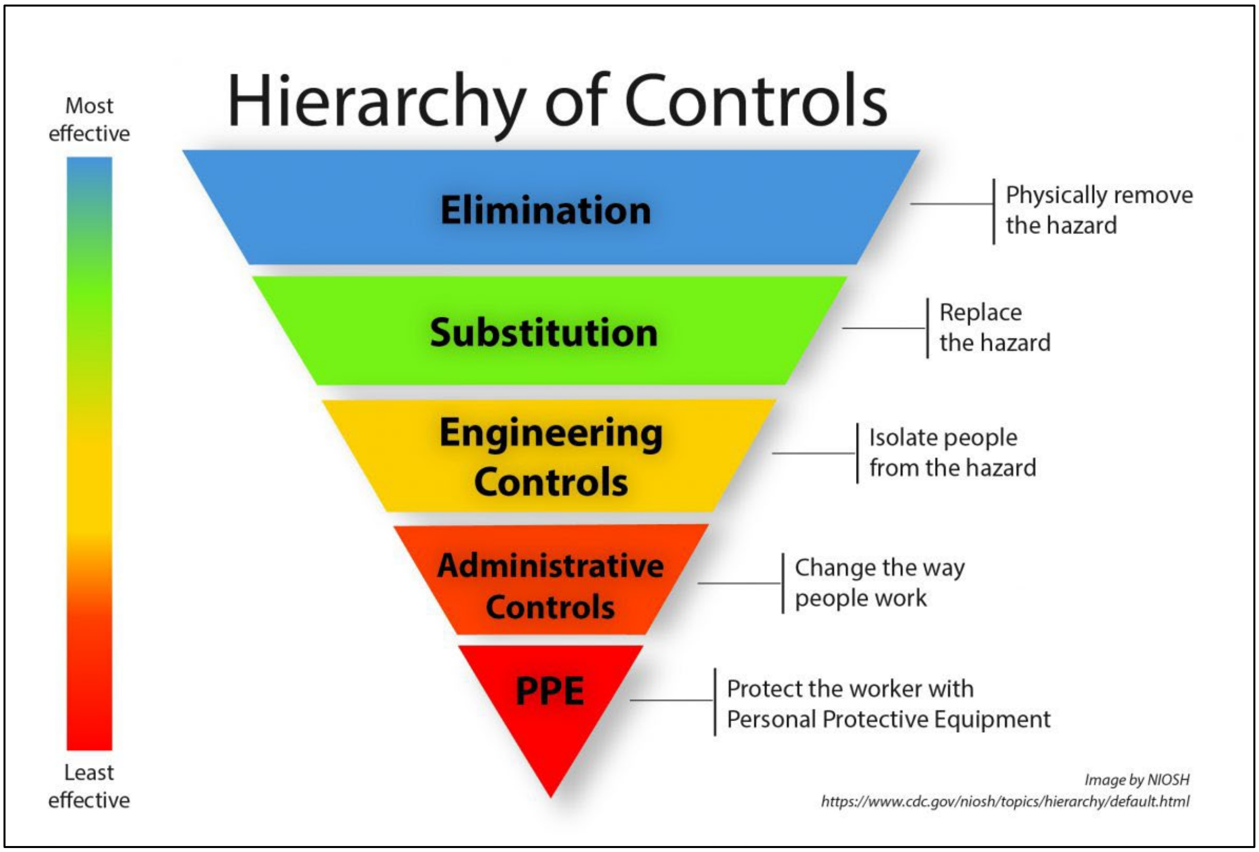
3.7.1 Affected Environment

Human health and safety describes the set of laws, regulations, practices, and norms pertaining to decisions at facilities to design safe environments and manage risks to the lives of people who work at or live near such facilities, including efforts to address past and ongoing risks posed by operations at semiconductor fabrication facilities.

3.7.1.1 Regulatory Framework

Several federal, state, and local laws and regulations aim to protect human health and safety at semiconductor fabrication facilities and in surrounding communities. The Occupational Safety and Health Administration (OSHA) has promulgated health and safety regulations for general industry at 29 C.F.R. Part 1910. These regulations address a wide range of topics related to workplace safety, including hazard communication, electrical safety, machinery and equipment safety, personal protective equipment (PPE), and training requirements. Semiconductor manufacturing facilities establish safety procedures in accordance with the OSHA regulations and typically apply the hierarchy of safety hazard controls from the National Institute for Occupational Safety and Health (NIOSH) to their operations (NIOSH, 2023). The NIOSH hierarchy of controls is shown in **Figure 3.7-1** below.

Figure 3.7-1. Hierarchy of Safety Hazard Controls



Source: NIOSH, 2023.

OSHA standards most relevant to the semiconductor manufacturing sector include:

- Subpart G, Occupational Noise Exposure, 29 C.F.R. § 1910.95, establishes guidelines and standards to protect workers from excessive noise in the workplace.

- Subpart H, Hazardous Materials, 29 C.F.R. § 1910.119, establishes requirements for preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals.
- Subpart H, Hazardous Materials, 29 C.F.R. § 1910.124, establishes general requirements for dipping and coating operations. The standards cover: dip tank construction and entry; ventilation, air recirculation, and exhaust hoods; first aid training, treatment, and supplies; required hygiene facilities; and dip tank cleaning, inspection, and maintenance.
- Subpart I, PPE, 29 C.F.R. § 1910.132, establishes requirements for PPE. The employer is responsible for ensuring the proper application, adequacy, and selection of PPE based on hazard assessment. The employer must provide PPE and associated training to employees. In addition, 29 C.F.R. § 1910.134 establishes specific respiratory protection requirements.
- Subpart Z, Toxic and Hazardous Substances, 29 C.F.R. Part 1910, provides requirements relating to employee exposures to air contaminants, including, among others, inorganic arsenic, 29 C.F.R. § 1910.1018, and lead, *id.* § 1910.1025, and includes provisions relating to access to employee exposure and medical records, *id.* § 1910.1020.

During OSHA inspections of semiconductor industry sites between October 2021 and September 2022, most citations (violations) related to noncompliance with the OSHA Hazard Communication standards, followed closely by noncompliance with the Respiratory Program (OSHA, 2023).

In addition to these occupational protections, semiconductor facilities are subject to EPA regulations and other requirements relating to worker safety, public safety, and the environment. Specifically, pursuant to CAA Section 112(r), and EPA regulations at 40 C.F.R. Part 68, facilities that use more than threshold quantities of hazardous air pollutants (HAPs) are required to develop and implement a risk management program and submit a risk management plan (RMP) to EPA. The RMP must identify the potential effects of a chemical accident, steps the facility is taking to prevent an accident, and emergency response procedures. Additional laws and regulations governing the use of hazardous and toxic materials at semiconductor facilities are discussed in **Section 3.8.1.1**.

Additionally, National Fire Protection Association (NFPA) standard 318, Standard for the Protection of Semiconductor Fabrication Facilities, provides standards to safeguard facilities with cleanrooms from fire and related hazards to protect against injury, loss of life, and property damage. NFPA 318 applies to fabrication processes, including research and development areas in which hazardous materials are used, stored, and handled, and to facilities containing a cleanroom, clean zone, or both (NFPA, 2022).

3.7.1.2 Industry Health and Safety Standards

OSHA permissible exposure limits (PELs) are legal limits on the exposure of an employee to a chemical or physical hazard (e.g., noise) adopted to serve as federal standards for occupational safety and health. PELs for general industry are contained in the Z-Tables, 29 C.F.R. § 1910.1000, and were adopted from the 1968 threshold limit values (TLVs) of the American Conference of Governmental Industrial Hygienists (ACGIH) (OSHA, No Date-b). ACGIH is a private, not-for-profit, nongovernmental scientific association that develops guidelines, such as TLVs, to assist in the control of occupational health hazards (OSHA, No Date-b). TLVs represent airborne concentrations of chemical substances under which it is believed nearly all employees may be exposed daily over a working lifetime without adverse effects. ACGIH TLVs are health-based values that give no consideration to economic or technical feasibility. Therefore, ACGIH does not intend TLVs to be adopted as enforceable standards in their entirety without additional multifaceted analysis.

Most enforceable OSHA PELs were issued shortly after the adoption of the Occupational Safety and Health Act in 1970 and have not been updated since (OSHA, No Date-b). Based on the experiences of industrial professionals, new technological developments, and scientific data, many PELs are found to be outdated and inadequate for protecting worker health, which has led many technical, professional, industrial, and governmental organizations in the United States and abroad to identify alternative exposure limits, as discussed further in subsection **3.7.1.5**.

OSHA's Hazard Communication standard, 29 C.F.R. § 1910.1200, App. D, requires all chemical and material safety data sheets (SDSs) to include both the relevant ACGIH TLVs and OSHA PELs for the applicable substances on the SDS, as well as any other exposure limit for the substances that is used or recommended by the chemical manufacturer, importer, or employer preparing the SDS. OSHA has amended its regulations (i.e., annotated the Z-Tables) with selected occupational exposure limits to provide employers, workers, and other occupational safety and health stakeholders with more comprehensive exposure limits, including, most notably, the California Division of Occupational Safety and Health (Cal/OSHA) PELs and the NIOSH Recommended Exposure Limits (RELs).

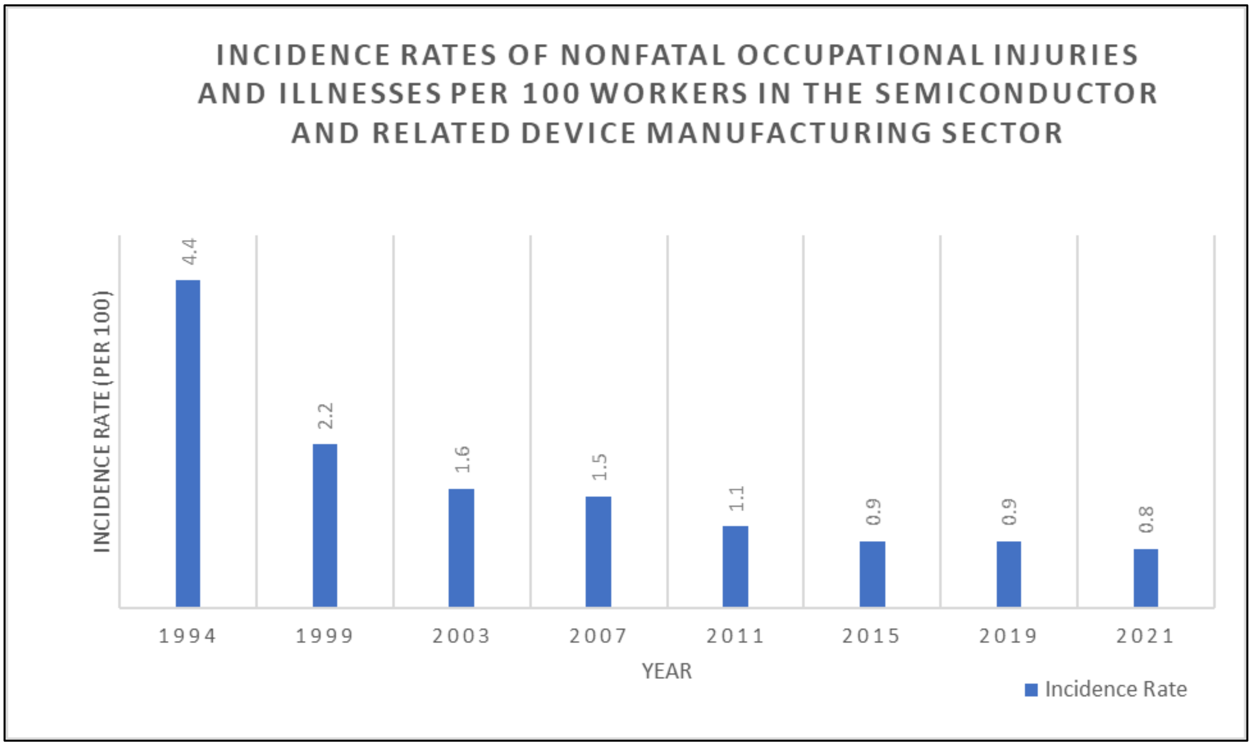
Like many other industries, the semiconductor industry has developed its own occupational safety and health hazard standards to supplement the OSHA PELs. Semiconductor Equipment and Materials International (SEMI) standard S21, *Safety Guideline for Worker Protection*, describes methods for protection against hazards that workers may encounter as they work on or around equipment used for semiconductor manufacturing. SEMI S2, *Environmental, Health and Safety Guideline for Semiconductor Manufacturing Equipment*, guides the manufacture and installation of tools for semiconductor fabrication facilities. SEMI S2 addresses environmental, health, and safety practices and incorporates several other standards, including equipment installation, gas effluent handling, exhaust ventilation, ergonomics, risk assessment, equipment decontamination, fire risk mitigation, and electrical design (SEMI, No Date). Additionally, SEMI S12, *Environmental, Health and Safety Guideline for Manufacturing Equipment Decontamination*, addresses decontaminating manufacturing equipment and parts that were or may have been exposed to hazardous materials and that are intended for further productive use. SEMI S16, *Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life*, provides design guides to minimize environmental impacts in consideration of the end of life of SME or its components.

Risk Management Measures (RMMs) practiced in the semiconductor industry are a result of numerous SEMI guidelines and collaboration between semiconductor fabricators and suppliers of process tools and chemicals. RMMs address chemical assessment, selection and control procedures, hazardous gas management systems, segregated exhaust systems, safety interlocks, and spill control and prevention (ISMI, 2006). Environmental health and safety personnel at semiconductor fabrication facilities establish PPE programs and safety protocols through hazard assessments to identify potential risks, in accordance with RMMs.

3.7.1.3 Industry Injury and Illness Rates

According to data from the U.S. Bureau of Labor Statistics (BLS), the injury and illness rate for the U.S. semiconductor industry was 0.8 cases per 100 workers per year. This is much lower than the overall incidence rate for all U.S. employees, which is 2.9 cases per 100 workers (BLS, 2021). Over the last three decades, the injury and illness rate in the semiconductor industry has steadily declined, as shown in **Figure 3.7-2**. The decline in injury and illness rates over the last 30 to 40 years is likely the result of a combination of increased regulation and regulatory scrutiny, public activism and lawsuits, development of stricter industry standards, and advances in semiconductor manufacturing technology, equipment safety features, and automation (Hicks, 2023).

Figure 3.7-2. Incidence Rates of Nonfatal Occupational Injuries and Illnesses per 100 Workers in the Semiconductor and Related Device Manufacturing Sector



Source: BLS, 2023. Notes: 1994-1999 BLS data for NAICS Code 3674; 2003-2021 data for NAICS Code 334413.

3.7.1.4 Historical Human Health Risks

Semiconductor manufacturing has a past history of causing harmful health effects to workers. In the United States, workers at California semiconductor production companies were subjected to chemical exposures, leading to a series of lawsuits in the 1990s and 2000s on the work-relatedness of employee cancers and their children's birth defects. In the mid-1980s, International Business Machines Corporation (IBM) commissioned a research project that found excess risk for brain tumor mortality among its engineers and programmers. A similar study reported that electromagnetic radiation exposure increased the risk for brain tumors, especially in design, manufacture, repair, and installation jobs (Kim et al., 2014). Exposure to ethylene glycol ethers was identified in the late 1980s as a likely cause of increased risk of miscarriages of cleanroom workers (Hecht, 1992).

3.7.1.5 Human Health and Safety Advancements

Over the past thirty years, regulators and industry have identified most of the root causes of environmental, health, and safety risks posed to broader communities located near semiconductor manufacturing facilities. EPA and other governmental authorities have since enacted more stringent storage tank regulations and monitoring requirements designed to protect human health and water supplies in the vicinity of semiconductor facilities, such as the NPDES limitations described in Section 3.6. In addition, more stringent air emission regulations applicable to the industry, such as the CAA provisions described in Section 3.5, require owners and operators of semiconductor facilities to monitor and report air emissions, including emissions of air toxics, from relevant facility sources, including the interior of fab buildings and elsewhere within the overall fab site. Further, under TSCA, EPA issues rules applicable to industry, including semiconductor manufacturers, requiring testing of specific chemicals prior to use and restricting the manufacturing, processing, distribution in commerce, use, and disposal of certain chemicals and mixtures. The Emergency Planning and Community Right-to-Know Act (EPCRA) requires facilities to provide EPA and the public with essential information about their storage and handling of hazardous and toxic chemicals that could pose environmental and safety hazards to surrounding communities. In addition to this legal and regulatory landscape, the semiconductor industry also is continuing to take steps to replace highly mutagenic and toxic materials used in the semiconductor manufacturing process with less hazardous materials.

Although these environmental laws and regulations have developed over the past few decades to address many of the risks from industrial facilities to surrounding communities, federal laws and regulations pertaining to occupational health and safety have not sufficiently advanced to address risks from industry developments and newer technology, including risks in the semiconductor industry. OSHA expressly acknowledges that many of its permissible exposure limits (PELs) are outdated and inadequate for ensuring protection of worker health. OSHA's mandatory PELs in the Z-Tables remain in effect, but OSHA specifically notes that "[i]ndustrial experience, new developments in technology, and scientific data clearly indicate that in many instances these adopted limits are not sufficiently protective of worker health" (OSHA, No Date-b). Therefore, OSHA recommends that employers consider using the alternative occupational exposure limits established in the ACGIH TLVs, NIOSH RELs, and Cal/OSHA PELs. In recognition of the inadequacy of OSHA PELs and to more appropriately provide for protection of their employees, many semiconductor employers apply the ACGIH TLVs and biological exposure indices (BEIs), NIOSH RELs, and Cal/OSHA PELs to their facility operations. Furthermore, the semiconductor industry has voluntarily adopted standards designed to provide more stringent and up-to-date exposure standards and limitations for workers. For example, SEMI S2 recommends that semiconductor facilities select the most stringent applicable occupational exposure limits (OELs) when sampling chemical emissions from manufacturing equipment.

Additional advancements incorporated by many semiconductor fabs include:

- Advanced leak detection systems in clean rooms and equipment that rapidly alert personnel and shut down equipment.
- Radiation sources in modern equipment are encapsulated to prevent exposure with detection and shutdown mechanisms and several interlocks to prevent unauthorized access.
- Chemicals are stored and delivered into the manufacturing area using secondary containment and methods to prevent personnel exposure. For example, in addition to leak detection safeguards, gases and chemicals are commonly transferred to process tools via double-walled transfer pipes, reducing the likelihood of leaks (Kreider, 2023).
- PPE has improved in recent decades to provide further worker protection (Hicks, 2023). Most semiconductor facilities require personnel to use PPE that meets or exceeds up-to-date safety and performance requirements.

Although semiconductor worker health and safety risks still exist, the industry's health and safety posture has improved over time as a result of regulatory changes, voluntary adoption of more up-to-date standards, and improvements in SME and industry processes, as evidenced in part by the declining semiconductor personnel nonfatal occupational injury and illness incidence rates shown in **Figure 3.7-2**.

3.7.1.6 Physical Hazards and Chemical Safety

Human health and safety concerns at semiconductor fabrication facilities involve physical and chemical occupational hazards. Physical hazards include ergonomic and auditory stress, slips and falls, electrostatic discharge, radiation, and pressurized source exposure (Beattie, 2021). Chemical hazards include the potential for direct and indirect exposure to hazardous materials; primarily organic solvents, acids, and metals (Kim et al., 2014).

Fabs often use engineering controls, such as totally enclosed processes, automation, and chemical delivery systems, to create barriers between workers and the process. This separation minimizes worker exposure to chemical and physical hazards. In many cases, secondary and even tertiary backup systems ensure the necessary protection will be provided if one control fails. Under normal operating conditions at state-of-the art semiconductor fabrication facilities, workers are not exposed to chemical or physical hazards due to considerable facility control measures (ISMI, 2006). Advances in robotics and automation systems also are helping to reduce safety incidents caused by human error.

As a safety precaution in cleanrooms, many facilities use systems capable of circulating cleanroom air through high-efficiency filters and replacing cleanroom air entirely with fresh outdoor air in a matter of minutes. Most fabs typically change out cleanroom air ten or more times per hour (ISMI, 2006).

In modern fabs, automated chemical delivery systems typically distribute chemicals from a remote location to their point of use. Bulk chemical delivery systems (for commonly used process chemicals) minimize handling and eliminate associated pouring and spill hazards. Processes such as etching, doping, and cleaning are carried out under appropriate fume hoods or under local exhaust ventilation to prevent dispersion into the air of dusts, fumes, mists, vapors, and gases in concentrations that could cause harmful exposure or reactivity hazards (ISMI, 2006).

Gas cabinets, specifically designed for use in the semiconductor industry, enclose and exhaust potentially hazardous leaks from gas cylinders. Gas cabinet safety features may include steel construction, self-closing doors, negative ventilation, automatic fire sprinkler systems, excess flow sensors, gas leak monitoring, and automatic shutoff (ISMI, 2006).

Semiconductor manufacturing also involves several types of process and metrology equipment that commonly use more than one type of hazardous energy. By consensus of the suppliers and users of this equipment, the industry relies primarily on SEMI S2 and other documents in the SEMI Standards “S” series that use hazardous energy control design methodologies to guide the safe design of such equipment (SEMI ICRC, 2016).

Hazardous energies in the semiconductor industry include:

- Distributed electrical (high voltages, high currents);
- Gravitational energy (suspended, hinged loads);
- Stored electrical (capacitors, batteries);
- Kinetic energy (moving robots, linear drives, gears);
- Pressurized liquids (hydraulic, pumped);
- Thermal/cryogenic energy (hot and cold temperatures);
- Compressed gases (liquefied, pressurized);
- Chemical energy (heat of reaction, toxicity);
- Electromagnetic radiation (X-ray, radio frequency (RF), infrared (IR), or ultraviolet (UV) lasers);
- Stored mechanical energy (springs, elastic seals); and
- Static magnetic fields (permanent magnets).

Accidents or exposures to hazardous energies can harm personnel, tools, the facility, and the environment. The semiconductor industry is highly automated, and few tasks are performed directly by workers during production. Modern equipment that produces hazardous energies encapsulates radiation sources in housings with leak detection sensors that can trigger an alarm and shut down equipment (Hicks, 2023). Human interaction with equipment that emits hazardous energies occurs mainly during scheduled or unscheduled downtime. Equipment must be 'locked-out' to prevent unexpected startup or re-energization when work is performed in an area subject to risk of unexpected startup or re-energization (SEMI ICRC, 2016).

Each cleanroom worker must follow strict cleanroom entry and exit procedures (Blackridge, 2023). These procedures are designed to protect workers from hazards in the cleanroom and to prevent particulate contamination of interim and final products. The protective suits worn by workers in the semiconductor industry are designed to protect the integrity of the semiconductor and its components and to also protect the workers from exposure to potentially hazardous materials (Nichols, 2016). PPE required within cleanrooms includes gloves, safety glasses or goggles, face masks or shields, body coverings such as coveralls or aprons, and safety shoes. Certain tasks may require a hardhat, respirator, skin protection, radiation protection, or hearing protection devices. Workers who commonly handle hazardous chemicals and materials in a cleanroom environment must be properly trained in chemical handling, hygiene, hazard communication, and emergency response procedures pursuant to OSHA regulations (SEMI, 2018).

Semiconductor manufacturing facilities typically have onsite industrial hygienists, safety specialists, and environmental engineers who review and approve chemicals before their purchase and ensure the existence of process-specific safety procedures. In addition, these environmental, health, and safety (EHS) professionals develop and provide chemical and safety training and review and approve all new tool and chemical infrastructure installations before startup. Where there is a potential risk of exposure to chemicals, qualified EHS staff design any manual work tasks to minimize contact with chemicals and select PPE for workers that is suitable for the tasks.

Potential hazards associated with semiconductor manufacturing processes are summarized in **Table 3.7-1**.

Table 3.7-1. Potential Hazards in the Semiconductor Manufacturing Process

Potential Hazard	Hazard Description	Associated Production Processes
Machinery and Nuisance Dust	Possible employee exposure to machinery-related hazards and nuisance dust during cutting, grinding, lapping, polishing, sanding, sorting, testing, and other process steps.	• Lithography • Backlapping and backside metallization • Dicing
Electricity	Various hazards associated with the use of high-voltage electrical equipment, including electric shocks, electrocution, fires, and explosions.	• Doping • Deposition • Metal deposition • Metal etching • Testing and quality control
Lasers	Hazards associated with the use of high energy lasers for annealing (ion implantation), marking, or scribing (causes additional vaporization hazard).	• Doping • Dicing

Potential Hazard	Hazard Description	Associated Production Processes
RF Radiation	RF is associated with induction heating and backside metallization. RF can be used as an ionizing and power source.	• Oxidation • Etching • Photoresist stripping • Doping • Deposition • Metal deposition • Backside metallization
IR Radiation	IR radiation (thermal energy or extreme heat) is emitted from molten material or furnaces.	• Oxidation • Doping • Deposition
UV Radiation	Possible exposure to UV radiation during photo exposure.	• Mask alignment and photo exposure
X-Ray Radiation	Possible employee exposure to X-ray radiation during diffraction operations, when used as a source for photo exposure, during ion implantation, or from e-beam evaporation.	• Mask alignment and photo exposure • Doping • Metal deposition
Flammable and Explosive Pyrophoric Gases and Liquids	Possible ignition of flammable, explosive, and pyrophoric gases, resulting in fire or explosion. Employees also may be exposed to gases above permissible limits.	• Oxidation • Doping • Deposition • Lithography • Alloying and annealing
Toxic, Irritative, Corrosive, and Reactive Gases and Liquids	Possible exposure to toxic, irritative, and corrosive gases and liquids and to fluorinated, chlorinated, and other reactive gases used for dry etching.	• Oxidation • Soft and hard bake • Doping • Deposition • Alloying and annealing • Passivation • Etching
Solvents	Possible exposure to solvents used during cleaning, rinsing, stripping, package labeling, or maintenance operations.	• Cleaning, rinsing, or package labeling • Lithography • Developing • Photoresist stripping • Doping • Metal deposition • Silylation • Testing
Acids and Caustic Solutions	Possible exposure to acid and caustic solutions during cleaning, caustic solutions and aerosols during developing, and acids used for wet chemical etching/stripping.	• Cleaning • Developing • Etching • Photoresist stripping

Potential Hazard	Hazard Description	Associated Production Processes
Photoresist Chemicals	Possible exposure to photoresist chemicals.	• Lithography
Thermal Burns	Possible thermal burns due to contact with hot equipment or exposure to high temperatures.	• Soft and hard bake • Doping • Deposition • Metal deposition • Alloying and annealing
Reaction-Product Residues	Potential chemical exposures to maintenance personnel working on reaction chambers, pumps, and other associated equipment that may contain reaction-product residues. Substances such as arsenic, arsine, and phosphine may be found in ion implantation equipment.	• Etching • Doping • Deposition
Metals	Possible employee exposure to various metals during evaporator cleaning and maintenance operations and to mercury from lamp rupture.	• Metal deposition • Alloying and annealing • Backlapping and backside metallization • Mask alignment and photo exposure
Noise	Possible exposure to noise above permissible limits, which could temporarily or permanently damage hearing.	• A combination of production processes can contribute to environmental noise levels.

Sources: OSHA, No Date-a; UL, 2021.

3.7.1.7 Chemicals of Concern

As discussed in **Section 3.6.1.2 (Wastewater Characterization)**, the semiconductor industry has introduced new process chemistries as technological advances have occurred. Although the semiconductor manufacturing process involves several chemicals that could have effects on human health, two categories of chemicals are of particular concern to human health.

The first category is per- and polyfluoroalkyl substances (PFAS), a group of chemicals used to make coatings and products resistant to external elements. PFAS are used in a wide range of modern semiconductor production processes, such as lithography, etching, and cleaning. In 2021, EPA released a PFAS Strategic Roadmap to characterize toxicities, understand exposure pathways, and identify new methods to avert and remediate PFAS pollution. Specific persistent, bio-accumulative, and toxic (PBT) PFAS likely will be the focus of new regulations in the coming years, based on a body of growing scientific evidence and EPA's directives to research, restrict, and remediate their use (EPA, 2021a). Under developing regulatory frameworks, EPA expects to allow the use of certain PBT PFAS in semiconductor manufacturing, if: (1) such chemicals are used in closed systems that minimize worker exposures; (2) they can be sufficiently mitigated through occupational safeguards; and (3) there will be no exposures from consumer product use (EPA, 2023j). For more information about the use of PFAS in semiconductor fabrication facilities and emerging PFAS standards, see **Appendix C**.

The second category is glycol ethers. Specifically, the semiconductor industry has undertaken efforts to replace glycol ethers due to reproductive effects associated with exposures. Glycol ethers are solvents used in etching circuit patterns on silicon wafers. Chemicals such as xylene, n-butyl acetate, acetone, and 1,1,1-trichloroethane have been used as substitutes for glycol ethers (OSHA, No Date-a).

3.7.1.8 Noise

Fabs typically have a large number of concentrated noise sources associated with high volumes of intake and circulation air required to maintain cleanrooms and complex exhaust and pollution-control systems. Sources of noise include air units, exhaust fans, cooling towers, boilers, compressed air vents, emergency generators, pumps, valves, piping, and delivery traffic. Most fabs produce continuous noise, as they usually operate on a 24-hour schedule.

Most fabs implement robust hearing conservation programs to protect workers in compliance with OSHA and other noise exposure standards. Noise abatement also is a critical component of campus design and building layout due to the sensitive nature of the manufacturing process. It is common to locate noise-generating equipment in a central utility building or separate area of the campus yard. In addition, cleanroom air systems are often housed on a separate floor, protecting workers and vibration-sensitive manufacturing processes. Engineering controls to reduce noise may include silencers, enclosures or barriers, air flow straighteners, and reduced fan speeds (Gendreau and Wu, 1999).

3.7.2 Environmental Consequences

This section analyzes the potential consequences of a project under the Proposed Action and the no action alternative on human health and safety.

3.7.2.1 Proposed Action

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of the CHIPS financial assistance, changes to the facility's chip production capacity and manufacturing processes could lead to changes to the types and volumes of hazardous materials used and stored at the facility, and to the potential hazards associated with the manufacturing process. For example, modernization projects could alter material chemistries used in the manufacturing process, increase the volume of hazardous materials used and stored at the fab, or increase potential physical hazards from installation of new SME or other machinery. CPO's evaluation of the potential human health and safety risks from a proposed project will begin with the CPO due diligence process described in **Appendix A**.

- As part of its due diligence, CPO will require the applicant to demonstrate compliance with all applicable laws, regulations, and standards relating to occupational health and safety as well as those relating to protecting surrounding communities and the public from effects of facility operations. This includes requiring the applicant to detail which health and safety standards and exposure limits (mandatory and voluntary) its facility currently follows, including those discussed in this section (e.g., OSHA PELs; ACGIH TLVs and BEIs; NIOSH RELs; Cal/OSHA PELs; SEMI standards; NFPA standards; TSCA, EPCRA, and other EPA testing, use, monitoring, and reporting requirements).
- In addition, CPO will review the applicant's compliance history for recent, current, or pending notices of violation of EHS laws or regulations or other evidence of material human health and safety incidents. CPO also will require the applicant to submit information on its total recordable

incident rate (TRIR) and injury and illness recordkeeping forms (OSHA 300 series or other, as applicable) to determine whether the applicant's facility shows evidence of ongoing health and safety risks. CPO may request copies of internal or third-party EHS audits of facility compliance.

- As applicable, CPO will require the applicant to demonstrate whether the facility has a risk management plan and has adopted appropriate risk management measures. CPO also will request information on the facility's approach to hazard communication, lock-out-tag-out procedures, selection and use of PPE (including respiratory PPE), and industrial hygiene.
- CPO will require the applicant to submit information on proposed SME purchases and plans for fab modernization re-designs to determine the extent to which modernization projects will incorporate state-of-the-art safety features, such as leak detection instruments and sensors, lock-out and shutoff mechanisms, fire protection systems, and other controls to protect worker safety.
- CPO will require the applicant to demonstrate whether its proposed new or replacement SME will meet the most up-to-date government and industry standards for safety and incorporate engineering controls, physical barriers, and other safety features to protect workers from chemical and physical hazards.
- CPO will require the applicant to provide proposed fab modernization or expansion construction plans to ensure they include relevant health and safety features and follow industry standards, and will request the applicant to detail the extent to which its project construction and equipment installation plans will involve upgrades to the lighting, ventilation, fire suppression, piping, and electrical systems, incorporate automated chemical distribution systems, and/or use new room layouts to enhance workflows.
- Finally, CPO will require the applicant to state whether it is taking any steps to address its facility's use of PFAS, glycol ethers, or other existing or emergent chemicals of concern.

Separate from the issues discussed above that CPO will address in the due diligence process, **Appendix B** includes multiple human health and safety BMPs that could be applied to proposed modernization and expansion projects. CPO notes that several of these BMPs include SEMI standards addressing EHS practices for SME installation (SEMI S2), methods for worker protection against equipment operation hazards (SEMI S21), safety performance criteria for equipment exhaust ventilation (SEMI S6), and end of life equipment decontamination and removal (SEMI 12 and SEMI S16). These standards draw upon various other recognized governmental and industry standards.

Modernization projects could increase production volumes, increase hazardous chemical use, require additional workforce, and require revised RMPs and/or additional RMMs to address new processes and orient staff in accordance with applicable occupational health and safety standards. Projects may require revisions to facility industrial hygiene plans, PPE procedures, or other increased worker protection measures to ensure that facilities maintain and continue to minimize illness and injury incidence rates. Projects also may need to update emergency plans and safety procedures developed in accordance with OSHA, EPA, NFPA, and industry standards to ensure adequate coverage in the event of hazardous exposures and other safety and health risks associated with increased production. Facilities also may need to update or adopt additional measures to restrict access to certain active areas and require increased use of lock-out/tag-out procedures or other engineering controls for newly installed SME to ensure workers are protected from chemical and physical hazards.

Summary of Effects

As discussed in **Section 2.4**, most fab modernization projects would involve expanding fab cleanroom space or upgrading, replacing, or adding new SME. The practical effects of these actions may vary, but CPO generally anticipates that modernization or expansion using CHIPS financial assistance will result in varying degrees of increased chip production capacity.

In general, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in increased human health and safety risks, particularly to fab workers, unless projects demonstrate sufficient workplace environmental, health, and safety procedures, including measures to protect against human exposure to chemical and physical hazards, or commit to appropriate BMPs or other relevant mitigation measures to augment such procedures. At a minimum, such procedures should include appropriately tailored:

- Inspections of modernized SME equipment and expanded facilities at the start-up stage;
- Chemical evaluation programs;
- Exposure assessment programs;
- Employee training programs;
- Hazard communication programs; and
- Standard operating and maintenance procedures.

CPO notes that many of the OSHA PELs are outdated and inadequate for ensuring protection of worker health. Therefore, CPO will require all proposed projects under the PEA to review all chemical occupational health and safety exposure limits (e.g., OSHA, ACGIH, NIOSH, and Cal/OSHA) and commit to apply the lowest (i.e., most protective) limit for each chemical used in its operations. CPO will incorporate this requirement as a mandatory BMP in the NEPA decision for the project and in the final award agreement between CPO and the applicant.

CPO concludes that modernization and expansion projects that demonstrate compliance with the EHS and occupational health and safety measures described above or that are undertaken with appropriate BMPs or mitigation measures, such as those listed in **Appendix B**, likely would have *temporary to permanent*, *negligible to minor*, *local* effects on human health and safety. The effects of specific projects may vary depending on the degree to which each project demonstrates it has or will implement rigorous standards, procedures, and controls in this area.

3.7.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur. Fabs would be required to continue to follow all regulations protecting worker health and safety, but existing human health and safety risks at fabs could persist in the absence of additional regulatory action or voluntary improvements. Under the no action alternative, there would continue to be *temporary to permanent*, *negligible to minor*, *local* effects on human health and safety, depending on the degree of risks already posed by existing semiconductor fab operations. Overall, the human health and safety effects of the no action alternative would represent the business-as-usual scenario for semiconductor facility health and safety practices.

3.8 HAZARDOUS AND TOXIC MATERIALS

This section analyzes the affected environment and the potential consequences of hazardous and toxic materials use for a project under the Proposed Action and the no action alternative.

3.8.1 Affected Environment

Hazardous and toxic materials used for semiconductor fabrication, if improperly stored, produced, transported, handled, or disposed of, may affect air quality, water quality, and human health and safety; these effects are also analyzed in **Sections 3.5**, **3.6**, and **3.7**, respectively. While those sections focused on the effects that certain chemical substances may have on specific resource areas, this section focuses on the general effects that may result from the storage of numerous chemical substances at semiconductor fabrication facilities. CPO has compiled in **Appendix D** a representative, non-exhaustive list of chemical substances that CPO has identified as historically or currently used at semiconductor fabrication facilities. The types of chemicals used at semiconductor fabrication facilities and their specific applications may vary among facilities.

3.8.1.1 Regulatory Framework

The following federal laws are applicable to hazardous and toxic materials used for semiconductor fabrication:

Toxic Substances Control Act

The Toxic Substances Control Act (TSCA), 15 U.S.C. § 2601 *et seq.*, authorizes EPA to regulate the production, use, and disposal of chemicals that have the potential to cause harm to human health or the environment. TSCA Section 8(b) requires EPA to compile, keep current, and publish a list of chemical substances that are manufactured or processed, including imports, in the United States for uses under TSCA. This list, known as the TSCA Inventory, plays a central role in the regulation of most industrial chemicals in the United States.

EPA maintains a TSCA Work Plan, a list of chemicals that EPA has identified for further assessment of potential hazards (EPA, 2014). With input from stakeholders and the public, EPA originally released a work plan in 2012 that identified chemicals for inclusion using a two-step process. During Step 1, EPA identified an initial group of 345 candidate chemicals that meet one or more of the following factors using a select set of data sources:

- Chemicals potentially of concern to children's health (e.g., due to reproductive or developmental effects) or used in children's products;
- Chemicals with neurotoxic effects;
- Chemicals that are persistent, bioaccumulative, and toxic (PBT);
- Chemicals that are probable or known carcinogens; and
- Chemicals detected in biomonitoring programs.

Candidate chemicals from Step 1 were screened in Step 2 using information from additional exposure and hazard data sources to produce the final 2012 Work Plan list of 83 chemicals. The Work Plan was updated in October 2014 to reflect more recent information submitted in 2012 under the Chemical Data Reporting (CDR) rule and data reported in 2011 to the Toxics Release Inventory (TRI) under EPCRA. The 2014 update included re-screening the 345 candidate chemicals identified in 2012 and resulted in the removal of 15 original chemicals and the addition of 23 chemicals, for a total of 90 chemicals in the updated Work Plan. **Table 3.8-1** below shows TSCA Work Plan chemicals that are used in semiconductor manufacturing.

The Work Plan chemicals list includes a description of the hazard, exposure, and persistence and bioaccumulation criteria met by each chemical, as well as a Hazard Score, an Exposure Score, and a Persistence and Bioaccumulation Score. Each score is a numerical ranking of either 1 (Low), 2 (Moderate), or 3 (High). EPA's TSCA Work Plan Chemicals Methods Document includes more detailed Score calculation methodology (EPA, 2012b).

The Hazard (H) Score encompasses human health and environmental toxicity concerns and was developed using readily available, authoritative data, such as data from the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS) (EPA, 2012b). To determine a chemical's overall Hazard Score, EPA assigned a hazard rank score of 1, 2, or 3 to each of ten human health and environmental toxicity categories for the chemical; the highest hazard rank score a chemical received for any category became the chemical's overall Hazard Score. The ten human health and environmental toxicity categories are acute mammalian toxicity, carcinogenicity, mutagenicity/genotoxicity (i.e., the capacity to induce genetic mutations), reproductive toxicity, developmental toxicity, neurotoxicity, chronic toxicity, respiratory sensitization, acute aquatic toxicity, and chronic aquatic toxicity.

The Exposure (E) Score represents the sum and normalization to the High-Moderate-Low scale of three sub-scores: Use Score, General Population and Environmental Exposure Score, and Release Score (limited to air, water, and non-contained land releases) (EPA, 2012b). The Use Score was calculated based on a chemical's presence and characteristics of use in consumer, commercial, or industrial products. The General Population and Environmental Exposure Score was calculated based on information from databases and peer-reviewed studies, with the highest ranking based on a chemical's presence in living organisms (humans, fish, animals, or plants) and in indoor air, house dust, or drinking water, the middle ranking based on a chemical's reported presence in two or more environmental media (e.g., outdoor air or water), and the lowest ranking based on a chemical's reported presence in one environmental medium. To calculate the Release Score, EPA used the distribution in pounds released as reported to the TRI to infer exposure potential for chemicals subject to TRI reporting. For chemicals not on the TRI, the Release Score was calculated using a method to infer exposure potential involving the chemical production volume, number of sites where the chemical is used, and the type of use.

The Persistence and Bioaccumulation (P&B) Score represents the sum and normalization to the High-Moderate-Low scale of two sub-scores: Persistence, and Bioaccumulative Potential (EPA, 2012b). Persistence was calculated using the potential half-life (i.e., the time it takes a chemical to be reduced to half of its original amount) of a chemical in air, water, soil, and sediment. Bioaccumulative Potential was calculated using bioaccumulation or bioconcentration data. When bioaccumulation or bioconcentration data were not available, EPA used modeling data from Estimation Program Interface (EPI) Suite version 4.10 to assess a chemical's potential biodegradation, hydrolysis, atmospheric oxidation, bioaccumulation or bioconcentration, and environmental partitioning.

Table 3.8-1. TSCA Work Plan Chemicals Used in Semiconductor Manufacturing

Chemical Name, CAS Number, and Use	Hazard	Exposure	Persistence & Bioaccumulation	H, E, and P&B Scores		
Antimony oxide (Sb2O3)- (and antimony compounds) 1309-64-4 Consumer industrial, including thin film deposition	• Possible human carcinogen. • Developmental and reproductive toxicity. • Acute and chronic toxicity from inhalation exposures.	• Widely used in consumer products. • Present in biomonitoring, drinking water, surface water, ambient air, and soil. • High reported releases to the environment.	• High environmental persistence. • Moderate bioaccumulation potential.	3	3	3
Methane, tetrachloro- 56-23-5 Industrial	• Probable human carcinogen.	• Used in commercial and industrial products. • Present in biomonitoring, drinking water, indoor environments, surface water, ambient air, groundwater, and soil. • High reported releases to the environment.	• High environmental persistence. • Low bioaccumulation potential.	3	3	2
Chromium oxide (and chromium compounds) 11118-57-3 Industrial, including deposition	• Known human carcinogens. • Reproductive toxicity. • Developmental toxicity. • Acute and chronic toxicity from inhalation exposures.	• Used in commercial and industrial products. • Present in ambient air. • High reported releases to the environment.	• High environmental persistence. • Moderate bioaccumulation potential.	3	1	3
Cobalt (and cobalt compounds) 7440-48-4 Industrial	• Cardiovascular and central nervous system effects. • Acute and chronic toxicity from inhalation exposures.	• Used in consumer products. • Present in biomonitoring, surface water, ambient air, and soil.	• High environmental persistence. • Moderate bioaccumulation potential.	3	3	3

Chemical Name, CAS Number, and Use	Hazard	Exposure	Persistence & Bioaccumulation	H, E, and P&B Scores		
		• High reported releases to the environment.				
Potassium cyanide (KCN) (Cyanide compounds) 151-50-8 Consumer industrial	• Neurotoxicity. • Reproductive toxicity. • Central nervous system effects.	• Widely used in consumer products. • Present in drinking water, surface water, and soil. • High reported releases to the environment.	• Moderate environmental persistence. • Low bioaccumulation potential.	3	3	2
Ferrate(3-), hexakis(cyano-.kappa.C)-, potassium (1:3), (OC-6-11)- 13746-66-2 Consumer industrial, including wet and dry etching	• Neurotoxicity. • Reproductive toxicity. • Central nervous system effects.	• Widely used in consumer products. • Present in drinking water, surface water, and soil. • High reported releases to the environment.	• Moderate environmental persistence. • Low bioaccumulation potential.	3	3	2
Ethene, 1,2-dichloro-, (1E)- 156-60-5 Consumer industrial, including miscellaneous use in fabs	• Chronic toxicity.	• Widely used in consumer products. • Present in biomonitoring, drinking water, surface water, ambient air, groundwater, soil.	• Moderate environmental persistence. • Low bioaccumulation potential.	2	3	2
Benzene, ethyl- 100-41-4 Consumer industrial, including photoresist coating	• Possible human carcinogen.	• Used in consumer products. • Present in biomonitoring, drinking water, indoor environments, surface water, ambient air, groundwater, and soil.	• Low environmental persistence. • Low bioaccumulation potential.	3	3	1

Chemical Name, CAS Number, and Use	Hazard	Exposure	Persistence & Bioaccumulation	H, E, and P&B Scores		
		• High reported releases to the environment.				
Lead (Pb) 7439-92-1 Consumer industrial, including raw material for chip fabrication	• Neurotoxicity. • Developmental toxicity. • Reproductive toxicity.	• Widely used in consumer products. • Present in biomonitoring, drinking water, indoor environments, surface water, ambient air, and soil. • High reported releases to the environment.	• High environmental persistence. • Moderate bioaccumulation potential.	3	3	3
Methane, dichloro- 75-09-2 Miscellaneous	• Probable human carcinogen.	• Widely used in consumer products. • Present in drinking water, indoor environments, ambient air, groundwater, and soil. • High reported releases to the environment.	• Low environmental persistence. • Low bioaccumulation potential.	3	3	1
2-Pyrrolidone, 1-methyl- or NMP (C5H9NO) 872-50-4 Photolithography	• Reproductive toxicity.	• Widely used in consumer products. • Present in drinking water and indoor environments. • High reported releases to the environment.	• Low environmental persistence. • Low bioaccumulation potential.	3	3	1
Phenol, isopropylated, phosphate (3:1)* 68937-41-7 Consumer industrial	• Neurotoxicity. • Aquatic toxicity.	• Widely used as a flame retardant.	• High environmental persistence. • High bioaccumulation potential.	3	3	3

Chemical Name, CAS Number, and Use	Hazard	Exposure	Persistence & Bioaccumulation	H, E, and P&B Scores		
Ethene, 1,1,2,2-tetrachloro- 127-18-4 Consumer dispersive industrial, including miscellaneous use at fabs	• Probable human carcinogen.	• Widely used in consumer products. • Present in biomonitoring, drinking water, indoor environments, ambient air, groundwater, soil. • High reported releases to the environment.	• High environmental persistence. • Low bioaccumulation potential.	3	3	2
Ethene, 1,1,2-trichloro- 79-01-6 Consumer industrial, including miscellaneous use at fabs	• Probable human carcinogen.	• Widely used in consumer products. • Present in drinking water, indoor environments, surface water, ambient air, groundwater, and soil.	• High environmental persistence. • Low bioaccumulation potential.	3	3	2
Benzene, 1,2-dimethyl- 95-47-6 Consumer industrial	• Chronic toxicity.	• Used in consumer products. • Present in biomonitoring, drinking water, indoor environments, surface water, ambient air, groundwater, and soil. • High reported releases to the environment.	• Low environmental persistence. • Low bioaccumulation potential.	3	3	1

Source: EPA, 2014. *EPA added phenol, isopropylated, phosphate (3:1) in 2014.

Emergency Planning and Community Right-to-Know Act

The purpose of the Emergency Planning and Community Right-to-Know Act (EPCRA), 42 U.S.C. § 11001 *et seq.* is to help communities plan and prepare for chemical emergencies. EPCRA and the EPCRA regulations at 40 C.F.R. Parts 350, 355, 370, and 372 require commercial and industrial facilities to report storage, usage, and releases of certain listed hazardous substances to federal, state, and local governmental authorities to improve chemical safety and protect public health and the environment. EPCRA provisions applicable to facilities include:

- **Sections 301 to 303 (Emergency Planning)** and the regulations at 40 C.F.R. Part 355, Subpart B require Local and Tribal Emergency Planning Committees (LEPCs and TEPCs) to prepare and review chemical emergency response plans. State and Tribal Emergency Response Commissions (SERCs and TERCs) are required to oversee and coordinate local planning efforts. Facilities that store extremely hazardous substances onsite in quantities in excess of applicable threshold planning quantities must cooperate with state and tribal authorities in emergency plan preparation. The list of extremely hazardous substances and their threshold quantities is codified at 40 C.F.R. Part 355, Appendix A.
- **Section 304 (Emergency Release Notification)** and the regulations at 40 C.F.R. Part 355, Subpart C require facilities to immediately report a release of any reportable quantity (RQ) of an extremely hazardous substance under EPCRA or a hazardous substance under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 U.S.C. § 9601 *et seq.* RQs for extremely hazardous substances are listed at 40 C.F.R. Part 355, Appendices A and B. RQs for CERCLA hazardous substances are listed in Table 302.4 at 40 C.F.R. § 302.4. In addition to immediately reporting any release, facilities must provide a follow-up report with additional information on response actions taken, known or anticipated health risks, and advice regarding medical attention necessary for exposed individuals, where appropriate (EPA, 2023k). SERCs, TERCs, LEPCs, and TEPCs are required to make facility reports available to the public.
- **Sections 311 to 312 (Hazardous Chemical Inventory Reporting)** and the regulations at 40 C.F.R. Part 370 require facilities to submit safety data sheets (SDSs) for each OSHA hazardous chemical that meets or exceeds reporting thresholds to the relevant SERC or TERC, LEPC or TEPC, and local fire department. Section 312 also requires facilities covered by Section 311 to submit annual emergency and hazardous chemical inventory forms under a process known as Tier II reporting.
- **Section 313 (Toxics Release Inventory (TRI))** and the regulations at 40 C.F.R. Part 372 establish a mandatory federal reporting program that tracks the release and waste management of certain listed toxic chemicals that may pose a threat to human health and the environment. Generally, chemical substances listed on the TRI are known to cause cancer or other chronic human health effects, substantial adverse acute human health effects, and/or substantial adverse environmental effects (EPA, 2023k). There are currently 770 individually listed chemicals and 33 chemical categories covered by the TRI program (EPA, 2023l). **Section 3.9** discusses the transfer and release of TRI chemicals from the semiconductor industry in more detail.

3.8.1.2 Hazardous and Toxic Material Use in Semiconductor Fabrication

Semiconductor fabrication facilities store, produce, and use numerous hazardous materials. Hazardous process chemicals commonly used in semiconductor manufacturing are categorized in **Table 3.8-1**. Modern fabs use totally enclosed processes, automated chemical delivery, gas management systems, segregated exhaust systems, safety interlocks, centralized chemical storage, and spill control and prevention measures. Process and engineering controls help prevent accidental releases (ISMI, 2006).

The semiconductor industry continues to actively research alternative chemicals that may be less hazardous or toxic to humans and the environment (EPA, 2022a). Use of more environmentally friendly or biodegradable chemicals can reduce the potential safety and environmental hazards onsite. For example, traditional solvents used in fab cleaning processes contain N-Methylpyrrolidone (NMP), which is known to cause harm to reproductive systems. Therefore, some manufacturers have begun to replace conventional solvents with NMP-free varieties (UMC, 2021). In addition, the industry is under pressure to avoid or minimize use of certain PFAS substances; some semiconductor manufacturers are researching replacements to reduce the environmental and health hazards associated with PFAS in the fabrication process (TSMC, 2022; Intel, 2023a; Samsung, 2023a). See **Appendix C** for more detailed information on PFAS use in semiconductor fabrication facilities.

This Section describes the hazardous and toxic materials used in semiconductor fabrication facilities including a description of their use within the fab process steps, such as photolithography, wet and dry etching, implant and diffusion, and cleaning (Bolmen, 1997):

- The photolithography process uses many chemicals during fabrication. Photoresists are the main set of chemicals used and consist of solvents, additives, polymers, and sensitizers. Chemical mixtures containing PFAS are used in the lithography and etching processes.
- Wet etching and cleaning processes can use strong oxidizers, including hydrogen peroxide, and acids, such as hydrofluoric acid (HF). According to a study from the Semiconductor Industry Association (SIA), an industry association for semiconductor manufacturers, the use of HF accounts for over 40 percent of the total hazardous materials produced from semiconductor manufacturing industry processes (Shen et al., 2018).
- Dry etching can use gases which can be highly toxic and highly reactive. When exposed to oxygen, highly reactive materials can cause physical hazards, such as explosions, which can also generate and release toxic materials.
- During the implantation and diffusion process, dopant materials can be added to the wafer, which may create off-gases during the process.
- Chemical mechanical planarization can use chemical slurries that typically contain particles composed of alumina, silica, and ceria, which are suspended in an acidic or basic solution (3M, 2011). Chemical slurries can be corrosive, reactive, and/or toxic, depending on their composition.
- Wafer cleaning can involve strong acids and oxidizer mixtures to clean organic materials from the wafer surface.

Raw materials used in semiconductor manufacturing are discussed in **Section 2.2.3**. Hazardous raw materials include silicon (flammable), gallium arsenide and lead (toxic), phosphorous (spontaneously combustible), and spin-on glass (flammable and combustible).

Table 3.8-2 summarizes frequently used hazardous process chemicals according to their hazard class, based on the International Sematech Manufacturing Initiative (ISMI) Guideline for Environmental Characterization of Semiconductor Process Equipment.

Table 3.8-2. Hazardous Process Chemicals Used in Semiconductor Manufacturing

Chemical Category	Use(s)	Process Chemical	Hazard Class
Aqueous solutions (commonly acids and bases)	To wet-etch or clean the surface of the wafer; as part of the photolithography process.	Hydrochloric acid, HF, sulfuric acid, nitric acid, ammonium hydroxide, potassium hydroxide	8 Corrosive Material
		Ammonium fluoride	6.1 Poisonous Materials
		Hydrogen peroxide	5.1 Oxidizer
Specialty gases	As precursors to deliver a substance such as arsenic or tungsten onto the wafer or into the silicon lattice (used in small quantities); to dry-etch a pattern onto the surface of the wafer.	Silane	2.1 Flammable Gas
		Ammonia, nitrogen trifluoride, sulfur hexafluoride	2.2 Non-Flammable Compressed Gas
		Ammonia, phosphine, tungsten hexafluoride, arsine, CO, fluorine, chlorine, diborane	2.3 Poisonous Gas
Organic compounds (commonly solvents)	As constituents in specialty chemicals; to clean the wafer; as part of the photolithography process.	Isopropanol, xylene, propylene glycol ethers, acetone	3 Flammable and Combustible Liquid
Metallic compounds	Applied to the wafer in specific locations to create transistors; to plate wafers to provide electrical connections.	Copper sulfate	9 Miscellaneous Hazardous Material

Sources: ISMI, 2006; 49 C.F.R. Part 172; EPA, 2022a.

3.8.2 Environmental Consequences

This section analyzes the potential consequences of hazardous and toxic materials use at semiconductor fabrication facilities for a project under the Proposed Action and the no action alternative.

3.8.2.1 Proposed Action

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of the CHIPS financial assistance, changes to the facility's chip production capacity and manufacturing processes could lead to changes to the types or quantities of hazardous and toxic materials used or stored at the facility.

CPO's evaluation of the potential hazardous and toxic materials risks from an applicant's proposed project will begin with the CPO due diligence process described in **Appendix A**. As part of its due diligence, CPO will require the applicant to demonstrate compliance with all applicable laws, regulations, and standards relating to occupational health and safety, including any EPCRA Tier II reporting requirements applicable to the proposed project facility's storage of extremely hazardous substances. CPO also will require the applicant to demonstrate that its facility has an appropriate emergency chemical response plan in place and is prepared to work with state, tribal, and local emergency planning committees in the event of any release. In addition, CPO will require the applicant to state whether its facility has recently experienced any chemical release incidents and issued any emergency release notifications and/or follow-up reports to relevant authorities.

Proposed project modernization and expansion activities likely would require temporary onsite storage and use of hazardous materials, such as diesel fuel, welding gases, paint, adhesives, thinners, and solvents, all of which could increase the risk of accidental releases. Accidental leaks and discharges from equipment or through material handling and transfers could be reduced through adherence to facility EHS plans requiring spill monitoring to avoid, detect, and clean up spills. Facilities may have trained EHS personnel and established plans in place for hazardous material monitoring, safe storage, and spill mitigation. Fabs with adequate procedures in place could immediately contain spills of hazardous material and safely dispose of wastes in accordance with federal, state, and local laws and regulations.

Overall, modernization and expansion projects could result in increased potential for releases of hazardous and toxic materials. Some of the materials currently used heavily in fab operations, such as HF, are critical process materials without readily available alternatives. Increased production capacity at project facilities could increase output of materials such as HF and hazardous materials generated by their use. In addition, increased demand for raw materials could increase hazardous material production and transport by suppliers, indirectly increasing the potential for release incidents if storage and handling requirements are not properly followed.

Separate from the issues discussed above that CPO will evaluate in the due diligence process, **Appendix B** includes hazardous and toxic material BMPs that could be applied to proposed modernization and expansion projects. These include measures such as updating facility spill prevention, control, and countermeasure plans, installing and maintaining hazardous chemical leak sensors and alarms, and installing fixed gas detection systems used to monitor for safety of fab personnel and the local community and environment. Automated chemical delivery systems and other engineering controls, such as those discussed in **Section 3.7**, could reduce the potential for incidents. Recent sustainability reports from semiconductor manufacturers emphasize goals to improve source reduction and the reuse of hazardous materials (TSMC, 2023; UMC, 2021). Modernization projects that enable tool or process innovation could allow for enhanced reduction, reuse, and recycling of hazardous or toxic substances as compared to current conditions. In addition, process innovation could lead to procurement of materials that are safer and more sustainable (Samsung, 2023b). According to EPA's TRI Toxics Tracker, process and equipment modifications were the most common category of source reduction activities in semiconductor and related device manufacturing from 2013-2022 (EPA, 2023m).

Summary of Effects

As discussed in Section 2.4, under the Proposed Action, most fab modernization projects would involve expanding fab cleanroom space or upgrading, replacing, or adding new SME. The practical effects of these actions may vary, but CPO generally anticipates that modernization or expansion using CHIPS financial assistance will result in varying degrees of increased chip production capacity.

In general, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in increased generation of hazardous and toxic materials, as some materials critical to the fabrication process, such as HF, do not have readily available alternatives. Projects may add new chemistries to the manufacturing process, which also could generate new hazardous and toxic materials. Accordingly, the risk of hazardous and toxic material releases at semiconductor fabs will always be present, and projects may need to commit to appropriate safeguards or BMPs to plan and prepare for these risks.

CPO concludes that modernization and expansion projects undertaken that demonstrate commitment to the safeguards described above or that are undertaken with appropriate BMPs, such as those listed in **Appendix B**, likely would have *temporary to short term*, *negligible to minor*, *local* adverse effects in the event of a release. Specific projects that maximize use of automated chemical delivery systems and chemical and gas leak detection and shutoff systems may have comparatively reduced effects.

3.8.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur. In this scenario, the types and amounts of hazardous and toxic materials used at a facility would not increase, but the potential risks of their release would remain. Under the no action alternative, there would continue to be the risk of *temporary to short term*, *negligible to minor, local* adverse effects in the event of a material release incident.

3.9 HAZARDOUS AND SOLID WASTE MANAGEMENT

This section analyzes the affected environment and the potential consequences of hazardous and solid waste management for a project under the Proposed Action and the no action alternative.

3.9.1 Affected Environment

Semiconductor fabrication facilities generate both hazardous and nonhazardous solid waste that require proper management under the Resource Conservation and Recovery Act (RCRA), 42 U.S.C. § 6901 *et seq.* Solid waste includes garbage or refuse and other discarded material resulting from industrial and commercial operations. 40 C.F.R. § 261.2. Solid waste encompasses more than physically solid materials and includes waste in liquid, semi-solid, and contained gas form. Hazardous waste is a subset of solid waste that either (1) exhibits hazardous characteristics (ignitability, corrosivity, reactivity, or toxicity) that pose a substantial threat to human health or the environment or (2) is listed as hazardous waste under RCRA. 40 C.F.R. § 261.3.

3.9.1.1 Regulatory Framework

Federal laws and regulations that govern solid and hazardous waste management include:

- RCRA Subtitle C establishes a system for controlling hazardous waste from the time it is generated until its ultimate disposal (i.e., from "cradle to grave").
- The RCRA hazardous waste generator regulations at 40 C.F.R. Part 262 establish criteria for the identification of hazardous waste and standards for hazardous waste generators. Generators are classified as very small quantity generators (VSQGs), small quantity generators (SQGs), or large quantity generators (LQGs) based on how much waste they generate each month. Federal regulations require large and small quantity generators of hazardous waste to obtain an EPA Identification (EPA ID) number. Generators also are subject to onsite accumulation quantity, time limit, and management requirements, as well as requirements for personnel training, emergency

planning, container emissions, land disposal restrictions, closure, waste minimization, packaging and labeling, tracking, reporting, and recordkeeping.

- RCRA Subtitle D regulates the disposal of non-hazardous solid waste and sets minimum federal criteria for municipal waste and industrial waste landfills, including design, location restrictions, financial assurance, corrective action, and closure requirements. It also encourages states to develop comprehensive plans to manage nonhazardous industrial solid waste and municipal solid waste.
- State hazardous waste programs, authorized under RCRA, may have more stringent requirements than federal requirements for the storage, treatment, transport, and disposal of solid waste.
- Section 6607 of the Pollution Prevention Act of 1990 (PPA) requires data on source reduction activities and waste management via TRI reporting.
- The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as the Superfund law, addresses the cleanup of hazardous waste sites and chemical spills that pose a threat to public health and the environment. The law empowers EPA to remediate contaminated sites and holds responsible parties accountable for cleanup costs.

3.9.1.2 Historic Site Contamination

The semiconductor industry has a history of site contamination. For example, after a 1979 spill of 4,100 gallons of 1,1,1-trichloroethane (TCA) at IBM's Endicott facility in New York, groundwater testing revealed extensive contamination from previous releases, including carcinogenic trichloroethylene (TCE) and tetrachloroethylene (PCE). The toxic plume contaminated soil and groundwater onsite and caused soil vapor intrusion in structures offsite. Adverse health impacts included cancer and birth defects (Forand et al., 2012). TCE was heavily used in the production of semiconductors and is the main toxin in 23 Santa Clara County Superfund sites (Nieve, 2018). TCE has been phased out due to health and environmental concerns.

3.9.1.3 Waste Management

Solid waste generated by semiconductor fabrication facilities can be categorized as either hazardous or nonhazardous waste. In modern facilities, solid nonhazardous and hazardous waste is minimized at the source, then segregated, reused, recycled, or disposed of (ISMI, 2021). Nonhazardous waste includes plastic waste, metal waste, kitchen waste and general office waste (Intel, 2019). Hazardous waste includes acids, solvents, copper sulfate, and containers (UMC, 2021). Filters from hoods and local exhaust ventilation systems, sludge from scrubbers or wastewater treatment, and E-waste from semiconductor fabrication (electronic components such as defective chips or circuits) also are sources of hazardous waste.

EPA's *National Biennial RCRA Hazardous Waste Report* tracks the generation, management, and disposal of hazardous waste by LQGs. LQGs under Semiconductor and Related Device Manufacturing, NAICS Code 334413, reported disposal of approximately 116,000 tons of hazardous waste in 2021 (EPA, 2021b). This accounted for 0.32 percent of hazardous waste generated in the United States in 2021 (EPA, 2021c).

Progressive Waste Management

Solid waste generated from semiconductor fabrication and related facility operations can be managed through reuse, recycling, recovery, storage, treatment, or disposal. Generally, facility solid waste is transported offsite, where it is managed by a series of service providers that include waste transporters, waste handlers, and waste treatment, storage, and disposal facilities (Jones, 2021). However, liquid waste requires treatment to remove solids prior to disposal (Veolia, 2023). Solvent and metal collection systems are used to segregate untreated liquids. Many liquid wastes can be neutralized, recycled, or reclaimed. When treatment is not possible (e.g., some solvents), spent chemicals are collected and shipped to vendors for purification and reuse or to permitted treatment and disposal facilities (ISMI, 2021).

Many semiconductor companies have circular economy initiatives that aim to increase recycling and decrease generation of hazardous waste (Intel, 2021; Intel, 2023a; Nikon, 2023; Samsung, 2020; UMC, 2021). For example, Intel reported recycling 85 percent of hazardous waste generated in 2022. Hazardous waste was 42 percent of its total waste generated; recycling increased by 15 percent and generation decreased by 13 percent from 2021 (Intel, 2023a).

Modernization projects that enable equipment or process innovation could allow waste recycling and reuse to replace or minimize the need for incineration or landfill disposals associated with current manufacturing processes. For example, the Samsung fabrication facility in Austin, Texas, earned a Gold-level Zero Waste to Landfill validation from Underwriters Laboratory (UL), a global safety agency, by applying new technology and shifting waste streams (Samsung, 2020). Sustainability improvements through the modernization of equipment and fabs could eliminate or reduce certain solid waste streams through new and improved technology that allows source reduction, reuse, recovery, and closed-loop recycling. Most major semiconductor fabrication companies have set aggressive goals to divert most of their hazardous and solid waste from landfills, benefiting both their profit margins and the environment.

Solid waste also can include obsolete, old, or unusable semiconductor manufacturing tools that could be reused, recycled, or landfilled. Tools could be reused if they are refurbished and sold. For example, Nikon has been buying and refurbishing old lithography equipment for close to 20 years. Nikon has been able to resell 449 systems, reducing landfill waste by 4,100 tons (Nikon, 2023). Tools could be disassembled to sell or recycle parts. According to Intel's 2022-2023 Corporate Sustainability report, more than 1,000 tools and 755,000 parts were harvested for reuse (Intel, 2023a). Examples of equipment used in the semiconductor industry that may need to be disposed and could be recycled include (Singh et al., 2023):

- photolithography tools;
- etch and clean systems;
- deposition and implantation machines;
- diffusion machines for thermal treatments;
- process control equipment;
- wafer handling tools; and
- planarization tools.

Many semiconductor fabricators have invested in new technologies to reuse and recover materials, such as metals and solvents, from their processes (Shen et al., 2018). **Table 3.9-1** summarizes semiconductor manufacturing waste streams with potential for progressive management methods.

Table 3.9-1. Traditional and Progressive Waste Management Methods of Major Semiconductor Manufacturing Waste Streams

Manufacturing Waste Stream	Traditional Disposal Methods	Progressive Management Methods
Ammonium sulfate	Wastewater treatment	Fertilizer manufacturing
Calcium fluoride	Landfill; cement kiln recycle	Cement product; cement kiln recycle

Manufacturing Waste Stream	Traditional Disposal Methods	Progressive Management Methods
Lithography-related solvents	Fuel blend	Cyclohexanone recovery; paint thinners
Metal plating waste	Landfill; wastewater treatment	Metal recovery
Specialty base cleaners	Incineration	Water recovery; organic high BTU fuel
Spent sulfuric acid	Wastewater treatment; stabilize and landfill	Recovery offsite

Source: Intel, 2019.

Releases of TRI-Listed Chemicals that Include Chemical Waste

TRI reports are a means to quantify the amount of certain chemicals that move from a facility to offsite locations as chemical waste. Under EPA's TRI program, facilities meeting certain employee, industry sector (NAICS Code), and chemical threshold criteria must annually report under EPCRA Section 313.

Semiconductor fabrication facilities covered under NAICS Code 334413, Semiconductor and Related Device Manufacturing, are required to report if the facility has 10 or more full time employees and it manufactures, processes, or otherwise uses more than a threshold amount of a TRI-listed chemical.

Industrial facilities report how they are managing chemical waste through:

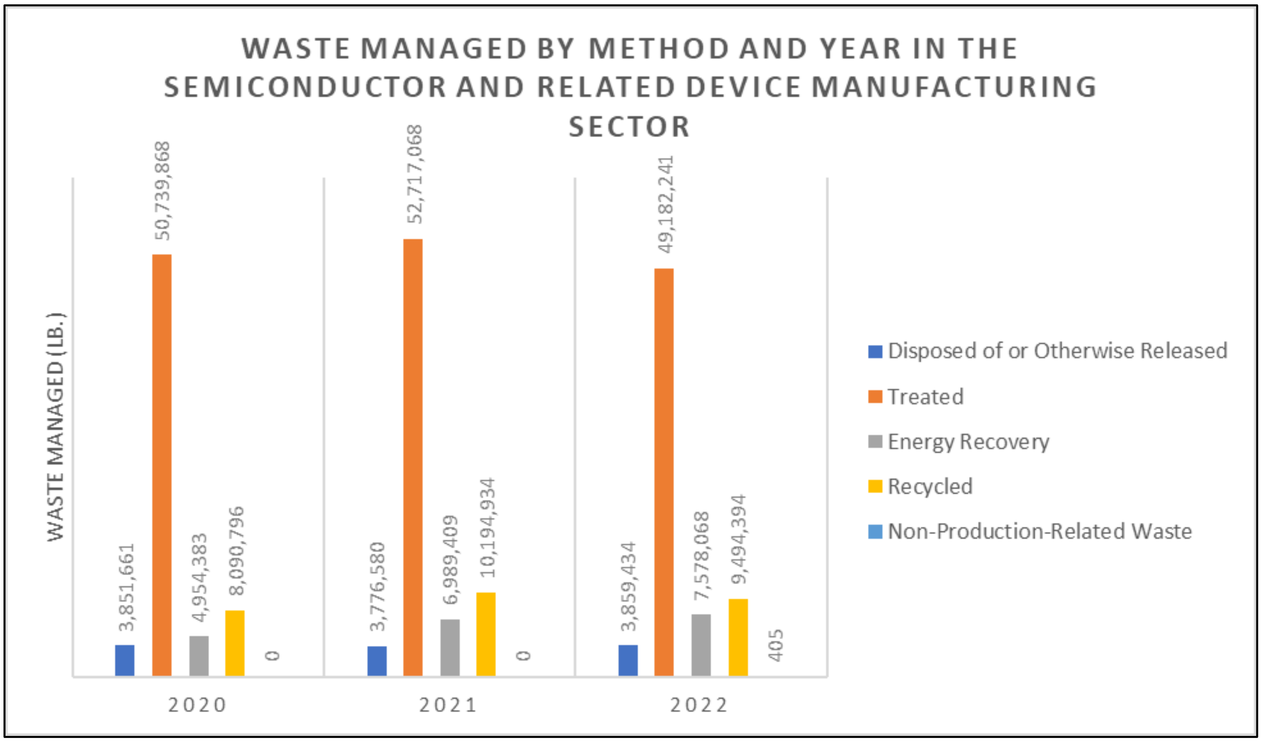
- Environmental releases (into the air, water, and land);
- Recycling;
- Energy recovery;
- Treatment; and
- Disposal.

Additionally, facilities report to EPA how they are reducing the amount of chemical waste that enters the environment and/or how they are preventing waste from being created in the first place.

The term "release" is defined broadly under EPCRA, RCRA, and CERCLA. Onsite releases to the environment include spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing. "Release" also includes transfer of TRI-listed chemicals to offsite facilities for the purposes of recycling, energy recovery, treatment, or disposal (EPA, 2023p). Except for offsite transfers for disposal, these amounts do not necessarily represent entry of the chemical into the environment.

Figure 3.9-1 shows the waste managed by method and year for NAICS code 334413. Under this sector, facilities largely treat their waste on- or offsite rather than dispose or recycle it. In 2022, approximately 70 percent of all managed TRI wastes were treated (EPA, 2023m). In 2022, more waste was managed through recycling and energy recovery than in 2020.

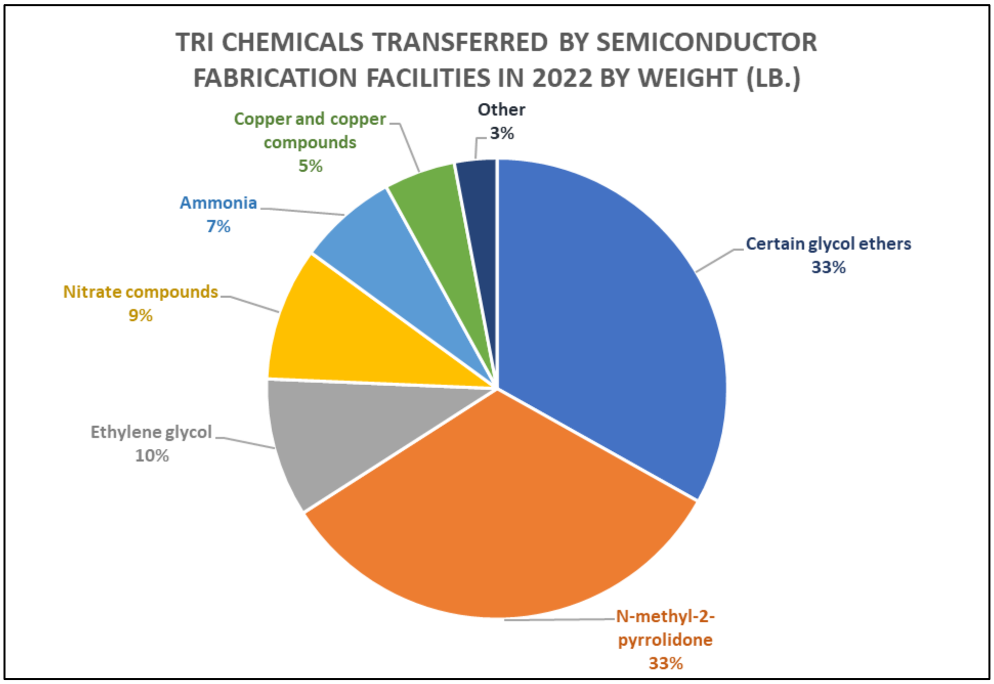
Figure 3.9-1. Waste Managed by Method and Year in the Semiconductor and Related Device Manufacturing Sector



Source: EPA, 2023m. Note: TRI data under NAICS 334413 is not limited to semiconductor fabrication facilities.

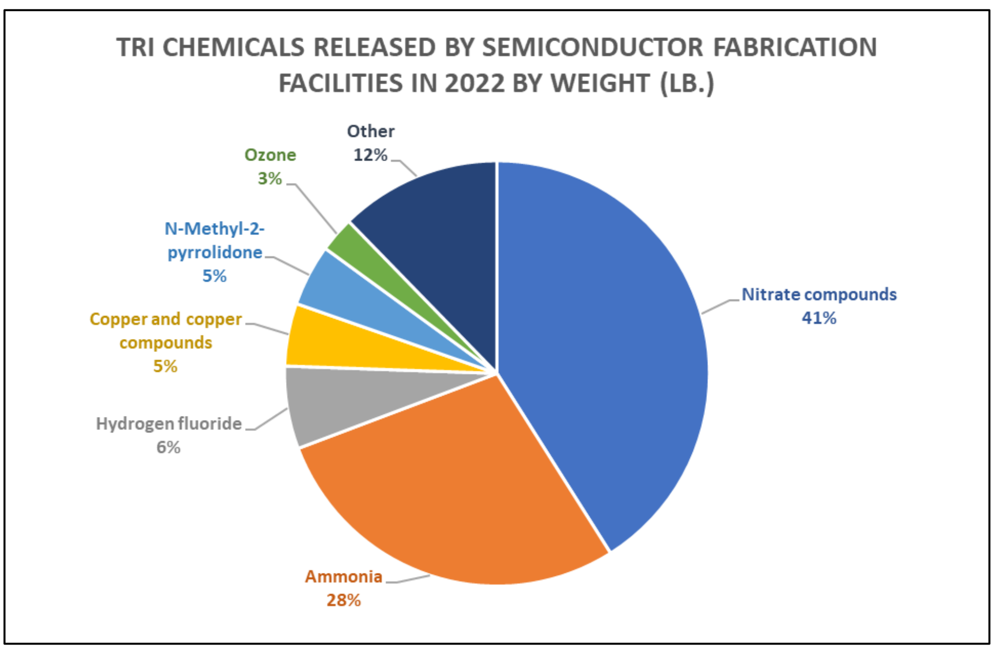
Figures 3.9-2 and **3.9-3** show the primary chemicals from semiconductor fabrication facilities that were transferred and released, respectively, based on TRI reports from 2022. TRI reports were filtered to include semiconductor fabrication facilities that fall under the Semiconductor and Related Device Manufacturing Sector (NAICS Code 334413). Facilities whose industrial activity could not be confirmed were filtered out. The 65 U.S. semiconductor fabrication facilities that were analyzed transferred approximately 18 million pounds of TRI chemicals to offsite disposal, storage, or recovery facilities. These fabrication facilities released approximately 2.5 million pounds of TRI chemicals to the environment (EPA, 2022c).

Figure 3.9-2. TRI Chemicals Transferred by Semiconductor



Source: EPA, 2022c.

Figure 3.9-3. TRI Chemicals Released by Semiconductor Fabrication Facilities in 2022 by Weight (lb.)



Source: EPA, 2022c.

EPA's Risk-Screening Environmental Indicators (RSEI) model compiles TRI data and other information and provides relative comparisons of potential health-related impacts from reported toxic chemical waste management activities. RSEI Hazard, also called toxicity-weighted pounds, is a descriptor of relative potential harm to human health and consists of the pounds of a chemical released to the environment or transferred off site, multiplied by the chemical's toxicity weight. The main types of chemicals with high RSEI Hazard values that were transferred or released by semiconductor fabrication facilities in 2022 include heavy metals and heavy metal compounds, chlorine, sulfuric acid (acid aerosols), and hydrogen fluoride (EPA, 2022c; EPA, 2023m).

3.9.2 Environmental Consequences

This section analyzes the potential consequences of hazardous and solid waste management at semiconductor fabrication facilities for a project under the Proposed Action and the no action alternative.

3.9.2.1 Proposed Action

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of the CHIPS financial assistance, changes to the facility's chip production capacity and manufacturing processes could lead to changes to the facility's hazardous waste and solid waste management through changes in the types and amounts of waste generated that would need to be managed.

Modernization and expansion project activities could require building more cleanroom space or installing supporting infrastructure, which could cause a temporary increase in the generation of nonhazardous solid waste. This nonhazardous waste could include cardboard, plastic, aluminum, metals and wallboard. The volume of waste could be reduced by separating construction waste and instituting a comprehensive recycling program.

Construction activities could require onsite use and temporary storage of hazardous materials, which could increase the risk of an accidental spill at the facility, resulting in additional waste generation. However, BMPs as described in **Appendix B** could be implemented to reduce the likelihood of spills.

Fab modernization could involve replacing equipment that is obsolete, less capable, and less efficient to operate and maintain. Obsolete, old, or unusable semiconductor manufacturing tools could be reused, recycled, or landfilled. Tools could be reused if they are refurbished and sold. Tools also could be disassembled to sell or recycle parts. In some cases, tools or parts thereof may need to be landfilled. To satisfy the federal, state, and local regulations, decommissioned tools may need to be properly decontaminated. If decontamination and end-of-life disposal is required, facilities should uphold industry standards and safety guidelines, as described in **Appendix B.** Tools and parts discarded under the Proposed Action may meet the definition of RCRA "hazardous waste" and require treatment as such.

SEMI publishes standards for decontamination, recycling, and reuse of manufacturing equipment. SEMI S12 and S16 can provide guidance on how to best reduce the environmental effects associated with equipment disposal (SEMI, 2023).

A proposed project involving expansion and fab modernization at an existing fab that increases production would likely generate more hazardous and nonhazardous waste. Increased hazardous waste production may cause a SQG to be reclassified as a LQG if the facility exceeds state or federal quantity limits. LQGs are subject to more stringent standards for waste storage, handling, reporting, and contingency planning. However, personnel at SQG facilities may be experienced with many aspects of RCRA compliance, allowing them to efficiently build on existing requirements to meet stricter LQG standards.

The facility may require more space for waste storage and adjusted disposal timelines. Since most fabrication facilities rely on waste management services, facility waste managers would need to ensure their local providers can meet changing facility needs. A facility may need to ship waste further if it exceeds local waste management capacity. As stated in **Section 3.9.1** above, the LQGs in the Semiconductor and Related Device Manufacturing sector generated approximately 116,000 tons of hazardous waste, or 0.32 percent of hazardous waste generated in the United States in 2021 (EPA, 2021b). U.S. semiconductor fabrication facility hazardous waste therefore would remain a small percentage of the total hazardous waste produced annually nationwide, even if a large number of fabs were to increase the amount of hazardous waste they generate. In addition, the Semiconductor and Related Device Manufacturing sector treats approximately 70 percent of managed TRI wastes, reducing the need for disposal (EPA, 2023m). Additional hazardous wastes generated by a proposed project facility would connect to existing waste streams and require similar management already in place at the facility.

Under the Proposed Action, semiconductor fabrication facility modernization and expansion projects are expected to cause minor increases in hazardous and solid waste volumes from associated construction, equipment disposal and replacement, and increased production. However, modernization could include waste treatment technology improvements that could potentially reduce the amounts of hazardous and solid waste generated long-term to offset increases in production. CPO would evaluate each applicant's waste management compliance history as described in **Appendix A** and may require an applicant to adopt BMPs such as those in **Appendix B**, where appropriate, that would reduce waste generation.

Summary of Effects

As discussed in **Section 2.4**, under the Proposed Action, most fab modernization projects would involve expanding fab cleanroom space or upgrading, replacing, or adding new SME. The practical effects of these actions may vary, but CPO generally anticipates that modernization or expansion using CHIPS financial assistance will result in varying degrees of increased chip production capacity.

In general, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in increased generation of hazardous and solid waste. CPO concludes that modernization and expansion projects likely would have *negligible to minor* adverse environmental effects from hazardous and solid waste generation. Specific projects that implement new facility measures to reduce, reuse, and recover materials, thereby diverting waste from landfills, may have potentially beneficial effects. Modernization and expansion projects undertaken with appropriate BMPs, or that demonstrate adequate waste management practices, likely would be better equipped to manage and dispose of hazardous and solid waste in line with their existing generator category or take on additional responsibilities under a new generator category, if required.

3.9.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur. In this scenario, increased hazardous and nonhazardous waste generation likely would not occur. Accordingly, the no action alternative likely would have no new environmental effects from the generation of hazardous and solid waste.

3.10 UTILITIES

This section analyzes the affected environment and the potential consequences of utilities usage at semiconductor fabrication facilities, including electricity, natural gas, and water, for a project under the Proposed Action and the no action alternative.

3.10.1 Affected Environment

Semiconductor manufacturing processes consume substantial amounts of energy and water, as discussed below and in **Section 2.2.3**. However, semiconductor manufacturers also are pursuing practices and projects to make their operations more sustainable by reducing energy and water use (TSMC, 2023; UMC, 2021; Samsung, 2023a; Global Foundries, 2023; Intel, 2023a; Texas Instruments, 2022).

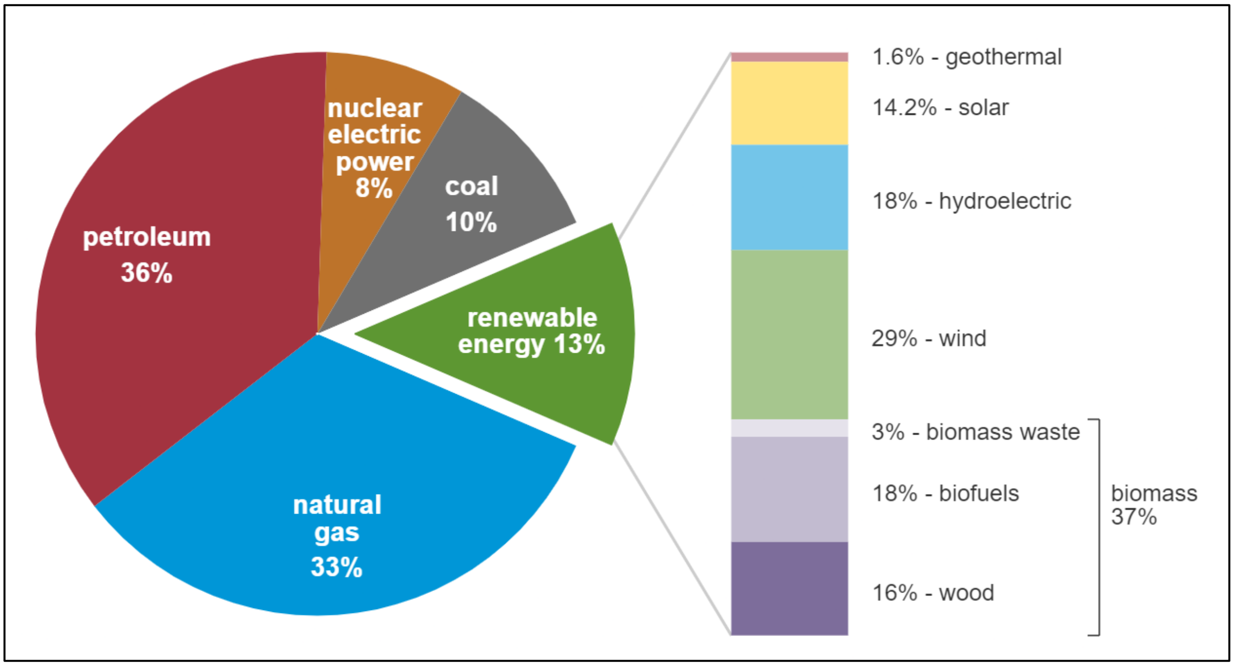
3.10.1.1 Energy Use

Semiconductor fabrication relies heavily on energy for various processes and support equipment, with lithography, etching, and deposition being particularly energy intensive. Cleanrooms also demand energy for air circulation, temperature control, and contamination prevention. Despite differing energy needs across facilities, a median usage of approximately 2.74 million MWh was reported in 2021, highlighting the critical reliance on consistent power to avoid disruptions and semiconductor wastage. Such issues can be addressed through uninterruptible power supplies (UPS) that bridge power gaps during outages (Wang et al., 2023a).

The majority of energy used during semiconductor fabrication is to power manufacturing process equipment, air conditioning systems for cleanrooms, and air handling equipment, such as compressors, exhaust fans, and chillers. The high ventilation rates needed to achieve the air purification required in cleanrooms can be 30 to 50 times more energy intensive than air handling systems in an average commercial building. The air conditioning systems for cleanrooms can consume about 30 to 65 percent of total energy used in a semiconductor fabrication facility (Yin et al, 2020). Maintaining an ultra-clean environment in a cleanroom requires temperature and humidity controls that also can be energy intensive. Lithography, etching, ion implantation, and deposition tools have high power requirements and may be run continuously with little idle time.

Approximately 83.7 percent of total semiconductor facility energy use is primarily sourced from offsite energy resources, including through public power utilities (Wang et al., 2023a). As of 2022, coal- and natural gas-fired power plants continue to generate the majority of electricity for public utilities. **Figure 3.10-1** shows the nationwide distribution of energy sources as of 2022.

Figure 3.10-1. Nationwide Energy Source Distribution in 2022



Source: EIA, 2023. Note: Sum of components may not equal 100 percent because of independent rounding.

Among states with existing semiconductor fabrication facilities, public utilities have highly variable energy generation portfolios. As of 2022, states with existing semiconductor fabrication facilities had carbon pollution-free electricity (CFE) generation ranging from 5.6 percent in Delaware to 99.6 percent in Vermont (EIA, 2024a). Nationwide, states with low CFE generation are on track to increase the share of renewable energy in public utilities, including Delaware, which has mandated a minimum 40 percent of electricity come from renewable sources by 2035 (EIA, 2024b).

Individual facilities where public utilities provide low-share CFE can supplement their net annual CFE by purchasing CFE from specific utility providers, acquiring energy attribute certificates (EACs), and through the onsite generation of CFE. EACs must be bought from sources that produce CFE within the same grid region as the facility. Examples of onsite CFE generation include solar panels, wind turbines, geothermal generators, and electrical energy generation from fossil resources to the extent there is active capture and storage of carbon dioxide emissions that meets EPA requirements. Currently, onsite electricity generation among semiconductor fabrication facilities is primarily fossil fuel combustion (12 percent of total energy usage) with renewable (2.7 percent), or other sources (1.7 percent) lagging far behind (Wang et al., 2023a). For the modernization of facilities, adding onsite renewable energy sources is beneficial for reducing dependence on fossil fuel energy. Modern photovoltaic solar panels with an efficiency of 20 percent produce approximately 18.6 watts per square foot (e.g., a 1.0 million square foot facility in an area of five hours per day annual sunlight could produce 33,900 MWh annually). In comparison, the average 2.5 to 3.0-megawatt (MW) onshore wind turbine produces 6,000 MWh per year depending on wind power class (Inspire Clean Energy, 2020).

Semiconductor manufacturers are taking significant steps to move to a 100 percent renewable energy future. Intel, for example, is working towards 100 percent renewable energy for its global operations by 2030 and towards achieving net zero GHG emissions by 2040 (Intel, 2023b). In addition, Taiwan Semiconductor Manufacturing Company has announced plans to accelerate its 100 percent renewable energy commitment by a decade, moving its target from 2050 to 2040, while also raising its 2030 target for company-wide renewable energy consumption from 40 to 60 percent (TSMC, 2023). In 2022, one U.S. semiconductor fabrication facility achieved 100 percent renewable electricity using solar hot and cooling water systems, geothermal energy, micro wind turbine systems, and solar parking lot canopies, among other technologies (Infineon, 2024).

Semiconductor fabrication facilities also may use a strategic energy management practice that focuses on continuous improvements, performing more efficiently, and reducing energy use over time. EPA offers energy management guidance through ENERGY STAR Guidelines. ENERGY STAR Guidelines are provided by a public-private partnership between EPA and non-governmental organizations to deliver cost-saving energy efficiency solutions that protect the climate, improve air quality, and protect public health. ENERGY STAR's energy management program for industrial plants is a five-step guide that recommends facilities: (1) identify potentially missing energy management practices; (2) fill gaps with energy management guidance following ENERGY STAR Guidelines; (3) build an energy team; (4) raise awareness and engage sites; and (5) advance the energy program (ENERGY STAR, No Date).

The implementation of specific energy-efficient equipment and practices can reduce total facility energy usage. For example, Intel has completed more than 2,000 energy conservation projects in the last decade, saving 4.5 million MWh (Intel, 2020). The company has introduced several practices leading to greater energy efficiency and reducing energy intensity, namely:

- **Chillers:** Chillers are necessary for semiconductor fabrication in various processes because of the criticality of thermoregulation. Chillers work as heat-exchangers, cooling specific processes while heat is produced as a byproduct. Some chillers use water as their heat exchanger in conjunction with cooling towers to remove excess heat. In addition to reducing the load on cooling towers, the heat generated by chillers can be directed to cleanroom air, potentially reducing the fossil fuel used in boilers by over 30 percent. Chillers can be converted from fixed pumps to new variable flow systems, which can reduce pump energy use on average by 20 percent (Intel, 2020).
- **Heat Pumps:** Due to the temperature needs of semiconductor fabrication, traditional heat pumps are unable to heat water to sufficient temperatures. Thus, the introduction of new, high temperature heat pumps could replace outdated, fossil fuel boiler systems (Intel, 2020). Heat pumps are significantly more efficient than boilers as the coefficient of performance (COP) for a heat pump is between 3 and 5 (i.e., it can transfer 300 to 500 percent more energy, in the form of heat, than it consumes, or it produces 3 to 5 kW of heat for every 1 kW of electrical input) whereas a boiler has a COP of 0.90 to 0.94 (Johnson Controls, 2021).
- **Dry Systems and Compressors:** Semiconductor fabrication relies on the use of clean, dry air produced by dryer systems and compressors. Typically, compressing air results in a loss of over 80 percent of the energy as heat. Using a centralized heat recovery system with variable frequency compressors can improve energy performance by 20 percent (a variable frequency compressor can save energy compared to a fixed speed compressor). It is possible to use the recovered heat for other processes that require heat (Intel, 2020).
- **Integrated Sensors:** Integrating sensors into equipment and controlled-condition spaces can provide real-time data to enable further optimization of energy use and thus improve energy efficiency (Intel, 2020).

To ensure continuation of operations during electrical grid outages or disruptions, semiconductor fabrication facilities use large-scale back-up generators as a critical contingency measure. Emergency back-up generators are essential for maintaining the continuous operation of sensitive manufacturing equipment, such as semiconductor fabrication tools, assembly lines, and testing stations. By providing a reliable source of back-up power, these generators help prevent production downtime, minimize financial losses, and safeguard against potential damage to expensive equipment and electronic components caused by sudden power interruptions.

As discussed in **Section 3.5**, emergency back-up generators for semiconductor fabrication facilities are typically diesel- or natural gas-powered. Fossil fuel sources provide notable benefits for sizeable industrial manufacturing operations: reliability, longevity, near-immediate response, high power output, and low maintenance costs (GenServe, 2023). Diesel and natural gas emergency back-up generators have specific design considerations for their implementation. Diesel generators have higher upfront costs and more significant emissions (as noted in **Section 3.5**) than natural gas generators; however, diesel generators are more efficient (between 20 and 40 percent) and last up to twice as long as natural gas generators (GenServe, 2023).

3.10.1.2 Water Use and Wastewater Generation

Semiconductor fabrication plants consume millions of gallons of water daily, with the majority being used in the manufacturing process as ultra-pure water (UPW). In 2021, the median UPW use across 29 facilities was 4.25 billion gallons, or 1.16 million gallons per day. Semiconductor fabrication facilities typically source water from surface water (47.0 percent), municipal water supply (35.3 percent), groundwater (8.5 percent), third party supply (which includes any water commission, parent, or subsidiary of such municipality or private entity (BCWA, 2014); 5.8 percent), reclaimed water supply (3.2 percent), and rainwater (0.3 percent) (Wang et al., 2023a). With the increased scale of the semiconductor industry globally, water use is expected to increase at a similar pace unless greater water use reduction practices are implemented. Global water use within the semiconductor industry increased by 24.5 percent from 2019 to 2023 (Wang et al., 2023a).

Facilities use water for semiconductor processing (48 percent); facility support, such as cooling (23 percent); abatement technologies to remove hazardous gases from SME (20 percent); and non-industrial uses (less than 1 percent). UPW treatment results in a minor loss of water (9 percent) (IEEE, 2023). Manufacturing process water is first converted to UPW before it is used for wafer production, wet etching, solvent processing, and planarization (MKS, 2023). However, UPW requires a much higher state of purification (i.e., thousands of times purer than drinking water) that can only be obtained through energy-intensive chemical treatments (IEEE, 2023). It takes roughly 1,400 to 1,600 gallons of municipal water to make 1,000 gallons of UPW (Govindan, 2022). The calculated global UPW use is equal to 87 percent of global water use in semiconductor fabrication facilities (Wang et al., 2023a). As such, the production process for UPW results in high energy and economic cost, combining multiple physical and chemical treatment technologies to ensure the final effluent water purity (Wang et al., 2023b).

Given the use of UPW in various semiconductor manufacturing steps, recycling UPW wastewater is the most effective way to reduce overall water consumption. As of 2022, the average semiconductor fabrication facility recycles between 40 and 70 percent of received water using conventional onsite wastewater treatment (IEEE, 2023). In recent years, multiple large semiconductor manufacturers have achieved an over 80 percent UPW recycling rate for processing activities, while most corporations have wastewater collection and treatment systems in the production process to maximize the use of internal water resources and UPW (Wang et al., 2023b; Wang et al., 2023a).

Specific practices and technologies to reduce water usage for UPW purification include counterflow reverse osmosis, which enables much higher levels of water recovery than conventional reverse osmosis technology, thus providing higher efficiency water filtration than conventional means (Johnson, 2022). By treating wastewater through onsite reclamation using this technology, water can be returned to recharge local aquifers, which reduces impacts to affected watersheds. For example, a facility in Arizona returned about 95 percent of water used in 2020 (City of Chandler, 2021).

Many semiconductor corporations have set goals to reduce overall water use as shown in **Table 3.10-1**. Generally, reductions in water use can be achieved by implementing four approaches:

1. Replacing wet processes with dry processes;
2. Improving existing UPW production efficiency;
3. Optimizing the tools and procedures utilizing UPW; and
4. Reusing rinse waters and other wastewater streams from existing production processes (Donavon, No Date).

Table 3.10-1. Worldwide Semiconductor Fabrication Company Water Use Targets

Company	Future Target	Target Year
Intel	Accomplish net positive water use through water conservation.	2030
Micron	Reuse, recycle, and restore 75 percent of the water used in operations.	2030
NXP	Recycle 60 percent of water used in production.	2027
Renesas	Reduce water use by a third.	2030
SK hynix	Cumulative water saving reaches 600 million meters cubed.	2030
TSMC	Supply 67,000 meters cubed per day of water from reclaimed water plants.	2024
UMC	Ratio of recycled water usage reaches 40%.	2030
VIS	Compared to 2015, reduce water use per unit product by 10 percent.	2030

Source: Wang et al., 2023b.

3.10.2 Environmental Consequences

This section analyzes the potential consequences of utilities use for a project under the Proposed Action and the no action alternative.

3.10.2.1 Proposed Action Alternative

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of the CHIPS financial assistance, changes to the facility's chip production capacity and manufacturing processes could lead to changes to the fab's utilities use by increasing its energy and water demands and utility source requirements.

CPO's evaluation of the potential increased energy and water demands of an applicant's proposed project will begin with the CPO due diligence process described in **Appendix A**. Each applicant is required to submit a *Climate and Environmental Responsibility Plan* describing how its project will maximize sourcing and use of renewable energy and water recycling. CPO will review the plan to determine whether a proposed project would pose burdens to local community resources and whether the project's rate of utility consumption would be sustainable over the long term. CPO may require the applicant to provide information concerning the fab's current energy and water source portfolio (including the existing amount of electricity it consumes from fossil fuel versus renewable energy sources), energy and water consumption rates, and the volume of wastewater it generates and the extent to which wastewater currently is recycled.

Full-scale increased production after modernization and expansion likely would require increased utility use. Increased fab energy and water use as a result of increased chip production could result in indirect increased adverse effects on climate change, air quality, water quality, and environmental justice, potentially compounding the adverse effects on those resources discussed in this Chapter. For example, increased fab energy demand that requires the fab to procure additional power from public utilities generating electricity from fossil fuel sources could increase the effects of fossil fuel electricity generation in the fab's region, resulting in increased generation of GHGs, power plant air and water pollutant loads, and potential disproportionate and adverse pollution effects on communities with EJ concerns. Increased fab water demand could directly or indirectly strain local or regional surface water or groundwater resources, particularly where fabs are located in arid, drought-prone, or water scarce regions. Increased fab water demand likely would lead to increased volumes of wastewater, which, if not sufficiently reused or recycled, could lead to additional direct effects on water quality. In sum, CPO will consider a proposed project's utility use holistically to determine whether the direct, indirect, or cumulative effects of increased energy and water demand as a result of CHIPS financial assistance and increased chip production would lead to significant effects.

Separate from the issues discussed above that CPO will begin to evaluate in the due diligence process, **Appendix B** includes BMPs that could be incorporated in proposed modernization and expansion projects to address increased energy and water use issues. These BMPs aim to leverage efforts to increase semiconductor fab energy and water efficiency, renewable energy sourcing, and water recycling, including through new technologies. For semiconductor manufacturing to become less energy intensive even as production rates increase and technological advancements accelerate, the industry must consider increasing the CFE share of fab energy usage and investing in more energy-efficient equipment and practices. Currently, semiconduction fabrication facilities rely heavily on public utilities for energy generation with 83.7 percent of total energy usage being sourced from the grid (Wang et al., 2023a). While public utilities nationwide are working to increase CFE generation, semiconductor fabs may opt to increase their share of CFE usage by purchasing CFE from specific utility providers, acquiring energy attribute certificates (EACs), or generating CFE onsite.

Semiconductor fabs also should consider adopting and implementing EPA's ENERGY STAR Guidelines for industrial plants or other energy management strategies designed to focus facilities on continuous improvements, performing more efficiently, and reducing energy use over time.

Further, fabs should consider reducing energy consumption through the most state-of-the-art, energy efficient SME upgrades, including installation of more energy-efficient chillers, heat exchangers, and dry systems and compressors, and using sensor integration. Chillers can be converted from fixed pumps to new variable flow systems, which can reduce pump energy use on average by 20 percent. Heat pumps are between 3.2 and 5.6 times more efficient than boilers for use as heat exchangers. Typically, compressing air results in a loss of over 80 percent of the energy as heat; however, using a centralized heat recovery system with variable frequency compressors can improve energy performance by 20 percent. Integrating sensors into equipment and controlled-condition spaces can provide real-time data to enable further optimization of energy use and thus improve energy efficiency (Intel, 2020).

Semiconductor fabs should consider all appropriate practices and technological improvements to address increased water use. Given that UPW accounts for 87 percent of fab water use, it is imperative that fabs work to improve water reclamation systems and implement greater UPW recycling (Wang et al., 2023a). UPW recycling from reject process outflows such as reverse osmosis, condensation, sampling/analysis, and final rinse are relatively simple to implement and provide a baseline of 30 percent UPW recycling. Fabs could reduce water use further by replacing wet processes with dry processes, improving existing UPW production efficiency, optimizing tools and procedures that use UPW, and reusing rinse water and other wastewater streams from existing production processes.

Summary of Effects

As discussed in Section 2.4, most fab modernization projects would involve expanding fab cleanroom space or upgrading, replacing, or adding new SME. The practical effects of these actions may vary, but CPO generally anticipates that modernization or expansion using CHIPS financial assistance will result in varying degrees of increased chip production capacity.

In general, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in increased energy and water use and wastewater generation. CPO concludes that modernization and expansion projects likely would have *temporary to permanent*, *minor*, *local to regional* environmental effects due to increased energy and water use. The exact effects of specific projects may vary depending on the degree to which each project implements more sustainable energy and water use and sourcing and water recycling.

3.10.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur. In general, fab utility use would continue at current levels. Under the no action alternative, there would continue to be *temporary to permanent*, *minor,* and *local to regional* effects on the environment from utility use. Overall, the effects of the no action alternative would represent the business-as-usual scenario for semiconductor fab utility use, with concomitant indirect adverse impacts on climate change, air quality, water quality, and other resources given the industry's rates of energy and water consumption described above.

3.11 ENVIRONMENTAL JUSTICE

This section analyzes the affected environment and the potential consequences of projects under the Proposed Action and the no action alternative for environmental justice (EJ).

3.11.1 Affected Environment

Executive Order 14096, Revitalizing Our Nation's Commitment to Environmental Justice for All, defines "environmental justice" as the just treatment and meaningful involvement of all people, regardless of income, race, color, national origin, tribal affiliation, or disability, in agency decision making and other federal activities that affect human health and the environment so that people: (i) are fully protected from disproportionate and adverse human health and environmental effects (including risks) and hazards, including those related to climate change, the cumulative impacts of environmental and other burdens, and the legacy of racism or other structural or systemic barriers; and (ii) have equitable access to a healthy, sustainable, and resilient environment in which to live, play, work, learn, grow, worship, and engage in cultural and subsistence practices.

Accordingly, the goal of "just treatment" is the protection of all people against disproportionate and adverse effects, whereas the goal of "meaningful involvement" is to ensure that all persons or communities have the opportunity to participate in public decision making processes that affect their health and environment, which could include ensuring opportunities for the public to share information and concerns, fully considering public input received, ensuring access for individuals with limited English proficiency (LEP) or individuals with disabilities, and providing technical assistance, tools, and resources to assist in facilitating meaningful and informed public participation, whenever practicable and appropriate.

This section of the PEA interprets the affected environment for EJ to include identification of any disproportionate and adverse effects on minority and low-income communities that may have environmental justice concerns (collectively referred to in this section as "communities with EJ concerns"), along with identification of alternatives that may mitigate those effects.

3.11.1.1 Regulatory Framework

This section provides an overview of the regulatory framework for the consideration of effects to EJ under NEPA:

- EO 12898, *Federal Actions to Address EJ in Minority Populations and Low-Income Populations*, requires federal agencies to consider as a part of their actions any disproportionately high and adverse human health or environmental effects to minority and low-income populations. Federal agencies are required to ensure that these potential effects are identified and addressed.
- EO 13166, *Improving Access to Persons with Limited English Proficiency*, requires federal agencies to develop and implement a plan to provide services to LEP individuals to ensure meaningful access to programs and activities conducted by federal agencies.
- EO 13175, *Consultation and Coordination with Indian Tribal Governments*, requires federal agencies to uphold the unique "government-to-government" sovereign relationship between the U.S. government and federally recognized Native American (American Indian) tribes and Alaska Natives in the development of policies that have tribal implications.
- EO 14030, *Climate Related Financial Risks*, requires federal investments to account for climate-related financial risks and address any disparate effects on disadvantaged communities and communities of color.
- EO 14008, *Tackling the Climate Crisis at Home and Abroad*, requires federal agencies to consider measures to address and prevent disproportionate and adverse environmental and health effects on communities, including the cumulative effects of pollution and other burdens like climate change. EO 14008 established the Climate and Economic Justice Screening Tool, which allows agencies to identify disadvantaged communities that are marginalized, underserved, and overburdened by pollution. The federal decision making process also involves solicitation of input from federally recognized Indian tribes and Alaska Natives on matters having substantial direct effects on them.
- EO 13045, *Protection of Children from Environmental Health Risks and Safety Risks*, requires federal agencies to identify and assess environmental health risks and safety risks that may disproportionately affect children and ensure that policies, programs, activities, and standards address disproportionate risks to children.
- EO 14096, *Revitalizing Our Nation's Commitment to Environmental Justice for All*, directs all federal agencies, by October 2024, to submit to the Chair of CEQ and make available to the public an Environmental Justice Strategic Plan that sets forth the agency's vision, goals, priority actions, and metrics to address and advance environmental justice, including through the identification of new staffing, policies, regulations, or guidance documents. No later than two years after submission of an Environmental Justice Strategic Plan, each agency must submit, and make available to the public, an Environmental Justice Assessment that evaluates the effectiveness of the agency's Environmental Justice Strategic Plan, including the agency's implementation process, any identified implementation barriers, and steps taken to address identified barriers.

- EO 14091, *Further Advancing Racial Equity and Support for Underserved Communities through the Federal Government*, directs all federal agencies to adopt and implement an Equity Action Plan by September 2023, and on an annual basis thereafter, which "uses the agency's policy, budgetary, programmatic, service delivery, procurement, data collection processes, grantmaking, public engagement, research and evaluation, and regulatory functions to enable the agency's mission and service delivery to yield equitable outcomes for all Americans, including underserved communities." Section 5 of the EO further directs agencies, consistent with applicable law, to "create more flexibilities, incentives, and guidelines for all recipients of federal funding and permits to proactively engage with underserved communities as projects are designed and implemented."

3.11.1.2 Identification of Communities with EJ Concerns

The affected environment for EJ must include identification of any disproportionate and adverse effects on minority communities and low-income communities. A site-specific analysis will normally present income level and other demographic information (which could include education level, unemployment, wealth, or life expectancy) for populations affected by the undertaking and identify communities with EJ concerns that could be disproportionately affected. At the PEA stage, the specific sites at which applicants' proposed projects would occur are unknown. This subsection presents the methodology that CPO and applicants must use on a case-by-case basis to determine the presence of communities with EJ concerns at the specific locations where proposed projects would occur.

CEQ's EJ Guidance states that "minority populations should be identified where either: (a) the minority population of the affected area exceeds 50 percent, or (b) the minority population percentage of the affected area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis" (CEQ, 1997). CEQ also recommends the identification of a geographic unit of analysis that accurately represents the occurrence and distribution of minority and low-income communities in the project area, generally referred to as the region of influence (ROI) (CEQ, 1997). This is the region where potential effects with the greatest intensity and longest duration would occur from the implementation of a proposed project.

Due to the site-specific nature of any given fab modernization and expansion project, the ROI could comprise one or more census tracts (CTs) or block groups (BGs):

- **Census tracts** are small, relatively permanent statistical subdivisions of a county or equivalent entity, generally with a population size between 1,200 and 8,000 people. A CT usually covers a contiguous area, and its boundaries usually follow visible and identifiable features (e.g., road, river). The spatial size of CTs varies widely depending on the density of settlement. CTs were designed to be relatively homogeneous units with respect to population characteristics, economic status, and living conditions. In addition, tribal CTs are defined for federally recognized American Indian tribes with reservations or off-reservation trust land and can cross state and county boundaries. A single tribal CT typically consists of a population of less than 2,400 people. Tribal CTs may be completely different from the standard CTs defined for the same area (USCB, 2022).
- **Block groups** are statistical divisions of CTs and are generally defined to contain between 600 and 3,000 people. BGs are composed of clusters of census blocks within the same CT. A census block is the smallest geographic area for which the U.S. Census Bureau (USCB) collects and tabulates decennial census data. A BG usually covers a contiguous area. Each CT contains at least one BG, and BGs are uniquely numbered within the CT. Tribal BGs are separate and unique geographic areas defined within federally recognized tribal reservations and can cross state and county boundaries (USCB, 2022).

CPO will select either a CT or BG around the relevant fab depending on the project scope and location, as appropriate.

Following the identification of the appropriate ROI, the income level and other demographic data for the ROI would be compared with data for the region of comparison (ROC), or the "general population" as it corresponds to the CEQ definition. The ROC is the unit of geographic analysis (e.g., county, state, or region) that provides a baseline for comparison of health and environmental effects between communities with EJ concerns and the "general population" of the region.

The USCB American Community Survey (ACS) 5-year estimates are typically used to describe and compare the demographic characteristics of the ROI and ROC. The ROI may be considered a community with EJ concerns based on the factors described below.

In addition to identifying and characterizing communities in accordance with federal guidance, consideration of state- and local-level EJ laws, ordinances, policies, and guidance would also be required. Several states have released new or updated EJ policies focusing on public participation, permitting reforms, monitoring, and compliance, and some local jurisdictions have adopted ordinances related to permitting and cumulative impacts and/or community benefits. For example, in June 2022, the Maryland Department of the Environment released an EJ Screening Tool to enhance communication and outreach between the agency and overburdened or underserved communities in the state (ELI, 2023). In September 2020, New Jersey passed "An Act Concerning the Disproportionate and Public Health Impacts of Pollution on Overburdened Communities", which requires EJ impact statements for projects in communities with EJ concerns that must obtain New Jersey Department of Environmental Protection permits (Gerrard and McTiernan, 2021).

The federal criteria for identifying communities with EJ concerns are described below.

Minority Populations

CEQ defines the term "minority" to include the following population groups: American Indian or Alaska Native; Asian or Pacific Islander; Black, not of Hispanic Origin; or Hispanic (CEQ, 1997). CEQ defines a minority population in the following ways:

- "…the minority population of the affected area exceeds 50 percent..." (CEQ, 1997).
- "…the minority population percentage of the affected area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis" (CEQ, 1997).

For proposed projects under the PEA, CPO will consider a project ROI to constitute a community with EJ concerns in either of the following scenarios: (1) where more than 50 percent of the population within the project ROI consists of minority populations; and/or (2) where the discrepancy between minority populations and the general population within the project ROI is 10 percent or greater (i.e., "meaningfully greater") than the discrepancy between minority populations and the general population in the ROC.

Low-Income Populations

"Low-income populations" are defined as populations with household incomes below the federal poverty level (ASPE, 2024). There are two slightly different versions of the federal poverty measure: poverty thresholds defined by the USCB and poverty guidelines defined by the U.S. Department of Health and Human Services.

The USCB revises defined poverty thresholds annually. The USCB uses a set of income thresholds that vary by family size and composition (number of children and elderly) to determine who is in poverty. If a family's total income is less than the poverty threshold, then that family and every individual in it is considered in poverty. The same applies for a single individual. The official poverty definition considers pre-tax income and does not include capital gains or non-cash benefits, such as public housing, Medicaid, or food stamps (CEQ, 1997). Poverty thresholds are primarily used for statistical purposes, such as calculating poverty population figures or estimating the number of Americans in poverty each year. CEQ EJ Guidance recommends that USCB poverty thresholds be used to identify low-income populations (CEQ, 1997). Therefore, this section uses USCB poverty thresholds to identify low-income populations.

CEQ guidance does not specify a threshold for identifying low-income populations. Therefore, CPO will apply the same approach as above with respect to minority populations to low-income populations. For proposed projects under the PEA, CPO will consider a project ROI to constitute a community with EJ concerns in either of the following scenarios: (1) where more than 50 percent of the population within the project ROI consists of low-income populations; and/or (2) where the discrepancy between low-income populations and the general population within the project ROI is 10 percent or greater (i.e., "meaningfully greater") than the discrepancy between low-income populations and the general population in the ROC.

Native American Tribes

As described above, the CEQ EJ Guidance recommends that when selecting a geographic unit of analysis for EJ, consideration should be given to the spatial distribution of minority and low-income populations, which may reside in tightly clustered communities or may be evenly or unevenly distributed throughout the general population. As such, federal agencies are required to identify federally recognized tribes that reside in reservations, or in concentrated "pockets" in or outside of the ROI, that engage in unique cultural and traditional practices (e.g., subsistence and ceremonial fishing), and that are directly dependent on the resources in the ROI.

For proposed projects under the PEA, CPO will take a holistic approach to identifying tribal populations within the ROI, in line with the CEQ EJ Guidance and the CPO due diligence process for engaging in government-to-government consultation with Native American Tribes as described in **Appendix A**.

Additional Considerations

In addition to the factors described above, the tools listed in **Table 3.11-1** below may be used to screen for the presence of communities with EJ concerns in the ROI and to determine the possibility of disproportionate and adverse effects on such communities.

CPO notes that this table includes the commonly used tools for EJ analysis but is not an exhaustive list. The state in which a proposed project will be located may have its own EJ screening tool or similar resources that would need to be consulted to ensure that project effects on communities with EJ concerns are considered in accordance with state and local authorities.

Table 3.11-1. Tools for Identifying Communities with EJ Concerns

Tool	Description
EPA EJScreen	EPA's EJ mapping and screening tool provides high-resolution environmental and demographic information for the identification of areas with: • People of color and/or low-income populations; • Percent persons with a disability at the census block level; • Potential environmental quality issues; • A combination of environmental and demographic indicators that is greater than usual; and • Other factors that may be of interest. In addition to EJScreen, EPA has also developed other data and mapping tools and compiles several different state-level EJ mapping tools (EPA, 2023q).
CEQ Climate and Environmental Justice Screening Tool (CEJST)	CEQ's CEJST provides socioeconomic, environmental, and climate information to inform decisions that may affect disadvantaged communities. The tool highlights CTs that are overburdened and underserved and identifies them as "disadvantaged." Federally recognized tribes, including Alaska Native villages, are also considered disadvantaged communities (CEQ, 2023b).
CDC National Environmental Public Health Tracking Network (Tracking Network)	The Centers for Disease Control and Prevention (CDC)'s Tracking Network provides environmental health data that includes the following: • Health conditions and diseases (e.g., asthma); • Contaminants in the environment (e.g., air pollution); • Climate (e.g., extreme heat events); • Community design (e.g., access to parks); • Behaviors (e.g., smoking); and • Population characteristics (e.g., age and income). (CDC, No Date).
EPA Health Impact Assessment (HIA) Resource and Tool Compilation	This is a compilation of tools and resources related to the HIA process that can be used to collect and analyze data, establish a baseline profile, assess potential health effects, and establish benchmarks and indicators for monitoring and evaluation. These resources include literature and evidence bases, data and statistics, guidelines, benchmarks, decision and economic analysis tools, scientific models, methods, frameworks, indices, mapping, and various data collection tools (EPA, 2016c).
EPA AirNow Portal	EPA's AirNow Portal provides local, state, national, and world-wide air quality data. It makes use of EPA's Air Quality Index to designate the air quality as healthy or unhealthy in the selected area (EPA, 2023r).
CDC Social Vulnerability Index	The CDC's and the Agency for Toxic Substances and Disease Registry's Social Vulnerability Index is a place-based index, database, and mapping tool that helps in the identification and characterization of communities that are less able to prepare for, respond to, and recover from public health crises. This index uses U.S. Census data to determine the social vulnerability of every CT (ATSDR, 2024).

3.11.2 Environmental Consequences

This section analyzes the potential consequences of the Proposed Action and the no action alternative on communities with EJ concerns at the programmatic level. CPO will conduct a site-specific EJ analysis for a proposed semiconductor modernization or expansion project during the due diligence phase of the application process.

3.11.2.1 Proposed Action

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. A proposed project would have the potential to affect communities with EJ concerns by introducing new or increased environmental exposures and health and safety hazards as a result of fab modernization, equipment installation, and subsequently expanded operations, including from activities such as construction noise, unsafe traffic patterns, or increased pollution levels. Communities with EJ concerns may be present in the project area, offsite staging areas, or routes of travel to the project area.

As part of the CPO due diligence process, CPO will conduct an EJ analysis of an applicant's proposed project to identify any communities with EJ concerns within the project ROI as defined above. For any such communities identified during due diligence, CPO will analyze the site-specific effects of the proposed project to determine whether the project would have disproportionate and adverse effects on those communities. As part of its overall EJ analysis for any project, CPO will conduct:

1. A demographic assessment of the project ROI to identify the presence or absence of Tribal members and communities with EJ concerns that may be affected; and

2. An integrated assessment to determine whether the project would have any disproportionate and adverse effects, including cumulative effects, on Tribal members or communities with EJ concerns present in the ROI. Types of potential effects on such groups that CPO will consider include:

    a. Social and economic effects, whether adverse, or beneficial (including benefits of direct, indirect, and induced jobs created as a result of the project);

    b. Health and safety risks (especially to workers) arising from proposed semiconductor modernization and expansion activities and induced effects of expanded operations;

    c. Noise disturbances from proposed modernization activities;

    d. Restricted or delayed access to schools, residential areas, public transportation, or hospital and health care facilities due to traffic and time delays; and

    e. Effects to the unique cultural and traditional practices of Native American Tribes and tribal-affiliated and Indigenous Peoples.

As discussed in **Section 3.12 (Socioeconomics)**, the Proposed Action likely would result in the creation of short-term construction jobs, some of which may be filled by members of communities with EJ concerns. Depending on a proposed project's location, the majority of the project's short-term labor needs may be sourced from specialized contractors located outside the ROI; however, a project may fill a relatively small number of positions from within the ROI. The Proposed Action also may lead to the creation of longer-term or permanent full-time positions at the fab. Although jobs for communities with EJ concerns may provide a socioeconomic benefit, individuals hired to work on proposed projects could experience health and safety risks, as described in **Section 3.7**.

There may be short-term noise and air emissions associated with SME and supporting infrastructure removal, replacement, installation, or upgrades, or conversion of fab spaces to new cleanrooms, including interior renovation activity, outdoor heavy equipment operation, and use of cranes and forklifts to move equipment and materials. Modernization projects generally would not result in more than minor increases in local traffic from new staffing. Accordingly, commuter vehicle emissions, public transportation access, and traffic patterns generally would remain unchanged absent substantial increases in a fab's long-term workforce.

Modernization projects also may result in the use of greater quantities of energy and water and generate more solid waste, hazardous waste, air contaminants, and wastewater. As discussed in the other resource sections of the PEA, CPO will evaluate proposed project effects in each of these areas and require each applicant to demonstrate compliance with all applicable federal, state, and local environmental permits, and may require an applicant to commit to BMPs, pollution abatement and control technologies, or other forms of mitigation, as appropriate, to minimize site-specific adverse effects of modernization and fab operations, including effects on communities with EJ concerns.

CPO will require all recipients of CHIPS financial assistance to conduct meaningful public engagement and outreach to communities with EJ concerns and maximize community benefits from their projects, as reflected in the *Climate and Environmental Responsibility Plan* the applicant is required to develop as described in **Appendix A**. This plan must include "a description of the applicant's strategies for minimizing the potential for adverse impacts to the local community, including communities with environmental justice concerns."

Summary of Effects

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of the CHIPS financial assistance, changes to the facility's chip production capacity and manufacturing processes could lead to increased environmental exposures and health and safety hazards to communities with EJ concerns.

CPO notes that proposed projects could potentially have beneficial effects to communities with EJ concerns if they result in direct, indirect, or induced employment opportunities for members of such communities during shorter-term modernization or longer-term operational project phases. However, such opportunities will depend on the extent to which CHIPS financial assistance allocates funds to provide training to disadvantaged individuals for their workforce development and job placement, as well as employment decisions by applicants. CPO will evaluate on a project-specific basis whether an applicant is being considered for such workforce development funding for its project and whether it is making relevant workforce development commitments to determine whether the project would have any beneficial effects in this area.

However, CPO concludes that, in general, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in increased environmental effects as discussed above and in the other resource sections of this Chapter, unless projects commit to mitigation, appropriate use of BMPs, or other pollution control measures.

Where communities with EJ concerns exist within project ROIs, modernization and expansion projects undertaken likely would have *temporary to permanent*, *minor to moderate*, *local* adverse effects on such communities. Projects could produce temporary effects on communities with EJ concerns from project modernization activity noise and air emissions. In addition, longer-term modernization project operations could produce disproportionate and adverse effects on such communities due to increased emissions of air and water pollutants, if not adequately controlled, as discussed in Sections 3.5 and 3.6, as well as disproportionate and adverse effects on workers hired from such communities due to human health and safety concerns, as discussed in Section 3.7. Such effects would be minimized by developing and implementing appropriate BMPs. CPO will evaluate the potential for such disproportionate and adverse effects throughout the due diligence process, when conducting the assessments described in this Section, and in the site-specific NEPA review of each proposed project.

3.11.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur. Therefore, the no action alternative would not result in new effects on communities with EJ concerns. However, existing effects on such communities in the vicinity of fabs likely would continue.

3.12 SOCIOECONOMICS

This section analyzes the affected environment and the potential consequences of the Proposed Action and the no action alternative on socioeconomics.

3.12.1 Affected Environment

The analysis of socioeconomic effects identifies those aspects of the social and economic environment that are sensitive to changes and that may be affected by semiconductor fabrication modernization projects. The affected environment for socioeconomics in a site-specific analysis would normally describe the socioeconomic characteristics of the project area, also called the region of interest (ROI), that could be potentially affected by the proposed project and compare it with the socioeconomic data for the region of comparison (ROC) (see **Section 3.11 (Environmental Justice)** for detailed descriptions of the ROI and ROC). These characteristics include local demographics, labor force participation and employment, and income. However, site-specific socioeconomic information is not available at the programmatic level. Therefore, this section analyzes the likely broad-level socioeconomic effects of semiconductor modernization and expansion projects, and includes an overview of the U.S. semiconductor industry, the challenges facing it, and the economic implications of the CHIPS Act. CPO will use this analysis to inform its site-specific socioeconomic reviews of proposed projects under the PEA.

3.12.1.1 Overview of the U.S. Semiconductor Industry

Semiconductors are critical to nearly all industrial sectors and play an instrumental role in technologies that address a variety of national needs, such as defense weapon systems, medical equipment, automobiles, industrial machinery, consumer electronics, and environmental systems (CRS, 2022). Semiconductors play an integral role in emerging technologies in numerous related fields, such as artificial intelligence, high performance computing, and autonomous systems (SIA, 2022). In addition, chips are indispensable components of the renewable energy transition (Favino, 2024). The U.S. government and private companies pioneered advancements in semiconductor technology through the 1960s and 1970s, and formerly led the world in semiconductor manufacturing (CRS, 2023). Six U.S.-headquartered or foreign-owned semiconductor manufacturing companies currently operate 20 fabrication facilities in the U.S. (CRS, 2022).

The U.S. semiconductor industry accounts for nearly half of the global semiconductor market share and remains the world leader for chips sales. Additionally, the industry maintains a highly competitive position in research and development (R&D), design, and manufacturing process technology (SIA, 2022).

The U.S. semiconductor industry contributes substantially to U.S. Gross Domestic Product (GDP) and income. In 2021, the Gross Value Added (GVA) contribution of the U.S. semiconductor industry to U.S. GDP totaled $276.9 billion. The industry also generated $165.1 billion in income in 2021, supporting 1.84 million U.S. jobs in 2021. The industry directly employs more than 277,000 domestic workers in R&D, design, and manufacturing activities, among others. For each U.S. worker directly employed by the semiconductor industry, an additional 5.7 indirect or induced jobs are supported across a wide and diverse distribution of downstream economic sectors, including construction, financial activities, and leisure and hospitality (SIA, 2022).

U.S. exports of semiconductors totaled $62 billion in 2021, making it the fourth-highest export behind only airplanes, refined oil, and crude oil. The R&D expenditures of the U.S. semiconductor industry have grown by nearly 7.2 percent from 2000 to 2020. In 2021, the industry's investment in R&D totaled $50.2 billion. The semiconductor industry is second only to the U.S. pharmaceutical and biotechnology industry in terms of the rate of R&D spending as a percent of sales (SIA, 2022).

On a global scale, the semiconductor industry reported $440.4 billion in sales in 2020, which grew by a record 26.2 percent to $555.9 billion in 2021. Per industry estimates, the worldwide semiconductor industry sales were projected to be between $618-$633 billion in 2022. The market for semiconductors and related products is expected to continue growing in the future (SIA, 2022).

3.12.1.2 Challenges to the U.S. Semiconductor Industry

Although the U.S. semiconductor industry continues to dominate many parts of the semiconductor supply chain, a variety of factors over the years have led to the concentration of semiconductor manufacturing in East Asia (CRS, 2023). The U.S. share of semiconductor fabrication capacity was 12 percent in 2020, down from 13.8 percent in 2015, continuing a long-term decline from around 40 percent in 1990. This decline is expected to continue as new facilities open globally in the next few years, particularly in East Asian countries – South Korea, Taiwan, Japan, and China (CRS, 2022). Some of the challenges currently encountered by the U.S. semiconductor industry include (CRS, 2023):

- Decline in the U.S. position in semiconductor manufacturing and technology and potential rise in foreign industrial and technological competitiveness;
- Inadequate domestic manufacturing capability to meet U.S. national security and economic needs;
- U.S. reliance on global supply chains and production concentrated in East Asia;
- Supply chain disruptions due to the Coronavirus Disease 2019 (COVID-19) pandemic;
- Sustaining the ability of the industry to improve semiconductor performance while decreasing cost through technological innovation; and
- Retaining and growing high-skilled and high-paying U.S. semiconductor industry jobs.

3.12.2 Environmental Consequences

This section analyzes the potential consequences of the Proposed Action and the no action alternative on socioeconomics.

3.12.2.1 Proposed Action

Under the Proposed Action, CPO would provide financial assistance to a proposed semiconductor fab modernization or expansion project involving facility and equipment expansion or upgrades within the existing fab facility footprint. As a result of the CHIPS financial assistance, modernization and expansion projects may create specialized direct employment opportunities associated with the removal of outdated SME, upgrades to existing SME, installation of modernized SME, and/or conversion of fab spaces. Proposed projects likely would require both skilled tradespeople (e.g., electricians, pipefitters, and HVAC contractors), laborers, and specialized SME installation technicians. Projects resulting in substantially increased fab production may create new full-time, well-paying jobs. Jobs and income are strongly associated with beneficial health outcomes, such as an increase in life expectancy, improved child health status, improved mental health, and reduced rates of chronic and acute disease morbidity and mortality (HDA, 2004; Cox et al., 2004).

Modernization and expansion projects also may create indirect employment opportunities and economic effects, such as increased market demand for and jobs with SME manufacturers and material suppliers. Such entities may be located outside of project ROIs, resulting in benefits that could extend over a much larger region. Local retail stores and establishments where fab workers spend their wages may also benefit, potentially creating additional jobs. These benefits would primarily be experienced by businesses and populations located within the ROI, in the vicinity of the facility. Induced effects could also occur when employees of the directly and indirectly affected industries spend the wages they receive. The magnitude of the direct and indirect beneficial effects would depend on the amount of funding received by the applicant fab; a greater funding amount would generate substantially larger direct, indirect, and induced economic effects.

Summary of Effects

As discussed in **Section 2.4**, under the Proposed Action, most fab modernization projects would involve expanding fab cleanroom space or upgrading, replacing, or adding new SME. The practical effects of these actions may vary, but CPO generally anticipates that modernization or expansion using CHIPS financial assistance will result in varying degrees of increased chip production capacity. These scenarios could result in increased socioeconomic benefits, including direct job creation, improved health outcomes, and increased economic activity in local communities, as well as indirect benefits to the end-use markets that rely on semiconductors, such as automobile, communication, defense, information technology, manufacturing, medical technology, renewable energy, and aerospace industries. Increased modernization ultimately could reduce chip shortages in these industries, which would benefit U.S. consumers and the economy (SIA, 2022). These effects also would contribute to U.S. GDP, create additional employment in sectors dependent on semiconductors, and increase overall earnings.

CPO concludes that, on balance, semiconductor fab modernization or expansion projects under the Proposed Action likely would result in direct, *temporary to permanent*, *minor to moderate*, *local to regional* beneficial socioeconomic effects by creating specialized employment opportunities and attendant improved health outcomes and increased economic activity, particularly within project ROIs. Projects also likely would result in indirect, *temporary to permanent*, *minor to moderate*, *local to national* beneficial socioeconomic effects by stimulating indirect job growth, economic activity, and consumer benefits.

3.12.2.2 No Action Alternative

Under the no action alternative, CPO would not provide federal financial assistance for applicants' proposed projects and applicants would not complete proposed modernization or expansion projects. Fabs would continue their existing production at current rates, using existing equipment. Without federal financial assistance to modernize and install upgraded, replacement, or new SME, such installations would not occur. Although private investment could assist fab modernization activities, the pace of such modernization in the industry could be slower when compared to CHIPS financial assistance to the industry. The no action alternative likely would result in direct and indirect *temporary to permanent*, *negligible to minor*, *local to regional* beneficial economic effects due to reduced job growth, economic activity, and contributions to U.S. GDP when compared to the Proposed Action.

3.13 SUMMARY OF POTENTIAL EFFECTS

Table 3.13-1 below provides a summary of the potential environmental effects of projects under the Proposed Action and the no action alternative and the consequences for the resource areas analyzed in this Chapter.

As part of the due diligence process to apply for CHIPS financial assistance, an applicant must demonstrate compliance with all existing facility permits. Upon completing modernization and/or expansion projects, the facility would be required to comply with any additional or amended permit conditions based on any changes to the facility's operations. CPO may require an applicant to commit to mitigation or best management practices (BMPs) (see **Appendix B**) to reduce the environmental effects summarized below.

CPO will work with applicants to determine mitigation and BMPs appropriately tailored to address potential environmental effects and will incorporate all such relevant commitments in the NEPA decision and as conditions of any final CHIPS award. CPO reiterates that proposed projects that are not able to commit to appropriate mitigation and BMPs to address site-specific effects may not be appropriate for consideration under the PEA and may require standalone NEPA review.

Table 3.13-1. Summary of Potential Effects

Resource Area	Proposed Action	No Action Alternative
Climate Change and Climate Resilience	Projects likely would have direct, *temporary to permanent, minor to moderate,* and ultimately national or global effects on climate change and climate resilience, depending on the degree to which the project implements BMPs or other mitigation measures, such as installation of abatement systems for fluorinated gases, chip manufacturing process improvements and source reductions, or use of alternative or substitute chemicals. Projects also likely would have indirect, *temporary to permanent*, *negligible to minor* climate effects primarily due to increased emissions from construction and increased indirect emissions from energy use during operation.	The climate effects of the no action alternative would represent the business-as-usual scenario for semiconductor facility emissions, with continued adverse impacts on climate change and climate resilience given the relatively high level of GHG emissions, including a disproportionately high level of fluorinated gas emissions from this sector. Effects would continue to be *temporary to permanent*, *minor to moderate*, *national* to potentially global effects on climate change and climate resilience.
Air Quality	Projects likely would have direct, *temporary to permanent*, *minor*, and *local to regional* effects on air quality. Projects that maximize use of abatement technologies, to reduce overall air pollutant loads and emissions may have comparatively reduced air quality effects.	No changes in the amount or pollutant load of air emissions would occur because the same existing equipment and processes would be used in the same configuration. There would be no new effects to localized or regional air quality. Effects would continue to be *temporary to permanent*, *minor,* and *local to regional* effects on air quality. Fabs would continue to be subject to all applicable laws, regulations, and air permitting requirements.
Water Quality	Projects likely would have *temporary to permanent, minor*, and direct local effects on water quality (for direct dischargers) and regional effects (for indirect dischargers). Projects that maximize use of pretreatment technologies, solvent management plans, segregation of wastewater flows, and wastewater recycling or reuse may have comparatively reduced water quality effects.	No changes in the amount or pollutant load of facility wastewater would occur and laws, regulations, and permitting requirements would remain in place; therefore, there would be no new effects to localized or regional water quality.

Resource Area	Proposed Action	No Action Alternative
		Effects would continue to be *temporary to permanent, minor*, and local or regional effects on water quality, depending on the discharger.
Human Health and Safety	Projects likely would have *temporary to permanent*, *negligible to minor*, *local* effects on human health and safety, depending on the degree to which each project demonstrates sufficient EHS and occupational health and safety measures or that are undertaken with appropriate BMPs.	Overall, the human health and safety effects of the no action alternative would represent the business-as-usual scenario for semiconductor facility health and safety practices. Effects would continue to be *temporary to permanent*, *minor*, *local* effects on human health and safety, depending on the degree of risks already posed by existing semiconductor fab operations.
Hazardous and Toxic Materials	Projects likely would have *temporary to short term*, *minor to moderate*, *local* effects in the event of a release. Projects that maximize use of automated chemical delivery systems and chemical and gas leak detection and shutoff systems may have comparatively reduced likelihood of such effects.	Fabs would continue their existing production at current rates, using existing equipment. In this scenario, the types and amounts of hazardous and toxic materials used at a facility would not increase, but the potential risks of their release would remain. Effects would continue to be the risk of *temporary to short term*, *minor to moderate, local* adverse effects in the event of a material release incident.
Hazardous and Solid Waste Management	Projects likely would have *negligible to minor adverse* environmental effects from hazardous and solid waste generation, or potentially *beneficial* effects if new facility measures are implemented to reduce, reuse, and recover materials, thereby diverting waste from landfills.	Fabs would continue their existing production at current rates, using existing equipment. In this scenario, increased hazardous and nonhazardous waste generation likely would not occur. The no action alternative likely would have no new environmental effects from the generation of hazardous and solid waste.

Resource Area	Proposed Action	No Action Alternative
Utilities	Projects likely would have *temporary to permanent, minor, local to regional* environmental effects due to increased energy and water use, depending on the degree to which each project implements more sustainable energy and water use and sourcing and water recycling.	Fabs would continue their existing production at current rates, using existing equipment. In general, fab utility use would continue at current levels. Effects would continue to be *temporary to permanent*, *minor,* and *local to regional* effects on the environment from utility use.
Environmental Justice	Where communities with EJ concerns exist within project ROIs, projects undertaken likely would have *temporary to permanent*, minor *to moderate*, *local* adverse effects on such communities. Projects could produce temporary effects on communities with EJ concerns from project modernization activity noise and air emissions. Longer-term modernization project operations could produce disproportionate and adverse effects on such communities due to increased emissions of air and water pollutants, if not adequately controlled, as well as disproportionate and adverse effects on workers hired from such communities due to human health and safety concerns.	The no action alternative would not result in new effects on communities with EJ concerns. However, existing effects on such communities in the vicinity of fabs likely would continue.
Socioeconomics	Projects likely would result in direct, *temporary to permanent*, *minor to moderate*, *local to regional* beneficial socioeconomic effects by creating specialized employment opportunities and attendant improved health outcomes and increased economic activity, particularly within project ROIs. Projects also likely would result in indirect, *temporary to permanent*, *minor to moderate*, *local to national* beneficial socioeconomic effects by stimulating indirect job growth, economic activity, and consumer benefits.	The no action alternative likely would result in direct and indirect *temporary to permanent*, *negligible to minor*, *local to regional* beneficial economic effects due to reduced job growth, economic activity, and contributions to U.S. GDP when compared to the Proposed Action.

4.0 CUMULATIVE EFFECTS

Cumulative effects on the environment result from the incremental effects of an action when added to the effects of other past, present, and reasonably foreseeable actions, regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time. 40 C.F.R. § 1508.1(g)(3).

This Chapter analyzes past, present, and reasonably foreseeable actions in connection with the Proposed Action, i.e., the cumulative effects of multiple semiconductor fab modernization and expansion projects supported with CHIPS financial assistance. This discussion focuses on the following foreseeable trends and actions within the semiconductor ecosystem:

- Development of semiconductor fabrication facility clusters in the United States.
- Economic effects of increased semiconductor manufacturing in the United States (including CHIPS financial assistance for new manufacturing facilities).
- Semiconductor manufacturing industry GHG emissions and climate change trends.
- Semiconductor manufacturing industry trends corporate responsibility and environmental sustainability trends.

4.1 CLUSTERING OF SEMICONDUCTOR FABRICATION FACILITIES IN THE UNITED STATES

Modernizing an existing semiconductor fabrication facility likely would not be enough of an investment in a given geographic area to induce the creation of new semiconductor clusters at that location. However, creating beneficial and sustainable semiconductor clusters is an initiative of the CHIPS Act. The goal of the CHIPS Act is to boost U.S. semiconductor research, development, and production and bolster U.S. innovation and investment in semiconductors, related supply chains, and technologies of the future. The Act provides federal funds to invest in regional innovation and technology hubs that will create jobs and spur economic development. These hubs, or clusters, often provide competitive advantages, including:

- Attracting and concentrating specialized labor pools;
- Increasing proximity of supplier and service firms to allow for economies of scale with regard to transportation, supply chains, infrastructure, communications and logistics; and
- Advancing technologies through increased communication and knowledge sharing among firms, suppliers, and researchers (Shivakumar et al., 2023).

Although industrial clusters often confer economic benefits, the environmental effects of such density can sometimes be detrimental to affected communities (Fagbohunka, 2015). Clustering can cause direct/primary and indirect/secondary population growth, leading to overcrowding and traffic, resulting in increases in air pollution and wastewater flows within a concentrated area. Substantial increases in localized water and energy use also could occur in the case of semiconductor manufacturing. Water use is a significant concern given the vast quantities of water required by semiconductor fabrication facility operations. Major adverse cumulative effects to constrained fresh water supplies also could occur (e.g., depletion of rivers, reservoirs, and aquifers) if several fabrication facilities are concentrated in a cluster, if local and state governments do not adequately model, plan, and develop water efficiency, conservation, and reclamation projects to meet all the water needs of their area.

At the same time, clustering can provide opportunities for local and state agencies to develop more effective strategies to reduce or offset environmental impacts through large infrastructure projects that might not be financially feasible for single semiconductor fabrication facilities. Such infrastructure projects could include local or regional water treatment and recycling projects, utility-scale renewable energy projects, regional transportation improvement projects, and improvements to or expansion of public transit options. The CHIPS Incentives Program prioritizes financial assistance that creates “spillover benefits that improve regional economic resilience and support a robust semiconductor ecosystem, beyond assisting a single company.” This means prioritizing local and state investment in inputs to industry cluster development that the market tends to underprovide, such as infrastructure, workforce development, and research and development (Muro et. al., 2023). Infrastructure projects funded by local and state governments are often focused on providing adequate transportation and utility capacity that can also incorporate environmental improvements. State and local environmental regulators can develop regulations, guidelines, and enforcement inspection schedules to address concerns specific to the environmental conditions of the cluster location.

The CHIPS Incentives Program Notice of Funding Opportunity (NOFO) was published in February 2023 and amended in June 2023 to fund large-scale semiconductor materials and manufacturing equipment facilities for which the capital investment equals or exceeds $300 million. A second NOFO was released in September 2023 to strengthen the resilience of the semiconductor supply chain facilities for which the capital investment falls below $300 million. This federal funding opportunity focuses on bolstering domestic supply chains to create vibrant and sustainable semiconductor clusters. The goal of the second NOFO is to close the critical gaps in the supply chain landscape by making the critical investments in proposed projects that support the key U.S. semiconductor fabs with other regional entities like local and state governments. One key caveat with this funding opportunity is that applicants are required to demonstrate that their proposed projects have anchor institution supports, such as semiconductor fabrication facilities, which have the potential to create clustering effects. It is anticipated that most of the new clustering effects would occur around new leading edge semiconductor fabrication facilities and not around facilities receiving federal financial assistance for modernization or expansion of existing current-generation and mature-node semiconductor fabrication facilities.

The Proposed Action of modernizing an existing semiconductor fabrication facility likely would not induce creation of new semiconductor clusters at that location. The potential for increased production at an existing fab likely would not be substantial enough to necessitate or prompt existing or new service partners or suppliers to relocate to that site. Many existing semiconductor fabrication facilities are also constrained by surrounding development that does not allow co-location of supporting service industries and suppliers. Modernization projects, due to their relatively small size, should not substantially increase water and energy use and wastewater generation. These proposed projects may also incorporate tooling and facility improvements to conserve water and energy. Although the Proposed Action would help meet other goals of the CHIPS Incentives Program, it likely would not cause significant cumulative environmental effects in association with existing or planned semiconductor clusters.

4.2 ECONOMIC EFFECTS OF THE CHIPS ACT IN THE UNITED STATES

The CHIPS Act resulted in the announcement of dozens of proposed projects to increase U.S. domestic semiconductor manufacturing capacity. According to SIA, over 60 new projects have been announced with over $210 billion in private investments across 22 states, expected to create 44,000 new high-quality jobs (Casanova, 2022). In a 2021 SIA-Oxford economic study, for each U.S. worker directly employed by the semiconductor industry, an additional 5.7 jobs are supported in the wider U.S. economy. The industry is projected to need an additional 90,000 workers by 2025 (Eightfold AI, 2021). The Act provides workforce and education funding to assist in growing the semiconductor workforce.

The CHIPS Act also aims to spur growth in scientific research and allocates funds for material science, quantum computing, and biotechnology. Under the Act, DOE is developing a plan to reduce energy use of microelectronics chips, circuits, architecture, and software by 1000 times in the next 20 years (Bui, 2023).

The CHIPS Act also authorized the creation of a Public Wireless Supply Chain Innovation Fund within the National Telecommunications and Information Administration (NTIA). This fund aims to foster competition, lower costs for consumers and network operations, support innovation across the global telecommunications ecosystem, and strengthen the 5G supply chain (NTIA, 2023). Expansion of 5G networks drives economic growth and provides benefits from expanded education and employment opportunities like remote learning and job-seeker services, higher wages, and telehealth services. The Boston Consulting Group, in collaboration with NTIA, estimates that by 2030, 5G development will contribute \$1.4 trillion to \$1.7 trillion to the U.S. gross domestic product (GDP) and create between 3.8 and 4.6 million jobs (Melo et al., 2021).

Private funding of semiconductor manufacturing projects will far exceed the financial assistance authorized under the CHIPS Act (i.e., private investments will remain the primary driver of growth in this sector over the next decade). A modernization project under the Proposed Action would increase jobs by a small fraction when compared to projects constructing entirely new leading-edge semiconductor fabrication facilities or initiatives to develop new clusters. A modernization project under the Proposed Action would also increase manufacturing productivity and foster production of advanced chips, but on a relatively small scale. Cumulatively, semiconductor fabrication facility modernization projects along with other initiatives under the Act and increased private investments in the U.S. semiconductor industry should reduce potential semiconductor shortages in the future, promote new semiconductor jobs and job training, increase economic growth, advance new technology, enhance national and economic security, and increase supply chain resilience to the semiconductor ecosystem.

4.3 CLIMATE CHANGE TRENDS AFFECTING THE SEMICONDUCTOR INDUSTRY AND SECTOR GREENHOUSE GAS EMISSIONS

As described in **Section 3.4**, consequences of climate change are numerous and relevant. The Fifth National Climate Assessment on climate change impacts, risks, and responses asserts that anthropogenic GHG emissions are resulting in rapid warming and other large-scale changes, including rising sea levels, melting ice, ocean warming and acidification, changing rainfall patterns, and shifts in timing of seasonal events (Jay et al., 2023).

The U.S. semiconductor industry, through its direct, onsite emissions from manufacturing processes and offsite fossil energy used to generate the electricity it consumes, is estimated to contribute approximately 0.18 percent of aggregate annual U.S. GHG emissions, or approximately 11.5 MMT, expressed in CO_2e. The sector provides 1.4 percent of total U.S. manufacturing employment (CRS, 2020) and directly contributed approximately 1.2 percent to the U.S. GDP in 2020 (Oxford Economics, 2021).

Indirect emissions from offsite fossil fuel combustion to generate electricity account for almost half of total GHG emissions from the semiconductor manufacturing sector. Companies have greater options to reduce energy consumption or select from various electricity supply choices. Options may include reducing tool-related energy consumption by upgrading and replacing tools with more energy-efficient ones and/or implementing smart control systems to regulate operation of support facilities and manufacturing equipment for optimal integration and efficiency. Facility-related energy consumption can be reduced by implementing greater energy efficiency of buildings and replacing existing lighting in fabs with LED fixtures. Facilities can choose to reduce Scope 2 emissions by purchasing renewable energy credits or other methods of sourcing lower-carbon or carbon-free electricity (McKinsey, 2022a).

Between 1990 and 2021 overall emissions in the U.S. semiconductor sector have resulted in a net increase in emissions of approximately 45 percent with a peak in 1999 of 8.4 MMT prior to the adoption of emissions reduction technologies (including but not limited to abatement technologies) and shifts in gas usages. The annual total direct GHG emissions across the U.S. semiconductor sector have remained consistent since 2017 with between 4.1 and 4.5 MMT of CO_2e per year, with 2019 and 2020 having the lowest levels (with 47 companies reporting) and 2021 the highest (with 46 companies reporting). Total emissions from semiconductor manufacture in 2021 were higher than 2019 or 2020 emissions (increasing by approximately 10 percent) due to increased F-GHG emissions from SF_6 in 200 mm and CF_4 in 300 mm wafer size manufacturing facilities without adequate abatement systems (EPA, 2023t).

In 2021, U.S. semiconductor fabrication facilities released approximately 4.8 MMT CO_2e emissions from all F-GHGs and N_2O from deposition, etching, and chamber cleaning processes. While emissions from F-GHGs have decreased by 43 percent since 1999, emissions are still 45 percent higher than in 1990 (EPA, 2023t). Semiconductor fabrication facilities have varying abilities to reduce direct emissions from using F-GHG compounds in onsite manufacturing processes. Reducing direct F-GHG emissions depends on facility-specific circumstances (EPA, 2015). For new fabrication facilities, a variety of techniques to reduce F-GHGs are available. Point-of-use (POU) abatement systems reduce F-GHG emissions by either: (1) the combustion of released gases combined with wet or dry scrubbing of by-products; or (2) the use of plasma (at atmospheric or sub-atmospheric pressures) to dissociate emitted gases (EPA, 2024). In contrast to modern facilities, older fabrication facilities may be unable to install comparable systems due to space limitations. In these cases, plasma abatement systems may be more practical because they are smaller than combustion abatement systems, but they are limited to etching processes (EPA, 2024). Additional abatement technologies include NF_3 remote plasma cleaning, which replaces chamber cleaning technologies that emit a significant fraction (20 to 90 percent) of the input gas with a technology that emits a much smaller fraction (2 to 3 percent) and generalized process optimization and gas replacement (EPA, 2024). Current 200- and 300-mm wafer production facilities are better equipped for F-GHG abatement; as such, new facility construction may be prioritized over the modernization of older facilities that cannot be retrofitted to the current best available technologies.

U.S. semiconductor sales grew 5 percent between 2014 and 2025, adjusted for inflation, which is in line with the relatively flat increase in GHG emissions. Sector GHG emissions likely will increase over the next decade based on the anticipated increase in new fab construction to expand semiconductor manufacturing. Semiconductor markets are forecasted to grow by an average of 6 to 8 percent per year up to 2030 (McKinsey, 2022b). Thus, the sector likely will increase its global share of GHGs when compared to current levels. **Section 4.4** below describes the industry's past, present, and reasonably foreseeable actions to address GHGs and other areas of environmental stewardship. However, continued improvements in semiconductor technology have and will continue to reduce the environmental effects of other industries that rely on them, such as transportation, energy, industry, agriculture and food, and retail and entertainment, resulting in reduced emissions across multiple sectors (Falk et al., 2020).

The multi-sector influence of improved semiconductor technology could reduce overall GHG emissions by up to 15 percent, or nearly one-third of the 50 percent emission reduction required by 2030 under the U.S. national climate commitment (Falk et al., 2020). Applicants are required to submit a *Climate and Environmental Responsibility Plan* under the NOFO. Applicants are encouraged to use renewable energy to the maximum extent possible for operation of their proposed projects, and applicants constructing new fabs are encouraged to achieve a 100 percent renewable energy goal through on-site generation, power purchase agreements, or utility green tariffs or equivalent approaches.

A modernization project under the Proposed Action would be relatively minor in size since there would be no increase in the existing fab facility footprint; it would increase GHGs emissions only slightly when compared to levels associated with the expected growth of the industry in the United States. Proposed projects receiving CHIPS financial assistance would be encouraged to reduce their GHG footprints through use of renewable energy and by incorporating more energy efficient manufacturing equipment as part of their modernization efforts. Overall, a project funded under the Proposed Action would contribute negligible cumulative effects on GHGs and climate change.

4.4 TRENDS IN CORPORATE RESPONSIBILITY AND ENVIRONMENTAL STEWARDSHIP IN THE SEMICONDUCTOR INDUSTRY

Industry organizations, such as the SIA and World Semiconductor Council (WSC), have promoted a variety of environmental stewardship programs over the last three decades. For example, under a Memorandum of Understanding with EPA in 2001, SIA members voluntarily reported on their emissions of perfluorochemicals (PFCs), a category of potent GHGs (EPA, 2001b). SIA members have reduced their aggregate U.S. emissions of fluorinated gases by more than 50 percent from their peak in 1999 under this agreement. Through the WSC, the global industry committed to a 10 percent reduction of PFCs, and in 2011 the industry announced that it far surpassed this goal and achieved a reduction of 32 percent in absolute emissions. To build on this success, the global industry is implementing another reduction goal to achieve a PFC emissions reduction rate of 85 percent reduce PFC emission rates by 85 percent by 2030 (with a baseline of 81 percent in 2021) (WSC, 2023).

SIA also provides standards for energy conservation to reduce energy use, costs, and associated GHGs, most notably SEMI S23 - *Guide for Conservation of Energy, Utilities and Materials Used by Semiconductor Manufacturing Equipment* (first published in 2005) (Nguyen, 2021). The S23 standard allows device manufacturers to compare systems and consider energy efficiency in their equipment selection process, thus incentivizing equipment manufacturers to improve the efficiency of their products. It also provides an objective basis for equipment manufacturers to evaluate their efforts and promote that progress in the marketplace (Jones, 2022).

Additional SIA standards (E175 and E167) guide communication between production equipment and subsystems (vacuum pumps and gas abatement systems) to trigger energy saving modes (e.g., sleep modes) when systems are not in use.

In 2022, the semiconductor industry formalized a commitment to sustainability by launching the Semiconductor Climate Consortium (SCC), governed by SIA (Hilson, 2022). The SCC enables members to collaborate and align on common approaches, technology innovations, and communications channels to continuously reduce GHGs emissions. Transparency will come in the form of publicly reported progress annually, including on both direct and indirect GHG emissions. Members are setting near- and long-term decarbonization targets with the aim of reaching net zero emissions by 2050. All founding members have affirmed their support of the Paris Agreement – adopted in 2015 by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France – the aim of which is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels” (UNFCC, No Date-b).

SIA also published new and revised standards for water re-use in 2021. The standard provides guidance on how to incorporate wastewater segregation and water reuse and recycling into semiconductor tool and facility design, and strategies to reduce a facility’s water footprint (Kerr et al., 2021).

Modernization activities under the Proposed Action would occur at an existing semiconductor site that is likely to have a mature environmental program that tracks and discloses environmental performance. Semiconductor industry commitments and standards to reduce emissions and water use and increase transparency would have beneficial cumulative impacts to the environment over the long term.

Modernization activities under the Proposed Action would provide further opportunities for a facility to reduce its adverse environmental effects. Cumulatively, any changes (positive or negative) of these proposed projects to the environment would be minor when compared to the overall expected expansion of the U.S. semiconductor sector.

4.5 SUMMARY OF CUMULATIVE EFFECTS

Modernization activities under the Proposed Action would occur at an existing, mature semiconductor facility that would generally be 'stand-alone' and not likely to induce the types of cumulative adverse local effects that proposed geographic clusters might. Activities under the Proposed Action would likely include production increases with resulting minor environmental effects. A project funded under the Proposed Action could streamline production and increase tooling efficiency in line with the latest industry standards that could reduce energy and water use, as well as GHG emissions. Industry goals to reduce GHGs and ongoing trends to provide standards to reduce energy and water use would cumulatively provide beneficial effects over the long term. Modernization actions under the Proposed Action would provide avenues to improve processes that would increase productivity and could also assist companies to meet their environmental goals, although any reductions in environmental effects would be minor when compared to the expected overall expansion of the industry.

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APPENDIX A: CPO ENVIRONMENTAL DUE DILIGENCE PROCESS FOR MODERNIZATION AND EXPANSION PROJECTS AT EXISTING SEMICONDUCTOR FABRICATION FACILITIES

APPENDIX A: CPO ENVIRONMENTAL DUE DILIGENCE PROCESS FOR MODERNIZATION AND EXPANSION PROJECTS AT SEMICONDUCTOR FABRICATION FACILITIES

The CHIPS Program Office's (CPO) environmental review process, which begins before the National Environmental Policy Act (NEPA) analysis begins, is discussed in Section 1.0 of this Programmatic Environmental Assessment (PEA).

The environmental review process begins with a merit review evaluation of the Environmental Questionnaire, cited under the Notice of Funding Opportunity (NOFO) and included in the funding grant application. This review includes an evaluation of questions on the project scope, local environment, potential for environmental effects, and permits required for construction of improvements and operation of the upgraded facility.

The NOFO also requires the submission of a *Climate and Environmental Responsibility Plan* that is also evaluated during merit review. The *Climate and Environmental Responsibility Plan* must include the following contents according to the NOFO.

- **Energy**: A description of how the applicant will use renewable energy to the maximum extent possible. Transitioning to a clean energy supply will bring down the long-term cost of operations as the cost of using renewable energy decreases.
- Climate Resilience: A description of design features, construction methods, and operation strategies that the applicant will employ to increase resilience from weather- and climate-related risks (e.g., increased flooding, wildfires) that may occur over the lifetime of the facility.
- Water: A description of the applicant's water conservation efforts, such as plans to fund water restoration projects, increase water reuse and recycle rates year over year, and other progressive strategies to achieve more ambitious water conservation goals over time.
- Sustainability Transparency: A description of the metrics and processes the applicant will use to measure, track, and report publicly on its climate and environmental responsibility goals and commitments.
- Community and Environmental **Justice Impacts**: A description of the applicant's strategies for minimizing the potential for adverse impacts to the local community, including communities with environmental justice concerns.

Following completion of the merit review and concurrent with the NEPA review, CPO conducts broader due diligence investigation of the Proposed Project.

Due diligence includes a deeper evaluation of site-specific aspects of the Proposed Project and a validation of the environmental information provided by the applicant. Site-specific information to be reviewed includes but is not limited to:

- Environmental justice (EJ) local population analysis using EPA's EJScreen or other government tools.
- Identification of Native American Tribes for Government-to-Government consultation, as applicable, through Bureau of Indian Affairs resources, the U.S. Department of Housing and Urban Development's Tribal Director Assessment Tool, or other relevant federal and state resources.

- Compliance history of the facility using EPA Environmental Compliance History Online (ECHO). ECHO provides facility-level compliance information under the Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act, and Safe Drinking Water Act, plus Toxic Release Inventory history and Clean Water Act Discharge Monitoring Report pollutant loadings.
- Identification of whether projects are located in nonattainment or maintenance areas pursuant to applicable Clean Air Act National Ambient Air Quality Standards.
- State and local permitting databases.
- Wetlands inventories listed in the U.S. Geological Survey (USGS) National Wetlands Inventory (NWI) database and other federal and state sources.
- Facility GHG reporting through the EPA Greenhouse Gas Reporting Program (GHGRP).
- Facility-specific health and safety data or reports (where available). (Note: Enhanced OSHA reporting under 29 C.F.R. Part 1904 with public access commenced on January 2, 2024).
- Company websites that may contain published environmental data as well as corporate sustainability reports.
- Federal, state, or local climate action plans as they pertain to the project.
- Federal, state, or local water conservation plans and studies as they pertain to the project.
- Federal, state, or local traffic and transportation studies or plans as they pertain to the project.
- Site-specific details associated with environmental issues, permits, and initiatives.
- Water, power, and wastewater infrastructure requirements and demand.

APPENDIX B: BEST MANAGEMENT PRACTICES FOR MODERNIZATION AND EXPANSION PROJECTS AT SEMICONDUCTOR FABRICATION FACILITIES

APPENDIX B: BEST MANAGEMENT PRACTICES FOR MODERNIZATION AND EXPANSION PROJECTS AT SEMICONDUCTOR FABRICATION FACILITIES

Proposed semiconductor fab modernization or expansion projects considered under the PEA may require or include mitigation measures or BMPs to avoid or minimize environmental effects. If CPO requires a mitigation measure or specific BMP to be incorporated as a mandatory commitment in the NEPA decision for a proposed project, that BMP also will be incorporated as an enforceable condition in the final award agreement between CPO and the applicant.

Examples of potential mandatory BMPs CPO could require include:

- Reduce GHG emissions by maximizing use of nitrogen trifluoride (NF_3) remote clean technology for chamber cleaning processes and installing high-DRE (destruction or removal efficiency), non-carbon tetrafluoride (CF_4) generating fluorinated gas abatement equipment on etching and thin-film deposition (TFD) tools to the maximum extent allowed by space constraints. Track and benchmark facility fluorinated gas reduction performance.
- Reduce GHG emissions by tracking and minimizing emissions of fluorinated heat transfer fluids. Implement leak detection and repair for chillers and properly recover and reuse or dispose of fluorinated heat transfer fluids when chillers are serviced or retired. Track and benchmark facility fluorinated gas reduction performance.
- Reduce GHG and air pollutant emissions associated with onsite emergency backup generators, either by installing emission control devices, replacing older engines with higher tier engines, or replacing internal combustion generators with cleaner battery storage, fuel cell micro-turbines, or clean energy microgrid options.

Table B-1 below is a non-exhaustive list of BMPs that could be applied to semiconductor fabrication facility modernization and expansion projects. The BMPs are categorized by the resource areas discussed in Chapter 3 of the PEA. CPO will determine whether these or other BMPs will be required or should be incorporated as part of a proposed project on a project-specific basis. If an applicant proceeds past merit review and its project is to be covered under the PEA, CPO will work with the applicant to identify all appropriate mitigation measures, BMPs, and best available technologies to incorporate into the proposed project. Adhering to incorporated mitigation commitments, BMPs, and best available technologies will be required to remain consistent with the effect determinations described in Chapter 3 of the PEA and will be subject to all applicable applicant responsibilities under final award agreements with CPO.

Table B-1. Best Management Practices for Modernization and Expansion Projects at Semiconductor Fabrication Facilities

Resource Area	Project Phase	Best Management Practice
• Climate Change and Climate Resilience • Air Quality • Utilities	• Planning • Construction • Operations	Reduce energy consumption and GHG and air pollutant emissions associated with electricity consumption through increased energy-efficiency measures and energy management practices such as: • Setting an energy use target for the project design that is below current energy consumption to ensure no net increase in energy consumption. Model energy use to guide design choices to ensure the energy use will not exceed the target. • Enhancing building energy-efficiency through LEED design guidelines. • Upgrading/replacing old tools with more energy-efficient ones. • Optimizing tool processes to reduce power consumption. • Replacing less-efficient HVAC equipment with more efficient equipment. • Replacing lighting with LED fixtures. • Using smart regulation and coupling to increase efficiency between facility operations and manufacturing tools and equipment. • Utilizing waste heat recovery systems. • Installing sub-meters on significant energy-using equipment that are integrated into building and energy management information systems. • Ensuring large energy-using systems are fully commissioned. • Benchmarking facility energy use performance. • Appointing a facility energy manager. • Conducting periodic Energy Star Treasure Hunts or Energy Assessments to identify energy waste and opportunities for reducing energy waste (ENERGY STAR, No Date). • Purchasing renewable energy credits within the regional electric pool and in accordance with the ISO 50001 energy management standard.
• Climate Change and Climate Resilience • Water Quality • Utilities	• Planning • Construction • Operations	• Reduce impacts to water supplies by implementing BMPs under EPA's "WaterSense at Work: Best Management for Commercial and Institutional Facilities" (EPA, 2012a): • Conducting a facility water use assessment. • Creating an action plan to reduce water losses and increase water efficiency of fixtures, equipment, systems, and processes. • Educating employees about water-saving behaviors.

Resource Area	Project Phase	Best Management Practice
		• Reusing onsite alternative water that would otherwise be discarded or discharged to the sewer.
• Air Quality	• Construction	Use zero-emission construction equipment wherever possible.
• Air Quality	• Construction	Use low sulfur fuels in construction equipment in accordance with Federal, state, or local requirements.
• Air Quality	• Construction	Reduce fugitive dust by covering exposed material piles, installing wind breaks, water spray, street sweeping, and paving frequented haul roads. See EPA's "Fugitive Dust Control Measures and Best Practices" (EPA, 2022d).
• Air Quality	• Construction	Minimize use of fossil-fueled generators and preferentially use land-based power sources to reduce air emissions where practicable.
• Air Quality	• Construction	Ensure adequate maintenance of construction equipment, including proper engine maintenance, and proper maintenance of pollution control devices.
• Air Quality	• Construction	The applicant and its contractors will reduce construction equipment idling to the maximum extent practicable.
• Air Quality	• Planning • Construction • Operations	Implement outgassing abatement systems (such as thermal, catalytic, or plasma systems) to reduce process gas emissions for new or existing tools. Consider outgassing systems process optimization.
• Water Quality	• Planning • Construction	Incorporate facility effluent segregation processes that allow for enhanced water treatment, testing, and recycling.
• Water Quality	• Planning • Construction	Facility compliance with SEMI F98 – *Guide for Water Reuse in Semiconductor Industry*.
• Water Quality	• Construction • Operations	Implement and maintain BMPs identified in applicable Spill Prevention Control and Countermeasure (SPCC) and Stormwater Pollution Prevention Plans (SWPPPs).
• Human Health and Safety	• Planning • Construction	Limit construction activities, including operation of heavy machinery, to normal business hours or hours specified in local noise ordinances.
• Human Health and Safety	• Planning • Construction	Where feasible, avoid engaging in outdoor construction activities within 200 feet of noise-sensitive receptors such as schools, hospitals, residential areas, nursing homes, etc.

Resource Area	Project Phase	Best Management Practice
• Human Health and Safety	• Planning • Construction	Ensure equipment at the project site uses the manufacturer's standard noise control devices (i.e., mufflers, baffling, and/or engine enclosures).
• Human Health and Safety	• Planning • Construction	When applicable, adopt measures to minimize traffic impacts during construction such as providing warning signage, limiting the use of public rights-of-way for staging of equipment or materials, use of flag-persons when needed, and coordinating detours if traffic access points will be obstructed.
• Human Health and Safety	• Planning • Construction	Implement fencing, signage, and other necessary site safety controls to reduce unauthorized access to construction zones. The applicant and its contractors will develop a project-specific construction safety plan and ensure all workers are trained in its provisions.

• Human Health and Safety	• Planning
	• Construction
	• Operations
		Install tools and equipment in accordance with SEMI S2 to addresses environmental, health, and safety practices and incorporates several other standards, including but not limited to: equipment installation, gas effluent handling, exhaust ventilation, ergonomics, risk assessment, equipment decontamination, fire risk mitigation, electrical design. Referenced Standards:
		• American National Standards Institute (ANSI) Standards
		  o ANSI/Robotics Industries Association [RIA] R15.06ANSI/International Society of Automation [ISA] 84.00.01
		• European Harmonized Standards (EN)
		  o EN/Manipulating Industrial Robots [EN] 775
		  o EN/Safety of Machinery/Principals of Risk Assessment [EN] 1050
		  o EN/Explosion Prevention and Protection/Part 1: Basic Concepts and Methodology [EN] 1127-1
		• Deutsches Institut für Normung (DIN) Standards
		  o DIN V VDE/Principals for Computer Safety Related Systems [DIN] 0801
		• International Electrotechnical Commission (IEC) Standards
		  o IEC/Safety of Lazer Products/Part 1: Equipment Classification, Requirements [IEC] 60825-1
		  o IEC/Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use/ Part 1: General Requirements [IEC] 61010-1

Resource Area	Project Phase	Best Management Practice
		o IEC/Functional Safety of Electrical/Electronic/ Programmable Electronic Safety-Related Systems [IEC] 61508 • Institute of Electrical and Electronics Engineers (IEEE) Standards o IEE/Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 2kHz to 300 GHz [IEEE] C95.1 • International Organization for Standardization (ISO) Standards o ISO/Forged Shackles for General Lifting Purposes Dee Shackles and Bow Shackles [ISO] 2415 o ISO/Robots and Robotic Devices/Safety Requirements for Industrial Robots/Part 1: Robots [ISO] 10218-1 o ISO/Safety of Machinery/Safety-Related Parts of Control Systems/Part 1: General Principles for Design [ISO] 13849-1 • National Fire Protection Association (NFPA) Standards o NFPA/Standard on Carbon Dioxide Extinguishing Systems [NFPA] 12 o NFPA/Standard for the Installation of Sprinkler Systems [NFPA] 13 o SFPA/National Fire Alarm and Signaling Code [NFPA] 72 o NFPA/Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas [NFPA] 487 o NFPA/Standard System for the Identification of the Hazards of Materials for Emergency Response [NFPA] 704 o NFPA/Standard on Clean Agent Fire Extinguishing Systems [NFPA] 2001 • Underwriters Laboratories (UL) Standards o UL/Standard for Industrial Control Panel [UL] 508A • United States (US) Code of Federal Regulations (CFR) o 21 CFR/Food and Drug Administration/Center for Devices and Radiological Health (FDA/CDRH), Performance Standards for Electronic Products [Title 21 CFR, Parts 1000-1050] • American Conference of Governmental Industrial Hygienists (ACGIH), Industrial Ventilation Manual

Resource Area	Project Phase	Best Management Practice
		• American Society of Hearing, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 110 • Semiconductor Exhaust Ventilation Guidebook • Uniform Building Code • Uniform Fire Code

• Human Health and Safety	• Planning
	• Operations
		Operate tools in accordance with SEMI S21 – *Safety Guideline for Worker Protection.* S21 describes methods for protection against hazards that workers may encounter as they work on or around equipment used for semiconductor manufacturing.
		Referenced Standards:
		• ANSI Standards
		  o ANSI/Safety Requirements for Machine Tools Using Lasers for Processing Materials [ANSI] B11.21
		  o ANSI/Safe Use of Lasers [ANSI] Z136.1
		  o ANSI/NFPA/Standard for Electrical Safety Requirements for Employee Workplaces [ANSI/NFPA] 70E
		• European Committee for Standardization (CEN) Standards
		  o EN/Personal Eye-Protection/Filters and Eye-Protection Against Laser Radiation [EN] 207
		  o EN/Personal Eye-Protection/Eye Protection for Adjustment Work on Lasers and Laser Systems [EN] 208
		• IEC Standards
		  o IEC/Safety of Laser Products/Part 1: Equipment Classification, Requirements and User Guide [IEC] 60825-1
		• Japanese Industrial Standards (JIS) Standards
		  o JIS/Safety of Laser Products [JIS] C 6802
		• Occupational Safety and Health Administration (OSHA) Standards
		  o CFR/The Control of Hazardous Energy (lockout/tagout) [Title 29 CFR Part 1910.147]
		  o CFR/ Hazard Communication [Title 29 CFR Part 1910.1200
		  o CFR/Fall Protection Systems Criteria and Practices [Title 29 CFR Part 1926.502]

Resource Area	Project Phase	Best Management Practice

• Human Health and Safety	• Planning
	• Operations
		Design and operate exhaust ventilation utilities in accordance with SEMI S6 – *Environmental, Health, and Safety Guidelines for Exhaust Ventilation of Semiconductor Manufacturing Equipment.* S6 provides safety performance criteria for exhaust ventilation of semiconductor manufacturing equipment and test methods for assessing conformance.
		Reference Documents:
		• ACGIH Document
		  o Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices
		• ACGRAE Standard
		  o Standard/Method of Testing Performance of Laboratory Fume Hoods [ACGRAE] 110-1995
		• American Society for Testing and Materials (ASTM) Standards
		  o ASTM/Practice for Use of Electron Capture Detectors in Gas Chromatography [ASTM] E697
		  o ASTM/American National Standard for Use of the International System of Units (SI): The Modern Metric System [IEEE/ASTM]SI 10
		• Compressed Gas Association (CGA) Standards
		  o CGA/Standard for the Classification of Toxic Gas Mixtures [CGA] P20
		  o CGA/Standard for Categorizing Gas Mixtures Containing Flammable and Nonflammable Components
		• European Standards
		  o EN/Explosive Atmospheres/Explosion Prevention and Protection/Part 1: Basic Concepts and Methodology [EN] 1127-1
		• European Directives
		  o EU/Directive 2014/34/EU Of The European Parliament and The Council of 26 February 2014 on the harmonization of the laws of the Member States relating equipment and protective systems intended for the use in potentially explosive atmospheres (recast) [2014/34/EU]
		• NFPA Standards
		  o NFPA/Uniform Fire Code [NFPA] 1

Resource Area	Project Phase	Best Management Practice
		○ NFPA/Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas [NFPA] 497 ○ NFPA/Standard System for the Identification of the Hazards of Materials for Emergency Response [NFPA] 704 • National Institute for Standards and Technology (NIST) Document ○ Special Publication 330(SP 330), "The International System of Units (SI)"
• Human Health and Safety	• Planning • Construction	Conduct decontamination and removal of manufacturing equipment in accordance with SEMI S12 and S16. These standards can provide guidance to reduce the environmental effects and health and safety risks associated with equipment decommissioning. S12 – *Environmental, Health, and Safety Guideline for Manufacturing Equipment Decontamination*, addresses decontaminating manufacturing equipment and parts that were or may have been exposed to hazardous materials and which are intended for further productive use. Referenced Standards and Documents: • NFPA Standard ○ NFPA/Standard for Electrical Safety in the Workplace [NFPA] 70E • S16 – *Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life*, provides design guides to minimize environmental impacts in consideration of end of life of semiconductor manufacturing equipment or its components. Referenced Standards and Documents: • ISO Standards ○ ISO/Plastics; Generic Identification and Making of Plastic Products [ISO] 11469 ○ ISO/Environmental Management Systems, Specifications with Guidelines for Use [ISO] 14001

Resource Area	Project Phase	Best Management Practice
• Human Health and Safety	• Planning • Construction • Operation	Participate in the Clean Electronics Production Network's (CEPN) Toward Zero Exposure program to protect workers from chemical hazards in the electronics supply chain. Program signatories commit to (CEPN, 2023a): 1. Protect workers from exposure to CEPN Priority Chemicals in the electronics supply chain, prioritizing elimination or substitution with safer alternatives and protecting workers until that is achieved. 2. Collect data on company and supplier facility use of process chemicals, using the CEPN Process Chemicals Data Collection Tool, to support collective mapping across supply chains. 3. Build safety systems and culture around process chemical management through support for the maturation of governance systems that protect the health of workers, where workers are consulted, informed, and actively participating. 4. Work with selected suppliers to join the Commitment Program to reduce worker exposures to toxic chemicals in the extended electronics supply chain, 5. Ensure progress towards implementing the Commitments through verification and annual reporting to workers and the public. 6. Continuous improvement across all areas above.
• Human Health and Safety	• Planning • Construction • Operation	• Joint chemical safety committees will be formed to engage workers and management in the decision-making process to promote a safe and healthy work environment. CEPN's Joint Chemical Safety Committee Guidance will be consulted during the establishment of worker safety committees. Joint committees serve to protect the • health of workers and ensure workers are consulted, • informed, and actively participating in their protection. Successful Joint Committees (CEPN, 2023b): • Demonstrate management commitment, • Communicate effectively, • Have policies workers can participate without fear of retaliation, • Allow members to do Committee work and training on paid time, • Assign responsibility addressing issues to individuals with relevant authority and resources, and • Ensure that workers and management are trained.

Resource Area	Project Phase	Best Management Practice
• Hazardous and Toxic Materials	• Construction	Establish plans to eliminate and minimize oil or fuel spills from construction equipment.
• Hazardous and Toxic Materials	• Construction	Properly maintain potential sources of spills and leaks, keeping them in good operating condition. Regularly inspect areas where spills might occur to ensure that spill response procedures are in view and adequate stocks of cleanup equipment are readily accessible.
• Hazardous and Toxic Materials	• Operations	Update the facility spill prevention and response plan to reflect changes in hazardous materials resulting from facility modernizations and expansions.
• Hazardous and Toxic Materials	• Planning • Construction • Operations	Install closed loop automated chemical delivery systems to reduce worker exposure to hazardous materials. SEMI F22 and F106 present best management practices for chemical delivery systems: • F22 – Guide for Bulk and Specialty Gas Distribution Systems • F106 – Test Method for Determination of Leak Integrity of Gas Delivery Systems by Helium Leak Detector
• Hazardous and Toxic Materials	• Planning • Construction • Operations	Install and maintain hazardous chemical leak sensors and alarms in accordance with SEMI S15 – Safety Guideline for the Evaluation of Toxic and Flammable Gas Detection Systems and SEMI F1 – Specification for Leak Integrity of High-Purity Gas Piping Systems and Components. • S15 provides considerations for the evaluation of fixed gas detection systems used to monitor for safety of plant personnel, product and materials, the local environment and community. • F1 defines the leak testing requirements and leakage rates for high-purity gas piping systems and components used in semiconductor manufacturing.
• Hazardous Waste and Solid Waste Management	• Construction • Operations	Handle, manage, and dispose of all solid and hazardous waste in accordance with requirements of local, state, and Federal laws, regulations, ordinances, and industry standards. Ensure that all debris is separated and disposed of in a manner that maximizes recycling and is consistent with applicable regulations. In accordance with SEMI S12, the following should be determined prior to decontamination of the manufacturing equipment: the anticipated waste stream(s) to be generated; the owner of each waste stream; the proper location(s) for reuse, recycling or disposal; responsible party(ies) for packaging and removal; and the needs of all parties involved with the handling, storage, and packaging of wastes generated during decontamination procedures.

Resource Area	Project Phase	Best Management Practice
• Hazardous Waste and Solid Waste Management	• Operations	Eliminate or reduce certain solid waste streams through new and improved technology that allows source reduction, reuse, recovery, and closed-loop recycling. In accordance with SEMI S2, equipment should be designed to: prevent the mixing of incompatible waste streams with partitions, double-contained lines, or other similar design features; prevent unintended releases; allow connection to a central waste collection system or segregated collection system to facilitate recycling or reuse; and address construction material and component reuse, refurbishment, and recycling.
• Environmental Justice	• Planning	Identify potential EJ communities and assess any disproportionate health effects the project may have on those communities. Conduct community outreach sessions with EJ populations to understand their concerns. Develop site-specific impact abatement strategies to lessen effects on EJ communities.

APPENDIX B REFERENCES

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APPENDIX C: USE OF PFAS IN SEMICONDUCTOR FABRICATION FACILITIES AND EMERGING PFAS STANDARDS

ACRONYMS AND ABBREVIATIONS

3D NAND	high-aspect ratio channel
ALD	atomic layer deposition
ATPS	assembly, test, packaging, and substrate
BEOL	back end of line
CAR	chemically amplified resist
CAS	Chemical Abstract Service
C-F	carbon-fluorine
-CF2-	fluorinated methylene
-CF3	fluorinated methyl
CMP	chemical mechanical planarization
CPSC	U.S. Consumer Product Safety Commission
CVD	chemical vapor deposition
CWA	Clean Water Act
DUV	deep ultraviolet light
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ETFE	ethylene tetrafluoroethylene
EUV	extreme ultraviolet light
FEOL	front end of line
FFKM	perfluoro elastomer
F-HTF	fluorinated heat transfer fluid
FOSA	perfluorinated sulfonamide
FOSAA	perfluorinated sulfonamidoacetic acid
FOSE	perfluorinated sulfonamide ethanol
FP	fluoropolymer
FTCA	fluorotelomer carboxylic acid
FTS	fluorotelomer sulfonic acid
HFC	hydrofluorocarbon
HFE	hydrofluoroether
HFO	hydrofluoroolefin
HFPO-DA	hexafluoropropylene oxide dimer acid, also known as Gen-X
HTF	heat-transfer fluid
MAC	multiply-alkylated cyclopentane
MCL	maximum containment level
MEMS	microelectromechanical system
NPDWR	National Primary Drinking Water Regulation
OTM	Other Test Method
PAG	photo-acid generator
PBO	polybenzoxazole
PFAS	per- and polyfluoroalkyl substances
PFBS	perfluorobutanesulfonic acid
PFC	perfluorocarbon
PFCA	perfluoroalkyl carboxylic acid
PFECA	per- and polyfluoroether carboxylic acid
PFESA	ether sulfonic acid
PFHpA	perfluoroheptanoic acid
PFHxS	perfluorohexanesulfonic acid
PFNA	perfluorononanoic acid
PFOA	perfluorooctanoic acid
PFOS	perfluoroctane sulfonate
PFOSA	perfluorooctane sulfonamide
PFOSAA	perfluorooctane sulfonamidoacetic acid
PFOSE	perfluorooctane sulfonamide ethanol
PFPE	perfluoropolyether
PFSA	perfluoroalkyl sulfonic acid
PI	polyimide
Plan 15	Effluent Guidelines Program Plan 15
POTW	publicly owned treatment works
ppt	parts per trillion
PTFE	polytetrafluoroethylene
PVD	physical vapor deposition
PVDF	polyvinylidene fluoride
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
TARC	top antireflective coating
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
UCMR 5	Fifth Unregulated Contaminant Monitoring Rule

APPENDIX C: USE OF PFAS IN SEMICONDUCTOR FABRICATION FACILITIES AND EMERGING PFAS STANDARDS

INTRODUCTION

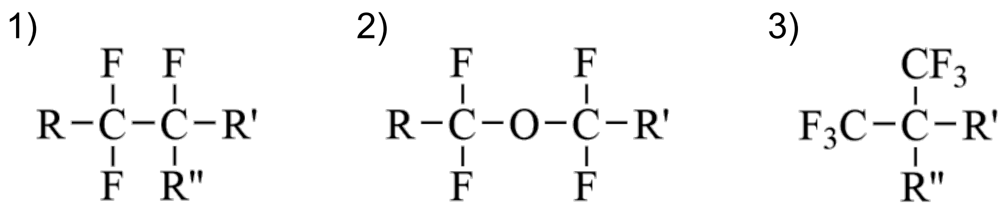
Per- and polyfluoroalkyl substances (PFAS) are a vast group of manufactured chemical compounds that can be broadly defined as containing molecules with a -CF_2- and/or -CF_3 group (SIA, 2023a). Under section 8(a)(7) of the Toxic Substances Control Act (TSCA) and the TSCA implementing regulations at 40 C.F.R. Part 705, EPA defines PFAS as any chemical substance or mixture that contains at least one of the following three sub-structures (**Figure C-1**):

1) R-(CF_2)-CF(R′)R″, where both the CF_2 and CF groups are saturated carbons (carbons which are single-bonded to their maximum stable number of atoms or groups).

2) R-CF_2OCF_2-R′, where R and R′ can either be F, O, or saturated carbons.

3) $CF_3C(CF_3)$R′R″, where R′ and R″ can either be F or saturated carbons.

Figure C-1. TSCA PFAS-Defining Sub-Structures



The Organization for Economic Cooperation and Development notes that the term "PFAS" can be used as a broad, general, and nonspecific term that does not necessarily indicate whether a particular compound is harmful but may merely communicate as a technical matter that the compound has a fully fluorinated methyl or methylene carbon moiety. Under the broadest definitions of PFAS, the term can group together gases, liquids, and solids with vastly different properties and hazards (SIA, 2023a). A 2023 U.S. Consumer Product Safety Commission (CPSC) report compiled available sources from EPA to form a list of 16,229 distinct and currently identified PFAS chemistries (CPSC, 2023). PFAS may range in size from trifluoroacetic acid (CF_3CO_2H) to large, highly complex organic polymers and surfactants (EPA, 2022; SIA, 2023a). PFAS are characterized as either long-chain, which contain six or more linked carbon atoms, or short-chain, which contain fewer than six carbon atoms. To date, most PFAS regulatory efforts have focused on addressing long-chain PFAS; short-chain PFAS are more environmentally mobile and therefore generally more difficult to regulate and remediate (Liang et al., 2023).

PFAS have a variety of unique properties that arise from their chemical structure, mainly through the immense strength of their C-F bonds. Due to these bonds, PFAS are highly stable and extremely durable, allowing for key properties such as heat resistance and water and oil repellency (Leung et al., 2023). Water and oil repellency, also known as hydrophobicity and oleophobicity, allow PFAS to be extremely useful in nonstick and stain repellant applications. Due to these properties, PFAS have been widely used in various industries and products since their introduction in the 1940s. PFAS are key components within countless industrial settings and consumer products, including in: cleaning products, personal care products, and food packaging; fire extinguishing foam and manufacturing; and chemical production facilities (EPA, 2023a). Facilities that manufacture PFAS are referred to as primary manufacturing facilities, whereas facilities that use PFAS to manufacture other products are referred to as secondary manufacturing facilities (EPA, 2023a).

The characteristic stability of PFAS chemicals provides resistance to natural degradation processes, including hydrolytic, photolytic, and oxidative reactions, earning them the name “forever chemicals”. In other words, certain PFAS are environmentally persistent, resisting chemical decomposition or biodegradation (EPA, 2023a). PFAS are often released into the environment during manufacturing and processing as well as during industrial and commercial use. Products known to contain PFAS are regularly disposed of in landfills and by incineration, which can also lead to the release of PFAS (EPA, 2023a). As of February 2024, there are 5,021 PFAS-contaminated sites in the United States (EWG, 2024).

Only a small portion of PFAS, primarily perfluorooctanoic acid (PFOA) and perfluoroctane sulfonate (PFOS), have been well-studied for their environmental deposition mechanisms, human and animal exposure effects, or toxicological effects. Similar to other PFAS, the environmental release of PFOA and PFOS occurs in and around primary and secondary manufacturing facilities (ATSDR, 2019). PFOS has been found in surface water and sediment downstream of manufacturing facilities, wastewater treatment plant effluent and sewage sludge, and landfill leachate in several U.S. cities. In addition, PFOA and PFOS products may contain PFAS precursors in the form of impurities or residuals that can be converted to PFOA or PFOS post-release through biotic or abiotic environmental processes. PFOA and PFOS have been found in remote areas, including in oceans and the Arctic, suggesting the long-range transport potential of PFAS chemicals. As of 2016, PFOA and PFOS have been phased out and replaced with other short-chain PFAS (ATSDR, 2019; EPA, 2023a; HHS, 2016).

Once in the environment, PFAS are inhaled or ingested by humans and animals. Ingestion through drinking water is the primary exposure pathway for humans, although dermal absorption through the skin is also possible, but limited (ATDSR, 2019). Because animals, including humans, are continually exposed to PFAS through ingestion or inhalation, the chemicals gradually build up, leading to the process of bioaccumulation. PFOS in particular has been shown to bioaccumulate in both terrestrial and aquatic animals, whereas PFOA has been shown to bioaccumulate only in terrestrial animals. A growing body of scientific evidence shows that exposure at certain levels to specific PFAS can adversely impact health (EPA, 2023a). These human health effects may include impacts to reproductive, immune, or endocrine (i.e., hormone) systems, as well as an increased risk of cancer, high cholesterol, or obesity (EPA, 2023a). People who work at, or live or recreate near a PFAS-producing facility have higher exposure risk.

Certain demographics also may be more susceptible to higher PFAS exposure risk. Typically, pregnant women, lactating women, and children drink more water per pound than other groups, thus increasing their exposure to contaminated water (depending on the drinking water source). Some PFAS, such as PFOA, can cross the placenta and enter umbilical cord blood (ATSDR, 2019). Infants and young children can be exposed through breast milk, formula, water, or food that contains PFAS, as well as through household items and environmental sources (EPA, 2023a). Children exposed to certain levels of PFAS may experience developmental effects or delays. In the United States and other industrialized countries, most people have measurable amounts of protein-bound and free PFAS chemicals in their blood (ATSDR, 2019).

The 2015-2016 National Health and Nutrition Examination Survey found that average blood levels of PFOA and PFOS, respectively, in U.S. citizens 12 years and older was 1.56 and 4.72 parts per billion (ppb) (ATSDR, 2019). 95 percent of the U.S. population has PFOA and PFOS blood levels less than 4.2 and 18.3 ppb, respectively. PFOA and PFOS bind to tissue proteins and accumulate primarily in the blood, but also in the liver, kidneys, and brain. Persistence of PFAS chemicals in humans and animals is measured as a biological half-life, which is the amount of time in years it takes for half (50 percent) of a particular chemical to be metabolized and/or eliminated from the body (ATSDR, 2019). The biological half-lives of PFOA and

PFOS are approximately 2 to 10 years and 3 to 17 years, respectively (ATSDR, 2019). Most PFAS are not metabolized by the body and are excreted primarily via urine, but also via menstruation, breast milk, and feces.

METHODS FOR THE DETECTION OF PFAS IN THE ENVIRONMENT

PFAS tend to elude conventional detection and remediation technologies due to their innate chemical properties, which has spurred the development of novel detection techniques, but at increased cost and lengthier detection and remediation times (Ross et al., 2018). The detection of PFAS often requires the development and validation of a unique set of detection methodologies.

Despite these challenges, the environmental and human health effects of certain PFAS call for regulatory attention. In response to emerging health concerns related to specific PFAS, EPA and state environmental agencies are updating and developing additional PFAS standards to regulate the manufacture, use, and disposal of PFAS (EPA, 2021a). In addition, the U.S. Department of Agriculture (USDA), U.S. Food and Drug Administration (FDA), U.S. Geological Survey (USGS), U.S. Department of Defense (DOD), and the Centers for Disease Control and Prevention (CDC) have also developed and published PFAS detection methods (EPA, 2024a).

Available PFAS detection methods vary depending on the medium (potable drinking water, wastewater, or source air emissions) (EPA, 2024a). EPA currently employs two methods to detect PFAS in potable drinking water sources in support of the Safe Drinking Water Act (SDWA). Method 537.1 version 2.0 and Method 537 can detect up to 18 and 25 PFAS compounds in drinking water, respectively (EPA, 2019; EPA, 2020). EPA has developed methods for aqueous and solid non-potable water samples primarily through the Clean Water Act (CWA) and methods for solid waste (SW-846) under the Resource Conservation and Recovery Act (RCRA). EPA Method 8327 is suitable for the detection of 24 PFAS in non-potable water (wastewater, surface water, or groundwater), whereas Method 1633 detects 40 PFAS in wastewater, surface water, groundwater, soil, biosolids, sediment, landfill leachate, and fish tissue (EPA, 2024b).

EPA utilizes two Other Test Methods (OTM) for PFAS and fluorinated compounds in source air emissions. OTM-45 focuses on 50 semi-volatile and particulate-bound PFAS, whereas OTM-50 measures 30 specific volatile fluorinated compounds (potential indicators of PFAS) from stationary sources (EPA, 2023b; EPA, 2024c). Method 1633 and OTM-45 were instated in January 2024 alongside Method 1621. Method 1621 was designed to detect adsorbable organic fluorine in aqueous matrices, thus allowing the method to broadly screen for thousands of known PFAS compounds at the part per billion level in aqueous (water) samples. Method 1621 currently is not required for CWA compliance monitoring at the national level, but EPA is considering whether to promulgate it as a mandatory test method through rulemaking (EPA, 2024d).

Table C-1 lists all PFAS that can be detected in the environment via current EPA methods, in addition to their full name, abbreviation, and Chemical Abstract Service (CAS) number.

Table C-1. EPA Methods for the Detection of PFAS in the Environment

EPA Method Number(s)	Analyte Name	Analyte Acronym	CAS Number
Ether sulfonic acids (PFESAs)			
537.1, 533, 1633, OTM-45	9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS (F-53B Major)	756426-58-1
537.1, 533, 1633	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS (F-53B Minor)	763051-92-9
533, 1633, OTM-45	Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	113507-82-7
Fluorotelomer carboxylic acids (FTCAs)			
1633, OTM-45	3:3 Fluorotelomer carboxylic acid	3:3 FTCA	0356-02-05
1633, OTM-45	5:3 Fluorotelomer carboxylic acid	5:3 FTCA	914637-49-3
1633, OTM-45	7:3 Fluorotelomer carboxylic acid (3-perfluoropheptyl propanoic acid)	7:3 FTCA or FhpPA	812-70-4
Fluorotelomer sulfonic acids (FTSs)			
533, 8327, 1633, OTM-45	1*H*,1*H*,2*H*,2*H*-Perfluorohexane sulfonic acid	4:2 FTS	4:2FTS
533, 8327, 1633, OTM-45	1*H*,1*H*,2*H*,2*H*-Perfluorooctane sulfonic acid	6:2 FTS	27619-97-2
533, 8327, 1633, OTM-45	1*H*,1*H*,2*H*,2*H*-Perfluorodecane sulfonic acid	8:2 FTS	39108-34-4
OTM-45	1*H*,1*H*,2*H*,2*H*-Perfluorododecane sulfonate	10:2 FTS	120226-60-0
Per- and Polyfluoroether carboxylic acids (PFECAs)			
537.1, 533, 1633, OTM-45	4,8-dioxa-3*H*-perfluorononanoic acid	ADONA	919005-14-4
537.1, 533, 1633, OTM-45	Hexafluoropropylene oxide dimer acid	HFPO-DA (Gen X)	13252-13-6
533, 1633, OTM-45	Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	151772-58-6

EPA Method Number(s)	Analyte Name	Analyte Acronym	CAS Number
533, 1633, OTM-45	Perfluoro-3-methoxypropanoic acid	PFMPA	377-73-1
533, 1633, OTM-45	Perfluoro-4-methoxybutanoic acid	PFMBA	863090-89-5
Perfluoroalkyl carboxylic acids (PFCAs)			
533, 8327, 1633, OTM-45	Perfluorobutanoic acid	PFBA	375-22-4
537.1, 533, 1633, OTM-45	Perfluorodecanoic acid	PFDA	335-76-2
537.1, 533, 1633, OTM-45	Perfluorododecanoic acid	PFDoA	307-55-1
8327	Perfluorododecanoic acid	PFDoDA	307-55-1
537.1, 533, 1633 OTM-45	Perfluoroheptanoic acid	PFHpA	375-85-9
537.1, 533, 8327, 1633, OTM-45	Perfluorohexanoic acid	PFHxA	307-24-4
OTM-45	Perfluoro-n-hexadecanoic acid	PFHxDA	67905-19-5
OTM-45	Perfluoro-n-octadecanoic acid	PFODA	16517-11-6
537.1, 533, 8327, 1633, OTM-45	Perfluorononanoic acid	PFNA	375-95-1
537.1, 533, 8327, 1633, OTM-45	Perfluorooctanoic acid	PFOA	335-67-1
533, 8327, 1633, OTM-45	Perfluoropentanoic acid	PFPeA	2706-90-3
537.1	Perfluorotetradecanoic acid	PFTA	0376-06-07
8327, 1633, OTM-45	Perfluorotetradecanoic acid	PFTeDA	0376-06-07
537.1, 8327, 1633, OTM-45	Perfluorotridecanoic acid	PFTrDA	72629-94-8
8327, OTM-45	Perfluoroundecanoic acid	PFUnDA	2058-94-8
537.1, 533, 1633	Perfluoroundecanoic acid	PFUnA	2058-94-8
Perfluoroalkyl sulfonic acids (PFSAs)			
8327, 1633, OTM-45	Perfluoro-1-decanesulfonic acid	PFDS	335-77-3
8327, 1633, OTM-45	Perfluoro-1-nonanesulfonic acid	PFNS	68259-12-1
537.1, 533, 8327, 1633, OTM-45	Perfluorobutanesulfonic acid	PFBS	375-73-5

EPA Method Number(s)	Analyte Name	Analyte Acronym	CAS Number
1633, OTM-45	Perfluorododecane sulfonate	PFDoS	79780-39-5
533, 8327, 1633, OTM-45	Perfluoroheptanesulfonic acid	PFHpS	375-92-8
537.1, 533, 8327, 1633, OTM-45	Perfluorohexanesulfonic acid	PFHxS	355-46-4
537.1, 533, 8327, 1633, OTM-45	Perfluorooctanesulfonic acid	PFOS	1763-23-1
533, 8327, 1633, OTM-45	Perfluoropentanesulfonic acid	PFPeS	2706-91-4
Perfluorinated sulfonamide ethanols (FOSEs)			
OTM-45	2-(N-ethylperfluoro-1-octanesulfonamido)-ethanol	N-EtFOSE	1691-99-2
OTM-45	2-(N-methylperfluoro-1-octanesulfonamido)-ethanol	N-MeFOSE	24448-09-07
Perfluorinated sulfonamides (FOSAs)			
OTM-45	N-ethylperfluorooctanesulfonamide	EtFOSA	4151-50-2
OTM-45	N-methylperfluorooctanesulfonamide	MeFOSA	31506-32-8
OTM-45	Perfluoro-1-octanesulfonamide	FOSA	754-91-6
Perfluorinated sulfonamidoacetic acids (FOSAAs)			
OTM-45	N-ethyl perfluorooctanesulfonamidoacetic acid	EtFOSAA	2991-50-6
8327	N-ethylperfluoro-1-octanesulfonamidoacetic acid	N-EtFOSAA	2991-50-6
8327	N-methyl perfluoro-1-octanesulfonamidoacetic acid	N-MeFOSAA	2355-31-9
OTM-45	N-methyl perfluorooctanesulfonamidoacetic acid	MeFOSAA	2355-31-9
Perfluorooctane sulfonamide ethanols (PFOSEs)			
1633	N-ethyl perfluorooctanesulfonamidoethanol	NEtFOSE	1691-99-2

EPA Method Number(s)	Analyte Name	Analyte Acronym	CAS Number
1633	N-methyl perfluorooctanesulfonamidoethanol	NMeFOSE	24448-09-7
Perfluorooctane sulfonamides (PFOSAs)			
1633	N-ethyl perfluorooctanesulfonamide	NEtFOSA	4151-50-2
1633	N-methyl perfluorooctanesulfonamide	NMeFOSA	31506-32-8
8327, 1633	Perfluoro-1-octanesulfonamide	PFOSA	754-91-6
Perfluorooctane sulfonamidoacetic acids (PFOSAAs)			
537.1, 1633	N-ethyl perfluorooctanesulfonamidoacetic acid	NEtFOSAA	2991-50-6
537.1, 1633	N-methyl perfluorooctanesulfonamidoacetic acid	NMeFOSAA	2355-31-9
Additional Targets			
OTM-45	2-perfluorodecyl ethanoic acid	10:2 FDEA	53826-13-4
OTM-45	2-perfluorohexyl ethanoic acid	6:2FTCA or 6:2 FHEA	53826-12-3
OTM-45	2-perfluorooctyl ethanoic acid	8:2 FTA or FOEA	27854-31-5
OTM-45	2*H*-perfluoro-2-decenoic acid	8:2 FTUCA or FOUEA	70887-84-2
OTM-45	2*H*-perfluoro-2-octenoic acid	6:2 FHUEA	70887-88-6
OTM-45	Decafluoro-4-(pentafluoroethyl)cyclohexanesulfonate)	PfecHS	67584-42-3

Sources: EPA, 2024a; EPA, 2019; EPA, 2020; EPA, 2021b; EPA, 2021c; and EPA, 2024b. Note: Methods SW-846, TO-15, OTM-50, and Method 1621 do not list specific, detectable PFAS chemicals.

FEDERAL PFAS RULEMAKINGS

Several proposed federal rulemakings pertain to the use and release of PFAS by industrial facilities.

WASTEWATER

In January 2024, EPA established two new analytical methods to test for PFAS compounds in wastewater and other environmental media. Methods 1621 and 1633 are described in this Appendix under "Methods for the Detection of PFAS in the Environment" (EPA, 2024b; EPA, 2024c).

In January 2023, EPA released Effluent Guidelines Program Plan 15 (Plan 15), which describes analyses, studies, and rulemakings related to effluent limitations guidelines and pretreatment standards. Notably, Plan 15 details EPA's intent to collect and publish nationwide data on industrial discharges of PFAS to publicly owned treatment works (POTWs) in a POTW Influent Study. In addition, EPA will continue monitoring the electrical and electronic component category for PFAS discharge data through implementation of the POTW Influent Study. The POTW Influent Study will help EPA verify sources of PFAS wastewater and assess the need for control measures at the source (EPA, 2023b; EPA, 2022). Data on specific PFAS chemicals used, concentrations in discharges, and whether PFAS discharges are controlled by solvent management plans is limited. Some permitting and control authorities are beginning to include PFAS monitoring requirements in permits; however, monitoring efforts have been limited by the lack of analytical methods for monitoring PFAS in wastewater discharges (EPA, 2022).

DRINKING WATER

In the last two years, EPA advanced a variety of drinking water regulations and standards for PFAS. In August 2023, EPA released the first set of data collected under the fifth Unregulated Contaminant Monitoring Rule (UCMR 5) to improve EPA's understanding of the frequency and concentrations of 29 PFAS in the nation's drinking water systems. As part of UCMR 5, EPA is conducting the most comprehensive monitoring effort for PFAS to date, at every large and midsize public water system in America, and at hundreds of small water systems (EPA, 2024e).

In March 2023, EPA proposed the National Primary Drinking Water Regulation (NPDWR) to establish federally enforceable standards for six types of PFAS known to occur in drinking water: PFOA, PFOS, perfluorononanoic acid (PFNA), hexafluoropropylene oxide dimer acid, also known as Gen-X, (HFPO-DA), perfluorohexanesulfonic acid (PFHxS), and perfluorobutanesulfonic acid (PFBS) (EPA, 2024e). *See* 88 Fed. Reg. 18638 (Mar. 29, 2023).

As shown in **Table C-2** below, the NPDWR PFAS standards include health-based, enforceable maximum containment level (MCL) goals in parts per trillion (ppt, also expressed as nanograms/liter) (EPA, 2024f). In 2022, EPA established non-regulatory, non-enforceable interim drinking water health advisories for four PFAS: PFOA, PFOS, HFPO-DA, and PFBS and its related compound, potassium perfluorobutane sulfonate (EPA, 2023b). The purpose of drinking water health advisories is to provide information on contaminants that can cause human health effects and are known or anticipated to occur in drinking water.

Table C-2. EPA Drinking Water PFAS MCL Goals

Compound	Proposed MCL Goal	Proposed MCL Goal (enforceable levels)
PFOA	Zero	4.0 ppt
PFOS	Zero	4.0 ppt
PFNA	1.0 (unitless) Hazard Index	1.0 (unitless) Hazard Index
PFHxS		
PFBS		
HFPO-DA (GenX)		

Source: EPA, 2024f.

TOXIC SUBSTANCES CONTROL ACT

EPA has been pursuing the regulation of PFAS manufacturing under TSCA since 2019. In October 2023, EPA promulgated TSCA Section 8(a)(7) Reporting and Recordkeeping Requirements for PFAS, requiring any person who has manufactured or imported PFAS or PFAS-containing articles since January 1, 2011 to report usage, production volume, disposal, exposure, and hazard information to EPA (EPA 2023b). Prior to this final rule, EPA also released a framework for TSCA new chemical review of PFAS premanufacture notices and significant new use notices. EPA's 2023 "PFAS Framework" assures consistency with the provisions of TSCA Sections 2 and 5, which regulate chemicals in a manner that promotes technological innovation while ensuring that chemicals are safe for humans and the environment (EPA. 2023b).

EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT

Under the Emergency Planning and Community Right-to-Know Act (EPCRA), certain PFAS are listed under the Lower Thresholds for Chemicals of Special Concern (EPA, 2023c). Additionally, as of November 30, 2023, the *de minimis* exemption under the EPCRA Section 313 Toxic Release Inventory (TRI) that allowed facilities to avoid reporting information on PFAS when those chemicals were used in small concentrations is no longer available. Certain PFAS are now subject to the same reporting requirements as other chemicals of special concern under EPCRA, and EPA is expected to receive more comprehensive data on these PFAS accordingly.

STATE PFAS STANDARDS

As of 2024, 28 states have adopted 141 measures regulating PFAS, and 34 states have introduced 269 measures to regulate PFAS. These regulations vary from banning PFAS throughout a wide range of products (e.g., cosmetics and firefighting foam) to restricting PFAS use in a variety of industries and products (e.g., food packaging, carpet/rug treatments, and textiles). In addition, ten states have adopted enforceable PFAS drinking water standards, whereas 13 states have issued guidance levels, notification levels, and/or health advisories for PFAS in drinking water (Safer States, 2024).

Some states also have begun to monitor for PFAS in industrial wastewater effluent. North Carolina requires PFAS monitoring of POTW influent, and Hillsboro, Oregon, has established quarterly PFAS sampling requirements for industrial dischargers. In addition, EPA identified one permit issued in 2021 by the Vermont Department of Environmental Conservation to semiconductor manufacturer GlobalFoundries that includes quarterly PFAS monitoring requirements for the first year and annual PFAS monitoring beginning in 2022 (EPA, 2022).

Table C-3 below lists any current drinking water MCL standards or guidance issued for specific PFAS in states where semiconductor fab modernization or expansion projects eligible for CHIPS financial assistance may be located.

Table C-3. State PFAS Standards

State	Regulatory Authority	Drinking Water Standards
Arizona	None	None
Californis	California Environmental Protection Agency Office of Environmental Health Hazard Assessment Notice of Adoption of Public Health Goals for Perfluorooctanoic Acid and Perfluorooctane Sulfonic Acid in Drinking Water	PFOA: 0.007 ppt – Guidance PFOS: 1 ppt – Guidance
Colorado	Colorado PFAS Policy 20-1 5 Colorado Code of Regulation 1002-31, Section 31.11(1)(a)(iv) and 1002-41, Section 41.5(A)(1)	PFBS: 400,000 ppt – Guidance PFHxS: 700 ppt – Guidance PFNA, PFOA, and PFOS (combined): 70 ppt – Guidance
Idaho	None	None
Kansas	None	None
Minnesota	Minnesota's PFAS Blueprint	PFBA: 2,000 ppt – Guidance PFBS: 4,000 ppt – Guidance PFHxS: 47 ppt – Guidance PFOA: 35 ppt – Guidance PFOS: 15 ppt – Guidance
New Hampshire	New Hampshire House Bill 1264	PFHxS: 18 ppt – MCL PFNA: 11 ppt – MCL PFOS: 15 ppt – MCL PFOA: 12 ppt – MCL
New Mexico	None	None
New York	Public Water Systems and New York State Drinking Water Standards for PFAS and Other Emerging Contaminants	1,4-dioxane: 1,000 ppt – Guidance PFAS: 10 ppt – MCL PFOA: 10 ppt – MCL

State	Regulatory Authority	Drinking Water Standards
Ohio	Ohio PFAS Action Plan for Drinking Water	HFPO-DA: 21 ppt – Guidance PFBS: 140,000 ppt – Guidance PFHxS: 140 ppt – Guidance PFNA: 21 ppt – Guidance PFOA and PFOS (combined): 70 ppt – Guidance
Oregon	EPA Unregulated Contaminant Monitoring Rule	PFHxS, and PFNA, PFOA, and PFOS, (combined): 30 ppt – Guidance
Texas	None	None
Utah	None	None
Vermont	Act 21 (Senate Bill 49): Vermont 2019 PFAS Law	Perfluoroheptanoic acid (PFHpA), PFHxS, PFNA, PFOA, PFOS (combined): 20,000 ppt – MCL
Virginia	None	None

Sources: BCLP, 2022; MPCA, 2021; NHGC, 2020; NYSDOH, 2022; NCSL, 2023; Ohio EPA, 2019; OHA, No Date; TriHydro, 2023; VTGA, 2019; and BCLP, 2024.

PFAS IN SEMICONDUCTOR MANUFACTURING FACILITIES

Semiconductor device fabrication is a highly specialized manufacturing process, the steps of which vary depending on the manufacturer and the type of chip being produced. Semiconductor manufacturers use PFAS as an essential material in multiple steps in the fabrication process (Isaacs, 2023). This subsection describes the role of PFAS in the fabrication process and is followed by **Table C-4**, which summarizes the key steps in the semiconductor fabrication process that use PFAS.

The general process for semiconductor manufacturing includes the following steps: oxidation, lithography, etching, deposition, ion implantation, metallization and interconnects, passivation, chemical mechanical planarization, dicing, and testing and quality control. PFAS are most utilized during the lithography, etching, and deposition processes, in addition to being used throughout some general processes and equipment (e.g., wet chemical process, heat-transfer fluids [HTFs], assembly, test, packaging and substrate [ATPS], pump fluids and lubricants, and articles) (SIA, 2023a).

The semiconductor fabrication process employs photolithography, a specific subset of lithography, which utilizes a light-sensitive coating, known as photoresist. First, a photoresist is applied to a wafer, which is then exposed to deep or extreme ultraviolet (DUV or EUV) light projected through a photomask (a transparent plate containing a circuit pattern) to transfer a pattern to the chip. After the exposed photoresist pattern undergoes a chemical change, the wafer is then baked to harden undissolved photoresist and developed to dissolve portions hit by light so that the photoresist coating is washed away to reveal a three-dimensional pattern. Etching defines the now-exposed pattern by removing the oxidation layer (deposited during the oxidation step). Etching is typically “wet” or “dry”; in wet etching, the wafer is washed in a chemical bath, while dry etching uses gases to define the exposed pattern. After etching, deposition applies thin layers of a wide range of materials, including metals, insulators, and semiconductors, to the wafer’s surface by using either chemical vapor deposition (CVD) or physical vapor deposition (PVD). This process creates metal (conducting) layers or dielectric (insulating) layers (Khan et al., 2021).

Photolithography currently relies on two crucial PFAS-containing materials: photo-acid generators (PAGs), and top antireflective coatings (TARCs) (SIA, 2023b).

PAGs are a vital component of many semiconductor photolithography formulations, especially chemically amplified resists (CARs), a necessary component for the manufacturing of advanced semiconductors (Ober et al., 2022; SIA, 2023c). PAG acid anions are fluorinated to enable the generation of very strong acids during the imaging process. The strong acids migrate through the photoresist layer at a controlled rate to react with acid-labile (i.e., sensitive) protecting groups in the photoresist polymer and render them soluble in an aqueous base during the photolithography development step (Klikovits et al., 2017). PAGs generally use C2 to C4 (two to four carbon) PFAS-containing perfluoroalkyl acid compounds (SIA, 2023c).

TARCs are applied with photoresist coatings to eliminate UV reflections to increase lithography precision (Ober et al., 2022). TARCs must not intermix with the photoresist and must be easily removed; these properties are enabled by various specialized PFAS (SIA, 2023c).

Other examples of PFAS-containing photolithography components include: (1) photoresist polymers, especially in EUV applications, where PFAS increase EUV absorbance, improve dissolution properties, and increase resolution; and (2) PFAS surfactants, which have unique properties, such as very low surface tension and a combination of hydrophobic and oleophobic behavior, that have been utilized in various types of photolithographic materials used in advanced semiconductor manufacturing (photoresists (248nm, 193nm, immersion, thick film, etc.), chemically amplified polybenzoxazoles/polyimides (PBO/PIs), filter photoresists for imaging, and rinse solutions) (SIA, 2023c).

Additional PFAS-containing compounds are primarily used for etching silicon and silicon-based dielectrics. Etching uses two TSCA-listed PFAS as wet chemicals: hexafluoroethane (CAS number 76-16-4) and perfluorocyclobutane (CAS number 115-25-3) (SIA, 2023d). Additionally, PFAS molecules are used in thermal (plasma-free) selective chemical vapor etching of metals for their selectivity and self-limiting manner (SIA, 2023d).

Deposition uses PFAS for two properties: high volatility and good thermal stability. In atomic layer deposition (ALD) processes, precursors must be thermally stable so that material can be selectively deposited in a self-limiting manner as a monolayer on a chemically activated substrate. PFAS also are used in surface deposition on microelectromechanical systems (MEMS); MEMS require low-energy molecules to reduce surface forces and increase functionalization. PFAS provide very low surface energies due to their highly stable C-F bonds, making them essential in current MEMS fabrication (SIA, 2023d).

PFAS also are used in various direct and indirect processes during semiconductor fabrication. At the ATPS stage of semiconductor fabrication, PFAS-containing, heat-dissipating elements, such as fluorinated heat transfer fluids (F-HTFs), are used for their ability to be simultaneously electrically non-conductive, to be compatible with sensitive electrical components, to remain within suitable toxicity and flammability limits, and to be resistant to catastrophic contamination (SIA, 2023e). The packaging of chips for distribution uses PFAS materials to seal against moisture, provide environmental and mechanical isolation and stability, and reduce stress on solder joints. Packaging uses PFAS in some packaging flux (a liquid used to eliminate oxides and other contaminants), surfactants, and adhesives. PFAS can also be present in manufacturing equipment, such as high-purity water distribution systems (SIA, 2023a).

Lastly, in addition to semiconductor fabrication processes that use PFAS, a significant number of semiconductor articles (i.e., an object of a manufactured shape, surface, or design that determines its function to a greater degree than its chemical composition) contain PFAS (SIA, 2023f). There are five categories of PFAS-containing articles: 1) articles made entirely from fluoropolymers (FPs); 2) articles (assemblies) containing at least one FP article; 3) articles with FP coatings; 4) non-FP articles containing or coated with a PFAS; and 4) non-FP articles containing PFAS processing aids or additives. These articles vary in size from simple components (wiring, tubing, gaskets, etc.), to simple assemblies (capacitors, batteries, sensors, etc.) and complex assemblies (power supplies, controllers, and handling robots) (SIA, 2023f). Examples of PFAS found in articles include four TSCA-listed PFAS: polytetrafluoroethylene (PTFE, CAS 9002-84-0); polyvinylidene fluoride (PVDF, CAS 24937-79-9); perfluoro elastomers (FFKM, CAS 26425-79-6); and perfluorobutanesulfonic acid (PFBS, CAS 375-73-5) (SIA, 2023f).

ENVIRONMENTAL CONCERNS

Wastewater discharge from semiconductor fabrication facilities presents a substantial risk for PFAS contamination of the environment. Although most photolithography waste is handled as a solvent and incinerated, most facilities send 100 percent of TARC waste to industrial wastewater drains, unless segregated in a separate drain and collection system for disposal. TARCs currently account for over 50 percent of total PFAS used in photolithographic processes worldwide and thus contribute a large portion of the PFAS found in wastewater discharges. Worldwide PFAS discharges from photolithography are estimated to be between 2,830 and 38,400 lbs./year (RINA, 2023). Currently, semiconductor fabrication facilities use onsite abatement systems for air emissions and wastewater pretreatment or treatment systems before discharging wastewater; however, the industry is actively continuing to research PFAS-specific treatment technologies for wastewater. Furthermore, analytical methods for the detection of PFAS compounds in wastewater are needed to determine the removal efficiency of such treatment technologies. The current EPA method for detecting PFAS in wastewater is limited to 44 PFAS compounds (EPA, 2021a; EPA, 2021b).

Over the past two decades, the semiconductor manufacturing industry has replaced or reduced the use of certain PFAS. Long-chain PFAS compounds, such as PFOS, have been replaced by short-chain PFAS. Another long-chain PFAS, PFOA, was phased out in the United States by 2015 and is projected to be eliminated globally by 2025 (EPA, 2022; WSC, 2023). Additionally, the global semiconductor industry has worked to limit non-essential uses of PFAS. However, PFAS compounds are challenging to replace entirely. Due to the chemical stability of PFAS, there are currently few adequate substitutes for PFAS in semiconductor fabrication (SEMI, No date). In most photolithography processes, PFAS-free alternatives are expected to take from 15 to 20 years to develop, whereas PFAS-free PAGs are projected to take more than 25 years to develop (RINA, 2023).

Table C-4. Key PFAS Use Applications in Semiconductor Fabrication

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Photolithography	PAGs	Precursor for the photo-acid catalyst needed for CARs, PBO/PI, BARCs, and color filter resists.	Perfluoroalkyl-sulfonates C4 or lower and C4 or lower substituted superacid anions, such as C1. For some advanced resists, these are bound to polymers.	PFAS component of PAGs generates strong acids that do not show side reactions that interfere with the chemical amplification process.
Photolithography	Photoresists – polymers	Control pattern profile in EUV lithography.	C1 PFAS polymer	Increases absorbance, improves dissolution properties, and increases resolution.
Photolithography	Pattern collapse mitigation/ EUV anti-collapse rinses	Prevent pattern collapse.	PFAS-containing materials are used in many formulations that mitigate pattern collapse issues, including fluorinated surfactants, surface modification treatment materials, displacement fluids, and organic solvents.	Low surface tension and high contact angle to reduce capillary forces.
Photolithography	TARCs	Control of thin film interference effects in resists.	Fluorinated water and developer-soluble polymers	High fluorine content is needed to achieve the low refractive index needed to effectively suppress film interference effects.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Photolithography	Surface protectors/ immersion barriers (immersion topcoats)	Protection of the resist from immersion liquid and of the exposure process equipment from contamination. Prevent water film pulling and resist component leaching in immersion topcoats.	Spin-on barriers: water-insoluble and developer-soluble polymers with fluorinated side chains. Embedded barriers (in situ topcoats): oligomeric or low molecular weight polymeric highly fluorinated compounds. Fluoroalcohol methacrylate polymers with high water contact angles (>90º).	Soluble in casting solvents and developer, insoluble in water, and do not intermix with photoresists. Hydrophobicity and control of contact angle, inertness under 193 nanometer (nm) radiation, and transparency.
Photolithography	Surfactants	Improved coating uniformity in photoresists, PBO/PI, BARCs, and color filter resists.	Longer-chain PFAS (C6-C8) and telomer alcohols form polymer backbones. Now mostly replaced by C4 pendant chains.	Low surface tension and control of contact angle.
Photolithography	PBO/PI	Provide protection from electrical, thermal, mechanical, and moisture-related impacts.	Water-insoluble C1 PFAS polymers	C1 PFAS groups, attached to the polymer backbone, provide solubility in environmentally friendly casting solvents and enable aqueous development.
Plasma etch, chamber clean, and deposition	Back end of line (BEOL) interconnect patterning (damascene process)	Definition of trench and via patterns in dielectric films before filling with metal.	Octafluorocyclobutane (C_4F_8)/(RC318) Hexafluoro-1,3-butadiene (C_4F_6) Tetrafluoromethane (CF_4)/(R14) Trifluoromethane (CHF_3)/(R23)	Selectivity to mask materials, selectivity to different dielectrics (ability to stop on certain layers), and profile control of trench/via sidewalls.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Plasma etch, chamber clean, and deposition	High-aspect ratio channel (3D NAND)	Definition of ultra-high-aspect-ratio channel in multiple dielectric layers.	C_4F_8 C_4F_6 CF_4 CHF_3	Selectivity to mask materials, selectivity to different dielectrics, profile control of channel, and high-etch-rate anisotropic process.
Plasma etch, chamber clean, and deposition	Waveguide fabrication in silicon photonics processes	Patterning of waveguides into silicon and silicon-based dielectric materials.	CF_4 CHF_3	Selectivity to mask materials and ability to reduce line-edge and line-width roughness of patterned features to reduce transmission losses caused by scattering.
Plasma etch, chamber clean, and deposition	Front end of line (FEOL) hard mask patterning	Transfers lithographic patterns into a hard mask for subsequent definition of transistors.	CF_4 CHF_3	Selectivity to mask materials, ability to reduce line-edge and line-width roughness of patterned features to reduce transmission losses caused by scattering, and ability to detect process endpoints from the optical emission signature of carbon-containing byproducts such as C-O and C-N.
Plasma etch, chamber clean, and deposition	FEOL spacer patterning	Define spacer structures (dielectric encapsulation that protects the sidewalls of transistor features).	CHF_3	High selectivity to transistor gate materials and underlying substrate.
Plasma etch, chamber clean, and deposition	Through-silicon via etch	Create deep via structures through entire wafers for packaging applications.	C_4F_8 C_4F_6	Thermal resistance, inertness toward aggressive chemicals, nonflammability, low vapor pressure and off-gassing at high operating temperatures and low pressures, and good stick-slip behavior.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Plasma etch, chamber clean, and deposition	Cleaning processes for CVD and PVD chambers	Remove deposit buildup on chamber walls to ensure reproducibility and prevent yield loss caused by contamination.	CF_4 Hexafluoroethane (C_2F_6)/(R116) Octafluoropropane (C_3F_8)/(R-218)	N/A
Plasma etch, chamber clean, and deposition	Deposition precursors for ALD	Improved volatility and stability of ligands for the uniformity of metal deposition and reproducibility of processes.	Transition metal compounds containing the 1,1,1- trifluoro-2,4-pentane-dionate and 1,1,1,5,5,5-hexafluoro- 2,4-pentane-dionate ligands	No known viable alternatives.
Plasma etch, chamber clean, and deposition	Surface treatment processes for area-selective ALD processes	Remove metal-oxide contaminants from surfaces before deposition.	N/A	Unknown
Miscellaneous wet chemical processes (wet chemical etching; planarization; electroplating; and wafer cleaning, rinsing and drying)	Wet etching	Facilitate entry of the wet etchant into - and reaction products out of - a capillary space by reducing the surface tension of the fluid and the contact angle with the solid. Adsorb to a surface to prevent the deposition of metals that are introduced into the solution during an etching process or to suppress etching of one material while another material is preferentially removed. Mitigate the formation of air bubbles.	Aqueous etch/clean formulations Organic-based etch formulations	PFAS additives are critical for some, but not all wet-etch applications. The requirement for a PFAS additive depends on the physical dimensions and aspect ratio of the device feature being etched, and the particular set of materials exposed to the etchant during etching.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Miscellaneous wet chemical processes	Chemical mechanical planarization (CMP)	Surfactants and surface-active materials disperse the particles, provide slurry stability, control the wettability of films and polishing pads, and reduce corrosion.	Oxide CMP slurries Metal CMP slurries Post-CMP cleaning solutions	Fluorinated surfactants are critical to achieving CMP performance requirements in certain situations. In particular, they enable selective film inhibition and the wetting of low-surface-energy substrates.
Miscellaneous wet chemical processes	Cleaning/ stripping	Some wafer clean/strip formulations and cleaning operations conducted on parts outside of clean rooms require organic solvents to provide the necessary solvency and fluid-handling characteristics.	In some applications, these mixtures comprise fluorinated organic solvents and/or fluorinated organic alternatives.	PFAS-containing solvent mixtures are critical for some, but not all solvent-clean applications. The requirement for a PFAS depends on the material properties of the substance that needs removing.
Miscellaneous wet chemical processes	Plating and electroless plating	Surfactants and surface-active materials reduce surface tension to improve wetting and access to the plating bath solution; and mitigate hydrogen gas inclusion and bubble and/or mist formation.	Fluorinated surfactants	Fluorinated surfactants can achieve low aqueous surface tensions. Fluoroalkyl acid surfactants are uniquely strong acids that remain ionized and hydrophilic even if the pH of the plating solution approaches zero.
Lubrication	Oils and greases in vacuum pumps	Effective lubrication of bearings, gears, and seals.	Perfluoropolyether (PFPE) oil Greases containing PFPE base oils with PTFE thickener	Thermal resistance, inertness toward aggressive chemicals, nonflammability, low vapor pressure and outgassing at high operating temperatures and low pressures, stability under high shear forces, low aggression to metals and elastomers. No known viable alternative for PTFE-thickened greases

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Lubrication	Greases and solids used in vacuum processing environments	Lubrication within low-pressure and high-temperature environments that require high purity for low wafer contamination.	Greases containing PFPE base oils with PTFE thickener Greases containing multiply-alkylated cyclopentane (MAC) base oils with PTFE thickener PTFE in solid lubricants	Thermal resistance, inertness toward aggressive chemicals, nonflammability, low vapor pressure and outgassing at high operating temperatures and low pressures, complete oxidation resistance, and good stick-slip behavior. No known viable alternative for PTFE-thickened greases and PTFE solids.
Lubrication	Greases and solids used to lubricate robotic systems, O-rings, and seals	Effective lubrication and sealing within low-pressure and high-temperature environments that require high purity for low wafer contamination.	Greases containing PFPE base oils with PTFE thickener PTFE in solid lubricants	Thermal resistance, inertness toward aggressive chemicals, nonflammability, low vapor pressure and outgassing at high operating temperatures and low pressures, complete oxidation resistance, and good stick-slip behavior. No known viable alternative for PTFE-thickened greases and PTFE solids.
Lubrication	Greases used in photolithography applications	Effective lubrication of moving parts within environments exposed to UV light.	Greases containing PFPE base oils with PTFE thickener	Low outgassing and UV stability. No known viable alternative for PTFE- thickened greases.
Lubrication	Greases used to lubricate gears and bearings	Effective lubrication.	Greases containing PFPE base oils with PTFE thickener	Thermal resistance, inertness toward aggressive chemicals, nonflammability, low vapor pressure and outgassing at high operating temperatures and low pressures, stability under high shear forces, and low aggression to metals and elastomers. No known viable

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
				alternative for PTFE- thickened greases
Lubrication	Greases and solids used to lubricate linear guides, slides, ball screws, and valves	Effective lubrication of mechanical parts that move at high speeds within environments that require high purity for low wafer contamination.	Greases containing PFPE base oils with PTFE thickener PTFE in solid lubricants	Thermal resistance, inertness toward aggressive chemicals, nonflammability, low vapor pressure and outgassing at high operating temperatures and low pressures, and good stick-slip behavior. No known viable alternative for PTFE-thickened greases and PTFE solids.
Heating and cooling	HTFs	F-HTFs are used to transfer heat between process equipment and chillers to provide precise temperature control for specific manufacturing operations.	F-HTF classes include: PFPEs Perfluorocarbons (PFCs) Hydrofluorocarbons (HFCs) Hydrofluoroethers (HFEs) Hydrofluoroolefins (HFOs) Fluorinated ketones Other fluorinated liquids	F-HTFs are electrically nonconductive, compatible with all construction materials including sensitive electrical components, nonflammable, and useful within the operational range required for the manufacturing and testing of semiconductor products. No known viable alternative can meet all these requirements at once.
Heating and cooling	Refrigerants	Fluorinated refrigerants are used within closed systems that undergo repeated phase changes to help transfer heat from process equipment to a facility's central cooling system.	Fluorinated refrigerant classes include: PFCs HFCs HFOs Fluorinated ketones Other fluorinated liquid	The most critical performance requirement of the refrigerant is the ability to maintain the lowest operational set point while avoiding a catastrophic phase shift to a solid form, as the refrigerant must remain in a gaseous or liquid form to remain pumpable and useful for temperature control.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
ATPS	Substrate/printed circuit board	PFAS-containing substrate materials exhibit low dielectric constants and loss, have low moisture absorptivity, can be used over a wide temperature range, and are nonflammable.	PTFE-containing dielectric polymers	Among all polymeric dielectrics, PFAS-containing polymers have the lowest dielectric constants (1.9 to 2.1) and are widely used as substrate materials. Alternatives are viable though with greater dielectric constants.
ATPS	Encapsulants	Encapsulants provide environmental and mechanical isolation of semiconductors and wire bonds in addition to heat conductivity to ensure optimum semiconductor performance.	Fluorinated polymers	PFAS provide low thermal expansion while being electrically insulator and hydrophobic. Alternatives are viable.
ATPS	Release layer	Fluorinated polymers act as “anti-adhesion” or release layers for temporary bonding debonding.	Fluorinated polymers	Fluorinated polymers act as strong release layers but are not critical; alternatives are viable.
ATPS	Adhesive tapes	As a generic adhesive, PFAS-containing materials can help prevent sticking of thermal or UV-curable materials to an applicator during processing.	N/A	Strong alternatives are viable.
ATPS	Flux/surfactants	PFAS-containing chemicals can help control flux spread during high-temperature exposure, so that the flux can remain in the solder joint area during soldering and improve the solder joint quality and yield.	N/A	PFAS-containing surfactants are typically more heat-resistant, with wetting properties that control spread.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
ATPS	Die overcoat/ adhesive	Packaging applications need hermetic and chemical resistance adhesive coatings.	N/A	Adhesive materials required for use in semiconductor packaging must have the ability to simultaneously meet ultra-low dielectric constant property targets as well as reliability requirements such as adhesion to ultra-low roughness and unroughened copper under high-humidity, high-temperature conditions.
ATPS	Underfills	Underfills are typically polymer materials that bind the package to the printed circuit board and reduce stress on the solder joints.	Fluorinated polymers and fluorinated rubbers, such as: Vinylidene fluoride-propylene hexafluoride copolymer; and Tetrafluoroethylene-propylene copolymer.	Underfill will contain approximately 50% silica materials, with the remainder polymeric materials with high viscosity and low volatility.
ATPS	Mold compounds, release layers, and films	Mold compounds are used as a protective outer layer covering most or all of the semiconductor package substances.	PTFE or ethylene tetrafluoroethylene (ETFE)	PTFE is essential for release sheets and there are currently no known alternatives.
ATPS	Thermal interface materials	In order to prevent dual-layer thermal interfaces from ripping, tearing or otherwise losing or disrupting their dielectric or thermal properties during assembly, the material-comprising layer must be tear-resistant and have a high tensile strength.	Fluorinated resins: Fluorocarbon resins; Fluororesins; and Fluorinated polyallyl ether.	Fluorinated resins help achieve high thermal conductivity and can also help hold the components during processing due to high viscosity and elasticity.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
ATPS	Die passivation	PFAS-containing materials are used as part of the controlled collapse of chip connection (C4) bumping process that connects the chip to the interposer.	PFAS-containing polyimide, polybenzoxazole and other epoxy-based passivation.	There are no known alternatives.
Miscellaneous	Articles	PFAS-containing articles includes essential equipment that processes substrates (silicon wafers, reticles); its component parts; and its auxiliary, support or peripheral equipment (chemical controllers, chemical delivery systems, vacuum pumps).	FP and non-FP components containing: PTFE, PVDF, FFKM, and PFBS	The potential substitution of fluoropolymers with alternative materials is problematic, because in general, identifying an alternative that meets the characteristics required for each fluoropolymer article has not been successful and will require invention.

Sources: SIA, 2023a; SIA, 2023b; SIA, 2023c; SIA, 2023d; SIA, 2023e; SIA, 2023f; SIA, 2023g; SIA, 2023h; and SIA, 2023i.

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APPENDIX D: CHEMICAL SUBSTANCES USED AT SEMICONDUCTOR FABRICATION FACILITIES

APPENDIX D: CHEMICAL SUBSTANCES USED AT SEMICONDUCTOR FABRICATION FACILITIES

Table D-1 below is a representative, non-exhaustive list of chemical substances that CPO has identified as historically or currently used at semiconductor fabrication facilities (CPO, 2023a). The types of chemicals used at semiconductor fabrication facilities and their specific applications may vary among facilities. CPO will use Table D-1 to inform its analysis of the potential environmental effects from hazardous and toxic materials used at an applicant's facility on a project-specific basis.

Table D-1. Chemical Substances Used at Semiconductor Fabrication Facilities

CAS Number	Systematic Name	Alternate Name(s)	Purpose
10024-97-2	Nitrogen oxide (N_2O)	Nitrous oxide	Deposition
10025-78-2	Silane, trichloro-	Trichlorosilane	Deposition
10025-87-3	Phosphoric trichloride	Phosphorous oxychloride (POCl3)	Deposition
10026-04-7	Silane, tetrachloro-	Silicon tetrachloride (SiCl4)	Deposition; Wet Etch
10035-10-6	Hydrobromic acid	Hydrogen bromide	Deposition
100-41-4	Benzene, ethyl-	Ethylbenzene	Photoresist Coating
10045-89-3	Sulfuric acid, ammonium iron(2+) salt (2:2:1)	Ferrous ammonium sulfate	Miscellaneous
10102-43-9	Nitrogen oxide (NO)	Nitric oxide	Deposition
10124-56-8	Metaphosphoric acid ($H_6P_6O_{18}$), sodium salt (1:6)	Sodium hexametaphosphate; Hexasodium hexametaphosphate	Miscellaneous
102-71-6	Ethanol, 2,2',2''-nitrilotris-	Triethanolamine	Deposition; Lithography
10294-33-4	Borane, tribromo-	Boron tribromide	Miscellaneous
10294-34-5	Borane, trichloro-	Boron trichloride	Deposition; Dry Etch
10421-48-4	Nitric acid, iron(3+) salt (3:1)	Ferric nitrate	Wet Etch
106-43-4	Benzene, 1-chloro-4-methyl-	p-Chlorotoluene	Photoresist Coating

CAS Number	Systematic Name	Alternate Name(s)	Purpose
107-21-1	1,2-Ethanediol	Ethylene glycol	Wet Etch; Cooling Medium; Dehumidifying Agent
108-10-1	2-Pentanone, 4-methyl-	Methyl isobutyl ketone	Lithography; Photoresist Coating
108-65-6	2-Propanol, 1-methoxy-, 2-acetate	PGMEA (PM Acetate) (C6H12O3), Propylene glycol monomethyl ether acetate, 1-Methoxy-2-propyl acetate	Lithography; Photoresist Coating; Photoresistor Thinners
108-88-3	Benzene, methyl-	Toluene	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; Miscellaneous
108-94-1	Cyclohexanone	Cyclohexanone	Lithography
108-95-2	Phenol	N/A	Lithography
110-43-0	2-Heptanone	Heptan-2-one , Methyl n-amyl ketone (FIFRA-Inerts), Methyl Amyl Ketone	Lithography; Photoresist Coating; Photoresist Solvent
111-15-9	Ethanol, 2-ethoxy-, 1-acetate	Ethylene glycol monoethyl ether acetate	Photoresist Coating
11118-57-3	Chromium oxide	N/A	Deposition
111-65-9	Octane	n-Octane	N/A
111-76-2	Ethanol, 2-butoxy-	Butoxy ethanol, Ethylene glycol monobutyl ether , Ethylene glycol monobutyl, Ethylene glycol monobutyl ether, 2-Butoxy ethanol	N/A
111-96-6	Ethane, 1,1'-oxybis[2-methoxy-	Diethylene glycol dimethyl ether	Lithography
112-04-9	Silane, trichlorooctadecyl-	Octadecyltrichlorosilane, n-octadecyltrichlorosilane, Trichloro(octadecyl)silane	Deposition; Self-assembled monolayer thin films on silicon dioxide substrates
115-25-3	Cyclobutane, 1,1,2,2,3,3,4,4-octafluoro-	C4F8; halocarbon 318, Perfluorocyclobutane	Dry Etch

CAS Number	Systematic Name	Alternate Name(s)	Purpose
116-15-4	1-Propene, 1,1,2,3,3,3-hexafluoro-	Hexafluoropropylene	Miscellaneous
12033-89-5	Silicon nitride (Si_3N_4)	N/A	Raw material
120-80-9	1,2-Benzenediol	Catechol	Wet Etch
120-92-3	Cyclopentanone	Cyclopentane	Lithography
12125-01-8	Ammonium fluoride ($(NH_4)F$)	Ammonium fluoride	Wet Etch
121-43-7	Boric acid (H_3BO_3), trimethyl ester	Trimethylborate	Deposition
121-44-8	Ethanamine, N,N-diethyl-	Triethylamine	Miscellaneous
121-45-9	Phosphorous acid, trimethyl ester	Trimethylphosphite	Deposition
12185-10-3	Phosphorus, mol. (P_4)	Phosphorus (white or yellow)	Deposition
123-41-1	Ethanaminium, 2-hydroxy-N,N,N-trimethyl-, hydroxide (1:1)	Choline hydroxide, Ethanaminium, 2-hydroxy-N,N,N-trimethyl-, hydroxide	Wet Etch
123-86-4	Acetic acid, butyl ester	N-butyl acetate	Lithography; Photoresist Coating
124-38-9	Carbon dioxide	Methanedione	Deposition
126-33-0	Thiophene, tetrahydro-, 1,1-dioxide	Tetrahydrothiophene-1,1-dioxide, Sulfolane	Semiconductor Cleaning
127-18-4	Ethene, 1,1,2,2-tetrachloro-	Perchloroethylene (PCE); Tetrachloroethylene	Miscellaneous
1303-00-0	Gallium arsenide (GaAs)	N/A	Deposition; Raw Material
1305-78-8	Calcium oxide (CaO)	Calcium oxide, Lime	Miscellaneous
1309-64-4	Antimony oxide (Sb_2O_3)	Antimony trioxide	Deposition
1310-58-3	Potassium hydroxide (K(OH))	Potassium hydroxide	Photoresist Coating; Wet Etch

CAS Number	Systematic Name	Alternate Name(s)	Purpose
1310-73-2	Sodium hydroxide (Na(OH))	N/A	Photoresist Coating; Wet Etch
1330-20-7	Benzene, dimethyl-	Xylene	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; Wafer Cleaning
1333-74-0	Hydrogen	H2	Carrier Gas
1333-82-0	Chromium oxide (CrO_3)	Chromium trioxide; Chromium(VI) trioxide, chromic acid	Wet Etch
1336-21-6	Ammonium hydroxide ((NH_4)(OH))	Ammonium hydroxide	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; Wafer Cleaning
13746-66-2	Ferrate(3-), hexakis(cyano-.kappa.C)-, potassium (1:3), (OC-6-11)-	Potassium ferricyanide	Wet Etch
141-43-5	Ethanol, 2-amino-	Ethanolamine	Wet Etch
141-78-6	Acetic acid ethyl ester	Ethyl acetate	Photoresist Coating
142-82-5	Heptane	N/A	Miscellaneous
144-62-7	Ethanedioic acid	Oxalic Acid	Miscellaneous
150-46-9	Boric acid (H3BO3), triethyl ester	Triethylborate (TEB)	Deposition
151-50-8	Potassium cyanide (K(CN))	Potassium cyanide	Wet Etch
1522-22-1	2,4-Pentanedione, 1,1,1,5,5,5-hexafluoro-	N/A	Deposition
156-60-5	Ethene, 1,2-dichloro-, (1E)-	Trans-1,2-dichloroethylene; Trans L-C	Deposition; Miscellaneous
15785-09-8	Cerium hydroxide ($Ce(OH)_3$)	Cerium(3+) trihydroxide	Chemical Mechanical Planarization
1590-87-0	Disilane	silanidylidynesilanylium, H_2Si_2	Deposition

CAS Number	Systematic Name	Alternate Name(s)	Purpose
16774-21-3	Cerate(2-), hexakis(nitrato-.kappa.O)-, ammonium (1:2), (OC-6-11)-	Cerate(2-), hexakis(nitrato-.kappa.O)-, diammonium, (OC-6-11)-	Wet Etch
19287-45-7	Diborane(6)	Diborane, boranylidyneborane	Deposition; Doping Agent
2110-78-3	Propanoic acid, 2-hydroxy-2-methyl-, methyl ester	Methyl 2-hydroxyisobutyrate (HBM)	Lithography; Photoresist Thinner
2314-97-8	Methane, trifluoroiodo-	Trifluoriomethane; Trifluoroiodomethane	Miscellaneous
24937-79-9	Ethene, 1,1-difluoro-, homopolymer	Vinylidene fluoride	Lithography
25101-45-5	Ethene, 1-chloro-1,2,2-trifluoro-, polymer with ethene	Ethene, chlorotrifluoro-, polymer with ethene	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging
2551-62-4	Sulfur fluoride (SF_6), (OC-6-11)-	Sulfur hexafluoride	Deposition; Dry Etch; Plasma Etching Processes
25617-97-4	Gallium nitride (GaN)	N/A	Deposition; Raw Material
26655-00-5	Propane, 1,1,1,2,2,3,3-heptafluoro-3-[(1,2,2-trifluoroethenyl)oxy]-, polymer with 1,1,2,2-tetrafluoroethene	Perfluoro(alkoxy alkane), PFA Fluoropolymer Resin, Poly[tetrafluoroethylene-CO-perfluoro (alkyl vinyl ether)]	Lithography
28906-96-9	Formaldehyde, polymer with 2-(chloromethyl)oxirane and 4,4'-(1-methylethylidene)bis[phenol]	SU-8 Series Resists (Organic Resin Solution); 2-(Chloromethyl)oxirane;formaldehyde;4-[2-(4-hydroxyphenyl)propan-2-yl]phenol; eTECTX Series Resists (trade name)	Lithography
367-57-7	2,4-Pentanedione, 1,1,1-trifluoro-	1,1,1-Trifluoropentane-2,4-dione	Deposition
409-21-2	Silicon carbide (SiC)	N/A	Deposition; Raw Material

CAS Number	Systematic Name	Alternate Name(s)	Purpose
4109-96-0	Silane, dichloro-	Dichlorosilane (Cl_2H_2Si)	Deposition
4394-85-8	4-Morpholinecarboxaldehyde	Morpholine-4-carbaldehyde	N/A
463-58-1	Carbon oxide sulfide (COS)	Carbonyl sulfide (COS), Carbon oxysulfide, Carbonyl sulfide, Carbon oxide sulfide (COS)	Deposition; Precursor for Sulfur Doping; Metal-Organic Chemical Vapor Deposition (MOCVD); Surface Passivation; Gas Sensing
50-21-5	Propanoic acid, 2-hydroxy-	Lactic acid	Miscellaneous
540-42-1	Propanoic acid, 2-methylpropyl ester	2-Methylpropyl propanoate; Isobutyl propionate	Wet Etch
559-40-0	Cyclopentene, 1,2,3,3,4,4,5,5-octafluoro-	Octafluorocyclopentene	Miscellaneous
56-23-5	Methane, tetrachloro-	Carbon tetrachloride (CTC)	Wet Etch
593-53-3	Methane, fluoro-	Methylene fluoride; methyl fluoride; HFC-41	Deposition; Dry Etch; Miscellaneous; Dry Etching
6074-84-6	Ethanol, tantalum(5+) salt (5:1)	Tantalum ethoxide, Ethanol, tantalum(5+) salt	Deposition
630-08-0	Carbon monoxide	Carbon monoxide	Deposition
64-17-5	Ethanol	N/A	Miscellaneous
64-19-7	Acetic Acid	N/A	Wet Etch
67-56-1	Methanol	Methyl alcohol	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; Miscellaneous
67-63-0	2-Propanol	Isopropyl alcohol, Isopropanol, Propan-2-ol	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; Wafer Cleaning
67-64-1	2-Propanone	Acetone	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; Wafer Cleaning

CAS Number	Systematic Name	Alternate Name(s)	Purpose
678-26-2	Pentane, 1,1,1,2,2,3,3,4,4,5,5,5-dodecafluoro-	Perfluoropentane	Wet Etch
685-63-2	1,3-Butadiene, 1,1,2,3,4,4-hexafluoro-	Hexafluoro-1,3-Butadiene, 1,3-Butadiene, 1,1,2,3,4,4-hexafluoro-	Dry Etch
68937-41-7	Phenol, isopropylated, phosphate (3:1)	Isopropylated phenol phosphate (3:1)	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; N/A
697-11-0	Cyclobutene, hexafluoro-	C_4F_6	Miscellaneous
71449-78-0	Sulfonium, diphenyl[4-(phenylthio)phenyl]-, (OC-6-11)-hex fluoroantimonate(1-) (1:1)	SU-8 Series Resists (Organic Resin Solution); P-Thiophenoxyphenyldiphenylsulfonium Hexafluoroantimonate	Lithography
7429-90-5	Aluminum	Aluminum	Deposition; Raw Material
7439-92-1	Lead (Pb)	N/A	Packaging; Raw Material
7439-97-6	Mercury	N/A	Photoresist Coating
7440-01-9	Neon	N/A	Miscellaneous
7440-21-3	Silicon	N/A	Raw Material
7440-22-4	Silver (Ag)	N/A	Raw Material
7440-25-7	Tantalum	N/A	Deposition; Physical Vapor Deposition (PVD)
7440-31-5	Tin	N/A	Packaging; Raw material
7440-32-6	Titanium	N/A	Photoresist Coating; Photocatalytic Baseline
7440-36-0	Antimony	N/A	Deposition
7440-37-1	Argon	N/A	Deposition; Dry Etch; Carrier Gas
7440-42-8	Boron	N/A	Raw Material
7440-47-3	Chromium	N/A	Deposition

CAS Number	Systematic Name	Alternate Name(s)	Purpose
7440-48-4	Cobalt	N/A	Photoresist Coating
7440-50-8	Copper	N/A	Raw Material
7440-56-4	Germanium	N/A	Raw Material
7440-57-5	Gold (Au)	N/A	Packaging; Raw Material
7440-59-7	Helium	N/A	Deposition; Carrier Gas
7440-63-3	Xenon	N/A	Deposition; Dry Etch
7446-09-5	Sulfur dioxide	N/A	Miscellaneous
7447-40-7	Potassium chloride (KCl)	N/A	Miscellaneous
74-82-8	Methane	CH_4	Miscellaneous
74-86-2	Ethyne	Acetylene	Miscellaneous
74-98-6	Propane	N/A	Miscellaneous
75-09-2	Methane, dichloro-	Methylene chloride	Deposition; Lithography; Wet Etch; Packaging; Miscellaneous
75-10-5	Methane, difluoro-	HFC-32	Deposition; Dry Etch
75-24-1	Aluminum, trimethyl-	Trimethylaluminum, Trimethylalumane	Deposition
75-46-7	Methane, trifluoro-	HFC-23; Trifluoromethane	Deposition; Dry Etch
7550-45-0	Titanium chloride (TiCl4) (T-4)-	Titanium tetrachloride, Titanium(4+) tetrachloride	Deposition
7553-56-2	Iodine	N/A	Wet Etch
75-59-2	Methanaminium, N,N,N-trimethyl-, hydroxide (1:1)	Tetramethylammonium hydroxide	Lithography; Wet Etch
75-65-0	2-Propanol, 2-methyl-	Tert-butyl alcohol (TBA), tert-Butanol, tert-Butyl alcohol	Deposition; Lithography; Photoresist Coating; Cleaning

CAS Number	Systematic Name	Alternate Name(s)	Purpose
75-71-8	Methane, dichlorodifluoro-	CFC-12	Dry Etch
75-73-0	Methane, tetrafluoro-	CF4	Deposition; Lithography; Photoresist Coating; Dry Etch; Packaging
75-76-3	Silane, tetramethyl-	Tetramethylsilane	Deposition; Wet Etch; Precursors for low-K barrier films, etch hard masks, and carbon-doped silicon films and silicon carbide-like films
75995-72-1	Butane, 1,1,1,2,3,4,4,4-octafluoro-	Octafluorobutane, 2H,3H-Perfluorobutane	Dry Etch
7601-90-3	Perchloric acid	N/A	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; Wafer Cleaning
76-03-9	Acetic acid, 2,2,2-trichloro-	Trichloroacetic acid	Miscellaneous
76-16-4	Ethane, 1,1,1,2,2,2-hexafluoro-	Hexafluoroethane; perfluoroethane; PFC-116	Dry Etch; Wafer Cleaning
76-19-7	Propane, 1,1,1,2,2,3,3,3-octafluoro-	C3F8; Perfluoropropane; Octafluoropropane; R-218; HALOCARBON 218; Perflutren	Deposition; Dry Etch
7631-86-9	Silica	Silicon dioxide (SiO_2)	Deposition; Miscellaneous
7631-90-5	Sulfurous acid, sodium salt (1:1)	Sodium bisulfite (anhydrous)	Miscellaneous
7637-07-2	Borane, trifluoro-	Boron trifluoride	Deposition
7647-01-0	Hydrochloric acid	Hydrogen chloride; mur+B115+B114; Muriatic acid (27.92%)	Deposition; Wet Etch; Thin Film Deposition/Usually in Single Wafer and Batch Processing; Wafer Cleaning
7647-14-5	Sodium chloride (NaCl)	N/A	Miscellaneous
7647-19-0	Phosphorane, pentafluoro-	Phosphorus pentafluoride	Deposition

CAS Number	Systematic Name	Alternate Name(s)	Purpose
7664-38-2	Phosphoric acid	N/A	Wet Etch
7664-39-3	Hydrofluoric acid	Hydrogen fluoride	Wet Etch; Dry Etch
7664-41-7	Ammonia (NH_3)	N/A	Deposition
7664-93-9	Sulfuric acid	N/A	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging; Wafer Cleaning
7681-11-0	Potassium iodide (KI)	N/A	Wet Etch
7697-37-2	Nitric acid	N/A	Deposition; Lithography; Photoresist Coating; Wet Etch; Packaging
7705-08-0	Iron chloride ($FeCl_3$)	Ferric chloride	Wet Etch
7722-64-7	Permanganic acid (HMnO4), potassium salt (1:1)	Potassium permanganate	Wet Etch
7722-84-1	Hydrogen peroxide (H_2O_2)	N/A	Deposition; Lithography; Wet Etch; Packaging; Wafer Cleaning
7723-14-0	Phosphorus (P)	N/A	Deposition; Raw Material
7726-95-6	Bromine	N/A	Miscellaneous
7727-37-9	Nitrogen	N2	Deposition; Dry Etch; Carrier Gas
7727-54-0	Peroxydisulfuric acid ($[(HO)S(O)_2]_2O_2$), ammonium salt (1:2)	Ammonium peroxydisulfate; ammonium persulfate	Lithography
7758-98-7	Sulfuric acid copper(2+) salt (1:1)	Copper sulfate; Cupric sulfate; copper (II) sulfate; Copper(2+) sulfate	Deposition; Electrodeposition
7782-41-4	Fluorine	N/A	Deposition; Dry Etch; Chemical Vapor Deposition; Plasma Etching; Cleaning (Fluorine compounds)
7782-44-7	Oxygen	O_2 (general grade)	Dry Etch

CAS Number	Systematic Name	Alternate Name(s)	Purpose
7782-50-5	Chlorine	N/A	Dry Etch
7782-65-2	Germane	N/A	Deposition
7783-54-2	Nitrogen fluoride (NF3)	Nitrogen trifluoride	Dry Etch; Wet & Dry Etching/Remove silicon and silicon-compounds
7783-55-3	Phosphorous trifluoride	N/A	Deposition
7783-58-6	Germane, tetrafluoro-	Germanium tetrafluoride	Deposition
7783-61-1	Silane, tetrafluoro-	Silicon tetrafluoride (SiF_4)	Deposition
7783-82-6	Tungsten fluoride (WF_6), (OC-6-11)-	Tungsten hexafluoride	Deposition
7784-42-1	Arsine (AsH_3)	Arsane	Deposition
7790-91-2	Chlorine fluoride (ClF_3)	Chlorine trifluoride, Trifluoro-lambda~3~-chlorane	Dry Etch
7803-51-2	Phosphine	N/A	Deposition; Doping Agent
7803-62-5	Silane	Monosilane, silicon hydride, silicon tetrahydride, silicane	Deposition; Lithography; Dry Etch
78-10-4	Silicic acid (H_4SiO_4), tetraethyl ester	Teos ($C_8H_{20}O_4Si$); Tetraethyl silicate; Tetraethyl orthosilicate	Deposition
78-40-0	Phosphoric acid, triethyl ester	Triethyl phosphate	Deposition
78560-45-9	Silane, trichloro(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)-	Trichloro((perfluorohexyl)ethyl)silane; Trichloro(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silane	Deposition
78-79-5	1,3-Butadiene, 2-methyl-	Isoprene	Photoresist Coating
78-93-3	2-Butanone	Methyl ethyl ketone, Butan-2-one	Lithography
79-01-6	Ethene, 1,1,2-trichloro-	Tricholoroethylene	Deposition; Miscellaneous

CAS Number	Systematic Name	Alternate Name(s)	Purpose
84133-50-6	Alcohols, C12-14-secondary, ethoxylated	Tergitol	Miscellaneous
872-50-4	2-Pyrrolidinone, 1-methyl- or NMP (C_5H_9NO)	NMP (C_5H_9NO), N-Methyl-2-pyrrolidone	Lithography
89452-37-9	Sulfonium, (thiodi-4,1-phenylene)bis[diphenyl-, (OC-6-11)-hexafluoroantimonate(1-) (1:2)	SU-8 Series Resists (Organic Resin Solution); Sulfonium, (Thiodi-4,1-Phenylene) Bis[Diphenylbis](OC-6-11) Hexafluoroantimonate (1-)]	Lithography
9002-84-0	Ethene, 1,1,2,2-tetrafluoro-, homopolymer	Teflon; Polytetrafluoroethylene (PTFE)	Lubrication; Miscellaneous
9011-14-7	2-Propenoic acid, 2-methyl-, methyl ester, homopolymer	Methyl methacrylate homopolymer	Photoresist Coating
95-14-7	1H-Benzotriazole	1,2,3-Benzotriazole; 1,2-Aminozophenylene	Chemical Mechanical Planarization
95-47-6	Benzene, 1,2-dimethyl-	o-Xylene	Photoresist Coating
96-48-0	2(3H)-Furanone, dihydro-	Butyrolactone, Gamma-Butyrolacton (GBL)	Deposition; Lithography; Photoresist Coating; Cleaning
97-93-8	Aluminum, triethyl-	Triethylaluminum	Deposition; Atomic Layer Deposition (ALD)
992-94-9	Silane, methyl-	Methylsilane	Deposition
993-07-7	Silane, trimethyl-	Trimethyl silane	Deposition
999-97-3	Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl)-	Hexamethyldisilizane	Lithography; Photoresist Coating

Sources: CPO, 2024; EPA, 2023.

Note: Deposition generally refers to thin film deposition unless otherwise specified.

APPENDIX D REFERENCES

(CPO, 2024). CHIPS Program Office. Sept. 2023 to May 2024. CPO-derived list of chemicals used at semiconductor fabrication facilities compiled from various sources including federal and state regulations and semiconductor industry information.

(EPA, 2023). U.S. Environmental Protection Agency. 2023. Substance Registry Services. https://cdxapps.epa.gov/oms-substance-registry-services (last accessed Feb. 22, 2024).

APPENDIX E: RESPONSES TO COMMENTS

APPENDIX E: RESPONSES TO COMMENTS

The public has a critical role in helping the CHIPS Program Office (CPO) understand the environmental impacts of the Proposed Action analyzed in the PEA. Public participation promotes transparency, facilitates better decision making, and helps federal agencies identify data gaps and sources of potential concern regarding the environmental impacts of a proposed action. CPO received seven public comment submissions containing comments that addressed a range of issues in the following areas:

- Technical Corrections;
- Due Diligence;
- Application of NEPA;
- Application of the PEA;
- Range of Alternatives;
- Climate Change and Climate Resilience;
- Air Quality;
- Water Quality;
- Human Health and Safety;
- Hazardous and Toxic Materials;
- Hazardous and Solid Waste Management;
- Environmental Justice;
- Socioeconomics;
- Mitigation and Monitoring;
- Best Management Practices; and
- Other Topics.

CPO has considered the comments received and provides responses in **Table E-1** below.

Table E-1: Responses to Comments

Subject	Comment	CPO Response
Technical Corrections	Several commenters suggested technical edits, updates, and corrections to the PEA.	CPO has made technical edits, updates, and corrections to the PEA where appropriate in response to suggestions from commenters.
Technical Corrections	A commenter stated that the first step of semiconductor manufacturing should be defined as the production of semiconductor-grade polysilicon and compound semiconductor substances, not wafer production.	CPO has revised the first paragraph of **Section 2.2.2** to include the production of semiconductor-grade polysilicon and compound semiconductor substances in the description of the semiconductor manufacturing process.
Due Diligence	A commenter requested that CPO make the Environmental Questionnaire available to the public, as well as responses by applicants.	CPO has made the Environmental Questionnaire publicly available on the CPO website[4] as part of the application process and to demonstrate the types of information CPO requires applicants to provide in due diligence. CPO is generally prohibited from disclosing information submitted by applicants under the confidentiality provisions of the CHIPS Act, 15 U.S.C. § 4652.
Due Diligence	Several commenters stated that CPO needs to conduct due diligence and share information with the public.	CPO conducts a rigorous environmental due diligence process for all proposed projects, as discussed in **Section 2.4**, in **Chapter 3**, and **Appendix A**. CPO is generally prohibited from disclosing information submitted by applicants under the confidentiality provisions of the CHIPS Act, 15 U.S.C. § 4652. Environmental impact statements and environmental assessments prepared by CPO will be made publicly available and posted on CPO's website.
Due Diligence	Several commenters stated that CPO must hold funding recipients accountable, as well as obtain historical information about them (e.g., as related to environmental violations or previous facility owners).	CPO conducts a rigorous environmental due diligence process for all proposed projects, as outlined in **Appendix A**, which includes obtaining information on past and pending facility environmental violations. CPO also evaluates environmental risk as part of its review of a proposed project's technical feasibility, which may include a review of historical information if appropriate. These evaluations inform CPO's NEPA reviews. When mitigation measures are necessary

[4] https://www.nist.gov/system/files/documents/2023/12/27/PRA%20Environmental%20Questionnaire-20230825v3.pdf.

Subject	Comment	CPO Response
		to avoid, minimize, or reduce potential adverse environmental effects of providing CHIPS financial assistance to a proposed project, CPO will include such mitigation measures in the NEPA decision and require monitoring of mitigation implementation, and may incorporate enforceable mitigation measures or conditions into CHIPS award agreements.
Due Diligence	A commenter expressed concern that the Climate and Environmental Responsibility Plan that applicants are required to submit to CPO may cover some issues but not others (i.e., although the plan would address project renewable energy use, resilience from weather- and climate-related risks, water conservation, and potential for adverse effects on local communities, it does not require the applicant to describe how it plans to address certain other issues, such as reducing the use of PFAS and other hazardous chemicals, greenhouse gases, and solid and hazardous waste).	Each applicant for CHIPS financial assistance must submit a Climate and Environmental Responsibility Plan as part of its application in response to the NOFO so that CPO may consider the applicant's efforts to go beyond existing climate and environmental requirements. This requirement is separate from and in addition to the CPO NEPA process. As part of the NEPA process, each applicant will still be required to submit detailed information to CPO about all relevant potential environmental effects that would need to be considered in the NEPA review, including effects relating to hazardous chemicals, greenhouse gas emissions, and waste.
Due Diligence	Several commenters stated that the Environmental Questionnaire does not require information from applicants on how they will reduce the use of hazardous substances and that the information it requires applicants to submit is not sufficient to support the PEA's analysis of the potential effects of hazardous and toxic materials at applicants' facilities.	The Environmental Questionnaire is only one early step in the CHIPS application process and is designed to assist CPO in obtaining initial information necessary to determine the appropriate level of environmental review required under the National Environmental Policy Act (NEPA) and other applicable environmental laws. CPO does not rely exclusively on the Environmental Questionnaire and conducts a rigorous environmental due diligence process, as described in **Appendix A**. The applicant is responsible for providing all necessary analysis and documentation to enable CPO to comply with NEPA and other applicable environmental laws. CPO requests additional information or documentation from each applicant as needed on a case-by-case basis. As part of the due diligence process, CPO reviews the compliance history of an applicant's facility, including site-specific information and data in regulatory databases relevant to hazardous and toxic materials. As discussed in **Section 3.8** of the Final PEA, CPO will

Subject	Comment	CPO Response
		require applicants to demonstrate that appropriate safeguards are in place to manage hazardous and toxic materials at a proposed project facility and may require a project to implement BMPs or other relevant mitigation measures to safeguard against hazardous and toxic chemical releases.
Application of NEPA	A commenter stated that projects eligible for coverage under the PEA should not automatically require NEPA review and that projects should be evaluated for whether they constitute a major federal action.	CPO is responsible for ensuring that it satisfies all applicable environmental laws and requirements in connection with activities that receive federal financial assistance through the CHIPS Incentives Program. All CHIPS applicants are responsible for preparing environmental review documents under CPO supervision, as well as obtaining any necessary permits, such as Clean Water Act or Clean Air Act permits. The PEA provides for a more efficient NEPA review process for proposed projects to modernize and expand existing fabs. As discussed in **Section 1.1**, CPO will determine whether an applicant's proposed project is appropriate for consideration under the PEA using a PEA Decision Document (PDD). If CPO determines that the proposed project's environmental effects are not expected to be significant, CPO will finalize the PDD as the NEPA decision for the project. CPO expects the NEPA review process to be completed efficiently for modernization and expansion projects appropriate for the PDD.
Application of the PEA	A commenter requested that CPO clarify in the Final PEA how tiering would occur and stated that CPO NEPA reviews of proposed projects that involve activities beyond modernization or expansion of existing semiconductor fabrication facilities should be able to tier off of the analysis in the PEA.	CPO has revised **Section 1.1** and included **Figure 1.1-1** in the Final PEA to clarify the process CPO will use to determine whether a proposed project is appropriate for coverage under the PEA, and whether a project would require the preparation of a tiered EA. As shown in **Figure 1.1-1**, in general, projects that would avoid potential non-negligible effects on resource areas not analyzed in the PEA and that would avoid potential significant adverse effects on the resource areas analyzed in the PEA may be covered under the PEA using the PDD. If a project could have non-negligible or significant adverse effects on those respective resource areas, CPO will require the preparation of a tiered EA. The tiered EA would be able to tier off of the analysis in the PEA where appropriate.

Subject	Comment	CPO Response
		For NEPA reviews of projects that involve activities beyond modernization or expansion of existing semiconductor fabrication facilities (i.e., that do not fit the description of the Proposed Action in **Section 2.4**), the project may not be eligible for coverage under the PEA, and CPO may require the preparation of a standalone environmental assessment or environmental impact statement, as applicable.
Application of the PEA	A commenter stated that Figure 2.1-1 in the Draft PEA (map of existing semiconductor fabrication facilities in the U.S.) did not reflect an exhaustive list of existing semiconductor facilities and requested that the figure be modified to include the private establishments engaged in semiconductor and related device manufacturing identified by the Bureau of Labor Statistics.	CPO agrees that the map was not an exhaustive representation of semiconductor fabrication facilities in the United States and has removed **Figure 2.1-1** from the Final PEA. To determine whether a proposed project to modernize or expand an existing semiconductor fabrication facility is appropriate for coverage under the PEA, CPO will follow the process described in **Section 1.1** and illustrated in **Figure 1.1-1** of the Final PEA.
Application of the PEA	Several commenters stated that the PEA should not be limited to current-generation and mature-node facilities and should also apply to leading-edge manufacturing, back-end manufacturing, and wafer production.	CPO agrees that node size is not necessarily indicative of potential environmental effects and has revised the PEA to include proposed modernization or expansion of all semiconductor manufacturing facilities, including leading-edge facilities, and to include both front- and back-end manufacturing. CPO has not revised the PEA to include facilities that only produce wafers used as inputs or substrates in manufacturing semiconductor chips. Although such facilities are eligible for funding under the NOFO, the environmental effects have not been analyzed sufficiently for coverage under the Final PEA.
Application of the PEA	Several commenters recommended that CPO include expansion of facilities onto previously disturbed land as part of the existing fab facility footprint and contended that expansions need not necessarily be “internal” to fall within the scope of this PEA.	CPO agrees with the comment and has revised the PEA to clarify that a proposed project that includes expansion of facilities onto previously disturbed land may still be considered under the PEA using a PDD. However, CPO will require a tiered EA to be prepared for any proposed project involving expansion onto previously undisturbed land or involving large ground disturbing activities.

Subject	Comment	CPO Response
Application of the PEA	Several commenters recommended that the PEA analyze environmental effects that are related to land disturbance (e.g., visual resources, vegetation, wildlife).	As stated in **Section 3.0** of the Final PEA, CPO anticipates that potential effects relating to land use, terrestrial biological resources, and visual resources would be negligible or non-existent for proposed projects reviewed under the PEA using the PDD. If a proposed project could have more than negligible potential effects on such resource areas based on site-specific conditions, CPO will require the preparation of a tiered EA.
Application of the PEA	A commenter stated that the PEA should address traffic and how it can be accommodated with existing or planned infrastructure improvements.	As stated in **Section 3.0** of the Final PEA, CPO anticipates that most proposed projects considered under the PEA would involve only operational changes in peak and average daily traffic falling below any federal, state, or local thresholds for conducting a Traffic Impact Analysis or equivalent study. CPO will review project-specific federal, state, or local traffic and transportation studies or plans as part of the due diligence process as described in **Appendix A**. If a proposed project could have more than negligible transportation or traffic effects, CPO will require the preparation of a tiered EA.
Range of Alternatives	Commenters stated that CPO should allow for the full range of possible outcomes under the PEA or state the case for limiting the range of alternatives to proposed action and no action.	Under the CHIPS Act, Congress has directed the Department of Commerce to provide federal financial assistance to incentivize certain investments in semiconductors. CPO must implement the CHIPS Incentives Program in accordance with the CHIPS Act, and has done so in part through issuing the Commercial Fabrication Facilities Notice of Funding Opportunity (NOFO). As explained in **Section 1.2** of the Final PEA, CPO action to provide incentives for the modernization and expansion of existing semiconductor fabrication facilities eligible under the NOFO is needed for CPO to fulfill its CHIPS Act responsibilities, including the requirements of 15 U.S.C. § 4652. Accordingly, and pursuant to NEPA, CPO considered a range of alternatives that would meet the PEA purpose and need. As described in **Section 2.1** of the Final PEA, CPO has determined that the Proposed Action is the only alternative that meets the purpose and need for CPO to support modernization and expansion at existing semiconductor fabrication facilities. The PEA therefore analyzes only the Proposed Action and the no action alternative.

Subject	Comment	CPO Response
Climate Change and Climate Resilience	Several commenters asked that CPO re-evaluate the conclusion that GHG emissions from an individual modernization project would be negligible compared to overall emissions.	CPO has re-evaluated its analysis in **Section 3.4.2** in the Final PEA and concludes that, on balance, semiconductor fab modernization or expansion projects likely would have *minor to moderate* direct effects on climate change. The effects of specific projects may vary depending on the size of the project and the degree to which the project implements BMPs or other mitigation measures, such as installation of abatement systems for fluorinated gases, chip manufacturing process improvements and source reductions, or use of alternative or substitute chemicals. CPO will require larger modernization or expansion projects that could have significant effects to incorporate at least one of those BMPs or mitigation measures, any of which would generally be sufficient to avoid significant effects.
Climate Change and Climate Resilience	A commenter asked that the PEA consider the positive effects of advanced semiconductors in reducing GHG emissions from carbon-intensive industries as a result of advanced chips' increased energy efficiency.	CPO acknowledges the possibility that certain advanced semiconductor chips may be more energy efficient and enable some devices powered by chips to consume less electricity when compared to devices that are powered by older-generation chips. However, in analyzing the potential direct and indirect GHG effects of modernization and expansion projects under the PEA, CPO must consider additional factors, such as the prevalence of high GWP fluorinated gases used in the semiconductor manufacturing process, including for advanced chips. As explained above, CPO concludes that, on balance, semiconductor fab modernization or expansion projects likely would have *minor to moderate* direct effects on climate change. The effects of specific projects may vary depending on the size of the project and the degree to which the project implements BMPs or other mitigation measures, such as installation of abatement systems for fluorinated gases, chip manufacturing process improvements and source reductions, or use of alternative or substitute chemicals. CPO will require larger modernization or expansion projects that could have significant effects to incorporate at least one of those BMPs or mitigation measures, any of which would generally be sufficient to avoid significant effects.

Subject	Comment	CPO Response
Climate Change and Climate Resilience	Several commenters stated that the PEA should require and incentivize applicants to take steps to reduce GHG emissions and require equipment installed to control or abate GHG emissions to be evaluated for secondary releases.	CPO has included several BMPs in the Final PEA designed to abate or reduce facility GHG emissions, including installation of equipment to abate Scope 1 GHG emissions, implementation of fab energy efficiency measures, and purchases of renewable energy credits. As explained above, CPO concludes that, on balance, semiconductor fab modernization or expansion projects likely would have *minor to moderate* direct effects on climate change. The effects of specific projects may vary depending on the size of the project and the degree to which the project implements BMPs or other mitigation measures, such as installation of abatement systems for fluorinated gases, chip manufacturing process improvements and source reductions, or use of alternative or substitute chemicals. CPO will require larger modernization or expansion projects that could have significant effects to incorporate at least one of those BMPs or mitigation measures, any of which would generally be sufficient to avoid significant effects.
Air Quality	A commenter stated that, in certain instances, the PEA should include supplementary analysis to better support its conclusions regarding potential impacts to air quality.	The sections of the PEA discussing potential impacts to air quality have been revised, and additional analysis has been provided.
Water Quality	Several commenters stated that CPO should require pre-treatment (removal for subsequent treatment) of PFAS-containing wastewater at the point of use.	CPO does not have the statutory authority to regulate PFAS or to impose or require any specific standards across the industry. CPO may require projects to commit to specific BMPs related to PFAS on a case-by-case basis, after determining whether and to what extent PFAS-related environmental effects from the proposed project need to be mitigated and the most effective means of accomplishing that mitigation, if required.

Subject	Comment	CPO Response
Water Quality	A commenter stated that where land within the fab facility footprint includes wetlands subject to an existing or pending Clean Water Act Section 404 permit, CPO should rely on the NEPA analysis of the Section 404 permitting authority when evaluating potential effects on wetlands.	CPO will take the Section 404 permit process and existing NEPA analysis into account when evaluating a proposed project that may include effects on wetlands, and may incorporate by reference other environmental analysis, as appropriate. As described in **Section 3.6.1.1**, modernization and expansion projects under the PEA normally would not be expected to involve discharge of dredged or fill material in wetlands or other water resources, but applicants will be required to state whether their projects would involve such discharges so that CPO may consider the appropriate level of environmental review that may be required accordingly.
Human Health and Safety	Several commenters suggested that CPO promulgate health-protective limits, standards, guidelines, and/or programs (e.g., EPA Joint Health and Safety Committee Guidance; California Accident Release Prevention Program) that are more stringent than OSHA standards and are not industry-only (e.g., SEMI) standards.	CPO does not have the statutory authority to impose or require any specific standards broadly across the industry. CPO reviewed multiple standards and worker safety regulations, including those developed by industry, in order to better understand current industry practice. CPO will use BMPs to ensure that applicants protect the health and safety of workers.
Human Health and Safety	A commenter recommended that the PEA include a more robust discussion of current industrial hygiene practices and engineering controls currently employed by the semiconductor manufacturing industry.	CPO has revised the Final PEA to include additional discussion of third-party industrial hygiene standards.

Subject	Comment	CPO Response
Human Health and Safety	Multiple commenters requested that CPO use or require certain sets of workplace standards such as those created by public agencies, the EPA, and/or CEPN, to regulate the use of toxic chemicals. CPO should not rely on proprietary standards developed by industry.	The development of new workplace standards is beyond the scope of this PEA. Furthermore, CPO does not have the statutory authority to impose or require any specific standards. CPO reviewed multiple standards, including those developed by industry, in order to better understand current industry practice. CPO may also use standards from a variety of sources as support for development of best management practices that can be used as mitigation for potential impacts from specific proposed projects. Congress has specifically directed federal agencies to use technical standards that are developed or adopted by voluntary consensus standards bodies (such as SEMI) to carry out their policy objectives and activities. *See* Section 12 of the National Technology Transfer and Advancement Act, available at 15 U.S.C. 272 note.
Human Health and Safety	Several commenters stated that OSHA standards are out of date and insufficiently protective, and one commenter expressed concern that SEMI standards may use OSHA standards as a starting point.	CPO reviewed multiple standards, including those developed by industry, in order to better understand current industry practice, and used standards from a variety of sources to inform development of best management practices that can be used as mitigation for potential impacts from specific proposed projects. The SEMI S2 guidelines specify that chemical emission to the workplace environment during normal equipment operation must result in ambient air concentrations that are less than 1% of the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) or permissible exposure limit (PEL) during normal equipment operation.
Hazardous and Toxic Materials	Several commenters recommended that the PEA better capture information on hazardous materials.	To better understand the potential impacts from hazardous materials used in semiconductor manufacturing, CPO evaluated publicly available information on hazardous and toxic chemicals used in the semiconductor industry, and a compilation of the types of chemicals used are included in **Appendix D** of the Final PEA. CPO also added **Table 3.8-1** that shows TSCA Work Plan Chemicals that are used in semiconductor manufacturing. The Work Plan chemicals list includes a description of the hazard, exposure, and persistence and bioaccumulation criteria met by each chemical, as well as a Hazard Score, an Exposure Score, and a Persistence and Bioaccumulation

Subject	Comment	CPO Response
		Score. Each score is a numerical ranking of either 1 (Low), 2 (Moderate), or 3 (High).
Hazardous and Toxic Materials	One commenter stated that, because PFAS compounds pose a widespread risk to the environment, and regulatory agencies have only begun establishing mandatory exposure standards for a handful of those compounds, it important to monitor air, water, and solid wastes for total organic fluorine, and to implement management practices that remove all PFAS from releases.	CPO does not have the statutory authority to regulate PFAS or to impose or require any specific standards across the industry. CPO will develop and require specific BMPs related to PFAS on a case-by-case basis, after determining what impacts from proposed projects need to be mitigated and the most effective means of accomplishing that mitigation. While this is beyond the scope of the PEA, CPO is interested in working with NGOs and industry to learn about potential substitutes and abatement technologies.
Hazardous and Toxic Materials	One commenter provided a series of recommendations intended to improve Appendix C of the PEA, *Use of PFAS in Semiconductor Fabrication Facilities and Emerging PFAS Standards*. The comments indicated that the narrative descriptions of semiconductor manufacturing processes and the role of PFAS were overly general and imprecise, and did not fully capture the complexity of semiconductor manufacturing processes and the many different and unique application-specific roles that PFAS plays. The commenter provided suggestions for direct edits.	CPO has included a reference to a definition of PFAS materials and has updated the discussion in **Appendix C** to reflect the information provided by the commenter whenever citations were provided or supporting information was available.
Hazardous and Solid Waste Management	Multiple commenters requested that the PEA provide more details about the disposal of hazardous wastes (e.g., methods, locations, cumulative impacts, monitoring, and reporting).	CPO believes that providing additional detail on hazardous waste disposal methods, locations, monitoring, and reporting beyond describing regulatory requirements is too dependent on site-specific information, and, thus, cannot be evaluated effectively in a programmatic document. As appropriate, CPO will tier off of the PEA and incorporate material by reference in any subsequent, site-specific environmental review document to focus on site-specific impacts.

Subject	Comment	CPO Response
Environmental Justice	Several commenters noted that the analysis of the potential effects of proposed projects on communities with environmental justice concerns must consider the cumulative effects of project activities on air and water quality.	CPO will consider cumulative effects on communities with EJ concerns in the environmental justice analysis when applying the PEA to specific projects or in a tiered EA.
Environmental Justice	A commenter requested that CPO's due diligence ensure that communities and tribes receive the maximum possible benefits, are consulted, and receive health and safety information.	As discussed in the Final PEA, CPO will complete an environmental justice analysis during due diligence for every project. As part of the NHPA Section 106 consultation process, CPO will conduct government-to-government consultation with any federally recognized tribe that requests such consultation in connection with a proposed project and will consider effects to historic properties or properties of religious and cultural significance to the tribe in the proposed project area. CPO will make its NEPA review documents and Section 106 agreements publicly available.
Environmental Justice	Commenters recommended that CPO add additional discussion or analysis in the Environmental Justice section.	As discussed in the Final PEA, identification of communities with EJ concerns is most appropriately performed on a site-specific basis. Given the number of facilities potentially eligible under the NOFO and the uncertainty regarding the nature and extent of potential projects, CPO cannot perform an analysis for all potential scenarios, nor is such site-specific analysis appropriate in a programmatic EA. CPO will complete a site-specific environmental justice analysis during due diligence for every project that will be documented in either a decision document for that project or a tiered EA.
Socioeconomics	A commenter recommended that CPO work with the Department of Labor to ensure equity and job quality principles.	Although outside the scope of the PEA, the Department of Commerce and the Department of Labor previously published the Good Jobs Principles.[5] CPO will continue to work to advance these principles through its implementation of the CHIPS Incentives Program and continued collaboration with the Department of Labor. As explained in **Section 3.12**, CPO concludes in the Final PEA that projects under the PEA likely would result in beneficial socioeconomic effects by creating

[5] *See* https://www.dol.gov/general/good-jobs/principles.

Subject	Comment	CPO Response
		specialized employment opportunities and by stimulating indirect job growth and economic activity.
Socioeconomics	Several commenters requested that the PEA include statistics and detailed information related to workforce metrics (e.g., job categories, job numbers, education and certifications needed, wages, training, and apprenticeships).	Although outside the scope of the PEA, CPO included detailed requirements with respect to applicant workforce plans in the NOFO. Applicants are required to collect and subsequently report disaggregated data on outreach, recruitment, hiring, education and outcomes (including job placement and wages) of skills training programs and upskilling efforts, disaggregated data on workforce demographics (including measures of job quality), and efforts to implement training approaches, such as registered apprenticeships. As explained in **Section 3.12**, CPO concludes in the Final PEA that projects under the PEA likely would result in beneficial socioeconomic effects by creating specialized employment opportunities and by stimulating indirect job growth and economic activity.
Socioeconomics	Several commenters stated that the Department of Commerce should ensure that jobs are accessible to a diverse workforce.	Although outside the scope of the PEA, as stated above, CPO included detailed applicant workforce plan requirements in the NOFO. With respect to workforce diversity, applicants must develop an equity strategy, in concert with their partners, to create equitable workforce pathways for economically disadvantaged individuals in their region. Applicants must also take other steps to ensure jobs are equally accessible, such as describing any wraparound services and other barrier reductions they or partners will provide to workers to facilitate access and completion of training as well as transition into and progression in a job. Applicants seeking more than $150 million in CHIPS financial assistance must provide a plan to provide access to childcare.
Mitigation and Monitoring	Several commenters recommended that the PEA articulate clear monitoring and reporting requirements for releases of hazardous and toxic materials and human exposures, including occupational exposures, and stated that monitoring data should be made publicly available.	When mitigation measures are necessary to avoid, minimize, or reduce potential adverse environmental impacts, CPO will require monitoring and may incorporate enforceable conditions into award documents. This determination will be made on a site-specific basis. CPO will also work with companies to identify mechanisms to make information related to the environment and sustainability publicly available, acknowledging the need to balance the public interest with the need to protect confidential and proprietary information.

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Mitigation and Monitoring	Multiple commenters contended that monitoring of PFAS should use Best Available Technology and measure both targeted compounds and total organic fluorine. Monitoring should show that PFAS is being removed from wastewater and not spreading in the environment.	Although the development of improved monitoring methods and requirements for detection of PFAS is beyond the scope of this PEA and CPO's statutory authority, CPO is working with the Administration and other federal agencies to reduce the environmental and human health impacts of PFAS; to identify cost effective alternatives to PFAS that are designed to be safer and more environmentally friendly, methods for removal of PFAS from the environment, and methods to safely destroy or degrade PFAS; and to establish goals and priorities for Federally-funded PFAS research and development.
Mitigation and Monitoring	A commenter requested that medical surveillance/monitoring be required for all workers potentially exposed to hazardous materials.	Requiring medical surveillance/monitoring for workers potentially exposed to hazardous materials is beyond the scope of this PEA and CPO's statutory authority. However, CPO is interested in working with community groups and the public to explore ways to improve worker safety in semiconductor facilities.
Best Management Practices (BMPs)	Commenters provided suggested requirements for funding recipients as part of funding agreements. For example, commenters recommended that the final PEA include BMPs; that funding agreements contain enforceable requirements; that all applicants for CHIPS funding be required to demonstrate that any subsurface contamination at their facilities has been remediated; and that all applicants provide public timetables describing their permit applications and permit modifications.	CPO does not have the statutory authority to promulgate environmental regulations or to impose or require any specific measures broadly across the industry. CPO will require specific BMPs as part of the NEPA process on a project-specific basis, when determining whether application of the PEA to a proposed project will require adoption of mitigation, which would state the most effective means of accomplishing that mitigation and state enforceable mitigation requirements or commitments. Other measures suggested by commenters (such as requiring remediation of subsurface contamination) are beyond the scope of the PEA.
BMPs	Several commenters provided suggestions for BMPs that should be included in the PEA, including the use of worker health and safety standards that are more protective than OSHA's permissible exposure limits (PELs), as well as various tools developed by the Clean Electronics Production Network (CEPN).	CPO appreciates the suggestions for additional BMPs and has incorporated many of them into the final PEA. Please refer to **Appendix B** of the final PEA. OSHA has publicly acknowledged that compliance with OSHA PELs alone is inadequate to avoid potential adverse impacts to worker health and safety from chemical exposures. CPO will require any recipient of CHIPS funding to incorporate, as a mandatory BMP, compliance with alternative exposure limits pursuant to the NIOSH recommended exposure limits (RELs), American

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		Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs), or California Division of Occupational Safety and Health (Cal/OSHA) PELs. In certain other instances, suggested BMPs were beyond the scope of the PEA and could not be incorporated, such as a request for CPO to require source reduction and substitution of hazardous materials.
BMPs	Some commenters stated that the PEA should not rely on SEMI standards because the SEMI standards are private, proprietary, not established through a multi-stakeholder process, and are not publicly available without charge.	CPO reviewed multiple standards, including those developed by governmental authorities as well as by industry, in order to inform development of BMPs that can be used to mitigate potential impacts from proposed projects. Under the National Technology Transfer and Advancement Act (NTTAA), Congress has specifically directed federal agencies to use technical standards developed or adopted by voluntary consensus standards bodies (such as SEMI) to carry out their policy objectives and activities.[6] NIST fulfills its role under the NTTAA consistent with OMB Circular A-119, which further directs government strategy for standards development and promotes agency participation on standards bodies.[7] As part of this process, NIST regularly participates in the standards development process with approved voluntary consensus standards bodies, including SEMI. NIST will work with the relevant standards developers to ensure that standards cited in the PEA are reasonably available, as directed by OMB Circular A-119.
Other Topics	Several commenters believe that Commerce needs to play a role in ensuring that the positive impacts of semiconductor manufacturing are shared equitably between	While these goals are outside the scope of the PEA, CPO's goals include generating benefits for a broad range of stakeholders and communities, creating quality jobs, and supporting well-crafted

[6] *See* 15 U.S.C. § 272, Statutory Notes, Utilization of Consensus Technical Standards by Federal Agencies (added by Section 12 of the National Technology Transfer and Advancement Act of 1995, Pub. L. 104-113, § 12(d), Mar. 7, 1996, 110 Stat. 775), https://uscode.house.gov/view.xhtml?req=(title:15%20section:272%20edition:prelim).

[7] U.S. Office of Management and Budget, Revised Circular No. A-119 (Jan. 27, 2016), https://www.nist.gov/system/files/revised_circular_a-119_as_of_01-22-2016.pdf.

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	different groups; that semiconductor companies treat employees well and foster employee growth and development; and that companies that have higher standards for environmental protection and worker safety are not placed at a disadvantage.	workforce programs. See A Strategy for the CHIPS for America Fund (Department of Commerce, September 6, 2022).