Draft

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

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ACRONYMS AND ABBREVIATIONS

BG	block group
BLS	United States Bureau of Labor Statistics
BMP	best management practice
BPSG	borophosphosilicate glass
CAA	Clean Air Act
CDC	Centers for Disease Control and Prevention
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CMP	Chemical Mechanical Polishing
CO_2e	carbon dioxide-equivalent
CPO	Creating Helpful Incentives to Produce Semiconductors Program Office
CT	census tract
CVD	Chemical Vapor Deposition
CWA	Clean Water Act
DOC	United States Department of Commerce
DUV	Deep Ultraviolet
E&EC	Electrical and Electronic Components
EHS	Extremely Hazardous Substances
EJ	environmental justice
ELGS	Effluent Limitations Guidelines and Standards
EO	Executive Order
EPA	United States Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EUV	Extreme Ultraviolet
F-HTF	fluorinated heat transfer fluid
FLIGHT	Facility Level Information on Greenhouse Gases Tool
FR	Federal Register
GDP	Gross Domestic Product
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GWP	global warming potential
HAP	hazardous air pollutants
HFCs	hydrofluorocarbons
HIA	Health Impact Assessment
HVAC	Heating, Ventilation, and Air Conditioning
IR	Infrared

ISO	International Organization for Standardization
L	liter
lb.	pounds
LED	Light-Emitting Diode
LEPC	Local Emergency Planning Committees
LQG	Large Quantity Generator
MACT	Maximum Achievable Control Technology
mm	millimeter
MMT	million metric tons
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
nm	nanometers
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
OSHA	Occupational Health and Safety Administration
PBT	persistent, bio-accumulative and toxic
PCB	polychlorinated biphenyls
PEA	Programmatic Environmental Assessment
PFAS	per- and polyfluoroalkyl substances
PFC	perfluorocarbon
POTWs	Publicly Owned Treatment Works
POU	point of use
PPA	Pollution Prevention Act of 1990
PPE	personal protective equipment
PSD	Prevention of Significant Deterioration
PTE	Potential to Emit
PVD	Physical Vapor Deposition
RCRA	Resource Conservation and Recovery Act
RF	Radio Frequency
RMMs	Risk Management Measures

RMP	risk management plan
ROC	Region of Comparison
ROI	Region of Influence
RPC	Remote Plasma Clean
RSEI	Risk-Screening Environmental Indicators
RTO	regenerative thermal oxidizer
SEMI	Semiconductor Equipment and Materials International
SERC	State and Emergency Response Commissions
SIA	Semiconductor Industry Association
SIP	State Implementation Plan
SME	Semiconductor Manufacturing Equipment
SQG	Small Quantity Generator
TEPC	Tribal Emergency Planning Committees
TERC	Tribal Emergency Response Commissions
TMAH	Tetramethylammonium hydroxide
TO	Thermal Recuperative Oxidizer
tpy	tons per year
TRI	Toxic Release Inventory
TSCA	Toxic Substances Control Act
U.S.	United States
U.S.C.	United States Code
UL	Underwriters Laboratory
UPS	uninterruptable power supply
UPW	ultra-pure water
USCB	United States Census Bureau
UV	Ultraviolet
VOC	volatile organic compounds
WOTUS	Waters of the United States
WQS	water quality standards
WSC	World Semiconductor Council
°C	degrees Celsius
°F	degrees Fahrenheit
μg	microgram

1.0 INTRODUCTION

The Creating Helpful Incentives to Produce Semiconductors (CHIPS) Incentives Program was authorized by Title XCIX—Creating Helpful Incentives to Produce Semiconductors for America of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 (Pub. L. 116-283, as amended by the CHIPS Act of 2022 (Division A of Pub. L. 117-167) (the “CHIPS Act” or “Act”). 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 of Commerce (Department) to help revitalize the United States (U.S.) semiconductor industry, including $39 billion dedicated to semiconductor manufacturing initiatives. The Act will bolster U.S. leadership in semiconductors, promote innovation in wireless supply chains, and advance technologies of the future. CHIPS financial assistance will be provided for American semiconductor research, development, manufacturing, and workforce development (NIST, 2023).

The CHIPS Incentives Program is administered by the CHIPS Program Office (CPO) within the National Institute of Standards and Technology (NIST) of the Department. The CHIPS Incentives Program Commercial Fabrication Facilities Notice of Funding Opportunity (NOFO) was published in February 2023 and amended in June 2023. The NOFO solicits applications for the construction, expansion, or modernization of commercial facilities for the front- and back-end fabrication of leading-edge, current-generation, and mature-node semiconductors; commercial facilities for wafer manufacturing; and 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 loan or loan guarantees.

The National Environmental Policy Act (NEPA), as amended (42 United States Code [U.S.C.] 4321 et seq.), requires federal agencies to consider the potential consequences of major federal actions to both the natural and human environments as part of their planning and decision-making processes. A Programmatic Environmental Assessment (PEA) can be utilized by a federal agency when the actions under a specific program are routine actions done repeatedly and therefore are likely to have similar impacts that can be similarly evaluated because of like technologies and construction practices. This helps agencies to eliminate repetitive discussions of the same issues, focus on the actual issues ripe for decision, and exclude from consideration issues already decided or not yet ripe at each level of environmental review (40 CFR 1501.11 & 1502.4(b)). This PEA will address financial assistance for the proposed modernization or internal expansion of an existing current-generation or mature-node commercial facility (hereinafter referred to as “facility”) within its existing facility footprint (hereinafter referred to as the “Proposed Action”). The Proposed Action being evaluated would not include facilities that manufacture equipment used in current-generation and mature-node semiconductor fabrication facilities, nor does it include facilities that perform only research and development or fabless firms (i.e., firms that produce their own designs for semiconductors but do not have their own production facilities).

An applicant must be a “covered entity” as defined by the NOFO to be eligible to receive CHIPS financial assistance. An applicant is required to complete a multi-step application process as outlined in the NOFO. One step of the application process is the completion of an Environmental Questionnaire that includes 26 questions on the project scope, local environment, potential for environmental effects, and permits required for construction of improvements and operation of the upgraded facility. 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 a Preliminary Memorandum of Terms for review and negotiation prior to or upon entering the due diligence phase for the application. CPO is responsible for completion of the NEPA process before financial assistance can be provided and may require applicants to commit to appropriate best management practices (BMPs) within the industry to reduce environmental effects resulting from implementation of modernization and/or internal expansion projects. BMPs are listed in **Appendix A**. The NEPA review informs the decision of whether to provide financial assistance for the proposed project.

1.1 PROGRAMMATIC SCOPE

Programmatic consideration of environmental effects and mitigation is a pathway for more meaningful and efficient NEPA review. A programmatic approach provides the most benefit when proposals share a common technology, context, and federal action (e.g., providing financial assistance). To that end, CPO is preparing this PEA under NEPA to examine the expected direct, indirect, and cumulative effects of actions associated with modernization and internal expansion at existing current-generation and mature-node semiconductor fabrication facilities. This Draft PEA provides the public and responsible agencies with information about the Proposed Action and potential effects on the environment.

CPO recognizes that many current-generation semiconductor manufacturers may seek financial assistance to only upgrade their existing equipment and thus could be covered by this PEA. Proposed modernization and internal expansion projects will vary in terms of project or activity size, complexity, geographic location and timing. For a proposed project to be covered under this PEA, CPO will evaluate the project for consistency with the scope of this PEA using an inclusion analysis document (e.g., memo, form, or checklist). This analysis document will include the relevant information learned from a site-specific review and serves as the NEPA analysis documentation for the administrative record as applied to specific projects. If the proposed project includes activities outside of the scope of this PEA, then an additional or tiered NEPA document may be required. This PEA can be used as a planning tool to support tiered, site-specific analyses by narrowing the spectrum of environmental impacts to focus on project-level reviews as needed. The following scenarios describe the possible application of the PEA to a proposed project and whether additional environmental review under NEPA is required:

1. All proposed project activities are described in the PEA or the activities are similar enough to the activities analyzed in the PEA to support a conclusion that their impacts will not be different from those described in the PEA; therefore, no additional NEPA review required;
2. One or more proposed project activities are within the scope of the PEA and others are not; therefore, additional NEPA review would be required; and
3. None of the proposed project activities are within the scope of the PEA; therefore, additional NEPA review would be required.

1.2 PURPOSE AND NEED

The purpose of the Proposed Action is to invest in U.S. production of strategically important semiconductor chips, and assure a sufficient, sustainable, and secure supply of older and current generation chips for national security purposes and for 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 within the existing facility footprint of eligible current-generation and mature-node semiconductor fabrication facilities. Such projects include the replacement or upgrade of existing equipment, the addition of new semiconductor manufacturing equipment within the existing facility footprint, and expansion of cleanroom space.

The Proposed Action is needed to address decades of decline in the U.S. semiconductor manufacturing sector and to promote the production of a domestic supply of advanced semiconductors for 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 communications and navigations systems and complex weapons systems such as those found in sophisticated fighter jets. Semiconductors are key to the technologies of the future, including artificial intelligence and 5G. The U.S., however, 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 some specialty chemicals. The U.S. fabricates only 10 percent of global chip capacity today, and provides only 3 percent of global packaging, assembly, and test capacity (DOC, 2022).

1.3 PUBLIC INVOLVEMENT

This Draft PEA is available for download and review on the Department's CHIPS Incentives Program website at National Environmental Policy Act (NEPA) | NIST. The 30-day public review and comment period will close on January 25, 2024. Comments submitted within the 30-day public comment period will be part of the Administrative Record. CPO will consider any relevant, substantive comments received before finalizing the document.

Comments will be accepted until January 25, 2024. Please follow the online instructions for submitting comments. For additional submission methods, the full public comment policy, information about Confidential Business Information or multimedia submissions, and general guidance on making effective comments, please visit the CHIPS Incentives Program website at National Environmental Policy Act (NEPA) | NIST. Additionally, questions on this PEA can be directed to Mr. David Frenkel by email at chipsnepa@chips.gov.

2.0 DESCRIPTION OF THE PROPOSED ACTION AND ALTERNATIVES

The National Environmental Policy Act (NEPA) requires federal agencies to analyze reasonable alternatives to the proposed agency action. To be considered a reasonable alternative, the Creating Helpful Incentives to Produce Semiconductors for America (CHIPS) Program Office (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 data needs.

The Department of Commerce's (Department's) Proposed Action evaluated in this Programmatic Environmental Assessment (PEA) is for CPO to provide funding for the modernization and expansion of current-generation and mature-node semiconductor fabrication facilities within their existing facility footprint. Specifically, the PEA covers proposed project activities that will take place within existing buildings. The CHIPS Act authorizes the Department to provide financial assistance to incentivize the U.S. production of strategically important semiconductor 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 for critical manufacturing industries. The Proposed Action addressed by this PEA falls within that scope. Therefore, this PEA only considers one action alternative and the No Action alternative.

2.1 SCOPE

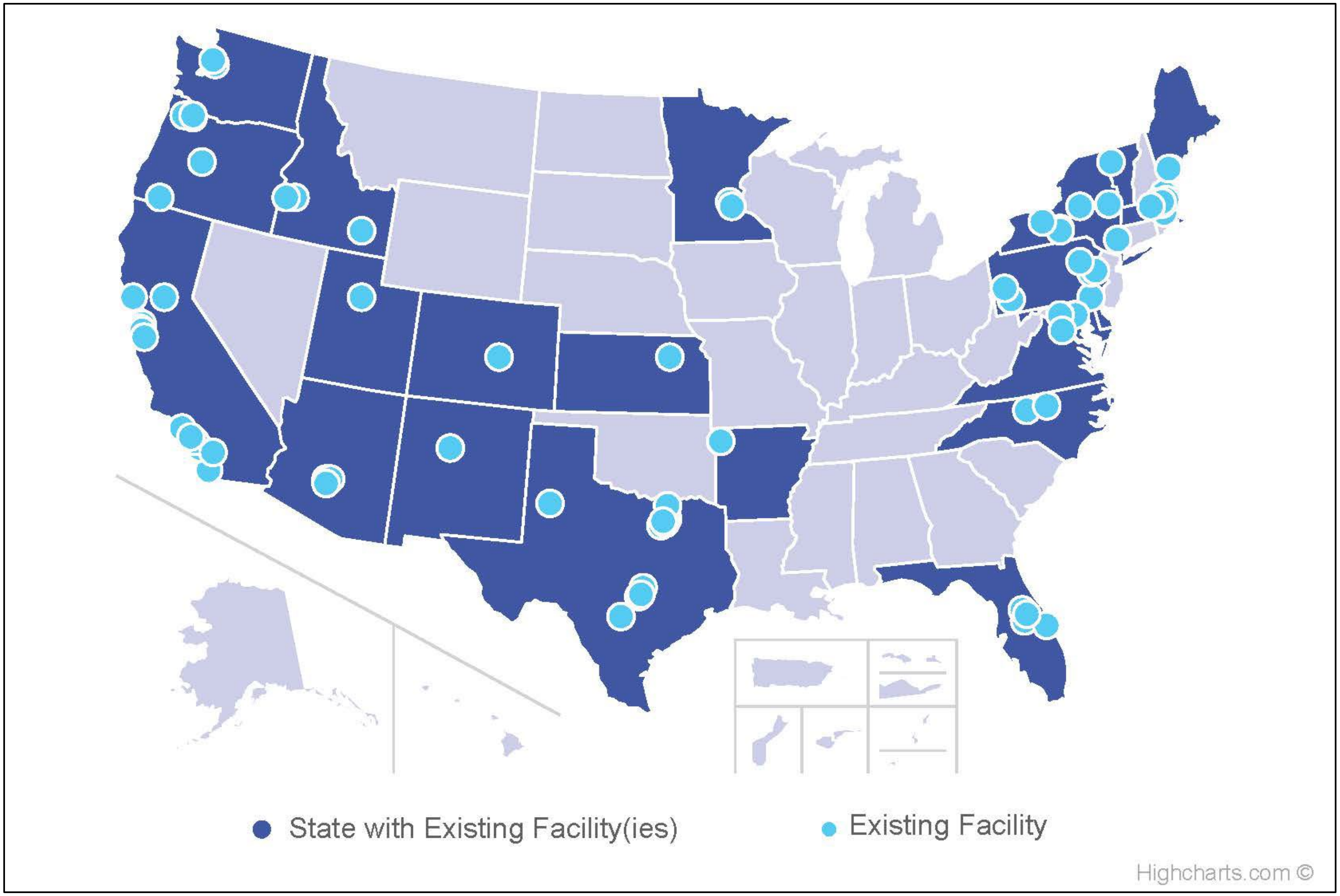
Through the CHIPS Incentives Program, CPO proposes to provide financial assistance for modernization and internal expansion of private industry current-generation and mature-node semiconductor fabrication facilities. This could be accomplished by one or more of the following activities that are included in the scope of this PEA:

- Replacing existing equipment;
- Upgrading of existing equipment;
- Adding new semiconductor manufacturing equipment;
- Expanding cleanroom space and adding new cleanroom equipment; or
- Disposing of equipment that is replaced.

Any of the activities noted above must occur within the existing facility footprint to be covered by this PEA. No additional land disturbance would occur.

Current-generation facilities produce semiconductors using up to 28-nanometer (nm) process technologies and include logic, analog, radio frequency, and mixed-signal devices (not leading edge). Mature-node facilities fabricate generations of: (a) logic and analog chips that are not based on fin field-effect transistor (FinFET), 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. This PEA does not cover facilities that manufacture equipment that is used in current-generation and mature-node semiconductor fabrication facilities, nor does it include facilities that perform only research and development or fabless firms.

The action area, or geographic scope, of the PEA encompasses U.S. states with existing facilities. **Figure 2.1-1** below depicts the distribution of existing facilities throughout the U.S. using the best available industry data; however, this may not be an exhaustive list. There are no existing facilities in Alaska or Hawaii.



Source: SIA, 2023.

Figure 2.1-1. Existing Semiconductor Fabrication Facilities in the U.S.

The time period in which projects under the Proposed Action would occur would vary by project, depending on the size and complexity of the project and the specific activities funded.

2.2 SEMICONDUCTOR MANUFACTURING OVERVIEW

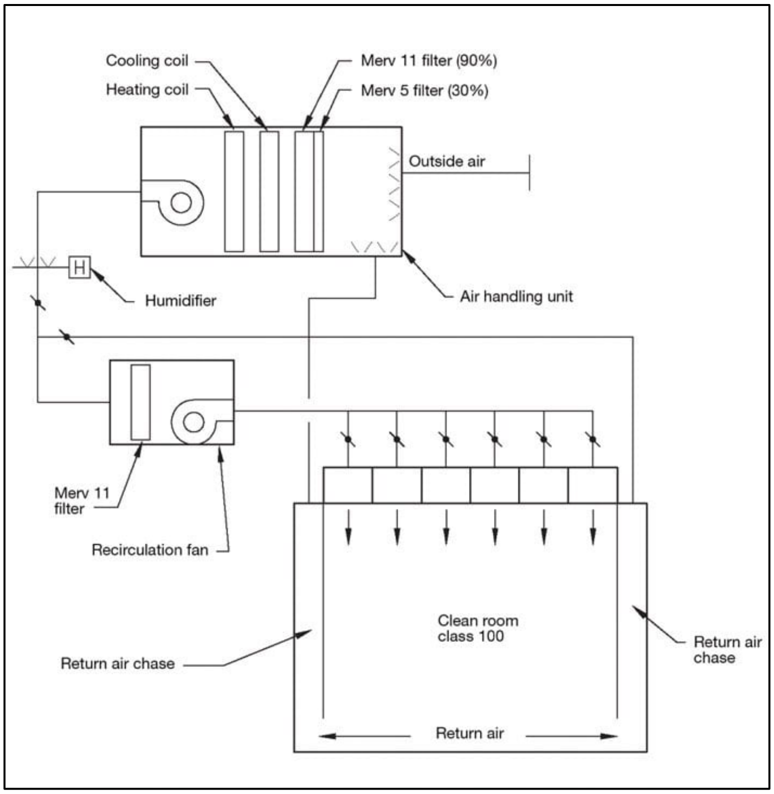
The process of creating a semiconductor chip consists of thousands of steps and can take more than 90 days from design to production. Semiconductor chip manufacturing is conducted in cleanrooms to maintain quality and purity.

2.2.1 Cleanrooms

In most cases, semiconductor cleanrooms must comply with International Organization for Standardization (ISO) 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 micrometer (µm) or smaller. Semiconductor cleanrooms must also meet the requirements of ISO 14644-2, which imposes a quality control system in order to maintain these standards. However, not all processes require such stringent control; for example, the testing of manufactured wafers could be performed in ISO Class 7 or ISO Class 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 may also have its own filtration system to remove particles from exhaust. An example of the airflow system for a cleanroom is shown below in **Figure 2.2-1**.



Source: Sakraida, 2008

MERV: Minimum Efficiency Reporting Value, a measure of a filter's ability to capture larger particles between 0.3 and 10 µm.

Figure 2.2-1. Example Clean Room Airflow System

Semiconductor cleanrooms also must be controlled for other 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 wafer production. Wafers are typically 99.999 percent pure silicon, sliced from a cylinder of silicon (known as an ingot) to the appropriate thickness. Wafers may also be created from other materials such as gallium nitride, gallium arsenide, germanium, and silicon carbide which may be used for certain high-temperature or high-speed chips (e.g., defense applications) (Khan et al., 2021). The wafers are then polished to create an extremely smooth surface and transported to semiconductor fabrication facilities such as those that are covered under this PEA. Facilities dedicated solely to wafer production are not covered under this PEA.

Once the wafer is at a semiconductor fabrication facility, the semiconductor fabrication process continues with the following essential steps as described below for a standard silicon wafer in **Figure 2.2-2**:

- **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: positive and negative. Positive resist becomes more soluble when exposed to ultraviolet (UV) light, so that it can be removed through the etching step. Positive resist 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 photomask, a transparent plate containing a circuit pattern to transfer the pattern to the chip. This causes the 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, while 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 are called dopants and they 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, which 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 polyimide, which offer good adhesion, low moisture permeability, and compatibility with the underlying semiconductor materials.
- **Chemical Mechanical Planarization:** Once one layer is complete, it is flattened and the process repeats 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:** Tests of the chips include temperature, speed and operation to ensure the semiconductor performs properly.

The process described above is known as "front-end semiconductor manufacturing" and refers to the process steps from a blank wafer to a completed wafer; all subsequent steps are referred to as back-end manufacturing. As a wafer proceeds through the front-end process, hundreds of individual process tools, or Semiconductor Manufacturing Equipment (SME), are used and require a range of chemicals, water, and energy as inputs. Within each type of SME, a facility will typically have up to a dozen or more pieces of equipment from different suppliers. **Table 2.2-1** summarizes the types of SME used in the manufacturing steps as well as the general industry trends for pollution control and conservation of water and energy.

After the front-end semiconductor manufacturing process is complete, the chips are transported offsite to a packaging facility where each chip is mounted, interconnected, and encapsulated in a protective housing. The housing is a protective metal container with a cooling system to ensure the chips do not overheat. Separate packaging facilities are not covered under this PEA. If, however, packaging or wafer production occurs at the same facility as chip production, then they could be covered under this PEA.

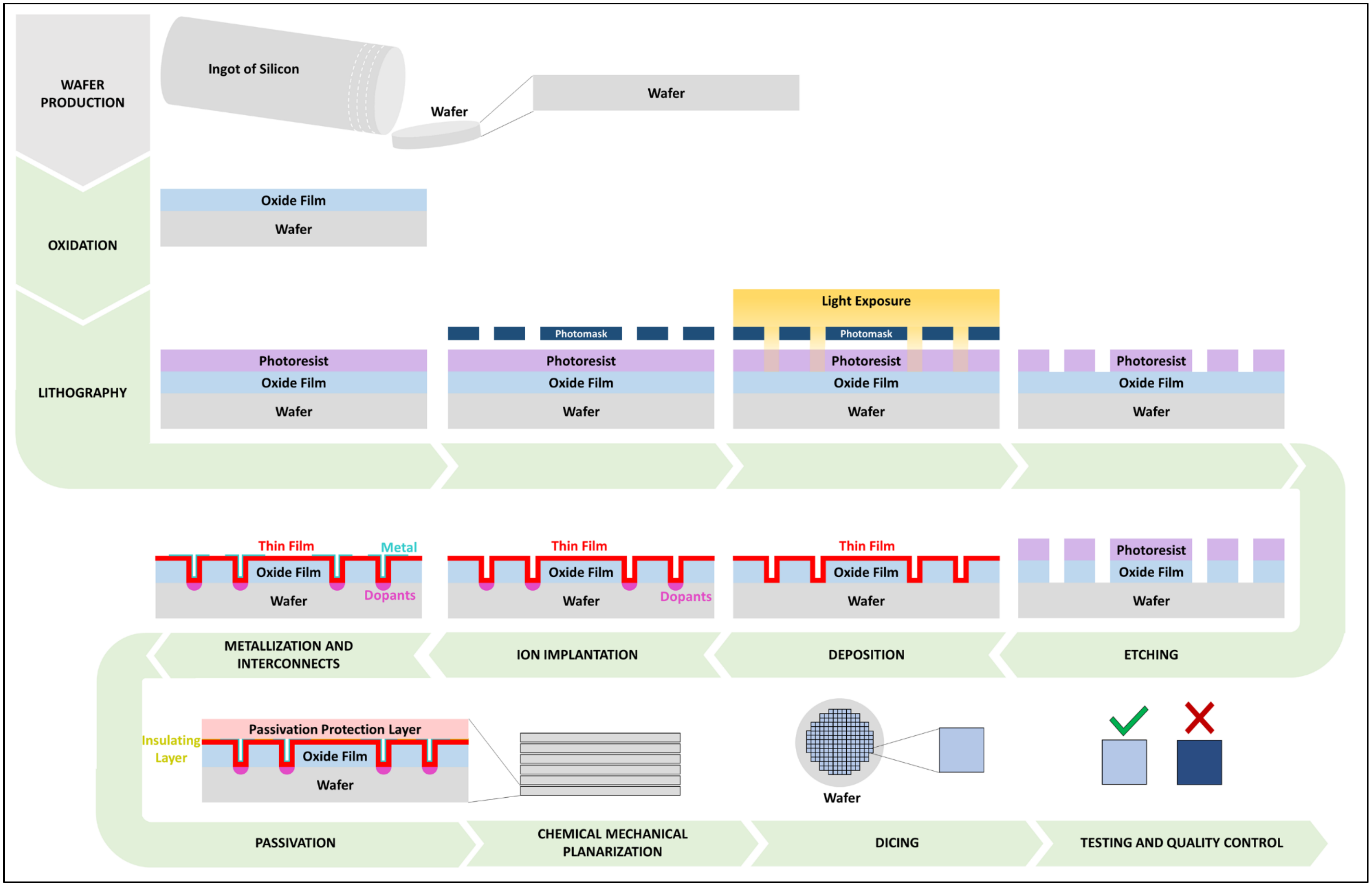


Figure 2.2-2. Front-End Semiconductor Manufacturing Process

Table 2.2-1. Semiconductor Manufacturing Process and Equipment

Production Process	Semiconductor Manufacturing Equipment (SME)	Pollution Control, Water and Energy Conservation Trends
Oxidation	• Wet or dry thermal oxidation equipment • Plasma-enhanced CVD equipment • Electrochemical anodic oxidation equipment • Diffusion/oxidation furnaces	Manufacturers are increasingly using single wafer cleaning processes, which increases energy and water consumption per wafer; however, facilities 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 Pod (FOUPs) and other types of automated wafer handling systems • Resist processing (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, would reduce the consumption of water, chemicals, and energy needed in the process.

Production Process	Semiconductor Manufacturing Equipment (SME)	Pollution Control, Water and Energy Conservation Trends
Etching	• Dry (gas) etching which may include equipment for conductor etching, dielectric etching, ion milling, and/or dry stripping • Dry cleaning equipment • Wet etching and wet 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. PFAS compounds are resistant to hydrolytic, photolytic, and oxidative reactions which limits wastewater treatment technologies to high temperature processes (high cost) or adsorption onto a media. Adsorption has limitations on the ability to remove small molecules and requires disposal of the media. 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 B** for more detailed information on PFAS use in semiconductor fabrication facilities.
Deposition and Passivation	• CVD equipment including those for plasma CVD, low pressure CVD, high temperature CVD, and atomic layer deposition. • PVD • Electrochemical coating • Spin-coating • Rapid thermal processing • Tube-based diffusion and deposition • Deposition (non-integrated circuits)	Deposition and dry etching use high global warming potential (GWP), fluorinated greenhouse gases (GHGs) (F-GHGs) including perfluorochemicals (PFCs), hydrofluorocarbons (HFCs), and nitrous oxide (N_2O). Facilities are reducing these emissions through process optimization, alternative chemistries, and/or abatement.
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.

Production Process	Semiconductor Manufacturing Equipment (SME)	Pollution Control, Water and Energy Conservation Trends
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	Facilities are trending towards 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 area, and ultra-pure water (UPW) to support a given number of wafers, which drives more water, energy, and chemical demand.
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 • Systems-on-a-chip (SoC) test • Burn-in test • Linear and discrete test • Handlers & 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.

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

2.2.3 Utilities/Resources Used in Manufacturing

An average semiconductor fabrication facility uses millions of gallons of water per day. Water consumption in semiconductor fabrication facilities will typically fall 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 (< 1 percent). Most of the process water used in a facility is purified to provide UPW and supplied to various wet processing semiconductor manufacturing equipment. Cooling towers are the single largest loss of process water from semiconductor fabrication (IEEE, 2023).

All SME and associated support equipment, such as vacuum pumps and local exhaust abatement, require energy to operate. Lithography, etching, and deposition tend to be the most energy intensive process steps. Energy is also used for generating nitrogen, which is used to protect wafers from moisture and oxygen as described below, and for purifying other bulk gases. Cleanrooms require energy for recirculation air flow, temperature and humidity control, and make-up air to meet contamination control requirements. Large semiconductor facilities can use up to 100 megawatt-hours of power every hour. Reliable power is essential to support the manufacturing process. Any electricity supply issue, such as a power outage or voltage sag, can disrupt operations and lead to wasted batches of semiconductors. An uninterruptable power supply (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 power to the main is restored or until gas or diesel generators can be fired up to temporarily support the load.

2.2.4 Materials Used in Manufacturing

The most commonly used bulk gases are nitrogen, hydrogen, helium, and argon. A modern semiconductor fabrication facility 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 is also an inert gas with a low ionization energy; therefore, it is used as a plasma gas for etching and deposition reactions as well as in lithography (Air Products PLC, 2022).

The semiconductor fabrication process uses a wide range of raw materials, and the following is a list of the most frequently used materials and their purpose:

- **Silicon (Si):** Silicon's properties as a semiconductor makes 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 of metals, 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 since it provides a valence electron when it bonds with silicon.
- **Platinum silicate (PtSi):** Platinum silicate is a substance 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 is a compound of silicon and chromium 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 is a better conductor than copper and gold, silver 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 is used similarly as lead, to solder the external leads of integrated circuit packages (IEEE, 2020).

2.2.5 Manufacturing Waste Streams

Waste streams from the manufacturing process are discussed at a facility level rather than for each process step because facilities may combine, treat, and reuse waste streams at various points in the manufacturing process using a variety of methods. This section summarizes the general contents of waste streams and reuse and treatment methods prior to discharge.

Semiconductor fabrication facilities employ a range of chemistries throughout the manufacturing process. Chemicals used may include sulfuric acid, phosphoric acid, litho developer (containing Tetramethylammonium hydroxide [TMAH]), polar and non-polar organic solvents, nitric acid, citric acid and many others. The use of such chemistries generates wastes and wastewater, including concentrated salt solutions, or brine, that require treatment prior to disposal. These waste streams are treated and reused; treated and disposed; or disposed without treatment. Common constituents of wastewater streams include hydrofluoric (HF) acid; ammonium $[NH_4]^+$, solvents including isopropyl alcohol (IPA), glycols, ethers, and polar and non-polar photoresist; metals; concentrated sulfuric acid (H_2SO_4); other acidic and alkaline compounds; suspended solids include silicon; litho developing waste containing TMAH; and concentrated phosphoric acid (IEEE, 2023).

GHG and carbon emissions are primarily driven by the facility's energy use, which is in turn driven by water purification and treatment systems, including brine management (IEEE, 2023). Additionally, deposition and dry etching use high GWP gases, such as F-GHGs (including PFCs), hydrofluorocarbons (HFCs), and nitrous oxide (N_2O) as well as fluorinated heat transfer fluids. EPA has estimated that between 10 to 80 percent of these F-GHGs pass through the manufacturing tool chambers unreacted and are released into the air (EPA, 2023a). **Section 3.5 Air Quality** of this PEA provides a detailed description of emissions control technologies and practices.

2.3 NO ACTION ALTERNATIVE

Under the No Action Alternative, CPO would not provide funding for the applicant's proposed project. The No Action Alternative therefore assumes that the applicant would not complete the proposed modernization/expansion project, and the facility would continue production at the same rate, using the same equipment, and within its existing facility footprint. For the purpose of this analysis only, CPO would assume that applicable permit conditions and regulatory standards would be met by the facility.

2.4 PROPOSED ACTION ALTERNATIVE

The Proposed Action evaluated in this PEA is for CPO to provide federal financial assistance to an applicant for its proposal to modernize and expand an existing current-generation and mature-node semiconductor fabrication facility within its existing facility footprint. An applicant may propose any combination of equipment upgrades, equipment replacement, and equipment additions, described in **Section 2.2** of this Draft PEA, in its modernization and expansion project, as long as the existing footprint of the facility is not changed. The resulting modernization and/or expansion of the facility could increase production of the facility's current product; continue production at the same rate but produce an improved product; expand production and improve the product; or reduce production but improve the product. Possible project scenarios are described below in **Section 2.4.1**.

As part of the due diligence process to receive CHIPS Incentives Program funding, an applicant must demonstrate compliance with all existing facility permits. Upon completing modernization and/or internal 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. Additionally, the facility may be required to commit to appropriate best management practices (BMPs) within the industry to reduce environmental effects resulting from implementation of the modernization and/or internal expansion project. The resource-specific analysis in this PEA indicates whether adhering to BMPs and/or using the best available technologies would be required to remain consistent with the environmental effects described. BMPs are included in **Appendix A**.

2.4.1 Modernization to Produce an Improved Product

Modernization of a facility can lead to an improved product. For example, until approximately five years ago, gallium nitride semiconductor devices had only been demonstrated in 150-millimeter (mm), or smaller, wafer diameter facilities 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 facility's equipment 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.

2.4.2 Expansion of Cleanroom Space

Converting a portion of the internal space within the fabrication facility into new cleanroom space could allow a facility to increase production within its existing facility footprint. Interior spaces that can be converted into cleanroom spaces include storage space, office space, and obsolete processing spaces. New semiconductor manufacturing equipment would be added to the new cleanroom space to increase the number and types of semiconductors that can be manufactured at the facility.

Supporting infrastructure at the facility may need to be upgraded or refreshed to support the additional capacity. This 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, as well as upgrades to electrical connections, wiring, installation of new air handler units and replacement or change out of existing air handler units. All of these improvements to auxiliary process support infrastructure must occur on previously disturbed spaces within the existing facility footprint, such as existing concrete pads or other areas already significantly modified from the previous natural state (e.g., conversion of a parking lot space into a gas tank storage space would be covered as the area being modified had previously been converted from its natural state to a human-made structure.)

2.4.3 Modernization to Increase Production

Some facilities would not require an increase in cleanroom space in order to increase production volumes. For instance, a facility might undergo manufacturing equipment replacement if the equipment has reached or exceeded industry lifecycles, has limited remaining capability, or utilizes lagging technology. The supporting fabrication facility infrastructure systems would need to be refreshed or upgraded to handle new manufacturing equipment or types of semiconductor wafers. 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 facility refurbishment could also include the purchase and installation of the latest semiconductor manufacturing equipment, replacing tools that are obsolete, less capable, and significantly more expensive to operate and maintain. The new equipment that is being installed is also likely to be more space efficient, allowing the facility to allocate valuable cleanroom space for additional capacity and capability into the future, increasing the economic competitiveness of the facility.

Upgrades to the facility 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 upgrades to the fire alarm, emergency power, and manufacturing chemical distribution systems equipment. Projects that would abate GHG emissions could include conversions of certain CVD tools to remote nitrogen trifluoride (NF_3) plasma clean sources and installation of combustion abatement units.

3.0 AFFECTED ENVIRONMENT AND ENVIRONMENTAL CONSEQUENCES

This chapter discusses the existing conditions for resource areas that may be affected by the Proposed Action and the environmental consequences of the Proposed Action and No Action alternatives.

Resource Areas Considered but not Carried Forward for Full Analysis

All potentially relevant environmental resource areas were considered for analysis in this Draft Programmatic Environmental Assessment (PEA). To focus the analysis, potential effects to the following resource areas were not analyzed in detail as they are anticipated to be negligible or non-existent based on the scope of proposed projects to be covered under this Draft PEA. Further environmental analysis will be conducted if there are exceptional instances in which potential effects to these resource areas could occur:

- Land Use: Under the Proposed Action, equipment modernization and internal expansion would occur within the existing facility footprint and not alter existing land use. Temporary storage areas may be needed for construction; however, these staging, or laydown, areas will be restricted to already disturbed areas. Accordingly, direct effects to land use are not analyzed. Federal funding for modernization could induce additional private investment to expand semiconductor manufacturing at existing or new locations, which could affect future land use. As a result, potential cumulative effects to land use are discussed in **Chapter 4.0 Cumulative Effects** of this Draft PEA.
- Cultural and Historic Resources: The first semiconductor device was first developed in 1901; however, modern production of semiconductors began around 1960. Existing facilities for semiconductor fabrication and research largely consist of newer buildings that likely are not eligible for the National Register of Historic Places. Additionally, because the funding under the Proposed Action must be used to modernize equipment and expand production within the existing facility footprint, archaeological sites, tribes, or traditional cultural properties are unlikely to be affected.
- Geology, Topography, and Soil: Under the Proposed Action, equipment modernization and internal expansion will occur within the existing facility footprint and would not cause disturbance of geological resources.
- Coastal Barrier Resources and Wild and Scenic Rivers: Under the Proposed Action, equipment modernization and internal expansion will occur within the existing facility footprint and not include disturbance to coastal barrier resources or rivers.
- Wetlands and Floodplains: Under the Proposed Action, equipment modernization and internal expansion will occur within the existing facility footprint and will not include disturbance to wetlands and floodplains.
- Terrestrial Biological Resources: As the Proposed Action will occur within the existing facility footprint in industrial settings, the action will not modify, physically disturb, or disrupt any terrestrial vegetation, terrestrial wildlife, or terrestrial special status species such as migratory birds. Terrestrial biological resources will not be affected by the Proposed Action.
- Visual Resources: As the Proposed Action will occur within the existing facility footprint in industrial settings, no permanent changes to visual resources are expected to occur.
- Transportation and Traffic: This PEA covers proposed projects where the anticipated operational change in peak and average daily traffic falls below any local, state, and federal thresholds for conducting a Traffic Impact Analysis or equivalent study.

3.1 AFFECTED ENVIRONMENT METHODOLOGY

The affected environment sections describe the existing conditions from a nationwide, programmatic perspective and discuss specific components of regulations related to the existing conditions where appropriate.

3.2 ENVIRONMENTAL CONSEQUENCES METHODOLOGY

The environmental consequences analysis considers how the condition of a resource may change as a result of implementing the two alternatives and describes the potential effects in terms of type (i.e., direct, indirect, cumulative, beneficial, adverse), context, duration, and intensity, which are considered in combination to determine significance.

3.2.1 Types of Effects

According to the Council on Environmental Quality's (CEQ's) National Environmental Policy Act (NEPA) Regulations under 40 Code of Federal Regulations (CFR) 1500-1508, 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 CFR 1508.8(a)).
>
> **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 CFR 1508.8(b)).

Identified effects may be either adverse or beneficial or both. The CEQ NEPA Regulations describe the need for identifying and differentiating between adverse and beneficial effects, but do not define these terms. Under this Draft PEA, both adverse and beneficial effects are defined as:

> **Adverse effects**: Those effects having a negative and harmful effect on the analyzed resource. An adverse effect causes a change that moves the resource away from a desired condition or detracts from its appearance or condition.
>
> **Beneficial effects**: Those effects having a positive and supportive effect on the analyzed resource. A beneficial effect constitutes a positive change in the condition or appearance of the resource or a change that moves the resource toward a desired condition.

3.2.2 Significance Criteria

Significance criteria provide a structured framework for assessing effects, supporting conclusions regarding the significance of effects, and comparing effects between alternatives. To aid federal agencies in determining significance, the regulations published by CEQ in 1978 established broad criteria directing agencies to base such determinations on evaluations of both the context and intensity of the effect(s) of a proposed action. In the 2020 regulations, CEQ replaced the terms "context" and "intensity" but preserved their fundamental concepts [85 *Federal Register* 43322 (July 16, 2020)]. Like the 1978 regulations, the 2020 CEQ regulations establish two broad criteria for evaluating significance. The 2020 CEQ regulations direct agencies to analyze: (i) the potentially affected environment (formerly "context") and (ii) the degree of the effects (formerly "intensity") of the proposed action [40 CFR 1501.3(b)].

Evaluation of the affected environment refines the former "context" and focuses on the proposed action's setting, geographic extent of the affected area (e.g., a site-specific project likely involves effects on the local area), and the occurrence and condition of the physical, ecological, and socioeconomic resources [40 CFR 1501.3(b)(1)]. The second criterion, similar to the "intensity" or "severity" concept, directs agencies to consider the "degree" of effect on these resources [40 CFR 1501.3(b)].

The 2020 regulations further explain that agencies should consider whether effects will be short-term or long-term; will be adverse or beneficial; will affect public health and safety; or will cause a violation of federal, state, tribal or local law protecting the environment [40 CFR 1501.3(b)(ii)-(iv)]. Agencies should also consider whether the proposed action is related to other "connected actions" (defined at 40 CFR § 1501.9(e)(1)) in determining significance [40 CFR 1501.3(b)]. Analyses prepared under the 2020 regulations, therefore, require express consideration of both the affected environment and the degree to which the proposed action is likely to affect resources within the affected environment.

To aid in consideration of the affected environment or "context," the CHIPS Program Office (CPO) considered whether potential effects would be:

- Localized – Effects would affect the resource in the immediate vicinity of the semiconductor fabrication facility.
- Regional – Effects would affect the resource on a regional level, extending well past the immediate vicinity of the semiconductor fabrication facility.
- National – Effects would affect the resource on a nationwide level, extending well past the region in which the facility is located.

To aid in determination of the degree to which effects on resources would occur, or their "intensity," CPO considered both their potential duration and the potential magnitude of effects. In addition to the definitions below, effects could be continuous (i.e., constant) or intermittent (i.e., recurring or periodic). Continuous and intermittent effects could occur temporarily or in the short or long term.

- Temporary – Effects would occur only during the time that a semiconductor fabrication facility is under active construction for modernization, equipment replacement, or internal expansion.
- Short-term – Effects would likely continue beyond the time of active construction but would not last more than several months.
- Long-term – Effects would likely continue well beyond the time of construction for several months or longer, but not indefinitely.
- Permanent – Effects would last indefinitely or for the life of a semiconductor fabrication facility.

Four impact descriptors are used to categorize the potential magnitude of effects: negligible, minor, moderate, and major, as defined below:

- Negligible – Minimal impact on the resource would occur; any change that might occur would be barely perceptible and would not be easily measurable.
- Minor – Change in a resource would occur, but no substantial resource impact would result; the change in the resource would be detectable but would not alter the condition or appearance of the resource.
- Moderate – Noticeable change in a resource would occur and this change would alter the condition or appearance of the resource; the integrity of the resource would remain intact.
- Major – Substantial impact or change in a resource would occur that is easily defined and highly noticeable and that measurably alters the condition or appearance of the resource; the integrity of the resource may not remain intact.

3.3 RELEVANT ENVIRONMENTAL LAWS AND REGULATIONS

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

Table 3.3-1. Regulatory Requirements Addressed in the Draft PEA

Environmental Law and Regulations	Responsible Agency	Summary	Site-Specific Compliance Requirements
Clean Water Act (CWA) 33 United States (U.S.) Code (U.S.C.) 1251 et seq.	U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (USACE), and State Agencies	The CWA established the basic structure for regulating pollutant discharges into the waters of the U.S. The National Pollutant Discharge Elimination System (NPDES) (Section 402) regulations apply to point sources that discharge pollutants to waters of the U.S., including stormwater from any construction activities that disturb more than 5 acres of land. Section 404 regulates the discharge of dredged or fill material into waters of the U.S., including wetlands.	NPDES Permit (Section 402) and Section 404 Permit
Clean Air Act (CAA) 42 U.S.C. 7401 et seq.	EPA and State/Local Air Pollution Control Agencies	The CAA is designed to control air pollution on a national level. The CAA established various permitting programs which are mostly implemented by states, local agencies, and approved tribes and sometimes implemented by EPA Regional Offices.	Title V Operating Permit, New Source Permit, and Green House Gas (GHG) Permit
Toxic Substances Control Act (TSCA) 15 U.S.C. 2601 et seq.	EPA	TSCA requires reporting, record-keeping and testing requirements, and restrictions relating to chemical substances and/or mixtures including the use, and disposal of specific chemicals including 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 chemicals 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 into the environment.	Toxics Release Inventory (TRI) Program and Tier II Reporting
Occupational Safety and Health Act 29 U.S.C. 651 et seq.	Occupational Health and Safety Administration (OSHA)	OSHA ensures safe and healthy working conditions by authorizing the enforcement of the standards for worker health and safety and public safety.	Compliance with OSHA standards

Environmental Law and Regulations	Responsible Agency	Summary	Site-Specific Compliance Requirements
Resource Conservation and Recovery Act (RCRA) 29 U.S.C. 651 et seq.	EPA	RCRA authorizes the EPA to regulate hazardous waste and non-hazardous solid waste. Hazardous waste is regulated from cradle to grave, including the 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 Act (AIM) 42 U.S.C. 7675 et seq.	EPA	AIM directs EPA to reduce production and consumption of hydrofluorocarbons (HFCs) in the U.S. by 85 percent over 15 years beginning in 2021.	Adherence to HFC production and consumption allowances; recordkeeping and reporting requirements

Compliance with the EOs listed in **Table 3.3-2** has been considered in the preparation of this Draft PEA based on federal funding of the facility's proposed scope of action.

Table 3.3-2. Executive Orders Considered in Preparation of the Draft PEA

Executive Orders	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 to advance 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** of this Draft PEA
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.	For more information see **Section 3.11 Environmental Justice** of this Draft PEA

Executive Orders	Summary	Additional Information
EO 13693, Planning for Federal Sustainability in the Next Decade	Requires federal agencies to improve environmental and energy efficiency and sustainability, including reducing greenhouse gas emissions, fleet performance, energy conservation, solid waste diversion, and pollution prevention	For more information **see Section 3.4 Climate Change and Resiliency** of this Draft PEA
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 Resiliency and Chapter 4.0 Cumulative Effects on the Environment** of this Draft PEA
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

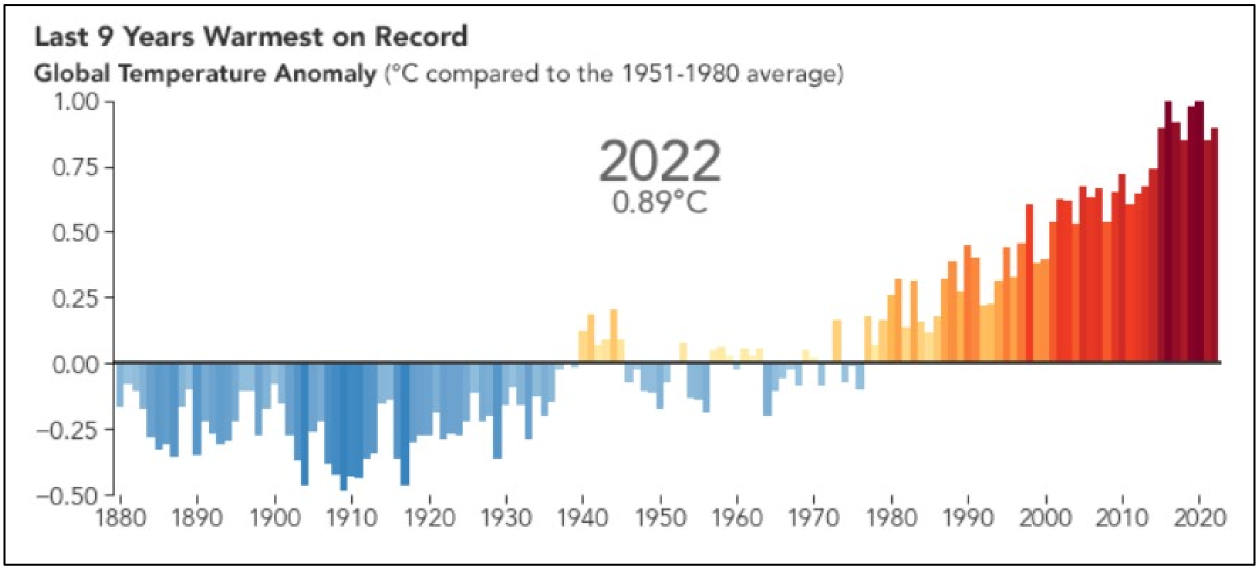
This section describes the affected environment and the consequences of climate change and climate resiliency on the Proposed Action and the No Action Alternative.

3.4.1 Affected Environment

Climate refers to the predictable, average weather, temperature, and precipitation patterns that characterize a region, while **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 resiliency and adaptation refer to "changes in processes, practices and structures to moderate potential damages to or benefit from opportunities associated with climate change" (UNFCC, No Date-b). It is the capacity of countries and communities to successfully cope with current and future impacts from climate changes, while working to prevent those impacts from worsening.

Since the 19th 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).



Source: NASA Earth Observatory, 2022

Figure 3.4-1. Average Temperatures at the Earth's Surface from 1880 to 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 (U.N., No Date).

3.4.1.1 Regulatory Framework for Climate Change and Climate Resilience

Executive Orders

On February 19, 2021, President Biden's Executive Order (EO) 13990, *Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis*, reinstated the Obama Administration's Climate Change EO 13653, *Preparing the United States for the Impacts of Climate Change*, and the White House 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 appropriate context when analyzing a proposed action's climate impacts.

In May 2021, President Biden's EO 14030 *Climate-Related Financial Risk,* reinstated the Obama Administration's EO 13690, *Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input.* This EO establishes the Federal Flood Risk Management Standard (Standard), "a flexible framework to increase resilience against flooding and help preserve the natural values of floodplains," through amendments to EO 11988, *Floodplain Management*.

Laws and Regulations

In 2021, Congress passed the American Innovation and Manufacturing Act (AIM). It directs the United States (U.S.) Environmental Protection Agency (EPA) to reduce production and consumption of hydrofluorocarbons (HFCs) in the U.S. by 85 percent over the next 15 years, a measure 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 these requirements, which can be found under 40 CFR Part 84. EPA issued HFC production and consumption allowances in accordance with the final rule for the 2024 calendar year. From 2024-2028, these allowances will be capped at 40 percent below their baseline historic levels (40 CFR Part 84 and EPA, 2023b).

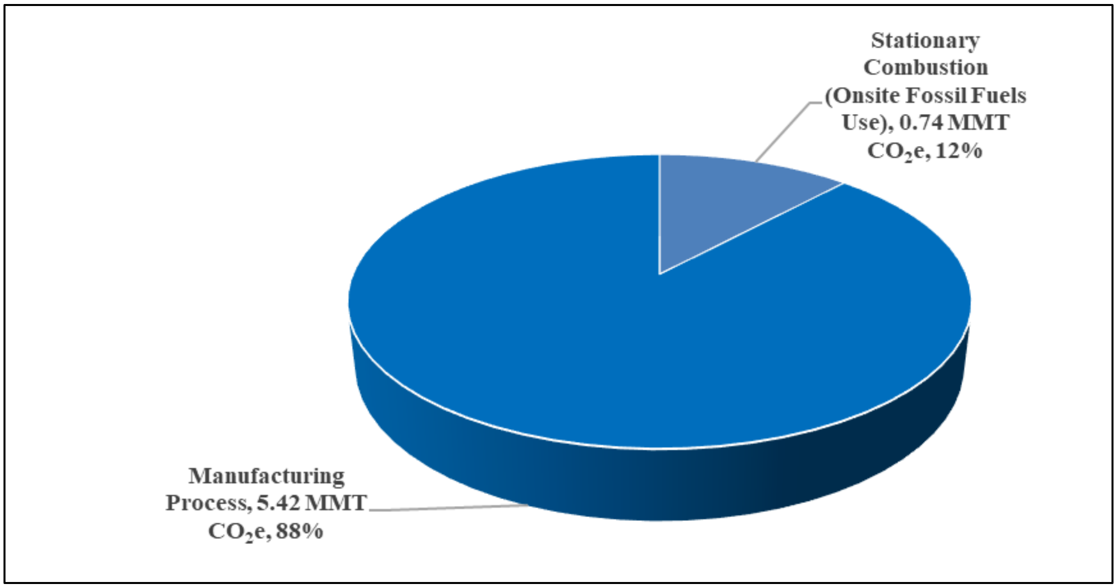
EPA's Mandatory Greenhouse Reporting for GHG emissions regulations are under 40 CFR Part 98. Subparts C and I pertain to reporting requirements for the Electronics Manufacturing Sector, which encompasses Semiconductors and Related Devices. Facilities emitting more than 25,000 metric tons (MT) of CO_2e annually are required to report emissions of fluorinated GHGs and fluorinated heat transfer fluids, 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 fabrication facilities that are within the scope of this PEA as well as wafer production facilities and facilities that manufacture other products including transistors, solar cells, and other optoelectronic devices. EPA makes reporting information publicly available through its GHG Reporting Program (GHGRP) and associated databases.

3.4.1.2 Greenhouse Gas 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. If a facility uses a Continuous Emissions Monitoring System (CEMS) to measure both the process emissions and the combustion emissions, then the combustion emissions are reported with the process emissions. Indirect GHG emissions result from onsite electricity consumption from offsite fossil fuel energy generation (EPA, 2023c). Both direct GHG and indirect GHG emissions must be included for a full accounting of the carbon footprint associated with the semiconductor industry sector.

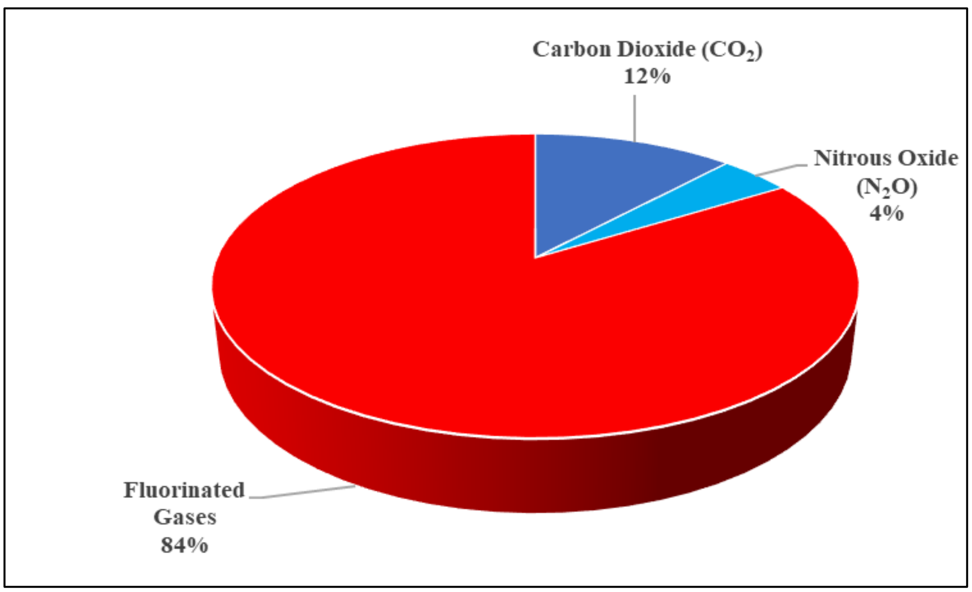
CPO analyzed data from the GHGRP databases for the years 2014-2022 for Semiconductors and Related Devices (NAICS Code 334413). Semiconductor fabrication facilities first reported direct emissions under the program in 2014, when the total direct emissions for the category were 6.18 MMT $CO2_e$. Direct GHG emissions reached their peak in 2015 at 6.4 MMT $CO2_e$ and a low of 5.9 MMT CO2e in 2016 and 2017. In 2022, total direct GHG emissions for NAICS Code 334413 were 6.2 MMT $CO2_e$. On average during this period, manufacturing processes contributed 88 percent and onsite stationary combustion sources represent 12 percent of the total direct emissions (**Figure 3.4-2**).

During the period of 2014-2022 for NAICS Code 334413, fluorinated gases contributed 84 percent of the average GHG 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) comprise by far the highest percentage of direct emissions. Sulfur hexafluoride (SF_6) is next at 12 percent of direct emissions, while CO_2 from onsite stationary combustion sources also contributes 12 percent.



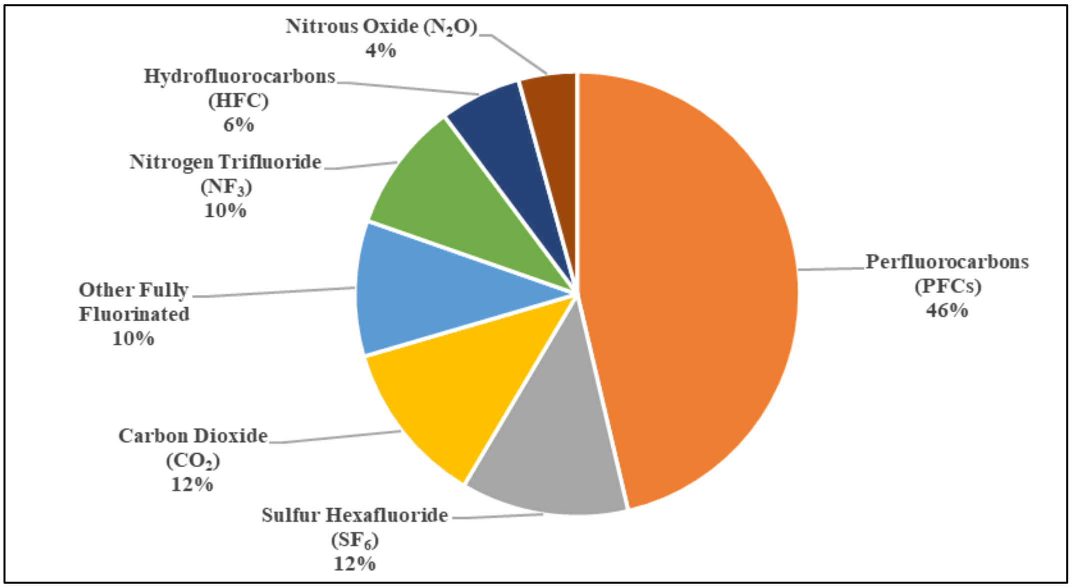
Source: EPA, 2023c

Figure 3.4-2. Average Annual Direct Greenhouse Gas Emissions from Semiconductors and Related Devices Manufacturing Facilities (NAICS Code 334413), 2014-2022



Source: EPA, 2023c

Figure 3.4-3. Composition of Direct Greenhouse Gas Emissions from Semiconductors and Related Devices Manufacturing Facilities (NAICS Code 334413), 2014-2022



Source: EPA, 2023c

Figure 3.4-4. Composition of Direct GHG Emissions by Constituent for Semiconductors and Related Devices (NAICS Code 334413), 2014-2022

DOE's 2018 Manufacturing Energy and Carbon Footprint (last updated in 2021) for the Semiconductor and Related Devices Manufacturing Industry (NAICS Code 334413) estimates 5.3 MMT CO_2e of **indirect** GHG emissions from manufacturing resulting from electricity consumption supplied from offsite fossil fuel generation (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 provides the best available estimate for the total GHG footprint of 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 of 2.5 million gasoline-powered cars, energy use of 1.5 million homes, three coal-fired power plants, or 29 gas-fired power plants. Offsetting this level of emissions would, for example, require 3,198 wind turbines operating (and displacing fossil fuel emissions) for a year (EPA, 2023d).

Fluorinated Gas Emissions

Most of the GHG emissions from semiconductor fabrication facilities are fluorinated gases such as PFCs and SF_6. The use of fluorinated gases did not begin in the semiconductor industry until the late 1980's. Under normal operating conditions, EPA estimates that 10 to 80 percent of these gases pass through the manufacturing process unreacted and are released into the atmosphere. Once released, the lifetime of these chemical compounds in the atmosphere can range from 270 to 50,000 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 of time (in this case, 100 years), relative to the emission of 1 ton of carbon dioxide (CO_2) (EPA, 2023f). **Table 3.4-1** shows the 100-year GWP of select GHGs associated with semiconductor manufacturing.

Hydrofluorocarbons (HFCs) are widely used in semiconductor facilities to print circuits on wafers, to clean chemical vapor deposition (CVD) chambers, and as fluorinated heat transfer fluids (FHTFs) (Ruberti, 2023). As shown in **Figure 3.4-4**, HFCs represent, on average, 6 percent of the GHG emissions from semiconductor and related device manufacturing facilities. These chemicals were adopted by the semiconductor industry as alternatives to ozone-depleting refrigerants (chlorofluorocarbons or 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	Global Warming Potential (GWP)-100 Year
PFC-14	7,390
PFC-116	12,200
PFC-218	8,830
Sulfur Hexafluoride (SF6)	22,800
Carbon Dioxide (CO_2)	1
Nitrogen Trifluoride (NF_3)	17,200
Nitrous Oxide (N_2O) emissions	298
HFC-23	14,800
HFC-32	675
HFC-41	92
HFC-125	3,500
FHF-43-10mee	1,640
HFC 143a	4,470

Source: 40 CFR Part 98 Subpart A, Table A-1

Many semiconductor facilities have identified means of abating GHG emissions through removal or destruction technologies, source reduction and process improvement, and use of alternative chemicals (EPA, 2023e). EPA's 2022 GHG Reporting Database for Semiconductors and Related Devices (NAICS Code 334413) shows that 24 semiconductor fabrication facilities reported using GHG abatement systems, with removal or destruction efficiencies ranging from 0.34 to 70 percent. Another 27 semiconductor fabrication facilities reported that they did not use GHG abatement systems (EPA, 2023c). Per 40 CFR 98.93, the effect of abatement systems is included in GHG emissions estimates.

3.4.2 Environmental Consequences

This section discusses the potential effects from climate change and climate resilience under the No Action Alternative and the Proposed Action Alternative.

3.4.2.1 No Action Alternative

Under the No Action Alternative, federal financial assistance for the modernization and internal expansion of the semiconductor fabrication facility would not be made available and no modernization and internal expansion would take place. The facility would continue to operate as it does at present, in the same manner and at the same scale. Without financial assistance to modernize the facility and install upgraded manufacturing tools that are more energy-efficient, these upgrades would not occur. Reduction of GHG emissions through energy efficiency and improved process tools and/or installation of GHG abatement systems would not occur.

Under the No Action Alternative there would continue to be a *negligible* to *minor*, *adverse*, *long-term*, *global* effect on GHG emissions and resultant climate change and climate resiliency. Overall, there would be no new effects to climate change and climate resiliency under the No Action Alternative.

3.4.2.2 Proposed Action Alternative

Under the Proposed Action, the semiconductor fabrication facility would modernize equipment and potentially expand production. If the modernization and internal expansion would require the use of additional energy that would be directly or indirectly (i.e., via electricity) provided by fossil fuels such as natural gas or coal-fired power plants, there would be additional fuel combustion and thus increased GHG emissions. With modernization, production capacities could increase, which would result in increased direct GHG emissions, including CO_2, methane, nitrous oxide (N_2O), HFCs, and other fluorinated gases. Crucial facility processes are heavily dependent upon high-GWP HFCs, and to the extent the use of HFCs would be increased, there would be a greater potential to contribute to GHG emissions. Although GHG emissions could increase as a result of improving and expanding production capacities associated with modernization, CHIPS Act funding represents an opportunity for facilities to modernize their tools and change processes to minimize direct emissions from semiconductor manufacturing processes.

Abatement of direct GHG emissions, including N_2O and HFCs, resulting from the manufacturing process has the potential to reduce overall GHG emissions from semiconductor fabrication facilities. EPA cites: 1) process improvements/source reduction; 2) alternative chemicals; and 3) destruction technologies as available approaches for reducing GHG emissions. Examples of projects that could abate GHG emissions are conversions of certain chemical vapor deposition (CVD) tools to remote NF_3 plasma, Remote Plasma Clean (RPC) sources, and installation of combustion abatement units (EPA, 2023b).

Due to the semiconductor manufacturing industry's heavy reliance on electricity for its manufacturing processes, many companies are shifting to renewable energy sources, which could result in a substantial reduction in facility GHG emissions Addition information on energy use by the semiconductor manufacturing industry can be found in **Section 3.10 Utilities** of this Draft PEA.

A facility may implement appropriate best management practices (**Appendix A**) to reduce GHG emissions. Direct GHG emissions could be reduced from the installation of improved process technologies, emissions abatement equipment, and onsite renewable energy generation. Indirect GHG emissions could be reduced from increased use of off-site renewable energy. However, production increases would increase GHG emissions. Thus, the effects could be *adverse* or *beneficial*, but given the high GWP of some of the GHG constituents from semiconductor fabrication facilities, effects are more likely to be *adverse*.

Under the Proposed Action, a facility modernization and expansion project would have a *negligible* to *minor, long-term, global* effect on climate change from GHG emissions. As discussed above, modernization projects present an opportunity for facilities to modernize their tools and change processes to minimize direct emissions from semiconductor manufacturing processes. Even if such improvements are not made, however, the marginal increase in GHG emissions from an individual modernization project would be *negligible* compared to overall U.S. emissions and emissions from the semiconductor industry sector.

3.5 AIR QUALITY

This section describes the affected environment and environmental consequences for air quality under the Proposed Action and No Action Alternatives.

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, including smoke from wildfires, dust, and wind erosion, or human-made, including emissions from vehicles, industrial facilities, agriculture, construction sites, dust from unpaved roads, or smoke from human-caused wildfires. Air quality can also be affected by an area's surface topography, air basin size, prevailing meteorological condition, and climate conditions.

Air pollutant emissions from semiconductor fabrication facilities are regulated under state and federal law, and facilities must follow regulatory standards to control emissions from process equipment vents and storage tanks. Emission limits are based on factors including the manufacturing processes performed, the raw materials and chemicals used in the facility, and local air quality conditions. Semiconductor fabrication facilities also are sources of GHG emissions as discussed under **Section 3.4 Climate Change and Resiliency** of this Draft PEA.

3.5.1.1 Regulatory Framework

The Clean Air Act (CAA) (42 U.S.C. §7401 et seq.) is the primary regulatory driver for promoting air quality in the U.S to protect human health and the environment. With ambient air quality provisions under the National Ambient Air Quality Standards (NAAQS) and stationary source air pollutant control provisions under the National Emission Standards for Hazardous Air Pollutants (NESHAP), these requirements form the basis for maintaining a healthy level of air quality in the U.S.

Under Title V of the CAA, EPA established a national, federally enforceable operating permit program. EPA promulgated implementing regulations under 40 CFR Part 70 that require each state or local permitting authority to develop a federally enforceable facility operating permit program. Title V is intended to further facilitate and enhance air quality planning, emission controls, and compliance, and to improve existing emission inventories. EPA typically delegates its permitting authority to the states, and thus, permits are generally issued by states or local agencies, although some are issued by EPA Regions (SMAQMD, 2017).

NAAQS

The CAA requires the EPA to set NAAQS for the following six common air pollutants, known as “criteria air pollutants” (40 CFR §7409):

1. particulate matter,
2. photochemical oxidants (including ozone),
3. carbon monoxide,
4. sulfur oxides,
5. nitrous oxides, and
6. lead.

The CAA identifies two types of NAAQS: primary standards that provide public health protection, including protecting the health of sensitive populations such as asthmatics, children, and the elderly; and secondary standards that provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. 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 corresponding to higher emission levels and higher averaging times corresponding to lower emission levels.

Delegated CAA programs to the state require the state to administer NAAQS compliance through development of a State Implementation Plan (SIP). Areas that comply with NAAQS are designated within the SIP as “attainment areas”, and those that are not in compliance are designated as “nonattainment areas”. Attainment is when air quality within an area is equal or better than the NAAQS level and proposed actions must maintain clean air; whereas nonattainment is when air quality is worse than the NAAQS level and these areas must take actions to improve air quality and attain and there is no air quality data, the area is treated as in attainment. Emission control standards for semiconductor fabrication facilities typically are set within the SIP and are influenced by whether the facility is within an attainment area or nonattainment area.

General Conformity Rule

The purpose of the CAA's General Conformity rule (40 CFR Part 93 Subpart B) is to ensure that:

- Federal activities do not cause or contribute to new violations of NAAQS;
- Federal actions do not worsen existing violations of the NAAQS; and
- Attainment of the NAAQS is not delayed.

Under the General Conformity Rule, applicants for federal financial assistance for semiconductor fabrication facility modernization and internal expansion projects under the CHIPS Incentives Program must work with the state agency responsible for a nonattainment or maintenance area to ensure federal actions conform to the state's air quality plans established in the SIP.

Major and Minor Sources

A "major source" of air pollution is defined under the CAA §112 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 emit 10 tons per year (tpy) of any single hazardous air pollutant (HAP), 25 tpy of any combination of HAPs, or more than 100 tpy of any criteria pollutant". Sources that emit less than these thresholds are designated as "minor sources". Lower thresholds for major sources may apply in nonattainment areas where air quality is worse than the NAAQS.

National Emission Standards for Hazardous Air Pollutants

EPA developed NESHAPs to federally regulate sources and source categories that emit HAPs that pose risks to human health. HAPs are a list of 187 pollutants identified by the EPA 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 there are also mobile sources of HAPs (e.g., internal combustion engines) and indoor sources of HAPs (e.g., building materials and cleaning processes).

In 2008, EPA issued amendments to the NESHAP for semiconductor manufacturing (40 CFR Part 63 Subpart BBBBB). These amendments established a new MACT standard for existing and new combined process vent streams containing inorganic and organic HAPs. The amendments also clarify the emission requirements for process vents by adding definitions for organic, inorganic, and combined HAP process vent streams that contain both organic and inorganic HAPs. Under the regulations, controls on the emission of air pollutants from process vents and storage tanks at new, reconstructed, or existing sources at semiconductor fabrication facilities, as defined at 40 CFR Part 63 Part BBBBB, are required. There are 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, 2007). Emissions from process vents containing organic air toxics must be reduced by 98 percent or to below 20 parts per million (ppm) by volume, and emissions from inorganic process vents are required to be reduced by 95 percent or to below 0.42 ppm by volume. Emissions from storage tanks greater than 1,500 gallons are required to be reduced to the same level of control as inorganic process vents (EPA, 2007).

New Source Performance Standards

New source performance standards (NSPS) implement CAA §111(b) and are issued for categories of sources that EPA has listed because they cause, or contribute significantly to, air pollution, which may reasonably be anticipated to endanger public health or welfare. The primary purpose of the NSPS is to attain and maintain ambient air quality by ensuring that the best demonstrated emission control technologies are installed as industrial infrastructure is modernized (42 U.S.C. §7411).

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). Some of the proposed semiconductor manufacturing modernization projects would involve upgrades to tools covered by NSPS. Most semiconductor facilities must also comply with 40 CFR Subparts 60 Db-Dc (boilers), JJJJ, (stationary spark ignition internal combustion engines) and KKKK (generators). Compliance with NSPS is required for both minor and major sources.

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 modern pollution control equipment for newly built facilities and existing facilities that are undergoing expansion or renovations that significantly increase emissions. Under the NSR program, if so delegated, the state or local air pollution agency issues the required permits. If not delegated, EPA Regional offices will issue the permits. There are three types of NSR permitting requirements. A source may have to meet one or more of these permitting requirements:

- **Prevention of Significant Deterioration (PSD)** permits are required for new or major sources making a major modification in attainment or unclassifiable areas;
- **Nonattainment NSR permits** are required for new major sources or major sources making a major modification in nonattainment areas; and
- **Minor source permits** are required for pollutants from stationary sources that do not require PSD or nonattainment NSR permits. The purpose of minor NSR permits is to prevent the construction of sources that would interfere with attainment or maintenance of a NAAQ or violate the control strategy in nonattainment areas.

The following are specific minor sources that are also included in minor source permit requirements:

- ***True minor source***: a source that emits, or has the potential to emit, 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 CFR § 49.153, without the need to take a federally enforceable restriction to reduce its Potential to Emit (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 has implemented a federally enforceable restriction so that its PTE is less than such amounts for major sources.
- ***Synthetic minor HAP source:*** is 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 PTE is less than such amounts for major sources.

The designation of synthetic minor source is allowed for both regulated NSR pollutants and HAPs. Once a permittee has accepted an enforceable emission limitation, it must comply with that limitation. This is necessary to ensure that it is legally prohibited from operating as a major source. If the permittee applies for a synthetic minor source or synthetic minor HAP source, it must comply with the same public participation requirements and the same procedures for final permit issuance and administrative and judicial review found under 40 CFR 49.157 and 40 CFR 49.159, respectively.

3.5.1.2 Air Emissions Sources and Characterization

A variety of air pollutants may be emitted from semiconductor manufacturing facilities. These include acid fumes and organic solvent emissions from cleaning, rinsing, resist drying, developing, and resist stripping; HCl emissions from etching; and other various emissions from spent etching solutions, spent acid baths, and spent solvents (EPA, 2001a). Processes related to semiconductor manufacturing, 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. For more information on health effects from exposures, refer to **Section 3.7 Human Health and Safety** of this Draft PEA (EPA, 2001a). 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).

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).

Cleanrooms have more stringent air quality requirements than average industrial spaces; therefore, most semiconductor fabrication facilities 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 semiconductor fabrication facility consist of two different classes: acids and organics. These two classes of emissions are separated at the facility so they can be treated by the appropriate control device. Each facility 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 GHGRP, owners and/or 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 the EPA. See **Section 3.4** of this Draft PEA for more information.

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 on air discharge streams to reduce or remove pollutants 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 substances. It is a combustion device that controls volatile organic compounds (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).

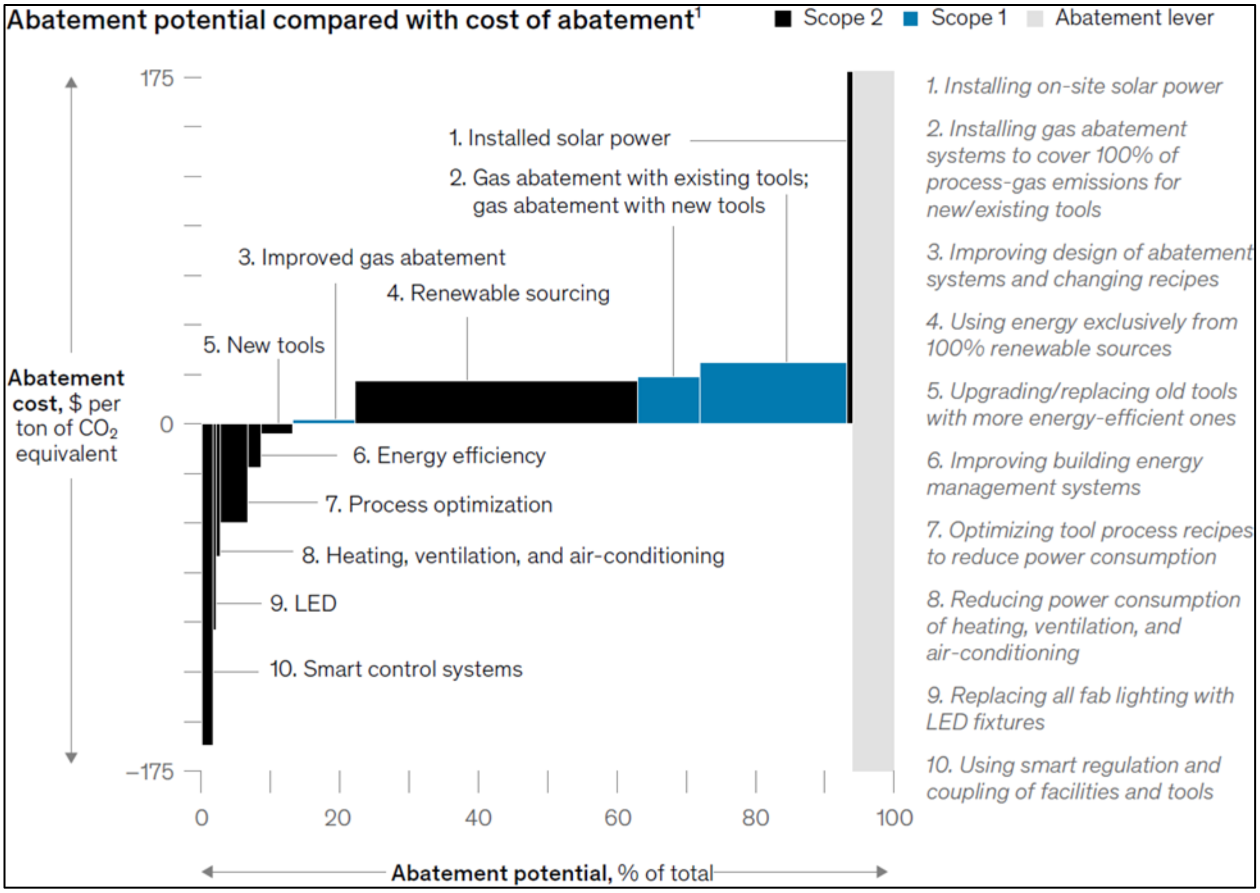
Thermal Recuperative Oxidizers (TOs) destroy air pollutants emitted from process exhaust streams at temperatures ranging from 760°C (1,400 °F) to 815°C (1,500 °F). TOs utilize a multi-pass shell-and-tube type heat exchanger fabricated of heavy-duty stainless steel. Oxidation is achieved as pollutants 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 nitrogen oxide (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.

There are a number of 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 concepts. **Figure 3.5-1** shows a comparison of 10 pollution abatement concepts along with their respective strategies to reduce air emissions in comparison to their relative cost of implementation.



Source: McKinsey, 2022a

[1]For an average 200-millimeter (mm) to 300-mm high-volume facility with trailing node size. Value reflects higher potential for process optimization in older, trailing node facilities. Cost strongly dependent on facility location and availability of renewables. Not including potential emissions from onsite power generation.

Note: Scope 1 emissions are those from direct or controlled sources at the manufacturing facility; Scope 2 emissions are from generation of purchased electricity, steam, heating, and cooling equipment. An Abatement lever is an abatement technique or technology.

Figure 3.5-1. Air Pollution Abatement Concepts and Comparative Costs

3.5.2 Environmental Consequences

This section discusses the potential effects to air quality under the No Action Alternative and the Proposed Action Alternative.

3.5.2.1 No Action Alternative

Under the No Action Alternative, the semiconductor fabrication facility would not modernize or expand because it would not receive financial assistance from the CHIPS Incentives Program. 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 changes to local or regional air quality. The facility would continue to produce semiconductors at the same rate, using the same equipment within the existing facility footprint. Under the No Action Alternative, laws, regulations, and permitting requirements would remain in place, and facility would be expected to continue to comply with all regulations and permit requirements. The effects of the No Action Alternative would be *direct*, *adverse*, *negligible* to *minor*, *long-term* in duration, and *localized* to *regional* in extent.

3.5.2.2 Proposed Action Alternative

Under the Proposed Action, the semiconductor fabrication facility modernization and expansion project would have the potential to cause *adverse* effects on air quality from increases in the quantity of pollutants generated from semiconductor production processes. Increases in pollutant loads and changes in the types of pollutants emitted to the air could be caused by increases in semiconductor production due to the implementation of the Proposed Action to expand the manufacturing space within the existing facility footprint for additional and/or new equipment, and modernization of manufacturing processes. An increase in air pollution due to construction activities would be *short-term* and *minor* since the modernization would occur within the existing facility footprint and the only anticipated emission effects would be from operation of light duty construction equipment such as cranes, light trucks, and generators while the modernization is in progress. The implementation of modernized equipment and processes under the Proposed Action may also offer the opportunity for use of improved abatement or best available control technologies that result in a reduction in existing air pollutant levels for the same semiconductor output depending on planned expansions, or increased semiconductor output that would not cause emissions to exceed existing pollutant levels. This opportunity must also account for additional emissions from potential ancillary and other supporting systems.

These effects would not exceed the *localized* or *regional* air quality standards because facilities would still need to comply with air permit limits. Treatment of criteria and HAPs to meet existing air permit requirements would be achieved through use of emissions control technologies as discussed in **Section 3.5.1.3** of this Draft PEA. For some potential pollutants, existing emissions control technologies would be utilized with satisfactory results. There is potential for air quality effects to be reduced with the implementation of the Proposed Action if the proposed project included new abatement equipment and best available control technologies practices to treat air emissions or prevent pollutants from entering the atmosphere.

As part of the due diligence process to receive CHIPS Incentives Program funding, an applicant would be required to demonstrate compliance with all existing facility permits. Upon completing modernization and/or internal expansion projects, the facility would still be required to comply with permit limits, although permit limits may be revised if the proposed project triggers new source requirements. Additionally, a facility may implement appropriate best management practices (**Appendix A)** as provided by CPO or as conditions of revised permits stemming from implementation of the Proposed Action.

Overall, the effects of modernization and internal expansion at a semiconductor fabrication facility under the Proposed Action would be *direct* and *long term* and *localized* to *regional* because of increases in air emissions resulting from increased production. These effects would be *adverse* and *negligible* when compared to current conditions, but they could be *beneficial* and *minor* if new air pollution control measures and best available control technologies were introduced with the modernization to reduce the overall pollutant load in air emissions from facility operations.

3.6 WATER QUALITY

This section describes the affected environment and consequences to water quality under the Proposed Action and the No Action Alternative.

3.6.1 Affected Environment

Water quality describes the condition of water, including chemical, physical, and biological characteristics. The most common standards used to monitor and assess water quality convey the health of ecosystems, safety of human contact, extent of water pollution, and condition of drinking water. Water quality standards (WQS) are provisions of state, territorial, authorized tribal, or federal law approved by the EPA that describe the desired condition of a water body and the means by which that condition will be protected or achieved (EPA, 2022a). States, territories, and authorized tribes establish WQS for U.S. waters to protect human health and aquatic life. WQS form a legal basis for controlling pollutants entering the waters of the U.S. (WOTUS). WOTUS includes, waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide, the territorial seas, or interstate waters; impoundments of waters; tributaries of waters that are relatively permanent, standing or continuously flowing bodies of water; wetlands adjacent to the preceding waters; and intrastate lakes and ponds that are relatively permanent, standing or continuously flowing bodies of water with a continuous surface connection to the preceding waters (33 CFR 328; 40 CFR 120).

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 may also be significantly affected by agricultural, industrial, urban, and other human actions.

3.6.1.1 Regulatory Framework

There are numerous laws and regulations that protect water quality at the federal, state, and regional levels. At the federal level, the primary law protecting the "chemical, physical, and biological integrity of the nation's waters" is the Clean Water Act (CWA) (EPA, 2023h). Water quality is regulated within the context of meeting standards established for compliance with the CWA, specifically:

- Section 303(d) – this section mandates states to develop lists of all impaired waterbodies and prioritize these waters for establishment of plans to restore degraded areas. EPA is also authorized to assist states, territories, and authorized tribes in listing impaired waters and developing Total Maximum Daily Loads (TMDLs) for these waterbodies.
- Section 305(b) – This section requires states to report on the overall condition of aquatic resources.
- Section 401 – This section establishes the authority for EPA to develop effluent limitations guidelines for existing sources, standards of performance for new sources, and pretreatment standards for new and existing sources. Effluent limitations guidelines and standards (ELGs) for semiconductor fabrication facilities are included in the Electrical and Electronic Components (E&EC) Category under 40 CFR Part 469.
- Section 402 – This section establishes the National Pollutant Discharge Elimination System (NPDES) program to address water pollution by regulating point sources that discharge pollutants to waters of the U.S. unless authorized by an NPDES permit. A NPDES permit contains limits on what can be discharged as well as monitoring and reporting requirements, and other provisions to ensure that the discharge does not degrade water quality or human health. EPA can authorize state, tribal, and territorial governments to administer the NPDES program to include permitting, administration, and enforcement.
- Section 403 – This section establishes National Pretreatment Standards to control pollutants which pass through or interfere with treatment processes in Publicly Owned Treatment Works (POTWs), or which may contaminate sewage sludge. The national pretreatment program is a cooperative effort of federal, state, and local environmental regulatory agencies established to protect water quality and designed to reduce conventional and toxic pollutant levels discharged by industries into municipal sewer systems and into the environment. EPA and authorized NPDES state pretreatment programs approve local municipalities to perform permitting, administration, and enforcement for discharges to the municipalities' POTW.

In a recent report, EPA found that the majority of semiconductor fabrication facilities are indirect dischargers of wastewater to local or regional POTWs (EPA, 2022a). These facilities are subject to the general pretreatment regulations for existing and new sources of pollution under 40 CFR Part 403 and the standards for E&EC Point Source Category under 40 CFR Part 469. Some facilities may generate wastewater from metal finishing and/or electroplating operations as well as E&EC operations; therefore, facilities also may be subject to ELGs for the Metal Finishing and Electroplating Point Source Categories under 40 CFR part 433 and part 413, respectively.

Pretreatment permits are issued by the POTW if it has an approved local pretreatment program by the state or EPA. Pretreatment permits issued to semiconductor fabrication facilities may contain local limits for specific parameters in addition to limits that enforce the general and specific prohibitions in 40 CFR 403.5 and the technology-based pretreatment standards in 40 CFR Part 469, E&EC ELGs. Indirect discharging semiconductor fabrication facilities are required to conduct self-monitoring and submit monitoring reports to the pretreatment control authority (POTW, state, or EPA) at least twice a year. Monitoring reports generally include the nature and concentration of pollutants with 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 to a water of the U.S. is subject to the NPDES permit program, with permits issued by EPA or authorized states (EPA, 2022b). These permits must include applicable technology-based ELGs for the industry per 40 CFR Part 469 as well as any necessary permit limits and conditions to protect water quality in the receiving water body. As a result, more stringent water quality-based effluent limitations and/or limits for additional pollutants and/or other requirements may be included in the NPDES permit compared to the requirements in the ELGs. Direct dischargers must also submit discharge monitoring reports to the permitting authority in compliance with the NPDES permit.

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 including 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 most organic contaminants from entering the wastewater. Some facilities 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 waste allows facilities to treat, dispose, or reclaim wastes in more cost-effective manners. Facilities keep wastewaters with different wastes separated prior to treatment and segregate solvents-containing wastes for disposal. Automated water treatment systems are programmed to accept or divert wastewaters 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 is treated onsite, producing calcium-based solid waste which can be reused elsewhere outside of the semiconductor facility.
- **Ammonium $[NH_4]^+$ Wastewater:** Can contain hydrogen peroxide and is treated onsite, producing ammonium sulfate solution for offsite recycle/disposal.
- **Solvent Wastewater:** Contains isopropyl alcohol (IPA) and other solvent waste (e.g., glycols, ethers, polar and non-polar photoresist) and can be corrosive and/or contain hydrogen peroxide or PFAS substances. Solvent collection systems prevent untreated liquid waste from mixing with other

wastewater streams. Solvents not treated onsite are shipped offsite to vendors for re-use after purification or to approved treatment and disposal facilities.

- **Metal Wastewater:** Can contain metals and metallic compounds. Metal collection systems allow for on 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 are combined and neutralized by sulfuric acid or sodium hydroxide before discharging.
- **Concentrated Sulfuric Acid (H_2SO_4) Waste:** Waste sulfuric acid can contain impurities. Can be collected in tanks for onsite or offsite reuse in other industries. Onsite reuse typically is only in waste treatment; unless it is refined to electronic grade for reuse.
- **Wastewater Containing Suspended Solids** (e.g., silicon from backside grinding, 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 TMAH):** Can be treated on or offsite. Typically, concentrated organic solvents are segregated from other wastewaters 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 is only 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.

Pollutants currently regulated under 40 CFR 469 include (EPA, 2022b):

- Indirect dischargers: Total Toxic Organics and arsenic.
- Direct dischargers: Total Toxic Organics, arsenic, pH, fluoride, and total suspended solids.

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 at 40 CFR 469. The Metal Finishing Category effluent limitations guidelines (40 CFR 433) also apply to semiconductor fabrication facilities that are generating 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 semiconductor 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, some facilities send approximately 40 percent of waste antireflective coating (containing PFAS) to wastewater treatment facilities. For more information about the use of PFAS in semiconductor fabrication facilities and emerging PFAS standards, see **Appendix B**. In addition, some facilities may be discharging more substantial quantities of certain previously considered and/or regulated pollutants, including copper and fluoride, due to manufacturing process changes while phasing out the use of other pollutants, such as organic chemicals.

A recent EPA report confirmed that updated manufacturing processes introduce new pollutants in the wastewater due to new materials, lithography process chemistries, and advancement of tools required to keep up with rapidly changing technology demands (EPA, 2022b). Most noteworthy of the new pollutants 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 and conserving water. EPA concluded that the existing ELGs are sufficient to prevent interference or upset at POTWs and to protect water quality of receiving waters, but that 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 Effluent Guidelines Program Plan 15 released in 2023, EPA 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 revise the ELGs for the Metal Finishing and Electroplating Point Source Categories (40 CFR part 433 and part 413, respectively) to address wastewater discharges of PFAS from chromium finishing operations (EPA, 2023i)

3.6.2 Environmental Consequences

This section discusses the potential effects to water quality under the No Action Alternative and the Proposed Action Alternative.

3.6.2.1 No Action Alternative

Under the No Action Alternative, no new effects would occur to water quality from the semiconductor manufacturer modernizing its equipment and facilities with financial assistance received from the CHIPS Incentives Program. The No Action Alternative assumes that the proposed projects would not be implemented, and therefore no changes in the amount or pollutant load of facility wastewater would occur.

Since laws, regulations, and permitting requirements would remain in place, no new effects would occur to water quality.

3.6.2.2 Proposed Action Alternative

A proposed project involving equipment and facility modernization and internal expansion within an existing facility footprint with CHIPS financial assistance would have the potential to affect water quality through changes in the volume and/or pollutant load of generated wastewater. Wastewater from semiconductor fabrication may contain a variety of pollutants including organic compounds, heavy metals, nitrogen, and phosphorus. The semiconductor fabrication facility would have the potential to cause a large effect on water quality and is thus subject to strict environmental regulations and permitting as discussed in **Section 3.6.1.1** of this Draft PEA. To satisfy national and local regulations, the facility's wastewater would have to be properly treated prior to discharge.

Semiconductor manufacturing facilities use a number of management practices to control the toxic compounds found in wastewater, including solvent management plans, segregation of wastes, and waste disposal alternatives. Segregation of waste allows facilities to treat, dispose, or reclaim wastes in more cost-effective manners, by keeping wastewaters containing different pollutants separate prior to treatment and segregating certain pollutant-containing wastewaters for disposal. With new and modernized equipment, effective effluent segregation could include (IEEE, 2023):

- Segregating out high concentrated wastes with subsequent disposal (or ideally reuse) to reduce contamination and complexity of the wastewater treatment and reclamation.
- Segregating higher purity streams to allow for recycling those within the process or reusing within the facility.

- Segregating streams with specific contaminants which are of concern for environmental regulatory compliance, relatively easy to treat (e.g., N-methyl-pyrrolidone [NMP]), or difficult to treat (e.g., TMAH) to achieve a more sustainable and cost-effective wastewater management solution.

Such practices could result in fewer toxic compounds in wastewater, resulting in *minor*, *beneficial* effects.

Heavy metals are among the most harmful water pollutants due to their non-degradable properties. Despite the national and international standards stipulated by the World Health Organization (WHO) and the EPA that drinking water should not exceed very low maximum concentrations, heavy metals can accumulate in the ecosystem and enter the human body through food. Heavy metals present in wastewaters, such as cadmium, chromium, arsenic, lead, zinc, copper and mercury are highly toxic for 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 enzymes denaturation, ion replacement, and protein inactivation.

Removing heavy metals from wastewaters is a challenging process that requires constant attention and monitoring. Modernized, onsite equipment has the potential to remove heavy metal ions from wastewater; methods could include 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, CMP uses a large amount of water and accounts for approximately 40 percent of water consumption in the semiconductor industry (Lee et al., 2022). In addition, CMP generates 30–50 liter (L) of waste slurry containing chemicals per 200 mm wafer. After CMP, the wastewater containing various chemicals and slurry particles is disposed of after removing the particles through electrodecantation and electrocoagulation. CMP wastewater produced during CMP and post-CMP cleaning processes, contain 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.

As part of the due diligence process to receive CHIPS Incentives Program funding, applicants would be required to demonstrate compliance with all existing facility permits. Following modernization and/or expansion related projects, facilities would still be required to comply with permit limits, although permit limits may be revised if the proposed project triggers new source requirements. Permit violations at existing direct and indirect discharging facilities were determined by EPA to be rare, isolated exceedances that do not represent consistent issues at any specific facility or across the industry (EPA, 2022b). This level of compliance would be expected to continue following implementation of the modernization and expansion projects.

EPA found that most pollutants are detected in screening data used for permit development and are observed at concentrations that do not pose a threat to cause interference or upset at the POTW or were at concentrations lower than local water quality standards (EPA, 2022b). The industry continues to rapidly change as new technologies are developed and new chemicals used in the semiconductor manufacturing process. A few 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).

CPO will review the compliance history of companies during the due diligence phase as described in **Appendix A** to determine if there are ongoing, systemic water quality permitting issues. There is the potential for effects to be reduced with the implementation of the Proposed Action if the proposed project includes new pollution control equipment and practices to treat wastewater or to prevent pollutants from entering wastewater.

Under the Proposed Action, the proposed semiconductor fabrication facility modernization and expansion project would cause *direct*, *adverse* effects on water quality from the introduction of pollutants associated with increased production. Long-term changes in the volume and concentration of wastewater would have *localized* effects for direct dischargers and *regional* effects for indirect dischargers. Effects to water quality would be *minor* because the facility would still be required to comply with wastewater discharge permit limits and conduct routine monitoring to confirm compliance. The modernization of equipment and the facility under the Proposed Action would have *direct*, *long-term*, *localized* to *regional* effects on water quality; these effects would be *adverse* and *minor* compared to current conditions. If the proposed action included new measures to reduce the pollutant load in the wastewater there could potentially be *beneficial* and *minor* effects.

3.7 HUMAN HEALTH AND SAFETY

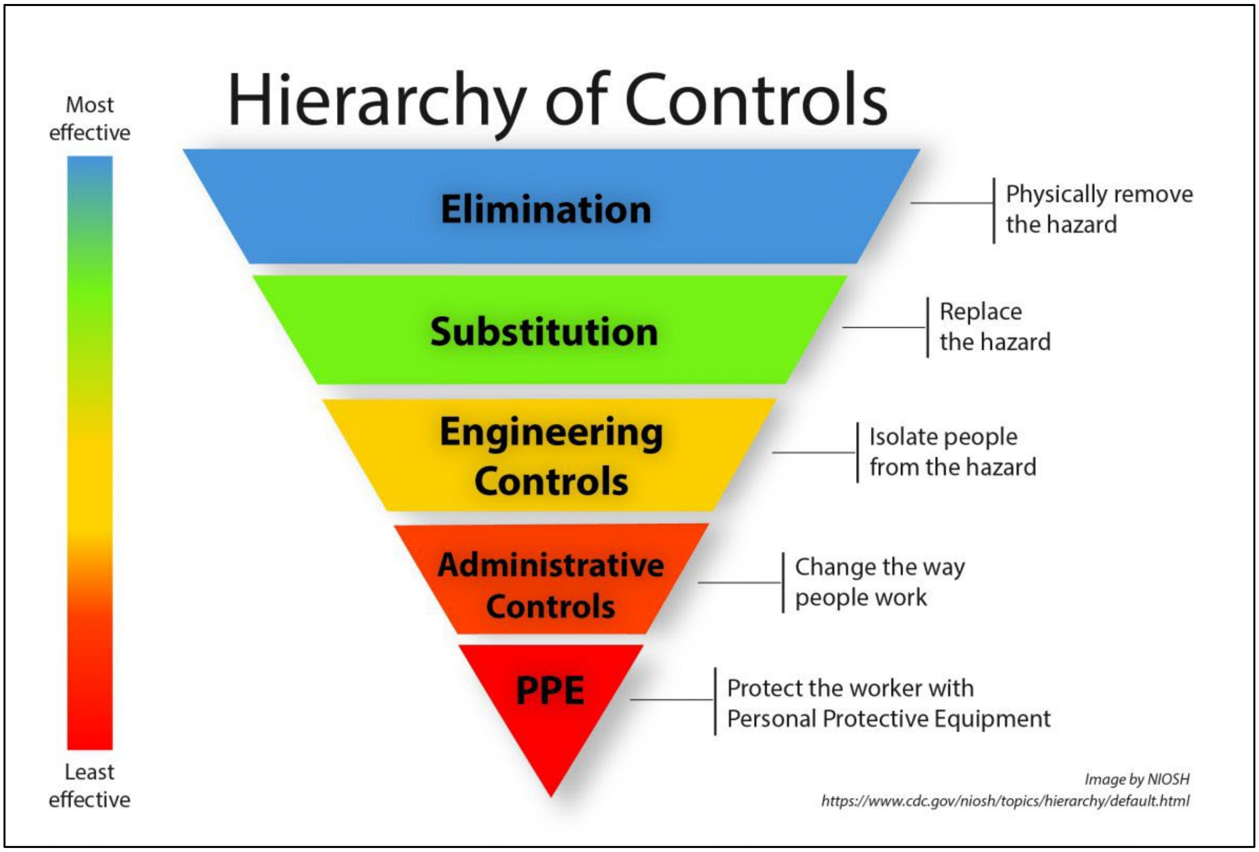
This section describes the affected environment and environmental consequences to human health and safety of the Proposed Action and the No Action Alternative.

3.7.1 Affected Environment

A proposed project under the Proposed Action would occur within the existing facility footprint, so the affected environment for human health and safety is onsite at the applicant's facility.

3.7.1.1 Health and Safety Regulatory Frameworks

Numerous federal, state, and local laws and regulations aim to protect human health and safety at semiconductor manufacturing facilities. The Occupational Safety and Health Administration (OSHA) promulgates health and safety regulations for general industry (29 CFR 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 fabricators establish safety procedures in accordance with OSHA and typically apply the hierarchy of safety hazard controls from the National Institute for Occupational Safety and Health (NIOSH) (NIOSH, 2023). The NIOSH hierarchy of controls is shown in **Figure 3.7-1** below.



Source: NIOSH, 2023

Figure 3.7-1. Hierarchy of Safety Hazard Controls

OSHA standards most relevant to the semiconductor manufacturing sector include:

- Subpart G, Occupational Noise Exposure – 1910.95 establishes guidelines and standards to protect workers from excessive noise in the workplace.
- Subpart H, Hazardous Materials – 1910.119 establishes requirements for preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals.
- Subpart H, Hazardous Materials – 1910.124 establishes general requirements for dipping and coating operations. The standards cover: dip tank construction and entry; ventilation, air recirculation, exhaust hoods; first aid training, treatment, and supplies; required hygiene facilities; dip tank cleaning, inspection, and maintenance.
- Subpart I, PPE – 1910.132 establishes general requirements for PPE. The employer is responsible for ensuring the proper application, the adequacy, and selection of PPE based on hazard assessment. The employer must provide PPE and associated training to employees. 1910.134 establishes specific respiratory protection requirements.
- Subpart Z, Toxic and Hazardous Substances –
    - 1910.1018 Inorganic arsenic
    - 1910.1020 Access to employee exposure and medical records
    - 1910.1025 Lead

During OSHA inspections of semiconductor industry sites between October 2021 and September 2022, most citations (violations) were for Hazard Communication, followed closely by Respiratory Program (OSHA, 2023).

EPA promulgates Chemical Accident Prevention Provisions to protect public health and the environment (40 CFR Part 68). Facilities holding more than a threshold quantity of a regulated substance in a covered process 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 which govern the use of hazardous and toxic materials in the U.S. are summarized in **Section 3.8.1.1** of this Draft PEA.

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

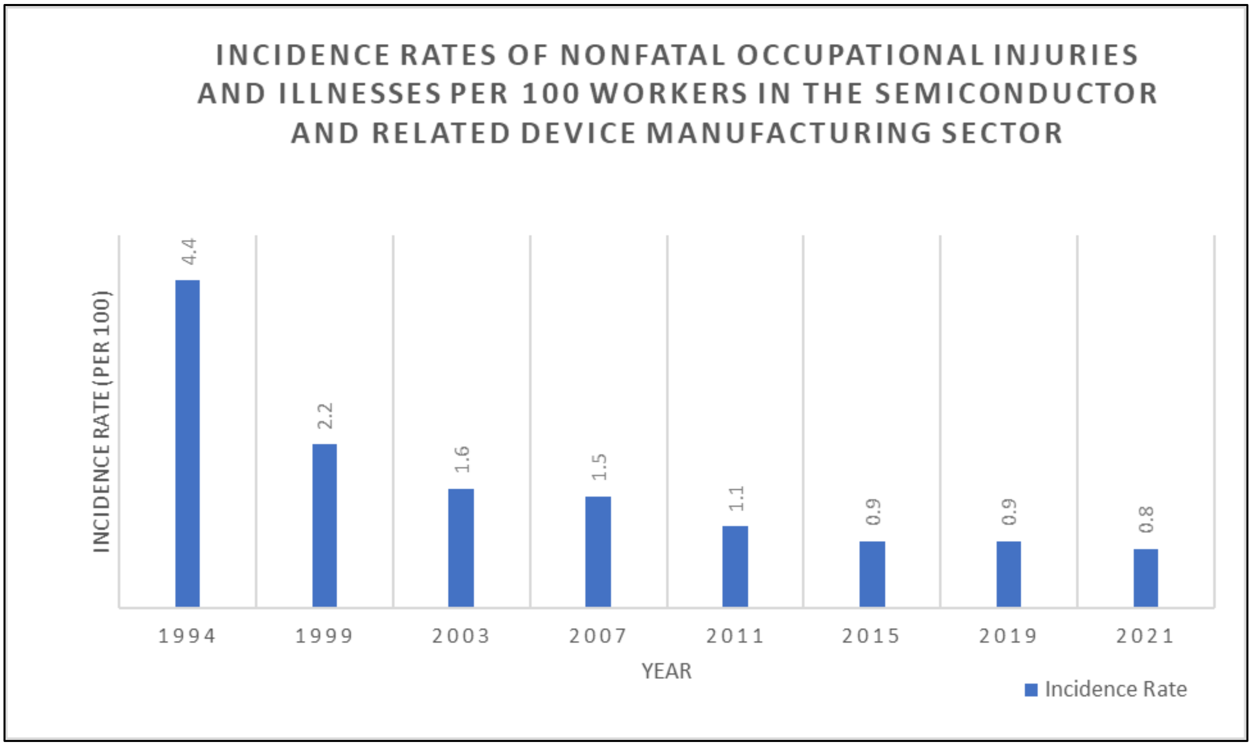
3.7.1.2 Industry Standards

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. 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 which 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 end of life of semiconductor manufacturing equipment 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/prevention (ISMI, 2006). Environmental health and safety personnel at semiconductor fabrication facilities establish PPE programs and safety protocols through hazard assessments to identify the potential risks in accordance with RMMs.

3.7.1.3 Industry Injury and Illness Rates

According to 2021 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 manufacturing sector has steadily declined, as shown in **Figure 3.7-2**. The decline in injury and illness rates over the last 30 to 40 years are 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).



Notes: 1994-1999 BLS data for NAICS Code 3674; 2003-2021 data for NAICS Code 334413; Data after 2021 were not available on the BLS website.

Source: BLS, 2023

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

3.7.1.4 Historical Health Risks

Semiconductor manufacturing in the U.S. and abroad has a legacy of causing harmful effects to worker health. Exposures to ethylene glycol ethers were identified in the late 1980s as a likely cause of increased risk of miscarriages of clean room workers (Hecht, 1992). While glycol ethers are not banned in the U.S., they are subject to new use reporting under Toxic Substances Control Act.

Additionally, across several decades, workers at California semiconductor production companies had been 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). While these are just some examples of historical health risks, there is a strong pattern of past chemical and radiation exposures to workers in the semiconductor industry.

Many of the root causes of semiconductor manufacturing-associated health risks have been addressed over the last thirty years. Stricter storage tank regulations and monitoring requirements by EPA provide additional protection to water supplies and human health. Air emission regulations and limits are also stricter with rigorous monitoring and reporting. Regulations and reporting under the Toxic Substances Control Act (TSCA) and the Emergency Planning and Community Right-to-Know Act (EPCRA) provide communities with essential information about hazardous material use in their neighborhoods. The industry continues to replace highly mutagenic and toxic materials with less hazardous materials.

Clean rooms and equipment now incorporate advanced leak detection methods 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. Additionally, personal protective equipment has improved in recent decades to provide further worker protection (Hicks, 2023). Overall, modern health, safety, and environmental regulations plus improvements in semiconductor manufacturing equipment and processes have greatly improved the health and safety posture of the industry, as evidenced by the declining incidence rates of nonfatal occupational injuries and illnesses of workers shown in **Figure 3.8-2.**

3.7.1.5 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 or 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).

Fabrication facilities 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 back-up systems ensure the necessary protection will be provided if one control fails. Under normal operating conditions, workers are not exposed to chemical or physical hazards due to considerable control measures within a state-of-the-art semiconductor fabrication facility (ISMI, 2006). Advances in robotics and automation systems are helping eliminate opportunities for human error, which reduces safety incidents while fostering productivity.

In modern fabrication facilities, 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 the 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 and/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 cabinets 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 to guide the safe design of equipment. The industry has a strong safety record which demonstrates the effectiveness of the hazardous energy control design methodologies selected (SEMI ICRC, 2016).

The 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, cold temperatures)
- Compressed Gases (liquefied, pressurized)
- Chemical Energy (heat of reaction, toxicity)

- Electromagnetic Radiation (X-Ray, Radio Frequency (RF), Infrared (IR), Ultraviolet (UV), lasers)
- Stored Mechanical Energy (springs, elastic seals)
- 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 encapsulate 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 clean room worker must follow strict clean room entry and exit procedures (Blackridge, 2023). These procedures are designed to protect workers from hazards in the clean room 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 also protect the workers from exposure to potentially hazardous materials (Nichols, 2016). PPE required within clean rooms 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 clean room environment must be properly trained in chemical handling, hygiene, hazard communication, and emergency response procedures pursuant to OSHA regulations (SEMI, 2018).

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 so forth.	• Lithography • Backlapping and backside metallization • Dicing
Electricity	Various hazards associated with the use of high-voltage electrical equipment, including electric shock, electrocution, fires, explosions, and so forth.	• Doping • Deposition • Metal deposition • Metal etching • Testing and quality control
Lasers	Laser hazards associated with the use of high energy lasers for annealing (ion implantation), marking, or scribing (causes additional vaporization hazard).	• Doping • Dicing
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

Potential Hazard	Hazard Description	Associated Production Processes
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. • from e-beam evaporation.	• Mask alignment and photo exposure • Doping • Metal deposition
Flammable, Explosive, Pyrophoric Gases and Liquids	Possible ignition of flammable, explosive, and pyrophoric gases, resulting in fire or explosion. Employees may also 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. Possible employee exposure 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. • acids used for wet chemical etching/stripping.	• Cleaning • Developing • Etching • Photoresist stripping
Photoresist Chemicals	Possible exposure to photoresist chemicals.	• Lithography

Potential Hazard	Hazard Description	Associated Production Processes
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, phosphine, etc., may be found in ion implantation equipment.	• Etching • Doping • Deposition
Metals	Possible employee exposure to various metals during evaporator cleaning and maintenance operations. Possible employee exposure 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.; UL, 2021

3.7.1.6 Noise

Semiconductor manufacturing facilities typically implement robust hearing conservation programs to protect workers in compliance with OSHA Standards. Noise abatement is also a critical component of campus design and building layout due to the sensitive nature of the manufacturing process. Facilities typically have a large number of concentrated noise sources associated with high volumes of intake and circulation air required to maintain cleanrooms and the complex exhaust and pollution-control systems. Sources include air units, exhaust fans, cooling towers, boilers, compressed air vents, emergency generators, pumps, valves, piping, and delivery traffic. Most facilities produce continuous noise, as they usually operate on a 24-hour a day schedule. 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).

3.7.1.7 Chemicals of Concern

As discussed in **Section 3.5.1.2 Wastewater Characterization** of this Draft PEA, the semiconductor industry introduced new process chemistries as technological advances occurred. Certain chemicals in the industry are of emergent concern to human health. Notably, PFAS are used in a wide range of modern semiconductor production processes like lithography, etching, and cleaning.

In 2021, the EPA released the 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 will likely be the focus of new regulations in the coming years, based on a body of growing scientific evidence and the EPA's directives to research, restrict and remediate their use (EPA, 2021a). Under the new framework, the EPA expects to allow the use of certain PBT PFAS in semiconductor manufacturing if they are used in closed systems with appropriate occupational safeguards and when disposal and consumer exposure risks are shown to be low (EPA, 2023j). For more information about the use of PFAS in semiconductor fabrication facilities and emerging PFAS standards, see **Appendix B**.

In addition, there has been an effort in the industry to replace glycol ethers due to reproductive effects associated with exposures. Glycol ethers are solvents used in etching circuit patterns on silicon wafers. Solvents have included chemicals such as xylene, n-butyl acetate, acetone, and 1,1,1-trichloroethane as a substitute for glycol ethers (OSHA, No Date).

3.7.2 Environmental Consequences

This section discusses the potential effects to human health and safety under the No Action Alternative and the Proposed Action Alternative.

3.7.2.1 No Action Alternative

The No Action Alternative assumes the proposed project would not be implemented, and therefore current health and safety aspects at the semiconductor facility would not change. The facility would continue to follow all regulations protecting worker health and safety. Thus, the No Action Alternative would have no new effects on health and safety.

3.7.2.2 Proposed Action Alternative

CPO will evaluate the health and safety practices and safety compliance program of applicants, as described in **Appendix A**. CPO will review proposed equipment purchases and facility re-designs to promote installation of state-of-the-art safety features, such as leak detection/sensors, lock-out mechanisms, fire-protection systems, and similar controls to protect worker safety.

Effects of Construction and Installation

Projects under the Proposed Action would modernize and expand fabrication spaces and equipment within the existing facility footprint. These actions could increase production, alter material chemistries used, and improve automation. Increased production would likely increase the volume of hazardous materials stored and used at these facilities. However, modernized equipment meeting the most recent industry and government standards for safety would incorporate engineering controls, physical barriers, and other safety features to protect workers from chemical and physical hazards. During construction and equipment installation, upgrades to the lighting, ventilation, fire suppression, piping and electrical systems, incorporation of automated chemical distribution systems, and new room layouts to enhance workflows have the potential to improve safety-related engineering controls. Facility reconfiguration provides opportunities to incorporate or enhance worker safety and health protections that could otherwise be unpractical. CPO will review applicant construction plans to ensure they include relevant health and safety features and follow industry standards.

Increased vehicle traffic associated with construction workers and deliveries could temporarily increase noise along local roads. Installation of new equipment could generate noise during transport and positioning. **Appendix A** describes human health and safety BMPs that could be applied to reduce construction noise and promote safety at construction sites. Overall, noise and safety effects during construction would be *direct*, *negligible* to *minor*, *temporary* and *localized* as those terms are defined under **Section 3.2.2** of this Draft PEA.

Effects of Increased Production

Modernization projects could increase production volumes, increase hazardous chemical use, and require additional workforce. These operational changes could result in *long-term*, increased safety and health risks that are *negligible* to *minor* because operators, maintenance and service personnel would be trained in the task they are intended to perform and follow facility-specific RMMs and RMPs. In addition, health and safety training would be required to address new processes and orient new staff in accordance with OSHA and SEMI standards. These standards also require worker access to adequate hygiene facilities and require updated health and safety plans. Worker protections and processes already in place at semiconductor fabrication facilities would continue to minimize illness and injury incidence rates under the Proposed Action. Emergency plans and safety procedures developed in accordance with OSHA, EPA, NFPA, and industry standards (**Appendix A**) could lower the potential for hazardous exposures and other safety and health risks associated with increased production. In general, *adverse* effects could be *direct*, *long-term*, *negligible* to *minor*, and *localized*, depending on the proficiency of the environmental, health, and safety program at a facility.

Effects of Equipment Disposal

Removal of existing equipment and utility connections would require purging or decontamination of hazardous materials and gases that would require development of task-specific safety plans. As described in **Appendix A**, adhering to industry standards SEMI S12 and S16 – *Reduction of Environmental Impact at End of Life and Decontamination* for decontamination and removal of manufacturing equipment would reduce health and safety risks. With proper training, planning, and controls, in accordance with laws, regulations, and industry standards, adverse effects to workers and technicians reconfiguring facilities and removing equipment during the implementation phase would likely be *direct*, *negligible* to *minor*, *temporary*, and *localized*. Measures to restrict access to active construction areas, use of lock-out/tag-out, and other engineering controls would further protect the workforce from hazards.

Summary

Overall, modernization of equipment and facilities at semiconductor fabrication facilities under the Proposed Action would likely align with the low and falling rate of injuries and illnesses across the semiconductor manufacturing sector. The opportunity for fabrication facilities to modernize would be beneficial to address any prior safety deficiencies and would increase use of engineering controls, automation, lock-out mechanisms, sensors, and other safety features often incorporated into modern equipment. The use of these BMPs in the planning, construction, and operations phases to promote safe construction sites and install tools and equipment meeting current standards would further promote worker health and safety. The Proposed Action would provide *direct*, *beneficial*, *negligible* to *minor*, *long-term*, and *localized* effects for worker health and safety.

3.8 HAZARDOUS AND TOXIC MATERIALS

This section describes the affected environment and consequences of hazardous and toxic materials use in semiconductor fabrication under the Proposed Action and the No Action Alternative.

3.8.1 Affected Environment

The affected environment section discusses the customary hazardous and toxic materials used and the laws and regulations that govern their use. 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 analyzed separately in **Sections 3.5, 3.6, and 3.7**, respectively, of this Draft PEA. The environmental consequences section discusses the effects of construction, increased semiconductor production, potential chemical substitution, and source reduction methods on hazardous or toxic materials.

3.8.1.1 Regulatory Framework

There are several federal laws and regulations applicable to hazardous and toxic materials in the U.S.:

<u>TSCA</u>

TSCA, 15 U.S.C. §2601 et seq., provides the U.S. Environmental Protection Agency (EPA) with authority to regulate the production, use, and disposal of chemicals that have the potential to cause harm to human health or the environment. TSCA § 8 (b) requires EPA to compile, keep current and publish a list of each chemical substance that is manufactured or processed, including imports, in the United States for uses under TSCA. This list is known as the "TSCA Inventory", and it plays a central role in the regulation of most industrial chemicals in the United States. Many of the chemical substances used in semiconductor manufacturing facilities are listed on the TSCA inventory as reflected in **Appendix C**. Solvents, photoresists, etchants, deposition gases, cleaning agents, and dopants typically contain TSCA-regulated substances.

<u>EPCRA</u>

EPCRA, 42 U.S.C. Chapter 116, authorized by Title III of the Superfund Amendments and Reauthorization Act (SARA), to help communities plan for chemical emergencies. It requires facilities to report storage, usage, and releases of hazardous substances to federal, state and local government in an effort to improve chemical safety and protect public health and the environment. Specific EPCRA requirements for facilities:

- ***Sections 301 to 303***. ***Emergency Planning*** (40 CFR 355 Subpart B): Helps communities prepare for potential emergencies. Local and Tribal Emergency Planning Committees (LEPCs and TEPCs) are required 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 maintain threshold quantities of "extremely hazardous substances" (EHS) (40 CFR 355 Appendix A) onsite must cooperate in emergency plan preparation.
- ***Section 304***. ***Emergency Release Notification*** (40 CFR 355 Subpart C): Facilities must immediately report releases of a "reportable quantity" (RQ) of an EHS or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) "hazardous substance". RQs for EHSs are listed in Appendices A and B of 40 CFR Part 355. RQs for CERCLA hazardous substances are listed in Table 302.4 of 40 CFR 302.4. In addition to initial notifications, notifying facilities must provide a follow-up report to update the original notification to provide additional information on response actions taken, known or anticipated health risks, and, if appropriate, advice regarding any medical care needed by exposure victims (EPA, 2023k). SERCs, TERCs, LEPCs, and TEPCs are required to make these reports available to the public.
- ***Sections 311 and 312. Hazardous Chemical Inventory Reporting*** (40 CFR Part 370): Requires facilities to submit a safety data sheet (SDS) for each OSHA "hazardous chemical" that meets or exceeds reporting thresholds to the facility's SERC or TERC, LEPC or TEPC, and local fire department. Section 312 also requires facilities covered by Section 311 to submit an emergency and hazardous chemical inventory form annually.
- ***Section 313***. ***TRI*** (40 CFR Part 372): Establishes a mandatory federal reporting program that tracks the release and waste management of "toxic chemicals" that may pose a threat to human health and the environment. Generally, chemical substances classified as TRI chemicals 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** of this Draft PEA 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 hazardous materials. Hazardous process chemicals commonly used in semiconductor manufacturing are categorized in **Table 3.8-1**. Modern semiconductor facilities use totally enclosed processes, automated chemical delivery, gas management systems, segregated exhaust systems, safety interlocks, centralized chemical storage, and spill control/prevention measures. Process and engineering controls help prevent accidental releases (ISMI, 2006).

The semiconductor industry actively seeks to research and develop replacement chemicals that are less toxic to 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 contain N-methyl-pyrrolidinone (NMP), which is known to cause harm to reproductive systems. Therefore, some manufacturers have begun to replace traditional solvents with NMP-free varieties (UMC, 2021). In addition, the industry is under pressure to avoid or minimize use of certain PFAS substances, and leading firms are making efforts to find replacements to reduce the overall environmental and health hazards of semiconductor products (TSMC, 2022; Intel, 2023a; Samsung, 2023a). See **Appendix B** 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 process steps such as photolithography, wet etching, dry etching, implant and diffusion, and cleaning (Bolmen, 1997).

- The photolithography process uses the most 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 use strong oxidizers, including hydrogen peroxide, and acids, such as HF. According to a study from the Semiconductor Industry Association, HF accounts for over 40 percent of the total hazardous materials produced from this industry (Shen et al., 2018).
- Dry etching uses 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 are added to the wafer which may create off-gasses during the process.
- Chemical mechanical planarization uses 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 based on composition.
- Wafer cleaning involves strong acids and oxidizer mixtures to clean organic materials from the wafer surface.

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

Table 3.8-1 summarizes frequently used hazardous process chemicals according to their hazard class.

Table 3.8-1. 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, carbon monoxide, 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 CFR Part 172; EPA, 2022a

3.8.2 Environmental Consequences

This section discusses the potential effects of hazardous and toxic materials used in semiconductor fabrication facilities under the No Action Alternative and the Proposed Action Alternative.

3.8.2.1 No Action Alternative

Under the No Action Alternative, the semiconductor manufacturer would not modernize its facility, equipment and processes with CHIPS financial assistance. The No Action Alternative assumes that the proposed projects would not be implemented, and the rate of hazardous and toxic material use and their effects would not change. The No Action Alternative would have no new effects on hazardous material use.

3.8.2.2 Proposed Action Alternative

Effects of Facility-Specific Reduction and Substitution

A facility modernization and internal expansion project under the Proposed Action may affect the types and amounts of hazardous or toxic materials used. 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. These projects could result in *direct*, *localized*, *long-term*, and *beneficial* effects. 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).

Effects of Construction

Construction activities to modernize or internally expand operations would likely require the 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. However, accidental leaks and discharges from equipment, or through material handling and transfers, would be reduced through adherence to project-specific construction environmental, health, and safety plans. These plans would require onsite spill kits, spill reporting, and spill monitoring avoid, detect, and clean up spills. In addition, facilities undergoing modernization would likely have established environmental, health, and safety personnel and plans in place for hazardous material monitoring, safe storage, and spill mitigation. Any spills of hazardous material would be immediately contained and wastes would be disposed of in accordance with federal, state, and local regulations. An accidental spill could result in a temporary increase in the amount of hazardous waste generated at the facility site; therefore, if a spill were to occur, adverse effects could be *direct*, *short-term*, *minor,* and *localized*.

Effects of Increased Production

Projects that increase production under the Proposed Action would likely increase the quantity of hazardous and toxic materials used. Some of these materials currently do not have less-toxic replacements, such as HF, which is a critical process chemical. The increased demand for hazardous materials by the semiconductor fabrication industry could also increase hazardous material production at supplier facilities. The volume of materials shipped to fabricator facilities would likely increase, causing *indirect* and *regional* effects due to transport. Adverse effects would be minimized through the proper handling, storage, and use of hazardous and toxic materials in compliance with local, state and federal regulations. The increase in hazardous material use and storage at a facility could result in greater potential for environmental releases. However, automated chemical delivery systems and other engineering controls would lower the risk of accidental releases, as discussed in **Section 3.7** of this Draft PEA.

Under the Proposed Action, semiconductor facility modernization and expansion projects could cause *direct*, *adverse* effects due to increases in the quantities of hazardous and toxic material associated with increased production. Effects could be *long term*, because the effects would last for several months or longer; *localized* to *regional*, because the effects have the potential to extend from the project site to the surrounding community; and *negligible* to *minor* due to active monitoring of hazardous substances of concern, reduction or substitution with less hazardous materials, and use of engineering controls such as automated chemical delivery systems. However, for projects included under the Proposed Action, some adverse effects could be offset through process and technology improvements which reduce hazardous and toxic materials. In addition, CPO will review the environmental compliance history of companies as described in **Appendix A**.

3.9 HAZARDOUS WASTE AND SOLID WASTE MANAGEMENT

This section describes the affected environment and environmental consequences for hazardous and solid waste management 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). “Solid waste” is defined as any garbage or refuse; sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility; and other discarded material resulting from industrial, commercial, mining, and agricultural operations, or from community activities (EPA, 2023n; 40 CFR 261.2). Solid waste encompasses more than physically solid materials, and can also be in liquid, semi-solid, and contained gas form. “Hazardous waste” is a subset of solid waste that is classified based on characteristics such as ignitability, corrosivity, reactivity, and toxicity that pose a substantial threat to human health, the environment, or both (EPA, 2023n; 40 CFR 261.3).

3.9.1.1 Regulatory Framework

The federal laws and regulations which govern solid and hazardous waste management in the U.S. are:

- RCRA, as amended (42 U.S.C. 6901, et seq.)
    - Subpart B establishes criteria for the identification of hazardous waste and standards for hazardous waste generators. Generators are classified as very small quantity generators, Small Quantity Generators (SQGs), or Large Quantity Generators (LQGs) based on how much waste they generate each month (40 CFR 262). Permitted facilities are identified by their EPA ID number and subject to onsite accumulation quantity, time limits, and management requirements. There are requirements for personnel training, emergency planning, container emissions, land disposal restrictions, closure, waste minimization, packaging and labeling, tracking, reporting, and recordkeeping (EPA, 2023o).
    - RCRA Subtitle C, establishes a system for controlling hazardous waste from the time it is generated until its ultimate disposal, i.e., “cradle to grave”.
    - RCRA Subtitle D (40 CFR 257), encourages states to develop waste management plans, sets criteria for solid waste disposal facilities, and prohibits the open dumping of solid waste.
    - State and local programs, authorized under RCRA, may potentially have more stringent requirements for 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.
- 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 instance, 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, re-used, recycled, or disposed of (ISMI, 2021). Nonhazardous waste can include plastic waste, metal waste, kitchen waste and general office waste (Intel, 2019). Hazardous waste can include acids, solvents, copper sulfate, containers, and others (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) could also be sources of hazardous waste.

EPA's *National Biennial RCRA Hazardous Waste Report* tracks the generation, management, and disposal of hazardous waste by facilities with reporting requirements. Semiconductor and Related Device Manufacturing that met the LQG threshold, under 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 U.S. 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 includes 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). Semiconductor manufacturing-related waste is also discussed in **Section 2.2.4 Manufacturing Waste Streams** of this Draft PEA.

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 their 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 facilities 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 can also 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 22-23 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
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 defined by NAICS codes, and chemical threshold criteria must annually report under EPCRA §313.

Semiconductor manufacturing 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.

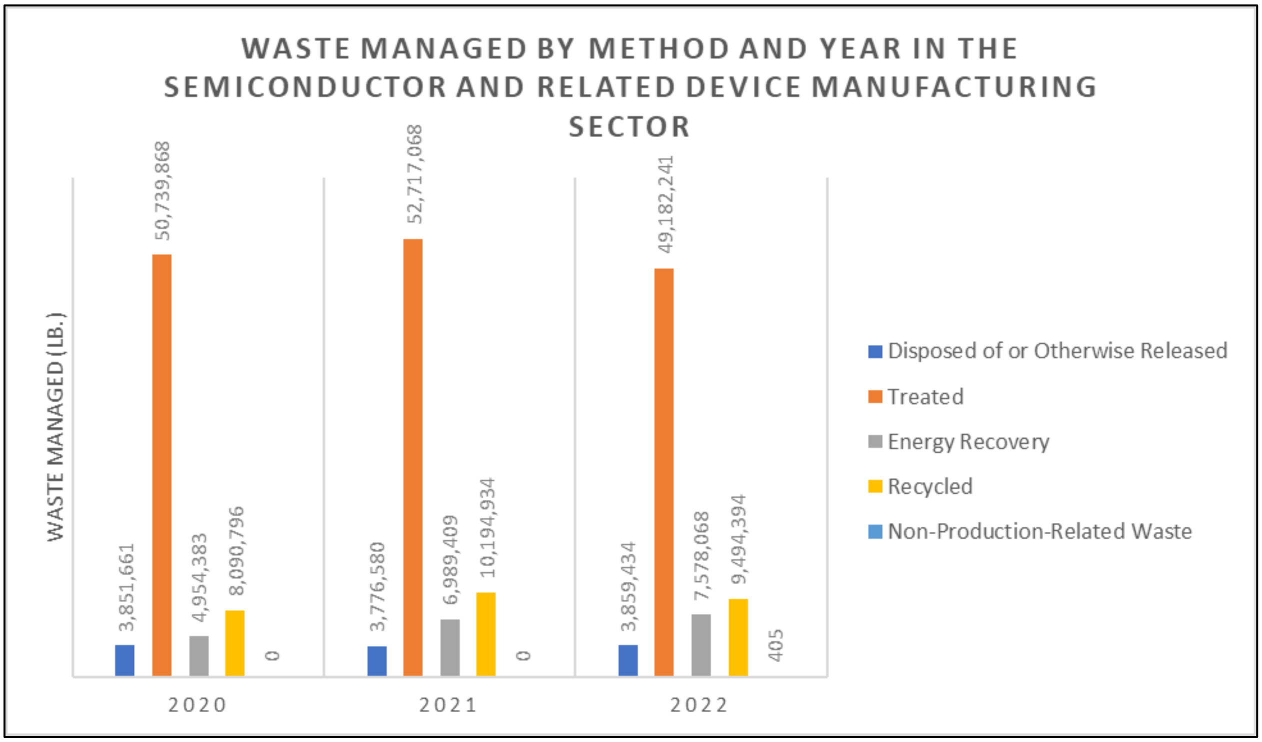
Industrial facilities report data about how they are managing chemical waste through:

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

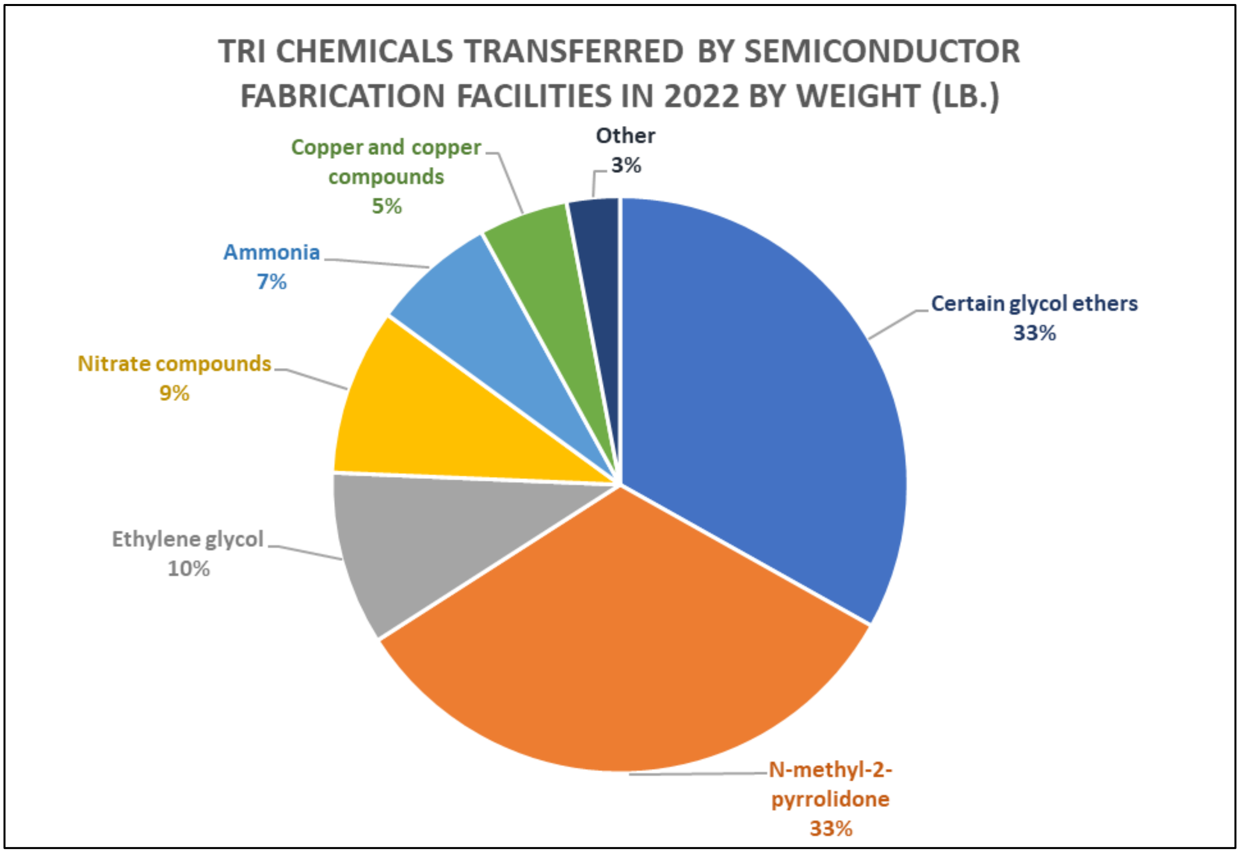


Source: EPA, 2023m

Note: TRI data under the NAICS code 334413 is not limited to semiconductor fabrication facilities

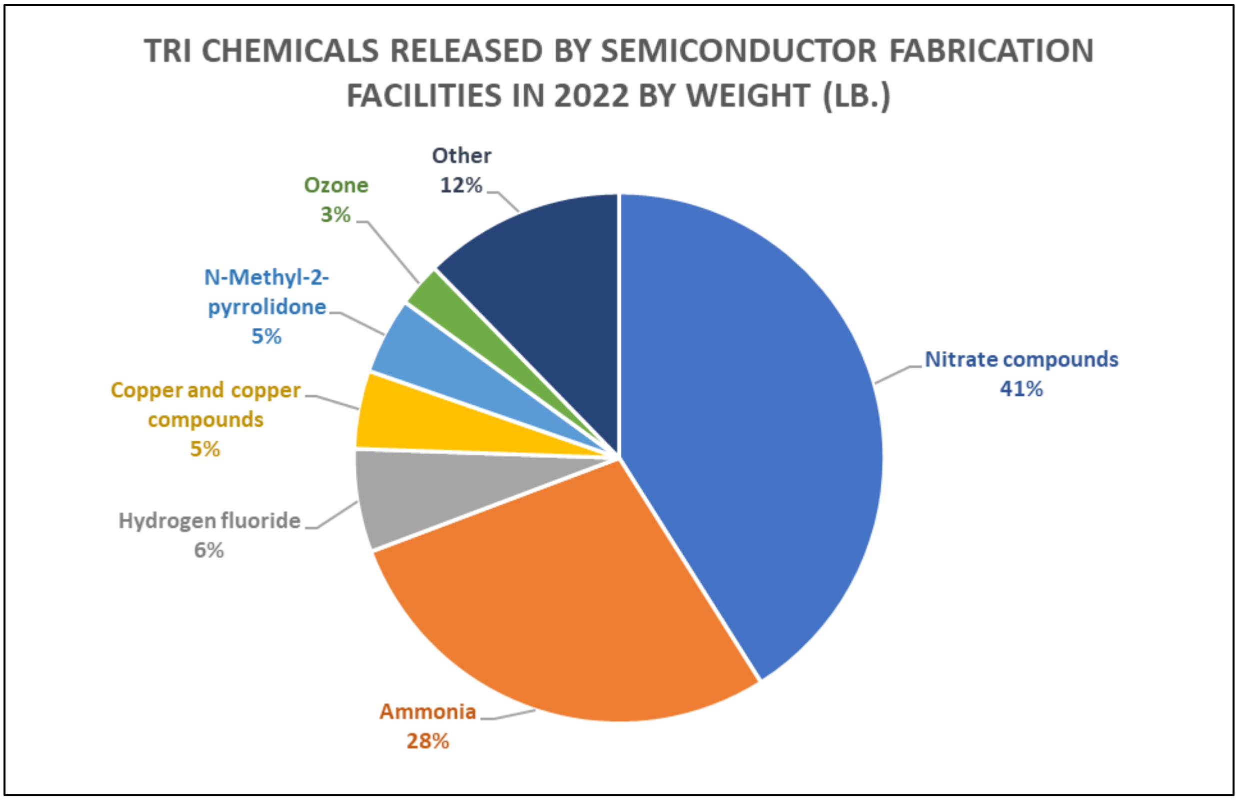
Figure 3.9-1. Waste Managed by Method and Year in the Semiconductor and Related Device Manufacturing Sector

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 (lb.) of TRI chemicals to offsite disposal, storage, or recovery facilities. These fabrication facilities released approximately 2.5 million lb. of TRI chemicals to the environment (EPA, 2022c).



Source: EPA, 2022c

Figure 3.9-2. TRI Chemicals Transferred by Semiconductor Fabrication Facilities in 2022 by Weight (lb.)



Source: EPA, 2022c

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

EPA's Risk-Screening Environmental Indicators (RSEI), a screening-level tool that compiles TRI data along with other information, 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 Hazards 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 discusses the potential effects of hazardous and solid waste management under the No Action Alternative and the Proposed Action Alternative.

3.9.2.1 No Action Alternative

The No Action Alternative assumes that the proposed modernization project would not occur. Increased hazardous and nonhazardous waste generation, associated with the Proposed Action below, would not occur. Accordingly, the No Action Alternative would have no new effects on the generation of hazardous wastes.

3.9.2.2 Proposed Action Alternative

A proposed project involving internal expansion and facility modernization at an existing semiconductor fabrication facility has the potential to affect the amount and type of hazardous and nonhazardous solid waste generated. This could also affect human health and the environment.

Effects of Construction and Installation

A modernization and expansion project may require construction within the existing facility footprint to build more cleanroom space or install supporting infrastructure. A temporary increase in nonhazardous solid waste generation could occur due to construction, renovation, and demolition. Nonhazardous waste could include cardboard, plastic, aluminum, and other construction material. *Adverse* effects to solid waste management from the construction of the Proposed Action project would be *direct*, *short-term*, *minor*, and *localized* in extent. Adverse effects could be reduced by separating construction waste and instituting a comprehensive recycling program.

Construction activities could require the 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 A** could be implemented to reduce the likelihood of spills. Any accidental spills would result in a temporary increase in the amount of hazardous waste generated at the facility site; therefore, if a spill were to occur, adverse effects would be *direct, temporary, minor to negligible,* and *localized.*

Effects of Equipment Disposal

Facility modernization under the Proposed Action could include replacement of 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 A.** Tools and parts discarded under the Proposed Action may meet the definition of RCRA "hazardous waste" and require treatment as such.

SEMI, an industry association for semiconductor manufacturers, 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). If decommissioned equipment is landfilled as nonhazardous or hazardous waste, adverse effects are expected to be *direct*, *short-term*, *minor*, and *localized* to *regional* in extent.

Effects of Increased Production

A proposed project involving internal expansion and facility modernization at an existing semiconductor fabrication facility that increases production will likely generate more hazardous and nonhazardous waste. Increased hazardous waste production may cause a Small Quantity Generator (SQG) to be reclassified as a LQG if the facility exceeds state or federal quantity limits. LQGs have more rigorous standards for waste storage, handling, reporting, and contingency planning. It is likely that personnel at SQG facilities would 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, waste managers should ensure their local providers can meet their changing 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 in 2021 (EPA, 2021b). This accounted for 0.32 percent of hazardous waste generated in the U.S. in 2021 (EPA, 2021c). U.S. semiconductor fabrication facilities would remain a small percentage of the total hazardous waste produced annually in the U.S. even if a large number of them were to increase the amount of 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). It is expected that the additional hazardous wastes generated by a project 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 production if increases in production were to occur. 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 will evaluate each applicant's waste management compliance history as described in **Appendix A** and adopt BMPs, where applicable, that would reduce waste generation.

Overall, the effects of the Proposed Action on hazardous and solid waste management could be *direct* and *indirect*, *short* to *long-term*, and *localized* to *regional* in extent; these effects would be *adverse* and *negligible* to *minor* compared to current conditions, but they could potentially be *beneficial* and *minor* if new measures were introduced to reduce, reuse, and recover materials, thereby diverting waste from landfills.

3.10 UTILITIES

This section describes the affected environment and environmental consequences of utilities used by semiconductor fabrication facilities, including electricity, natural gas, and water.

3.10.1 Affected Environment

Semiconductor manufacturing processes consume substantial amounts of energy and water as discussed in **Section 2.2.3** of this Draft PEA. Semiconductor manufacturers also are pursuing practices and projects to make their operations more sustainable, including reducing energy and water use (TSMC, 2023; UMC, 2021; Samsung, 2023a; Global Foundries, 2023).

3.10.1.1 Energy Use

Energy consumption from semiconductor production is primarily for the operation of fabrication tools, air conditioning systems for cleanrooms, and other 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 can also be energy intensive. Lithography, etching, ion implantation, and deposition tools have high power requirements and may be run continuously with little idle time.

Electricity is typically sourced from a public utility; however, it can also be supplemented from onsite renewable sources such as wind or solar. Public utilities across the U.S. often supply electrical energy from a mixture of conventional and green energy sources, including but not limited to nuclear; fossil fuels such as natural gas or coal; solar array farms; hydroelectric; geothermal; wind; and biomass (PAPUC, No Date). Renewable energy can be supplied through the purchase of renewable energy certificates (RECs), power purchase agreements (PPA), and participation in green power programs.

The semiconductor manufacturing industry is increasingly sourcing energy from renewable sources (TechHQ, 2023). In 2022, one semiconductor fabrication facility in the U.S. achieved 100 percent renewable electricity through the use of solar hot and cooling water systems, geothermal energy, micro wind turbine systems, and solar parking lot canopies, among other technologies. Off-site renewable energy can also be supplied from solar, wind, hydroelectric, and geothermal sources for electricity through utility programs and RECs (Intel, 2023b). By investing in technology and modernization of semiconductor equipment, more than 2,000 energy conservation projects were completed in the last decade that amounted to a savings of 4.5 billion kilowatt-hours (kWh), which is equivalent to the electricity needed to power 400,000 homes for one year. At another facility, installation of Light Emitting Diode (LED) fixtures in cleanrooms resulted in 80 to 95 percent savings in electricity operating costs (Intel, 2020). Chiller technology for cooling water can be converted from fixed pumps to new variable flow pump systems which can reduce energy use on average by 20 percent. Integrating sensors into equipment and conditioned spaces can provide real-time data to enable further optimization of energy use and thus, improve energy efficiency (Intel, 2020).

Natural gas also is used by semiconductor fabrication facilities to heat buildings and generate steam for humidity and is sourced by the public power grid (NXP, 2023; Global Foundries, 2023). Natural gas use can be reduced through waste heat recovery systems and adjusting air temperature and flow rates in outdoor air handling units (Samsung, 2023a).

Semiconductor manufacturing relies on the use of clean, dry air produced by energy-consuming dryer systems and compressors. Typically, compressing air results in a loss of over 80 percent of the energy as heat. The use of a centralized heat recovery system with the use of variable frequency compressors has the potential to improve energy performance by 20 percent (a variable frequency compressor can save energy compared to a fixed speed compressor). It is possible to source heat from equipment for other processes requiring heat (also known as heat recovery). Chiller condenser water can supply heat for incoming public utility water, reducing the load on cooling towers. Chillers can heat cleanroom air reducing fossil fuel use in boilers by over 30 percent. New higher temperature heat pumps can also replace old boiler systems (U.S. Chamber of Commerce Foundation, No Date).

3.10.1.2 Water Use and Wastewater Generation

Water within a semiconductor manufacturing facility is used for processing, cooling, abatement, Ultra-pure Water (UPW), and non-industrial uses. Manufacturing process equipment uses the most water (approximately 48 percent for a typical semiconductor fabrication facility). Cooling systems to manage a facility's heat load account for approximately 20 percent of overall water use. Evaporation from cooling towers causes the single largest loss of water, resulting in the loss of up to billions of gallons of water per year per manufacturing site.

Water can be supplied to semiconductor fabrication facilities from local groundwater; reclaimed water; municipal water; surface water sources such as rivers, condensation, and rainwater; and/or third-party suppliers (Wang et al., 2023). Typical water conveyance, purification, treatment, and reclamation systems present within a modern semiconductor campus include (IEEE, 2023):

- **Raw Water Systems:** Potable, Non-Potable Industrial Water, Fire Protection Water, Irrigation Water
- **Mechanical Systems:** Process Heating and Cooling, Critical Process Cooling, Heating, Ventilation, and Air Conditioning including Cooling Towers responsible for water evaporation, Humidification and dehumidification within make-up air handlers
- **Purified Water:** Softened Water, Reverse Osmosis Permeate, UPW, Critical UPW (i.e., specialized point-of-use treatment), Hot UPW, Functionalized UPW

- **Wastewater Treatment and Waste Collection Systems**: Facility-specific systems for treating and pre-treating wastewater flows to neutralize and/or remove hazardous substances (acids, metals, inhibitors, oxidizers, bases, organics, solvents, corrosives, specialty chemicals, etc.)
- **Reclaim Systems:** Depending on the configuration and complexity of the site there may be multiple reclaim systems of varying complexity, reclaiming up to 100 percent of the recoverable water.

Based on a survey of 28 semiconductor facilities, most of the water (83 percent) delivered to semiconductor fabrication facilities comes from either surface water sources or municipal water systems that treat water to meet drinking water standards (Wang et.al., 2023). The Safe Drinking Water Act protects public health by regulating the nation's public drinking water supply. This act authorizes the EPA to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water (EPA, 2023q). However, UPW (used for wafer production, wet etching, solvent processing and planarization (MKS, 2023) requires a much higher state of purification (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, with typical semiconductor fabrication facilities using up to 5 million gallons of UPW daily (Govindan, 2022).

Recycling of wastewater and process water is becoming more commonplace at semiconductor fabrication facilities. In 2022, conventional onsite treatment of wastewater enabled semiconductor fabrication facilities to recycle between 40 to 70 percent of received water. A near zero wastewater system at a facility can essentially provide a closed water loop that requires minimal amounts of makeup water to operate, potentially improving water recycling up to 98 percent (for example, a 10 million gallon per day water demand could be reduced to 200,000 gallon per day) (Johnson, 2021).

One example of best available technology developed to provide high efficiency water filtration is based on counterflow reverse osmosis, which enables much higher levels of water recovery than preexisting reverse osmosis technology. The technique reduces the amount of energy consumption for a given amount of water treated (Johnson, 2021). 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 was able to return approximately 95 percent of water used in 2020 (City of Chandler, 2021).

3.10.2 Environmental Consequences

This section discusses the potential effects to utilities under the No Action Alternative and the Proposed Action Alternative.

3.10.2.1 No Action Alternative

Under the No Action Alternative, a semiconductor fabrication facility would not receive funding for modernization or internal expansion of existing current-generation and mature-node commercial facilities. The facility would continue the use of existing equipment to maintain production at the same rate with the same emissions and operational profiles. As such, utility use would continue at current levels and no new effects on utilities would be anticipated under the No Action Alternative.

3.10.2.2 Proposed Action Alternative

Modernization or internal expansion actions may increase semiconductor production and associated energy and water use. Proposed projects involving equipment and facility modernization within an existing facility with financial assistance received from the CHIPS Incentives Program also have the potential to reduce the amount of energy and water used through new technologies and more efficient processes.

Achieving reduced energy consumption through equipment upgrades can be done with minimal impact to production. Efficiency improvements in direct equipment components such as dry pumps, local exhaust abatement, heat exchangers, and chillers can be implemented. Minimizing heat used for hot UPW by recycling water locally or maximizing heat recovery can substantially impact facility energy demand. The use of green fuels such as hydrogen fuel and onsite energy generation using solar and wind sources can offset fossil fuel-based energy use (IEEE, 2023). Reducing or reusing cooling tower evaporation through the use of variable speed pumps and motors and avoiding high-temperature dissipation would decrease the need for cooling, thereby reducing demand on HVAC systems (IEEE, 2023).

The intensive water consumption required by semiconductor fabrication facilities has the potential to limit water availability for local households, businesses, and wildlife in the community where a facility is located. Water demand can be reduced through technology improvements by implementing UPW recycling while ensuring water quality. This can be achieved by providing adequate segregation to prevent contamination and through targeted treatment. Equipment water demand should be reduced through each step or operation. Adding process steps and equipment may increase water demand. Optimizing fabrication equipment and using water-efficient systems could be solutions to ensure that wafer yield and environmental compliance for wastewater discharges are not compromised.

As the semiconductor industry continues to grow and the demand for semiconductor chips rises, adverse effects may continue to occur as increased production creates an increased demand for energy and water. However, for proposed projects that are under consideration for CHIPS federal financial assistance, these adverse effects could be reduced through semiconductor facility modernization and recycling and reclamation projects which would reduce energy and water use. Adverse effects are likely to be greater in drought-prone, water scarce regions or where there is overdemand for electricity; for more information see **Section 3.4, Climate Change and Resilience** and **Chapter 4.0, Cumulative Impacts** of this Draft PEA.

Applicants are required to submit a *Climate and Environmental Responsibility Plan* which describes their plans for maximizing the use of renewable energy and water recycling. CPO plans to work with applicants to incorporate or increase energy and water saving technologies or practices where practicable as discussed in **Appendix A**. CPO would evaluate each proposed project's energy and water use (in the context of the site's climate change challenges and other potential cumulative effects,see **Section 3.4, Climate Change and Resilience** and **Chapter 4.0, Cumulative Impacts** of this Draft PEA) to ascertain whether the proposed project would pose a burden on local community resources and determine whether the rate of utility consumption would be sustainable over the long-term. Across the industry, companies are making progress to reduce costs for energy and water and meet local utility requirements through greater efficiency, reductions in electricity and natural gas use, reduction of freshwater withdrawal, and reclamation and reuse of water. Energy and water usage are interdependent, so as the demand for water is reduced, energy demand is also reduced (IEEE, 2023). The implementation of BMPs would provide opportunities to reduce impacts to utilities from semiconductor manufacturing over the long term (see **Appendix A** for a list of potentially applicable BMPs).

Overall, effects of the Proposed Action on energy and water use would be *direct*, *adverse*, *long term*, *minor*, and *localized* to *regional* for a facility that increased production as part of its proposed project; however, effects would be reduced by installation of improved, more energy- and water-efficient process tools and related infrastructure and could potentially be *beneficial* and *minor* if the facility implemented overall improvements to reduce water and energy consumption through water reclamation, reuse, and recycling and use of renewable energy. Effects would also be *long term, beneficial* and *minor* if a facility upgraded its equipment and infrastructure without increasing production as new equipment would be more efficient...

3.11 ENVIRONMENTAL JUSTICE

This section describes the affected environment and consequences to Environmental Justice (EJ) from the Proposed Action and the No Action Alternative.

3.11.1 Affected Environment

EPA defines "environmental justice" as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (EPA, 1998). The goal of "fair treatment" is not to shift risks among different populations but to identify potential disproportionately high and adverse effects on minority communities and low-income communities and identify alternatives that may mitigate these effects (EPA, 1998).

This section of the Draft PEA interprets the affected environment for EJ to include identification of any disproportionately high and adverse effects on minority communities and low-income communities along with 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 action any disproportionately high and adverse human health or environmental effects to minority and low-income populations (collectively referred to as "populations with EJ concerns" throughout this section). Federal agencies are required to ensure that these potential effects are identified and addressed.
- 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 Alaskan 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, as well as Alaskan 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.

3.11.1.2 Identification of Populations with EJ Concerns

The affected environment for EJ must include identification of any disproportionately high and adverse effects on minority communities and low-income communities. While a site-specific analysis would normally present race and income information for populations affected by the undertaking and identify minority or low-income populations that could be disproportionately affected, due to the programmatic nature of this PEA, site-specific information for the Proposed Action is unknown. Instead, this section presents the methodology that applicants and CPO must use to determine the presence of populations with EJ concerns at the specific locations where the Proposed Action would occur.

CEQ's EJ Guidance under NEPA 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 the Proposed Action.

Due to the site-specific nature of any given facility modernization and internal expansion proposal, the ROI could comprise one or more census tracts (CTs) or block groups (BGs). The type of geographic unit selected for analysis (i.e., either CT or BG) would depend on the project scope and location. These units are briefly described below:

- **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. 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).

Following the identification of the appropriate ROI, the race, ethnicity, and income 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. ROC is the unit of geographic analysis (e.g., county, state, or region) that provides a baseline for comparison of health and environmental effects on populations of EJ concerns with the effects on 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 population with EJ concerns based on the factors described below. In addition to identifying and characterizing communities in accordance with federal guidance, consideration of state-level EJ laws, 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. 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 EJ communities subject to the state's Department of Environmental Protection permits (Gerrard and McTiernan, 2021).

The federal criteria for identifying communities of EJ concern are described below:

Minority Populations

The CEQ defines "minority" as including the following population groups: American Indian or Alaskan Native; Asian or Pacific Islander; Black, not of Hispanic Origin; or Hispanic (CEQ, 1997). The CEQ defines a minority population in the following ways:

- "…the minority population of the affected area exceeds 50 percent... (CEQ, 1997)." [As this definition applies to the Proposed Action and alternatives, if more than 50 percent of the population in the ROI consists of minorities, this would qualify as constituting a population with EJ concerns.]
- "…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 purposes of this analysis, a discrepancy of 10 percent or more between minorities (the sum of all minority groups) in the ROI would be considered "meaningfully greater than" minorities in the ROC and would categorize the ROI as constituting a minority population with EJ concerns.]

Low-Income Populations

"Low-income populations" are defined as households with incomes below the federal poverty level (ASPE, No Date). There are two slightly different versions of the federal poverty measure: poverty thresholds defined by the USCB and poverty guidelines defined by the Department of Health and Human Services.

Poverty thresholds are defined by and updated each year by the USCB. 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, and 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 under NEPA recommends that USCB poverty thresholds be used to identify low-income populations (CEQ, 1997). As such, this section uses USCB poverty thresholds to identify low-income populations.

Because CEQ guidance does not specify a threshold for identifying low-income populations, the same approach used to identify EJ minority populations is applied to low-income populations. The ROI would be defined as a low-income population or population with EJ concerns if:

- More than 50 percent of the ROI consists of families or persons below the poverty threshold; or
- The percentage of low-income families or persons in the ROI is meaningfully greater than the percentage in the ROC. A discrepancy of 10 percent or more between the ROI and the ROC would be considered "meaningfully greater" and would categorize the ROI as constituting a low-income population with EJ concerns.

Native American Tribes

As described above, the CEQ EJ Guidance under NEPA 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 concentrated "pockets" or reservations in and outside the ROI and that engage in unique cultural and traditional practices (e.g., subsistence and ceremonial fishing) that are directly dependent on the resources occurring in the ROI.

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 disproportionately high and adverse effects on such communities.

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

Tool	Description
EJScreen	EPA's EJ mapping and screening tool provides high-resolution environmental and demographic information for the identification of areas with (EPA, 2023r): • People of color and/or low-income populations; • 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, 2023r).
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).
National Environmental Public Health Tracking Network (Tracking Network)	Centers for Disease Control and Prevention's (CDC) Tracking Network provides environmental health data that includes the following (CDC, No Date): • 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); • Population characteristics (e.g., age and income)
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, 2016).
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, 2023s).

Tool	Description
Social Vulnerability Index	CDC's and 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, No Date).

*Please note that this is not an exhaustive list but includes the commonly used tools for EJ analysis. The state in which the Proposed Action is located may have its own EJ screening tool or similar resources that should be consulted to ensure that EJ communities are also evaluated according to relevant state and local guidelines.

3.11.2 Environmental Consequences

This section discusses the potential effects to EJ under the No Action Alternative and the Proposed Action Alternative.

3.11.2.1 No Action Alternative

Under the No Action Alternative, a semiconductor fabrication facility would not receive funding for modernization or internal expansion of existing current-generation and mature-node commercial facilities. The facility would continue the use of existing equipment to maintain production at the same rate with the same emissions and operational profiles. As such, no new effects to identified EJ communities would be anticipated under the No Action Alternative.

3.11.2.2 Proposed Action Alternative

A proposed project involving equipment and facility modernization and expansion within the existing facility footprint that receives financial assistance from the CHIPS Incentives Program could potentially affect EJ communities by introducing new or increased health and safety hazards during the construction and operations, such as noise, unsafe traffic patterns, or pollution levels. EJ communities might be present in the project area. An EJ analysis would be conducted for the proposed project to ensure there would not be disproportionately high and adverse effects on EJ populations. This analysis would be documented by CPO during due diligence and prior to the proposed project receiving any funding. Consideration of the potential consequences for EJ requires three main components.

1. A demographic assessment of the affected community to identify the presence or absence of minority populations, low-income populations, and Native American tribes that may be affected.
2. An assessment of all potential effects identified to determine if any could result in adverse effects to the affected environment.
3. An integrated assessment to determine whether any disproportionately high and adverse effects exist for minority populations, low-income populations, and Native American tribes present in the ROI.

In general, the types of potential effects on populations with EJ concerns could include:

- Social and economic benefits of direct, indirect and induced jobs created;
- Health risks (especially to workers) from the proposed construction, expansion, and modernization activities;
- Noise disturbances;
- Restricted or delayed access to schools, residential areas, public transportation, or hospital and health care facilities due to traffic and time delays; and

- Effects to the unique cultural and traditional practices of Native American tribes.

As discussed in **Section 3.12 Socioeconomics**, the Proposed Action would likely result in the creation of short-term construction jobs, some of which may be filled by populations with EJ concerns. Depending on the project location, the majority of the labor involved may be sourced from specialized contractors located outside the ROI; however, these revenues may also result in the creation of a relatively small number of jobs sourced from within the ROI. The Proposed Action also may lead to the creation of additional, long-term or permanent full-time positions at the facility. If populations with EJ concerns are hired to work on these proposed projects, they could experience *negligible* to *minor* health benefits through economic pathways in the *short* and *long term*.

There may be short-term construction noise and air emissions associated with equipment removal, installation of new, modernized equipment, upgrades to existing equipment, or conversion of internal spaces to new cleanrooms. Because modernization projects would largely include renovation of interior spaces, outdoor heavy equipment operation would be *minor* (such as use of cranes to move heavy equipment and forklifts to move materials). As such, the effects from noise and air emissions associated with the construction equipment for each project would be *negligible* and *temporary*. Modernization projects would generally result in minor increases in staffing, resulting in negligible to minor effects on local traffic. Accordingly, commuter vehicle emissions, public transportation access, and traffic patterns would generally be unchanged and not pose adverse effects to local communities, including EJ communities, unless there is substantial increase in long-term workforce.

The Proposed Action may result in the use of greater quantities of energy and water and generate more solid waste, hazardous waste, air contaminants, and wastewater. CPO would evaluate applicant proposals to ensure applicable federal, state, and local environmental permits are received and, where applicable, promote applicant commitments to BMPs or best available control technologies to minimize adverse effects of their operations on the health of EJ communities as outlined in **Appendix A.**

A recipient of CHIPS Incentives Program funding would be expected to conduct meaningful public engagement and outreach to EJ communities. The facility would be expected to design its projects to minimize the potential for adverse effects on the environment and the local community, including communities with EJ concerns as reflected in the facility's required Climate and *Environmental Responsibility Plan* 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."

In summary, effects to EJ from the Proposed Action could be both beneficial and adverse. Beneficial effects could result from the direct, indirect, and induced employment opportunities associated with the construction and operational phases of the proposed project. Such effects would be *negligible* to *minor* and range from *short-term* to *long-term* or *permanent*. Allocation of funds to provide training to disadvantaged individuals for their workforce development and job placement, as incentivized by the CHIPS Act, would result in *mino*r to *moderate*, *long-term beneficial* effects to such populations. These *beneficial* effects would be *regional in* extent.

Negligible, temporary, and *localized* adverse effects from noise and air emissions may occur on the health and well-being of populations with EJ concerns hired to work at the applicant facilities. Any potential for disproportionately high and adverse effects to such communities due to the increased quantities of wastes generated and the higher volumes of resources utilized by the facilities would be addressed in the due diligence process. Such effects may be *minor* to *moderate*, *short-term* to *long-term*, and *localized* or *regiona*l in extent and would depend on the scope and location of the facility modernization or internal expansion project. Such effects would be minimized by developing and implementing appropriate BMPs.

3.12 SOCIOECONOMICS

This section describes the affected environment and consequences to socioeconomics from the Proposed Action and the No Action Alternative.

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 ROI, that could be potentially affected by the proposed project and compare it with the socioeconomic data for the ROC (see **Section 3.10 Environmental Justice** for detailed descriptions of ROI and ROC). These characteristics include local demographics, labor force participation and employment, and income. However, due to the programmatic nature of this PEA, site-specific information for the Proposed Action is unknown. Instead, this section presents an overview of the U.S. semiconductor industry, the challenges facing it, and the economic implications of the CHIPS Act of 2022.

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, 2022). The U.S. government and 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 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 the 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

While 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 semiconductor industry jobs in the U.S.

3.12.2 Environmental Consequences

This section discusses the potential effects to socioeconomics under the No Action Alternative and the Proposed Action Alternative.

3.12.2.1 No Action Alternative

Under the No Action Alternative, a semiconductor manufacturing facility would not receive federal funding for modernization or internal expansion of existing current-generation and mature-node commercial facilities. The facility would continue the use of existing equipment to facilitate production at the same rate and would not produce chips needed by emerging technologies. While private investment could assist modernization activities, the pace could be slower when compared to receiving CHIPS financial assistance under the Proposed Action. The socioeconomic effects of the No Action Alternative could result in fewer jobs and reduced contribution to GDP when compared to the Proposed Action Alternative.

3.12.2.2 Proposed Action Alternative

The Proposed Action would have *direct, beneficial, short-term* effects on socioeconomics due to the creation of specialized employment opportunities associated with the removal of outdated equipment, installation of modernized equipment, upgrades to existing equipment, or conversion of internal spaces within the existing facility footprint to create new cleanrooms. Modernization projects would likely require both skilled tradespeople (electricians, pipe-fitters, heating/ventilation/cooling contractors, etc.), laborers, and specialized semiconductor manufacturing equipment installation technicians depending on the project scope. Where a facility's production is expanded substantially, there would likely be creation of direct, full-time well-paying jobs. Individuals hired to work on these proposed projects could experience *negligible* to *minor* health benefits through economic pathways in the *short* and *long* term. 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).

Indirect economic effects would also result from directly affected industries, such as facilities that manufacture equipment and materials for semiconductor manufacturing. Such entities may be located outside of the ROI, resulting in benefits that could extend over a much larger region. In addition, local retail stores and establishments where workers spend their wages should 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 facility; a greater funding amount would generate substantially larger direct, indirect, and induced economic effects.

The Proposed Action may result in one of the following scenarios for facilities receiving CHIPS financial assistance: increased production of their current product, continued production at the same rate but production of an improved product, both the expansion of production and product quality improvement, or reduction in production but improvement in product quality. This could result in indirect benefits to the end-use markets that rely on semiconductors, such as industries like automobile, communication, defense, information technology, manufacturing, medical technology, renewable energy, and aerospace. Increased modernization could ultimately reduce chip shortages among these industries, which would benefit U.S. consumers and the economy overall (SIA, 2022). These effects would also contribute to the GDP, create additional employment in sectors dependent on semiconductors, and increase overall earnings.

As such, the Proposed Action would have *direct, minor, short-term* to *long-term* beneficial effects on socioeconomics due to the creation of specialized employment opportunities. The indirect socioeconomic effects to downstream industries would be *long-term, beneficial,* and *moderate*. All socioeconomic effects would be *regional* to *national* in extent.

3.13 SUMMARY OF POTENTIAL EFFECTS

Table 3.13-1 below provides a summary of anticipated effects from the No Action and Proposed Action Alternatives. As part of the due diligence process to receive CHIPS Incentives Program funding, an applicant must demonstrate compliance with all existing facility permits. Upon completing modernization and/or internal 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. Additionally, the facility may be required to commit to appropriate best management practices (BMPs) within the industry (see **Appendix** A) to reduce environmental effects resulting from implementation of the modernization and/or internal expansion project.

Prior to issuing funding, the DOC would evaluate whether the proposed project and its associated effects are covered under the PEA or whether additional NEPA analysis is needed.

Table 3.13-1. Summary of Potential Effects

Resource Area	No Action Alternative	Proposed Action Alternative
Climate Change and Resiliency	Ongoing emissions trends of GHGs from semiconductor manufacturing facilities would remain the same, and there would continue to be a negligible to minor, adverse, long-term, global effect on U.S. GHG emissions and resultant climate change and climate resiliency. Overall, there would be no new effects on climate change and resiliency from the No Action Alternative.	Effects to climate change and resiliency would be negligible to minor, long-term, and global. Direct and indirect GHG emissions could be reduced through use of energy-efficient technologies and implementation of BMPs; however, increased production, if implemented, would increase GHG emissions. Effects could be adverse or beneficial, but given the high GWP of some GHG constituents effects are more likely to be adverse.
Air Quality	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.	An increases in semiconductor production may cause an increase in pollutant loads and changes in the types of pollutants emitted, resulting in adverse effects on air quality. Effects on air quality would be direct; long term, because the effects would last for several months or longer; and localized to regional, because the effects have the potential to extend from the project site to the surrounding community. These effects would be adverse and negligible when compared to current conditions, but they could be beneficial and minor if new air pollution control measures were introduced with the modernization to reduce the pollutant load in air emissions.
Water Quality	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.	A semiconductor fabrication facility modernization and expansion project would cause direct, adverse effects on water quality from the introduction of pollutants associated with increased production. Long-term changes in the volume and concentration of wastewater would have local effects for direct dischargers and regional effects for indirect dischargers. Effects to water quality would be minor because facilities would still be required to comply with wastewater discharge permit limits and conduct routine monitoring to confirm compliance. Modernization of equipment and the facility would have direct, long-term, localized to regional effects on water quality; these effects would be adverse and minor compared to current conditions.

Resource Area	No Action Alternative	Proposed Action Alternative
Human Health and Safety	The proposed project would not be implemented, but the facility would continue to follow all regulations protecting worker health and safety. There would be no new effects to human health and safety.	Effects of construction would be direct, negligible to minor, temporary, and localized. Effects of increased production would be direct, long-term, negligible to minor, and localized. Effects of decontamination and removal of manufacturing equipment would be direct, negligible to minor, temporary, and localized.
Hazardous and Toxic Materials	The rate of hazardous and toxic material use would not change; there would be no new effects on hazardous material use.	Effects of facility-specific reduction and substitution would be direct, localized, long-term, and beneficial. Effects of construction would be direct, short-term, minor, and localized. Effects of increased production would be indirect, adverse, and regional. Overall, effects to hazardous and toxic materials would be direct, adverse, negligible to minor, long-term, and localized to regional.
Hazardous Waste and Solid Waste Management	No new effects on the generation of hazardous waste would occur.	Overall effects from construction, equipment disposal, and increased production would be direct and indirect, short- to long-term, and localized to regional in extent. Effects would be adverse and negligible to minor compared to current conditions, but could be beneficial and minor of new measures were introduced to reduce, reuse, and recover materials.
Utilities	The facility would continue to use the same equipment at the same production rate and no new effects to utilities would occur.	Overall, effects to energy and water use would be direct, adverse, long-term, minor, and localized to regional for a project that increases production; effects would be reduced by improvements in technologies and practices. Effects would be long-term, beneficial, and minor for facilities that upgrade equipment and infrastructure without increasing production.
Environmental Justice	No new effects to identified Environmental Justice communiities would occur.	Effects to EJ from the Proposed Action could be both beneficial and adverse. Such effects would be negligible to minor, range from short-term to long-term or permanent, and regional. Negligible, temporary, and localized adverse effects from noise and air emissions may occur on the health and well-being of populations with EJ concerns hired to work at the applicant facilities. An EJ analysis would be conducted for proposed projects to ensure there would not be disproportionately high and adverse effects on EJ populations. This analysis would be documented by CHIPS during due diligence and prior to a proposed project receiving any funding.

Resource Area	No Action Alternative	Proposed Action Alternative
Socioeconomics	The No Action Alternative would result in fewer jobs and reduced contribution to GDP when compared to the Proposed Action Alternative.	The Proposed Action would provide an economic boost to the U.S. semiconductor industry by increasing production of advanced chips. The Proposed Action would have direct, beneficial, short-term effects on socioeconomics due to the creation of specialized employment opportunities associated with the removal of outdated equipment, installation of modernized equipment, upgrades to existing equipment, or conversion of internal spaces within the existing footprint to create new cleanrooms. Indirect economic effects would also result from directly affected industries, such as facilities that manufacture equipment and materials for semiconductor manufacturing. Overall, direct effects would be minor, short-term to long-term, and beneficial due to the creation of specialized employment opportunities. The indirect socioeconomic effects to downstream industries would be long-term, beneficial, and moderate. All socioeconomic effects would be regional to national in extent.

4.0 CUMULATIVE EFFECTS

Cumulative effects on the environment occur from the incremental impact of the Proposed Action when added to other past, present, and reasonably foreseeable future actions regardless of who undertakes such actions. Cumulative impacts can result from individually minor, but collectively substantial, actions taking place over time.

Past, present, and future actions analyzed under cumulative impacts should have a connection to the Proposed Action for internal modernization of semiconductor fabrication facilities, where additive or synergistic effects (beneficial or non-beneficial) are possible that would affect local, regional, or global environmental resources. This discussion on cumulative impacts focuses on the following trends and foreseeable actions related to the overall semiconductor ecosystem:

- Creation of semiconductor fabrication facility clusters in the U.S.
- Economic effects of increased semiconductor manufacturing in the U.S. (including CHIPS Incentives Program funding of new manufacturing facilities).
- Semiconductor manufacturing industry emissions of greenhouse gases (GHGs) and climate change trends.
- Trends in corporate responsibility and environmental stewardship in the semiconductor manufacturing industry.

4.1 CLUSTERING OF SEMICONDUCTOR FABRICATION FACILITIES IN THE U.S.

Modernizing an existing semiconductor fabrication facility would likely 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, wireless 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).

While 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 could also occur in the case of semiconductor manufacturing. Water use is a great concern because of the vast quantities of water required by semiconductor fabrication facility operations. There is the potential for major adverse cumulative effects to constrained fresh water supplies could occur (e.g., depletion of rivers, reservoirs, and aquifers) by concentrating several fabrication facilities 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.

Clustering also 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 environmental concerns specific to the industry at that location’s environmental conditions.

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 internal expansion of existing current-generation and mature-node semiconductor fabrication facilities.

The Proposed Action of modernizing an existing semiconductor fabrication facility would likely not induce creation of new semiconductor clusters at that location. The potential for increased production at an existing facility would likely 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. While the Proposed Action would help meet other goals of the CHIPS Incentives Program, it would likely not cause significant cumulative environmental impacts in association with existing or planned semiconductor clusters.

4.2 ECONOMIC EFFECTS OF THE CHIPS ACT IN THE U.S.

The CHIPS Act resulted in the announcement of dozens of proposed projects to increase manufacturing capacity in the U.S. According to the Semiconductor Industry Association (SIA), over 60 new projects have been announced with over $210 billion in private investments across 22 states with an expected 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 is also aimed at spurring growth in scientific research and allocates funds for material science, quantum computing, and biotechnology. The Department of Energy (DOE) is developing a plan to reduce energy use of microelectronics chips, circuits, architecture, and software by 1000 times in the next 20 years under the CHIPS Act (Bui, 2023).

The Public Wireless Supply Chain Innovation Fund investments are also authorized through the CHIPS Act. The funds are aimed at fostering competition, lowering costs for consumers and network operations, supporting innovation across the global telecommunications ecosystem, and strengthening 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. By 2030, the Boston Consulting Group in collaboration with NTIA, estimates 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).

While the CHIPS Act is an important component to spur private investments, 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 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** of this Draft PEA, consequences of climate change are increasing and resulting in more intense droughts, water scarcity, flooding, severe wildfires, melting polar ice and glaciers, more catastrophic storms, and declining biodiversity (U.N., No Date).

The semiconductor industry in the U.S., 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. greenhouse gas emissions (GHG) or approximately 11.5 million metric tons (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 accounts for almost half of total GHG emissions from the semiconductor manufacturing sector. Direct emissions from the use of fluorinated compounds in onsite manufacturing processes are more difficult for manufacturers to reduce. 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).

The annual total direct GHG emissions across the U.S. semiconductor sector have remained consistent between 5.9 and 6.4 MMT a year, with 2019 having the lowest levels (with 47 companies reporting) and 2021 the highest (with 46 companies reporting). U.S. semiconductor sales grew 5 percent between 2014 and 2020 adjusted for inflation, which is in line with the relatively flat increase in GHG emissions. Sector

GHG emissions will likely increase over the next decade based on the anticipated increase in new fab construction to expand semiconductor manufacturing.

McKinsey predicted (based on a range of macroeconomic assumptions) that semiconductor markets will grow by an average of 6 to 8 percent a year up to 2030 (McKinsey, 2022b). Thus, the sector will likely increase its global share of GHGs when compared to current levels. Below, **Section 4.4** describes the industry's past, present, and future actions to address GHGs and other areas of environmental stewardship.

Applicants are required to submit a *Climate and Environmental Responsibility Plan* under the Notice of Funding Opportunity. 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 facility footprint; it would increase GHGs emissions only slightly when compared to levels associated with the expected growth of the industry in the U.S. and worldwide. Proposed projects receiving CHIPS federal financial assistance would be encouraged to reduce their GHG footprint 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 greenhouse gases 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 (MOU) with the U.S. Environmental Protection Agency (EPA) in 2001, SIA members voluntarily reported on their emissions of perfluorochemicals (PFCs), a category of 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 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 greenhouse gas 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" (UNCC, No Date).

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 typically 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 minor production increases with resulting *minor* environmental effects as compared to construction of new semiconductor fabrication facilities. 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 impacts 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: ENVIRONMENTAL DUE DILIGENCE PROCESS AND BEST MANAGEMENT PRACTICES FOR MODERNIZATION AND INTERNAL EXPANSION PROJECTS AT EXISTING SEMICONDUCTOR FABRICATION FACILITIES

APPENDIX A
ENVIRONMENTAL DUE DILIGENCE PROCESS AND BEST MANAGEMENT PRACTICES FOR MODERNIZATION AND INTERNAL EXPANSION PROJECTS AT SEMICONDUCTOR FABRICATION FACILITIES

The environmental review process that the CHIPS Program Office (CPO) completes prior to starting the National Environmental Policy Act (NEPA) analysis is discussed in Section 1.0 of the Draft Programmatic Environmental Assessment (PEA). This includes a merit review evaluation of the Environmental Questionnaire that includes 26 questions on the project scope, local environment, potential for environmental effects, and permits required for construction of improvements and operation of the upgraded facility.

Concurrent with the NEPA review, CPO conducts wider due diligence on the proposed project which includes reviewing facility environmental permits. CPO completes a review of the company's environmental compliance status, history, and permitting pathway for the new project as part of due diligence.

The Commercial Fabrication Facilities Notice of Funding Opportunity (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 Commercial Fabrication Facilities 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.

CPO also evaluates site-specific aspects of a proposed project and provides its own validation of the environmental information provided by the applicants for inclusion in the permitting due diligence documentation. These additional considerations that are part of due diligence contribute to the development of Best Management Practices (BMP) recommendations for individual sites. Site-specific review includes (where applicable and available), but is not limited to:

- Environmental justice (EJ) local population analysis using U.S. Environmental Protection Agency (EPA) EJScreen or other government tools.

- Identification of Native American Tribes for Government-to-Government consultation, as applicable, through Bureau of Indian Affairs (BIA) resources, Housing and Urban Development Tribal Director Assessment Tool, or other relevant federal and state resources.
- Identification of whether projects are situated in nonattainment or maintenance areas pursuant to the National Ambient Air Quality Standards.
- Compliance history of the facility using the EPA Environmental Compliance History Online (ECHO). ECHO provides facility-level compliance information with regard to 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.
- Federal, state, and local permitting databases.
- Wetlands inventories per the United States Geologic Survey (USGS) National Wetlands Inventory (NWI) database and other federal and state sources.
- Facility greenhouse gas (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 CFR Part 1904 with public access will commence 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.

Best Management Practices

Some proposed projects may require or include as a matter of practice the application of appropriate mitigation measures or BMPs to avoid or minimize environmental effects.

Below is a list of BMPs that could be applied to semiconductor fabrication facility modernization and internal expansion projects categorized by the resource areas discussed in Chapter 3 of the PEA. The use of these BMPs will be determined on a project-specific basis. If an applicant proceeds past merit review and their project is to be covered under the PEA, CPO would provide a Preliminary Memorandum of Terms to include BMPs and best available technologies. Adhering to the BMPs and using the best available technologies would be required to remain consistent with the effect determinations described in Chapter 3 of the PEA.

Table 1. Best Management Practices for Semiconductor Fabrication Facilities

Resource Area(s)	Project Phase(s)	Best Management Practice
• Climate Change and Climate Resilience • Air Quality • Utilities	• Planning • Construction • Operations	Reduce GHG and air pollutant emissions associated with electricity consumption by purchasing renewable energy or carbon-free electricity through Renewable Energy Credits or Power Purchase Agreements, or by installing on-site renewable energy projects.
• 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: • Enhancing building energy-efficiency through LEED design and building energy management systems. • 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. • Benchmark facility energy use performance.
• 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, 2012): • 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. • Reusing onsite alternative water that would otherwise be discarded or discharged to the sewer.
• 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.

Resource Area(s)	Project Phase(s)	Best Management Practice
• 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 (SWP3).
• 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.
• 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 right-of-ways 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, and electrical design.

Resource Area(s)	Project Phase(s)	Best Management Practice
• 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.
• 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. • 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.
• 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.

Resource Area(s)	Project Phase(s)	Best Management Practice
		• 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.
• 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 (EJ)	• 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.

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

USE OF PFAS IN SEMICONDUCTOR FABRICATION FACILITIES AND EMERGING PFAS STANDARDS

INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are a group of manufactured organic chemicals composed of a chain of carbon-fluorine (C-F) bonds—one of the strongest chemical bonds (AWWA, 2019). There are more than 3,000 PFAS manufactured and used in the United States (U.S.). Novel PFAS compounds are frequently developed in laboratories and manufactured in factories. PFAS are divided into two primary types: long-chain, which contain six or more linked carbon atoms and short-chain, which contain fewer than six carbon atoms.

In general, PFAS are highly stable, water- and oil-resistant, and exhibit other properties that make them useful in nonstick and water-repellant applications. Due to these properties, PFAS have been widely used in various industries and products since the 1940s. PFAs can be found in household items, personal care products, food and food packaging, fire extinguishing foam, and manufacturing or chemical production facilities (EPA, 2023a). Facilities that manufacture PFAS are referred to as primary manufacturing facilities, while facilities that use PFAS to manufacture other products are secondary manufacturing facilities (EPA, 2023a).

The characteristic stability of PFAS chemicals also makes them resistant to natural degradation processes, including hydrolytic, photolytic, and oxidative reactions, earning them the name "forever chemicals." In other words, they are persistent, resisting chemical decomposition or biodegradation. Their subsequent accumulation in the environment, in ecological food chains, and in organisms is known as bioaccumulation (EPA, 2023a). Although they are not naturally occurring, PFAS chemicals can be present in our water, soil, air, and food. PFAS can enter the environment via dust, surface water, soil, and groundwater from manufacturing and processing, waste disposal, and the use of PFAS-containing products (EPA, 2023a).

Once in the environment, PFAS may be incidentally inhaled or ingested by animals or humans. Ingestion is the primary exposure pathway for the general population (ATSDR, 2019). Dermal absorption of PFAS through the skin is possible but limited and is of minimal concern as an exposure pathway (ATDSR, 2019). Environmental or occupational exposure to certain PFAS may lead to adverse health outcomes (EPA, 2023a). Human health effects from exposure to certain levels of PFAS may include impacts to reproductive, immune, and/or endocrine (i.e., hormone) systems, as well as an increased risk of cancer, high cholesterol, or obesity (EPA, 2023a). People have higher exposure risk if they work at, live, or recreate near a PFAS-producing facility. Pregnant women, lactating women, and children tend to drink more water per pound of body weight than the average person and as a result they may have higher PFAS exposure compared to other people if it is present in their drinking water. Some PFAS, such as perfluorooctanoic acid (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 U.S. and other industrialized countries, most people have measurable amounts of protein-bound and free PFAS chemicals in their blood (ATSDR, 2019).

Only a small portion of PFAS, primarily PFOA and perfluorooctane sulfonate (PFOS), are well-studied in terms of their transport and fate in the environment, exposure to humans and animals, and/or toxicological effects in humans and animals. Note that in the U.S. as of 2015, PFOA and PFOS have both been replaced with other short-chain PFAS (ATSDR, 2019; EPA, 2023a; HHS, 2023). Like other PFAS, PFOA and PFOS are released to the environment in and around primary and secondary manufacturing facilities (ATSDR, 2019). PFOS has been found in surface water and sediment downstream of manufacturing facilities; in wastewater treatment plant effluent and sewage sludge; and in 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 relatively remote areas, including in oceans and the Arctic, suggesting the long-range transport potential of PFAS chemicals. PFOS has been shown to bioaccumulate in both terrestrial and aquatic animals, but PFOA has been shown to bioaccumulate in terrestrial animals only, including humans.

The 2015-2016 National Health and Nutrition Examination Survey (NHANES) 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% 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-life of PFOA and PFOS, respectively, is approximately 2-10 years and 3-17 years (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

Due to the large and ever-increasing number and variety of PFAS compounds, the vast majority of PFAS are not well researched, making it difficult for governments to set PFAS regulatory limits. Detection of PFAS in the environment is difficult and costly because each type of PFAS often requires the development and validation of a unique set of detection methodologies. Two EPA detection methods (numbers 537.1 and 533) can detect up to 43 PFAS compounds (of the more than 3,000 known to exist) in drinking (potable) water (EPA, 2023i). Four other EPA methods (numbers 8327, OTM-45, SW-846, and TO-15) are suitable for PFAS detection in non-potable water (wastewater, surface or groundwater), and air emissions, including volatiles or semi/non-volatiles (EPA, 2023i; EPA, 2023f; MIDEQ, 2014). **Table 1** lists all PFAS that can be detected in the environment via current EPA Methods; note that available documentation for Methods SW-846 and TO-15 does not list specific PFAS chemicals that can be detected using Methods SW-846 and TO-15. One method (number 1633) for the detection of PFAS in non-potable water, soil, biosolids (treated sewage sludge), sediment, landfill leachate (forms when rainwater filters chemicals out of waste), or fish tissue is in development. EPA is considering developing new methods for the detection of PFAS in ambient air, as well as methods to quantify large groups of PFAS and PFAS precursors in various environmental samples (EPA, 2023i; EPA, 2023d; EPA, 2023e; EPA, 2023g). Once detected in the environment, PFAS tend to elude conventional remediation technologies due to their innate chemical properties, requiring the development of novel techniques and increasing remediation difficulty, time, and cost (Ross et. al, 2018).

Despite these challenges, the environmental and human health effects of PFAS call for regulatory attention. In response to emerging health concerns, the U.S. Environmental Protection Agency (EPA) and state agencies are updating and developing additional PFAS standards to regulate the manufacture and use of PFAS (EPA, 2023a).

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

EPA Method Number(s)	Analyte Name	Analyte Acronym	Analyte CAS Number
537.1, 533	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS (F-53B Minor)	763051-92-9
533, 8327, OTM-45	1H,1H, 2H, 2H-Perfluorodecane sulfonic acid	8:2 FTS	39108-34-4
533, 8327, OTM-45	1H,1H, 2H, 2H-Perfluorohexane sulfonic acid	4:2 FTS	4:2FTS
533, 8327, OTM-45	1H,1H, 2H, 2H-Perfluorooctane sulfonic acid	6:2 FTS	27619-97-2
OTM-45	1H,1H,2H,2H-perfluorododecane sulfonate	10:2 FTS	120226-60-0
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
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	2H-perfluoro-2-decenoic acid	8:2 FTUCA or FOUEA	70887-84-2
OTM-45	2H-perfluoro-2-octenoic acid	6:2 FHUEA	70887-88-6
OTM-45	3:3 Fluorotelomer carboxylic acid	3:3 FTCA	0356-02-05
537.1, 533, OTM-45	4,8-dioxa-3H-perfluorononanoic acid	ADONA	919005-14-4
OTM-45	5:3 Fluorotelomer carboxylic acid	5:3 FTCA	914637-49-3
OTM-45	7:3 Fluorotelomer carboxylic acid or 3-perfluoropheptyl propanoic acid	7:3 FTCA or FHpPA	812-70-4
537.1, 533, OTM-45	9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid	9Cl-PF3ONS (F-53B Major)	756426-58-1
OTM-45	Decafluoro-4-(pentafluoroethyl)cyclohexanesulfonate)	PFecHS	67584-42-3
537.1, 533, OTM-45	Hexafluoropropylene oxide dimer acid	HFPO-DA (Gen X)	13252-13-6
537.1	N-ethyl perfluorooctanesulfonamidoacetic acid	NEtFOSAA	2991-50-6
OTM-45	N-ethyl perfluorooctanesulfonamidoacetic acid	EtFOSAA	2991-50-6
8327	N-ethylperfluoro-1-octanesulfonamidoacetic acid	N-EtFOSAA	2991-50-6
OTM-45	N-ethylperfluorooctanesulfonamide	EtFOSA	4151-50-2
537.1	N-methyl perfluorooctanesulfonamidoacetic acid	NMeFOSAA	2355-31-9
OTM-45	N-methyl perfluorooctanesulfonamidoacetic acid	MeFOSAA	2355-31-9
8327	N-methylperfluoro-1-octanesulfonamidoacetic acid	N-MeFOSAA	2355-31-9

EPA Method Number(s)	Analyte Name	Analyte Acronym	Analyte CAS Number
OTM-45	N-Methylperfluorooctanesulfonamide	MeFOSA	31506-32-8
533, OTM-45	Nonafluoro-3,6-dioxaheptanoic acid	NFDHA	151772-58-6
8327, OTM-45	Perfluoro-1-decanesulfonic acid	PFDS	335-77-3
8327, OTM-45	Perfluoro-1-nonanesulfonic acid	PFNS	68259-12-1
8327	Perfluoro-1-octanesulfonamide	PFOSA	754-91-6
OTM-45	Perfluoro-1-octanesulfonamide	FOSA	754-91-6
533, OTM-45	Perfluoro-3-methoxypropanoic acid	PFMPA	377-73-1
533, OTM-45	Perfluoro-4-methoxybutanoic acid	PFMBA	863090-89-5
OTM-45	Perfluoro-n-hexadecanoic acid	PFHxDA	67905-19-5
OTM-45	Perfluoro-n-octadecanoic acid	PFODA	16517-11-6
533, OTM-45	Perfluoro(2-ethoxyethane)sulfonic acid	PFEESA	113507-82-7
537.1, 533, 8327, OTM-45	Perfluorobutanesulfonic acid	PFBS	375-73-5
533, 8327, OTM-45	Perfluorobutanoic acid	PFBA	375-22-4
537.1, 533, OTM-45	Perfluorodecanoic acid	PFDA	335-76-2
OTM-45	Perfluorododecane sulfonate	PFDoS	79780-39-5
537.1, 533, OTM-45	Perfluorododecanoic acid	PFDoA	307-55-1
8327	Perfluorododecanoic acid	PFDoDA	307-55-1
533, 8327, OTM-45	Perfluoroheptanesulfonic acid	PFHpS	375-92-8
537.1, 533, OTM-45	Perfluoroheptanoic acid	PFHpA	375-85-9
537.1, 533, 8327, OTM-45	Perfluorohexanesulfonic acid	PFHxS	355-46-4
537.1, 533, 8327, OTM-45	Perfluorohexanoic acid	PFHxA	307-24-4
537.1, 533, 8327, OTM-45	Perfluorononanoic acid	PFNA	375-95-1
537.1, 533, 8327, OTM-45	Perfluorooctanesulfonic acid	PFOS	1763-23-1
537.1, 533, 8327, OTM-45	Perfluorooctanoic acid	PFOA	335-67-1
533, 8327, OTM-45	Perfluoropentanesulfonic acid	PFPeS	2706-91-4
533, 8327, OTM-45	Perfluoropentanoic acid	PFPeA	2706-90-3
537.1	Perfluorotetradecanoic acid	PFTA	0376-06-07

EPA Method Number(s)	Analyte Name	Analyte Acronym	Analyte CAS Number
8327, OTM-45	Perfluorotetradecanoic acid	PFTeDA	0376-06-07
537.1, 8327, OTM-45	Perfluorotridecanoic acid	PFTrDA	72629-94-8
537.1, 533	Perfluoroundecanoic acid	PFUnA	2058-94-8
8327, OTM-45	Perfluoroundecanoic acid	PFUnDA	2058-94-8

Sources: EPA, 2023i; EPA, 2023d; EPA, 2023e; EPA, 2023g

PFAS IN SEMICONDUCTOR FABRICATION FACILITIES

Semiconductor fabrication facilities use PFAS as an essential material in several steps in the fabrication process. 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. However, all manufacturers use PFAS in multiple steps within the fabrication process (Isaacs, 2023). **Table 2** summarizes the key PFAS use applications in semiconductor fabrication. The general process for semiconductor manufacturing is broken down into six general steps: deposition, photoresist coating, lithography, etching, ion implantation, and packaging. Of the six steps, PFAS are utilized during the photoresist coating, lithography, etching, and packaging steps. Photoresist coating is the application of a light-sensitive coating, known as photoresist, to the wafer. Lithography involves exposing the photoresist to an ultraviolet light (UV) patterned blueprint – changing the solubility of the exposed photoresist. After lithography, the wafer is etched to partially remove the photoresist to define the now-exposed pattern. 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. The final step, packaging, includes the separation of each chip from the wafer, the addition of baseboards substrates to the chips, the topping of the chips with heat-dissipating elements, and the packaging of the chips for distribution to clients (Timings, 2021).

While PFAS are used throughout the semiconductor fabrication process, the most abundant use occurs during photolithography, which includes the photoresist coating, lithography, and etching steps (Jones, 2022; Timings, 2021). Two crucial PFAS-containing substances used in photolithography include photo-acid generators (PAGs) and top antireflective coatings (TARCs), the largest single source of PFAS in semiconductor manufacturing. PAGs are used in chemically amplified photoresists (CAP), a necessary component for the manufacturing of advanced semiconductors (Ober et al., 2022). PAGs utilize fluorine to enable greater solubility and development during the etching process. PAGs use short-chain perfluoroalkyl acid compounds (fewer than four C-F bonds) (Jones, 2022). TARCs are applied in conjunction with photoresist coatings. TARCs eliminate UV reflections to increase the precision of lithography (Ober et al., 2022). TARCs must not intermix with the photoresist and must be easily removed; various specialized PFAS enable these properties (Jones, 2022; Hsu et al., 2008). Supplementary examples of PFAS usage during photolithography include providing thermal stability and low surface energy to substances and acting as surfactants (leveling agents) to improve coating uniformity (Jones, 2022; SEMI, No date).

Beyond photolithography, PFAS are used in various direct and indirect processes during semiconductor fabrication. Two Toxic Substances Control Act (TSCA)-listed PFAS, hexafluoroethane (CAS number 76-16-4)) and perfluorocyclobutane (CAS number 115-25-3) are used for etching (EPA, 2023j). In the packaging step, PFAS-containing, heat-dissipating elements such as fluorinated heat transfer fluids (F-HTF) are used for their ability to be simultaneously electrically non-conductive, compatible with all materials of construction including sensitive electrical components, within suitable toxicity and flammability limits, and resistant to catastrophic contamination (Jones, 2022). The packaging of chips for distribution additionally 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 (Jones, 2022). Three additional TSCA-listed PFAS, hexafluorocyclobutene (CAS number 697-11-0), octaflurorcyclopentene (CAS number 559-40-0), and polytetrafluoroethylene (CAS number 9002-84-0), are used in miscellaneous semiconductor fabrication processes (EPA, 2023a).

Wastewater discharge from semiconductor manufacturing facilities presents the greatest risk for PFAS contamination of the environment. While most photolithography waste is handled as a solvent and incinerated, only 40 percent of TARC waste is treated. 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 pounds/year (Jones, 2022). 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 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 detection methods are limited to a few PFAS compounds (Jones, 2022).

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 U.S. by 2015 and is projected to be eliminated globally by 2025 (EPA, 2022; WSC, 2018). 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 while PAGs are projected to take more than 25 years (Jones, 2022).

FEDERAL PFAS REGULATIONS

At the federal level, there are several proposed and upcoming regulations pertaining to the use and environmental release of PFAS by industrial facilities.

WASTEWATER

In January of 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 Components (E&EC) 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, 2023j; EPA, 2022). Data on specific PFAS chemicals used, concentrations in discharges, and if 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 March of 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 (88 FR 18638):

- PFOA;
- PFOS;
- perfluorononanoic acid (PFNA);
- hexafluoropropylene oxide dimer acid (HFPO-DA, commonly known as GenX Chemicals);
- perfluorohexane sulfonic acid (PFHxS); and
- perfluorobutane sulfonic acid (PFBS).

EPA anticipates finalizing the rule by the end of 2023 (EPA, 2023h). In 2022, EPA also established non-regulatory, non-enforceable interim drinking water health advisories for four PFAS: PFOA, PFOS, hexafluoropropylene oxide (HFPO) dimer acid and its ammonium salt (known as GenX Chemicals), and perfluorobutane sulfonic acid (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.

TSCA

In October of 2023, EPA published a final rule under TSCA requiring any person who, since January 1, 2011, has manufactured or imported PFAS or PFAS-containing articles to report usage, production volume, disposal, exposure, and hazard information to EPA (EPA, 2023c).

EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT (EPCRA)

EPA released a final rule under EPCRA and the Pollution Prevention Act pursuant to the National Defense Authorization Act for Fiscal Year 2020 that added certain PFAS to the list of Lower Thresholds for Chemicals of Special Concern (EPA, 2023c). This rule, effective on November 30, 2023, will increase reporting of PFAS to the Toxics Release Inventory (TRI) by eliminating an exemption (*de minimis*) that allowed facilities to avoid reporting information on PFAS when those chemicals were used in small concentrations. Under this new rule, certain PFAS will be subject to the same reporting requirements as other chemicals of special concern and EPA will receive more comprehensive data on PFAS. Chemicals of special concern are excluded from the *de minimis* exemption, may not be reported on Form A (Alternate Threshold Certification Statement), and have limits on the use of range reporting.

STATE PFAS STANDARDS

Many states have already implemented restrictions or set standards for use of PFAS in product manufacturing and to regulate concentrations of PFAS in drinking water by parts per trillion (ppt) (NCSL, 2023). These states include Alaska, Arizona, California, Colorado, Connecticut, Delaware, Illinois, Iowa, Kentucky, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Ohio, Rhode Island, Vermont, and West Virginia. 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 GlobalFoundries that includes quarterly PFAS monitoring requirements for the first year and annual PFAS monitoring beginning in 2022 (EPA, 2022). Current standards for states in which semiconductor fabrication facilities may be modernized using Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022 grant funding are listed in **Table 3**.

Table 2. 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, barrier layer polymers (PBO/PI), bottom anti-reflective coatings (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 extreme ultraviolet (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 a number of different formulations that are used to 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 top coats): 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 chemical vapor deposition (CVD) and physical vapor deposition (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 atomic layer deposition (ALD)	Improved volatility and stability of ligands for the uniformity of metal deposition and reproducibility of processes.	Transition metal compounds containing the tfac (1,1,1-trifluoro-2,4-pentane-dionate) and hfac (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.	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
		Mitigate the formation of air bubbles.		
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.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Lubrication	Oils and greases in vacuum pumps	Effective lubrication of bearings, gears, and seals.	Perfluoropolyether (PFPE) oil Greases containing PFPE base oils with polytetrafluoroethylene (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
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.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Lubrication	Greases used in photo-lithography 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 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.

Semiconductor Fabrication Process(es)	Use Application for PFAS	Function	Types of PFAS-Containing Materials in Use	PFAS Criticality
Heating and cooling	Heat transfer fluids (HTFs)	Fluorinated- 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.

Sources: SIA, 2023a; SIA, 2023b; SIA, 2023c; SIA, 2023d; SIA, 2023e

Table 3. State PFAS Standards

State	Regulatory Authority	Drinking Water Standards
Arizona	None	None
Colorado	Colorado PFAS Policy 20-1 5 Colorado Code of Regulation (CCR) 1002-31, Section 31.11(1)(a)(iv) and 5 CCR 1002-41, Section 41.5(A)(1)	PFBS: 400,000 ppt PFHxS: 700 ppt PFNA, PFOA, and PFOS (combined): 70 ppt
Idaho	None	None
Kansas	None	None
Minnesota	Minnesota's PFAS Blueprint	PFBA: 2,000 ppt PFBS: 4,000 ppt PFHxS: 47 ppt PFOA: 35 ppt PFOS: 15 ppt
New Hampshire	New Hampshire House Bill 1264	PFHxS: 18 ppt PFNA: 11 ppt PFOS: 15 ppt PFOA: 12 ppt
New York	Public Water Systems and New York State (NYS) Drinking Water Standards for PFAS and Other Emerging Contaminants	1,4-dioxane: 1,000 ppt PFAS: 10 ppt PFOA: 10 ppt
Ohio	Ohio PFAS Action Plan for Drinking Water	HFPO-DA: 21 ppt PFBS: 2,100 ppt PFHxS: 140 ppt PFNA: 21 ppt PFOA and PFOS (combined): 70 ppt
Oregon	Unregulated Contaminant Monitoring Rule (UCMR3)	PFHxS, and PFNA, PFOA, and PFOS, (combined): 30 ppt
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

Sources: BCLP, 2022; MNPCA, No date; NHGC, 2020; NYSDOH, 2022; NCSL, 2023; OHEPA, No date; ORHA, No date; TriHydro, 2023; and VTGA, 2019.

ACRONYMS

3D NAND	high-aspect-ratio channel
ALD	atomic layer deposition
BEOL	back end of line
BARC	bottom anti-reflective coating
CAP	chemically amplified photoresists
CAS	Chemical Abstracts Service
CCR	Colorado Code of Regulations
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CMP	chemical mechanical planarization
CVD	chemical vapor deposition
C-F	carbon-fluorine
EPA	United States Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EUV	extreme ultraviolet
FEOL	front end of line
F-HTF	fluorinated heat transfer fluids
HFC	hydrofluorocarbon
HFE	hydrofluoroether
HFO	hydrofluoroolefins
HFPO-DA	hexafluoropropylene oxide dimer acid
HTF	heat transfer fluid
MAC	multiply-alkylated cyclopentane
NHANES	National Health and Nutrition Examination Survey
nm	nanometer
NYS	New York State
PAG	photo-acid generator
PBO/PI	barrier layer polymers
PFAS	Per- and Polyfluoroalkyl Substances
PFBS	perfluorobutane sulfonic acid
PFC	perfluorocarbon
PFHpA	perfluoroheptanoic acid
PFHxS	perfluorohexane sulfonic acid
PFNA	perfluorononanoic acid

PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
PFPE	Perfluoropolyether
POTW	publicly-owned treatment works
Ppb	parts per billion
ppt	parts per trillion
PTFE	polytetrafluoroethylene
PVD	physical vapor deposition
TARC	top antireflective coating
TSCA	Toxic Substances Control Act
UCMR3	Unregulated Contaminant Monitoring Rule
U.S.	United States
UV	ultraviolet light

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APPENDIX C: SEMICONDUCTOR FABRICATION CHEMICALS AND MATERIALS LISTED ON THE TOXIC SUBSTANCES CONTROL ACT INVENTORY

SEMICONDUCTOR FABRICATION CHEMICALS AND MATERIALS LISTED ON THE TOXIC SUBSTANCES CONTROL ACT (TSCA) INVENTORY

TSCA Inventory Name (Systematic Name)	Alternate Name(s)	Chemical Abstracts Service (CAS) Number	Purpose
1,2-Ethanediol	Ethylene glycol	107-21-1	Cooling medium; Dehumidifying agent
1,3-Butadiene, 1,1,2,3,4,4-hexafluoro-	Hexafluoro-1,3-Butadiene; Hexafluoro-1,3-butadiene; 1,3-Butadiene, 1,1,2,3,4,4-hexafluoro-	685-63-2	Dry etching
1H-Benzotriazole	N/A	95-14-7	Chemical Mechanical Planarization
1-Propene, 1,1,2,3,3,3-hexafluoro-	Hexafluoropropylene	116-15-4	Miscellaneous
2(3H)-Furanone, dihydro-	Butyrolactone; Gamma-Butyrolacton (GBL)	96-48-0	Cleaning
2,4-Pentanedione, 1,1,1,5,5,5-hexafluoro-	N/A	1522-22-1	Thin film deposition
2,4-Pentanedione, 1,1,1-trifluoro-	1,1,1-Trifluoropentane-2,4-dione	367-57-7	Thin film deposition
2-Heptanone	Heptan-2-one; Methyl n-amyl ketone; Methyl Amyl Ketone	110-43-0	Lithography (photoresist solvent)
2-Pentanone, 4-methyl-	Methyl isobutyl ketone	108-10-1	Photolithography
2-Propanol	Isopropyl alcohol	67-63-0	Wafer Cleaning
2-Propanol, 1-methoxy-, 2-acetate	PGMEA (PM Acetate) ($C_6H_{12}O_3$); Propylene glycol monomethyl ether acetate, 1-Methoxy-2-propyl acetate	108-65-6	Photolithography, Photoresistor thinners
2-Propanol, 2-methyl-	Tert-butyl alcohol (TBA); tert-Butanol; tert-Butyl alcohol	75-65-0	Cleaning
2-Propanone	Acetone	67-64-1	Wafer Cleaning
2-Pyrrolidinone, 1-methyl-	N-Methyl-2-pyrrolidone (NMP); C_5H_9NO	872-50-4	Photolithography
4-Morpholinecarboxaldehyde	Morpholine-4-carbaldehyde	4394-85-8	N/A
Acetic Acid	N/A	64-19-7	Wet & Dry Etching
Acetic acid, 2,2,2-trichloro-	Trichloroacetic acid	76-03-9	Miscellaneous
Acetic acid, butyl ester	N-butyl acetate	123-86-4	Photolithography

TSCA Inventory Name (Systematic Name)	Alternate Name(s)	Chemical Abstracts Service (CAS) Number	Purpose
Components are listed	Alloy 42 (alloy of iron, nickel, manganese, and cobalt)	N/A	Raw material
Alcohols, C12-14-secondary, ethoxylated	Tergitol	84133-50-6	Miscellaneous
Aluminum	N/A	7429-90-5	Raw material
Aluminum, triethyl-	Triethylaluminum	97-93-8	Deposition, atomic layer (ALD)
Aluminum, trimethyl-	Trimethylaluminum; Trimethylalumane	75-24-1	Thin film deposition
Ammonia	NH_3	7664-41-7	Thin Film Deposition; Miscellaneous
Ammonium fluoride	$((NH_4)F)$	12125-01-8	Wet & Dry Etching
Ammonium hydroxide	$((NH_4)(OH))$	1336-21-6	Wafer Cleaning
Antimony oxide	Antimony trioxide (Sb_2O_3)	1309-64-4	Thin Film Deposition
Argon	N/A	7440-37-1	Carrier Gas
Arsine (AsH_3)	N/A	7784-42-1	Thin Film Deposition
Benzene, dimethyl-	Xylene	1330-20-7	Wafer Cleaning
Benzene, methyl-	Toluene	108-88-3	Miscellaneous
Borane, tribromo-	Boron tribromide	10294-33-4	Miscellaneous
Borane, trichloro-	Boron trichloride	10294-34-5	Thin Film Deposition
Borane, trifluoro-	Boron trifluoride	7637-07-2	Thin Film Deposition
Boric acid (H_3BO_3), triethyl ester	Triethylborate (TEB)	150-46-9	Thin Film Deposition
Boric acid (H_3BO_3), trimethyl ester	Trimethylborate	121-43-7	Thin Film Deposition
Boron	N/A	7440-42-8	Raw material
Components are likely listed	Borophosphosilicate glass (BPSG)	N/A	Raw material
Bromine	N/A	7726-95-6	Miscellaneous
Butane, 1,1,1,2,3,4,4,4-octafluoro-	Octafluorobutane, 2H,3H-Perfluorobutane	75995-72-1	Dry etching
Calcium oxide (CaO)	Lime	1305-78-8	Miscellaneous
Carbon dioxide	N/A	124-38-9	Thin Film Deposition
Carbon monoxide	N/A	630-08-0	Thin Film Deposition

TSCA Inventory Name (Systematic Name)	Alternate Name(s)	Chemical Abstracts Service (CAS) Number	Purpose
Carbon oxide sulfide	Carbonyl sulfide (COS); carbon oxysulfide; carbonyl sulfide; carbon oxide sulfide	463-58-1	Precursor for sulfur doping; Metal-organic chemical vapor deposition (MOCVD); Surface passivation; Gas sensing
Cerium hydroxide	Cerium(3+) trihydroxide ($Ce(OH)_3$)	15785-09-8	Chemical Mechanical Planarization
Chlorine	N/A	7782-50-5	Wet & Dry Etching
Chlorine fluoride	Chlorine trifluoride; ClF_3	7790-91-2	Wet & Dry Etching
Chromium oxide	Chromium trioxide; chromic acid; CrO_3	1333-82-0	Wet & Dry Etching
Components are listed	Chromium silicon; sichrome	N/A	Raw material
Copper	N/A	7440-50-8	Raw material
Components are likely listed	Cupraselect ($C_{10}H_{13}CuF_6O_2Si$)	N/A	Thin Film Deposition
Cupric sulfate	Copper sulfate; copper (II) sulfate	7758-98-7	Electrodeposition
Cyclobutane, 1,1,2,2,3,3,4,4-octafluoro-	C_4F_8; halocarbon 318	115-25-3	Wet & Dry Etching
Cyclobutene, hexafluoro-	C_4F_6	697-11-0	Miscellaneous
Cyclohexanone	Cyclohexanone	108-94-1	Photolithography
Cyclopentanone	Cyclopentane	120-92-3	Photolithography
Cyclopentene, 1,2,3,3,4,4,5,5-octafluoro-	Octafluorocyclopentene	559-40-0	Miscellaneous
Diborane	N/A	19287-45-7	Thin Film Deposition (doping agent)
Disilane	H_2Si_2	1590-87-0	Thin Film Deposition
Ethanamine, N,N-diethyl-	Triethylamine	121-44-8	Miscellaneous
Ethanaminium, 2-hydroxy-N,N,N-trimethyl-, hydroxide (1:1)	Choline hydroxide	123-41-1	Wet & Dry Etching
Ethane, 1,1,1,2,2,2-hexafluoro-	Hexafluoroethane; perfluoroethane; PFC-116	76-16-4	Etching and Wafer Cleaning
Ethanedioic acid	Oxalic Acid	144-62-7	Miscellaneous
Ethanol	N/A	64-17-5	Miscellaneous
Ethanol, 2,2',2''-nitrilotris-	Triethanolamine	102-71-6	Thin Film Deposition

TSCA Inventory Name (Systematic Name)	Alternate Name(s)	Chemical Abstracts Service (CAS) Number	Purpose
Ethanol, 2-amino-	Ethanolamine	141-43-5	Wet Etching
Ethanol, 2-butoxy-	Butoxy ethanol; Ethylene glycol monobutyl ether; Ethylene glycol monobutyl; 2-Butoxy ethanol	111-76-2	N/A
Ethanol, tantalum(5+) salt (5:1)	Tantalum ethoxide	6074-84-6	Thin Film Deposition
Ethene, 1,1,2,2-tetrachloro-	Perchloroethylene (PCE); Tetrachloroethylene	127-18-4	Miscellaneous
Ethene, 1,1,2,2-tetrafluoro-, homopolymer	Polytetrafluoroethylene (PTFE)	9002-84-0	Lubrication
Ethene, 1,1,2,2-tetrafluoro-, homopolymer	Teflon; Polytetrafluoroethylene	9002-84-0	Miscellaneous
Ethene, 1,1,2-trichloro-	Tricholoroethylene	79-01-6	Miscellaneous
Ethene, 1,2-dichloro-, (1E)-	Trans-1,2-dichloroethylene; Trans L-C	156-60-5	Miscellaneous
Ethyne	Acetylene	74-86-2	Miscellaneous
Ferrate(3-), hexakis(cyano-.kappa.C)-, potassium (1:3), (OC-6-11)-	Potassium ferricyanide	13746-66-2	Wet & Dry Etching
Fluorine	N/A	7782-41-4	Chemical vapor deposition, Plasma etching, cleaning (Fluorine compounds)
Formaldehyde, polymer with 2-(chloromethyl)oxirane and 4,4'-(1-methylethylidene) bis[phenol]	SU-8 Series Resists (Organic Resin Solution)	28906-96-9	Photolithography
Gallium arsenide (GaAs)	N/A	1303-00-0	Raw material
Gallium nitride (GaN)	N/A	25617-97-4	Raw material
Germane, tetrafluoro-	Germanium tetrafluoride	7783-58-6	Thin Film Deposition
Germanium	N/A	7440-56-4	Raw material
Gold (Au)	N/A	7440-57-5	Raw material
Helium	N/A	7440-59-7	Carrier Gas
Heptane	N/A	142-82-5	Miscellaneous
Hydrobromic acid	Hydrogen bromide	10035-10-6	Thin Film Deposition

TSCA Inventory Name (Systematic Name)	Alternate Name(s)	Chemical Abstracts Service (CAS) Number	Purpose
Hydrochloric acid	Hydrogen chloride; muriatic acid	7647-01-0	Thin Film Deposition/ Usually in Single Wafer and Batch processing
Hydrochloric acid	Muriatic acid (27.92%)	7647-01-0	Wafer Cleaning
Hydrofluoric acid	Hydrogen fluoride	7664-39-3	Wet & Dry Etching
Hydrogen	H_2	1333-74-0	Carrier Gas
Hydrogen peroxide	H_2O_2	7722-84-1	Wafer Cleaning
Components are listed	Kovar (alloy of iron, nickel, manganese, & cobalt)	N/A	Raw material
Lead	Pb	7439-92-1	Raw material
Metaphosphoric acid (H6P6O18), sodium salt (1:6)	Sodium hexametaphosphate	10124-56-8	Miscellaneous
Methanaminium, N,N,N-trimethyl-, hydroxide (1:1)	Tetramethylammonium hydroxide	75-59-2	Photolithography
Methane	CH_4	74-82-8	Miscellaneous
Methane, dichloro-	Methylene chloride	75-09-2	Miscellaneous
Methane, fluoro-	Methylene fluoride; methyl fluoride	593-53-3	Miscellaneous; Wet & Dry Etching
Methane, tetrafluoro-	CF_4	75-73-0	Wet & Dry Etching
Methane, trifluoroiodo-	Trifluoriomethane; Trifluoroiodomethane	2314-97-8	Miscellaneous
Methanol	Methyl alcohol	67-56-1	Miscellaneous
Components are listed	Naptha	N/A	Miscellaneous
Neon	N/A	7440-01-9	Miscellaneous
Nitric acid	N/A	7697-37-2	Wet & Dry Etching
Nitrogen	N_2 (gas or liquid)	7727-37-9	Carrier Gas
Nitrogen fluoride (NF_3)	Nitrogen trifluoride	7783-54-2	Wet & Dry Etching/Remove silicon and silicon-compounds
Nitrogen oxide (N_2O)	Nitrous oxide	10024-97-2	Thin Film Deposition
Nitrogen oxide (NO)	Nitric oxide	10102-43-9	Thin Film Deposition
Components are likely listed	Nova Strip	N/A	Miscellaneous

TSCA Inventory Name (Systematic Name)	Alternate Name(s)	Chemical Abstracts Service (CAS) Number	Purpose
Octadecyltrichlorosilane	n-octadecyltrichlorosilane, Trichloro(octadecyl)silane	112-04-9	Self-assembled monolayer thin films on silicon dioxide substrates
Octane	n-Octane	111-65-9	N/A
Oxygen	O_2 (general grade)	7782-44-7	Wet & Dry Etching
Perchloric acid	N/A	7601-90-3	Wafer Cleaning
Permanganic acid ($HMnO_4$), potassium salt (1:1)	Potassium permanganate	7722-64-7	Wet & Dry Etching
Phosphine	N/A	7803-51-2	Thin Film Deposition (doping agent)
Phosphorane, pentafluoro-	Phosphorus pentafluoride	7647-19-0	Thin Film Deposition
Phosphoric acid	N/A	7664-38-2	Wet & Dry Etching
Phosphoric acid, triethyl ester	Triethylphosphate	78-40-0	Thin Film Deposition
Components are listed	Phosphoric Etch (phosphoric acid 39%, nitric acid 38%, water 21-25%)	N/A	Wet & Dry Etching
Phosphoric trichloride	Phosphorous oxychloride ($POCl_3$)	10025-87-3	Thin Film Deposition
Phosphorous acid, trimethyl ester	Trimethylphosphite	121-45-9	Thin Film Deposition
Phosphorous trifluoride	N/A	7783–55–3	Thin Film Deposition
Phosphorus	Phosphorous	7723-14-0	Thin Film Deposition
Phosphorus	P	7723-14-0	Raw material
Potassium chloride	KCl	7447-40-7	Miscellaneous
Potassium hydroxide (K(OH))	Potassium hydroxide	1310-58-3	Wet & Dry Etching
Potassium iodide	KI	7681-11-0	Wet & Dry Etching
Propane	N/A	74-98-6	Miscellaneous
Propane, 1,1,1,2,2,3,3,3-octafluoro-	C_3F_8; Perfluoropropane; Octafluoropropane; R-218	76-19-7	Thin film deposition
Propanoic acid, 2-hydroxy-	Lactic acid	50-21-5	Miscellaneous
Propanoic acid, 2-hydroxy-2-methyl-, methyl ester	Methyl 2-hydroxyisobutyrate (HBM)	2110-78-3	Lithographpy (photoresist thinner)
Propanoic acid, 2-methylpropyl ester	2-Methylpropyl propanoate; isobutyl propionate	540-42-1	Etching
Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl)-	Hexamethyldisilizane	999-97-3	Photolithography

TSCA Inventory Name (Systematic Name)	Alternate Name(s)	Chemical Abstracts Service (CAS) Number	Purpose
Silane	Monosilane, silicon hydride, silicon tetrahydride, silicane	7803–62–5	Thin Film Deposition
Silane, dichloro-	Dichlorosilane (Cl_2H_2Si)	4109-96-0	Thin Film Deposition
Silane, methyl-	Methylsilane	992-94-9	Thin Film Deposition
Silane, tetrachloro-	N/A	10026-04-7	
Silane, tetrachloro-	Silicon tetrachloride ($SiCl_4$)	10026-04-7	Thin Film Deposition
Silane, tetrafluoro-	Silicon tetrafluoride (SiF_4)	7783-61-1	Thin Film Deposition
Silane, tetramethyl-	Tetramethylsilane (EPA Registry Name)	75-76-3	Precursors for low-K barrier films; etch hard masks; and carbon-doped silicon films and silicon carbide-like films
Silane, trichloro-	Trichlorosilane	10025-78-2	Thin Film Deposition
Silane, trimethyl-	Trimethyl silane	993-07-7	Thin Film Deposition
Silica	Silicon dioxide (SiO_2)	7631-86-9	Miscellaneous
Silicic acid (H_4SiO_4), tetraethyl ester	Teos ($C_8H_{20}O_4Si$)	78-10-4	Thin Film Deposiition
Silicon	N/A	7440-21-3	Raw material
Silicon carbide	SiC	409-21-2	Raw material
Silicon nitride	Si_3N_4	12033-89-5	Raw material
Silver	Ag	7440-22-4	Raw material
Components are listed	Slope Etch (water, acetic acid, ammonium fluoride, and hydrofluoric acid)	N/A	Wet & Dry Etching
Sodium chloride	NaCl	7647-14-5	Miscellaneous
Sodium hydroxide	(Na(OH))	1310-73-2	Wet & Dry Etching
Components are listed	Spin-on glass	N/A	Raw material
Components are listed	SU-8 Series Resists (Organic Resin Solution)	N/A	Photolithography
Sulfonium, (thioditedded-4,1-phenylene)bis[diphenyl-, (OC-6-11)-hexafluoroantimonate(1-) (1:2)	SU-8 Series Resists (Organic Resin Solution)	89452-37-9	Photolithography

TSCA Inventory Name (Systematic Name)	Alternate Name(s)	Chemical Abstracts Service (CAS) Number	Purpose
Sulfonium, diphenyl[4-(phenylthio)phenyl]-, (OC-6-11)-hexafluoroantimonate(1-) (1:1)	SU-8 Series Resists (Organic Resin Solution)	71449-78-0	Photolithography
Sulfur dioxide	N/A	7446-09-5	Miscellaneous
Sulfur fluoride (SF_6), (OC-6-11)-	Sulfur hexafluoride	2551-62-4	Thin Film Deposition/ Plasma etching processes
Sulfuric acid	N/A	7664-93-9	Wafer Cleaning
Sulfuric acid, ammonium iron(2+) salt (2:2:1)	Ferrous ammonium sulfate	10045-89-3	Miscellaneous
Sulfurous acid, sodium salt (1:1)	Sodium bisulfite (anhydrous)	7631-90-5	Miscellaneous
Tantalum	N/A	7440-25-7	Physical vapor deposition (PVD)
Thiophene, tetrahydro-, 1,1-dioxide	Tetrahydrothiophene-1,1-dioxide, Sulfolane	126-33-0	Semiconductor cleaning
Tin	Sn	7440-31-5	Raw material
Titanium	N/A	7440-32-6	Photocatalytic baseline
Titanium chloride ($TiCl_4$) (T-4)-	Titanium tetrachloride; Titanium(4+) tetrachloride	7550-45-0	Thin Film Deposition
Tungsten fluoride (WF_6), (OC-6-11)-	Tungsten hexafluoride	7783-82-6	Thin Film Deposition
Components are listed	Ultraslope Etch (water, ammonium fluoride, and hydrofluoric acid)	N/A	Wet & Dry Etching
Xenon	N/A	7440-63-3	Etching and Deposition

Sources: EPA, 2023; CPO, 2023

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