Environmental Impact and Implications of Semiconductor Manufacturing: Overview and NSF Funding Opportunities

Mamadou Diallo, PhD

Program Director, Environmental Engineering

Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET)

Directorate for Engineering, National Science Foundation (NSF)

17th ROK-USA Forum on Nanotechnology

"Next Generation Semiconductors and the Environmental Implications of Semiconductor Manufacturing"

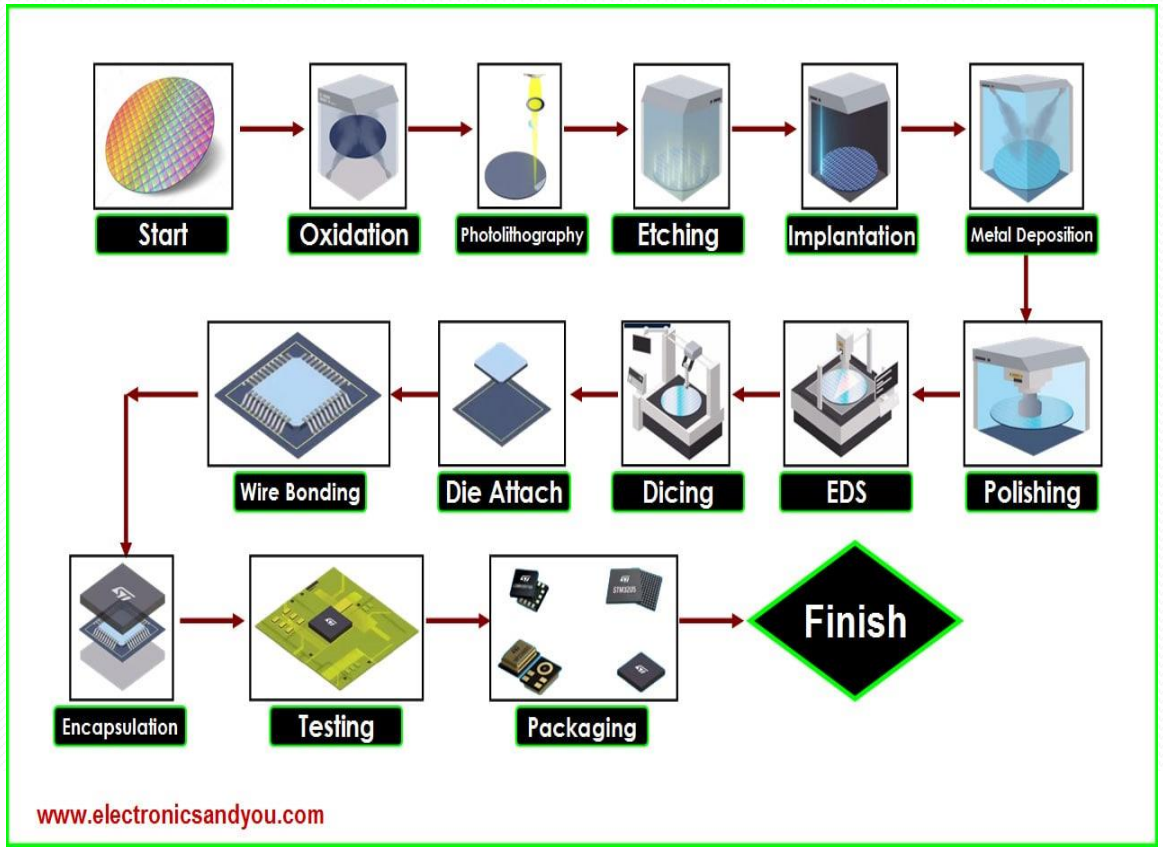
April 3-5, 2023, Seoul, Republic of Korea

Disclaimer: *The opinions expressed in this presentation are those of the author and do not necessarily reflect the views of the National Science Foundation.*

Presentation Outline

- Environmental Implications/Impact of Semiconductor Manufacturing
- Examples of Research on the Environmental Implications/Impact of Semiconductor Manufacturing @ NSF
- Opportunities for International Collaborations
- Q & A

Environmental Implications and Impact of Semiconductor Manufacturing



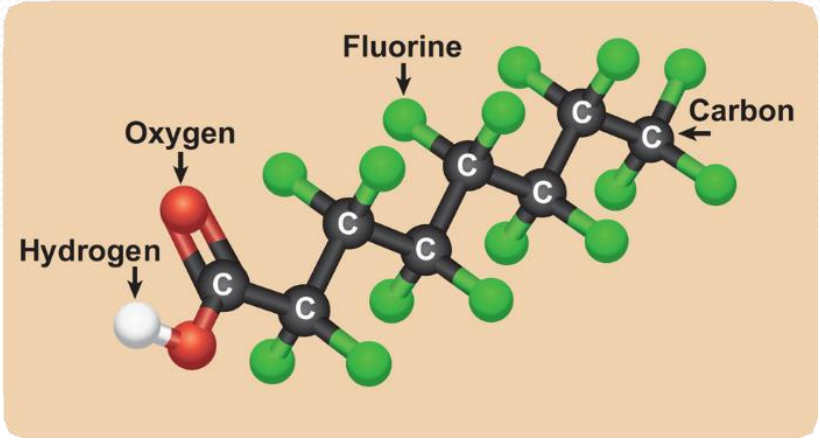
- Requires significant amount of energy and water including ultrapure water
- Requires significant amounts of bulk chemicals and specialty chemicals including materials of high concern (MoHC)
- Generates aqueous waste streams containing hazardous chemicals
- Generates greenhouse gases and gaseous waste streams containing air pollutants

Source: https://www.electronicsandyou.com/blog/semiconductor-manufacturing-process-steps-and-technology-used.html

Environmental Impact of Semiconductor Manufacturing: PFAS as Materials of High Concern (Focus of today's presentation)

- Per- and polyfluoroalkyl substances (PFAS) are synthetic organofluorine chemicals that have been manufactured and used in consumer products and industrial applications since the 1940s including firefighting foams, food packaging and contact materials, textiles, and various other industrial uses including **semiconductor manufacturing.**

- All PFAS contain a chain of carbon atoms bonded to fluorine atoms. They are among the most stable chemicals ever produced. During the last two decades, increasing detection of PFAS in various environmental media has raised significant concerns about their persistence, stability, and adverse impact including toxicity to living organisms and humans.

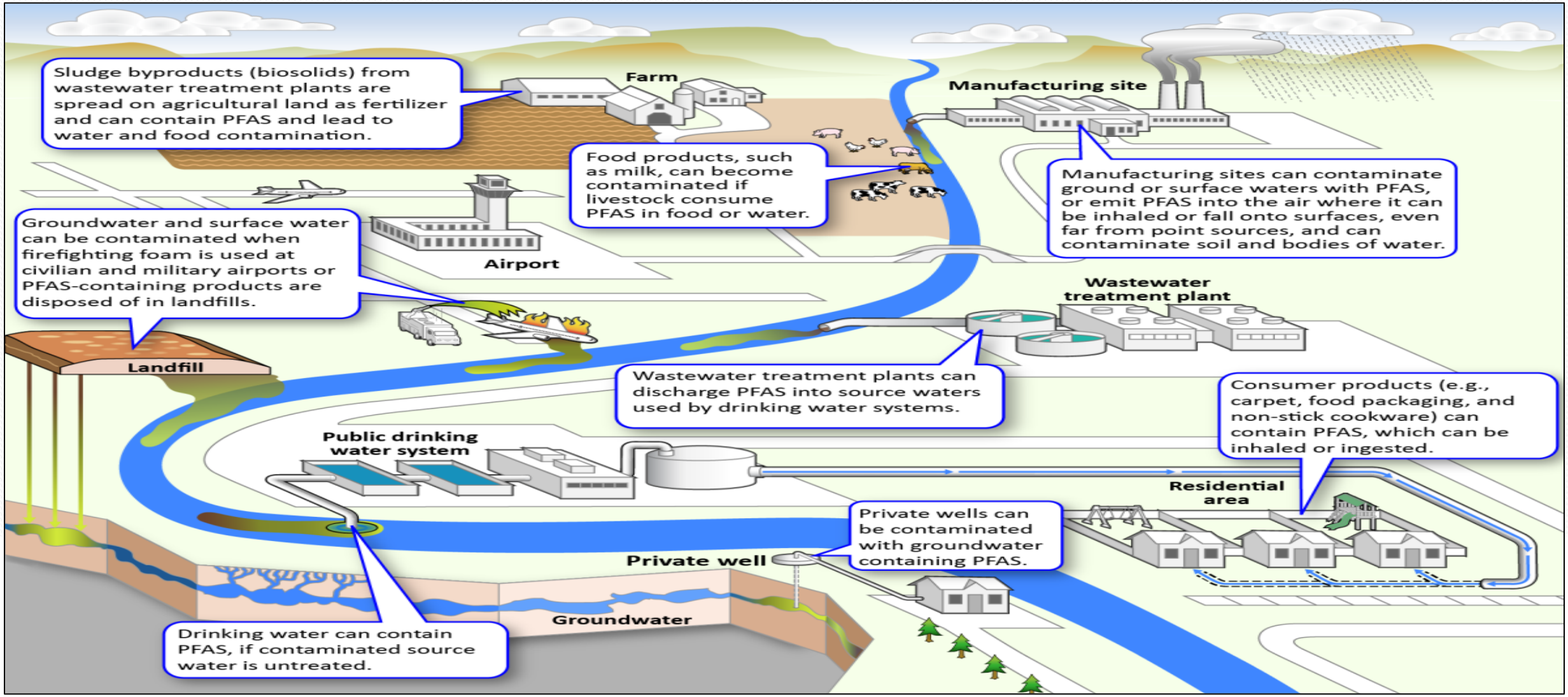


PFAS Uses in Semiconductor Manufacturing

- Past and Current Uses
  - Anti-reflective coatings
  - Photoacid generators
  - Etching and resist materials
  - High-purity drying and cleaning fluids
  - Polymers for processing
  - Wetting surfactants
  - Gaskets, tanks, pipes, valves and pumps for severe environments
  - Class B AFFF
- Potential Waste Streams
  - Wastewater
  - Air
    - Vapors
    - Incineration
  - Direct discharges to ground or surface water
  - Solid Waste
  - Secondary distribution
    - Aerial deposition
    - Biosolids

Source: https://sesha.org/wp-content/uploads/2019/11/Kellogg-Hollerbach-PFAS.pdf

Possible routes for PFAS release into the environment (https://www.gao.gov/assets/gao-22-105088.pdf)



Emerging PFAS regulations (EPA) and production phase out (3M) are causing major concerns within the semiconductor manufacturing industry

SIA SEMICONDUCTOR INDUSTRY ASSOCIATION (/)

Public Statement of the Semiconductor PFAS Consortium

Per- and poly-fluoro alkyl substances (PFAS) are used in chemical formulations, components of manufacturing process tools, facilities infrastructure and packaging used to make the semiconductor devices that are integral to our modern world. Concerns regarding the persistence, mobility and potential toxicity of certain PFAS are driving governments across the globe to propose broad PFAS restrictions.

The semiconductor industry is an acknowledged global leader in promoting environmental sustainability in the design, manufacture, and use of its products, as well as the health and safety of its operations and impacts on workers in semiconductor facilities (fabs).
The industry and its key suppliers have formed a Semiconductor PFAS Consortium to collect the technical data needed to better inform public policy and legislation, including:

- Identification of critical uses,
- Application of the pollution prevention hierarchy to, where possible: reduce PFAS consumption or eliminate use, identify alternatives, and minimize and control emissions,
- Identification of research needs, and
- Development of socioeconomic impact assessments.

The consortium membership includes semiconductor manufacturers and members of the supply chain including chemical, material and equipment suppliers.

NSF 20-090: Dear Colleague Letter: Engineering Research to Advance Solutions for Environmental PFAS (ERASE-PFAS)

National Science Foundation
WHERE DISCOVERIES BEGIN

Contact | Help

Search

NSB | Research Areas | Funding | Awards | Document Library | News | About NSF

Engineering (ENG)

- Engineering (ENG) Home
- Chemical, Bioengineering, Environmental and Transport Systems (CBET)
  - About
  - Programs
  - Staff
  - Funding
  - Awards
  - News
  - Events
  - Additional Resources

Home › Research Areas › Engineering

Email | Print | Share

Engineering Research to Advance Solutions for Environmental PFAS (ERASE-PFAS)

Special funding focus on new science and technologies for the mitigation, remediation, and/or treatment of per- and polyfluoroalkyl substances (PFAS) to improve and protect public and environmental health.

PFAS

READ MORE

Announcements

CBET proposal submission information **Read More ›**

Research collaboration opportunity in Europe for NSF awardees **Read More ›**

News

Researchers develop mathematical model to predict disease spread patterns
MAY 18, 2021

New law of physics helps humans and robots grasp the friction of touch

NSF Invests in Engineering Research to Remove PFAS From the Environment (Press Release on August 10, 2021)

- With more than $4.1 million in combined funding from the NSF ENG/CBET Environmental Engineering program and an unrestricted gift to NSF from DuPont de Nemours Inc., the new research projects will use a variety of approaches to treat PFAS contamination, whether by capturing/removing the chemicals from environmental media (water, soil) or by breaking the carbon-fluorine bonds to transform PFAS into benign products.

- The NSF ERAS-PFAS awardees will investigate a variety of PFAS remediation technologies including:
  - **Chemical Catalysis**
  - **Photolysis and Photocatalysis**
  - **Biological Treatment Processes**
  - **Physical Treatment Processes**
  - **And combinations of chemical-physical-biological processes**

Press Release

PFAS Projects Funded by NSF/ENG/CBET Environmental Engineering in FY21

Lead Proposal ID	ID/URL	Title	PI Name	Institution
	2047062	**CAREER: ERASE-PFAS: Mechanistic Investigation of Thermal Decomposition of Poly- and Perfluoroalkyl Substances in the Soil Environment**	**Xiao, Feng**	**University of North Dakota**
2041060	2041060	**Collaborative Research: ERASE-PFAS: A "concentrate-and-destroy"; technology for treating per- and polyfluoroalkyl substances using a new class of adsorptive photocatalysts**	**Zhao, Dongye (Don)**	**Auburn University**
2041060	2041059	Collaborative Research: ERASE-PFAS: A "concentrate-and-destroy"; technology for treating per- and polyfluoroalkyl substances using a new class of adsorptive photocatalysts	Blaney, Lee	University of Maryland Baltimore Co.
2050934	2050934	**ERASE-PFAS: Collaborative Research: Development of Quantitative Tools to Assess the Mechanisms and Full Potential of UV-ARPs for the Treatment of PFASs in Water**	**McKay, Garrett**	**Texas A&M Engineering Expt. Station**
2050934	2050882	ERASE-PFAS: Collaborative Research: Development of Quantitative Tools to Assess the Mechanisms and Full Potential of UV-ARPs for the Treatment of PFASs in Water	Mezyk, Stephen	California State University-Long Beach
	2051260	**ERASE-PFAS: Electrocatalytic Hydrodefluorination of PFAS Using Molecular, Metal-Free Catalysts**	**Jiang, Jianbing**	**University of Cincinnati**
	2052772	**ERASE-PFAS: Understanding the surface-active properties of PFAS for enhanced removal by bubbling-assisted water treatment processes**	**Venkatesan, Arjunkrishna**	**SUNY at Stony Brook**
	2055015	**ERASE-PFAS: Microbial electrochemical defluorination of PFAS using bioaugmented Acidmicrobium sp. Strain A6**	**Jaffe, Peter**	**Princeton University**
2120418	2120418	**ERASE-PFAS: Collaborative Research: Nickel and Palladium Single-Atom Electrocatalysts for Selective Capture and Destruction of PFAS in Complex Water Matrices**	**Kim, Jaehong**	**Yale University**
2120418	2120452	ERASE-PFAS: Collaborative Research: Nickel and Palladium Single-Atom Electrocatalysts for Selective Capture and Destruction of PFAS in Complex Water Matrices	Yang, Yang	Clarkson University
	2131745	**ERASE-PFAS: Tunable Vacuum-Ultraviolet Irradiation Systems with Highly Polarized Redox Environment for Treatment of Per- and Polyfluoroalkyl Substances**	**Liu, Haizhou**	**University of California-Riverside**
2112201	2112201	**Collaborative Research: ERASE-PFAS: Remediation of Per- and Polyfluoroalkyl Substances in Wastewater using Anaerobic Membrane Bioreactors**	**Aga, Diana**	**SUNY at Buffalo**
2112201	2112651	Collaborative Research: ERASE-PFAS: Remediation of Per- and Polyfluoroalkyl Substances in Wastewater using Anaerobic Membrane Bioreactors	Smith, Adam	University of Southern California

PFAS Projects Funded by NSF/ENG/CBET Environmental Engineering in FY22

Lead Proposal ID	ID/URL	Title	PI Name	Institution
	2145613	**CAREER: PFAS-BioAction: Innovative treatment of municipal solid waste organics through insect-mediated bioprocessing and sequestration of poly- and perfluoroalkyl substances**	**Bischel, Heather**	**University of California-Davis**
	2145128	**CAREER: 3D Printed Carbon-Metal Nanohybrid Aerogels for Highly Efficient Adsorptive/Catalytic Removal of PFASs**	**Aich, Nirupam**	**SUNY at Buffalo**
	2144550	**CAREER: Establishing a Knowledge Base for the Consumption, Accumulation, and Discharge of Poly- and Perfluoroalkyl Substance**	**Jiang, Daqian**	**University of Alabama Tuscaloosa**
	2143301	**CAREER: Targeted Catalytic Reduction of Persistent Organohalogens in Wastewater using a Novel V2C MXene-Imprinted Polymer Composite**	**Ray, Jessica**	**Univ of Washington**
2207235	2207235	**Collaborative Research: ERASE-PFAS: Hydrothermal Treatment as a Strategy for Simultaneous PFAS Destruction and Recovery of Energy and Nutrients from Wastewater Residual Solids**	**Strathmann, Timothy**	**Colorado School of Mines**
2207235	2207191	Collaborative Research: ERASE-PFAS: Hydrothermal Treatment as a Strategy for Simultaneous PFAS Destruction and Recovery of Energy and Nutrients from Wastewater Residual Solids	Guest, Jeremy	U of Ill Urbana-Champaign
2225596	2225596	**Collaborative Research: ERASE-PFAS: Stabilization of Per- and Polyfluorinated Substances in Sewage Sludge Intended for Land-application**	**Liang, Yanna**	**SUNY at Albany**
2225596	2225535	Collaborative Research: ERASE-PFAS: Stabilization of Per- and Polyfluorinated Substances in Sewage Sludge Intended for Land-application	Mckenzie, Erica	Temple University
2225596	2225750	Collaborative Research: ERASE-PFAS: Stabilization of Per- and Polyfluorinated Substances in Sewage Sludge Intended for Land-application	Guo, Bo	U of Arizona
	2149235	**Collaborative Research: Environmental Sensing of Per and Polyfluoroalkyl Substances in Water Utilizing a Microelectrode Sensor Array Platform and Machine Learning Enabled Detection**	**Chaplin, Brian**	**U of Illinois Chicago**
	2226329	**ERASE-PFAS: Bottom-up synthesis of polymeric membranes for PFAS sequestration**	**Hernandez Sanchez, Raul**	**U of Pittsburgh**
	2219832	**Collaborative Research: ERASE-PFAS: Thermal Regeneration of PFAS-laden Granular Activated Carbon presents an Opportunity to Break the Forever PFAS Cycle**	**Apul, Onur**	**University of Maine**
	2219833	Collaborative Research: ERASE-PFAS: Thermal Regeneration of PFAS-laden Granular Activated Carbon presents an Opportunity to Break the Forever PFAS Cycle	Hanigan, David	U of Nevada Reno

Opportunities for International Collaborations in PFAS Remediation, Mitigation, and Substitution in Semiconductor Manufacturing

- Supplements to existing NSF grants for U.S. PIs who wish to collaborate with Korean partners who are already funded by (or can get funding from) Korea NRF
- Joint funding of topical regional workshops (USA, ROK, Taiwan, and Japan) on the environmental impact and implications of semiconductor manufacturing including PFAS remediation, mitigation and substitution

Thank You