Every Click We Make:
Tech's Hidden Environmental Impacts

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Most people are aware that driving a vehicle with an internal combustion engine pollutes the environment and contributes to climate change. They might still drive that vehicle, but they know.

Few people are aware that every click we make on our computers, smart phones, or other devices also pollutes. The impact of each click is small, but they add up. What's more, that cost is remote and external. That is, we receive no feedback about the environmental costs, so we are unlikely to take steps, individually or collectively, to minimize those impacts. It's time to acknowledge the impacts and take steps to mitigate them.

The root of the problem is Moore's Law, the 1965 prediction by semiconductor industry pioneer Gordon Moore that the number of transistors that could be etched into a flake of silicon—a chip, or integrated circuit—would double roughly every two years. The rate of doubling may have slowed, but the impact of increasing microcircuit density has exploded.

With each new generation of chip comes new devices and applications. We started out with pocket calculators and digital watches, moving through personal computers to smart phones. Today new chips are driving innovations such as large-language models and generative artificial intelligence (AI).

Those new chips and the equipment that use them bring enormous environmental challenges. They use hazardous chemicals such as PFAS "forever chemicals" and release them into the environment. They emit significant quantities of potent, persistent global-warming greenhouse gases. They also gobble up vast quantities of water, natural gas, and electricity, but the focus of this summary is *hazardous substances.*

In the rush to create integrated circuits with features less that 2 billionths of a meter and build data centers covering more than a million square feet, few governments, companies, and consumers weigh the environmental costs. Unless the nascent pushback grows, we may become locked into digital conveniences that undermine the quality of life of ours and future generations and diminish the habitability of our planet. (I just used an AI tool to look up the size of advanced data centers.)

Chipmaking

The manufacture of integrated circuits is divided into three major steps:

- Design is computer work, conducted in offices.
- Wafer fabrication, in which sub-microscopic features are etched onto silicon disks currently as large as 300 mm, is a chemical-intensive process that uses large amounts of water and

energy. Those wafers are chopped into the flakes that are the brains—either memory or logic—of each chip.

- Assembly-Packaging-and-Testing historically uses fewer chemicals and a lot of low-cost labor. Conventional assembly, in which the silicon flakes are connected to caterpillar-like devices—is done outside the U.S., primarily in East Asia, but as the industry moves toward "advanced" packaging, where the silicon flakes are directly stacked, some of it will be carried out domestically.

Most of the billions of dollars in new semiconductor facilities is going to build and operate wafer fabrication factories, known as fabs. Using prevailing technologies, the use of hazardous substances, including hundreds of different PFAS "forever chemicals," is essential, as is the massive consumption of water, much of which is treated to become ultra-pure. Enormous amounts of electricity and natural gas are required, and the continuous, precarious nature of production requires an uninterrupted supply. Much of the piping and equipment are made from fluoropolymers. Processing, internal maintenance, and cooling all rely on fluorinated gases, much—perhaps most—of which are PFAS, and all of which are potent, persistent, greenhouse gases.

The best information we have about the environmental impact of chipmaking fabs comes from the Final Environmental Impact Statement (FEIS) for Micron Technology's planned four-fab complex in Clay, New York, just outside of Syracuse.[1] The FEIS downplays the negative environmental impacts, but it contains a great deal of useful data. This results, in part, from extensive public involvement in the scoping and drafting processes. Other large new semiconductor plants have been exempted from full environmental review. Still, the draft environmental assessments that were prepared but not completed for Intel, Taiwan Semiconductor, and Micron's Boise, Idaho expansion suggest that the Clay FEIS is representative of the major new fabs, with variations by company, location, and timing.

Hazardous Liquids: Solvents and PFAS

Wafer fabrication is multi-step photolithographic process that relies heavily on the use of solvents. Silicon Valley and Phoenix, where most U.S. semiconductor companies got their start, are dotted with large groundwater plumes of trichloroethylene (TCE), a chlorinated solvent known to increase the risk of several cancers, neurological disease such as Parkinson's, and cardiac birth defects. Many of these are on U.S. EPA's Superfund National Priorities List and are still undergoing remediation decades after the leaks and spills occurred.

More recently, chipmakers have been using NMP. A federal environmental assessment completed before the industry was exempted from review explained, "For example, traditional solvents used in fab cleaning processes contain N-Methylpyrrolidone (NMP), which is known to cause harm to reproductive systems."[2]

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[1] *Micron Semiconductor Manufacturing Project, Clay, NY Final Environmental Impact Statement,* Onondaga County Industrial Development Authority, EISX-006-55-CPO-001, November 2025, https://ongoved.com/micronfeis2025

[2] *Final Programmatic Environmental Assessment for Modernization and Expansion of Existing Semiconductor Fabrication Facilities under the CHIPS Incentives Program,* U.S. Department of Commerce, NIST-CPO/EA-001, June 28, 2024,

Today, semiconductor manufacturers use hundreds of per- and polyfluoroalkyl substances (PFAS) throughout the wafer fabrication process. These toxic compounds are known as forever chemicals because they do not break down into safer chemicals. Semiconductor companies have phased out two of the most toxic PFAS, but they do not fully disclose which chemicals they are using. Most of what we know about the use of these chemicals is through the sampling of chip plant wastewater, but outside of academic studies, effluent monitoring misses a majority of the PFAS released.[3] I know of no fab where the discharge of PFAS into wastewater is regulated. Thus, PFAS is discharged either directly to surface waters or to wastewater treatment plants which 1) discharge PFAS-containing effluent to surface waters, 2) collect PFAS in biosolids, which in many cases are spread on agricultural land, and 3) if captured by filtration methods, sent to incinerators where the emissions pollute the environment.

Hazardous Gases

Wafer fabrication relies on the routine use of lethal gases such as arsine and phosphine and larger quantities of acidic gases such as hydrogen chloride and hydrogen fluoride. The former are supposed to be tightly contained. The emissions of the latter are supposed to be continuously treated. In the early decades of semiconductor production, leaks were commonplace. Now they are less common, but they do occur.

In the 1980s in Silicon Valley, we enacted toxic gas ordinances that evolved into California's strong Accidental Release Prevention Program.[4] Users of hazardous gases are supposed to report their storage above chemical-specific thresholds and create Risk Management Plans to guide response to releases. There is a federal counterpart, which applies in other chipmaking states, but the federal reporting and planning thresholds are generally an order of magnitude weaker than California's. Thus, reporting on extremely hazardous gases is sketchy.

Fluorinated Gases

Semiconductor fabs also rely on fluorinated gases, most of which are toxic and many of which are PFAS. These are persistent, potent greenhouse gases. Manufacturers incinerate the gases used in production, creating other toxic substances, but they still release significant quantities into the environment. They also use fluorinated gases as heat-transfer fluids (HTF)—that is, refrigerants. Those are contained in so-called closed loop systems, but they too leak into the environment.

The following table (with emphasis added), extracted from the Micron Clay FEIS, estimates the anticipated greenhouse gas emissions from the facility.[5] While in theory the

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https://www.nist.gov/system/files/documents/2024/06/28/Final%20PEA%20for%20Modernization%20and%20Expansion%20of%20Semiconductor%20Fabs%206-28-2024%20-%20OGC-508C.pdf , p. 77 of PDF

[3] Paige Jacob, Kristas Barzen-Hanson, and Damian Helbling, "Target and Nontarget Analysis of Per- and Polyfluoroalkyl Substances in Wastewater from Electronics Fabrication Facilities," *Environmental Science & Technology,* February 16, 2021, https://pubs.acs.org/doi/10.1021/acs.est.0c06690; Lenny Siegel, "PFAS Discharges from a Typical Semiconductor Plant, GlobalFoundries, Essex Junction, Vermont," Center for Public Environmental Oversight, August 23, 2024

[4] California Accidental Release Prevention Program, https://calepa.ca.gov/california-accidental-release-prevention/

[5] *Micron Final EIS,* p. 334 of PDF

emissions from electricity generation can be reduced by developing carbon-free sources, the other uses and emissions are considered essential.

Table 3.7-11 Proposed Project Total GHG Emissions (GWP100)

Emission Source	Scope 1 CO_2e	Scope 2 CO_2e	Scope 3 CO_2e	Total Emissions
	(metric tons per year, GWP100)			
Semiconductor Process Tools	**881,699**	--	--	**881,699**
Fuel Combustion in PEECs and POUs	322,821	--	132,451	455,272
Fuel Combustion in RCTOs	285,704	--	117,223	402,927
Fuel Combustion in WBVs	73,285	--	30,172	103,457
Fuel Combustion in Boilers	125,863	--	51,818	177,682
Fuel Combustion in Emergency Generators	14,934	--	3,417	18,351
Heat Transfer Fluids	**199,699**	--	-	**199,699**
Fuel Combustion in RCS	11,278	--	4,627	15,905
Fuel Combustion in Fire Pump Engine	47	--	11	58
Biological Wastewater Treatment (Micron Campus and IWWTP).[1]	165,346	--	--	165,346
Circuit Breakers	8,547	--	--	8,547
IWWTP Combustion	--	--	18,115	18,115
Electricity Usage (Micron Campus) – National Grid Utility	--	2,273,587	--	2,273,587
4 MW Campus Solar Panels	--	-503	--	-503
Total Emissions	2,089,224	2,274,089	357,834	4,721,148

Hazardous Solids

Much of the equipment and piping in modern fabs are made from fluoropolymers such as PFA (perfluoroalkoxy alkane). In late 2023, the CEO of Chemours, the only domestic producer of PFA, told Forbes: "You cannot make chips without a whole PFA infrastructure… We estimate that in a modern-day fab, there's a half-kilo of PFA in every square foot. So in a 400,000- to 600,000-square-foot fab, that's 200 to 300 metric tons of this stuff."[6]

[6] Amy Feldman, "More Domestic Chip-Making Means More 'Forever Chemicals,'" *Forbes*, October 5, 2023. https://www.forbes.com/sites/amyfeldman/2023/10/05/more-domestic-chip-making-means-more-forever-chemicals/

Unless the PFA degrades, it doesn't get discharged into fab wastewater. Instead, the environmental risk is created at the plants where it is made, such as Chemours facility on the Ohio River, in Parkersburg, West Virginia—known to the nation from the *Dark Waters* movie. Disposing of PFA at the "end of life" is another significant source of PFAS pollution.

Data Centers

Data Centers, what we used to call Server Farms, are large buildings stuffed with interconnected data processing units—that is, computers. Advanced integrated circuits are their "grey matter." They support Cloud computing and so-called artificial intelligence, especially large language models and related generative AI. Some of their environmental impacts are similar to semiconductor plants, but compared to fabs, many more are being built these days, throughout the United States and beyond.

Cooling

Like wafer fabs, data centers require large quantities of uninterrupted electrical power and natural gas. Historically, they have been large consumers of water, primarily for evaporative cooling.

New data centers tend to run hot, due to their size and the increased computational density of integrated circuits. Water and air-based cooling systems are not powerful enough to hold down operational temperatures, so industry is transitioning to fluorinated gas-based refrigerants, such as HFCs (hydrofluorocarbons), hydrofluoroolefins (HFOs), and hydrochlorofluoroolefins (HCFOs). Though circulated in closed-loop systems, they leak and rise to the upper atmosphere.

This transition is new, so I am just beginning to collect data on the environmental impact of fluorinated-gas cooling systems.

One company cooling-system provider, Accelsius, explains the fate and transport of its refrigerants:

> In the event of a leak, the PFAS refrigerants vaporize and eventually make their way into the upper atmosphere. In the upper atmosphere, two things can happen based on the global warming potential (GWP) of the vaporized PFAS refrigerant.
>
> 1. For PFAS with high GWP, the PFAS remains in the upper atmosphere, where it has a high potential to warm the globe …
>
> 2. For PFAS with low GWP, the PFAS substance breaks down in a matter of days into the naturally occurring compound trifluoroacetic acid (TFA)[7]

Neither outcome is desirable.

[7] Richard Bonner III, Bill Grieco, and Liz Cruz, "Understanding PFAS Concerns for Two-Phase Cooling of Data Centers, Accelsius, https://accelsius.com/wp-content/uploads/PFAS-Whitepaper-Feb_2024.pdf

At least one company, Accelsius, is promoting cooling systems based upon low GWP fluorinated gases, arguing that trifluoroacetic acid is not a health hazard.[8] But there is strong evidence to the contrary. A team of European experts recently concluded otherwise:

> Trifluoroacetic acid (TFA) is a persistent and mobile substance that has been increasing in concentration within diverse environmental media, including rain, soils, human serum, plants, plant-based foods, and drinking water. Currently, TFA concentrations are orders of magnitude higher than those of other per- and polyfluoroalkyl substances (PFAS). This accumulation is due to many PFAS having TFA as a transformation product, including several fluorinated gases (F-gases), pesticides, pharmaceuticals, and industrial chemicals, in addition to direct release of industrially produced TFA. Due to TFA's extreme persistence and ongoing emissions, concentrations are increasing irreversibly. What remains less clear are the thresholds where irreversible effects on local or global scales occur. There are indications from mammalian toxicity studies that TFA is toxic to reproduction and that it exhibits liver toxicity. Ecotoxicity data are scarce, with most data being for aquatic systems; fewer data are available for terrestrial plants, where TFA bioaccumulates most readily. Collectively, these trends imply that TFA meets the criteria of a planetary boundary threat for novel entities because of increasing planetary-scale exposure, where potential irreversible disruptive impacts on vital earth system processes could occur. The rational response to this is to instigate binding actions to reduce the emissions of TFA and its many precursors.[9]

Fluoropolymers

Like the semiconductor industry, the advanced data center industry relies increasingly on fluoropolymers:

> Advanced Cooling Systems—AI workloads produce significantly more heat than traditional computing tasks. To help prevent overheating and maintain performance, data centers increasingly rely on liquid cooling systems. Fluoropolymer tubing is used to transport cooling fluids through high-temperature, high-pressure environments. These materials help resist chemical degradation, prevent contamination, and maintain integrity under extended extreme conditions.[10]

Transparency and Regulation

Neither the semiconductor industry nor the data center industry is the largest U.S. user of hazardous substances, be they liquids, gases, or solids. But they are important, growing sources. As they grow and extract subsidies and laxity from governments at all levels, we must demand that their releases be carefully regulated. Since persistent pollutants such as PFAS and other fluorinated gases simply build up in the environment, governments at all levels should set a goal of zero pollution.

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[8] *Ibid*.

[9] Hans Peter H. Arp *et al*, *The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA), Environ. Sci. Technol.* 2024, 58, p. 19925, https://pubs.acs.org/doi/10.1021/acs.est.4c06189

[10] "Fluoropolymer Chemistries Are Critical to America's AI Future," Performance Fluoropolymer Partnership, October 6, 2025, https://fluoropolymerpartnership.com/fluoropolymer-chemistries-ai-future/

- There needs to be full disclosure of the chemicals used and released by semiconductor manufacturing and data center operations, as wells as the energy, water, and other resource used by these facilities.
- As we click on our smartphones, computers, and other devices, we should be informed of the cumulative environmental costs.
- Decisions to approve, expand, or fund tech facilities must fully consider their environmental impacts, beginning when facilities are in the planning stage.
- The regulation of discharges, emissions, and hazardous waste disposal from tech operations must be updated to address current and emerging operations, sooner rather than later.