

Invitation to Collaborate

Research and Development for Circular Semiconductor Technology

Circular Semiconductors Research Network (CSRN)

Questions should be directed to: csrns@semi.org

Proposal Due Date: May 30, 2025

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Purpose of this Solicitation

The Circular Semiconductor Research Network (CSRN), co-created and managed by SEMI and imec, seeks research affiliates who align with our objective to build a circular, localized supply chain for sustainable semiconductor manufacturing.

We invite applications from collaborators that actively seek to:

- A. Develop onsite technology to allow for purification and re-use without getting a hazardous waste permit onsite that is less costly than current state off the shelf technology
- B. Develop technology to allow for purification and resale of a chemical at a permitted hazardous waste facility that is less costly than current state of the shelf technology
- C. Develop technology to allow for purification and resale of chemicals at a recycling facility that will not require hazardous waste permits that is less costly than current state of the shelf technology
- D. Develop technologies or processes that address the input or total chemical consumption amount

About imec

imec is a **non-profit** research and innovation center specializing in nanoelectronics and digital technologies. Imec leverages its state-of-the-art infrastructure (**including 300mm and 200 mm state-of-the art clean rooms**) and its team of more than **6000 employees** and top researchers. imec works in a neutral and open innovation model that encompasses the full ecosystem from industrial partners to startups and universities. Imec is headquartered in Leuven (Belgium) and has research sites across Belgium, in the Netherlands, the UK and the USA, and representation in three continents.

About SEMI

SEMI is the leading microelectronics and semiconductor design and manufacturing industry association with programs and events to help more than 3,500 members grow their business and address top challenges worldwide. Among its many programs both globally and regionally, SEMI

- Drives alignment on sustainability goals and emissions reporting.
- Fosters public-private collaboration on key issues with its unique global platform.
- Brings talent to the industry with career awareness, apprenticeship, and veterans programs.
- Guides the adoption of AI and digital twins to optimize chip design and manufacturing efficiencies.

1. Mission and Objective:

The SEMI Circularity Working Group was established in 2023 to convene experts from industry and research institutions to strengthen the circular economy across the semiconductor value chain.¹ With approximately 49 participating member organizations, the working group is an industry-leading network with global reach and expertise.

In 2024, the group began collaborating with the Sustainable Semiconductor Technologies and Systems (SSTS) program at imec, the world's largest independent innovation center for nanoelectronics and digital technology.

The SEMI-imec collaboration has worked to define priority materials for circularity activities across four semiconductor segments (see Figure 1): (1) Equipment, Subsystem & Components, (2) Fab and Foundry, Facilities and Infrastructure, (3) Outsourced Semiconductor Assembly and Test (OSAT), Electronics Manufacturing Services (EMS), (4) End Product and Application manufacturers. In Q4 2024, the SEMI-imec collaboration produced a list of 69 unique materials prioritized for circularity by and for the semiconductor value chain. This inventory is a novel contribution to industry and a means for mobilizing research and development (R&D). In parallel, the prioritization methodology that underlies the inventory's structure is anticipated to be made open-source, with publication in progress. A report is available.

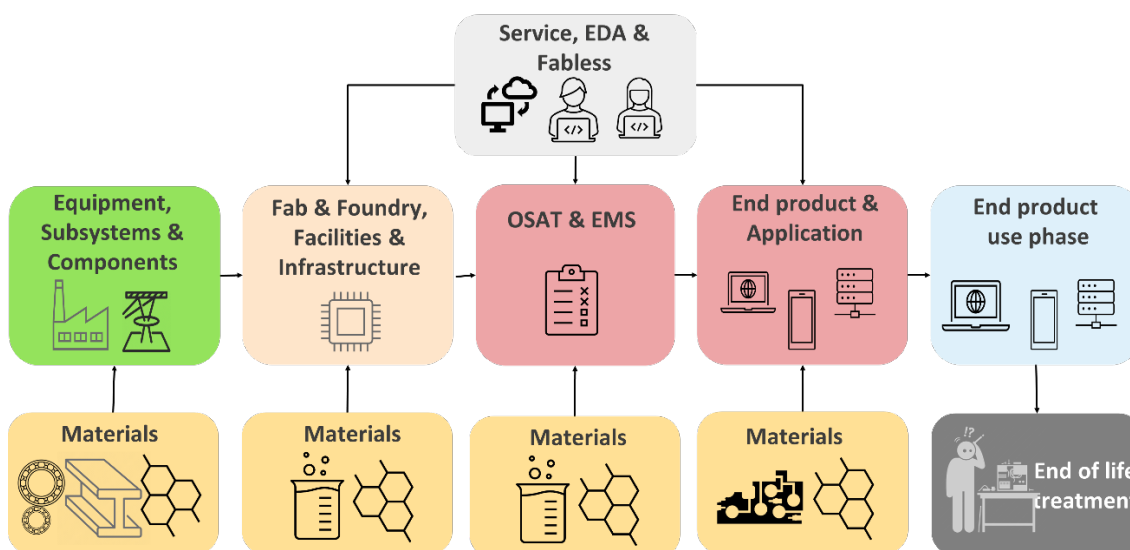


Figure 1: Selection of Value Chain Segments, source: imec

The next phase is to establish the Circular Semiconductors Research Network to drive a shift from linear to circular economy. The network serves as a platform to connect research teams with prospective industry adopters to accelerate validation, adoption, and deployment. It does not disburse funding nor provide facilities for experimentation; however, successful proposals will benefit from the exposure to the industry and may realize the potential for industry adoption

¹ On the concept of circular economy, see Ellen MacArthur Foundation, "Circular Economy Introduction," <https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview>.

facilitated by participation in the Circular Semiconductors Research Network. The network will leverage the SEMI Circularity Working Group, which is composed of member companies and research organizations that will provide industry guidance, expertise, and a platform for production readiness.

imec and SEMI invite collaborators to develop circularity technology across the semiconductor value chain. Ideal collaborators can substantiate Technology Readiness Level (TRL) 4 or greater and seek industry validation, adoption and acceleration of circularity solution deployment aimed to purify, reuse, and/or resell spent materials and by-products -- either onsite or offsite at a permitted facility under the conditions in the Solicitation Topics section (see below).

Research teams with relevant subject matter expertise for this research in an exploratory phase or lower TRL that have been endorsed by SEMI members, are welcome to submit proposals.

2. Problem Statement

The semiconductor value chain needs circular technologies for critical and other strategic materials that can embed into existing supply chains and create clear value.

As semiconductor companies and their business partners have seen periods of rapid growth,² increases in spent materials and chemicals have enlarged the value chain's adverse environmental impacts, thereby driving a rise in liability and disposal costs.³ Contrary to many other sectors, in the semiconductor industry larger company size, higher value added per unit of production, and higher technological capacity are not always related to lower quantities of waste per unit of production.⁴ Concerning material use, to date, most of the industry has been part of the linear economy of take, make, and waste. Optimizing within the linear economy will only delay the inevitable issues of business resilience and license to operate that underpin this system.

There are two interrelated, politico-economic drivers that make this project fundamental for industry.

First, many critical materials utilized by the semiconductor value chain are also critical for the transition to low-carbon energy and climate-impact reduction technologies.⁵ For example,

² Inna Skvortsova and Boris Metodiev, "Semiconductor Manufacturing Monitor," (October 2024), <https://www.semi.org/en/products-services/market-data/manufacturing-monitor>.

³ Marcello Ruberti, "The Chip Manufacturing Industry: Environmental Impacts and Eco-Efficiency Analysis," *Science of The Total Environment* 858, no. 2 (2023): 159873, <https://doi.org/10.1016/j.scitotenv.2022.159873>.

⁴ Marcello Ruberti, "The Chip Manufacturing Industry: Environmental Impacts and Eco-Efficiency Analysis," *Science of The Total Environment* 858, no. 2 (2023): 159873, <https://doi.org/10.1016/j.scitotenv.2022.159873>.

⁵ J. Teer and M. Bertolini, "Reaching breaking point: The semiconductor and critical raw material ecosystem at a time of great power rivalry," The Hague Centre for Strategic Studies (October 2022), <https://hcass.nl/report/reaching-breaking-point-semiconductors-critical-raw-materials-great-power-rivalry/>.

gallium and germanium are essential for manufacturing certain types of semiconductors and solar cells.

Second, low-carbon energy technology components rely to different degrees on certain minerals, which in turn have different criticality profiles dependent on factors such as price volatility and stability of the producer country.⁶ Some suppliers and refineries for these minerals are highly concentrated in a few countries.⁷ Therefore, supply chain security for critical materials used in semiconductor manufacturing has become a strategic issue for governments and the private sector, not only because it could affect the pace of the energy transition but also because materials sourcing has become contested among geopolitical rivalries and alliances.⁸ Demand for semiconductors is projected to grow in the next decade, leading to increased demand for critical raw materials.⁹ As a means for business resilience, circular strategies in the semiconductor value chain must account for the criticality of materials in geopolitical, macroeconomic context.

Early circularity strategies anchored primarily to waste management, waste-to-energy, waste diversion, and recycling programs. But now they are expanding to focus on re-use and reduction opportunities. This is a vast opportunity for companies because using spent chemicals as a feedstock can cut costs, reduce greenhouse gas emissions, create opportunities for brands, and bolster social license to operate.

However, there is a significant complication that this invitation to collaborate seeks to address. Companies in the semiconductor value chain face practical hurdles when navigating regulatory frameworks that govern their use of onsite versus offsite facilities for reuse and recycling of materials. The call for collaboration seeks to amplify research and development of technologies that comply with applicable regulations and meet one of the following conditions: (1) the owner/operator does not need to obtain a waste permit, or (2) the technology needs to be put offsite at a permitted waste facility.

3. Solicitation Topics

We seek research affiliates who align with our objective to build a circular, localized supply chain through considerations of sustainable semiconductor manufacturing.

We invite applications from collaborators that actively seek to:

- A. Develop onsite technology to allow for purification and re-use without getting a hazardous waste permit onsite that is less costly than current state off the shelf technology; or

⁶ See, e.g., Jane Nakano, “The Geopolitics of Critical Minerals Supply Chains,” Center for Strategic and International Studies (CSIS) (March 1, 2021), <https://www.jstor.org/stable/resrep30033>.

⁷ International Energy Agency, “Global Critical Minerals Outlook 2024,” (2024), <https://www.iea.org/reports/global-critical-minerals-outlook-2024>.

⁸ Kimberley Botwright and Guillaume Dabré, “Translating Critical Raw Material Trade into Development Benefits,” World Economic Forum (May 2024), <https://www.weforum.org/publications/translating-critical-raw-material-trade-into-development-benefits/>.

⁹ Linda R. Rowan, “Critical Mineral Resources: National Policy and Critical Minerals List,” U.S. Congressional Research Service R47982 (April 8, 2024), <https://crsreports.congress.gov>; O. Goswami, “Chipping In: Critical Minerals for Semiconductor Manufacturing in the U.S.,” *MIT Science Policy Review* 4 (2023), 118–126, <https://doi.org/10.38105/spr.tnepby7ntp>.

- B. Develop technology to allow for purification and resale of the chemical at a permitted hazardous waste facility that is less costly than current state of the shelf technology; or
- C. Develop technology to allow for purification and resale of the chemical at a recycling facility that will not require hazardous waste permits that is less costly than current state of the shelf technology; or
- D. Develop technologies or processes that address the input or total chemical consumption amount

Essential regulatory considerations

Proposals must address regulatory variance across regions by anchoring to a specific jurisdiction or jurisdictions and meeting these explanatory requirements:

- If the technology is to be placed **onsite at a manufacturing facility**, then proposals need to explain the regulatory framework to enable this. The equipment shall not require the site to get a permit for hazardous waste. The proposal must provide an environmental regulatory analysis of the permitting requirements and waste regulatory requirements to demonstrate comprehension of impact to the integrated pollution license or air or water permits. Most semiconductor plants do not have a hazardous waste permit, and the holistic permit impacts need to be understood.
- For **offsite** technology the proposal must provide an environmental regulatory assessment of how to enable the technology at an advanced recycling facility or a permitted waste facility.

Preference will be given to proposals that address one or more materials listed in an inventory of priority materials for circularity in the semiconductor value chain that we have established based on their Weighted Prioritized Score (see our report, “Material Circularity across the Semiconductor Value Chain: Prioritizing and Mobilizing Action,” found [here](https://discover.semi.org/material-circularity-across-the-semiconductor-value-chain-download-form.html)). (https://discover.semi.org/material-circularity-across-the-semiconductor-value-chain-download-form.html). See the report for a full listing of materials. Quick reference to materials that received a weighted prioritized score of 0.53 or higher, organized by the relevant segment of the value chain, is provided in the following tables:

1) Equipment Subsystems and Components:

Spent Materials	Uses	Weighted Prioritized Score	Comment
Aluminum	Equipment structure	0.78	
Magnets	Part of the machines	0.63	This is where the rare earth metals which are critical materials are found
Fluorine	Fluorine-containing equipment parts, tubing, O-rings,...	0.63	Fluorinated polymers are used to manufacture equipment, for example PFA tubing.
Copper	Wiring	0.63	
Wood from Crates/Pallet	Crating and Pallets for equipment	0.54	

2) Wafer Fabrication Plants, Foundries, Facilities and Infrastructure

Spent Materials	Uses	Weighted Prioritized Score	Comment
Hydrofluoric Acid	Wet Etch	0.86	Over a tanker a day or 18 tons a day for a 300 mm 5000 wafer start per week fab.
Calcium Fluoride	Treatment of HF and fluoride bearing wastewaters	0.80	
Cobalt in an acid solution	Plating	0.73	
Cupric Sulfate	Plating	0.70	
Neon	Photolithography	0.68	
Acids containing Gold and Palladium	Plating	0.68	
Silica Slurry	Chemical Mechanical Polish	0.67	
Copper Slurry	Chemical Mechanical Polish	0.67	Over 18 tons a day or a tanker a day
Solvents (IPA, Cyclohexanone, NMP, Cyclopentanone, PGME, PGMEA, Polyimide)	Photolithography and wet etch	0.66-0.47	Over 40 tons a day all combined or 2 tankers a day
Ceria Slurry	Chemical Mechanical Polish	0.65	
HFCs	Various tools	0.64	
Ruthenium	Lens for Photolithography tools	0.54	

3) Outsourced and other Assembly Test and Manufacturing Facilities

Spent Materials	Uses	Weighted Prioritized Score	Comment
Gold		0.68	Very little waste <1 ton per month per OSAT factory
Indium		0.64	Very little waste <1 ton per month per OSAT factory
Batteries		0.64	Very little waste <1 ton per month per OSAT factory

Tin		0.63	Very little waste <1 ton per month per OSAT factory
Copper		0.53	Very little waste <1 ton per month per OSAT factory

4) End Product and Application

Spent Materials	Uses	Weighted Prioritized Score	Comment
Gold		0.68	Very little waste <1 ton per month
Dysprosium (rare earth metal)		0.66	Very little waste <1 ton per month
Tantalum - Ta		0.65	Very little waste <1 ton per month
Cobalt		0.63	Very little waste <1 ton per month
Aluminum		0.62	Very little waste <1 ton per month
Praesodymium (rare earth metal)		0.62	Very little waste <1 ton per month
Lithium		0.57	Very little waste <1 ton per month
Copper		0.55	Very little waste <1 ton per month
Zinc		0.55	Very little waste <1 ton per month
Tungsten		0.53	Very little waste <1 ton per month

Cost analysis

Proposals for solicitation topics A, B, or C (see above) should include an analysis demonstrating how cost savings could be enabled relative to current technologies that are used for spent materials recycling. Proposals should contain a return on investment analysis, measured in U.S. dollars, over three, five, and ten years. See Table 1 for current state of the shelf technologies.

Table 1: Current Technologies

Spent Materials	State of the Shelf Technology
Acids containing copper or cobalt	Electrowinning or precipitation
Solvents	Direct re-sale, distillation and then sold onto the merchant market, or waste to energy
Spent acids	Direct re-sale
Wood pallets	Re-used onsite or sold

Mixed solvents	Blended with other waste and used as a fuel for cement kilns or distilled then sold onto the merchant market
Empty plastic drums/totes	Triple rinsed, sent for plastics recycling

Requirements for Collaboration in the Circular Semiconductors

Research Network

Ideal Candidates

A multidisciplinary committee will select applicants to collaborate in the CSRN. Ideal candidates are already engaged in research in this space and need a means for industry validation, adoption, and acceleration of technology deployment. Preferential consideration will be given to applicants who have reached Technology Readiness Level (TRL) 4 OR have the relevant subject matter expertise for this research OR those that are in exploratory phase (lower TRL) and have been endorsed by our committee members as a credible partner for engagement.

Teams from academia, non-profit research institutions, the private sector, and the public sector are welcome to apply.

The Circular Semiconductors Research Network is a platform to connect research teams with prospective industry adopters to accelerate validation, adoption, and deployment. It does not disburse funding nor provide facilities for experimentation; however, the successful proposal will benefit from the potential for industry adoption facilitated by the CSRN. The network will leverage the SEMI Circularity Working Group, which is composed of member companies and research organizations that will provide industrial guidance, expertise, and a platform for production readiness.

The SEMI Circularity working group operates as a global network, facilitating participation across time zones to foster inclusivity and equitable access for all members, regardless of their geographic location.

Proposal Process

Process:

- 1) Invitation for collaboration is released online
- 2) Proposal deadline May 30, 2025
 - Please note, if applicant wishes to include a non-disclosure agreement (which is optional), the fully executed version signed by all parties must be included with the proposal submittal. Allow 3 weeks to obtain signatures from imec and SEMI.
- 3) Selected affiliates announced by July 1, 2025
- 4) Final research due July 15, 2026 (affiliates will be asked to submit a progress report)

Proposal Instructions

Proposals should include:

1. Overview of the proposed technology
2. Which spent materials the technology is focused upon
3. The tonnage per year to be managed via that technology
4. Basic environmental regulatory assessment of the proposed technology
5. Market analysis for the relevant spent materials, including time to market and how to bring to market
6. Return on investment analysis
7. Anticipated positive environmental impact or socioeconomic benefits from adoption of the innovation
8. Narrative discussion of benefits for the generator of the spent materials
9. Viability of the proposed solution either onsite or offsite
10. Proof of funding or a methodology to be funded
11. [Optional] Non-disclosure agreement (NDA) *

**A non-disclosure agreement is optional. If applicant wishes to use an NDA, it must be fully executed before the proposal deadline of May 30, 2025. Contact csrn@semi.org to request a template or inquire for information.*

Email a **single** attachment to csrn@semi.org. Attachments should be in .pdf, .doc, or .docx formats.

Proposal Evaluation Criteria

Proposals will be evaluated on the following criteria:

- 1) Comparison versus state of the shelf technology
- 2) Potential return on investment as measured in dollars over three, five and ten years
- 3) Regulatory assessment completeness
- 4) Ability to handle an adequate rate of flow or tonnage of the chosen waste stream
- 5) Market analysis for the spent material that is being recovered or refined

Definitions

Waste

Waste is the discarded products or byproducts designed in the processes of design and manufacture of a product. Waste is due to an active decision made during the design phase. Waste and pollution are not created by accident. Waste is something that we no longer want, or a byproduct of manufacturing, and we throw it away. It's discarded material which may include liquids, contained gases, or solids. The common way of visualizing this is:

Types of Waste

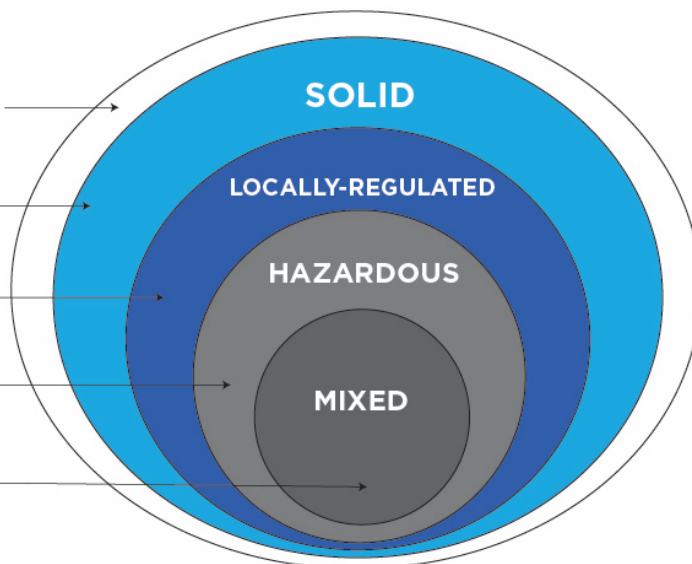
Not a Waste: Products still being used, used material recycled or exempted.

Solid: Discarded materials which may include liquids, contained gases or solids.

Locally-Regulated: Petroleum contaminated soils, e.g.

Hazardous: Subject to federal waste regulations

Mixed: Radioactive and hazardous waste.



Technology Readiness Level:

Technology readiness levels (TRLs) are a method for estimating the maturity of technologies during the acquisition phase of a program. TRL is determined during a technology readiness assessment (TRA) that examines program concepts, technology requirements, and demonstrated technology capabilities. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.

Technology Readiness Level	Description per the EU methodology
TRL1	Basic principles observed
TRL2	Technology concept formulated
TRL3	Experimental proof of concept
TRL4	Technology validated in lab
TRL5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL7	System prototype demonstration in operational environment
TRL8	System complete and qualified
TRL9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Source: <https://euraxess.ec.europa.eu/career-development/researchers/manual-scientific-entrepreneurship/major-steps/trl>

Contact

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