The Environmental effect of IC Chip Manufacturing: A closer look at the wet chemical contribution

Andrea Firrincieli

Sustainable Semiconductor Technologies and Systems (SSTS), imec

State of affairs

CO_2 emissions from semiconductor industry in perspective

~ 50 billion tons

World-wide

Source: https://www.ipcc.ch/report/ar6/syr/figures/figure-2-1
(Excluding land use, land-use change and forestry)

~ 1.2 billion tons

ICT Industry

Source: Freitag, C. Et al. 2021.
http://arxiv.org/abs/2102.02622

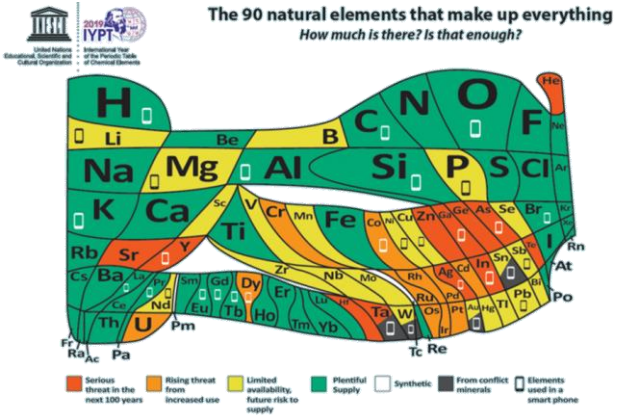
~ 175 million tons

Semiconductor manufacturing

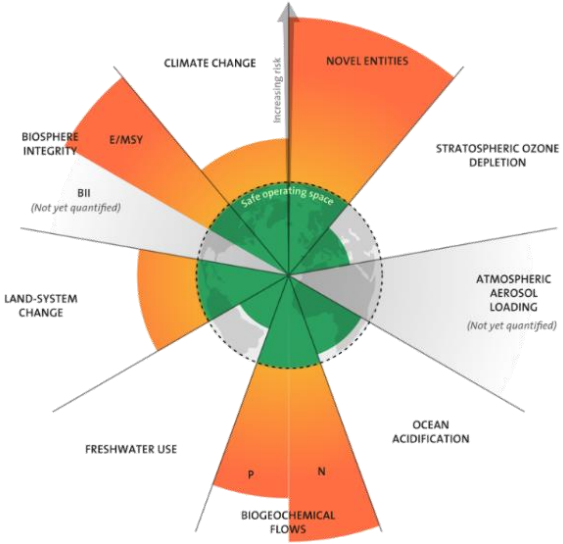
Includes Scope 1, scope 2 and scope 3 consumables and services. For industry in 2021.
Source: SEMI SCC Whitepaper on Transparency, Ambition, and Collaboration - 2023

Other areas of concern

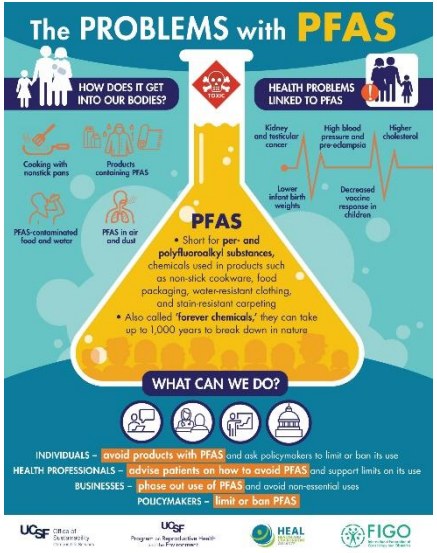
Stress points beyond climate change



Resource depletion and geopolitical tensions on material sourcing



Other planetary boundaries



Toxic substances

Credits:

- *Azote for Stockholm Resilience Centre, based on analysis in Persson et al 2022 and Steffen et al 2015.*
- *https://www.euchems.eu/newsletters/euchems-periodic-table-element-scarcity-in-the-spotlight/*
- *Health and Environment Alliance | How PFAS chemicals affect women, pregnancy and human development: Health actors call for urgent action to phase them out (env-health.org)*

Semiconductor & Tech companies accelerating on sustainability

Hand-picked press releases

News - 28 August, 2023

ASM first in semiconductor industry to have net-zero target verified by SBTi

Almere, The Netherlands
August 28, 2023

Press releases | ASM

PRESS RELEASE • September 12, 2023

Apple unveils its first carbon neutral products

The new Apple Watch lineup marks major progress toward ambitious Apple 2030 climate goal

Product Environmental Report

Advanced materials for sustainable electronics

April 21, 2023 Press release Air Liquide

January 31, 2023 Press Release Amazon

Amazon Sets a New Record for Most Renewable Energy Purchased by a Single Company

Transparency, Ambition, and Collaboration:

Advancing the Climate Agenda of the Semiconductor Value Chain

SCC White Paper

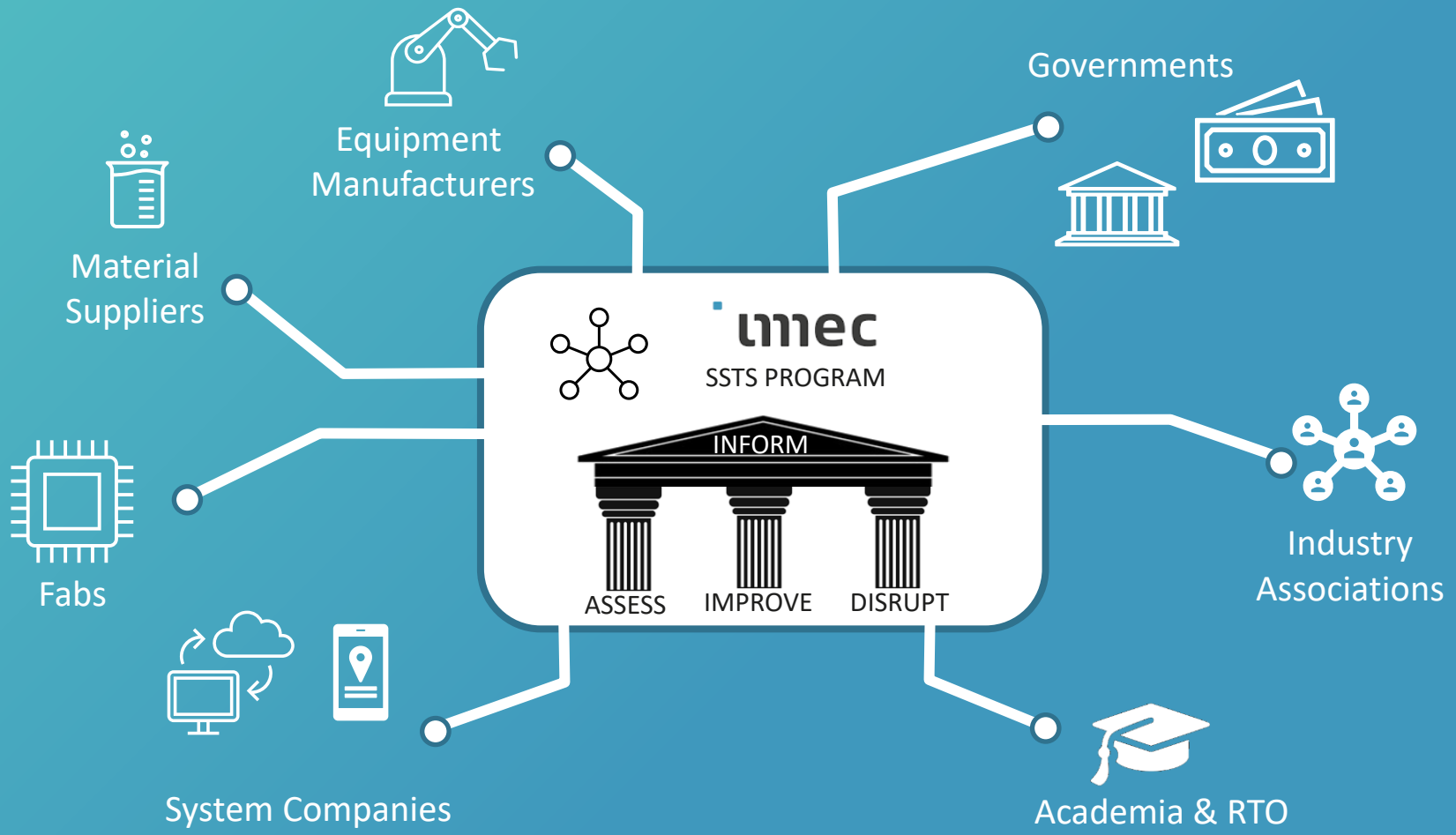
Semiconductor Climate Consortium

TSMC Accelerates Renewable Energy Adoption and Moves RE100 Target Forward to 2040

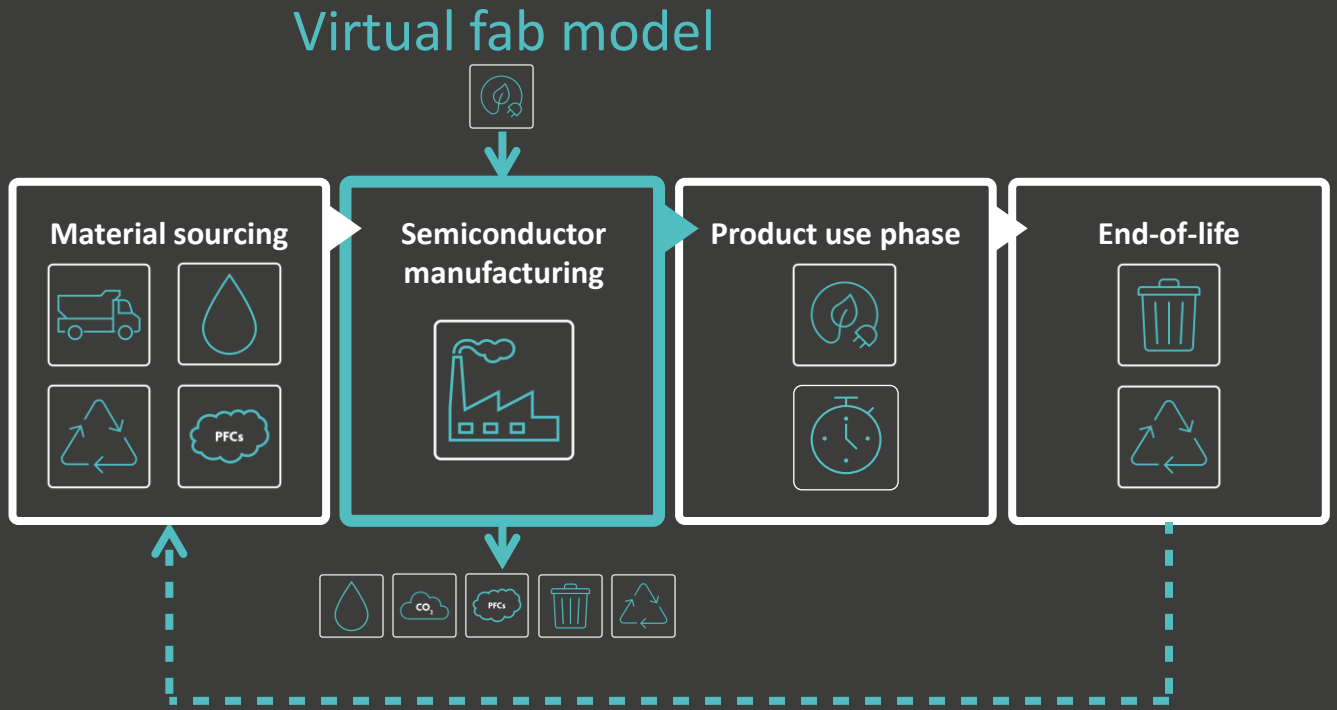
Issued by: TSMC
Issued on: 2023/09/15

Press release TSMC

TSMC Accelerates Renewable Energy Adoption and Moves RE100 Target Forward to 2040


Equipment Manufacturers
Governments
Material Suppliers
imec
SSTS PROGRAM
INFORM
ASSESS
IMPROVE
DISRUPT
Fabs
Industry Associations
System Companies
Academia & RTO

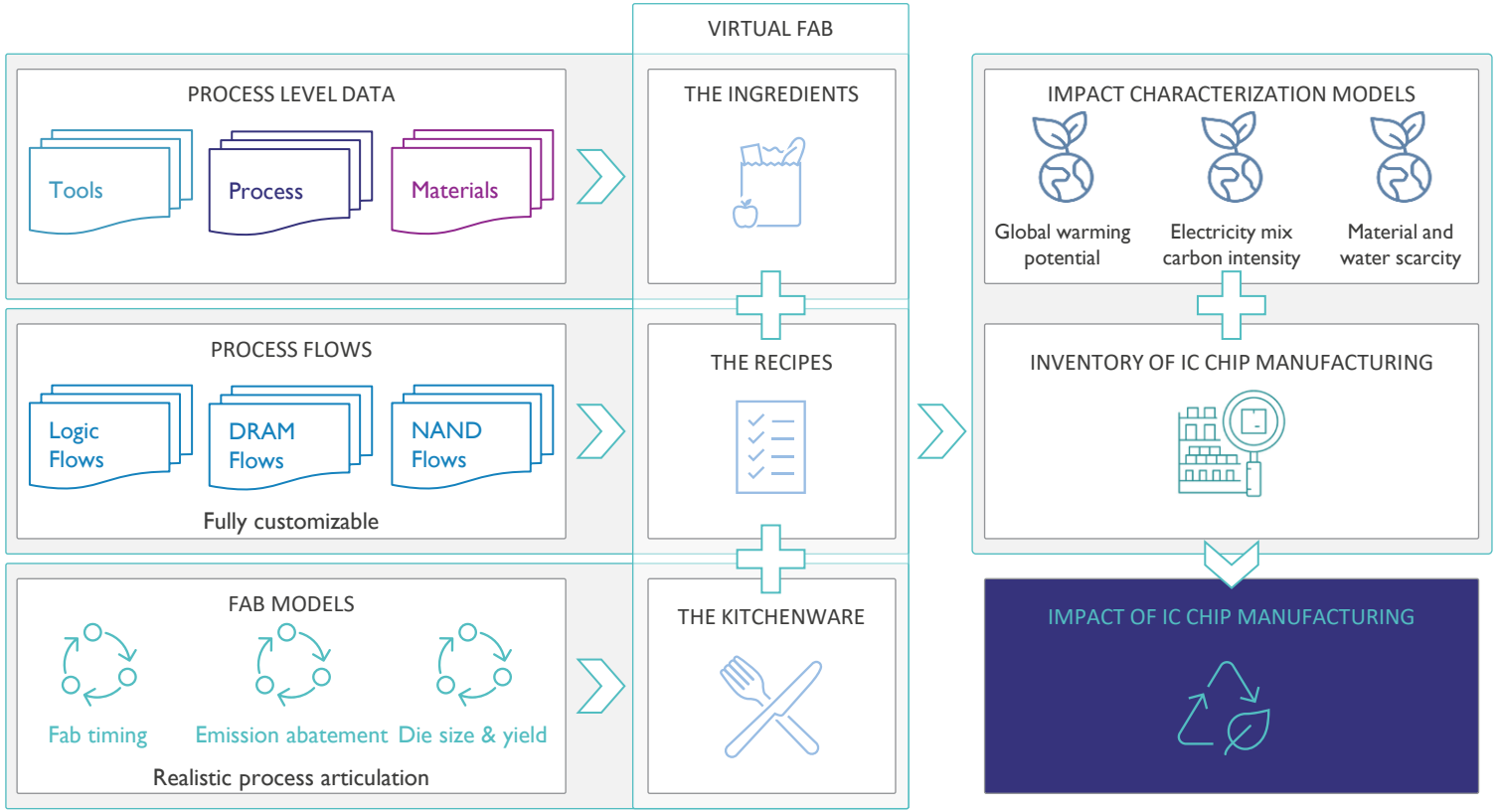
Putting the E in PPAC-E



imec

imec.netzero – a bottom-up virtual fab model

Quantify the footprint of a chip

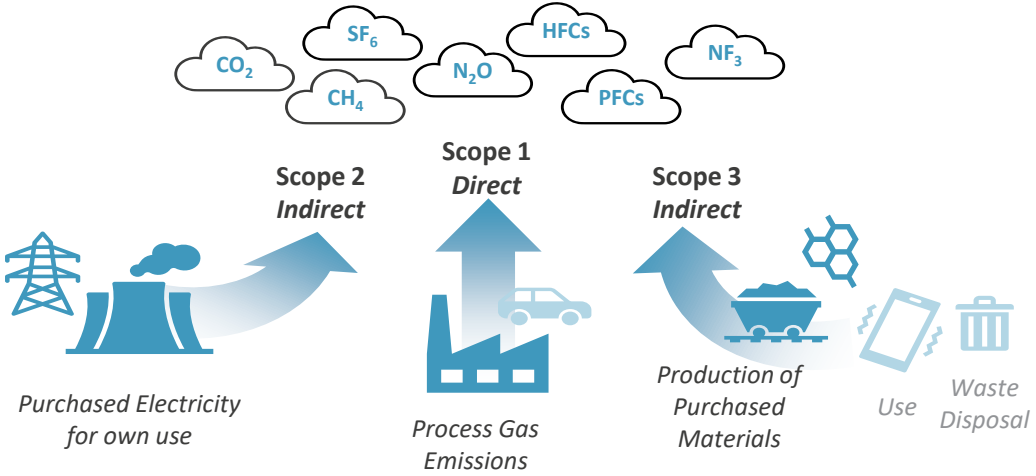


Levers towards netzero IC manufacturing

Per GHG protocol scopes from the fab perspective

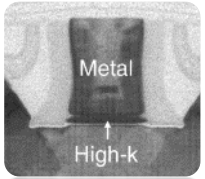
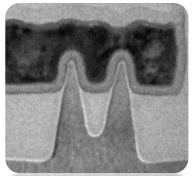
Act on the three scopes to reduce:

1. direct emissions through abatement and replacement
2. electrical energy impact with improved efficiency and clean energy
3. upstream material impact by leveraging the supply chain to reduce *their* scopes 1 to 3...



The impact from IC manufacturing

Logic nodes in imec.**netzero** for public

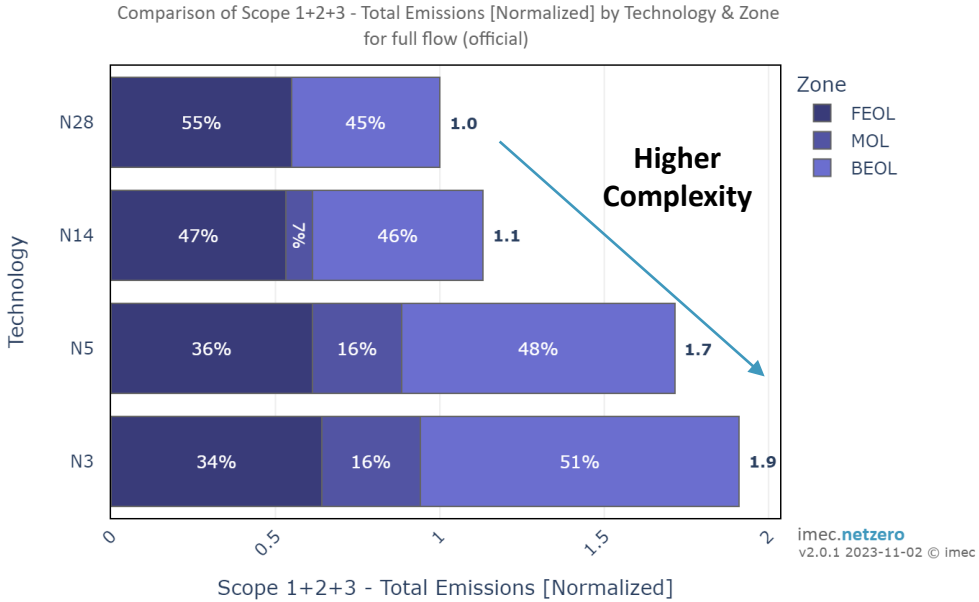
Year of Introduction	2008	2010	2013	2016	2018		2020
Technology Node	**N28**	**N20**	**N14**	**N10**	**N7**	**N7_EUV**	**N5**
Mint Metal Pitch (MP) [nm]	80	64	64	44	40	40	28
Standard Cell Track height	9T	9T	9T	7,5T	7T	7T	6T
Device Topology	 Planar				 FinFET		
RMG Stacks	HKF (2x)	HKL (2x)	HKL (3x)	HKL (3x)	HKL (5x)	HKL (5x)	HKL (5x)
Scaling Boosters	High-k/MG		FinFET				SAGC
BEOL Metal Stacks	10		11	12	13	13	14
Lithography	Immersion (193i)						EUV

Based on the imec logic technology roadmap tailored for SoC mobile applications

Emissions are increasing for more advanced technology nodes

From the IC fab perspective

- Mobile SoC assumption
  - Increase in interconnect levels
  - Increase in complexity
- Higher use of energy, utilities, gases, water, chemicals and other materials → Increase in the IC chip embodied emissions

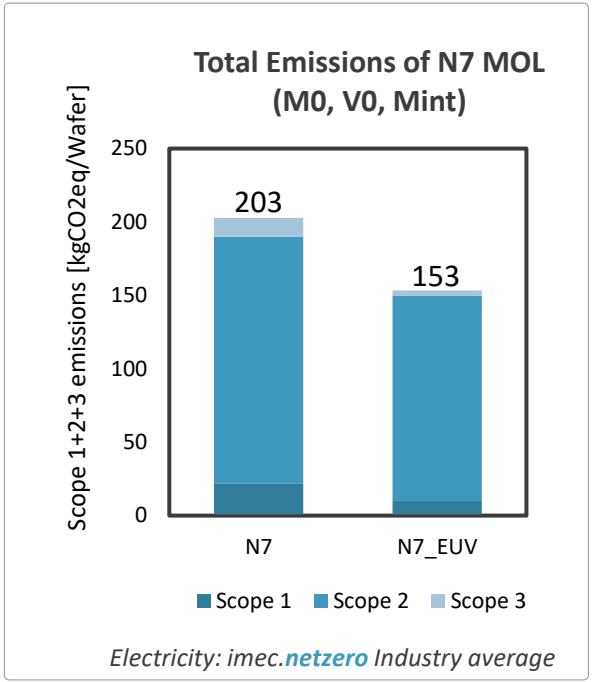


Process optimization towards reduced emissions

Example of EUV introduction in MOL in N7

- Process simplification of N7 MOL:
  - 193i SADP M0 + 193i LELELE V0 → EUV LE for M0 and V0
  - 3x reduction in masks and 2.4x reduction in process steps

- Total reduction in emissions: **-24%**
  - Scope 1 (less etch and deposition): -71%
  - Scope 2 (less of most, more energy for EUV): -17%
  - Scope 3 (less materials consumed): -54%



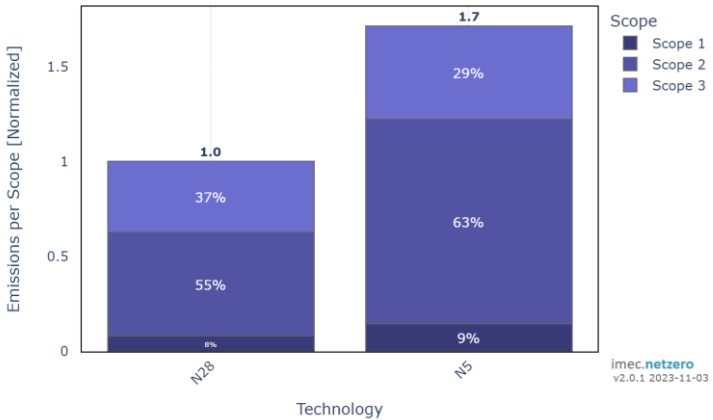
For the impact of High-NA: Emily Gallagher / Carlo Luijten: "High NA EUV introduction – a sustainable choice?"

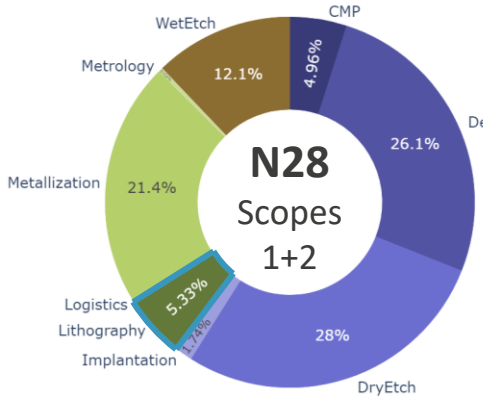
Wet clean process impact

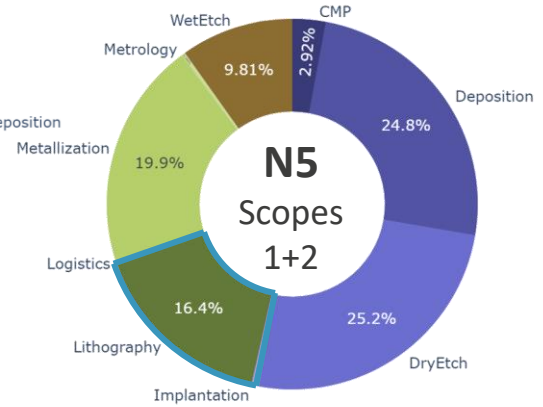
What process areas contribute the most?

Evolution of advanced technologies

- Lithography contribute more in advanced nodes
  - While other process areas are reduced
- These trends are due to less multi patterning (SADP, LELE etc) with EUV



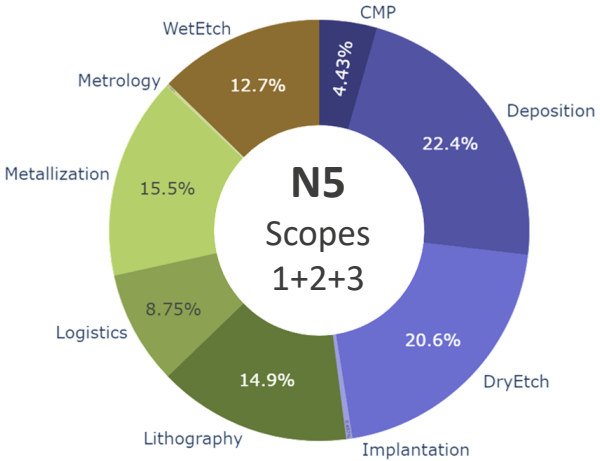


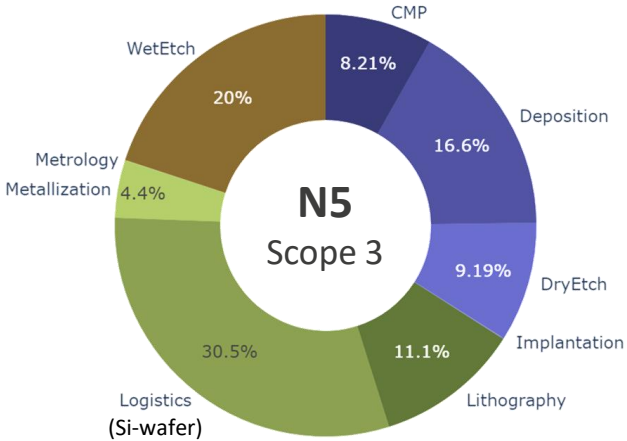


Imec.netzero industry average electricity mix (0.454 kgCO2eq/kWh)
100% deployed abatement assuming IPCC Tier2C and GWP from IPCC AR6

Including the material impact

- **Total Emissions**: Deposition and Etch dominate (~43%)
- **Scope 3**: The Si-wafer followed by wet processing dominate (~50%)
  - Let's have a closer look at Scope 3





imec.netzero
v2.0.31 2023-11-08 © imec

Imec.netzero industry average electricity mix (0.454 kgCO2eq/kWh)
100% deployed abatement assuming IPCC Tier2C and GWP from IPCC AR6

Scope 3: Upstream material emissions – very complicated

Full Supply chain must be involved

1. Quartz

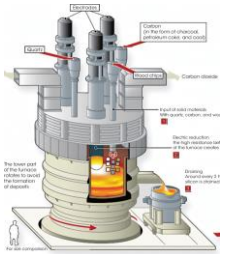
2. MG Si

3. EG Si

4. Si ingot

5. Si Wafer

Reduction

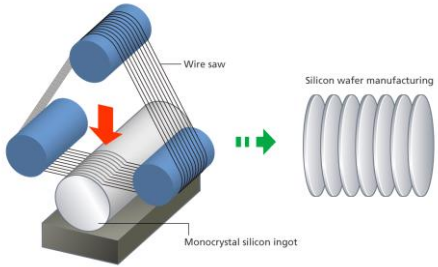


Purification

Polysilicon rods after CVD-Process

Czochralski process

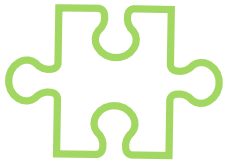
Slicing – Polishing - Cleaning



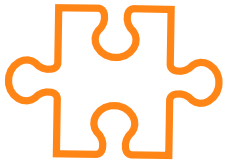
Characterizing of LCI – the ideal case

Bill of materials

Wafer/ elements



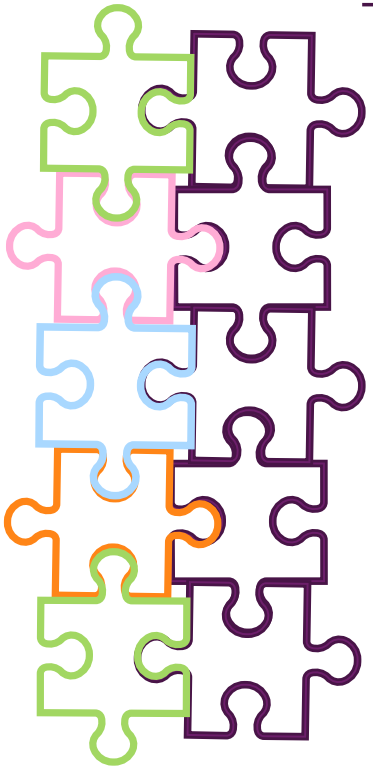
Wet chemicals



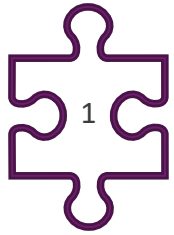
Bulk gases

Precursors/ specialty gases

material CF



Cradle-to-gate characterization factors (CF)s for input materials



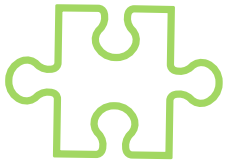
Perfect Fit

CF specific to input material from partners/supply chain

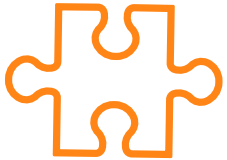
Characterizing of LCI – current reality ⇔ Need for supplier data

Bill of materials

Wafer/ elements

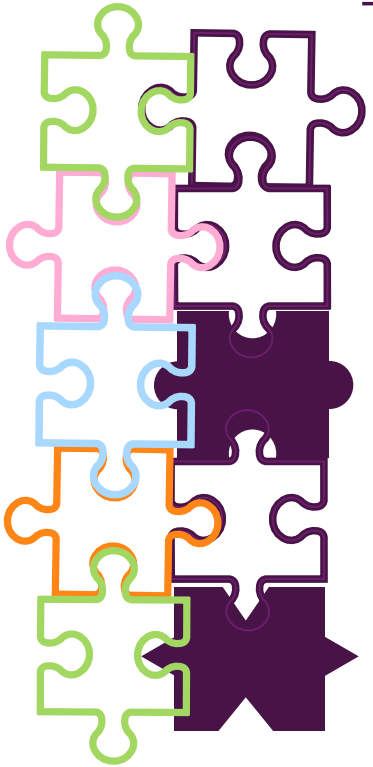


Wet chemicals

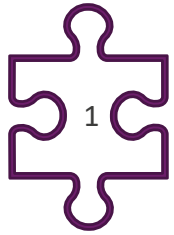


Bulk gases

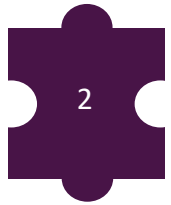
Precursors/ specialty gases



Cradle-to-gate characterization factors (CF)s for input materials



CF specific to input material from partners/supply chain



CF specific to input material from LCA database or scientific literature

Proxy CF for a related input material from LCA database or scientific literature

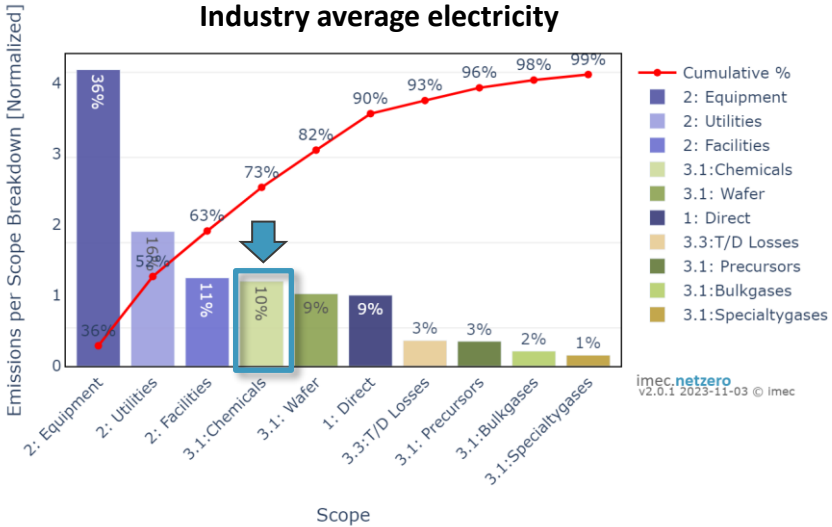
Generic proxy CF for an input material

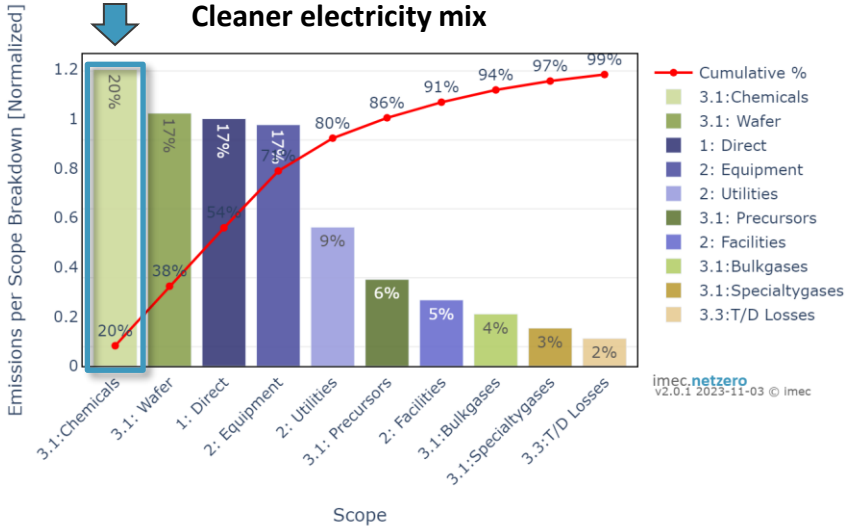
imec

Emission breakdown by the different scopes

Advanced node N5 example

- In an average electricity mix the Scope 2 equipment, utilities and facilities dominates.
- In a clean energy scenario (here 0.11 kgCO2eq/kWh): Scope 3.1 of **Chemicals** dominate

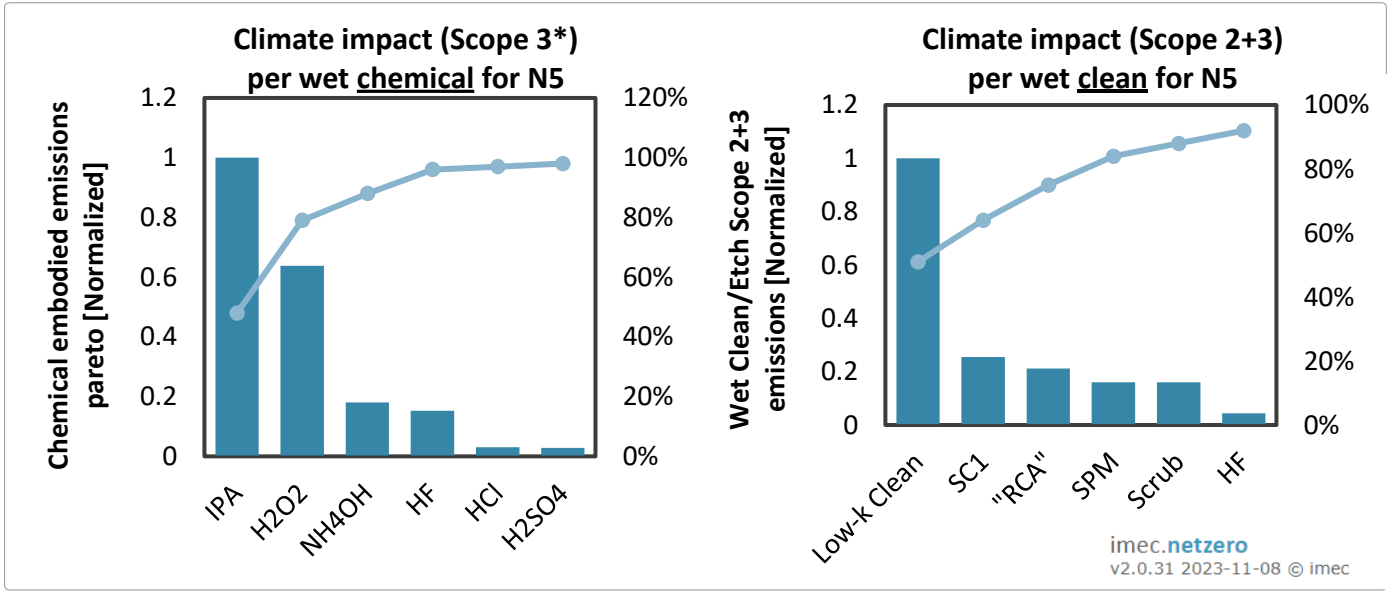




Priorities in terms of materials and wet clean steps

Advanced node N5 example

- Chemicals: IPA and H_2O_2 have largest impact
- Wet cleans: Low-k clean is the single largest impact (due to many repeats**)



*Emission conversion factors are from Ecoinvent 3.9.1
**N5 Mobile SoC assumed to have 14 Cu interconnect levels

Conclusions

Conclusions

- The impact for IC manufacturing is non-negligible
- The impact will increase due to more fabs and higher complexity in future technology nodes

- Estimating the impact of the fab consumables is complex: Collaboration across the supply chain is essential

- Wet processes contribute significantly to the Scope 3 emissions of the fab
- Current analysis identifies key chemicals and cleans for future work on improvements

embracing a better life