Future-Fit Heatmap
Semiconductor manufacturing

Introduction to semiconductor manufacturing

Nearly all current electronic technology uses semiconductors - electronics manufacturing services, original design manufacturing, the hardware industries, and increasingly the automobile and appliance industries. A typical company would manufacturers semiconductors or other integrated chips, encompassing semiconductor devices, integrated circuits and components (such as wafers, substrates and solutions), but excluding raw material input or equipment. [1] [2] [3]

A semiconductor is a material whose electrical conductivity is less than a conductor (such as metallic copper), but more than an insulator (such as glass). A semiconductor product (or 'integrated circuit', also known as a 'microchip', 'silicon chip' or 'computer chip') is composed of 'wafers', made from a base material such as silicon, germanium or gallium. The wafers are layered, each one customised through a series of processes, such as 'doping' - the addition of tiny quantities of impurities such as arsenic, boron or phosphorous, to alter its conductivity. As a result, a sterile environment and repeated cleaning of the wafers are crucial to the process.

The manufacturing process is highly technical and occurs in 'fabs' - specialised facilities that contain highly pure environments known as 'cleanrooms'. It requires the use of many specialised, and often hazardous chemicals, as well as a significant amount of energy to heat furnaces, power processing and cleaning machines, and vast quantities of water for continuous rinsing of equipment. Intellectual Property (IP) related to chemicals and production processes is critical in ensuring companies remain competitive in this fast-evolving industry.

Impact level definitions

Impact Level	Notation	Definition
Highest	◉	Typical business activities cause severe harm to people or planet in this issue area.
Highest/Medium	◉◉	Different subsets of typical business activities fall into either highest or medium impact levels.
Medium	◉	There is no evidence that typical business activities cause either severe or little harm to people or planet in this issue area.
Medium/Lower	◉◉	Different subsets of typical business activities fall into either medium or lower impact levels.
Lower	◉	Typical business activities cause little harm to people or planet in this issue.
Unlikely	◉	Typical business activities are unlikely to cause any harm to people or planet in this issue area.

Summary of Heatmap

Impact level	Break-Even Goal
Highest	**BE01**: Energy is from renewable resources
	BE02: Water use is environmentally responsible and socially equitable
	BE04: Procurement safeguards the pursuit of future-fitness

	BE05: Operational emissions do not harm people or the environment
	BE06: Operations emit no greenhouse gases
	BE07: Operational waste is eliminated
	BE09: Community health is safeguarded
	BE10: Employee health is safeguarded
	BE14: Employee concerns are actively solicited, impartially judged and transparently addressed
	BE19: Products can be repurposed
	BE22: Lobbying and advocacy safeguard the pursuit of future-fitness
Medium	**BE08**: Operations do not encroach on ecosystems or communities
	BE11: Employees are paid at least a living wage
	BE12: Employees are subject to fair employment terms
	BE13: Employees are not subject to discrimination
	BE17: Products do not harm people or the environment
	BE20: Business is conducted ethically
	BE21: The right tax is paid in the right place at the right time
Lower	**BE15:** Product communications are honest, ethical, and promote responsible use
	BE16: Product concerns are actively solicited, impartially judged and transparently addressed
	BE23: Financial assets safeguard the pursuit of future-fitness
Unlikely	**BE03**: Natural resources are managed to respect the welfare of ecosystems, people and animals
	BE18: Products emit no greenhouse gases

Property	Break-Even Goal	Impact level	Relevant Impact Characteristics	Rationale for Assessment
Energy	BE01: Energy is from renewable sources		A typical company requires a specialised environment which depends on high energy-input for its maintenance	The creation of semiconductors consumes significant amounts of electricity - up to 100 MWh of energy per hour. Fab infrastructure is responsible for 60% of total energy use through processes such as air filtering and ventilation in cleanrooms, as well as lighting and water treatment. Manufacturing tools, such as plasma-etching torches, consume the remaining 40%. [4] [1] [5]
Water	BE02: Water use is environmentally responsible and socially equitable		A typical company's operations depend on significant water consumption	Water is fundamental to the manufacturing of semiconductors. After each layer of material is added to the silicon wafer, it is typically rinsed with 'Ultra-Pure Water' (UPW) to remove chemical and particle impurities. As a result, creating one microchip can require 2,200 gallons of water. Machines used to dry clean final semiconductors, air conditioning units, cooling towers and other cleaning equipment also require water. [1] [6] [7]
			A typical company creates highly contaminated wastewater which requires specialised treatment	The production of semiconductors results in chemical-heavy wastewater. Chemicals include arsenic, hydrogen peroxide and ammonium hydroxide, which are toxic and highly corrosive. [8] [9] [1] [7]
Natural Resources	BE03: Natural resources are managed to respect the welfare of ecosystems, people and animals		A typical company does not manage natural resources	Natural resources such as germanium, boron, arsenic, gallium, graphite, copper and silicon are used in the production of semiconductors. However, because they are procured, rather than extracted by semiconductor companies, the impacts fall within **BE04: Procurement**. [10] [1] [11] [12]

Property	Break-Even Goal	Impact level	Relevant Impact Characteristics	Rationale for Assessment
Pollution	BE05: Operational emissions do not harm people or the environment		A typical company uses harmful substances as a product input or operational input	A multitude of harmful and toxic chemicals are used in the production of semiconductors. For example, chlorine is used to clean silicon and hydrofluoric acid is used to clean wafers. Chemical disposal methods include combustion or oxidation, which results in significant emissions. [1] [13] [14] [15]
			A typical company's activities lead to a significant risk of spills or leaks	Leakage of underground organic solvent storage tanks within fabs can also lead to toxic liquid emissions. These chemicals contaminate groundwater and drinking water. Such incidences have led to the designation of 'Superfund' sites in the US. [16] [1] [17] [18]
	BE06: Operations emit no greenhouse gases		**BE01: Energy** has been upgraded	Semiconductors are highly energy-intensive to produce, as explained under **BE01: Energy.**
			A typical company emits significant GHGs as operational by-product	The main source of greenhouse gases (GHGs) within this industry are perfluorocompounds (PFCs), 10-80% of which are released unreacted into the atmosphere. They are used in manufacturing processes, such as plasma etching and cleaning chemical vapour deposition chambers. This group of GHGs has a high Global Warming Potential (GWP) and a long atmospheric lifetime. [1] [15]
	BE17: Products do not harm people or the environment		No upgrading or downgrading characteristics are fulfilled	Semiconductors do not harm people or the environment during use. At end-of-life, electronic waste as a whole is considered hazardous to humans and the environment. [19] This is because people come into direct contact with harmful materials during the collection process, are exposed to toxic fumes when elements are burnt, and ecosystems are disrupted as metals leach into soil.

Property	Break-Even Goal	Impact level	Relevant Impact Characteristics	Rationale for Assessment
				However, while semiconductors exist in almost all forms of modern electronics, they are considered a relatively small component of this broader e-waste issue. [20] [21]
	BE18: Products emit no greenhouse gases		A typical company's products do not force user to emit GHGs during use or post-use	Semiconductors are a component of electronic goods. Such goods require electricity to function, which will have associated Scope 2 GHG emissions. However, semiconductors do not force the user to emit GHGs during or post-use and therefore do not fall under this goal.
Waste	BE07: Operational waste is eliminated		A typical company's operations create significant quantities of hazardous waste	The majority of chemical 'waste' created in the semiconductor industry escapes as gas, which is covered by **BE05: Operational Emissions**. [10] [1] [16] [22] However, semiconductor manufacturing generates spent solvent and aqueous metal containing hazardous waste. Typical hazardous waste streams include waste rinsing water, spent process baths waste acids and bases used for cleaning and metal salts. [23] Although tightening regulation has driven innovation to reduce use of harmful chemicals and increase recycling, hazardous waste is still inherent to the industry. It is emitted into air or water, stored in underground injection wells, or sent to landfill or incineration. [16]
	BE19: Products can be repurposed		A typical company's products are difficult to disassemble by end user	Electronic waste is considered the fastest growing stream of hazardous waste in the world. [24] [25] [26] Given the valuable virgin natural resources used in semiconductors, there is a need to improve repurposability of such components.
Physical Presence	BE08: Operations do not encroach on		No upgrading or downgrading characteristics are fulfilled	Fabs tend to cluster around urban hubs and there is no reason for fabs to be located near High Conservation Value land. There is

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	ecosystems or communities			some risk of fabs drawing water upstream of important municipal sources, which would put them at risk of encroachment. [12]
People	BE09: Community health is safeguarded	◉	A typical company relies on or produces significant quantities of harmful substances as a product, operational input or by-product	The activities of semiconductor production undermine community wellbeing in various ways. The industry uses harmful substances in its operational processes, such as hydrogen fluoride, ammonia and sulphuric acid. Post-use, these or reacted compounds become by-products or are stored as solvents. They may be emitted as gaseous emissions or as wastewater. Organic solvents from underground storage tanks can leak into local groundwater sources, having detrimental impacts on health including birth defects in children. Toxic air and groundwater pollution are also caused by wastewater and gaseous emissions. EPA cleanup 'Superfund' sites have been established across the US due to extensive contamination. [27] [7]
			A typical company's operations depend on significant water consumption or the industry uses water as a main or sole product input	As noted under **BE02: Water**, this is a highly water-intensive industry. This has created competition between semiconductor companies and local farmers, especially where there is a high concentration of fabs in one region. [7]
	BE10: Employee health is safeguarded	◉	A typical company potentially exposes employees to harmful substances as a product input, operational by-product or final product	Potentially hazardous chemicals such as photoactive chemicals, organic solvents, acids and toxic gases are used in the semiconductor industry. Employees are at risk of exposure to such chemicals – some with established carcinogenic qualities. Working in fabs also exposes employees to significant levels of radiation. Furthermore, the industry's reliance on IP, and consequent secrecy

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				around substance use, has made it difficult to investigate associated chronic health risks. [1] [28] [29]
	BE11: Employees are paid at least a living wage		No upgrading or downgrading characteristics are fulfilled	The semiconductor industry is highly technical and relies on high-skilled workers, such as engineers and scientists. However, there is evidence that the back-end activities needed to make semiconductors (assembly, testing, and packaging) are more labour-intensive than front-end work. These steps are generally outsourced to Asian countries with low labour costs. Therefore, there remains a risk of poor employment terms and wages for some employees. [30] [31] [32] [33]
	BE12: Employees are subject to fair employment terms		No upgrading or downgrading characteristics are fulfilled	See **BE11: Living Wage.**
	BE13: Employees are not subject to discrimination		No upgrading or downgrading characteristics are fulfilled	Instances of discrimination arise in all industries, and semiconductor manufacturing is no exception. [34] Senior management and senior technical roles have tended to fall to males. [35] This gender disparity creates potential for discrimination within the workplace.
	BE14: Employee concerns are actively solicited, impartially judged		**BE10: Employee Health, BE11: Living Wage, BE12: Employment Terms** or **BE13: Discrimination** have been upgraded	As noted in **BE10: Employee Health**, semiconductor workers are exposed to significant risk. As a result, if there is an issue related to health and safety procedures, it is imperative that employees have a clear channel to raise concerns.

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	and transparently addressed		A typical company is highly dependent on confidentiality	The highly guarded nature of IP within the semiconductor industry provides opportunities for unethical behaviour, and employees should be able to voice concerns confidentially. [36] [37] [1] [29]
	BE15: Product communications are honest, ethical, and promote responsible use	◉	A typical company's products are unlikely to cause significant harm to people or environment during intended use, if misused, or at end of life	Semiconductors are an intermediate good, as they form one component of a final electronic product: the industry is therefore predominantly involved in B2B relationships, with little reason to communicate with final consumers. A semiconductor itself is unlikely to cause harm, except as a small component of the broader e-waste issue noted under **BE19: Product Repurposing**.
	BE16: Product concerns are actively solicited, impartially judged and transparently addressed	◉	A typical company's products will not pose a risk to the user or the environment as a result of a fault in production or accidental misuse	Semiconductors are a specialised intermediate good as they form one component of a final electronic product: misuse is therefore extremely unlikely. They are unreactive and pose little risk to the user or the environment in the case of production fault or accidental misuse.
Drivers	BE04: Procurement safeguards the pursuit of future-fitness	◉	A typical company transforms raw materials or refines materials into other products	The semiconductor industry is premised on the transformation of raw materials into a manufactured good: procurement of such inputs is pivotal.
			A typical company's products are made of multiple materials or components	Semiconductors are dependent on the use of silicon, rare earth metals and other mined materials. As a result, product inputs are likely to have high intensity *Natural resource* hotspots. [38] [10] [1] [11]
	BE20: Business is conducted ethically	◉	No upgrading or downgrading characteristics are fulfilled	IP, namely patents and trademarks, is crucial to remaining competitive in the semiconductor industry. There is a potential issue around IP inhibiting research into health and safety of

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				chemicals central to production, and a lack of transparency makes regulation and ongoing progress in health and safety research difficult. [1] [39] [29]
	BE21: The right tax is paid in the right place at the right time		No upgrading or downgrading characteristics are fulfilled	The semiconductor industry does not have any characteristics that would make it more susceptible to breaching the 'spirit and the letter' of tax regulation.
	BE22: Lobbying and advocacy safeguard the pursuit of future-fitness		A typical company is highly reliant on intellectual property	IP, namely patents and trademarks, is crucial to remaining competitive in the semiconductor industry. There is a potential issue around IP inhibiting research into health and safety of chemicals central to production. Stricter regulation around management and disclosure of chemicals presents a potential conflict of interest between competitive advantage and employee health in the semiconductor industry. [36] [37] [1] [29] [39]
	BE23: Financial assets safeguard the pursuit of future-fitness		A typical company does not rely on the management or ownership of financial assets	The business model for the semiconductor industry does not rely on the ownership or management of financial assets.

Bibliography

[1] Sustainability Accounting Standards Board, "Semiconductors: Research Brief," 2014. [Online]. Available: https://www.sasb.org/wp-content/uploads/2019/08/SASB_Semiconductors_Brief.pdf. [Accessed 24 April 2020].

[2] S&P Global and MSCI, "Global Industry Classification Standard," 2018. [Online]. Available: https://www.spglobal.com/marketintelligence/en/documents/112727-gics-mapbook_2018_v3_letter_digitalspreads.pdf. [Accessed 10 June 2020].

[3] FTSE Russell, "Industry Classification Benchmark (Equity)," February 2019. [Online]. Available: https://research.ftserussell.com/products/downloads/ICB_Rules.pdf. [Accessed 10 June 2020].

[4] McKinsey & Company, "'Bringing energy efficiency to the fab'," 2013. [Online]. Available: https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/operations/pdfs/bringing_fabenergyefficiency.ashx. [Accessed 24 April 2020].

[5] Taiwan Semiconductor Manufacturing Company, "'Environmental Dimension'," 2016. [Online]. Available: https://www.tsmc.com/download/csr/2016_tsmc_csr/english/pdf/e_ch5.pdf. [Accessed 24 April 2020].

[6] Texas Instruments, "Water Usage in the Semiconductor Industry," 2009. [Online]. Available: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=2ahUKEwiywtuW5vnoAhUvREEAHZ0qBU

QQFjABegQIAxAB&url=https%3A%2F%2Fcommunity.asme.org%2Fcfs-file.ashx%2F__key%2Ftelligent-evolution-components-attachments%2F13-9031-00-00-00-0. [Accessed 24 April 2020].

[7] A. Baskaran, "Waste Not, Want Not - Water Use in the Semiconductor Industry," Sustainalytics, 2017. [Online]. Available: https://www.sustainalytics.com/esg-blog/world-water-day-water-use-semiconductor-industry/. [Accessed 24 April 2020].

[8] Modutek Corporation, "Wafer Cleaning Process," [Online]. Available: https://www.modutek.com/wet-processing-applications/wafer-cleaning-process/. [Accessed 24 April 2020].

[9] China Water Risk, "8 Things You Should Know About Semiconductors," 2013 July 11. [Online]. Available: http://www.chinawaterrisk.org/resources/analysis-reviews/8-things-you-should-know-about-water-and-semiconductors/. [Accessed 2020 April 2020].

[10] D. Heaven, "The humble mineral that transformed the world," BBC, [Online]. Available: http://www.bbc.com/future/bespoke/made-on-earth/how-the-chip-changed-everything/. [Accessed 24 April 2020].

[11] Foreign Policy, "Mining the Future, Analytics Special Report," 2019. [Online]. Available: https://docs.house.gov/meetings/II/II06/20190509/109423/HMTG-116-II06-20190509-SD002.pdf. [Accessed 24 April 2020].

[12] Semiconductor Industry Association, "Building America's Innovation Economy," [Online]. Available: https://www.semiconductors.org/semiconductors-101/industry-impact/. [Accessed 24 April 2020].

[13] IHS, "The Economic Benefits of Chlorine Chemistry in Semiconductors and Other Silicon-Based Products in the United States and Canada," July 2016. [Online]. Available: https://chlorine.americanchemistry.com/Chlorine-Benefits/Economic-Benefits/Silicon-based-Products.pdf. [Accessed 24 April 2020].

[14] European Semiconductor Industry Association, "Arsenic and Gallium Arsenide are fundamental to Semiconductor (Microchip) Manufacturing," August 2007. [Online]. Available:

https://rohs.exemptions.oeko.info/fileadmin/user_upload/HSE_RoHS_2008/Arsenic/ESIA_GaAs_Arsenic_technical_paper_Norway_Final_Aug_07.pdf. [Accessed 24 April 2020].

[15] United States Environmental Protection Agency, "Semiconductor Industry," [Online]. Available: https://www.epa.gov/f-gas-partnership-programs/semiconductor-industry. [Accessed 24 April 2020].

[16] C.-w. Shen, P. P. Tran and P. T. Minh Ly, "Chemical Waste Management in the US Semiconductor Industry," *Sustainability,* vol. 10, no. 1545, pp. 1-14, 2018.

[17] Semiconductor Industry Association , "Semiconductor Industry Statement to the UN Stockholm Convention POP-Review on Phase-Out of PFOS," 15 February 2018. [Online]. Available: https://www.semiconductors.org/wp-content/uploads/2018/06/Semiconductor-Industry-PFOS-Statement-to-POP-RC-Feb-15-2018.pdf. [Accessed 14 April 2020].

[18] Semiconductor Industry Association, "Submission of the Semiconductor Industry Association on Significant New Rules on Certain Chemical Substances," 15 November 2018. [Online]. Available: https://www.semiconductors.org/wp-content/uploads/2018/11/Comments-on-Significant-New-Use-Rules-on-Certain-Chemical-Substances-Nov-2018.pdf. [Accessed 24 April 2020].

[19] United Nations Enviornment Programme, "Basel Convention on the Control of Transboundary Movements of Hazardous Wastes," 1989. [Online]. Available: https://www.unenvironment.org/resources/report/basel-convention-control-transboundary-movements-hazardous-wastes. [Accessed 20 May 20].

[20] World Health Organisation, "Electronic Waste," [Online]. Available: https://www.who.int/ceh/risks/ewaste/en/. [Accessed 24 April 2020].

[21] R. Widmer, H. Oswald-Krapf, D. Sinha-Khetriwal, M. Schnellman and H. Boni, "Global perspectives on e-waste," *Environmental Impact Assessment Review,* vol. 25, no. 5, pp. 436-458, 2005.

[22] H. Ogata and N. Tanaka, "Reduction of Waste in Semiconductor Manufacturing Plant," *Oki Technical Review,* vol. 63, no. 160, pp. 41-44, 1998.

[23] D. Gilles, "Hazardous waste minimization in the semiconductor industry," April 1992. [Online]. Available: https://core.ac.uk/download/pdf/36716871.pdf. [Accessed 4 June 2020].

[24] Accenture, "Semiconductor Supply Chains: An Urgent Need for Change," [Online]. Available: https://www.accenture.com/us-en/_acnmedia/accenture/conversion-assets/dotcom/documents/global/pdf/technology_2/accenture-semiconductor-supply-chains-an-urgent-need-for-change.pdf. [Accessed 24 April 2020].

[25] B. J. G. Cristiana A Lucier, "Electronic Waste Recycling and Disposal: An Overview," 18 April 2019. [Online]. Available: https://www.intechopen.com/books/assessment-and-management-of-radioactive-and-electronic-wastes/electronic-waste-recycling-and-disposal-an-overview. [Accessed 24 April 2020].

[26] United Nations University, "Global E-Waste Volume Hits New Peak in 2014: UNU Report," 20 April 2015. [Online]. Available: https://unu.edu/news/news/ewaste-2014-unu-report.html. [Accessed 24 April 2020].

[27] T. Smith, D. Sonnenfeld and D. Pellow, Challenging the Chip: Labor Rights and Environmental Justice in the Global, Temple University Press, 2006.

[28] Semiconductor Industry Association, "Environment, Health and Safety: Addressing Chemicals of Concern," [Online]. Available: https://www.semiconductors.org/policies/environment-health-safety/. [Accessed 24 April 2020].

[29] S. Choi, S. Yoon, S. Kim, J. Kim, K. Ha and D. Park, "Comprehensive Evaluation of Hazardous Chemical Exposure Control System at a Semiconductor Manufacturing Company in South Korea," *International Journal of Environmental Responsibility to Public Health,* vol. 15, no. 6, pp. 1-14, 2018.

[30] National Research Council, "Semiconductors," in *Dispelling the Manufacturing Myth: American Factories Can Compete in the Global Marketplace*, National Academy of Sciences, 1992, pp. 45-60.

[31] Institute for Research on Labor and Employment, "Offshoring in the Semiconductor Industry: Historical Perspectives," May 2005. [Online]. Available: https://irle.berkeley.edu/files/2005/Offshoring-in-the-Semiconductor-Industry.pdf. [Accessed 24 April 2020].

[32] W. Lazonick, Sustainable Prosperity in the New Economy?, WE Upjohn Institute, 2009.

[33] A. Barbe, D. Kim and D. Riker, "Trade and Labor in the US Semiconductor Industry," *Journal of International Commerce and Economics,* 2018.

[34] JD Journal, "Former Broadcom Employee Claims Gender Discrimination," 2015 June 2015. [Online]. Available: https://www.jdjournal.com/2015/06/29/former-broadcom-employee-claims-gender-discrimination/. [Accessed 30 April 2020].

[35] SPTS, "Gender Pay Report 2019," 2019. [Online]. Available: https://www.spts.com/assets/media/spts-gender-pay-gap-report-2019.pdf. [Accessed 30 April 2020].

[36] Semiconductor Industry Association, "Environment, Health and Safety," [Online]. Available: https://www.semiconductors.org/policies/environment-health-safety/. [Accessed 24 April 2020].

[37] The CEO Water Mandate, "Guide to Responsible Business Engagement with Water Policy," 2010. [Online]. Available: https://ceowatermandate.org/files/Guide_Responsible_Business_Engagement_Water_Policy.pdf. [Accessed 24 April 2020].

[38] N-Able Group International, "Conflict Minerals in the Semiconductor Industry," 2012. [Online]. Available: https://www.gsaglobal.org/wp-content/uploads/2012/06/GSA-Conflict-Minerals-in-the-Semiconductor-Industry_hb.pdf. [Accessed 24 April 2020].

[39] Semiconductor Industry Association, "Intellectual Property," [Online]. Available: https://www.semiconductors.org/policies/intellectual-property/. [Accessed 24 April 2020].

[40] Carbon Tracker, "Wasted Capital and Stranded Assets," 2013. [Online]. Available: http://www.carbontracker.org/report/unburnable-carbon-wasted-capital-and-stranded-assets/. [Accessed 17 Aug 2017].

[41] Greenhouse Gas Protocol, "Scope 2 Guidance," 2015. [Online]. Available: http://www.ghgprotocol.org/scope_2_guidance. [Accessed 20 September 2017].

[42] E. Kolbert, Field Notes from a Catastrophe, Paperback ed., Bloomsbury USA, 2006, p. 225.

[43] NASA, "Evidence," 2017. [Online]. Available: https://climate.nasa.gov/evidence/. [Accessed August 2017].

[44] Semiconductor Technology, "Fundamentals: Doping," [Online]. Available: https://www.halbleiter.org/en/fundamentals/doping/. [Accessed 24 April 2020].

[45] F. Yoshida, The Economics of Waste and Pollution Management in Japan, New York: Springer, 2002.