McKinsey & Company

Sustainability in semiconductor - Path to net zero

GSA sustainability conference

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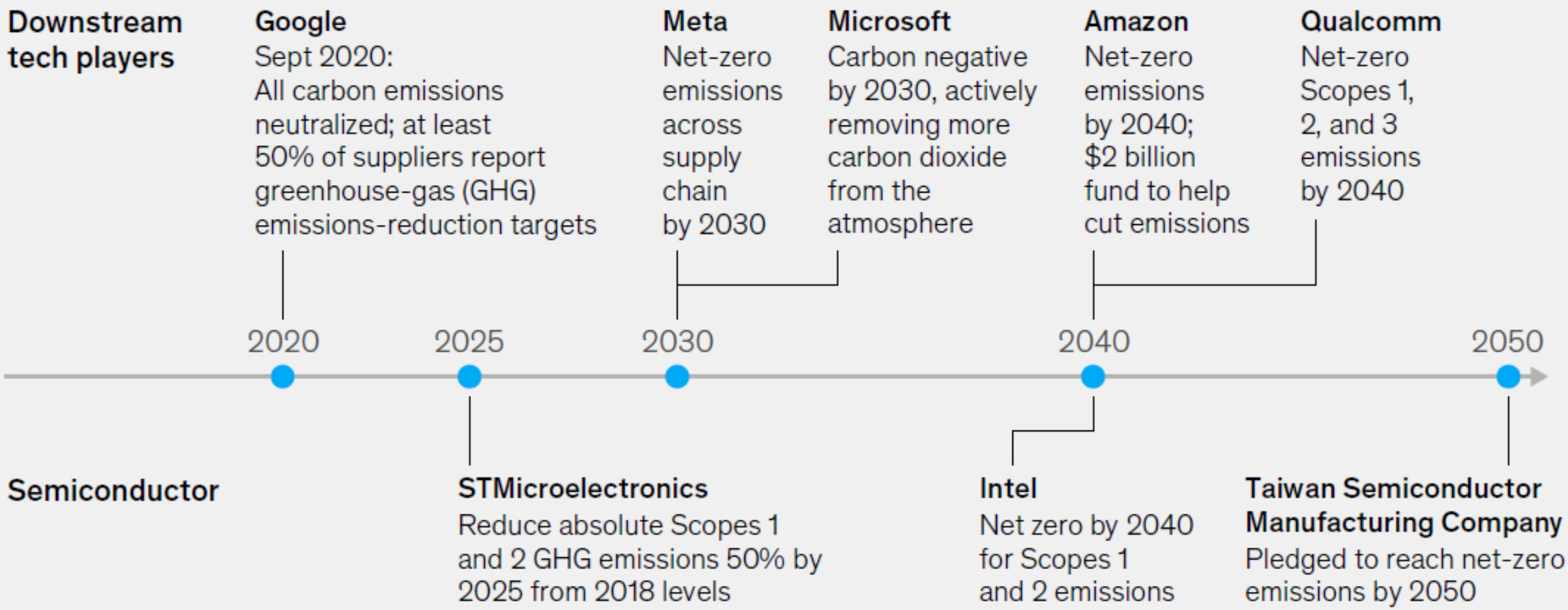
Key messages

1. **The momentum towards net zero is undeniable**
2. **Industry currently not on a path to net zero – players need to step up ambition level**
3. **Decarbonization actions semiconductor players can take now**

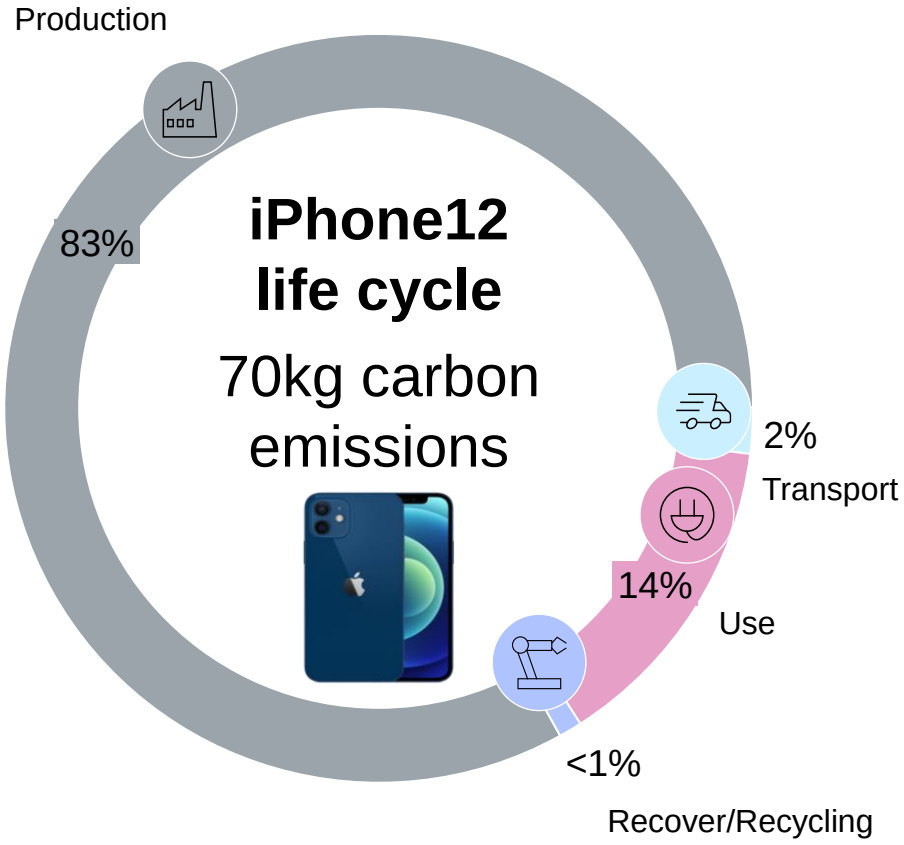
Many end customers have set ambitious targets to achieve net-zero emissions along their supply chains.

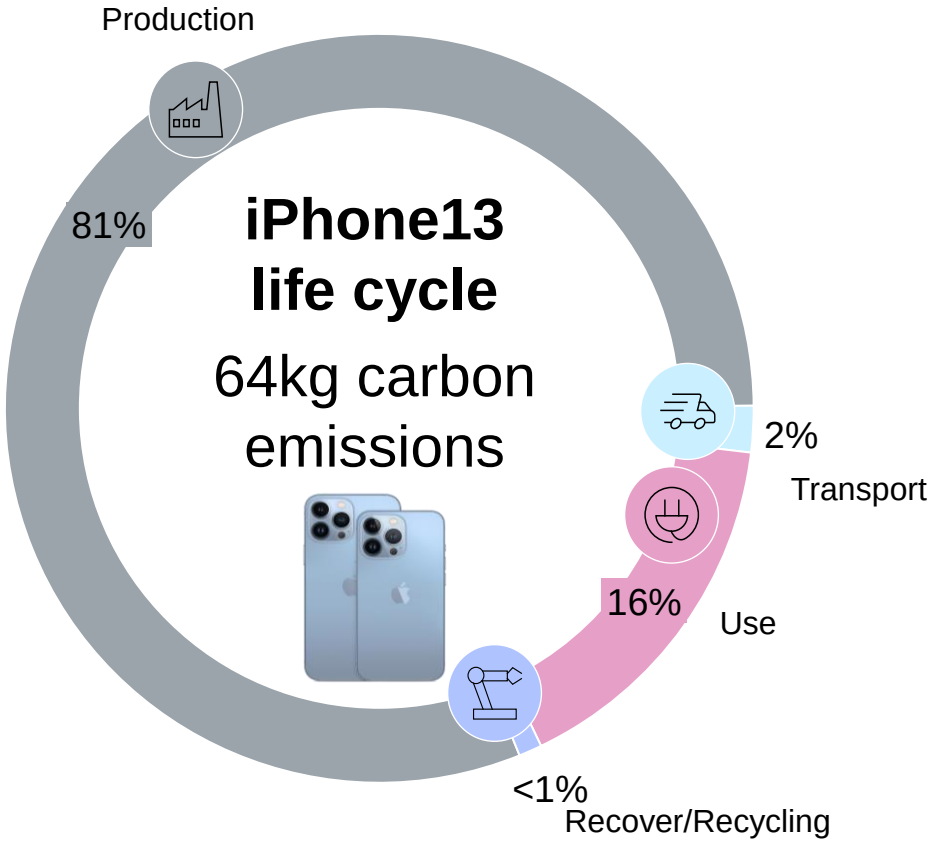
Example companies



Source: Corporate reports; corporate websites; press search; Science Based Targets initiative

Example: 80+% of iPhone carbon emission comes from production activity – and largely semiconductors





"IMEC: close to 75% of an iPhone or other mobile device's carbon dioxide emissions can be attributed to chip fabrication"

Production: Includes the extraction, production, and transportation of raw materials, as well as the **manufacture, transport, and assembly of all parts** and product packaging

Transport: Includes air and sea transportation of the finished product and its associated packaging from manufacturing site to regional distribution hubs and to end customers

Use: Apple assumes a three- or four-year period for power use by first owners based on the product type. Product use scenarios are based on historical customer use data for similar products

Recover/Recycling: Includes transportation from collection hubs to recycling centers and the energy used in mechanical separation and shredding of parts

Source: https://www.apple.com/environment/pdf/products/iphone/iPhone_12_PER_Oct2020.pdf, imec

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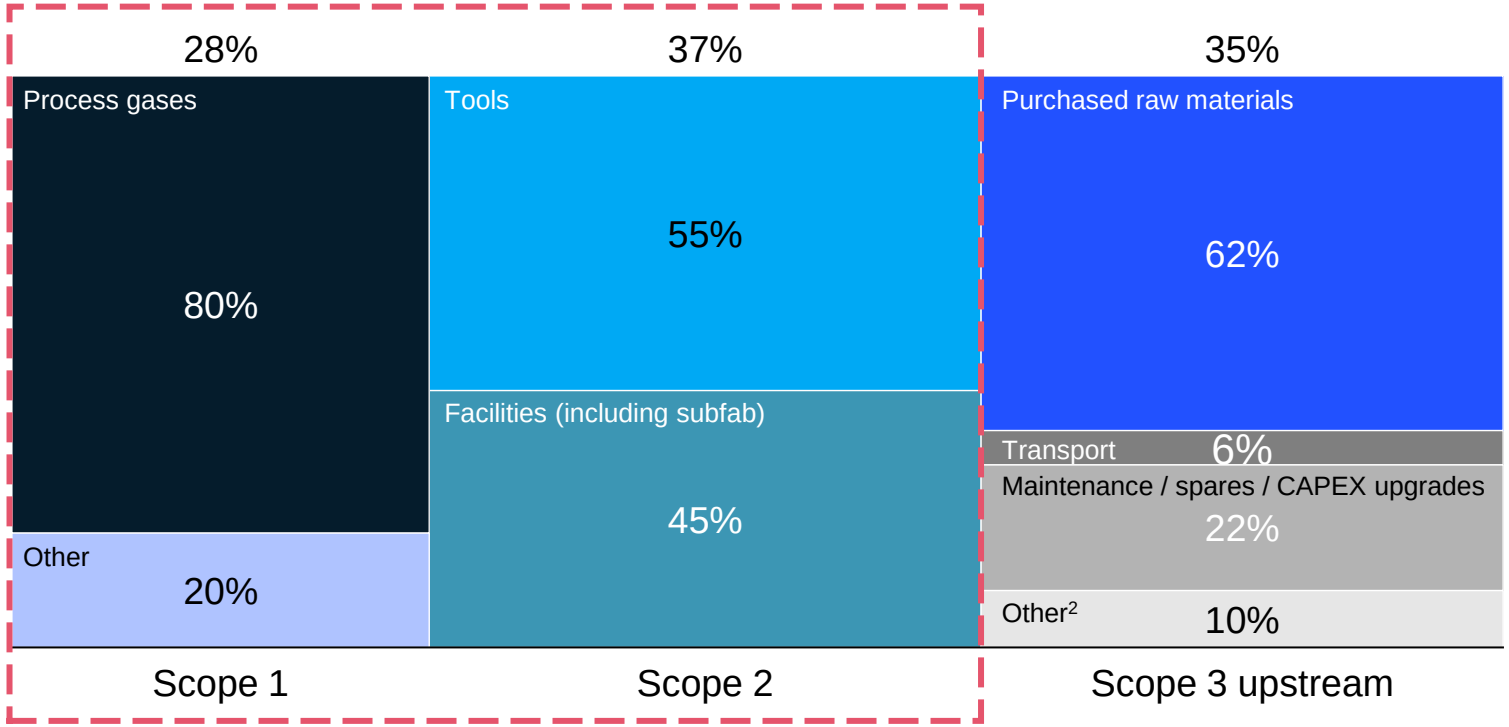
Distribution of Scope 1, 2, 3 emissions of an example fab

Focus of the remaining presentation

	Definition
Scope 1	Direct GHG emissions from sources that are owned or controlled by the company
Scope 2	Indirect GHG emissions from the generation of electricity, heat, or steam purchased by the company
Scope 3	GHG emissions from sources not owned or directly controlled by the company, but related to its supply chain activities

CO_2-equivalent emissions for typical fab profile[1], % of share



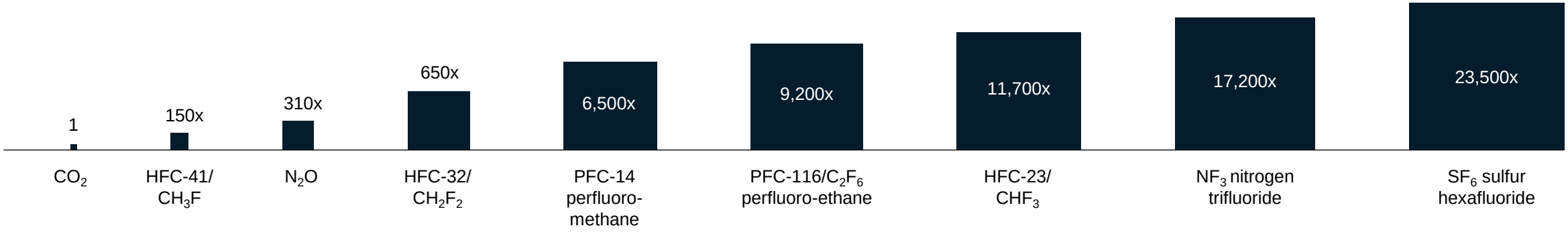
1. Emissions averaged across 300 mm semiconductor fabs with node sizes ranging 40-90 nm | 2. Including facilities (ultrapure water, waste management, etc.) and other business support (IT hardware and software, professional services, etc.)

Source: McKinsey FE Fab emissions database

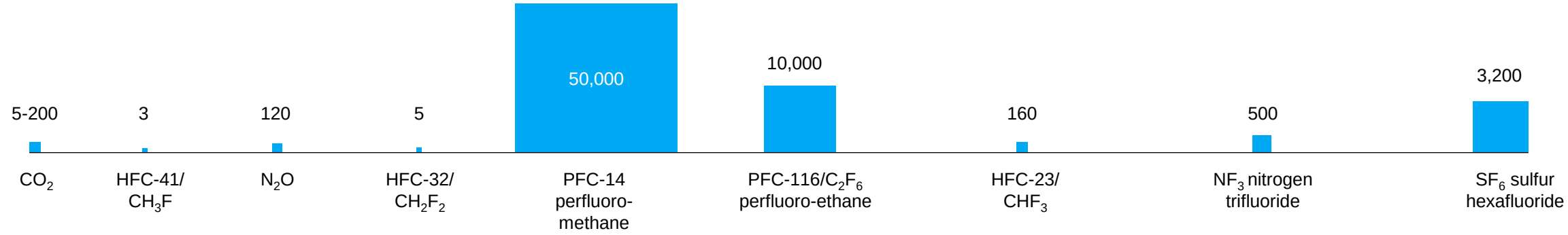
[Deep Dive] Manufacturing-process gases can have a significant impact on global warming

Environmental impact of key process gases

Global-warming potential, CO2-equivalent emissions,[1] multiples of CO_2[2]



Lifetime in atmosphere, years



1. Based on the UN Intergovernmental Panel on Climate Change's Second assessment report.
2. For all gases other than CO2, the numbers shown reflect their global-warming potential relative to CO_2.

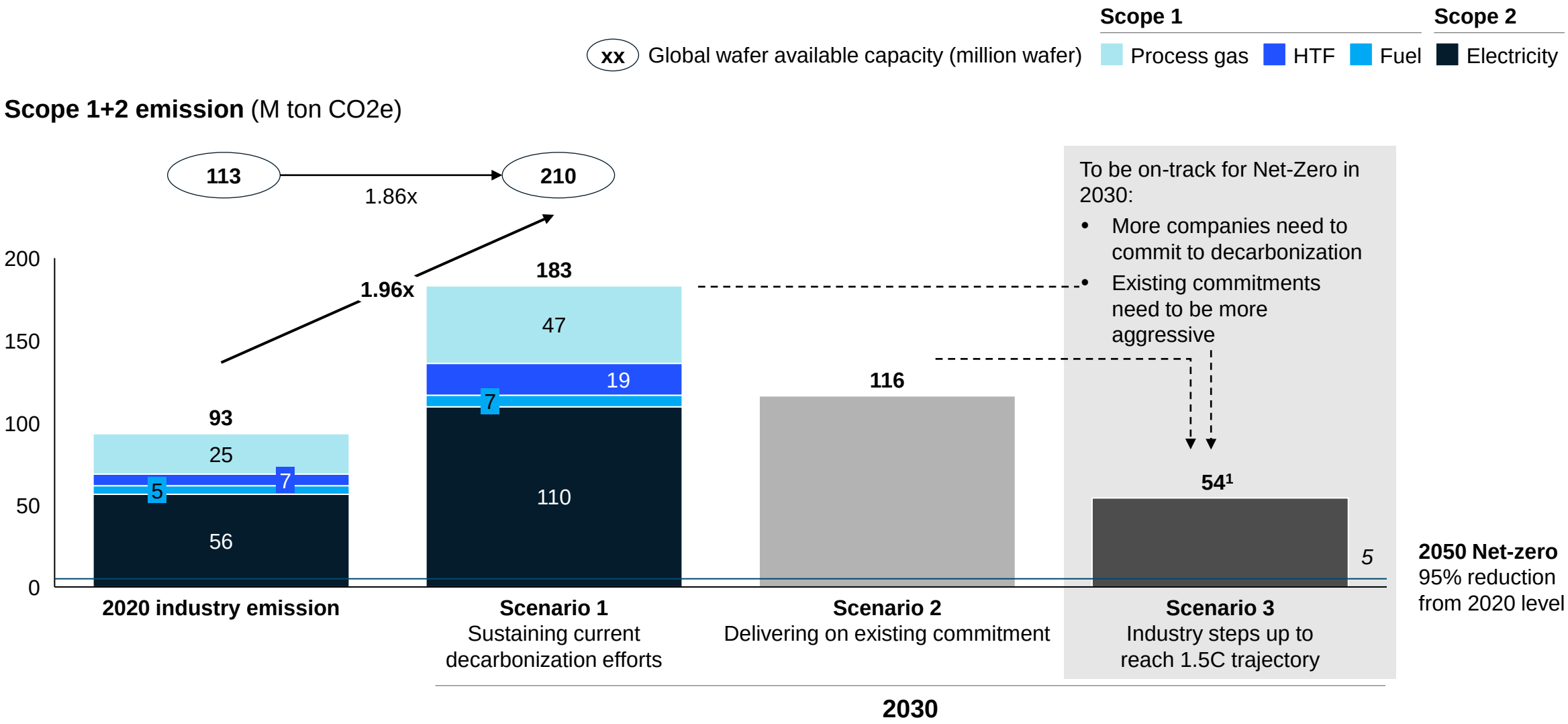
Source: : Enerdata; US Department of Energy

3 scenarios for semiconductor emissions development until 2030

Scenarios	Description
1 Sustaining current decarbonization effort	Assume 2020-level Scope 1 emission per wafer and electricity consumption per wafer per archetype: device type, tech node, geography, wafer size
2 Delivering on existing commitment	Assume companies achieve publicly announced Scope 1 and 2 emission targets[1]
3 Industry steps up to reach 1.5C trajectory by 2030	Industry-wide implementation of existing technologies to reduce Scope 1 emissions Significant sourcing of renewable energy to reduce Scope 2 emissions (1.8x higher than the share in the local grids in 2030)

1. Public announcement of 20 key players; assume base year 2020 if not specified

Despite current efforts, the semiconductor industry is likely falling short on 1.5-degree trajectory in 2030



1. Linear annual reduction of 4.2% between 2020 and 2030

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Decarbonization requires both immediate as well as strategic actions

Timeline	Description
A **Immediate (short term action)**	Existing levers that can be used now. This includes a mix of renewable sourcing (based on availability), energy savings measures as well as process gas abatement with existing technologies
B **Strategic (long term actions)**	Longer term (strategic) actions that require alignment with multiple stakeholders, technological advancements or innovation. Actions, however, need to be triggered now to generate desired impact on GHG emission reduction in the future

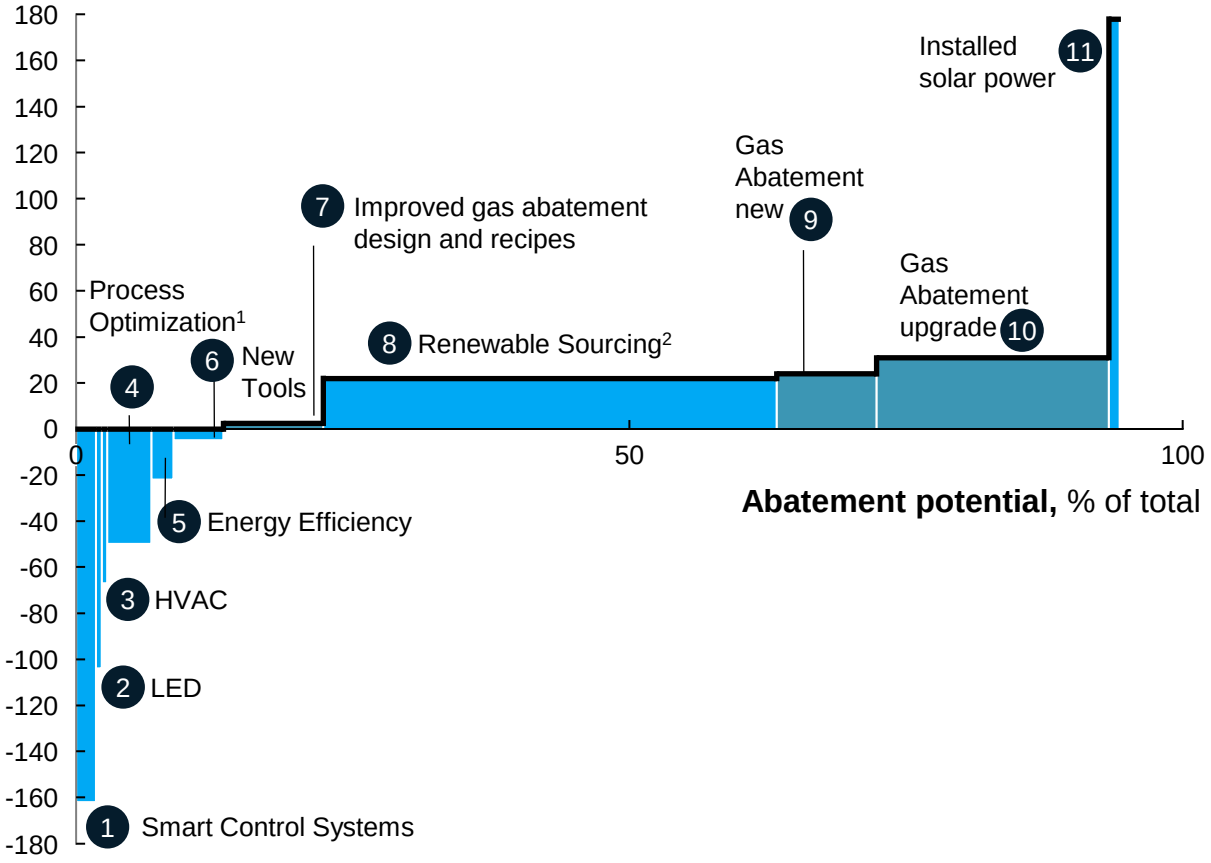
A. Analyze abatement cost curve to figure additional opportunities to reduce CO2 emission

McKinsey model for levers and business cases for emission reduction in semiconductor fabs[2]

Illustrative

Scope 1 Scope 2

Abatement cost[3], USD per tCO2e



Scope 1/2 abatement lever:

1. Smart regulation and coupling of facilities and tools (e.g., coupling tools and pumps to save energy during periods of low utilization; coupling furnaces/etch to abatement systems via RTD to anticipate low utilization)
2. Replacing all FAB lighting by LED light
3. Reduce power consumption of Heating, Ventilation, and Air Conditioning (reduce air flow in unused areas, heat recovery)
4. Optimizing tool process recipes to reduce power consumption (e.g., reduce process temperatures)
5. Improve Building Energy Management Systems
6. Upgrade/replace old tools by more energy efficient ones
7. Improve design of abatement systems and change recipes (e.g., alternative gases for etch recipes and chamber cleans)
8. Exclusive use of energy from 100% renewable sources
9. 10 Install gas abatement systems to cover 100% of process gas emissions (HF3, CF4, NF3) for new and existing tools
11. Installation of on-site solar power

1. Value reflects higher potential for process optimization in older, trailing node FABs | 2. Cost strongly depending on FAB location and availability of renewables
2. Not including potential emissions from on-site power generation
3. Represents average 200/300mm fab with trailing node size

Source: GHG emission repots from Semiconductor FABS in 2020 and 2021

A: Scope 1: 4 main levers to reduce emissions from process gases

Non-exhaustive

	Reduction lever	Description
1	**Process improvements**	Adjustment of process parameters like temperature, chamber pressure, and flow rate to increase utilization[1] of process gases, lowering the amount of emissions that exit the chamber
2	**Alternative chemistries**	Replacing current process gases with lower-GWP alternatives, or with alternative gases that are more completely utilized in the process chamber (e.g., replacement of C2F6 with NF3 in CVD chamber cleaning)
3	**Recycling**	Capture of unutilized process gases and process byproducts (e.g., via membrane separation, cryogenic recovery, adsorption, desorption), then refinement into pure process gases that can be used again
4	**Abatement**	Destruction or removal of process gas emissions through point of use or centralized abatement tools (e.g., thermal abatement)

1. Typical utilization of process gases in CVD, CVD chamber cleaning, and etching can range from 10 to 80%

Source: World Semiconductor Council, Illuzzi and Thewissen (2010), expert interviews

B: Scope 2 Renewable Energy common challenges & way forward

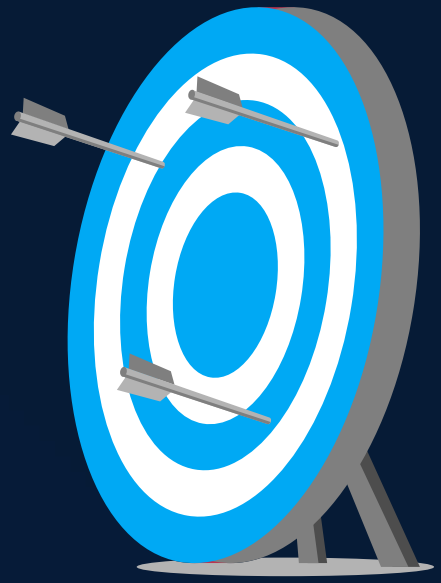
APAC specific example

Common challenges faced for RE development

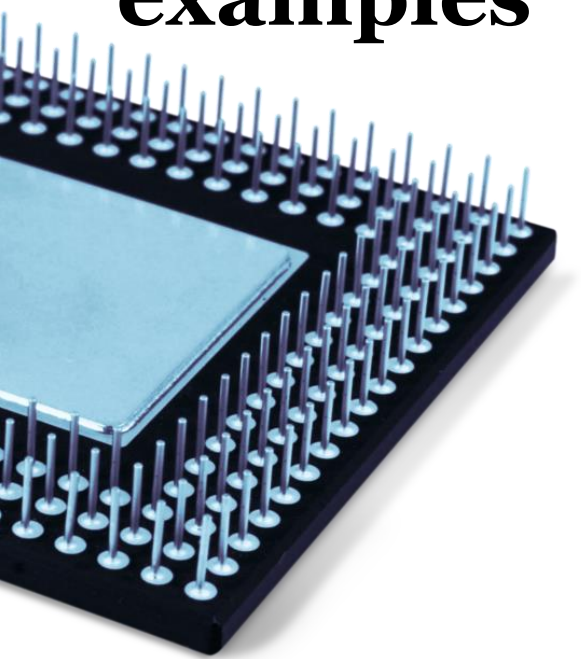
- Insufficient RE planning
- Regulatory complexity
- Public perception
- Financial difficulty

Cross industry collaboration required to solve challenges

- Work with public stakeholders to create awareness on renewable energy requirements and blocking points
- Joint investment of semiconductor players to create own renewable projects (e.g. solar)



B. Innovative technologies examples



Deep dive in the next page

	Known technology	Innovative technology
Process Gas	Alternative gases for NF3/CF4	Clean gas chemistry, chemical absorption, membrane filtration, PFC degradation with synthetic biology
Heat Transfer Fluid	HTF leakage reduction from chillers High GWP HTF replacement with non-fluorinated alternatives	Integrated tool and chiller design, centralized chiller system, smart leak-sensing technology, nano-particle based HTF
Fuel consumption	Alternative fuel, e.g., biomass, H2	
Electricity	RE sourcing (in grid and outside gride sourcing) Energy intensity reduction per wafer	Solar import, floating solar, etc.
Other		Direct air capture (DAC), nature-based removals (reforestation), bioenergy with carbon capture and storage

1. Public announcement of 20 key players; assume base year 2020 if not specified

B. Collaboration of players along the value chain required to develop process gas emission reduction solutions

Individual players facing uncertainty on actual industry needs and high initial cost

Semiconductor suppliers with lack of visibility on the actual needs of Fabs (e.g., alternative process gas required)

Semiconductor manufacturers facing high effort (cost, duration) for development and qualification of new solutions

… joint effort across value chain to unlock the current situation

Chemistry/gas suppliers (e.g., develop alternative materials)

Equipment players (e.g., develop and qualify new gases/chemicals)

Abatement suppliers (e.g., develop new abatement technologies)

Fab manufacturers (e.g., align technology development and qualification roadmap)

B. Scope 3 emissions need to be addressed in close supplier collaboration

Scope 3 upstream activity

- Purchased goods and services
- Capital goods, upstream leased assets
- Transportation
- Business travel/ Commuting

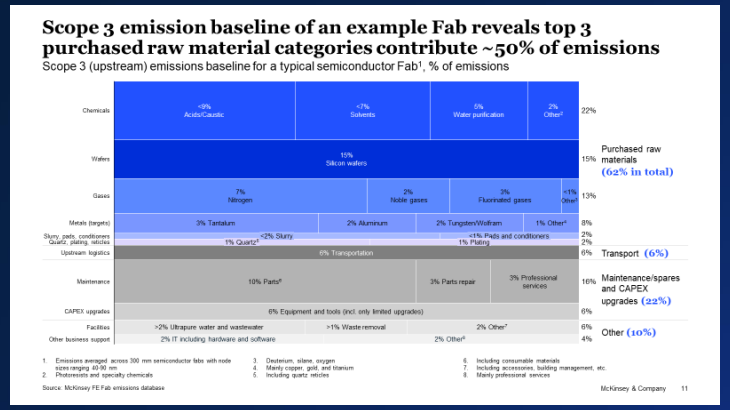
Scope 3 downstream

- Distribution
- Use of sold products
- Processing of sold products
- Investments, leased assets
- End of life treatment

~35% **of total emissions of a typical fab are Scope 3 upstream**

Holistic sustainability framework needed to accelerate supplier collaboration and build capabilities to achieve Supplier ESG goals

1. Create understanding of emission baseline and decarbonization levers for suppliers
2. For supplier, define decarbonization targets & strategies and prioritize involvement
3. Drive decarbonization strategy in existing supplier engagement. In addition, build on industrial enablers and overarching potentials



https://www.mckinsey.com/industries/semiconductors/our-insights/beyond-the-fab-decarbonizing-scope-3-upstream-emissions

Source: GHG emission repots from Semiconductor FABS in 2020 and 2021

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