SEMI's S23 Standard – Save Energy, Save Money, Save the Planet

CHRIS JONES, Edwards Vacuum

The greatest potential for immediate reductions in GHG emissions in semiconductor manufacturing lies in reducing the energy used by manufacturing equipment.

THAT THE EMISSION OF GREENHOUSE gases (GHG) is warming the planet is no longer in dispute, and industrial emissions account for about a third of the total. Though direct emissions of GHG from semiconductor manufacturing are small relative to some industries, our industry is a prodigious consumer of energy. The energy invested in a completed device can be 5.4 MJ (1.5 kWh) or more per square centimeter. Most of that energy is still generated by burning fossil fuels, the primary culprit in GHG emissions worldwide. Ultimately, the industrial sector, indeed all sectors, must transition to renewable energy sources wherever possible. But, if we want to minimize the worst effects of global warming, we must begin today to reduce energy consumption and improve energy efficiency. Fortunately, this need not be a purely altruistic effort – energy is expensive and reductions in energy consumption go directly to the bottom line, reducing costs and increasing profitability.

The SEMI™ S23 guidelines describe a methodology for semiconductor equipment manufacturers and the device manufacturers who use their products to evaluate the energy used by their equipment and their manufacturing processes. Establishing a standard framework for determining energy consumption is essential to reducing it. SEMI™ S23 allows device manufacturers to compare systems and consider energy efficiency in their equipment selection process, thus incentivizing equipment manufacturers to improve the efficiency of their products. And it provides an objective basis for equipment manufacturers to evaluate the success of their efforts to reduce energy consumption and promote that progress in the marketplace.

Measuring and reporting GHG

The Greenhouse Gas Protocol (GHGP) establishes comprehensive global standards for measuring and reporting greenhouse gas emissions from private and public sector operations (**FIGURE 1**). For convenience, emissions are reported as carbon dioxide equivalent (CO_2e). The CO_2e for a greenhouse gas (GHG) is the product of that gas's global warming potential (GWP) and its mass in, for example, metric tons. The GWP100 is

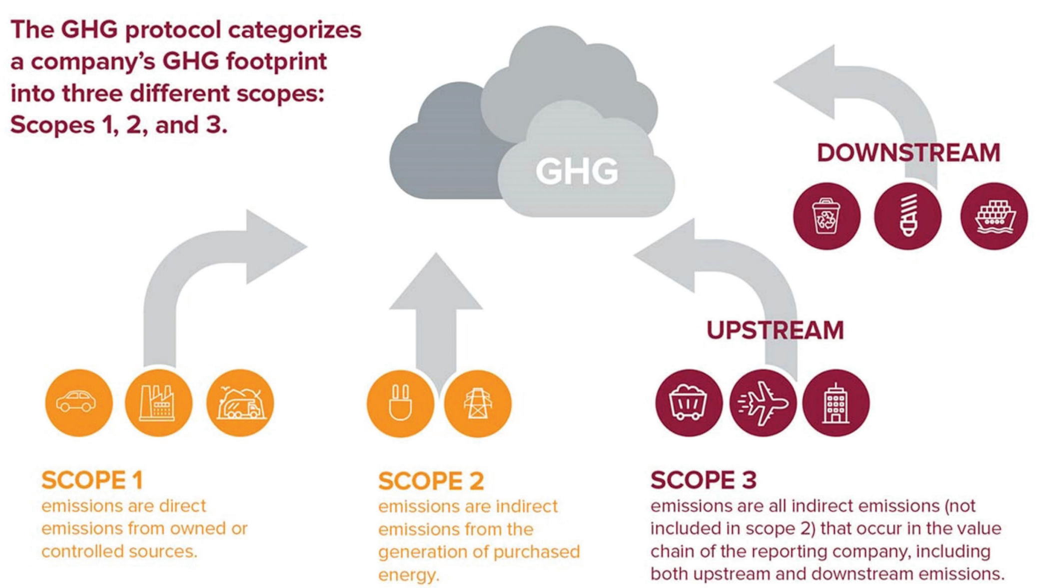

Figure 1. The GHG protocol categorizes a company's GHG footprint into three different scopes.

Figure 2. To make comparisons between SMEs easy, S23 establishes a standard time distribution over process, idle/rest/sleep, and down operating modes.

the integrated infra-red radiation absorbed over 100 years relative to carbon dioxide. CO_2e can be used to measure the global warming impact of many gases, including those emitted during the generation of electrical power by fossil fuels, where it can be calculated from the amount of carbon dioxide, methane, and nitrous oxide emitted per unit of energy.

The GHGP categorizes emissions into three scopes:

- Scope 1 emissions are direct emissions from owned or controlled sources.
- Scope 2 emissions are indirect emissions from the generation of purchased power
- Scope 3 emissions are all indirect emissions (not included in scope 2) that occur both upstream (CO_2e of incoming products and services) and downstream (CO_2e of outgoing products and services) in the value chain of the reporting company.

The power consumed by a vacuum pump in use at a fab will contribute to the scope 2 emissions for the fab. A GHG abatement device will mainly reduce the scope 1 emissions of a fab while consuming power, thereby adding a small amount of scope 2 emissions. Offsite provision of utilities such as nitrogen, water, and wastewater would be regarded as scope 3 upstream. Various types of equipment and facilities in a fab are sources of direct (scope 1) and indirect (scope 2) emissions or both. Emissions from gas-fired boilers and diesel emergency generators are almost entirely scope 1 from the fuel they burn. A wet scrubber, the heating, ventilation, air conditioning (HVAC) system, the ultrapure water production system, and the provision of process cooling water generate primarily scope 2 emissions from the electrical power they consume. An ammonia oxidation system and an MBR denitrification plant generate both scope 1 and scope 2 emissions.

Science-based targets and the science-based target initiative (SBTi) are terms often heard in discussions on climate change and GHG. Science-based targets are emission targets that align with what the latest climate science deems necessary to meet the goals of the Paris Agreement – limiting global warming to well below 2°C above pre-industrial levels and pursuing efforts to limit warming to 1.5°C. The initiative is an organization that encourages private sector companies to publicly commit to achieving science-based targets and guides them in establishing those targets.

Two other terms frequently heard are carbon-neutral and net-zero. Both refer to efforts to become aware of and reduce, offset, or remove GHG emissions. Carbon-neutral has a narrower emphasis on carbon only, while net-zero applies more broadly to all GHG.

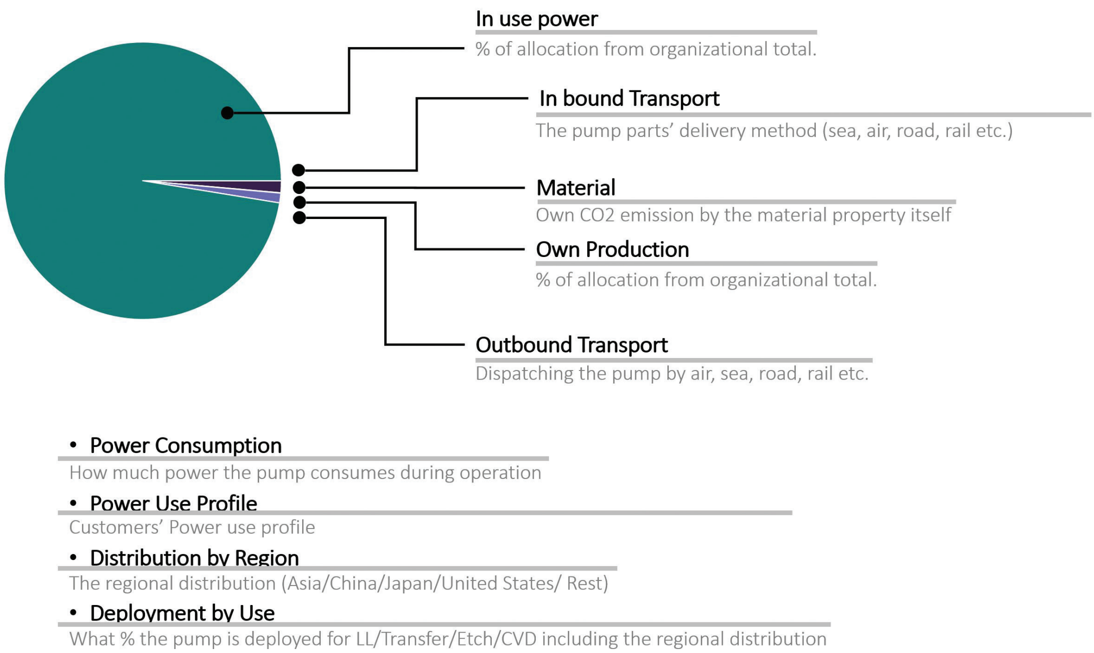

Figure 3. Relative Edwards emissions calculation, scopes 1, 2, and 3, for a vacuum pump manufactured and operated in Korea. More than 97% of GHG emissions come from generating the power used to operate the pump.

SEMI™ S23

Energy use is a major contributor to GHG emissions. Importantly, it is the contribution with the greatest potential for immediate reductions from interventions that do not require significant developments in technology or infrastructure. SEMI™'s S23 guidelines define procedures for calculating the energy use of semiconductor manufacturing equipment (SME). Though it acknowledges that energy consumption varies over the lifetime of the equipment, which includes raw materials procurement, manufacturing, packaging, shipment, use, decommissioning, and disposal, S23 focuses explicitly on the use phase that typically constitutes the preponderance of the life cycle. It recognizes that all SMEs consume energy, utilities, and materials. Its fundamental methodology is the conversion of material and utility consumption into a common unit of energy equivalence that reflects their energy content.

The standard also recognizes that most SMEs operate in a range of modes:

- process mode – the system is performing its intended function on target materials
- idle mode – the system is in a reduced energy ready mode but can return to process mode within 15 seconds
- rest mode – the system enters this mode automatically; the energy use rate is less than idle mode
- sleep mode – the system enters this mode in response to an external command, there will be a delay in returning to idle mode, but it is otherwise ready for processing,
- sleep level – one or more functional configurations in sleep mode; different sleep levels provide different energy use rates

To simplify comparisons, S23 defines a standard distribution of time spent in the various modes – 70% (6,132 hours/year) in process mode, 25% (2,190 hours/year) in idle, rest, or sleep modes, and 5% (438 hours / year) downtime (**FIGURE 2**). It allows some flexibility in reporting time in idle, rest, and sleep modes but requires that the distribution be specified. Standardizing the distribution facilitates comparisons among systems and helps to identify conspicuously large energy users.

S23 uses energy conversion factors (ECF) to establish an energy equivalence for utilities and materials. ECFs specify energy used in kilojoules (1kWh= 3600 kJ) per unit used, often per cubic meter. The energy actually consumed will vary for different locations, and the factors suggested in the standard are chosen to be broadly representative. As long as they are reasonable, they can be used to identify utilities and materials that have a high environmental impact. They also provide a convenient means to compare different SMEs.

S23 suggests ECF for many typical semiconductor manufacturing materials and utilities. Manufacturers can develop ECF for utilities "not declared" in the standard. They are also free to use alternatives to declared values but must justify and document the choice. One example of a utility not declared is water, both supply and waste. This may be because the energy intensity of locally supplied water and wastewater treatment varies widely.

Once power, utility, and material consumption have been tabulated for a piece of SME, it is a relatively simple matter to construct a calculator (spreadsheet) that multiplies each by the appropriate ECF and sums the results for a single number that is a relatively reliable and comprehensive indicator of energy consumption. It is possible to add different SME and facilities results to derive a number for any process or a whole fab.

The standard also includes numerous recommendations for energy-saving changes, such as using the highest available electrical supply voltage, warmer process cooling water and higher temperature differentials in cooling towers, lower utility gas pressures, lower chemical purity, substituting compressed dry air for nitrogen, and smart exhaust systems that run only as needed. It also strongly encourages the development of a roadmap for energy savings. The most recent version of the standard, released in October 2021, added substantial support for localized calculations of cooling water ECFs.

S23 energy to CO_2e emissions

Through its parent company Atlas Copco, Edwards is committed to the SBTi. Science-based targets go beyond the energy-based analysis of S23 with a comprehensive evaluation of GHG emissions. Specifically, SBTi reporting seeks to determine the carbon footprint (total annual GHG emissions in metric tons of CO_2e) of a company's operations, scopes 1, 2, and 3, including lifetime GHG in use emissions for all products shipped in the reporting year. Where S23 looks only at the annual energy consumption derived from materials, utilities, and energy of SMEs in use, SBTi considers all sources of GHG in the company's internal operations and throughout the supply chain as directed by the GHGP.

Of course, energy use is a substantial, if not dominant, part of the SBT analysis. Using Edwards products as examples:

- for vacuum pumps, the carbon footprint attributed to power consumption would be the annual power consumption (kWh) X pump lifetime (years) X number of pumps sold in the reporting year X emission factor for the electricity (kg CO_2e/kWh)
- for systems that burn fuel (abatement), in addition to the power consumption, add the annual fuel consumption (kWh equivalent) X system lifetime (years) X number of systems sold per year X emission factor for the fuel (kg CO_2e/kWh)
- for pumps that use refrigerant (cryopumps), in addition to the power consumption, add refrigerant leakage per year (kg) X pump lifetime (years) X number of pumps sold per year X global warming potential of refrigerant (kg CO_2e / kg refrigerant)

Where S23 is agnostic regarding the energy source, SBTi reporting accounts for the large differences in carbon emissions of various power generating technologies, from near zero for renewable sources to very high for oil- or coal-fired technologies. Companies should report both location-based and market-based emissions. Location-based accounting reflects the power generating mix of the local grid. Market-based accounting recognizes power purchased through renewable energy certificates in the US (renewable energy guarantees of origin in the EU), which allow a company to buy energy from a renewable source even though that source may not be connected to the local grid. This mechanism allows companies to lower their carbon footprint while supporting remotely located renewable suppliers, usually at a higher price point. Calculating the carbon footprint for thousands of products located around the world and accounting for the carbon intensities of local grids (which may change from year to year) can be a challenging task.

Figure 3 shows the result of a relative GHG emission calculation for a vacuum pump. Over its lifetime, more than 97% of GHG emissions result from energy used to operate the pump. The potential benefits from reducing power usage dwarf any savings available in other categories.

Conclusion

The ultimate solution to global warming is to transition from fossil fuels to renewable sources for power generation. However, the greatest potential for immediate reductions in GHG emissions in semiconductor manufacturing lies in reducing the energy used by manufacturing equipment. SEMI's S23 guidelines provide a framework for calculating energy consumption, including energy equivalents for materials and utilities. Consistent calculations of energy use will bring market forces to bear on the problem, incentivizing both customers and suppliers to use less energy.