SEMI S23-0311
GUIDE FOR CONSERVATION OF ENERGY, UTILITIES AND MATERIALS USED BY SEMICONDUCTOR MANUFACTURING EQUIPMENT

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1 Purpose

1.1 This guide addresses concepts related to energy, utilities and materials conservation on semiconductor manufacturing equipment.

1.2 This guide addresses measurements related to energy, utilities and materials usage on semiconductor manufacturing equipment.

1.3 This guide also addresses continuous improvement planning for energy, utilities and materials usage on semiconductor manufacturing equipment in order to promote energy, utilities and materials conservation.

1.4 This guide is a series of options and instructions intended to increase awareness of the reader to available techniques in the area of energy, utilities and materials conservation. A particular course of action is suggested for utilities and materials use measurement and conversion of use measurements into equivalent energy.

NOTE 1: Because this SEMI standard is a Guide, all criteria using "should" may be considered optional.

2 Scope

2.1 This guide is intended to be a tool that can be used to analyze energy, utilities and materials conservation on semiconductor manufacturing equipment.

2.2 This guide describes methods for reporting energy, utilities and material use rate, and the consumption reduction in semiconductor manufacturing equipment (SME).

2.3 This guide also suggests use of energy equivalent values in order to facilitate quantification of overall energy consumption and conservation related to SME as well as easy planning of energy conservation.

2.4 This guide focuses only on the use stage of equipment life cycle and addresses a limited set of utilities and materials to be considered.

2.5 Additionally, this guide describes setting targets for, verifying and improving utilities and materials use rate and energy conservation.

2.6 This guide contains the following sections:

- Purpose
- Scope
- Limitations-
- Referenced Standards and Documents
- Terminology
- General Concepts
- Life Cycle Assessment (LCA) of Energy Usage
- Baseline Process(es)
- Utilities and Materials Use rate Measurement

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- Conversion Factors for Equivalent Energy
- Target Setting and Improvement
- Monitoring and Reporting
- Related Documents

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This guide is not intended to supersede the applicable codes and regulations of the region where the equipment is used.

3.2 This guide is not intended to provide definite targets for utilities and materials usage or energy conservation.

3.3 The information suggested in this guide may be provided by the equipment supplier to the user if that is the agreement between those parties.

4 Referenced Standards and Documents

4.1 *SEMI Standards*

SEMI E6 — Guide for Semiconductor Equipment Installation Documentation

SEMI S2 — Environment, Health and Safety Guideline for Semiconductor Manufacturing Equipment

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *DIW* — de-ionized water

5.1.2 *ISMT* — International SEMATECH

5.1.3 *LCA* — life cycle assessment

5.1.4 *UPW* — ultra pure water

5.2 *Definitions*

5.2.1 Definitions defined in SEMI S2 and SEMI E6 are incorporated herein by reference unless a term is otherwise specified below.

5.2.2 *baseline* — for the purposes of this document, "baseline" refers to operating conditions, including process chemistry, for which the equipment was designed and manufactured (refer to SEMI S2).

5.2.3 *energy impact* — positive and negative effects on the amount of energy required to produce or provide an item or material, or to execute a process or step.

5.2.4 *environmental impact* — positive and negative effects to the earth environment from a variety of sources including people and their activities, and the operation of semiconductor manufacturing equipment and facilities

5.2.5 *exhaust* — airflow moving from semiconductor manufacturing equipment to a location outside of a fab or laboratory area.

5.2.6 *heat load* — the sum of all heat energy transferred by conduction, convection, and radiation outside the envelop of the equipment.

5.2.7 *idle mode* — the condition where the equipment is energized and readied for process mode (all systems ready and temperatures controlled) but is not actually performing any active function such as materials movement or processing (refer to SEMI E6).

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5.2.8 *life cycle assessment (LCA)* — a methodology used to evaluate the environmental impact of semiconductor manufacturing equipment throughout its life cycle, including raw material procurement, manufacturing, transportation, use and disposal.

5.2.9 *process mode* — the condition where the equipment is energized and performing its intended function on target materials (such as implanting wafers, pumping gas, or inspecting photo-masks).

5.2.10 *roadmap* — a sequence for the incremental introduction or improvement of technology over time with month or year milestones and supporting information.

5.2.11 *sleep mode* — the condition where the equipment is energized but it is using less energy than in idle mode. The sleep mode is primarily differentiated from idle mode in that it is initiated by a specific single command signal provided to the equipment, either from an equipment actuator, an equipment electronic interface, or a message received through factory control software (e.g., SECS). Other than the possible initiation the sleep mode by an equipment actuator, entry into the sleep mode does not require manual actions. The sleep mode can be characterized by a few specific metrics described § 11.

6 General Concepts

6.1 Energy is used to produce the various utilities and materials that go into the manufacturing, packaging, shipping, installing, use, decommissioning and disposing of a piece of semiconductor manufacturing equipment. Reducing the energy used in any of these life cycles will improve the environmental impact of the semiconductor manufacturing equipment.

NOTE 2: This guide focuses on only the use of the equipment life cycle stage.

6.2 Given the state of the industry with regard to energy conservation information and measurements, the use stage of the equipment life cycle appears to be the most effective stage to analyze for energy conservation opportunities. The energy used in the use stage is the best derived from the use rate of utilities and materials provided for the stage.

6.3 Various methods have been proposed for converting the use rate of specific utilities and materials into equivalent energy values. The energy used to produce any particular utility or material varies from location to location and from time to time. While any single set of energy conversion factors cannot be valid world wide, some parties find value in the conversion exercise, particularly in identifying a utility or material that has a greater energy impact than others.

6.4 The equipment suppliers should investigate the utilities and materials use rate of the equipment and identify and implement design or process changes that lessen the energy impact of the equipment. The expense of implementing these changes can be balanced against the potential energy impact improvement when developing an energy conservation plan.

NOTE 3: Changes in use rate can also affect the users cost of ownership for the equipment. This can also be considered in the cost-benefit analysis.

6.5 An equipment user can consider supplier-reported utilities and materials use rates, energy equivalent values, and planned improvements when making the purchasing decisions.

6.6 The use rate of utilities and materials for a piece of equipment depends on the particular control parameters used to achieve the desired effect on a wafer (i.e., it depends on the process recipe) as well as the particular hardware used in the equipment and the conditions under which the measurements are taken. It is important to record this and other particular information when use rate measurements are conducted.

6.7 Based on the above considerations, the equipment supplier should set targets for energy, utilities and materials conservation, and consider continuous improvement plans for energy, utilities and materials usage on semiconductor manufacturing equipment.

NOTE 4: The supplier may apply the concepts of this guide to the equipment model or models of their choice.

6.8 The characterization and quantification of energy, utilities and materials consumption should be based on a supplier baseline process.

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7 Life Cycle Assessment (LCA) of Energy Usage

7.1 Analyzing energy use during various stages in the life cycle of semiconductor manufacturing equipment can yield valuable information for promoting energy conservation.

7.2 There are many ways the equipment life cycle can be conceptually divided into different stages.

7.3 This guide focuses only on the use (or use) stage of equipment life cycle.

7.4 Other life cycle stages may include:

- raw materials procurement,
- manufacturing,
- packaging,
- transportation (shipment),
- decommissioning, and
- disposal.

7.5 The use stage can be further divided into process, idle, maintenance and service modes. This guide only addresses the process and idle modes.

7.6 Using the model methods of this guide, the equipment supplier may also analyze maintenance and service.

NOTE 5: The SEAJ standard "SEAJ-E-003E — Guideline for conducting an LCA of Semiconductor Manufacturing Equipment – Energy Saving Perspective" may be referenced for an example of a more complete life cycle analysis.

8 Baseline Process(es)

8.1 The measurement, conservation monitoring, improvement, and reporting methods should be based on one or several supplier baseline process(es). The equipment supplier is encouraged to consider baseline process(es) which also meet the needs of the users.

8.2 Considering the range of use a supplier intends for the equipment, several baseline processes may be used when utilities and materials use rate measurements are conducted.

8.3 The use rate and energy impact of any particular baseline process recipe can vary depending on the equipment optional hardware that is installed, whether the optional hardware is participating in the process or not (it may consume utilities and materials even when idle). Therefore, when baseline process(es) are designed, the particular hardware configuration can be a significant parameter and should be considered.

NOTE 6: In the course of analysis, the supplier may discover that for two or more recipes which have the same desired effect, one recipe is more energy efficient than another.

NOTE 7: For users to make effective cost of ownership or energy impact comparisons between equipment, it is useful to have supplier data derived from the same baseline process (i.e., achieving the same desired effect on a substrate or other material). It is recommended that suppliers discuss this with the users and gather data that will facilitate effective comparisons.

9 Utilities and Materials Use Rate Measurement

9.1 A first step in determining the energy impact of a particular piece of equipment during any life cycle stage is to measure the use rate of utilities and materials in that stage.

9.2 Table 1 contains the recommended minimum set of utility and material parameters to measure while the equipment is in its various modes (e.g., process, idle).

NOTE 8: Related Information 1 contains additional use rate information that may be useful.

NOTE 9: Many different chemicals may be used in the process mode. Process chemicals are not included in Table 1 because equivalent energy conversion factors are generally not available for them. The equipment supplier may, however, wish to measure and record their use rate anyway.

9.3 The units used in Table 1 are those used in SEMI E6 "Guide for Semiconductor Equipment Installation Documentation", which contains criteria for documenting all utility requirements for every connection point on a

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9.4 For the process mode measurements, the average value of each parameter over the course of several processing cycles should be recorded as well as the length of the cycle.

9.5 For the idle mode measurements, the average value of each parameter over a period of idling should be recorded as well as the length of the period.

NOTE 10: See Related Information 1 for additional recommendations.

Table 1 Recommended Minimum Set of Utility and Material Parameters

Utility or Material	*Basic Use Rate Metrics and Units*	*Related SEMI E6 Sections (0303 Version)*
Exhaust	Pressure (Pa) Flow (m^3/hr.) Inlet Temp (°C) Outlet Temp (°C)	§ 18
Vacuum	Pressure (Pa) Flow (m^3/hr.)	§ 17
Clean Dry Air High Pressure Clean Dry Air, and Nitrogen (N2)	Inlet Pressure (Pa) Flow (m^3/hr.) Inlet Temp (°C)	§ 16
Refrigerated Cooling Water or Tower-cooled Cooling Water	Inlet Pressure (kPa) Outlet Pressure (kPa) Flow (m^3/hr.) Inlet Temp (°C) Outlet Temp (°C)	§ 13
Ultra Pure Water (UPW) or De-Ionized Water	Purity Requirements Inlet Temp (°C) Flow (m^3/hr.)	§ 13
Electricity (Electrical Energy = Electrical Power Measurement Period)	Real Power[#1] (Watts) For single phase circuits, Real Power[#1] = $V_{RMS} \times I_{RMS} \times PF$ For three phase circuits, Real Power[#1] = $V_{RMS} \times I_{RMS} \times PF \times 1.73$ Alternately, the average Real Power as indicated by a power meter may be used.	§ 12

#1 "Real Power" is sometimes known as "True Power" or "Effective Power."

10 Conversion Factors for Equivalent Energy

10.1 Conversion factors can be used to convert the utility and material use rate data gathered for a particular baseline process recipe into equivalent energy consumption data.

10.2 The actual electrical energy required to provide a particular utility or material will, of course, vary among the locations where the equipment will be installed. Therefore, the output of the conversion calculation will not be correct for any particular location. However, if a reasonable set of conversion factors are used, the output of the conversion can be used to identify those utilities and materials which, generally speaking, have a higher environmental impact.

NOTE 11: The use of a standard set of conversion factors also allows comparison of results from tests of various equipment.

10.3 It is recommended that equivalent energy be reported on a per year basis.

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10.4 In Table 1, the use rate metrics have a per-hour basis. Therefore, the number of hours the equipment spends in the process and idle modes must be estimated to calculate per-year data.

10.5 Table 2 contains a recommended set of conversion factors. Comparison of different equipment based on the use of the conversion factors may be useful, even though the total calculated energy is correct only for the hypothetical facility for which the conversion factors are correct.

NOTE 12: Related Information 1 contains additional conversion factor information that may be useful.

10.6 The output units of all conversions are estimated *kJ* [*kWh* / (3.6 × 10^3)] (kJ: kilojoule, kWh: kilowatt hours). This can be understood as the energy impact of the particular utility or material used.

NOTE 13: See Related Information 1 for example calculations.

10.7 The equipment supplier may also use an alternate set of conversion factors.

NOTE 14: If alternate conversion factors are used, it is recommended that the factors be documented in the report of the results.

10.8 A conversion factor is better if it accurately represents the actual electrical energy required to create and distribute a particular utility or material at the equipment's end use location.

10.9 Determining reasonable energy conversion factors for most process chemicals has not yet entered the state of the art. Therefore, conversion factors are not recommended for them.

NOTE 15: See Related Information 1 for additional information.

Table 2 Recommended Energy Conversion Factors

Utility or Material	*Energy Conversion Factor*	*Supplementary Information*
Exhaust	1.33 × 10^1 kJ/m^3 (0.0037 kWh/m^3)	
Vacuum	2.16 × 10^2 kJ/m^3 (0.060 kWh/m^3)	
Clean Dry Air (CDA)	5.29 × 10^2 kJ/m^3 (0.147 kWh/m^3)	This conversion factor should be applied to the equivalent air volume at 101 kPa (1 atmosphere) and 20°C.
High Pressure Clean Dry Air (CDA) 827–1,034 kPa gauge (120–150 psig)	6.30 × 10^2 kJ/m^3 (0.175 kWh/m^3)	This conversion factor should be applied to the equivalent air volume at 101 kPa (1 atmosphere) and 20°C. It is recommended that pressures higher than 1,034 kPa gauge (150 psig) not be used because the related pressure systems may fall within scope of local high pressure gas laws.
Water Cooled by Refrigeration	5.62 × 10^3 kJ/m^3 (1.56 kWh/m^3) (at $\Delta T = 5$) {ECF = (0.258 × ΔT + 0.273) × 3.6 × 10^3 kJ/m^3 [(0.258 × ΔT + 0.273) kWh/m^3] }	The left formula should be used to determine the conversion factor. Where ΔT is the difference between the water inlet and outlet temperatures in degrees centigrade.
Water Cooled by Cooling-tower	9.36 × 10^2 kJ/m^3 (0.260 kWh/m^3)	Assume refrigerated cooling for water supplied to the tool at <25°C and cooling-tower for ≥25°C unless more specific information about the end-users facility is available.
UPW or DIW Temp ≤25°C	3.24 × 10^4 kJ/m^3 (9.0 kWh/m^3)	Because of the large amount of energy required for purification, no qualification is provided regarding water temperature.
Hot UPW or DIW pressurized Temp >85°C	3.32 × 10^5 kJ/m^3 (92.2 kWh/m^3)	There is no conversion factor stipulated for UPW or DIW supplied at a temperature between 25°C and 85°C.

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Utility or Material		*Energy Conversion Factor*	*Supplementary Information*
Heat Load[#2]	Heat removal via Air	1.17 kJ/m^3 °C (3.24 × 10^{-4} kWh/m^3 °C)	This conversion factor addresses the specific heat, and density of air.
	Heat removal via Water	4.18 10^3 kJ/m^3 °C (1.16 kWh/m^3 °C)	This conversion factor addresses the specific heat, and density of water.
	Cooling Load	0.287 kJ/kJ (kWh/kWh)	This conversion factor accounts for the energy that may be used to operate the clean room air conditioning.
N_2[#1]		9.00 × 10^2 kJ/m^3 (0.250 kWh/m^3)	This conversion factor should be applied to the equivalent nitrogen volume at 101 kPa (1 atmosphere) and 20°C.
Electricity		1.00 kJ/kJ (kWh/kWh)	A unity conversion factor is used at this time. Authors of future revisions may wish to account for the efficiency of generating electricity with a different conversion factor.

#1 Source for N_2: ISMI/Sematech "TEE Tool Correction Factor Calculator."

#2 The Heat Load conversion factor expresses the amount of energy that may be required to remove (i.e., refrigerate) 3.6 × 10^3 kJ (1 kWh) of radiant energy from the equipment environment.

11 Sleep Mode

11.1 Equipment suppliers can provide a sleep mode for their equipment. The goal of a sleep mode is to provide a means to coordinate a reduced energy use state of the equipment with demand gaps in the equipment utilization as understood by the facility control system(s) or personnel.

11.2 While provision of an effective sleep mode is recommend, it is not intended that a sleep mode be allotted any time percentage when calculating an equipment's annual energy use (reference ¶ R1-3.2).

11.3 If a sleep mode is provided, the equipment supplier should characterize the sleep mode of their equipment with at least the metrics given in § 11.5. The information should be included in the documents provided to the equipment user.

11.4 *Mode Differentiation* — If the equipment provides more than one level of sleep mode (e.g., each having different base energy use levels, or sleep or wake times), each level should be clearly titled, and the metrics given in § 11.5should be provided for each one. It is recommended that several sleep modes be differentiated in title by a very simple designation such as S1, S2, and so on.

11.5 *Sleep Mode Metrics*

11.5.1 *Functional Effect* — The equipment supplier should provide a narrative of the effect on the equipment of entering and leaving a sleep mode. For example, the information should discuss what valves, relays, actuators or other devices change state; which utility systems are affected; which indicators change state; what impact there is to equipment safety systems (if any); what equipment effluent streams might be altered; what particular pumps or motors are stopped; and any other information describing the functional reaction of the equipment. If the equipment reaction includes sleep mode coordination with sub-systems which have their own sleep modes (e.g., a dry pump or chiller), this detail should particularly be provided.

11.5.2 *Sleep Control* — The equipment supplier should describe what signals or commands are used to initiate and conclude the sleep mode. It is recommended that equipment which provides a sleep mode, have a command or control that causes it to transition into the sleep condition (e.g., a "sleep" command), and one that initiates the transition of the equipment from the sleep condition to the idle condition (e.g., a "wake" command). The sleep mode could be initiated, for example, by the press of a button, a key board command sequence, or a software command received by the equipment control system. The interface could be an electronic signal received at an interface connector.

11.5.2.1 It is recommended that the equipment provide an indication of when it is going into a sleep mode, when it has achieved the sleep mode, when it is recovering from a sleep mode, and when it is no longer in that mode. The

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