Standardization of ESH Metrics for Semiconductor Manufacturing Equipment

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Outline

- Facility ESH Metrics
- Project Objective
- Terms & Definitions
- Tool ESH Metrics
- Measurement
- Tool Energy Consumption
- Definitions
- Approach
- ISMT tools
- Results
- Summary
Facility ESH Metrics

- **Goal**: Quantitative comparison of the normalized ESH performance of worldwide SC sites. Identify focus areas for improvements.

- **Example**: SIA 5 site-environmental metrics normalized to product of total cm² of wafers manufactured X mask layers.
  - Total water supplied
  - Hazardous Waste
  - VOC Emissions
  - Total Reportable TRI Chemical Usage
  - Total Electrical Usage
Project Objective

Establish a **Tool-Specific ESH Metrics Database** for 200mm & 300mm tools

**Why?**

- Insufficient data is available to compare 300mm versus 200mm tools for ESH performance
- Identify areas to focus research on tool ESH improvements
- Site Energy Consumption

![Pie chart showing Energy Consumption: Facility Systems 59.3%, Process Tools 40.7%]
Terms and Definitions

• **Baseline process** and associated designed throughput (Reference: SEMI S2-0200 & ISMT Application Guide)

• Normalized to **per wafer pass**

• For energy and water consumption, specify **idle** and **process**

• **Tool energy consumption**: “Utility Consumption Characterization Protocol for Semiconductor Tools”, Doc # 00043939A-ENG
## ESH Metrics (1)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
<th>Normalizing Factors</th>
<th>DM</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Energy consumption when idle</td>
<td>Kilowatt</td>
<td>N/A</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2. Energy consumption when in process</td>
<td>Kilowatt--hour</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2a. peak current</td>
<td>A, amperage</td>
<td>N/A</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2b. inrush current</td>
<td>A, amperage</td>
<td>N/A</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2c. connected load</td>
<td>KVA</td>
<td>N/A</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2d. power factor</td>
<td>N/A. (between 0 and 1)</td>
<td>N/A</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3. DI water consumption when idle</td>
<td>Liters/min</td>
<td>N/A</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4. DI water consumption when in process</td>
<td>Liters/cm2</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

1. DM = Device manufacturers
2. X = ability for device manufacturers or equipment suppliers to provide ESH metric data.
## ESH Metrics (2)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
<th>Normalizing Factors</th>
<th>DM</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. hazardous waste generation</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5a. Aqueous waste</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5b. Liquid non-aqueous waste</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5c. Solid waste</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>6. Process chemical consumption (list by chemical)</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7. Specialty gas consumption</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>8. Bulk gas consumption</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>9. VOCs</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10. PFCs</td>
<td>CE Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>11. HAPs</td>
<td>Kg/cm²</td>
<td>Per wafer pass</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>12. Pac kaging</td>
<td>Kg/tool [the weight of non-divertible waste per piece of equipment]</td>
<td>Per piece of equipment delivered</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

1. DM = Device manufacturers
2. X = ability for device manufacturers or equipment suppliers to provide ESH metric data.
## ESH Metrics (3)
### Safety, Health & Operational

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
<th>Normalizing Factors</th>
<th>DM</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>13. S2 non-conformances</td>
<td>Number of non-conformances in S2 report</td>
<td>Per piece of equipment at delivery</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>14. S8 non-conformances</td>
<td>Number of non-conformances in S8 report</td>
<td>Per piece of equipment at delivery</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>15. Hazardous Tasks</td>
<td>Quantity of hazardous tasks requiring PPE</td>
<td>Per year per piece of equipment</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>16. Maintenance</td>
<td>hours/yr</td>
<td>Per year (in the past 12 month)</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

1. DM = Device manufacturers  
2. X = ability for device manufacturers or equipment suppliers to provide ESH metric data.
Measurement


• **Water consumption**: ultrasonic flow meter or equivalent

• **VOC, PFC, HAP emission**: “Guidelines for Environmental Characterization of Semiconductor Equipment”, Doc # 01104197A-XFR (http://www.sematech.org/public/resources/standards/300mm/guide.htm)

• **Others**: Document how the data was obtained. If by estimation, document the calculation.
Tool Energy Consumption

- elements that will be measured or back-calculated

Doc # 0043939A-ENG
## Definitions (1)

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline process</td>
<td>A representative process for which a significant number of end users actually use this tool. [SEMATECH Application Guide 2.0 for SEMI S2-93 and SEMI S8-95]</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Including the electricity/power consumption of (1) process tools and process tool subcomponents such as pumps, radio frequency (RF) power supplies (2) process cooling water (3) exhaust. Please refer to Technology Transfer document 00043939A-ENG “Utility Consumption Characterization Protocol for Semiconductor Tools” (<a href="http://www.sematech.org/public/resources/">http://www.sematech.org/public/resources/</a> stds/300mm/guide.htm)</td>
</tr>
<tr>
<td>DI water consumption</td>
<td>The use of mobile ultrasonic flow meters allows for non-intrusive measurements of UPW flow rates. The flow meter sensors, or transducers, are attached to the outside of the UPW feed or waste water lines and require no interference with normal tool operat</td>
</tr>
</tbody>
</table>
## Definitions (2)

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous waste generation</td>
<td>By-products of society that can pose a substantial or potential hazard to human health or the environment when improperly managed. Possesses at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity), or appears on special E</td>
</tr>
<tr>
<td>Aqueous waste</td>
<td>Primarily liquid waste that goes to wastewater treatment system</td>
</tr>
<tr>
<td>Liquid non-aqueous waste</td>
<td>Primarily liquid waste that does not go to wastewater treatment system, e.g., waste photoresist, H2SO4 collected for off-site recycling</td>
</tr>
<tr>
<td>Process chemical</td>
<td>Liquid chemicals except DI water. All chemicals used should be listed.</td>
</tr>
<tr>
<td>Specialty gas</td>
<td>Gases other than bulk gases, e.g., AsH3, PH3, Cl2, NF3, etc. May specify by chemicals for comparison purposes</td>
</tr>
<tr>
<td>Bulk gas</td>
<td>Gases supplied with bulk volume, including N2, O2, Ar, and H2.</td>
</tr>
</tbody>
</table>
### Definitions (3)

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFCs</td>
<td>Per-fluoro-compound, including CF₄, CHF₃, C₂F₆, C₃F₈, C₄F₈, NF₃, SF₆ so far based on the agreement by WSC (World Semiconductor Council). It is calculated to be carbon equivalent weight, CE Kg.</td>
</tr>
<tr>
<td>HAPs</td>
<td>Hazardous air pollutants, Chemicals that cause serious health and environmental effects. Health effects include cancer, birth defects, nervous system problems and death due to massive accidental releases such as occurred at the pesticide plant in Bhopal, India. Hazardous air pollutants are released by sources such as chemical plants, dry cleaners, printing plants, and motor vehicles (cars, trucks, buses, etc.) [US-EPA, <a href="http://www.epa.gov/trs/index.htm">www.epa.gov/trs/index.htm</a>]</td>
</tr>
</tbody>
</table>

Also refer to “Guidelines for Environmental Characterization of Semiconductor Equipment”, Doc # 01104197A-XFR (http://www.sematech.org/public/resources/stds/300mm/guide.htm)
### Definitions (4)

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous Tasks</td>
<td>Tasks associated with hazards. Hazard is defined as a “condition that creates or contributes to an increased risk that an event causing death or serious bodily harm will occur.” <a href="#">W. Scott Railton, OSHA Compliance Handbook, May 1992, page 65. ISBN: 0-86587</a></td>
</tr>
<tr>
<td>Maintenance</td>
<td>Hours of tool downtime due to ESH maintenance or retrofit activities.</td>
</tr>
<tr>
<td>Idle</td>
<td>The state when the tool is fully powered on and ready to process wafers but is not actually running a process. If there are different stages of idle mode (e.g. minimum/baseline idle and maintenance/high-flow idle for CMP tools), then average consumption s</td>
</tr>
<tr>
<td>Peak</td>
<td>The highest level of consumption of the utility by the equipment during normal use.</td>
</tr>
<tr>
<td>CE</td>
<td>Carbon equivalent</td>
</tr>
</tbody>
</table>
Approach:

• 16 Tool ESH Metrics to be collected for representative 200mm & 300mm tool sets
  ▪ Implant
  ▪ Etch
  ▪ Wet decks, etc.

• ESH Working Group to Benchmark Data:
  ▪ ITRS roadmap
  ▪ 200mm vs 300mm
  ▪ Member company comparison
  ▪ Tool Supplier comparison
  ▪ Confidentiality protected
International SEMATECH Fab (ATDF)
Initial tool sets in Tool ESH Metrics Database

Measurements performed in November 2001

- CVD (PECVD)
- Wet Bench (single wafer process)
- Implanter (can process 200mm & 300mm wafer, only running 200mm in 2001 because no other 300mm tools to support)
# Results from ATDF – Implanter (1)

<table>
<thead>
<tr>
<th>Tool</th>
<th>Implanter</th>
<th>Implanter</th>
<th>Implanter</th>
<th>Implanter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AsH3</td>
<td>AsH3</td>
<td>PH3</td>
<td>BF3</td>
</tr>
<tr>
<td>Baseline Process</td>
<td>&lt; 50 keV</td>
<td>&lt; 150 keV</td>
<td>&lt; 200 keV</td>
<td>&lt; 50 keV</td>
</tr>
<tr>
<td>Recipe Details</td>
<td>Associated Throughput</td>
<td>Wafer per hour</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Wafers Processed</td>
<td>25</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Metric</td>
<td>Unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Energy consumption when idle</td>
<td>Kilowatt</td>
<td>27.87</td>
<td>27.87</td>
<td></td>
</tr>
<tr>
<td>2. Energy consumption when in process</td>
<td>Kilowatt-hour</td>
<td>34.4154</td>
<td>2.8259</td>
<td></td>
</tr>
<tr>
<td>2a. peak current</td>
<td>A, amperage</td>
<td>92.84 (ph C)</td>
<td>124.7 (ph C)</td>
<td></td>
</tr>
<tr>
<td>2b. inrush current</td>
<td>A, amperage</td>
<td>92.84 (ph C)</td>
<td>124.7 (ph C)</td>
<td></td>
</tr>
<tr>
<td>2c. connected load</td>
<td>KVA</td>
<td>29.96</td>
<td>42.52</td>
<td></td>
</tr>
<tr>
<td>2d. power factor</td>
<td>N/A.</td>
<td>0.931</td>
<td>0.949</td>
<td></td>
</tr>
<tr>
<td>3. DI water consumption when idle</td>
<td>Liters/min</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>4. DI water consumption when in process</td>
<td>Liters/cm2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
## Results from ATDF – Implanter (2)

<table>
<thead>
<tr>
<th>Tool</th>
<th>Implanter</th>
<th>Implanter</th>
<th>Implanter</th>
<th>Implanter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Process</td>
<td>AsH3</td>
<td>AsH3</td>
<td>PH3</td>
<td>BF3</td>
</tr>
<tr>
<td>Recipe Details</td>
<td>&lt; 50 keV</td>
<td>&lt; 150 keV</td>
<td>&lt; 200 keV</td>
<td>&lt; 50 keV</td>
</tr>
<tr>
<td>Associated Throughput</td>
<td>Wafer per hour</td>
<td>20</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>Wafers Processed</td>
<td>25</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

### Metric

<table>
<thead>
<tr>
<th>Metric</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. hazardous waste generation</td>
<td></td>
</tr>
<tr>
<td>5a. Aqueous waste</td>
<td>Kg/cm²</td>
</tr>
<tr>
<td>5b. Liquid non-aqueous waste</td>
<td>Kg/cm²</td>
</tr>
<tr>
<td>5c. Solid waste</td>
<td>Kg/cm²</td>
</tr>
<tr>
<td>6. Process chemical consumption</td>
<td>Kg/cm²</td>
</tr>
<tr>
<td>7. Specialty gas consumption</td>
<td>Kg/cm²</td>
</tr>
<tr>
<td>8. Bulk gas consumption</td>
<td>Kg/cm²</td>
</tr>
</tbody>
</table>
## Results from ATDF – Implanter (3)

<table>
<thead>
<tr>
<th>Tool</th>
<th>Implanter</th>
<th>Implanter</th>
<th>Implanter</th>
<th>Implanter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Process</td>
<td>AsH$^3$</td>
<td>AsH$^3$</td>
<td>PH$^3$</td>
<td>BF$^3$</td>
</tr>
<tr>
<td>Recipe Details</td>
<td>&lt; 50 keV</td>
<td>&lt; 150 keV</td>
<td>&lt; 200 keV</td>
<td>&lt; 50 keV</td>
</tr>
<tr>
<td>Associated Throughput</td>
<td>Wafer per hour</td>
<td>20</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>Wafers Processed</td>
<td>25</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Metric</td>
<td>Unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. VOCs emission</td>
<td>Kg/cm$^2$</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>10. PFCs emission</td>
<td>CEKg/cm$^2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. HAPs emission</td>
<td>BF$^3$ Kg/cm$^2$</td>
<td></td>
<td></td>
<td>1.30723E-08</td>
</tr>
<tr>
<td></td>
<td>AsH$^3$ Kg/cm$^2$</td>
<td>4.0157E-08</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PH$^3$ Kg/cm$^2$</td>
<td></td>
<td>1.30723E-08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N2O Kg/cm$^2$</td>
<td></td>
<td></td>
<td>8.40378E-09</td>
</tr>
<tr>
<td></td>
<td>CO Kg/cm$^2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HF Kg/cm$^2$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results - Implanter

- **Electrical Energy**: 34.4 kWh
- **Arsine**: 0.0012 kg/sq cm
- **Implanter**
  - AsH$_3$ at <50 KeV
  - 25 wafers (200mm)
- **Cooling Water Energy**: 0.11 kWh
- **Exhaust Energy**: 0.10 kWh
- **Vacuum Pump Exhaust Emissions** (Before treatment)
  - Arsine
  - 4.015 E-08 kg/sq cm
Results – CVD Tool

CVD Tool (PECVD)
Silicon Oxide 5000 Ang
13 wafers (300mm)

- **Electrical Energy**: 15.0 kWh
- **Cooling Water Energy**: 2.38 kWh
- **Exhaust Energy**: 5.96 kWh

**Silane**
3.12 E-07 kg/sq cm

**Nitrogen Trifluoride**
8.38 E-06 kg/sq cm

**Nitrous Oxide**
1.40E-06 kg/sq cm

**Argon**
2.18 E-6 kg/sq cm

**Vacuum Pump Exhaust Emissions:** (Before POU and central treatment)

- **Nitrous Oxide**
  - 5.40 E-08 kg/sq cm
- **Carbon Monoxide**
  - 6.92 E-09 kg/sq cm
- **Hydrofluoric Acid**
  - 2.93 E-07 kg/sq cm
- **Nitrogen Trifluoride**
  - 5.64 E-03 CEkg/sq cm
- **Silane**
  - 1.46 E-09 kg/sq cm
- **Silicon Tetrafluoride**
  - 2.41 E-07 kg/sq cm
Results – Wet Spin Etcher

Wet Spin Etcher
11 wafers (300mm)

Electrical Energy
0.46 kWh

Cooling Water Energy
0.04 kWh

Exhaust Energy
0.11 kWh

City Water
1.01 E-4 lit/sq cm

49% Hydrofluoric Acid
2.63 E-05 kg/cm sq

Exhaust Emissions:
(Before central treatment)

- Silicon Tetrafluoride
  5.94 E-07 kg/sq cm
- Hydrofluoric Acid
  2.21 E-06 kg/sq cm
Summary

- Identified ESH parameters
- Agreed on units and normalizing factors
- Now building tool database
- Goal is to improve ESH performance of semiconductor tools