Enabling New Horizons

Integrated Waste Reduction Program for Semiconductor Facilities

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M+W Group at a Glance

- Leading global engineering and construction company
- Unique skillset in the delivery of complex technology-intensive factories and facilities
- Special expertise in cleanroom technology and controlled environments
- Established in Germany in 1912
- Figures 2015
  - Order Intake: €3 bn
  - Sales: €3 bn
  - Employees: 6,000

Mission Statement

“M+W creates customer value through a unique combination of lean and sustainable, high-technology engineering and project management solutions in an injury-free environment.”
Challenges in a Changing Industry... and More Sustainability

- “Nanoelectronics Everywhere” has created new high volume semiconductor user groups
- Internet of Things (IoT): First wide-spread applications
  - Medical, Agriculture, Traffic, Smart energy and homes
- Diversification of process technologies & applications
- In particular, high volume consumer markets drive:
  - Flexible manufacturing
  - Environmental-friendly green products
  - Corporate Social Responsibilities
- Growing environmental discharge limitations
  - International/national laws & corporate governance

Reduction of waste while maintaining cost-efficiency.
LCA is a systematic technique for the evaluation of (potential) environmental impacts associated with products, processes or services over their entire life cycle. Defined in ISO 14040 and ISO 14044

Calculate the environmental performance
- How big is the carbon footprint?
- How much water is used?
- What are my KEPIs?

Identify environmental hotspots
- Where is the environmental impact coming from?
- What is the biggest impact?

Assess, compare, optimize design options
- Which option is more sustainable?
- How can I improve my environmental performance?

LCA enables one to make environmentally sound decisions.
Life Cycle Assessment (LCA) Modeling
Operation Phase Dominates CO2 Footprint

Calculated Relative Contribution to Wafer Fab Life Cycle CO2 Footprint

**Outputs**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>8%</td>
</tr>
<tr>
<td>Operation</td>
<td>88%</td>
</tr>
<tr>
<td>Decommissioning</td>
<td>4%</td>
</tr>
</tbody>
</table>

**Emissions** (CO₂, SO₂, ..), Waste Water, Solid Waste, Waste Heat, Noise

**Inputs**

- Extraction of raw materials
- Manufacturing
- Use
- End-of-life

**Resources**

- Steel: 4%
- Concrete: 2%
- Transport: 1%
- Others: 1%
- Supply: 77%
- Production: 7%
- Disposal: 4%

**Outputs**

- Steel: 4%
- Concrete: 2%
- Transport: 2%
- Others: 2%

Source: M+W Group
Integrated Waste Reduction for Facility Systems
General Overview & Examples

Abbreviations:
MAHU = Make-up air handling unit,
RAHU = Recirc air handling unit,
GEX = General exhaust,
ACEX = Acid exhaust,
CAEX = Caustic exhaust,
PCW = Process cooling water,
UPW = Ultra pure water,
WWT = Wastewater

Energy Efficiency
- Solar Heating
- Concrete Cooling
- Decentralized RAHU
- Ground (Water) Cooling
- Chilled Water Temperature Optimization
- Solar Cooling

Water Efficiency
- MAHU Cooling Optimization
- GEX-MAHU Energy Recovery
- Free Cooling
- Heat Exchanger Temperature Optimization
- Low Chemistry Scrubber
- High Temperature PCW
- Organic Sanitary WW
- Slurry Treatment
- Advanced HF-Treatment
- Cu-WW Treatment
- Solvent Waste Treatment

Materials / Chemicals / Consumables Efficiency
- Drain Segregation
- Water re- & down cycling
- UPW Recycling
- Energy Recovery
- Low Chemistry Scrubber
- Exhaust recycling
- Water re-
- down cycling
- Drain Segregation
- Water re- & down cycling
- UPW Recycling

- TMAH Reclaim
- Ammonia Reclaim
- SEMI-Product Materials
- Building Materials
- Facility Consumables

- N2 Storage
- Photovoltaic
- WW Treatment Heat Recovery
- Cogeneration Trigeneration
- Solar Cooling
- Concrete Cooling
- Decentralized RAHU
- Ground (Water) Cooling
- Chilled Water Temperature Optimization
- Solar Heating

Source: M+W Group
High Leverage Waste Reduction Measures
UPW and Waste Water Systems

Additional measures can substantially improve overall site water recycling ratios from 50% to >75%.
Low-Chem UPW Make-Up
Electro De-Ionization

- Comparison based on installed systems for a major semiconductor facility, similar raw water inlet quality and UPW specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Standard</th>
<th>Low Chem</th>
<th>Pros &amp; Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Usage</td>
<td>Higher</td>
<td>Lower</td>
<td>80% Reduction</td>
</tr>
<tr>
<td>Energy Cons.</td>
<td>Lower</td>
<td>Higher</td>
<td>35% Increase</td>
</tr>
<tr>
<td>Water Demand</td>
<td>Higher</td>
<td>Lower</td>
<td>10% Reduction</td>
</tr>
<tr>
<td>Footprint</td>
<td>Larger</td>
<td>Smaller</td>
<td>25% Reduction</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Higher</td>
<td>Lower</td>
<td>5% Reduction</td>
</tr>
<tr>
<td>OPEX</td>
<td>Higher</td>
<td>Lower</td>
<td>3.5% Reduction</td>
</tr>
</tbody>
</table>

Source: M+W Group. Actual comparison for a semiconductor facility based on same raw water inlet quality and UPW specifications
Waste Water Systems
Advanced Segregation - High TOC Rinse

- Discrete rinse segregation required for high concentration organics
- Additional CAPEX for a dedicated drain collection system and advanced reclaim plant

<table>
<thead>
<tr>
<th>Sub-Fab</th>
<th>Cleanroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Scrubbers</td>
<td>Wet Etch</td>
</tr>
<tr>
<td>Films / Diffusion</td>
<td>Wet Strip</td>
</tr>
<tr>
<td>CMP / Backgrind</td>
<td>Wet Clean</td>
</tr>
<tr>
<td>Photo</td>
<td></td>
</tr>
</tbody>
</table>

**Description** | **Reclaim Rates**
--- | ---
Conventional Rinse Reclaim | ~ 25%
High TOC Rinse Reclaim | ~ 6% additional

Conventional Reclaim

HE-BD™ System

25%

6%

To UPW Plant
Waste Water Systems
High TOC Rinse Treatment

- High efficiency reclaim for high organics (μ >95%)
- Fast biological digestion (BD) system utilizing a SiC-based membrane
- TOC removal >99% and zero toxic waste using H₂O₂ resistant bacteria strains

### Sub-Fab

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<tr>
<th>Local Scrubbers</th>
<th>Films / Diffusion</th>
<th>CMP / Backgrind</th>
<th>Photo</th>
</tr>
</thead>
</table>

### Cleanroom

- Wet Etch
- Wet Strip
- Wet Clean

<table>
<thead>
<tr>
<th>Description</th>
<th>HE-BD™</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Usage</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Energy Cons.</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Water Demand</td>
<td>Reduced</td>
<td>&gt;95% reclaim possible</td>
</tr>
<tr>
<td>Footprint</td>
<td>&lt; 50 m²</td>
<td></td>
</tr>
<tr>
<td>CAPEX</td>
<td>&lt; 5 M USD</td>
<td>Add. segregation &amp; plant</td>
</tr>
<tr>
<td>OPEX</td>
<td>Small</td>
<td>Low chem. &amp; energy cons.</td>
</tr>
<tr>
<td>ROI</td>
<td>&lt; 24 months</td>
<td>For plant only</td>
</tr>
</tbody>
</table>

**Description**

- **HE-BD™ System by OVIVO**
  - High TOC Rinse (1 ... 100 ppm ++)
  - (IPA, Acetone, NMP, TMAH, Triazoles, Urea, MEK)
  - H₂O₂: ...500 ppm

**Diagram**

- Biofilter
- Filtrate Tank
- Sludge dehydration
- Aeration
- HE-BD™ System by OVIVO (to UPW Plant)

**Notes**

- **Air**
- **SiC**
Waste Water Systems
Discrete Oxide/Tungsten CMP Drain Segregation

- CMP buffing and cleaning waste water can be reclaimed for UPW
- Discrete drain segregation required at CMP Polisher & Cleaner Mainframe

### Description

<table>
<thead>
<tr>
<th>Description</th>
<th>CMP Segr.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Usage</td>
<td>Neutral</td>
<td></td>
</tr>
<tr>
<td>Energy Cons.</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Water Demand</td>
<td>Reduced</td>
<td>&gt;95% reuse possible</td>
</tr>
<tr>
<td>Footprint</td>
<td>&lt; 60 m²</td>
<td></td>
</tr>
<tr>
<td>CAPEX</td>
<td>&lt; 8 M USD</td>
<td>Add. segregation &amp; plant</td>
</tr>
<tr>
<td>OPEX</td>
<td>Small</td>
<td>Low chem. &amp; energy cons.</td>
</tr>
<tr>
<td>ROI</td>
<td>&lt; 24 months</td>
<td>For plant only</td>
</tr>
</tbody>
</table>

### Diagram

- **Sub-Fab**
  - Local Scrubbers
  - Films / Diffusion
  - Ox/W CMP Polisher & Cleaner

- **Cleanroom**
  - Photo
  - Wet Etch
  - Wet Strip
  - Wet Clean

- **Ultra Filtration / Ion Exchange**
  - Buffing Drain
  - Cleaner Drain
- **WW Treatment**
  - 9%
  - Slurry Drain
  - (to reuse)
  - (to UPW Plant)

Concept Proposal by OVIVO

Source: M+W Group
## Process Exhaust
### Waste Reduction Opportunities

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Description</th>
<th>Status</th>
<th>Potential Waste Red.</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat exhaust recycling</td>
<td>Non-toxic exhaust discharged into recirculation airstream</td>
<td>In Operation</td>
<td>Medium</td>
<td>Non-hazardous exhaust only. CAPEX saving potential (MAHU, chillers, boilers etc.)</td>
</tr>
<tr>
<td>PFC recycling</td>
<td>Etch/CVD chamber cleaning gases</td>
<td>Prototype</td>
<td>High</td>
<td>Reduced global warming gases. High purification requirements.</td>
</tr>
<tr>
<td>Dynamic Exhaust Volume Control</td>
<td>Multiple actuated dampers at process tools</td>
<td>Concept</td>
<td>Medium</td>
<td>Increased CAPEX for dampers &amp; FMCS system</td>
</tr>
<tr>
<td>Scrubber heat recovery</td>
<td>Pre-cooling of MAHU air (~16°C =&gt; 1 MW)</td>
<td>Concept</td>
<td>Medium</td>
<td>Regional dependent. Reduced chiller capacity, plus heat recovery system CAPEX</td>
</tr>
<tr>
<td>EXVO heat recovery</td>
<td>Approx. 200°C available for pre-heating hot water (~0.4MW)</td>
<td>Prototype</td>
<td>Low</td>
<td>Reduced boiler capacity, plus heat recovery system CAPEX</td>
</tr>
<tr>
<td>Reclaimed Scrubber Chemicals</td>
<td>Process waste water containing H2SO4 and NaOH</td>
<td>Concept</td>
<td>Low</td>
<td>Low potential waste streams and additional segregation</td>
</tr>
<tr>
<td>Solvent waste reuse</td>
<td>Fuel for EXVO (solvent exhaust treatment) or boilers</td>
<td>Other industries</td>
<td>Low</td>
<td>Low concentrated solvent waste discharge volumes.</td>
</tr>
</tbody>
</table>

| Example: Heat Exhaust Recycling    |                                                       |            |                      |                                                                               |

### Example Results

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEX-Recycling</td>
<td>290,000 m³/h (30% of total GEX)</td>
<td>GEX-Recycling</td>
</tr>
<tr>
<td>Electrical Power Saving</td>
<td>1,970 MWh/a</td>
<td>Electrical Power Saving</td>
</tr>
<tr>
<td>Natural Gas Savings</td>
<td>284,000 m³/a</td>
<td>Natural Gas Savings</td>
</tr>
<tr>
<td>CO2 Emission Savings</td>
<td>1,500 t/a</td>
<td>CO2 Emission Savings</td>
</tr>
<tr>
<td>Operation Cost Savings</td>
<td>300,000 €/a</td>
<td>Operation Cost Savings</td>
</tr>
<tr>
<td>Chiller &amp; Cooling Tower Capacity</td>
<td>3,000 kW</td>
<td>Chiller &amp; Cooling Tower Capacity</td>
</tr>
</tbody>
</table>

Source: M+W Group
Waste Reduction during Construction
Pre-Assembly and Modularization

Benefits
- Reduced materials, space and resources wasted on site (safety)
- High labor productivity through efficiency & less interface management
- Continuous manufacturing with less set-ups
- Established pre-qualification testing off-site
- Electronic records of as-builts
- Fast ramp-up of installation phase

Pre-Requisites
- Collaborative & experienced supply chain
- Early contractor engagement
- Detailed engineering and BIM/4D platform implementation

Traditional Stick Build Construction ➔ Design for Manufacturing/Assembly

Scan of actual sub fab area ➔ BIM Model development ➔ Scan of actual sub fab area ➔ Overlay of scan with model

Scan of actual sub fab area
BIM Model development
Scan of actual sub fab area
Overlay of scan with model

Source: M+W Group
Waste Reduction during Construction
Pre-Assembly and Modularization

Example: Distribution Pipe Racks

<table>
<thead>
<tr>
<th>Factors</th>
<th>KPI</th>
<th>Pre-Assembly</th>
<th>Observed impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field labor</td>
<td>Headcount</td>
<td>Lower</td>
<td>&gt; 30% Reduction</td>
</tr>
<tr>
<td>Shop labor</td>
<td>Productivity</td>
<td>Higher</td>
<td>~ 4-7x Increase</td>
</tr>
<tr>
<td>Shop labor</td>
<td>Headcount</td>
<td>Lower</td>
<td>1:10 vs. Field labor</td>
</tr>
<tr>
<td>VDC*</td>
<td>Time</td>
<td>Higher</td>
<td>~ 8-17% of labor</td>
</tr>
<tr>
<td>Overall Direct Labor</td>
<td>Headcount</td>
<td>Lower</td>
<td>&gt; 20% Reduction</td>
</tr>
<tr>
<td>Material Costs</td>
<td>Rework rate</td>
<td>Lower</td>
<td>2% to 25% Reduct.</td>
</tr>
<tr>
<td>Overall Overhead</td>
<td>Headcount</td>
<td>Higher</td>
<td>~ 4% Increase</td>
</tr>
</tbody>
</table>

* VDC = Virtual Design & Construction

Structural: Waffle Table Elements
Facilities: Skid-mounted Plant
Tool Install: Pre-config. Frames
Facilities: Gas line pre-fabrication
Facilities: Distribution Pipe Racks
Sustainable Energy Supply Options
Renewable Energy

- Renewable energy sources are site-dependent
- 100% renewable energy supply to a fab is unlikely
  - Space requirements
  - Remote locations inevitable
  - Energy storage required for high quality power supply

Potential CO2 reduction in case of 100% utilization of renewable energies is approx. 540,000 t/a*

* Assumes CO2 emission of 0.578 kg/kWh elec. For a 25k m² Fab with power demand of ~ 420 GWh/a

Photovoltaic

- PV Park 350 MWp
  - ~ 5 km² *

* Related to global irradiation of 1,300 kWh/m²/a

Wind

- Wind Park 22x 6 MW units
  - ~ 15 to 20 km² **

** Depending on annual and maximum wind conditions

Biomass

- Agriculture Area
  - Short Turnover Plantation ~ 330 km²
  - Crop Straw ~ 700 km²
Sustainable Energy Supply Options
Cogeneration & Trigeneration Plant Scenarios

- Alternative sustainable energy supply strategies effect CAPEX and ROI periods

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Type</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Load</td>
<td>Cogeneration</td>
<td>Provision of base load of hot water (summer) &amp; corresponding electrical power capacity</td>
</tr>
</tbody>
</table>
| Extended Load | Trigeneration | Provision of higher load of hot & chilled water & corresponding electrical power capacity  
  Winter: Hot Water (up to 100%)  
  Summer: Base Load of Hot Water & Share of Chilled Water |
| Full Load   | Trigeneration | Provision of full load of electrical power & hot and chilled water  
  Winter: 100% Hot Water & Share of Chilled Water  
  Summer: Base Load of Hot Water & 100% Chilled Water |

Example: 25k m² Wafer Fab in Asia, Electrical Power 80 €/MWh, Natural Gas 25 €/MWh (LHV)
Integrated Waste Reduction

Summary

- An Integrated Waste Reduction Program considers multiple interactions and dependencies by utilizing LCA methods.

- Waste reduction focuses on fab operations.
  - New water treatment technologies and advanced drain segregation can improve a site’s overall reclaim ratio >75%.
  - A reduction in process exhaust treatment volumes has a significant leverage on fab power and water demand.

- Improvements during fab construction include modular or pre-assembled building & facility systems or elements.

- Alternative energy supply concepts can further reduce energy demand and the CO₂ footprint of the wafer fab.
  - Tri-generation requires acceptance of ROI periods > 6 years, pending power to gas price ratio.

Resource efficiency and waste reduction have become major considerations for wafer fab design / operation.
THANK YOU

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