IH2655 Lecture on Sustainable fabrication

Assoc. Prof.
B. Gunnar Malm
KTH – School of ICT, 2013

Focus Topics

- Key challenges and approaches to ensure sustainable fabrication in semiconductor processing industry
- We will focus on resource conservation, environmental impact and touch upon concepts such as Life Cycle Analysis (LCA), Green Fab, Emerging Nanomaterials and so forth

Lecture breakdown

- Background: Industry and organizational joint efforts for sustainable manufacturing
- Sustainable resource supply
  - Raw materials including wafers, metals, and gasses
- Sustainable fab operations
  - Electricity, water consumption, recycling/reuse
- Environmental Impact
  - Direct and Indirect GHG emissions, contamination including emerging nanomaterials, exhaust/scrubbing

Reading List

- Chap 1, ”Cleanroom Technology” in ULSI Technology, Chang, Sze, McGraw-Hill, 1996
- Introduction to Microfabrication, 2nd Edition, Sami Franssila, Wiley, 2010
- VLSI Handbookl, 2nd Ed. Chapter 17 and 21, CRC Press, 2007
- ITRS, 2011 Edition, Chapter ESH + Excel Tables, online at www.itrs.net
- STMicroelectronics, ”Sustainability Report 2011”, online.
- Lifecycle Assessment (LCA) White Paper, #020114238A-TR, International SEMATECH, 2002
- Semiconductor Key Environment Performance Indicators Guidance, #09125069A-ENG, ISMI, 2009
- White Paper, Intel’s Effort to Achieve a ”Conflict-Free” Supply Chain, February, 2013, online
- Various company websites, Intel, Global Foundries, ST, TSMC

Acronyms Sustainability Context

Acronym	Meaning
3TG	
LCA	
CSR	
ESH	
GHG	
GWP	
UPW	
ITRS	
SEMATECH	
ISMI	
LEED	

QUIZ

Acronyms Sustainability Context

Acronym	Meaning
3TG	Conflict minerals Ta, Sn, W, Au
LCA	Life Cycle Analysis
CSR	Corporate Social Responsibility
ESH	Environment, Safety & Health
GHG	Green house gas
GWP	Global warming potential
UPW	Ultrapure water
ITRS	The International Technology Roadmap for Semiconductors
SEMATECH	Non-profit Manufacturing Consortium, US-based
ISMI	International SEMATECH Manufacturing Initiative (ISMI)
LEED	Leadership in Energy and Environmental Design (Rating for Green Buildings)

Background at Intel

- http://www.intel.com/technology/ecotech/index.htm?iid=tech_lhn+ecotech

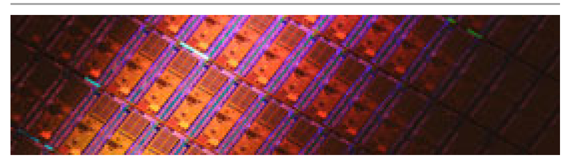
Eco-Technology

Recognized by the Environmental Protection Agency (EPA) for being the largest purchaser of green power in the US[1], Intel is helping drive sustainable technology through global standards, solutions, and products that deliver energy-efficient performance while reducing overall environmental impact.

Sustainable manufacturing

Committed to sustainable manufacturing, Intel has reduced operational energy consumption by 20 percent per product unit in the last three years, recycled or reused 87 percent of our chemical waste and 80 percent of our solid waste in 2007,[2] and has moved to lead-free[3] and halogen-free[4] products in 2008.

Energy-efficient performance



Engineers at Intel continuously look for new ways to increase performance while minimizing energy consumed. With the development of Intel® 45nm process technology, new hafnium-based circuitry helps to dramatically increase processor energy efficiency equating to more powerful computing experiences.

Background at Intel

- http://www.intel.com/technology/ecotech/index.htm?iid=tech_lhn+ecotech


Investing in Renewable Energy


Conserving Water

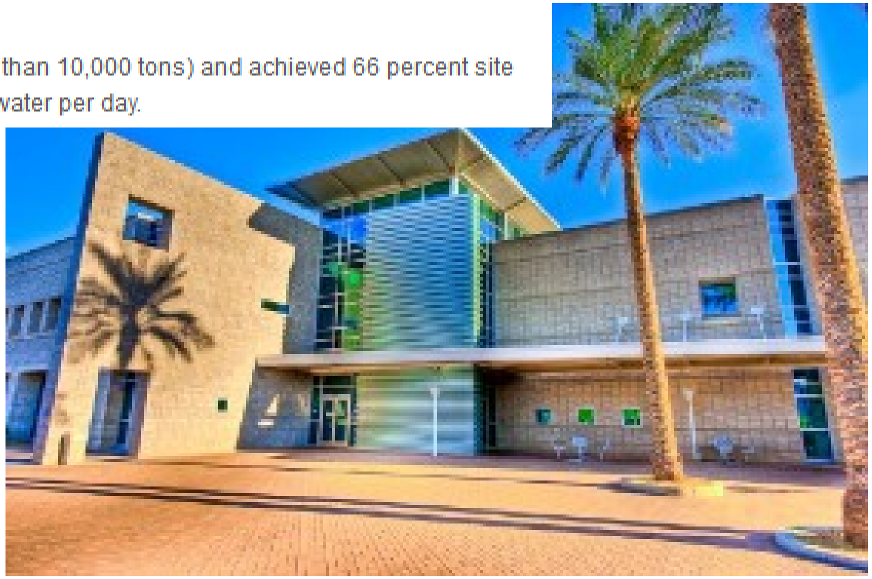

Reusing and Recycling


Building Facilities with the Environment in Mind

Rating Green Buildings

- All the big foundries have LEED certified Cleanrooms!
- http://en.wikipedia.org/wiki/Leadership_in_Energy_and_Environmental_Design

- Semiconductor Industry Association benchmark data shows that Intel's Ocotillo campus utilized 26 percent less energy than the average semiconductor campus.
- Two-hundred and 300 kW solar electricity support structures were erected in the Ocotillo campus parking lot in 2010. Currently ranking amongst the 10 largest solar installations in its utility territory, the Renewable Energy Certificates (RECs) generated by these installations are transferred to the local utility to support their regulatory obligations and programs.
- In 2010, the Ocotillo campus recycled 90 percent of its solid waste (more than 10,000 tons) and achieved 66 percent site wide water conservation, saving approximately 5 million gallons of fresh water per day.



Foundry Background

Sustainable Manufacturing: High Productivity with Low Impact

Sustainable, "eco-efficient" manufacturing combine- high productivity and low environmental impact. By implementing processes and technologies that reduce energy and water consumption while lowering emissions of greenhouse gases, GLOBALFOUNDRIES continually strives to minimize environmental impact per unit of production.

Our commitment to global climate protection is demonstrated by our wafer fabrication operations ("Fab1") in Dresden, Germany, which is powered by the highly efficient tri-generation Energy Centers, EVC1 and EVC2. The Energy Centers provide electricity, heating and cooling to the Dresden facilities, achieving thermal efficiencies greater than 82%. Fab 1 has applied best practices to minimize emissions of perfluorocompounds (PFCs) since the mid-1990's, and contributed to the World Semiconductor Council achieving its industry-wide goal to reduce PFC emissions 10% below 1995 levels by 2010.

GLOBALFOUNDRIES Singapore Fabs have a long-standing reputation for providing a safe work environment and strong environmental performance. These Fabs were the first in Singapore to adopt NEWater as feed stock to the ultrapure water production systems. NEWater is Singapore's initiative to reclaim black water for reuse, thus protecting one of this island nation's precious resources.

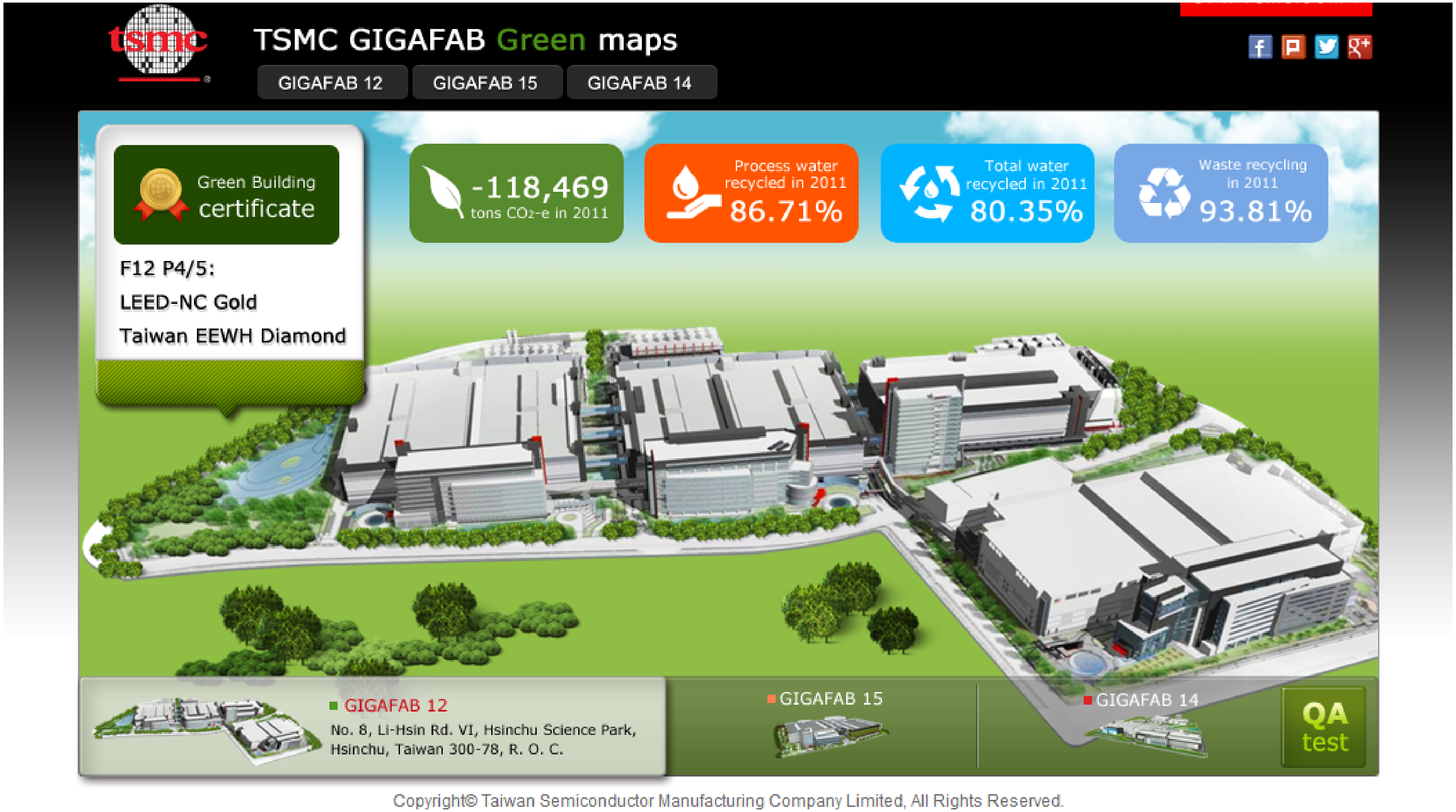
Fab 8 - Our new 300mm Fab currently beginning operations in Saratoga County, New York, has been designed as a "green fab" with the objective of delivering cost-effective and sustainable wafer manufacturing to our customers. From the foundation of collaboration with like-minded partners such as the Rocky Mountain Institute and the New York State Energy Research and Development Authority (NYSERDA), we strive for LEED (Leadership in Energy and Environmental Design) Gold certification.

- http://www.globalfoundries.com/about/environmental.aspx

UMC green fab

- http://www.umc.com/english/csr/D_5.asp

Fab comparisons



- http://www.tsmc.com/english/csr/green_manufacturing.htm
- http://www.tsmc.com/english/csr/campaign/index.html

Cleanroom operation

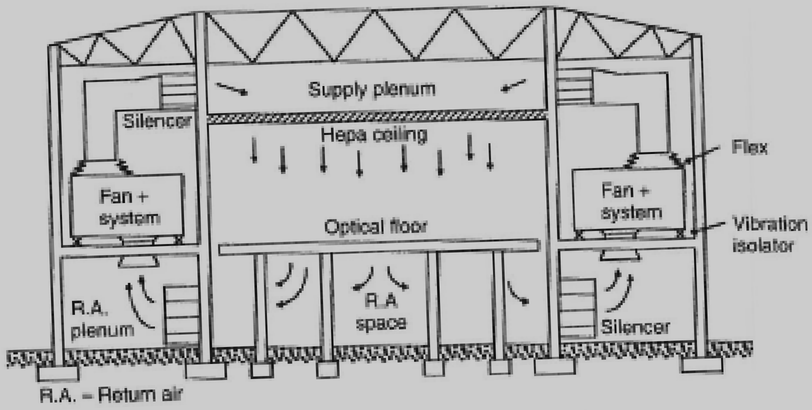


Figure 35.1 Cleanroom: fans generate unilateral airflow from HEPA (high efficiency particle) filter ceiling. Air is highly purified and temperature- and humidity-controlled. Optical floor, isolated from the rest of the building, prevents vibrations that would destabilize microlithography and microscopy operations. Source: Cleanroom Design, W. Whyte, 1999, © John Wiley & Sons, Ltd

Table 35.3 Fed. Std. class 1 cleanroom

Feature	Values
Cleanliness, process area	<35 particles/m^3, >0.10 μm
Temperature, lithography	22 °C ± 0.5
Temperature, other areas	22 °C ± 1.0
Humidity, lithography	43 ± 2%
Humidity, other	45 ± 5%
Air quality	
Total hydrocarbons	<100 ppb
NO_x	<0.5 ppb
SO_2	<0.5 ppb
Envelope outgassing	6.3×10^8 Torr L/cm^2/s
Pressure	typical 30 Pa relative to outside
Acoustic noise	<60 dB
Vibration	<3 μm/s (8–100 Hz)
Grounding resistance	1 Mohm
Magnetic field variation	< ±1 mG
Charging voltage	< ±50 V

Source: Cheng, H.P. & R. Jansen (1996)

- The cleanroom is a VERY tighly controlled enivorment, large power need
- Example: airspeed 0.45m/sec used in past now reduced to 0.35 m/sec. Large cost/energy reduction.

Power usage breakdown

Facility	Consumption
Office building	6%
Deionized (DI) water system	3%
Process tool	30%
Testing equipment	10%
Utility equipment	15%
Support cleanroom	3%
Fab recirculation fans	7%
Boilers	8%
Chillers	18%

- From ULSI p.24

Per Wafer Resources Breakdown

Other quantities of facilities required to complete the processing of a 200-mm, 16 Mbit DRAM wafer are as follows:

Chemicals	10 kg
Deionized water	4.5 ton
Compressed dry air	55 m^3
N_2	25 m^3
O_2	0.9 m^3
H_2	0.1 m^3
Power	470 Kwh

- Similar figures apply as wafer size scales to 300 and 450 mm
- From ULSI p.24

Prepared for future processes nodes

The facility systems should be designed to support at least three generations of process technology without major renovation. The following design principles are recommended:

- The quality of cleanroom, process chemicals, DI water, and process gases should be of state-of-the-art.
- The facility system should be highly flexibile with respect to future modification, tool change, and automation.
- The facility system should be capable of continuous operation while the facilities are undergoing expansion or modification.

Focus on ultrapure water (UPW)

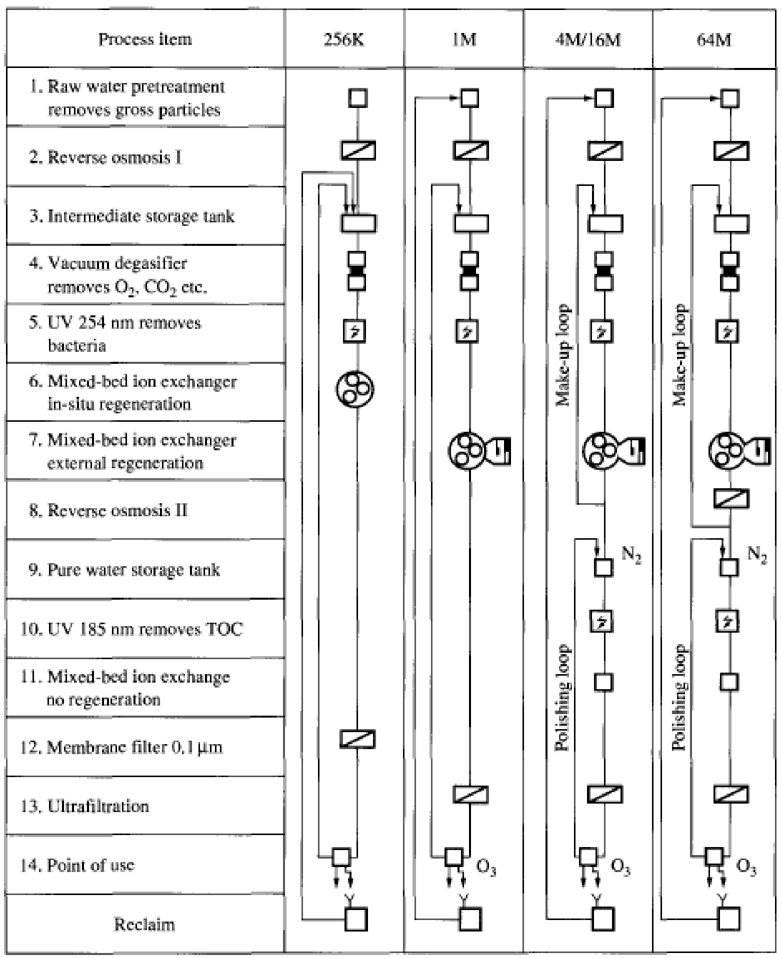


FIGURE 19
Evolution of ultrapure water system design. (*Courtesy of Christ AG. Switzerland.*)

- Process quality is critically dependent on ultra-pure water supply
- Used in every **cleaning** step
- Challenge is to waste minimum amount in complex preparation cycle
- Also reuse for other purposes, e.g. 70 % reclaim for 200 mm process. Much higher today.

Life Cycle Analysis LCA 1

1. “An LCA assesses the environment, safety, and health (ESH) burdens of a product or process beginning with the extraction of raw materials, material manufacturing, **then product manufacturing**, use, and disposal,” Sematech White Paper
2. To perform an LCA one needs a combo of database and a dedicated software tool

Life Cycle Analysis 2

“A full LCA boundary assesses the ESH burdens of a product or process beginning with the extraction of raw materials, material manufacturing, then product manufacturing, use, and disposal.

A modified LCA boundary could assess the ESH impacts of the manufacturing process.

It should be noted that in most cases a modified LCA approach is the most practical because nearly all of the ESH impacts lie with the processing and not with the processed wafer itself.

A modified LCA could be a gate-to-gate approach,”

From Sematech White Paper

LCA Case Study 1

- Two use clusters - infrastructure (fab), module (process)

” The environmentally significant areas were identified throughout the infrastructure and fab. The cooling water supply, recirculating air, and make-up air are the most energy-consuming processes in the infrastructure.

The thin films and dry etch modules are the most energy consuming fab processes. The most raw water used and wastewater generated are by the ultrapure water supply in the infrastructure and by the wafer cleaning/wet benches module in the fab.

The main consumer of organic chemicals is patterning/photoresist, while wafer cleaning/wet benches are the main consumers of inorganic chemicals.

The thermal, thin films, and ion implant processes use the most highly toxic and corrosive gases. Acidic and volatile organic compound (VOC) emissions are from thin film and patterning/photoresist, respectively.

The most waste generation comes from the wafer cleaning/wet benches processes due to the origin of sludge”

ISMI 2009

In January, ISMI launched its Environment, Safety and Health (ESH) Technology Center, dedicated to providing green solutions that lead to reduced energy consumption, lower costs, and greater productivity in chip manufacturing

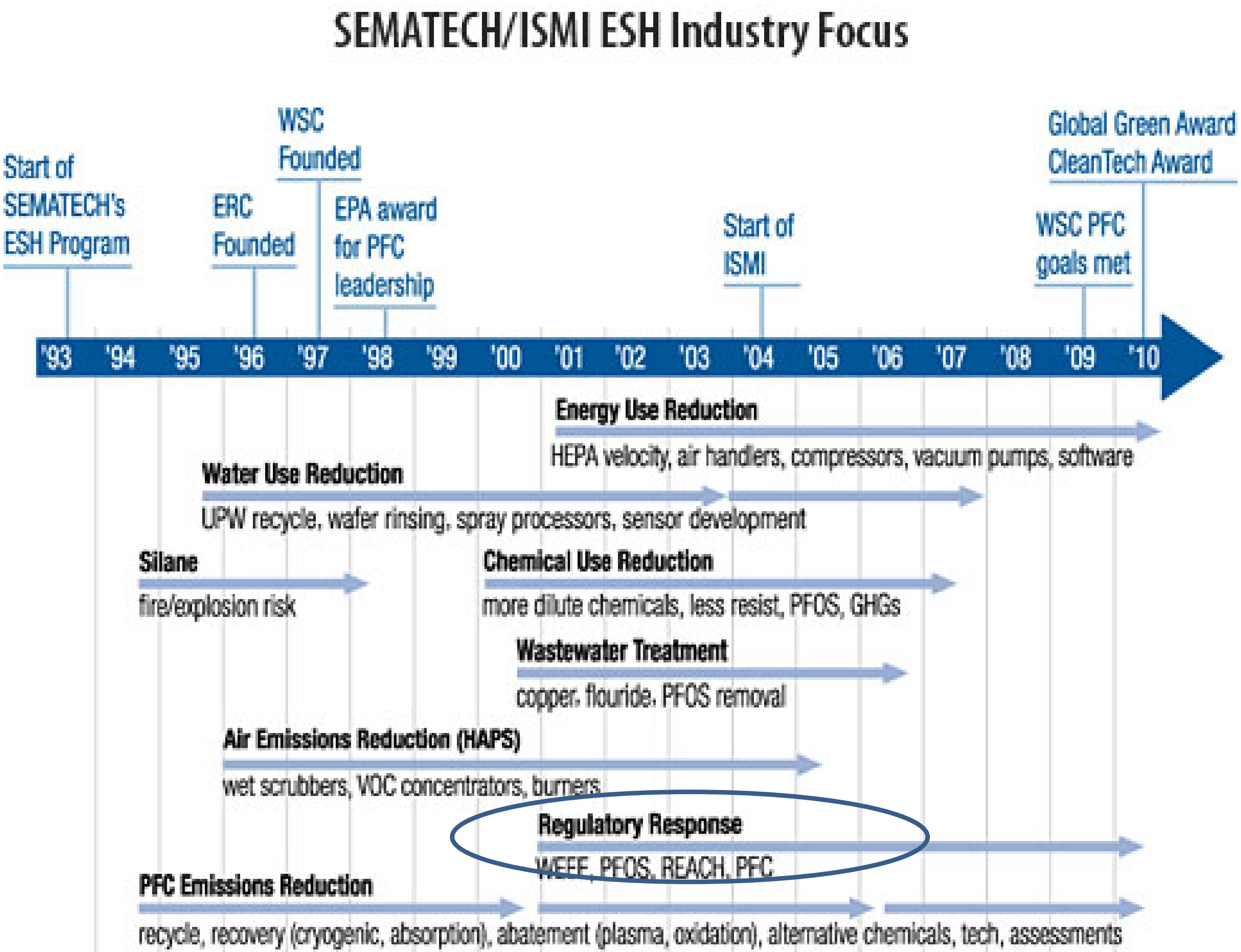
»» Promote energy and resource conservation through technical evaluations anddemonstrations

»» Advance green semiconductor operations and processes

»» Provide forums for sharing ESH benchmark data, surveys, and best practices

- http://ismi.sematech.org/research/esh/index.htm
- http://www.environmentalleader.com/2012/06/08/semiconductor-plants-show-dramatic-energy-reduction-says-report/

ISMI 2009


SEMATECH/ISMI ESH Industry Focus
Start of SEMATECH's ESH Program
ERC Founded
WSC Founded
EPA award for PFC leadership
Start of ISMI
WSC PFC goals met
Global Green Award
CleanTech Award
'93 '94 '95 '96 '97 '98 '99 '00 '01 '02 '03 '04 '05 '06 '07 '08 '09 '10
Energy Use Reduction
HEPA velocity, air handlers, compressors, vacuum pumps, software
Water Use Reduction
UPW recycle, wafer rinsing, spray processors, sensor development
Silane
fire/explosion risk
Chemical Use Reduction
more dilute chemicals, less resist, PFOS, GHGs
Wastewater Treatment
copper, flouride, PFOS removal
Air Emissions Reduction (HAPS)
wet scrubbers, VOC concentrators, burners
Regulatory Response
WEEE, PFOS, REACH, PFC
PFC Emissions Reduction
recycle, recovery (cryogenic, absorption), abatement (plasma, oxidation), alternative chemicals, tech, assessments

KEPI

Table 1 List of KEPIs

Category	KEPI Category	$KEPI_{Fab}$ Normalized [unit] per Product Type	$KEPI_{A/T}$ Normalized [unit] per Product Type	KEPI Reported Unit	References Data Source and Calculation Methods
Global Warming Impact	Direct GHG Emissions	kg CO_2 Eq / (cm^2 * # mask layers)	kg CO_2 Eq / (units * days)	kg CO_2 Eq	References Data Sources and Calculations
	Indirect GHG Emissions (Purchased Energy Usage)	kg CO_2 Eq / (cm^2 * # mask layers)	kg CO_2 Eq / (units * days)	kg CO_2 Eq	References Data Sources and Calculations
Water Resources	Total Input Water	Liters / (cm^2 * # mask layers)	Liters / (units * days)	liters	References Data Sources and Calculations
	Total Recycled/Reused Water	Liters / (cm^2 * # mask layers)	Liters / (units * days)	liters	
	Total Wastewater discharged from manufacturing and support operations	Liters / (cm^2 * # mask layers)	Liters / (units * days)	liters	
Chemicals	Total Chemicals	Kg / (cm^2 * # mask layers)	Kg / (units * days))	Kg	References Data Sources and Calculations
Waste	Total Waste	Kg / (cm^2 * # mask layers)	Kg / (units * days)	Kg	
	Total Haz Waste Recycled/ Re-used/ Re-claimed	Kg / (cm^2 * # mask layers)	Kg / (units * days))	Kg	
	Total Haz Waste Disposed/Treated	kg / (cm^2 * # mask layers)	Kg / (units * days)	Kg	
	Total Haz Waste Landfilled	Kg / (cm^2 * # mask layers)	Kg / (units * days)	Kg	
	Total Non-Haz Waste Recycled/ Re-used/ Re-claimed	Kg / (cm^2 * # mask layers)	Kg / (units * days)	Kg	
	Total Non-Haz Waste Disposed/Treated	Kg / (cm^2 * # mask layers)	Kg / (units * days)	Kg	
	Total Non-Hazardous Waste Landfilled	Kg / (cm^2 * # mask layers)	Kg / (units * days))	Kg	References Data Sources and Calculations

Key

Environmental

Performance

Indicators

(KEPIs)

Technology Transfer #09125069A-ENG
International SEMATECH Manufacturing Initiative
December 18, 2009

ITRS ESH Chapter

Table ESH1 ESH Difficult Challenges

Difficult Challenges ≥ 16 nm	*Summary of Issues*
Overall challenge	There is a need for Roadmap quality goals and metrics need to be defined for a substantial number of ESH technology requirements
Chemicals and materials management	• *Chemical Assessment*: There is a need for robust and rapid assessment methodologies to ensure that new chemicals/materials achieve timely insertion in manufacturing, while protecting human health, safety, and the environment. Given the global options for R&D, pre-manufacturing, and full commercialization, these methodologies must recognize regional regulatory/policy differences, and the overall trends towards lower exposure limits and increased monitoring. • *Chemical Data Availability*: Comprehensive ESH data for many new, proprietary chemicals/materials is incomplete, hampering industry response to the increasing regulatory/policy requirements on their use. In addition, methods for anticipating and forecasting such future regulatory requirements are not well developed.. • *Chemical Exposure Management*: There is incomplete information on how chemicals/materials are used and how process by-products are formed. Also, while methods used to obtain such information are becoming more standardized, their availability varies depending on the specific issue being addressed.
Process and equipment management	• *Process Chemical Optimization* There is a need to develop processes and equipment meeting technology requirements, while at the same time reducing their impact on human health, safety and the environment (e.g., using more benign materials, reducing chemical quantity requirements by more efficient and cost-effective process management). • *Environment Management*: There is a need to understand ESH characteristics, and to develop effective management systems, for process emissions and by-products. In this way, the appropriate mitigations (including the capability for component isolation in waste streams) for such hazardous and non-hazardous emissions and by-products can be properly addressed. Global Warming Emissions Reduction: There is a need to limit emissions of high GWP chemicals from processes which use them, and/or produce them as by-products. • *Water and Energy Conservation*: There is a need for innovative energy- and water-efficient processes and equipment. • *Consumables Optimization*: There is a need for more efficient chemical/material utilization, with improved reuse/recycling/reclaiming of them and their process emissions and by-products. • *Byproducts Management*: There is a need for improved metrology for by-product speciation. • *Chemical Exposure Management*: There is a need to design-out chemical exposure potentials and the requirements for personal protective equipment (PPE) • *Design for Maintenance*: There is a need to design equipment so that commonly serviced components and consumable items are easily and safely accessed, with such maintenance and servicing safely performed by a single person with minimal health and safety risks. • *Equipment End-of-Life*: There is a need to develop effective management systems to address issues related to equipment end-of-life reuse/recycle/reclaim.
Facilities technology requirements	• *Conservation*: There is a need to reduce energy, water and other utilities consumption and for more efficient thermal management of cleanrooms and facilities systems. • *Global Warming Emissions Reduction*: There is a need to design energy efficient manufacturing facilities, to reduce total CO_2 equivalent emissions.
Sustainability and product stewardship	• *Sustainability Metrics*: There is a need for methodologies to define and measure a technology generation's sustainability. • *Design for ESH*: There is a need to make ESH a design-stage parameter for new facilities, equipment, processes and products.

G450C Recommendations

- Establish Single Point of Contact for G450C and ITRS ESH TWG
- Balanced viewpoint of opportunities and challenges (i.e. emphasize how our technologies themselves can help address our ESH challenges)
- Define information flow, key roles/responsibilities, scope and ESH goals/requirements, technology gaps, overall objectives up front
- What are the tools needed for testing and characterization of the process
- Comprehend abatement (scale-up issues?) and opportunities for integrated solutions based on regional requirements (i.e. heat recovery, combined waste streams, capturing/re-use of waste to suppliers, to tools)
- Establish safety requirements that are needed (docs required, S2, S8?)
- Use total life cycle approach
- Integrate the concept of green engineering with green chemistry in the transition (establish the methodologies)
- Ensure proliferation of key learnings to existing technologies
- Innovative solutions for energy consumption in EUV, high gas (CO_2, H_2) usage, and safety of H_2 usage, novel tool design, materials efficiency, heat recovery and energy conservation
- Sensors for energy use and resource consumption are needed on 450mm tools with a focus on cost effectiveness (SEMI S23)
- Prioritize water and He usage as LIMITED RESOURCES

Table ESH2 ESH Requirements by Domain and Category

Restricted Chemicals	New chemicals	Nanotechnology
Assembly & Packaging	Intrinsic	Intrinsic
3D via etch **C(D)**	Chemical risk assessments **U**	Nanomaterials risk assessment methods **U**
FEP	ERM	ERM
Plasma Etch **C(D)**	Materials for novel logic & memory **C(N)**	Nanomaterials **C(N)**
Doping **C(N)**	FEP	
Interconnect	High-k & gate materials **I(N)**	
Plasma etch **C(D)**	Alternative surface prep **U**	
CVD chamber clean **C(D)**	Non-silicon, active substrates [channel] **C(N)**	
3D via etch **C(D)**	Novel memory materials **I(N)**	
Lithography	Interconnect	
PFOS/PFAS/PFOA materials **C(D)**	Low-k materials **I(N)**	
	Copper dep processes **I(N)**	
	Advanced conductors **U**	
	Planarization **I(N)**	
	Surface prep **I(N)**	
	Lithography	
	Novel patterning chemicals/materials **I(N)**	
Utilization/Waste Reduction	**Energy**	**Green Fab**
Intrinsic	Intrinsic	Intrinsic
Surface preparation UPW use **I(N)**	Total fab tools (kWh/cm^2) **I(D)**	Safety screening methodologies for new technologies **U**
Tool UPW usage **I(N)**	Total fab energy usage **I(D)**	Improvement in process chemical utilization **I(N)**
Assembly & Packaging	Total fab support systems energy usage **I(D)**	Reduce PFC emissions **C(D)**
Die thinning **U**	Factory Integration	Liquid and solid waste reduction **I(D)**
Molding processes **U**	Energy consumption **I(D)**	Reduce hazardous liquid waste by recycle/reuse **I(D)**
Waste & by-products **U**	Lithography	Reduce solid waste by recycle/reuse **U**
3D via etch **C(D)**	EUV **C(N)**	Define environmental footprint metrics for process, equipment, facilities, and products; reduce from baseline year **U**
ERM		Integrate ESH priorities into the design process for new processes, equipment, facilities, and products **U**
Nanomaterials **C(N)**		Facilitate end-of-life disposal/reclaim/
Materials for novel logic & memory **C(N)**		recycle **U**
Factory Integration		Factory Integration
Non-hazardous solid waste **U**		Fab eco-design **U**
Hazardous waste **I(D)**		Process eco-design **I(N)**

Table ESH3A ESH Intrinsic Requirements—Near-term Years

Year of Production	2011	2012	2013	2014	2015	2016	2017	2018	2019
I. Process and Equipment Technology Requirements									
Energy Consumption									
Total fab tools (kWh/cm^2) [1, 2] **Important**	0.43		0.35			0.30–0.25			
Water Consumption (driven by sustainable growth and cost)									
Surface preparation UPW use (% of 2011 baseline) **Important**	100		90			65			
Tool UPW usage (% of 2011 baseline) **Important**	100		90			65			
Chemical Consumption and Waste Reduction (driven by environmental stewardship and cost)									
Improvement in process chemical utilization (% of 2011 baseline) **Important**	100		90			65			
Limit PFC emission **Critical**	10% absolute reduction from 1995 baseline as agreed to by the World Semiconductor Council (WSC)		Maintain 10% absolute reduction from 1995 baseline						
Liquid and solid waste reduction (% of 2011 baseline) **Important**	100		90			65			
II. Facilities Technology Requirements									
Energy Consumption									
Total fab energy usage (kWh/cm^2) **Important**	0.85		0.7			0.6–0.5			
Total fab support systems energy usage (kWh/cm^2) [1] **Important**	0.43		0.35			0.30–0.25			
Chemical Consumption and Waste Reduction									
Reduce hazardous liquid waste by recycle/reuse* (% of 2011 baseline) **Important**	100		90			65			

[1] cm^2 per wafer out

[2] excluding EUV lithography

Manufacturable solutions exist, and are being optimized

Manufacturable solutions are known

Interim solutions are known

Manufacturable solutions are NOT known

ITRS specific process modules

- ***3.3.1 INTERCONNECT***
- The only explicitly-defined ESH goal for Interconnect is on copper recycle/reclaim.
- Planarization's increasing use presents particular issues both in consumables (e.g., slurries, pads, and brushes), as well as major chemicals and water use. Therefore, efforts should be made to develop planarization processes that will reduce overall water consumption, including the possible implementation of water recycle/reclaim for planarization and post-planarization cleans.
- High GWP (global warming potential) PFCs (perfluorocompounds) are used extensively in interconnect dry etch and chamber cleaning applications.

ITRS specific process modules

- ***3.3.2 FRONT END PROCESSING***
- There are no explicitly-defined ESH goals for Front End Processing. Thus, the discussion here is entirely on those issues which need to be addressed in setting Roadmap quality goals and metrics for the front end technology requirements judged to be Critical and Important.
- Alternative clean processes (e.g., dilute chemistries, solvent-based, sonic energy enhancement, simplified process flows, DI/ozone, gas phase, cryogenic, hot-UPW) may reduce ESH hazards and chemical consumption. The impact of such alternative cleaning methods on energy consumption should be addressed. Sustainable, optimized water use strategies (e.g., more efficient UPW production, reduced water consumption, and efficient rinsing) all can contribute to enhanced ESH performance.

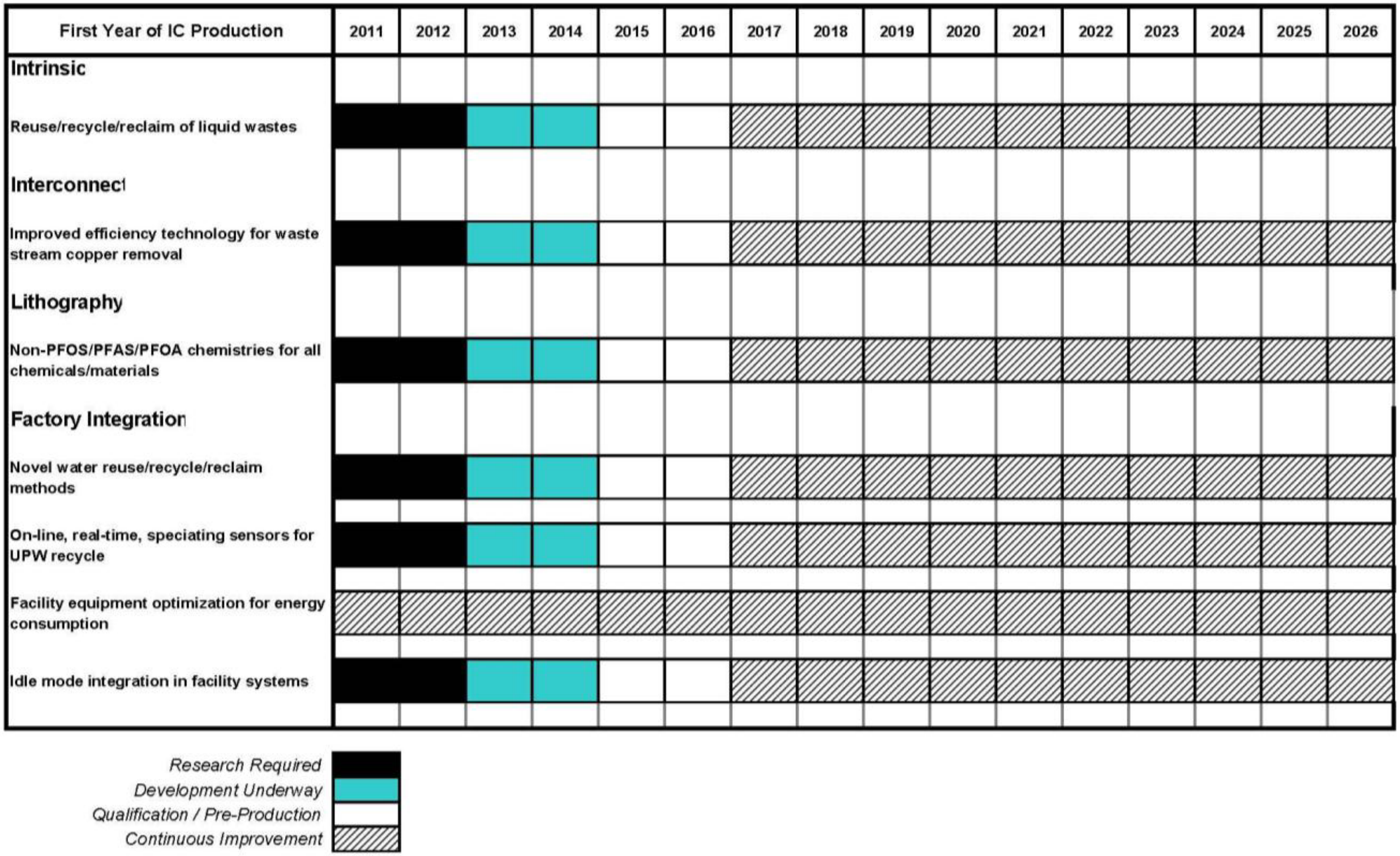
ITRS specific process modules

- ***3.3.3 LITHOGRAPHY***
- The only explicitly-defined ESH goal for Lithography is on PFOS/PFAS/PFOA alternatives development.
- In the process area, the concern is EUV technology, with energy consumption the major area to be addressed. The following brief analysis is only semi-quantitative, but serves to illustrate the nature of the concern. According to the Yield Enhancement thrust, a leading edge fab today consumes about 18 MW of power. According to the Lithography thrust, a single EUV exposure tool is expected to draw 0.5-2 MW. Thus, even for a fab containing only a few such tools, EUV process energy consumption becomes an important factor to be addressed in the industry's goals for energy metrics, carbon footprint, and greenhouse gas emissions.

ITRS specific process modules

- ***3.3.5 EMERGING RESEARCH MATERIALS***
- There are no explicitly-defined ESH goals for Emerging Research Materials.
- It is well known that nano-sized materials can have unique and diverse properties compared to their macro/bulk (even at micron dimensions) forms. These differences must be understood for the unique ESH challenges they may present. In addition, the new materials' small size may make standard ESH controls (e.g., emission control equipment) less than optimal. As a result, the following ESH considerations should be taken into account for future technology development:
- Developing effective monitoring tools to detect nanomaterials' presence in the workplace, in waste streams, and in the environment.
- Understanding new nanomaterials' toxicity as it may differ from their bulk forms. This goal involves both developing rapid nanomaterials toxicity assessment methods, as well as nanomaterials toxicity models.

ITRS potential solutions

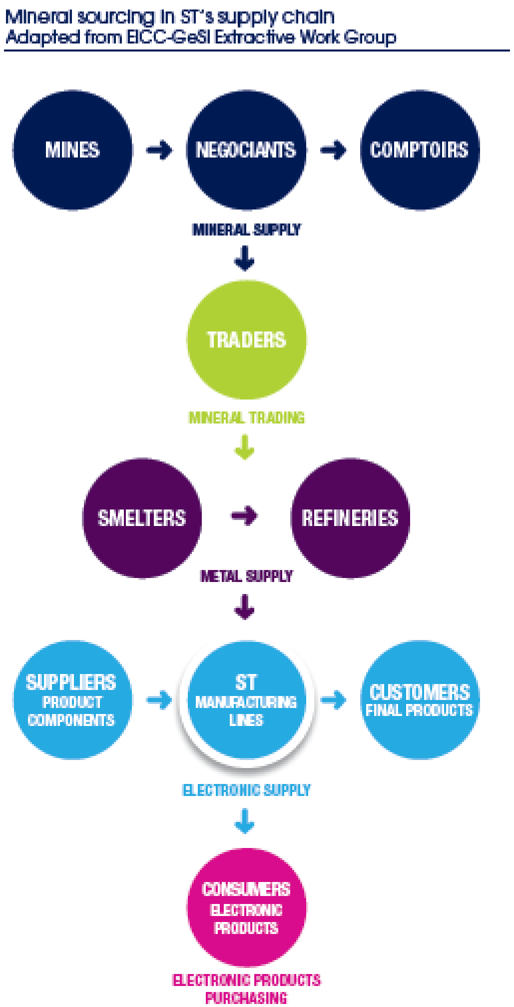


Supply Chain

- Semiconductor industry relies on supply of metal from conflict regions in central Africa
- Tantalum, Tin, Tungsten, Gold, also known as 3TG or 3T’s and Gold

- ST Sust. Report, p28, 2011
- http://www.intel.com/content/dam/doc/policy/policy-conflict-minerals.pdf

Supply Chain 3TG



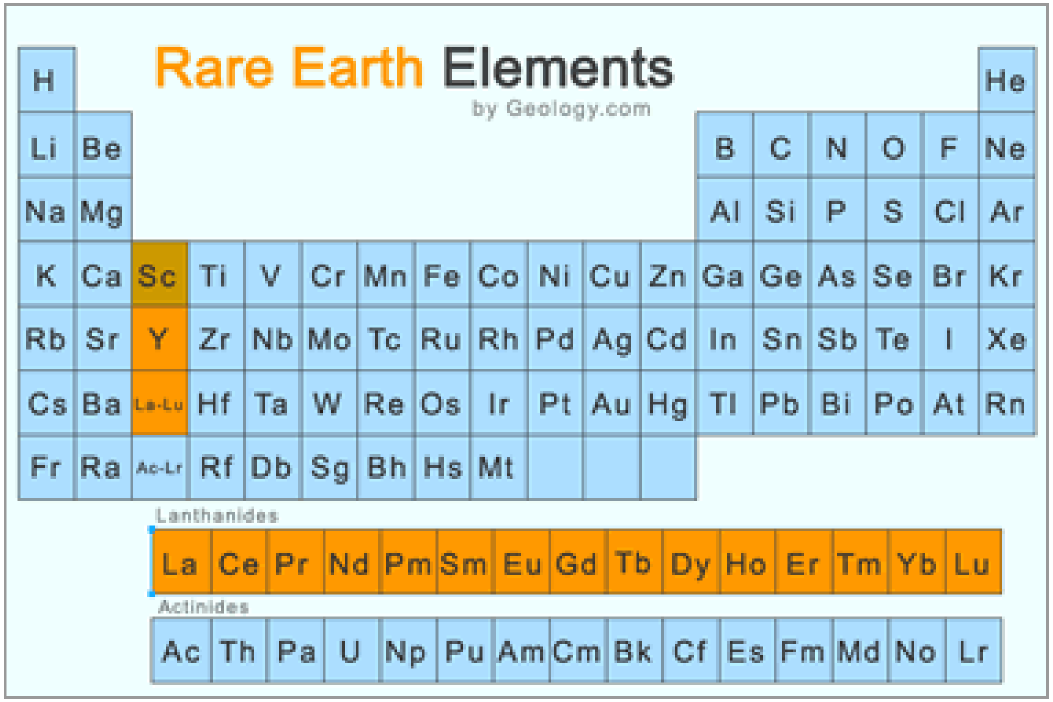
2011 results

Conflict Minerals

	2011
Number of materials suppliers and subcontractors involved in the EICC-GeSI Due Diligence survey	171
Number of suppliers and subcontractors that are associated with at least one 3TG metal (involved suppliers)	84
% (number) of involved suppliers and subcontractors that have completed the EICC-GeSI Due Diligence survey	100% (84)
Number of smelters identified in ST's raw materials supply chain	61
Number of smelters identified in ST subcontractors' supply chains	111
% of ST Tantalum suppliers that use conflict-free smelters	66%

Supply Chain Rare Earth Metals

Table 1. Metals under threat: the world total reserve of each, and the expected time of exhaustion based on current rates of production and their principal uses.
Aluminium, 32,350 million tonnes, 1027 years (transport, electrical, consumer-durables)
Arsenic, 1 million tonnes, 20 years (semiconductors, solar-cells)
Antimony, 3.86 million tonnes, 30 years (some pharmaceuticals and catalysts)
Cadmium, 1.6 million tonnes, 70 years (Ni-Cd batteries)
Chromium, 779 million tonnes, 143 years (chrome plating)
Copper, 937 million tonnes, 61 years (wires, coins, plumbing)
Gallium 1000 - 1500 tonnes, 5 - 8 years (semiconductors, solar cells, MRI contrast agents).
Germanium, 500,000 tonnes (US reserve base), 5 years (semiconductors, solar-cells)
Gold, 89,700 tonnes, 45 years (jewellery, "gold-teeth")
Hafnium, 1124 tonnes, 20 years (computer-chips, nuclear control-rods)
Indium, 6000 tonnes, 13 years (solar-cells and LCD's)
Lead, 144 million tonnes, 42 years (pipes and lead-acid batteries)
Nickel, 143 million tonnes, 90 years (batteries, turbine-blades)
Phosphorus, 49,750 million tonnes, 345 years (fertilizer, animal feed)
Platinum/Rhodium, 79,840 tonnes, 360 years for Pt (jewellery, industrial-catalysts, fuel-cells, catalytic-converters)
Selenium, 170,000 tonnes, 120 years (semiconductors, solar-cells)
Silver, 569,000 tonnes, 29 years (jewellery, industrial-catalysts)
Tantalum, 153,000 tonnes, 116 years, (cell-phones, camera-lenses)
Thallium, 650,000 tonnes, 65 years (High Temperature Superconductors, Organic Reagents)
Tin, 11.2 million tonnes, 40 years, (cans, solder)
Uranium, 3.3 million tonnes, 59 years (nuclear power-stations and weapons)
Zinc, 460 million tonnes, 46 years (galvanizing).

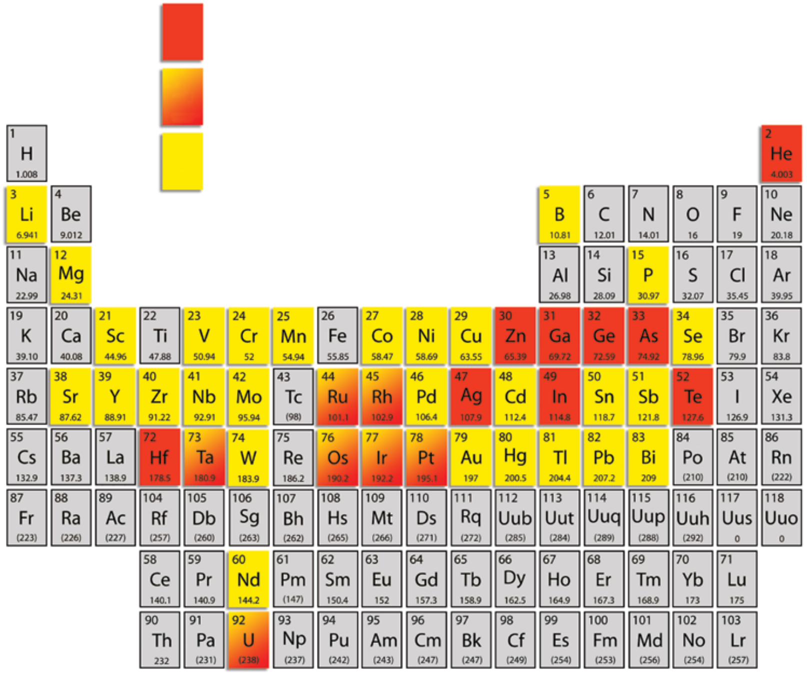


http://oilprice.com/Alternative-Energy/Renewable-Energy/Peak-Minerals-Shortage-of-Rare-Earth-Metals-Threatens-Renewable-Energy.html

Supply Chain Rare Earth Metals

Table 2. It is predicted that the growth in world population, along with the emergence of new technologies will result in some key-metals being used up quite rapidly, e.g.

Antimony, 15 - 20 years.
Gallium, 5 years.
Hafnium, 10 years.
Indium, 5 - 10 years.
Platinum, 15 years.
Silver, 15 - 20 years.
Tantalum, 20 - 30 years.
Uranium, 30 - 40 years.
Zinc, 20 - 30 years.



http://oilprice.com/Alternative-Energy/Renewable-Energy/Peak-Minerals-Shortage-of-Rare-Earth-Metals-Threatens-Renewable-Energy.html
http://www.rsc.org/images/Endangered%20Elements%20-%20Critical%20Thinking_tcm18-196054.pdf

Water Policy

- http://www.intel.com/content/www/us/en/policy/policy-water.html

Conserving Water

Water Policy Examples

2011 results

For more information on our environmental results, please refer to page 66

Consumption of water (per unit of production):
normalized values / EN8 / 2.2

Recycled and reused total water
/ EN10 / 2.2

	2007	2008	2009	2010	2011
Total water used (1,000m³)	29.567	27.791	25.622	27.736	**29.113**
Water recycling and re-usage rate (%)	26.51	34.53	36.20	37.29	**40.53**

Total water discharge / EN21

	2007	2008	2009	2010	2011
Water discharge (1,000m³)	17,934	14,931	12,867	14,000	**13,650**
Treated in ST waste water treatment plant (%)	54	76	75	73	**74**
Treated in external waste water treatment plant* (%)	59	51	43	57	**55**

** Part of this water has already been treated in ST's waste water treatment plant, meaning that 100% of water discharge is either treated internally, externally, or both*

- 40.5 % water reuse in scrubbers, cooling, etc. ST Sust. Report, p38, 2011
- Water footprint reduced by 73% since 1994.

Solar Power Intel Example

Solar Installations. Since 2009, we have partnered with third parties to complete 15 solar electric installations across nine Intel campuses in Arizona, California, New Mexico, Oregon, Israel, and Vietnam—collectively generating more than 5 million kWh per year of clean solar energy. The projects include a 1-megawatt solar field that spans nearly 6 acres of land on Intel's Folsom, California campus; 5 rooftop installations; and 8 solar support structures in Intel parking lots. Each U.S. installation was ranked among the 10 largest solar installations in its respective utility territory when installed. The RECs generated by these installations are often transferred to the local utility to support their regulatory obligations and programs.

In addition to these new installations, we had previously installed solar energy systems in India, New Mexico, and Oregon. Solar hot water systems now supply close to 100% of the hot water used at our two largest campuses in India, saving approximately 70,000 kWh annually.

Cleantech Investments. Since 2008, Intel Capital, Intel's global investment organization, has invested more than $175 million in the renewable energy, smart grid, and energy-efficiency sectors to accelerate innovation in over two dozen start-up companies in the U.S., China, India, and Latin America that are developing alternative power sources.

Investing in Renewable Energy

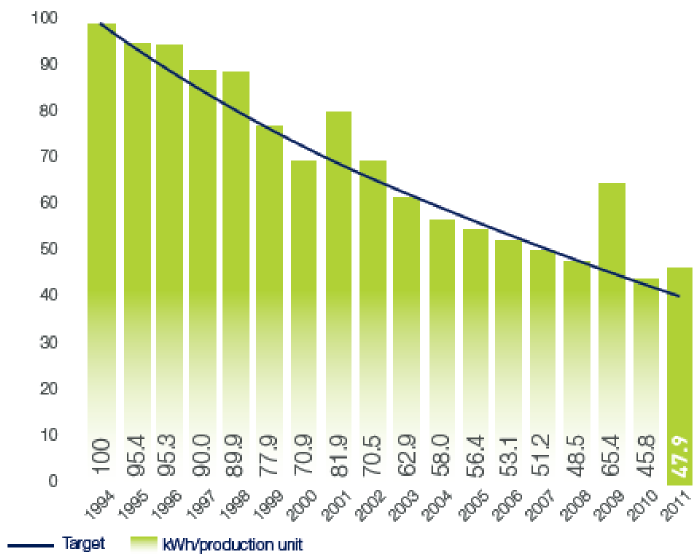
- http://newsroom.intel.com/community/intel_newsroom/blog/2011/02/01/intel-increases-renewable-energy-credit-purchase-to-25-billion-kilowatt-hours

Wind Power ST Example

2011 results

For more information on our environmental results, please refer to page 66

Consumption of energy (per unit of production): normalized values / EN4 / 2.1



Electricity produced by ST-owned windfarm
/ EN3 / 3.3

GWh

	2007	2008	2009	2010	2011
Electricity	30.0	21.7	22.7	23.8	25.1

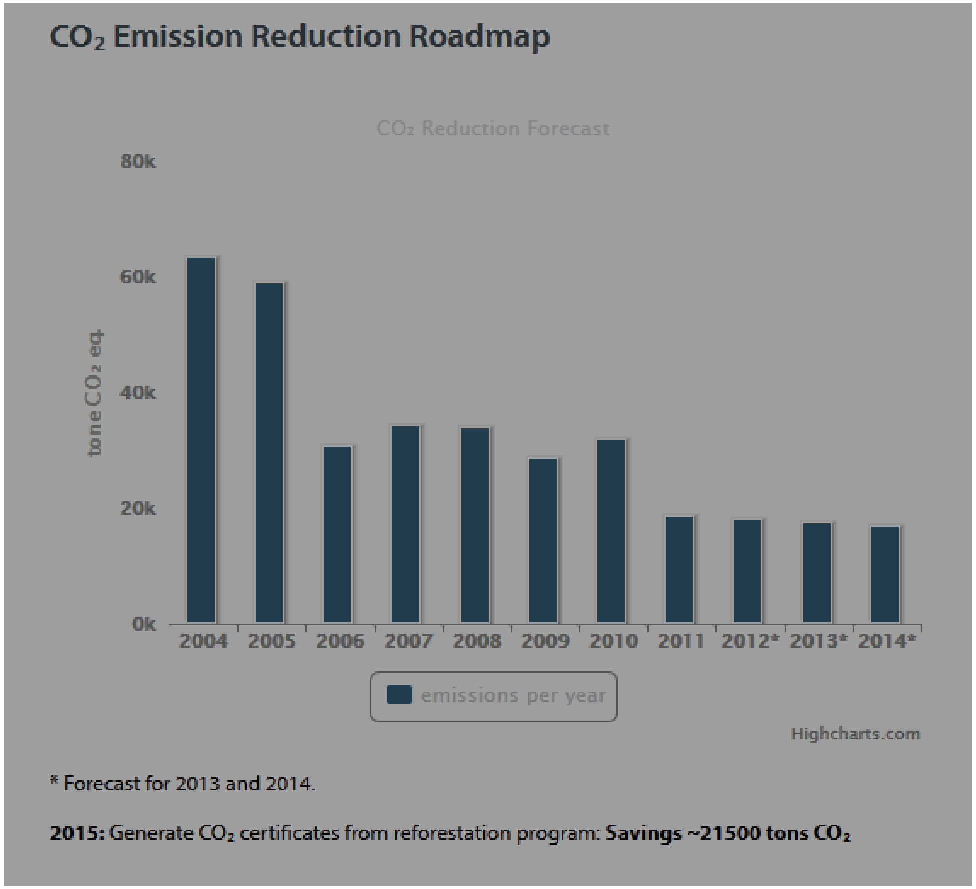
Tenders that incorporate criteria on energy efficiency and the use of CO_2 emission-free and/or renewable energy

%

	2011
Call for tenders that include criteria on energy efficiency and use of CO_2 emission-free and/or renewable energy	100
Retained offers with best environmental proposal	50

More performance indicators are available on pages 64 to 66

Carbon Neutral AMS Example



austriamicrosystems plans to be 100% carbon neutral by 2015

Have spent the last 2-years mapping its carbon footprint, IC manufacturer austriamicrosystems is targeting to become 100% carbon neutral by 2015. The Austria-based firm said that it had already achieved a 50% reduction of CO2 equivalents or 31,000 tons by the end of 2010 and expects CO2 emission equivalents to decline by more than 9,000 tons in 2011, by switching to 100% green electricity based mainly on hydro-electric power sources. The company wants other semiconductor firms to follow its example

GHG & GWP

2011 results

For more information on our environmental results, please refer to page 66

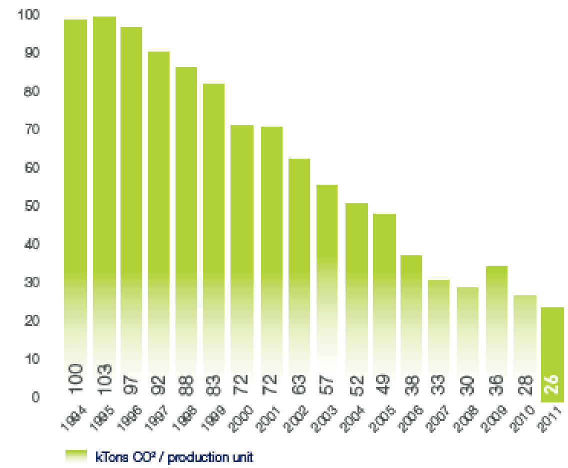
Summary of net CO_2 emissions

/ EN16 / EN17 / EN18 / EN29 / [2] 3.1 / 3.2 / 3.4

kTons

	2007	2008	2009	2010	2011
Direct emissions*	532	482	337	485	**493**
Direct emissions due to PFCs	481	439	296	453	**462**
Direct emissions due to boilers	51	43	41	32	**31**
Indirect emissions (purchased electricity)	1,029	882	876	907	**903**
Other indirect emissions (transportation**)	107	89	104	126	**116**
Total emissions***	1,668	1,453	1,317	1,518	**1,574**
Sequestration due to the implementation of reforestation projects****	133	176	215	249	**277**
Total direct net emissions	399	306	122	236	**216**

CO_2 emissions: normalized values / EN16[2] / 3.0



- ICT sector is responsible for 2.5 % of global carbon emissions

Summary

- Used many different sources as input for lecture material
- Industry show great activity, their overall focus is on GREEN FABS
- Organizational support for sustainablity metrics and indicators in semiconductor manufacturing from ISMI/ESH and ITRS
- KEPI and sustainability for specific process modules has been addressed
- Resource managment is important for UPW and energy use
- Raw material supply needs to be done in a fair and sustainable way
- Regulatory Response is only minor part of the sustainability effort

Extra 3TG

On July 21, 2010, the US President

signed into law the Dodd-Frank Act, drafted by the Securities and Exchange Commission (SEC), which

requires manufacturers of electronics devices

to undertake due diligence on their

3TG supply chains, to publicly disclose their conflict minerals policy and to enforce conflict-free

measures in their

procurement processes.

Conflict Minerals Free Management: The U.S. "Dodd-Frank Wall Street Reform and Consumer Protection Act"("Section 1502") and the Electronic Industry Citizenship Coalition (EICC) requires electronic product manufacturers to trace their metal mining sources, including gold, tantalum, tungsten and tin, to avoid minerals mined in conditions of environmental destruction and human rights abuses, notably in the eastern provinces of the Democratic Republic of the Congo. TSMC is conducting a supply chain survey to require suppliers to disclose the information of smelters and mines. Some suppliers are unwilling to reveal their name and origin of their suppliers due to commercial confidentiality. However, TSMC shall continue to require its suppliers to improve and expand their disclosures so as to fulfill regulatory and customer requirements.

Extra GHG

21.2.4.9 Environmental Health and Safety

As massive amount of consumables are used during IC manufacturing, environmental health and safety issues have become an important consideration for process design. As these issues are discussed in detail elsewhere in the handbook, we only briefly comment here on some etch relevant issues.

Etching utilizes gases that are often toxic, corrosive, or contribute to global warming. Many of these gases survive for a long time in the atmosphere (e.g., Half-life (CF_4)Z50,000 year, Half-life (c-C_4F_8)Z3200 year) in the atmosphere and have high global warming potential (e.g., GWP (C_2F_6)Z12500, GWP (SF_6)Z24,900). It is obvious that we cannot afford to release un-reacted etch gases in the atmosphere. Effort is therefore underway to reduce harmful etch relevant environmental impact through abatement and process optimization. Abatement devices are being developed that treat etch effluents and transform them into less harmful substances.[19] These abatement devices can however be expensive and add their own environmental risks by consumption of combustible materials and use of large quantities of water. In addition, etching gases with lower GWP are being developed (e.g., C_5F_8, C_4F_6) and are replacing the more environmentally harmful gases. In some cases, these alternate chemistries have shown to offer process advantages in addition to lower GWP.