Sustainable fabrication

Professor

B. Gunnar Malm

KTH Royal Institute of Technology

Sustainability definition

- Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs

https://en.wikisource.org/wiki/Brundtland_Report

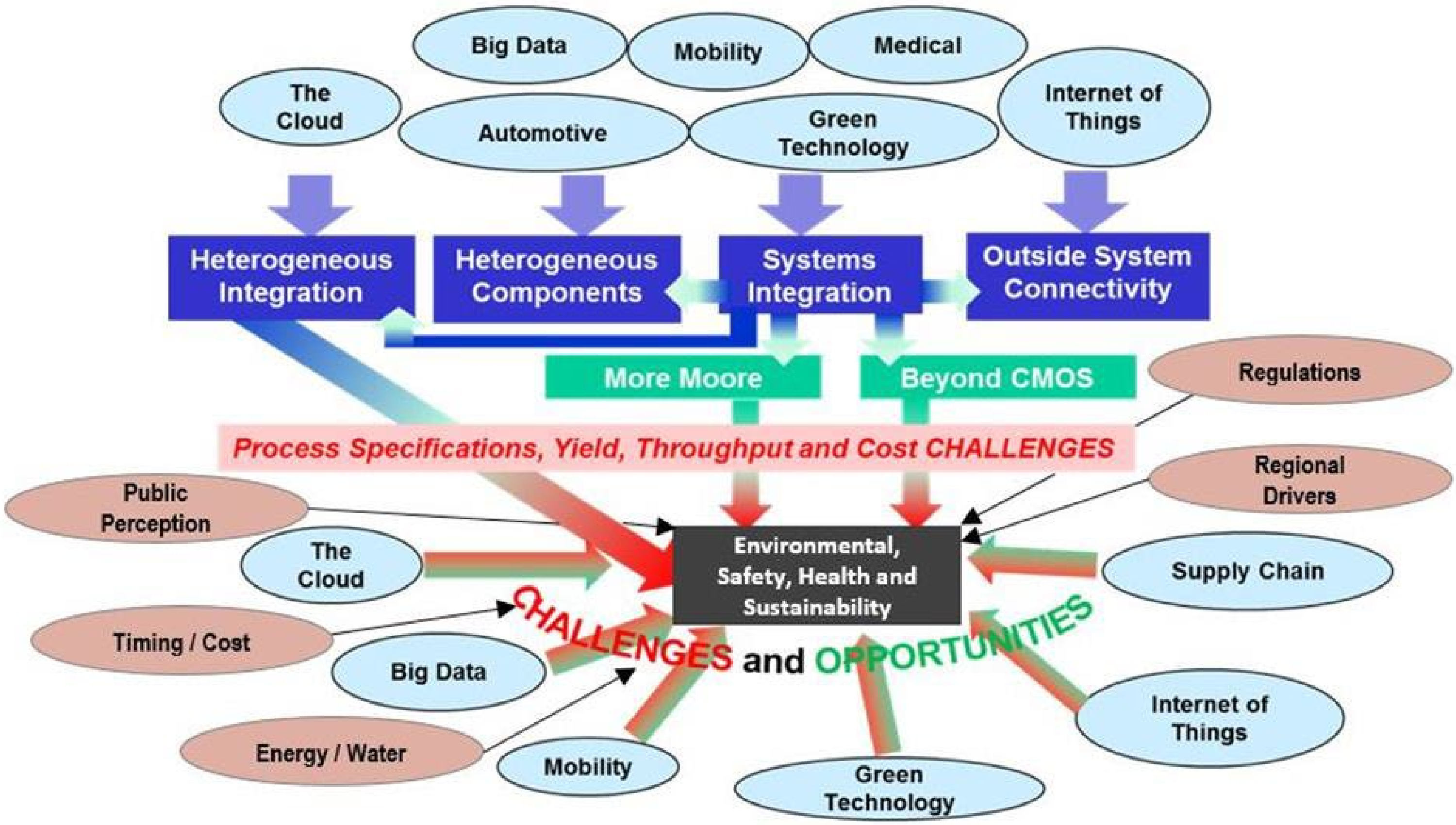
Topics

- 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

Topics cont.

- Sustainable fab operations
  - Electricity, water consumption, recycling/reuse
- Environmental Impact
  - Direct and Indirect GHG emissions, exhaust/scrubbing, contamination, including emerging nanomaterials
- Sustainable resource supply
  - Raw materials including wafers, metals, and gasses

Roadmap (IRDS 2017 & 2020)



ITTS Roadmap view (2013 to be updated)

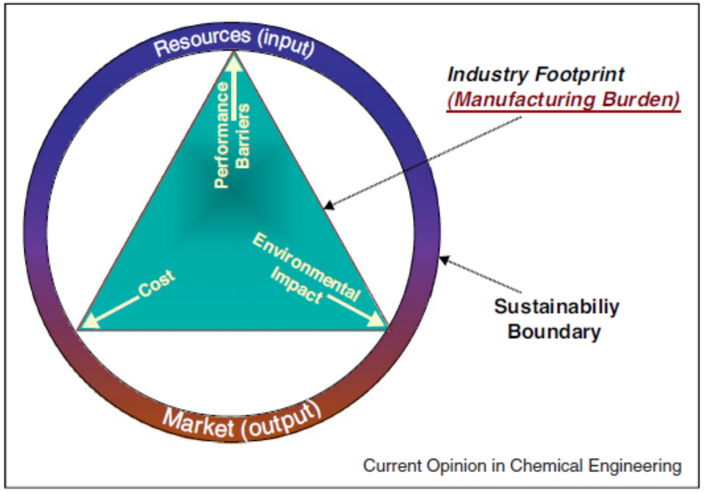
Table ESH5 Facilities Technology Requirements

Year of Production	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*
Facilities Design																
Facilities Design **Important**	Meet established goal and metrics						Meet established goal and metrics									
Water																
Total fab* water consumption (liters/cm^2) [1]																
300mm/450mm fabs	7.8	7.8	7.3	7.0	6.4	6.4	5.8	5.5	5.5	5.3	5.0	5.0	5.0	4.6	4.6	4.6
200mm fabs	7.6	7.6	7.0	6.4	5.8	5.8	5.0	4.8	4.8	4.3	4.1	4.1	3.9	3.5	3.5	3.5
Important																
Total UPW consumption (liters/cm^2) [1] **Important**	6.5	6.5	6.5	6.0	6.0	6.0	5.0	5.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Site water recycled/reclaimed** (% of use) **Important**	50%	50%	60%	60%	70%	70%	70%	75%	75%	75%	80%	80%	80%	90%	90%	90%
Energy (electricity, natural gas, etc.)																
Total fab energy usage (kWh/cm^2)																
Non EUV	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6
EUV			1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Important																
Waste																
Hazardous waste (g per cm^2) [1] **Important**		8			7.5		7.2	7.2	7.2	7.2	6.5	6.5	6.5	6	6	6
Air Emissions																
Volatile Organic Compounds (VOCs) (g per cm^2) [1] **Important**		0.06			0.055		0.05	0.05	0.05	0.05	0.045	0.045	0.045	0.045	0.045	0.045
Fluorinated greenhouse gases, fluorinated heat transfer fluids, and nitrous oxide **Critical**	Normalized emission rate (NER) to be 0.22 kg CO_2 equivalent/cm^2 by 2020 -- as agreed to by the World Semiconductor Council (WSC).			Normalized emission rate (NER) to be 0.22 kg CO_2 equivalent/cm^2 by 2020 -- as agreed to by the World Semiconductor Council (WSC).					Normalized emission rate (NER) <0.22 kg CO_2 equivalent/cm^2							

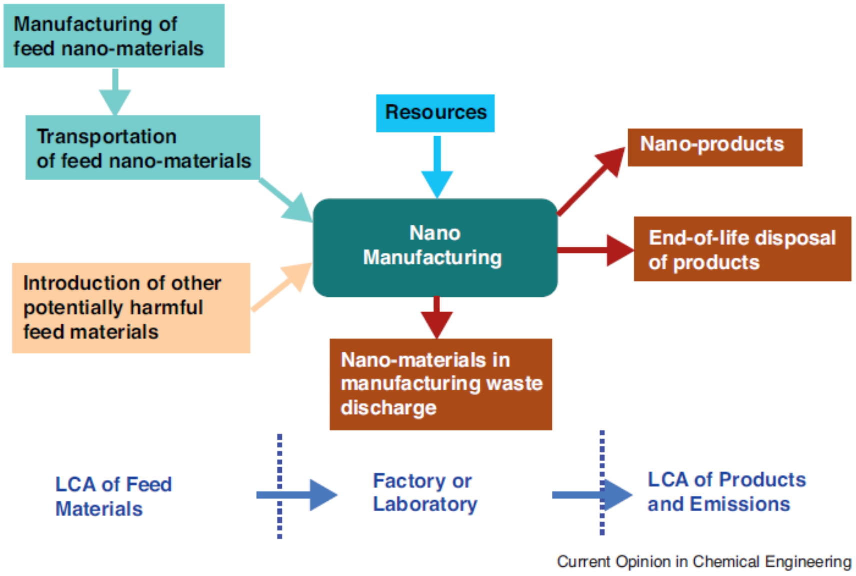
Manufacturable solutions exist, and are being optimized (white)
Manufacturable solutions are known (yellow)
Interim solutions are known (yellow/red hatched)
Manufacturable solutions are NOT known (red)

Notes for Table ESH5:

Sustainable nano-manufactuiring

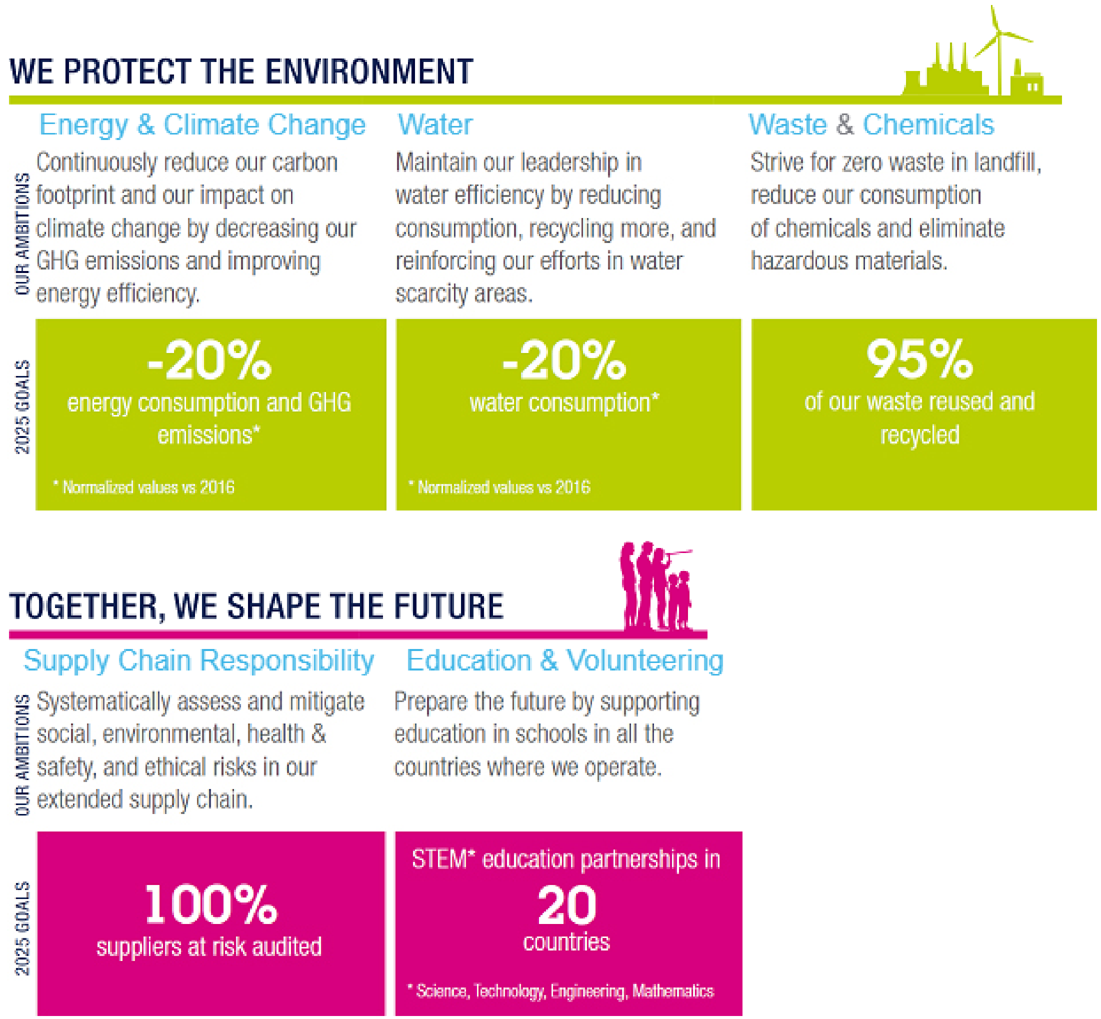


Relationship among factors that determine the sustainability of an industry or a manufacturing operation: basis for qualitative analysis and quantitative prediction.



http://dx.doi.org/10.1016/j.coche.2012.03.004

Example Sustainability Priorities



- European leader in microelectronics, downloaded, May 2021

Example Sustainability Priorities

We reduce our climate footprint by investing in alternative energy and smarter technologies. We increase our climate handprint by helping other sectors reduce their footprints. We also work with others to improve industry and policy. Since 2008, Intel has:

- Invested more than $145 million in energy-conservation projects (saving an estimated 3.19 billion kWh of energy)
- Installed more than 40 on-site projects that use solar, wind, fuel cell, and other alternative energy sources worldwide
- Remained the largest voluntary purchaser of green power in the United States

In 2015, we purchased 3.4 billion kWh of green power, enough to meet our US electricity use 100%. In October 2015, we joined the American Business Act on Climate Pledge.

- World leader in microelectronics, downloaded, May 2021

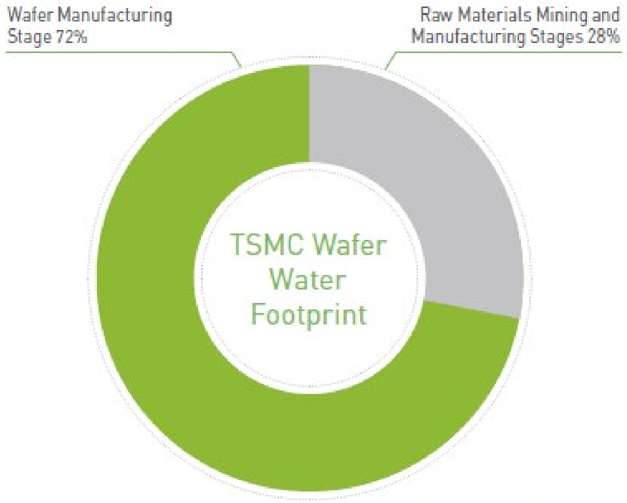
Fab comparisons progression (legacy data)

http://www.tsmc.com/english/csr/green_manufacturing.htm

Water usage reduction (legacy data)

TSMC Water Conservation Performance in Recent 5 years

Item	2011	2012	2013	2014	2015
Average process water recycling rate (%)[Note1]	84.6	86.5	86.9	87.6	87.3
Process water saved (Million m^3)	37.73	53.37	52.23	56.22	65.25
Water saved, measured by standard swimming pools[Note2]	15,094	21,347	20,918	22,490	26,101
Water saved, measured by the full capacity of Baoshan Reservoir II [Note3]	1.17	1.66	1.63	1.75	2.03
Process water saving/Total water usage	1.55	2.07	1.77	1.61	1.92



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%

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

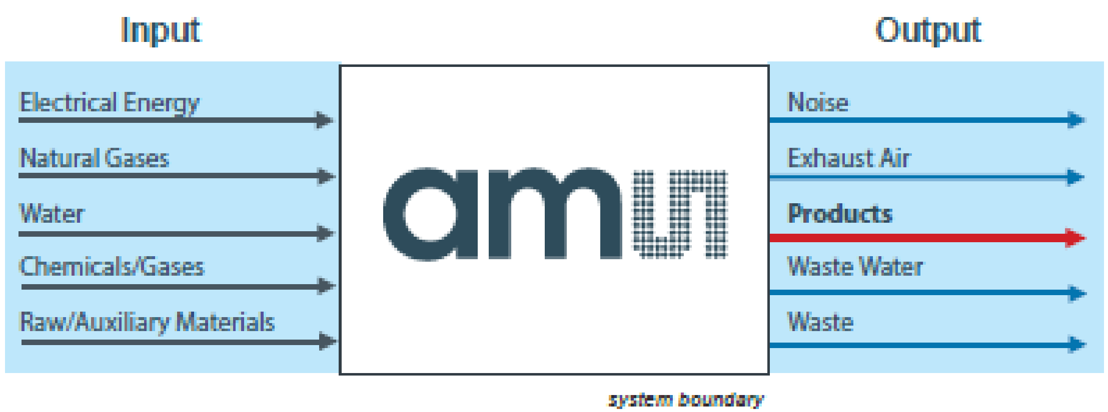
Resource needs cleanroom

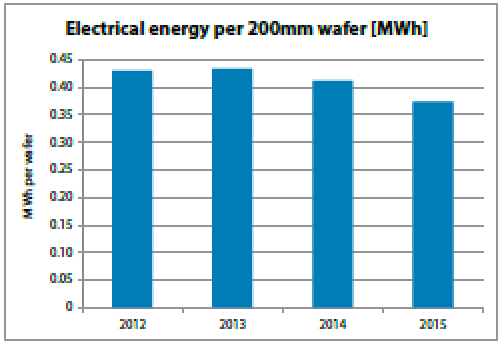
Category	Module or process
Energy for infrastructure	cooling water supply, recirculating air, and make-up air
Energy for processes	thin films and dry etch in future EUV litho
Chemicals	patterning/photoresist & wafer cleaning/wet benches
Emissions (VOC, GHG)	thin film and patterning/photoresist

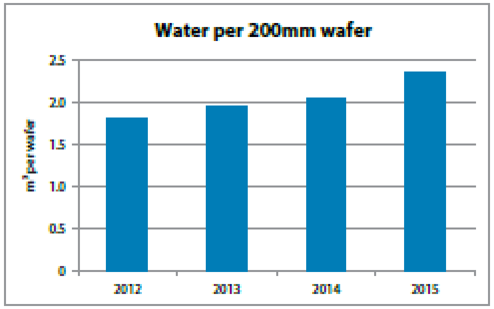
Microchip fabrication LCA AMS 2015

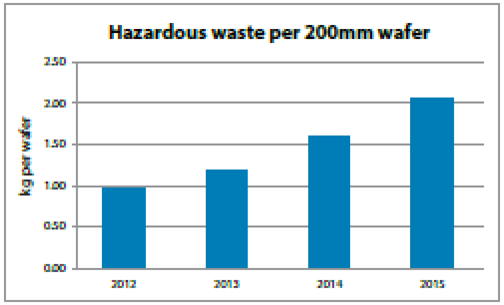
3.3. Environmental Aspects

The activities of ams in Premstaetten and Calamba give rise to impacts on the environment typical for semiconductor factories. This includes consumption of energy, use of water, generation of wastewater, exhaust air from production, emissions from the various boiler plants, vapor from the cooling towers and generation of wastes. The current environmental aspects at the location for the existing plant and the anticipated environmental aspects of our production line are explained in the following sections.



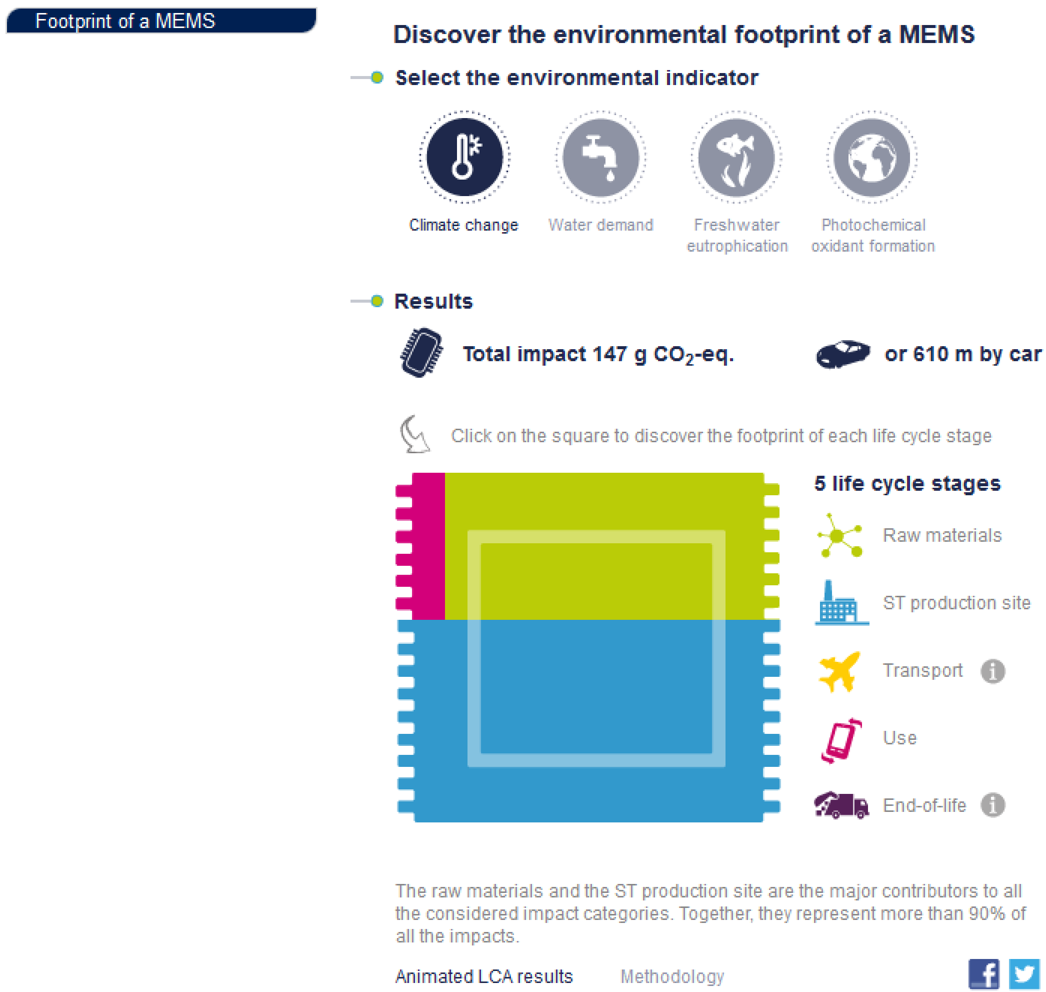






Footprint vs. product type

Footprint of a MEMS



http://www.st.com/web/en/about_st/mems_footprint.html?sc=mems-footprint

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

Mineral sourcing in ST's supply chain
Adapted from EICC-GeSI Extractive Work Group

2011 results

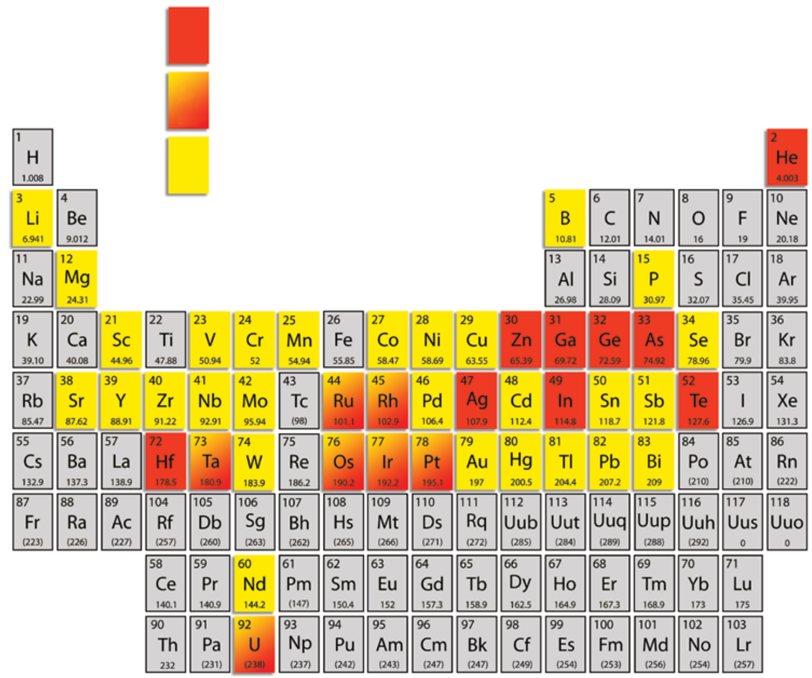
Conflict Minerals

	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 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://www.rsc.org/images/Endangered%20Elements%20-%20Critical%20Thinking_tcm18-196054.pdf

Green Chemistry

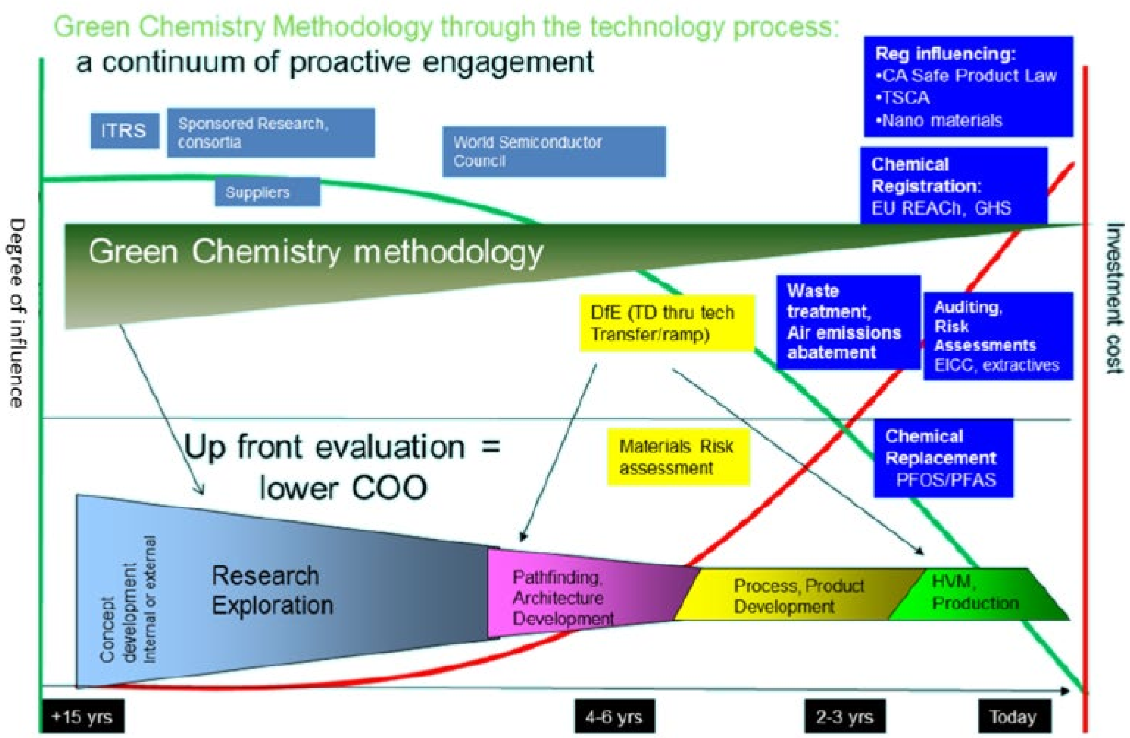


Figure ESH-2 ESH/S Engagements Across the Technology Lifecycle