NSF/SRC Engineering Research Center

Environmental Implications and Impact of Semiconductor Manufacturing

Farhang Shadman

A University-Industry Collaborative Program

Founding Universities (1996)

- U Arizona
- U California – Berkeley
- MIT
- Stanford

Other University members

- Arizona State U (1998 -)
- Columbia (2006 - 2009)
- Cornell (1998 -)
- Georgia Inst. of Tech. (2009 -)
- U Maryland (1999-2003)
- U Massachusetts (2006 - 2009)
- U North Carolina (2009 -)
- Purdue (2003 - 2008)
- U Texas - Dallas (2009 -)
- Tufts (2005 - 2008)
- U Washington (2008-)
- U Wisconsin (2009-)
- UCLA (2011 -)
- North Carolina A&T (2012 -)
- Johns Hopkins (2012 -)
- Colorado School of Mines (2012 -)

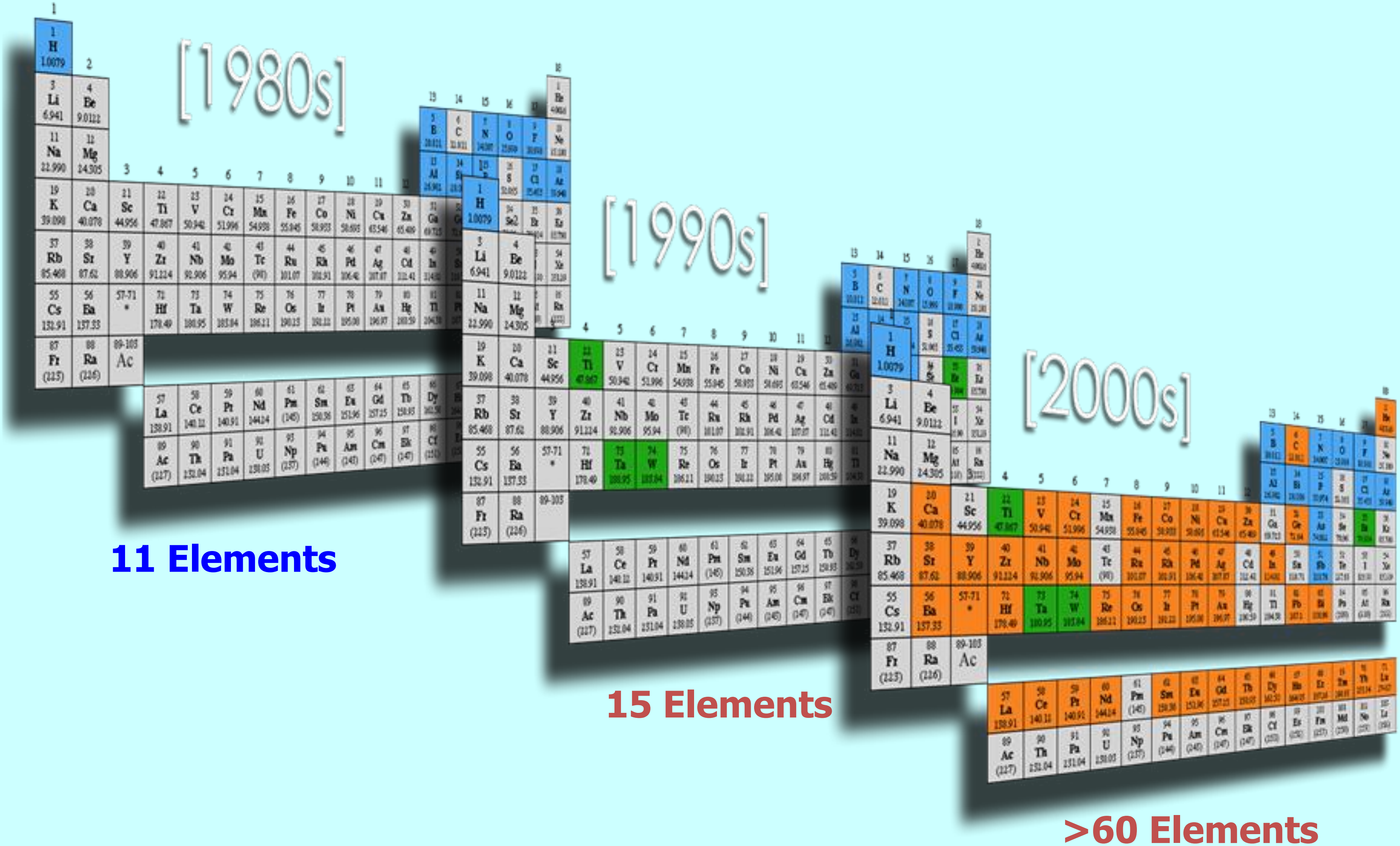
Presentation Overview

Nano-manufacturing is not simply an extrapolation or scale-down version of the larger-scale manufacturing:

a) **It has unique ESH and sustainability challenges.**

b) **It also presents opportunities for application of new tools and techniques.**

Introduction of New Materials



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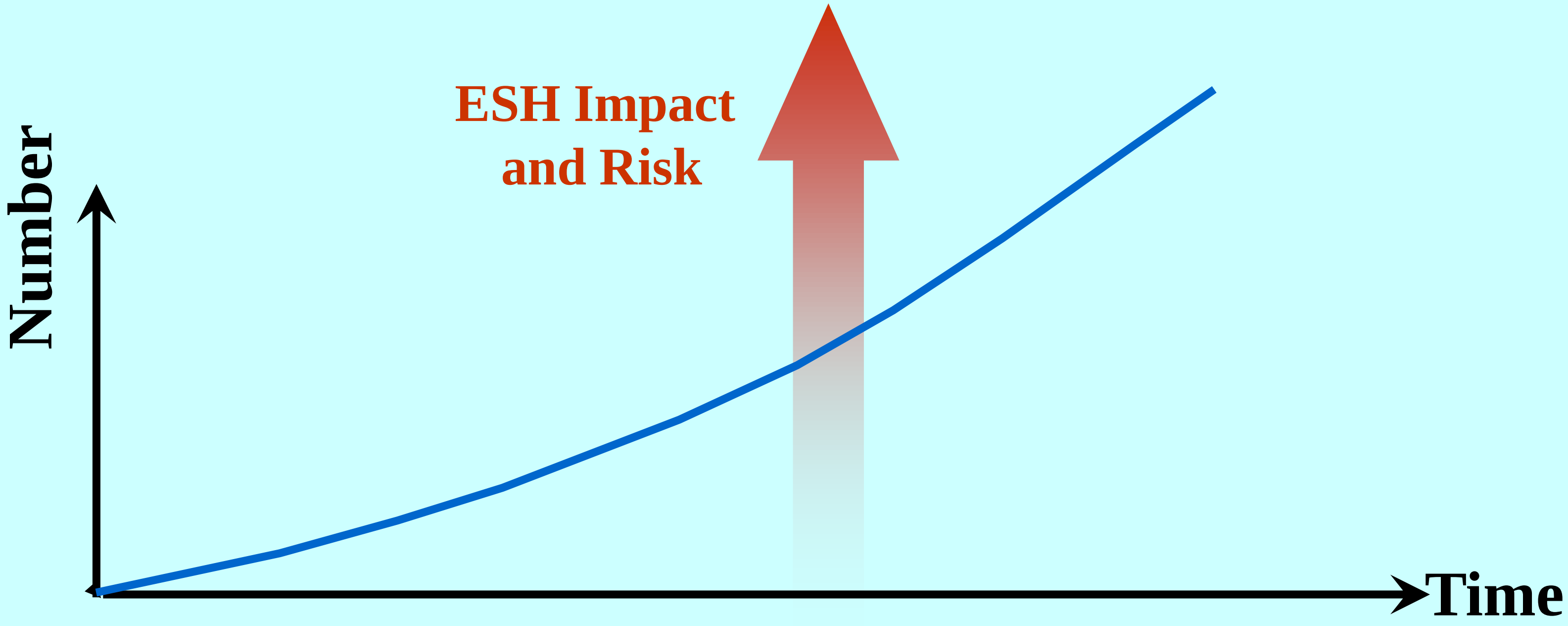

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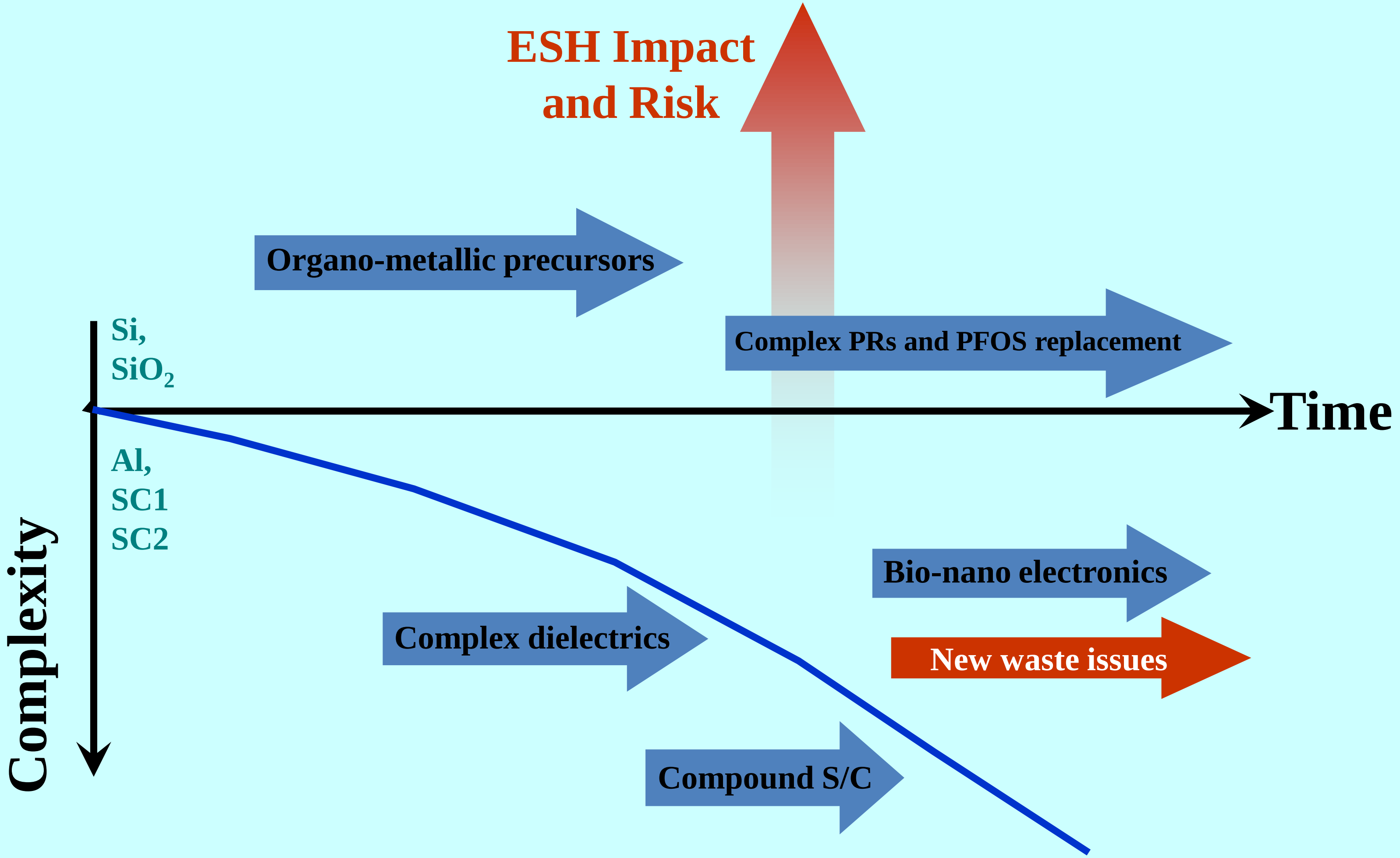

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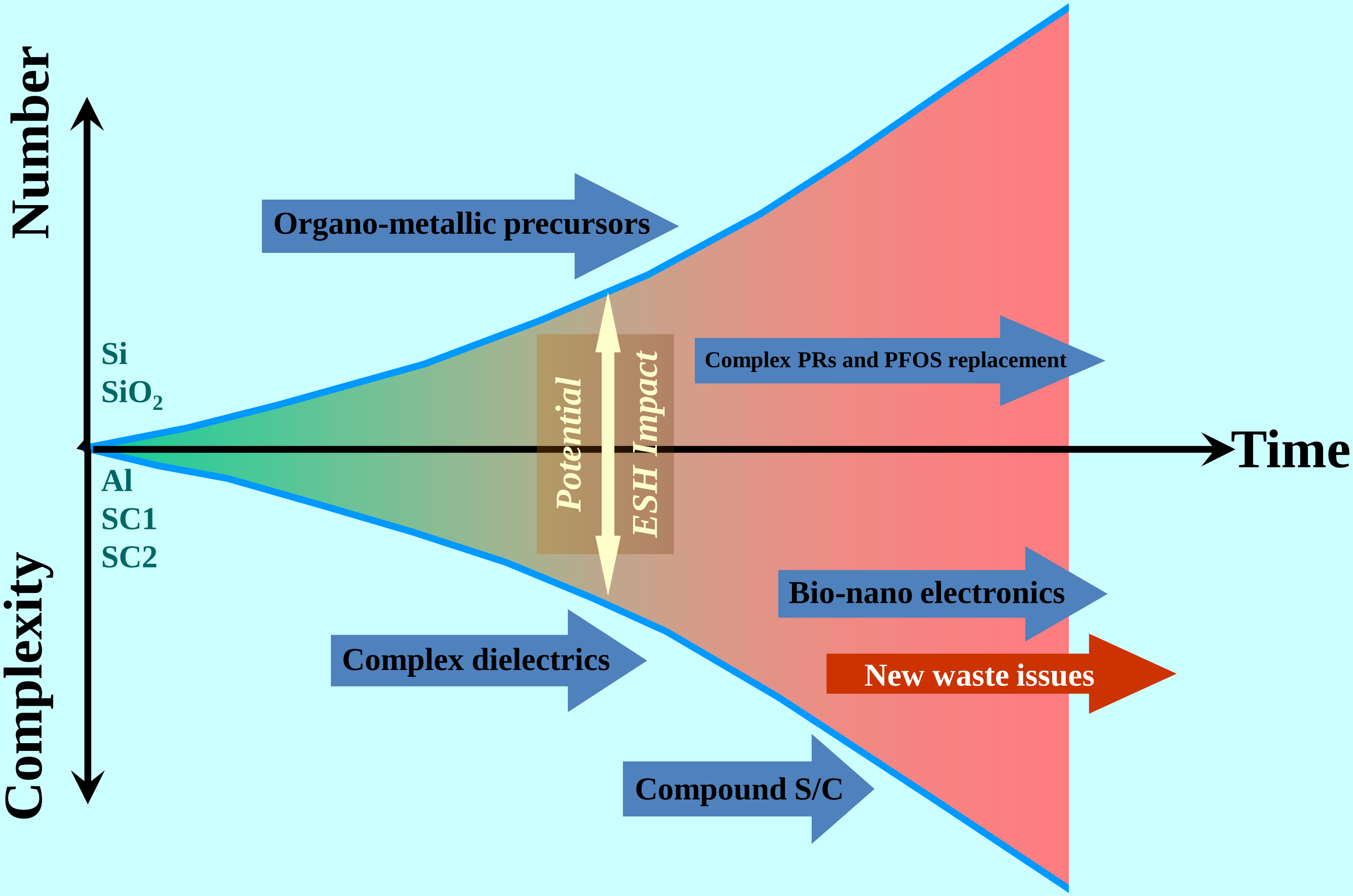


Unique Properties of Nano-Particles

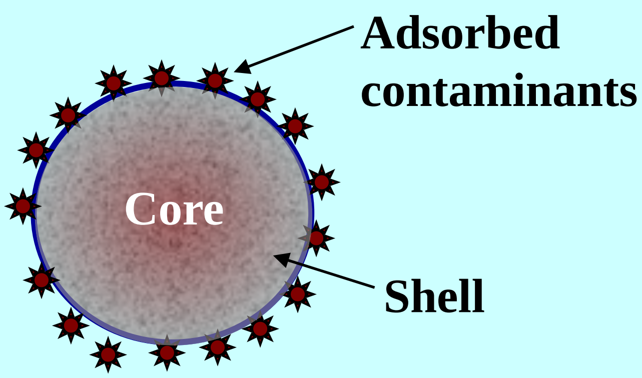
Treatment problem:

- Nano-particles cannot be effectively removed by conventional separation methods such as agglomeration, settling, and filtration.

Synergistic ESH impact of nano-particles:

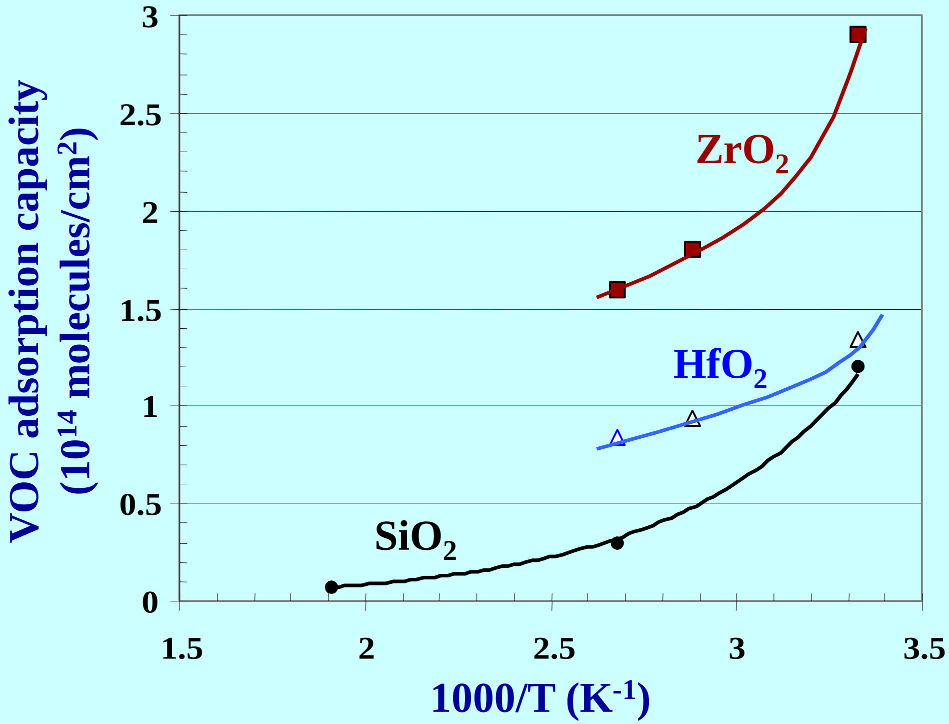
- *Active surface*
- *Selective adsorption*
- *Pore condensation* *(Kelvin Effect)*

Consequence
- *Concentration*
- *Facilitated transport*
- *Enhanced life-time*



Unique Properties of Nano-Particles

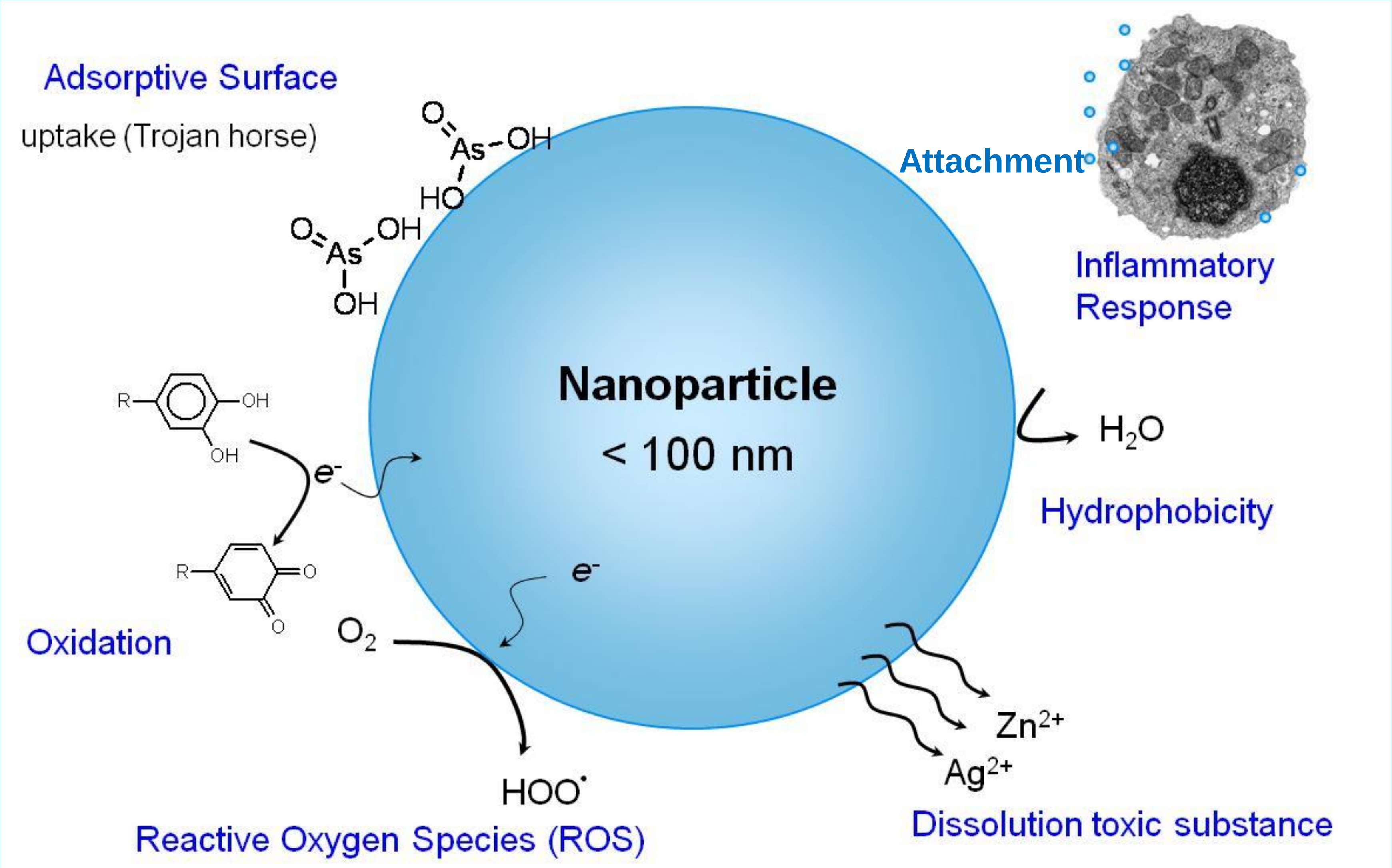
a) Nano-particles in the gas phase
15ppb VOC; 40 nm particles



b) Nano-particles in the wastewater

- 10 ppb of Cu^{++} in CMP wastewater results in $3x10^6$ ppb of adsorbed copper on 90 nm CeO_2 nano-particles
- 10 ppb of PFOS in wastewater results in $2.8x10^4$ ppb of contaminated 10 nm carbon nano-particles

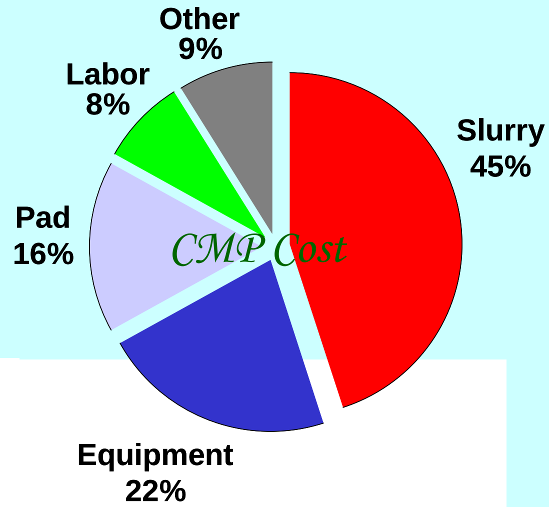
Toxicity of Nano-Particles

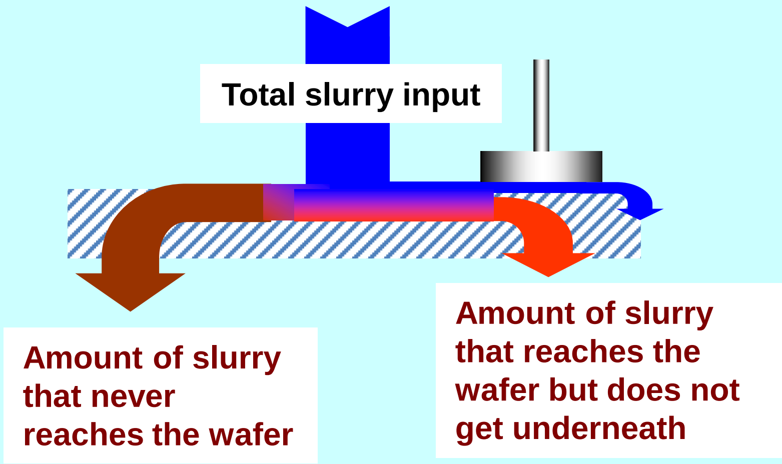


Nano-Particlces in CMP Process

Program Leader: Professor Ara Philipossian

- Major source of nano particle emission in S/C fabs.
- Costly and wasteful operation: For a typical 200-mm factory:
  - 6,000,000 liters of slurry per year
  - 300 metric tons of solid waste per year





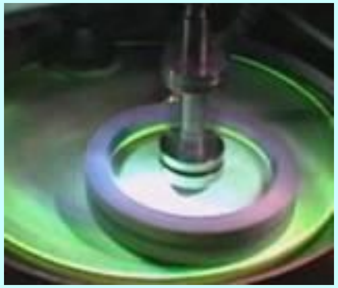
Amount of slurry that does the actual polishing is often <u>less than 10%</u>

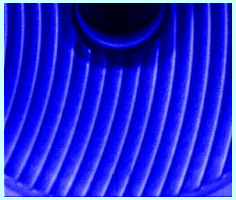
Integrated ESH-Friendly Planarization

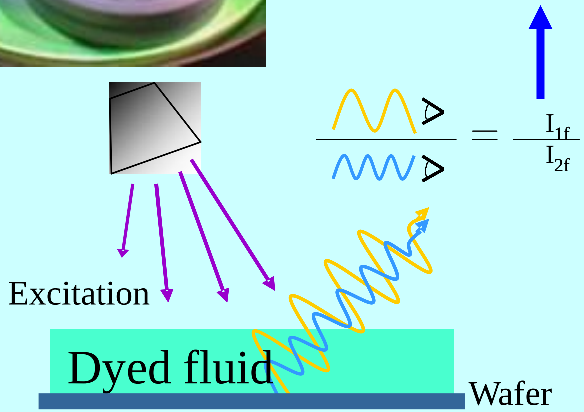
Program Leader: Professor Ara Philipossian

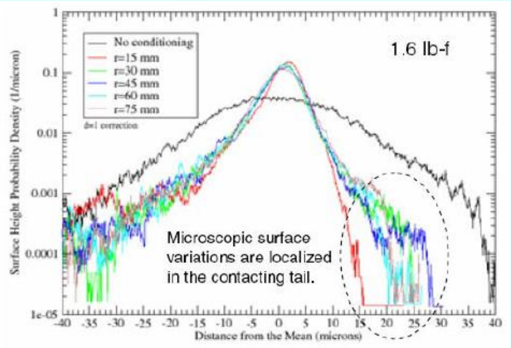
Integrated Technology for CMP:

- Reduced slurry usage by 20-40%
- Reduced Cu in waste stream) by 25%
- Increased pad life by 20-50%
- Reduced diamond disc consumption by 20%
- Shortened CMP polish time by 20-50%
- Improved yield by 1-2%
- Developed ESH-friendly chemicals for ECMP





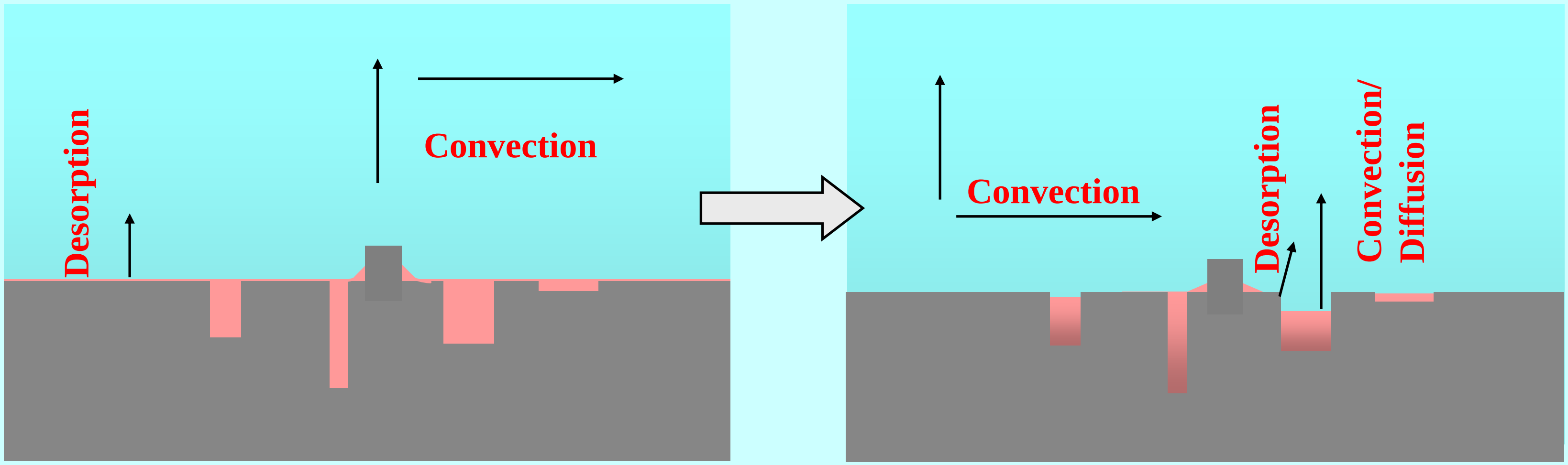




Impact of Nano-Scale Manufacturing on Resource Utilization

Water and Energy Use Reduction

Cleaning of Nano-Structures

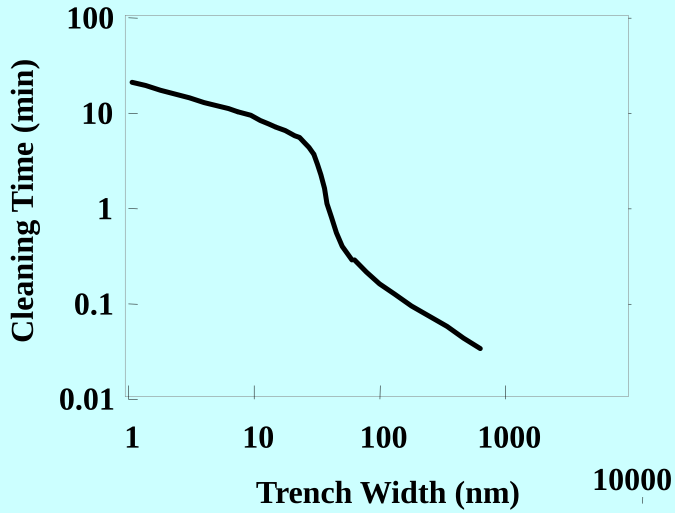


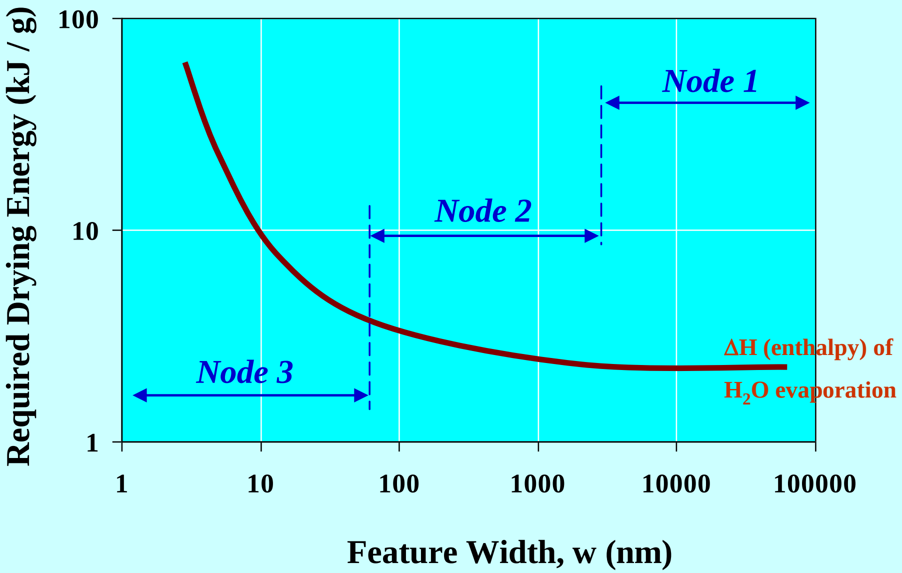
Mechanism	Time Scale	Flow Effect
Boundary Diffusion	$d^2/D \sim 10$ s	Indirect, mild
Convection	$d/u \sim 1\text{-}3$ s	Direct, strong
Desorption	$1/k_d \sim 0 - 10^5$ s	No effect

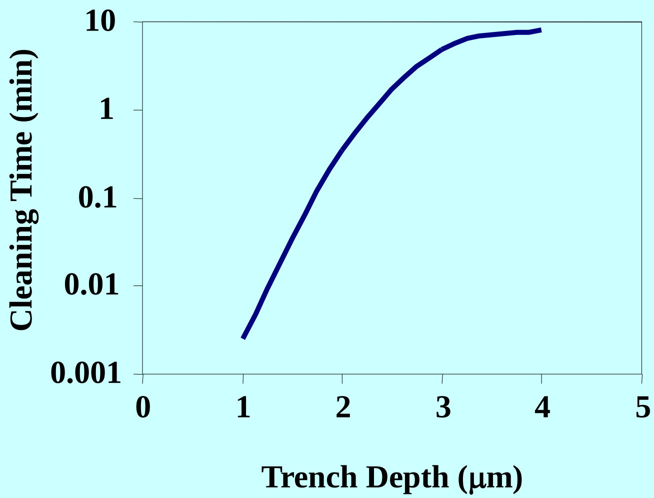
Needs:

- Lowering water and energy usage
- Better metrology and process control

Increased Use of Resources in Nano-Manufacturing



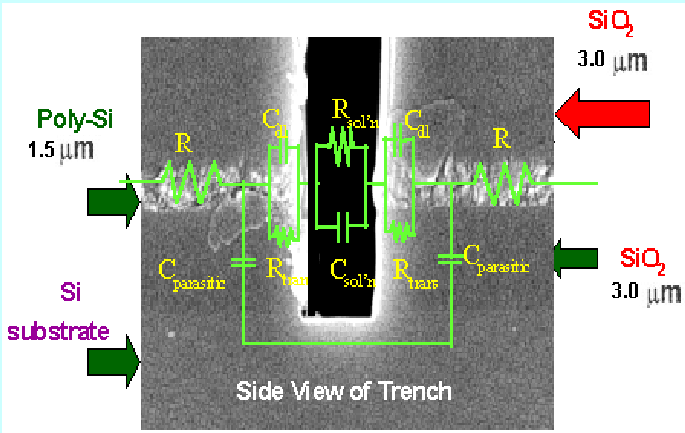


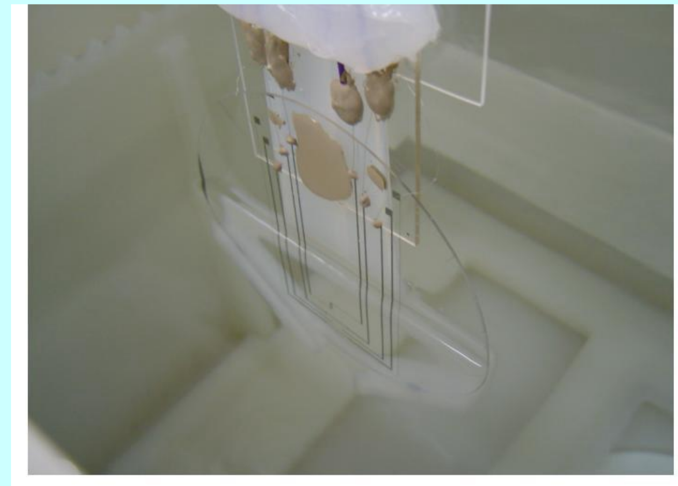


Trend: Large increase in *water, chemicals, and energy usage* as feature size decreases and wafer size increases.

A Novel Metrology Technology:

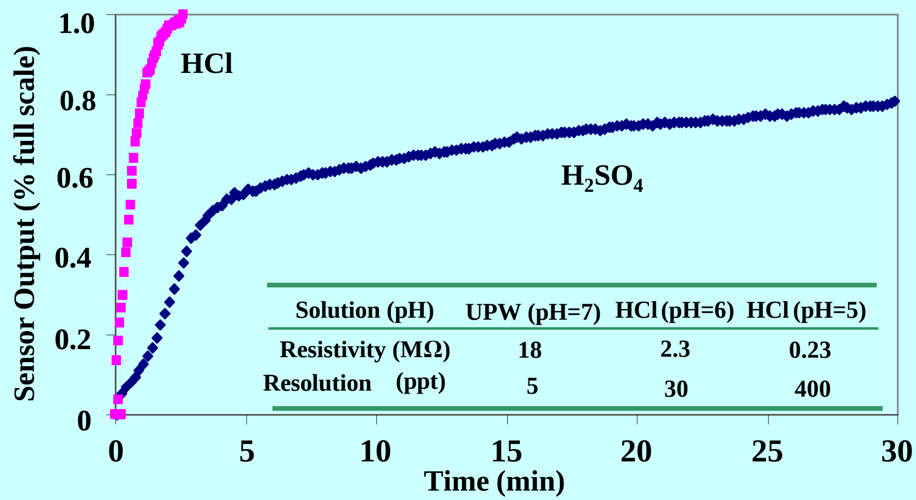
Electro-Chemical Residue Sensor (ECRS)



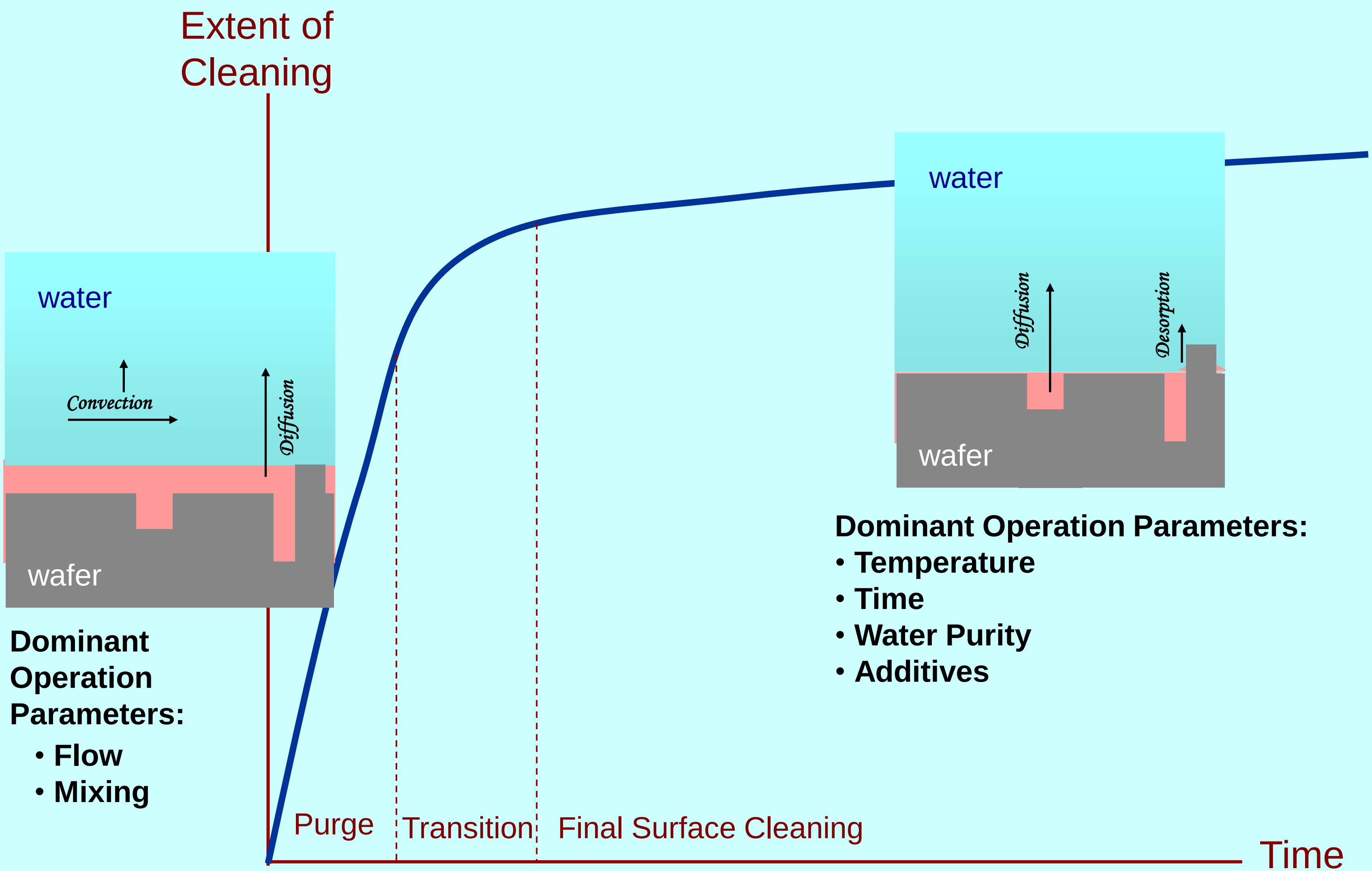


Unique Characteristics:

- **In-situ**
- **Real time**
- **On-line**
- **High sensitivity for small feature sizes**
- **Very short response time**
- **Total integration**



A Novel Staged Rinse Process



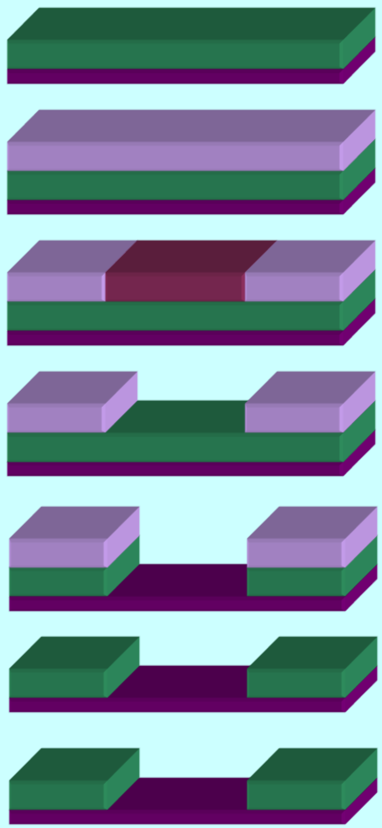
Major Paradigm Change: Application of New Manufacturing Concepts and Methods

1. ***Subtractive:*** **Carve the structural details in a solid block or solid deposited layers**

2. ***Additive:*** **Place the final materials only in places where they are needed.**

An Example of Subtractive Processing

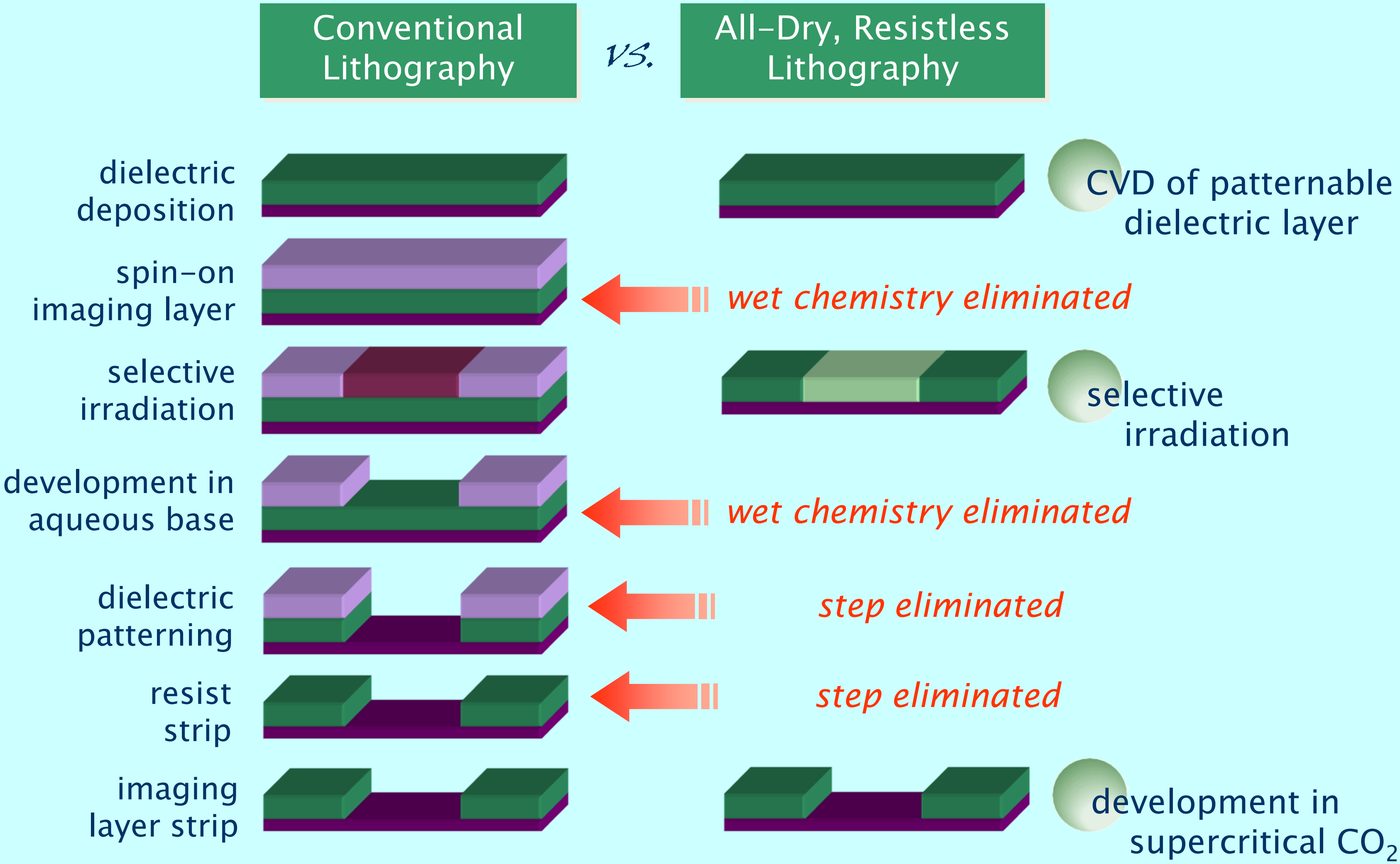
Deposition and Patterning of Dielectrics



Conventional Lithography	*ESH Issues*
dielectric deposition	**Precursors, HAPs, wastes**
spin-on imaging layer	**VOCs, waste**
selective irradiation	**VOCs, radiation**
development in aqueous base	**VOCs, HAPs**
dielectric patterning	**HAPs, PFCs**
resist strip	**A/B chemicals, solvents**
imaging layer strip	**A/B chemicals, UPW**

Deposition and Patterning of Dielectrics

Lead: Professors *Karen Gleason (MIT), Chris Ober (Cornell)*



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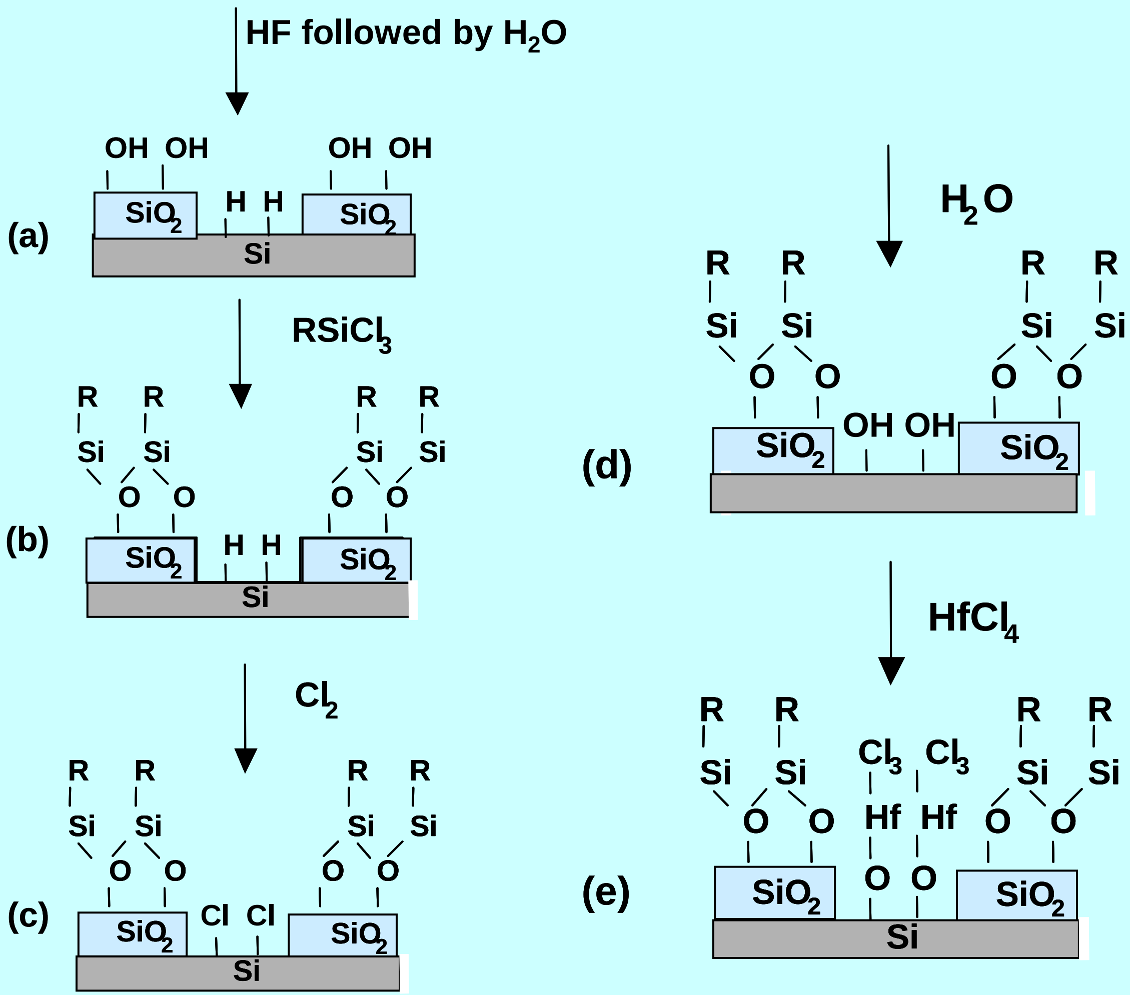
Reducing Environmental Impact by Additive Processing

Lead: Professor Anthony Muscat



a) Clean and Pattern Si

b) Protect SiO_2

c) Activate Si

d, e) Maskless selective ALD of high-k dielectric

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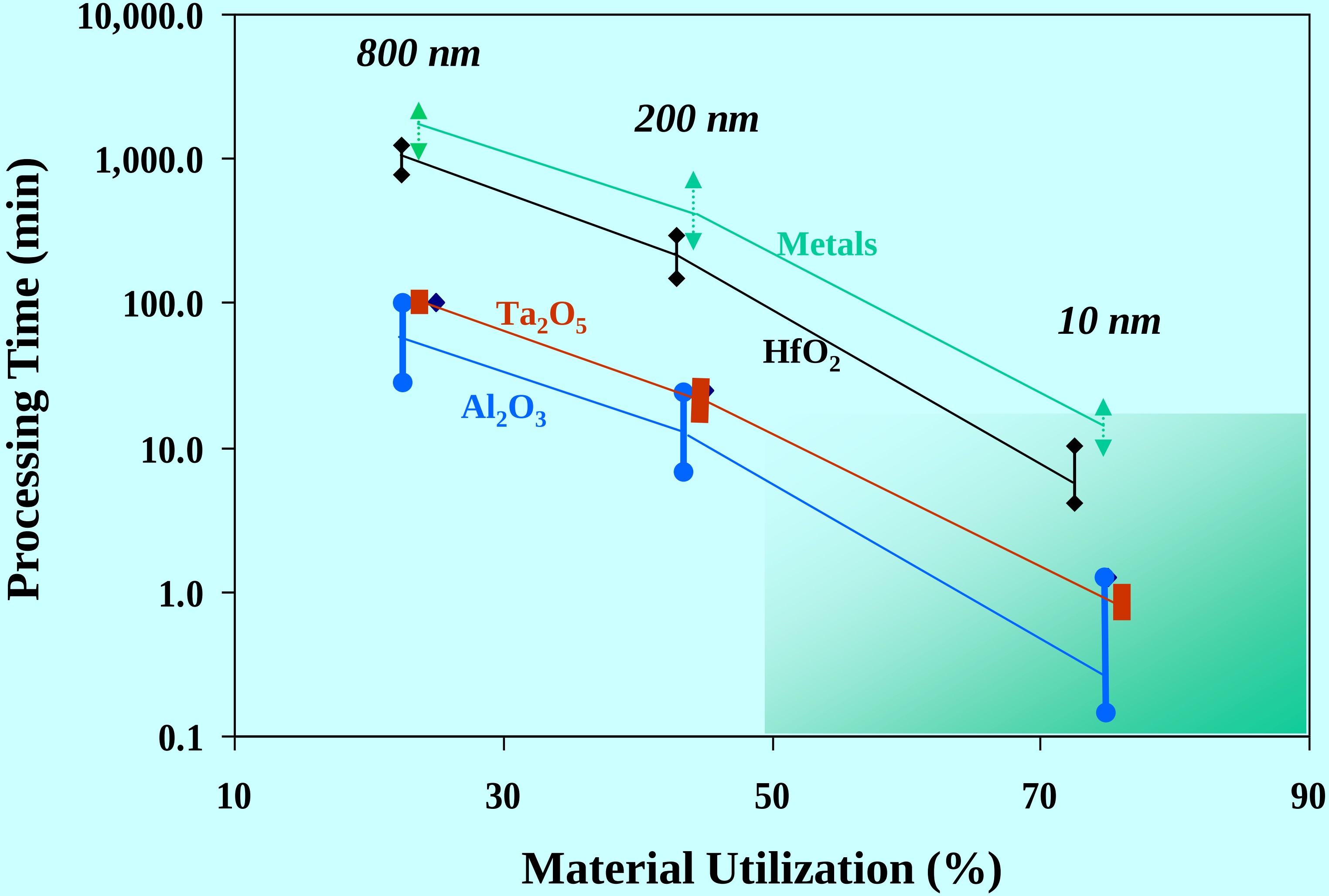
Feasibility of Additive Processing in Nano-Scale

Selective Atomic Layer Deposition (ALD)



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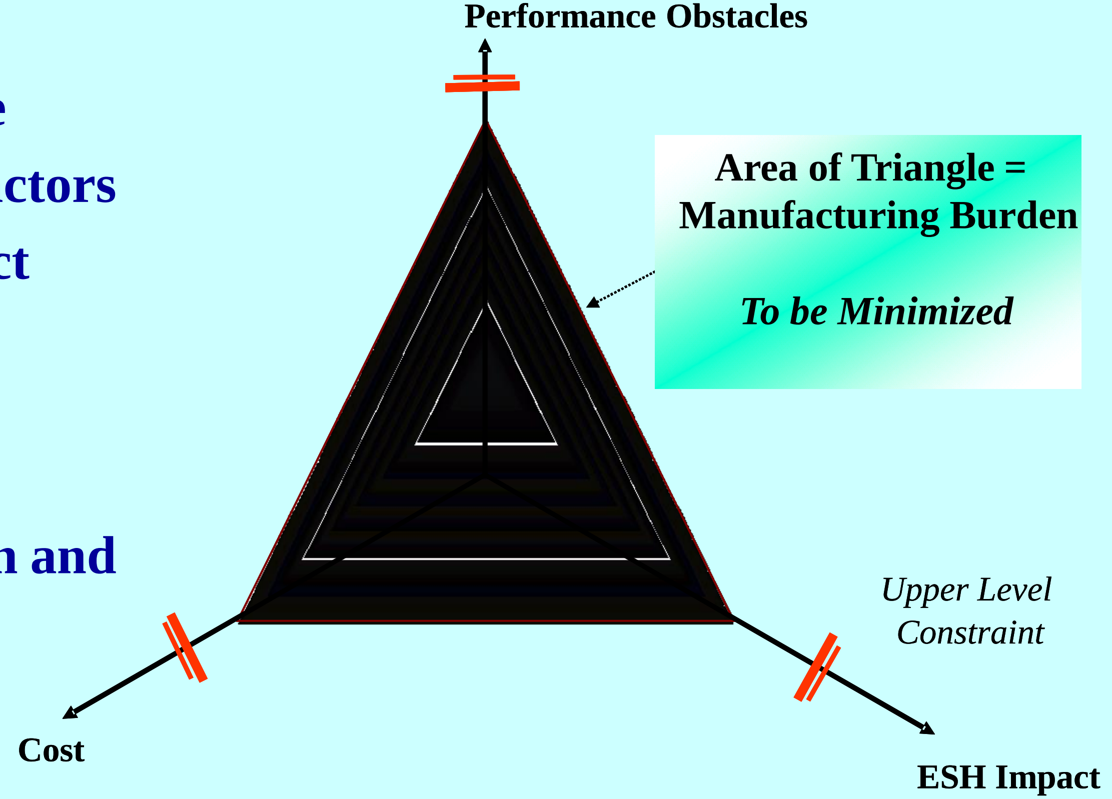
Quantifying Environmental Impact and Sustainability

Factors that determine the sustainability of *a product*, *a process*, or *a manufacturing technology:*

1. **Product performance**
2. **Cost and economic factors**
3. **Environmental impact**
   - **Safety and Health**
   - **Social factors and compatibility**
   - **Resource utilization and availability**



Summary

Nano-manufacturing is not simply an extrapolation or scale-down version of the larger-scale manufacturing:

a) There are unique ESH and sustainability challenges

b) There are also opportunities for application of novel approaches and introduction of new tools/techniques.