Consortium on Green Design and Manufacturing

Informing Design for Environment (DfE) in Semiconductor Manufacturing

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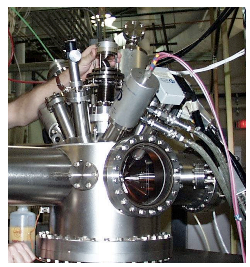
Content

- 1. LCA Context, Overview and Challenges
- 2. Overall, first-order semiconductor LCA results using Economic Input Output Methods
- 3. The Environmental Value Systems (EnV-S) Analysis
- 4. Connecting the EnV-S to LCA analyses: preliminary results

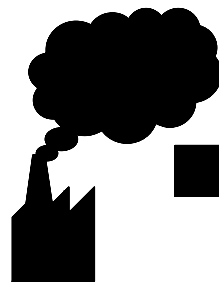
1. Context and Overview

from raw materials extraction to manufacture, use and end of life

Raw materials



Manufacturing



Use

End of life

Design: Ability to effect environmental improvements/changes -
Greatest leverage is during product design and development

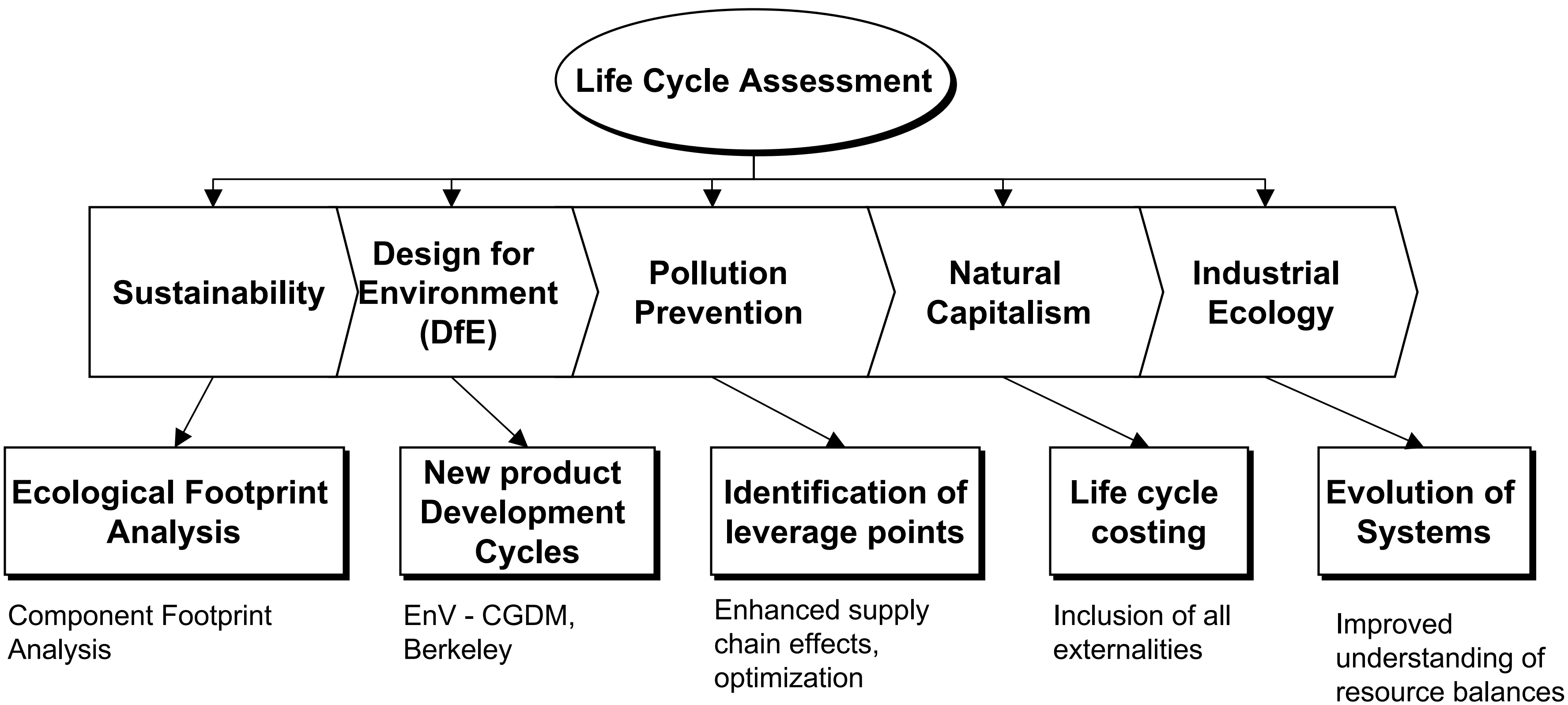
Environmental and health issues concerns arise at each stage

Human health impacts

Environmental impacts

Contextual background

- LCA as a support tool
- Strategies - inventory, impact, score
- Strategies - cradle to grave



Typical Methodologies for Implementation

- ‘Typical’ LCA Approach/SETAC
- Streamlined Approaches
- Economic Input Output
- Hybrid?

Pre - Analysis

- Why LCA?
- Kinds of results
- Scope
- Functional unit
- Fair comparison

Inventory Analysis

- Data sources and supplements
- Completeness - Cradle to grave?
- Scope and boundary

Impact Analysis

- Several Methods
- CML/SETAC

Classification

- Metrics scores
- Modeling intensive
- Damage functions?
- Weighting functions

Normalization

- Baseline effects
- Eco-indicator for Europe

Evaluation

- Weighting factors for one ‘score’
- Ecopoints?

- An ‘accurate’ LCA approach
- Entire product life cycle
- Quantitative inventory
- Cost and time intensive
- Data gaps
- Uncertainties

Typical Methodologies for Implementation

- Streamlined LCA (SLCA) - *Gradel*

Impacts	*Life cycle stage*	Raw materials	Manufacturing	Use	Disposal
Air pollution					
Energy use					
Water use					
Hazardous waste					
Toxic					
EHS costs					

•Simplified approach
•Cost and time improvements
•Similar results to full analysis?
•Unexpected results unseen

- Economic Input Output - *Green Design Initiative*

•Sectoral approach
•Circumvent data issues
•Economic ripple effect
•Cost and time improvements
•Approximate nature
•Temporally fixed on data
•$1million of asbestos related products

Asbestos products

Effects	Total
Economic Purchases [$ million]	2.136594
Electricity Used [Mkw-hr]	0.856254
Energy Used [TJ]	16.836959
Conventional Pollutants Released [metric tons]	29.902856
OSHA Safety [fatalities]	0.000517
Greenhouse Gases Released [metric tons CO2 equivalents]	1194.785867
Fertilizers Used [$ million]	0.000548
Fuels Used [metric tons]	445.846441
Ores Used - at least [metric tons]	258.587962
Hazardous Waste Generated [RCRA, metric tons]	51.675771
External Costs Incurred [median, $ million]	0.051903
Toxic Releases and Transfers [metric tons]	10.567005
Weighted Toxic Releases and Transfers [metric tons]	29.397856
Water Used [billion gallons]	0.010157

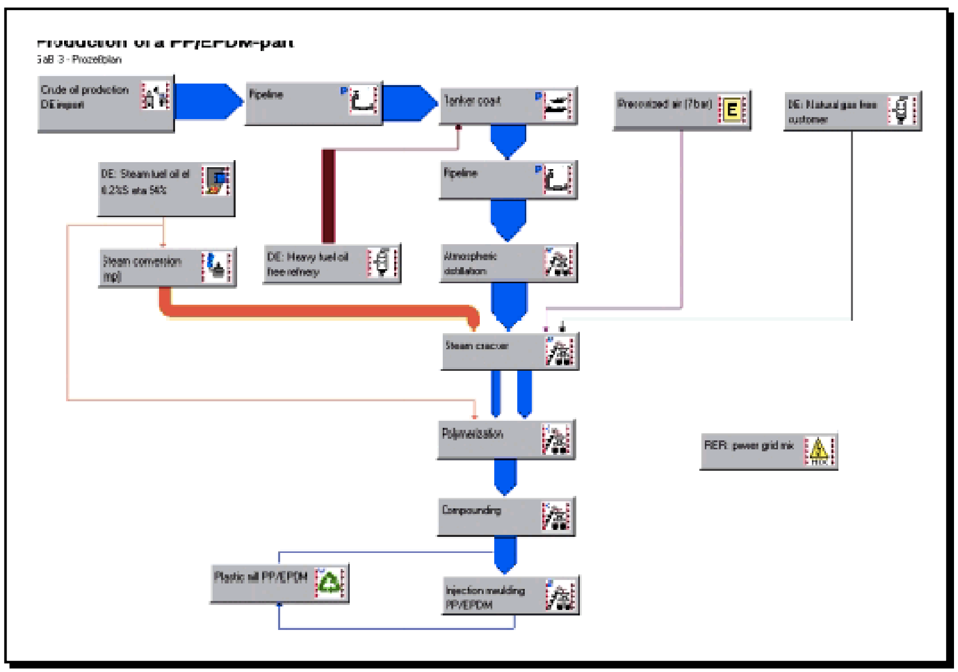
- *Hybrid Approaches*

•Combine strengths of various approaches
•Theoretically effective
•Practical/implementation issues?
•Case - specific application

Commercial Software

- Product Based
  - Gabi (Stuttgart)
  - Simapro (Pré consultants)
  - Umberto (ifu Hamburg)
  - Others (LCAit, KCL, Sylvatica)

•Tools use multiple databases/sources
•Ease of use
•Different valuation approaches
•Databases are site/region specific
•Databases are hidden - transparency issues
•Valuation issues - site specific and hidden

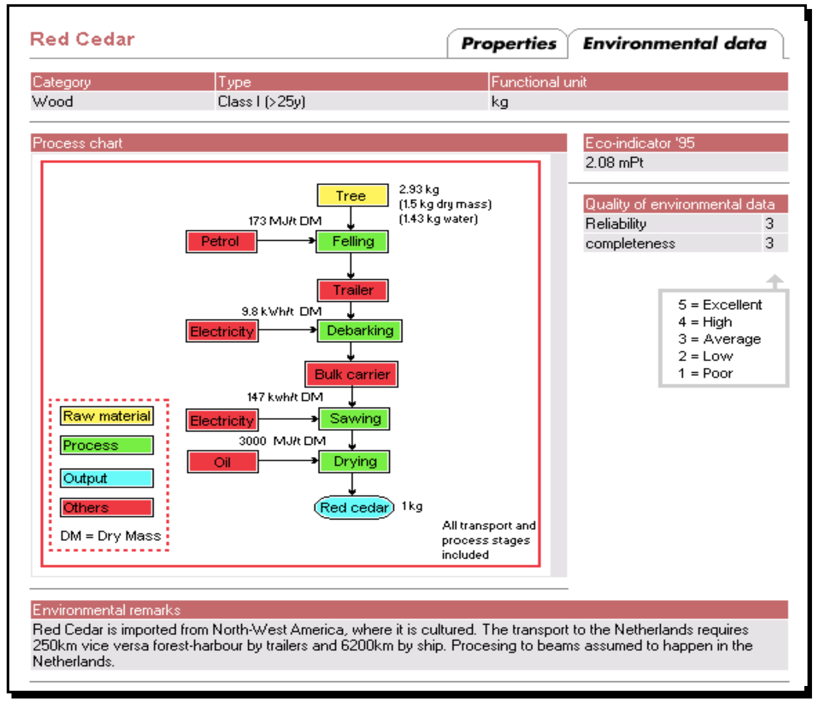


Sankey diagram - Gabi

Commercial Software (contd.)

- Process focus
  - Idemat (TU Delft)

•Process focus - unusual
•Still, data driven



  - Environmental Value Systems (EnV-S) Analysis (Berkeley)

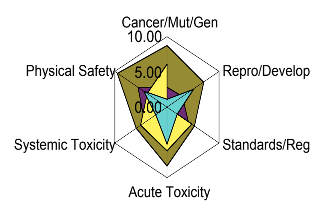
•Process focus
•Model based
•More information on model-based approaches later

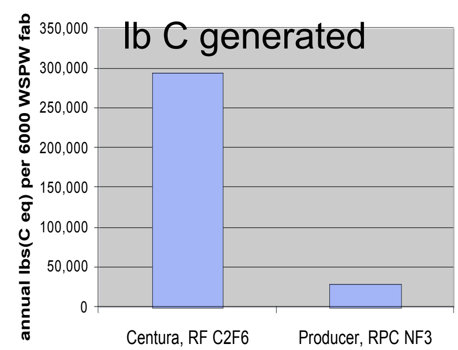
Challenges

Case Example *(Semiconductors)*

- Functional unit
  - •Important for a fair comparison
  - •*Perfluorocarbon (PFC) Abatement*
  - •comparison based on mass flow
  - •comparison based on wafer pass - 200, 300mm
- Temporal scale
  - •Analysis is static
  - •Time lags cannot be understood
  - •Copper in semiconductors
  - •idle flow, continuous flow (specification from the tool)
  - •copper discharge limits (bath dumps)
  - •Need average analysis and peak analysis
  - •Bay area - 2lb/day Cu discharge regulation, ~2ppm Cu concentration regulation
- Spatial scale
  - •Analysis of local Vs. global effects
  - •different at different stages of the inventory
  - •Health factors Vs. Environmental factors

Health Hazard scoring





Challenges adapted from - Krishnan, N, 'Understanding drivers, benefits and shortcomings of Life-Cycle Assessment (LCA): Strategies for a successful implementation in process type industries,' EH&S Performance and Corporate Responsibility: Building Bridges and Competitive Advantage, Pacific Industrial and Business Association, 9th Annual Silicon Valley EH&S Conference, February 26 and 27, 2002.

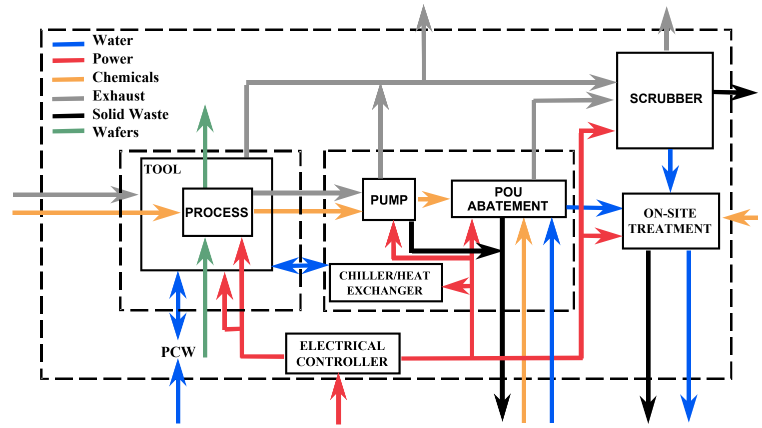
Challenges (contd.)

Case Example *(Semiconductors)*

- Boundary problem

•circumvented in Economic Input Output type analyses and streamlined analyses

Manufacturing phase



- Cost and time

•Variable and hard to judge
•circumvented in Economic Input Output type analyses

•Top down Vs. bottom up view of semiconductor manufacturing?

- Data availability

•Gaps
•Multiple, non-compatible sources
•Obsolete

•Monitoring energy consumption at tool
•Estimating from recipes
•Averaging from facilities

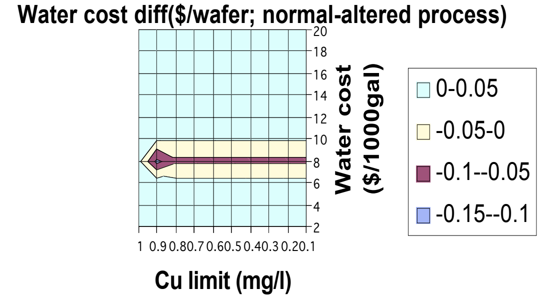
Challenges (contd.)

Case Example *(Semiconductors)*

- Product focus

•No process focus (ability to impact process
•No service focus (needs based analyses)

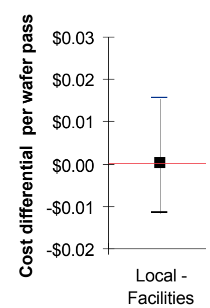
Inform design and decision making



- Uncertainty

•In methodology, data, impacts
•Quantitative? Comparative?

Variation in Environmental Cost of Ownership

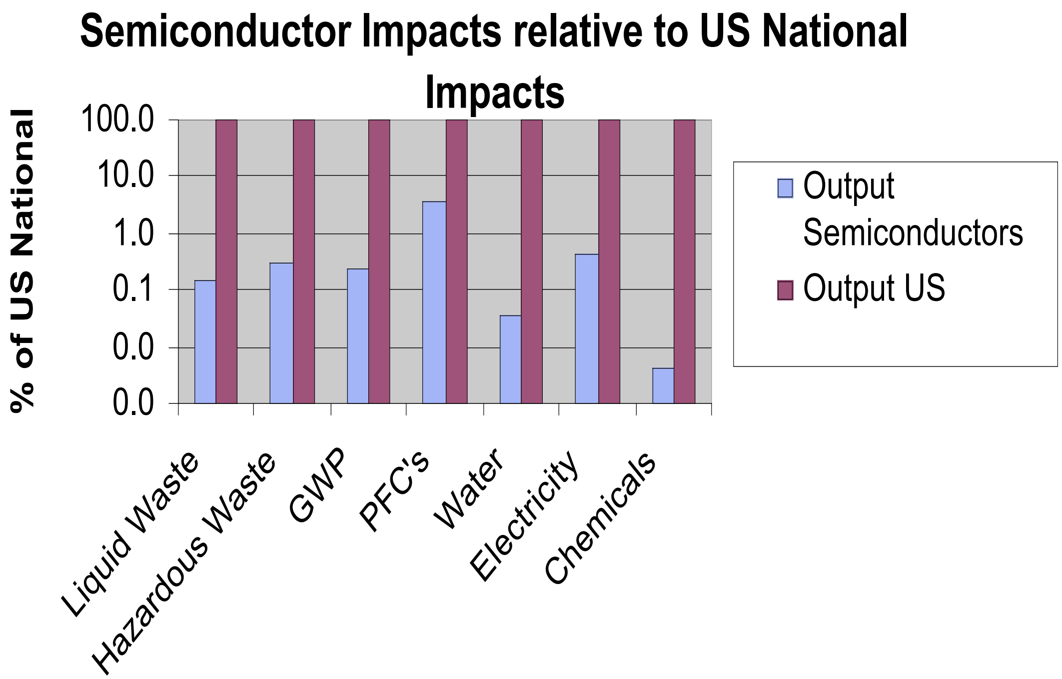


- Valuation

•Subjective decision making
•No ‘correct’ approach
•Site specific
•Perhaps no standardization feasible -or sensible, given uncertainties

•Present multiple impacts
•Health
•Environmental
•Manufacturing
•Process
•Cost

2. Environmental overview of the industry



	Output US	
Liquid Waste	8.03E+04	billion gallons
Hazardous Waste	40.0	Million Tons
GWP	1600.0	MMTCE
PFC's	37.1	MMTCE
Inputs		
Water	123735	billion gallons
Electricity	3652.0	billion KWhr
Chemicals	8500.0	Million Tons

Outputs from the Fab		Source	Inputs to the Fab		Source
Liquid Waste	75 gal/in^2	[1]	Water	30 gal/in^2	[3, 6, 2]
Hazardous Waste	0.1 kg/in^2	[1]	Electricity	10 KWhr/in^2	[2, 3]
GWP	2.6 kgCE/in^2	[2, 3, 4]	Chemicals	0.2 kg/in^2	[5]
PFC's	0.9 kgCE/in^2	[4]			
Toxic Releases	0.01 kg/in^2	[5]			

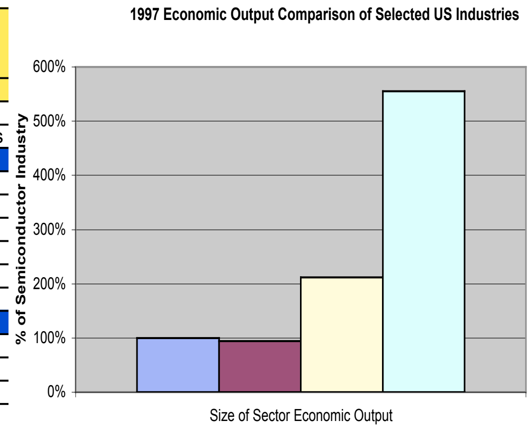
Impacts per square inch of Si

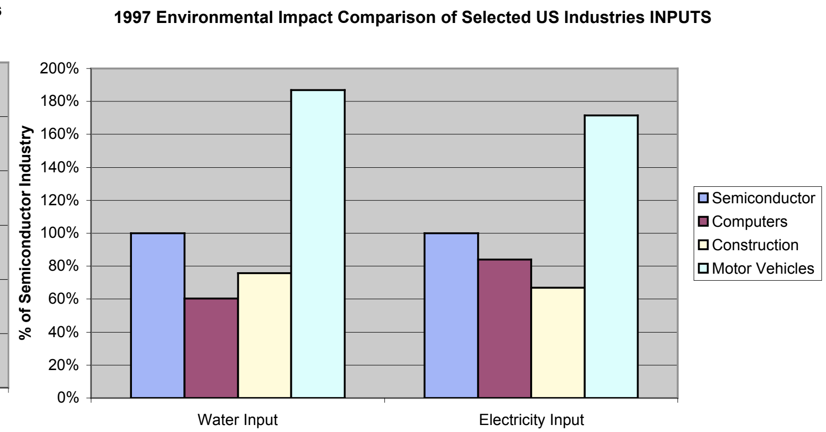
Life cycle environmental analysis for the semiconductor industry

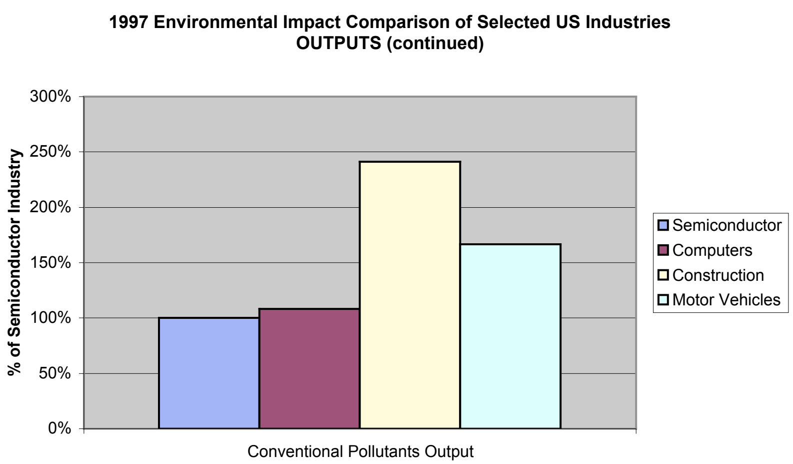
- Using Economic Input-Output Analysis

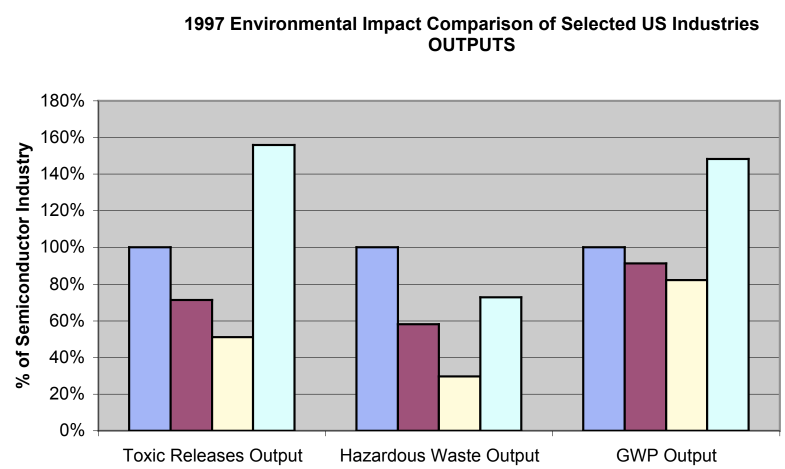
1997 Summary of sector life cycle results

Sector #570200: Semiconductors and related devices		
	Semiconductor	
	1997 Data (Adjusted)	
Size of Industry Output	52924	Millions of Dollars
Output Semiconductors		
Liquid Waste		Million Tons
Hazardous Waste	2.543	Million Tons
GWP	23.231	MMTCE
Toxic Releases	0.052	Million Tons
Conventional Pollutants	0.203	Million Tons
Input Semiconductors		
Water	137.484	billion gallons
Electricity	19.556	billion kW-hr
Chemicals		



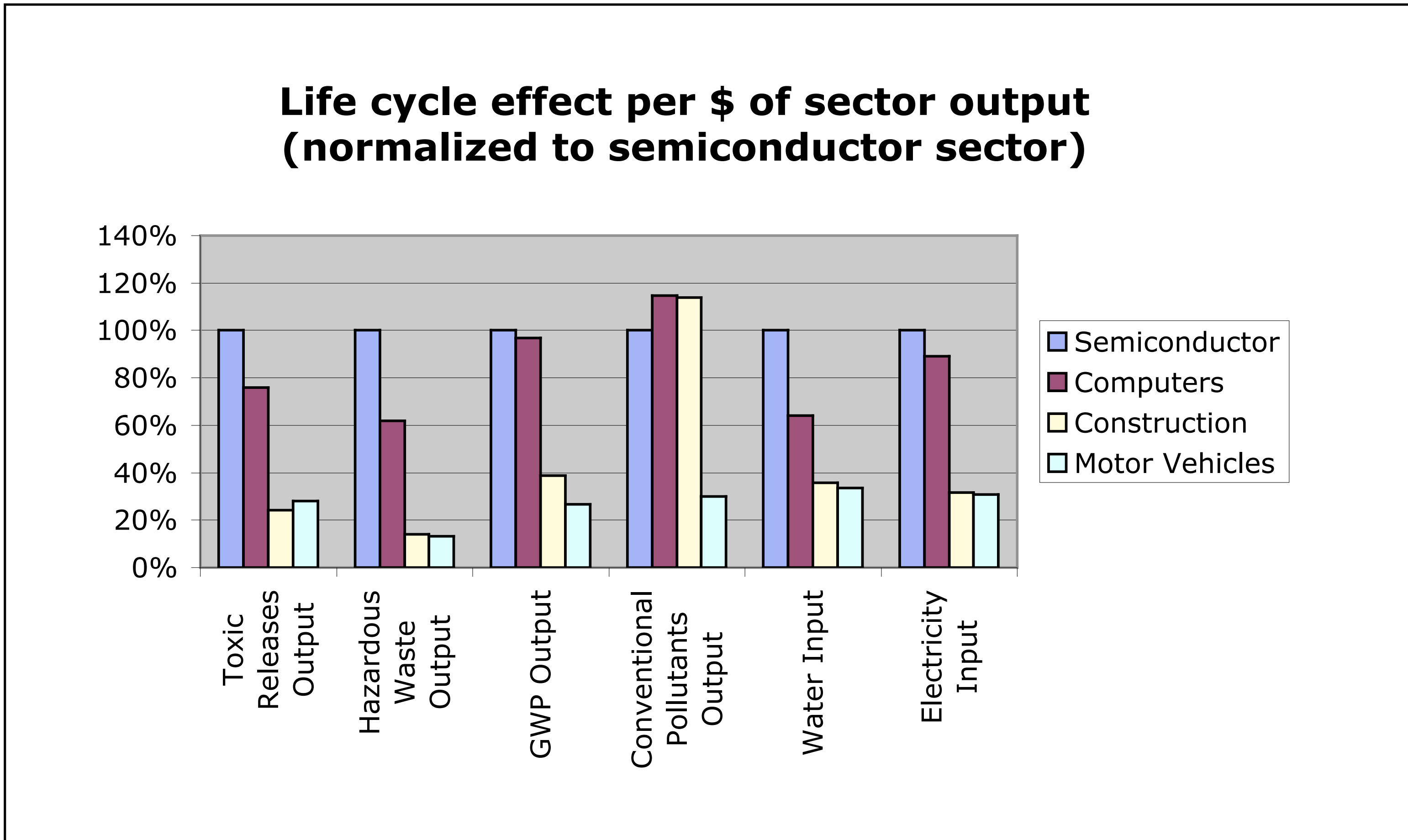






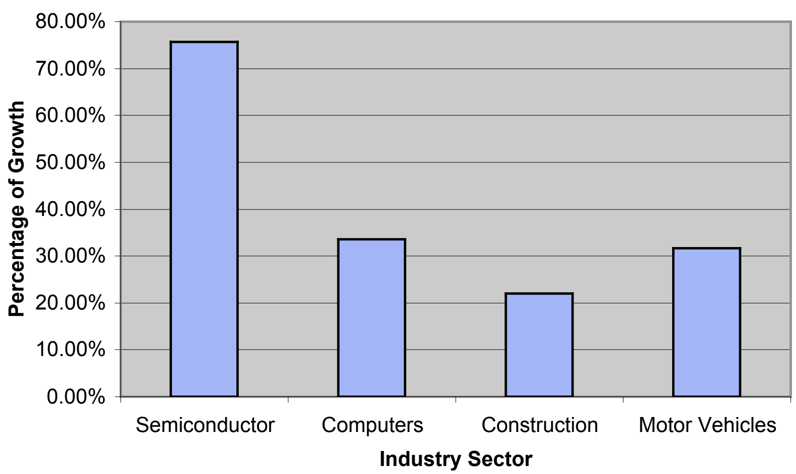
1997 impacts normalized to sector output

- Semiconductor sector is high when normalized per $ of output

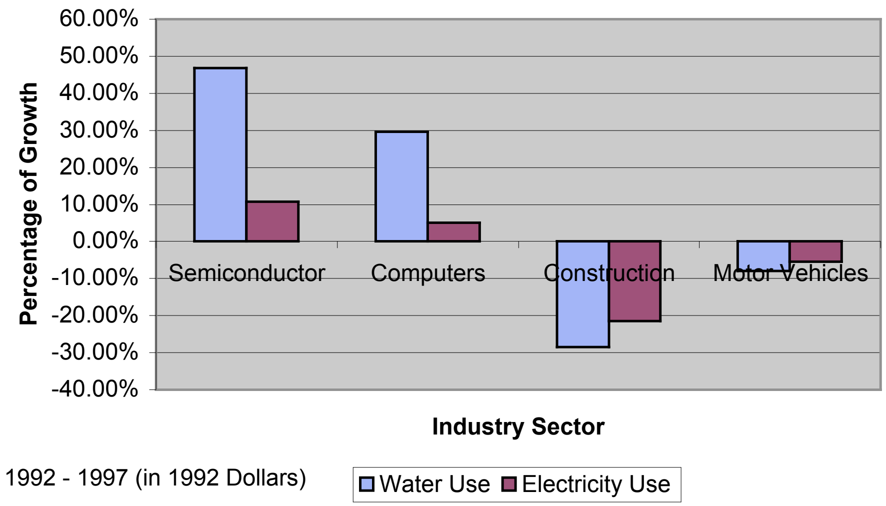


1997 and 1992 results comparison

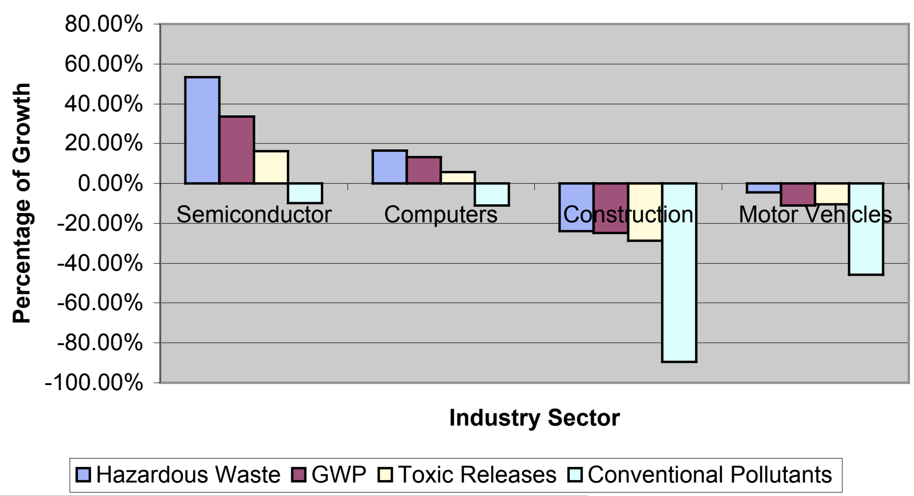
Industry Size Change from 1992 - 1997 (in 1992 Dollars)



Water and Energy Use Change from 1992 - 1997 (in 1992 Dollars)



Envirnomental Output Change from 1992 - 1997 (in 1992 Dollars)



3. The Environmental Value Systems (EnV-S) Analysis

Problem Statement & Baseline

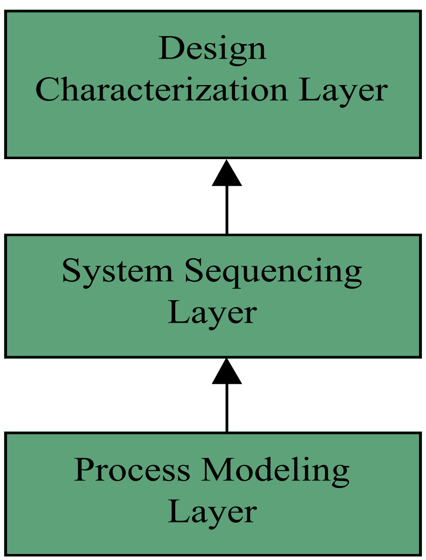
- Equipment manufacturers need a tool for the quantitative evaluation and comparison of <u>tool-centric</u> environmental solutions

- EnV-S Model Blueprint
  - Focus the model on the process tool and the support equipment
  - Ensure the model output is in terms of important business metrics such as CoO
  - Factor in all controllable variables that significantly affect the key outputs
  - Provide sensitivity analysis for those controllable variables
  - Enable "what-if" comparisons between various solutions
  - Make the tool suitable for the casual user (i.e., user-friendly)
  - Use industry norms for cost/performance parameters (e.g., UPW costs)
  - Make the tool readily available and, if possible, an industry standard

Slide adapted from Woolston, M., Francis, T., "Semiconductor EHS Goals - Why do we need an Environmental Value Systems Analysis Model?. . . a background," Seminar on the Environmental Value Systems (EnV-S) Analysis, SEMICON West 2002.

EnV-S Summary

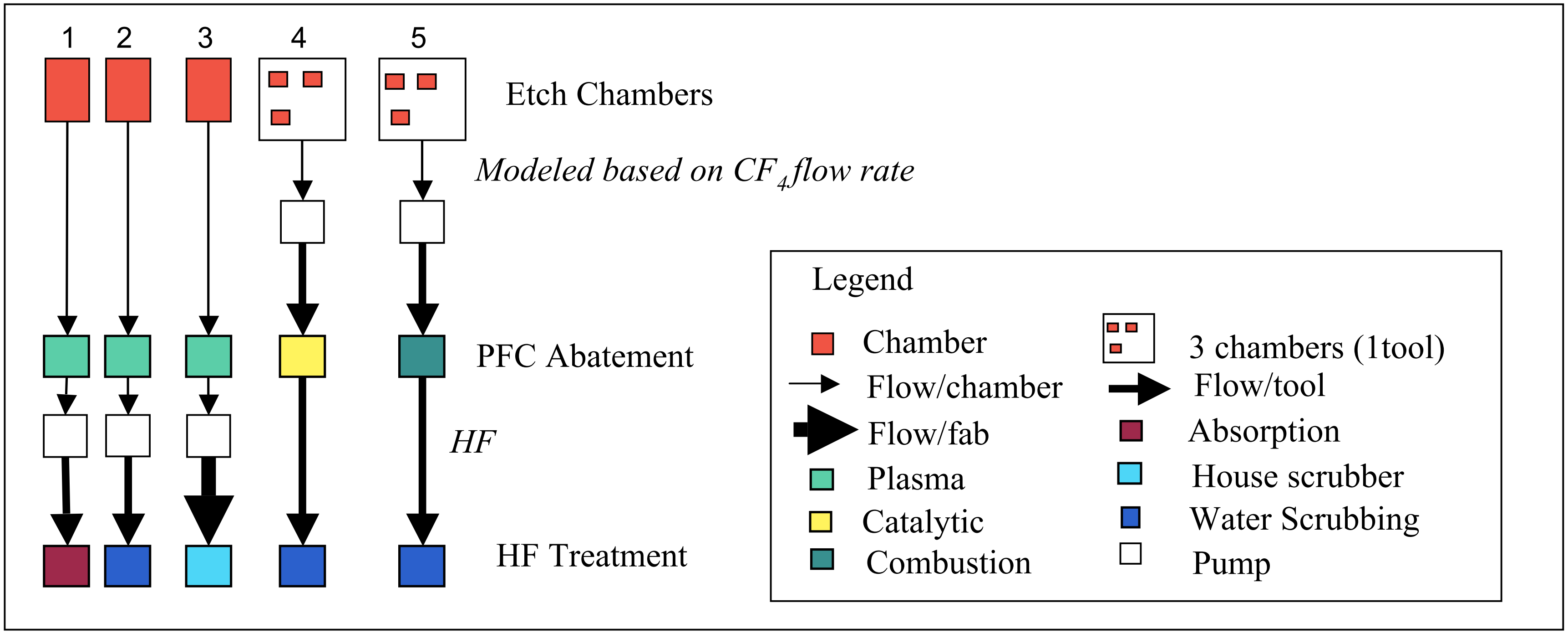
- The Environmental Value Systems (EnV-S) Analysis
  - Informing Design for Environment (DFE) in semiconductor manufacturing
  - Focus on bottom-up, tool-centric views - develop analysis for platforms
  - Inform design decisions for equipment suppliers



- Stepping stone to complete LCA - Spatial scale and boundary around the facility
- Bottom up as opposed to top down
  - Model as opposed to data based (temporal issues)
  - Data availability issues - better sensitivity analysis
- Valuation metrics
  - Discrete (uncombined)
  - Decisions are subjective and combinations of $ values, health and environmental and process issues
- Support equipment design, process design, new product development

Case study: PFC Abatement Option Space

Options space - Different combinations of abatement and downstream options

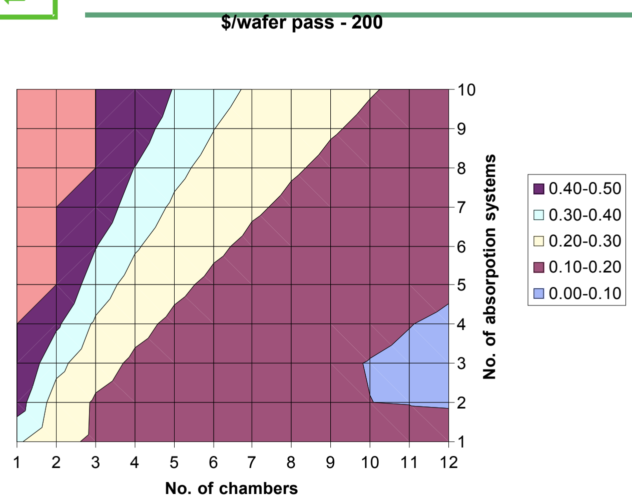


Analysis: (Environmental Cost of Ownership (COO))

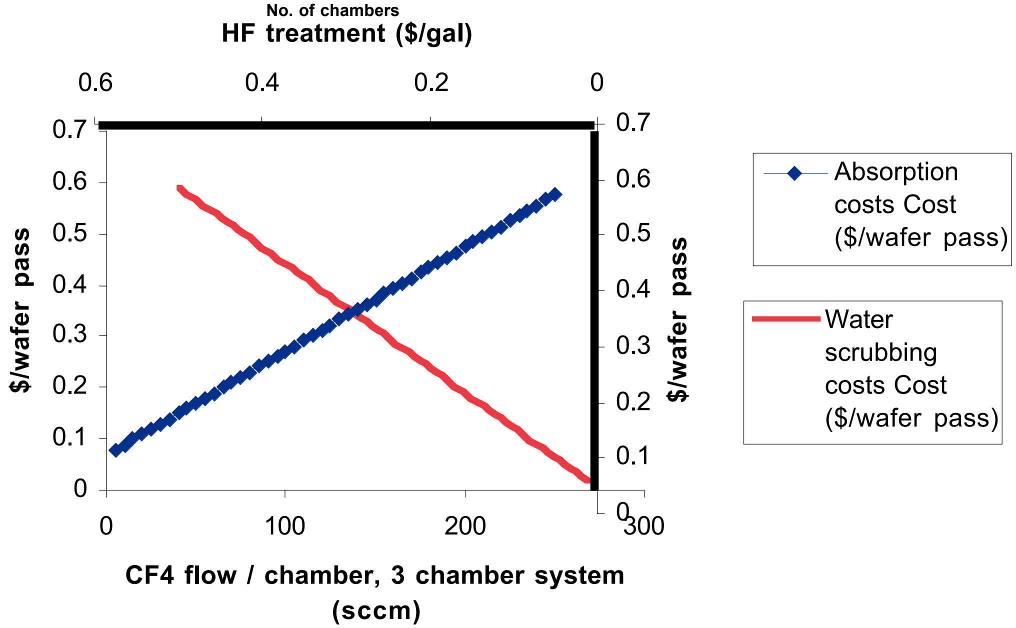
1. Sensitivity analysis of costs and cost differences
2. Cost of downstream HF treatment as a function of flow and configuration parameters

Case study adapted from, Krishnan, N., Woolston, M., Dornfeld, D., 'Exploring Environmental Cost of Ownership of Perfluorocarbon (PFC) Abatement Options and Decision Spaces using the Environmental Value Systems (EnV-S) Analysis,' Environmental Technologies and Manufacturing Practices, SEMICON West 2002

Design graphs and trade off analysis

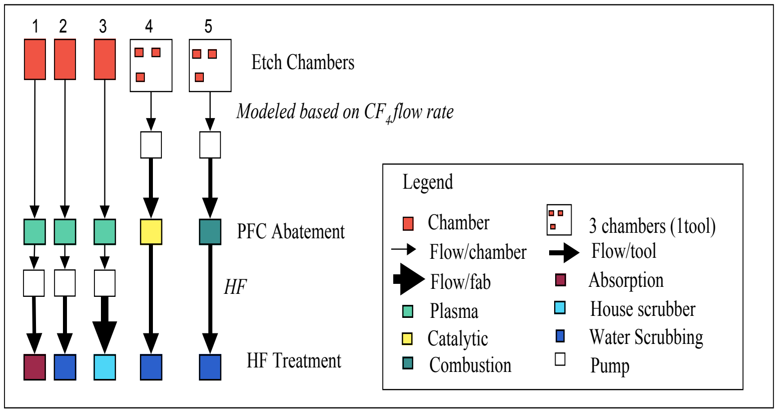


- 200mm flows are lower - there is region of operation (0-10c/wafer pass) With many chambers connected to a few absorption systems

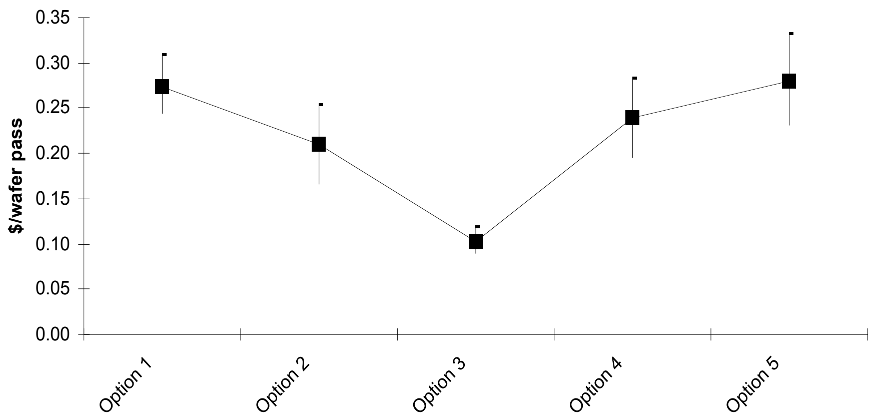


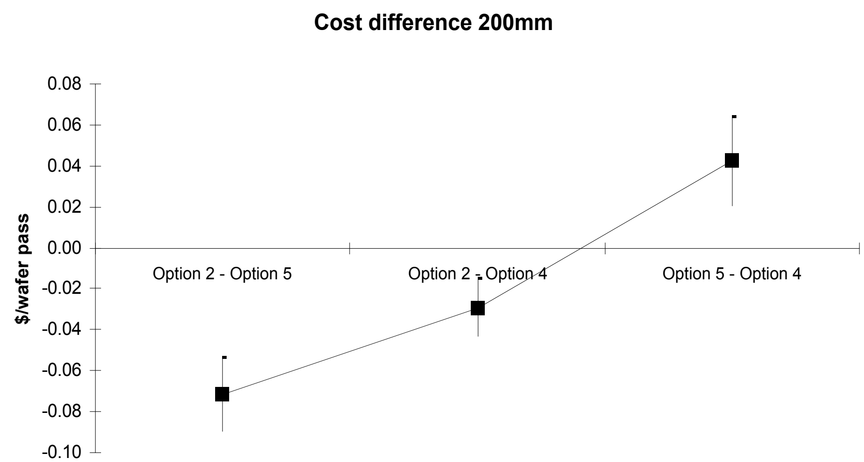
Trade off analysis in examining different HF treatment systems

PFC Abatement Cost Variability



- Uncertain cost of individual options, but robust selections between options!





4. Connecting the EnV-S to LCA tools

- The EnV-S can be used as a DfE tool for
  - *Semiconductor process and equipment design and selection*
- Current work is expanding the analysis to new Semiconductor modules by developing platform-based modules (CMP, etch, deposition, etc.)

- One of the future directions
  - Expand the analysis to look at life cycle effect during the design stage. ie, DFE with a Life cycle focus.
    - This has potentially different users or audiences
    - Different applications within product design cycles
- Two approaches to this hybrid analysis
  - 1. EnV-S + SETAC LCA Methods
  - 2. EnV-S + Economic Input Output Method
  - Preliminary results with the *second approach* are outlined here

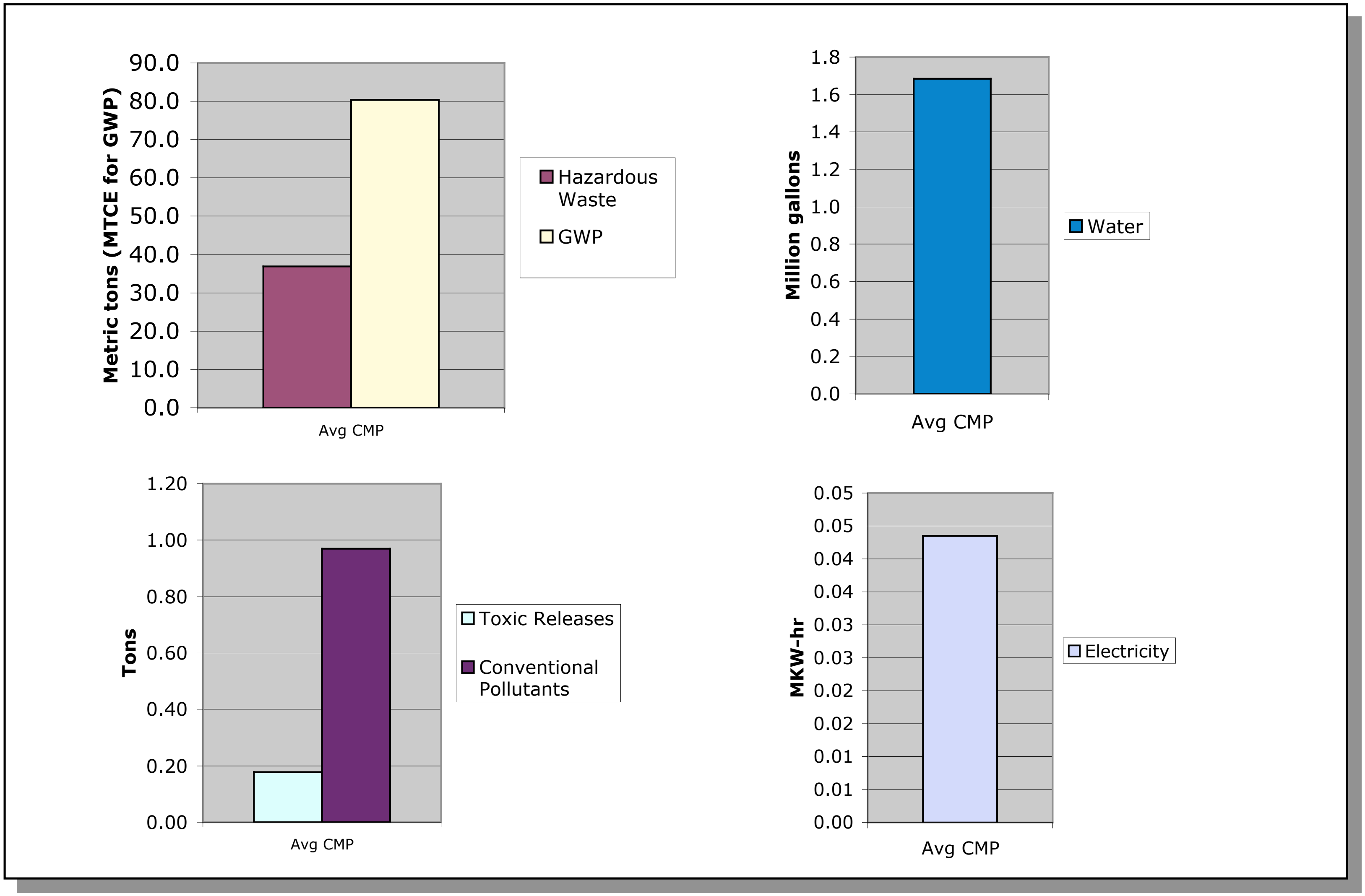
Case Study: the copper CMP process

Summary of parameters for a "typical" copper CMP process

Copper CMP totals for a "typical" process

Liquid		
Primer	21 g/min	0.01 $/wafer
UPW	7514 g/min	0.07 $/wafer
Slurry	0.13 gal/wafer	3.99 $/wafer
Other additives	0.08 g/min	0.00 $/wafer
Solid		
Pad	293 wafers/item	0.75 $/wafer
Pad conditioning	167 wafers/item	0.60 $/wafer
PVA brushes	2333 wafers/item	0.13 $/wafer
Other consumables	2933 wafers/item	0.26 $/wafer
Electricity	3000 W	0.01 $/wafer

Preliminary results - life cycle CMP effects



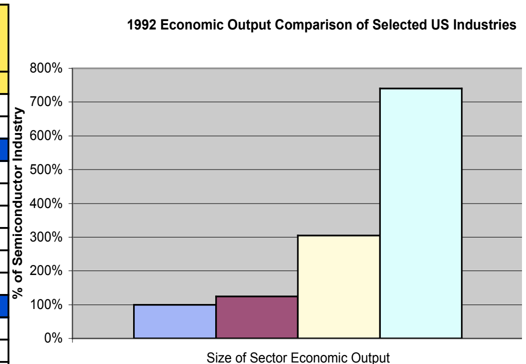
Summary and future work

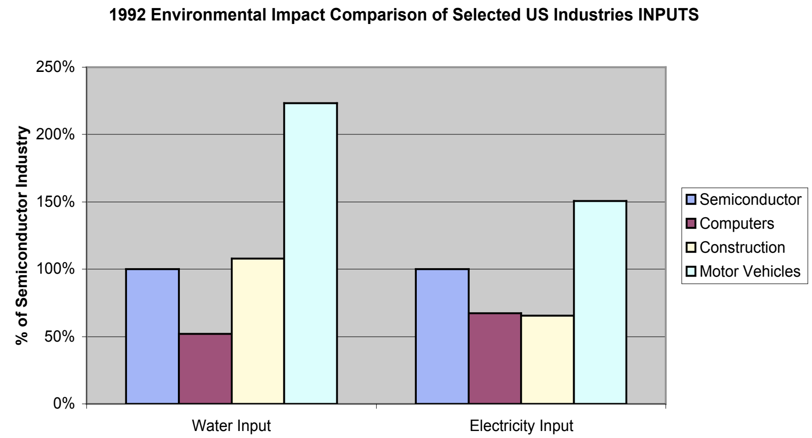
- Preliminary life cycle effects using EIOLCA
  - high growth rates
  - high impacts/$
  - Explore applicability of data further
- Develop combination of EnV-S and EIOLCA and other life-cycle approaches
  - Compare results with SETAC-type methods for a few case studies
  - This could offer a quick and easy way
    - to inform DFE for certain environmental issues during early product development phases
    - Or to draft/examine broad policy decisions

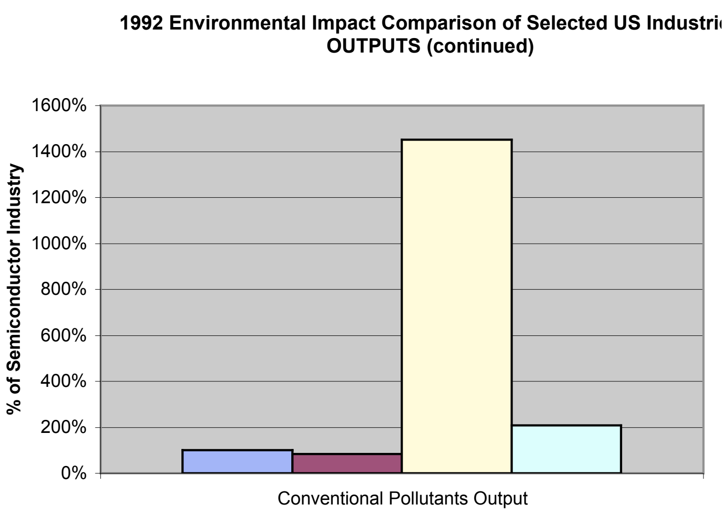
Appendix

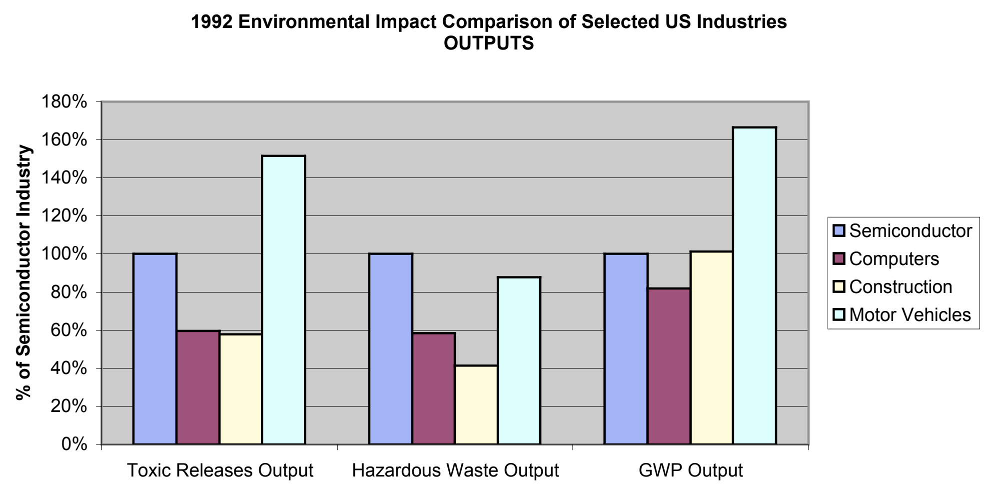
1992 summary of sector life cycle results

Sector #570200: Semiconductors and related devices		
	Semiconductor	
	1992 Data	
Size of Industry Output	30125	Millions of Dollars
Output Semiconductors		
Liquid Waste		Million Tons
Hazardous Waste	1.659	Million Tons
GWP	17.391	MMTCE
Toxic Releases	0.045	Million Tons
Conventional Pollutants	0.225	Million Tons
Input Semiconductors		
Water	93.670	billion gallons
Electricity	17.663	billion kW-hr
Chemicals		



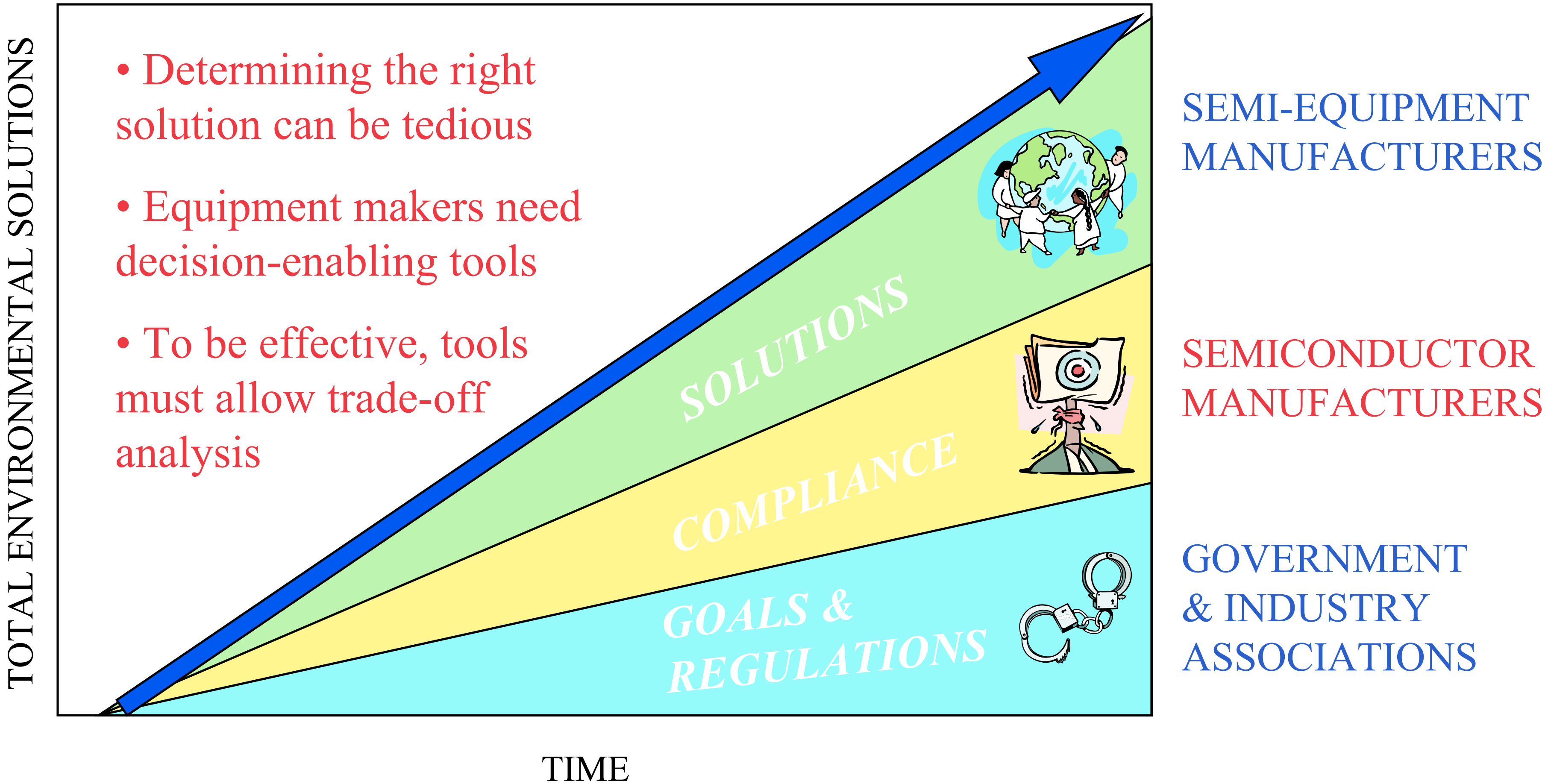






Environmental Trends

- Determining the right solution can be tedious
- Equipment makers need decision-enabling tools
- To be effective, tools must allow trade-off analysis



Slide adapted from Woolston, M., Francis, T., "Semiconductor EHS Goals - Why do we need an Environmental Value Systems Analysis Model?. . . a background," Seminar on the Environmental Value Systems (EnV-S) Analysis, SEMICON West 2002.

Typical Design Trade-Offs

Operation costs?

ROI?

Point Of Use or Centralized?

Capital costs?

Types of Technology?

Maintenance costs?

Energy Efficiency?

Byproduct treatments?

Modular?

Make or buy?

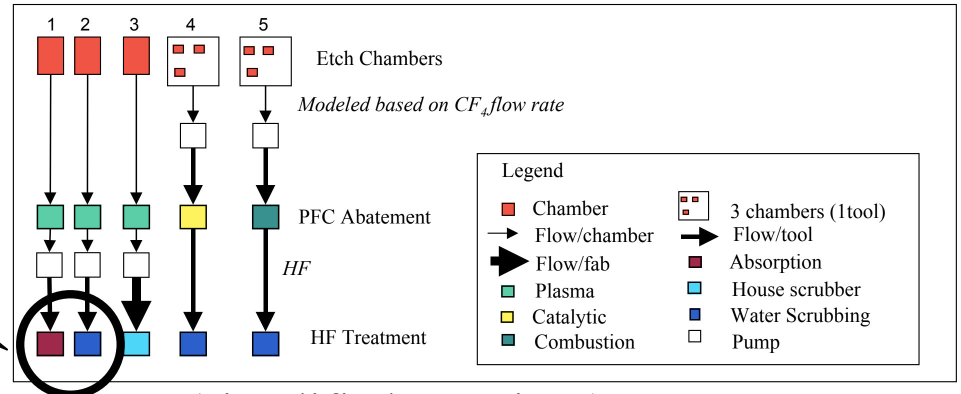
Slide adapted from Woolston, M., Francis, T., "Semiconductor EHS Goals - Why do we need an Environmental Value Systems Analysis Model?. . . a background," Seminar on the Environmental Value Systems (EnV-S) Analysis, SEMICON West 2002.

Summary of System Parameters

Summary of System Parameters (/chamber)	200mm	300mm
CF4 (sccm) flow from process chamber	50	250
Throughput (wafers/chamber)	15	15
Utilization (%)	70	70
Annual hours of proceessing	6115	6115
Pump dilution ratio (nitrogen to gas flow)	1000	1000
C equivalent (g/min)	332	1662
Cequivalent (g / wafer pass)	1330	6648
C/year for a 5 layer etch (tons). 5000 wsps	1728	8642
C from energy use (10KWhr/in^2, SIA Roadmap)	24937	56109
If unabated and unscrubbed, HF (g/wafer pass)	0.7	3.4
A difference of 1 c/wafer pass =	2751	$/Etch tool/year

Cost of HF treatment

2 choices were explored
- absorption
- water scrubbing



(simplified equations)

Absorption system details:
Could configure by
(i) cascading multiple chambers to an absorption system
(ii) Chaining multiple absorption systems together (essentially adjusting absorption capacity)

$$CoO_{abs} = \frac{a.(FC+UC)}{c.w} + \frac{CC+DC}{a.w}$$

Where,

CoO_{abs} = Absorption System Cost

a = Number of absorption systems cascaded together

c = Number of chambers connected to the systems

FC = Fixed costs/system/year

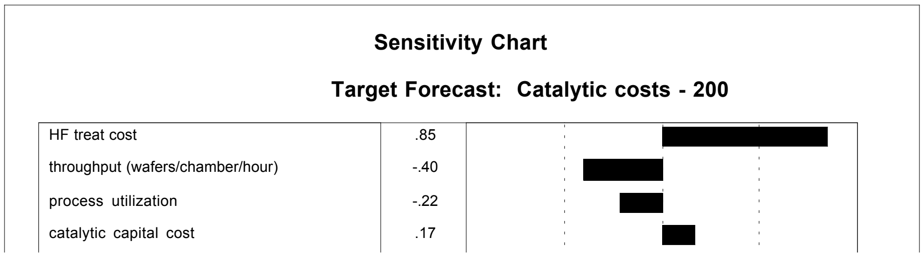
UC = Utility costs/system/year

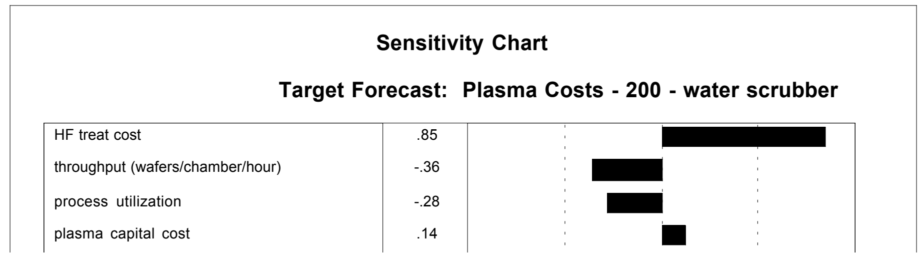
w = Number of wafers processed/year

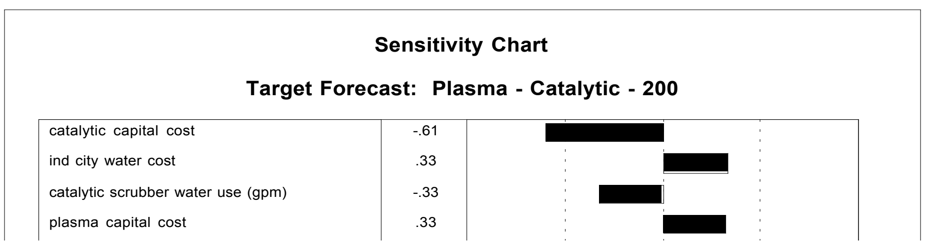
CC = Consumable costs

DC = Disposal costs

Determining Important Variables







- For the individual units (plasma and catalytic), HF treatment costs are the most important!
- But these disappear in the plasma-catalytic CoO difference. Now catalytic capital cost is the biggest cost factor!