Low-k Dielectric Deposition: A Case study using the Environmental Value Systems Analysis

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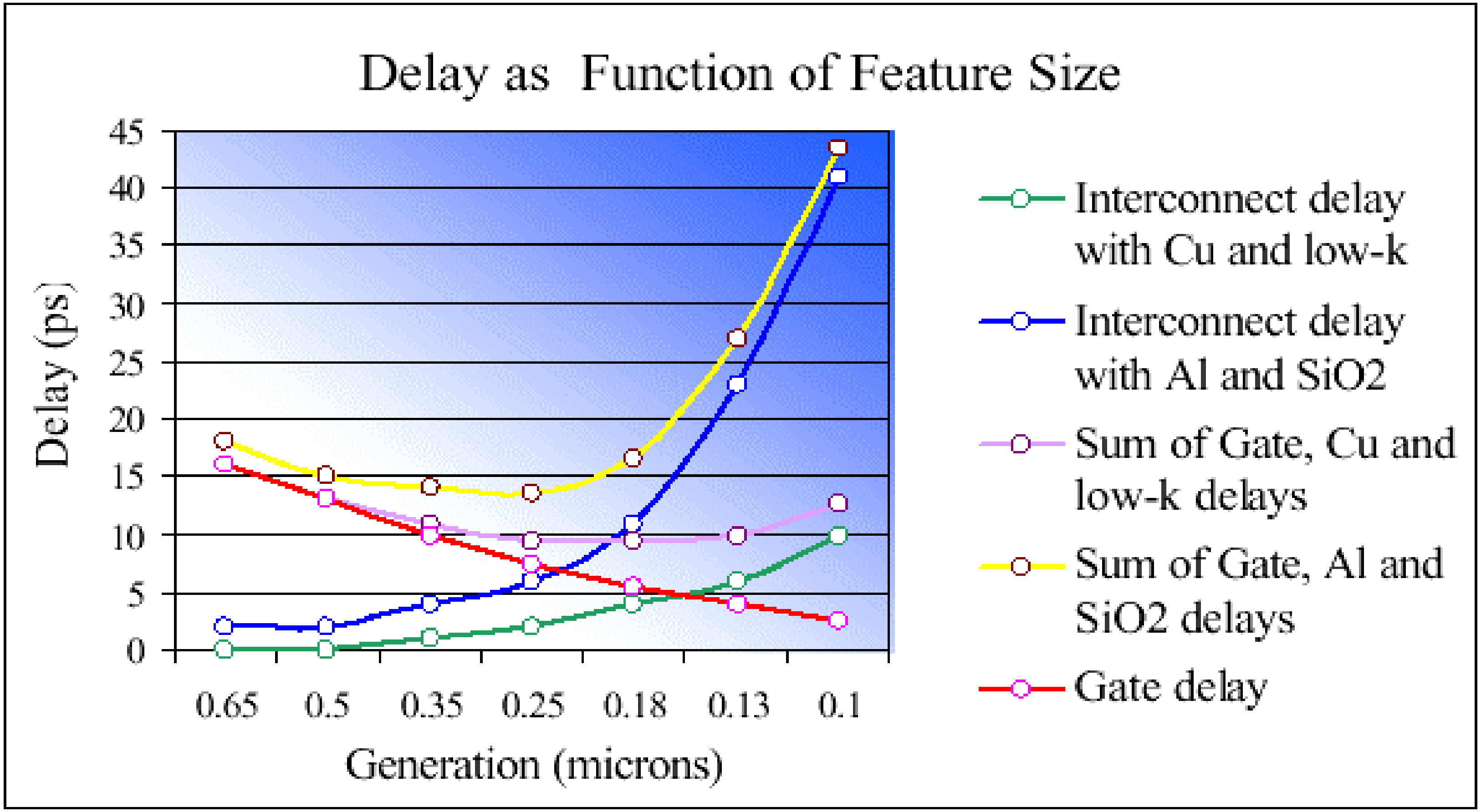
Contributions by ISMT, AMD, Applied Materials and Centrotherm are gratefully appreciated and acknowledged.

Why low-k?

- Device Speed = 1/(R x C)
  [R=resistance, C=capacitance]
- Reduction in capacitance in insulating materials
  - Reduces delays in circuit
  - Reduces cross-talk
- In order to reduce capacitance we need dielectrics with lower k-values (for SiO2, $k = 4.3$)
- Low-k Dielectrics defined as materials with $k < 3$
- Ultra low-k : $k<2.2$
- For currently used low-k materials: $2.5<k<3.0$

Why Low-k?



Source: Mykrolis.com – Application Notes

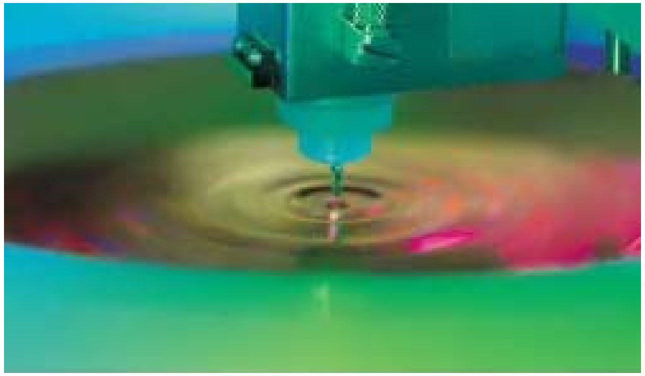
(Microprocessor production now at 0.13 micron)

SOD vs. CVD

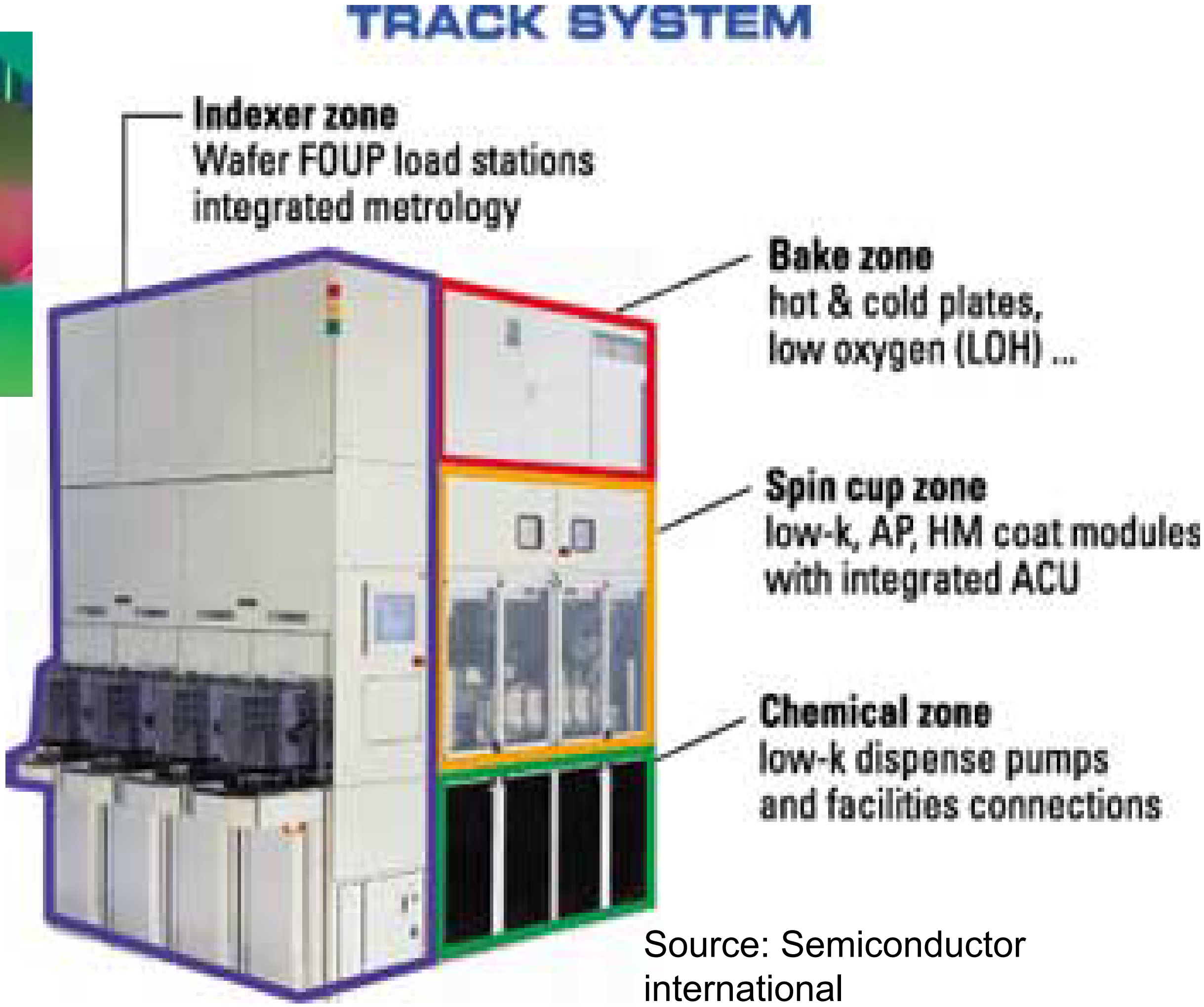
- Two methods for low-k integration
  - Spin-on low-k dielectric coating
    - Similar to tracks used for lithography
  - Chemical Vapor Deposition (CVD)
    - Extension of Conventional CVD

- Choosing between the two methods??
  - Cost considerations
  - Ease of integration
  - Process Performance and Yield criteria
  - "Scalability" to lower k values

Spin-On Deposition (SOD)



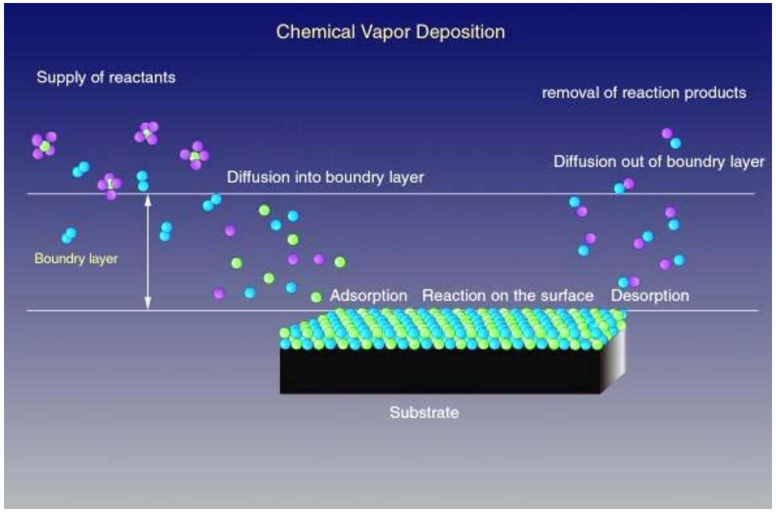
Source: telusa.com



Source: Semiconductor international

SOD in the fab: automatic dispense, exhausted, enclosed equipment similar to photolithography.

Chemical Vapor Deposition (CVD)



Source: everest-coatings.com

CVD in the Fab: automatic processing, exhausted, enclosed equipment with gas monitoring; abatement.

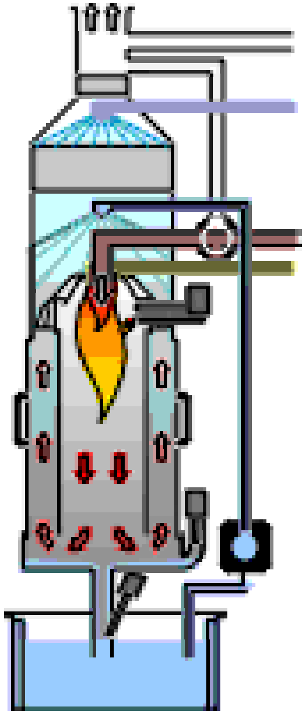
Source: Advanced Micro Devices

Point of Use Abatement for CVD

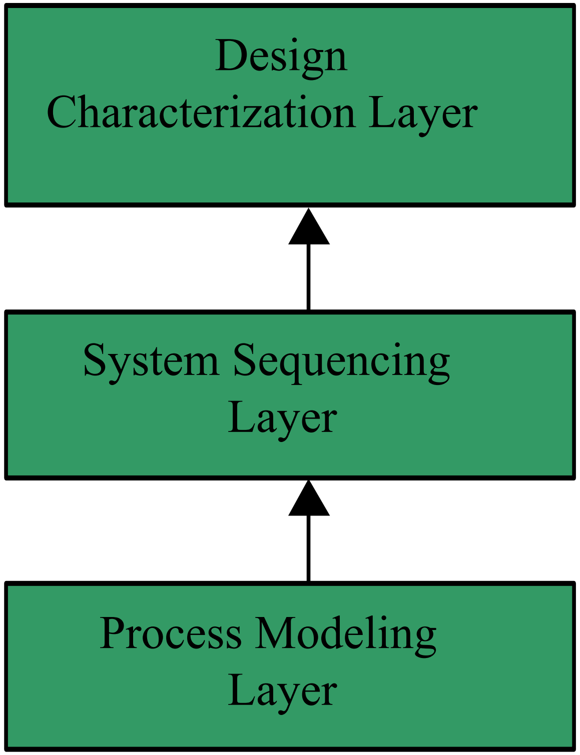
Centrotherm FLAWAMAT® point-of-use abatement system

Uses a three-step-technology:
- Combustion / thermal decomposition
- Rinsing
- Aerosol retaining

Source: Centrotherm



Environmental Value Systems Analysis (EnV-S)



Design Characterization Layer

System Sequencing Layer

Process Modeling Layer

Equipment and semiconductor manufacturers need a tool for the quantitative evaluation and comparison of tool-centric environmental solutions

EnV-S Model Blueprint*

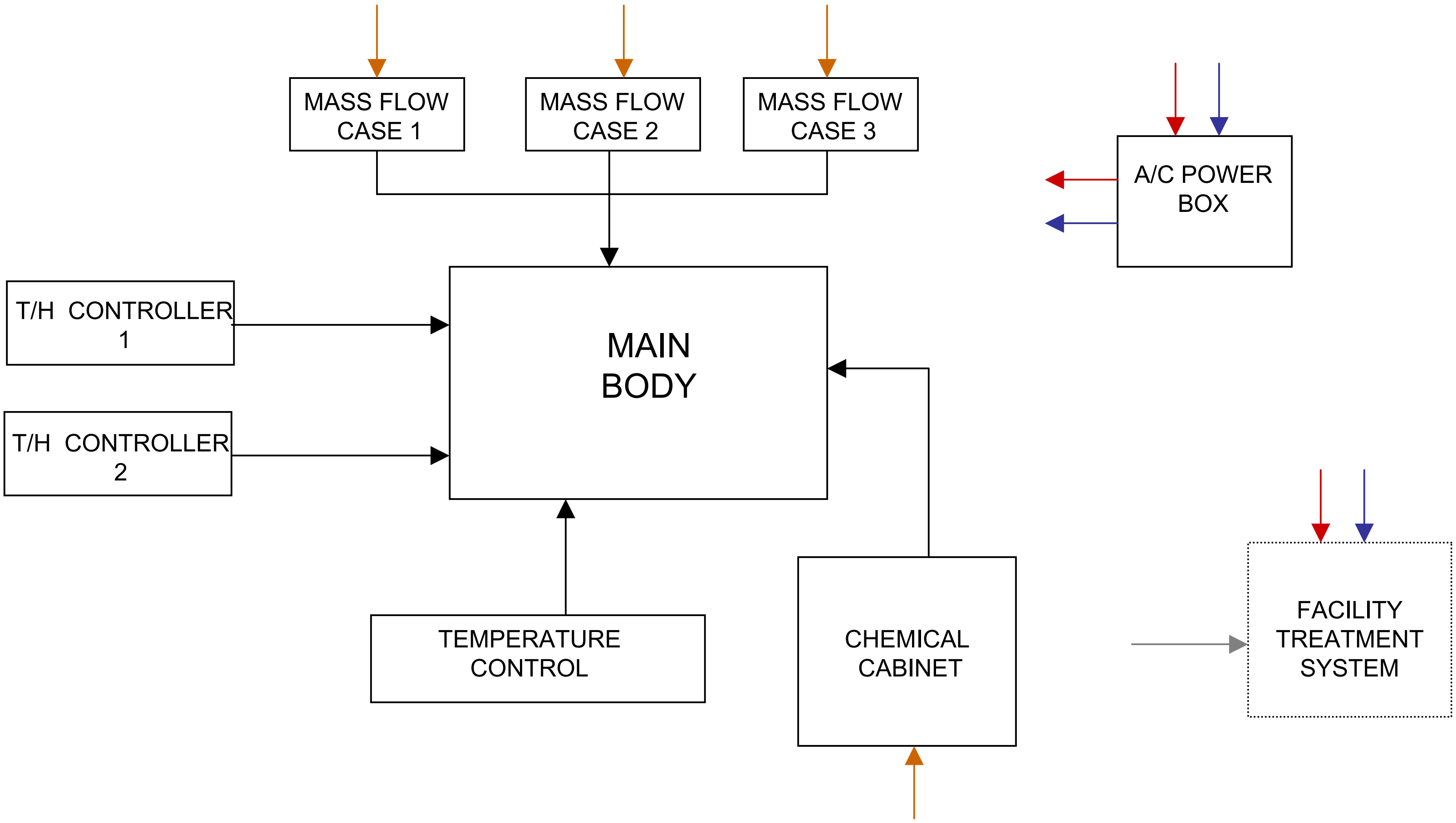
Focus the model on the process tool and the support equipment
Ensure the model output is in terms of important business metrics such as CoO
Factor in all controllable variables that significantly affect the key outputs
Provide sensitivity analysis for those controllable variables
Enable “what-if” comparisons 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

*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.

Methodology for low-k Case

1. EnV-S module development for tool and support equipment
   - Strength of EnV-S lies in the fact that the analysis is tool centric
2. Data collection
   - One of the toughest parts of the process!!
3. Cost of Ownership (CoO) Analysis
4. Uncertainty Analysis and Sensitivity Analysis
5. Environmental Impact Characterization (e.g. GWP, HAPs etc.)
6. Human Health impact characterization

SOD System Diagram



MASS FLOW CASE 1

MASS FLOW CASE 2

MASS FLOW CASE 3

A/C POWER BOX

T/H CONTROLLER 1

T/H CONTROLLER 2

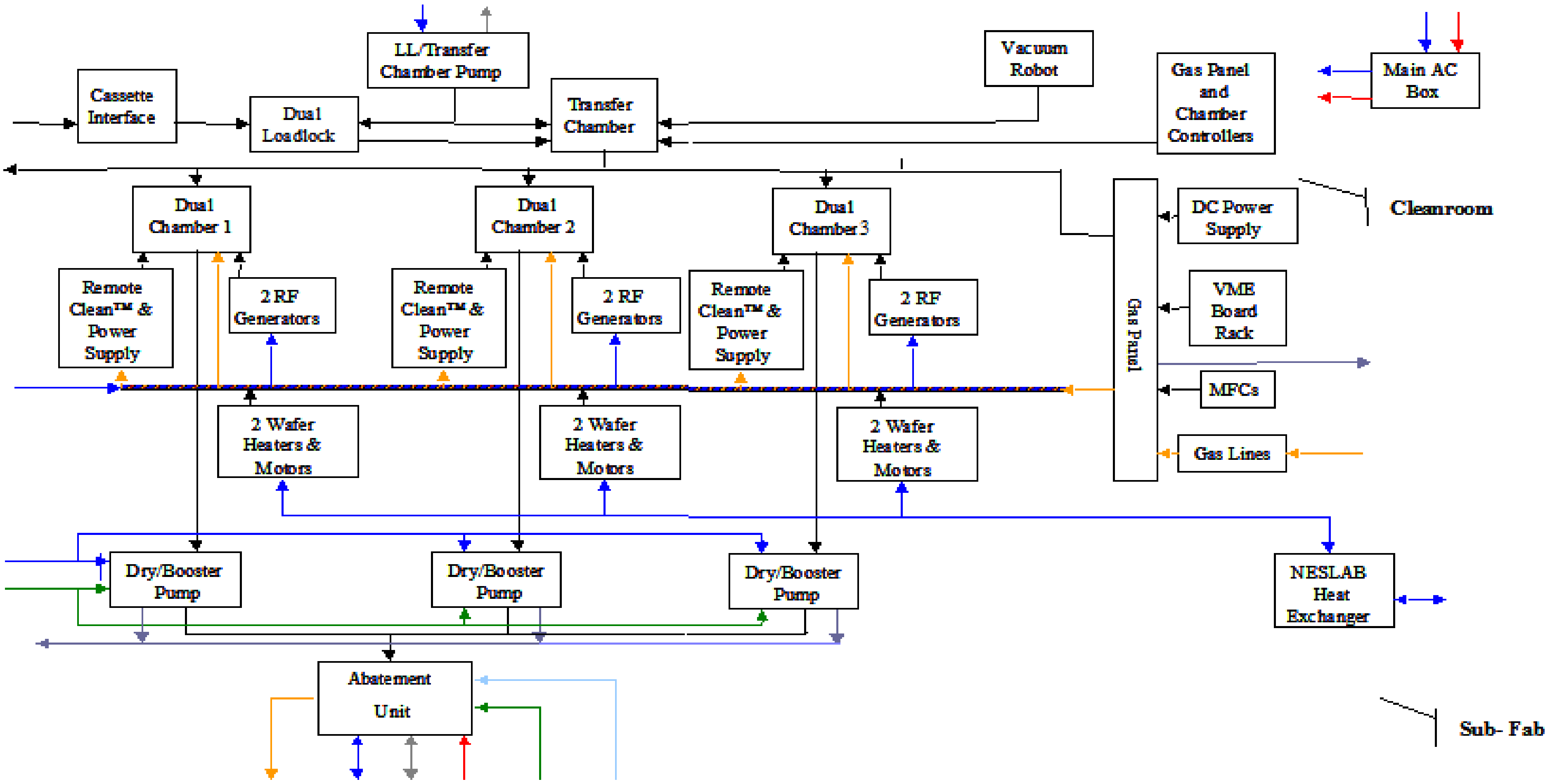
MAIN BODY

TEMPERATURE CONTROL

CHEMICAL CABINET

FACILITY TREATMENT SYSTEM

CVD System Diagram



Input Data examples

- Facility Data:
  - Wages, Shifts, Floor Space costs, utility costs etc.

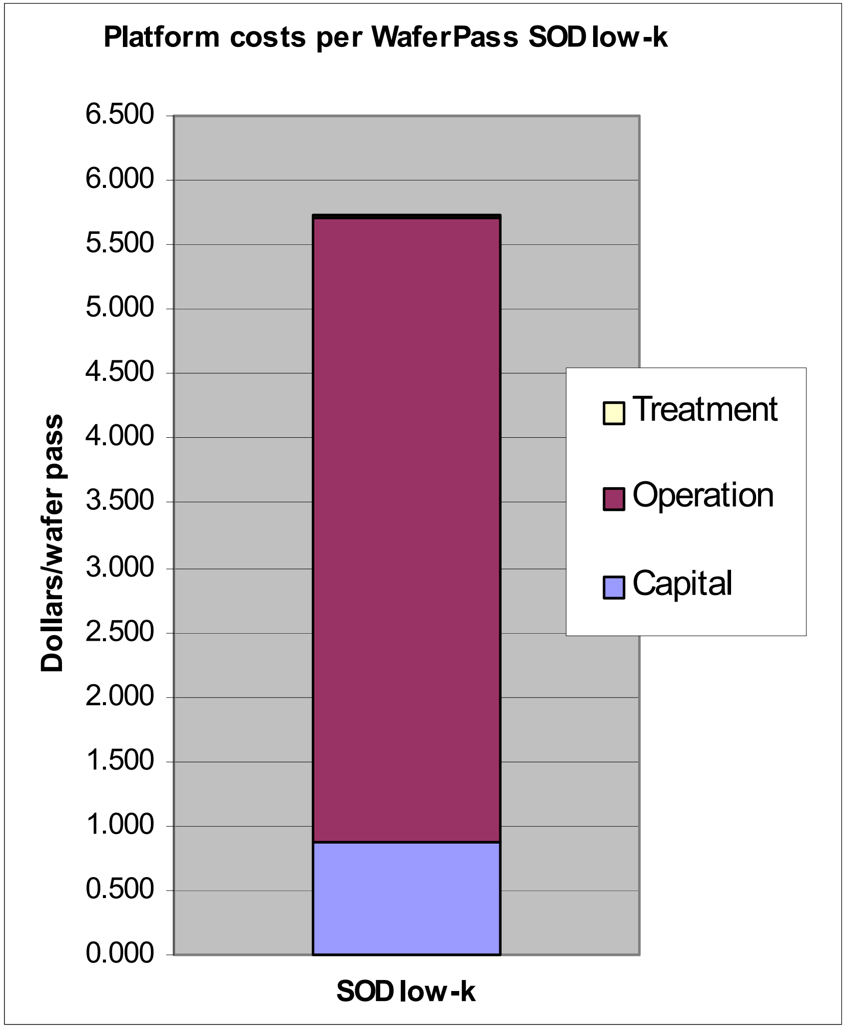
    (Aligned with ISMT/Selete Unified Equipment Performance Metrics for 130nm technology)
- Throughput Data:
  - Reliability Data
    - MTBF (Mean Time between Failures)
    - MTTR (Mean Time to Repair)
  - Scheduled downtime/maintenance
  - Percent utilization of tool

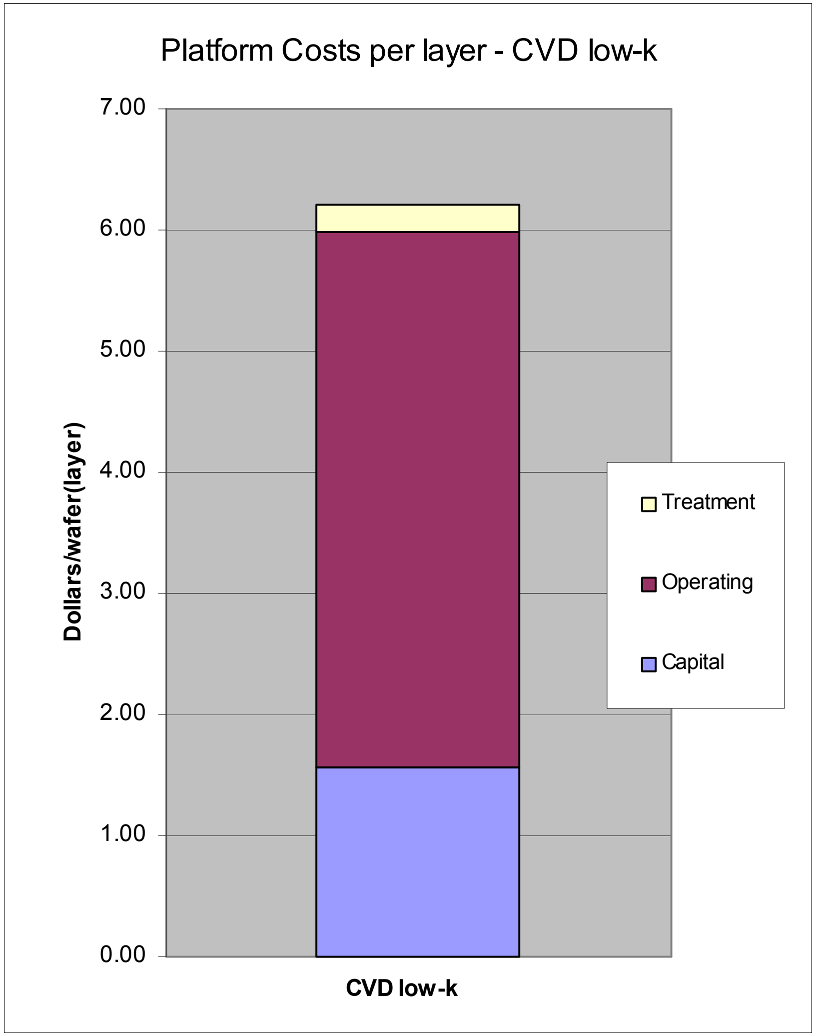
Input data examples (contd.)

- Equipment Data:
  - Cost of tool, abatement devices, pumps etc.
  - Installation costs – mechanical, electrical etc.
  - Maintenance Costs

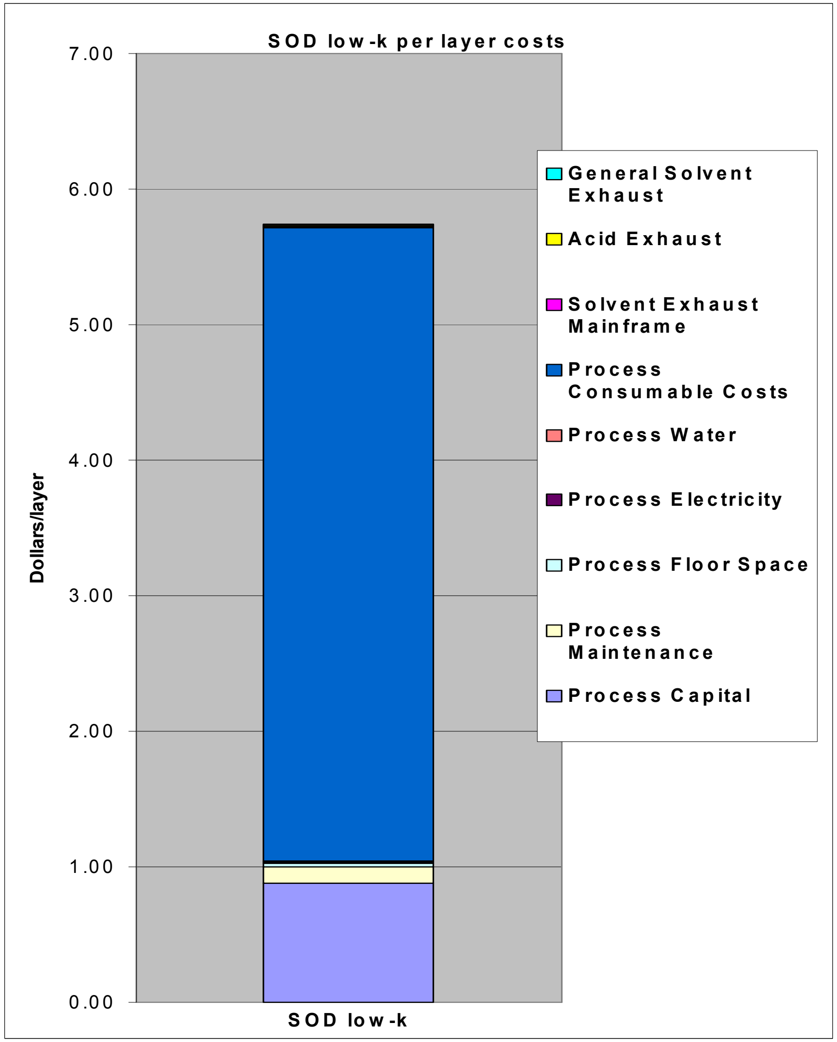
- Production Data:
  - Recipe Data (Flows, step times etc.) – Deposition and Clean recipe (CVD: Trimethyl Silane, O2, He, NF3; SOD: solvent component.)
  - Utility use – Electricity and water use
  - Consumables – Tool and abatement
  - Treatment/Disposal costs (Aligned with ISMT estimates for Fab utility costs)

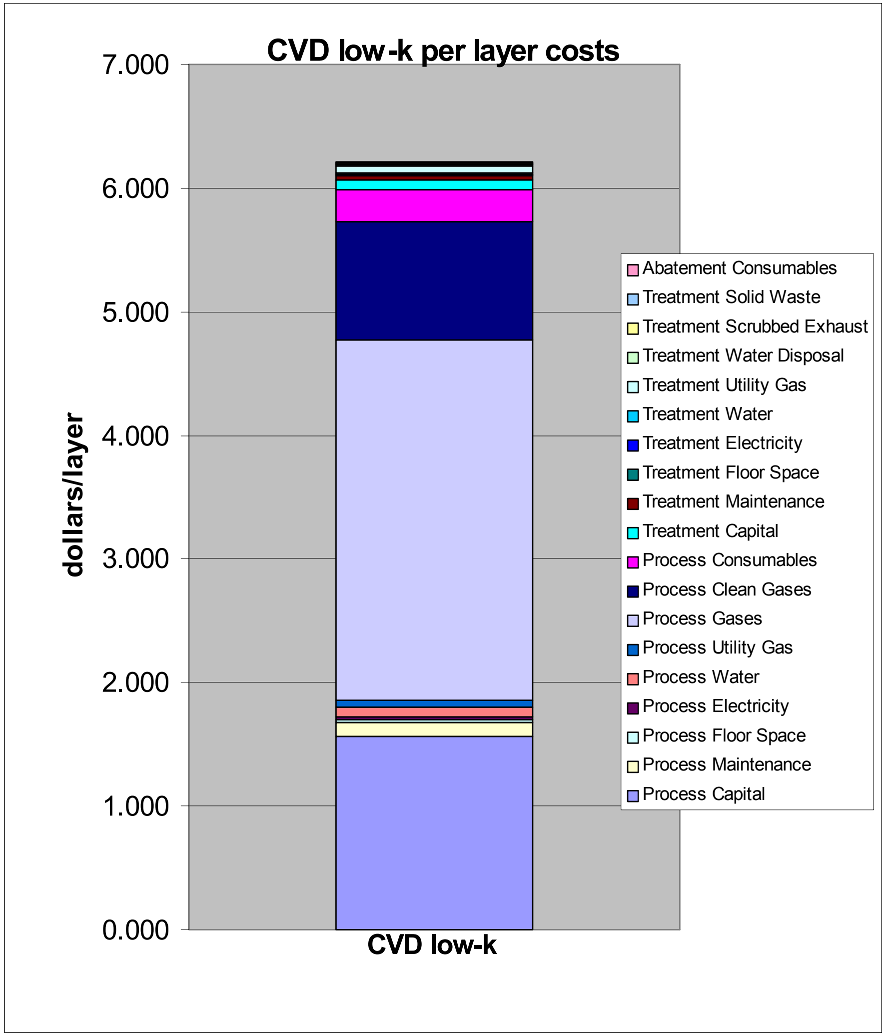
CoO Results


Platform costs per WaferPass SOD low-k
Dollars/wafer pass
6.500
6.000
5.500
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
SOD low-k
Treatment
Operation
Capital

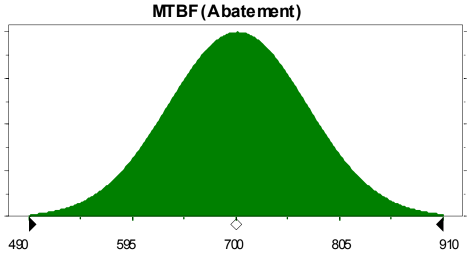

Platform Costs per layer - CVD low-k
Dollars/wafer(layer)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
CVD low-k
Treatment
Operating
Capital

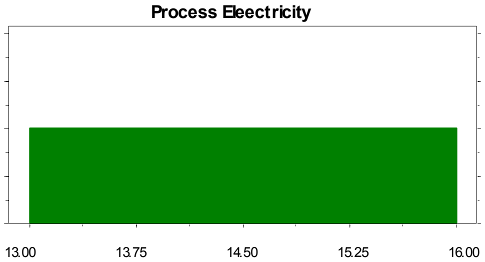
CoO Results (cont'd)

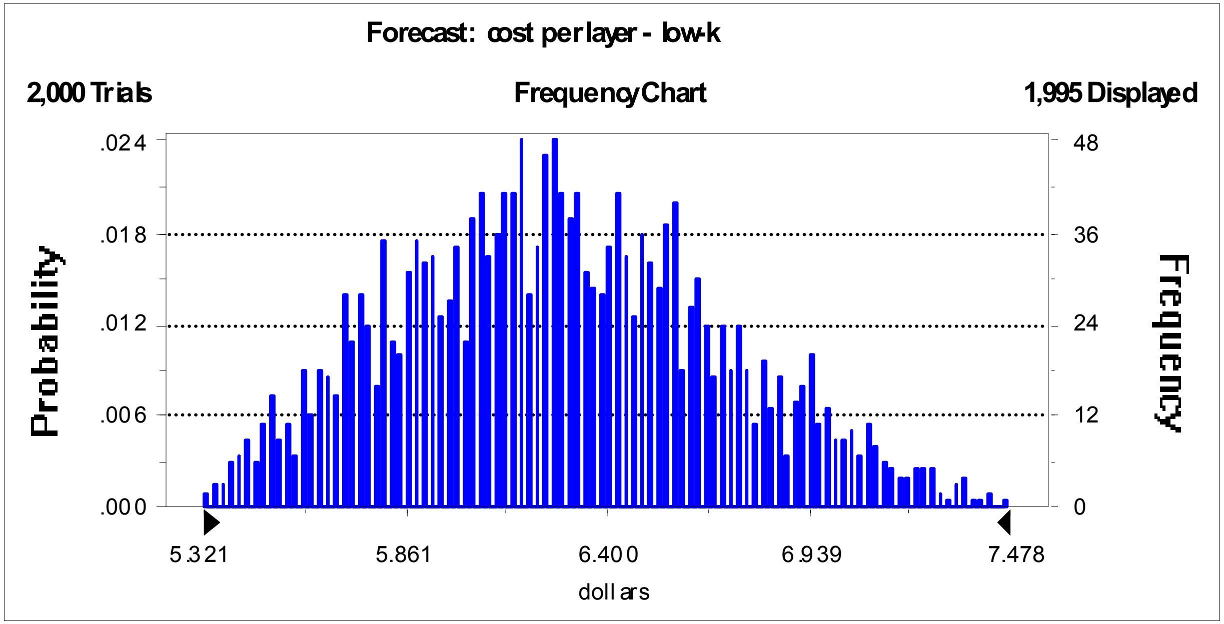




Uncertainty Analysis







Analysis performed by means of a Monte Carlo Simulation

Uncertainty in input variables modeled using probability distributions

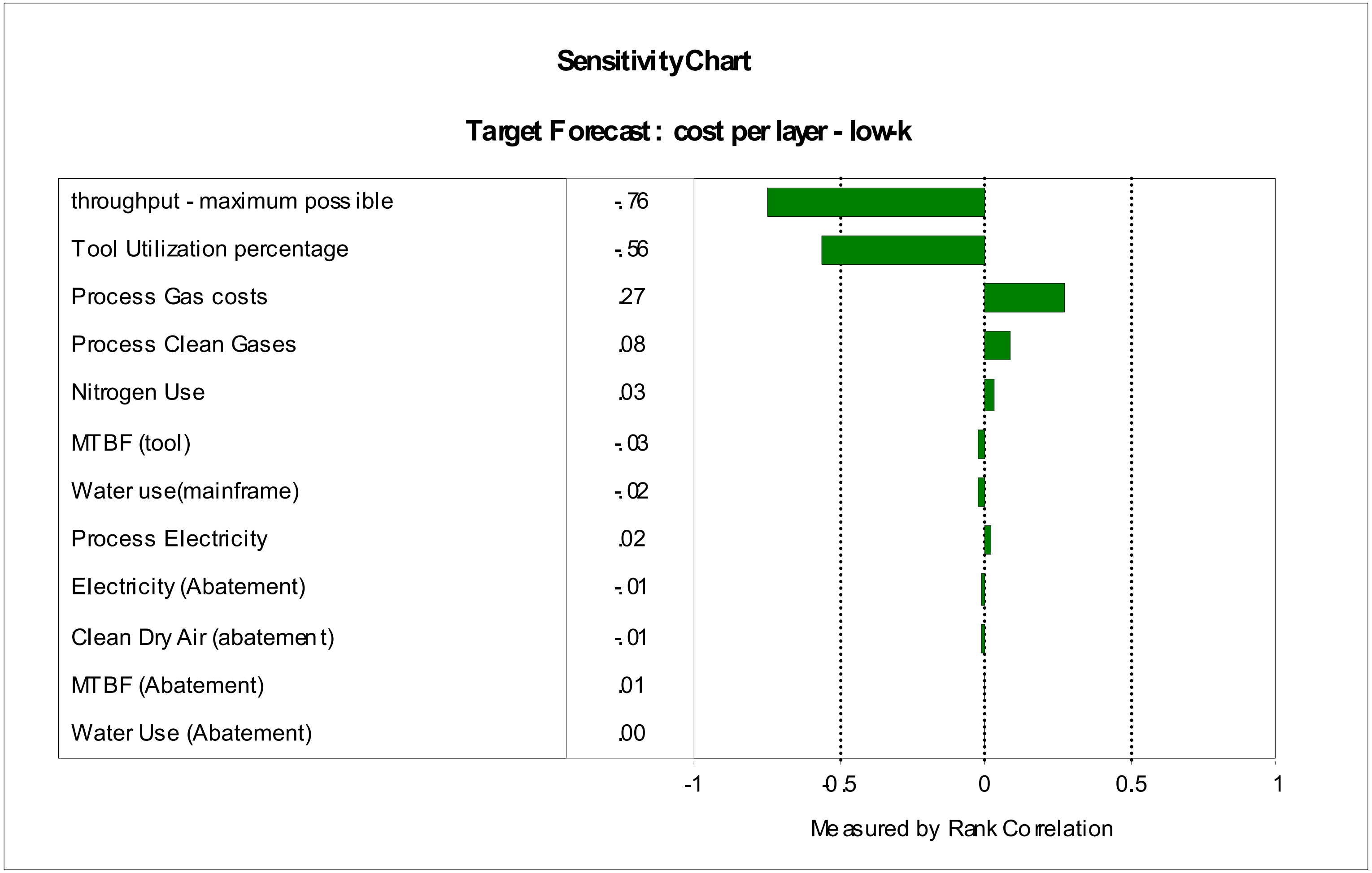
Output can be obtained in terms of Mean Cost, Median Cost and Cost Range (10th and 90th percentile) while taking uncertainties into account

Uncertainty Analysis Results

- CoO results

	Spin – On	CVD
Mean	5.86	6.27
Median	5.60	6.25
10th Percentile	4.17	5.71
90th Percentile	7.88	6.86

Sensitivity Analysis - CVD



Economic Input-Output LCA (EIOLCA)

Developed by the Green Design Initiative at Carnegie-Mellon University

- Sectoral approach using Leontief Matrices
- Basis of matrix - unit economic output of one sector links to economic outputs of many other sectors.
- The Department of Commerce's 485x485 commodity input-output model of the US economy serves as basis.
- Potentially more inclusive than typical SETAC based LCA methods.
- Dollar values are translated to environmental impacts using several different available databases.

Output from sectors	**Input to sectors**				**Intermediate output *O***	**Final demand *F***	**Total output *X***
	1	**2**	**3**	**n**			
1	X_{11}	X_{12}	X_{13}	X_{1n}	O_1	F_1	X_1
2	X_{21}	X_{22}	X_{23}	X_{2n}	O_2	F_2	X_2
3	X_{31}	X_{32}	X_{33}	X_{3n}	O_3	F_3	X_3
n	X_{n1}	X_{n2}	X_{n3}	X_{nn}	O_n	F_n	X_n
Intermediate input *I*	I_1	I_2	I_3	I_n			
Value added *V*	V_1	V_2	V_3	V_n		**GDP**	
Total input *X*	X_1	X_2	X_3	X_n			

Source: www.eiolca.net

EnV-S + EIOLCA Hybrid LCA: CVD TEOS

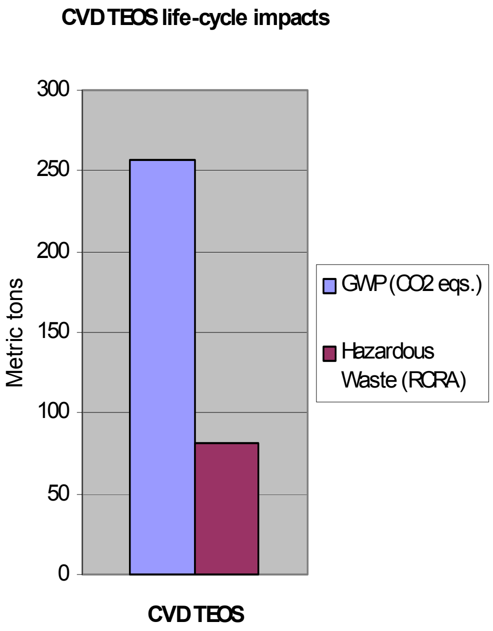
Totals for a"typical" CVD TEOS process

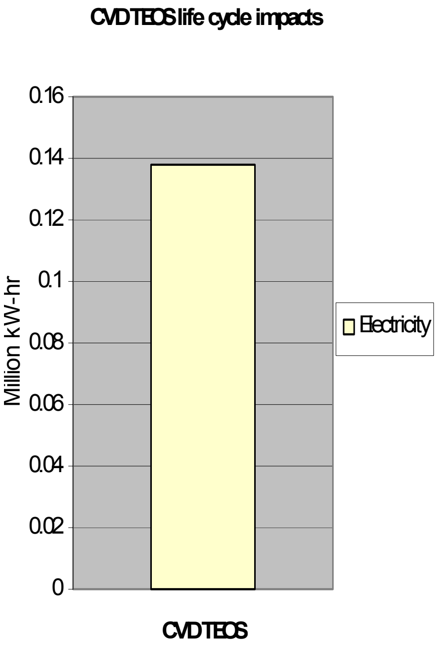
	Usage	Cost ($/100000 wafers)
Utilities		
Electricity*	0.6 kWHr/Wafer	3025
Industrial City Water**	32 gpm	7770
High Purity Nitrogen	60000 sccm	2800
Process Chemicals		210000
Chamber Clean Chemicals		56650
Consumables and Maintenance Parts		32570
Equipment (Mainframe and Abatement)	1 item/5 yrs	140270

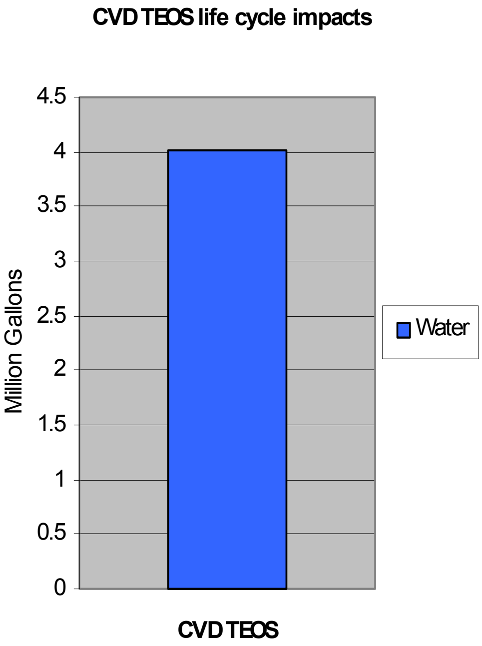
*Includes Mainframe and Abatement devices

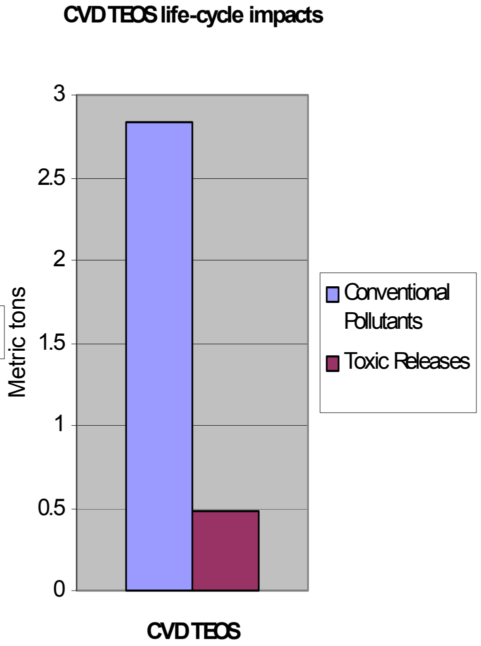
** Includes Mainframe, Abatement, Heat Exchangers and pumps

Hybrid LCA Results: CVD TEOS









Advantages and Limitations of EIOLCA

Advantages

- Quick-hit technique for estimating Life Cycle Impacts
- Highly compatible for use with EnV-S since inputs are in terms of dollar values
- Potentially more comprehensive than traditional SETAC-type LCA – accounts for all sectors of the economy
- Costs $ instead of $$$

Limitations

- Inputs have to be classified under predefined sectors and sub-sectors of the economy
- Environmental impacts scale directly with economic value of inputs – analysis is hence unsuitable for expensive specialty chemicals

Summary and Conclusions:

- EnV-S analysis of low-k dielectric deposition provides a basis for comparison and identifying potential areas for CoO reduction
- Overwhelming contribution of operating costs and material costs to overall CoO for CVD as well as SOD
- Preliminary analysis shows overall CoO for SOD to be marginally lower than that for CVD
  - Quality of SOD data has to be improved to make a final conclusion
- Facility-scale abatement for SOD has been studied. Other configurations can be investigated as data becomes available
- Hybrid LCA approach using EIOLCA with EnV-S can be a useful technique to get quick LCA results
  - Issues pertaining to specialty chemicals and other specialized first-tier suppliers have to be resolved.