

Strategic Cost Model

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Objective

- The semiconductor industry continuously undergoes rapid technological change.
- Successfully navigating the technology changes is critical to success of semiconductor companies and their suppliers.
- The semiconductor industry has produced a consensus view of the next fifteen years in the International Technology Roadmap for Semiconductors (ITRS).
- While a useful technology roadmap, the ITRS does not provide any guidance of the economics and market for the new technologies.

Strategic Cost Model

- Implements the most recent ITRS with regular updates to keep the model current.
- Converts the ITRS into detailed forecasts of processes, equipment and materials requirements, and wafer cost.
- Implements all years, half-pitches and products included in the ITRS.
- Has baseline defaults implemented for the entire roadmap.
- Allows full user customization of processes, equipment and materials.

Building a Model

- To build a model the user selects:
 - Year to model - 2000 to 2029 supported
 - Wafer size - 300mm or 450mm
 - Country – 13 supported
 - The initial and up to four fab upgrade configurations - each configuration includes year, process (1/2-pitch and product type) and capacity.
 - Utilization (optional) - default is 90%
 - Wafer yield (optional) - the model calculates a default

Building a Model

Fab definition

Year to model: 2013
Wafer size: 300mm
Country: United States

Fab configuration	Year	1/2 pitch - product	Capacity (wpm)	Error messages
Initial configuration	2013	180nm - RRAM-2D	30,000	
Upgrade 1	NA	180nm - RRAM-2D	NA	
Upgrade 2	NA	180nm - RF	NA	
Upgrade 3	NA	180nm - PCRAM	NA	
Upgrade 4	NA	180nm - NOR-FG	NA	
		180nm - MRAM		
		180nm - FeRAM		
		165nm - DRAM		
		150nm - RF		

Utilization: 90%

Wafer yield: default 98.6%

Fab definition screen with 1/2-pitch – product dropdown – dropped down – white area is editable

Customizing a Process

- The model supports: ASIC, DRAM, FeRAM, MRAM, NAND-2D, NAND-3D, NOR-CT, NOR-FG, PCRAM, RF, RRAM-2D, and RRAM-3D products and in each case every half-pitch listed in the ITRS.
- For each product type there is a user editable table of process blocks by half-pitch as well as pitch by mask layer.
- The process step that make up each process block are visible and editable by the user by half-pitch.
- Lithography calculations and default controls are visible and editable.
- A summary of process steps is also visible and editable.

Customizing a Process

Process type												
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
M1 1/2 pitch (nm)	45	38	32	27	24	21	18.9	16.9	15	13.4	11.9	10
Transistor printed gate length (nm)	41	35	31	28	25	22	19.8	17.7	15.7	14	12.5	11
Threshold voltages	4	4	4	4	4	4	4	4	4	4	4	4
Type of gate oxide	GL High-K	GL High-K	GL High-K	GL High-K	GL High-K	GL High-K	GL High-K	GL High-K	GL High-K	GL High-K	GL High-K	GL High-K
Number of gate oxides	2	2	2	2	2	2	2	2	2	2	2	2
Transistor type (from the ITRS)	Bulk	Bulk	Bulk	Bulk, FDSOI	Bulk, FDSOI	Bulk, FDSOI, MG	Bulk, FDSOI, MG	Bulk, FDSOI, MG	FDSOI, MG, III-V/Ge	FDSOI, MG, III-V/Ge	FDSOI, MG, III-V/Ge	MG, V/Ge
Transistor type selection	Bulk	Bulk	Bulk	MG	FDSOI	MG	MG	MG	MG	MG	MG	MG
Embedded memory	None	None	None	None	None	None	None	None	None	None	None	None
Metal layers	11	10	9	12	11	13	13	14	14	14	14	14

Process blocks	Masks	Actual											
		Actual	Actual	Actual	Actual	Actual	Actual	Actual	Actual	Actual	Actual	Actual	Actual
3D layer blocks (8 layers each) - Flash	2	0	0	0	0	0	0	0	0	0	0	0	0
3D layer blocks (8 layers each) - RRAM	2	0	0	0	0	0	0	0	0	0	0	0	0
3D pipe connection layer - Flash and RRAM	1	0	0	0	0	0	0	0	0	0	0	0	0
3D select gate - Flash	3	0	0	0	0	0	0	0	0	0	0	0	0
3D select gate - RRAM	3	0	0	0	0	0	0	0	0	0	0	0	0
Active - DRAM	1	0	0	0	0	0	0	0	0	0	0	0	0
Active - Flash	1	0	0	0	0	0	0	0	0	0	0	0	0
Active/Floating Gate - Flash	2	0	0	0	0	0	0	0	0	0	0	0	0
Additional Al layers with ILD	2	0	0	0	0	0	0	0	0	0	0	0	0
Air Gap	1	0	0	0	7	7	7	7	7	7	7	7	9
Al bond pads - Memory	1	0	0	0	0	0	0	0	0	0	0	0	0
Al layer 1	1	0	0	0	0	0	0	0	0	0	0	0	0
Alloy interconnect - All	0	1	1	1	1	1	1	1	1	1	1	1	1
Anneals - All	0	7	7	7	5	5	5	5	5	5	5	5	5
Assymetric channel implant (array) - DRAM	1	0	0	0	0	0	0	0	0	0	0	0	0
Capacitance implant - Logic	0	3	3	3	0	2	0	0	0	0	0	0	0
Charge Trap gate - Flash	1	0	0	0	0	0	0	0	0	0	0	0	0
Contact - Cu filled - DRAM	1	0	0	0	0	0	0	0	0	0	0	0	0
Contact - W - DRAM	1	0	0	0	0	0	0	0	0	0	0	0	0
Contact with ILD - Cu filled - Flash	1	0	0	0	0	0	0	0	0	0	0	0	0

Segment of the ASIC product sheet – showing blocks – white area is editable

Customizing a Process

<i>Year EUV enters production</i>		
ASIC	Default	2015
DRAM/FRAM	Default	2014
FeRAM/NAND/NOR/PCRAM/FRAM	Default	2015
MPURF	Default	2015

Segment of litho controls sheet – white area is editable

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Mix and match limits													
ASIC	4	4	4	4	4	4	4	4	4	4	4	4	4
DRAM/FRAM	4	4	4	4	4	4	4	4	4	4	4	4	4
FeRAM/NAND/NOR/PCRAM/FRAM	4	4	4	4	4	4	4	4	4	4	4	4	4
MPURF	2	2	2	2	2	3	3	3	3	3	3	3	3
Wavelength (W) in nm													
I-line	365	365	365	365	365	365	365	365	365	365	365	365	365
KrF	248	248	248	248	248	248	248	248	248	248	248	248	248
ArF	193	193	193	193	193	193	193	193	193	193	193	193	193
ArFi	193	193	193	193	193	193	193	193	193	193	193	193	193
EUV	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Numerical aperture (NA)													
I-line	0.60	0.60	0.62	0.62	0.62	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
KrF	0.75	0.80	0.82	0.82	0.82	0.85	0.90	0.92	0.92	0.93	0.93	0.93	0.93
ArF	0.68	0.85	0.85	0.85	0.85	0.92	0.93	0.93	0.93	0.93	0.93	0.93	0.93
ArFi	NA	NA	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
EUV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.25	0.25
NA*W													
I-line	0.0016	0.0016	0.0017	0.0017	0.0017	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018
KrF	0.0030	0.0032	0.0033	0.0033	0.0033	0.0034	0.0036	0.0037	0.0037	0.0038	0.0038	0.0038	0.0038
ArF	0.0035	0.0044	0.0044	0.0044	0.0044	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048
ArFi	NA	NA	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070
EUV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0185	0.0185
Minimum single exposure K₁													
I-line													
Memory	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Logic	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
KrF													
DRAM/FRAM	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
FeRAM/NAND/NOR/PCRAM/FRAM	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29

Customizing a Process

Product type		RRAM-2D	
Process Blocks Definition		Process Step Description	
		2000	2001
Half-pitch (nm)		250	250
3D layer blocks (8 layers each) - Flash	Usage	0	0
	FEOL critical clean	Clean - FEOL - Crit	Clean - FEOL - Crit
	3D layer deposition	ALD - 3D	ALD - 3D
	Memory plug mask	ALD - 3D	Litho
	Etch memory plug	ALD - GST ALD - Cap Electr	Etch - Si/trench
	FEOL critical clean	ALD - Cap High-k	Clean - FEOL - Crit
	ONO deposition	ALD - Gate High-k	ALD - ONO
	Polysilicon deposition	ALD - Metal Gate	ALD - NPoly
	Planarise polysilicon	ALD - Spacer ALD/PVD - TaNTaCu	MP - Poly
	Post CMP clean	Clean - FEOL - PostCMP	Clean - FEOL - PostCMP
	Control gate mask	Litho	Litho
	Trim and etch 8x	Etch - poly/gate	Etch - poly/gate
	Additional step	NA	NA
	Additional step	NA	NA
3D layer blocks (8 layers each) - RRAM	Usage	0	0
	FEOL critical clean	Clean - FEOL - Crit	Clean - FEOL - Crit
	3D layer deposition	ALD - 3D	ALD - 3D
	Memory plug mask	Litho	Litho
	Etch memory plug	Etch - Si/trench	Etch - Si/trench
	FEOL critical clean	Clean - FEOL - Crit	Clean - FEOL - Crit
	HfOx deposition	ALD - Gate High-k	ALD - Gate High-k
	TiN deposition	CVD - TiN	CVD - TiN
	Planarise TiN	CMP - MG	CMP - MG
	Post CMP clean	Clean - FEOL - PostCMP	Clean - FEOL - PostCMP
	Control gate mask	Litho	Litho
	Trim and etch 8x	Etch - poly/gate	Etch - poly/gate
	Additional step	NA	NA
	Additional step	NA	NA
3D pipe connection layer - Flash and RRAM	Usage	0	0
	FEOL critical clean	Clean - FEOL - Crit	Clean - FEOL - Crit
	Nitride deposition	CVD - Pad Nit	CVD - Pad Nit

Segment of the block sheet showing process steps – with dropdown dropped down - white area is editable

Customizing a Process

RRAM-2D															
Process	Initial process				First upgrade				Second upgrade				Third upgrade		
	1/2 pitch		180	nm	1/2 pitch		NA	nm	1/2 pitch		NA	nm	1/2 pitch		NA
	Process steps (default)	Process steps (user entered)	Select	Process steps used	Process steps (default)	Process steps (user entered)	Select	Process steps used	Process steps (default)	Process steps (user entered)	Select	Process steps used	Process steps (default)	Process steps (user entered)	Select
ALD - 3D	0		Default	0	0		Default	0	0		Default	0	0		Default
ALD - GST	0		Default	0	0		Default	0	0		Default	0	0		Default
ALD - Cap Electr	0		Default	0	0		Default	0	0		Default	0	0		Default
ALD - Cap High-k	0		Default	0	0		Default	0	0		Default	0	0		Default
ALD - Gate High-k	1		Default	1	0		Default	0	0		Default	0	0		Default
ALD - Metal Gate	0		Default	0	0		Default	0	0		Default	0	0		Default
ALD - Spacer	0		Default	0	0		Default	0	0		Default	0	0		Default
ALD/PVD - TaN/Ta/Cu	0		Default	0	0		Default	0	0		Default	0	0		Default
ALD - TaN/WN/W	0		Default	0	0		Default	0	0		Default	0	0		Default
Ashing	12		Default	12	0		Default	0	0		Default	0	0		Default
Backgrind	0		Default	0	0		Default	0	0		Default	0	0		Default
Bond - temp bond	0		Default	0	0		Default	0	0		Default	0	0		Default
Bond - debond	0		Default	0	0		Default	0	0		Default	0	0		Default
Clean - BEOL - BSB	0		Default	0	0		Default	0	0		Default	0	0		Default
Clean - BEOL - Cu	0		Default	0	0		Default	0	0		Default	0	0		Default
Clean - BEOL - PostAlEtch	3		Default	3	0		Default	0	0		Default	0	0		Default
Clean - BEOL - PostCMP	7		Default	7	0		Default	0	0		Default	0	0		Default
Clean - BEOL - PostVtch	5		Default	5	0		Default	0	0		Default	0	0		Default
Clean - FEOL - BSB	0		Default	0	0		Default	0	0		Default	0	0		Default
Clean - FEOL - Crit	16		Default	16	0		Default	0	0		Default	0	0		Default
Clean - FEOL - PostCMP	11		Default	11	0		Default	0	0		Default	0	0		Default
Clean - FEOL - SPM	11		Default	11	0		Default	0	0		Default	0	0		Default
CMP - Active	0		Default	0	0		Default	0	0		Default	0	0		Default
CMP - Cu	0		Default	0	0		Default	0	0		Default	0	0		Default
CMP - DSL	0		Default	0	0		Default	0	0		Default	0	0		Default
CMP - MG	0		Default	0	0		Default	0	0		Default	0	0		Default
CMP - Oxide	9		Default	9	0		Default	0	0		Default	0	0		Default
CMP - Poly	0		Default	0	0		Default	0	0		Default	0	0		Default
CMP - STI	1		Default	1	0		Default	0	0		Default	0	0		Default
CMP - W	8		Default	8	0		Default	0	0		Default	0	0		Default

Segment of the process step override sheet – white area is editable

Customizing an Equipment Set

- The equipment utilized to execute each process step with throughput by process step and year is visible and editable.
- A detailed list by equipment type with usage, throughout, tools required, equipment cost, and footprint is visible. Users may edit OEE, equipment cost and footprint.

Customizing an Equipment Set

Process Step	Equipment	Raw 300mm equipment throughput (wph)						
		2000	2001	2002	2003	2004	2005	2006
ALD - 3D	ALD	15.6	15.6	15.6	15.6	15.6	15.6	15.6
ALD - GST	ALD	60.0	60.0	60.0	60.0	60.0	60.0	60.0
ALD - Cap Electr	ALD	125.0	125.0	125.0	125.0	125.0	125.0	125.0
ALD - Cap High-k	ALD	125.0	125.0	125.0	125.0	125.0	125.0	125.0
ALD - Gate High-k	ALD	8.0	8.0	8.0	8.0	8.0	8.0	8.0
ALD - Metal Gate	ALD	8.0	8.0	8.0	8.0	8.0	8.0	8.0
ALD - Spacer	ALD	8.0	8.0	8.0	8.0	8.0	8.0	8.0
ALD/PVD - TaN/Ta/Cu	Ashing	8.0	8.0	8.0	8.0	8.0	8.0	8.0
ALD - TaN/WN/W	Backgrinder	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Ashing	Bond - Bonder	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Backgrind	CMP - Copper	208.6	208.6	208.6	208.6	208.6	208.6	208.6
Bond - temp bond	CMP - Dielectric	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Bond - debond	CMP - Polysilicon	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Bond - BEOL - BSB	Bond - Debonder	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Clean - BEOL - Cu	Wet - Clean - Single bath	200.0	200.0	200.0	200.0	200.0	200.0	200.0
Clean - BEOL - PostAlEtch	Wet - Clean - Single wafer	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Clean - BEOL - PostCMP	Wet - Clean - Single bath	200.0	200.0	200.0	200.0	200.0	200.0	200.0
Clean - BEOL - PostVtch	Wet - Clean - Single wafer	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Clean - FEOL - BSB	Wet - Clean - Single bath	200.0	200.0	200.0	200.0	200.0	200.0	200.0
Clean - FEOL - Crit	Wet - Clean - RCA	158.0	158.0	158.0	158.0	158.0	158.0	158.0
Clean - FEOL - PostCMP	Wet - Clean - Single bath	200.0	200.0	200.0	200.0	200.0	200.0	200.0
Clean - FEOL - SPM	Wet - Clean - Single bath	120.0	120.0	120.0	120.0	120.0	120.0	120.0
CMP - Active	CMP - Dielectric	86.0	86.0	86.0	86.0	86.0	86.0	86.0
CMP - Cu	CMP - Copper	60.0	60.0	60.0	60.0	60.0	60.0	60.0
CMP - DSL	CMP - Dielectric	86.0	86.0	86.0	86.0	86.0	86.0	86.0
CMP - MG	CMP - Tungsten	60.0	60.0	60.0	60.0	60.0	60.0	60.0
CMP - Oxide	CMP - Dielectric	86.0	86.0	86.0	86.0	86.0	86.0	86.0
CMP - Poly	CMP - Polysilicon	86.0	86.0	86.0	86.0	86.0	86.0	86.0
CMP - STI	CMP - Dielectric	86.0	86.0	86.0	86.0	86.0	86.0	86.0
CMP - W	CMP - Tungsten	60.0	60.0	60.0	60.0	60.0	60.0	60.0
CoWP	Plating	80.0	80.0	80.0	80.0	80.0	80.0	80.0
CVD - Cap Ox	CVD - Oxide	76.0	76.0	76.0	76.0	76.0	76.0	76.0
CVD - Compr	CVD - SiN	57.0	57.0	57.0	57.0	57.0	57.0	57.0
CVD - DGatePoly	CVD - Poly/gate	76.0	76.0	76.0	76.0	76.0	76.0	76.0
CVD - eSiC	CVD - Epi	15.2	15.2	15.2	15.2	15.2	15.2	15.2
CVD - eSiGe	CVD - Epi	15.2	15.2	15.2	15.2	15.2	15.2	15.2

Segment of the equipment selection sheet – with dropdown
dropped down - white area is editable

Customizing an Equipment Set

Wafer size	300mm												
Year	2013												
Products	RRAM-2D												
1/2-pitch (nm)	180												
Capacity	30,000												
Active	Yes												
	Default	Select	Value used										
OEE (average)	62.68%	Default	62.68%										
OEE (bottleneck)	87.76%	Default	87.76%										
Upgrade	0												
Critical masks	8												
Most critical lithography	ArF												
	Initial equipment set												
Equipment	Usage	Sampling plan (%)	Throughput (wph)	OEE select	Tools	Default equipment cost per tool (\$M)	User entered equipment cost per tool (\$M)	Source select	Extended equipment cost (\$M)	Default tool footprint (m2)	User entered tool footprint (m2)	Sources select	Extended tool footprint (m2)
ALD	1	100%	8.0	Average	9	\$4.10		Default	\$36.90	13.3		Default	119.7
Ashing	12	100%	208.6	Average	4	\$1.10		Default	\$4.40	10.1		Default	40.4
Backgrinder	0	100%	0.0	Average	0	\$1.00		Default	\$0.00	10.0		Default	0.0
Bond - Bonder	0	100%	0.0	Average	0	\$4.00		Default	\$0.00	10.0		Default	0.0
Bond - Debonder	0	100%	0.0	Average	0	\$1.00		Default	\$0.00	10.0		Default	0.0
CMP - Copper	0	100%	0.0	Average	0	\$2.95		Default	\$0.00	10.7		Default	0.0
CMP - Dielectric	10	100%	86.0	Average	8	\$2.95		Default	\$23.60	10.7		Default	85.6
CMP - Polysilicon	0	100%	0.0	Average	0	\$2.95		Default	\$0.00	10.7		Default	0.0
CMP - Tungsten	8	100%	60.0	Average	9	\$2.95		Default	\$26.55	10.7		Default	96.3
CVD - Doped poly	0	100%	0.0	Average	0	\$5.81		Default	\$0.00	13.3		Default	0.0
CVD - Epi	0	100%	0.0	Average	0	\$6.44		Default	\$0.00	13.3		Default	0.0
CVD - FCVD	0	100%	0.0	Average	0	\$6.44		Default	\$0.00	13.3		Default	0.0
CVD - Hard mask	1	100%	76.0	Average	1	\$5.81		Default	\$5.81	13.3		Default	13.3
CVD - HDP	1	100%	57.0	Average	2	\$6.44		Default	\$12.88	13.3		Default	26.6
CVD - ILD0	1	100%	76.0	Average	1	\$6.44		Default	\$6.44	13.3		Default	13.3
CVD - ILD1+	15	100%	76.0	Average	13	\$6.44		Default	\$83.72	13.3		Default	172.9
CVD - Metal	14	100%	85.5	Average	11	\$6.44		Default	\$70.84	13.3		Default	146.3
CVD - ONO	0	100%	0.0	Average	0	\$6.44		Default	\$0.00	13.3		Default	0.0
CVD - Oxide	1	100%	76.0	Average	1	\$5.81		Default	\$5.81	13.3		Default	13.3

Segment of the equipment sets sheet – white area is editable

Customizing Materials

- A list of the materials supported by the model with unit cost by year is visible and the user can edit the materials cost.
- A bill of materials table lists all of the process steps supported by the model with the materials type and consumption for each step. The user may edit the materials type and usage.

Customizing Materials

Year		2013													
Material	Units	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	Units
ALD - BST	g	\$12,988.35	\$12,598.70	\$12,220.74	\$11,854.12	\$11,498.49	\$11,153.54	\$10,818.93	\$10,494.37	\$10,179.53	\$9,874.15	\$9,577.92	\$9,290.59	\$9,011.87	/Kg
ALD - GST	g	\$8,587.34	\$8,329.72	\$8,079.83	\$7,837.43	\$7,602.31	\$7,374.24	\$7,153.01	\$6,938.42	\$6,730.27	\$6,528.36	\$6,332.51	\$6,142.54	\$5,958.26	/Kg
ALD - HfO/AIO	g	\$3,778.43	\$3,665.08	\$3,555.12	\$3,448.47	\$3,345.02	\$3,244.67	\$3,147.33	\$3,052.91	\$2,961.32	\$2,872.48	\$2,786.31	\$2,702.72	\$2,621.63	/Kg
ALD - HfOx	g	\$4,723.04	\$4,581.35	\$4,443.91	\$4,310.59	\$4,181.27	\$4,055.83	\$3,934.16	\$3,816.13	\$3,701.65	\$3,590.60	\$3,482.88	\$3,378.40	\$3,277.04	/Kg
ALD - High-k gate metal	g	\$12,881.01	\$12,494.58	\$12,119.74	\$11,756.15	\$11,403.47	\$11,061.36	\$10,729.52	\$10,407.64	\$10,095.41	\$9,792.54	\$9,498.77	\$9,213.80	\$8,937.39	/Kg
ALD - Ir(O2)	g	\$3,864.30	\$3,748.37	\$3,635.92	\$3,526.85	\$3,421.04	\$3,318.41	\$3,218.86	\$3,122.29	\$3,028.62	\$2,937.76	\$2,849.63	\$2,764.14	\$2,681.22	/Kg
ALD - nitride	g	\$2,146.84	\$2,082.43	\$2,019.96	\$1,959.36	\$1,900.58	\$1,843.56	\$1,788.25	\$1,734.61	\$1,682.57	\$1,632.09	\$1,583.13	\$1,535.63	\$1,489.57	/Kg
ALD - oxide	g	\$3,005.57	\$2,915.40	\$2,827.94	\$2,743.10	\$2,660.81	\$2,580.98	\$2,503.55	\$2,428.45	\$2,355.59	\$2,284.93	\$2,216.38	\$2,149.89	\$2,085.39	/Kg
ALD - PDMAT	g	\$21,468.35	\$20,824.30	\$20,199.57	\$19,593.58	\$19,005.78	\$18,435.60	\$17,882.54	\$17,346.06	\$16,825.68	\$16,320.91	\$15,831.28	\$15,356.34	\$14,895.65	/Kg
ALD - poly	g	\$1,537.13	\$1,491.02	\$1,446.29	\$1,402.90	\$1,360.81	\$1,319.99	\$1,280.39	\$1,241.98	\$1,204.72	\$1,168.58	\$1,133.52	\$1,099.51	\$1,066.53	/Kg
ALD - Ru(O2)	g	\$17,174.68	\$16,659.44	\$16,159.66	\$15,674.87	\$15,204.62	\$14,748.48	\$14,306.03	\$13,876.85	\$13,460.54	\$13,056.73	\$12,665.02	\$12,285.07	\$11,916.52	/Kg
ALD - SrRuO3	g	\$15,027.85	\$14,577.01	\$14,139.70	\$13,715.51	\$13,304.04	\$12,904.92	\$12,517.77	\$12,142.24	\$11,777.97	\$11,424.63	\$11,081.90	\$10,749.44	\$10,426.96	/Kg
ALD - STO	g	\$10,476.56	\$10,162.26	\$9,857.39	\$9,561.67	\$9,274.82	\$8,996.57	\$8,726.68	\$8,464.88	\$8,210.93	\$7,964.60	\$7,725.66	\$7,493.89	\$7,269.08	/Kg
ALD - TDMAT	g	\$1,545.72	\$1,499.35	\$1,454.37	\$1,410.74	\$1,368.42	\$1,327.36	\$1,287.54	\$1,248.92	\$1,211.45	\$1,175.11	\$1,139.85	\$1,105.66	\$1,072.49	/Kg
ALD - TMA	g	\$4,293.67	\$4,164.86	\$4,039.91	\$3,918.72	\$3,801.16	\$3,687.12	\$3,576.51	\$3,469.21	\$3,365.14	\$3,264.18	\$3,166.26	\$3,071.27	\$2,979.13	/Kg
ALD - ZrO2	g	\$5,152.40	\$4,997.83	\$4,847.90	\$4,702.46	\$4,561.39	\$4,424.54	\$4,291.81	\$4,163.05	\$4,038.16	\$3,917.02	\$3,799.51	\$3,685.52	\$3,574.96	/Kg
Bond - temp bond	ml	\$858.73	\$832.97	\$807.98	\$783.74	\$760.23	\$737.42	\$715.30	\$693.84	\$673.03	\$652.84	\$633.25	\$614.25	\$595.83	/gal
Clean - BEOL - PostVetch	ea	\$0.09	\$0.08	\$0.08	\$0.08	\$0.08	\$0.07	\$0.07	\$0.07	\$0.07	\$0.07	\$0.06	\$0.06	\$0.06	/ea
Clean - dilute TMAH and APM	ea	\$0.07	\$0.07	\$0.06	\$0.06	\$0.06	\$0.06	\$0.06	\$0.06	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	/ea
Clean - HA based	ml	\$51.52	\$49.98	\$48.48	\$47.02	\$45.61	\$44.25	\$42.92	\$41.63	\$40.38	\$39.17	\$38.00	\$36.86	\$35.75	/gal
Clean - proprietary	ea	\$0.21	\$0.21	\$0.20	\$0.20	\$0.19	\$0.18	\$0.18	\$0.17	\$0.17	\$0.16	\$0.16	\$0.15	\$0.15	/ea
Clean - semi aqueous	ml	\$30.91	\$29.99	\$29.09	\$28.21	\$27.37	\$26.55	\$25.75	\$24.98	\$24.23	\$23.50	\$22.80	\$22.11	\$21.45	/gal
Clean - solvent and H2O	ea	\$0.09	\$0.09	\$0.09	\$0.09	\$0.08	\$0.08	\$0.08	\$0.08	\$0.07	\$0.07	\$0.07	\$0.07	\$0.07	/ea
Clean - SPM and APM	ml	\$9.45	\$9.16	\$8.89	\$8.62	\$8.36	\$8.11	\$7.87	\$7.63	\$7.40	\$7.18	\$6.97	\$6.76	\$6.55	/ea
CMP - active pad	wafs/pad	\$644.05	\$624.73	\$605.99	\$587.81	\$570.17	\$553.07	\$536.48	\$520.38	\$504.77	\$489.63	\$474.94	\$460.69	\$446.87	/pad
CMP - active slurry	ml	\$25.76	\$24.99	\$24.24	\$23.51	\$22.81	\$22.12	\$21.46	\$20.82	\$20.19	\$19.59	\$19.00	\$18.43	\$17.87	/gal
CMP - Cu barrier/buff pad	wafs/pad	\$257.62	\$249.89	\$242.39	\$235.12	\$228.07	\$221.23	\$214.59	\$208.15	\$201.91	\$195.85	\$189.98	\$184.28	\$178.75	/pad
CMP - Cu barrier/buff slurry	ml	\$15.46	\$14.99	\$14.54	\$14.11	\$13.68	\$13.27	\$12.88	\$12.49	\$12.11	\$11.75	\$11.40	\$11.06	\$10.72	/gal
CMP - Cu bulk pad	wafs/pad	\$644.05	\$624.73	\$605.99	\$587.81	\$570.17	\$553.07	\$536.48	\$520.38	\$504.77	\$489.63	\$474.94	\$460.69	\$446.87	/pad
CMP - Cu bulk slurry	ml	\$39.50	\$38.32	\$37.17	\$36.05	\$34.97	\$33.92	\$32.90	\$31.92	\$30.96	\$30.03	\$29.13	\$28.26	\$27.41	/gal
CMP - Cu end-point pad	wafs/pad	\$644.05	\$624.73	\$605.99	\$587.81	\$570.17	\$553.07	\$536.48	\$520.38	\$504.77	\$489.63	\$474.94	\$460.69	\$446.87	/pad
CMP - Cu end-point slurry	ml	\$7.73	\$7.50	\$7.27	\$7.05	\$6.84	\$6.64	\$6.44	\$6.24	\$6.06	\$5.88	\$5.70	\$5.53	\$5.36	/gal
CMP - DSL pad	wafs/pad	\$644.05	\$624.73	\$605.99	\$587.81	\$570.17	\$553.07	\$536.48	\$520.38	\$504.77	\$489.63	\$474.94	\$460.69	\$446.87	/pad
CMP - DSL slurry	ml	\$34.35	\$33.32	\$32.32	\$31.35	\$30.41	\$29.50	\$28.61	\$27.75	\$26.92	\$26.11	\$25.33	\$24.57	\$23.83	/gal
CMP - MG pad	wafs/pad	\$644.05	\$624.73	\$605.99	\$587.81	\$570.17	\$553.07	\$536.48	\$520.38	\$504.77	\$489.63	\$474.94	\$460.69	\$446.87	/pad

Segment of materials definition sheet – white area is editable

Customizing Materials

Product		RRAM-2D									
1/2-pitch (nm)		180									
Wafer size		300mm									
Process step	Step usage	Film/operation	Material used	300mm qty per layer	Units	Material usage	Units	Price (\$)	Units	Cost per deposition/layer	Cost per wafer (\$)
CVD - Pad Nit	1	Clean	CVD - NF3	7.60	g	7.60E+00	g	\$40.00	/Kg	\$0.304	\$0.304
CVD - Pass	1	SiO2	CVD - TEOS	1.00	g	1.00E+00	g	\$50.00	/Kg	\$0.050	\$0.050
CVD - Pass	1	Si3N4	CVD - NH3	1.00	g	1.00E+00	g	\$40.00	/Kg	\$0.040	\$0.040
CVD - Pass	1	Clean	CVD - NF3	7.60	g	7.60E+00	g	\$40.00	/Kg	\$0.304	\$0.304
CVD - Pre Met	1	BPSG	CVD - TEOS	1.00	g	1.00E+00	g	\$50.00	/Kg	\$0.050	\$0.050
CVD - Pre Met	1	BPSG	CVD - TEOS	0.10	g	1.00E-01	g	\$5,000.00	/Kg	\$0.500	\$0.500
CVD - Pre Met	1	BPSG	CVD - TiCl4	0.10	g	1.00E-01	g	\$5,000.00	/Kg	\$0.500	\$0.500
CVD - Pre Met	1	Clean	CVD - TMA	7.60	g	7.60E+00	g	\$40.00	/Kg	\$0.304	\$0.304
CVD - Pre Met	1	Clean	CVD - TMI	7.60	g	7.60E+00	g	\$40.00	/Kg	\$0.304	\$0.304
CVD - Sac Ox	0	SiO2	CVD - TSA	2.40	g	0.00E+00	g	\$50.00	/Kg	\$0.120	\$0.000
CVD - Sac Ox	0	Clean	CVD - WF6	7.60	g	0.00E+00	g	\$40.00	/Kg	\$0.304	\$0.000
CVD - spacer- device	0	SiO2	Etch - FeRAM	1.00	g	0.00E+00	g	\$50.00	/Kg	\$0.050	\$0.000
CVD - spacer- device	0	SiO2	Etch - ILD trench	1.00	g	0.00E+00	g	\$50.00	/Kg	\$0.050	\$0.000
CVD - spacer- device	0	Si3N4	CVD - NH3	0.60	g	0.00E+00	g	\$40.00	/Kg	\$0.024	\$0.000
CVD - spacer- device	0	Si3N4	CVD - SiH4	0.60	g	0.00E+00	g	\$60.00	/Kg	\$0.036	\$0.000
CVD - spacer- device	0	Clean	CVD - NF3	7.60	g	0.00E+00	g	\$40.00	/Kg	\$0.304	\$0.000
CVD - spacer - litho	0	SiO2	CVD - TEOS	1.00	g	0.00E+00	g	\$50.00	/Kg	\$0.050	\$0.000
CVD - spacer - litho	0	Si3N4	CVD - NH3	0.60	g	0.00E+00	g	\$40.00	/Kg	\$0.024	\$0.000
CVD - spacer - litho	0	Si3N4	CVD - SiH4	0.60	g	0.00E+00	g	\$60.00	/Kg	\$0.036	\$0.000
CVD - spacer - litho	0	Clean	CVD - NF3	7.60	g	0.00E+00	g	\$40.00	/Kg	\$0.304	\$0.000
CVD - Tensl	0	SixNy	CVD - NH3	0.50	g	0.00E+00	g	\$40.00	/Kg	\$0.020	\$0.000
CVD - Tensl	0	SixNy	CVD - SiH4	0.50	g	0.00E+00	g	\$60.00	/Kg	\$0.030	\$0.000
CVD - Tensl	0	Clean	CVD - NF3	7.60	g	0.00E+00	g	\$40.00	/Kg	\$0.304	\$0.000
CVD - TiN	8	TiN	CVD - TiCl4	1.20	g	9.60E+00	g	\$500.00	/Kg	\$0.600	\$4.800
CVD - TiN	8	Clean	CVD - NF3	7.60	g	6.08E+01	g	\$40.00	/Kg	\$0.304	\$2.432
CVD - W	6	W	CVD - WF6	5.00	g	3.00E+01	g	\$150.00	/Kg	\$0.750	\$4.500
CVD - W	6	Clean	CVD - NF3	7.60	g	4.56E+01	g	\$40.00	/Kg	\$0.304	\$1.824
CVD - WSix	0	WSix	CVD - WF6	1.20	g	0.00E+00	g	\$150.00	/Kg	\$0.180	\$0.000
CVD - WSix	0	Clean	CVD - NF3	7.60	g	0.00E+00	g	\$40.00	/Kg	\$0.304	\$0.000
CVD/PVD - TaN/Cu	0	TaN	CVD - PDMAT	0.10	g	0.00E+00	g	\$25,000.00	/Kg	\$2.500	\$0.000
CVD/PVD - TaN/Cu	0	Cu	PVD - Cu	20,000.00	deps/target	0.00E+00	targets	\$8,000.00	/target	\$0.400	\$0.000
Etch - FeRAM	0	Etch	Etch - FeRAM	NA	ea	0.00E+00	operations	\$0.05	/ea	\$0.050	\$0.000

Segment of bill of materials sheet – with dropdown dropped down - white area is editable

Model Wide Defaults

Product		RRAM-2D		
	Default	User entered	Selection	Actual
Wafer type	Raw		Default	Raw
Starting wafer cost	\$85.00		Default	\$85.00
Monitor wafer cost	\$34.00		Default	\$34.00
Reticle set amortization	Yes		Default	Yes
Exposures per reticle	67,192		Default	67,192
Reticle cost				
ArF	\$4,400		Default	\$4,400
ArFi	\$0		Default	\$0
EUV1	\$0		Default	\$0
EUV2	\$0		Default	\$0
I-Line	\$2,013		Default	\$2,013
KrF	\$3,188		Default	\$3,188

Defaults sheet – white area is editable

Model Wide Defaults

450mm Utilities and Consumables Per Wafer Ratios

Factor	Default	Select	Actual
Year 450mm enters production	2018	Default	2018
ALD precursors usage per deposition	1.20	Default	1.20
Bulk gas volume	1.20	Default	1.20
Cleaning chemical cost per clean	1.20	Default	1.20
CMP pad cost per pad	1.60	Default	1.60
CMP slurry usage per operation	1.20	Default	1.20
CVD precursor usage per deposition	1.20	Default	1.20
Dry etch cost per etch	1.20	Default	1.20
Electric and natural gas usage	1.25	Default	1.25
Implant cost per implant	1.20	Default	1.20
Lithography usage per mask	1.10	Default	1.10
Plating solution usage per deposition	1.20	Default	1.20
PVD target cost per target	1.60	Default	1.60
Spin-on usage per deposition	1.20	Default	1.20
Temporary bond material usage per wafer	1.20	Default	1.20
Ultrapure water usage per wafer	1.20	Default	1.20

450mm Utilities and Consumables Ratios Guidance

300mm experience	ISMI guidance	IC Knowledge guidance
1.60	1.00	1.20
1.60	1.00	1.20
1.60	1.00	1.20
1.60	NA	1.60
1.60	1.00	1.20
1.60	1.00	1.20
1.60	1.00	1.20
1.26	1.00	1.25
1.60	1.00	1.20
1.10	1.00	1.10
1.60	1.00	1.20
1.60	NA	1.60
1.60	1.00	1.20
NA	1.00	1.20
0.74	1.00	1.20

450mm equipment settings used by the model

Equipment	Cost	Throughput	Footprint
ALD	1.23	1.00	1.30
Ashing	1.18	1.00	1.25
Backgrinder	1.18	1.00	1.13
Bond - Bonder	1.18	1.00	1.13
Bond - Debonder	1.18	1.00	1.13
CMP - Copper	1.18	1.00	1.38
CMP - Dielectric	1.18	1.00	1.38

450mm equipment settings guidance

Cost guidance		Throughput guidance			Footprint guidance	
200mm to 300mm experience	IC Knowledge projection	200mm to 300mm experience	IC Knowledge projection	SEMI projection	200mm to 300mm experience	ISMI guidelines
1.23	1.23	1.00	1.00	1.00	1.30	1.00
1.18	1.18	1.00	1.00	1.00	1.23	1.00
1.18	1.18	1.00	1.00	1.00	1.38	1.00
1.18	1.18	1.00	1.00	1.00	1.38	1.00
1.18	1.18	1.00	1.00	1.00	1.38	1.00
1.18	1.18	1.00	1.00	1.00	1.38	1.00
1.18	1.18	1.00	1.00	1.00	1.38	1.00

Segment of 450mm sheet – white area is editable

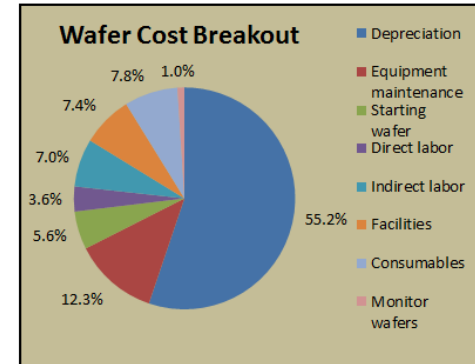
Model Outputs

- Wafer cost broken out into major categories.
- A detailed list of equipment with units required and cost for the initial equipment set and any upgrade sets.
- A detailed list of materials with quantity and cost per wafer and per year.

Model Outputs

Wafer cost

Cost category	\$M/yr	\$/waf	\$/cm2
Depreciation	\$273.92	\$845.42	\$1.196
Equipment maintenance	\$61.19	\$188.85	\$0.267
Starting wafer	\$27.54	\$85.00	\$0.120
Direct labor	\$18.05	\$55.72	\$0.079
Indirect labor	\$34.72	\$107.15	\$0.152
Facilities	\$36.90	\$113.87	\$0.161
Consumables	\$38.78	\$119.69	\$0.169
Monitor wafers	\$5.03	\$15.53	\$0.022
Total unyielded wafer cost	\$496.12	\$1,531.24	\$2.17
Wafer yield		98.6%	98.6%
Yielded wafer cost		\$1,553.61	\$2.20



Wafer cost summary output

Model Outputs

Material	Category	Cost (\$/waf)	Usage (/waf)	Units	Usage (/yr)	Units
ALD - BST	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - GST	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - HfO/AIO	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - HfOx	ALD	\$5.50	1.00E+00	g	324.00	Kg
ALD - High-k gate metal	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - Ir(O2)	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - nitride	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - oxide	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - PDMAT	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - poly	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - Ru(O2)	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - SrRuO3	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - STO	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - TDMAT	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - TMA	ALD	\$0.00	0.00E+00	g	0.00	Kg
ALD - ZrO2	ALD	\$0.00	0.00E+00	g	0.00	Kg
Bond - temp bond	Backgrind/bond	\$0.00	0.00E+00	ml	0.00	L
Clean - BEOL - PostVEtch	Cleaning chemicals	\$0.50	5.00E+00	operations	1,620.00	Koperations
Clean - dilute TMAH and APM	Cleaning chemicals	\$0.88	1.10E+01	operations	3,564.00	Koperations
Clean - HA based	Cleaning chemicals	\$0.71	4.50E+01	ml	14,580.00	L
Clean - proprietary	Cleaning chemicals	\$1.75	7.00E+00	operations	2,268.00	Koperations
Clean - semi aqueous	Cleaning chemicals	\$0.00	0.00E+00	ml	0.00	L

Segment of materials summary – this sheet is available in the materials version only

Model Outputs

Category	\$/waf
ALD	\$5.50
Backgrind/bond	\$0.00
Bulk gases	\$21.97
Cleaning chemicals	\$3.84
Cleanroom and safety supplies	\$5.61
CMP consumables	\$10.91
CVD precursors	\$34.00
Etch gases	\$1.09
Implant sources	\$1.51
Lithography materials	\$21.12
Plating chemicals	\$0.00
PVD targets	\$6.40
Quartzware	\$4.35
Reticles	\$1.08
Spin-on	\$2.00
Wet etch chemicals	\$0.30
Total	\$119.69

Consumables summary

Model Support

- The model price includes twelve months of updates and support.
- Updates are released as needed and are typically approximately six per year.
- Support is by email and phone with Web Ex training and support sessions available on request.

Model Versions

- Equipment Edition
 - Fab definition
 - Wafer cost
 - Full process customization
 - Full equipment customization
 - Summary materials information visible but not editable
- Materials Edition
 - All of the capabilities of the equipment edition.
 - Plus full materials customization

Conclusion

- Implements the current ITRS.
- Pre defined processes, equipment and materials.
- Full process, equipment and materials customization.
- Produces detailed equipment, materials, and wafer cost projections.