Cost and Investment Implications of 3D NAND

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FORWARD INSIGHTS

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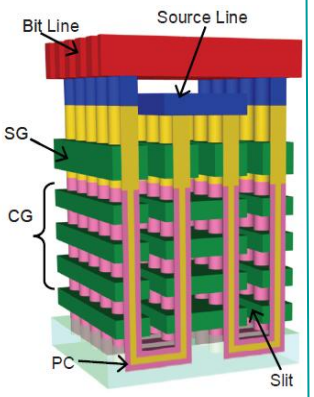
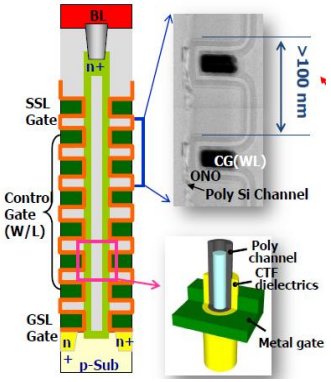
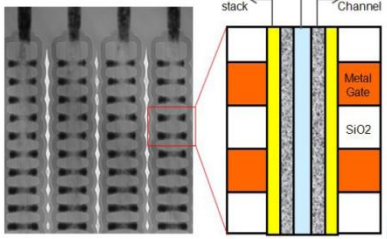
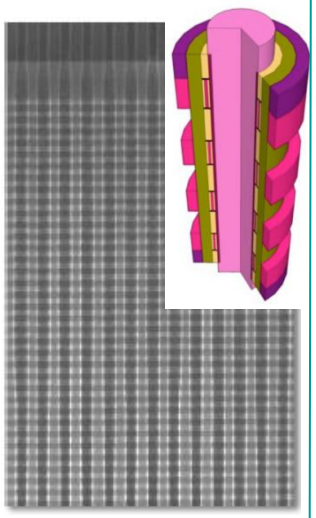
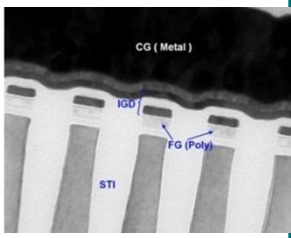
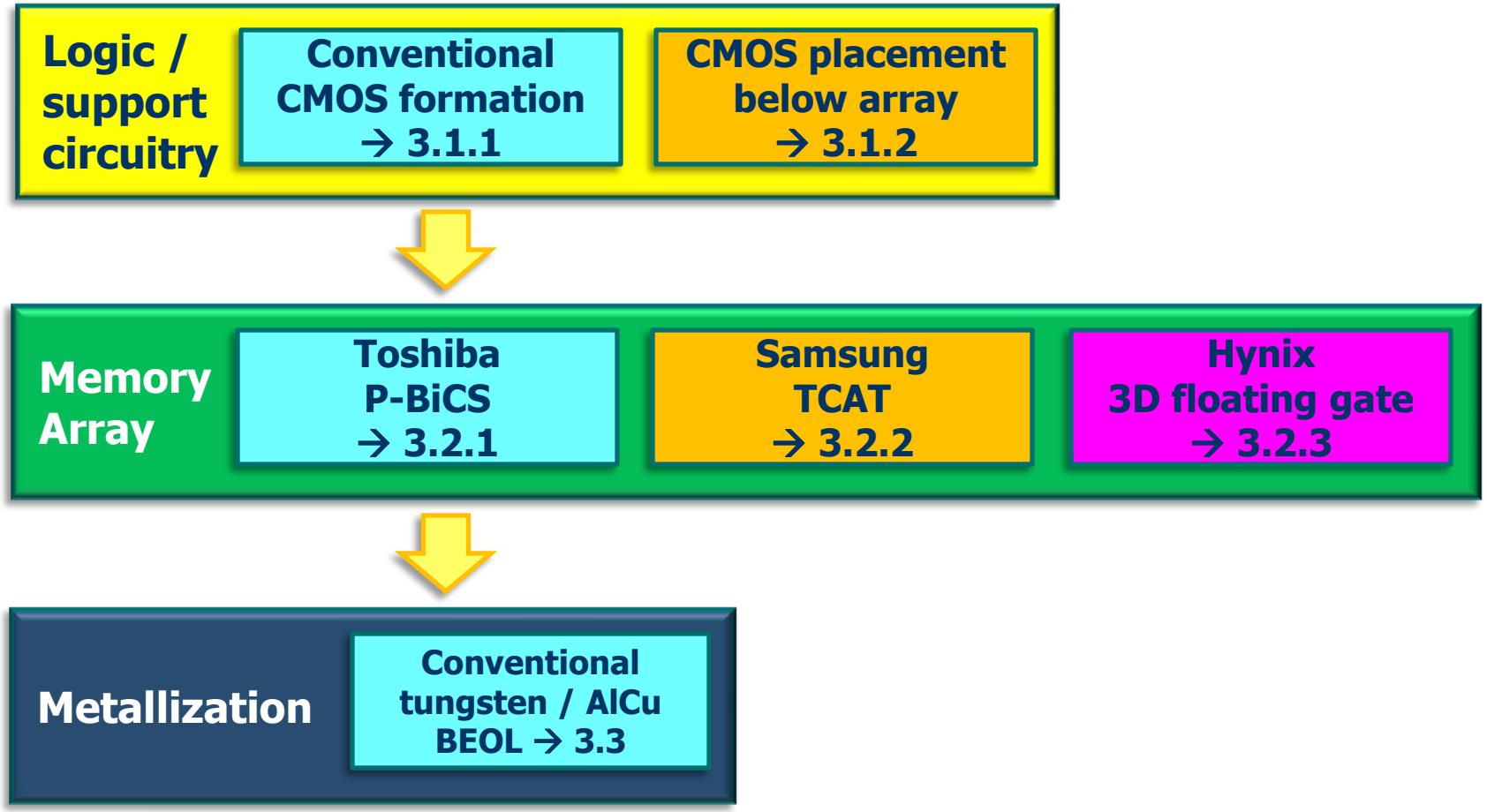
Agenda

- Process Flow Assumptions
- Process Complexity/Process Steps
- Greenfield Investment
- 2D to 3D NAND Conversion
- 32L to 64L 3D NAND Migration

Process Flow Assumptions

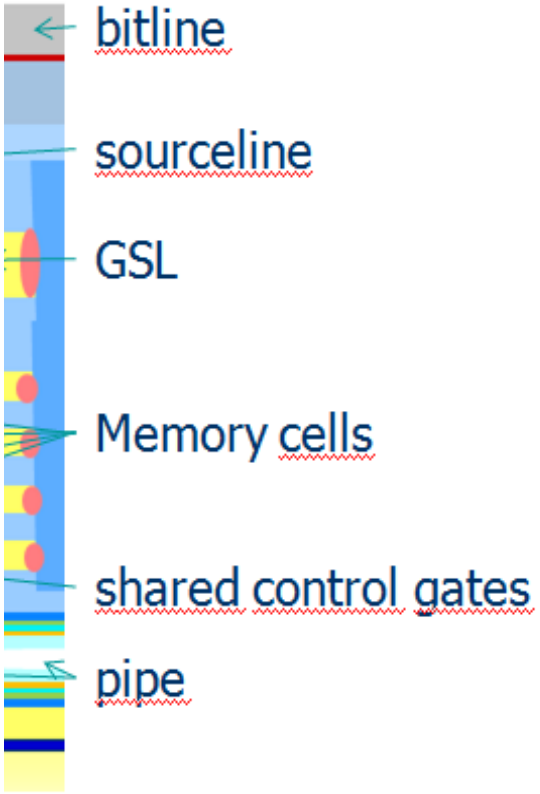
	p-BiCs (Toshiba/ SanDisk)	TCAT (Samsung)	SMArT (SK Hynix)	3D NAND (Micron/ Intel)	16nm Planar NAND (Micron)
Structure					
Key Features					
Key Issues					

3D NAND Construction Kit



CMOS below array with two finalized metal layer

Structure of the p-BiCS concept



Xxxxxxxxxxxxxxxxxxx formation by xxxxxxxxxx xxxxxxxxxxxxxxxxxxx

Xxxxxxxxx select gate xxxxxxxxxxxxx and removal of the xxxxxxxxxxxxxxxxxxxx to allow xxxxxxxx of all xxxxxxxxx

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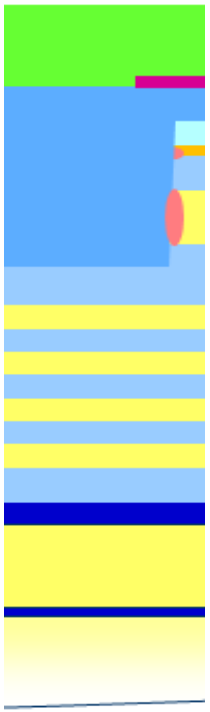
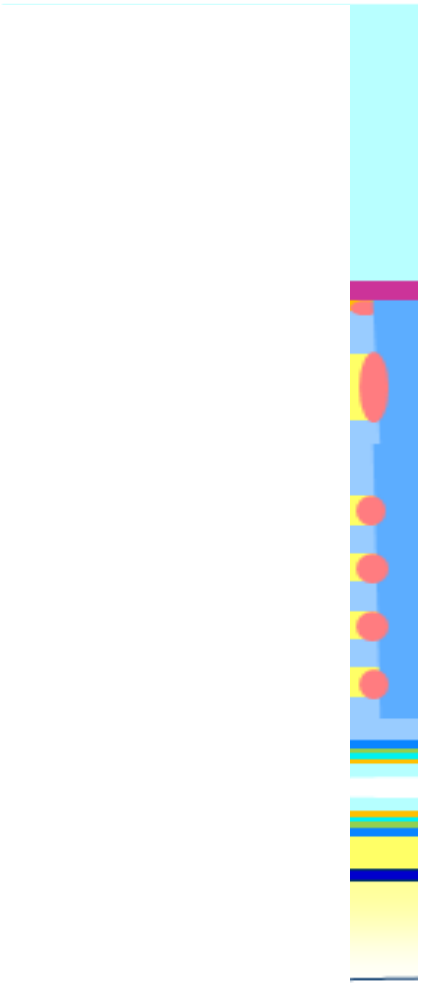
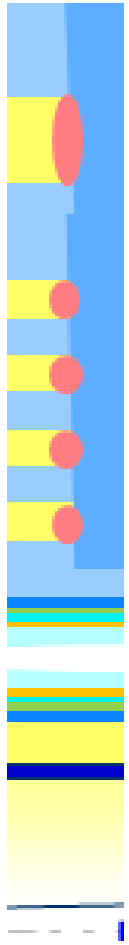
a) Initial etch step to form the stair case xxxxxxxxxxxxxxx xxxxxxxx, b) structure after xxxxxxxxxxxxxxxxxxxxxxxxxxx, the periphery is etched xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx



Finalization of the stair case xxxxxxxxxxxxxxxxxxxxxxxxxxx and xxxxxxxxxxxxxxxxxxxxxxxx



xxxxxxxxx formation to the xxxxxxxxxxxx to provide xxxxxxxxxxxxxxxxxxto the gate planes and CMOS part



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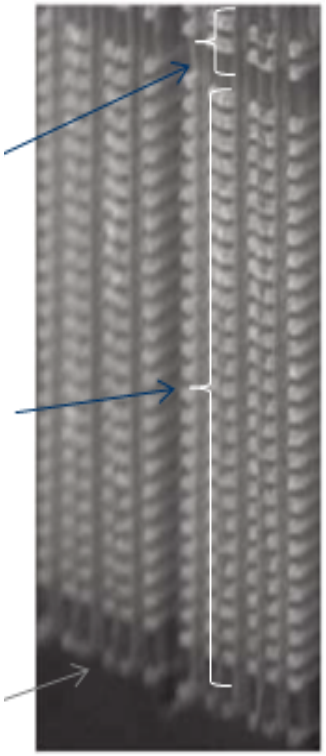
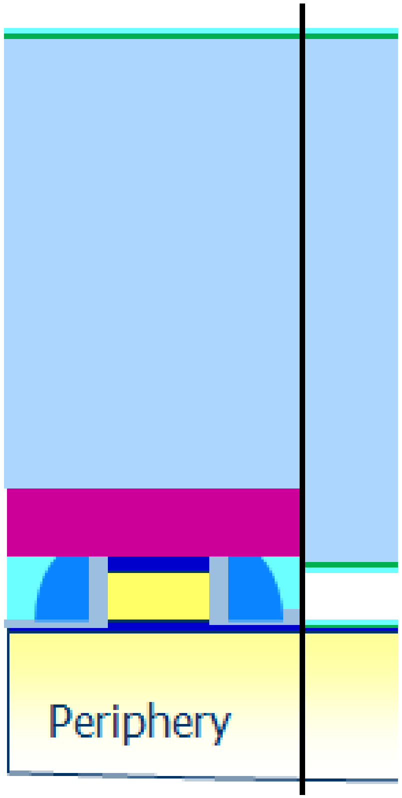
Schematic overview of the fundamental structure of the TCAT concept used in our proposal and the Samsung reference for V-NAND

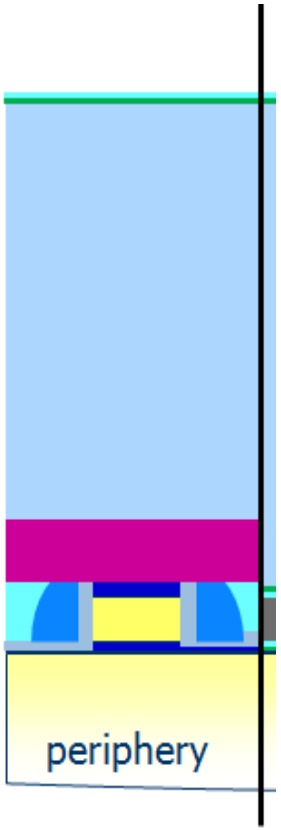


sourceline

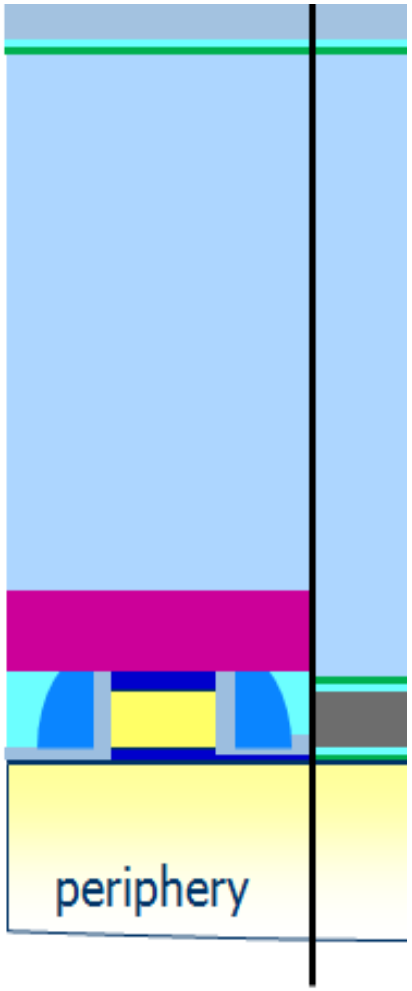
Intermediate TCAT structure with xxxxxxxxxxxxxxxxxxxxxxx, the charge trap stack is xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx



Finalization of the memory cells by deposition of the xxxxxxxxxx xxxxxxxxx, the electrical connection of the xxxxxxxxxxxxxxxxxx is solved by a xxxxxxxxxxxx through the xxxxxxxxx creating a rectangular xxxxxxxxxxxxxxx



The 3D structure after the xxxxxxxxx and subsequent xxxxxxxxxxxxxxxxxx, finally the xxxxxxxx is filled with xxxxxx and polished



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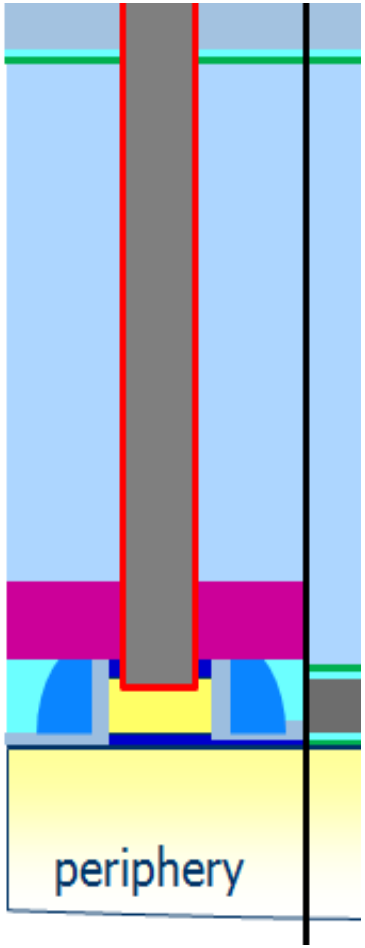
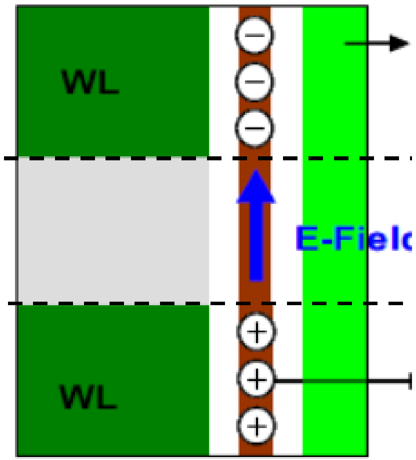
The xxxxxxxxxx gate planes and the CMOS devices are contacted in the xxxxxxxxxxxxxxxxx by contacts with a xxxxxxxxxxxxxx difference



Comparison of the charge trap layer arrangement in (a) BiCS and (b) TCAT and (c) SMArT



(a)

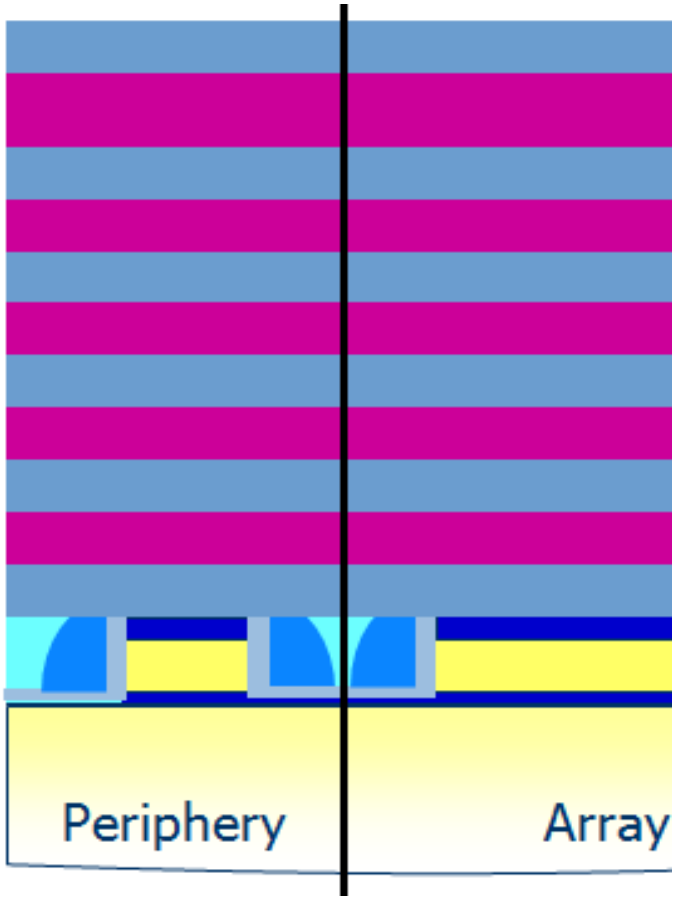
- In SMArT, the charge trap layer xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

3D floating gate approach, showing 4 FG cells per string and the respective select devices, b) xxxxxxxxxxxxxxxx xxxxxxxxxxxxxxx 3D FG structure with xxxxxxxxxxxxxxxx

a)

b)

Initial state of the 3D floating gate NAND fabrication after the multilayer deposition, xxxxxxxxxxxxxxxxxxxxxxx xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx



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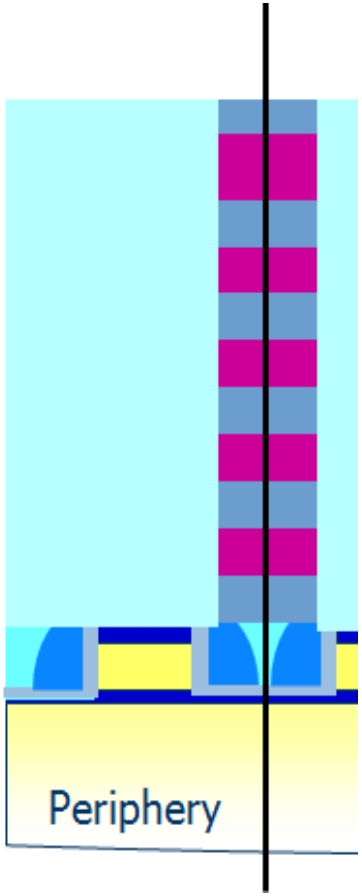
Vert. FG structure after xxxxxxxxxxxx removal to open the xxxxxxxxxxxxxxxxxx deposition and xxxxxxxxxxxxxxxx formation



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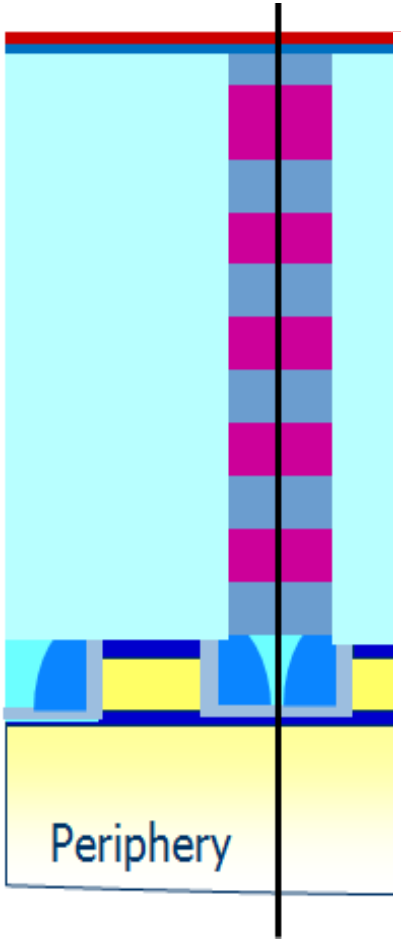
Vert. FG structure with finalized xxxxxxxxxxx and xxxxxxxxxxx after xxxxxxxxxxxxxxxxxx and subsequent xxxxxxxxxxxxxxxx



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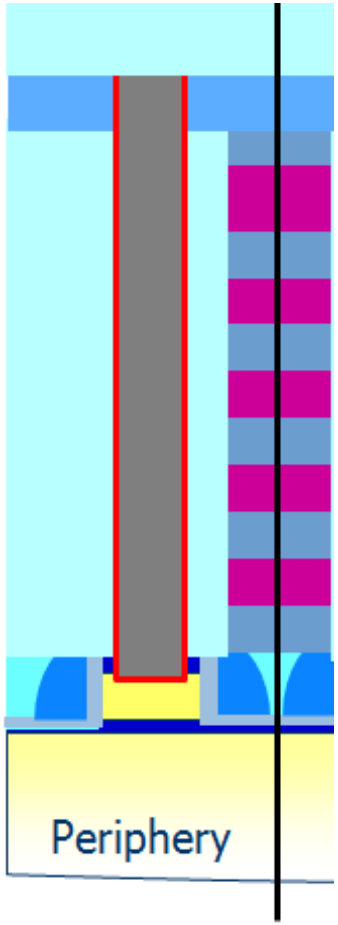
Vert. FG structure with formed connections to realize xxxxxxxxxxxxxxxxxxxxx



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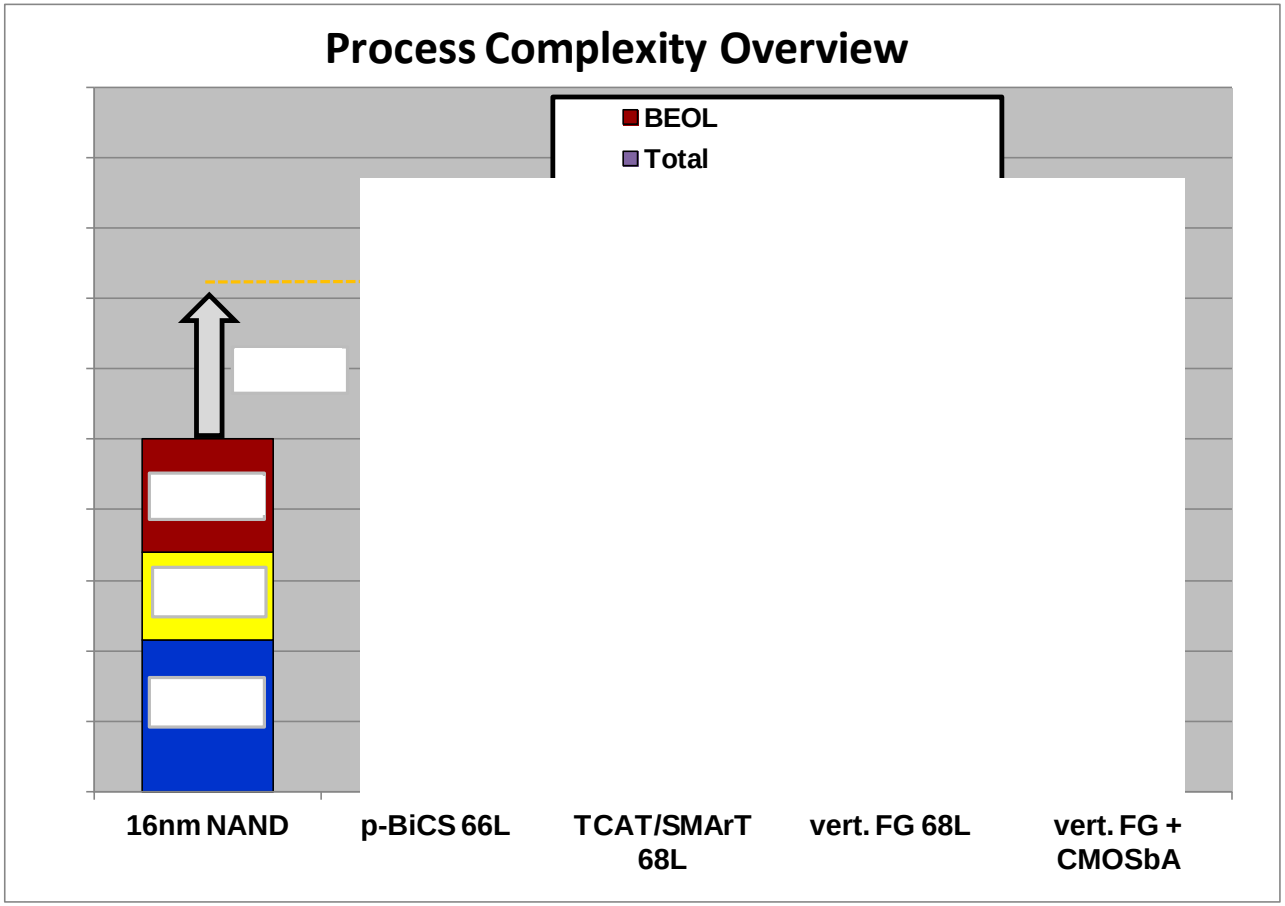
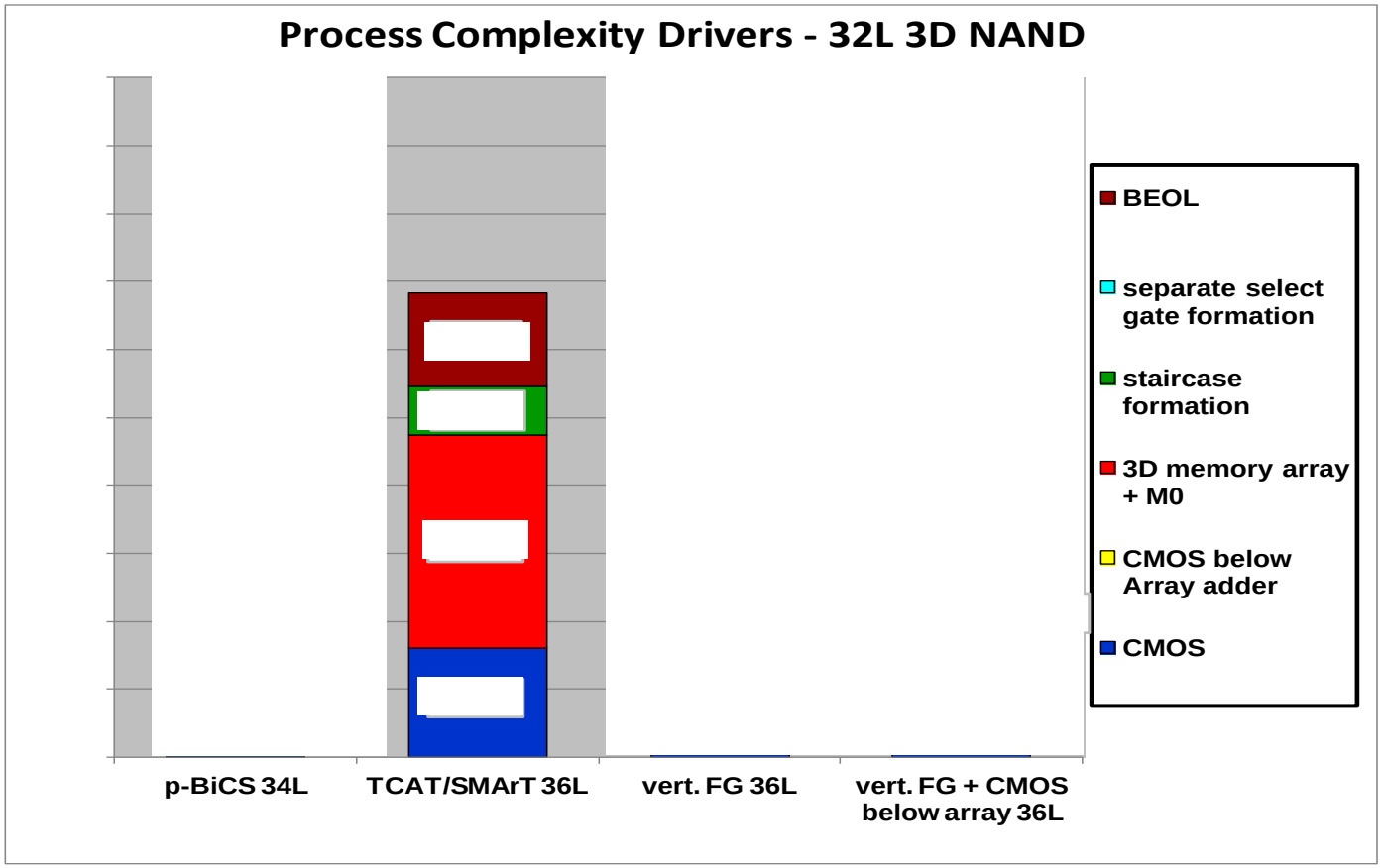
Process Complexity/Process Steps

Overview of the key contributors for 16nm NAND process complexity compared to 3D NAND



- Process complexity is at least xx% higher for 3D NAND vs. 2D NAND

Process Complexity Drivers – 32L 3D NAND



- xxxx higher process complexity due to more process steps for xxxxxxxxxxxxx and xxxxxxxxxxxxxxxxxxxxxxx independent of the memory device formation

- CMOS under the array has xx% adder due to xxxxxxxxxxxxxxxxx layers

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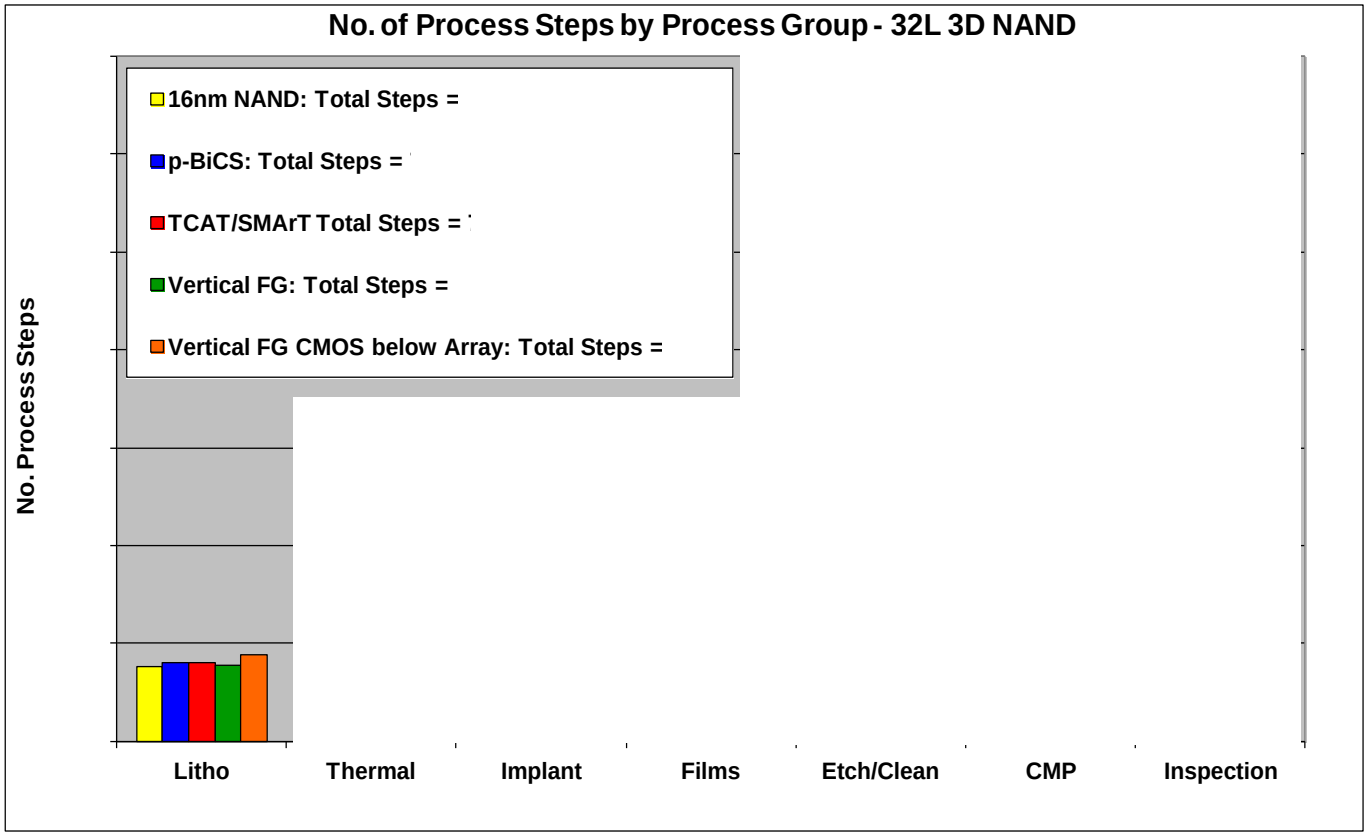
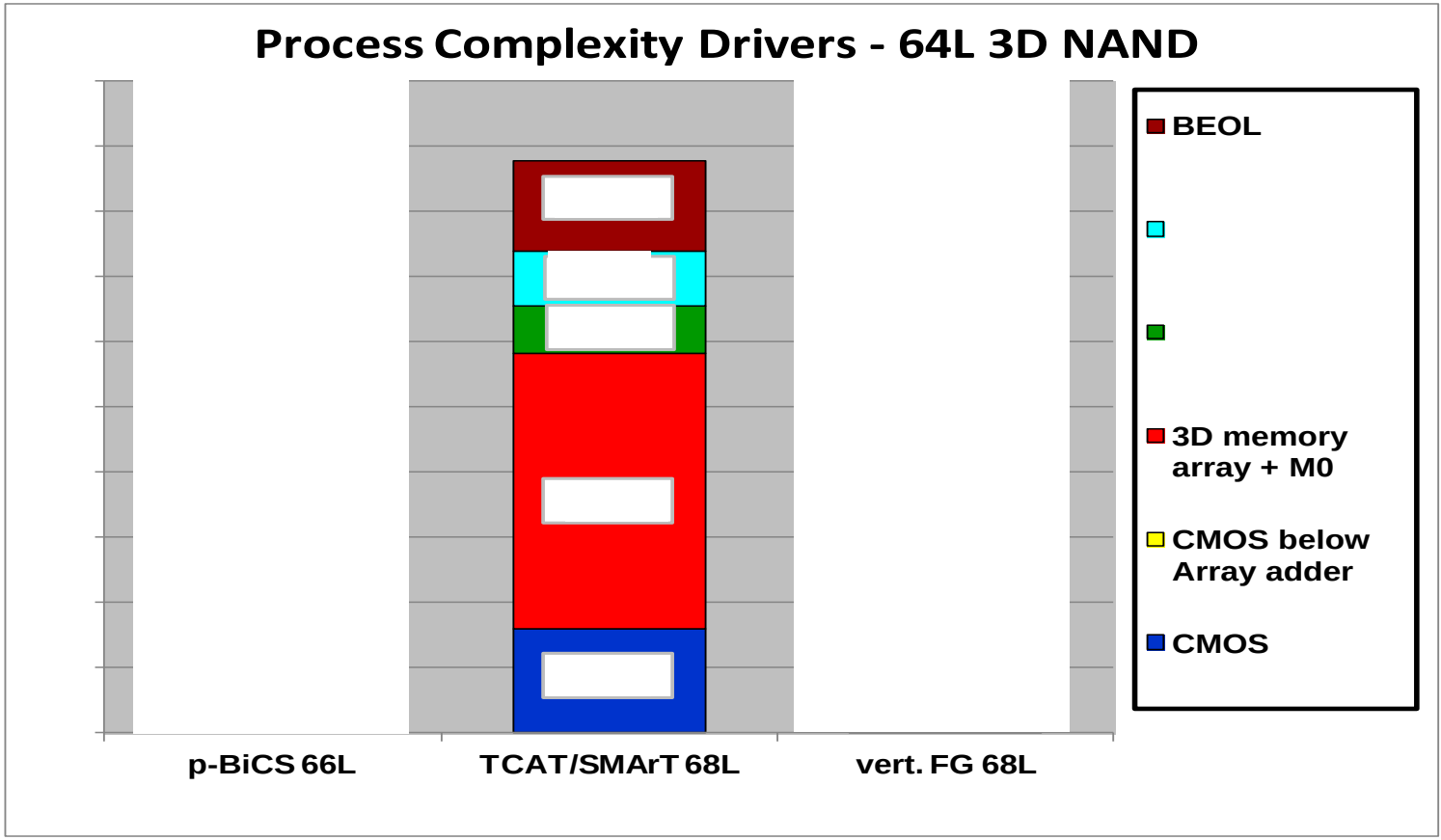
Number of process steps by process group – 32L 3D NAND



- xxxxxx process steps in 3D NAND driven by xxxxxxxxxxxxxxx and xxxxxxxxxxx steps for formation of xxxxxxxxxxxx and xxxxxxxxxxxxxxxxxxxxx

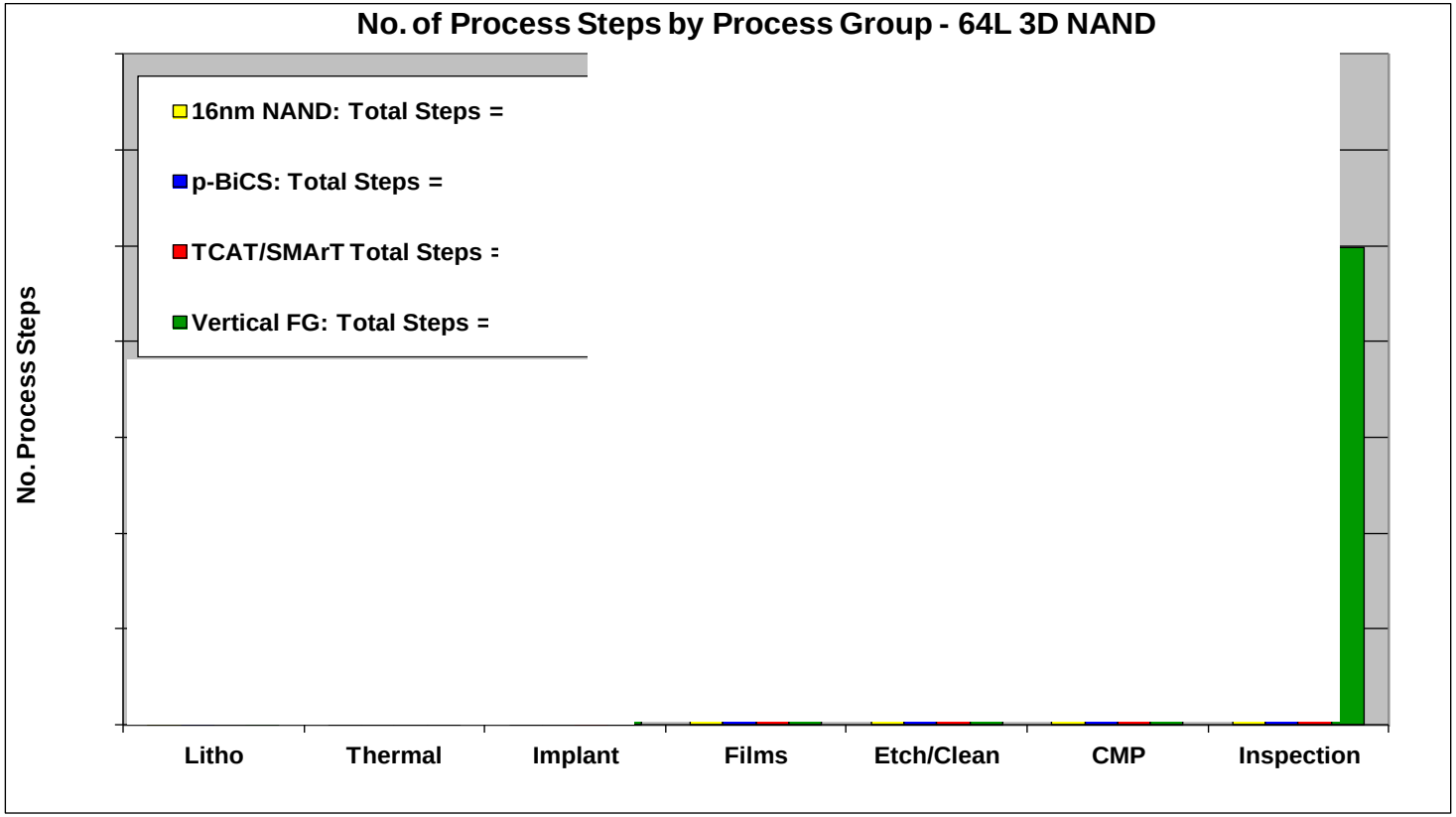
Process Complexity Drivers – 64L 3D NAND



TCAT/SMArT 36L

• if quality of the select gate is important for implementation of a long NAND string, then xxxxxxxxxxxxxxxxxxxxxxxx is required resulting in xxxxxxxxxx process complexity xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Number of process steps by process group – 64L 3D NAND



- xxxxxxxxxxxxx process steps are required for 64L vs. 32L, xxxxxxxxx ~xx%
- for example, 32L TCAT/SMArT has xxxx process steps

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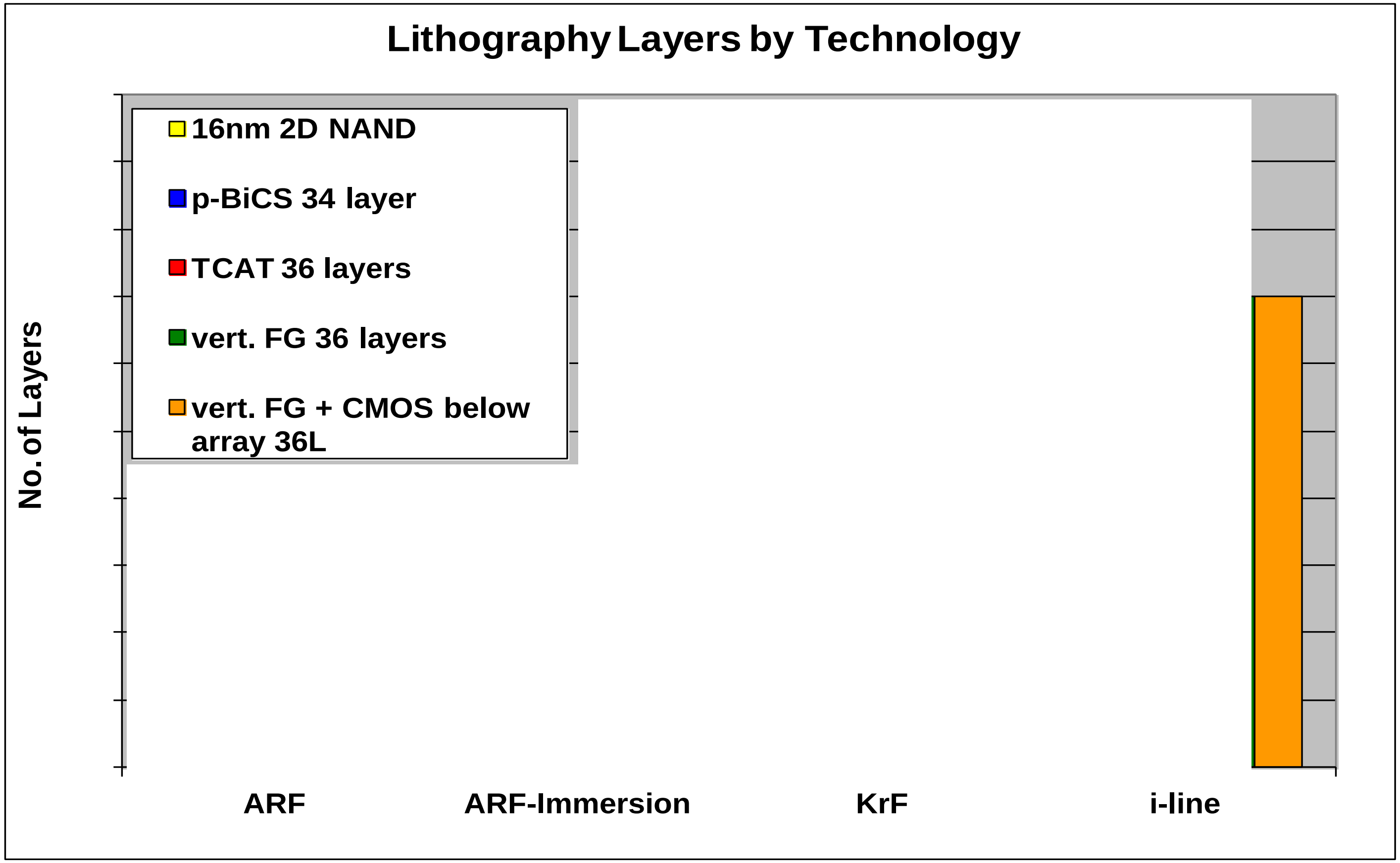
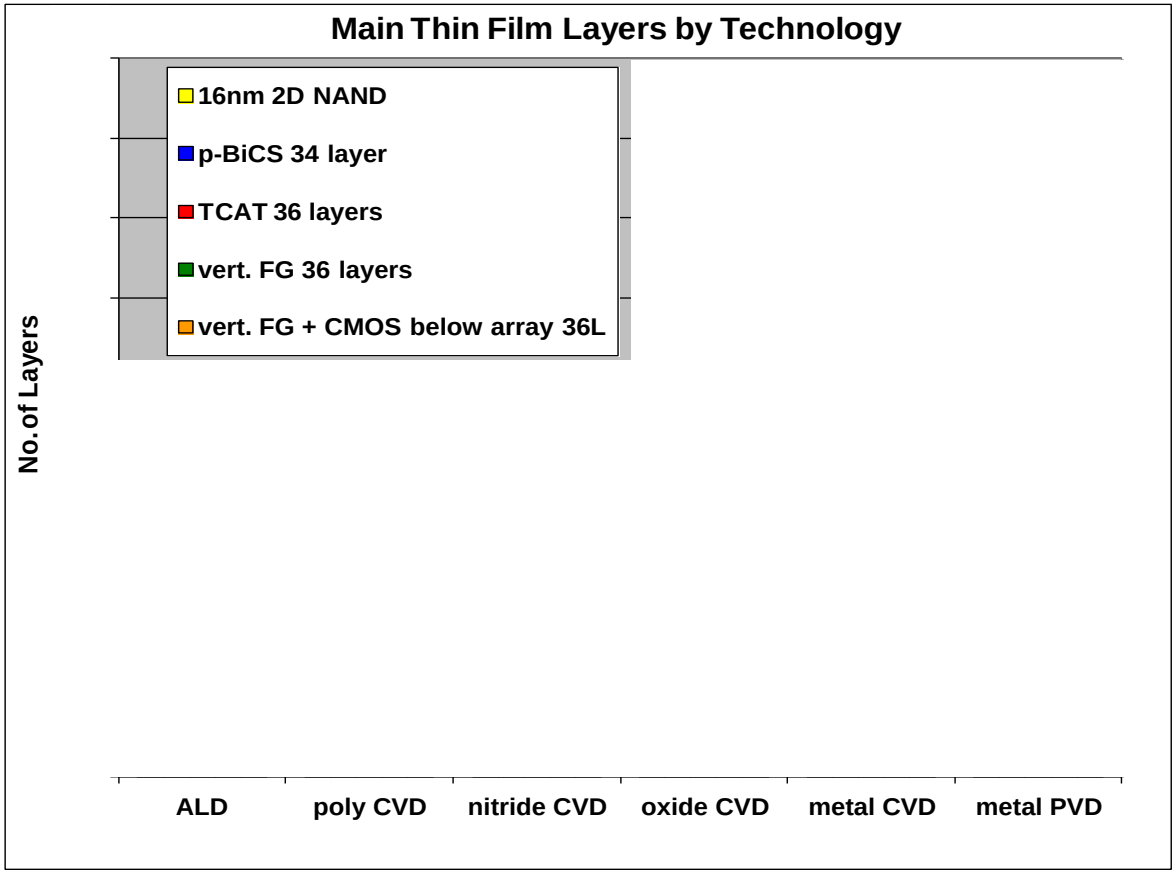
Lithography Layers by Technology



- ArF-immersion steps xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx xxxxxxxxxxxxxxxxxxxxxxxxx
- shift from xxxxxxxxxx to xxxxxxxxxxxxxxxxx litho steps for xxxxxxxxxxxxxxxxxxxx

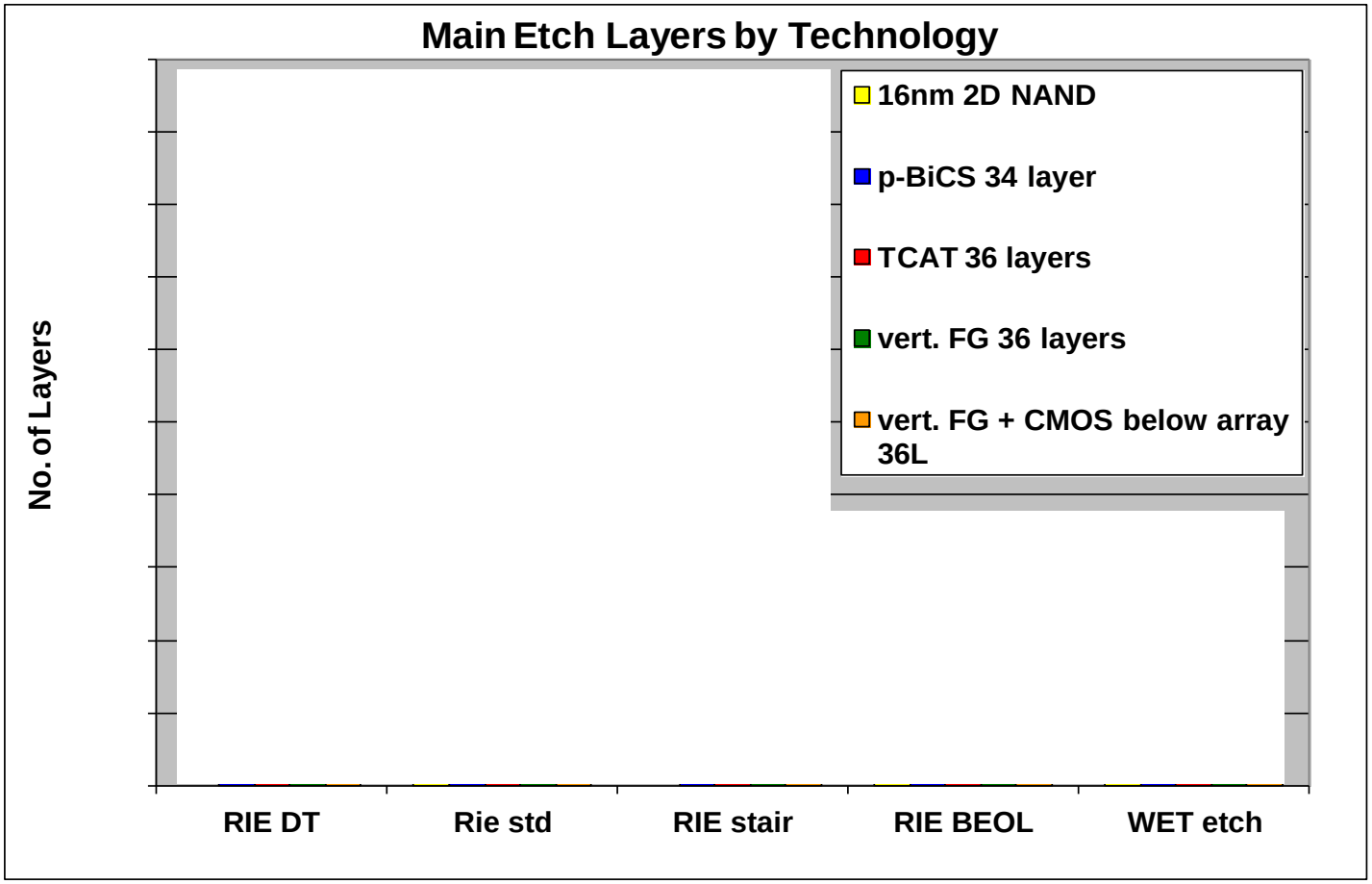
Main Thin Film Layers by Technology



- xxxxxxxxx for p-BiCS due to xxxxx deposition in xxxxxxxxxxxxxxxxxxxxxxxx; whereas other 3D concepts use xxxxxxxxxxxxxxxxxxxxx for xxxxxxxxxxxxxxx

- ALD for xxxxxxx formation in 16nm NAND; for xxxxxxxxxxxxxxxxxxx in 3D NAND

Main Etch Layers by Technology



- high aspect ratio RIE DT and RIE stair are xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
- RIE DT is xxxxxxxxxxxxx due to xxxxxxxxxxxxxxxxxxxxxxxx formation

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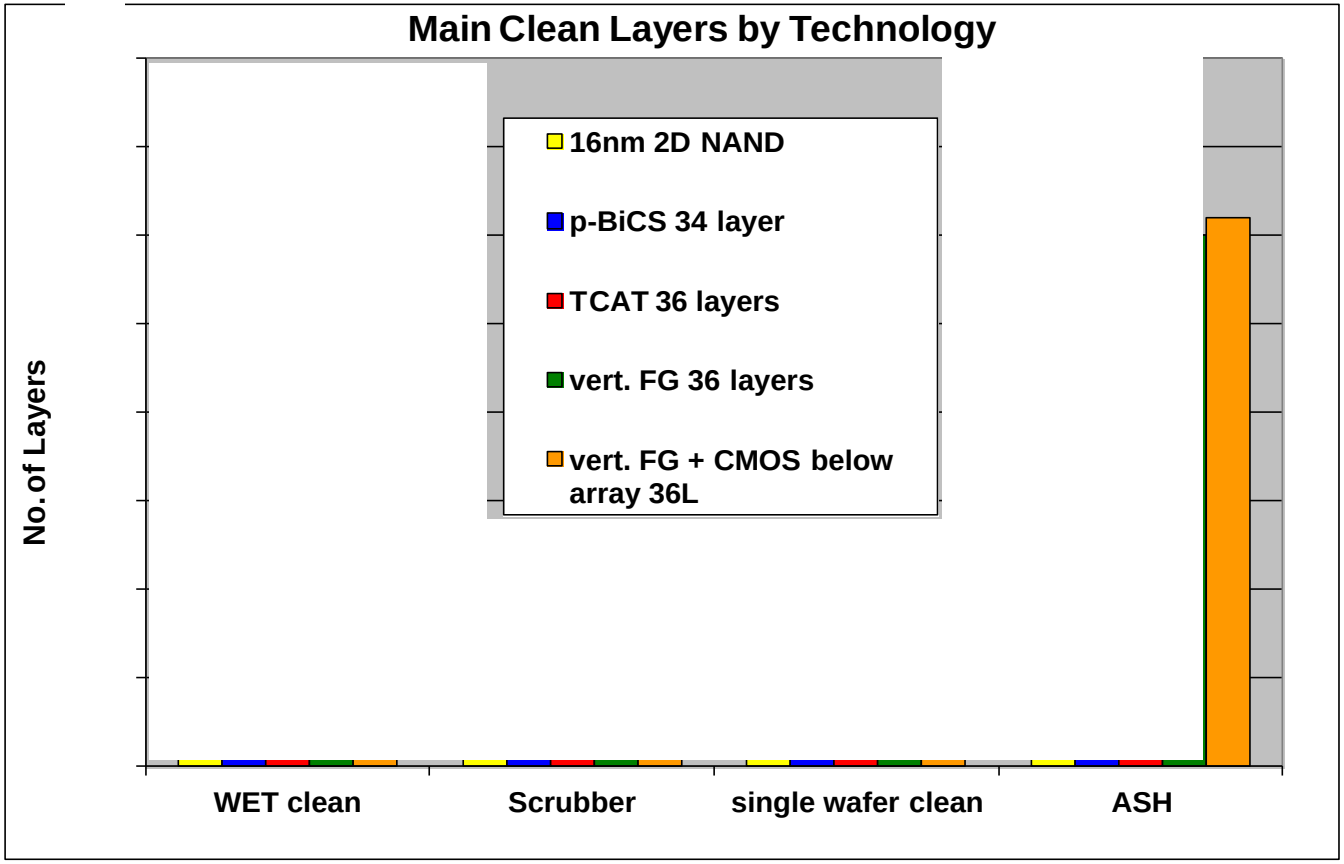
Main Clean Layers by Technology



- higher number of xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx in 2D NAND
- more xxxxxxxxxxxxxxxxxx for 3D NAND for better xxxxxxxxxxxxxxxxxxxxxxxxxx
- xxxxxxxxxxxx in 3D NAND for staircase xxxxxxxxxxxxxxxxxx

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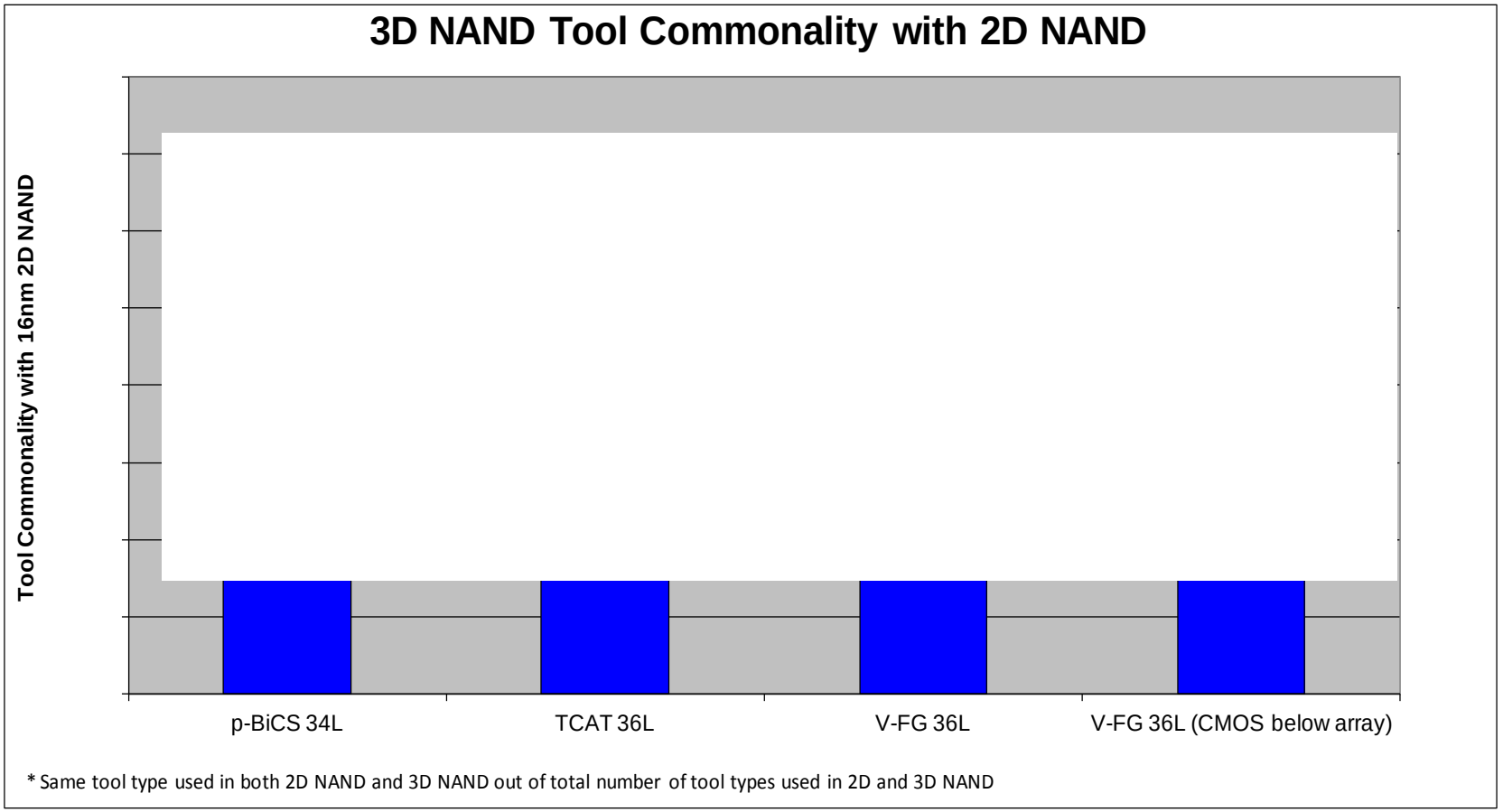
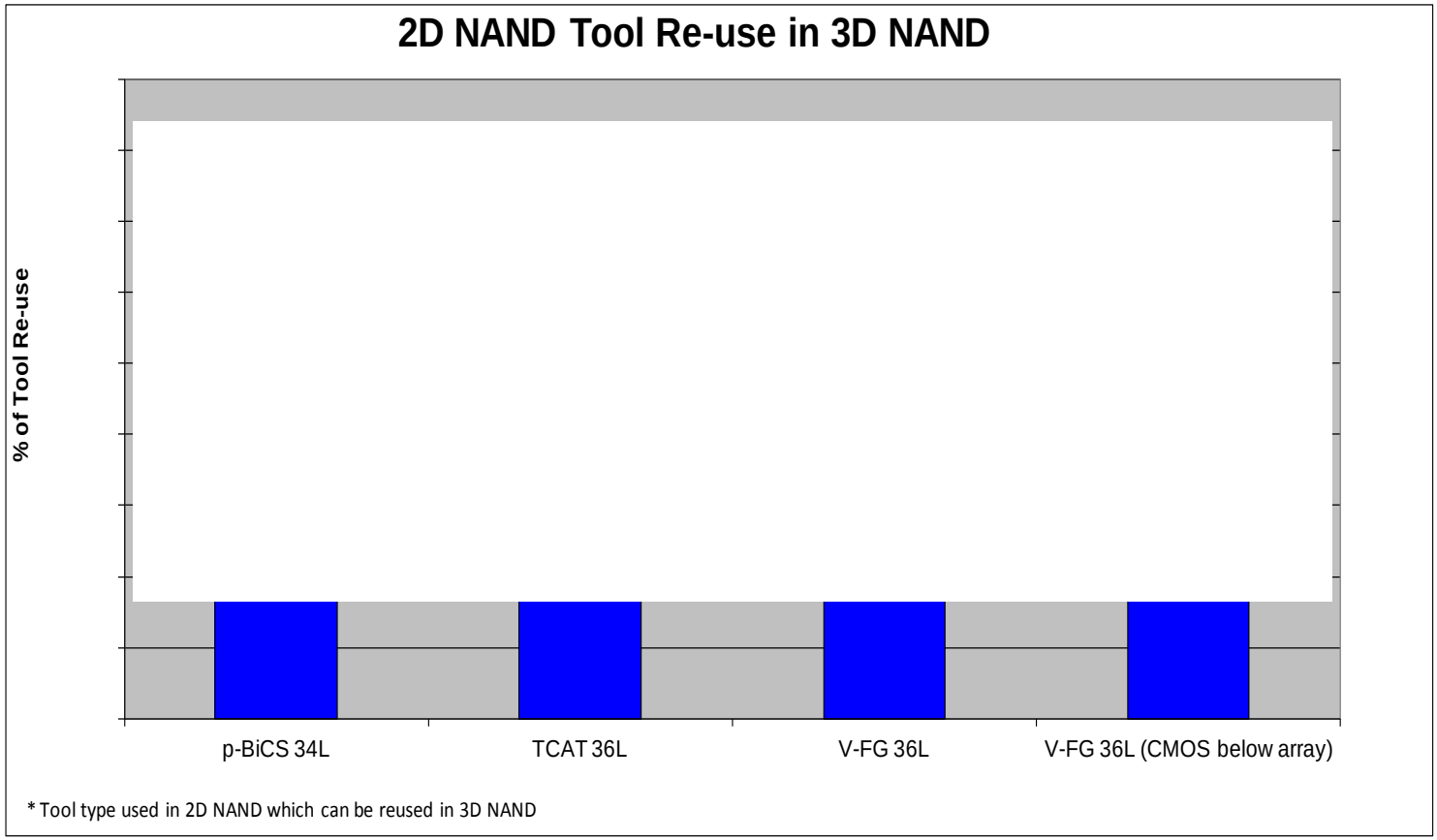
3D NAND Tool Commonality with 2D NAND



- xxxxx of the total tool types used in 2D NAND and 3D NAND are common

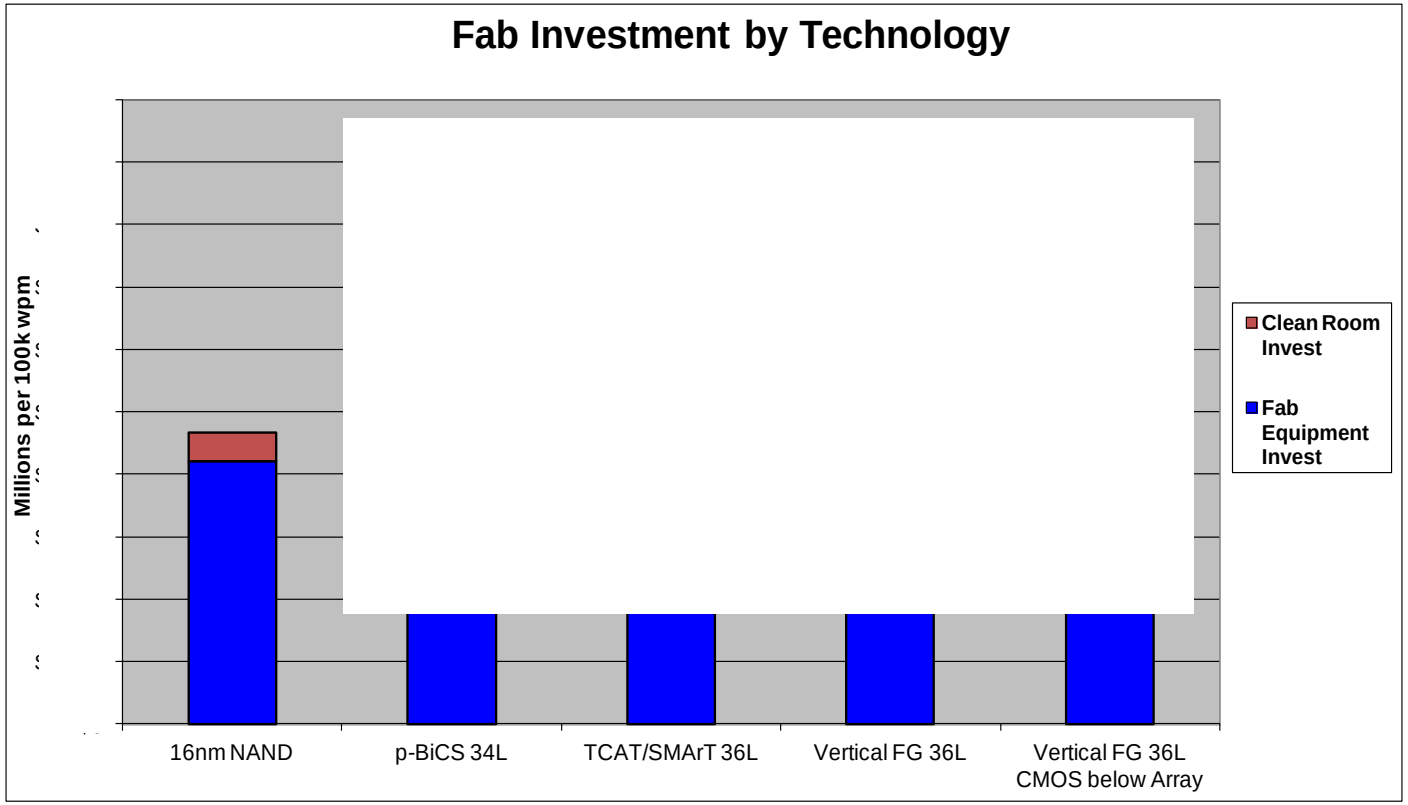
2D NAND Tool Re-use in 3D NAND



- xx% of the total tool types used in 2D NAND can be re-used in 3D NAND

Greenfield Investment

Fab Investment by Technology



- 3D NAND investment xxxxxxxxxxxxxxxxxxxxxxxxxxxx 2D NAND

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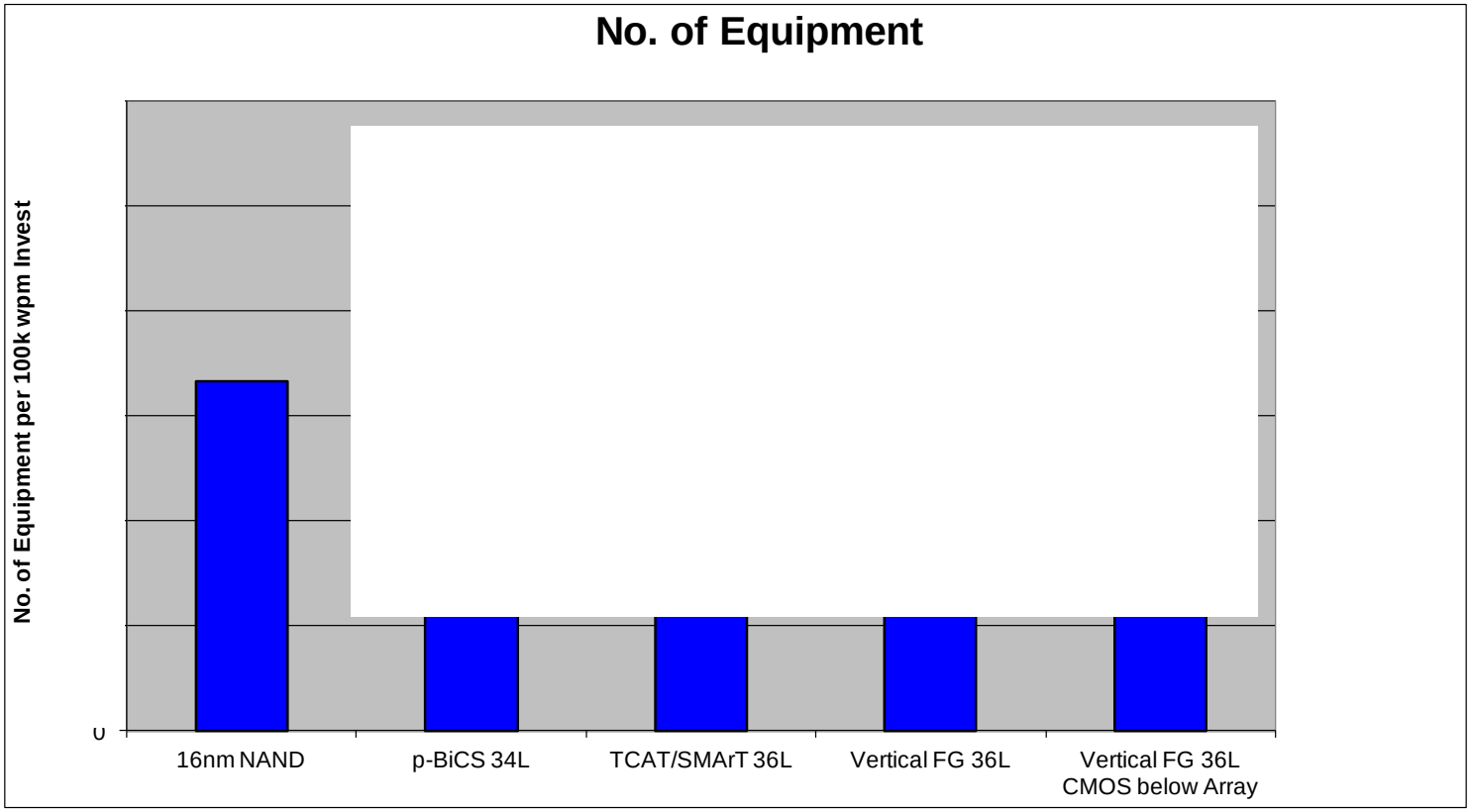
Number of Equipment



- xx-xx% xxxxxxx required for 3D NAND

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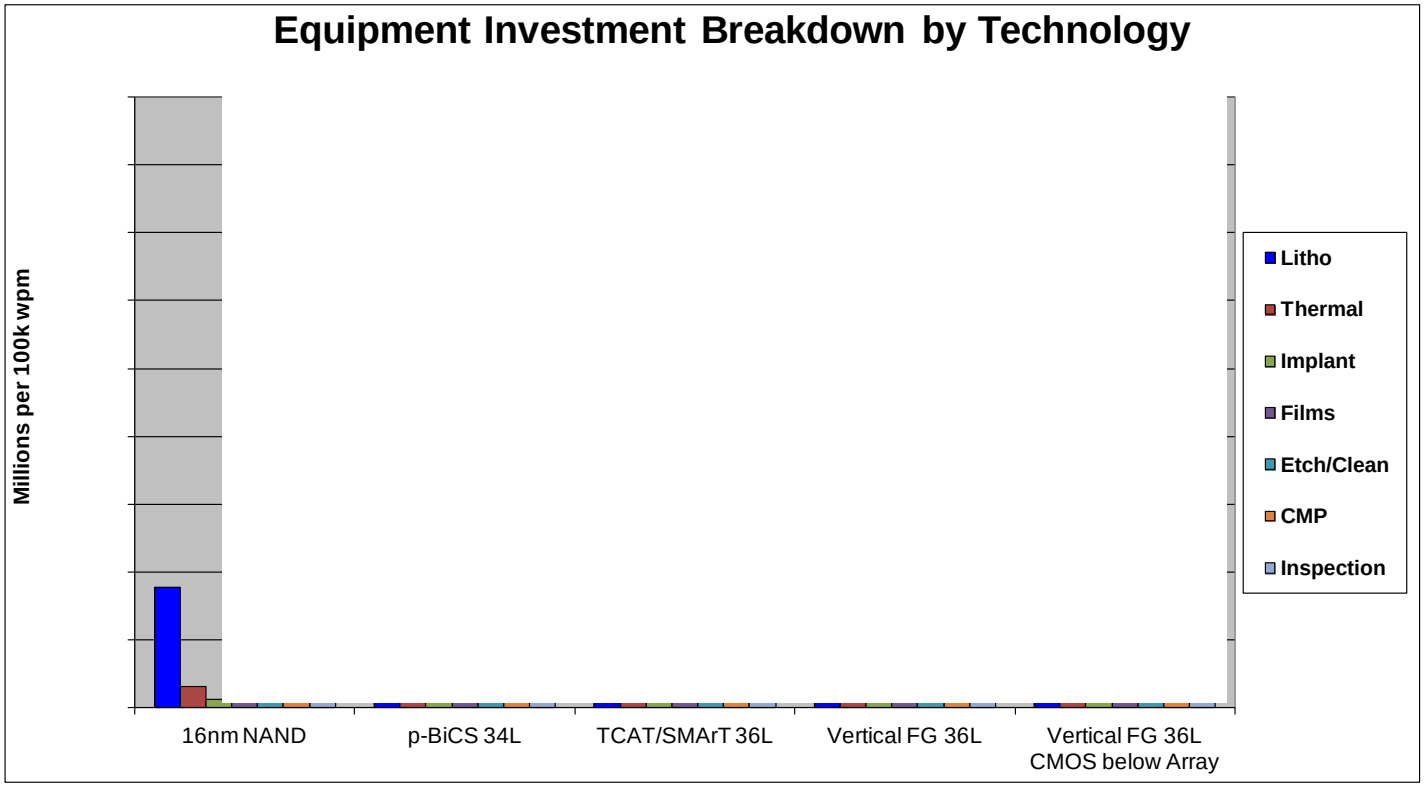
Equipment Investment Breakdown by Technology



- xxxxxxxxxxxxxxxx drive xxxxxxxxxxxx investment

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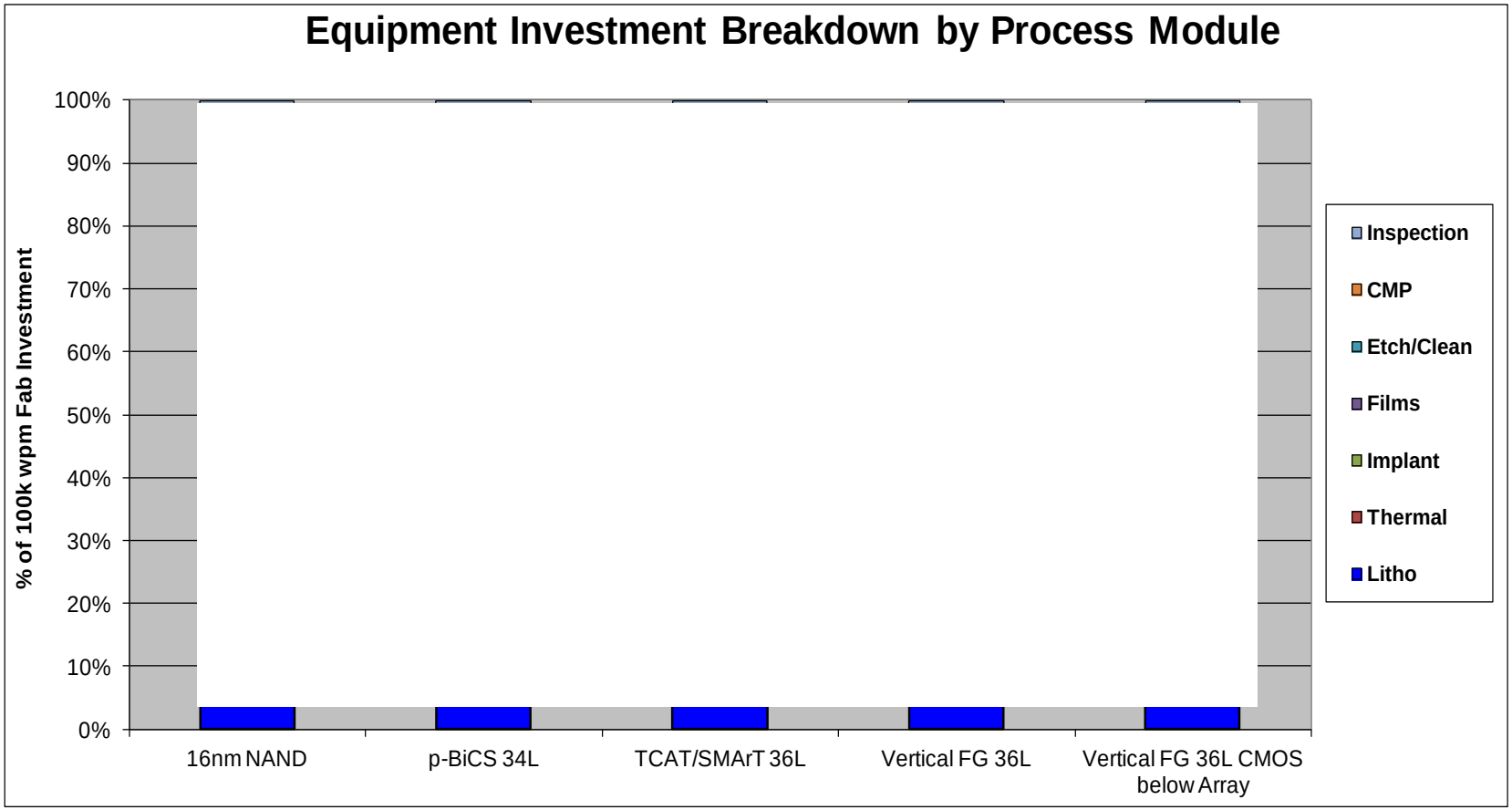
Equipment Investment Breakdown by Process Module



- etch/cleans + films accounts for over xx% vs. xx% for 2D NAND

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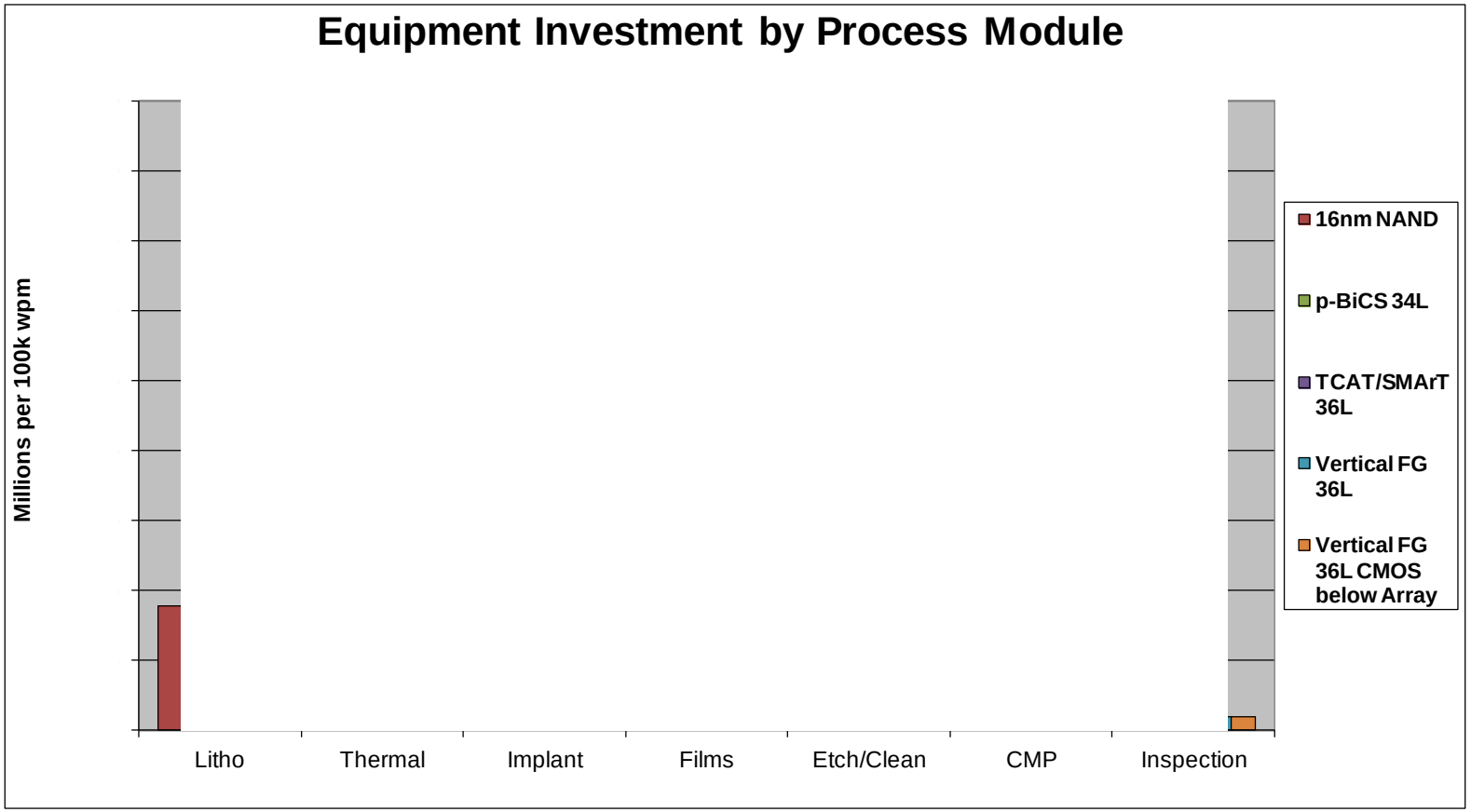
Equipment Investment Breakdown by Process Module



- xxxxxxxxxxxx investment by process module xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

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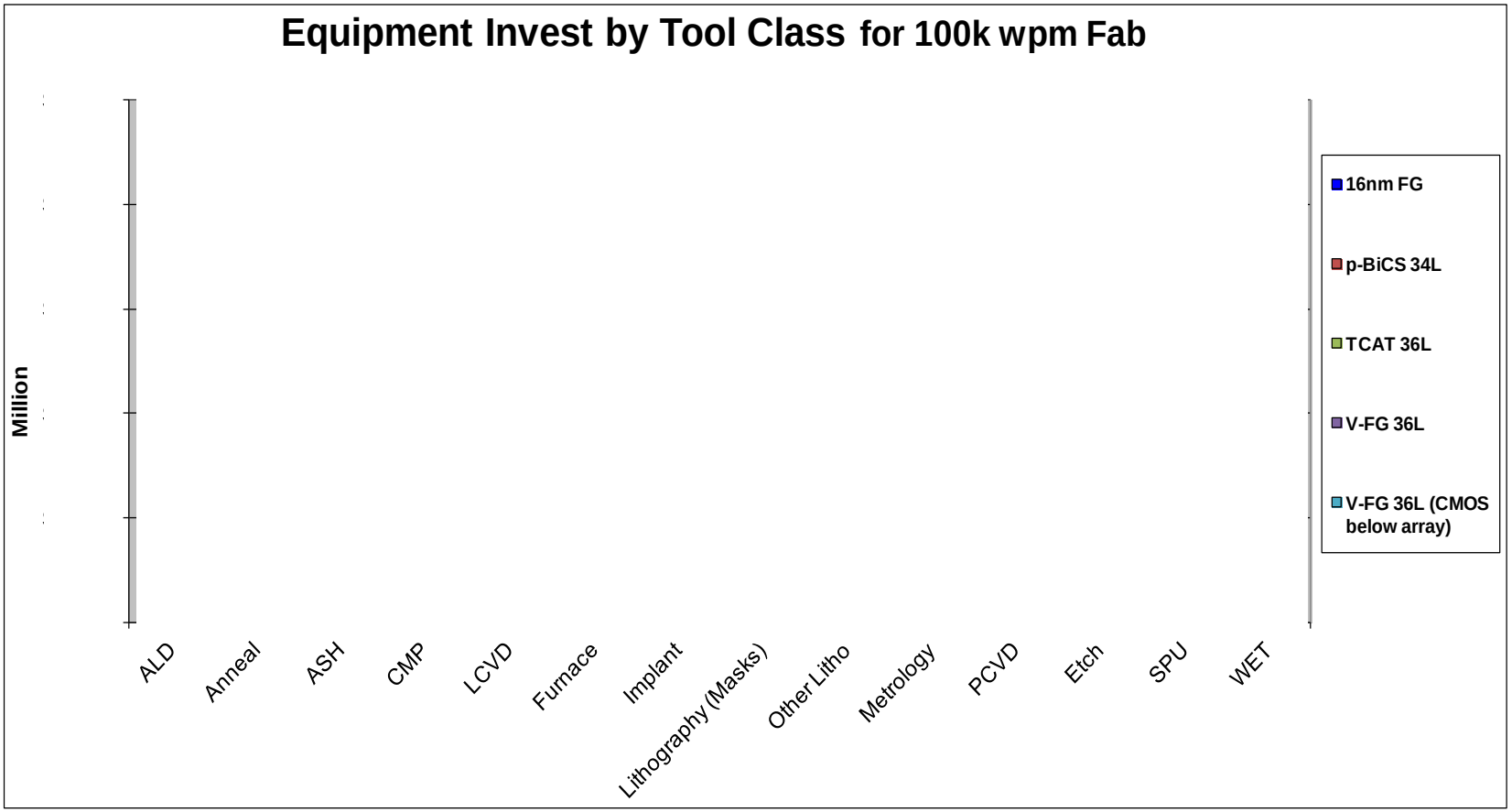
Fab Investment by Tool Class



- xxxxxxxx dominates investment followed by xxxxxxxx

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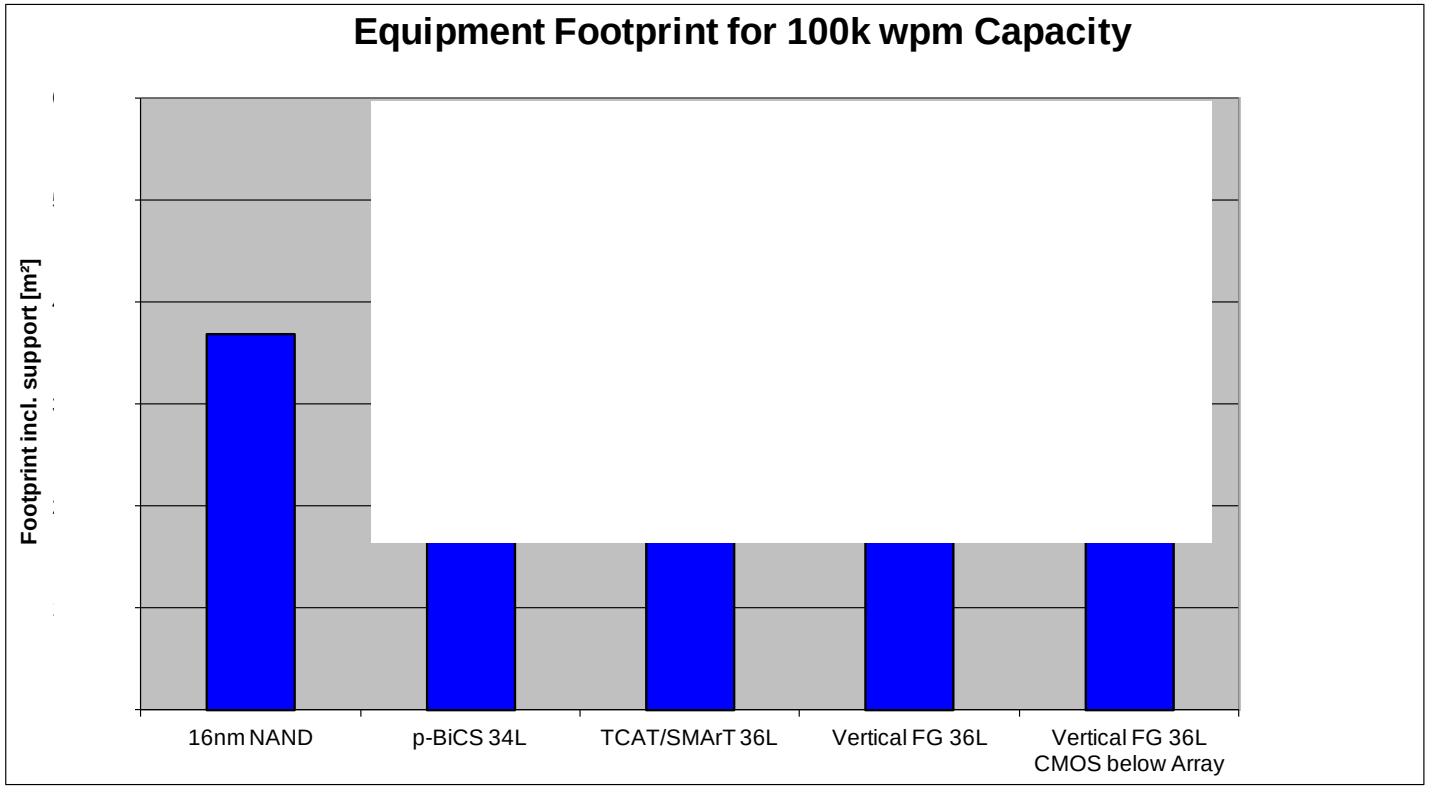
Equipment Footprint for 100kwpm Capacity



- xx-xx% xxxx space required for 3D NAND

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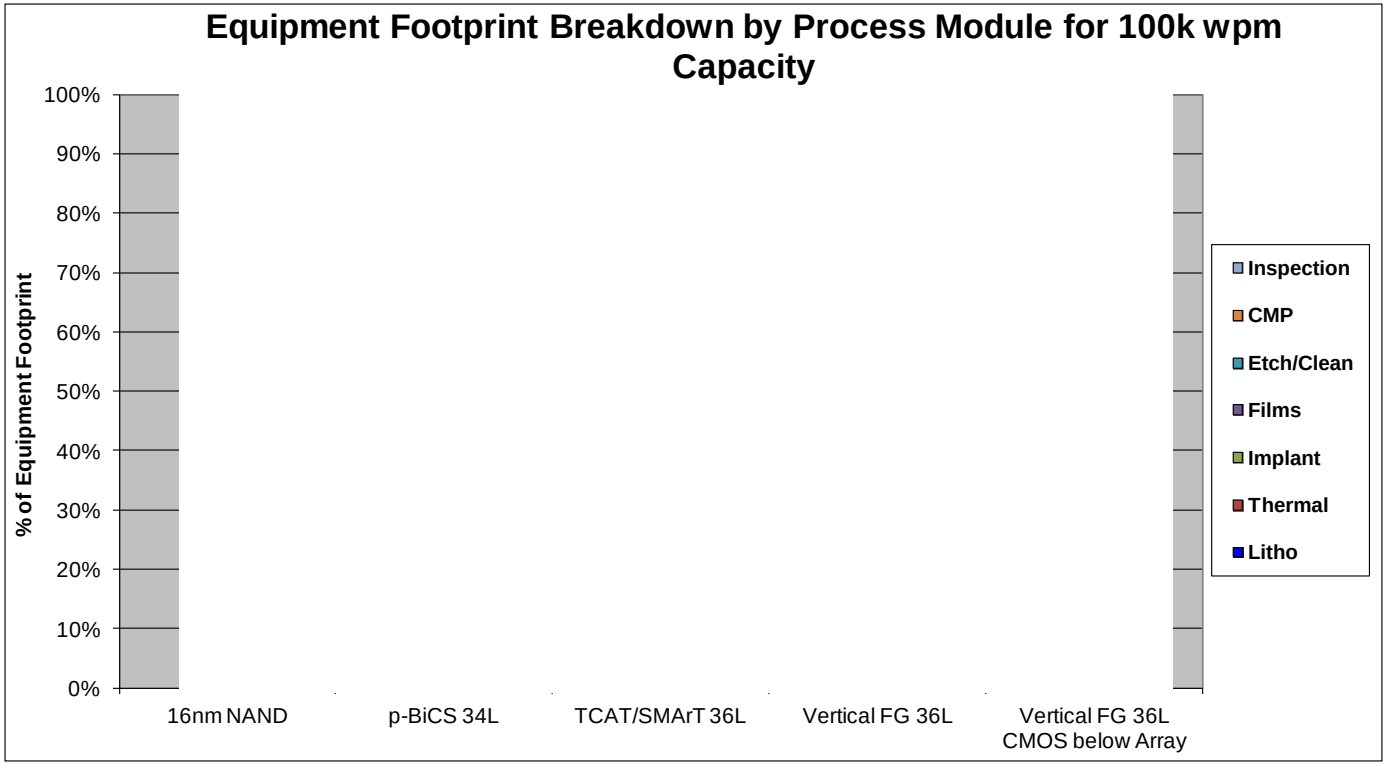
Equipment Footprint Breakdown by Process Module for 100k wpm Capacity



- etch/cleans + films accounts for xx% of footprint in p-BiCS; xxx for other 3D concepts and xx% in 2D NAND

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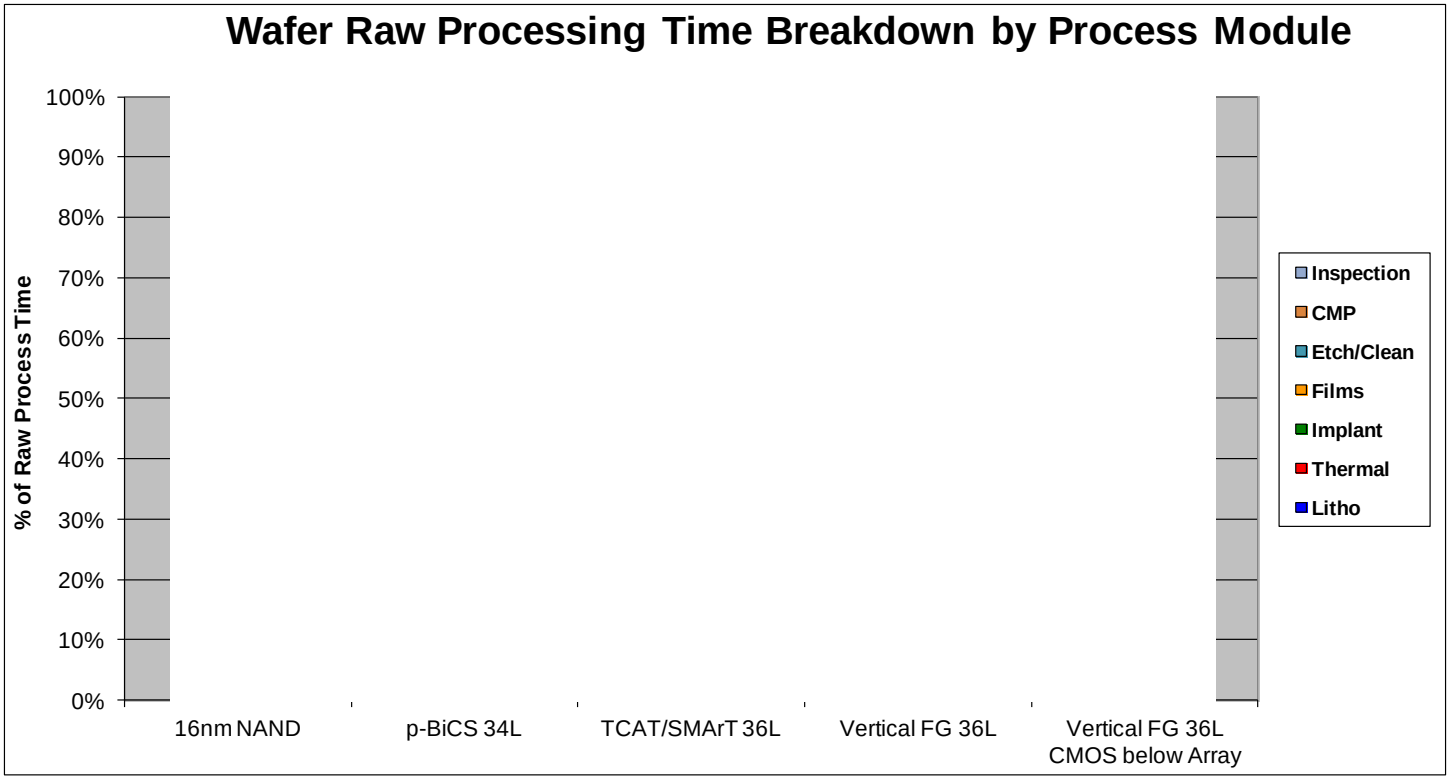
Wafer Raw Processing Time Breakdown by Process Module



- etch/cleans + films accounts for xx% in 3D NAND vs. xx% for 2D NAND

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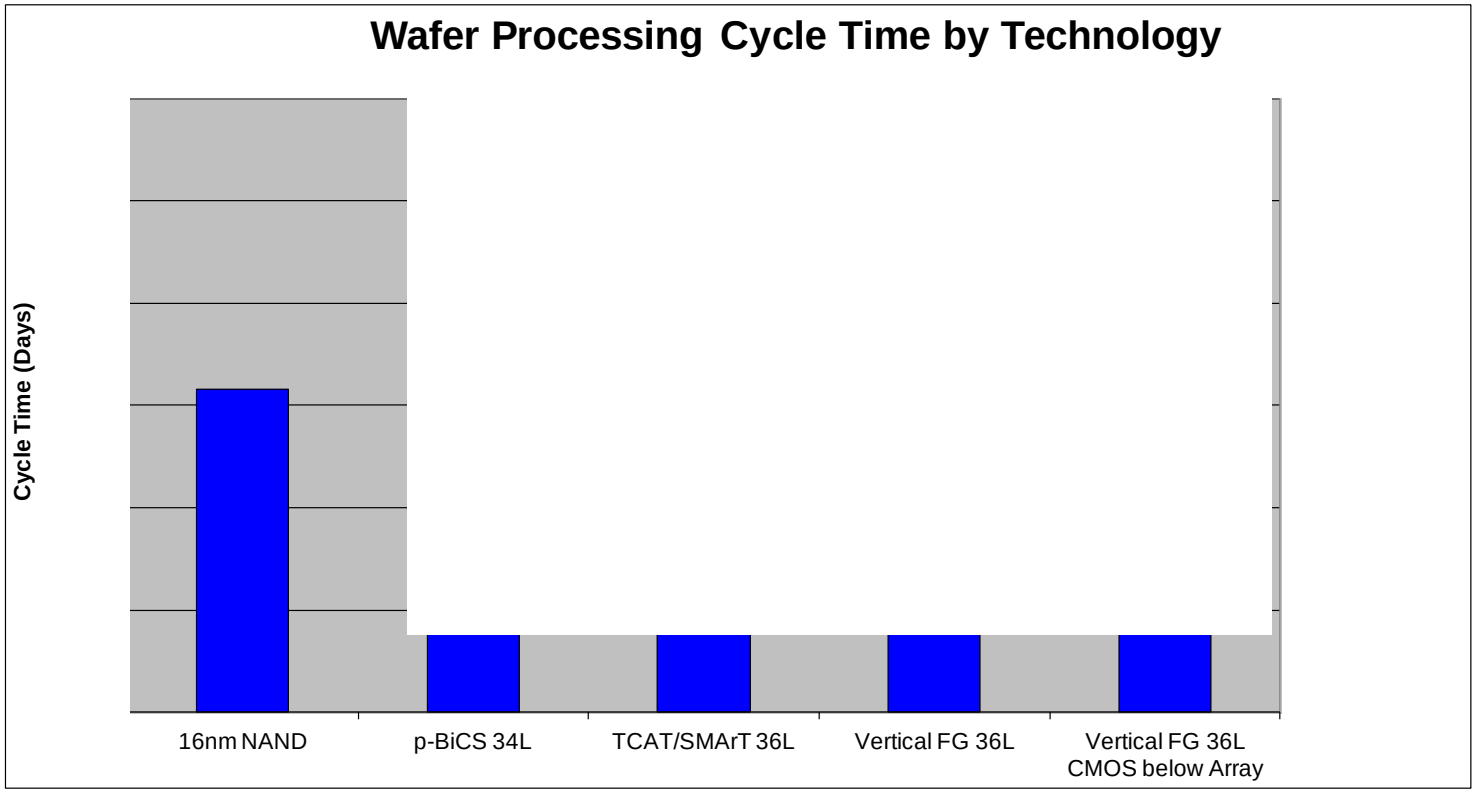
Wafer Processing Cycle Time by Technology



- cycle times are xx-xx% xxxxxxxx than 2D NAND

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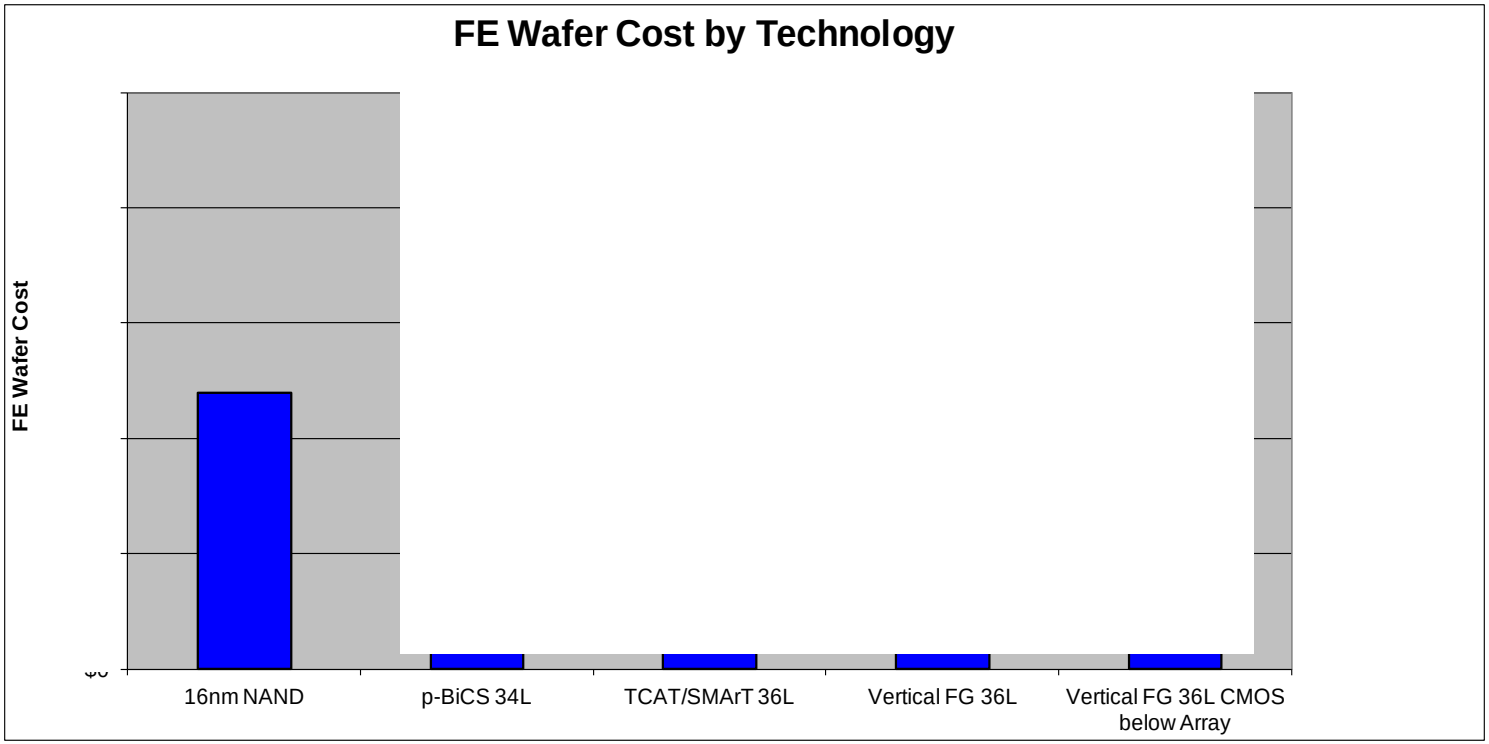
Front End Wafer Cost by Technology



- FE wafer cost is at xx% xxxxxx for 3D NAND

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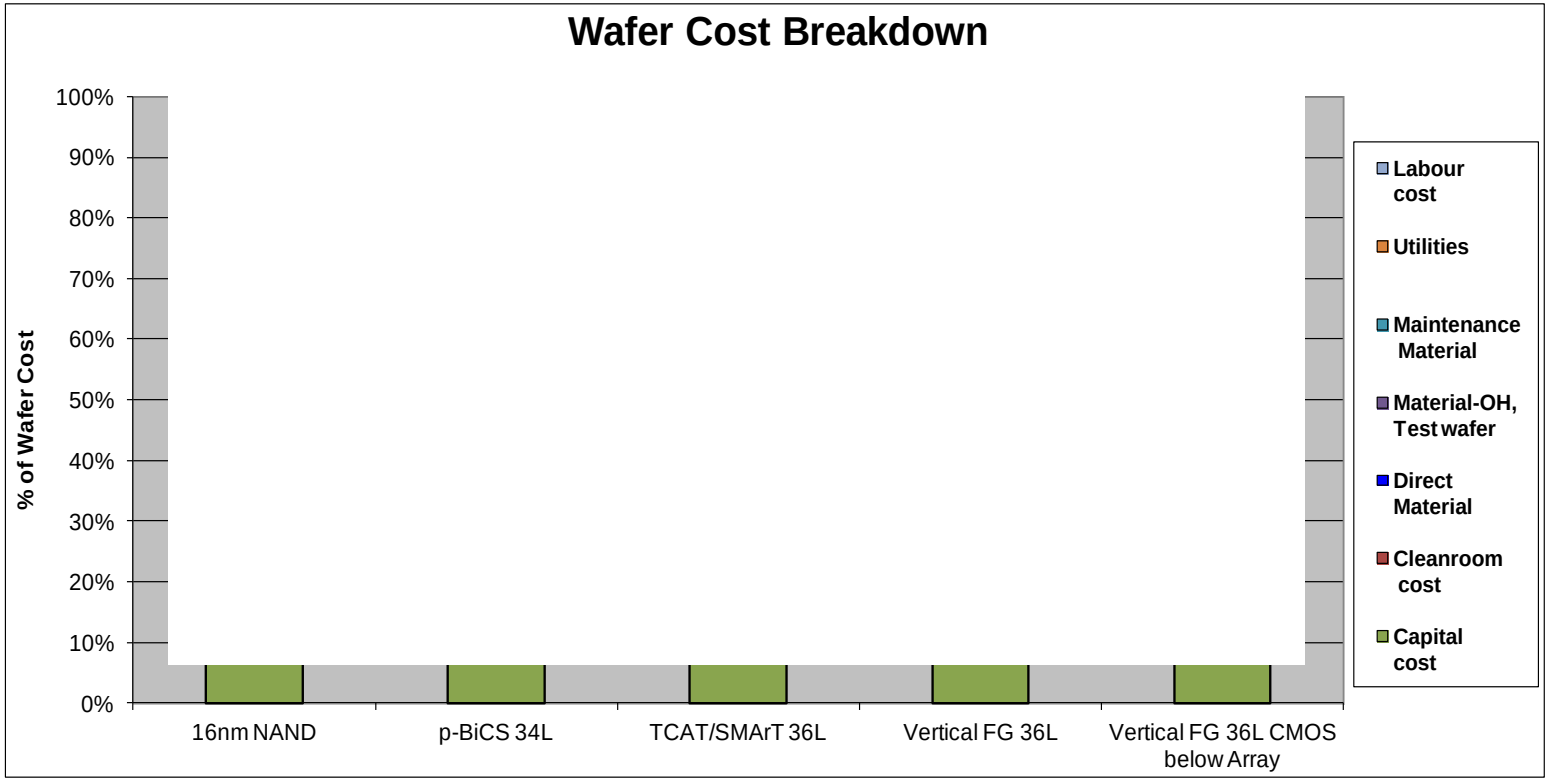
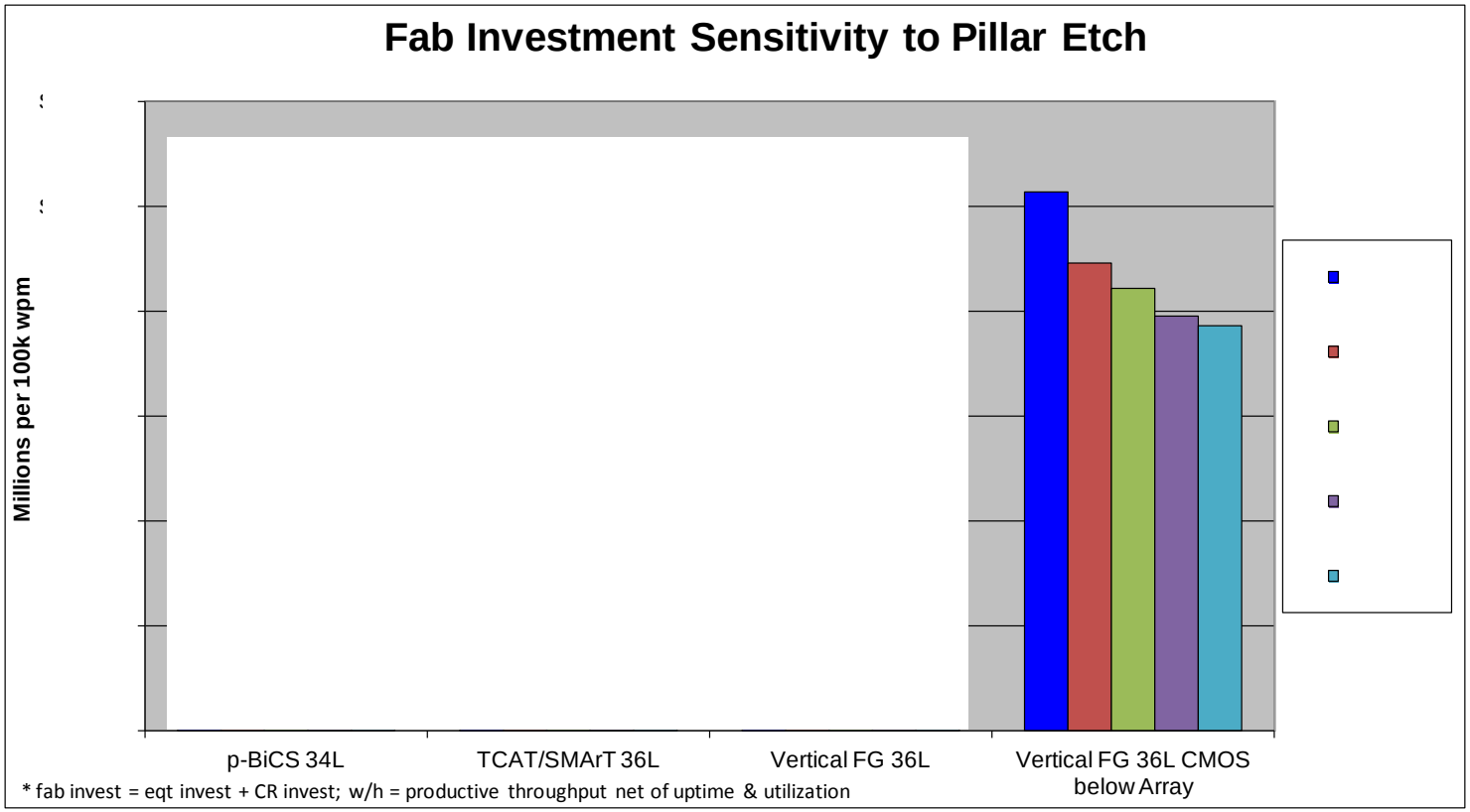
Front End Wafer Cost Breakdown



- capital cost accounts for xxxxx of FE wafer cost for 3D NAND

Fab Investment Sensitivity Analysis



- pillar/hole etch is xxxxxxxxxxxxxx and can xxxxxxxxxxxxxxxxxxxxxxxxxxxxx

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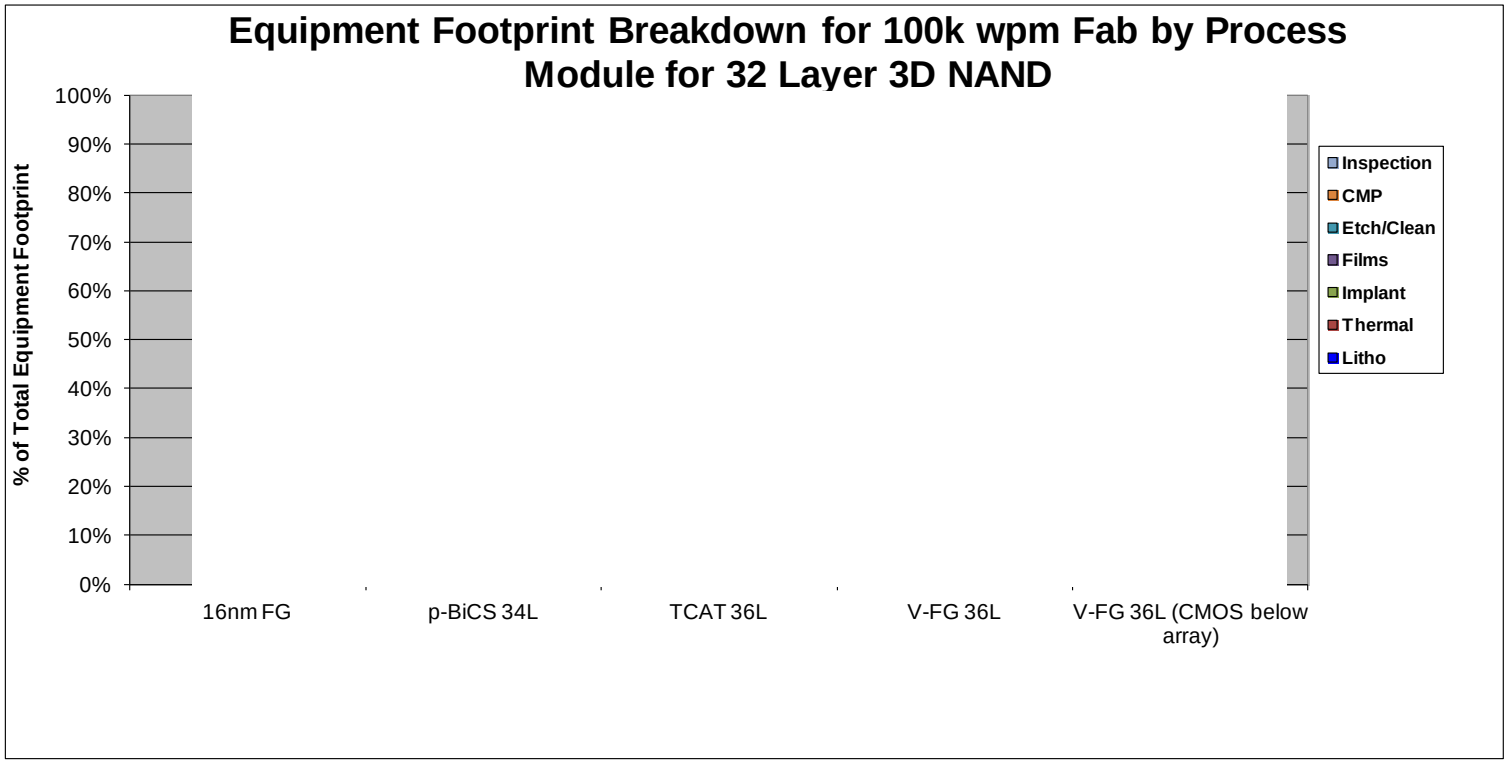
2D to 3D NAND Conversion

Equipment Footprint Breakdown for Given Area by Process Module for 32 Layer 3D NAND



- etch/cleans + films accounts for xxxx xxxxx vs. xx% for 2D NAND

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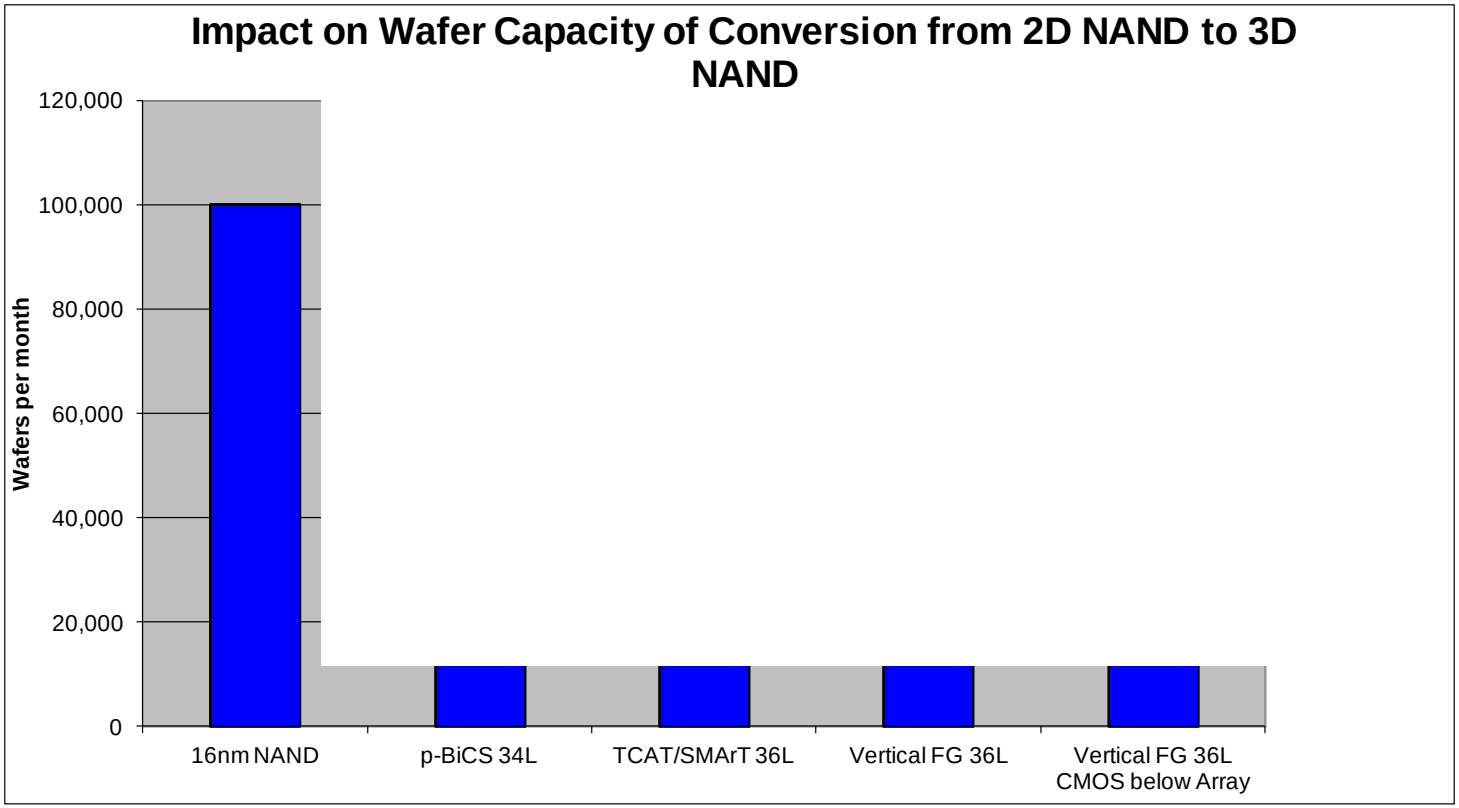
Impact on Wafer Capacity of Conversion from 2D NAND to 3D NAND



- xx-xx% wafer capacity xxxxxxxx for 3D NAND vs. 2D NAND

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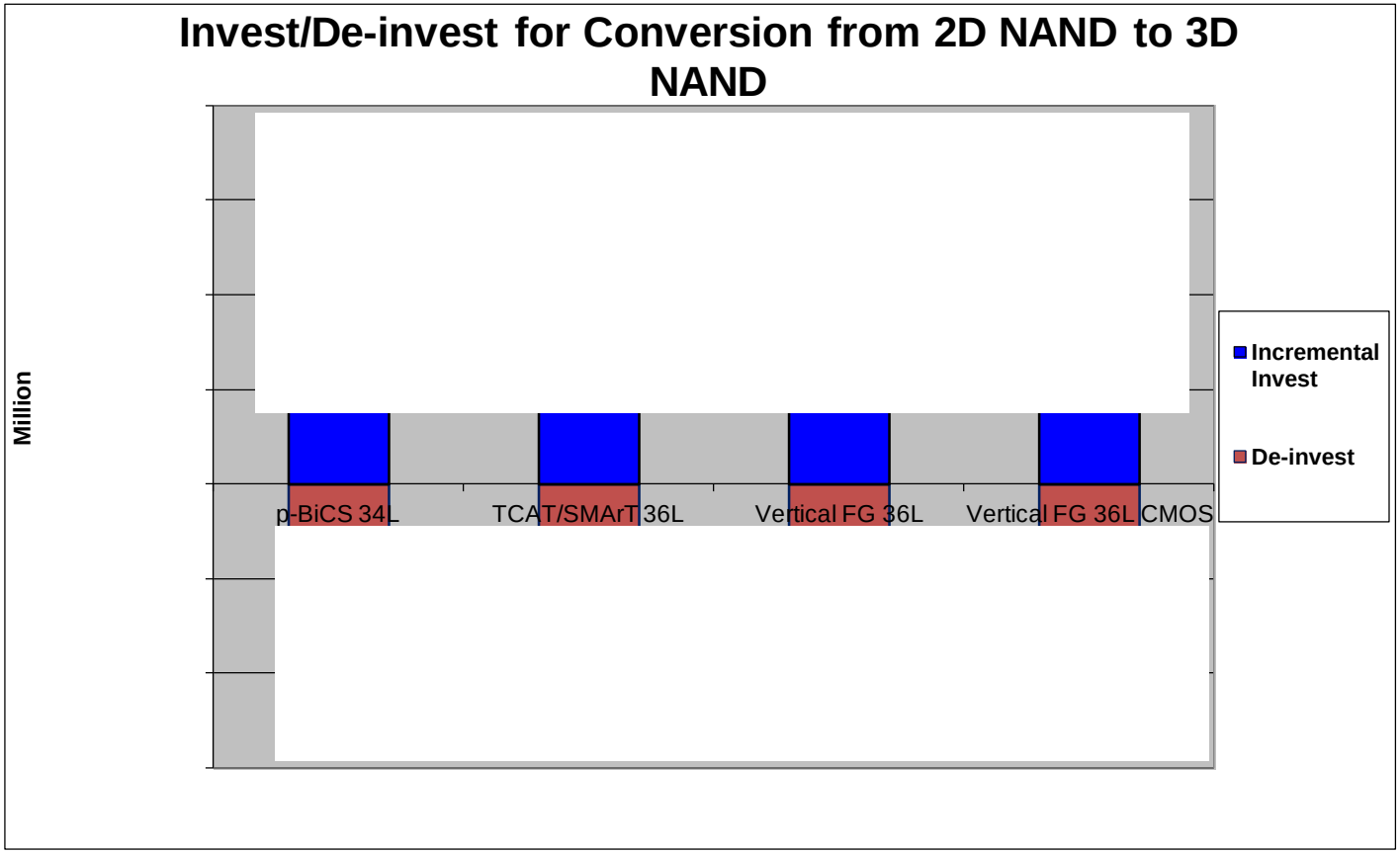
Invest/De-invest for Conversion from 2D NAND to 3D NAND



- xxxxxxxxxxxxxxx results in xxxxxxxxxxxxxx of ~$xxxx which must be sold or re-deployed

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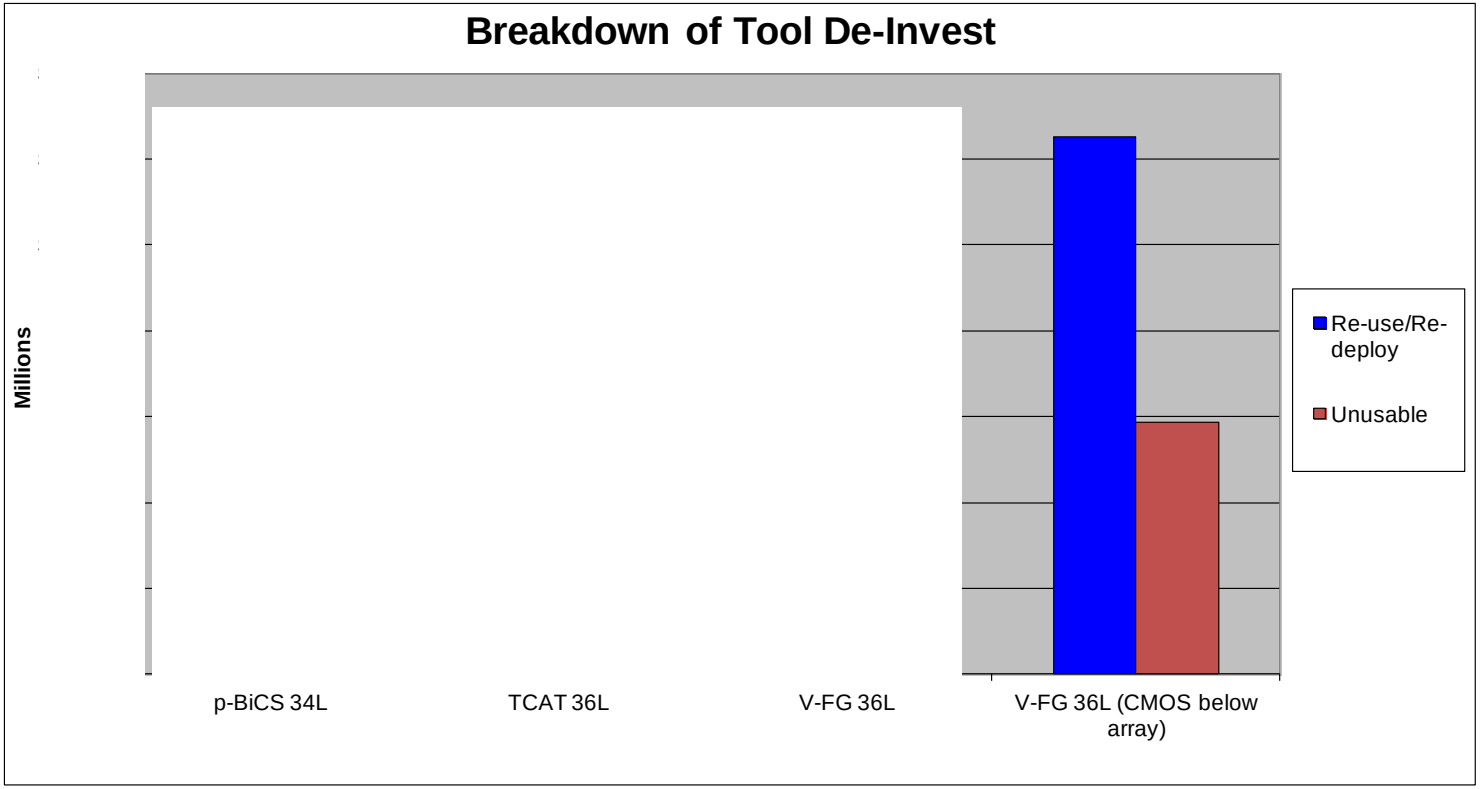
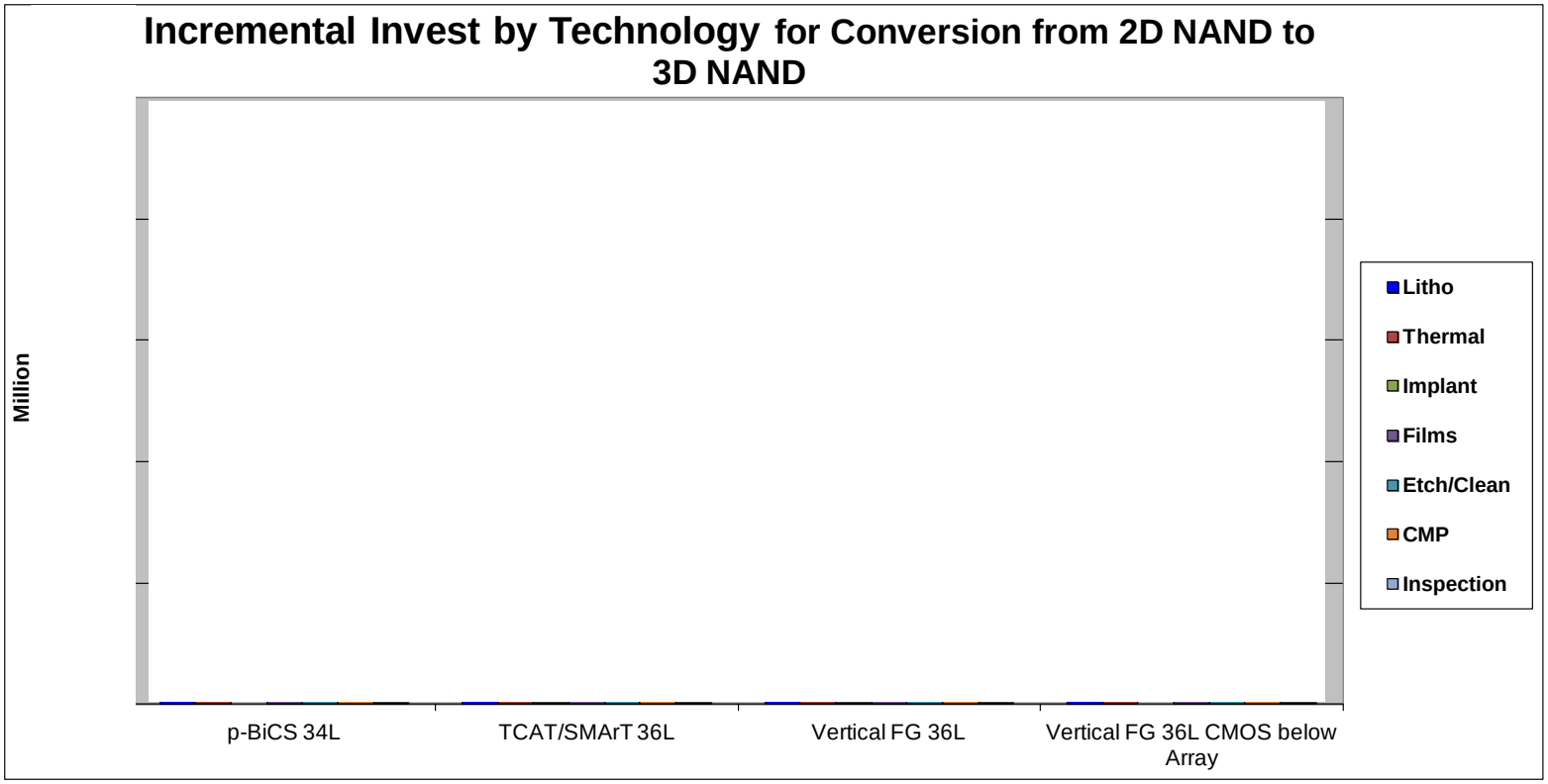
Breakdown of Tool De-invest



- xxxxxx is due xxxxxxxxxxxxxxxxxxxxx and can be re-used in 3D NAND production if there is xxxxxxxxxxxxxxxxxxxxxxxxx available

FORWARD INSIGHTS

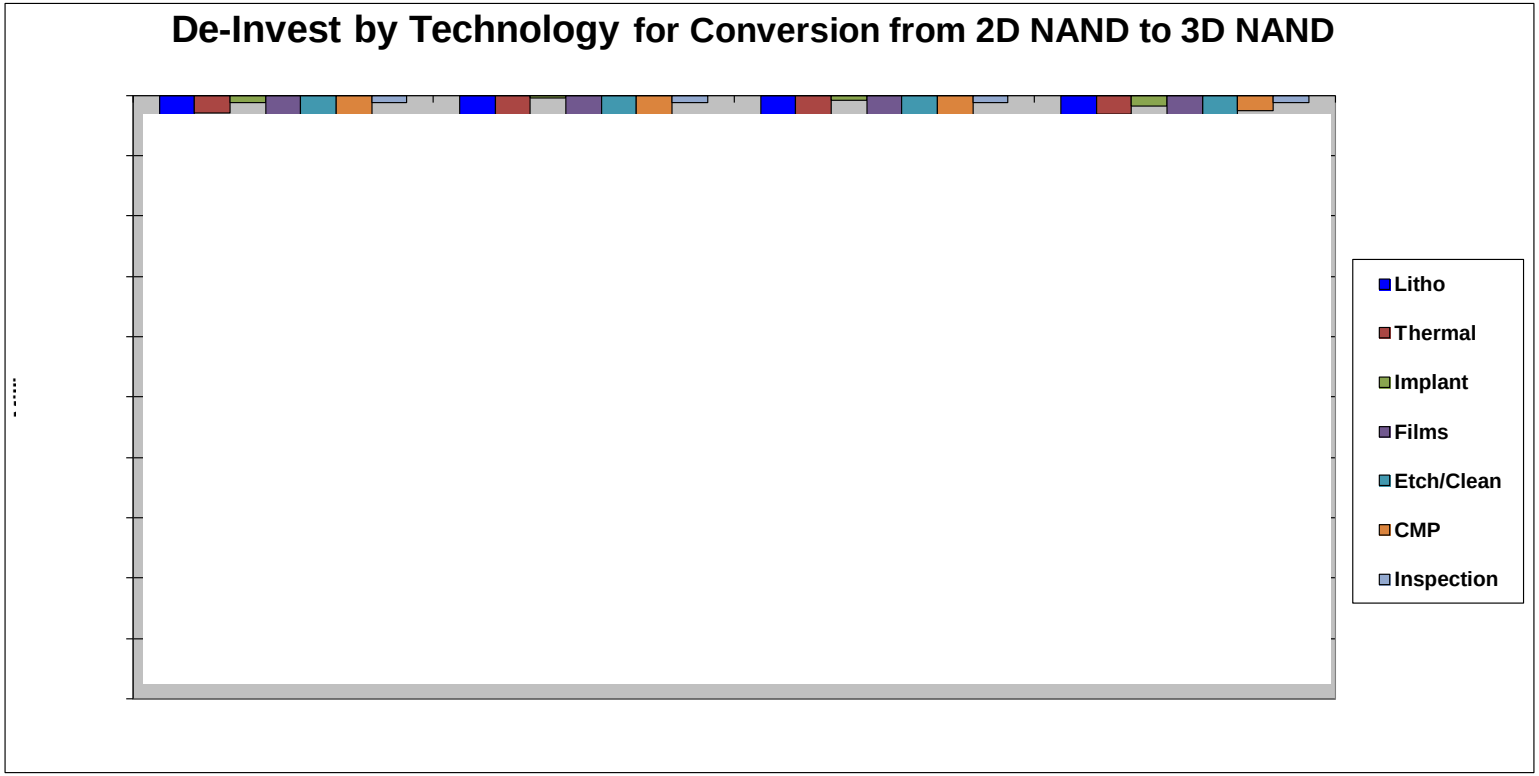
Incremental Invest by Technology for Conversion from 2D NAND to 3D NAND



- xxx% of the incremental investment for conversion to 3D NAND is in the xxxxxxxxxx and xxxxxxxxxx modules

FORWARD INSIGHTS

De-invest by Technology for Conversion from 2D NAND to 3D NAND

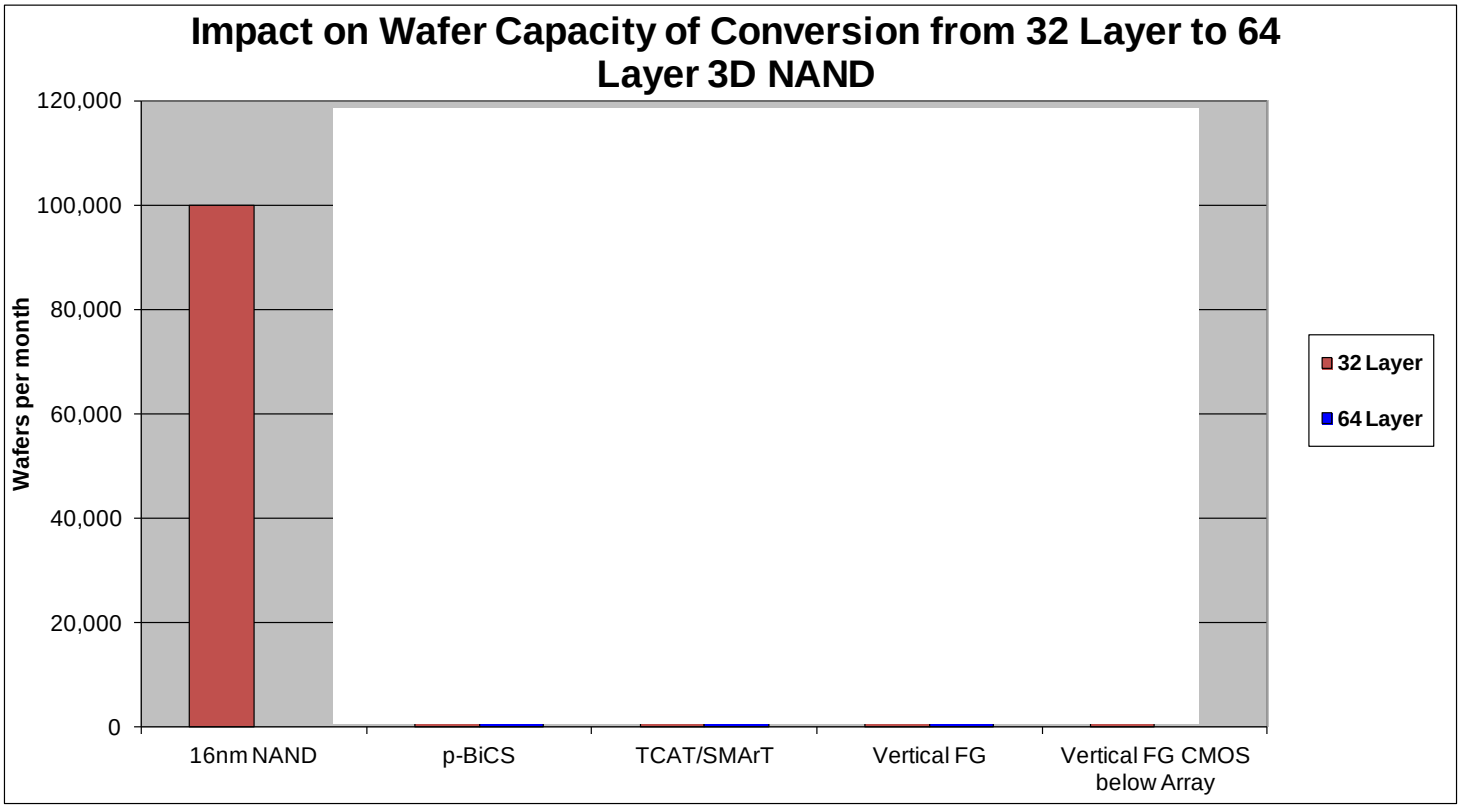


- de-investment in xxxxxxxxxxxxxx

FORWARD INSIGHTS

32L to 64L 3D NAND Migration

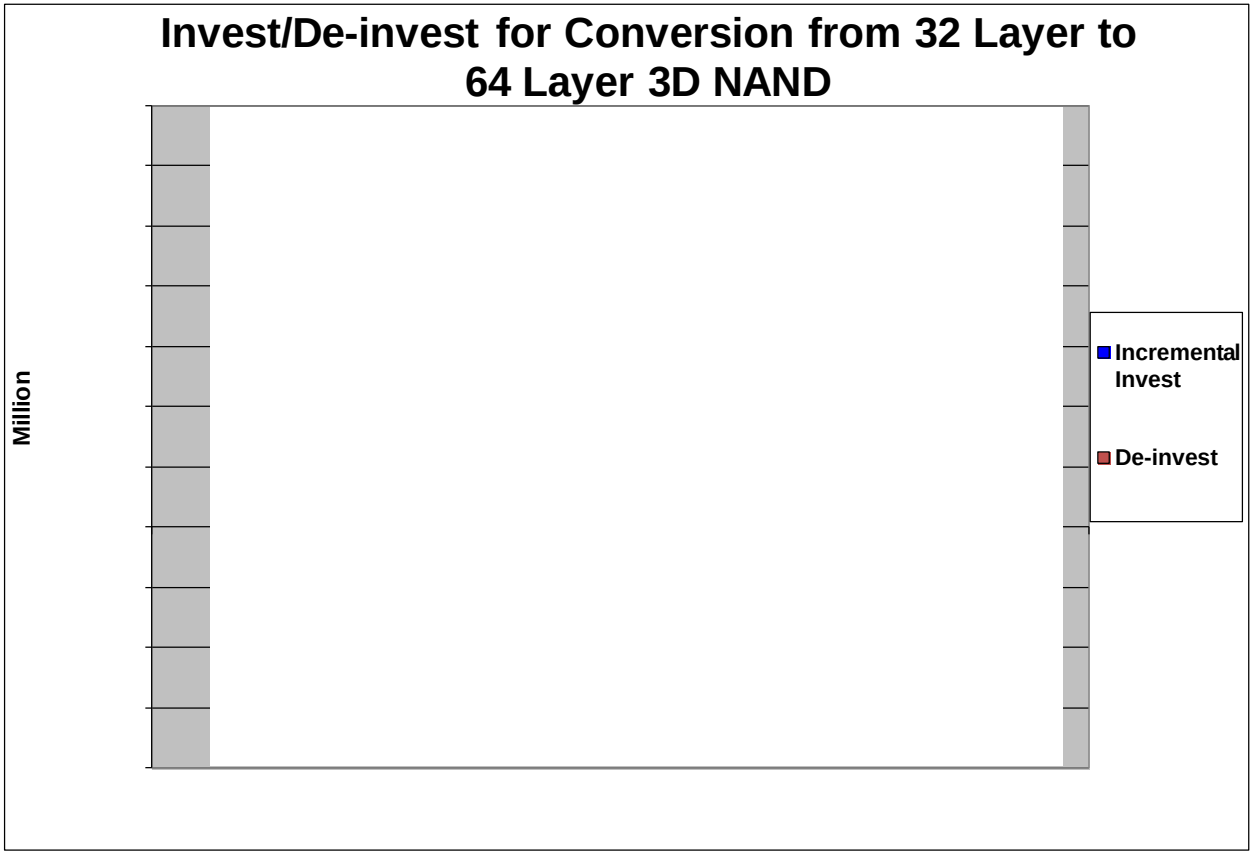
Impact on Wafer Capacity of Conversion from 32L to 64L 3D NAND



- increasing the number of layers from 32 to 64 results in xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx of xx% to almost xx%.

FORWARD INSIGHTS

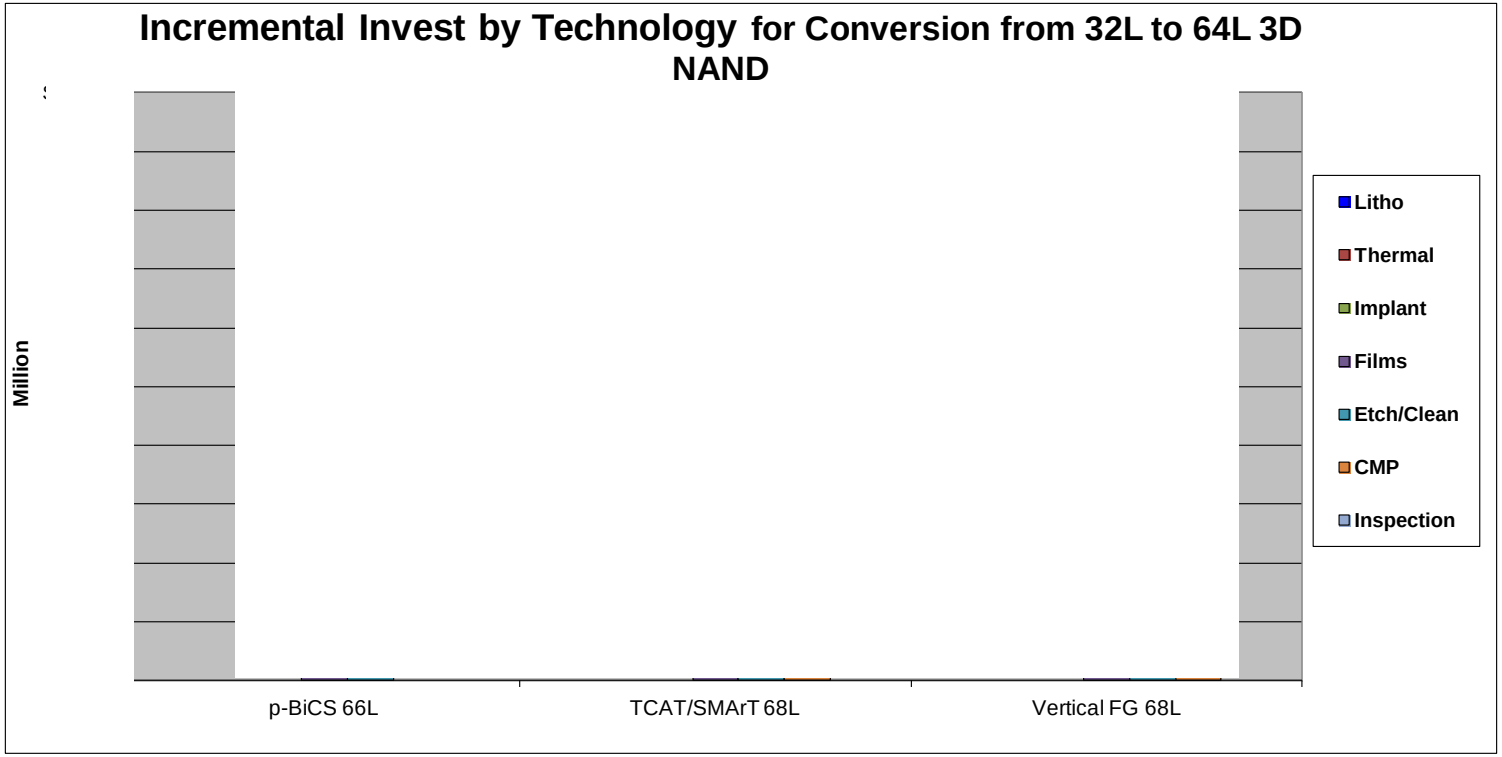
Investment/De-investment for Conversion from 32L to 64L 3D NAND



- upgrade invest xxxxx to xxxxx with de-invest $xxx-xxxm assuming xxxxxx converted to xxxxxxxxxxxxxx

FORWARD INSIGHTS

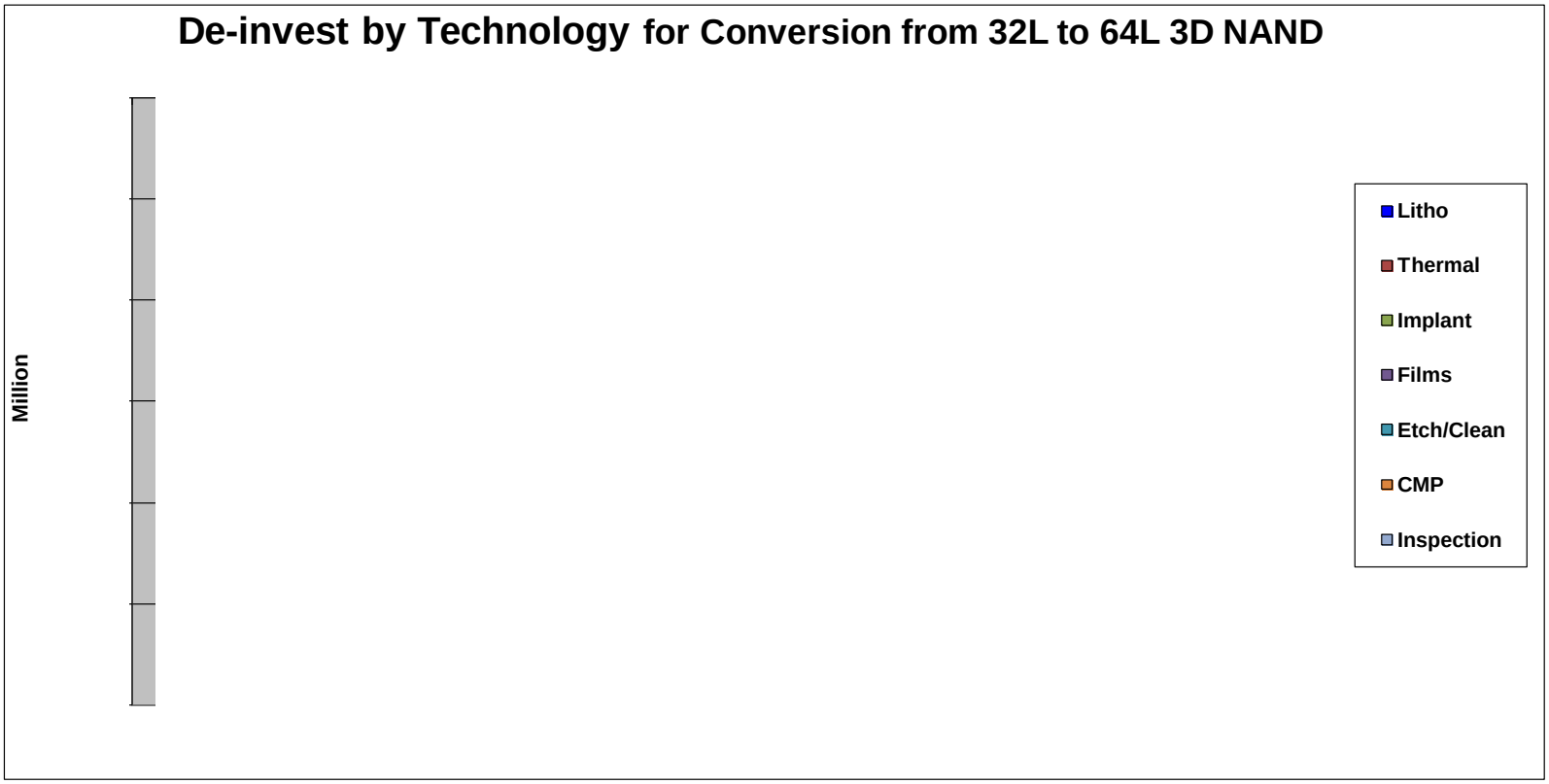
Incremental Investment by Technology for Conversion from 32L to 64L 3D NAND



- primarily xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx invest
- no additional xxxxxxxxxxxxxx invest if entire xxxxxxxxxxxxxxxx formation can be adequately addressed with xxxxxxxxxxxxxxxxxxxxxxx with subsequent xxxxxxxxxxxxxxxxxxxxxxxxxxx

FORWARD INSIGHTS

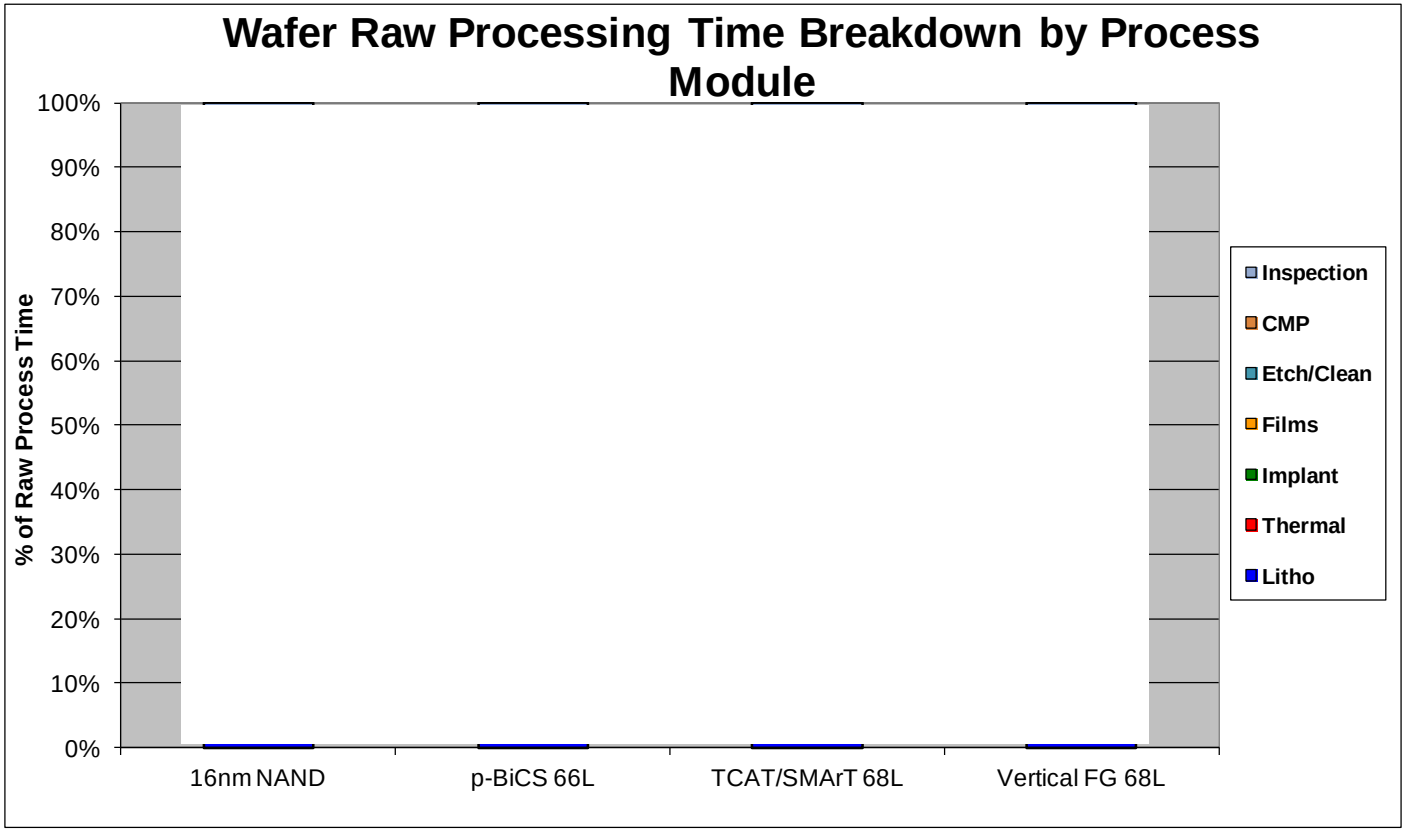
De-invest by Technology for Conversion from 32L to 64L 3D NAND



- de-invest primarily due to xxxxxxxxxxxxxxxxxxxxxx

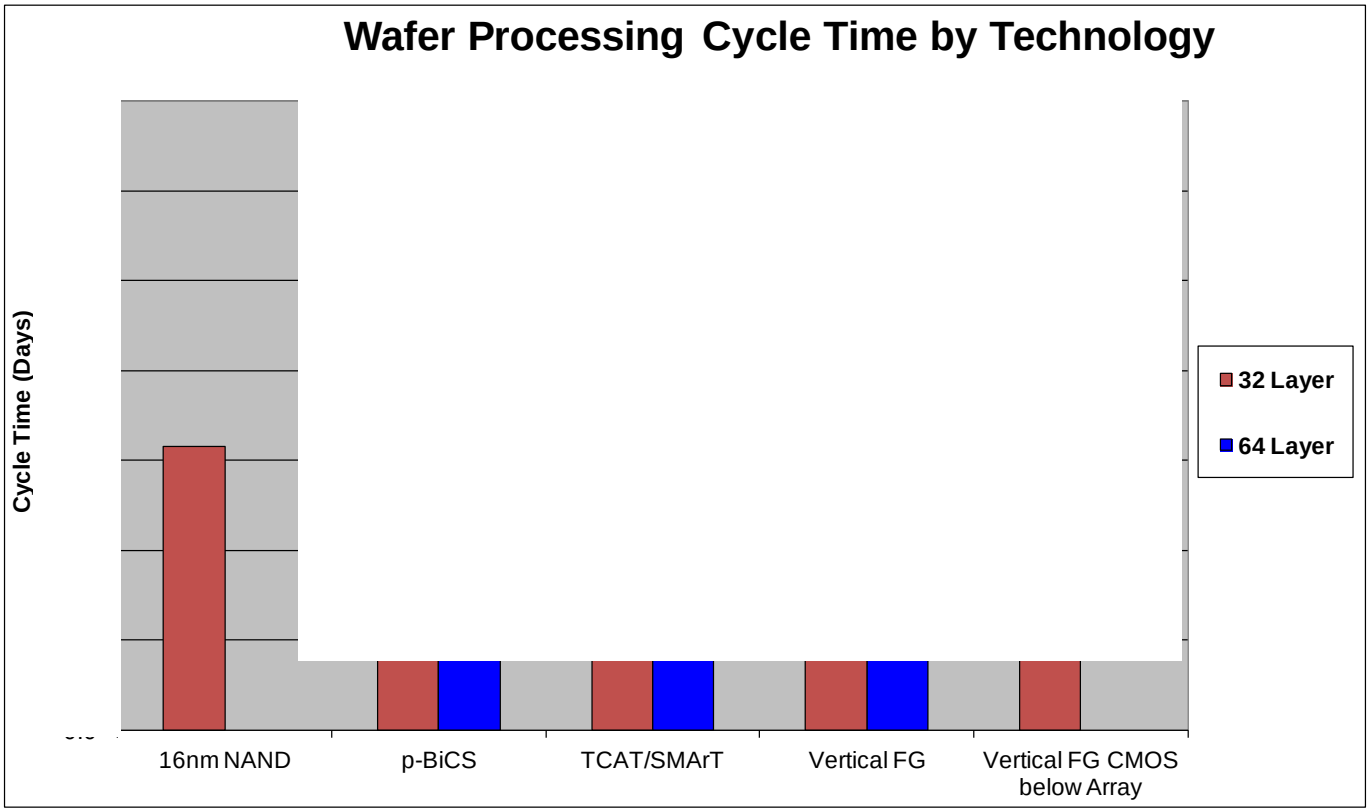
FORWARD INSIGHTS

Wafer Raw Processing Time Breakdown by Process Module



- Films and Etch/Clean accounts for xx% of the wafer raw processing time for a 64 layer 3D NAND, xxxxxxxxxxxxx xx% for 32 layer 3D NAND

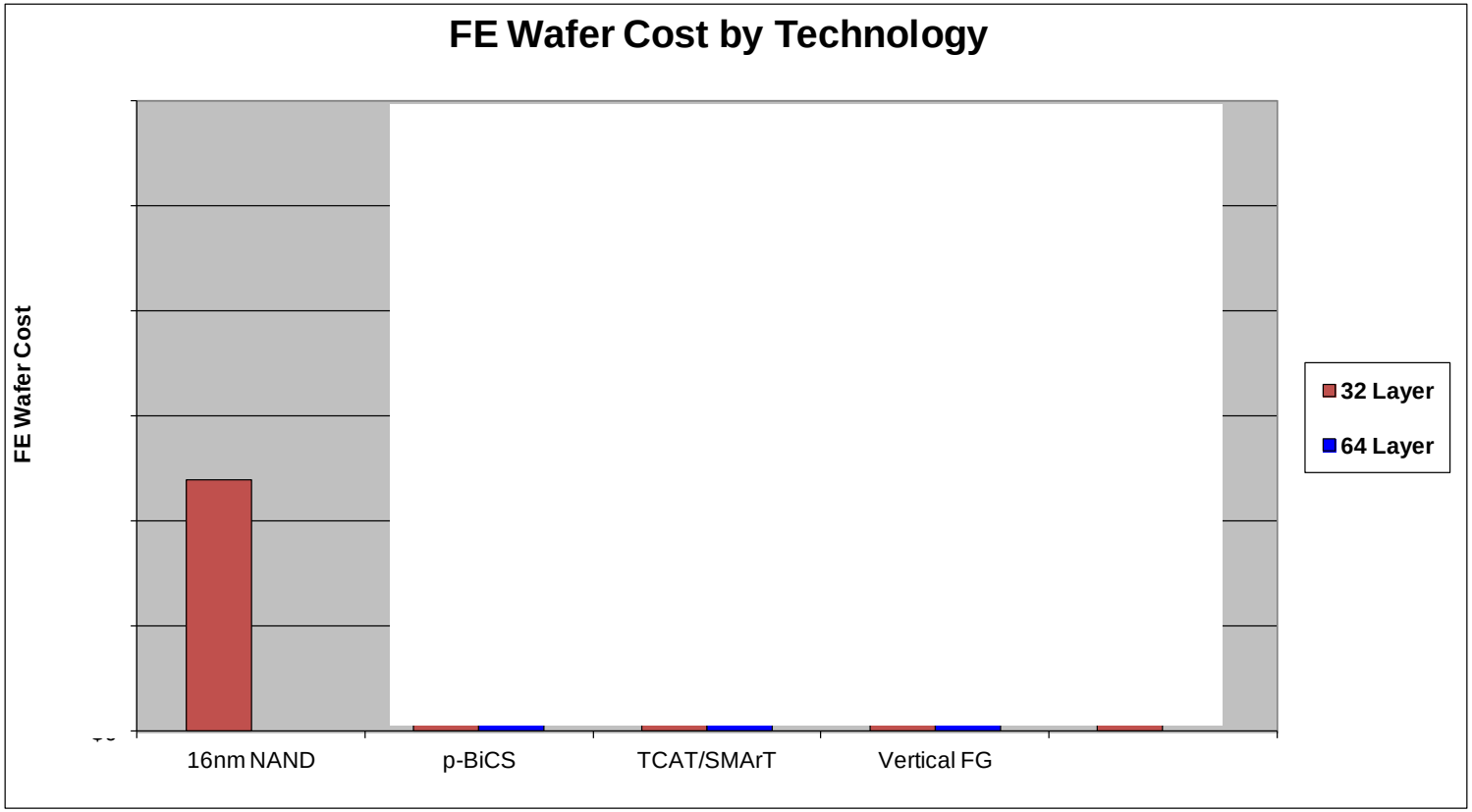
Wafer Processing Cycle Time by Technology



- fab cycle time is approximately xx% to xx% xxxxxxxxx for 64 layer 3D NAND compared to 32 layer 3D NAND

FORWARD INSIGHTS

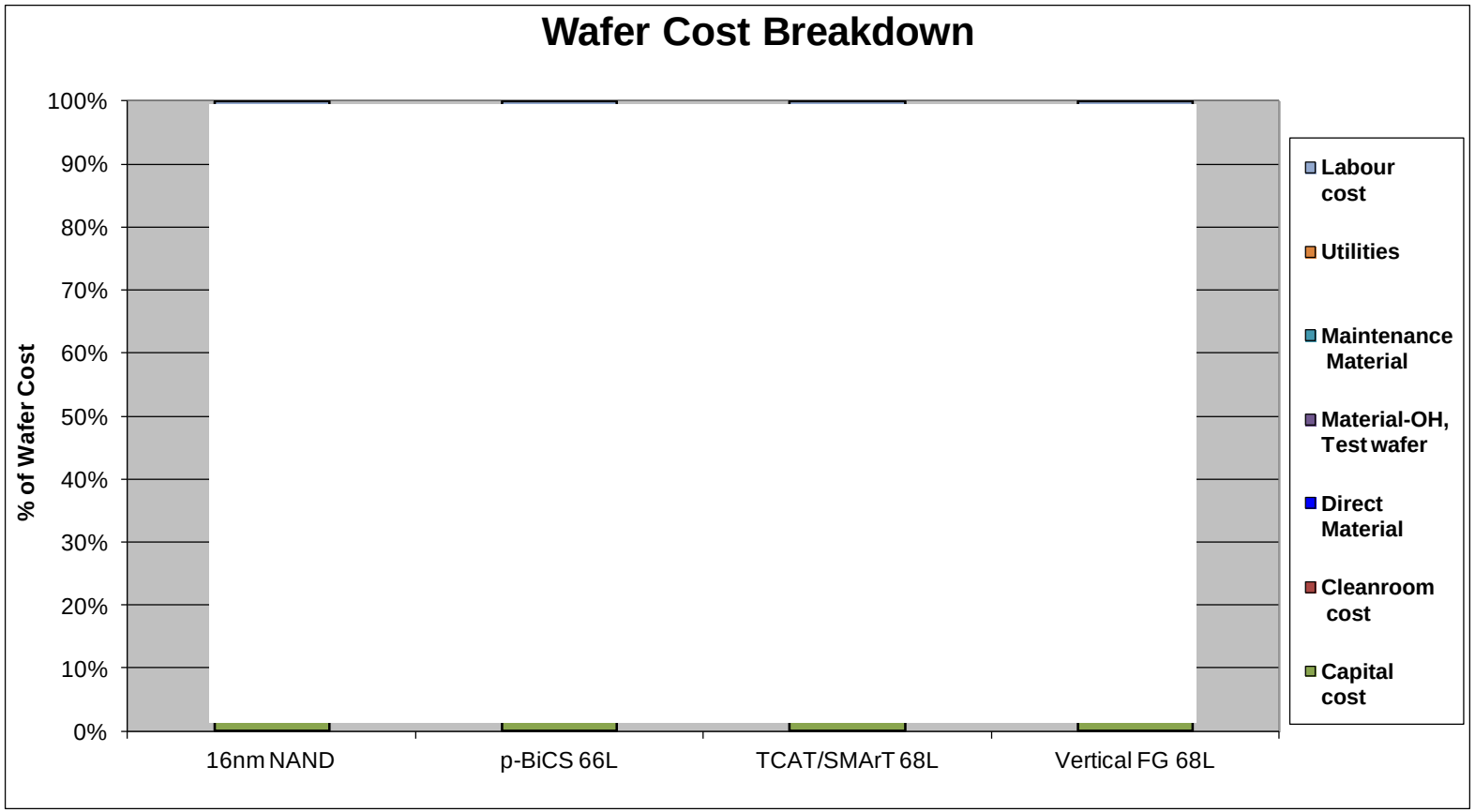
Front End Wafer Cost by Technology



- FE wafer cost for 64L 3D NAND xx-xx% xxxxxxxx than for 32L 3D NAND

FORWARD INSIGHTS

Front End Wafer Cost Breakdown



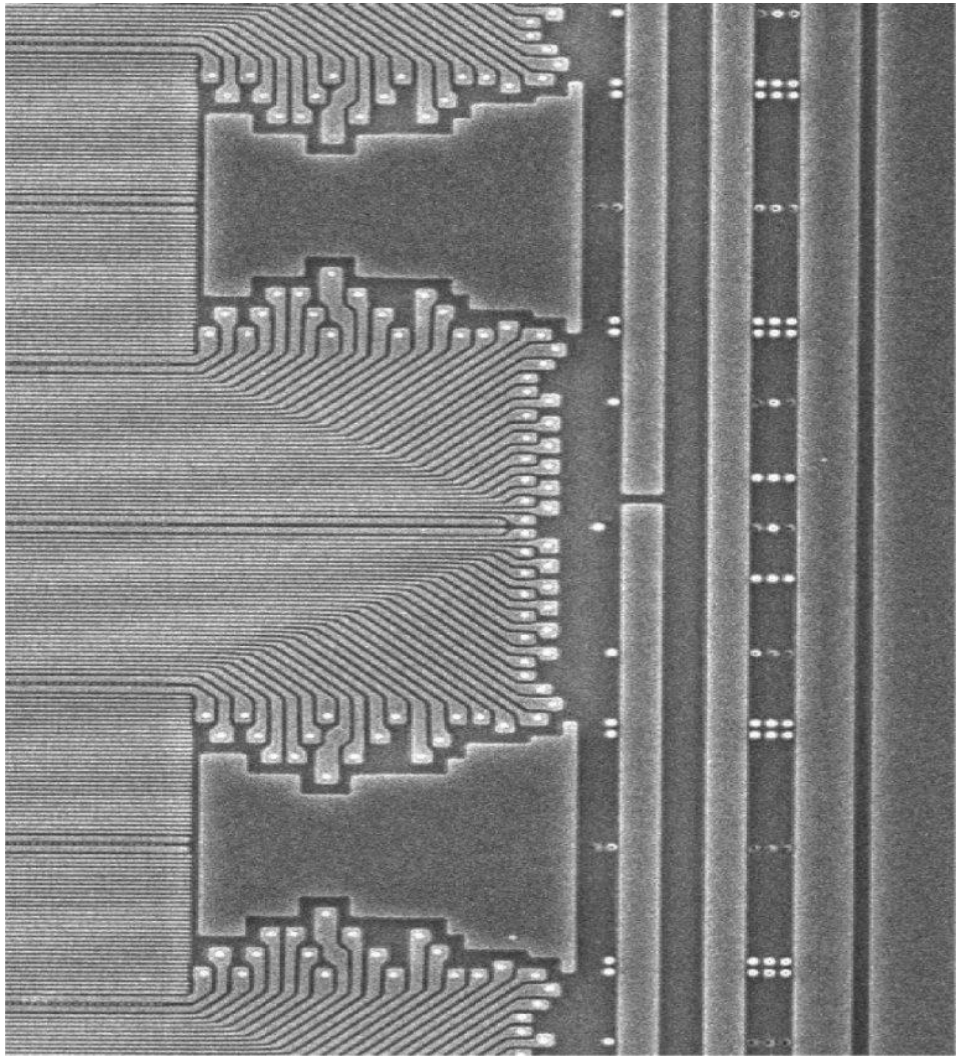
- capital cost accounts for xx-xx% of FE wafer cost

FORWARD INSIGHTS

Relative Comparison of 2D NAND and 3D NAND

	Relative Comparison of 2D NAND and 3D NAND			
	2D NAND	p-BiCS	TCAT/ SMArT	Vert. FG
Fab Investment				
Cleanroom Space				
Fab Cycle Time				
Wafer Cost				
Surplus Eqt from Tech Migration				
Wafer Capacity / sq. meter				

- 2D NAND is xxxxxxxxxxxxxxxxxxxxxxxxx, xxxxxxxxxx 3D NAND offers xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx



Market and Technical Intelligence for Semiconductor Memories, Emerging Memory Technologies and Solid State Storage

FORWARD INSIGHTS

Forward Thinking

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