



Flash Memory Technologies and Costs Through 2025 (C-9)

Mark Webb

MKW Ventures Consulting LLC

www.mkwventures.com

Mark@mkwventures.com



Flash Memory Summit



Contents

- NAND Companies and Current Status
- Next Generation Technologies/Announcements
- Model for Cost Reduction on 3D NAND Technologies
- Relative Die Costs for Current Manufacturers
- Future bit costs through 2025.
- ASP vs Bit Cost models



NAND Companies and Current Status

- The 96L generation (92-96 active layers) is the dominate technology today
 - Ideal for 512Gbit, works for 256Gbit, Capable of 1Tbit+
 - >50% of bits shipped
- 128L Generation (112-144L Active) is being introduced.
 - Less than 15% of bits in Q4 2020.
- 176L Generation (~160-192L) is being announced and developed
- 256L Generation is possible by all companies with no limit
- Note: We are doing new technologies for lower cost, not capacity



Company Updates

- Samsung: Moving to 128L, Still one string stack, no CUA (CMOS Under Array) yet. Shipping Today
- Hynix: Moving to 128L, 2 string stack, CUA (PUC).
- WDC/Kioxia: 112L, 2 String Stack, CUA expected
- Micron: Limited ramp on 128L 2 string stack, CUA on 1st gen RG (replacement gate=Charge trap) technology.
 - Micron is moving from floating gate to CTF
 - Minimal cost reduction expected over 96L in 2020-2021
- Intel: moving to 144L, Floating gate, CUA, 3 string stack?



Status YMTC

- YMTC: shipping 64L wafer bonded Xstacking technology.
- Moving to 128L, but 64L is just ramping so it is unclear when this would ramp. It won't be ramping in 2020. Maybe in 2021
- 64L product has excellent die size due to CUA provided by wafer stacking.
- This technology is very expensive and complex. It is seen as a way to allow periphery to be optimized but it is not cost competitive yet
 - Costs are 50% higher than competition IF they hit target yields
- YMTC is still less than 2% of the Industry bits shipped annually.
- If they execute to plan, they could grow to over 5% market share by 2025



Future Technologies



- All Companies have announced moves to 1yy technology in late 2021. 2xx (256L) technologies are possible.
- With Intel announcements of Hynix selloff, we would expect floating gate to end although Hynix announce continuation for 2-3 Generations
 - FYI: many companies have experimented with floating gate for alternative architectures (See IEDM papers)
- The 176L Nomenclature is being used for next generation. We expect companies to make pragmatic decision on number of layers based on yields and costs.
- With a 1-2 year cadence (18mo nominal), we expect companies to convert some but not all NAND products on each new generation.



QLC Models

- We were not originally a fan of QLC back in 2017. But it appears MLC/TLC history will repeat on QLC.
 - It will start as a little cheaper, with worse performance and endurance. Few adoptions, lots of complaints
 - Performance, caching, controllers will improve product.
 - Customers will become tolerant of issues
 - It will become dominant in bits over a 7-8 year timeframe.
- We model QLC percentage of bits around 15% in 2021, 50% after 2025.
 - Theoretically 25% cheaper, Actually 20-23% cheaper after accounting for some design and test overhead
- PLC is possible and we could expect the same timeline



MKW Ventures Model For NAND Cost Reductions

- Each generation we add 30-50% more layers.
- The goal is to improve manufacturing so that the output per tool is the same. Fabs and Tool vendors partner on this. No cost adder is goal
- In reality, we have typically added 10-15% to wafer cost for each new generation depending on inputs from tool vendors.
- String stacking adds to wafer cost. CUA adds to wafer cost
- On mature technologies, we assume ~5-10% wafer cost improvement/year
- Based on inputs from tool and NAND companies, we significantly increased wafer cost improvement rate on 3D NAND technologies
 - 3D NAND is becoming more efficient at a faster rate than previously estimated

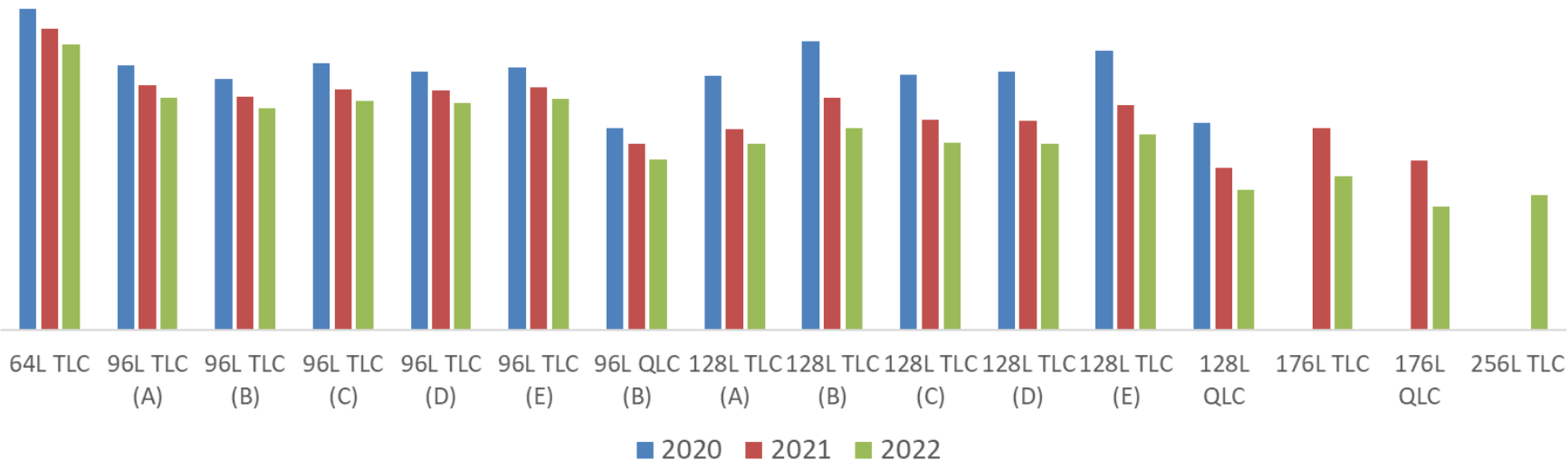


NAND Die Costs



Die Cost (A/T not included) for TLC/QLC NAND Technologies
A-E are NAND Suppliers

2021
YMTC
64L



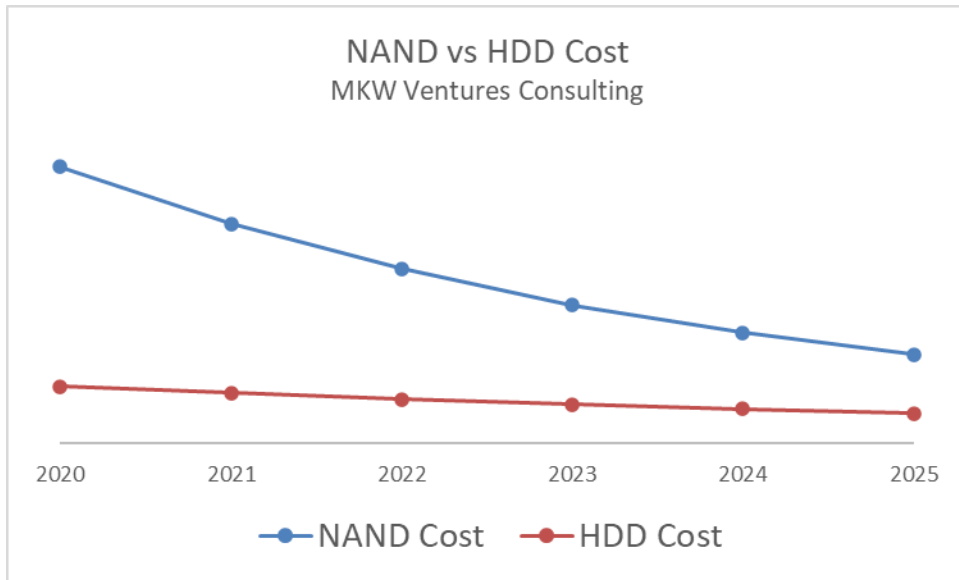


Key Takeaways from Cost Slide

- Costs are being reduced every year and with every new technology
- We have exact numbers, company names, and reasons for numbers available in follow up discussions
- Each company has a slightly different cost reduction path
- The Cost leader at 96L is not the cost leader at 128L (They are modeled as highest cost for 128L)
- We have line of sight to at least 256L



Overall Average Cost Trends



- NAND Average Costs Below 2c/GB after 2025
- Cost reduction for NAND is 20% per year on average
 - New technology+ Cost learning +QLC percentage
- NAND and HDD costs crossover sometime after 2033
- UPDATE: If we had 100% Penta-Level Cell, crossover is 2031
- Nearline HDDs will be around for a long time
- Numbers and Log plot available



NAND Market and ASPs



- The NAND pricing market recovered some in early 2020 but has since struggled
- NAND Operating margins are minimal
- Bit growth is unclear but probably around 30% CAGR
- Bit costs will drop 20% per year on average
- All of these numbers add up to a challenging financial model if prices drop >20% per year (20-25% is model)
 - Result would be a slow down in new technologies and capex



Summary

- No end in sight for NAND technology progression and cost reduction
 - There are no major limiters
- QLC improves costs and will grow to 50% of bits after 2025
- NAND Costs will reach 2c/GB after 2025.
- Cost leaders change over the next 5 years
- Costs are modeled to cross HDD cost after 2033



01000001 01110010 01110100 01101001 01100110 01101001 01100011 01101001 01100001 01101100 00100000 01001001 01101110 01110100 01100101 01101100 01101100 01101001 01100111 01100101 01101110 01100011

01100101 00100000 01100011 01101111 01101101 01100101 01110011 00100000 01101000 01101111 00100000 01110001 01110101 01100001 01101110 01110100 01110101 01101101 00100000 01100011 01101111 01101101 01110000 01110101 01110100



- All of the numbers, back up charts, company names and reasons for numbers are available. Call us to discuss
- Mark Webb
- www.mkwventures.com

Mark@mkwventures.com