NAND/Unit Cost Model

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NAND Cost Model Overview

- Model is used to predict NAND Die and Gbyte costs based on available inputs and modeled learning curves
- Die Size, Capacity are known or modeled based on reports
- Wafer cost including depreciation, Consumables, Gas and Chems, labor, overhead are models and checked with sources
- Wafer line yield, Wafer die yield, package test yields are included
- Packaging costs are modeled for average package
- Learning curves for wafer cost, die yield, packaged test yields are included
- Each company and usually multiple chips per company are modeled

Unique Expertise From Our Team

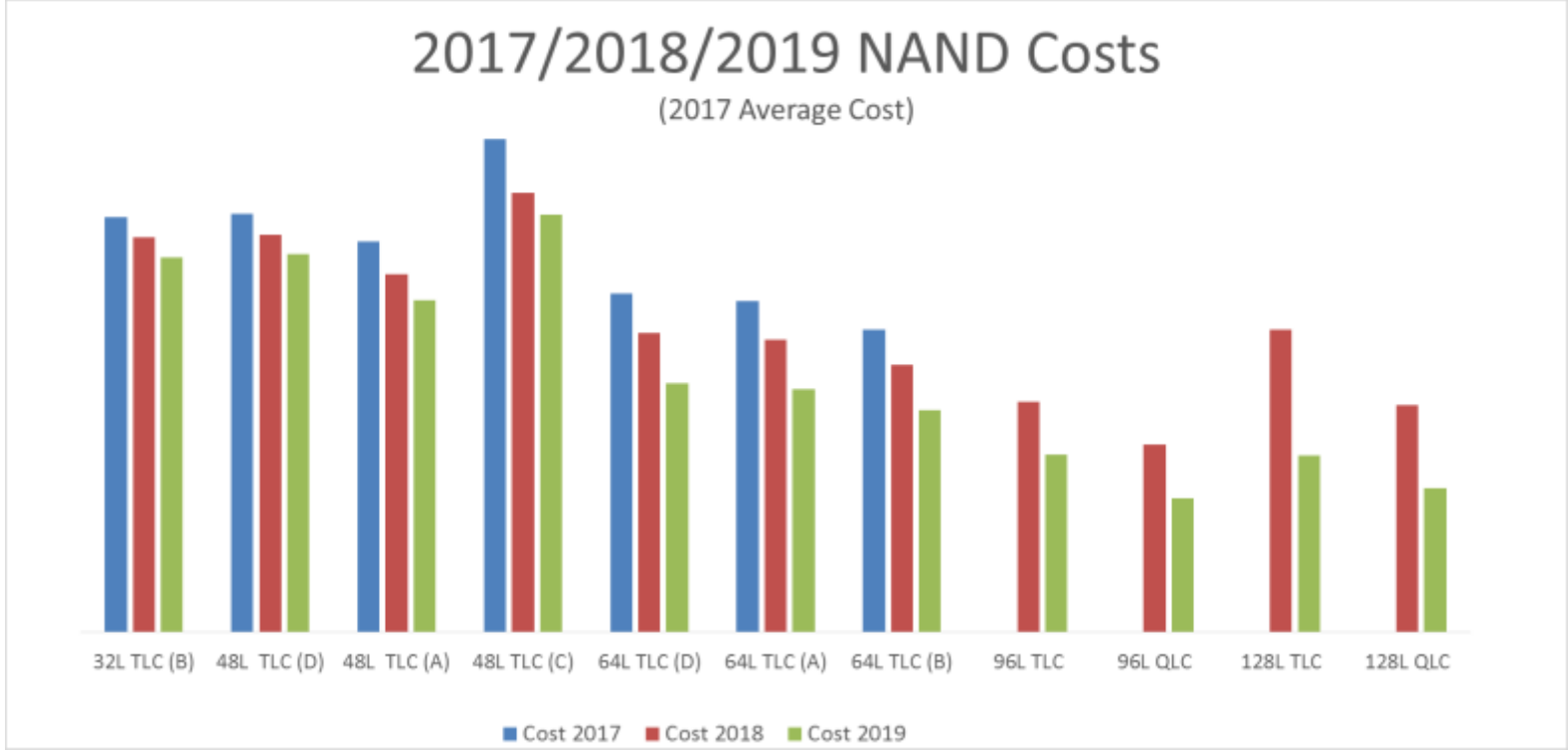
- Yield learning curves over time based on 20 years of experience
- Wafer cost today based on knowledge of cost components and reported technology
- Die Size is based on public data plus data from exclusive teardowns
- Wafer Cost reduction plans and expectations based on experience
- Company to company difference based on culture and history
- Cash vs non-cash costs, Fixed vs variable costs based on experience
- Feedback from experts in industry on accuracy and changes
- Ability to back calculate reported earnings and data to calibrate model

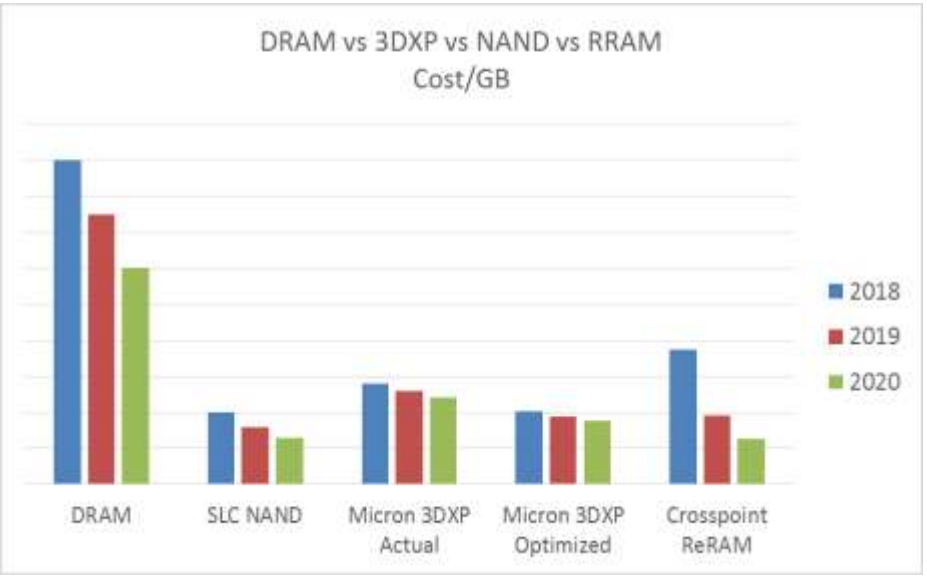
Typical output

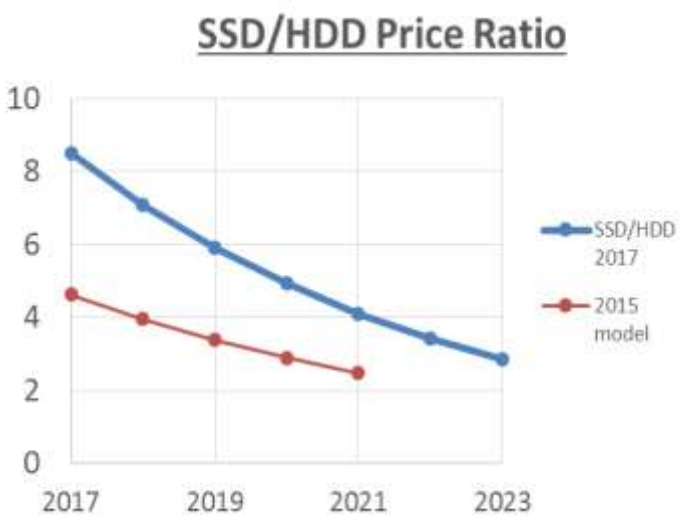
- Typical Output is bar graph comparing different chip Gbyte costs across multiple companies and generations
- Addition outputs are:
  - Average cost each year for NAND overall (industry cost)
  - Average cost for each generation across all companies (ex: 64L, 256Gbyte)
  - Costs for a given chip each year (shows learning rate)
  - Breakdown of cost components and changes over time (wafer cost vs Yield)
  - Fixed, variable, semi-variable costs and cash costs to predict decisions

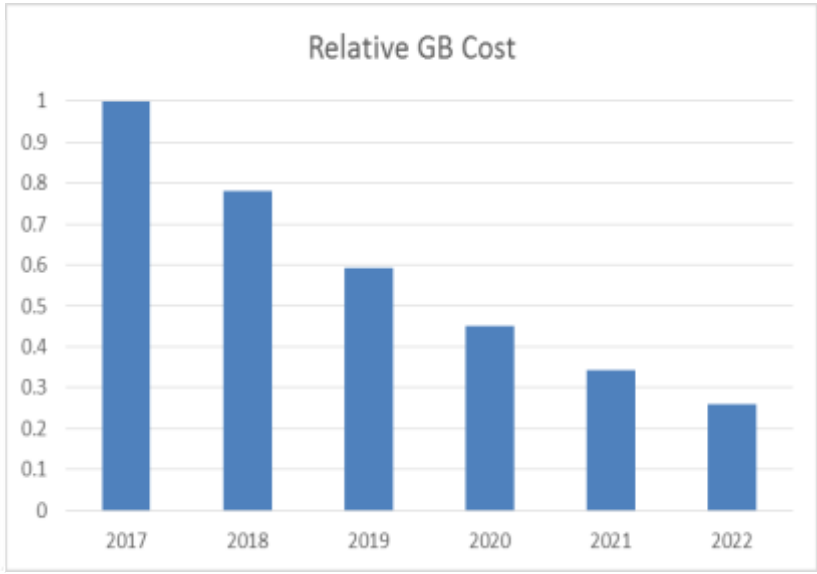
Output

Quantitative data available as well
NAND is most comprehensive Model
DRAM, ReRAM, MRAM all have models
Model is updated monthly





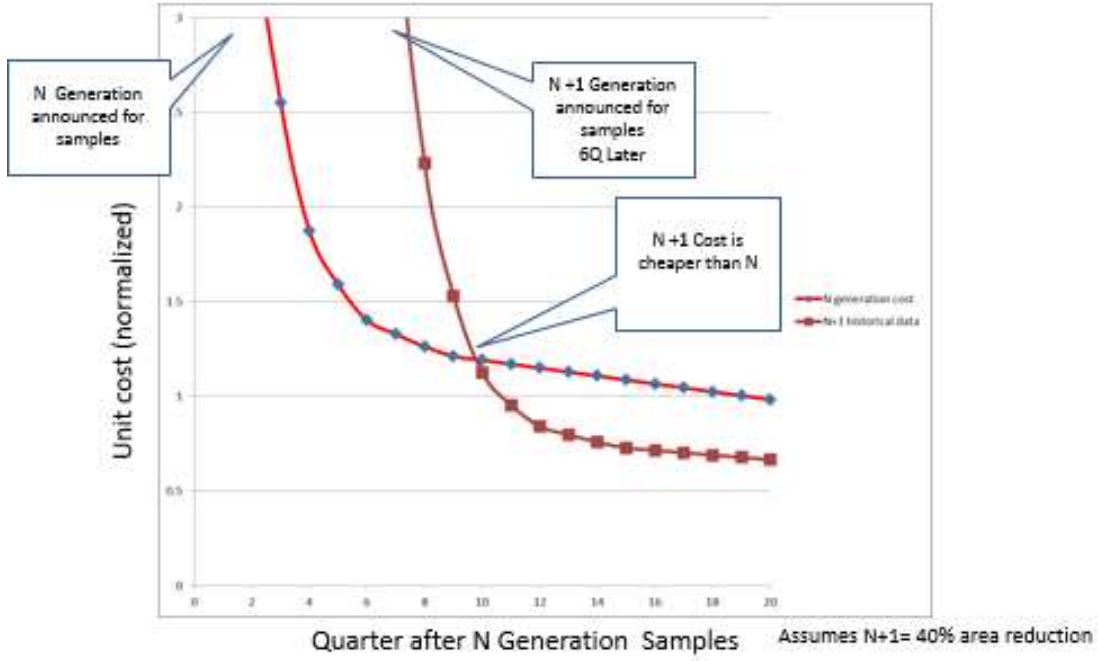




Backup

Evolution of Unit Cost over time

- Unit Costs for any given product and design improve drastically from initial silicon to Maturity
  - Wafer cost drops by ~50% (output per tool, development of lower cost processing)
  - Typical Yields go from 20% to 50% to 75+%
  - Volume lowers impact of overhead Costs
- Micron 64L Costs
  - 2016: Samples only, <4000 wafer per month, initial yields at 20%
  - 2017: Qualified in May, ~65% Yield, wafer cost near HVM by end of year 2017
  - 2018/19: continuous improvement in wafer cost and yields 75+%



Model Continuous Improvement and Comparison to Other Models

- Model is based on output parameters that factories use
  - Wafer cost:
    - Depreciation, output per tool, utilization, availability, outper/sqft, wafer yield
    - Gas and chemical usage, labor, spares, silicon cost, reticles, etc
  - Probe yield, assembly yield, Final test yield. Good die per wafer
  - Improvements in all of these are checked with sources and final number correlated to reported financials
    - Example: Unreported shrink for Samsung, high yields for Toshiba 15nm, Micron reported cost reduction.
- Other Models [Challenges]:
  - Bottoms up: List tool cost and advertised outs per wafer for each step [errors propagate, no one knows output per tool for 250 steps]
  - Base on impact of fully depreciated equipment in some fabs and greenfield in other [gives one time, one shot model based on accounting technicalities]

Typical Use of Model

- Model is updated monthly.
  - Minor tweaks (ramp/yield)
  - major changes with reported or unreported (xray/TEMS) on die size and processing specifics
  - Addition of new chips and process generations
  - Improvements Interviews with execs in 1:1s or at Analyst meetings
- Comparison of unit cost for all competitors
- Average cost for industry by year
- GB per wafer, GB per factory, GB for industry
- Performance impacts and applications are evaluated (ex: TLC vs MLC)

Current Publication Model with Clients

- Reports without commentary and continuous update is not as powerful in industry today (very dynamic)
- Each Month
  - Report with updated costs for each technology, added technology
  - Actual numbers vs relative or normalized output
  - 2-3 foils with summary of changes in model, sources of change, and impact
  - Customized numbers based on client needs (ex: MU vs SS improvement over time, 2020 GB per wafer, impact of new factory, Margin analysis)
  - 3 hours per month for follow up and customization work