# SSD Calculator Sources

**This document outlines the publicly-accessible data used to create the SSD calculator. This provides the sources used and screenshots that capture the information gathered, should the URL no longer be valid.**

**Please note that there is nothing vendor specific about the SSD calculator and because of this, you can use it for estimating the SSD cost for any vendor's SSD.**

## NAND Costs

One of the largest costs of an SSD is typically the NAND so this is the most important price/cost to get right. You can look at sources such as DRAMExchange to see the current spot pricing of NAND Flash or you can use cost analyses done by research firms.

**NAND Costs -- Using DRAM Exchange (https://www.dramexchange.com/):**
If the SSD you are trying to calculate the costs on uses 3D TLC, on DRAMExchange you can grab that pricing which I see as "3D TLC 256Gb" for $3.00 when I looked. Based on this, 256Gb converted to GB is 256Gb divided by 8 (Gb to GB conversion) = 32GB. So the per GB pricing here is $3.00 divided by 32GB = $0.09375/GB. Keep in mind that this is the *PRICE* to buy NAND Flash components and not the *COST* to make NAND Flash components.

**NAND Costs -- Using Cost Analyses by Research Firms**
In doing some Google searches, I came across a great analysis done on NAND costs for specific NAND generations. The great thing about this is that it lets you map NAND costs to the specific SSD you want to analyze. After all, if your largest cost is NAND you want to nail your $/GB on this one down to the generation of NAND you have. This is because costs can vary quite a bit between generations. If you look at analyst reports from Gartner, Forward Insights, IDC, etc you will see that NAND costs/prices drop between 15-35% per year. This research done helps us nail a particular generation of NAND and then we can just adjust for generational cost differences.

http://docplayer.net/47966703-Memory-technology-and-overall-trends-in-the-semiconductor-industry-dr-handel-h-jones.html

Check out the costs on Slide 6 of this presentation. They show us the costs for 3D NAND at 32L (32-layer), 48L, and 64L. This is great. Not only that, they show us the cost with and without depreciation. Depreciation refers to all the costs that NAND factories put into building the Fab lines to make NAND. As this is expensive, the NAND makers usually depreciate these assets over time and blend it into the costs. However, their “cash costs” are their actual costs to make the NAND. So, when NAND makers are struggling to sell NAND, they will be more likely okay accepting deals closer to “cash costs” (costs without depreciation). When they are selling their Flash easily, they will be unlikely to even approach their costs WITH depreciation. Since the NAND Flash industry is very cyclical, it is important to pay attention to which kind of market it is currently in so that you can determine which cost would be more appropriate to use at any given time. The best way is to search Google for “undersupply nand flash” or “oversupply nand flash” to see if you can find recent research reports done by the big analyst firms. They regularly cover this so it should be easy to find.

**Slide 6 of Handel H Jones presentation:**

NAND Flash Cost Summary

| Cost per GB ($) | MLC | TLC |
|---|---|---|
| **2D**<br>With depreciation | 0.318 | 0.230 |
| Without depreciation | 0.197 | 0.137 |
| **3D**<br>32 layers with depreciation | 0.281 | 0.190 |
| 32 layers without depreciation | 0.219 | 0.148 |
| 48 layers with depreciation | 0.173 | 0.116 |
| 48 layers without depreciation | 0.137 | 0.091 |
| 64 layers with depreciation | 0.157 | 0.105 |
| 64 layers without depreciation | 0.131 | 0.076 |

*Source: International Business Strategies, Inc.*

**Cost crossover between 3D NAND and 2D NAND**

SEMICON TAIWAN

semi

For the purpose of the SSD calculator built, I simply used a modest 15% reduction for newer generations. This means that my cost estimates are very conservative and the costs are likely to be lower when generational cost improvements were beyond 15%. This cost calculator is really an academic / educational tool so I didn’t refine it to be pinpoint accurate on costs. However, it should be directionally correct. You can always type in your own costs into the calculator if you have a better idea of what the costs are for the SSD you want to analyze.

Also note that there are two columns in the Handel presentation that indicate MLC (2 bits per cell) and TLC (3 bits per cell). This helps indicate the costs between the type of Flash for a particular generation. Calculations of SLC and TLC used the industry well known number of bits that are present to calculate them.  For example, MLC has 2 bits and SLC has 1 bit.  So, we can simply take the MLC price and multiply it by 2.

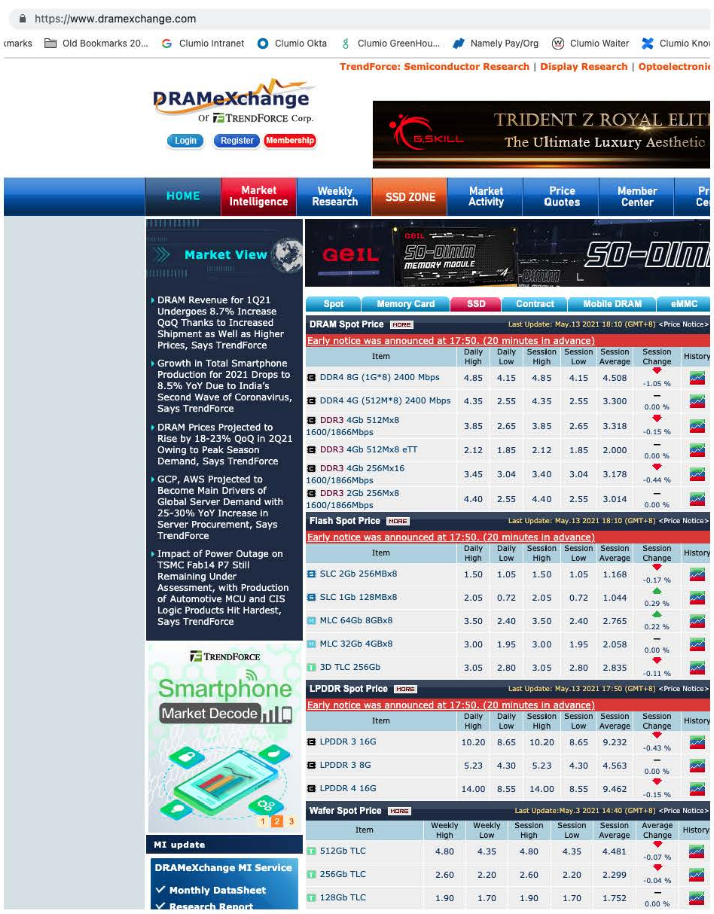
# DRAM Costs

DRAM costs you can grab straight from DRAMExchange or use whatever knowledge you have on DRAM costs.

DRAMExchange offers a view into spot pricing for customers to buy DRAM at this price. Although this is not “cost”, it does give you an indication of the cost to source DRAM components to build your own SSD.  If you want to extract assumed margin from the DRAM pricing you can have an estimated cost if you are really trying to hone in on manufacturing costs.

[https://www.dramexchange.com/](https://www.dramexchange.com/)

Seeing “LPDDR 3 8G” at around $5 is what we will use for the SSD calculator default values. The 8G in this case is referring to 8Gb (not GB) so we divide it by 8 to convert to GB which gives us $5 per GB.



## SSD Controller Costs

There is a single controller per SSD and this dictates the type of SSD you have. If your SSD controller is a PCIe drive, it is determined by the controller. If your SSD can do insane write speeds, it's because your SSD Controller has more NAND channels to write to more NAND chips at a time. And these differences drive cost differences. However, since this cost is fixed and doesn't change with larger capacity SSDs, this cost is pretty minimal since capacities of SSDs these days are quite large.

For these costs, you want to turn to the costs to buy a third party SSD controller from vendors like SMI, Marvell, Phison, etc. You can always get a quote from these vendors to get estimated costs. However, talking to an SSD analyst will easily provide you ballpark figures on this. I have had numerous conversations with SSD analysts. One such conversation, in 2018, was with an SSD analyst related to a blog post on NAND Flash crashing, resulted in the following ballpark figures for sourcing different kinds of controllers:

PC-based SATA Controllers: $5
PC-based PCIe Controllers: $6-7
Enterprise-based Controllers (any interface): $10-20 ($20-40 if you have less volume)

This mirrors many conversations I have had around this same topic and is a general cost to you to buy these third party controllers. If you are looking at an SSD with an FPGA as a controller, your costs can shoot up over $100-150.

## SSD Over-Provisioning Costs

Over-provisioning is the NAND reserved for offering higher WPD (Write Per Day) [aka higher endurance SSDs], or used for providing faster writes (due to treating some of the Flash as SLC). Even though you can't use the NAND Flash for storing your files on, you still have to consider these costs. You can find example over-provisioning levels for different capacity points. You can generally tell that over-provisioning is being done simply by looking at the capacity of the drive. Since memory/Flash is base-2 based, it means that natural capacity points would be 128, 256, 512GB, 1024GB, 2048GB, etc. However, if you see an SSD with 100GB, 120GB, then this would imply that over-provisioning is likely being used. You can see the below documented sources that highlight such popular over-provisioning levels used by all SSD vendors.

## Over-provisioning at different capacity points

https://www.seagate.com/tech-insights/ssd-over-provisioning-benefits-master-ti/

https://www.seagate.com/tech-insights/ssd-over-provisioning-benefits-master-ti/

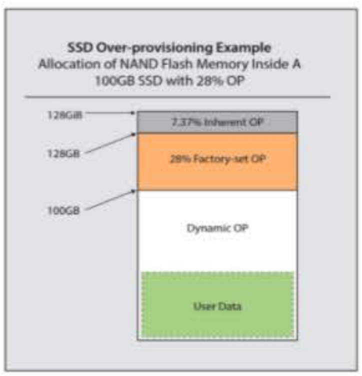
narks Old Bookmarks 20... Clumio Intranet Clumio Okta Clumio GreenHou... Namely Pay/Org

SEAGATE

| | | |
|---|---|---|
| # of Bytes | 1,000,000,000 | 1,073,741,824 |

So even if an SSD appears to be full, it will still have 7.37% of available space with which tc
performance will suffer at this level. (Think in terms of the 15 squares puzzle with just one f

In practice, an SSD's performance begins to decline after it reaches about 50% full. This is
user and set it aside as additional over-provisioning. For example, a manufacturer might re:
SSD with 28% over-provisioning. In actuality, this 28% is in addition to the built-in 7.37%, s
should also consider that an SSD in service is rarely completely full. SSDs take advantage
provisioning.



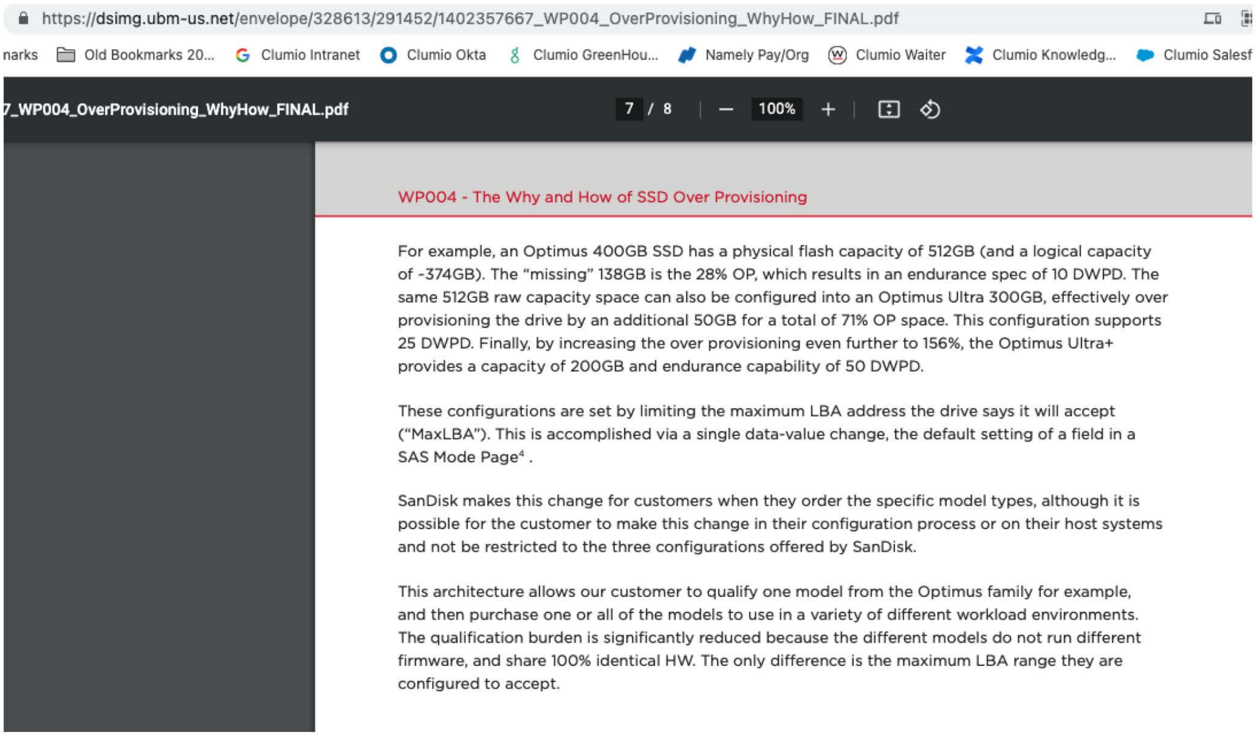

**Over-provisioning Percentages**

| **Marketed OP*** | **0%** | **7%** | **16%** | **28%** |
|---|---|---|---|---|
| True Physical OP* | 7% | 15% | 25% | 37% |
| **SSD Physical Cap** | **Resulting SSD User Capacity** | | | |
| 64 | 64 | 60 | 55 | 50 |
| 128 | 128 | 120 | 110 | 100 |
| 256 | 256 | 240 | 220 | 200 |

*Rounded results

## Extremely high over-provisioning for high WPD SSDs

https://dsimg.ubm-us.net/envelope/328613/291452/1402357667_WP004_OverProvisioning_WhyHow_FINAL.pdf



WP004 - The Why and How of SSD Over Provisioning

For example, an Optimus 400GB SSD has a physical flash capacity of 512GB (and a logical capacity of ~374GB). The "missing" 138GB is the 28% OP, which results in an endurance spec of 10 DWPD. The same 512GB raw capacity space can also be configured into an Optimus Ultra 300GB, effectively over provisioning the drive by an additional 50GB for a total of 71% OP space. This configuration supports 25 DWPD. Finally, by increasing the over provisioning even further to 156%, the Optimus Ultra+ provides a capacity of 200GB and endurance capability of 50 DWPD.

These configurations are set by limiting the maximum LBA address the drive says it will accept ("MaxLBA"). This is accomplished via a single data-value change, the default setting of a field in a SAS Mode Page[4] .

SanDisk makes this change for customers when they order the specific model types, although it is possible for the customer to make this change in their configuration process or on their host systems and not be restricted to the three configurations offered by SanDisk.

This architecture allows our customer to qualify one model from the Optimus family for example, and then purchase one or all of the models to use in a variety of different workload environments. The qualification burden is significantly reduced because the different models do not run different firmware, and share 100% identical HW. The only difference is the maximum LBA range they are configured to accept.

# Overview of BOM Costs for SSDs

This is a nice high level overview of BOM costs that go into SSDs. This is a well covered topic and is not specific to any SSD vendor. You basically have NAND, DRAM, Controller, and other fixed costs (such as the PCB, capacitors, casing, etc). For the purpose of the SSD calculator, I used some general ballparks given by analysts that take a swag at what these low cost "other" components cost.

https://www.flashmemorysummit.com/English/Collaterals/Proceedings/2015/20150811_FC12_Huang.pdf