Executive Summary

The NAND Flash demand has been growing almost exponentially, much of which is attributed to the growth of the avg. capacity in smartphones. In contrast, industry has been facing supply crunch as the 2D NAND output is no longer sufficient to cater to current and future rise in demand for smartphones as well as SSD demand in personal compute devices. To meet the growing demand and increase NAND bit outputs, the storage memory suppliers are transitioning from 2D NAND to 3D NAND technology & manufacturing, a necessary technology transition. However, slower than expected ramp from various players has hurt supply positions in the short - midterm. As a result, over the last eighteen months the NAND memory prices have risen in a range of 15% to 40% depending on the memory type and density. While the move to 64L 3D NAND (from 2D NAND or 32L/48L MLC 3D NAND) will ease supply a bit, the transition to and adoption of higher density TLC 3D NAND will be the key to ensure healthy supply & business continuity in the future.

The following whitepaper analyzes and highlights the demand drivers for NAND Flash memory followed by the status of the supplier landscape in transitioning to 3D NAND technology, the benefits of 3D NAND (especially the move to TLC) and recommendations to suppliers to sufficiently meet the exploding demand.
Industry Trends:

Rising NAND Flash Capacity in Smartphones

Smartphones have become the linchpin of our digital lives. According to our latest consumer study, almost half of the smartphone users spend more than five hours on their smartphones daily. Smartphones have thus become the gateway for connecting, communicating, commerce as well as the vehicle for creating and consuming content. Over 1.6 billion smartphones sold this year, will enhance the digital lives of potentially six billion mobile phone users on this planet.

There has been a dramatic rise in the capture of high-resolution images and high-definition 4K videos using multiple advanced cameras on the smartphones. RAW, burst multi-shots, panorama shots, slow-motion videos consume greater amount of on-board storage. These trends have accelerated the need for higher embedded Flash storage capacity in smartphones.

Furthermore, advanced OS capabilities, suite of productivity, commerce and social applications have eaten into the share of the available on-board storage for smartphone users. According to our research, on an average, a user has more than 90 apps installed on their phone occupying between 2GB & 8GB of space on their smartphones.

Additionally, OEMs such as Apple and others have been successful in upselling higher storage capacity. This has both been a value-added feature targeting power users while boosting OEM bottom lines.

Other Demand Drivers for Storage

- With advancement in networks moving to high throughput & low latency pre-5G and 5G era, we estimate the acceleration of “massive IoT” deployments globally. The Internet of Things (IoT) is witnessing multitudes of device categories becoming connected and smarter, from wearables, automobiles, drones to different connected elements making up smart homes or smart cities.
- 5G network will also enable newer high-resolution immersive and interactive content experiences in form of Augmented Reality (AR) or Virtual Reality (VR) or Mixed Reality (MR) touching different applications from live sports streaming, multi-player gaming, remote surgeries, enterprise communications and training, live designing and more. Most of these AR/VR devices will be standalone in next three to five years and will require not only higher capacity embedded flash storage but also demand higher performance.
- IoT gateway is another potential segment which will drive greater need for higher endurance, performance and capacity flash solutions to manage thousands of connected IoT devices.
- Furthermore, need for intelligence at the edge will drive storage needs across these IoT gateways and number of connected devices with apps and analytics on board.
- At home, the potential merger of home gateway with the Set Top Box making it a “Smart Home Control Hub” will also demand higher storage capacities, with use cases ranging from offline recorded DVR videos to applications for controlling different smart devices in the home to hours of HD surveillance camera footage.
- **Drones** are another potential category demanding higher capacity storage but with smaller footprint on board to store high definition videos and images. Surveying, Surveillance to hobbyists’ user generated content are some key use-cases demanding higher content.

- **As vehicles** get more autonomous features and become smarter, the amount of applications, HD maps, content, data from sensors which will all be stored inside the vehicles in addition to edge analytics capabilities, all demand high capacity storage. This will increase as we move up to higher levels of autonomy such as self-driving in the vehicles in coming years.

- **With tremendous growth in cloud computing** across enterprises as well as application/software developers banking on cloud storage repository players, the **Solid-State Drives (SSDs)** have consume a significant chunk of the NAND Flash production output. Most of the software, applications, IoT development, core network functions, content networks are getting virtualized accelerating the role of higher density flash storage. The higher density flash storage solutions are faster, offers greater reliability, endurance, performance benefits with a relatively smaller footprint.

  In smartphones, average embedded NAND Flash capacities have been rising fast. The average capacity in smartphones is estimated to crack 50GB per smartphone this year. In 2017, smartphones alone will consume 68 Exabytes of embedded NAND Flash demand, up 45% year-on-year. This demand from smartphones is further estimated to cross 91 Exabytes in 2018, up 34% year-on-year, slightly over 60GB per smartphone in Q4 2018.

  **Exhibit 1 : Global Average Smartphone NAND Flash Capacity Trend** (GB)

  *Top 25 OEMs unit sales ~85% of the total smartphone market unit volumes*
Suppliers Transition to Advanced NAND Technologies

In response to the NAND Flash shortage which started in 2H 2016, we are seeing significant efforts from the memory suppliers to offer advanced NAND flash memory solutions that can address these constraints without any compromise on performance, endurance or user experience.

Move to TLC NAND

With advances in NAND flash technology for smartphones, the industry has moved from SLC (single bit per cell) to 2-bit MLC (two bits per cell) to higher density TLC or 3-bit MLC (three bits per cell or triple-level-cell) to ease supply constraints by increasing the number of units and GB per wafer. Some of the leading vendors such as Apple & SanDisk (now WDC) have optimized the “managed NAND” for TLC flash with innovative proprietary architectures and intelligent controller & firmware. For example: SanDisk SmartSLC uses a hybrid architecture of SLC+TLC memory storage with an advanced controller to intelligently manage and satisfy the increasing need of burst memory read/write requirements in smartphones.

During the past two years, we have seen a steady adoption of TLC memory in smartphones across different price bands - from tier-1 brands to tier-3 brands that are looking to optimize BOM costs while delivering uncompromising performance. **TLC memory is now present in almost one out of every three smartphones sold globally.** The advancements in the NAND controller technology helped boost the performance of these higher density TLC NAND solutions and remain popular.

Transition to 3D NAND ESPECIALLY TLC 3D NAND will be the Key

However, this transition to TLC in the planar or 2D NAND technology is not enough and 2D NAND is reaching its limits in terms of scaling down to more advanced process technologies. Typically, shrinking to more advanced process technology, such as from 32nm to 20nm, comes with relatively greater cost benefits. However, it is becoming increasingly difficult and uneconomic to scale the technology below 15 nm.

As a result, **3D NAND** has emerged as the most promising technology to keep flash memory advances going. Unlike regular 2D NAND, where memory cells are arranged in a two-dimensional array on a silicon substrate, 3D NAND involves stacking the cells vertically thus enabling significant density increases. 3D NAND promises to offer even **better performance and endurance due to lower cell-to-cell interference.** 3D NAND architecture offers the least cell interference boosting reliability and narrower cell distribution improves the sequential write speed, boosting overall performance. 3D NAND boosts the bit growth at least by 30% compared to 2D planar NAND by stacking layers vertically instead of using photolithography eliminating flash patterning. Thus, with greater reliability and performance, **3D NAND also brings higher capacities, scalability with the increase of capacity per die.**

Compared to 2D NAND, 3D NAND promises many generations of continuing improvements in flash memory performance and decreases in costs and it is likely that 3D NAND will replace 2D NAND in smartphones, tablets and other consumer devices during the next two years. As we see the proliferation of planar TLC across the lower price-tiers, the transition to **3D NAND have already commenced** in higher capacity flagship models in 2017.
The transition to TLC 3D NAND will be important to boost the NAND factory output. The storage capacity is more than twice for TLC 3D NAND compared to Planar MLC NAND. For example: the mono die density for TLC 3D NAND is at 256Gb vs MLC 2D NAND at 128Gb. This makes it ideal for not only enterprise grade SSDs but also for mid- to premium-tier smart devices and other IoT applications. We estimate TLC will account to almost three-fourths of all industry output by end of this year 2017 and will rise to almost 90% level by end of 2019.

Supplier 3D NAND Roadmaps

Most memory vendors are already mass producing their second-generation 3D memory solutions. Most of suppliers are transitioning to 64 Layer/72 Layer 3D NAND solution from either 48 Layer 3D NAND or 14nm/15nm 2D NAND. The low yet evolving maturity of 3D NAND from some suppliers (which results in low yield/cost crossover) has also been one of the reasons affecting supply in the second half of 2017 until the 64L 3D NAND enters mass production. The 48L 3D NAND has been used moderately in mobile NAND products due to its cost / scale limitations.

Most of these suppliers expect the 3D NAND output to ramp and some of them expect to cross the 50% mark of their respective total flash memory output by end of 2017 especially Samsung (64L) or Intel/Micron (64L). For suppliers such as Western Digital (64L) & SK Hynix (72L) the 64L 3D NAND is estimated to account to more than half of the total respective output by mid-2018. This should somewhat ease the supply to cater to the unprecedented industry-wide demand for NAND flash memory. The move to TLC version of the 3D NAND Flash will be the key here though.

The overall 3D NAND Flash bit output is estimated to be half of the total industry NAND Flash bit output by end of 2017 and almost 70% by end of next year 2018, thus becoming mainstream.
Conclusion & Recommendations

It is crucial for the smartphone OEMs to adopt and transition to 3D TLC NAND in the near future. The transition to advanced 3D NAND is already happening, however, transition to higher density TLC 3D NAND will be critical to maximize the factory output and ease supply constraints. The need for successful migration to TLC 3D NAND from MLC 3D NAND is going to be important for all suppliers to drive up the overall industry bit output and drive down the costs. The potential bit output could go up by at least 25% if all the suppliers move to TLC 3D NAND.

However, for this to happen the suppliers also need to develop optimal NAND Flash solutions, a combination of controllers and FW, that can meet the quality and emerging use cases of flagship and high-end smartphones, a challenge for some 3D NAND suppliers. Banking on 3D MLC NAND solutions is no longer a valid strategy going into 2018, and in order to scale. In that sense, industry players such as Western Digital, Apple will greatly benefit having shipped products using optimal 3D TLC NAND controllers in the market.