Q4'19 WW Memory and Storage Update

Five Years Out

What's Changed in the Past Quarter

- Q3'19 quarterly market performance
  - DRAM: 3% QoQ resales increase – driven by continued oversupply and picking up due to mobile demand
  - NAND: 9% QoQ resales increase – still oversupply but demand is picking up slightly with hope of recovery in 2020
- ASPs for both DRAM and NAND cont'd to drop in Q3'19 due to oversupply
  - DRAM: 16% QoQ ASP decline, ASP forecast is that there may be slight increase in Q4 with recovery in mid 2020
  - NAND: 4% QoQ ASP decline, ASP forecast is that decline is to recover in Q4
- Forecast for 2020
  - More CPU products will drive memory growth
  - 5G-enabled smartphones should help lift the global memory market
  - Memory and Storage 2019 forecast estimates include
    - WW: Memory decline of 39%
    - Americas: Memory decline of 53%
- External uncertainties could cause sudden change in demand
  - US/China trade war ongoing, arguably further away from ever from an agreement
  - Japan/South Korea trade war, critical in production of semiconductors
  - Huawei ban along with other Chinese AI companies by US

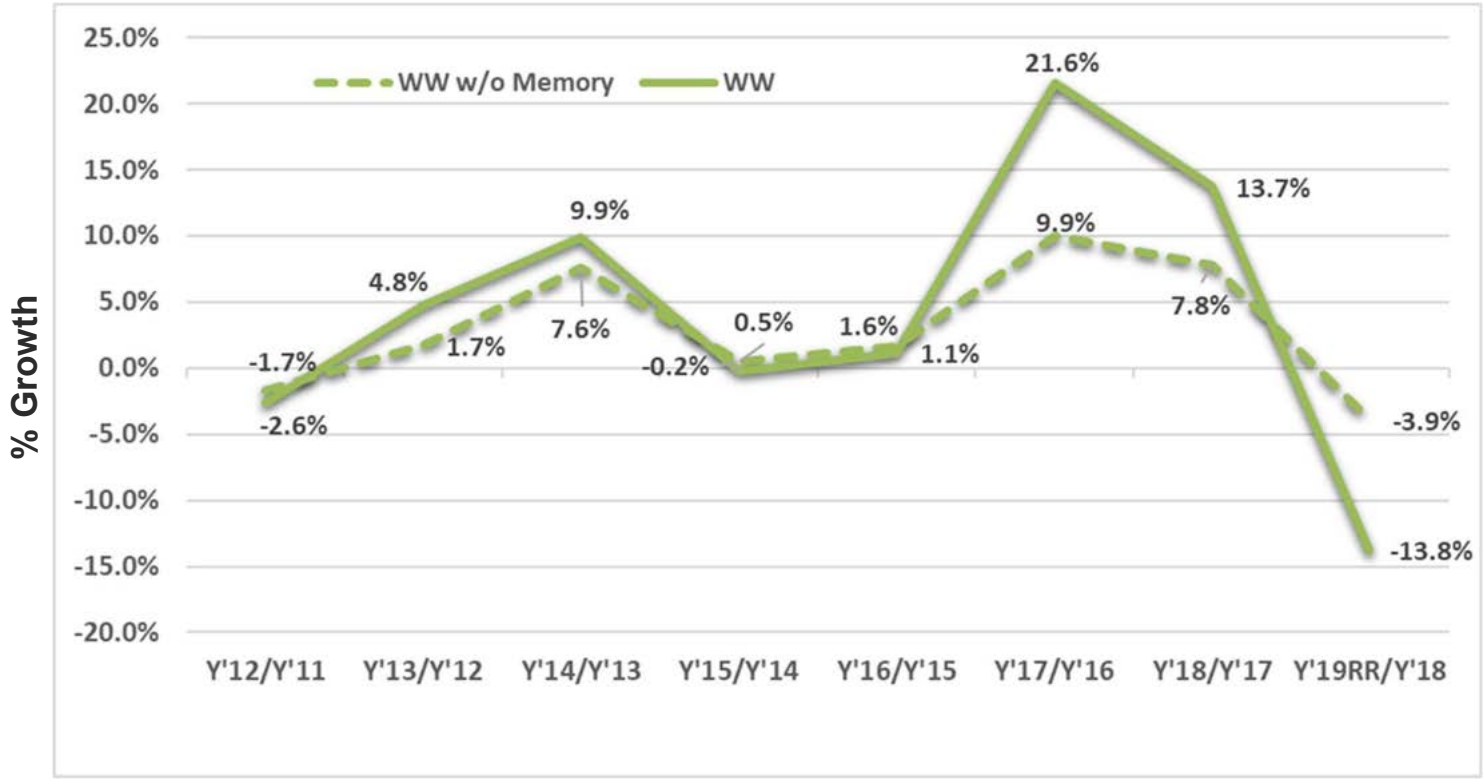
Key Takeaways

External uncertainties still causing oversupply, some early signs of recovery

- Memory market supply
  - DRAM: continued oversupply into 4Q19, supply to return to normal first half of 2020
  - NAND: continued oversupply into 4Q19, increased demand in data and mobile with 5G rollout
- Economic uncertainties could affect future market
  - US and China trade war continues
  - Japan and South Korea trade ware continues
  - Huawai ban along with other Chinese tech companies
- Decline projected for 2019
  - DRAM market expected to decline 45% YoY
  - NAND market is projected to decline 30% YoY
  - Memory decline will drive WW IC market down 14%

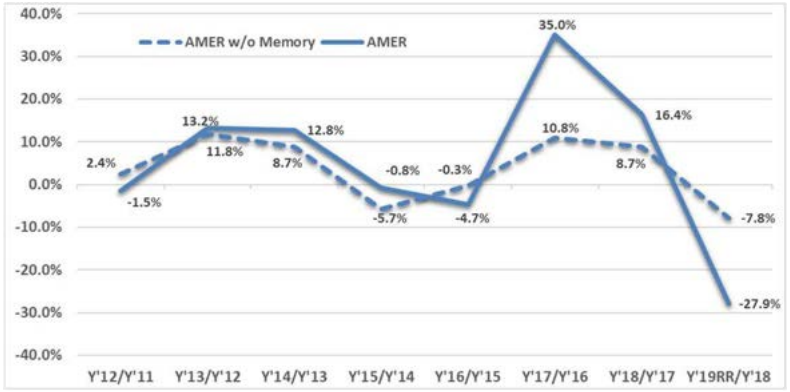
Source: IC Insights and WSTS

YoY Semiconductor Market Growth – with and without Memory

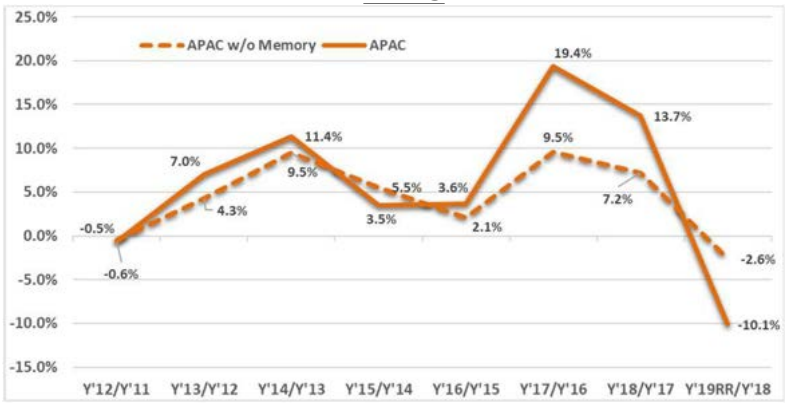


Regional Semiconductor Market Growth – with and without Memory

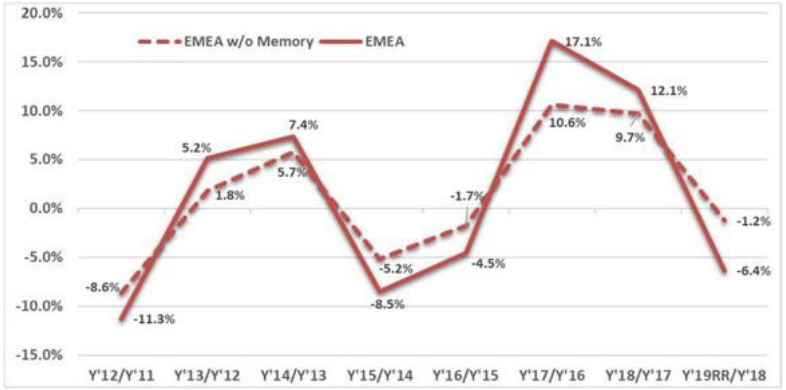
Americas



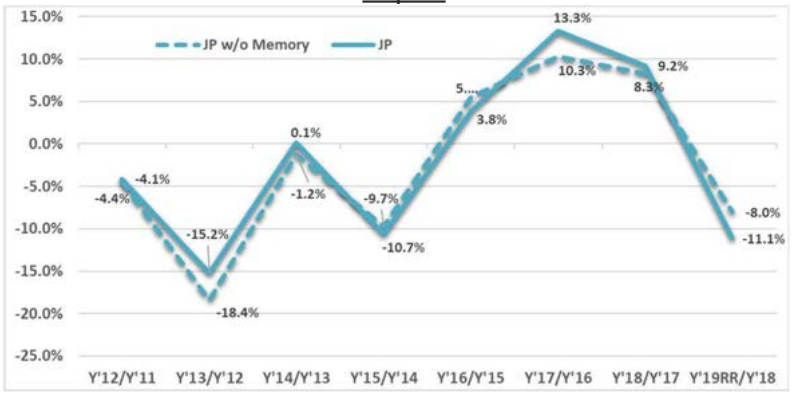
APAC



EMEA

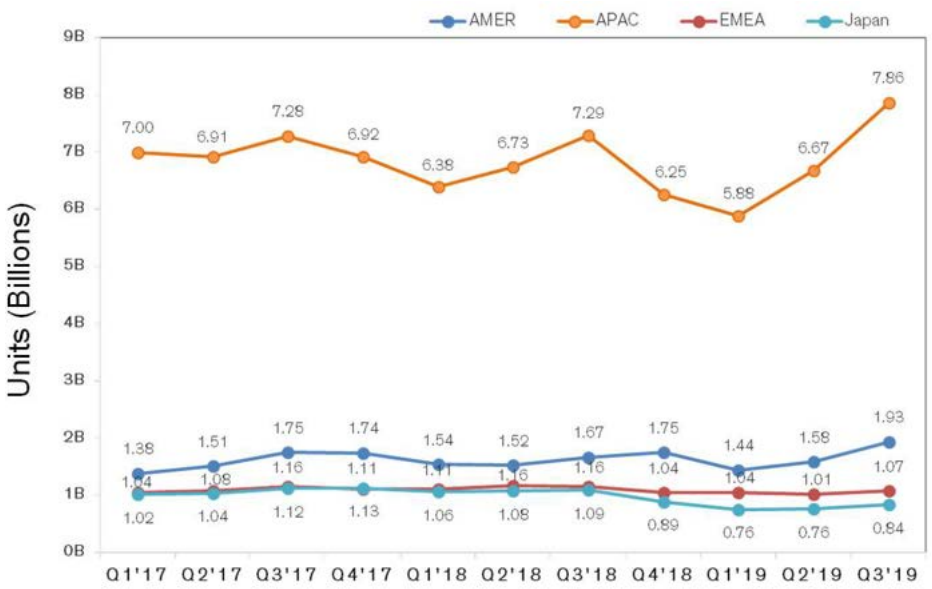


Japan



Memory QoQ Units/ASP Trends by Region

ASP erosion responsible for decline in sales



Source: WSTS

Q3’19 & YTD Total Memory and Storage Trends

Metrics	Region	2017	2018	2019	2019RR	Y'19RR/ Y'18	Y'19RR/ Y'17		Q3'18	Q2'19	Q3'19	QoQ	YoY
Resale	AMER	$41.2B	$51.6B	$20.1B	$26.9B	-48.0%	-34.8%		$14.8B	$6.3B	$7.0B	10.6%	-52.5%
	APAC	$70.1B	$91.3B	$50.7B	$67.7B	-25.9%	-3.5%		$25.2B	$16.3B	$16.9B	3.3%	-33.2%
	EMEA	$6.4B	$8.0B	$4.3B	$5.7B	-28.8%	-11.6%		$2.1B	$1.4B	$1.4B	2.3%	-32.0%
	Japan	$6.3B	$7.1B	$4.0B	$5.3B	-25.4%	-15.1%		$2.0B	$1.3B	$1.5B	17.3%	-24.1%
	WW	$124.0B	$158.0B	$79.1B	$105.5B	-33.2%	-14.9%		$44.1B	$25.3B	$26.8B	5.8%	-39.2%
Units	AMER	6.38B	6.47B	4.95B	6.61B	2.1%	3.5%		1.67B	1.58B	1.93B	22.3%	16.1%
	APAC	28.10B	26.66B	20.41B	27.22B	2.1%	-3.2%		7.29B	6.67B	7.86B	17.8%	7.8%
	EMEA	4.38B	4.47B	3.12B	4.17B	-6.8%	-5.0%		1.16B	1.01B	1.07B	5.5%	-7.5%
	Japan	4.30B	4.12B	2.35B	3.13B	-23.9%	-27.2%		1.09B	0.76B	0.84B	10.9%	-23.2%
	WW	43.18B	41.72B	30.84B	41.12B	-1.4%	-4.8%		11.21B	10.02B	11.70B	16.8%	4.4%
ASP	AMER	$6.46	$7.97	$4.06	$4.06	-49.0%	-37.1%		$8.87	$4.02	$3.63	-9.6%	-59.1%
	APAC	$2.49	$3.42	$2.49	$2.49	-27.4%	-0.3%		$3.46	$2.45	$2.14	-12.4%	-38.0%
	EMEA	$1.47	$1.79	$1.37	$1.37	-23.6%	-7.0%		$1.78	$1.35	$1.31	-3.0%	-26.5%
	Japan	$1.45	$1.73	$1.69	$1.69	-2.0%	16.6%		$1.83	$1.71	$1.81	5.8%	-1.1%
	WW	$2.87	$3.79	$2.57	$2.57	-32.2%	-10.7%		$3.93	$2.53	$2.29	-9.4%	-41.8%

DRAM Revenue and Forecast

DRAM still in oversupply although there is growth in shipments

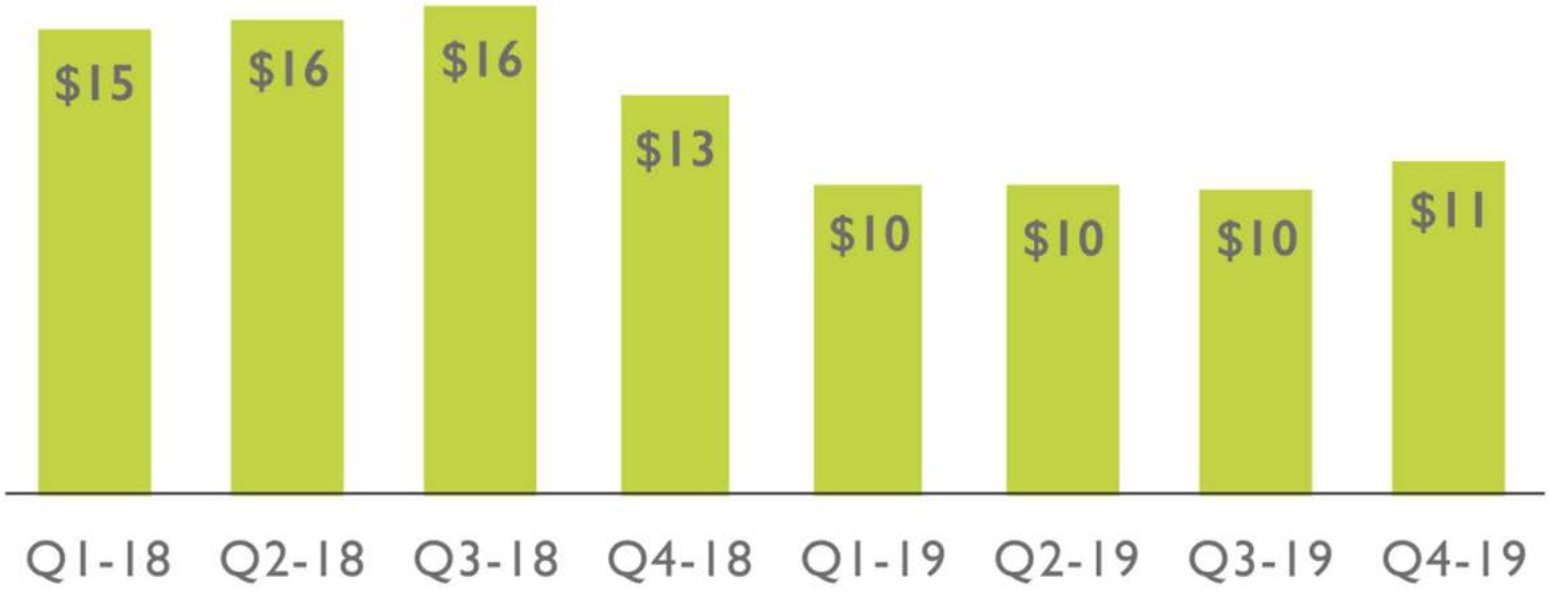
> ASPs still effected by oversupply with a 53% decrease in 2019, forecasted to continue into 2020

Source: Yole Developpment Q3 2019

NAND Revenue and Forecast

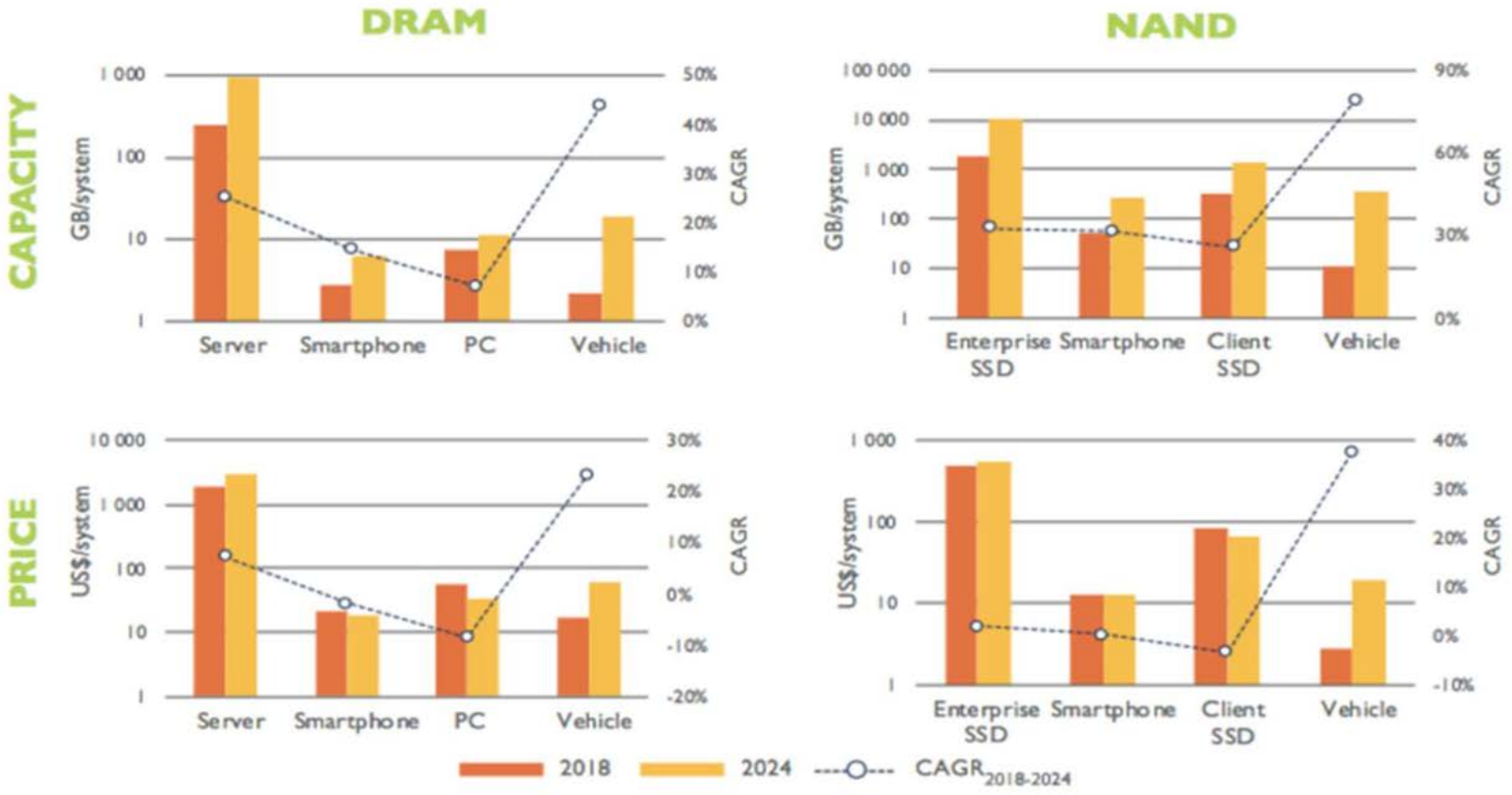
NAND market poised for rebound

> Showed stronger growth than predicted pushed by smartphone launches



Source: Samsung Q3 Earnings Report

DRAM & NAND: Average Capacity & Price Evolution Per System



Source: Yole Development

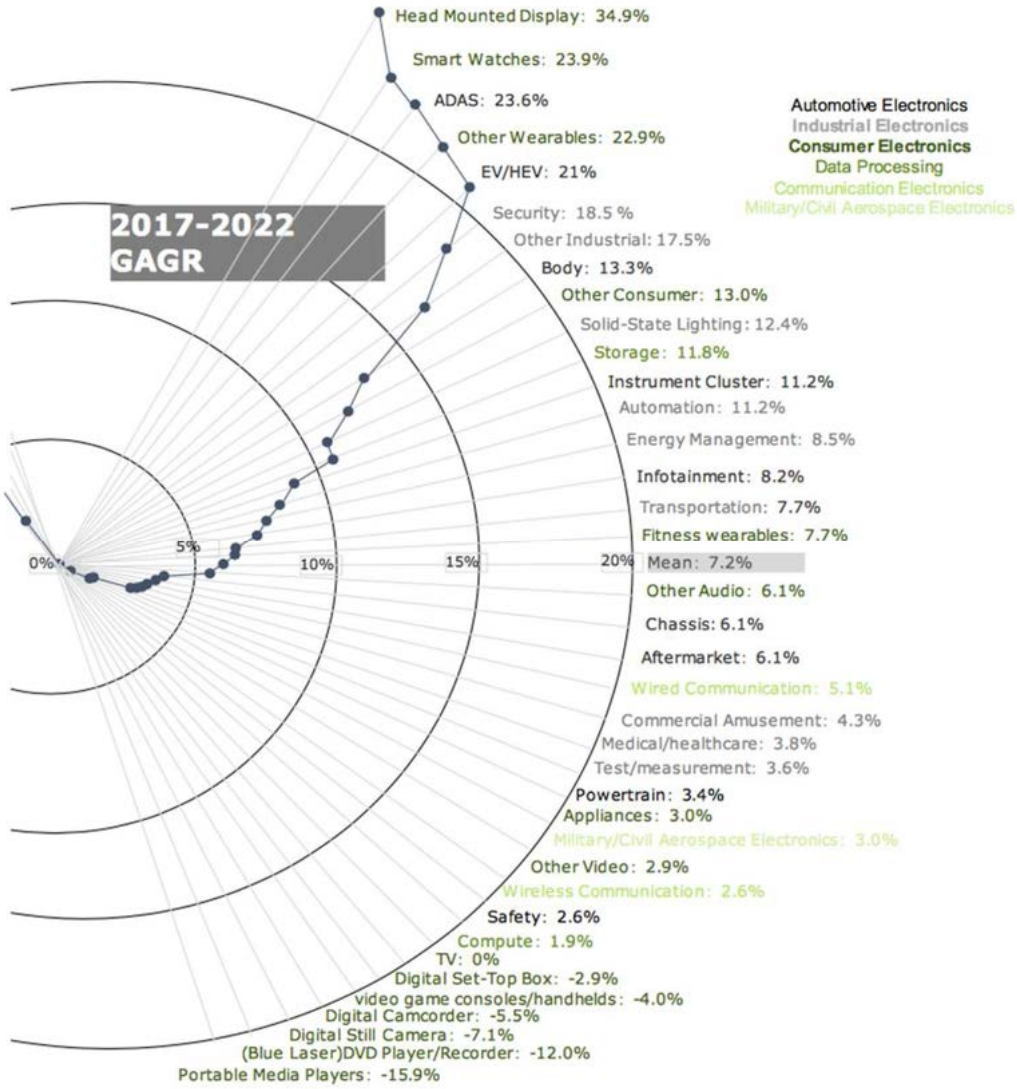
Arrow Memory and Storage Offerings

Breakdown by technology and sub-technologies

Type	Technology	Sub-technologies	Suppliers
Memory	DRAM	DDR4, DDR3, DDR2, DDR1, SDRAM	Micron, ISSI, Winbond, Nanya, Kingston, Samsung
	SRAM	Async SRAM and Sync SRAM	Cypress, ISSI, Microsemi (Mil), Renesas
Flash	NAND Flash	eMMC, Memory Cards and SSDs	Sandisk, Intel, Micron, Western Digital, Kingston, Swissbit, Virtium, Samsung, Toshiba (Rebranding to Kioxia Oct '19)
	NOR Flash	Parallel NOR, Serial NOR	Micron, Cypress/Spansion, Macronix, Winbond, Adesto, ISSI, Microchip

Market Drivers

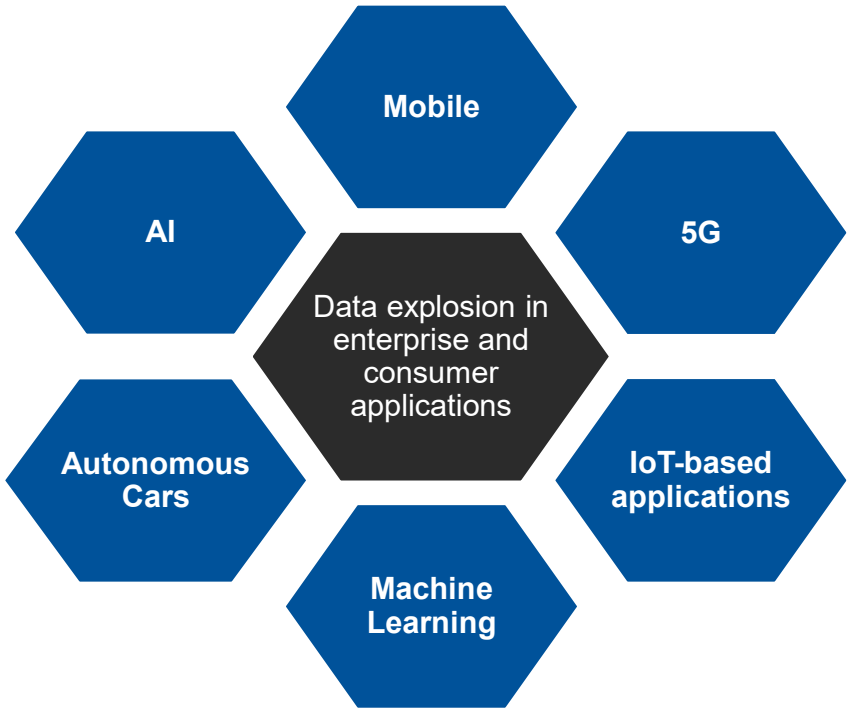
Five Years Out



Semiconductor revenue growth by electronic equipment type (2017- 2022)

Source: Deloitte

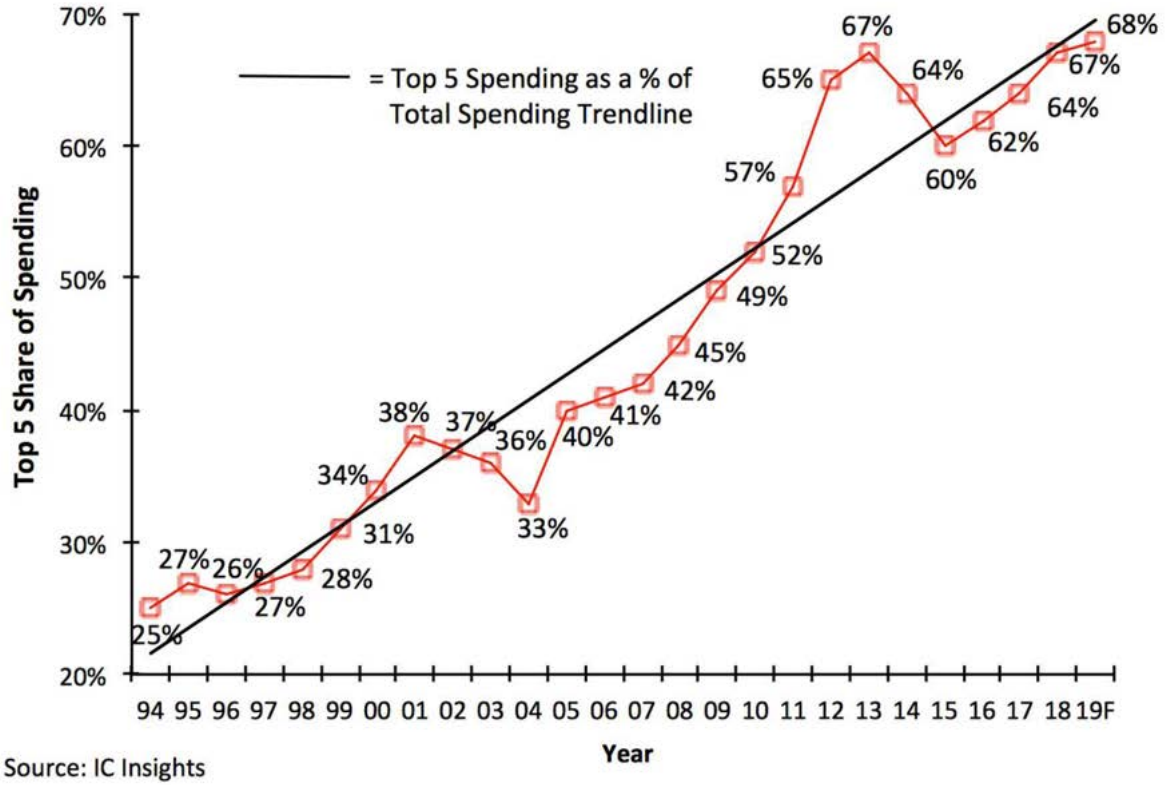
Top Memory Drivers vs. Top Technology Trends



Source: Trendforce

Top 5 Share of Total Semiconductor Capital Spending

The trend of the big companies increasing their share of capital spending continues unabated

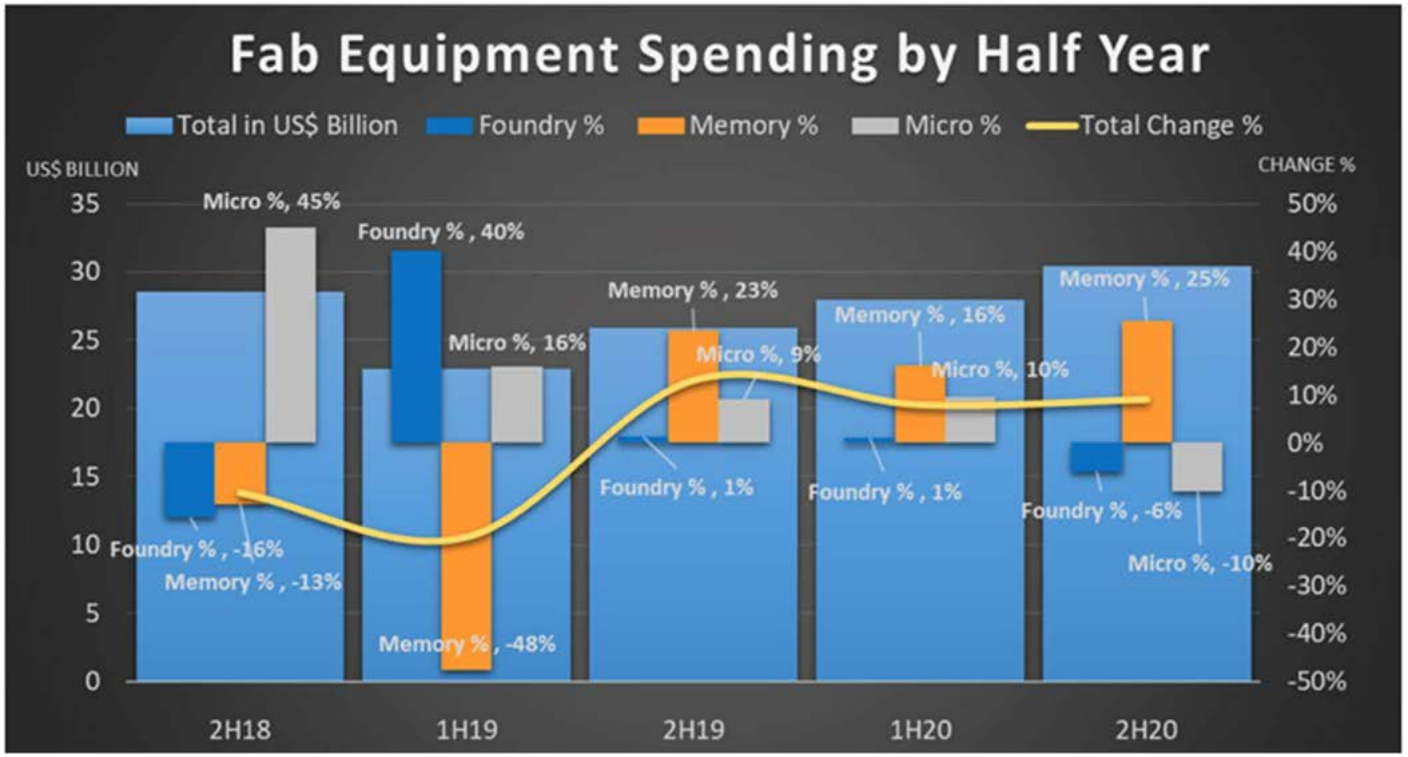


Source: IC Insights

Source: IC Insights

Global Fab Equipment Spending

Forecasted to rebound in 2020 with 20% growth



Source: Semi.org

Next Generation Memory Market – Growth Rate by Region (2019-2024)

Source: Mordor Intelligence

Closing Comments & Questions

Q4'19: DRAM POS Trends

Five Years Out

DRAM Market Summary

- 2019 is still expected to be a down year for DRAM, ASP expected to decline in 2019 due to oversupply and less than expected demand
- ASPs
  - Run-rated to decrease by 53% in 2019
  - QoQ decrease of 16%
- Units Shipped
  - Run rated to increase 17% in 2019
  - QoQ increase of 22%
- ASP decline continues due to oversupply amid the escalating trade war between the U.S. and China
- Anticipating several more quarters with falling prices but recovery coming in clearer focus

DRAM Market Dynamics – 2H'19

Supplier portfolio, demand/supply dynamics by sub-technology

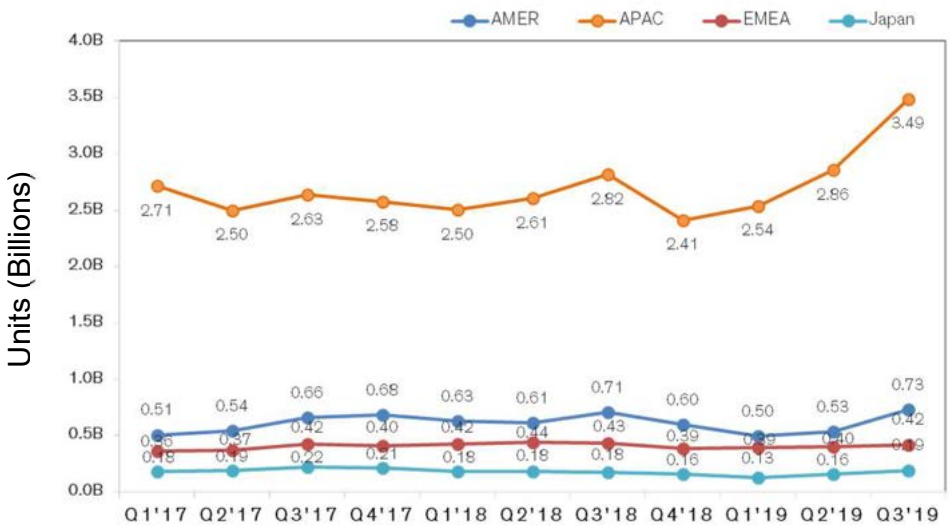
	Suppliers						
Type	Micron	ISSI	Winbond	Samsung	Kingston	Nanya	Demand dynamics
DDR4	X	X		X			> DDR4 demand primarily driven by consumer (PCs, laptops, mobile, etc.), server and data center market > Adoption in the industrial market in the very early stages
DDR3	X	X	X	X	X	X	> Mainstream DRAM memory in industrial and mass market > Demand continues to be strong for both Low-power (LP) and regular versions
DDR2	X	X	X	X		X	> Older designs, not used for new applications > Growth driven by ASP increases and unit volume
DDR1	X	X	X				> Legacy designs > Slight growth, driven by ASP increases
SDRAM	X	X	X				> Overall flat to declining technology

Q3'19 and Expected DRAM POS Trends – by Region

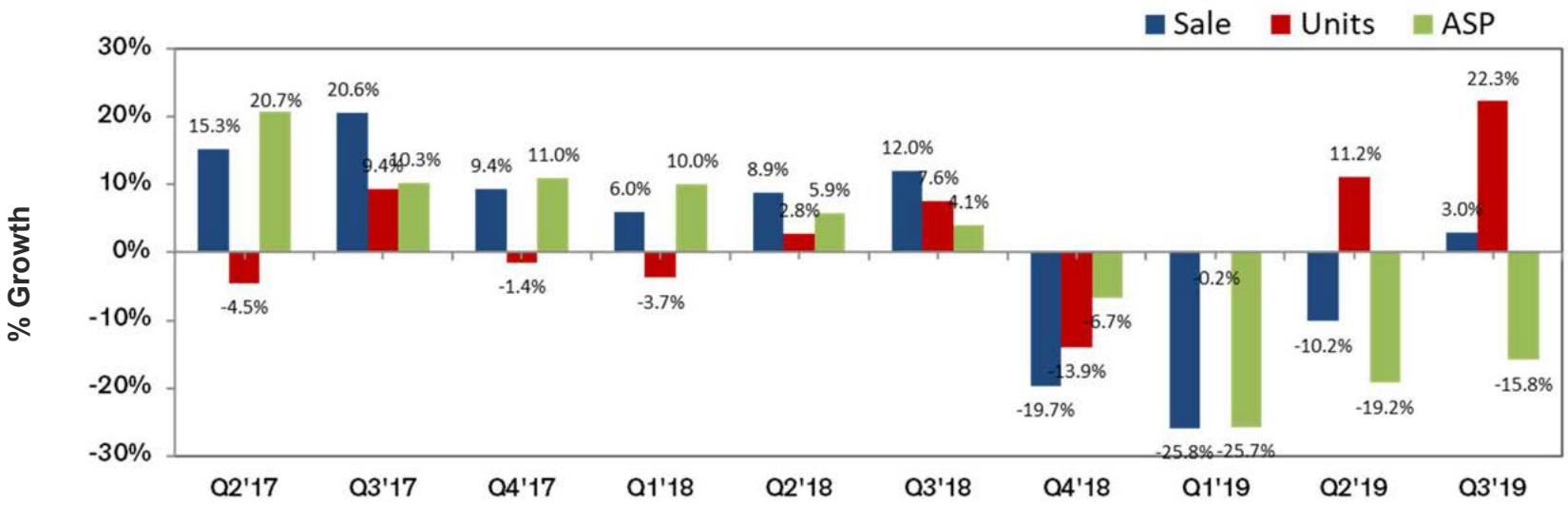
Metrics	Region	2017	2018	2019	2019RR	Y'19RR/ Y'18	Y'19RR/ Y'17		Q3'18	Q2'19	Q3'19	QoQ	YoY
Resale	AMER	$21.7B	$30.9B	$11.3B	$15.0B	-51.3%	-30.8%		$9.1B	$3.4B	$3.9B	14.8%	-57.5%
	APAC	$43.4B	$59.0B	$31.7B	$42.2B	-28.4%	-2.6%		$16.6B	$10.2B	$10.2B	-0.3%	-38.6%
	EMEA	$4.4B	$5.5B	$2.5B	$3.3B	-39.3%	-24.0%		$1.4B	$0.8B	$0.8B	-5.6%	-44.7%
	Japan	$3.3B	$4.0B	$2.1B	$2.7B	-31.4%	-18.0%		$1.1B	$0.7B	$0.7B	2.7%	-36.3%
	WW	$72.8B	$99.3B	$47.5B	$63.3B	-36.2%	-13.0%		$28.2B	$15.1B	$15.6B	3.0%	-44.9%
Units	AMER	2.38B	2.54B	1.76B	2.34B	-7.7%	-1.8%		0.71B	0.53B	0.73B	36.4%	3.2%
	APAC	10.42B	10.34B	8.88B	11.84B	14.6%	13.6%		2.82B	2.86B	3.49B	22.1%	23.8%
	EMEA	1.56B	1.68B	1.21B	1.61B	-4.0%	3.3%		0.43B	0.40B	0.42B	5.0%	-2.8%
	Japan	0.79B	0.70B	0.47B	0.63B	-9.4%	-20.4%		0.18B	0.16B	0.19B	23.0%	8.9%
	WW	15.16B	15.25B	12.32B	16.43B	7.7%	8.3%		4.13B	3.95B	4.83B	22.3%	16.9%
ASP	AMER	$9.12	$12.17	$6.42	$6.42	-47.2%	-29.6%		$12.96	$6.34	$5.34	-15.8%	-58.8%
	APAC	$4.16	$5.71	$3.57	$3.57	-37.5%	-14.3%		$5.88	$3.57	$2.92	-18.3%	-50.4%
	EMEA	$2.80	$3.26	$2.06	$2.06	-36.8%	-26.4%		$3.26	$2.06	$1.86	-10.1%	-43.2%
	Japan	$4.20	$5.72	$4.33	$4.33	-24.3%	3.1%		$6.42	$4.50	$3.76	-16.5%	-41.5%
	WW	$4.80	$6.51	$3.85	$3.85	-40.8%	-19.7%		$6.84	$3.83	$3.22	-15.8%	-52.9%

DRAM QoQ Units/ASP Trends by Region

ASP erosion continues for all regions however, increase in units sales stabilize DRAM revenue

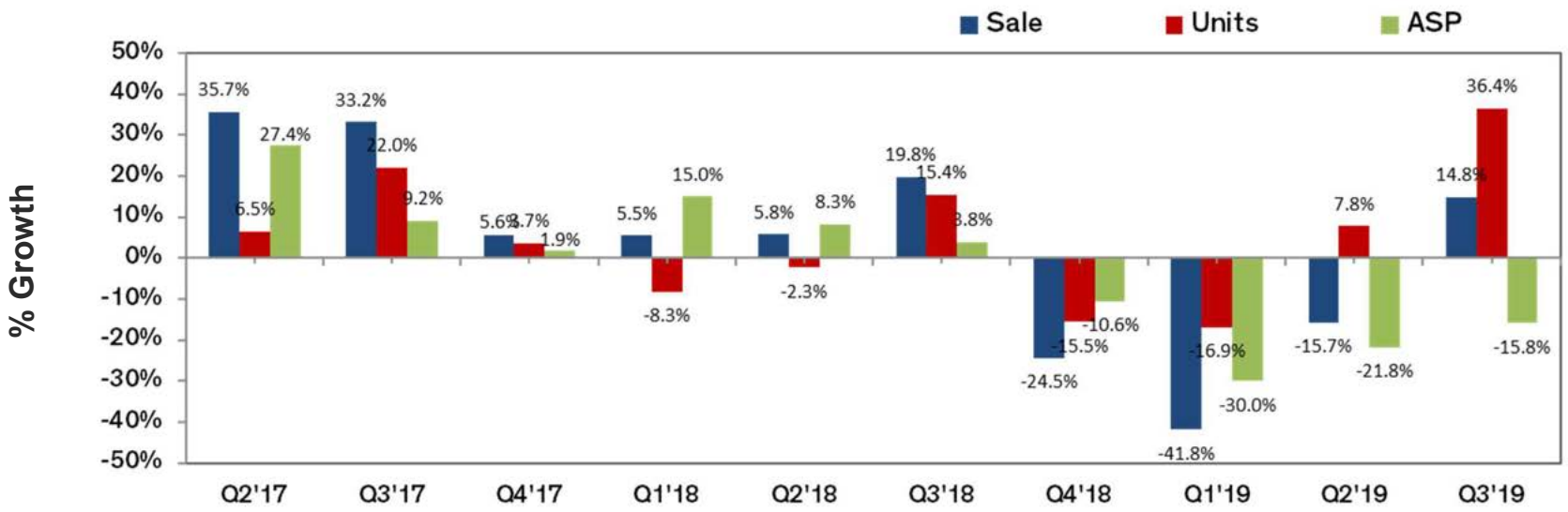


WW Sales, ASP and Units Trends for DRAM – QoQ Trend



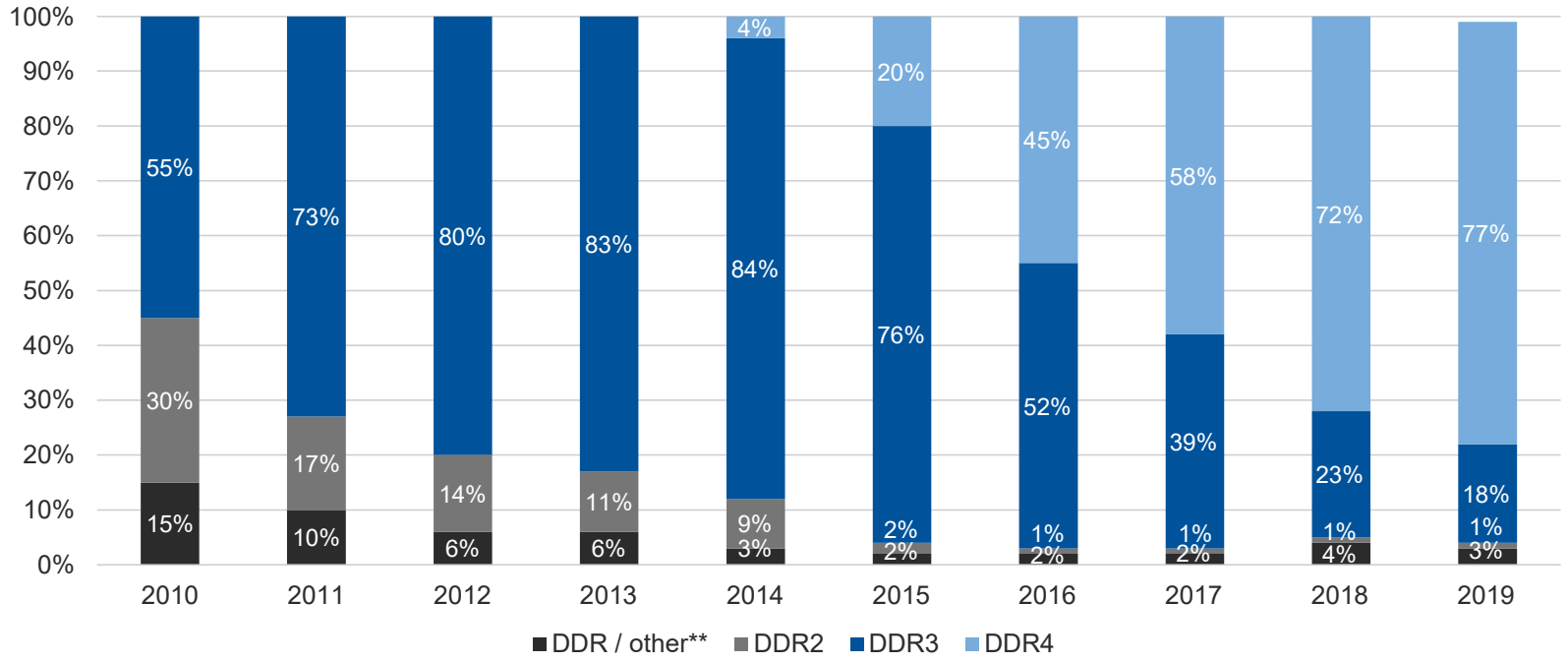
Prices for DRAM chips fall for four straight quarters. YTD ASP decline of 40.8% since 2018

America Sales, ASP and Units Trends for DRAM

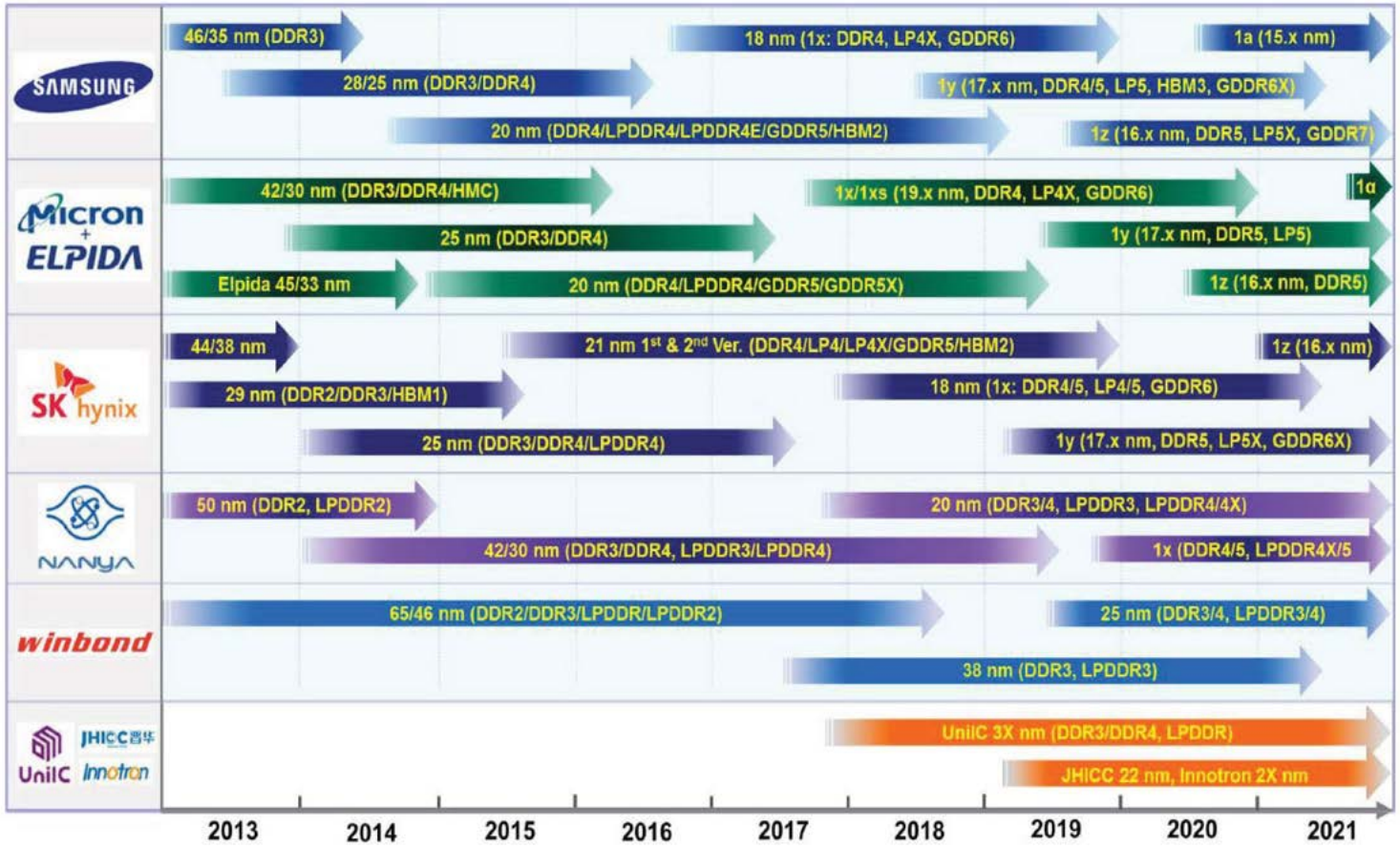


After three consecutive QoQ declines, DRAM quarterly sales up 14.8% in Q3'19. YoY sales declined 57.5% and ASP erosion responsible for lower sales compared to Q3'18

Distribution of DRAM Market Revenue WW *by Architecture

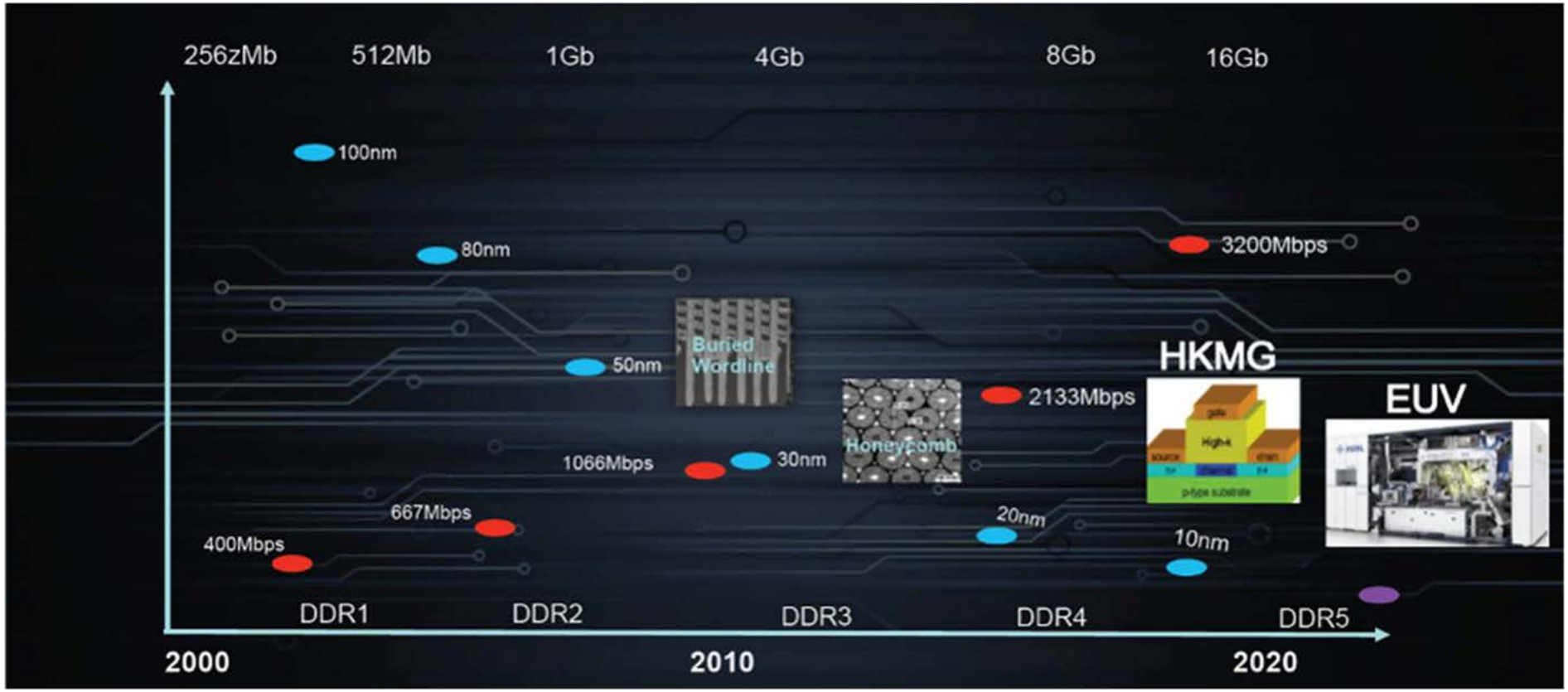


DRAM Memory Technology Roadmap



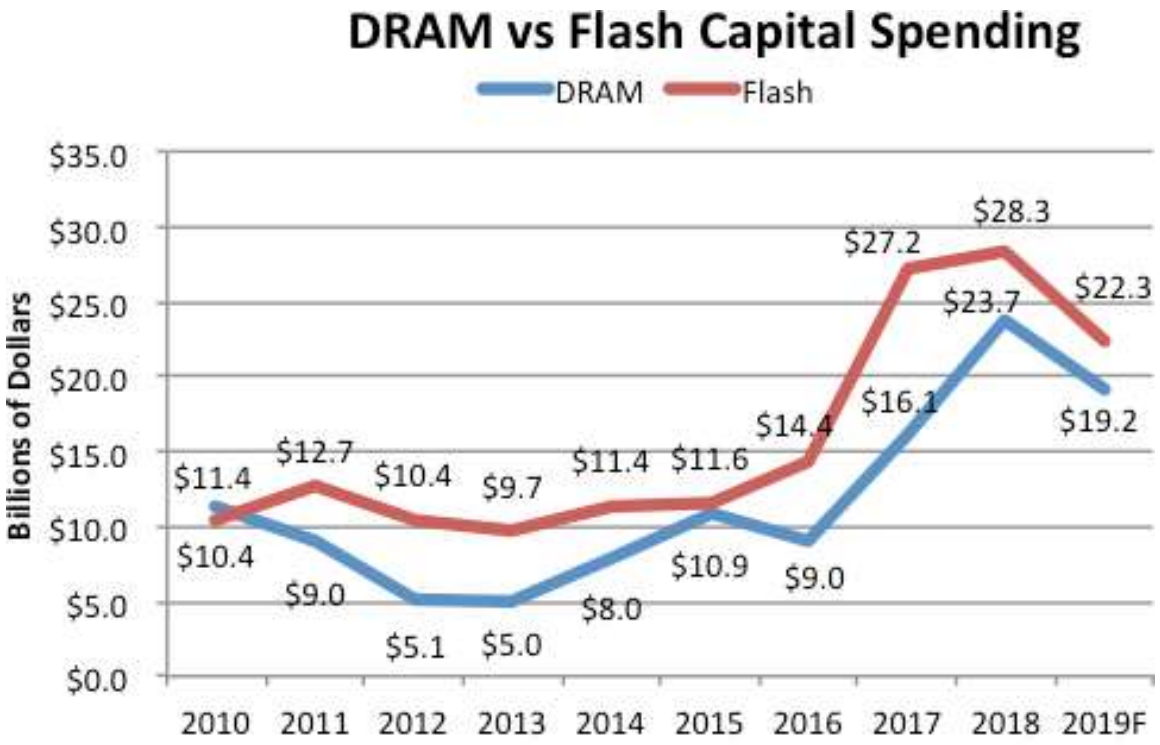
Source: Tech Insights, Q3'19

DRAM Technology Evolution



Source: Forbes

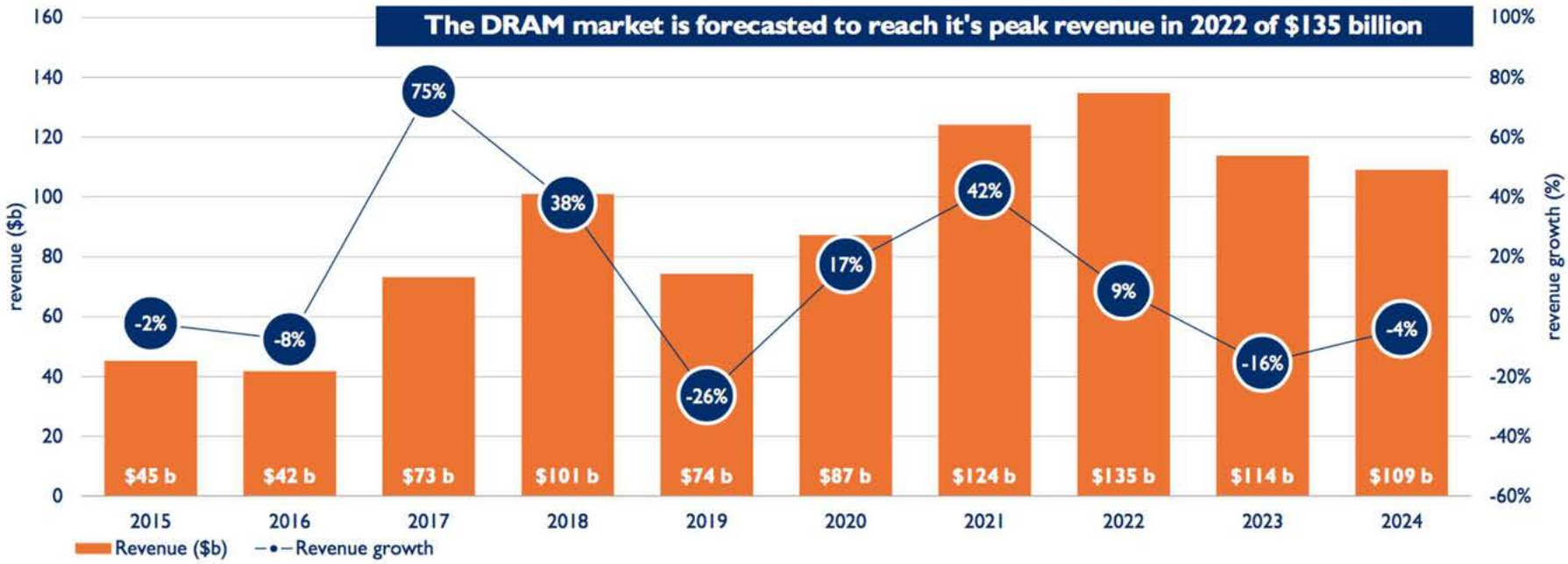
DRAM CapEx



DRAM CapEx fall of 19% in 2019

Source: IC Insights

DRAM Revenue and Forecast

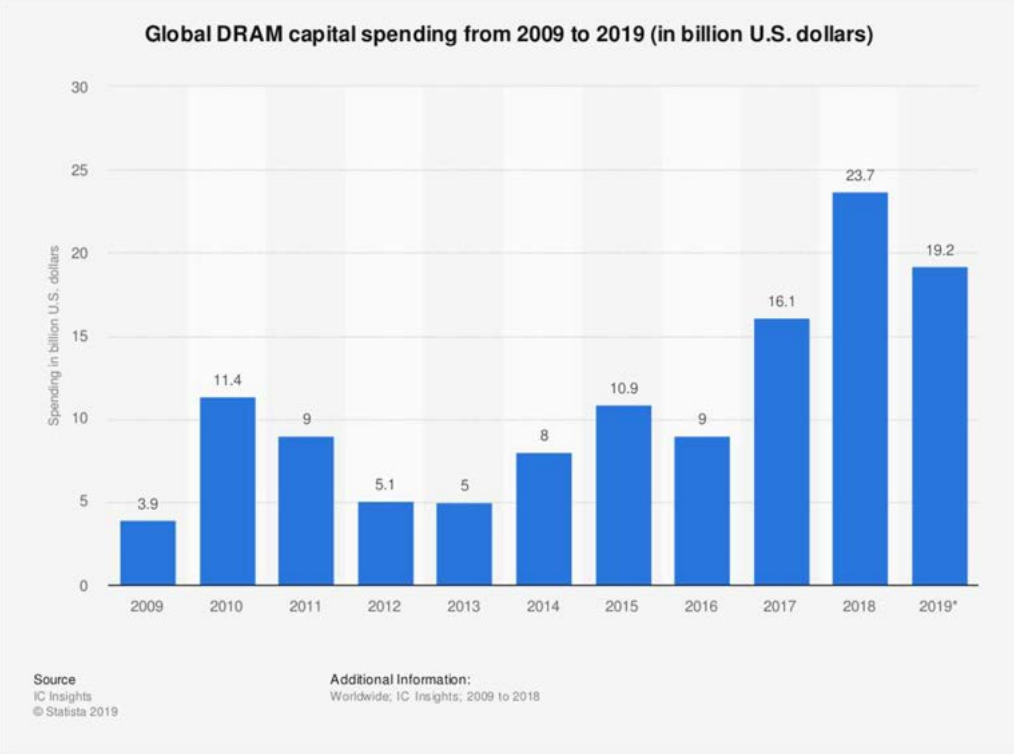


Market driven by mobile, hyperscale data centers, AI, machine learning and autonomous driving

Source: Yole Q3'19

DRAM Supply Dynamics

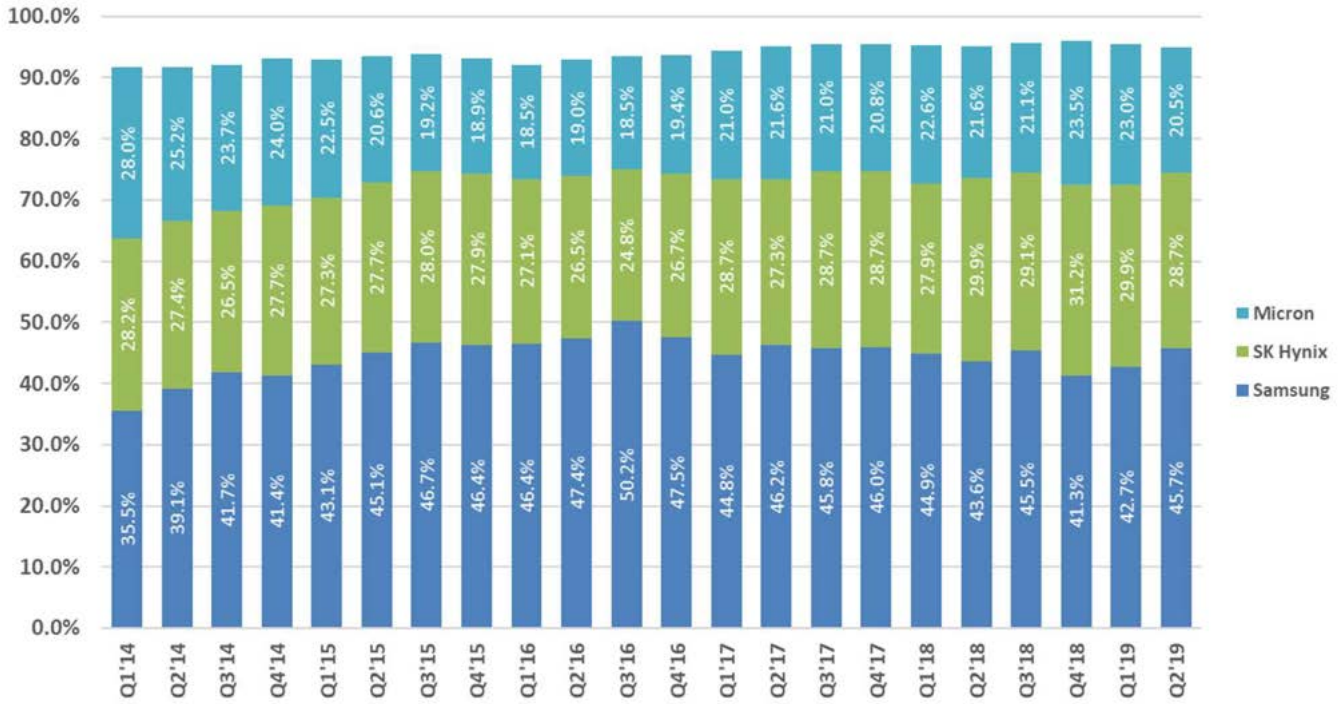
- > Inventories still high, due to continued oversupply, prices have dropped 16% in 3Q19.
- > High inventory levels expected to continue in 2020, mixed forecasts on recovery
  - > Chinese manufacturer CXMT ramping up production but will still be limited
  - > End demand will determine market stabilization
  - > US/China trade war continues to effect demand



Source: EE News, EPS News, SEMI

DRAM Supplier Market Share Trends

**Q3 statista data not yet available*

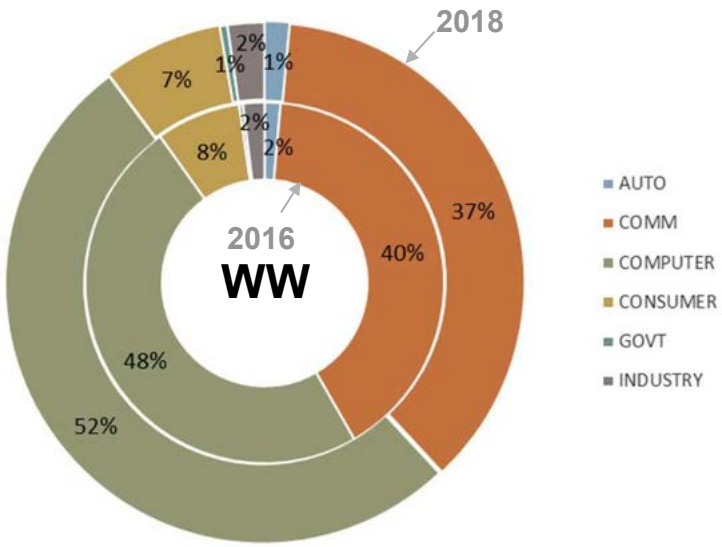


Source: Statista

DRAM Supplier Market Share – Tier 2 Players

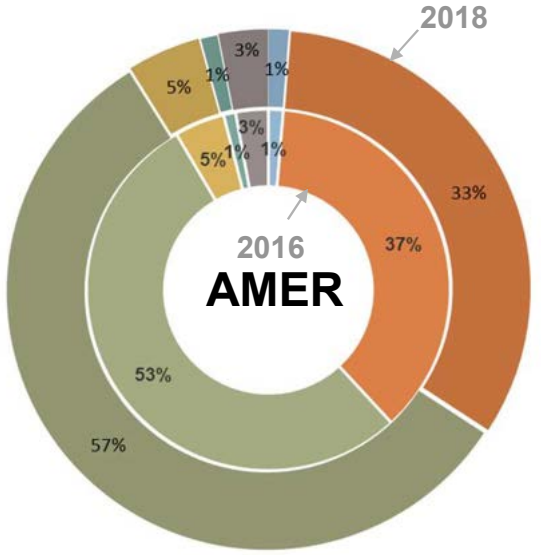
Source: Statista

2018 and 2016 DRAM Usage: WW and Americas



Market Segment	Y2016	Y2018	YoY
Auto	$0.6	$1.5	151.0%
Communications	$16.6	$36.3	119.0%
Computer	$19.9	$51.4	157.7%
Consumer	$3.1	$7.4	135.4%
Govt.	$0.1	$0.5	248.1%
Industrial	$0.8	$2.3	186.2%
Total	**$41.2**	**$99.3**	**141.2%**

Sales in $B



Market Segment	Y2016	Y2018	YoY
Auto	$0.1	$0.4	187.6%
Communications	$3.7	$10.2	172.0%
Computer	$5.4	$17.6	224.2%
Consumer	$0.5	$1.4	213.4%
Govt.	$0.1	$0.4	234.5%
Industrial	$0.3	$0.9	221.6%
Total	**$10.2**	**$30.9**	**204.1%**

Sales in $B

Q4'19 and YTD2019: NAND Flash Trends

Five Years Out

NAND Flash Market Summary

> NAND demand showed stronger growth than expected driven by mobile

> Decline in ASP's in Q3'19

  > Continued decline but should slow in Q4 due to supply, forecasted to rebound in 2020

> Supply Dynamics

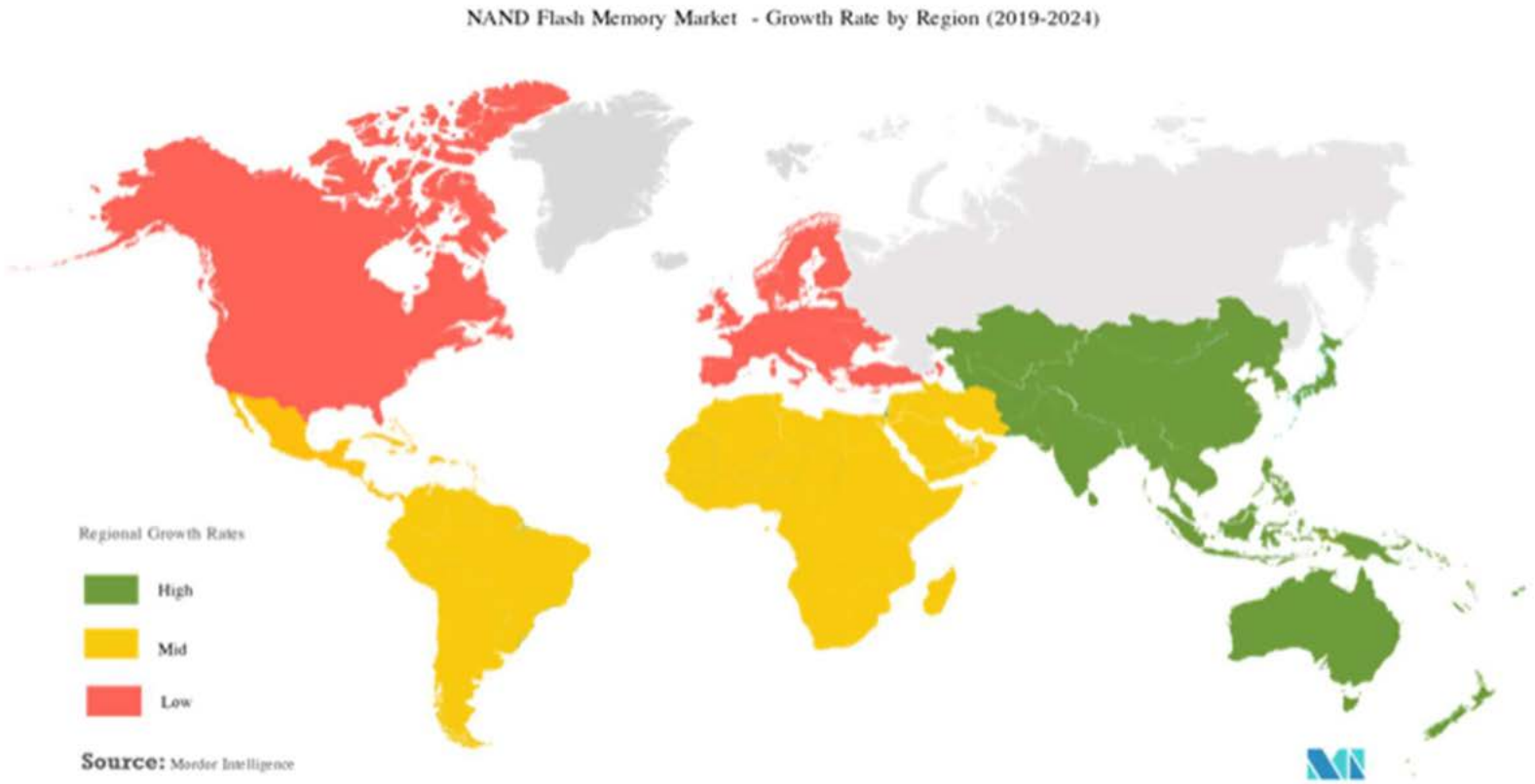
  > Customers still running thru inventory built up due to external uncertainties

  > The NAND flash market continues to be affected by the Japan/Korea trade war

  > New smartphone launches will help NAND market in 2020

> Toshiba Memory Official Rebranded to Kioxia (kee-ox-ee-uh) October 1, 2019

NAND Flash Market – Growth by Region



Source: Mordor Intelligence

SkyHigh Memory: Cypress and SK Hynix System ICJoint Venture For NAND Flash Business

- Joint venture: Owned 60% by SK Hynix System IC and 40% by Cypress
- Will manufacture and sell Cypress' existing single-level cell (SLC) NAND products
- Continued investments in next-generation NAND products
- Available through Arrow starting April 1st, 2019
  - Cypress will reject any NAND order placed after this date
- POs for NAND (SkyHigh Memory) must not be combined with Cypress products

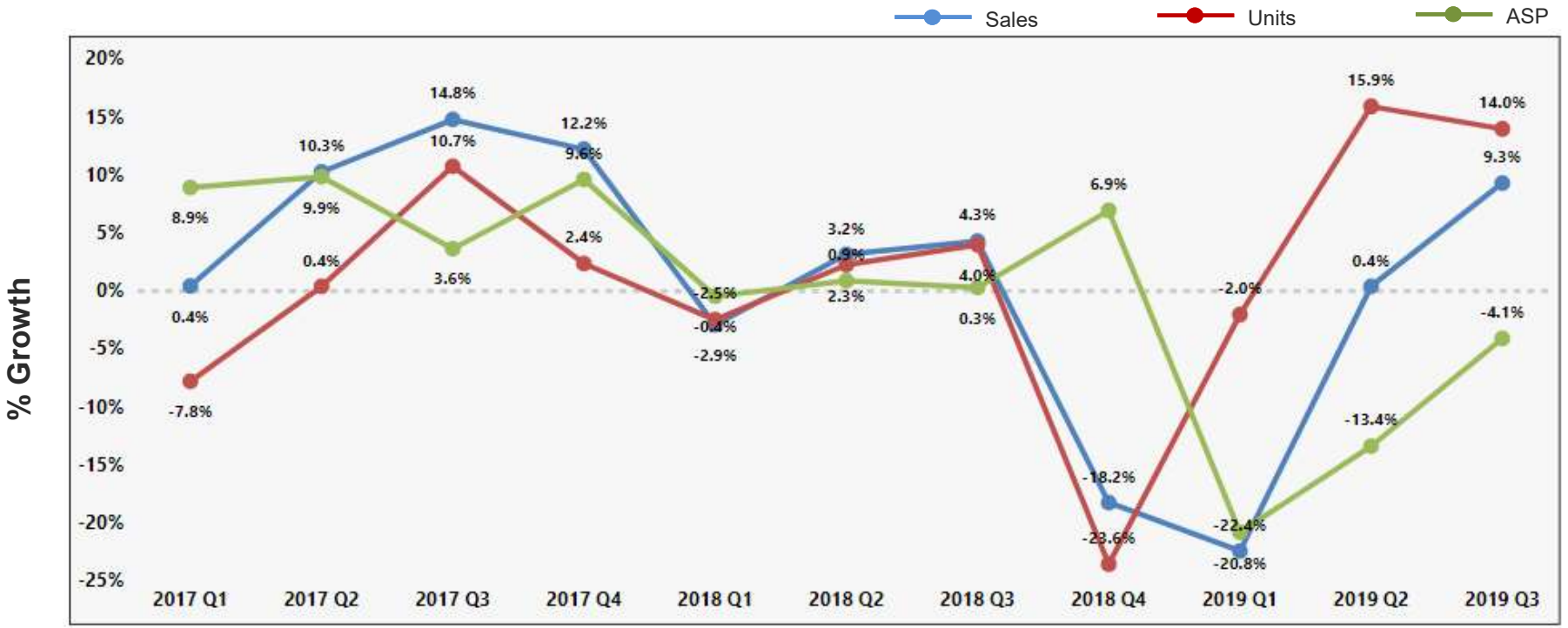
Arrow NAND Flash Portfolio

Type	Intel	Kingston	Micron	Samsung	SanDisk/ WD	SkyHigh Memory	Swissbit	Toshiba (Kioxia)	Virtuim
Cards		X			X		X	X	
eMMC		X	X	X	X	X	X	X	X
SSDs	X	X	X	X	X		X	X	X

Q3'19 and YTD 2019 NAND Flash Trends – by Region

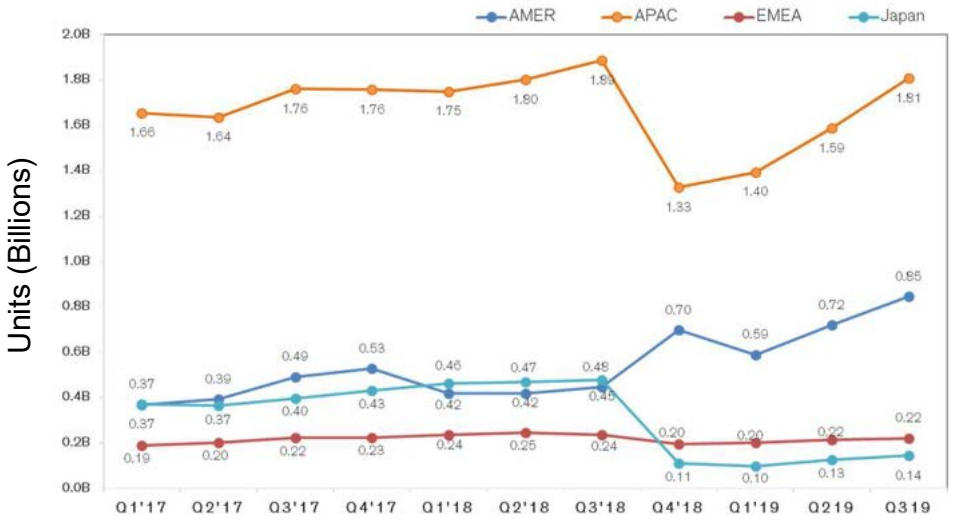
Metrics	Region	2017	2018	2019	2019RR	Y'19RR/ Y'18	Y'19RR/ Y'17		Q3'18	Q2'19	Q3'19	QoQ	YoY
Resale	AMER	$19.0B	$20.1B	$8.5B	$11.4B	-43.5%	-40.2%		$5.5B	$2.9B	$3.0B	6.2%	-44.7%
	APAC	$24.7B	$30.2B	$17.8B	$23.7B	-21.6%	-4.0%		$8.1B	$5.7B	$6.3B	9.9%	-23.1%
	EMEA	$1.6B	$1.9B	$1.4B	$1.8B	-2.2%	18.7%		$0.5B	$0.4B	$0.5B	21.4%	4.1%
	Japan	$2.0B	$2.0B	$1.1B	$1.5B	-26.7%	-26.6%		$0.5B	$0.4B	$0.4B	10.7%	-26.1%
	WW	$47.2B	$54.2B	$28.8B	$38.4B	-29.2%	-18.7%		$14.6B	$9.3B	$10.2B	9.3%	-30.4%
Units	AMER	1.78B	1.99B	2.16B	2.88B	44.8%	61.1%		0.45B	0.72B	0.85B	17.5%	88.8%
	APAC	6.81B	6.77B	4.79B	6.39B	-5.6%	-6.2%		1.89B	1.59B	1.81B	13.9%	-4.2%
	EMEA	0.84B	0.92B	0.64B	0.85B	-7.2%	1.3%		0.24B	0.22B	0.22B	3.1%	-6.8%
	Japan	1.56B	1.52B	0.37B	0.50B	-67.5%	-68.3%		0.48B	0.13B	0.14B	13.7%	-69.8%
	WW	11.01B	11.20B	7.96B	10.61B	-5.2%	-3.6%		3.05B	2.65B	3.02B	14.0%	-1.0%
ASP	AMER	$10.63	$10.13	$3.95	$3.95	-61.0%	-62.9%		$12.23	$3.96	$3.58	-9.6%	-70.7%
	APAC	$3.63	$4.47	$3.71	$3.71	-16.9%	2.4%		$4.31	$3.58	$3.46	-3.5%	-19.7%
	EMEA	$1.84	$2.05	$2.16	$2.16	5.5%	17.1%		$2.02	$1.91	$2.25	17.7%	11.6%
	Japan	$1.27	$1.31	$2.95	$2.95	125.5%	131.9%		$1.13	$2.83	$2.75	-2.6%	144.4%
	WW	$4.29	$4.84	$3.62	$3.62	-25.3%	-15.7%		$4.79	$3.52	$3.37	-4.1%	-29.7%

WW QoQ Sales, ASP and Units Trends for NAND Flash



NAND QoQ Units/ASP Trends by Region

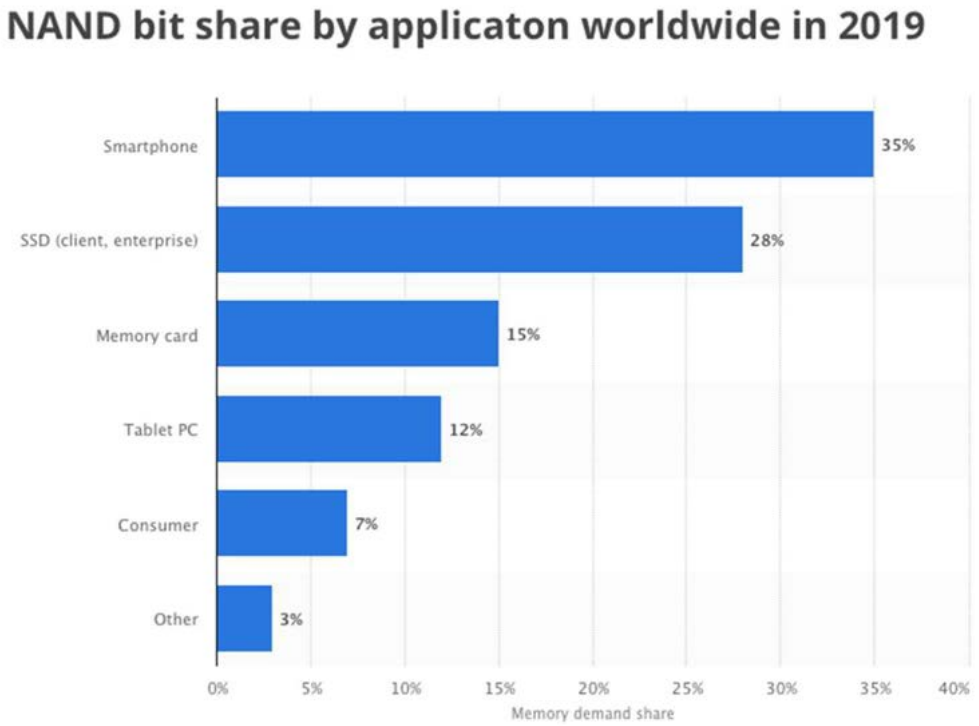
Increase in Units mostly responsible for increase in sales. NAND prices decreased further for all regions except EMEA (+17.7% QoQ gains in prices)



Source: WSTS

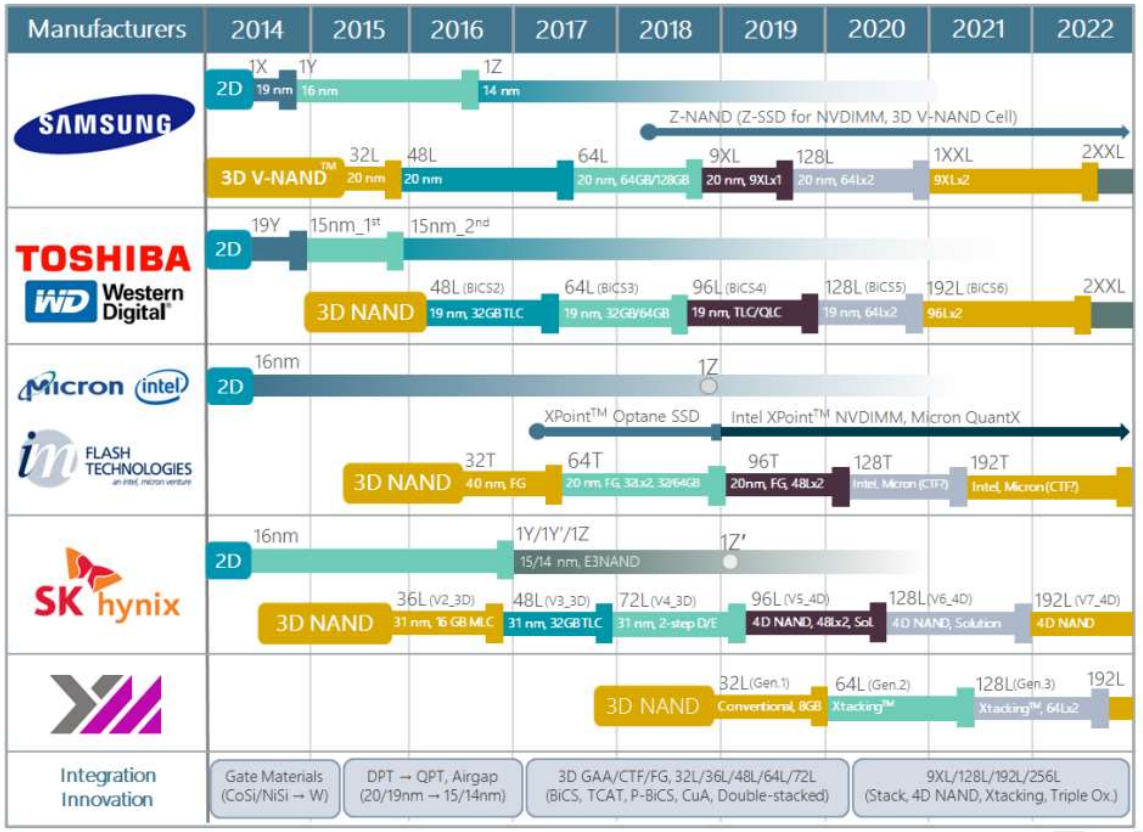
NAND Bit Share by Application

Mobile continues to dominate share in Q3



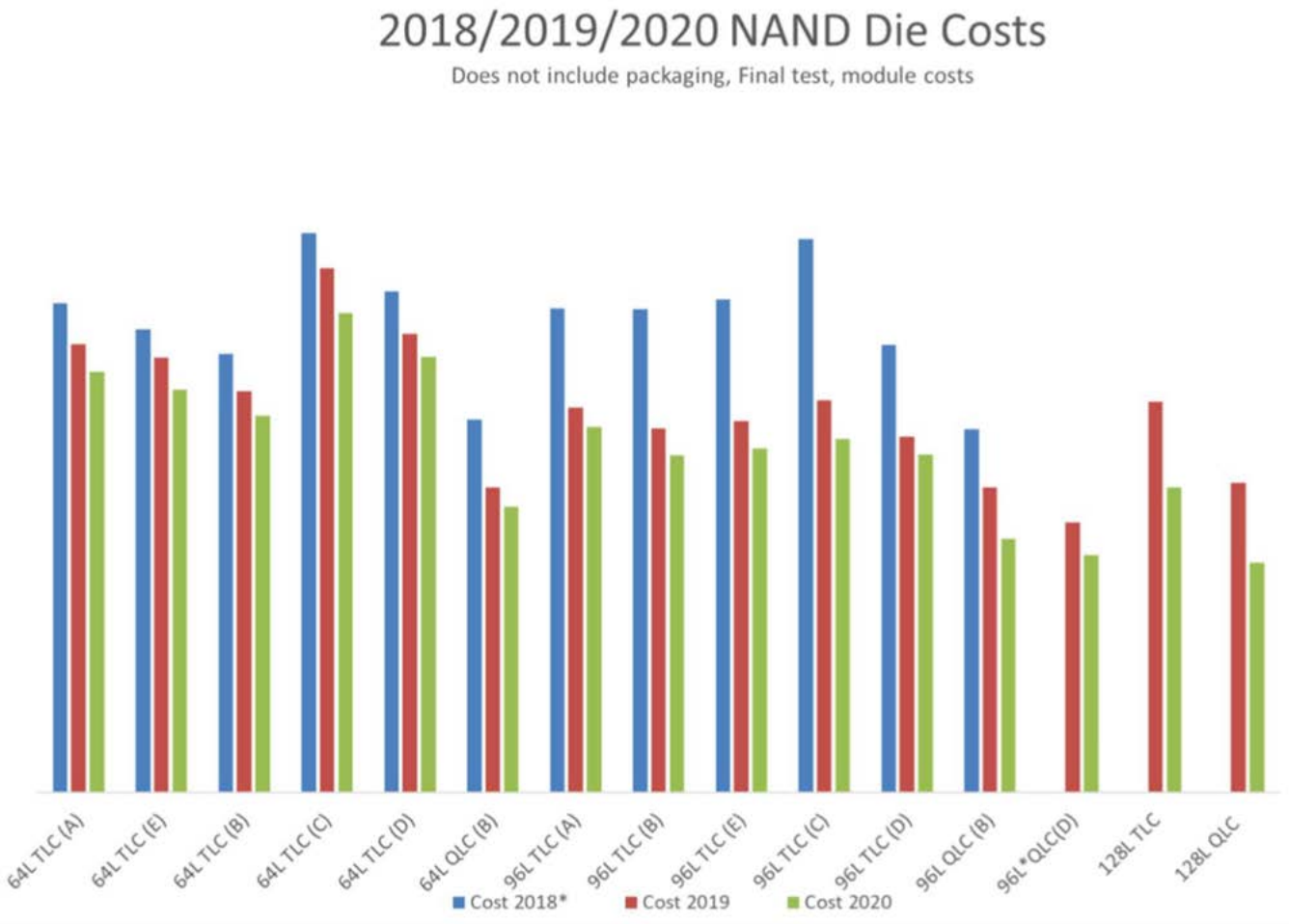
Source: Statista

NAND Flash Technology Roadmap



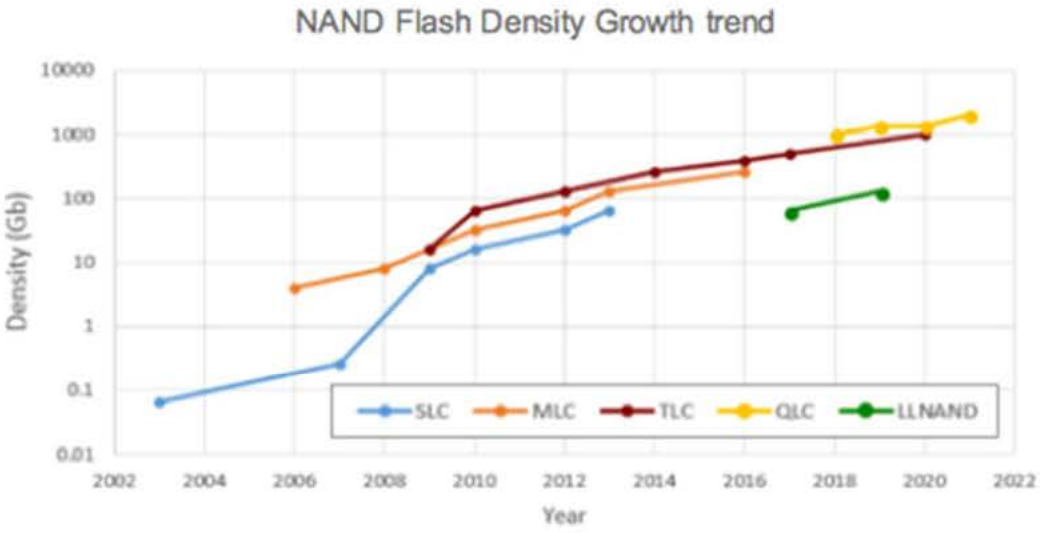
Source: Yole Q3'19

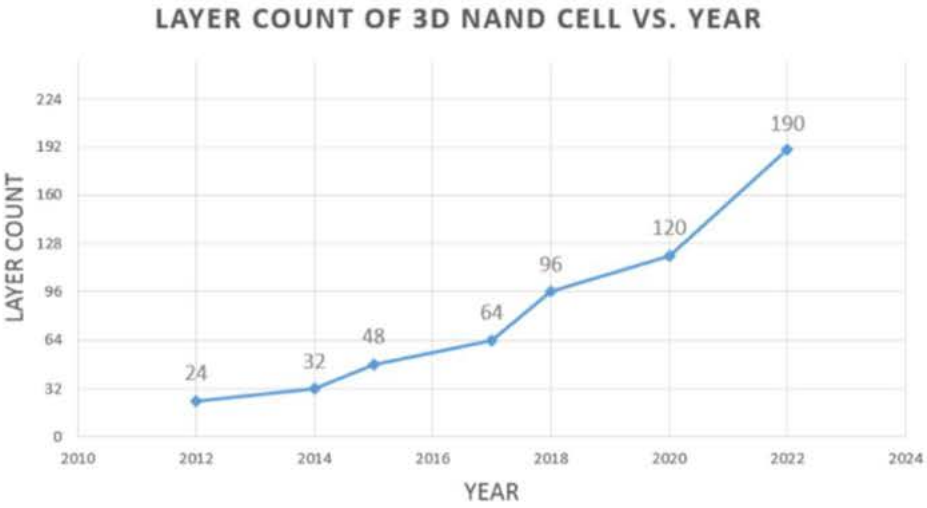
NAND Die Costs



Source: Flash Memory Summit

NAND Flash Density Trends

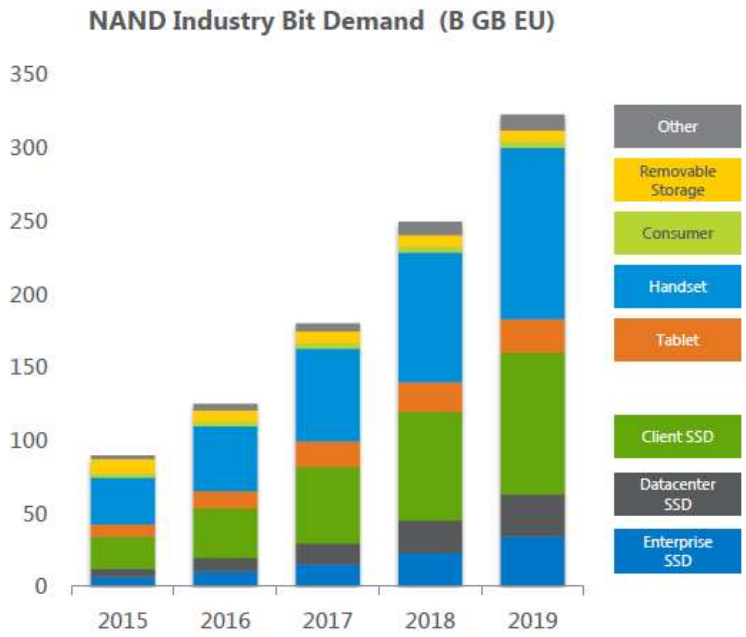


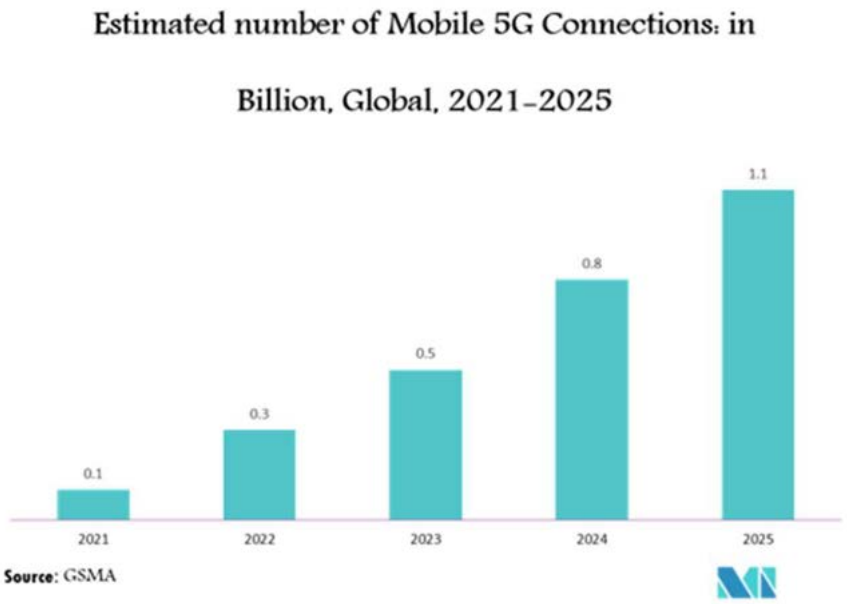


Source: Flash Memory Summit

NAND Bit Demand

Forecast hopeful 5G rollout will increase end demand in mobile market

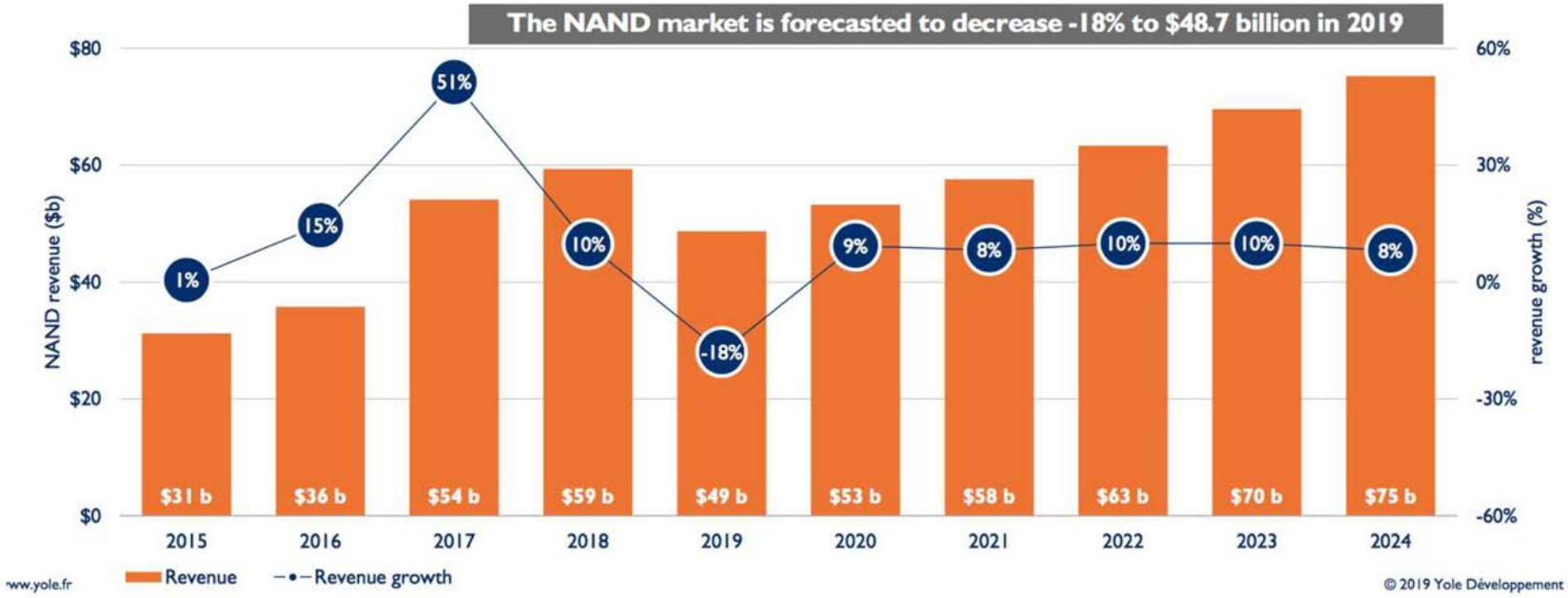




Source: Flash Memory Summit, Mordor

NAND Market Revenue and Forecast

Annual revenue and forecast

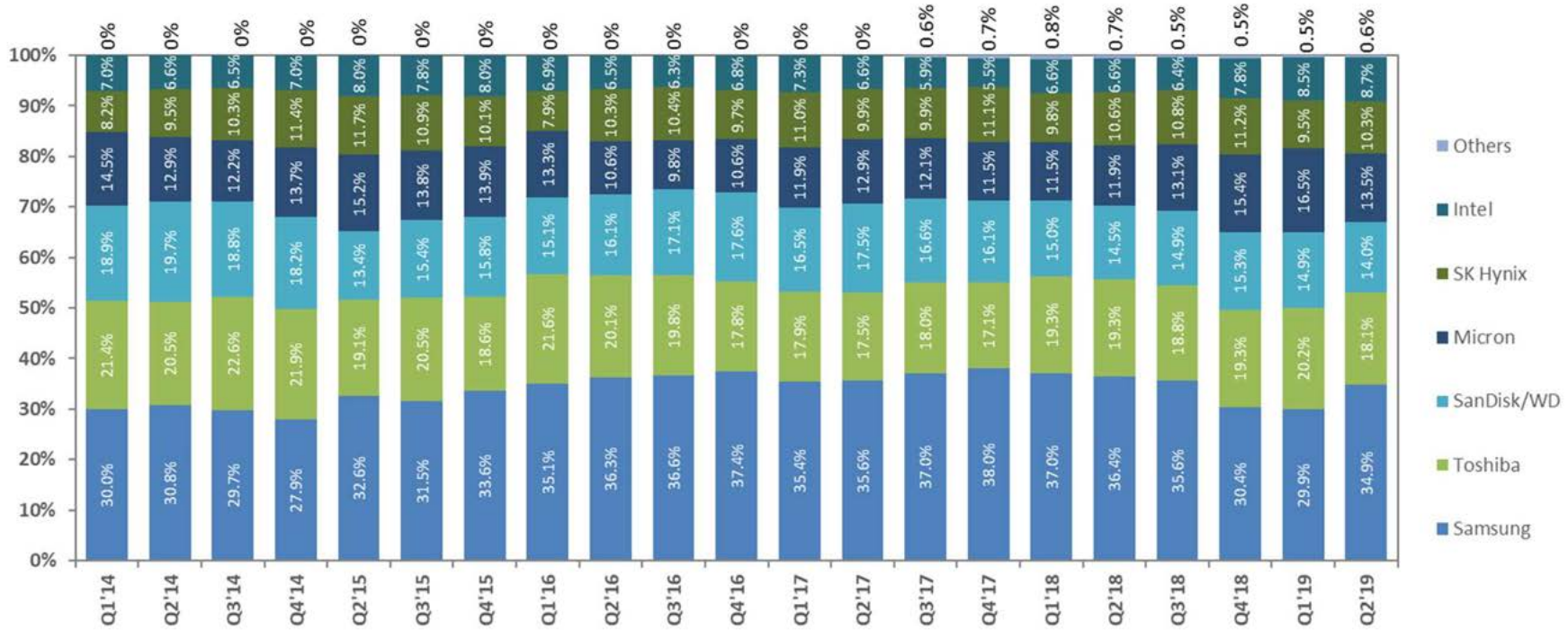


Inventory leveling off in Q419 with mobile end market increase forecasted for 2020

Source: Yole Development

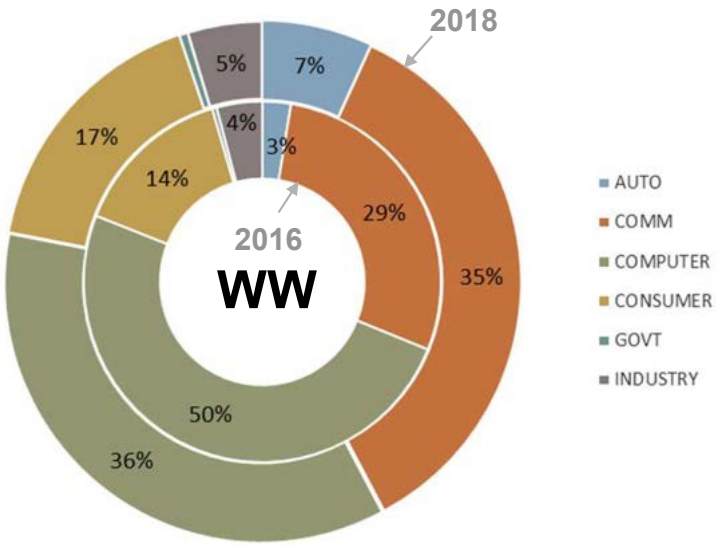
NAND Supplier Market Share

**Q3 statista data not yet available*



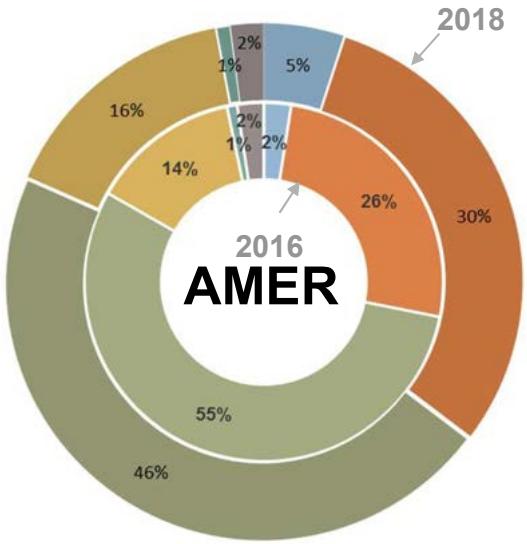
Source: Statista

2018 and 2016 Flash Usage: WW and Americas



Market Segment	Y2016	Y2018	YoY
Auto	$0.9	$3.9	345.5%
Communications	$9.6	$19.9	107.0%
Computer	$16.8	$20.2	20.1%
Consumer	$4.9	$9.4	93.1%
Govt.	$0.1	$0.3	124.4%
Industrial	$1.4	$2.6	89.9%
Total	**$33.7**	**$56.4**	**67.2%**

Sales in $B



Market Segment	Y2016	Y2018	YoY
Auto	$0.3	$1.0	234.4%
Communications	$3.2	$6.2	93.8%
Computer	$6.8	$9.4	37.7%
Consumer	$1.7	$3.1	88.0%
Govt.	$0.1	$0.2	61.2%
Industrial	$0.3	$0.4	42.7%
Total	**$12.4**	**$20.4**	**64.0%**

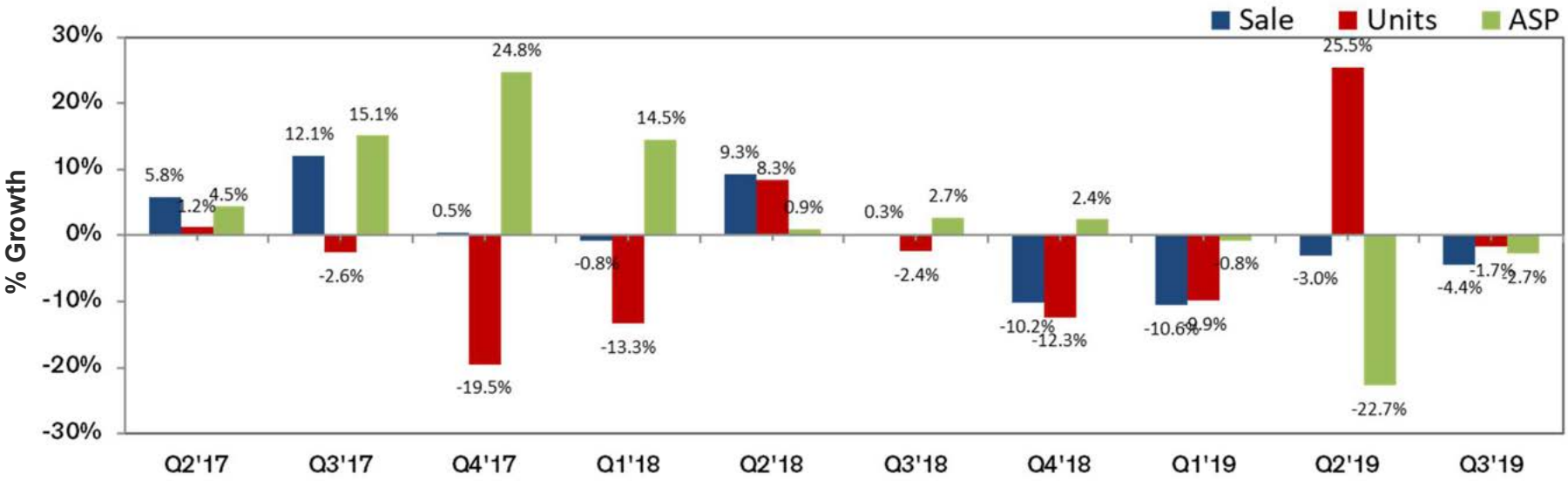
Sales in $B

Q4'19 and YTD2019: NOR Flash Trends

Five Years Out

NOR Flash Market Summary

NOR flash memory unit sales are down WW in 3Q19, severe price erosion continues to negatively affect sales revenue for America and APAC

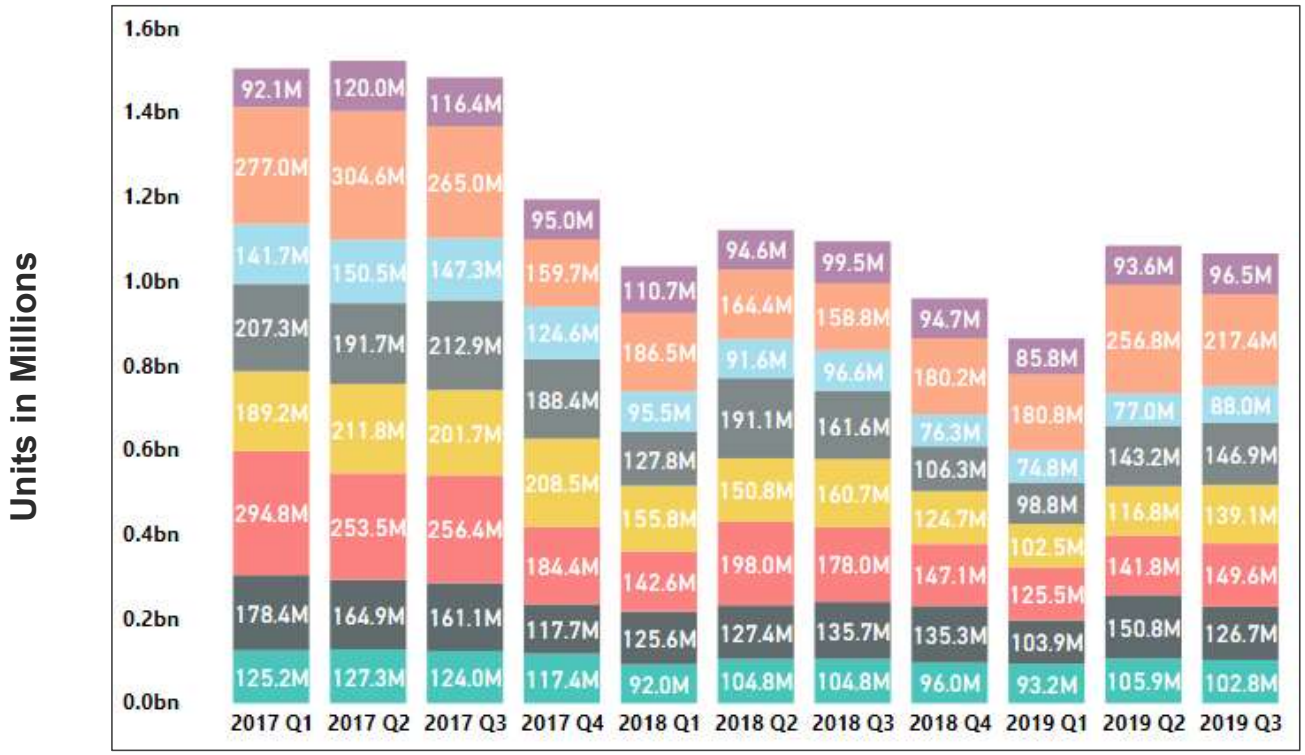


Source: WSTS

Arrow NOR Flash Offerings

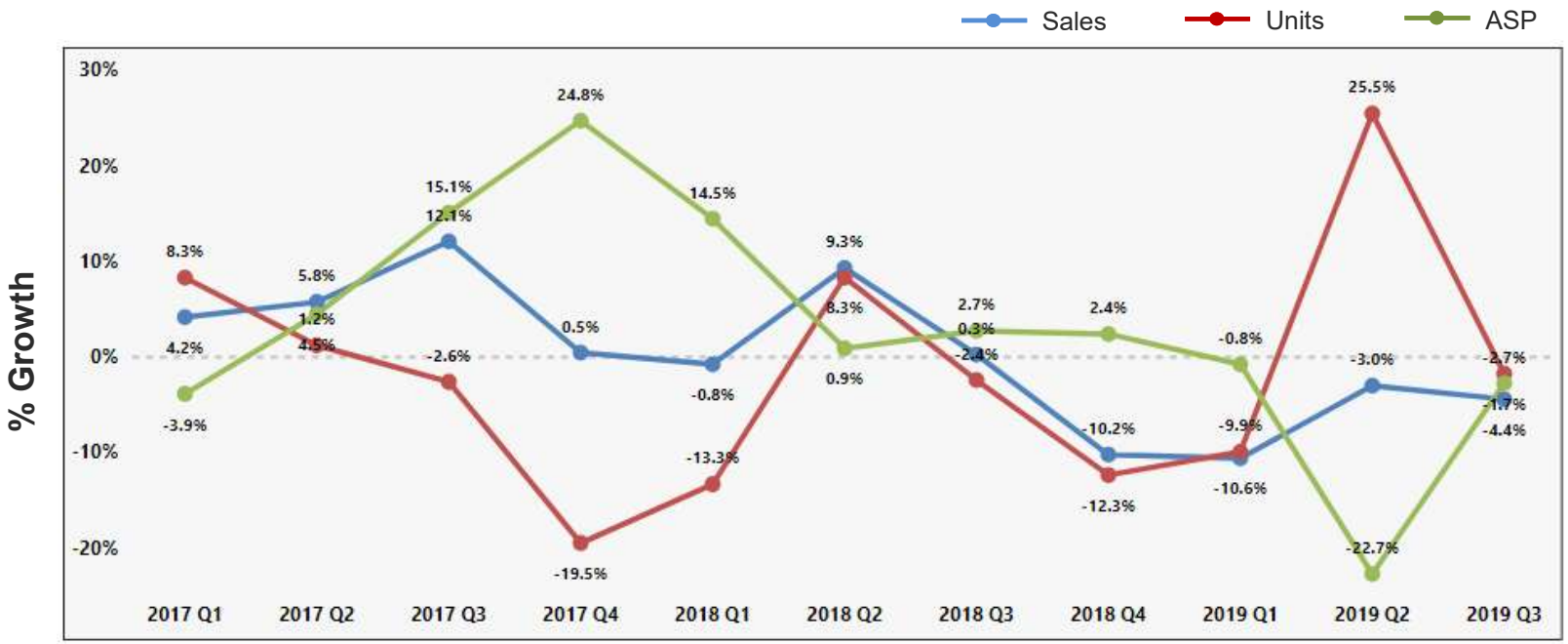
Type	Micron	Cypress/ Spansion	Macronix	Winbond	Adesto	ISSI	Microchip
Parallel NOR	X	X	X				X
Serial NOR	X	X	X	X	X	X	X

WW NOR Flash Units by Technology QoQ Trends



Severe price erosion responsible for revenue decline QoQ and YoY

WW Sales, ASP and Units Trends for NOR Flash

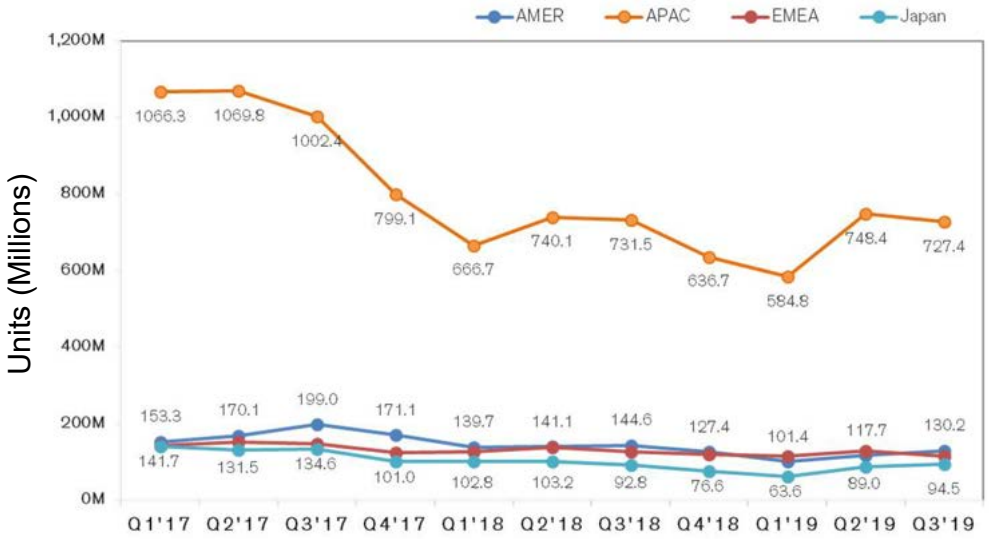


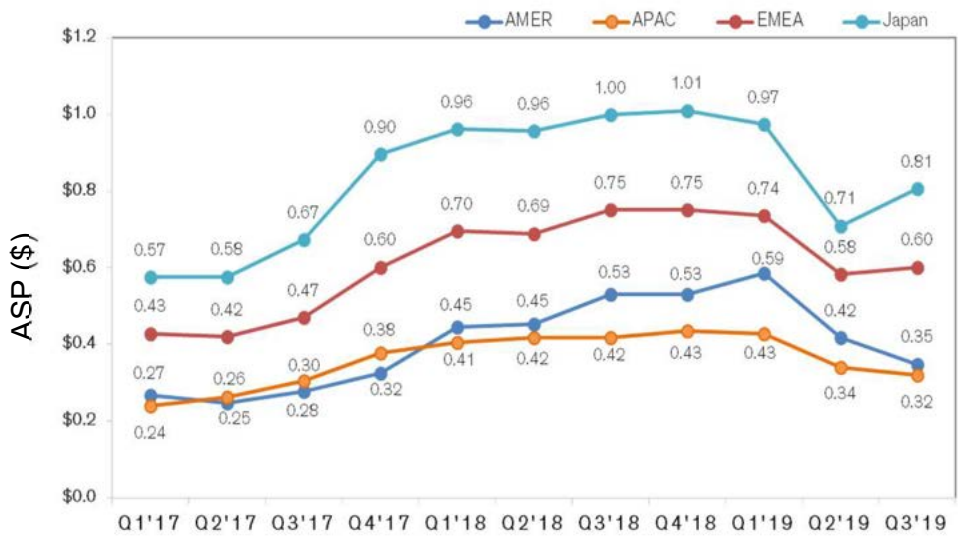
Sales, Units shipped and ASP all down in Q319

Source: WSTS

NOR QoQ Units/ASP Trends by Region

Continued ASP erosion for America and APAC





Source: WSTS

Q4'19 and YTD2019: SSD Trends

Five Years Out

SSD Market Dynamics – 3Q'19

Arrow SSD supplier portfolio

> Adoption of SSDs accelerating as price/GB gap between SSD and HDD is closing

> PCIe interface is quickly gaining share due to performance and efficiency advantages

> HDD replacement with SATA-based SSDs underway across all embedded applications

Suppliers	Applications			Protocol/Interface				Temp	
	Client	Enterprise	Embedded	NVMe	SATA	SAS	eUSB	Industrial	Automotive
Intel	X	X		X	X				
Kingston	X	X	X	X	X		X		
Micron*	X	X	X	X	X		X	X	X
PNY	X	X	X	X	X				
Samsung	X	X	X	X	X**	X			
Sandisk***	X	X	X	X	X				
Silicon Motion			X				X	X	
Swissbit	X		X	X	X			X	
Toshiba	X	X	X	X	X	X			
Virtium	X		X	X	X			X	

*: Micron includes Crucial (CPG Division)
**: Samsung announced that it will exit the SATA interface
***: A Western Digital company

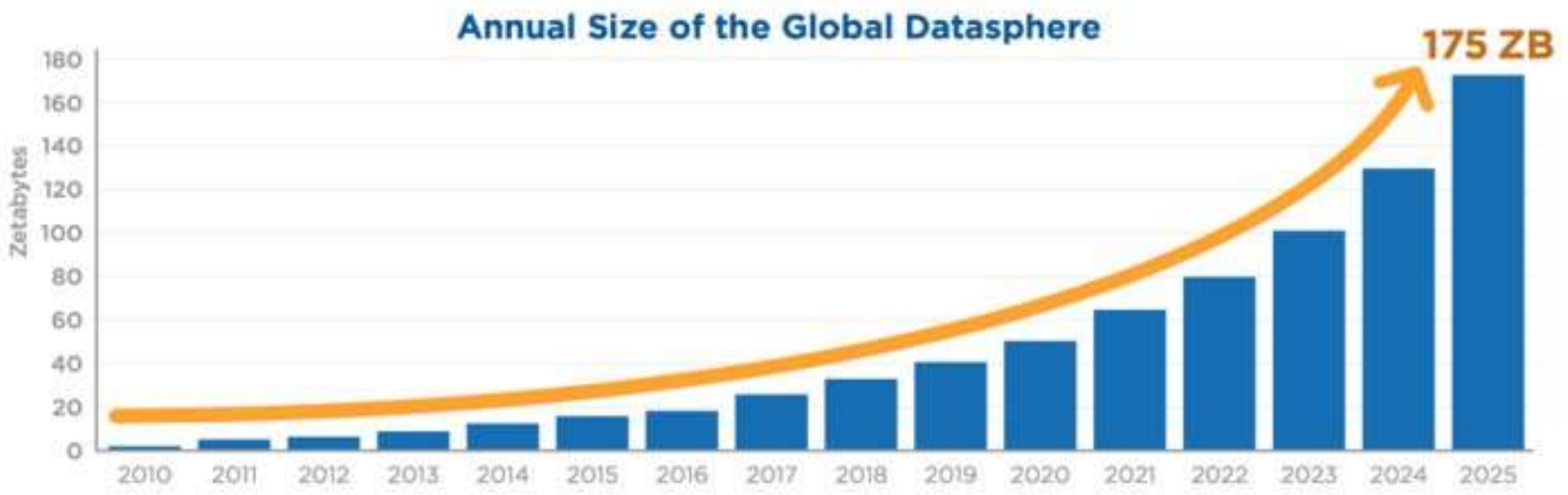
Data Growth Trends

175 zettabytes by 2025

Source: Flash Memory Summit

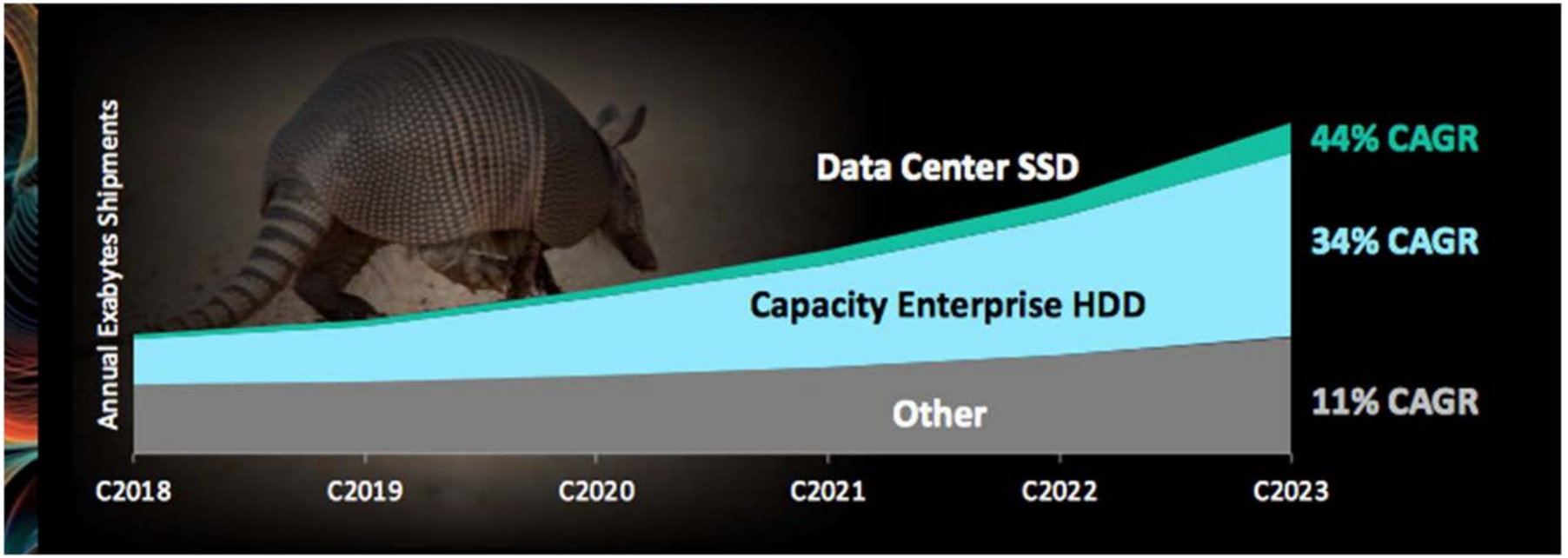
Data Growth Trends

Annual size of the global datasphere



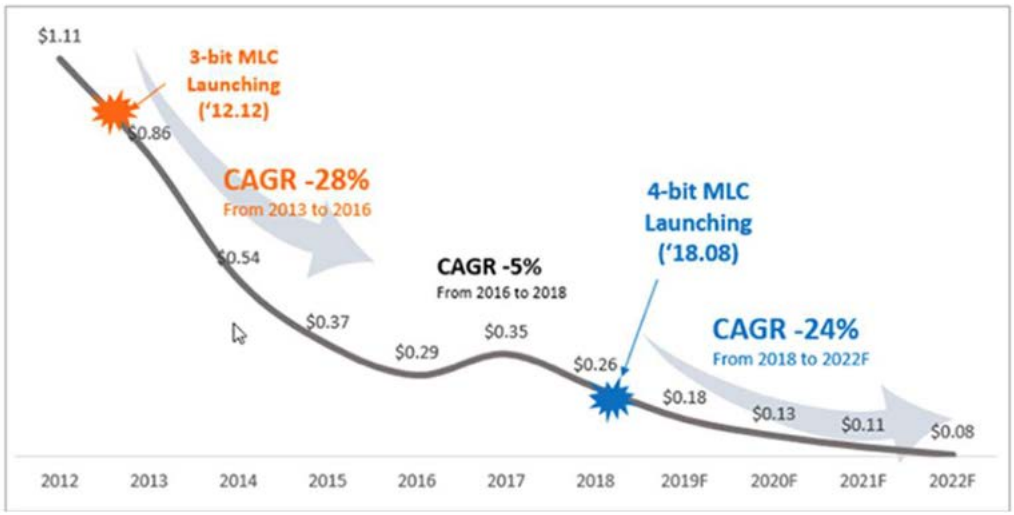
Source: Flash Memory Summit

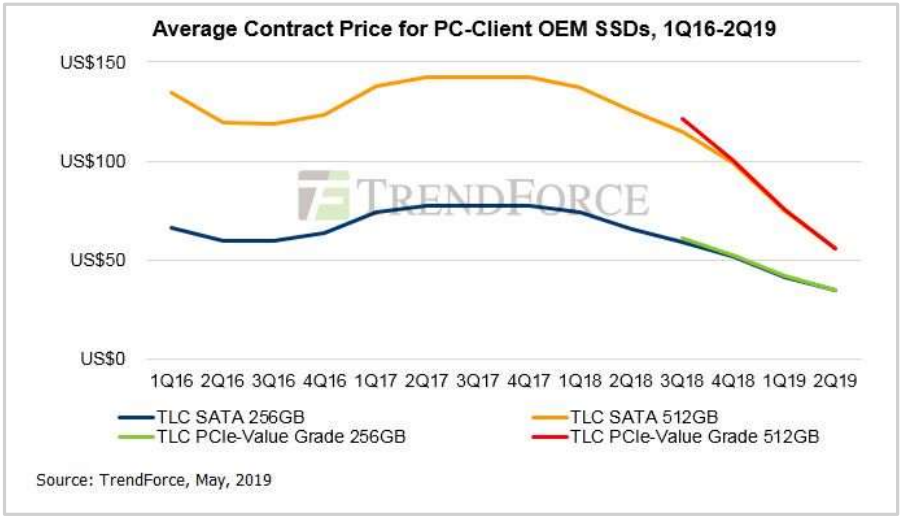
Storage Annual Exabyte Shipments



Source: Flash Memory Summit

SSD Price Trend and Forecast

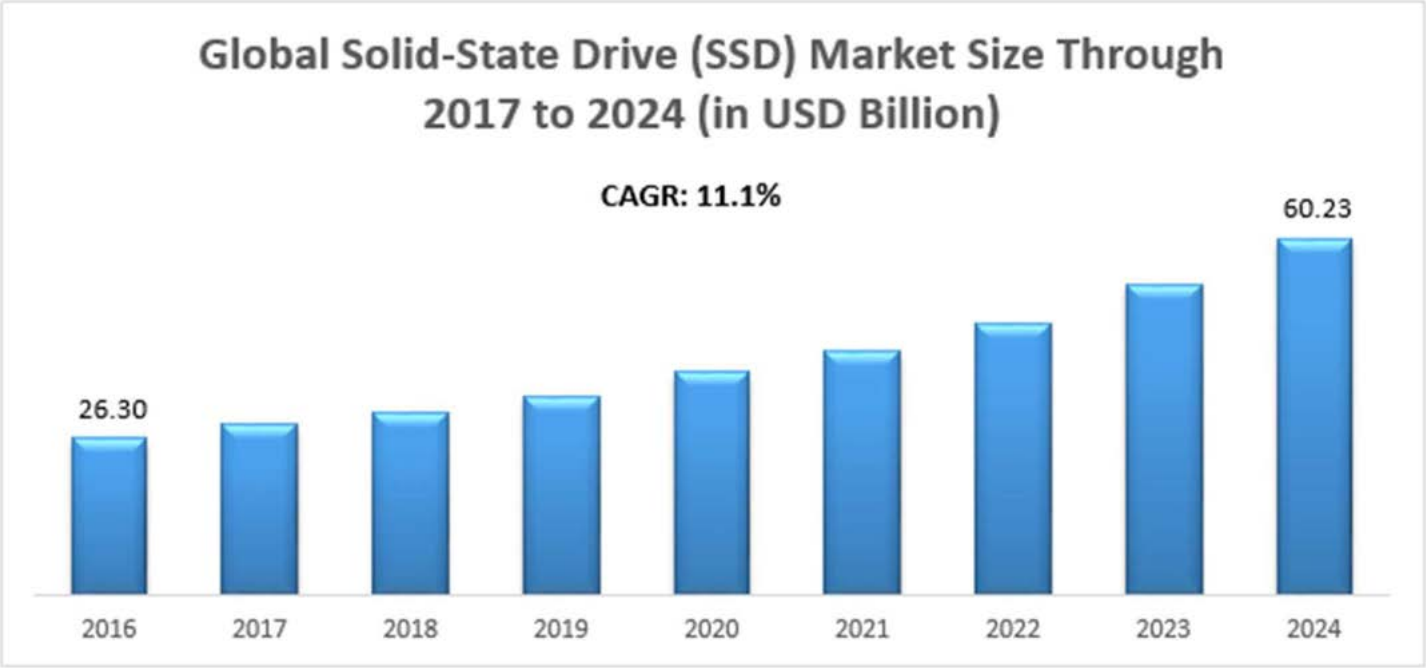




Source: I H S and Trendforce

SSD Market Size Forecast

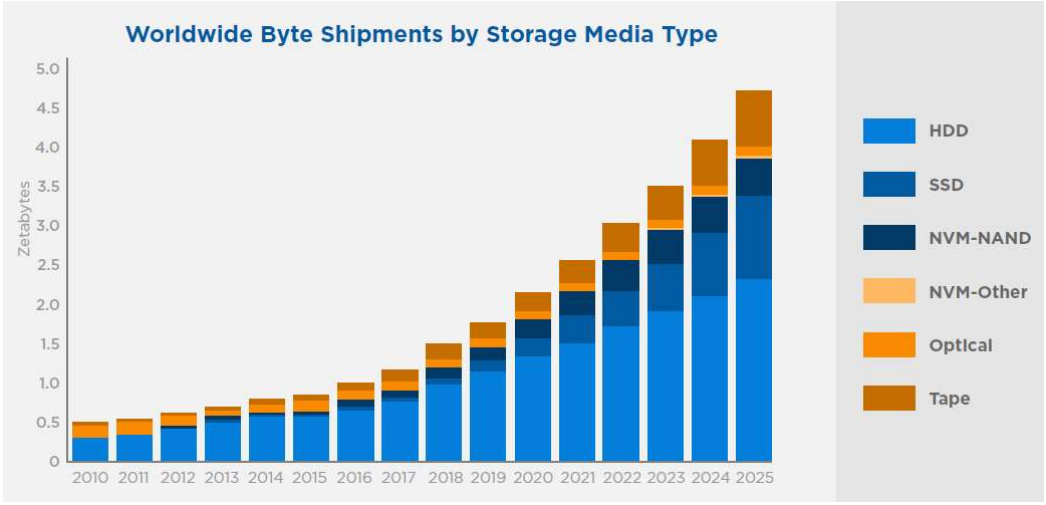
In USD billions

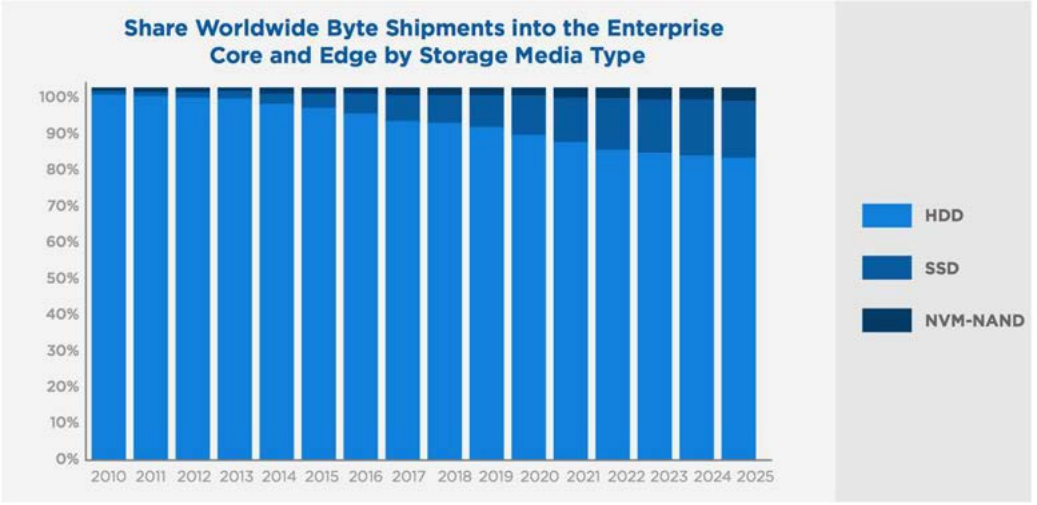


Source: Maximize Research

WW Byte Shipments

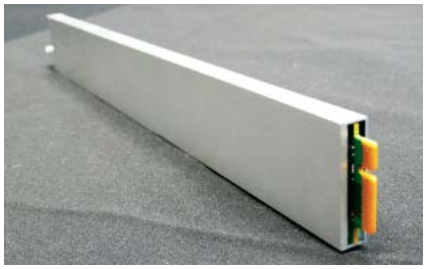
By Storage Media Type





Source: I H S and Trendforce

SSD Form Factors



Enterprise and Datacenter SSD Form Factor (EDSFF)

- Comes in three sizes for PCIe x4, x8, x16 links
- The smallest variant is 23.88mm wide, about the same size as a M.2 connector. The widest 4C variant is 57.02mm wide

M.2 SSD (22 mm x 80 mm single-sided)

M.2 SSD (22 mm x 60 mm double-sided)

- Comes with both traditional SATA or PCIe connectivity
- Designed to work with the AHCI or NVMe protocols
- Notebooks, ultrabook's and gaining popularity on motherboards

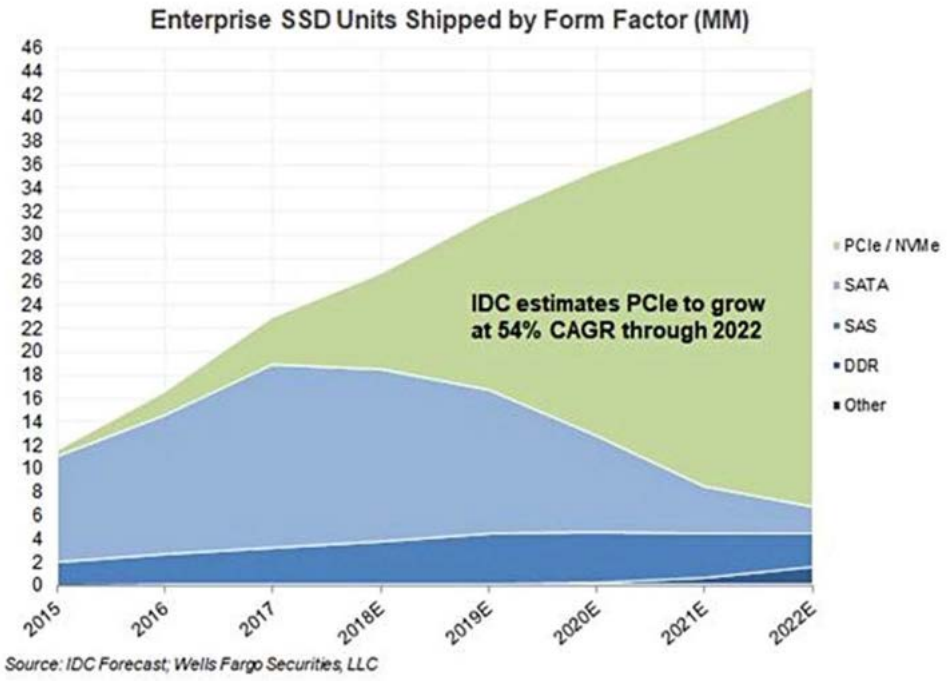
mSATA SSD

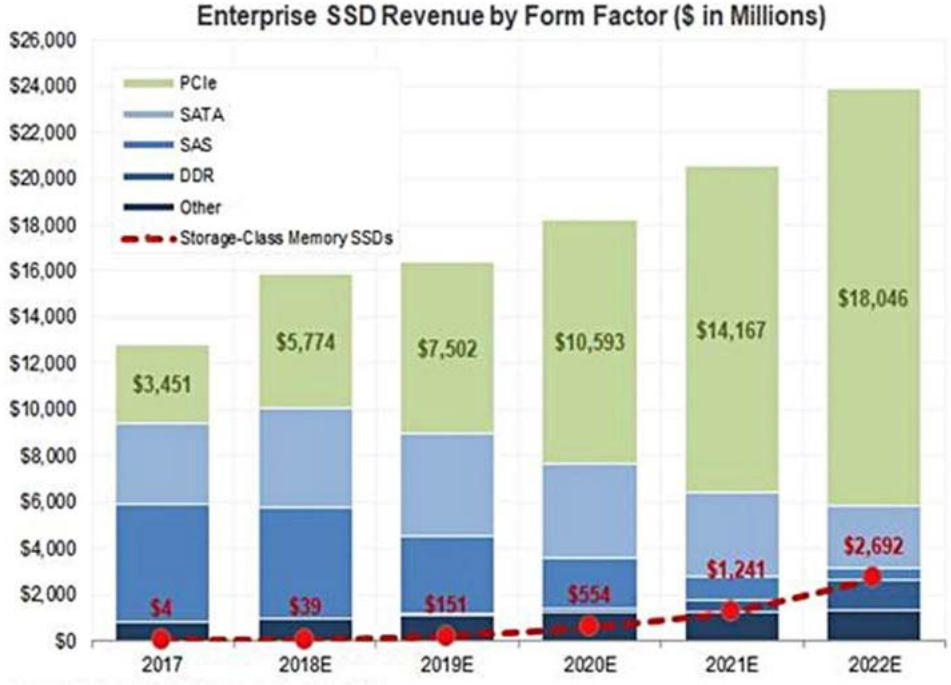
- Only comes in the SATA interface
- Does not use cables, fits directly into a slot
- Used in digital signs, point-of-sale devices, retail kiosks and multifunctional printers

2.5-inch SATA SSD

- Primarily used for HDD replacement to improve speed and general system performance

SSD Interfaces – PCIe, SATA and SAS

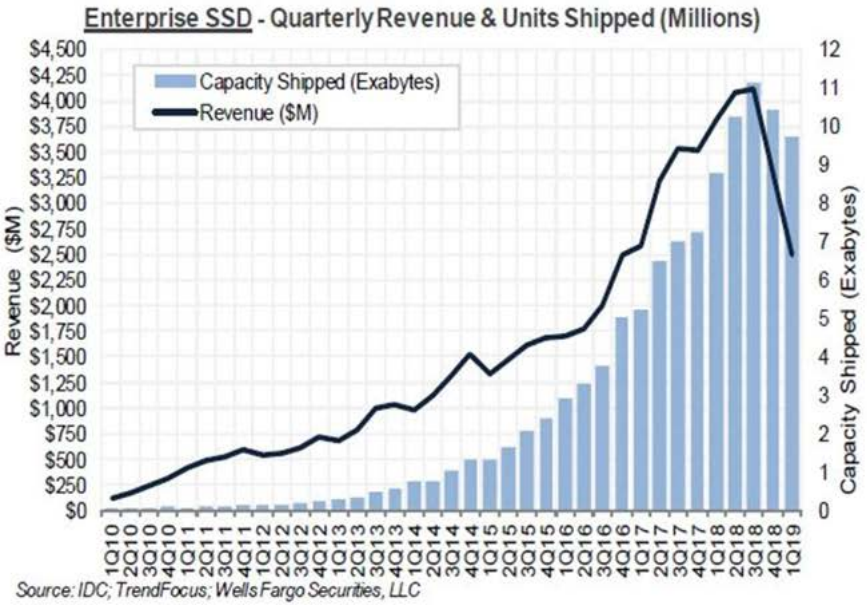


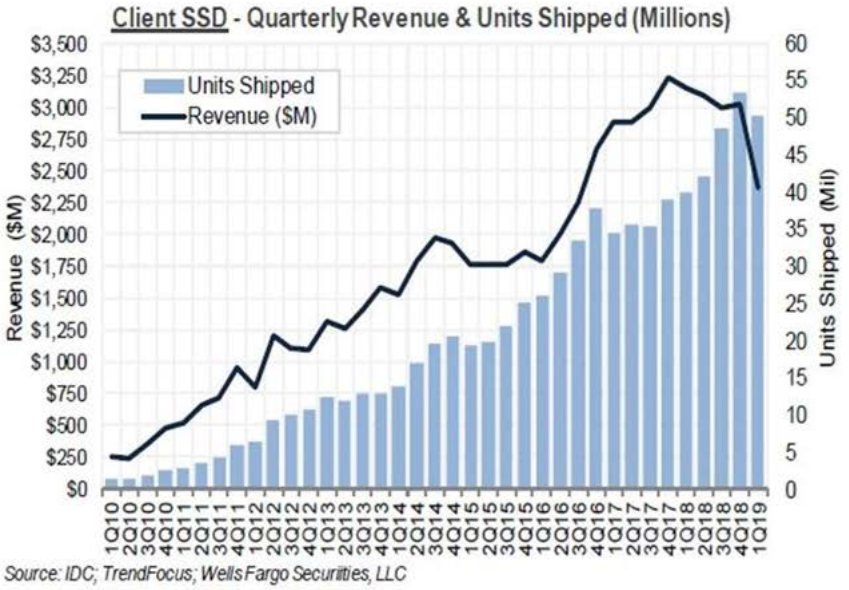


Source: IDC Forecast, Wells Fargo Securities

SSD Quarterly Revenue and Units Shipped

SSD revenue down

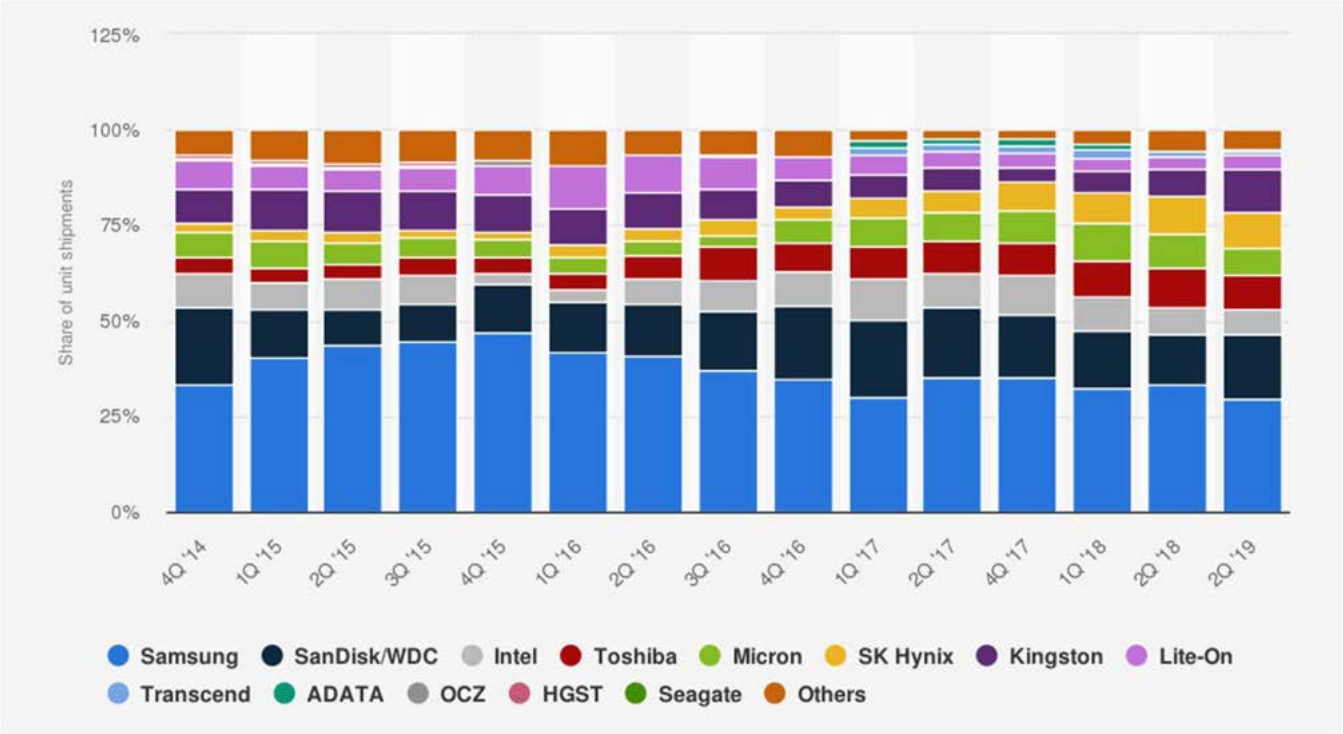




Source: Blocks and Files

SSD Units Shipped WW by Supplier

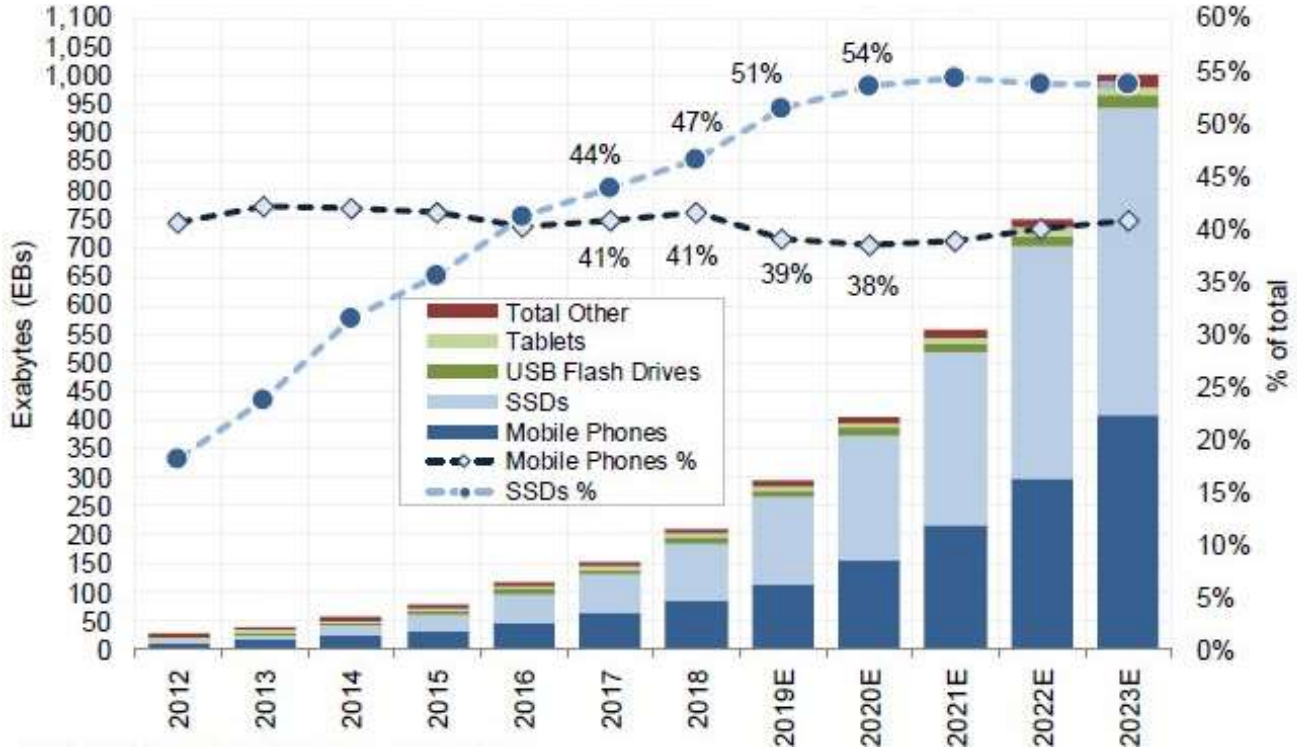
Samsung losing share, Western Digital and Kingston gaining



Source: Statista

NAND Flash Capacity by Application

SSDs expected to continue dominance as outpace growth



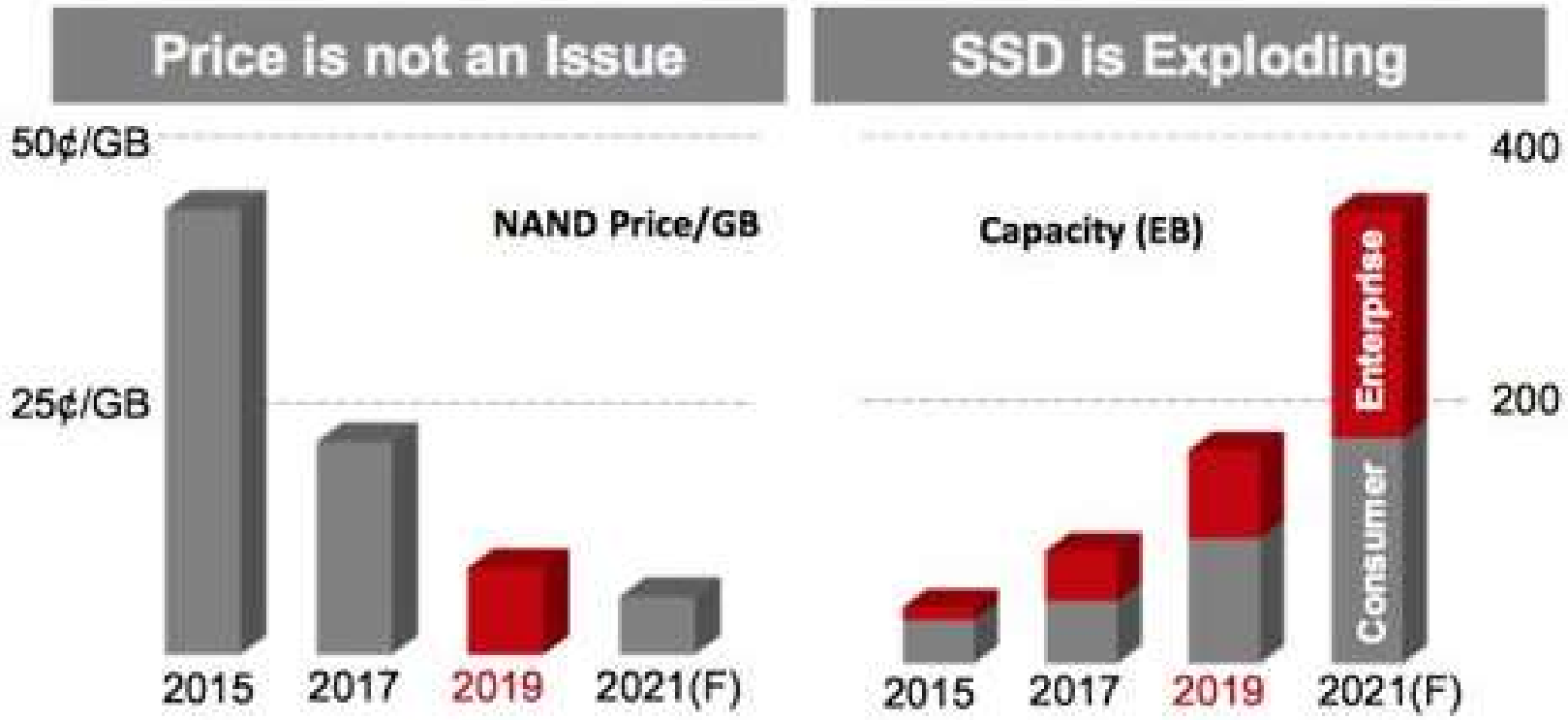
Source: IDC Forecast, Wells Fargo Securities

WW Shipments of HDD and SSD

In millions

Source: IHS

Enterprise SSD to Outgrow Overall SSD Market



Source: Flash Memory Summit

Top Growth Trends Among Flash Buyers

All-Flash Arrays	2H 2018	1H 2019	Change
Refresh legacy primary storage (driver)	19%	33%	**+74%**
Provide private cloud or cloud-like services (driver)	6%	10%	**+66%**
Policy-based automated tiering (feature)	5%	8%	**+60%**
Built-in storage analytics (feature)	7%	11%	**+57%**
Eliminate storage performance issues (driver)	23%	31%	**+35%**
Workload performance QoS (feature)	13%	15%	**+13%**

Hybrid Arrays	2H 2018	1H 2019	Change
Refresh legacy primary storage (driver)	20%	35%	**+75%**
Provide private cloud or cloud-like services (driver)	6%	8%	**+33%**
Improve existing application or database performance (driver)	16%	19%	**+19%**
Cloud integration (feature)	12%	14%	**+17%**
Ease of use (feature)	31%	35%	**+13%**
Capacity scalability (feature)	37%	41%	**+11%**

Source: Flash Memory Summit