Carnegie Mellon University

Data Storage Systems Center

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TMRC 2021 conference Technology Survey

Survey this year 1/2

*** 1. Describe your affiliation ?**

- ○ HDD Industry Member
- ○ MRAM Industry Member
- ○ Academia
- ○ Vendor
- ○ Other

Survey issued continuously over the meeting period. Differs from pre/post survey past years.

•The response rate was lower this year, so we consolidated the pre and post conference survey into one.

*** 2. What is the Maximum Areal Density Capability expected for Perpendicular/Shingled/Two dimensional - magnetic recording extensions?**

3. What is the expected Year of Technology introduction to HDD Products ?

	2020	2021	2022	2023	2024	2026	2028	2030	Never
BPM	○	○	○	○	○	○	○	○	○
HAMR	○	○	○	○	○	○	○	○	○
MAMR	○	○	○	○	○	○	○	○	○
HDMR(BPM+HAMR)	○	○	○	○	○	○	○	○	○

Survey this year 2/2

MRAM questions…
. And added a new storage tech question

4. What is the expected STAND_ALONE MRAM capacity (Mega/Gigabits) per chip in 2022?

256 Mb	512Mb	1 Gb	2 Gb	4 Gb	8 Gb	N/A
○	○	○	○	○	○	○

5. What is the expected EMBEDDED MRAM capacity (Mega/Gigabits) per chip in 2022?

256 Mb	512Mb	1 Gb	2 Gb	4 Gb	N/A
○	○	○	○	○	○

6. What is the expected NAND capacity (Terabits) per chip in 2022?

1 Tb	2 Tb	3 Tb	5 Tb	10 Tb	N/A
○	○	○	○	○	○

Other (please specify)

7. Which 3 new Emerging Memory Technologies are expected to be delivered in the next 5 Years

- ○ NRAM, FeFET, FeCAP
- ○ ARAM, xxRAM, NAND.
- ○ NRAM, NAND, STXRAM
- ○ DWM, FeFET, Yoda
- ○ None of the above

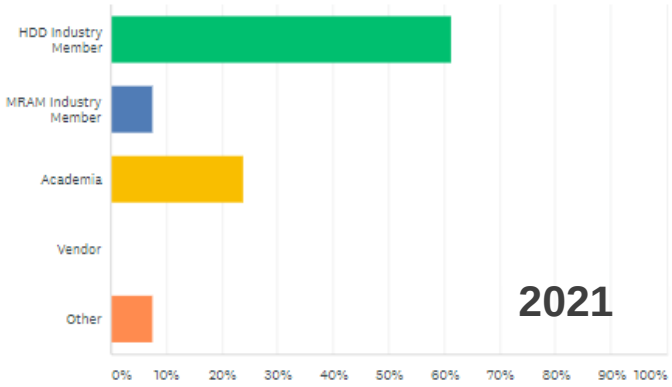
New this year

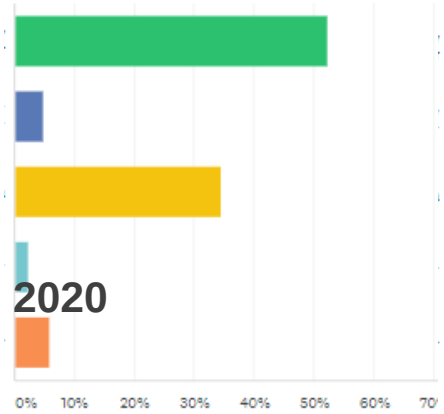
Population of respondents up to 08/26/20 (post conference)

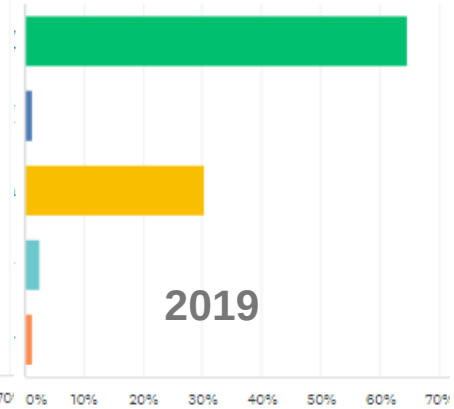
As with 2015-20.
Dominant responses from HDD members.
No vendors this year, MRAM industry to still to break 10%

Describe your affiliation ?

Answered: 67 Skipped: 0







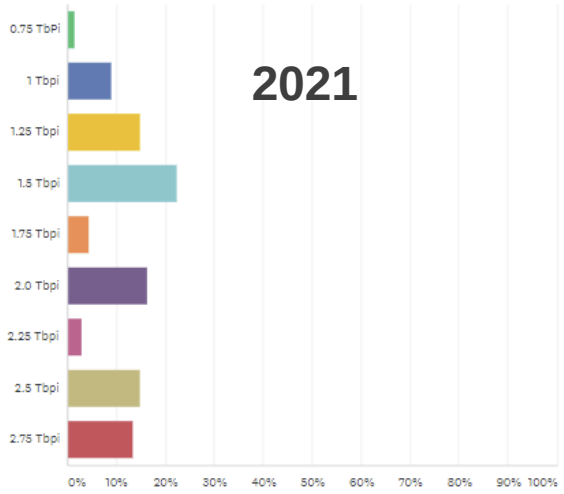
ANSWER CHOICES	RESPONSES	
HDD Industry Member	61.19%	41
MRAM Industry Member	7.46%	5
Academia	23.88%	16
Vendor	0.00%	0
Other	7.46%	5
TOTAL		67

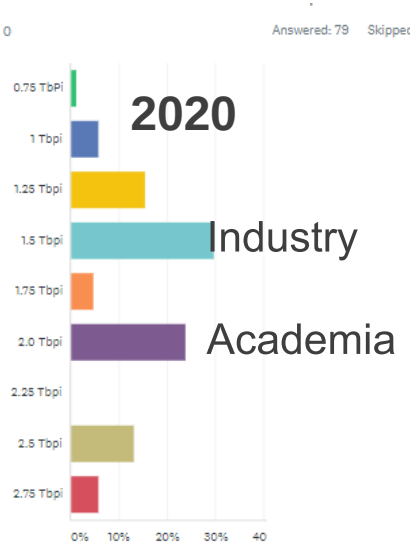
Maximum ADC, for conventional technology

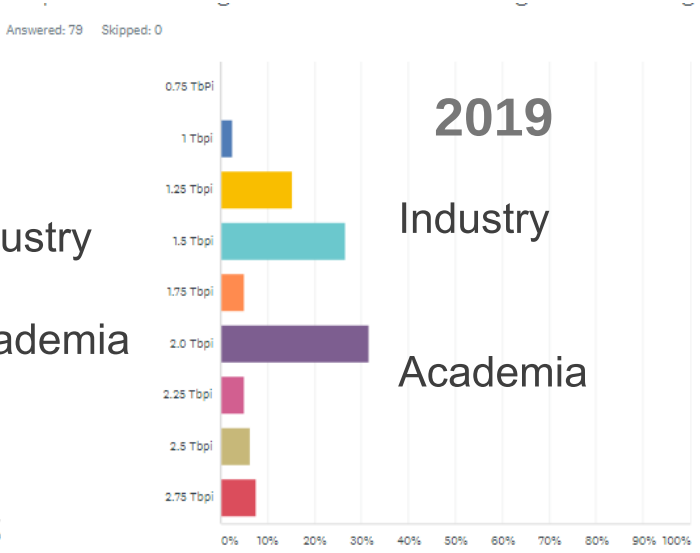
- **Median of 1.5Tb/inch^2 +/-0.25, mean of 1.75 Tb/inch^2**
- **A few optimistic voters for 2.5 Tb/inch^2, and above.**
- **Bimodality between Academia and Industry (lower mode for industry)**
- **Pattern very similar to 2020/2019/2018**

What is the Maximum Areal Density Capability expected for Perpendicular/Shingled/Two dimensional - magnetic recording extensions?

Answered: 67 Skipped: 0







ANSWER CHOICES	RESPONSES	
0.75 TbPi	1.49%	1
1 Tbpi	8.96%	6
1.25 Tbpi	14.93%	10
1.5 Tbpi	22.39%	15
1.75 Tbpi	4.48%	3
2.0 Tbpi	16.42%	11
2.25 Tbpi	2.99%	2
2.5 Tbpi	14.93%	10
2.75 Tbpi	13.43%	9
TOTAL		67

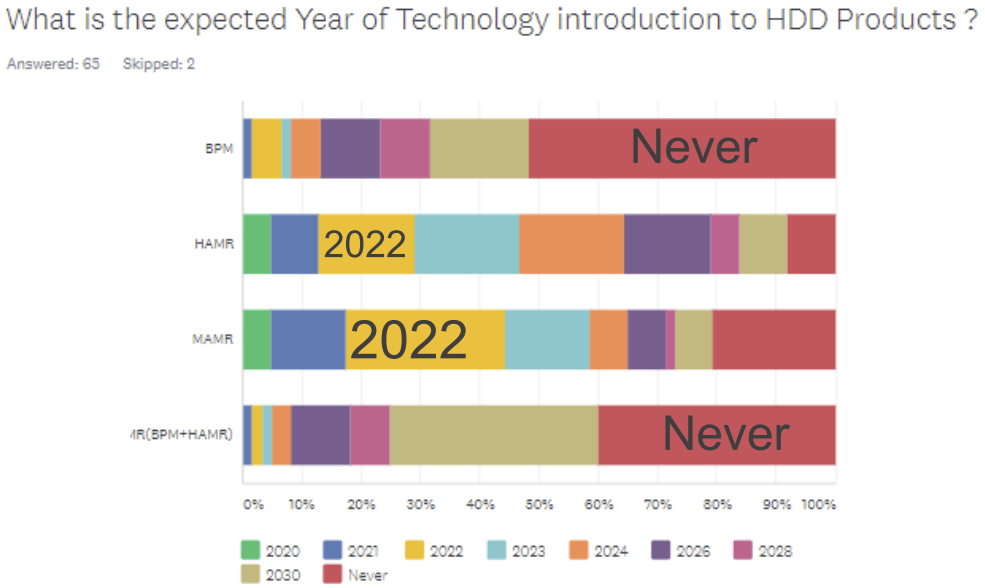
Expected introduction year

Pessimism for MAMR reduced in 2017, and improved 2018- drift back up 2019+ stayed.

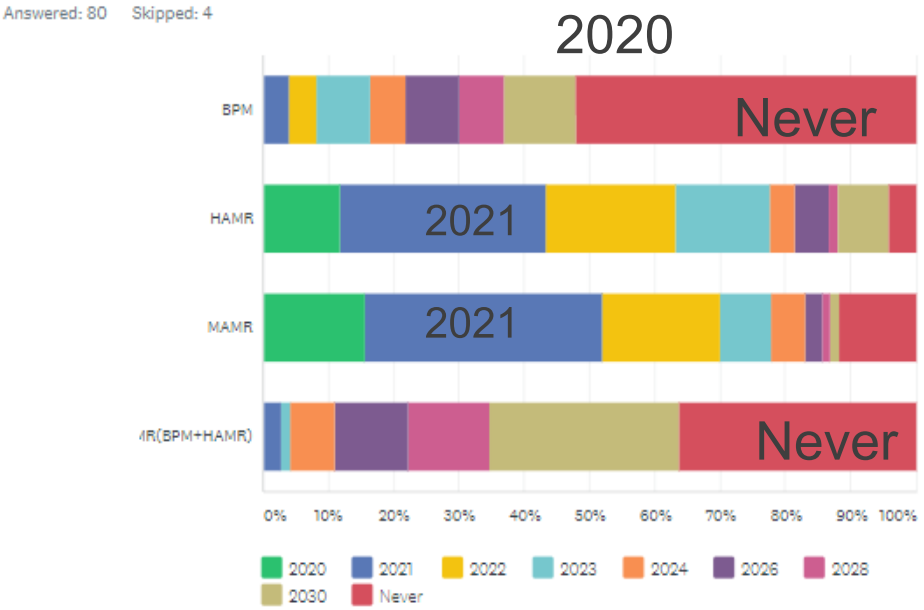
BPM/Heated Dot remains pessimistic

Focus in next slide on specific fraction of people that think a technology will not work

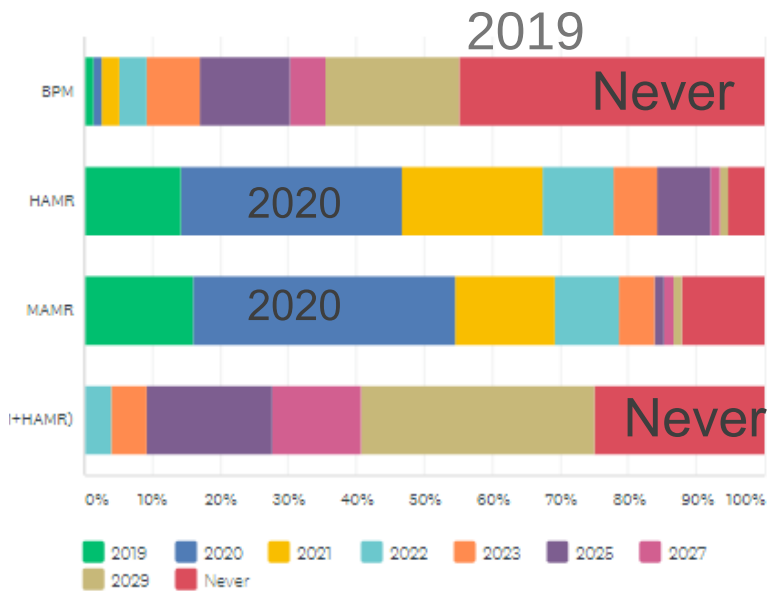
2021



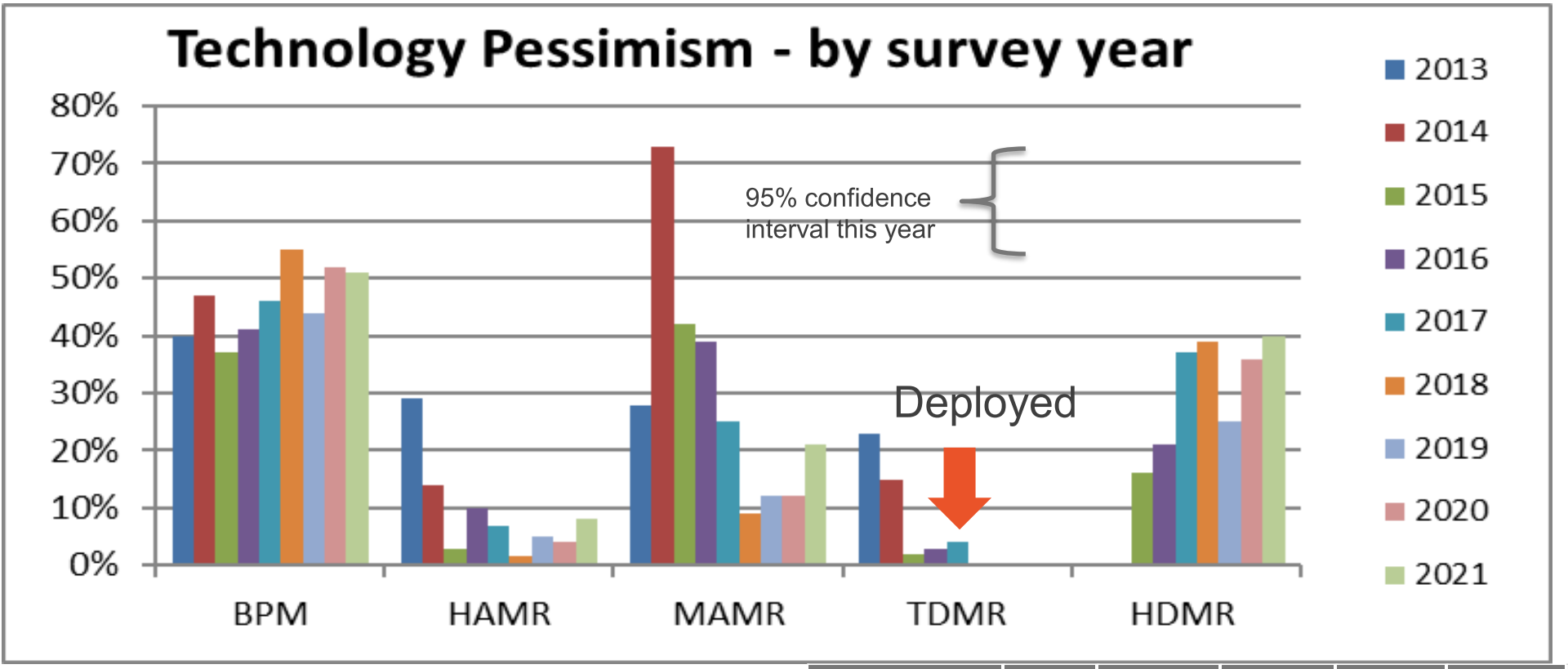
2020



2019



Technology pessimism(Never): Compare 2020 with 2019-2013



From left to right..

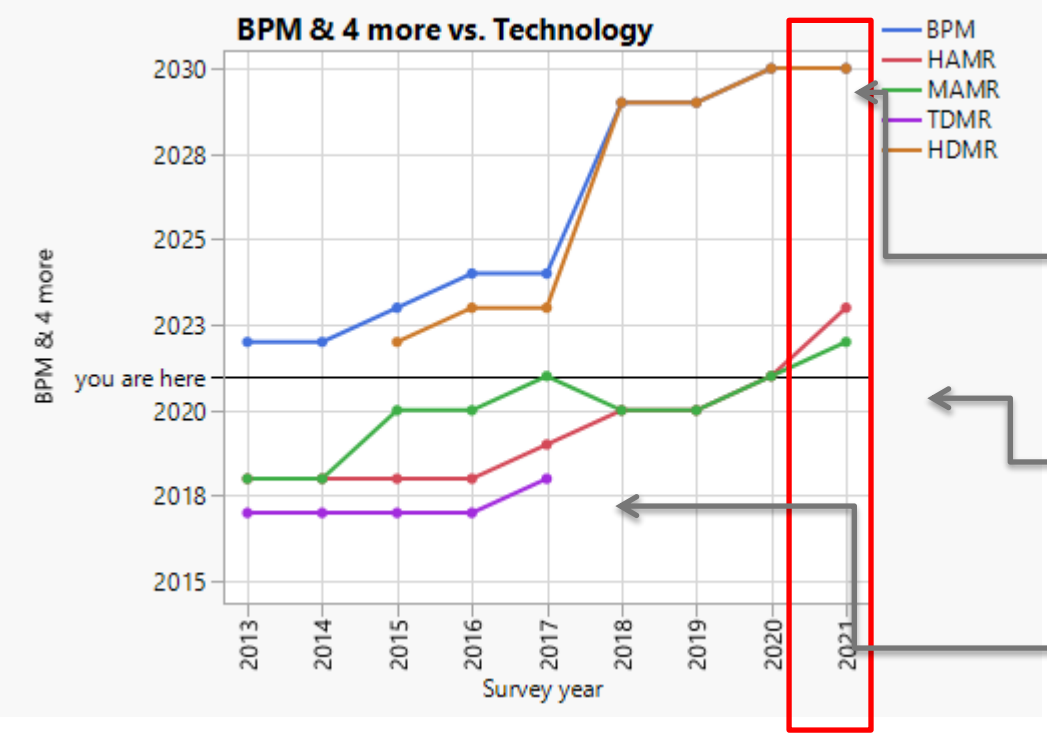
- **BPM appears stable and poor.**
- **HAMR confidence steady improved.**
- **MAMR hit a bad patch 2014, started recovery in 2016-2017, and significantly improved 2018- possible decline last 3 years..**
- **TDMR Launched 2017 into product – so removed 2018.**
- **HDMR confidence – higher than BPM but still poor.**

Technology	BPM	HAMR	MAMR	TDMR	HDMR
2013	40%	29%	28%	23%	
2014	47%	14%	73%	15%	
2015	37%	**3%**	42%	**2%**	16%
2016	41%	**10%**	39%	3%	21%
2017	46%	7%	**25%**	4%	**37%**
2018	55%	2%	**9%**		**39%**
2019	**44%**	5%	**12%**		**25%**
2020	**52%**	4%	**12%**		**36%**
2021	**51%**	8%	**21%**		**40%**

Technology Introduction year

Technology	BPM	HAMR	MAMR	TDMR	HDMR
2013	2022	2018	2018	2017	N/A
2014	2022	2018	2018	2017	N/A
2015	2023*	2018	2020*	2017	2022
2016	2024*	2018	2020*	2017	2023
2017	2024*	2019	2021*	2018	2023*
2018	2029*	2020	2020	-	2029*
2019	2029*	2020	2020	-	2029*
2020	2030*	2021	2021	-	2030*
2021	2030*	2023	2022	-	2030*

*Pessimism is high
So confidence on introduction year is poor.



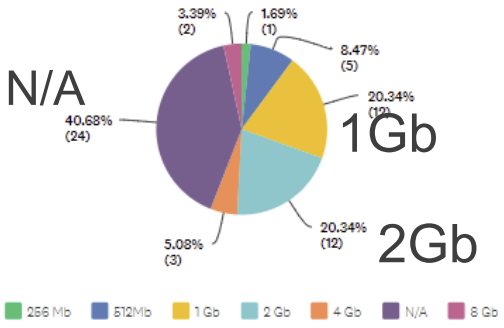
- BPM and HDMR continues to drift out.
- MAMR and HAMR both pushed out “just one more year”
- TDMR Launched 2017

MRAM questions- Stand Alone Memory

What is the expected STAND_ALONE MRAM capacity (Mega/Gigabits) per chip in 2022?

Answered: 59 Skipped: 8

2021



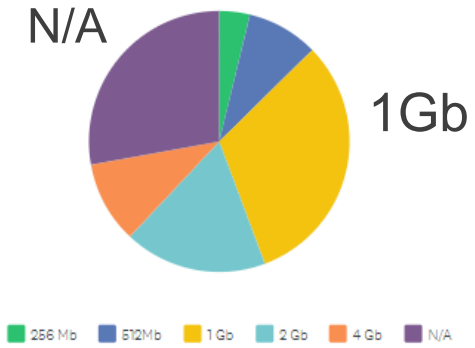
	256 MB (1)	512MB (2)	1 GB (3)	2 GB (4)	4 GB (5)	N/A	8 GB (7)	TOTAL	WEIGHTED AVERAGE
(no label)	1.69% 1	8.47% 5	20.34% 12	20.34% 12	5.08% 3	40.68% 24	3.39% 2	59	4.49

1 or 2 GB per chip remains most popular choice, and stable.

What is the expected STAND_ALONE MRAM capacity (Megabits) per chip in 2021?

Answered: 79 Skipped: 5

2020

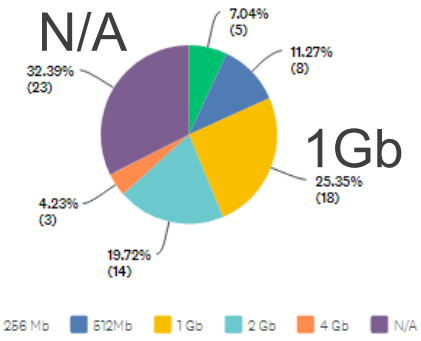


	256 MB	512MB	1 GB	2 GB	4 GB	N/A	TOTAL	WEIGHTED AVERAGE
(no label)	3.80% 3	8.86% 7	31.65% 25	17.72% 14	10.13% 8	27.85% 22	79	4.30

What is the expected STAND_ALONE MRAM capacity (Megabits) per chip in 2020?

nswered: 71 Skipped: 8

2019



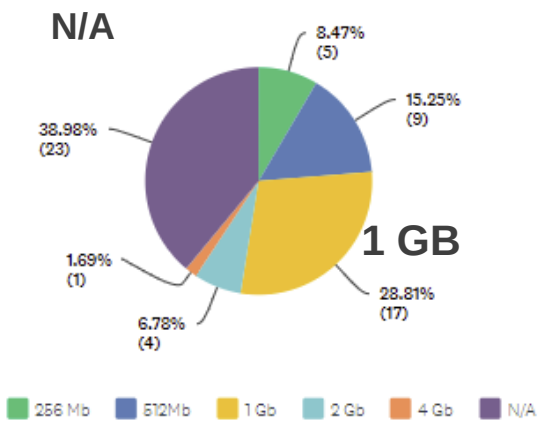
	256 MB	512MB	1 GB	2 GB	4 GB	N/A	TOTAL	WEIGHTED AVERAGE
(no label)	7.04% 5	11.27% 8	25.35% 18	19.72% 14	4.23% 3	32.39% 23	71	4.04

Embedded MRAM

Similar to 2018-202
512 and 1 Gb most popular
Moving more into 1Gb node.

What is the expected EMBEDDED MRAM capacity (Mega/Gigabits) per chip in 2022?

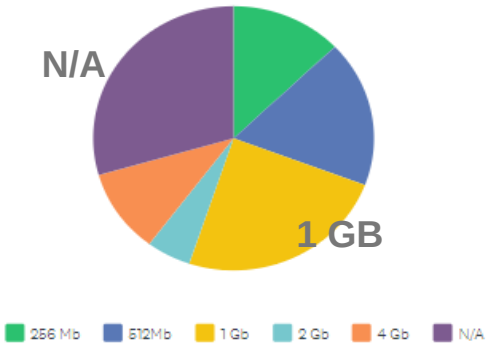
Answered: 59 Skipped: 8



	256 MB (1)	512MB (2)	1 GB (3)	2 GB (4)	4 GB (5)	N/A (6)	TOTAL	WEIGHTED AVERAGE
(no label)	8.47% 5	15.25% 9	28.81% 17	6.78% 4	1.69% 1	38.98% 23	59	3.95

What is the expected EMBEDDED MRAM capacity (Megabits) per chip in 2021 he expected EMBEDDED MRAM capacity (Megabits) per chip in

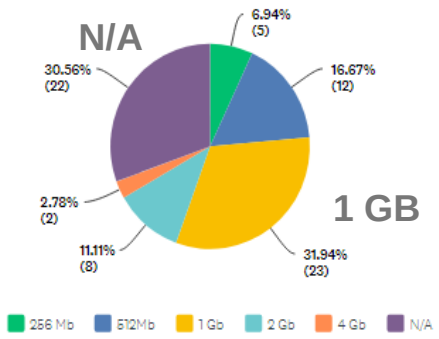
ewered: 78 Skipped: 6



2020

	256 MB	512MB	1 GB	2 GB	4 GB	N/A	TOTAL	WEIGHTED AVERAGE
(no label)	12.82% 10	17.95% 14	24.36% 19	5.13% 4	10.26% 8	29.49% 23	78	3.71

Skipped: 7



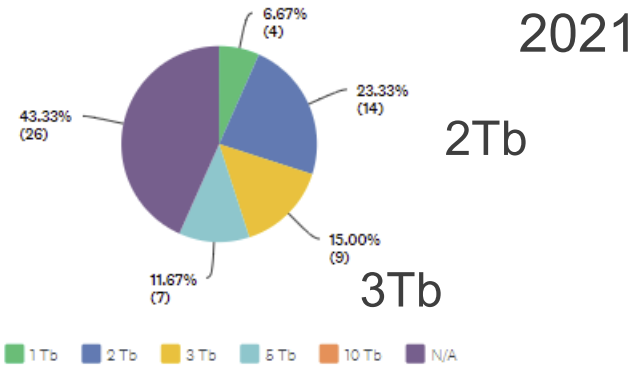
2019

	256 MB	512MB	1 GB	2 GB	4 GB	N/A	TOTAL	WEIGHTED AVERAGE
)	6.94% 5	16.67% 12	31.94% 23	11.11% 8	2.78% 2	30.56% 22	72	3.78

NAND Ouestion

What is the expected NAND capacity (Terabits) per chip in 2022?

Answered: 60 Skipped: 7



2021

2Tb

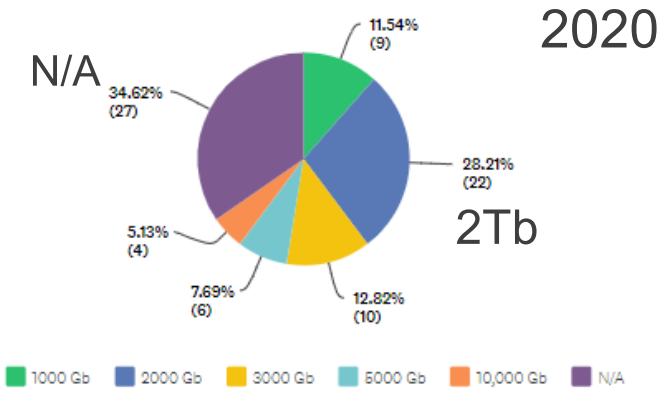
3Tb

	1 TB (1)	2 TB (2)	3 TB (3)	5 TB (4)	10 TB (5)	N/A	TOTAL	WEIGHTED AVERAGE
(no label)	6.67% 4	23.33% 14	15.00% 9	11.67% 7	0.00% 0	43.33% 26	60	2.58

2Tb is most popular node.
Which is a significant change in votes from 2018.
. But 3T also growing popularity

What is the expected NAND capacity (Gigabits) per chip in 2021?

Answered: 78 Skipped: 6



2020

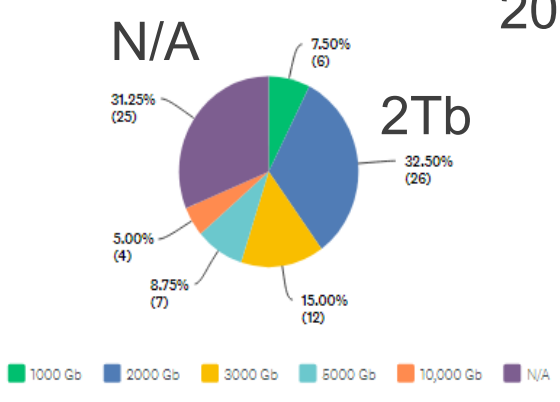
N/A

2Tb

	1000 GB	2000 GB	3000 GB	5000 GB	10,000 GB	N/A	TOTAL	WEIGHTED AVERAGE
(no label)	11.54% 9	28.21% 22	12.82% 10	7.69% 6	5.13% 4	34.62% 27	78	2.49

ıe expected NAND capacity (Gigabits) per chip in 2020?

kipped: 9



2019

N/A

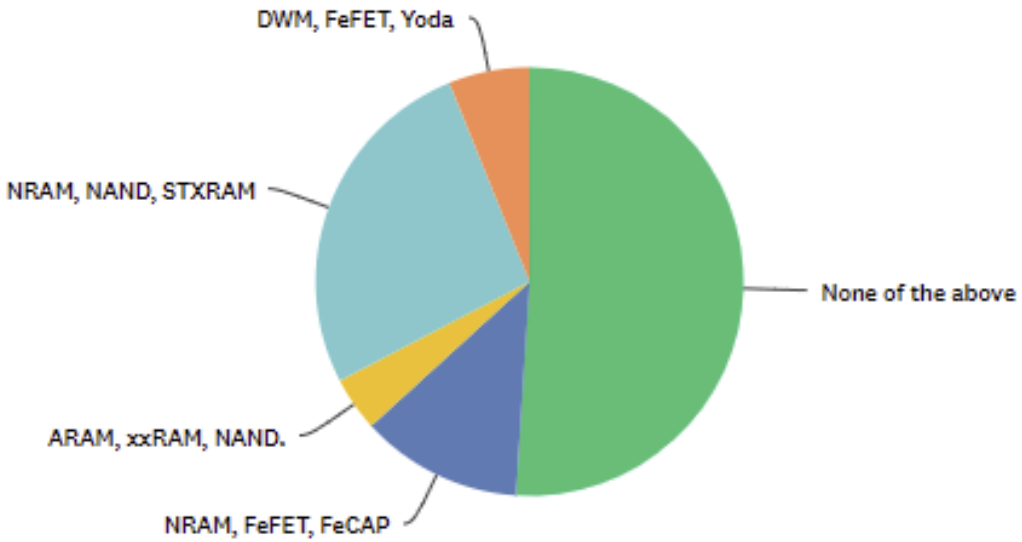
2Tb

	1000 GB	2000 GB	3000 GB	5000 GB	10,000 GB	N/A	TOTAL	WEIGHTED AVERAGE
	7.50% 6	32.50% 26	15.00% 12	8.75% 7	5.00% 4	31.25% 25	80	2.58

New question this year about solid state technologies.

Which 3 new Emerging Memory Technologies are expected to be delivered in the next 5 Years

Answered: 49 Skipped: 18



ANSWER CHOICES	RESPONSES	
None of the above	51.02%	25
NRAM, FeFET, FeCAP	12.24%	6
ARAM, xxRAM, NAND.	4.08%	2
NRAM, NAND, STXRAM	26.53%	13
DWM, FeFET, Yoda	6.12%	3
TOTAL		49

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Thank You