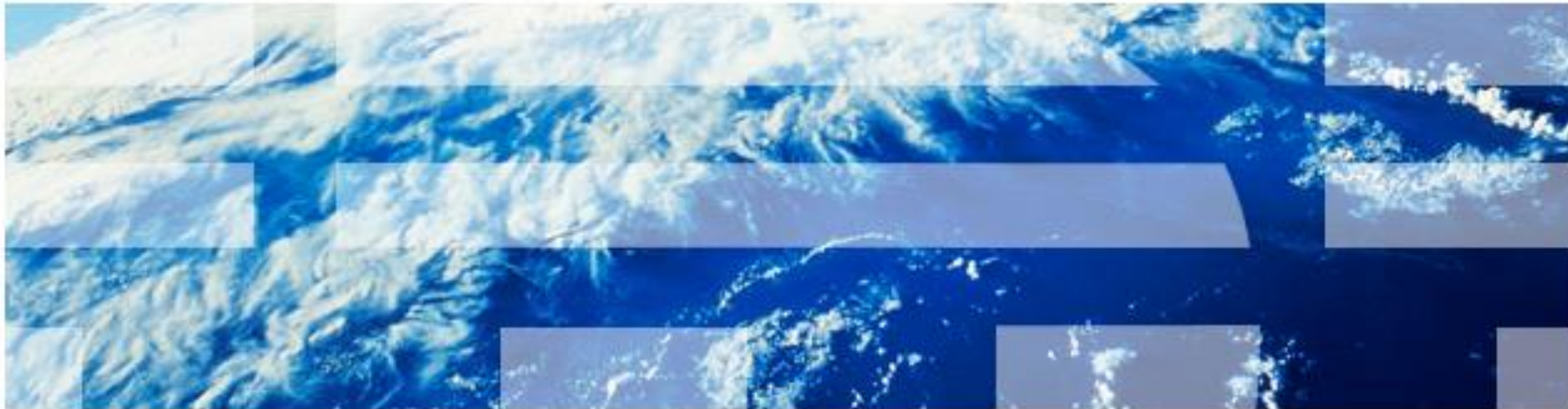


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## Tape Storage and the Cloud



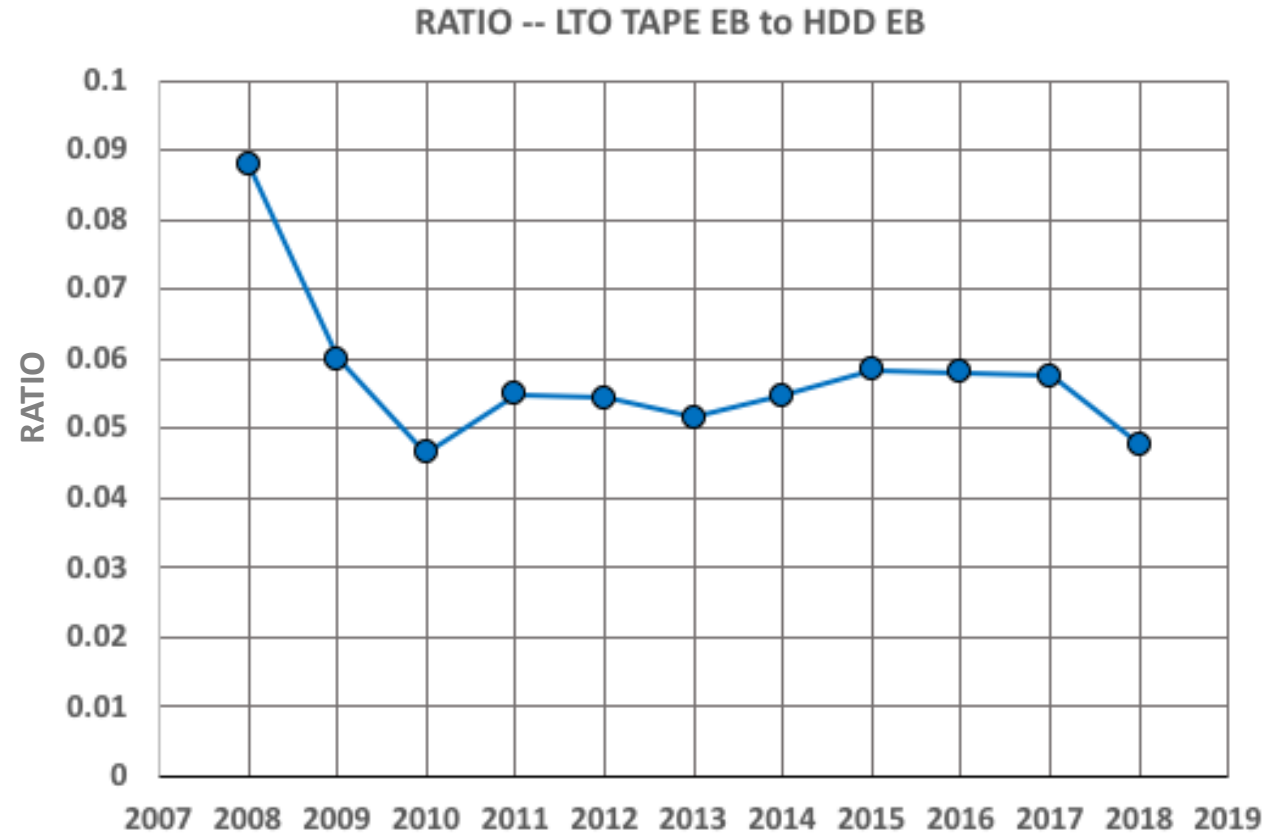
## Tape and the Cloud -- Observations

- Tape storage is strategic in public, hybrid, and private “Clouds”
- Tape storage is linked to HDD storage – everything stored on tape comes from HDD devices
- Tape, unlike HDD, has consistently achieved published capacity roadmaps
  - INSIC Tape Roadmap (2015)
  - LTO6, LTO7, LTO8, TS1155, TS1160 Comparisons to INSIC Roadmap Guidelines
  - 80 TB Cartridge Design Strategies in the 2025 time period
  - Evolutionary development independent of HDD revolutionary technologies like HAMR and MAMR
- A technology example – 0.25 um trackwidth sensors
- The 2018 storage environment

2018	HDD	NAND	LTO MEDIA	TOTAL
<b>Exabytes</b>	<b>938 EB (75%)</b>	<b>250 EB (20%)</b>	<b>44 EB (5%)</b>	<b>1232 GB</b>
<b>Revenue</b>	<b>\$26.4B (29.2%)</b>	<b>\$63.2B (70.0%)</b>	<b>\$0.5B (0.6%)</b>	<b>\$90.1B</b>
<b>Bit Cost</b>	<b>\$0.028/GB</b>	<b>\$0.252/GB</b>	<b>\$0.010/GB</b>	<b>\$0.073/GB</b>

## Tape and the Cloud – Observations and Topics

- Tape storage is linked to HDD storage – everything stored on tape comes from HDD devices
- For the last 8 years, the ratio of manufactured EB of tape to manufactured EB of HDD as remained constant in the 5.5% range.
- The 2008 to 2010 data are characterized by adoption of deduplication and other data consolidation strategies.



- Areal Density Growth rate is a measure of a storage technology vitality.
- Tape Areal Density Growth rate for the last 6 years has averaged ~30%/YR, achieving tape roadmap goals of doubling cartridge capacity every 2 years. In comparison HDD areal density growth for the last 6 years has been **less** than 15% annually
- 2015 INSIC Roadmap
  - Cartridge capacity doubles every 2 years (41%/YR)
  - Areal density increases 31% annually
  - Tape length increases 4% annually
  - Space allocation for overhead requirements (ECC,...) reduces 4% annually
- INSIC assumptions are benchmarked with a 2015 cartridge capacity of 8 TB. Roadmap assumptions are not directly related to products in the LTO or Enterprise families but rather reflect a blend of tape product characteristics
- Tape Areal Density benchmarks


• LTO6	2.0 Gbit/in <sup>2</sup>	• TS1155	9.6 Gbit/in <sup>2</sup>
• LTO7	4.3 Gbit/in <sup>2</sup>	• TS1160	12.0 Gbit/in <sup>2</sup>
• LTO8	7.9 Gbit/in <sup>2</sup>		

# Some Details of the 2015 Tape Roadmap

**Table 1: 2015 Tape Technology Roadmap Detail.**

Parameter/Year	2015	2017	2019	2021	2023	2025		
1. Capacity (TB)	8	16	32	63	125	248	41.00%	per year
2. Data rate per channel (MB/sec)	10.0	13.2	17.5	23.1	30.6	40.5	15.00%	per year
3. Total data rate (MB/sec)	320.0	480.2	720.6	1081.4	1622.7	2435.1	22.50%	per year
4. FC Speed Roadmap (MB/sec)**	3200	6400	12800	12800	25600	25600		
5. Number of channels	32	36	41	47	53	60	6.52%	per year
6. Tape thickness (um)	5.20	4.79	4.42	4.07	3.75	3.46	-4.00%	per year
7. Data capacity reserve	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%		defect reserve
8. Tape length that is recordable (meters)***	969	1051	1141	1238	1343	1457	3.90%	winding reserve
9. Tape length total (meters)****	1041	1129	1225	1330	1443	1565	4.17%	per year
10. Track density (TPI)	10,686	15,652	22,868	33,543	49,372	72,891	21.17%	per year
track pitch = 25400/tpi (um)	2.38	1.62	1.11	0.76	0.51	0.35		
11. Linear bit density (kfc)*****	480	581	703	850	1029	1245	10.00%	per year
fcmm = kfc/0.0254	18,898	22,866	27,668	33,478	40,509	49,016		
12. Areal density (Gbits/inch <sup>2</sup> )	5.13	9.09	16.07	28.52	50.80	90.75	33.28%	per year
13. Tape speed (m/sec)	5.4	5.8	6.2	6.7	7.2	7.7	3.61%	per year
14. Tape width in mm	12.65	12.65	12.65	12.65	12.65	12.65		
15. ECC and formatting overhead	22.00%	20.28%	18.69%	17.22%	15.87%	14.63%	-4.00%	per year
16. Servo track and layout overhead *****	15.80%	14.84%	13.46%	12.24%	11.17%	10.22%	-6.00%	per year
17. Number of passes to write a tape	140	183	239	314	412	541		
18. Number of passes to end-of-life (media)	27200	29194	31333	33630	36095	38741	3.6%	per year
19. Time to fill a tape in mins	417	552	731	969	1284	1701	15.10%	per year
20. Number of data tracks	4,481	6,639	9,856	14,660	21,842	32,593	21.95%	per year
21. Number of data bands	4	5	7	9	12	16	15.00%	per year
overall head span (um)	3,000	2,268	1,715	1,297	981	742		
22. Tape Dimensional Stability (ppm)	317	286	259	234	210	188	-5.09%	per year
23. Bit Aspect Ratio (BAR)	53	44	36	29	23	19	-9.80%	per year
24. Bit Error Rate	1.00E-19	5.00E-20	2.50E-20	1.25E-20	6.25E-21	3.12E-21	-29.29%	per year
** Reference: <a href="http://www.fibrechannel.org/roadmap/">http://www.fibrechannel.org/roadmap/</a>								
*** Defined as the length of tape required to store the defined tape capacity.								
It does not include the reserved space for possible defects.								
**** Defined as the total length of tape including length used for attachment and hub covering								
***** Defined as the 1T kfc where T is the data cell length								
***** On non-capacity reserve overhead only								

The 10 Year Tape Roadmap makes straightforward technical assumptions to achieve cartridge capacity doubling on a 2 year cycle

- BPI, TPI
- Media thickness and/or tape length
- Data rate and channel number

Meeting roadmap goals require sustained development commitment in multiple tape disciplines

- Media development (SNR and thickness)
- PES and Servo
- Heads
- Tape Dimensional Stability (TDS)

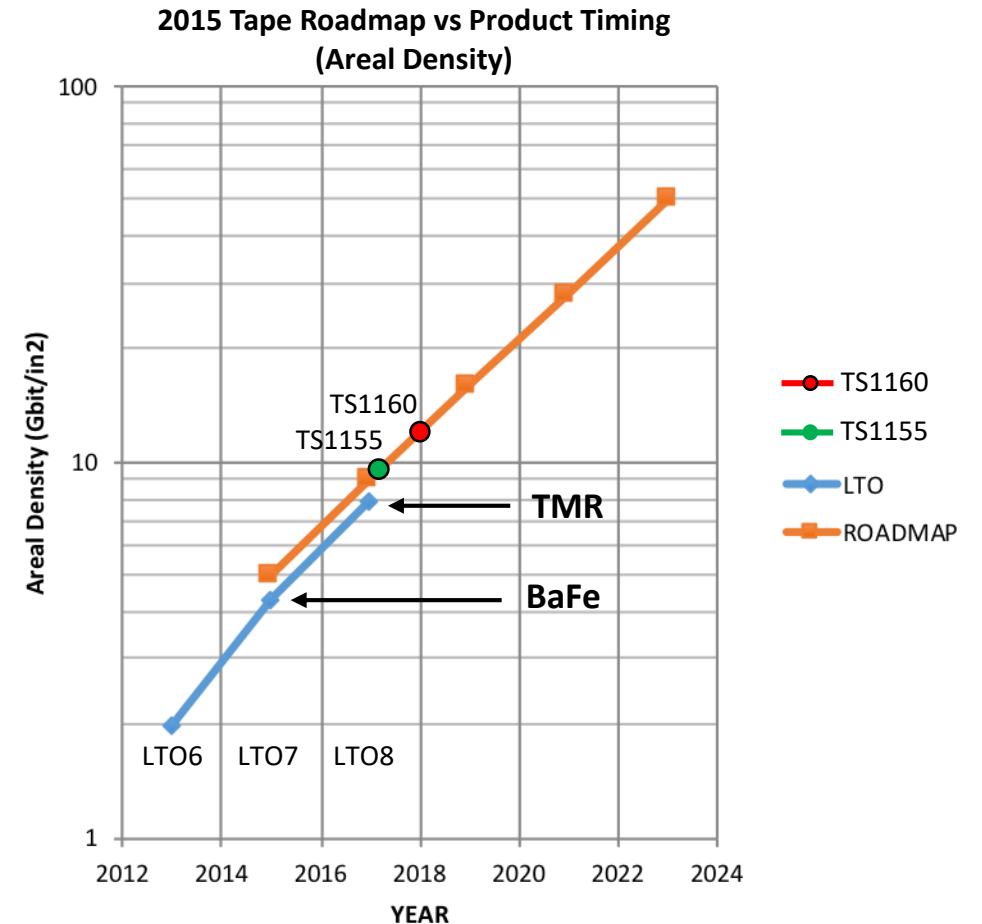
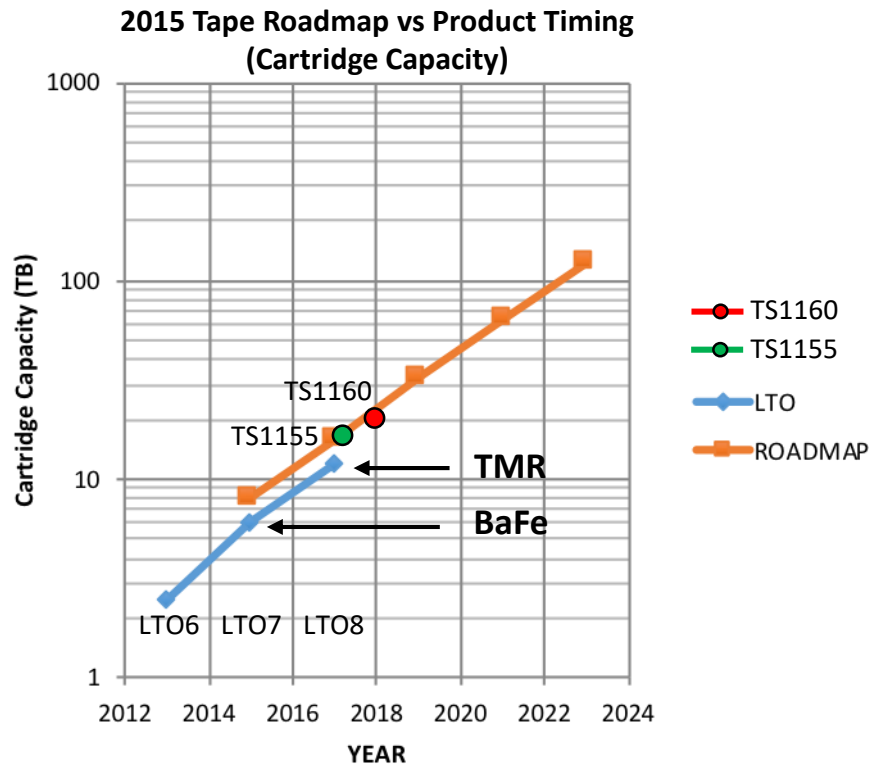
Advantage: Unlike HDD, tape magnetic physics is not the limiting issues since tape bit cells are 60X larger than HDD bit cells

Example: The projected tape areal density in 2025 (90 Gbit/in<sup>2</sup>) is 13x smaller than today's HDD areal density and has already been demonstrated in laboratory environments.

# LTO, TS1155 History vs Roadmap




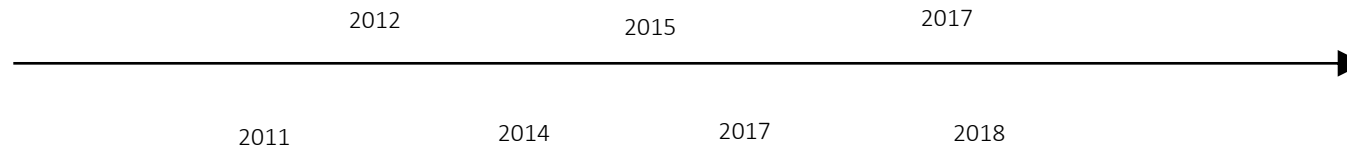
- LTO, TS1155, TS1160 cartridge capacity increases and areal density increases validate the INSIC Roadmap
- Major technical innovations enabled the density and capacity growth (SNR enhancements)
  - LTO7 to LTO8 → sensor changes from GMR to TMR
  - LTO6 to LTO7 → media changes from MP to BaFe
  - TS1155 → BaFe media, TMR sensor
  - TS1160 → Improved TMR sensor




# IBM Tape Drive History and Roadmaps

- Product history validating 2015 INSIC Roadmap → A credible tape technology development strategy

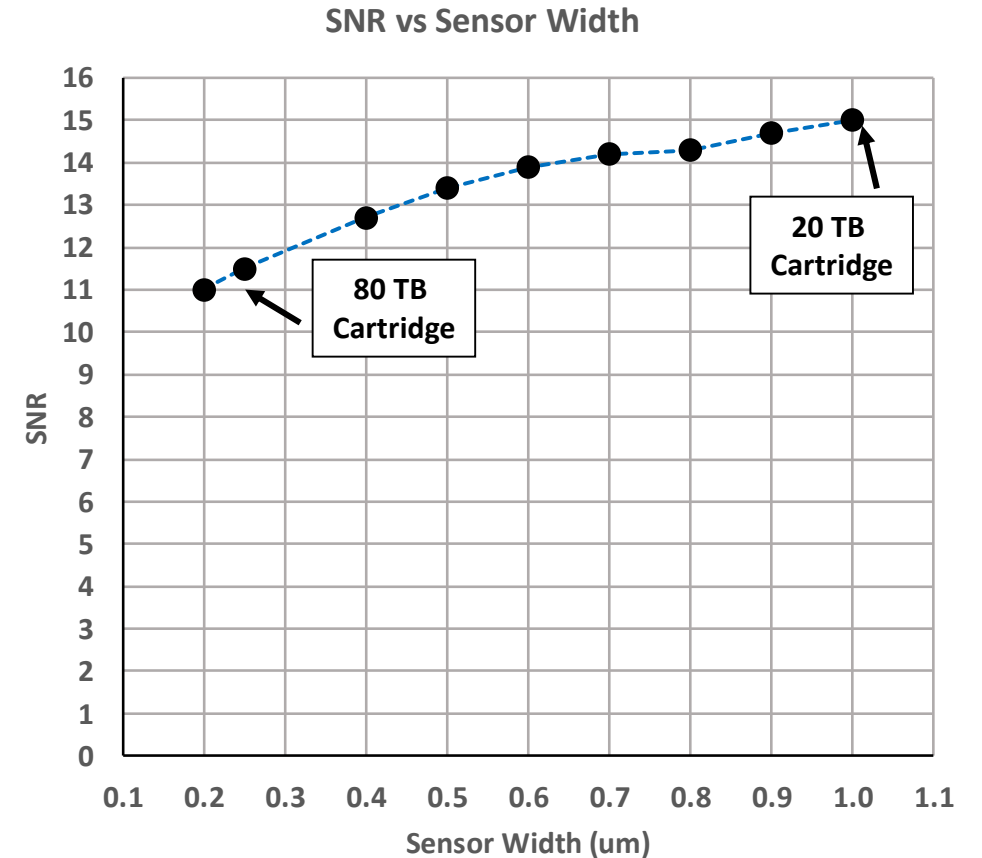
LTO Generations	LTO-6	LTO-7	LTO-8	LTO-9
New Format Capacity (Native) 	2.5 TB (L6)	6 TB (L7)	12 TB (L8)	Up to 24 TB (L9)
Other Format Capacities (Native)	1.5 TB (L5) (800 GB L4 R/O)	2.5 TB (L6) (1.5 TB L5 R/O)	6 TB (L7) 9 TB (M8)	12 TB (L8)
Native Data Rate	160 MB/s	300 MB/s	Up to 360MB/s	Up to 400 MB/s
Attachment	FC-8, SAS-6Gb	FC-8, SAS 6Gb	FC-8, SAS 6 Gb	FC-8, SAS-12 Gb



TS1100 Generations	TS1140	TS1150	TS1155	TS1160	TS1170
Max Native Capacity (media type) 	4 TB (JC)	10 TB (JD) 7 TB (JC)	15 TB (JD) 7 TB (JC)	20 TB (JE) 15 TB (JD) 7 TB (JC)	Up to 40 TB (JF) ? TB (JE) 15 TB (JD) 7TB (JC)
Native Data Rate	250 MB/s	360 MB/s	360 MB/s	Up to 400 MB/s	Up to 500 MB/s
Attachment	FC-8	FC-8	FC-8, 10 GigE (RoCE)	FC-16, 10/25 GigE (RoCEI)	FC-16, SAS12, 25GigE (RoCE)



- Tape drives supporting 20 TB cartridge capacity use 1.0  $\mu\text{m}$  read sensor widths
- Our laboratory has recently demonstrated SNR performance for read sensors varying in width from 0.20  $\mu\text{m}$  to 1.0  $\mu\text{m}$ .
- Data is from drives with 32 operating channels. The SNR is referred to as “channel” SNR from the composite of all 32 individual sensors
- The data suggest that sensor operation in 0.25  $\mu\text{m}$  range would support 4X capacity improvement over present cartridge capacities in the TS1160.
- SNR improvements would be required from the media with smaller particle Ba-Ferrite media
- Net Issue: Tape technology will sustain capacity improvements for several generations of products using evolutionary development strategies
- Details to be presented at the Magnetism and Magnetic Materials Conference, November 2019





## Summary

- Cloud providers are utilizing and demanding the incorporation of tape into the cloud storage environment
- Tape products follow the INSIC Roadmap for capacity and areal density
- Tape technology, unlike HDD technology, has a **stable** and well defined roadmap that has consistently achieved roadmap goals with products
- Tape technology requirements are evolutionary in nature. The tape bit cell is 60X larger in volume (V) than an HDD bit cell. This eliminates thermal stability issues, i.e.  $Hk \times V \gg kT$ . Hence the need for revolutionary heat assisted and/or microwave writing processes required for HDD areal density progress is eliminated.
- Tape cartridge capacity improvements based on the 2015 INSIC Roadmap will deliver 4X native capacity increases (60 TB to 80 TB cartridges) in the mid 2020's