The Memory of Cars

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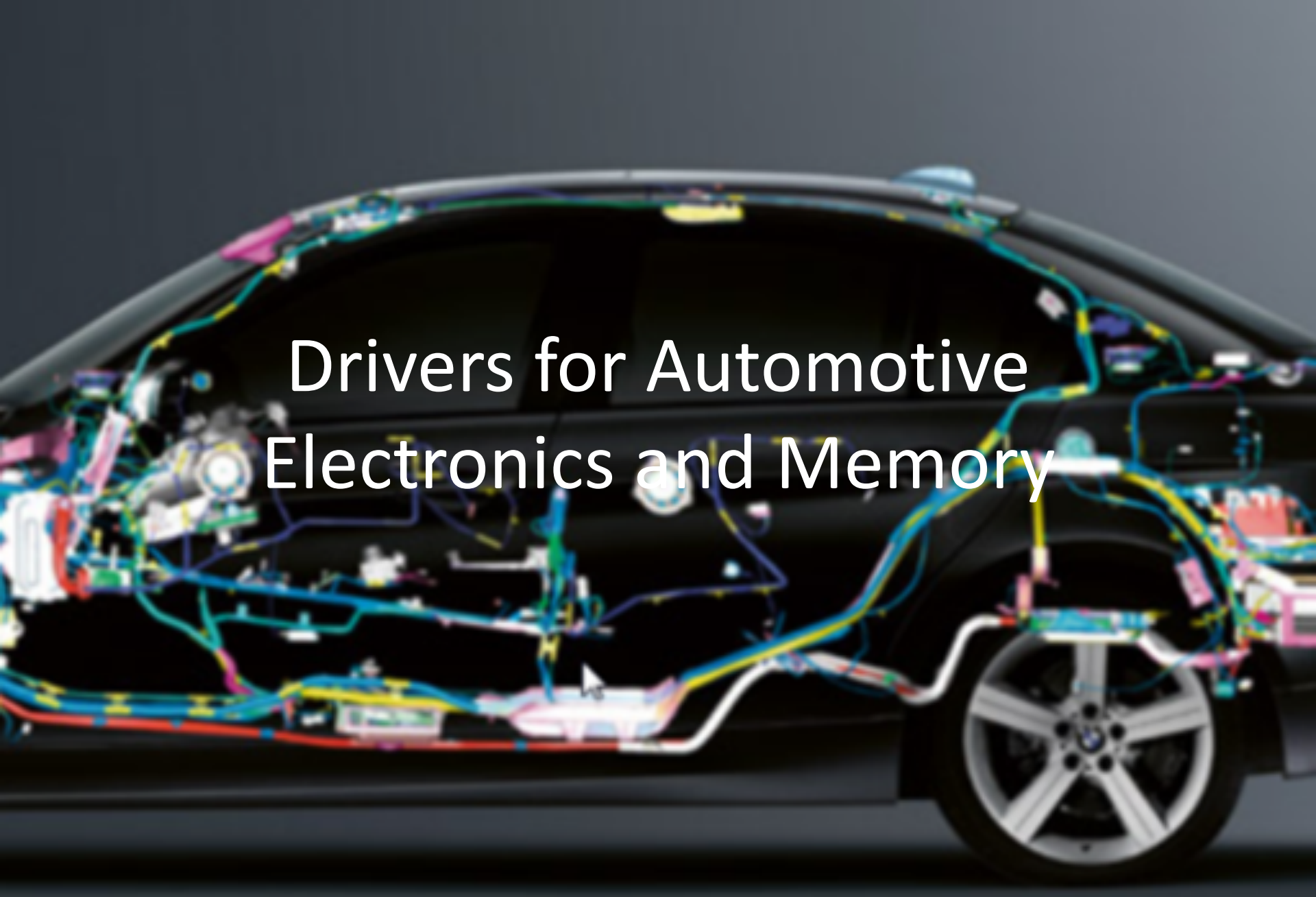
Austin-Healey 3000 Mk III at the Gibraltar Classic Car rally, Casemates Square, Joe Vivent, 2009 Creative Commons License

1970 AMC Hornet—My First Car

Outline

- Drivers for Automotive Electronics and Memory
- Data Requirements in Automobiles
- Modern Storage and Memory Technologies
- Sample Infortainment Application—BMW Digital Radio



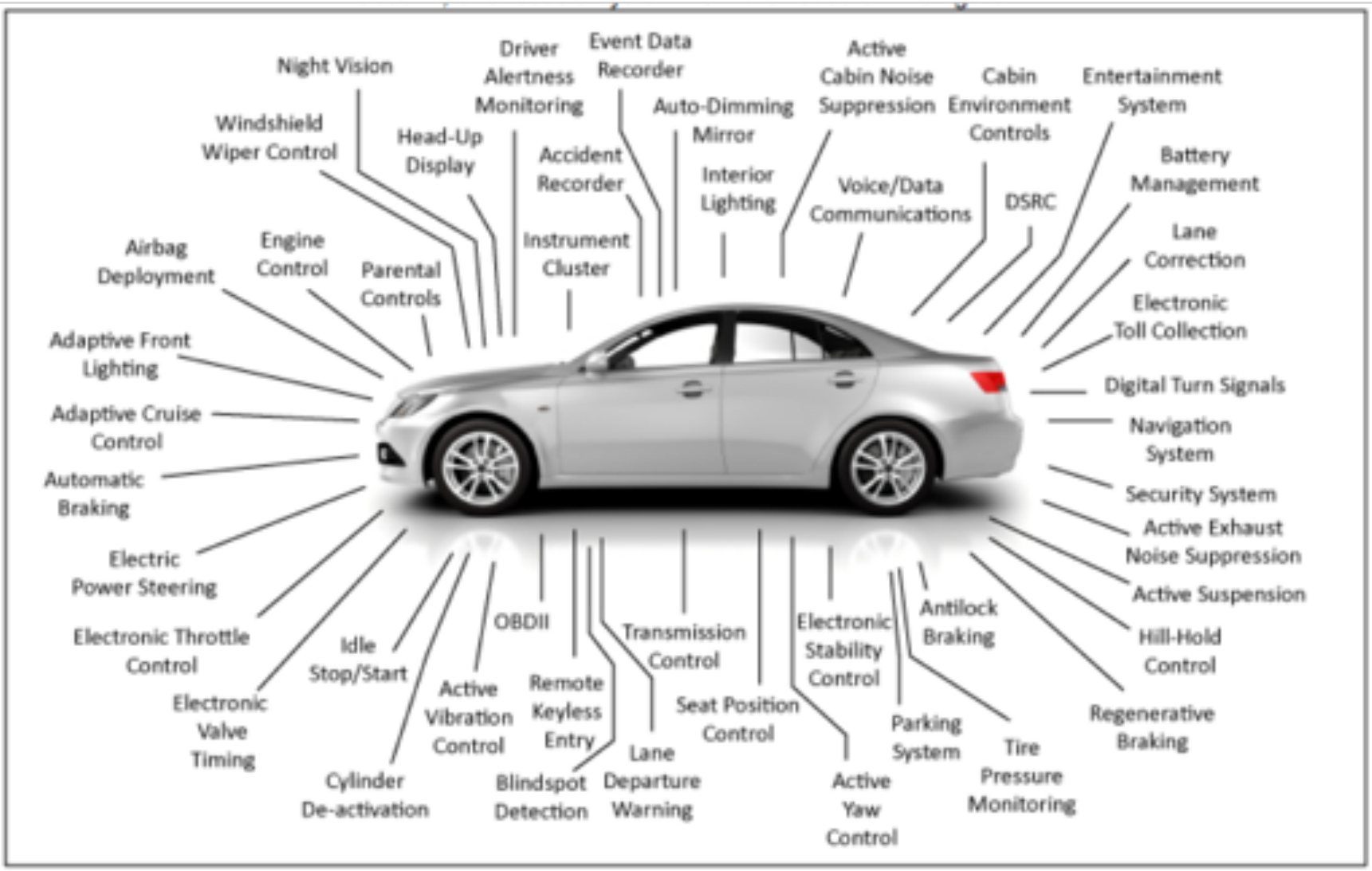
Drivers for Automotive Electronics and Memory

Automotive Technology Trends

- More Electric and Hybrid Automobiles
- More Connected Vehicles
  - Radios
  - Antennas
- Advanced Drive Assistance System (ADAS)
  - Sensors
  - Cameras
  - Machine learning
- Infotainment and Instrument Cluster
  - Augmented Reality (AR)
  - Virtual Reality (VR)—with autonomous vehicles or for passengers?
  - Higher definition, higher dynamic range, richer color displays
  - Targeted audio

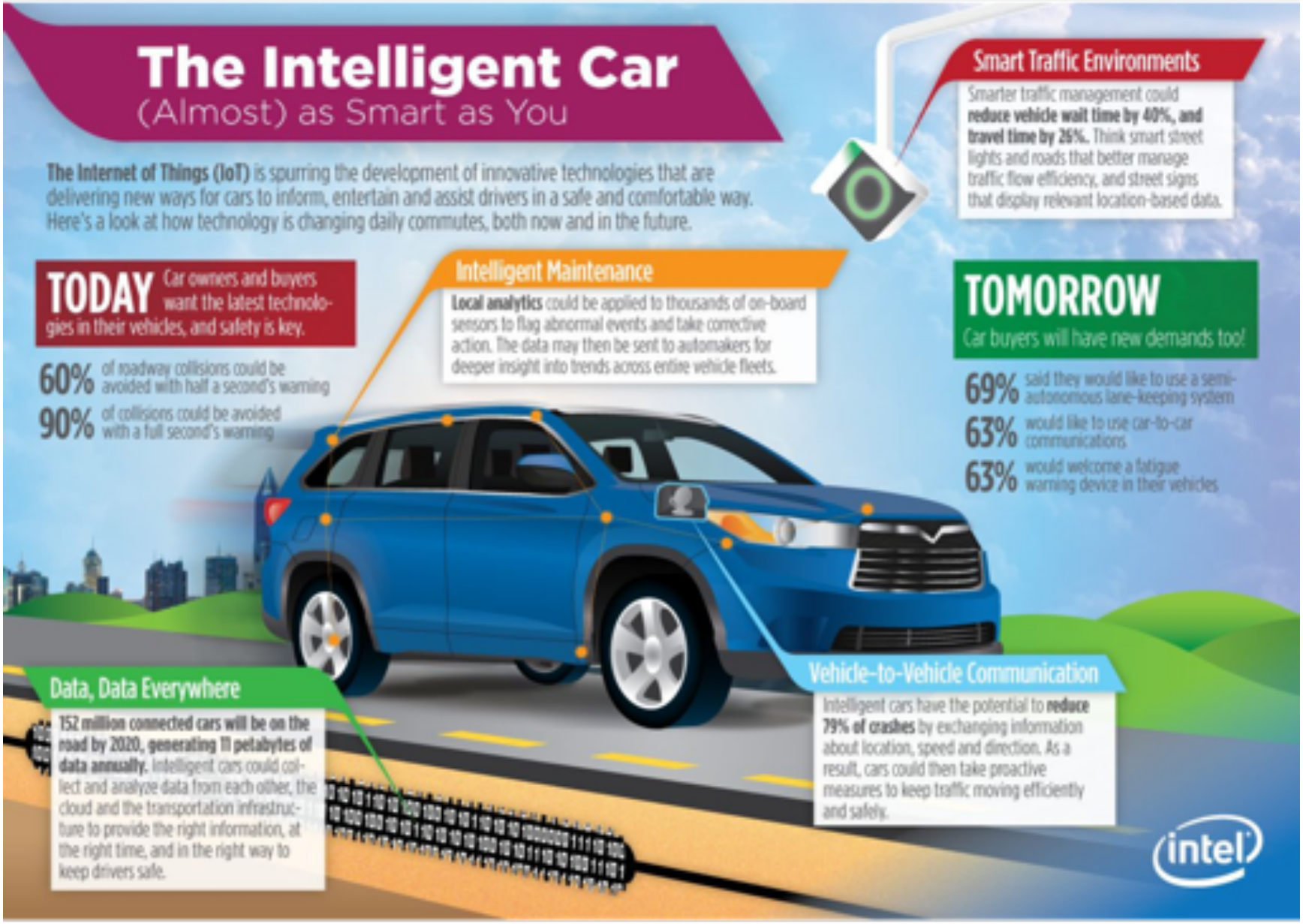
Electronics in Modern Automobiles

Source: Clemson University Vehicular Technology Lab

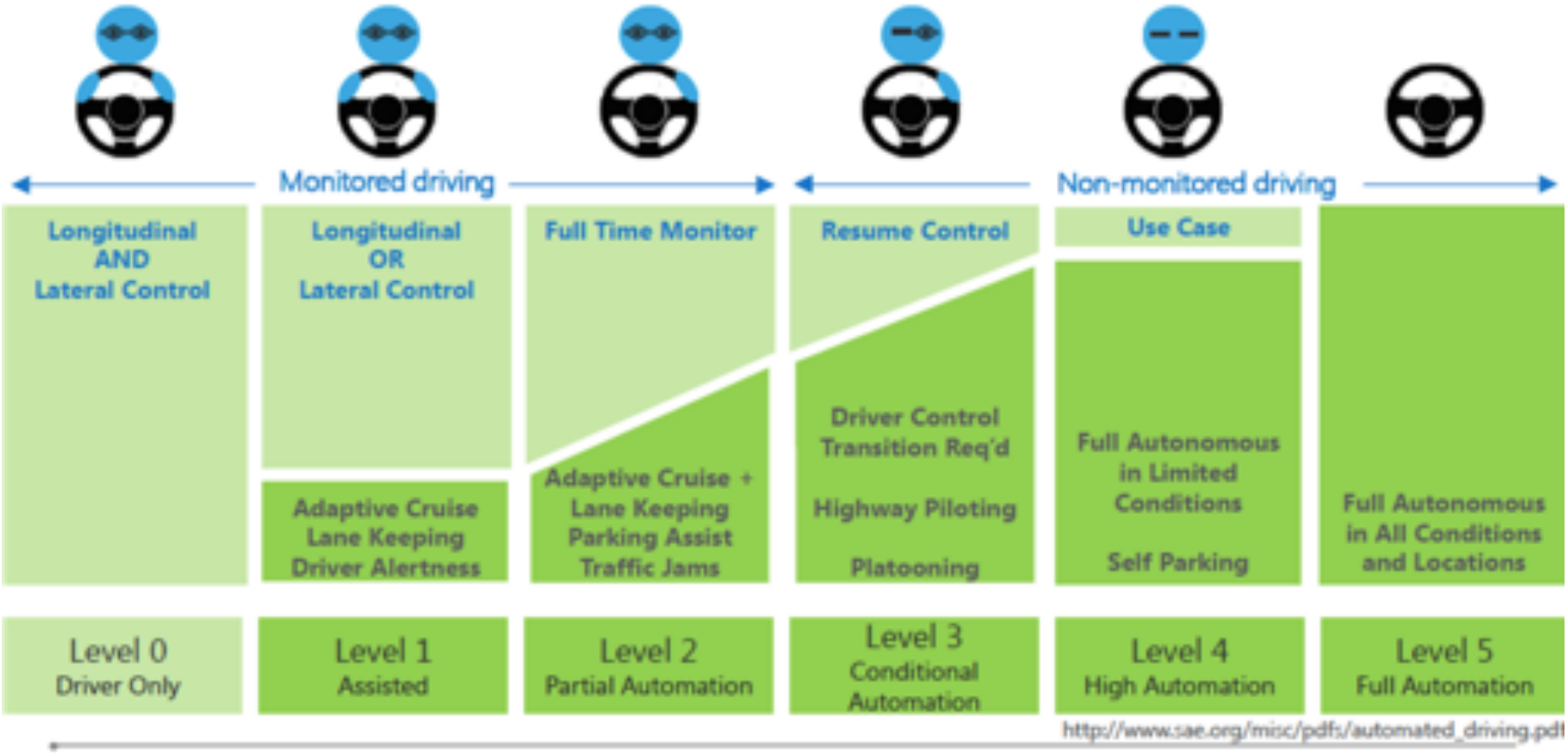


The Internet of Things (IoT)

- Interconnected intelligent devices(including vehicles) are all the rage in technology circles.
  - As the price declines and the availability of microprocessors increases, they are showing up in consumer products ranging from thermostats to refrigerators.
- The convergence of ubiquitous processing and networking is often referred to as the Internet of Things (IoT). As a result of the proliferation of smart connected devices, smart things will be in our homes, on our roads, in our factories, our gardens and in the air.


The Intelligent Car
(Almost) as Smart as You
The Internet of Things (IoT) is spurring the development of innovative technologies that are delivering new ways for cars to inform, entertain and assist drivers in a safe and comfortable way. Here's a look at how technology is changing daily commutes, both now and in the future.
TODAY Car owners and buyers want the latest technologies in their vehicles, and safety is key.
60% of roadway collisions could be avoided with half a second's warning
90% of collisions could be avoided with a full second's warning
Intelligent Maintenance
Local analytics could be applied to thousands of on-board sensors to flag abnormal events and take corrective action. The data may then be sent to automakers for deeper insight into trends across entire vehicle fleets.
Smart Traffic Environments
Smarter traffic management could reduce vehicle wait time by 40%, and travel time by 26%. Think smart street lights and roads that better manage traffic flow efficiency, and street signs that display relevant location-based data.
TOMORROW
Car buyers will have new demands too!
69% said they would like to use a semi-autonomous lane-keeping system
63% would like to use car-to-car communications
63% would welcome a fatigue warning device in their vehicles
Data, Data Everywhere
152 million connected cars will be on the road by 2020, generating 11 petabytes of data annually. Intelligent cars could collect and analyze data from each other, the cloud and the transportation infrastructure to provide the right information, at the right time, and in the right way to keep drivers safe.
Vehicle-to-Vehicle Communication
Intelligent cars have the potential to reduce 79% of crashes by exchanging information about location, speed and direction. As a result, cars could then take proactive measures to keep traffic moving efficiently and safely.
intel

SAE Levels of Autonomous Driving



Connected Vehicle Services

https://www.infosys.com/oracle-openworld/digital-library/connected-vehicles-technology.pdf

Automobiles Becoming a Web of Wireless Networks

- 4G or 5G: External communication to edge or cloud connections
- WiFi: Used for IP network connectivity within vehicles, e.g. connections to occupant devices
- BlueTooth: Personal device communication and entertainment
- RFID: Auto component communication, key fobs, toll and other electronic payments

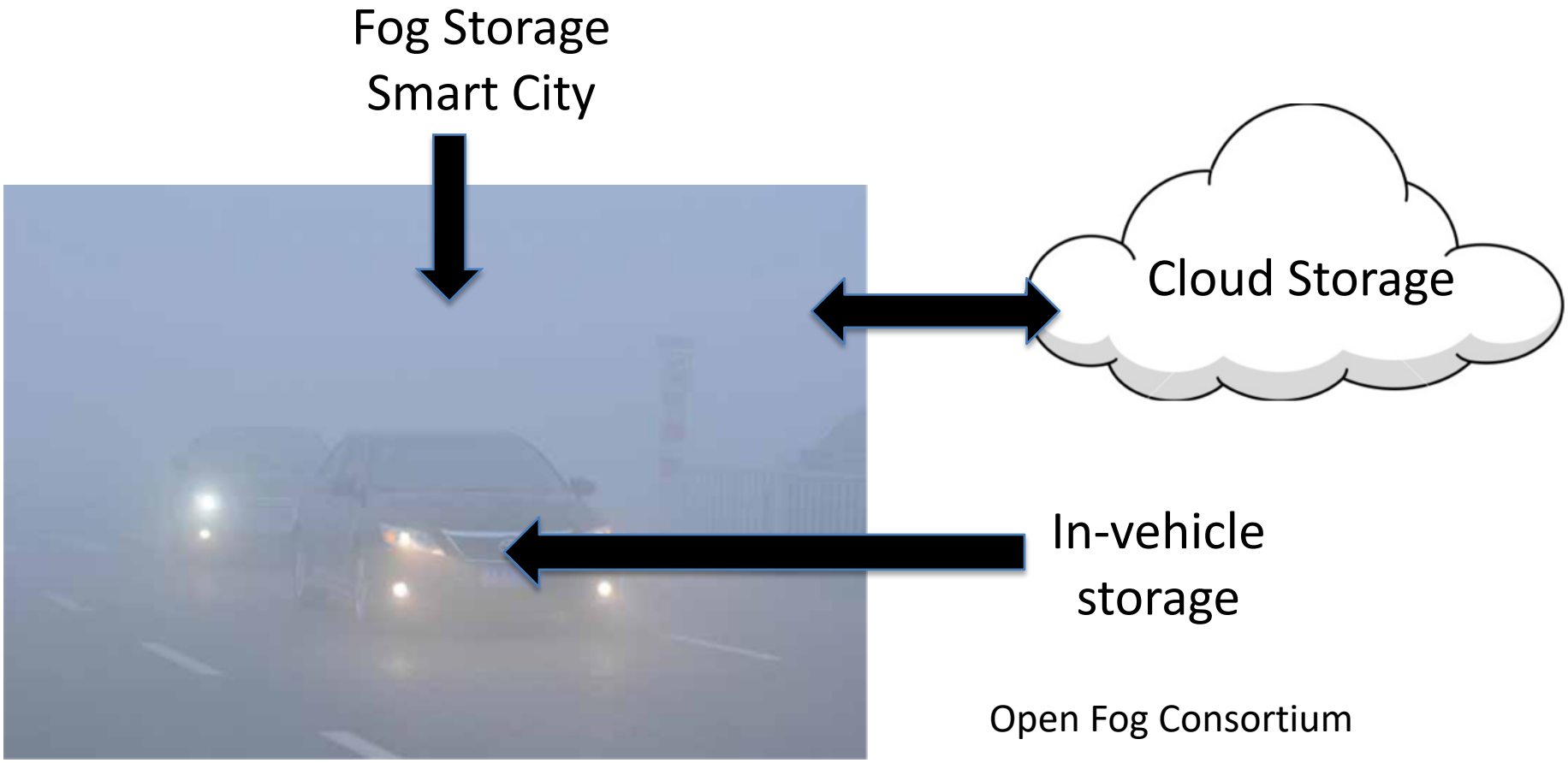
RFID in Cars

- Used for secure access
  - Key Fobs
  - Toll Payments, electronic payments
- Embedded ID and sensor measurements with RFID, in car components
  - getting information on the tire's internal temperature and pressure, how it's wearing and getting exercised, revolutions per mile and more
  - In the future, tires on autonomous cars might transmit what kind of surface is being traveled on—so the vehicle knows, for instance, the difference between gravel and snow.

RFID Key Fob

Formula-E Tires with Embedded sensors and RFID

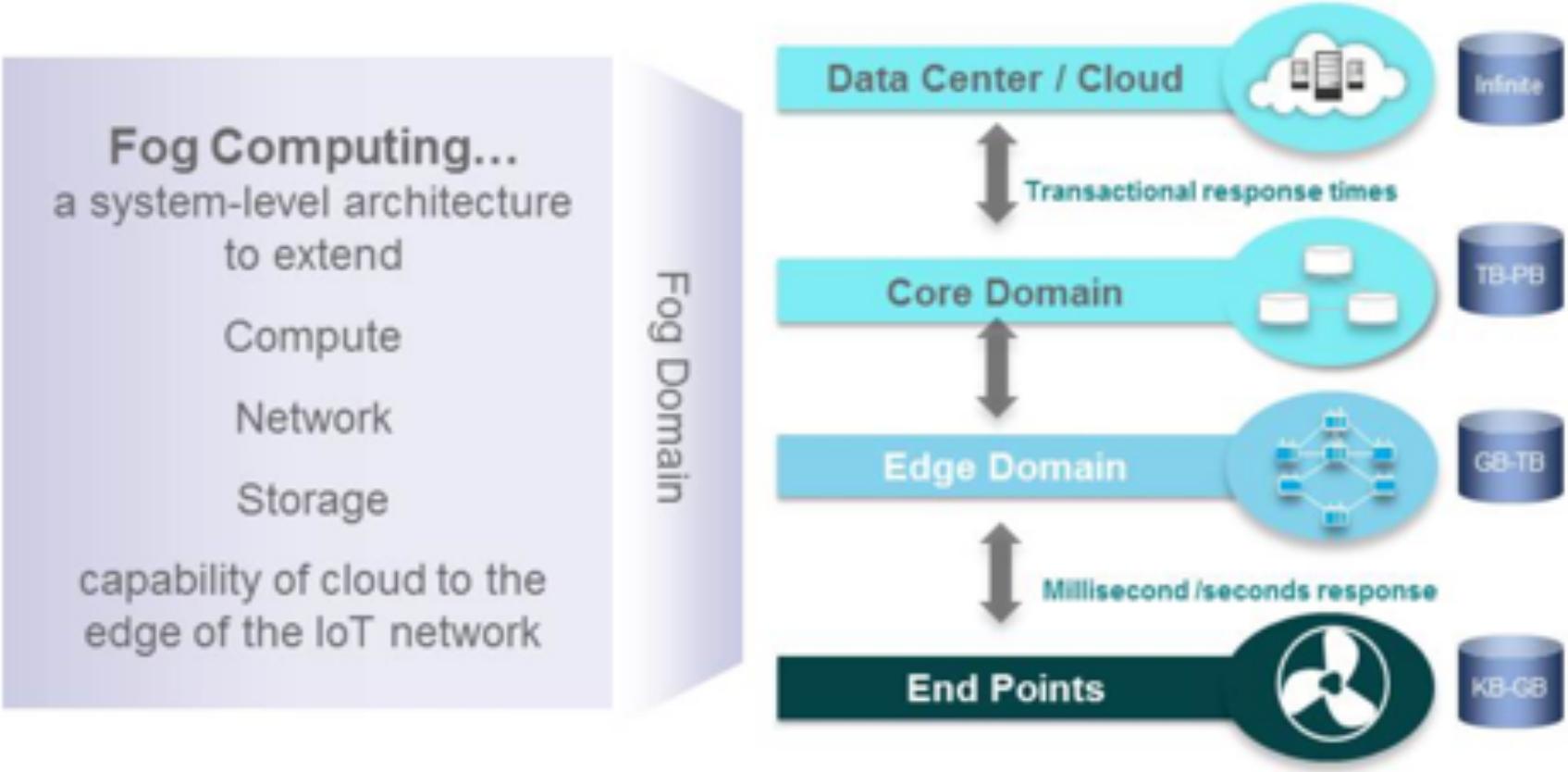
Location of Storage/Memory for Connected Cars (mostly LTE)



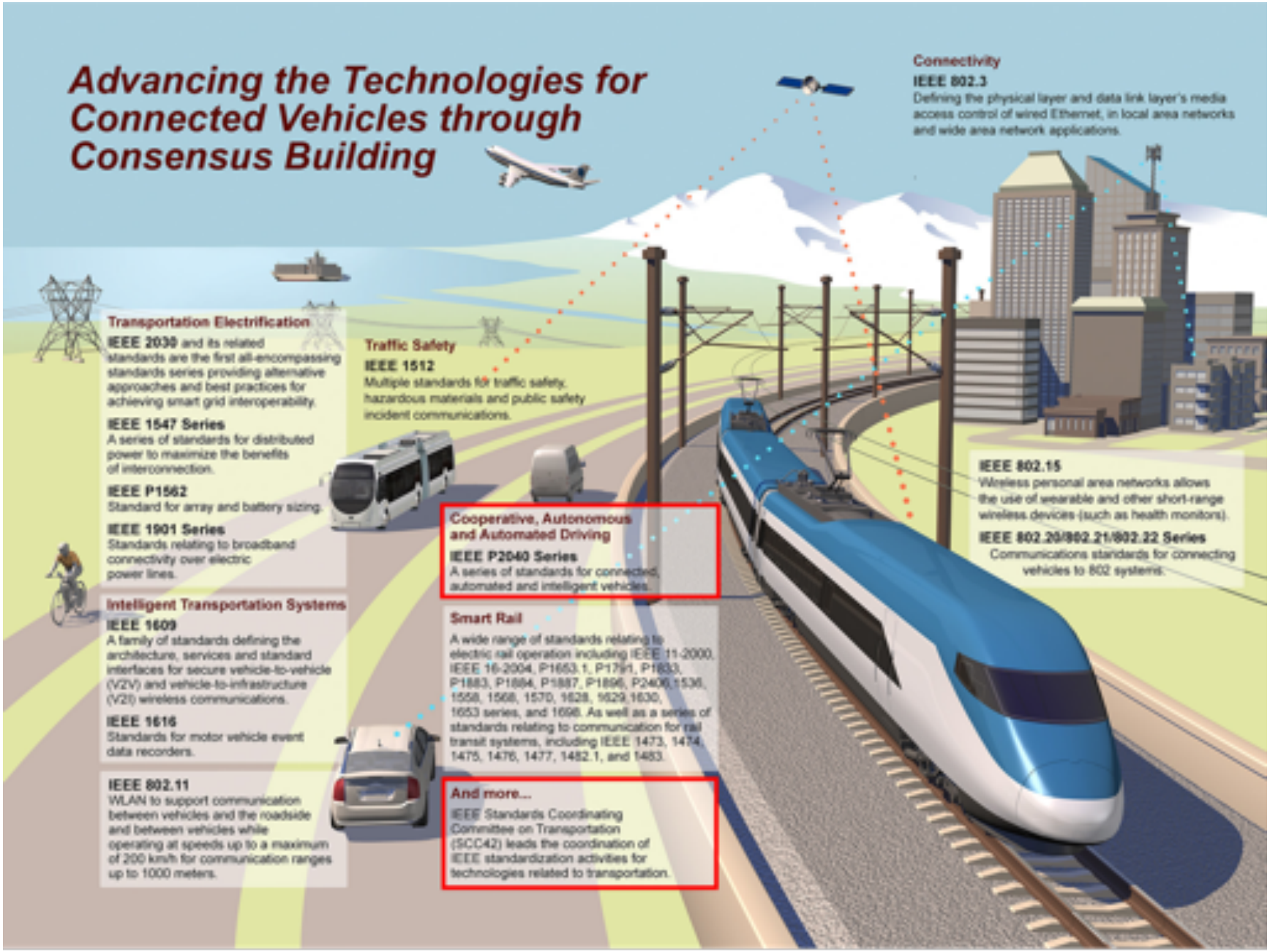
Open Fog Consortium

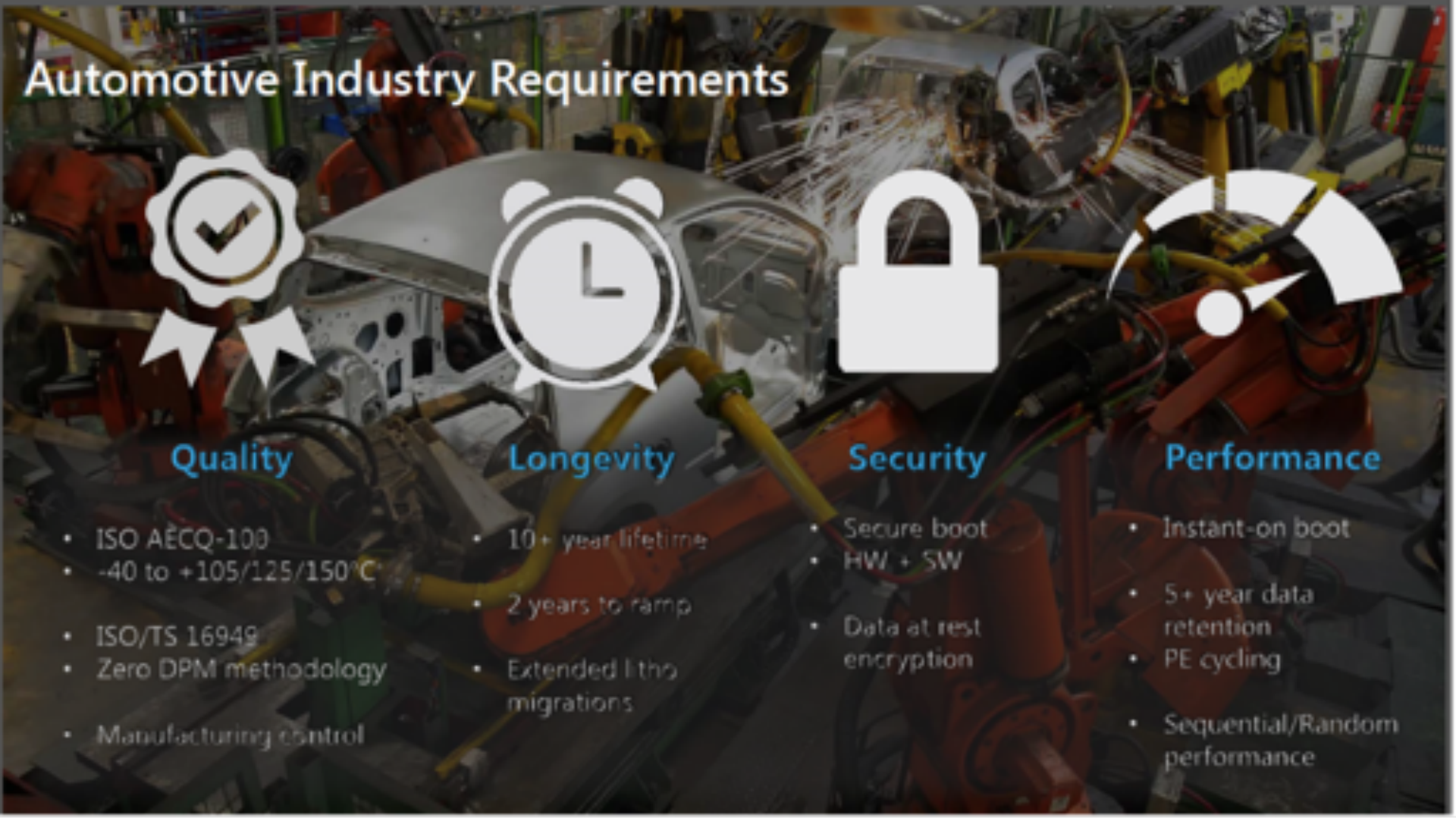
The Role of the Fog

Source: Fog Computing: Bringing Cloud Capabilities Down to Earth, Cisco Blog, August 2015



US DoT Project on Next Gen Connected Vehicles


Advancing the Technologies for Connected Vehicles through Consensus Building
Connectivity
IEEE 802.3
Defining the physical layer and data link layer's media access control of wired Ethernet, in local area networks and wide area network applications.
Transportation Electrification
IEEE 2030 and its related standards are the first all-encompassing standards series providing alternative approaches and best practices for achieving smart grid interoperability.
IEEE 1547 Series
A series of standards for distributed power to maximize the benefits of interconnection.
IEEE P1562
Standard for array and battery sizing.
IEEE 1901 Series
Standards relating to broadband connectivity over electric power lines.
Traffic Safety
IEEE 1512
Multiple standards for traffic safety, hazardous materials and public safety incident communications.
Cooperative, Autonomous and Automated Driving
IEEE P2040 Series
A series of standards for connected, automated and intelligent vehicles.
IEEE 802.15
Wireless personal area networks allows the use of wearable and other short-range wireless devices (such as health monitors).
IEEE 802.20/802.21/802.22 Series
Communications standards for connecting vehicles to 802 systems.
Intelligent Transportation Systems
IEEE 1609
A family of standards defining the architecture, services and standard interfaces for secure vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless communications.
IEEE 1616
Standards for motor vehicle event data recorders.
Smart Rail
A wide range of standards relating to electric rail operation including IEEE 11-2000, IEEE 16-2004, P1653.1, P1791, P1833, P1883, P1884, P1887, P1896, P2406,1536, 1558, 1568, 1570, 1628, 1629,1630, 1653 series, and 1698. As well as a series of standards relating to communication for rail transit systems, including IEEE 1473, 1474, 1475, 1476, 1477, 1482.1, and 1483.
IEEE 802.11
WLAN to support communication between vehicles and the roadside and between vehicles while operating at speeds up to a maximum of 200 km/h for communication ranges up to 1000 meters.
And more...
IEEE Standards Coordinating Committee on Transportation (SCC42) leads the coordination of IEEE standardization activities for technologies related to transportation.



Memory Development to Drive Autonomously, Kris Baxter, Micron, 2016 Flash Memory Summit

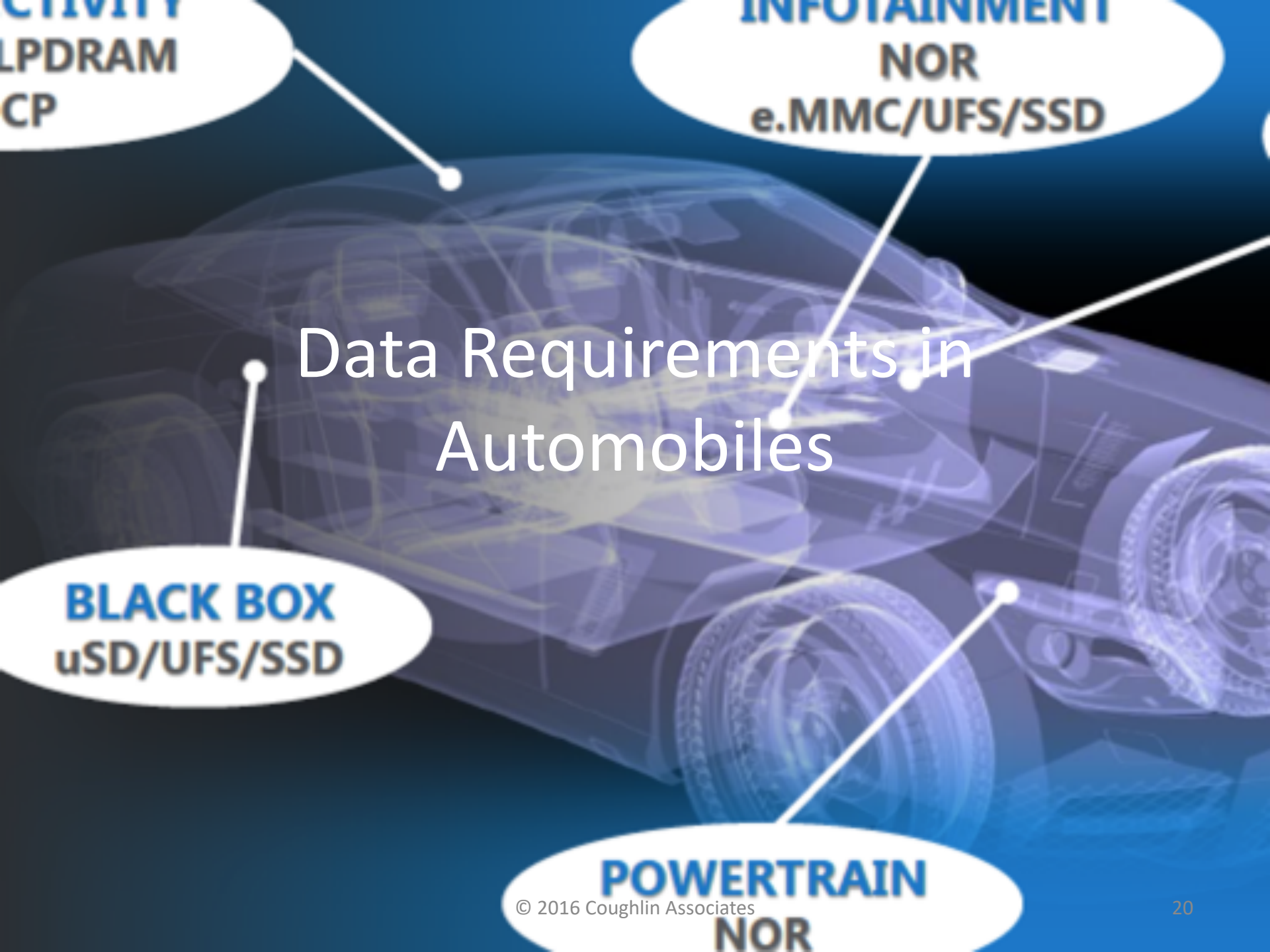
nVIDIA Autonomous Race Car

NVIDIA Drive PX Autonomous Car Development Platform

SENSOR FUSION

DRIVE PX can fuse data from 12 cameras, as well as lidar, radar, and ultrasonic sensors. This allows algorithms to accurately understand the full 360 degree environment around the car to produce a robust representation, including static and dynamic objects. Use of Deep Neural Networks (DNN) for the detection and classification of objects dramatically increases the accuracy of the resulting fused sensor data.

Data Requirements in Automobiles



The IoT Data Set

- The amount of data from networked devices may be small in itself but the resulting data set, including the metadata generated with the data can be much larger.
- This data set, including the metadata, is what is analyzed in big data analysis and adds enormously to the overall value of the raw data.
- Understanding and controlling access to metadata is one of the keys for protecting personal content

Data + Metadata

- a 4 byte raw piece of data from a sensor (such as a thermometer) can be associated with 100 bytes of metadata.
- This metadata can include time and location information, information about the sensor device itself and can include accumulating data over time.

Autonomous Cars = Big Data

(Source: DataFloo, https://datafloq.com/read/self-driving-cars-create-2-petabytes-data-annually/172)

- Google autonomous car generates about 1 GB/sec. Avg. US driver drives 600 hr/year. This would generate 2 PB/car/year.
- The number of cars worldwide will surpass 1 billion
- So the potential size of data generated by autonomous cars is huge
- Most of the resulting long term storage is in the cloud, which also does the bulk of analytics

Memory Development to Drive Autonomously, Kris Baxter, Micron, 2016 Flash Memory Summit

Memory Trends in Automobiles

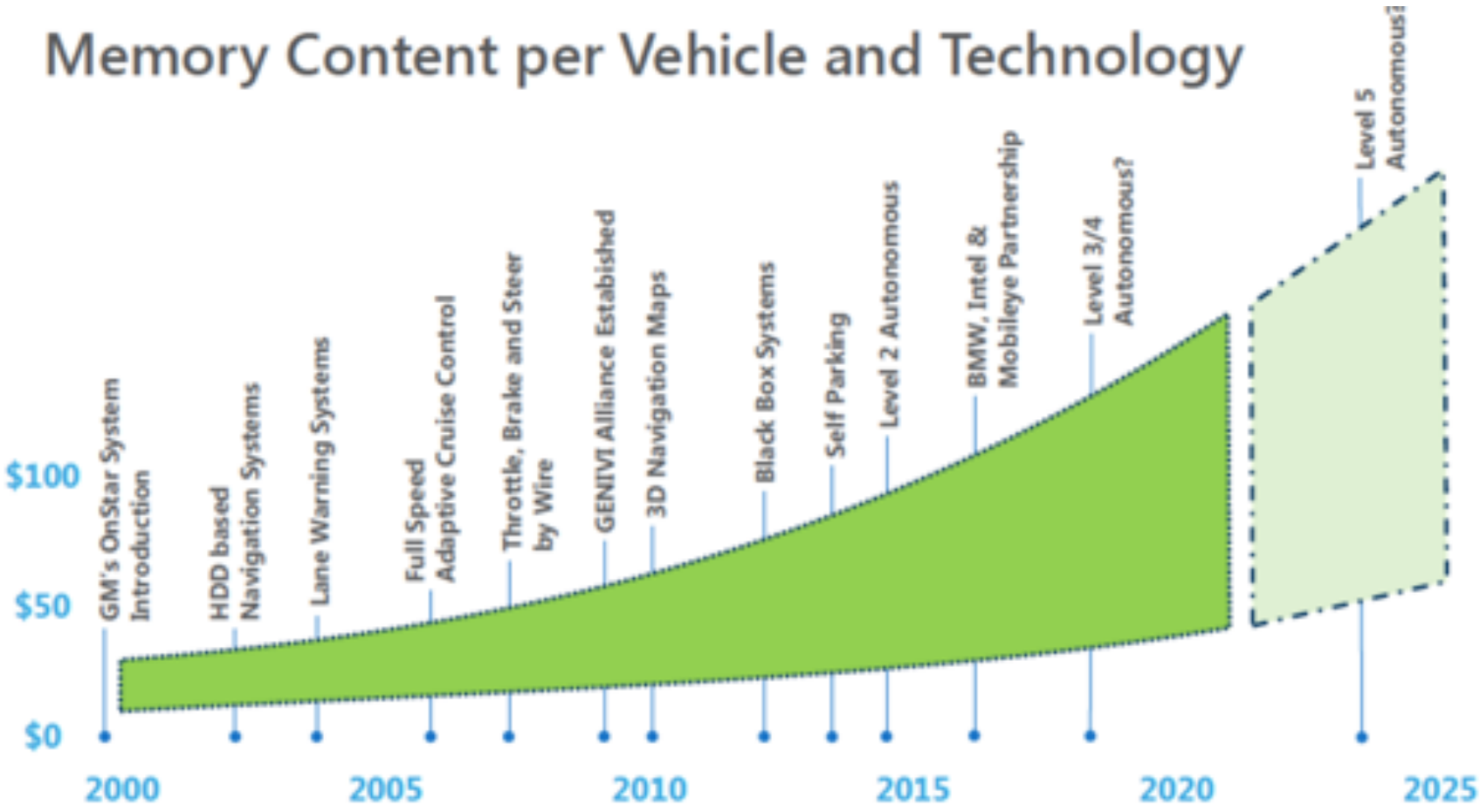
- The electric/electronic share of value added to a state-of-the-art vehicle is **already at 40 percent for traditional, internal combustion engine cars and jumps as high as 75 percent for electric or hybrid electric vehicles.**
- The total available market value for semiconductor memories in **automotive applications is expected to ….be well above the overall CAGR for the total memory semiconductor market**.
- **Automotives are about 5% of the memory market now but could grow to 10%** (2016 Micron Press Release)

2012 article from Micron in Embedded Computer Design

Local Memory & Storage Needs

- 3D Maps
- Real Time Data Capture
- Black Box Data Recording
- On Board 4K Content
- **Greater than 1 TB capacity** common in a car by 2020
- This is addition to storage in local and remote networks

Increasing Memory Content Per Vehicle



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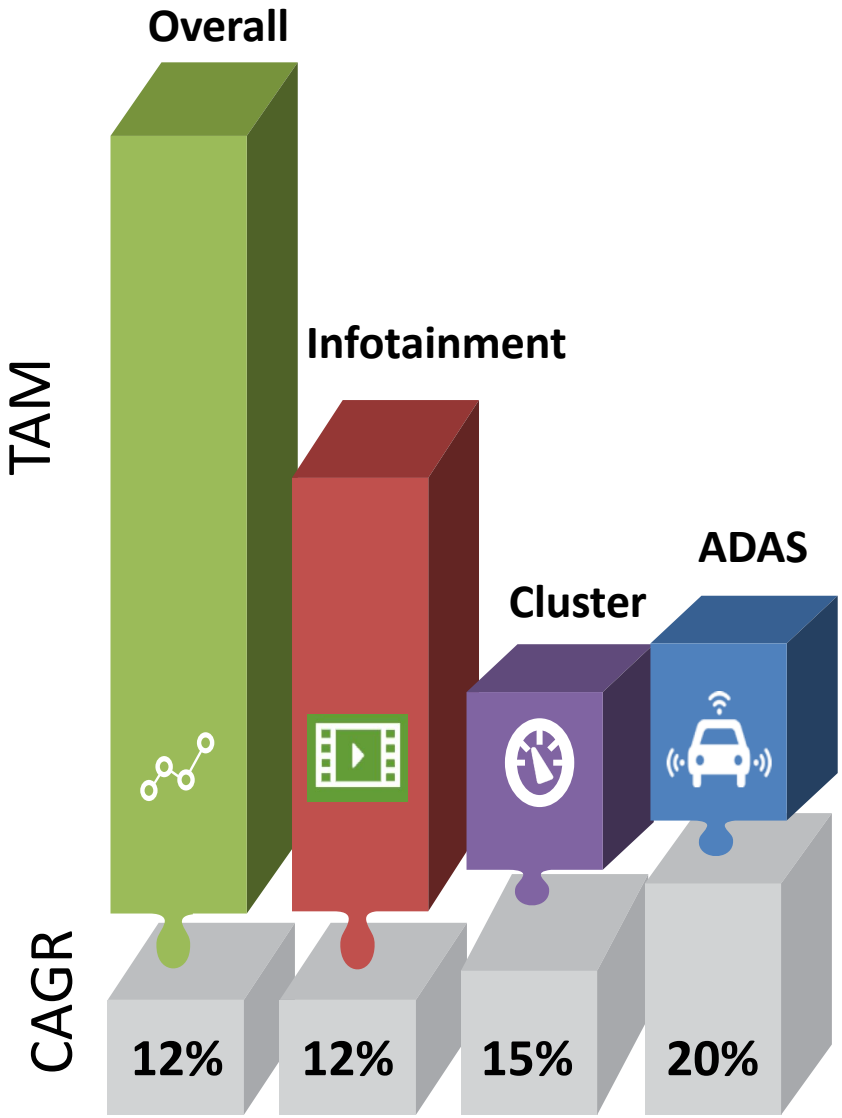
Automotive Memory Market



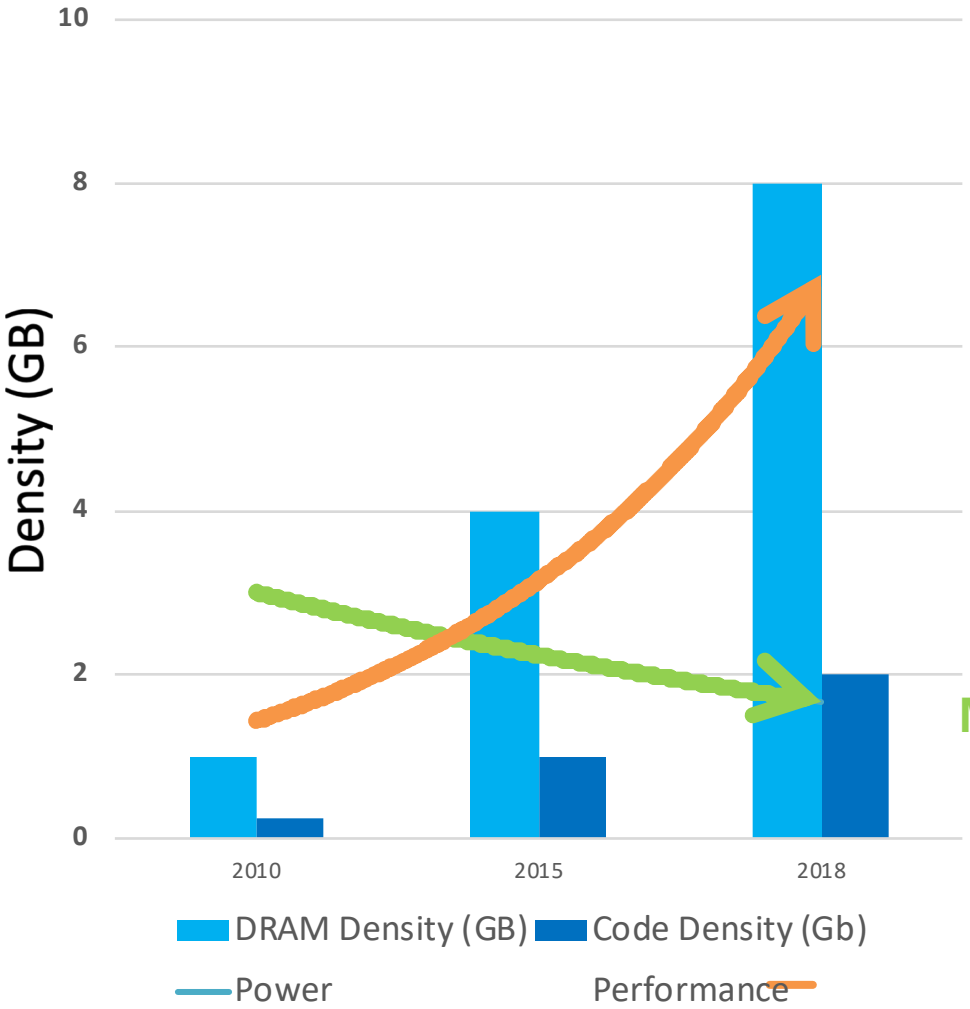
CAGR 2015 - 2020 Source: Micron, Analyst Inputs

Infotainment Matters

- *'I would switch to another manufacturer if it was the only one offering a car with full access to the applications, data and media'*
  - 85% increase in one year
  - In China: 60% would change brands
  - Under 40 years old: 50% would change

Source: McKinsey Connectivity and Autonomous Driving Consumer Survey 2014 & 2015

Infotainment Code Storage and Compute Memory Progression



4K Display

Accelerating adoption of leading edge technology

Instant On

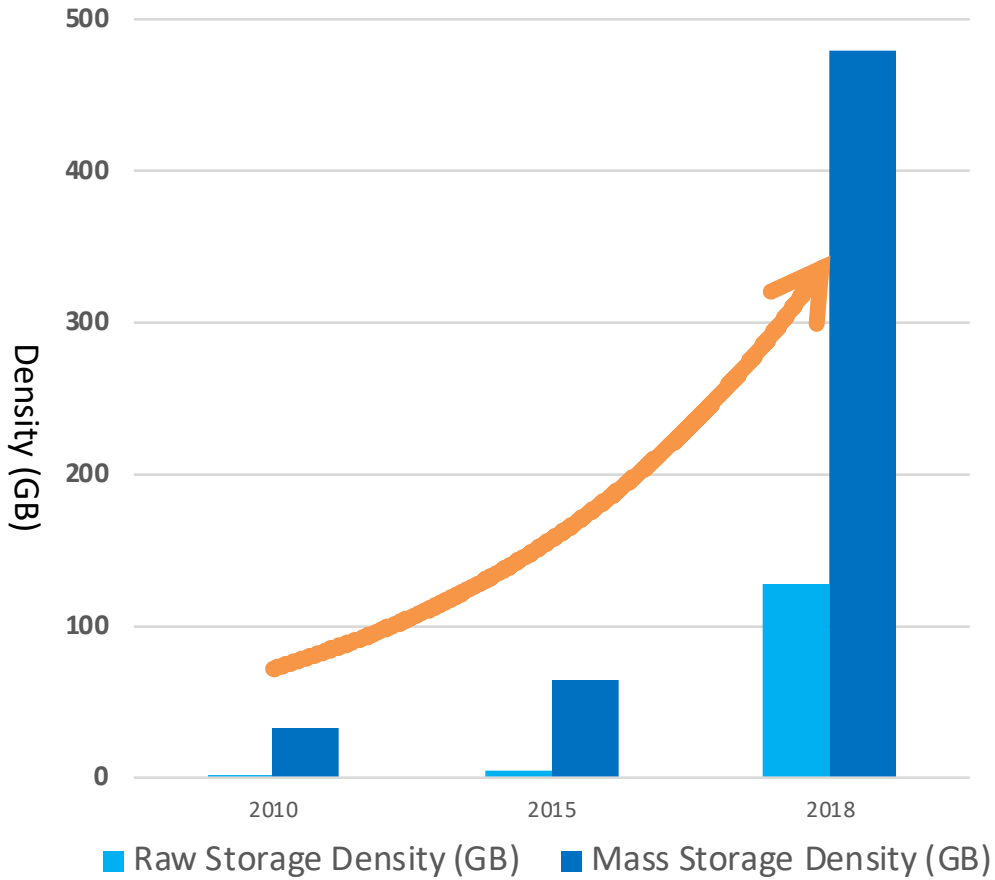
Low power requirements and fast boot NOR Flash

Multiple Displays

High bandwidth LPDRAM

Source: Micron

Infotainment Storage Progression



Note: Raw Storage is raw NAND or eMMC, mass storage is HDD/SSD

Smart Phone Integration

Raw storage of user preference and contacts

3D Maps

Higher density mass storage requirements

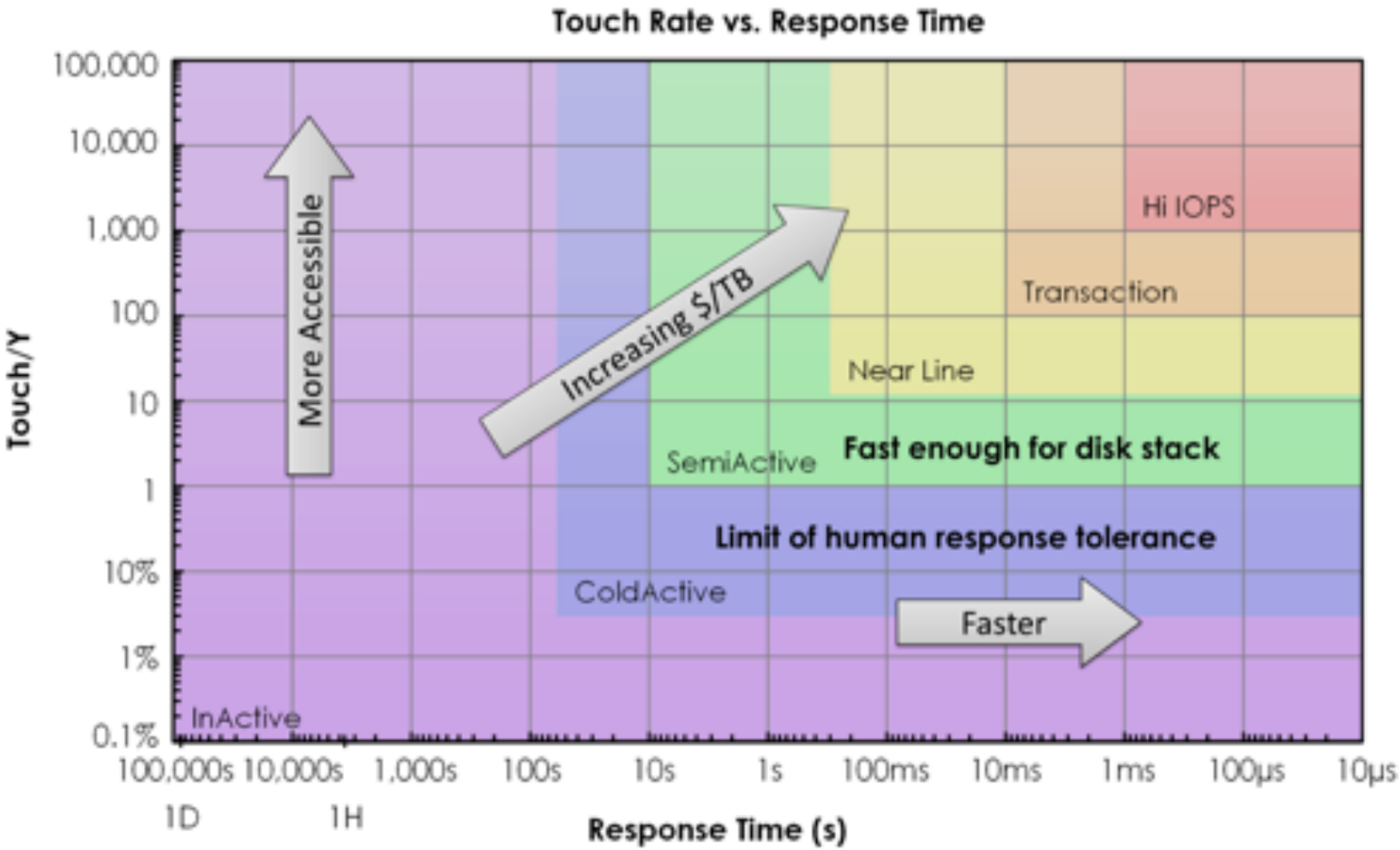
Streaming

Increased download buffer capability

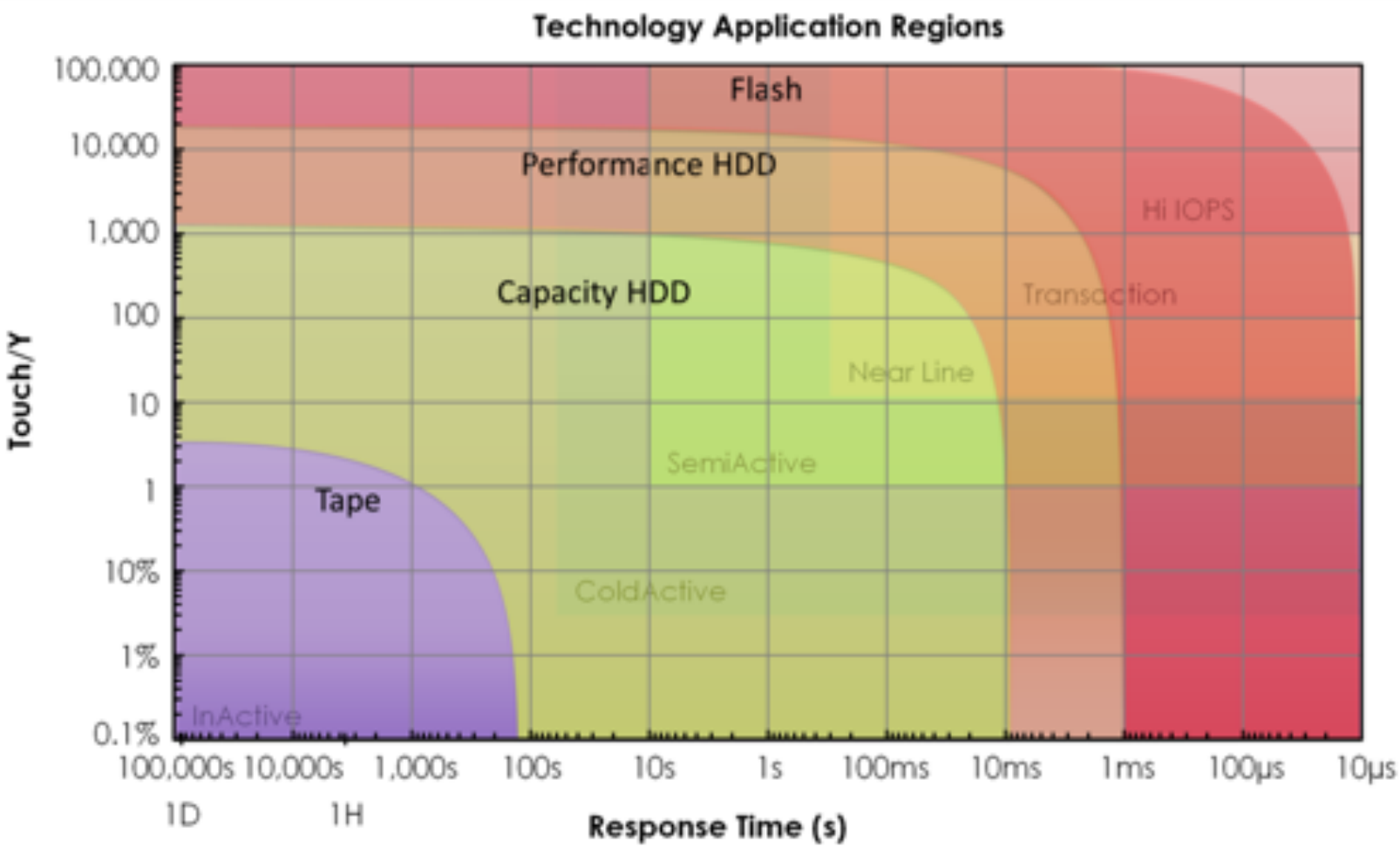
Source: Micron

Modern Storage and Memory Technologies

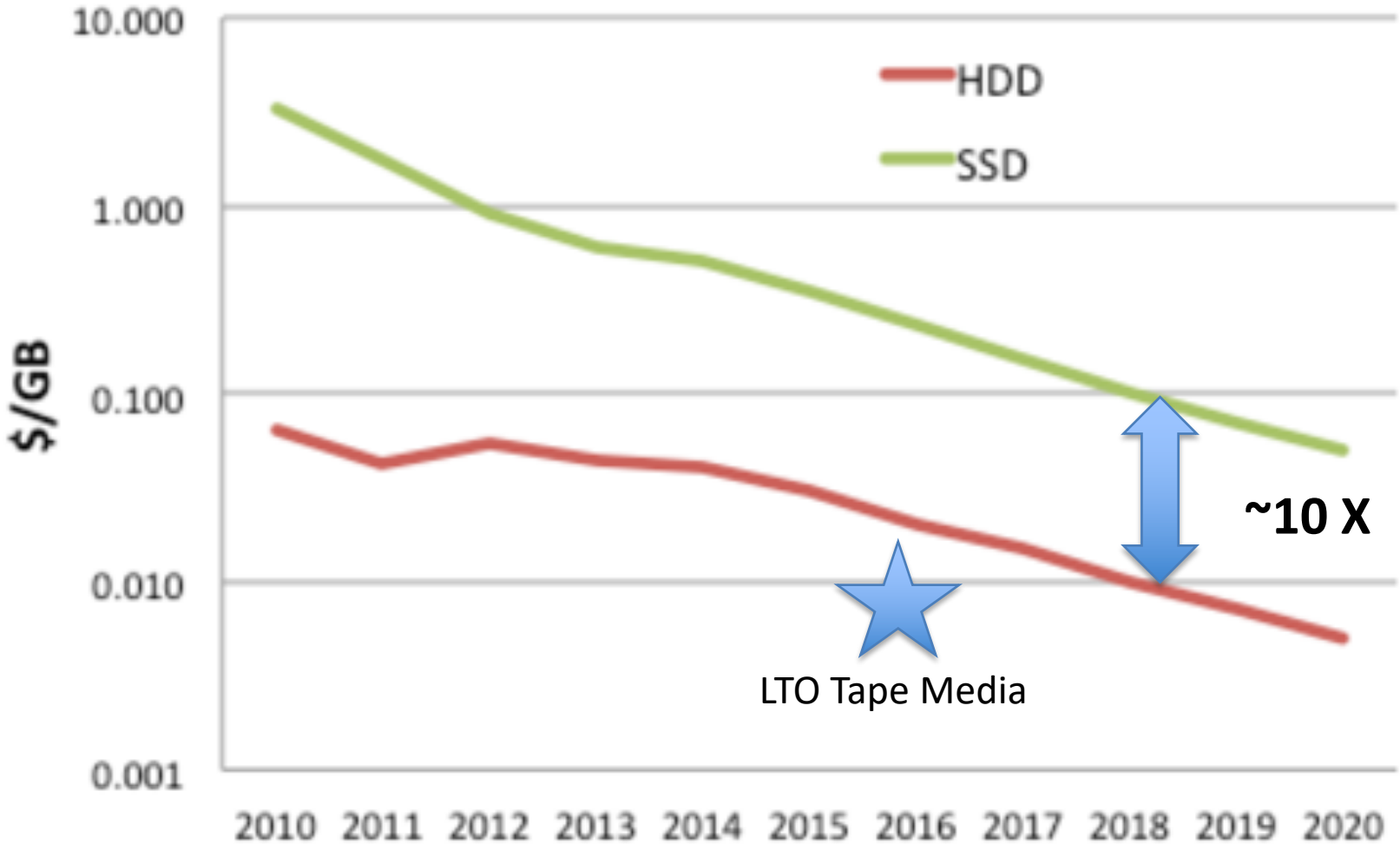
Touch rate versus response time indicating various types of uses



Digital storage technologies regions overlaid on the Touch Rate/Response Time chart



$/GB Trends



Automotive Code and Data Storage

- Connectivity: NAND, LPDRAM, MCP
- Infotainment: HDD, NOR, e.MMC, UFS, SSD
- Cluster: NOR, e.MMC, UFS, SSD
- ADAS: NOR, e.MMC, UFS, SSD
- Powertrain: NOR
- Black Box: EEPROM
- Auto DVR: HDD, uSD, UFS, SSD

Toshiba Automotive HDD

- **Toshiba's Storage Products HDDs geared to the automotive market**.
- The Toshiba MQ01AAD032C is a 320 GB single-platter SATA auto HDD with a rotation rate of 4,200 RPM and with an internal transfer rate of up to 976 Mbits/s and an average seek time of 12 ms

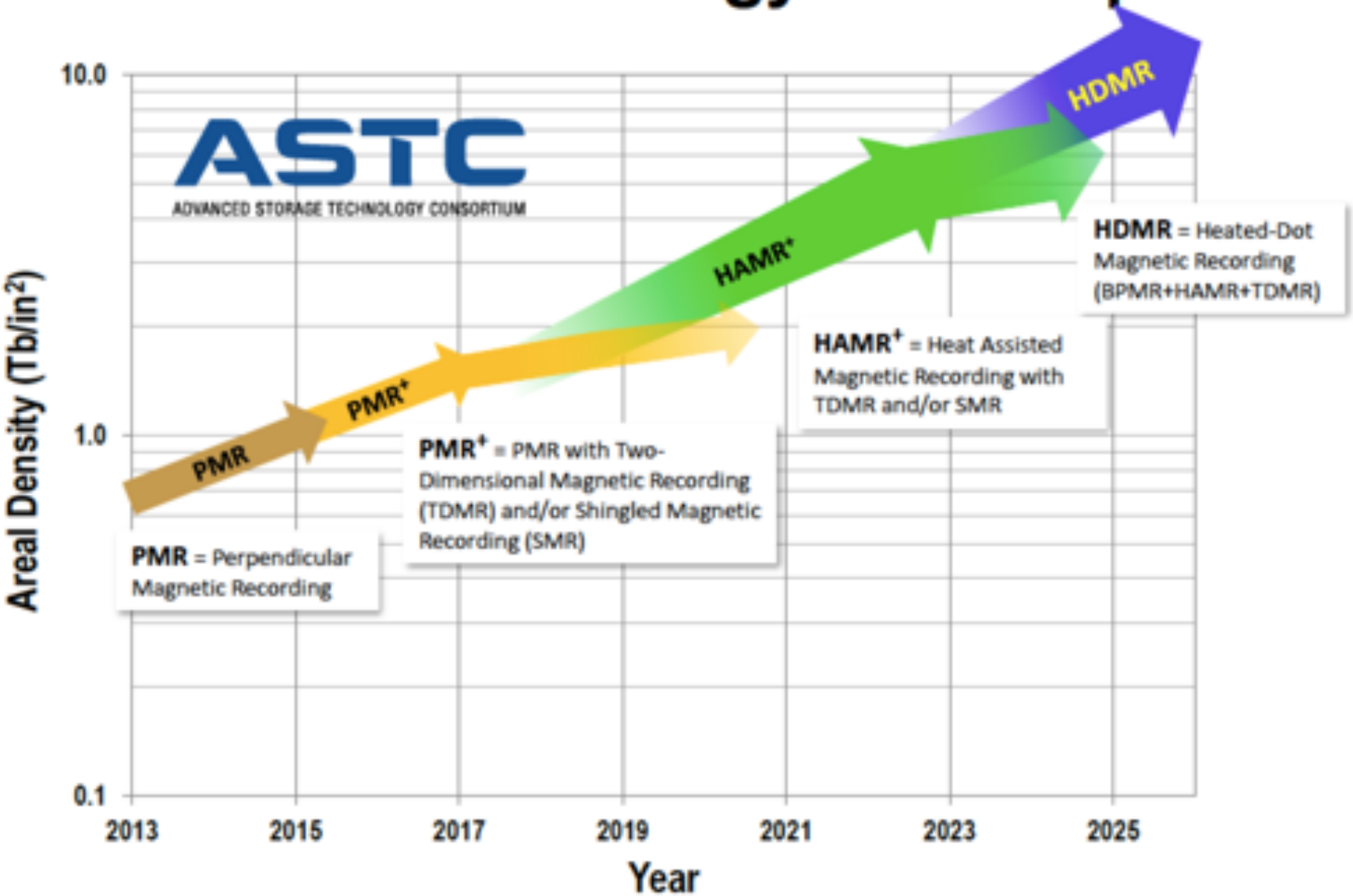
  These drives are optimized to handle temperatures between -22º to +185ºF, while in operation, and handle -40º to +203ºF during non-operation.

  With special aerodynamic technology in the magnetic head slider, the drive series can withstand altitudes up to 18,536 feet (higher than any city in the world) while in operation, and withstands up to 3G (29.4m/s^2) vibration tolerance during operation.

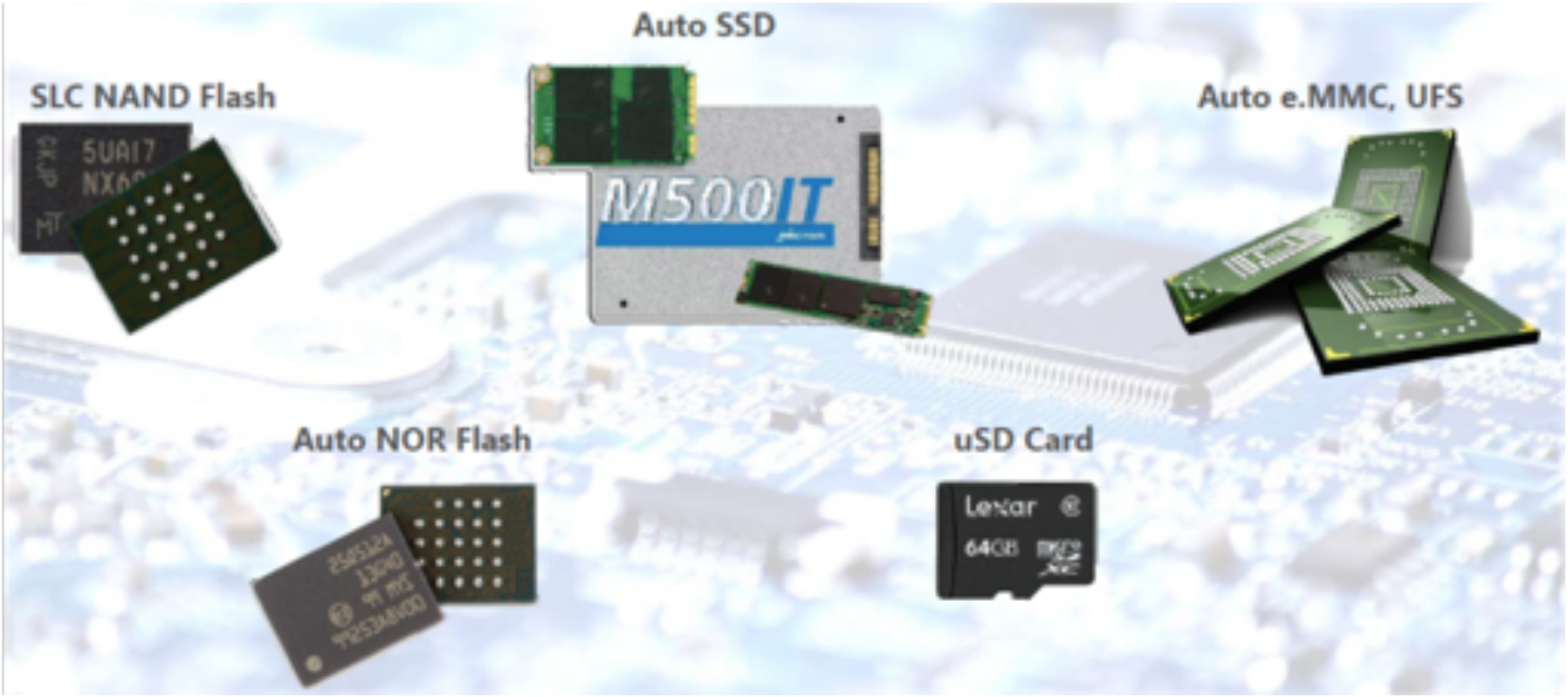
HGST Automobile HDD

- Endurastar J4K320
- 320GB, 250GB, 200GB,100GB & 80GB 2.5-inch Hard Disk Drive
- High operating altitude range of up to 5500 meters
- Wide operating temperature range from -30ºC to +85ºC
- 6th generation product, based on proven technology
- SATA interface

ASTC Technology Roadmap



Solid-State Automotive Memory and Storage



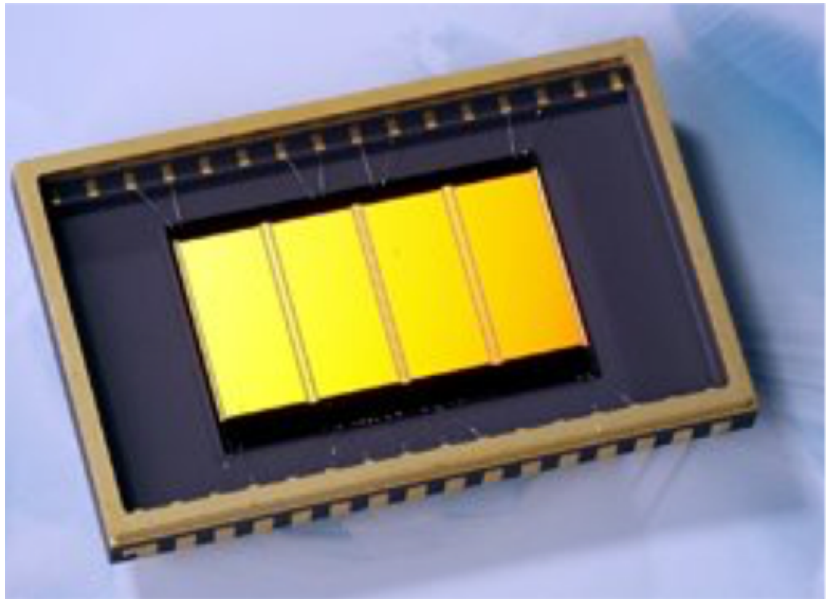
Memory Development to Drive Autonomously, Kris Baxter, Micron, 2016 Flash Memory Summit

Automotive Flash Memory

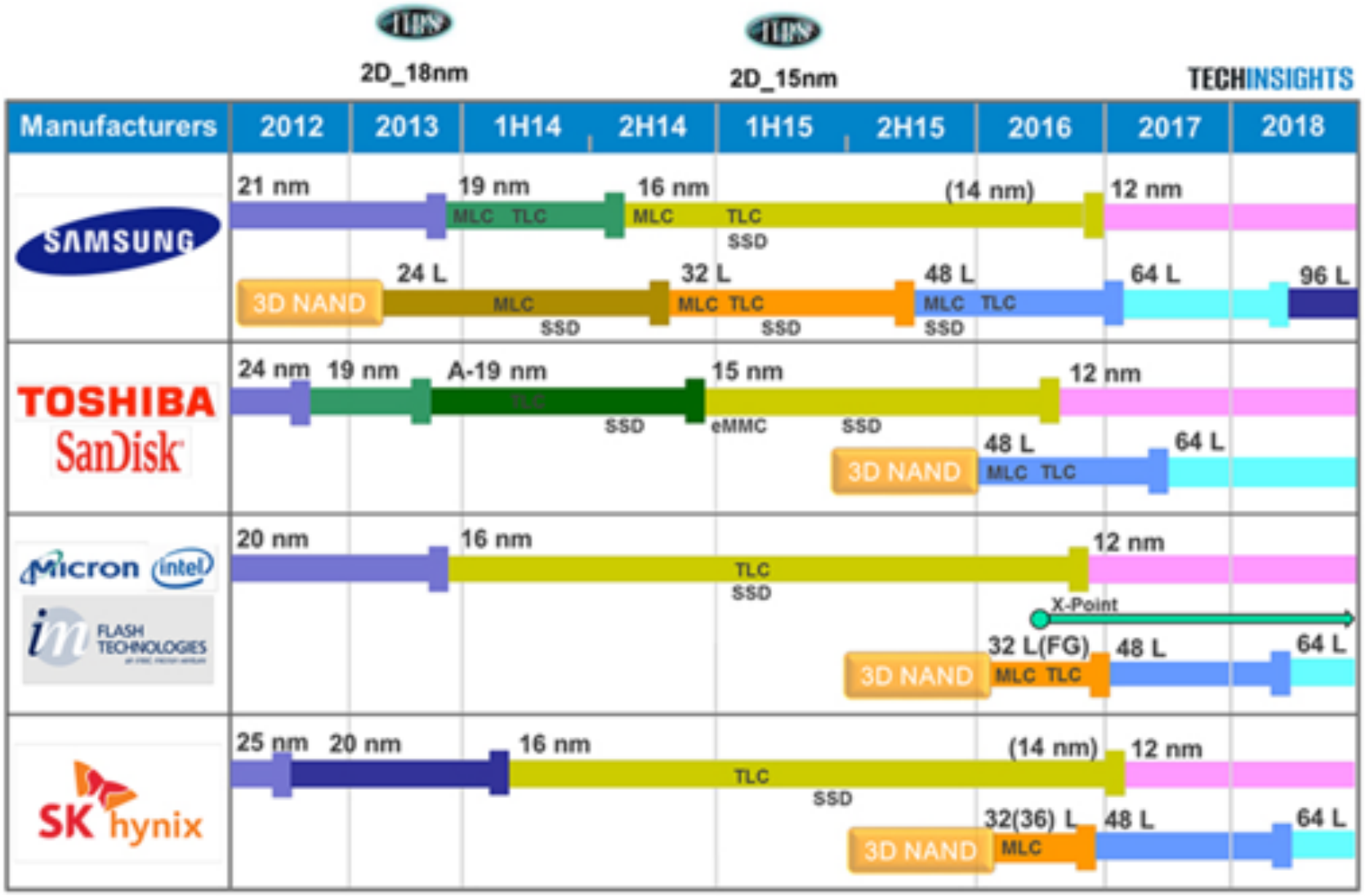
- The SanDisk Automotive portfolio of storage solutions includes an automotive grade SanDisk® SD™ card and iNAND™ embedded flash drive (EFD), which are available to automotive manufacturers in capacities up to 64GB
- Micron automotive SSDs are built to withstand the rigorous demands of automotive applications, with an extended temperature range and robust data protection features.

SLC Flash in Automotives

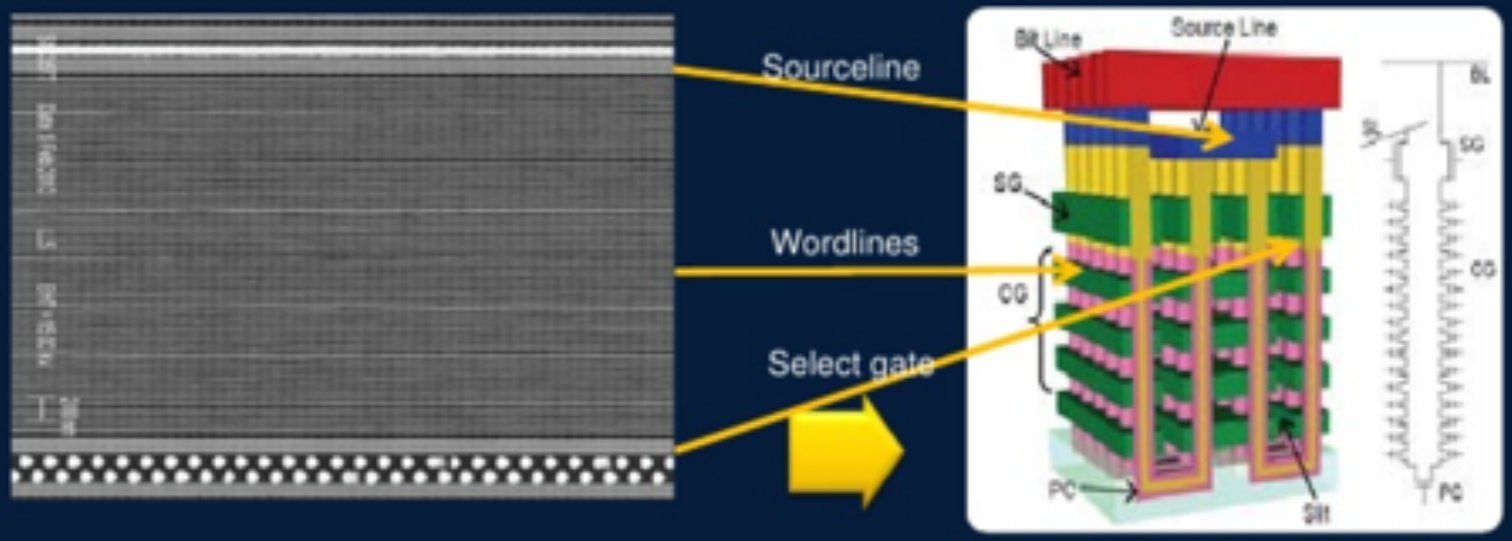
- Micron says that SLC (single level cell) NAND flash is replacing NOR flash in automobiles
- Its SPI and parallel NAND comes in 1, 2 and 4 Gb densities and has a 10-year data retention at 85 degrees Celsius.
- This temperature insensitivity is useful in fanless applications such as automotives



Flash memory roadmap



From 2D to 3D Flash NAND



- A folded, vertically stacked NAND string
- Cells are generated inside a high-aspect-ratio (HAR) contact hole
- Benefits:
  - Memory density is less dependent on patterning
  - Reduced coupling between memory cells
  - Cost scalability

Image Sources:
Left: IMFT 25-nm M/C NAND: technology scaling barriers broken, DONG Yi Technology Group, Published Date:2010-3-23
Right: Pipe-shaped BiCS Flash Memory with 16 Stacked Layers…Ryota Katsumata - 2009 Symposium on VLSI Technology

External Use

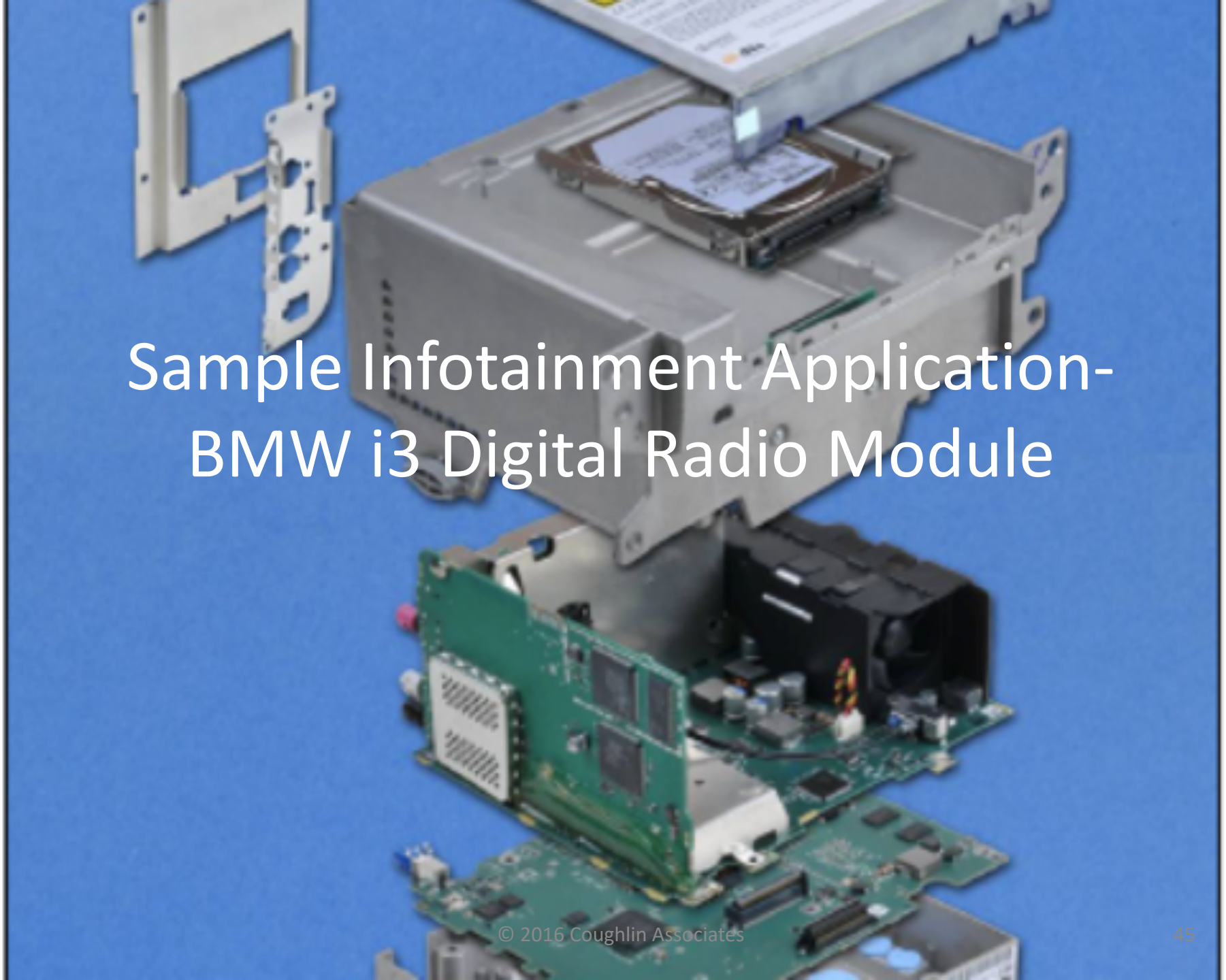
APPLIED MATERIALS

MRAM for Automobiles

Emerging NVM market could exceed $2 B by 2020

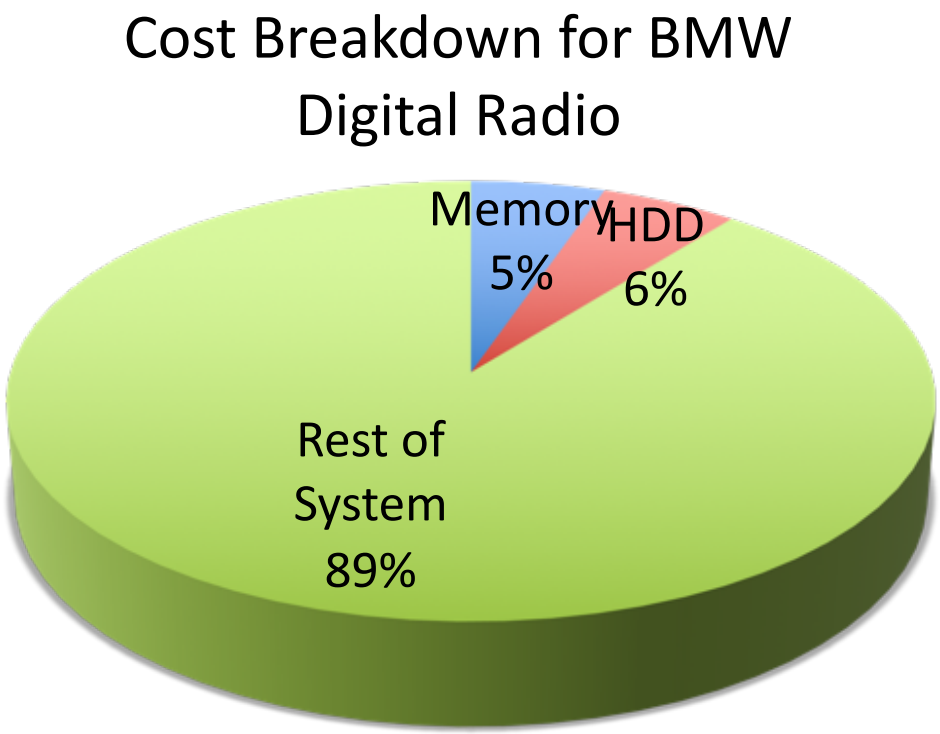
2015 Emerging Non-Volatile Memory & Spin Logic Technologies and Manufacturing Report, Coughlin Associates, , http://www.tomcoughlin.com/techpapers.htm.

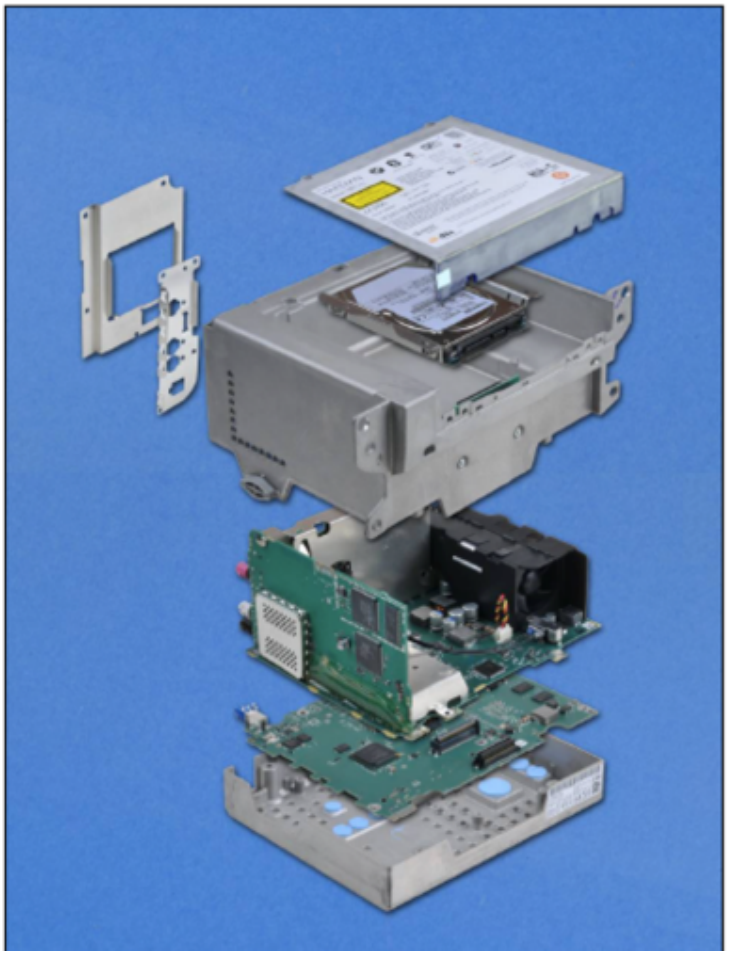
- Everspin, a pioneer in Magnetic Random Access RAM (MRAM) high performance MRAM automotive product line
- **The 16Mb MRAM** is available in the automotive temperature range of **-40 C to 125 C** and comes in both x8 and x16 IO configurations. With fast 45 ns read and write cycle times in a parallel asynchronous SRAM like interface
- **GLOBALFOUNDRIES' eMRAM 22FDX platform** is designed for both code storage (flash) and working memory (SRAM) to enable ultra-efficient memory sub-systems that can be power cycled without any energy or performance penalty. The power efficiency of FDX™ and eMRAM makes 22FDX **an ideal platform for battery-powered IoT products and automotive MCUs.**



Sample Infotainment Application- BMW i3 Digital Radio Module

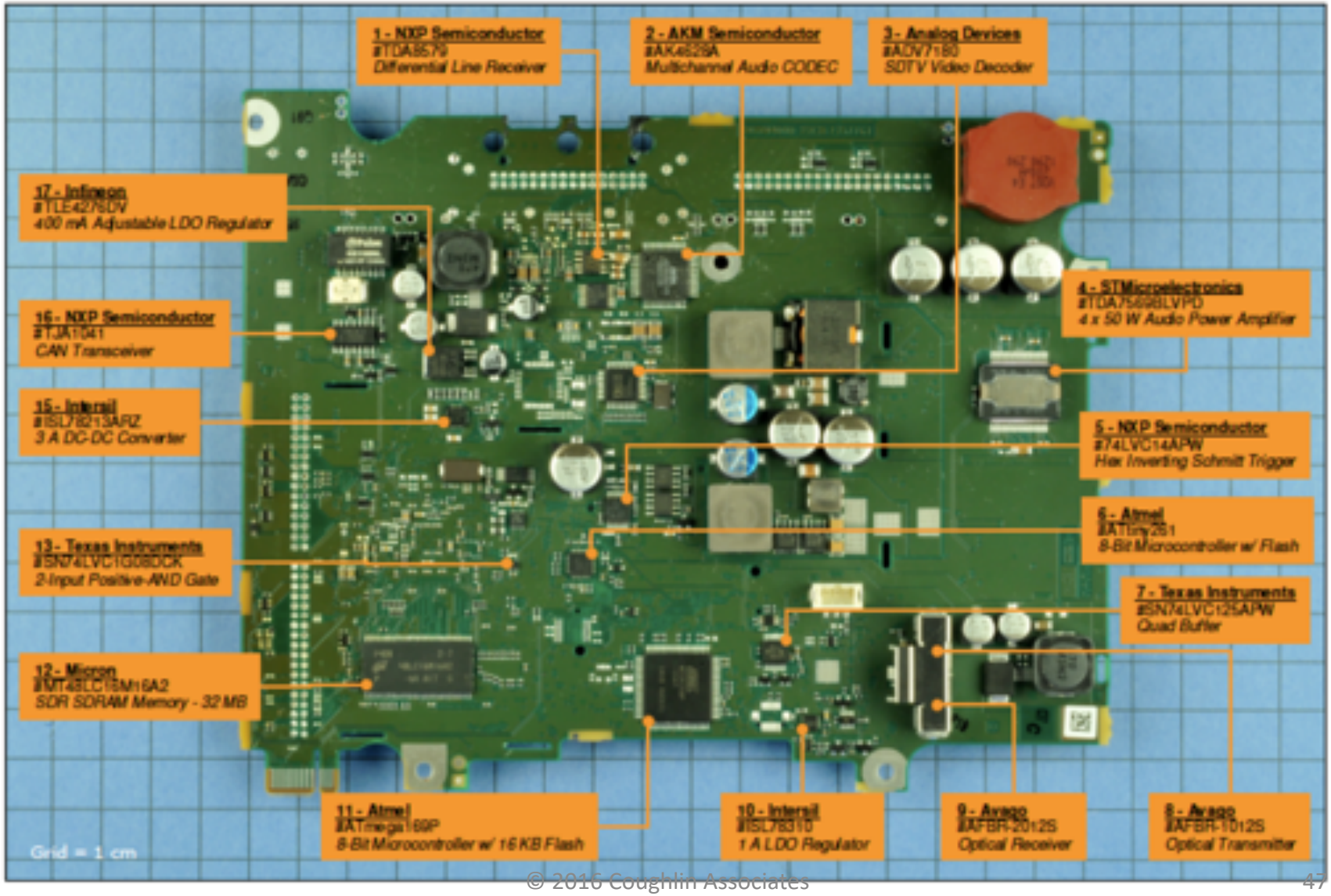
TechInsights BMW Digital Radio Teardown



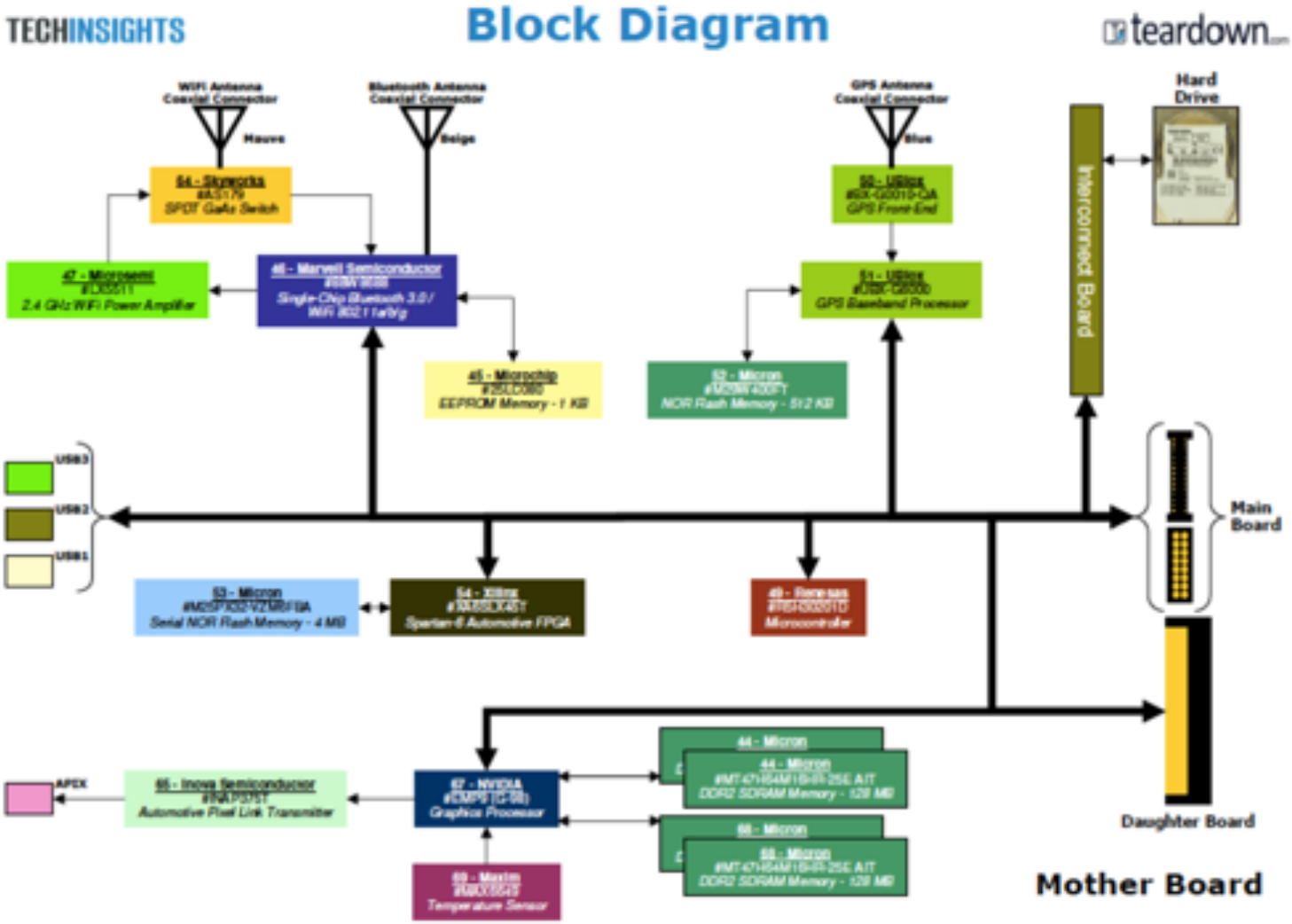


Source: TechInsights Deep Dive Report on BMW i3 Digital Radio Module HBB!@%

Main Board, Side 1



Partial Schematic of the Mother Board of the BMW HBB125



HDD in BMW Digital Radio

Hard Drive	
Brand	Toshiba
Part Number	MK2060GSC
Module Dimensions	100 x 69.6 x 9.5
Weight (grams)	88.40
Estimated Module Line Item Price	**$29.14**

Conclusions

- Although future cars will generate more data than ever before with connectivity and ADAS most of this data goes to the cloud—driving growth in data centers
- Automobiles will also be part of local networks both within the cars as well as between cars (the fog)—radios including LTE, WiFi, GPS, Bluetooth and RFID
- Automotive memory and storage is moving to solid state over the next few years including new entrants, like MRAM
- On the other hand much of the storage in the cloud to support these automobiles will likely be in HDDs

References

- Clemson University Vehicular Technology Lab
- Memory Development to Drive Autonomously, Kris Baxter, Micron, 2016 Flash Memory Summit
- Steve Hetzler and Tom Coughlin, Touch Rate: A metric for analyzing storage system performance, www.tomcoughlin.com/Techpapers
- T. M. Coughlin and S. L. Linfoot, a *Novel Taxonomy for Consumer Metadata*, Presented at 2010 ICCE Conference


Thanks