Web-Feet Research, Inc.

FlashMemory SUMMIT

Business Outlook for the NVM Market

Alan Niebel

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Nonvolatile Flash memory activity – markets

- 2005: $20.5 billion
- 2010: $51.8 billion
- CAGR: 20.4%

Nonvolatile memory activity – S&T and R&D

- 30+ technologies and technology variations

Content

- **Summary**

- New Market Segmentation

- Mobility Segment

- Non-Volatile Memory Market Forecast

- Conclusions

Web-Feet Research - Introduction

- Web-Feet Research:

    Web: connects the world wide web or internet

    Feet: provides direction

- **Vision:**

    - qualitatively and quantitatively define the Non Volatile Memory and Storage markets strategy

- **Charter:**

    - bridge or translate the concepts of the Non Volatile Memory and Storage technologies from research and development into component manufacturing

    - implementing these components into memory sub-systems

    - quantifying the market applications usage and its impact on the financial markets

Summary

- INFLECTION POINT drivers: markets, applications
    - Changing market structure
        - New market segmentation
        - New use models for electronic devices
    - More demanding system requirements
    - Managing growth in Storage (NAND) market
    - Need for rejuvenating Memory (NOR) market

- INFLECTION POINT implications: storage
    1. Linear increase in DEMAND for Memory cards, MCP / SiP, EFD, Solid state drives (SSD)
    2. Geometric increase in Capacity: components and bytes
    3. Increase in access performance and security
    4. Need for a flexible memory business structure

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- **New Market Segmentation**

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Market Changes – Function Model Evolution
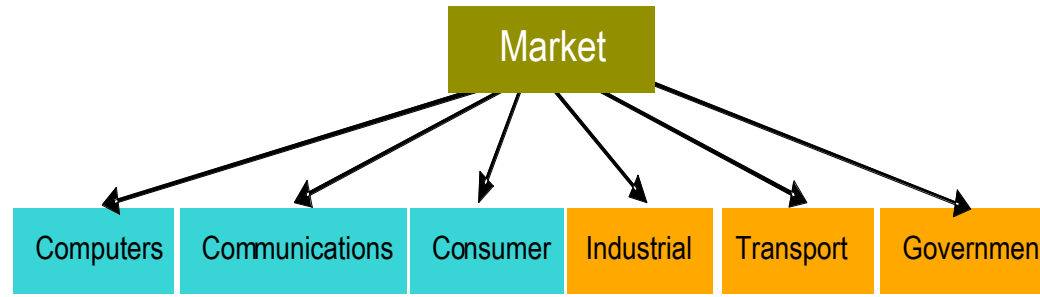
- Old function model market segmentation

  3C

  – Computers and Peripherals – PC, printers, Notebooks, HDD

  – Communications – Cell phones, modems, pagers, STB, Networking

  – Consumer – Digital cameras, MP3, Games, TV, camcorders

  – Industrial – Meters, sensors, medical, POS, industrial controllers

  – Transportation – Automotive, GPS

  – Government – Avionics, Guidance, Field Computers, ID tags

Market Changes – Use Model Evolution

MOBILITY use

PORTABILITY use

STATIONARY use

- New use model segmentation
    - STATIONARY – device cannot be easily moved
        - Mains powered
        - Wired connectivity
        - Examples: desk top PC, STB

    - PORTABILITY – device can be easily moved, but nor worn by user
        - Battery powered
        - Wired/wireless connectivity
        - Examples: notebook, game consoles

    - MOBILITY – device can be worn by user
        - Battery powered
        - Wireless connectivity
        - Very small form factor
        - Examples: cell phones, mobile terminals

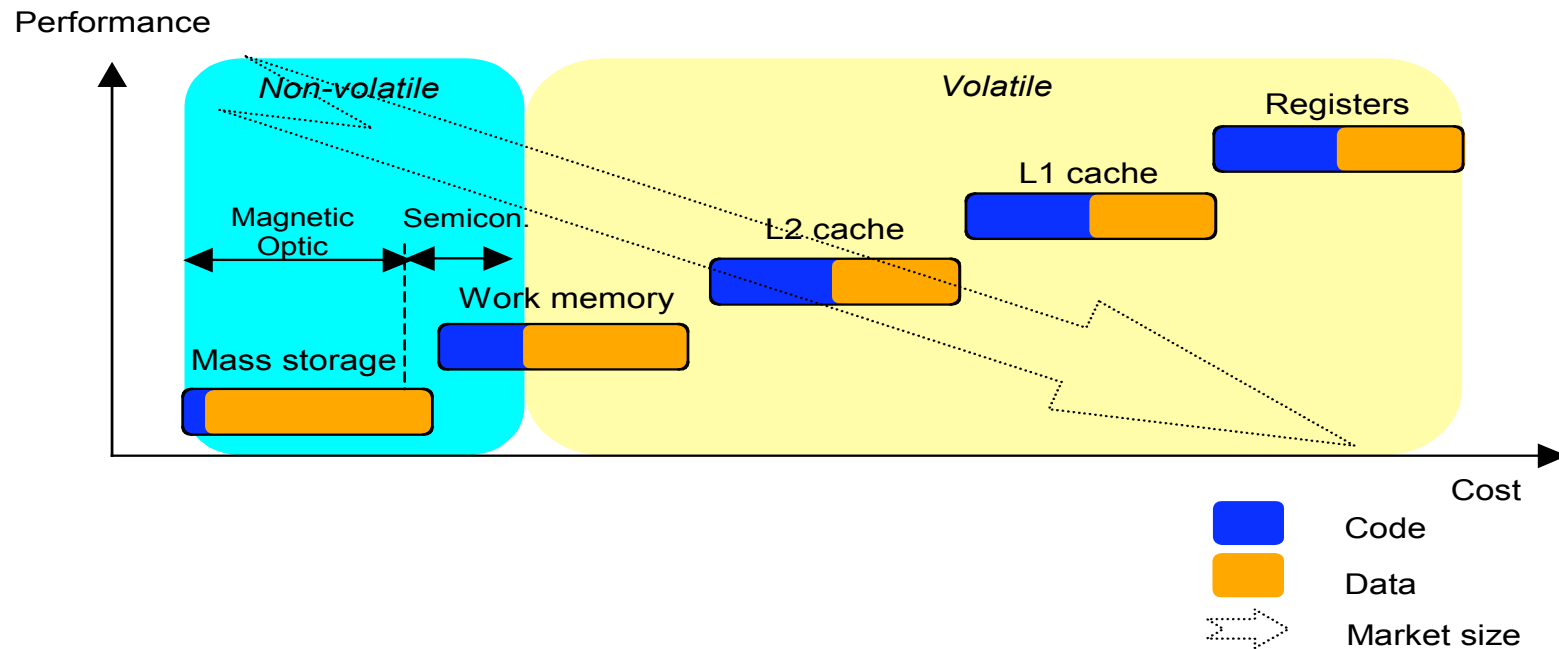# Market Changes – Device Functionality Evolution
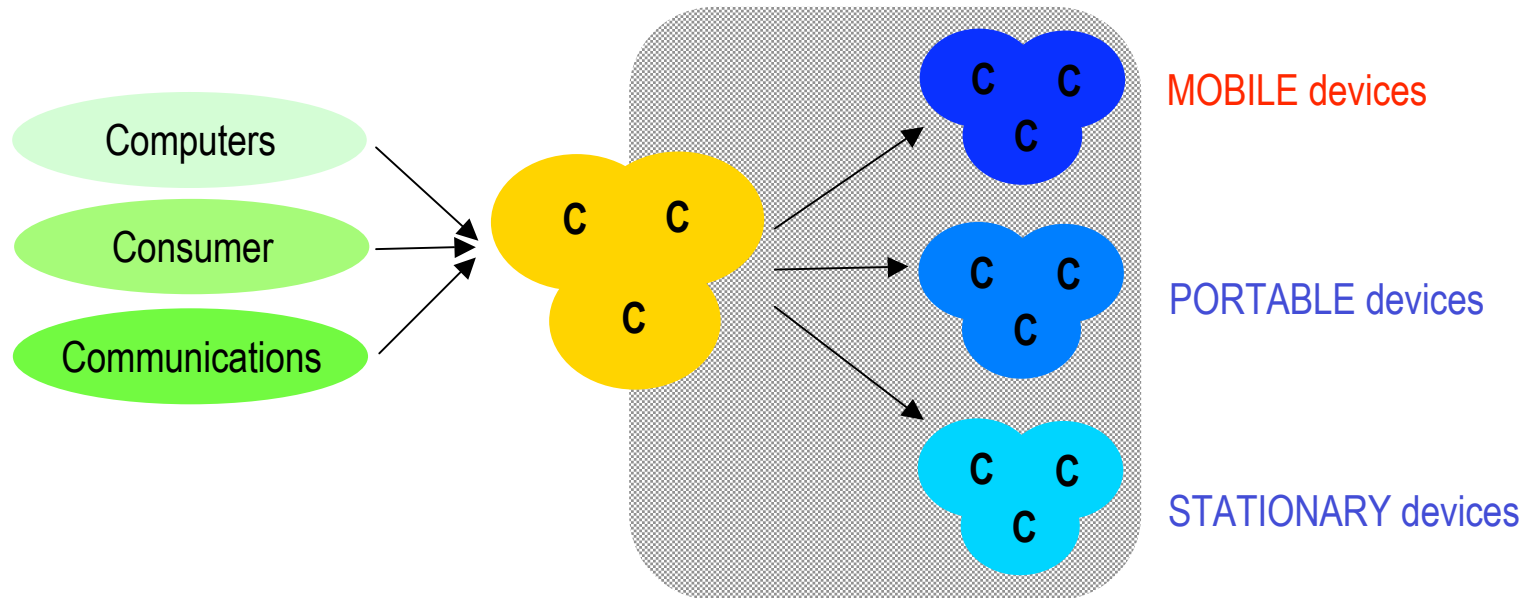
- Transition
  - From: MARKET FUNCTION-based segmentation
  - To: USE-MODEL-based segmentation
  - To: USE-FUNCTION-based converged segmentation

- MOBILITY
  - Drives the INFLECTION POINT for NV memories

- STATIONARY / PORTABILITY
  - Evolutionary, highly predictable
  - Changes in Computing memory subsystems, generates new inflection point

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- New Market Segmentation

- **Mobility Segment**

- Non-Volatile Memory Market Forecast

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Memory Hierarchies – General Computing Evolution

Performance

Non-volatile

Volatile

Registers

L1 cache

L2 cache

Magnetic Optic

Semicon.

Work memory

Mass storage

Cost

Code

Data

Market size

- Memory Hierarchy Evolution:

Registers: – Volatile: flip flops - no functional change

L1 cache: – Volatile: SRAM - no functional change

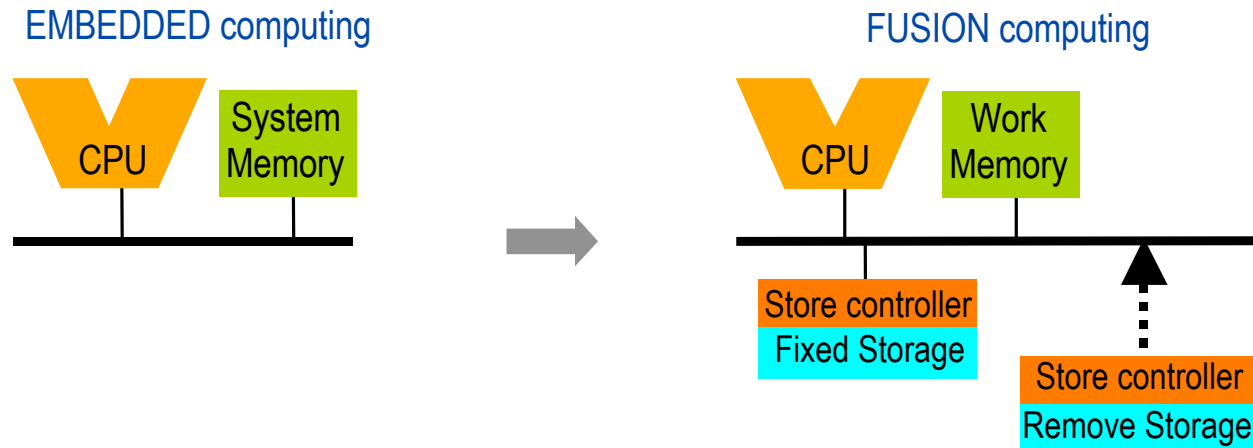L2 cache : – Volatile: SRAM no change, may add L3 cache

Work Memory: – Volatile: DRAM – PC-based system

– Non-Volatile: NOR – XIP for PC-based system

Storage: **New segment** – Non-Volatile: NAND – **Personal storage** > Mass storage

– Non-Volatile: HDD/Optical – Personal < Mass storage

Mobility – System Architecture

EMBEDDED computing

FUSION computing

CPU	System Memory

CPU	Work Memory

Store controller
Fixed Storage

Store controller
Remove Storage

- The MOBILITY segment begins to mature
    - In the '90s: dedicated MPU/MCU specifications
    - In the '00s: dedicated memory/storage components

- Fusion computing – the mobility architecture

- Fusion computing impact on system memory
    - <u>System memory</u> split into:
        1. Work memory: XIP
        2. Storage - Personal
    - *Many more key functions*

Mobility Memory – Evolution
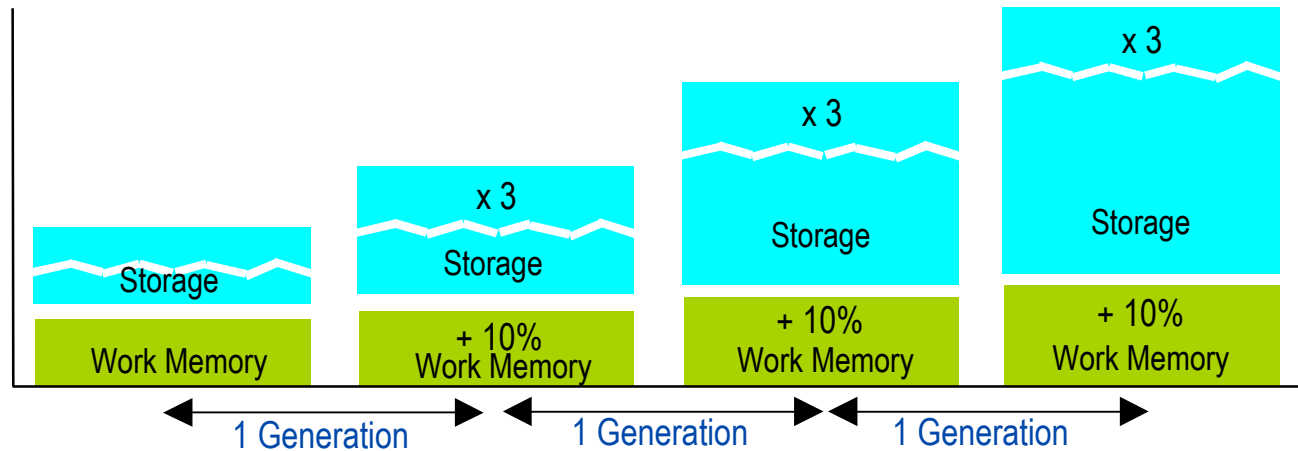
- WORK MEMORY vs. STORAGE
  - Capacity increase pace
    - WORK MEMORY   – Approx. 10% p.a. →   x 2 by 2010
    - STORAGE   – Approx.   X 3 p.a. → x 2,000 by 2010

  - Performance increase drivers
    - WORK MEMORY   – CPU performance driven
    - STORAGE   – Market / applications driven
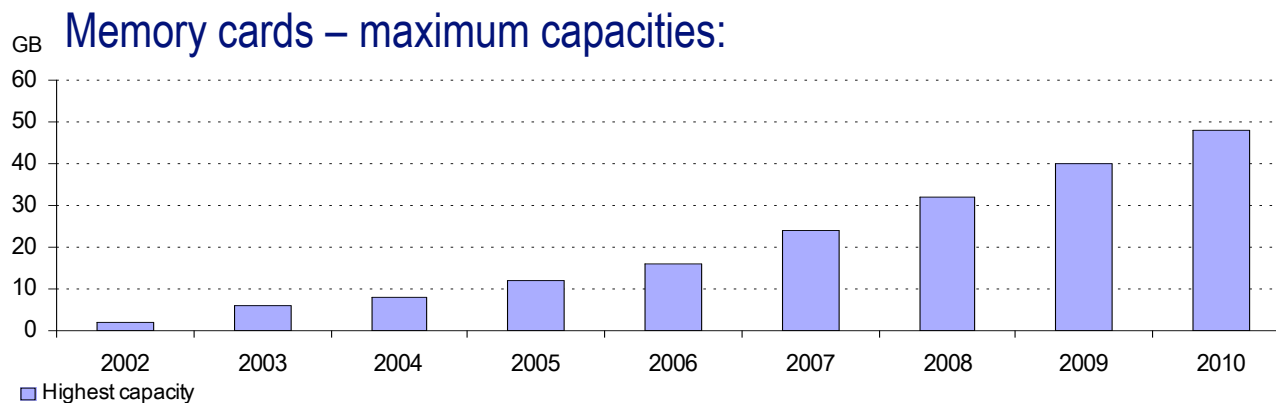
Mobility Market – Functionality Evolution
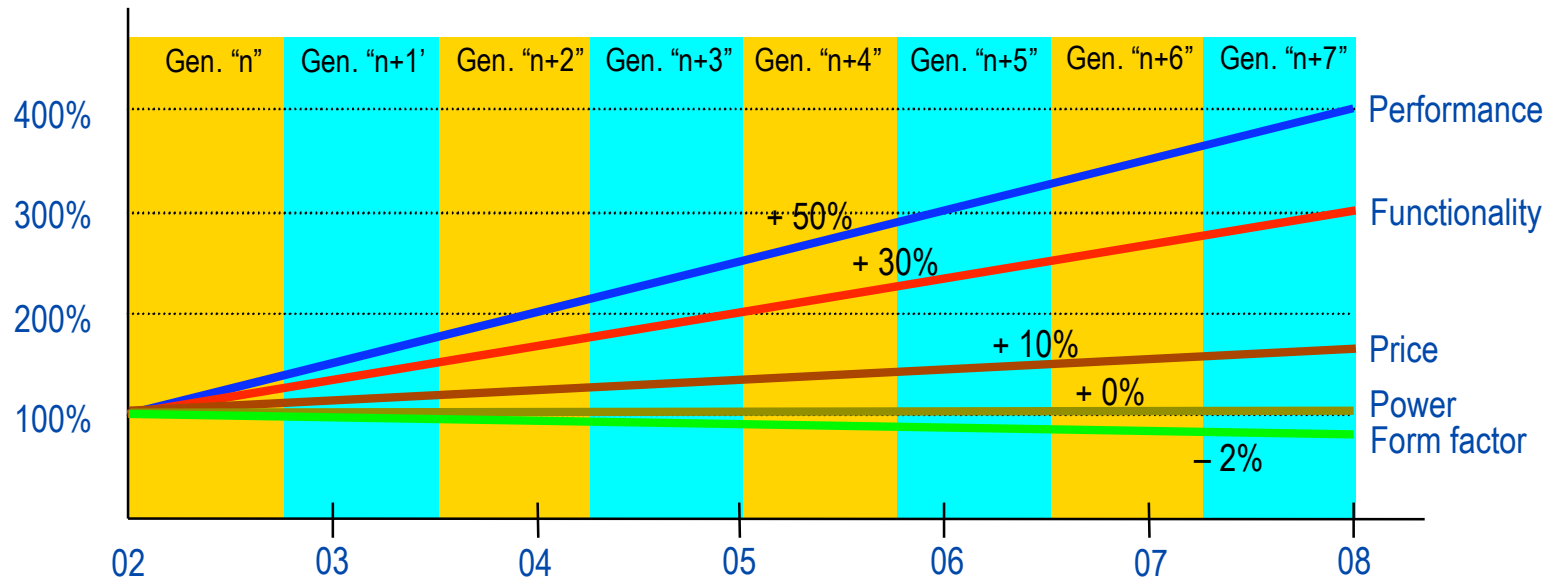
- Functionality evolution trend:

Generation life span:	– Approx. 9 months (trend – shorter over time)
Functionality:	– Needs to increase approx. 30% p.a.
Performance:	– Needs to improve approx. 50% p.a.
Power consumption:	– Needs to stay flat
Form factor:	– Cannot decrease much further (physiologics)
Price:	– Allowed to increase by max. 10% p.a.
	– (price/function has to decrease approx. 15% p.a.)
	– (cost/function has to decrease at a higher pace)

Mobility Market – Storage Performance Requirements 1

- Key performance driver:
  - Video (high definition) will migrate into the MOBILITY space the same way audio did
  - Time frame 2005 -2010
  - Preparations
    - MPEG 7 / MPEG 21 specifications
    - UDF specification to be replace by FAT (File Allocation Table) – file format for local audio/video storage in computers (including MOBILE)

Trend 1: need for higher storage capacity
  - Capacities
    - Up to 50GB (the new DVD standard for HDTV recording/playback)

- Forecast maximum capacity for memory cards (market driven):
  - Maximum capacity CAGR: 42%

Memory cards – maximum capacities:

Bar chart — GB, y-axis 0 to 60. Highest capacity by year:
2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010

■ Highest capacity

Mobility Market – Storage Performance Requirements 2

Trend 2: need for higher storage performance

– Write performance

  • 80Mbps (system level); corresponds to approx. 20MBps on component level

– Read performance

  • 80Mbps (system level); corresponds to approx. 20MBps on component level
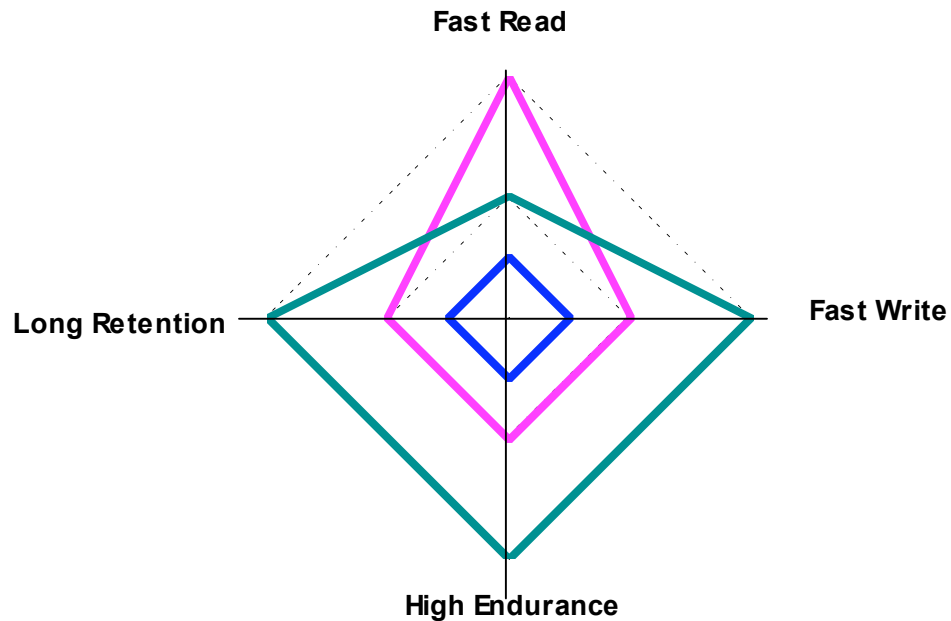
– Symmetrical read and write performance

• Market defined performance classes:

	Description	Pixel resolution	Colors	Frame speed	Bit rate
Clip	Picture clips	4 Mp-16 Mp	3x8	-------	-------
Clip-mot	Clip motion	4 Mp-16 Mp	3x8	8 fps	24 kbps
NB-Im	Narrow band imaging	VGA-XGA	1x8	15 fps	24-64 kbps
BB-Im	Broad band imaging	VGA-SXGA	2x8	15 fps	0.25-18 Mbps
NB-V/A	Narrow band video/audio	VGA-SVGA	2x8	30 fps	24-64 kbps
BB-V/A	Broad band video/audio	VGA-SVGA	3x8	30 fps	0.25-18 Mbps
Db/c-V/A	Digital broadcast video/audio	UXGA (HDTV)	3x8	30 fps	80 Mbps
Data	Computer files	-------	-------	-------	highest available

Trend 3: increased need security features

Trend 4: linearly increasing demand for mobile storage

Application Requirements

Legend: Data Storage (blue) — Code Execution/Data Storage (magenta) — SSD/Memory Cache (teal)

Radar chart axes: Fast Read (top), Fast Write (right), High Endurance (bottom), Long Retention (left)

- ### CONSUMER - Data Storage
  - Memory Cards, USB drives, PMP
    - 1b/c NAND, 2b/c NAND, NROM, AG-AND → 4b/c NAND, Quadbit NROM

- ### COMMUNICATION - Code Execution/Data Storage
  - Cellular phones, PDAs
    - 1b/c NAND, 2b/c NAND, NROM, AG-AND → 4b/c NAND, Quadbit NROM

- ### COMPUTING - SSD/Cache Memory
  - Desktop PC; PC laptops, DAS, SANs, RAID,
    - 1b/c NAND → 2b/c NAND

New Application - Hybrid Flash or Robson

1. **Hybrid Flash/Robson Benefits**:
   – Positioned between DRAM and HDD in Vista O/S
     • Faster Bootup – 3x faster
     • Fast Resume – 14sec vs 17sec
     • Application Acceleration – Super Fetch = 3x launch improvement
     • Power Reduction – 1 of 10 hits spin HDD
       – 9% more battery life = 30 min.
       – Reliability improvements = MTBF increases
   – Target Markets
     • Laptop PC – battery life, various HDD RPM speeds
     • Extreme Gamer PCs – performance is everything

2. **Hybrid Flash**:
   – NAND component densities: 512Mbit, 1Gbit, 2Gbit

   – Built into HDD BOM

   – Possible HDD RPM speed enhancement

3. **Robson Flash**:
   – PCI Express bus mini-module densities: 128MB, 256MB, 512MB, 1GB, 2GB, 4GB

   – Added as after-market Flash module

     • No impact on HDD BOM

     • More density = more acceleration

   – Possible upgrade configuration to existing Hybrid Flash in HDD
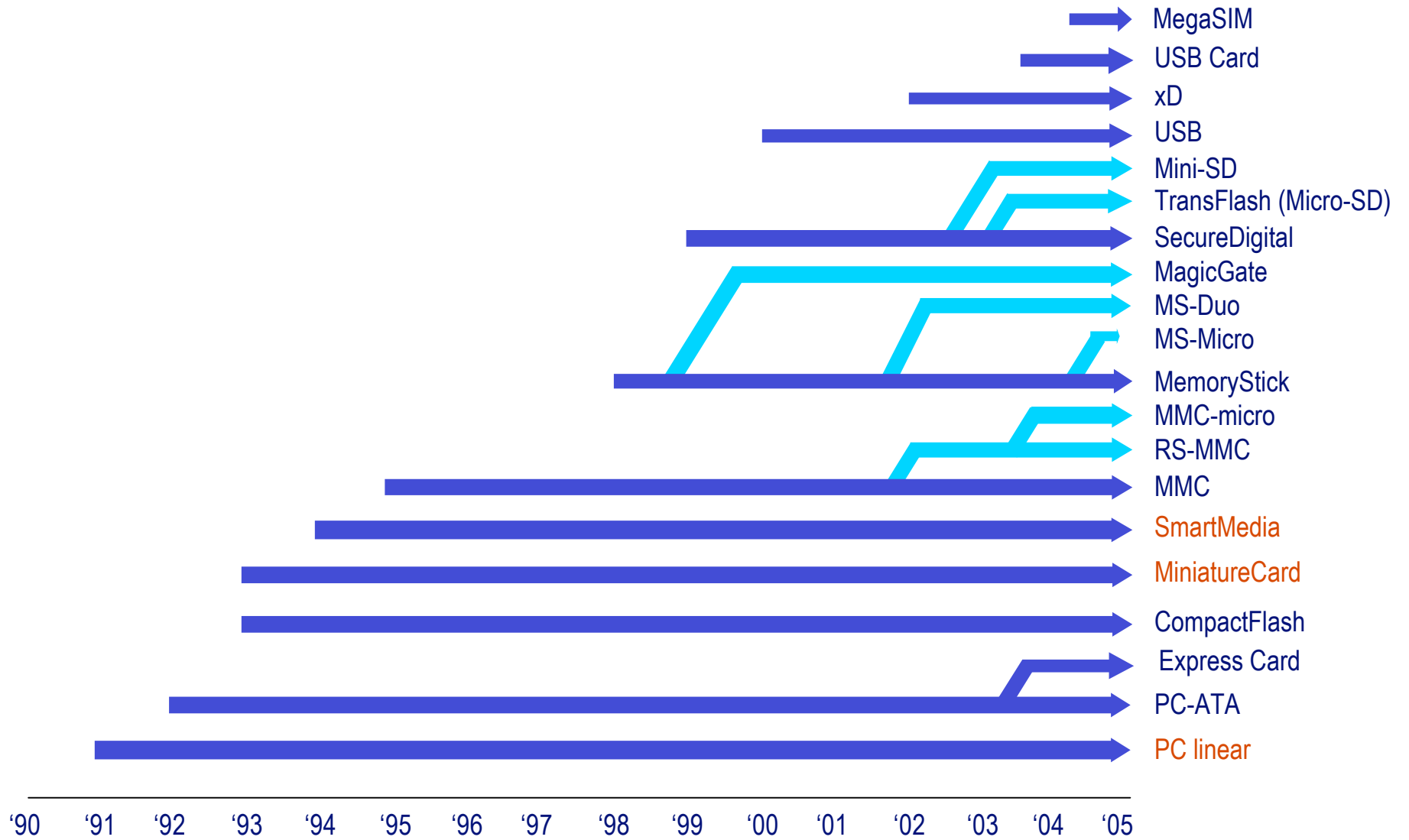
Memory Hierarchy – Mobile Storage

1. **Mobile Personal Storage**:

   – Personal preferences layer added to system

     • Firmware – U3 USB Smart Drives

     • Software – additional function in Vista O/S from Microsoft,

       – NomaDrive better than U3

   – Personalization and Security

     • Captures desktop settings, email, application programs, personal data files

     • Provides enhanced security, authentication, ecommerce, DRM
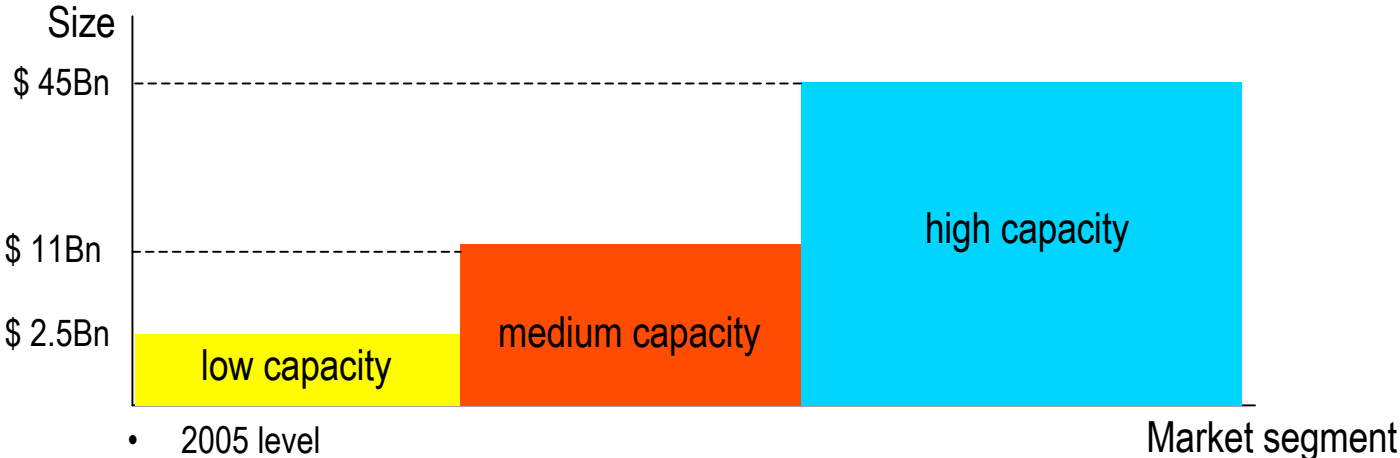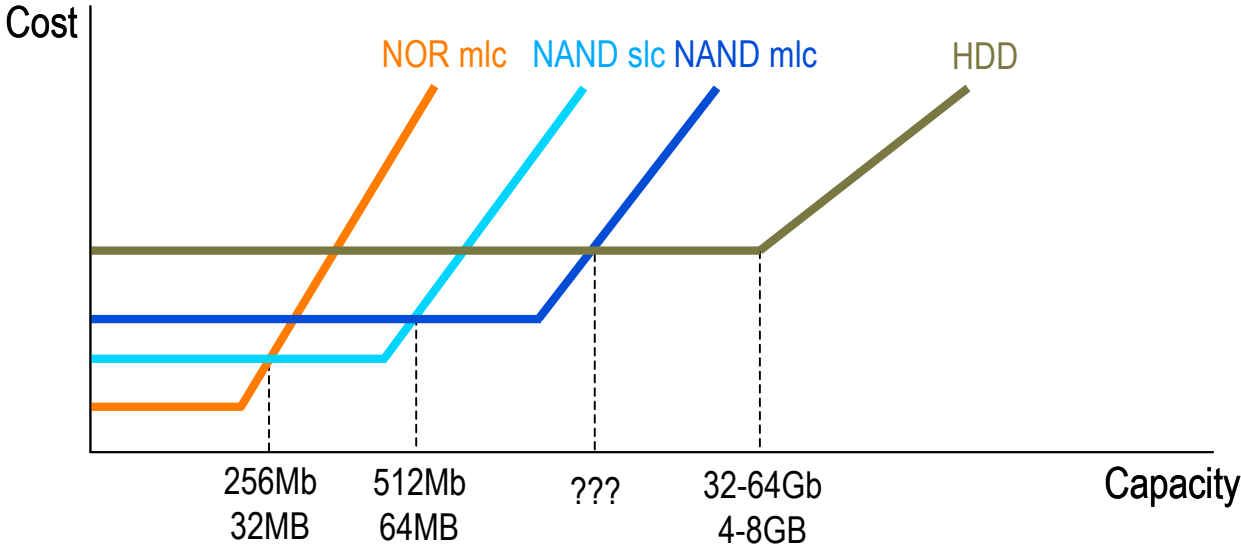
2. Mobile Mass Storage:

   – Blank Media – stores data in generic sense

   – Memory Cards: SD, MMC, CF, MS, xD, USB Drives, MegaSIM

   – Solid State Drives: Flash-based (NAND) Silicon Drive

     • Interfaces to system like HDD

Flash Cards – Form Factors

MegaSIM
USB Card
xD
USB
Mini-SD
TransFlash (Micro-SD)
SecureDigital
MagicGate
MS-Duo
MS-Micro
MemoryStick
MMC-micro
RS-MMC
MMC
SmartMedia
MiniatureCard
CompactFlash
Express Card
PC-ATA
PC linear

'90 '91 '92 '93 '94 '95 '96 '97 '98 '99 '00 '01 '02 '03 '04 '05

Storage Market Segmentation – By Capacity

Cost

NOR mlc   NAND slc   NAND mlc   HDD

256Mb   512Mb   ???   32-64Gb
32MB   64MB   4-8GB

Capacity

Size

$ 45Bn

$ 11Bn

$ 2.5Bn

low capacity   medium capacity   high capacity

- 2005 level   Market segment

Solid State Storage

New Battle Ground

MOBILITY STORAGE

HDD Storage

5GB

20GB

400GB
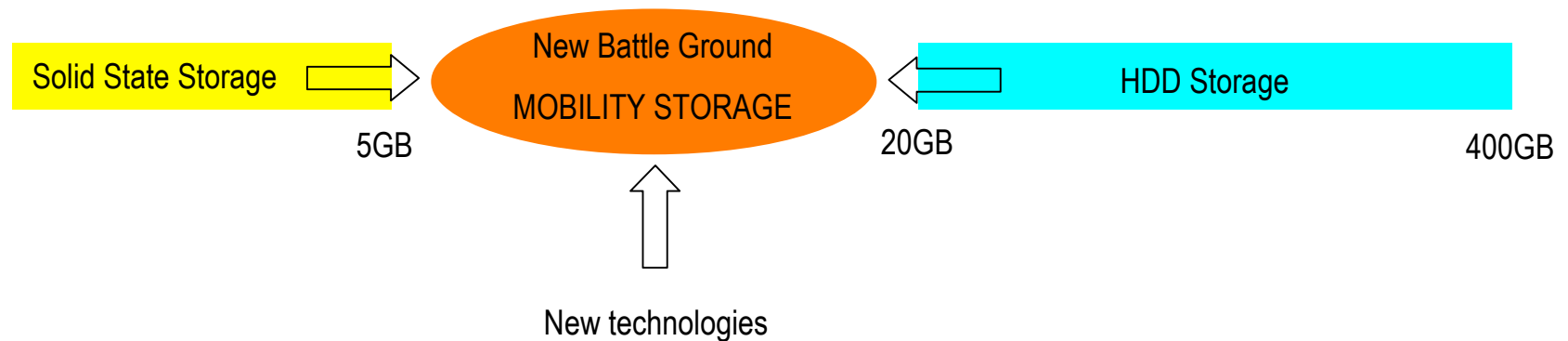
New technologies
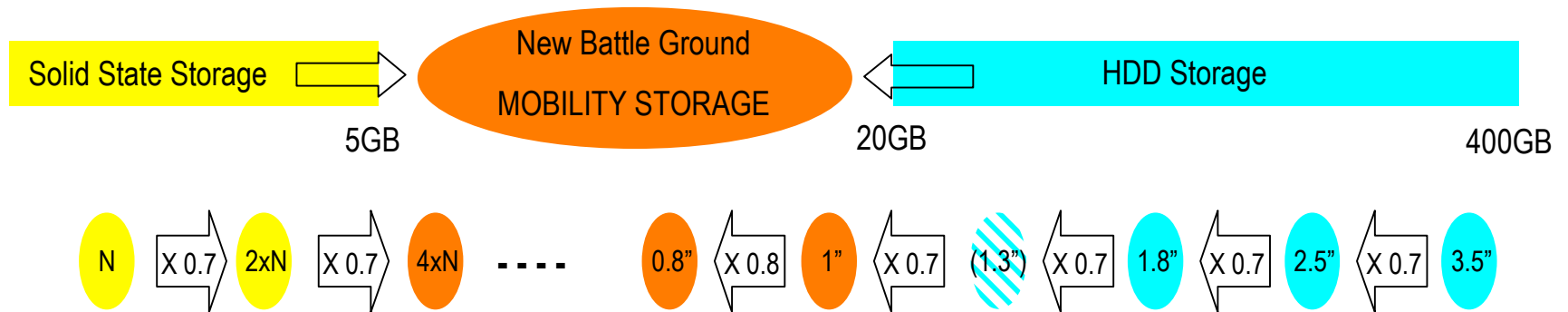
- New battle ground – the mobility space
- Mobility storage market trends
  - Fastest growing (CAGR ~16% over 10 years)
  - Attempts to penetrate this space by
    1. Solid State Storage (higher density / lower cost)
    2. HDD Storage (smaller form factors)
    3. New technologies (2 known so far)

Solid State Storage

New Battle Ground

MOBILITY STORAGE

HDD Storage

5GB

20GB

400GB

N   X 0.7   2xN   X 0.7   4xN   - - - -   0.8"   X 0.8   1"   X 0.7   (1.3")   X 0.7   1.8"   X 0.7   2.5"   X 0.7   3.5"

HDD strategy

• Create smaller form factors

Semiconductor strategy

– Keep form factor

– Increase volumetric density

Content

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- New Market Segmentation

- Mobility Segment

- **Non-Volatile Memory Market Forecast**

- Conclusions

Flash Memory Market Overview

- 2005 Flash memory revenues – $20.5 billion
    - 2006 Flash memory revenues – expands to $25.1 billion

- 2005 Flash memory units – grew 42% in 2005 to 5 billion
    - Main unit growth driver – double digit growth rates for applications
    - 6.6 billion in 2006

- NAND production
    - 2H of 2005 – production slightly below demand
    - 2006 – production higher than demand for overall year, end only 0.5% over

- NOR production
    - High density NOR – increasing density, sluggish production capacity
    - Low density NOR – teetering with oversupply, growing demand

Flash Revenue, Units and ASP Forecast
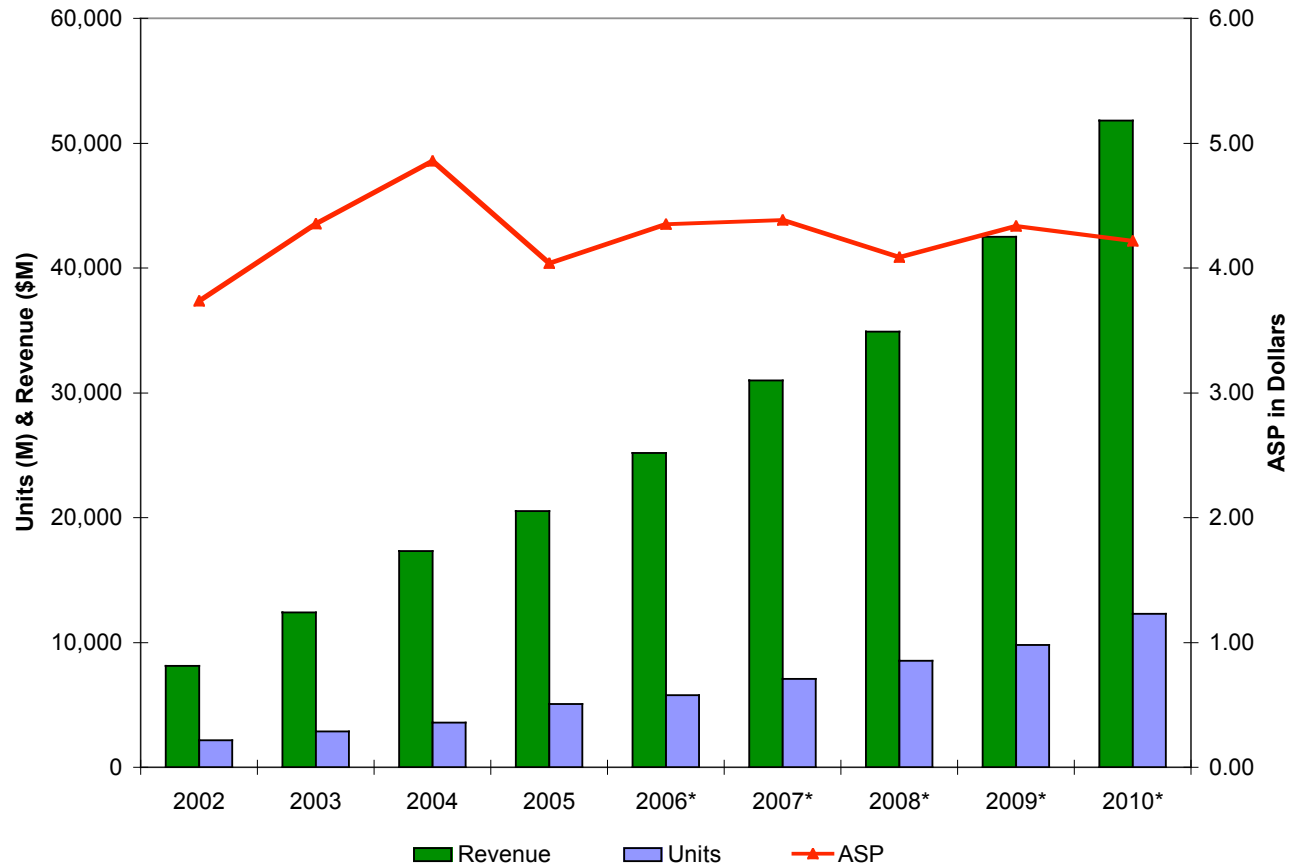
- Revenue and units demand growing linearly thru 2010

- Aggregate ASPs decline in 2005, excess NAND and financial markets force down prices

- Product mix shifts to higher ratio of high density and high priced parts, raises aggregate ASPs thru 2010

Flash Revenue Forecast
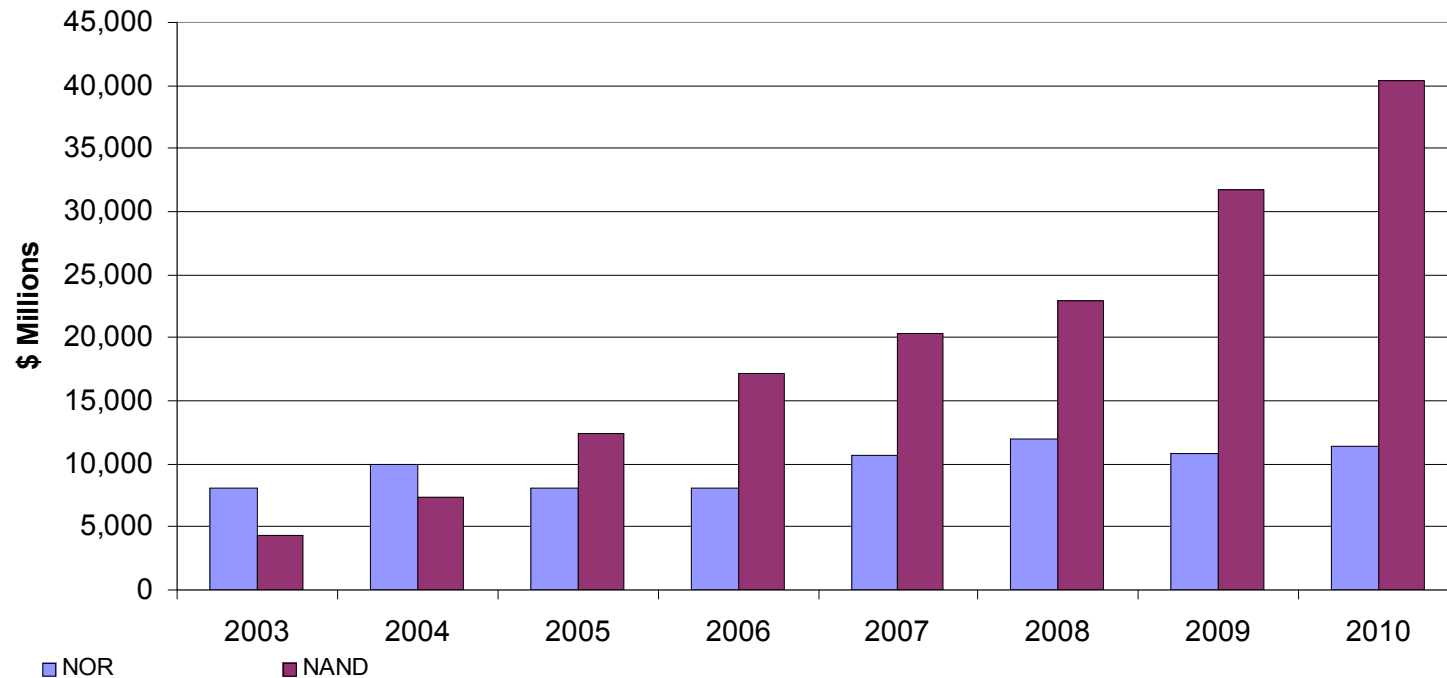
- NOR revenue mild growth until 2005, demand is offset by price declines, revenues reflect slight growth thru 2010

- NAND has accelerated high growth thru 2010, shipment volume much higher than annual price declines

- NAND demand stimulated by Mobile storage: Digital Still Camera, USB Flash Drives, MP3, and TV/Video recording in 2006 and beyond

Flash TeraByte Demand Forecast
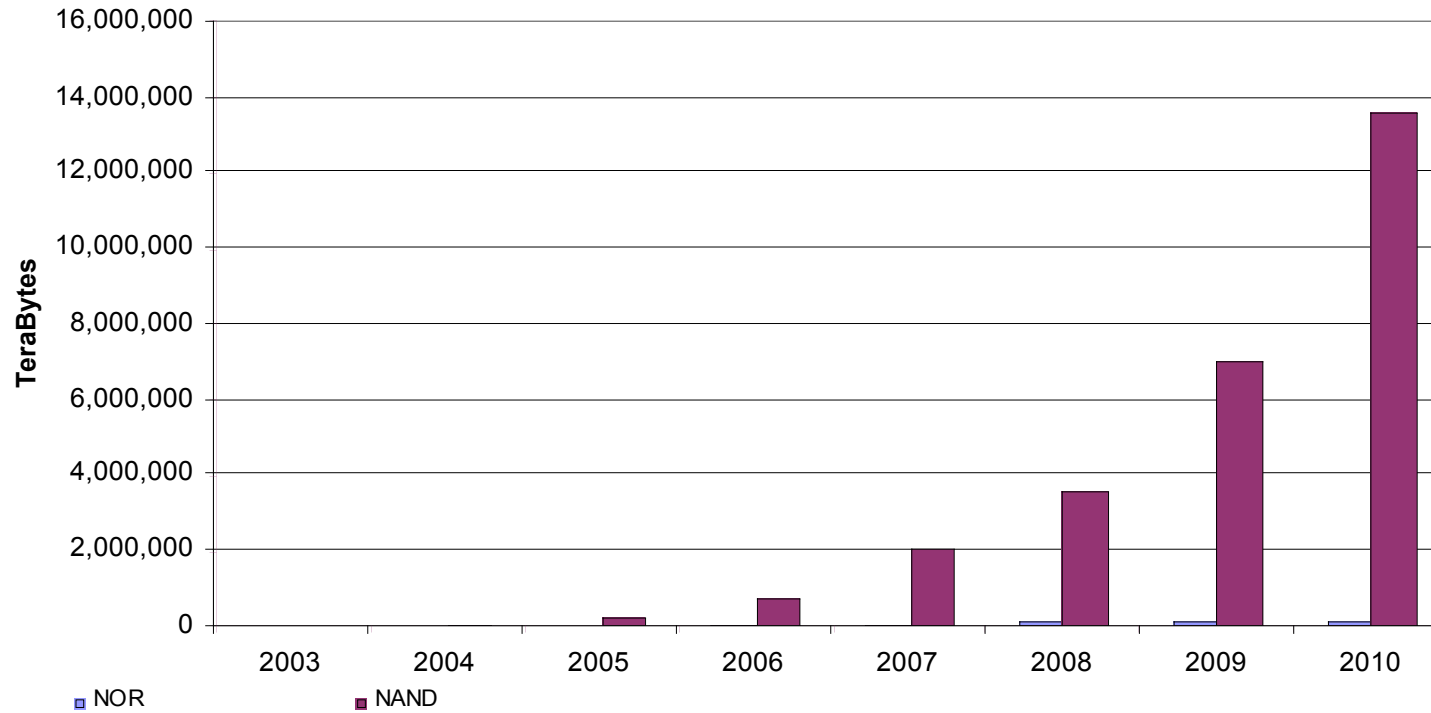
- Memory - NOR TeraByte growth 47.4% CAGR, only one tenth of NAND by 2005, 3% 2010

- Storage - NAND TB growth 122.9% CAGR, doubles through 2010

Revenue Forecast by All Mobile Non-Volatile Architectures
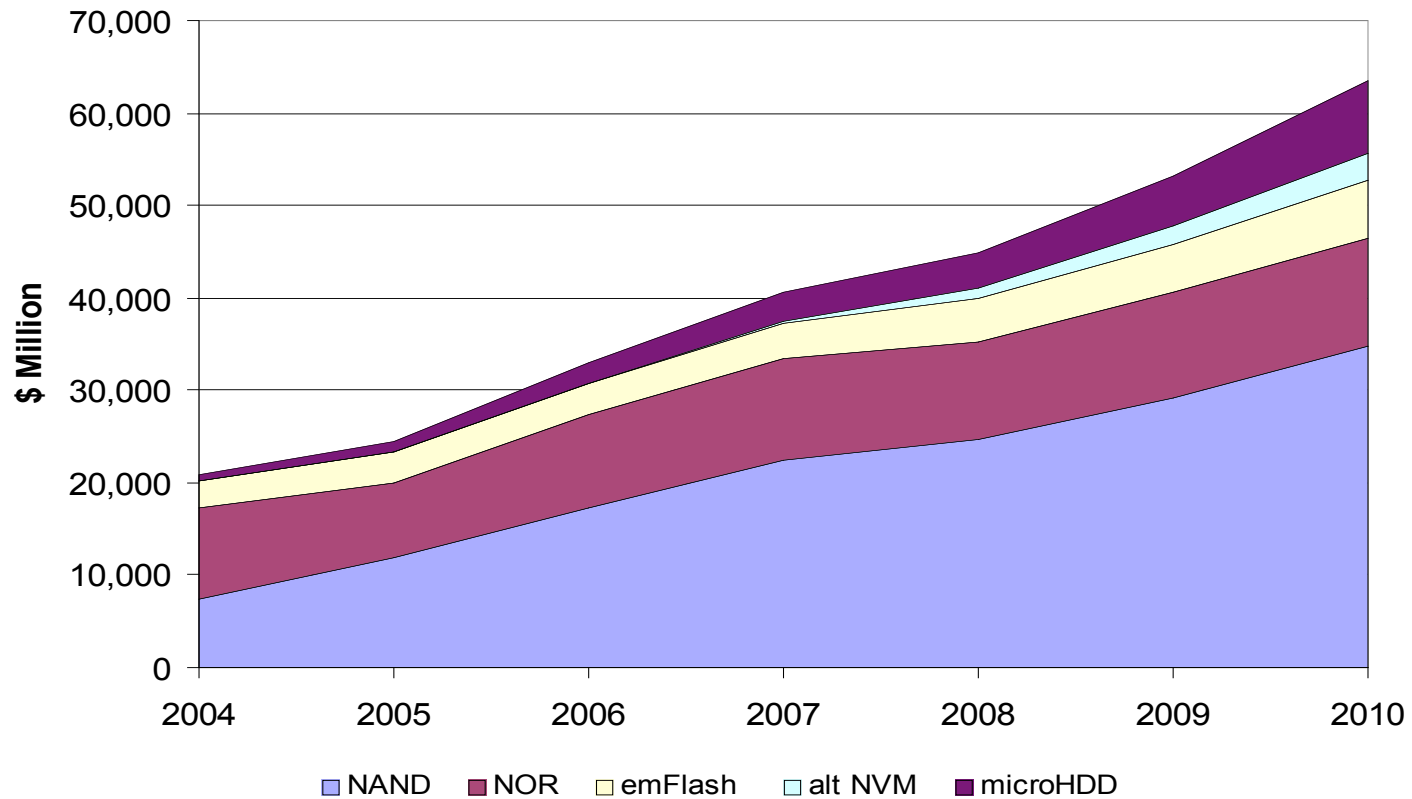
- NAND – includes Floating Gate, Trapped Charge

- NOR - includes FG, Trapped Charge

- emFlash – embedded Flash – monolithically integrated within same die with logic

- alternative NVM – FRAM, MRAM, CRAM, PFRAM, nanoRAM, RRAM, Probe Memories, PIRAM

- microHDD – 1" or .85" Hard Disk Drives for Mobile market – (system ASP instead of component)

Summary – NAND Flash Market Vendors 1

- **Samsung – generated highest sales of NAND**
  - Expand memory production with MLC 8Gbit by May 2006
  - Shipping OneNAND in wireless and addressing embedded NOR markets
  - Announced Hybrid Flash Drive and Solid State Drives for laptop 2007-2008
  - Increasing density from 1GB to 2GB for MMC micro
  - Major influence on market demand and production

- **Toshiba – produced NAND in second place in 2005 for all Flash**
  - Flash Alliance JV manufacturing with SanDisk
  - Ramping fab 3 production, announce fab 4 and fab 5 build
  - Production 70nm 4Gbit NAND SLC and 8Gbit MLC NAND
  - Promotes: 300mm Fab, MLC NAND, SD card form factors

- **Hynix/STMicro – shipping NAND, follows Samsung roadmap**
  - 512Mbit - 4Gbit NAND, MLC Q2 2006, MCP NAND
  - No pricing relief in 2006 with oversupply
  - Fastest NAND read speed 36MB/sec

- **Renesas – retiring from all Flash memory production**
  - Released 4Gbit Q4 2004, cancelled 8Gbit development
  - Possible licensing all AG-AND to PSC

Summary – NAND Flash Market Vendors 2

- Qimonda (formerly Infineon) – shipping Flash cards only
  - TwinNAND NROM-type (512Mbit and 1Gbit components) Flash, 1.8V/3V version
  - 2-4Gbit product in 2007, as QuadBit line comes on-line
  - IPO for Qimonda Summer 2006

- Micron – shipping 1-4Gbit NAND
  - Shipped 4Gbit NAND in Q4 2005
  - Purchased Lexar Media – merging two cultures

- IM Flash Technologies – Intel & Micron formed alliance to develop and manufacture NAND
  - JV develops and manufacture NAND: Boise 06, Manassas 2H 06, Lehi 07
  - 1, 2, 4Gbit SLC now, MLC in first phase development

- SanDisk – Flash Alliance joint production of NAND with Toshiba, Retail, IP businesses
  - Fab 4 announced for Q4 2007
  - Purchase of msystems
  - Product diversification
    - All Flash card form factors
    - U3 and USB Drives
    - MP3 Player
    - iNAND – stacked MCP EFD (Embedded Flash Drive)
- Saifun/SMIC – joint venture/foundry relationship
  - Scheduled to produce 2-bit and 4-bit QuadBit NROM 2006
  - Producing emFlash along with components

- Intel – regained first place in NOR 2005
    - Making most in saturated NOR market
    - Ramping StrataFlash for cellular, (embedded) market
    - Introduced 1Gbit Flash at 65nm production
    - Expand market share:
        - Attack 128M-1G NAND with lower cost NOR
        - Release 16M-128M NOR with SPI and lower cost

- Spansion – regained first place in NOR 1H 2006
    - IPO spun off Spansion as separate company – December 2005
    - Expand MirrorBit product line: SPI, ORNAND 1Gbit, QuadBit
    - Established foundry relationship with TSMC

- STMicro – NOR sales growth in declining price market
    - Considering memory division fate: Spin-off, merge, or make profitable
    - Developed MCP MLC NOR partnership with Intel, second source and standards
    - Introduced new line of MLC NOR products
    - Increasing serial Flash and FWH/LPC shipments

- Sharp – NOR sales to fourth place
    - Rumored to exit NOR Flash market

Summary – NOR Flash Market Vendors 2

- Samsung – generated MCP NOR
  - Developed NOR 32-256M products for MCP
  - Fab 6 will run EOL for MCP NOR then discontinue by 2008

- Toshiba – respectable MCP NOR shipments
  - Offsetting NOR MCP volumes with NAND MCP offerings in 2006

- Renesas – produced NOR
  - Maintaining market for Combo/MCP wireless sales

- SST – shipped NOR
  - Continuing to expand presence in low end of NOR market
  - Diversify to non-NOR peripherals and controllers

- Macronix – shipping higher volumes of NOR
  - Developing NROM-type high capacity product with Saifun – long term
  - Nbit NROM NOR-type MirrorBit compatible product line released then sued

Flash Components Market Shares

Rank			Flash Vendor	$ in Millions			%	Market Share %		
23	24	25		2003	2004	2005	Change	2004	2005	Change
1	1	1	Samsung	2952.0	4896.7	7015.0	43.3%	28.2%	34.2%	6.0
2	4	2	Toshiba	1912.0	2067.1	2569.6	24.3%	11.9%	12.5%	0.6
4	3	3	Intel	1673.7	2349.1	2295.0	(2.3%)	13.5%	11.2%	(2.3)
3	2	4	Spansion	1740.0	2411.3	2045.0	(15.2%)	13.9%	10.0%	(3.9)
23	11	5	Hynix	6.0	315.2	1551.0	392.1%	1.8%	7.6%	5.7
7	5	6	STMicroelectronics	783.0	1196.0	1321.0	10.5%	6.9%	6.4%	(0.4)
8	7	7	SanDisk	401.0	836.1	908.0	8.6%	4.8%	4.4%	(0.4)
5	6	8	Renesas	1040.0	864.6	651.0	(24.7%)	5.0%	3.2%	(1.8)
6	8	9	Sharp	819.0	801.0	522.0	(34.8%)	4.6%	2.5%	(2.1)
9	10	10	SST	249.0	346.6	363.0	4.7%	2.0%	1.8%	(0.2)
13	13	11	Micron	64.0	179.3	320.0	78.5%	1.0%	1.6%	0.5
10	9	12	Macronix	224.8	393.4	214.0	(45.6%)	2.3%	1.0%	(1.2)
NR	NR	13	M-Systems	n/a	73.2	194.5	165.7%	0.4%	0.9%	0.5
12	12	14	Atmel	150.9	192.0	157.0	(18.2%)	1.1%	0.8%	(0.3)
NR	15	15	Infineon	0.0	84.1	152.0	80.7%	0.5%	0.7%	0.3
11	14	16	NEC	203.0	151.3	71.0	(53.1%)	0.9%	0.3%	(0.5)
15	17	17	PMC	41.1	44.4	42.0	(5.4%)	0.3%	0.2%	(0.1)
14	16	18	Winbond	57.1	54.4	40.0	(26.5%)	0.3%	0.2%	(0.1)
17	22	NR	NexFlash	12.0	12.0	n/a	n/a	0.1%	n/a	n/a
22	21	19	EON	7.0	17.0	14.2	(16.5%)	0.1%	0.1%	(0.0)
21	19	20	AMIC	8.0	22.0	13.0	(40.9%)	0.1%	0.1%	(0.1)
16	18	21	Sanyo	25.0	25.0	12.0	(52.0%)	0.1%	0.1%	(0.1)
19	24	22	Matsushita	10.0	7.0	12.0	71.4%	0.0%	0.1%	0.0
18	23	23	Mosel Vitelic	10.0	8.0	9.0	12.5%	0.0%	0.0%	(0.0)
24	25	24	Catalyst	5.7	6.1	5.2	(14.8%)	0.0%	0.0%	(0.0)
25	26	25	IMT	5.0	5.0	5.0	n/a	0.0%	0.0%	(0.0)
NR	27	26	Excel	n/a	2.4	2.4	n/a	n/a	0.0%	n/a
20	20	27	Tower	9.0	18.0	0.0	n/a	0.1%	0.0%	(0.1)
27	28	28	Others	10.0	5.0	9.0	80.0%	n/a	0.0%	n/a
			Total	$12,418	$17,383	$20,513	18.0%	100%	118%	n/a

*NR= Not Ranked

Source: Web-Feet Research

Business Models – Storage/Memory Hardware Diversification

Develop various storage/memory subsystems

- Flash silicon components – 1-bit per cell, 2-bit per cell
  - NOR, NAND, TC, Alternative
- Embedded silicon memory – 1-bit per cell, 2-bit per cell
  - NOR, TC, Alternative
- Embedded Flash Drive – component + controller
  - MDOC, OneNAND, SuperAND
- Removable Flash Card – component + controller
  - Create new form factor, faster, secure, smaller

- Hybrid Drive or Robson – intermediate sub-system support
  - Shift caching, fetching, bootup, system reliability, application acceleration functions to HDD

- Solid State Drives
  - Complement not compete with HDD
  - Faster, smaller, ruggedized than HDD
- HDD
  - Reduce form factor, increase capacity

How much does developing new technology or sub-systems really benefit the user?

Conclusions

- INFLECTION POINT drivers: markets, applications
    - Changing market structure
        - New market segmentation
        - New use models for electronic devices
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- INFLECTION POINT implications: storage
    1. Linear increase in DEMAND for Memory cards, MCP / SiP, EFD, Solid state drives (SSD)
    2. Geometric increase in Capacity: components and bytes
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2006 Non Volatile Memory Conference
'Memory and Storage – Implementing Effective Applications'

Thursday, September 14, 2006
Santa Clara Marriott

Contact: www.web-feetresearch.com

Thank You