Accelerating MEMS Market to $Trillion/Trillion Units

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Meptec, May 23, 2012

Consumer Sensor Explosion

- Consumer sensor explosion in mobile market from 10M units in 2007 to 3B in 2012, to (currently) forecasted 16B in 2016 created multiple waves:
  - Dramatic cost reduction for multiple sensors.
  - Disruptive infrastructure improvements, including opening low cost wireless/ Internet connectivity and Cloud data storage for sensors.
  - Emergence of sensor data processing and sensor software companies.
- These factors enable adoption of sensor technologies outside consumer mobile market, bringing for the first time a potential for a Trillion unit $Trillion MEMS based market in 10 years.

Consumer MEMS

- Four market needs started a massive adoption of sensors in consumer market:
  - Wave solderable microphones for cell phones.
  - Portrait/landscape image rotation in iPhone (accel).
  - Gaming motion detection in WII (accel + gyro).
  - Camera image stabilization (gyro).

Proliferation of MEMS/Sensors in Cell Phones

2000	2005	2010	2015
Temperature	Temperature	Temperature	Temperature
Simple RF filters	Simple RF filters	Simple RF filters	Advanced RF MEMS
	Camera	Rear facing camera	Rear facing camera
	Microphone	Front facing camera	Front facing camera
		Microphone	Microphone array (2-5)
		Ambient light sensor	Ambient light sensor
		Proximity sensor	Proximity sensor
		Acceleration (iPhone)	Acceleration
		Gyro (iPhone4)	Gyro
		Compass (iPhone4)	Compass
		Touch screen	Touch screen
		GPS	GPS
			Altimeter
			Humidity sensor
			CO sensor
			Projector
			Health sensors and actuators

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Pointers to Accelerated MEMS Growth to a $Trillion/Trillion Units

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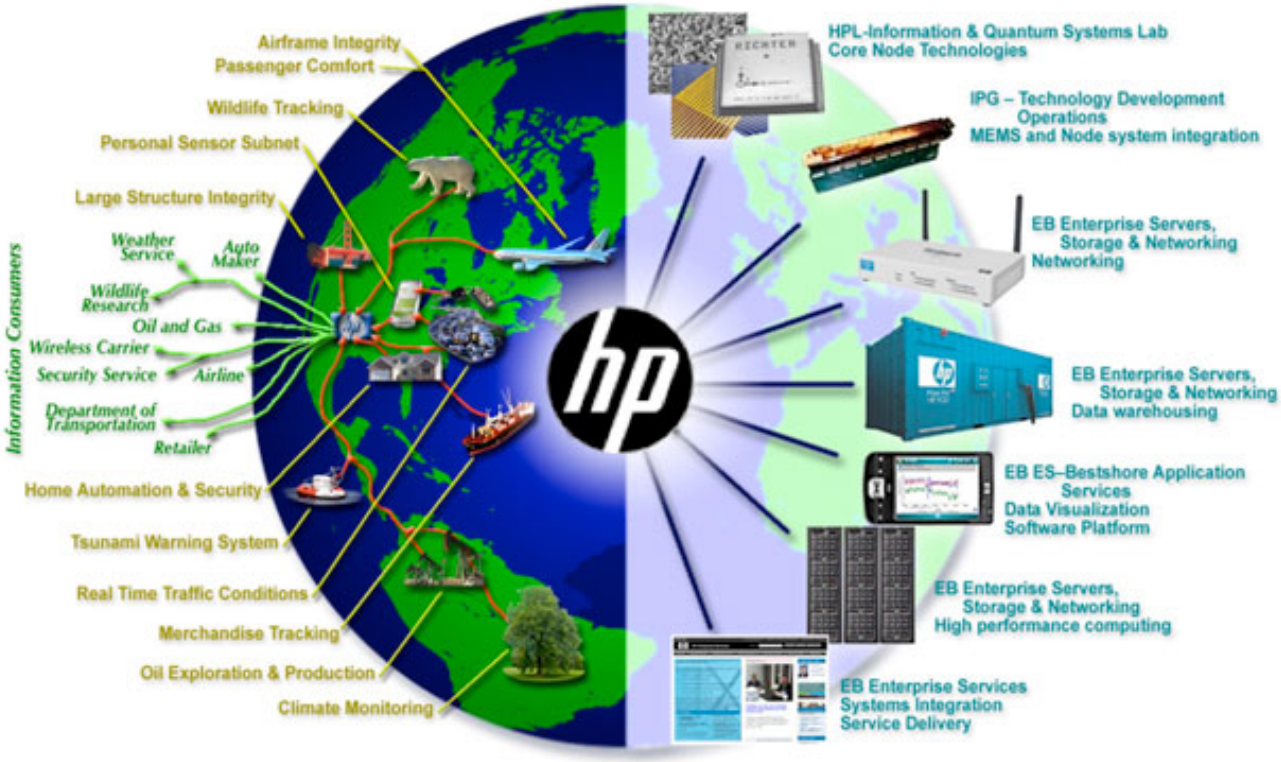
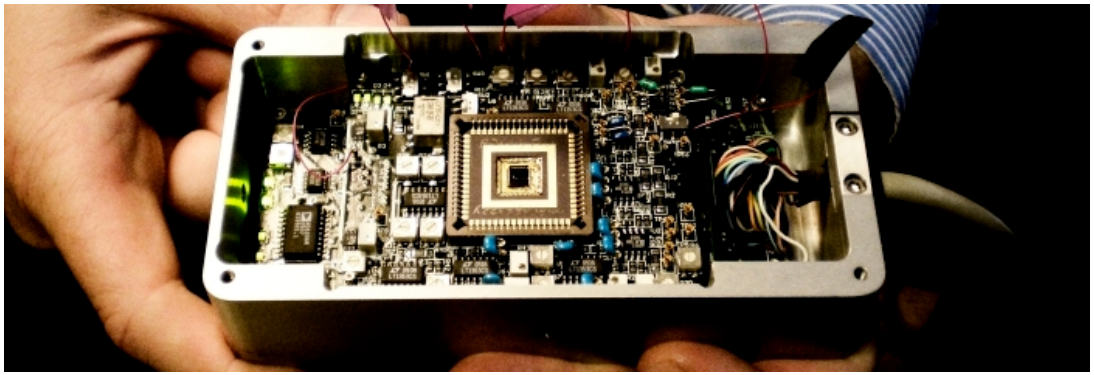
Central Nervous System for the Earth

- Starting in 2010, in multiple presentations, Hewlett-Packard outlined a vision for CeNSE, a Central Nervous System for the Earth.
- CeNSE is expected to deploy a trillion nano sensors and actuators.
- With a trillion nodes, the MEMS market would be large.
  - Assuming a smart Internet sensor node priced at just $1 would result in $1T market…





http://www.hpl.hp.com/news/2009/oct-dec/cense.html

CeNSE

- HP pointed to several markets for CeNSE:
  - Climate monitoring
  - Oil exploration and production
  - Assets and supply chain tracking
  - Smart highway infrastructure
  - Tsunami and earthquake warning
  - Smart grid and homes
  - Structural health monitoring
- Processing sensor information would require increasing the size of Internet 1000 times, creating along the way by 2013:
  - $70B global market for sensing systems,
  - $290B market for value added sensing services.
- First deployments:
  - 1M wireless sensors over 10 km^2 for Shell's oil exploration project.
  - 1000s of wireless sensors on large bridges.

Sensory Swarms

- Bosch presented a vision for 7 trillion devices consisting of Sensory Swarms connected to the Internet to serve 7 billion people by 2017.
  - In 2010 there were already 5 billion mobile phone subscribers.
- All devices would be a part of mobile internet servicing:
  - "Internet of People" (social people networking).
  - "Internet of Things" ("social" machine networking).
- This vision translates to 1000 sensors per average person.
  - Current applications supported by large number of sensors:
    - Advanced cars have close to 100 sensors.
    - Smart homes use 10s and 100s of sensors.
    - Smart phones use up to 18 sensors.
    - Medical diagnostics uses 10s of different sensors.
  - It is thus not too big of a stretch to foresee the growth outlined by Bosch.
- With a 7 trillion nodes, the market will be large…

http://www.kickstarter.com/projects/597507018/pebble-e-paper-watch-for-iphone-and-android

Smart Business to Drive Sensor Tornado

- Harbor Research introduced a concept of ***Smart Systems in the era of Pervasive Internet***.
  - People, devices, ***sensors*** and businesses are connected and able to interact.
    - Needs sensing the surrounding environment.
- Smart business practices will enable a truly connected converged physical and virtual world.
- Some of the leading markets for smart sensing systems include:
  - Cell phones
  - Health monitoring devices
  - Smart grid infrastructure
  - Automotive
  - IT
  - Industrial systems
- Smart business will enable collective awareness, creativity and better decision making capabilities, driving the

largest growth opportunity in the history of business.

http://www.harborresearch.com/Home.htm

Sensors for Internet of Things

	Temperature	Magnetic	Magnetic switch	Accel	Microphone	Pressure	Pulse	Respiration	Displacement	Ultrasound capacity	Ultrasound level	Force/Weight	Light	Infrared proximity	Ultraviolet (UVA, UVB)	Beta and Gamma radiation	Humidity	PH	Moisture in soil	Water and ice detection	CO	CO2	NOx	NHx	SHx	Hydrocarbon	Methane (CHx)	Dissolved oxegen	Turbulity	Liquid flow	Gas flow	Current/voltage	EKG	RFID and NFC tags	O2	H2	CHx	Isobutane	Ethanol	GPS	Cracks and propagation
Smart cities		X		X	X				X	X			X							X																					X
Smart environment	X			X					X								X		X		X	X	X		X	X	X														
Smart water											X							X											X	X	X										
Smart metering										X	X	X																		X											
Security and Emergencies			X												X	X																		X	X	X	X	X	X		
Retail												X																						X							
Logistics	X			X									X				X															X		X	X	X	X	X	X	X	
Industrial controls	X					X											X				X	X	X	X	X							X		X	X						
Smart agriculture	X					X							X				X		X																						
Smart animal farming	X																X							X	X											X				
Domotic and home automation	X		X			X								X			X													X	X	X		X	X						
eHealth	X			X			X						X		X																		X								

Libelium
http://www.electroiq.com/content/eiq-2/en/articles/sst/2012/05/top-50-internet-of-things-applications.html

Mobile Health

- Health cost is dramatically increasing.
  - In the US, it reached $2.5 trillion in 2009, representing 18% of the GDP.
    - (EE Times 12/9/09).
- Remote home care emerges as Tornado-in-making to reduce health care cost.
- Wearable (wireless) devices market (ABI Research) is forecasted to grow from 12M devices in 2010, to 420 million wearable health monitors in 2014.
  - 59 million to be used at home.
- By 2015, 30 percent of the world's smart phone users is expected to use mobile health product.
  - By 2020 most smart phones are likely to be connected to a variety of health device.
  - Activity sensors, bio-sensors, chemical sensors, spectrometers, microfluidic diagnostics and drug delivery devices, ultrasound scanners, proteomic analysis, gene analyzers, etc.
- Trillion dollar market for 7 billion mobile users would require:
  - $143 of medical devices per average user.
    - Easy target?
      - Mobisante's ultrasound scanner was introduced in 2011 at $7495.

Impact of Home Diagnostic

- About 90 percent of the visits to retail clinics were for 10 simple acute conditions and preventive care:
  - Upper respiratory infections, sinusitis, bronchitis, sore throat, immunizations, inner ear infections, swimmers ear, conjunctivitis, urinary tract infections, and either a screening test or a blood test.
  - The same conditions accounted for 18 percent of visits to primary care physician offices and 12 percent of emergency department visits. (Rand Corporation Study)
- In 2008 there were 578 million primary care visits and 123 million emergency department visits (UK?).
  - 104 million office visits and nearly 15 million emergency room visits are for common conditions that are also treated at retail clinics.
- 75% of these or 89 million visits annually could be handled by QuickCheck Health kit.
  - "Test at home, treat online": disruptive innovation in health care.
  - Accurate, rapid, OTC home diagnostic testing
  - An affordable and easy-to-access online clinic visit
  - A prescription within as little as 5 minutes if appropriate
  - $7.50/test as compared to $100s.

http://www.quickcheckhealth.com/

Home Diagnostics Patents Filing

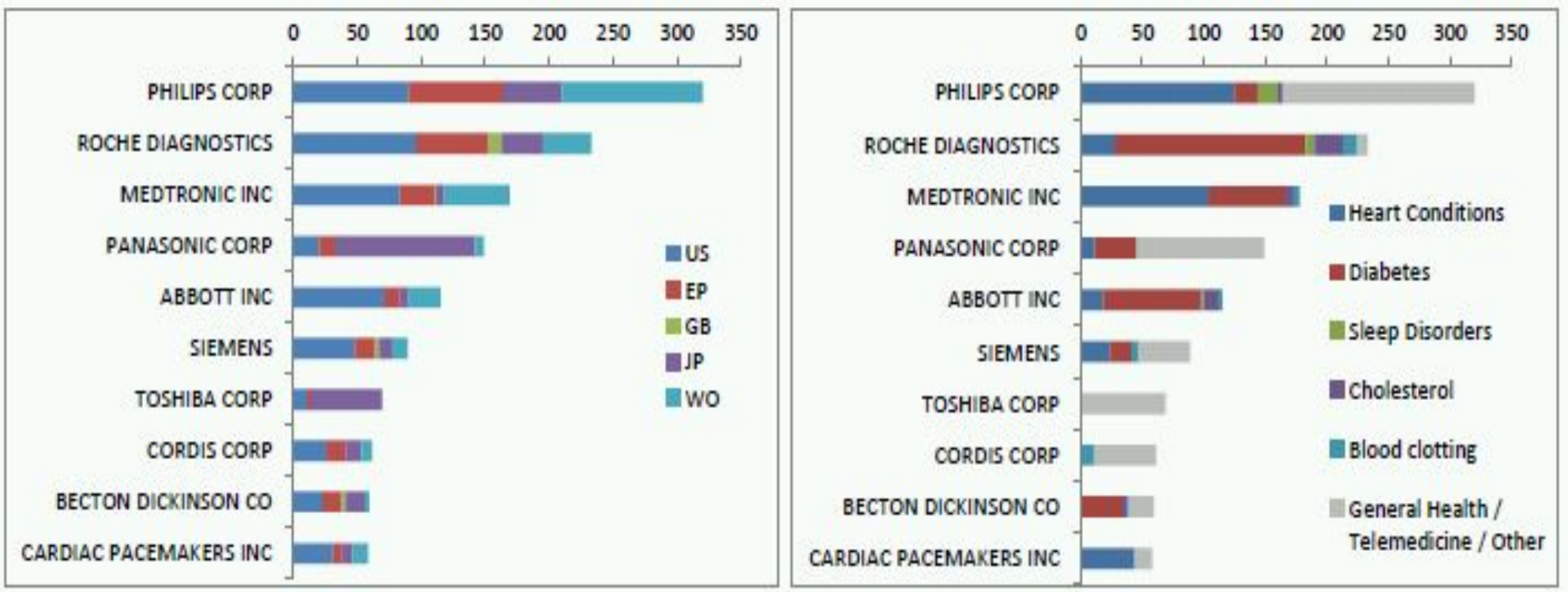


Figure 5. Home diagnostics patent filings from top 10 assignees with jurisdiction (left) and showing the technology spread across common diagnostic categories (right)

www.monaq.com

Top Microfluidic/LOC Patents Assignees

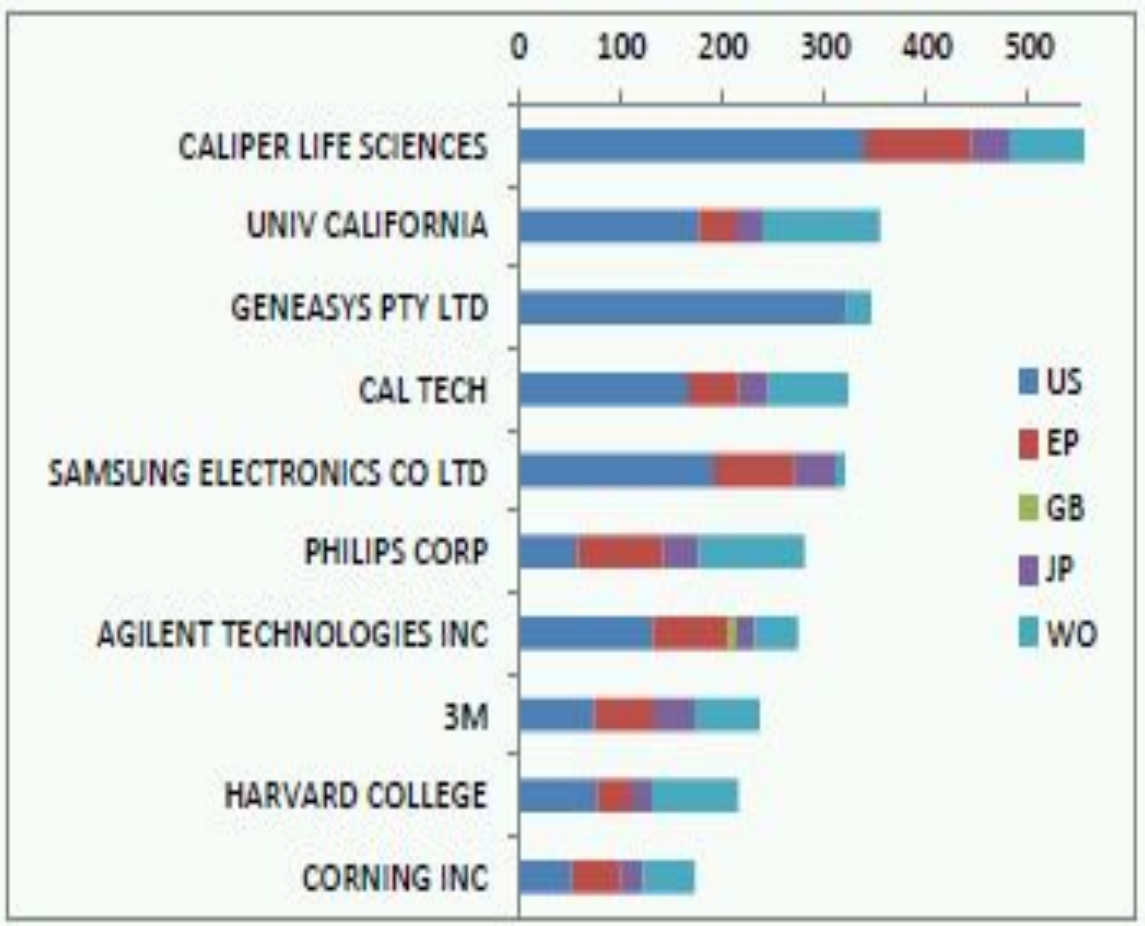


Figure 6. Top 10 microfluidics / lab-on-a-chip patent assignees with jurisdiction

www.monaq.com

Medical Mobile Tornado Started

- In 2011, first mobile products have received FDA clearance:
  - Blood pressure monitoring cuff.
  - CT-scan viewer.
- The cost and approval time should shrink in 2012.
  - FDA is expected to issue detailed guidelines about which mobile health devices and apps fall under its jurisdiction, and how it will regulate them.
    - There is a possibility that mobile health Tornado will overwhelm FDA and steamroll over their regulations…

Ultrasound machine from Mobisante went on sale in October 2011

Blood pressure monitoring cuff

http://www.deccanherald.com/content/230784/monitoring-your-health-mobile-devices.html

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Acceleration of MEMS Market Development

Historical MEMS Development Cycles

MEMS/MSTCOMMERCIALIZATION TIMETABLE

Product	Discovery	Product Evolution	Cost Reduction	Full Commercialization	Elapsed Time in Years
Pressure Sensors	1954-1960	1960-1975	1975-1990	1990	36
Accelerometers	1974-1985	1985-1990	1990-1998	1998	24
Gas Sensors	1986-1994	1994-1998	1998-2005	2005	29
Valves	1980-1988	1988-1996	1996-2002	2002	22
Nozzles	1972-1984	1984-1990	1990-2002	2002	24
Photonics/Displays	1980-1986	1986-1998	1998-2005	2005	25
Bio/Chemical Sensors	1980-1994	1994-2000	2000-2012	2012	30
Radio Frequency (R.F.)	1994-1998	1998-2001	2001-2008	2008	13
Rate Sensors	1982-1990	1990-1996	1996-2006	2006	22
Micro Relays	1977-1993	1993-1998	1998-2012	2012	32
Oscillators	1965-1980	1980-1995	1995-2011	2011	46
				Median	**28**

ROGER GRACE ASSOCIATES
MARKETING COUNSEL

Roger Grace's presentation at MEMS Technologies Summit, Oct 2010, Stanford University
http://www.rgrace.com/

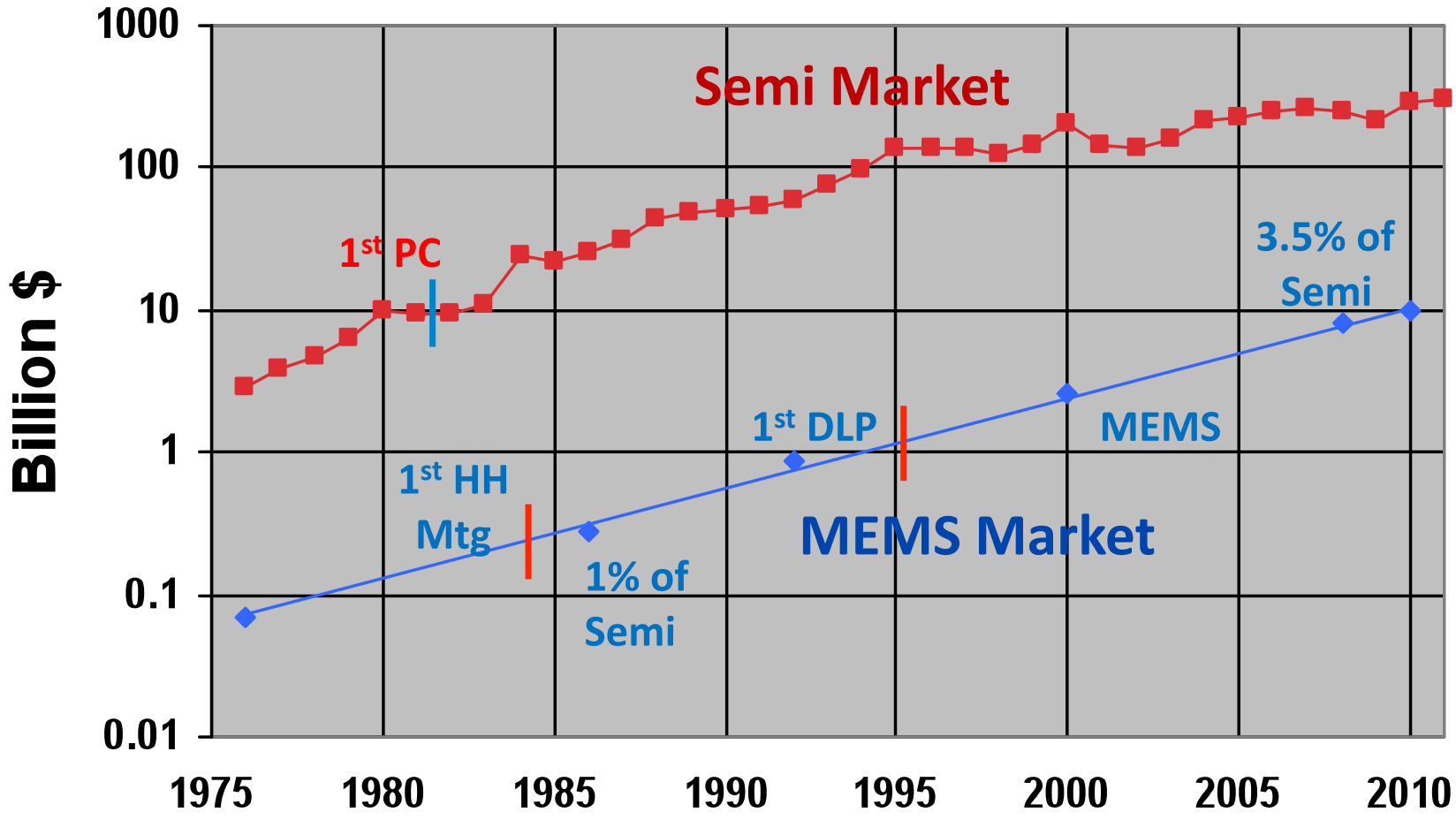
MEMS Fabrication

- Contrary to IC industry, MEMS still faces a “one product – one process – one package – one test system” reality.
- Standard MEMS processes are slowly emerging.
  - Sandia, MCNC, TSMC, ST proved it feasible.
    - For a narrow class of devices (e.g., group of mechanical sensors).
  - Need to enable customization, such as device thickness, trench width, etc.
    - Analogy: transistor design in a given process can deliver either low-noise low-power or high current.
- In parallel, the IC industry started to use selected MEMS unit processes for chip scale packaging and wafer stacking.
  - Promising wafer volumes significantly larger than the entire MEMS industry.
  - Drive pull for improved processing tools from IC tool vendors

MEMS Market Development Lag

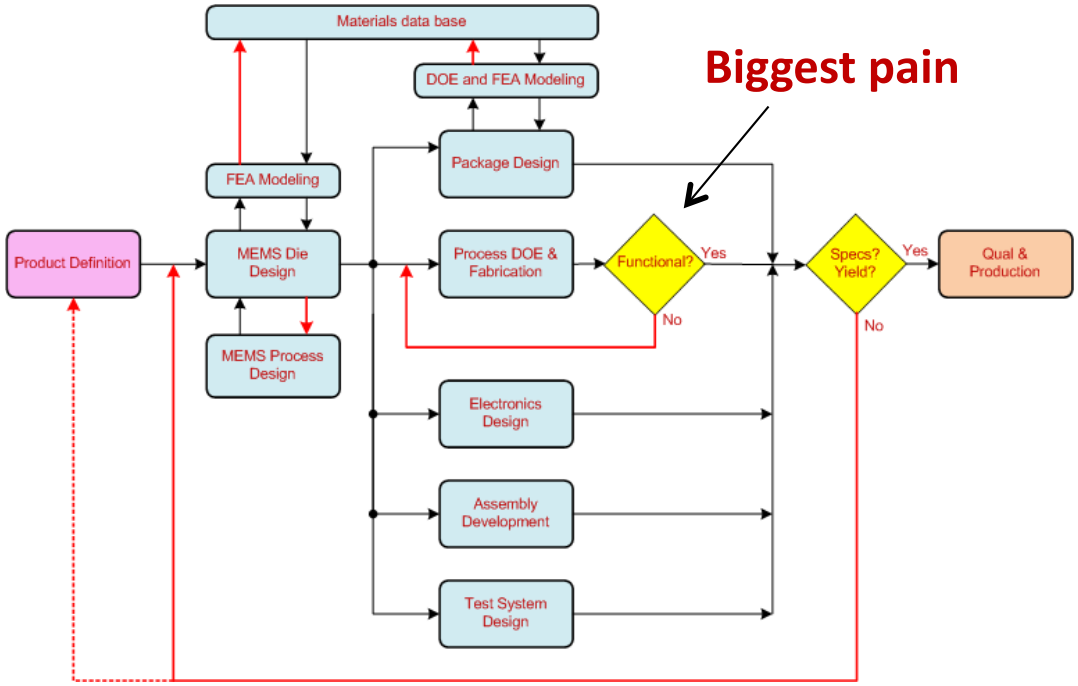
- Two elements slow down MEMS commercialization:
  - Slow MEMS process R&D cycles.
    - 80% of unit processes adopted from IC industry.
    - 20% are MEMS specific.
      - Development underfunded, as compared to IC processes ($M vs $B).
    - Major challenge: process integration.
      - Atomic level interaction (fusion bonding, stiction, outgassing, cleaning, etc.) still are not well understood and modeled.
    - 3 to 12 months per iteration.
    - 2-12 years to production.
  - Lack of standards:
    - Major headache: MEMS manufacturing processes.
    - Packages, test systems.

Semiconductor and MEMS Market Growth



Source: Kurt Petersen

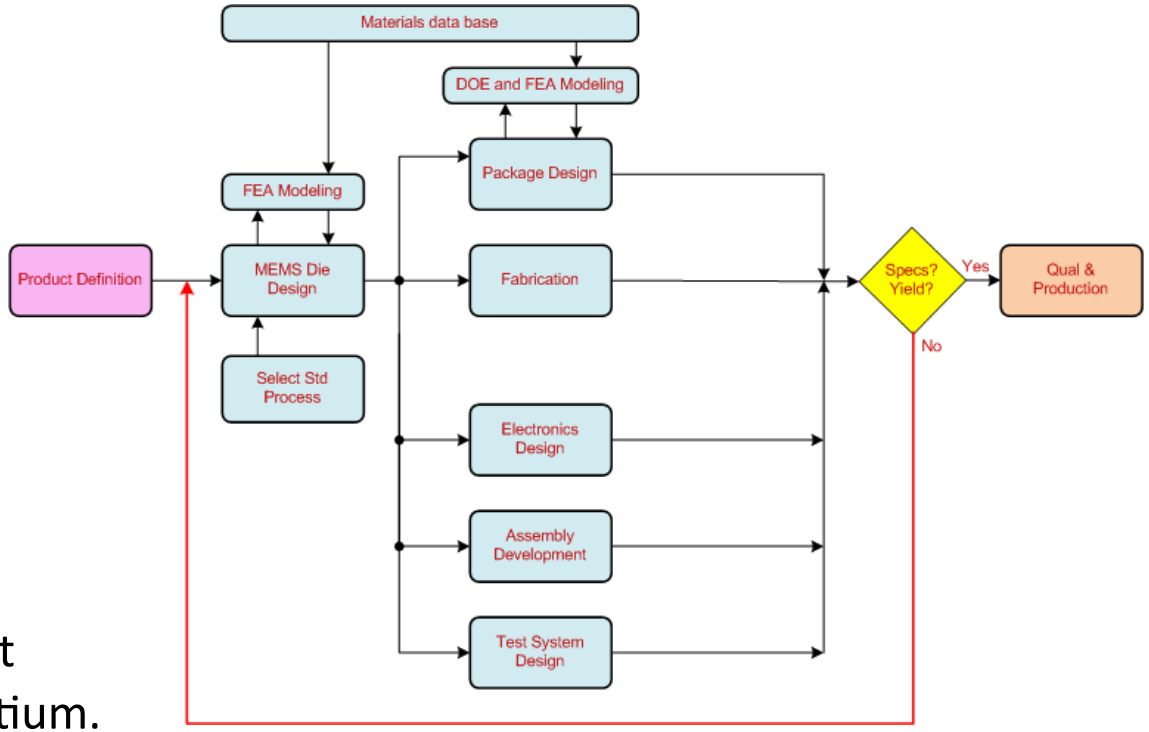
MEMS Product Development



Biggest pain

Current reality

If standard MEMS process is developed

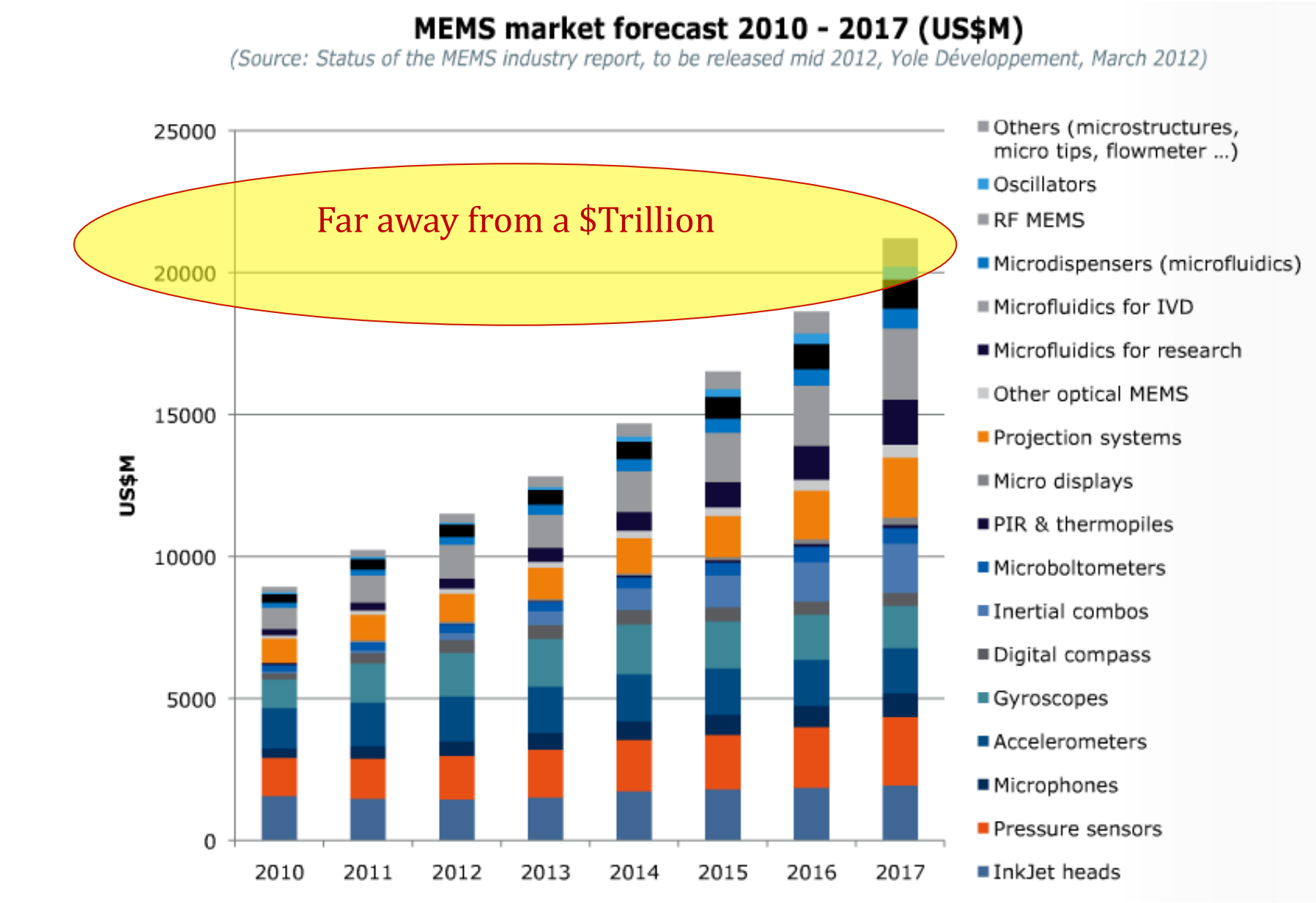


Transitioning will require a significant funding, perhaps an industry consortium.

Third Industrial Revolution

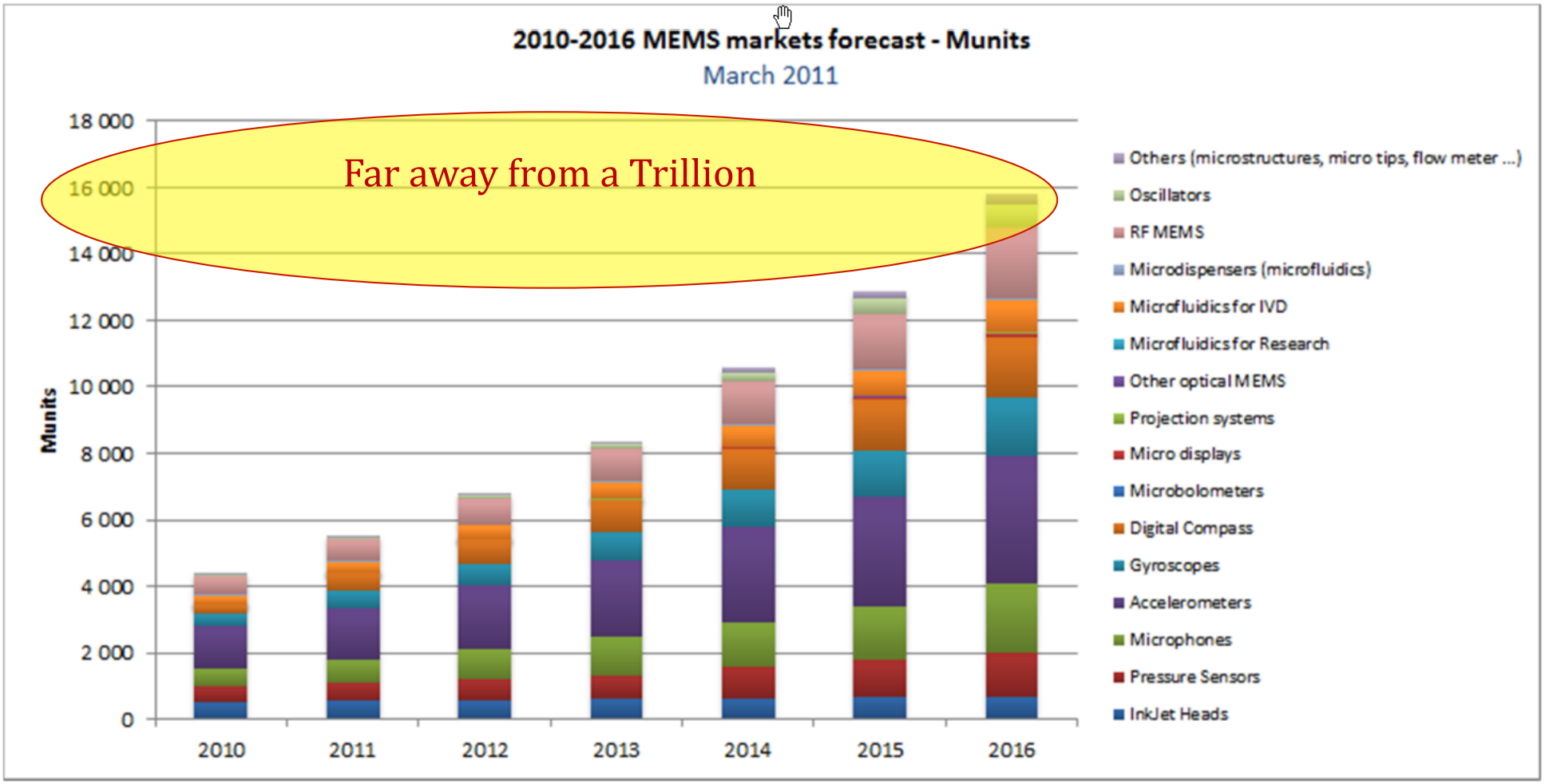
- Looking back, all major technologies coming to market were changing world's productivity and balance of power.
- In 2011, Vijay Ullal, VP of Maxim referenced three major technology revolutions:
  - 1st revolution increased productivity by bringing steam, electricity, internal combustion, radio and aeronautics.
  - 2nd revolution further increased productivity through transistors, computers and Internet, propelling the semiconductor market to $300B.
  - 3rd emerging revolution based on fusion of computing, communication and ***sensing***, will free humans for creative work and enable MEMS market to catch-up with semiconductor market.
- Pacing item: sensor growth, which could be significantly accelerated if:
  - MEMS R&D cycle would be increased to 15 cycles/year.
  - Standard MEMS processes become available (for the fastest growing products).
- Making this feasible would require significant funding exceeding capability of a single company.
- The attractiveness of competing in a $1T market by design-only using standard MEMS processes, as opposed to competing in a $10B market using both design and process, should entice competitors to cooperate, thus creating ***cooptition*** (cooperating competitors).

MEMS Market ($)


MEMS market forecast 2010 - 2017 (US$M)
(Source: Status of the MEMS industry report, to be released mid 2012, Yole Développement, March 2012)
Far away from a $Trillion
US$M
25000
20000
15000
10000
5000
0
2010
2011
2012
2013
2014
2015
2016
2017
Others (microstructures, micro tips, flowmeter …)
Oscillators
RF MEMS
Microdispensers (microfluidics)
Microfluidics for IVD
Microfluidics for research
Other optical MEMS
Projection systems
Micro displays
PIR & thermopiles
Microboltometers
Inertial combos
Digital compass
Gyroscopes
Accelerometers
Microphones
Pressure sensors
InkJet heads

MEMS Market (Units)

- **15.8 Bunits of MEMS devices in 2016 with a 24% CAGR over 2010-2016**



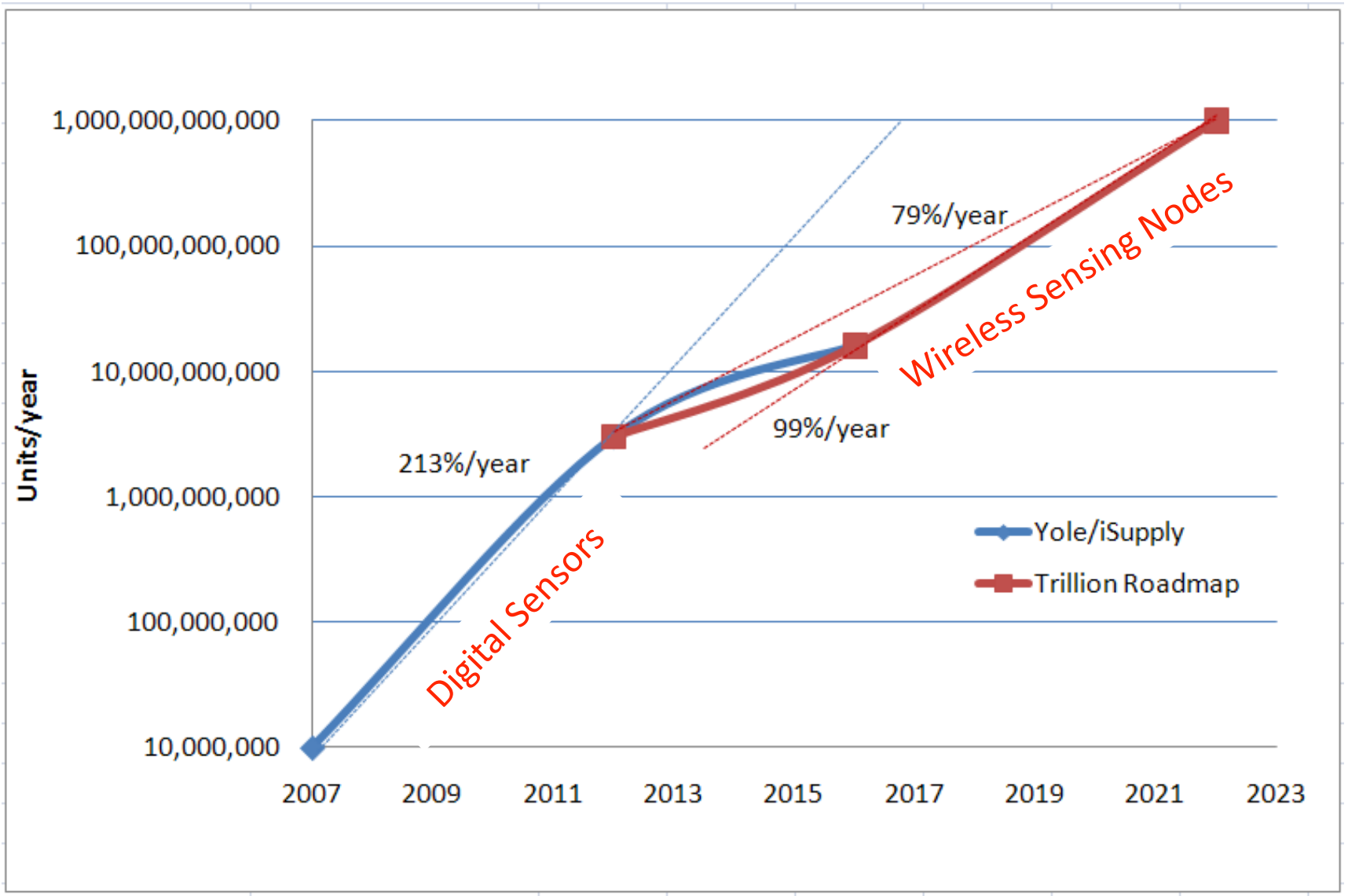
Yole 2011

Growth to a Trillion

Item	2012	2022		
ACGR		14%/y	42%/y	56%/y
Revenue	$12B	45B	$414B	$1 Trillion
ACGR		24%/y		79%/y
Units	7B	60B		1 Trillion

- Revenue growth
  - Without acceleration, MEMS market is expected to grow in 10 years to $45B.
  - To match the 2022 size of semiconductor market $414B (growing 3%/y), MEMS market would have to grow 42%/y.
  - To reach 1 $Trillion in 2022, MEMS market would need to grow 56%/y.
- Units growth
  - Without acceleration, MEMS market is expected to grow in 10 years to 60B units.
  - To reach trillion units in 10 years, growth needs to be accelerated to 79%/y.

Consumer Sensor Explosion



Job Creation

- Dramatic MEMS market growth would result in massive creation of new jobs.
- These high tech jobs may follow the iPhone value added model:
  - 3% ($14) assembly (China)
  - 32% ($178) components (global)
  - 66% ($368) Apple's slice (US)
  - 100% ($560) selling price
- Most of these jobs is thus likely to be in developed nations.
  - This will overshadow potential of most other considered approaches by Governments.
  - Will force Governments of different countries to compete for these jobs.
- Assuming the average revenue per employee $500,000/year (the average of 2011 Nasdaq 100 companies).
  - $Trillion dollar new revenue would results in about :
    - 2 million new direct jobs.
    - Twice as many indirect jobs.
    - Total of about 6 million new jobs.
- As a reference, US created only 1.3M new jobs in the last 10 years, primarily in Government and medical sectors.

Foundation for $Trillion/Trillion MEMS Unit

- Acceleration of MEMS market growth in the next 10 years can rely only on devices already demonstrated over the last 10 years.
  - More or less the list of MEMS devices from Yole's market forecast.
  - Potential for near term new Tornados:
    - Humidity sensors
    - Color sensors (RGB, spectrometers)
    - Chemical sensors (CO, CO_2, O_2, …)
    - Medical sensors and Labs-on-Chip
    - High performance inertial sensors
- Enhancements of MEMS devices will like be formed by:
  - Ultra-low power ultra-low cost wireless/Internet connectivity.
  - Multi-sensory systems on a chip or in a package.
  - Smart software.
  - Creative packaging.
  - MEMS/NEMS integration

$Trillion/Trillion MEMS Unit Roadmap

- Intended as a longer term (10 year) market study defining:
  - MEMS devices most likely contributing to a trillion unit market in 10 years.
- Once defined, the next step activities be the cooperative definition of:
  - Standard MEMS processes to be developed enabling fabrication of such devices.
  - New/modified MEMS processing tools necessary to support these devices.
  - Process modeling tools necessary to accelerate MEMS process development.
  - Standard package families to enable efficient packaging of fast growing MEMS devices.
  - Standard test systems to support the accelerated market growth.
  - Standard communication interfaces.
  - Funding needs for each of the above.
  - Potential industrial consortiums behind each of the above.
  - Organizations to be involved.
- Roadmap support to date:
  - Mancef (http://mancef.org) secured a seed funding to launch Roadmap.
  - iNEMI is performing internal analysis of what they could do.
  - MIG is digesting the information…
- The next PR event is planned at COMS 2012, June 2012 in Norway.

Summary

- Currently brainstorming ideas how to launch the Roadmap development.
- The byproduct of resulting new MEMS Tornados will be:
  - More fun for most of us, better healthcare and better quality of life.
    - How different from the first MEMS applications in 1960s aiming at better way to kill, driven by cold war…
  - New opportunities for all of us
    - Startups.
    - New industries.
    - First MEMS billionaires?
    - New jobs.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Dr. Janusz Bryzek