iNEMI Technology Roadmap on MEMS/Sensors

Speaker: Haley Fu, iNEMI
Chair: Michael Gaitan, NIST
MEMS and Sensor Session
FlexJapan, Shinagawa, Tokyo
April 20, 2018

iNEMI®
Advancing manufacturing technology

Outline

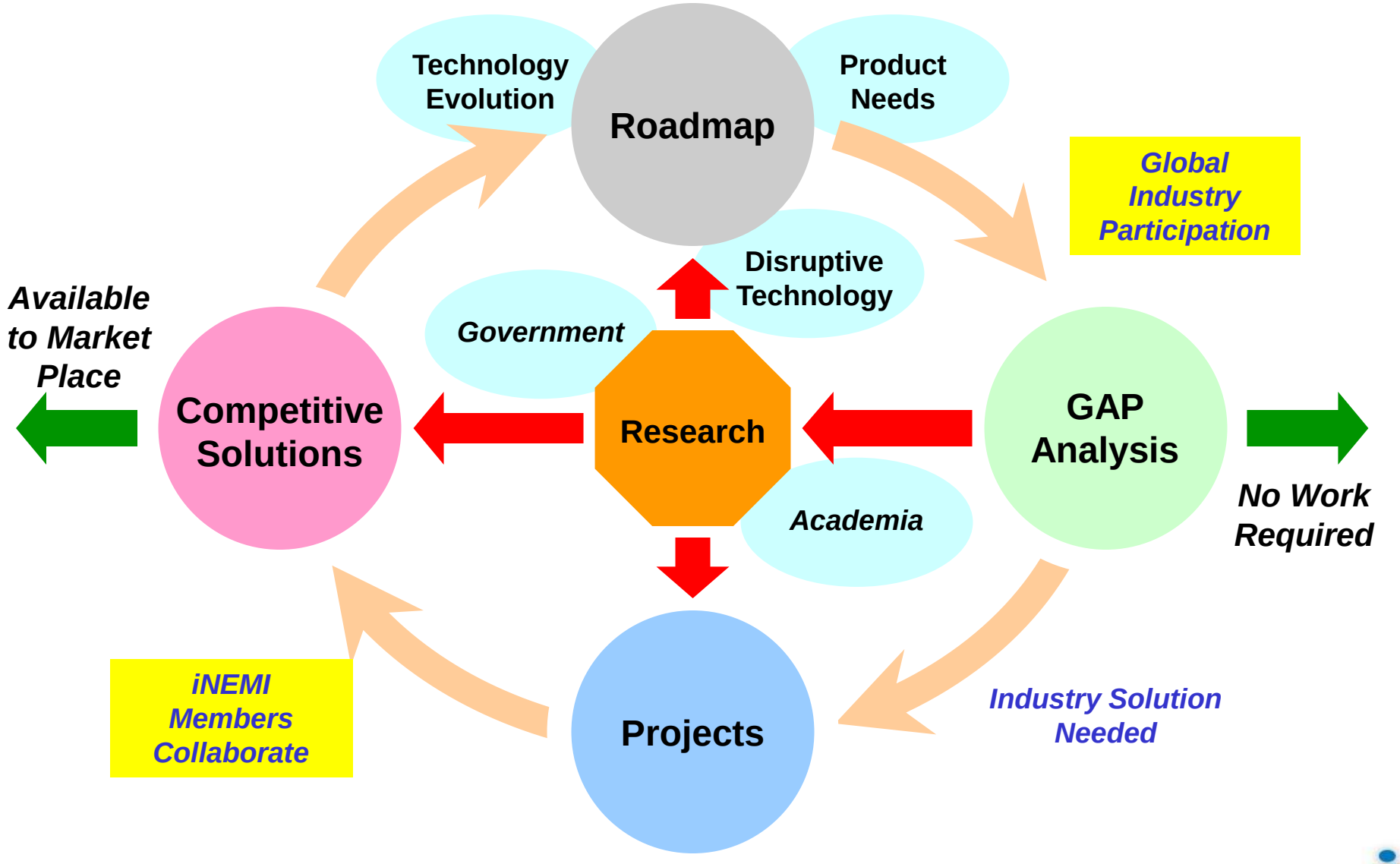
- About iNEMI
- iNEMI Roadmap
- MEMS/Sensors Roadmap
  - Background
  - Market Trend
  - Technology Needs
  - 2019 Roadmap Outlook
- Participation & Access
- Q&A

About iNEMI (International Electronics Manufacturing Initiative)

- **iNEMI Organization:**
  - Global corporate membership
  - Not-for-profit, R&D consortium
  - Collaboration defined by organization by-laws, intellectual property policy, and project agreements.
- **Member companies/Organizations:**
  - Leadership OEM, EMS, and Supplier companies
  - Government labs
  - Academic institutions.
- **Mission: Forecast and accelerate improvements in the electronics manufacturing industry for a sustainable future.**

iNEMI Members

iNEMI Methodology & Deliverables



Unique iNEMI Roadmap in Electronics Industry

Outlook the next 10 years, update every other year, global participation, covers the full supply chain for electronics manufacturing

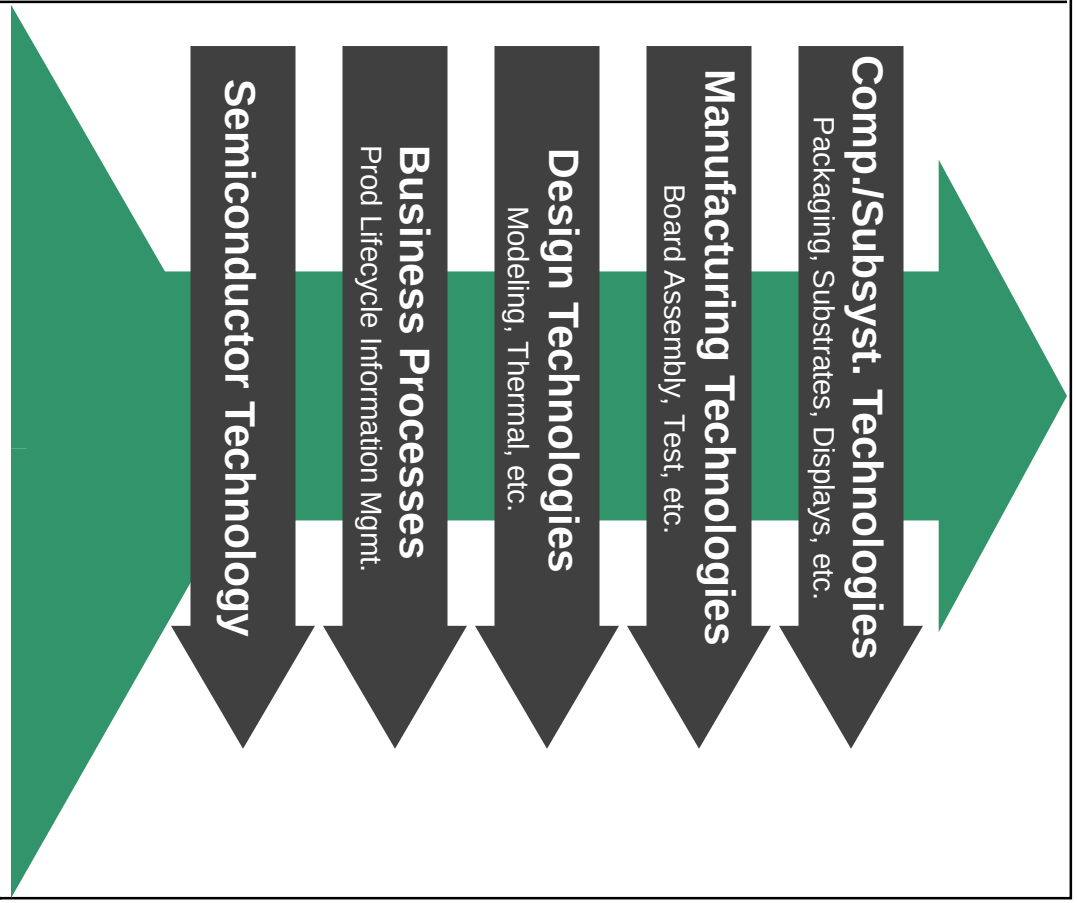
Statics of 2017 Roadmap

- **> 500 participants**
- **> 350 companies/organizations**
- **> 20 countries**
- **Greater than 10 man years of resources in the development**
- **21 Technology Working Groups (TWGs)**
- **7 Product Emulator Groups (PEGs)**
- **Nearly 2300 pages of information**
- **Roadmaps the needs for 2017-2027**

iNEMI Roadmap Development Process

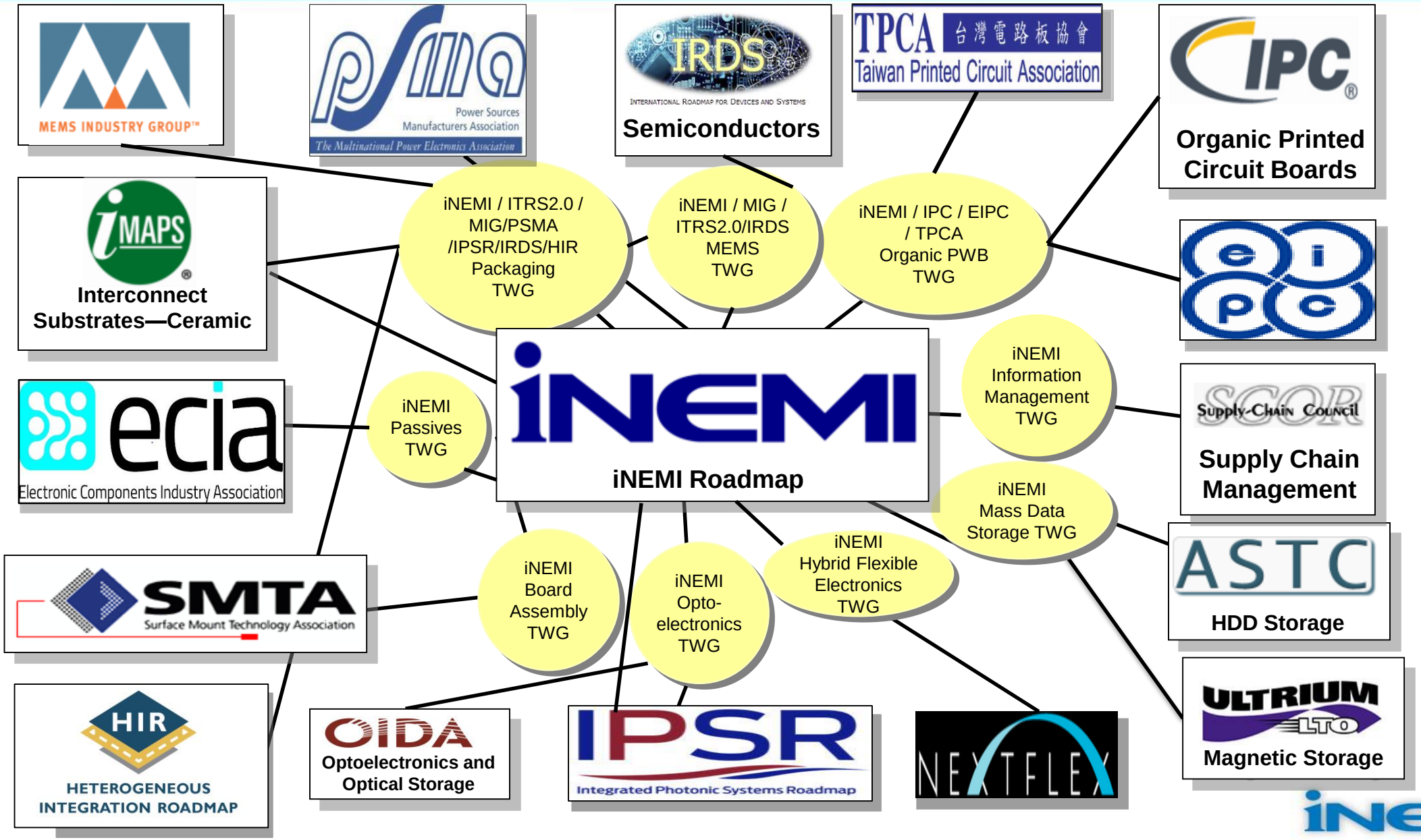
***Product Sector Needs* vs. Technology Evolution**

Product Emulator Groups	TWGs
Portable / Wireless	
Office / Consumer Systems	
High-End (e.g. netcom, server)	
Automotive	
Medical Products	
Defense and Aerospace	
IoT / Wearables	



** 2017 Roadmap PEGs*

Sixteen Contributing Organizations



MEMS/Sensors Roadmap

Chair: Michael Gaitan, NIST

iNEMI®
Advancing manufacturing technology

Background

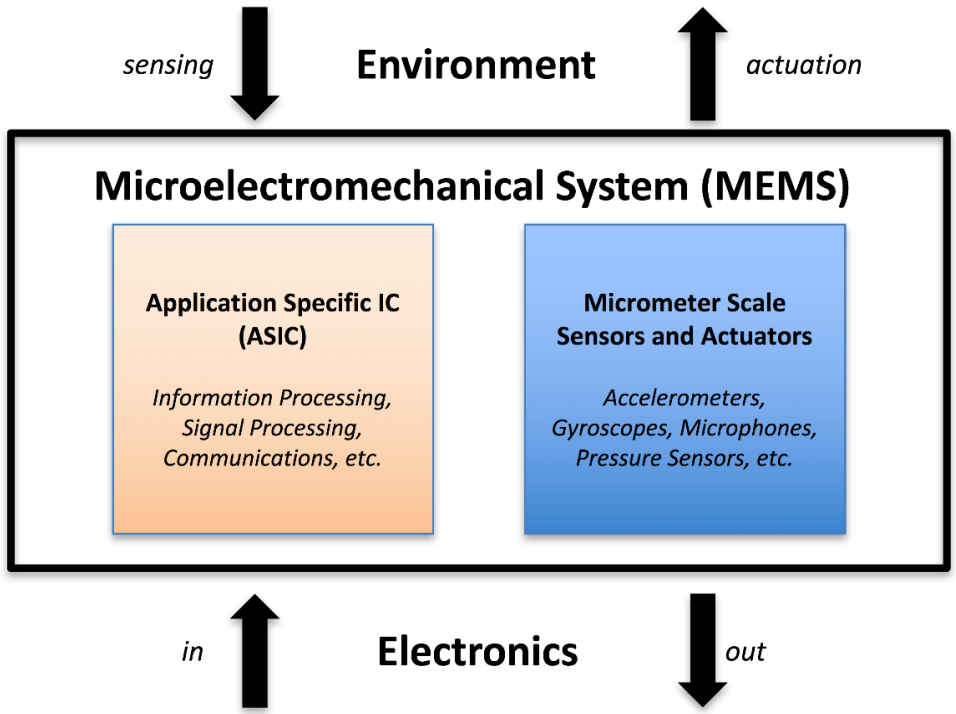
- **iNEMI has been roadmapping Sensor and RFID technology before MEMS/Sensor**
- **The iNEMI MEMS/Sensors TWG was established in 2010 and published its first roadmap in 2011**
- **We primarily work with the MEMS and Sensors Industry Group's (MSIG) member companies as well as other interested contributors**
- **The effort was motivated by a 2009 MSIG Workshop on Testing Needs for sensors manufacturers**
- **We also work with standards organizations (IEEE, SEMI) and in the past with the ITRS**

Roadmap Cross-cut Matrix

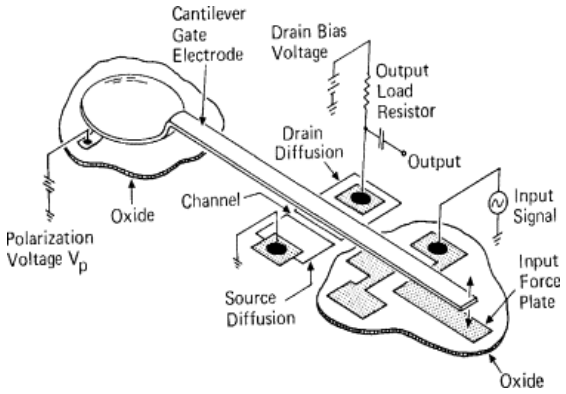
1	**Semiconductor Technology**
2	**Hybrid Flexible Electronics**
3	Environmentally Sustainable Electronics
4	Final Assembly
5	Interconnect PCB (Organic)
6	Mass Data Storage
7	Modeling, Simulation & Design Tools
8	Optoelectronics
9	**Packaging & Component Substrates**
10	**RF Components & Subsystems**
11	**Test, Inspection and Measurement**
12	Thermal Management
13	Board Assembly
14	Passive Components
15	Energy Storage
16	Interconnect Substrates (Ceramic)
17	Information Management
18	Electronic Connectors
19	MEMS/Sensors
20	Power Conversion Electronics
21	Solid State Illumination
22	Smart Manufacturing
23	**Office / Consumer**
24	**Portable / Wireless**
25	**Automotive**
26	**High-End Systems**
27	**Medical**
28	**IoT**
29	**Aerospace/Defense**

MEMS and Its Development

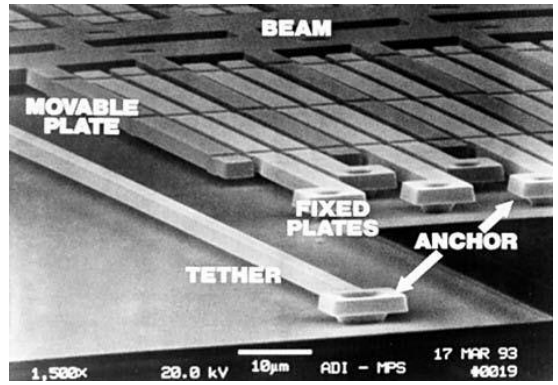
- **Microelectromechanical Systems (MEMS) are sensors and actuators that are fabricated using techniques like those used to manufacture integrated circuits such as computer chips and memory.**



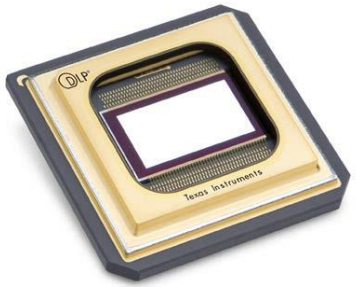
Monolithic integration vs. Co-integration



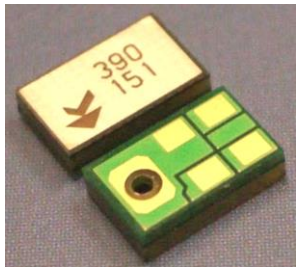
Resonant gate transistor reported by Nathanson et. al. in 1964



Analog Devices from 1993, surface micromachining, pillars in silicon



DLP by Texas Instruments, 1998

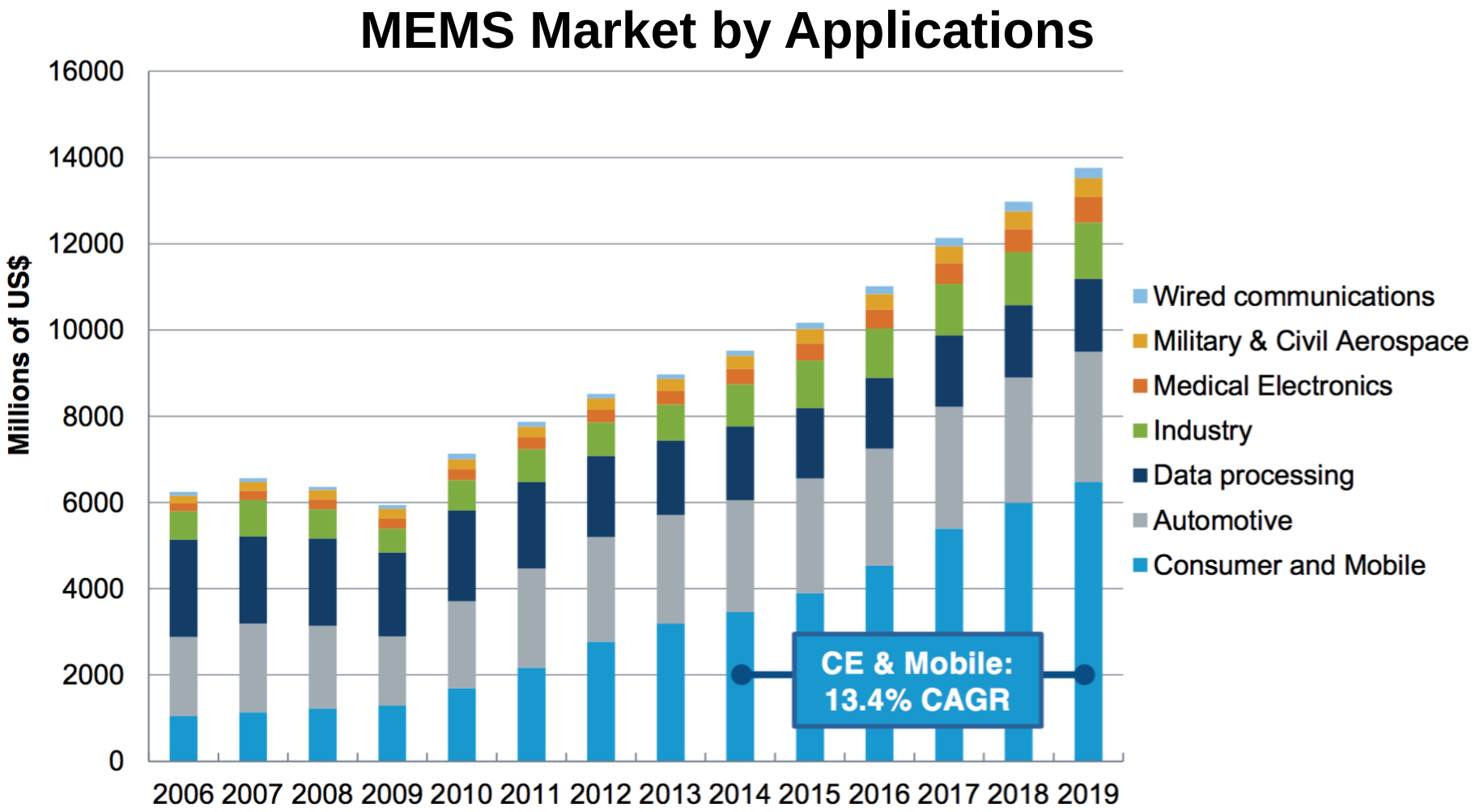


Knowles MEMS microphones, 2002

Analog Devices ADXL354C low noise, low drift, low power 3-axis accelerometer

Bosch Sensortec BME680 integrated environmental sensor

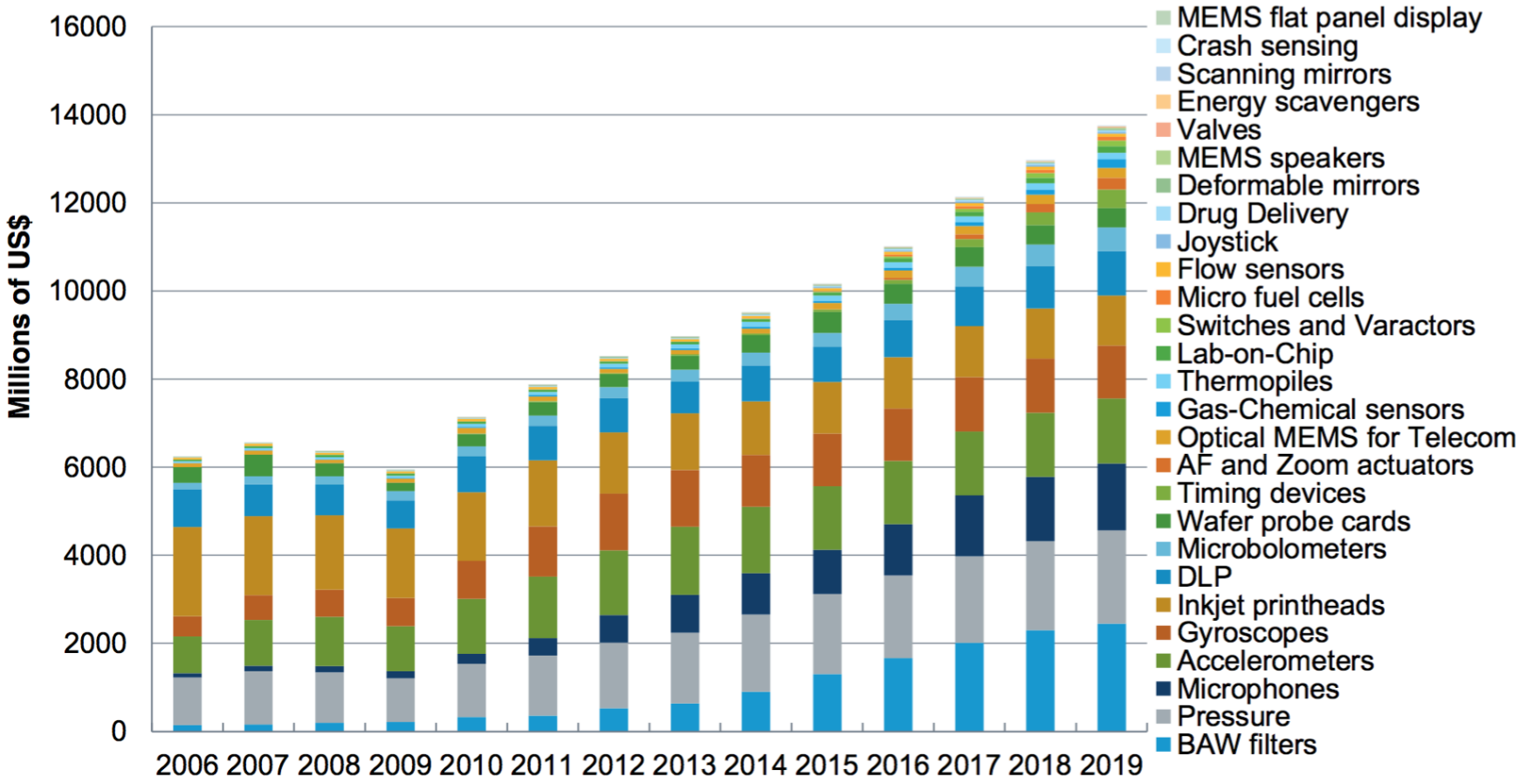
Market Trend



Source: IHS Markit public presentation

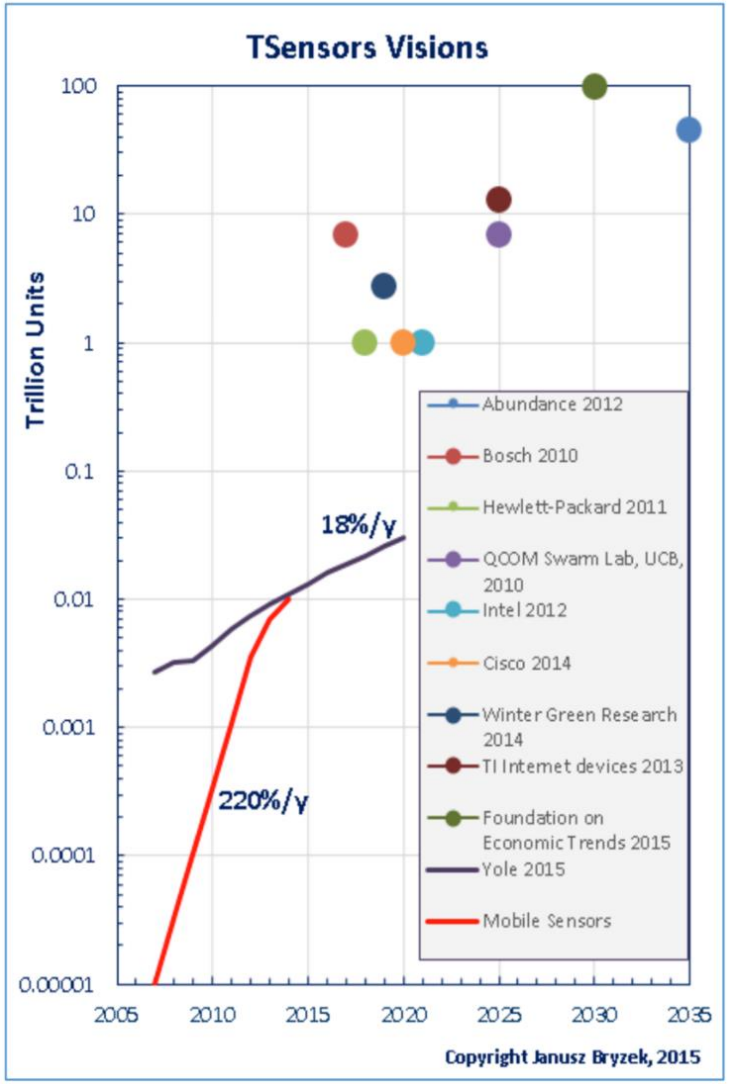
Market Trend

MEMS Market by Devices



Source: IHS Markit public presentation

IoT and the Trillion Sensors Initiative



TSensors Visions of the number of sensors to be deployed by 2035, from Janusz Bryzek, "TSesnors Strategic Markets and Technology Reviews Background Vision," White Paper

- **We introduced (starting in 2015) the drivers and need for new sensors manufacturing paradigms**
  - ***Based on MEMS and Sensors Industry Group's Trillion Sensors Initiative, the need for hybrid flexible manufacturing for MEMS/Sensors***

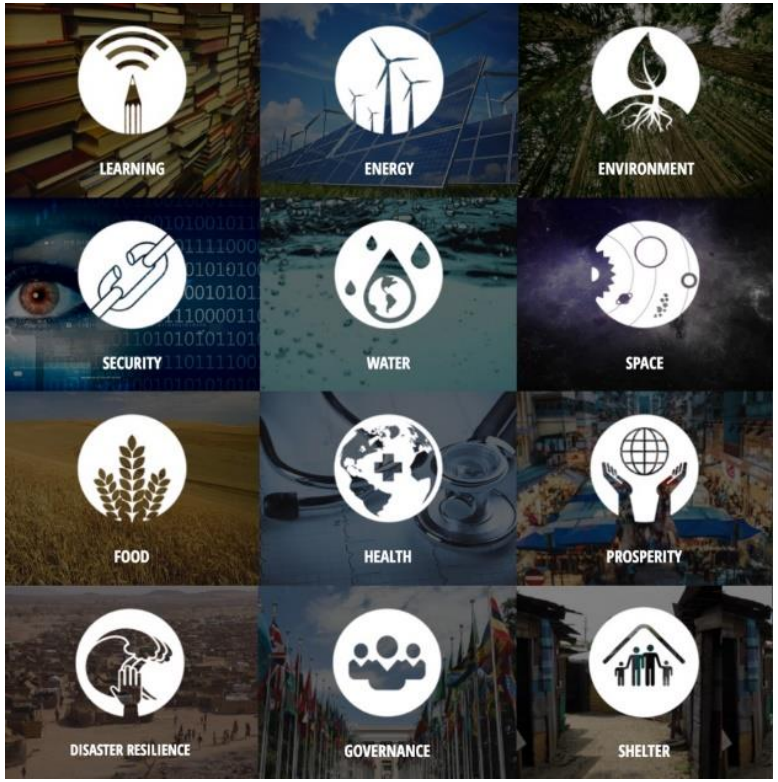


Diagram of Global Grand Challenges identified by Singular University, https://su.org/about/global-grand-challenges

Emerging Applications

- **Sensors for Energy Generation and Conservation**
- **Sustainable Solutions for the Global Environment through Novel Sensing**
- **Food and AgTech**
- **Disaster Resilience: Monitoring of Global Disasters and Aging Infrastructure**
- **Unobtrusive Health Monitoring**
  - Wearable sensors
  - Motion sensors
  - Tattoo sensors
  - Optical sensors
  - Hyperspectral sensors
  - Thermal sensors
  - Radar, THz, Microwave sensors
  - Smart fabrics sensors
  - Breath sensors
  - Voice derived health sensors
  - Body fluid sensors (saliva, sweat, urine, stool, blood)
  - Microfluidic sensors
  - Ultrasound sensors
  - Radiation (Gas Discharge Visualization) sensors

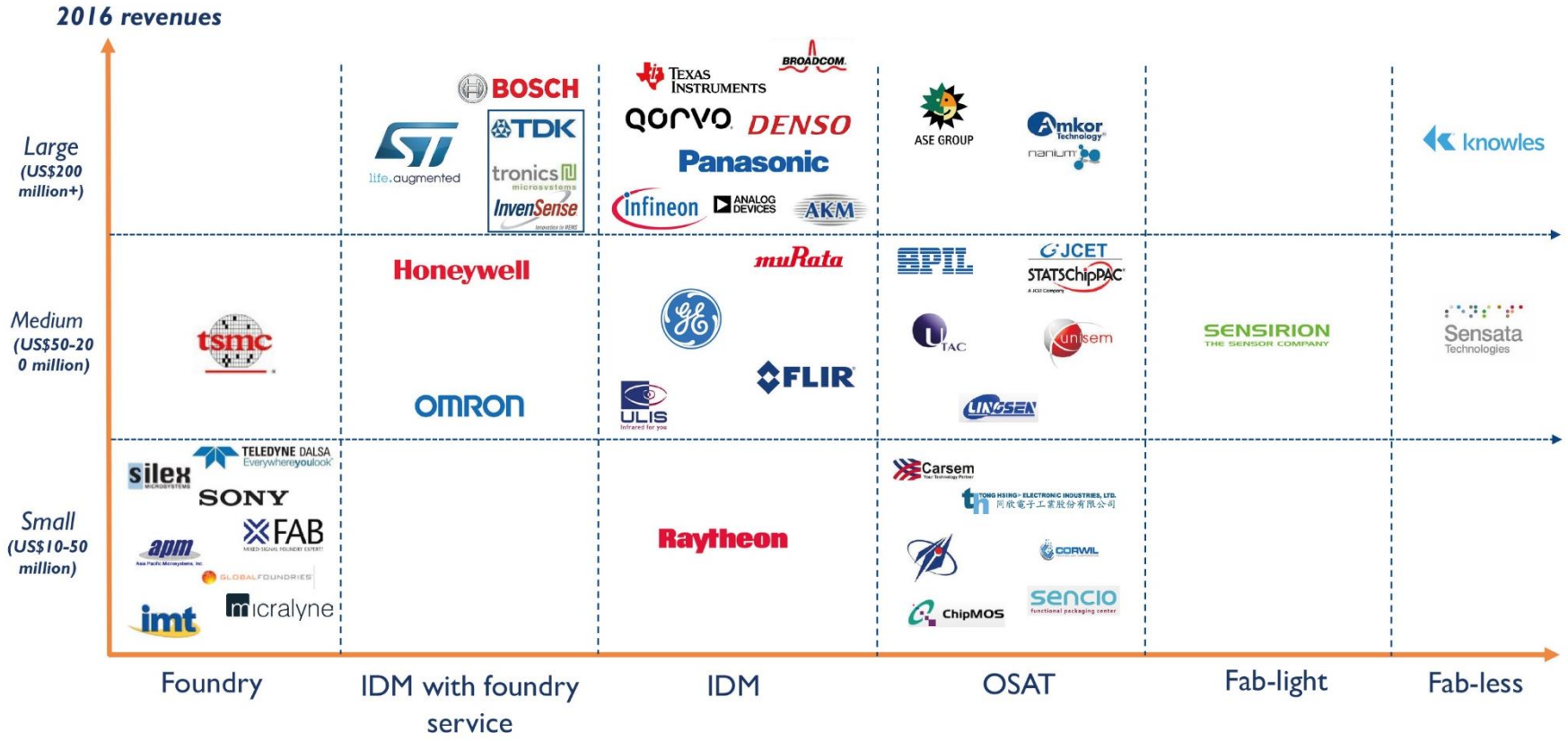
Example of Mapping Air Pollution Levels for NO2 by Sensors Instrumented by Aclima Onto Google Cars

The Wize Mirror Being Developed by a Consortium of Researchers and Industry Partners From Seven European Countries

MEMS Manufacturing Industry

MEMS industry: business models & revenues in 2016*

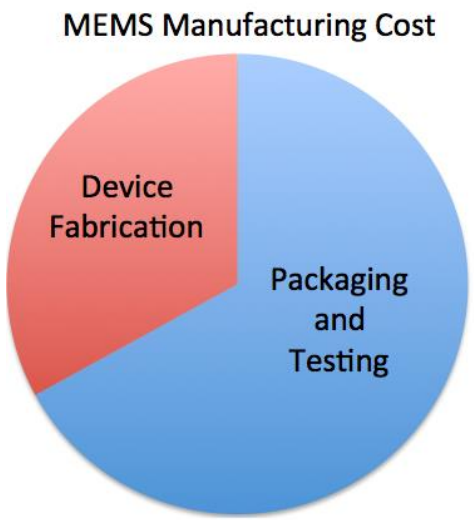
(Source: MEMS packaging report, Yole Développement, 2017)

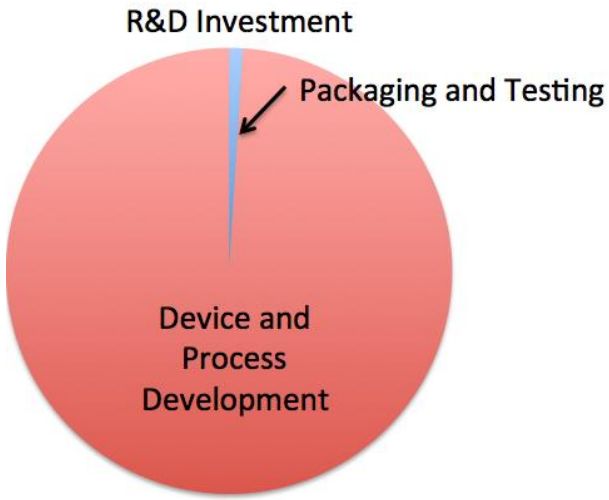


* Non-exhaustive list of companies

Testing for MEMS/Sensors

- **We reported (starting in 2011) on the increasing cost of testing and the need for design for test and design for no test**
  - ***Manufacturers now use statistical sampling for some applications***
- **There were no standards for reporting device performance in datasheets**
  - ***An iNEMI project was organized to review and reported on current practices and candidate testing methods***
  - ***The sensor manufacturers and systems integrators formed the IEEE P2700 working group and published a standard for digital sensor performance parameters***





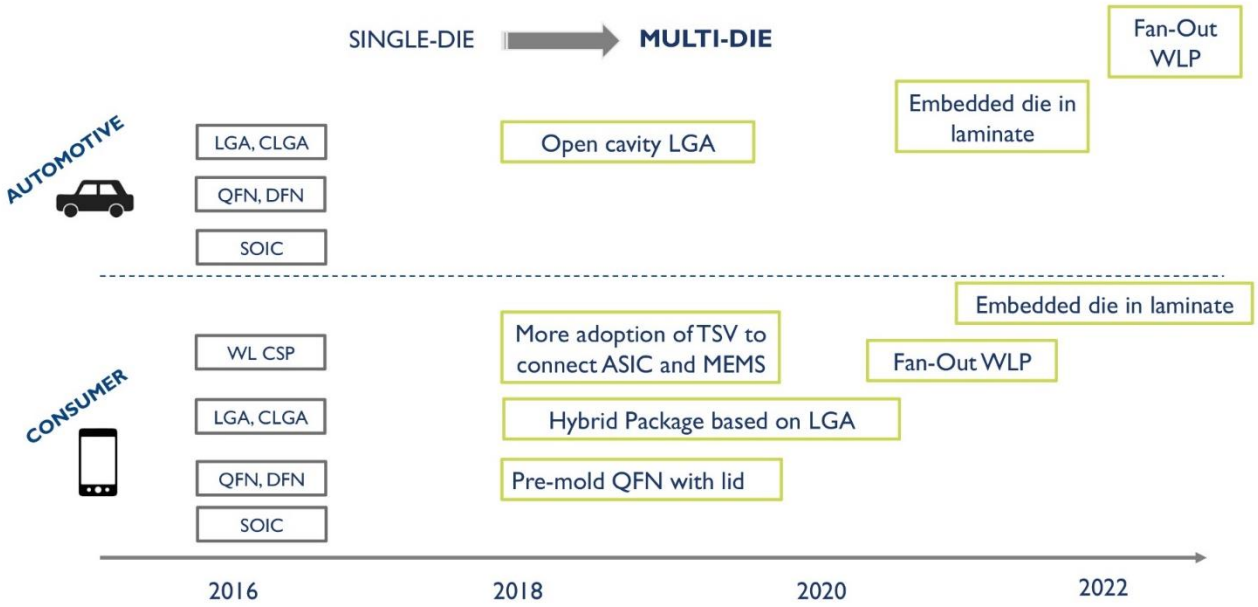
Packaging & Integration Path

- **We examined (starting 2013) the integration path of inertial sensors**
  - ***We proposed that sensors with similar packaging requirements would be candidates for an integration path and that environmental sensors were candidates for such integration***

Bosch BME680 integrated environmental sensor for pressure, humidity, temperature, and gas announced in 2017

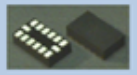
MEMS packaging roadmap

(Source: MEMS Packaging 2017 Report, Yole Développement, October 2017)



Product Performance Differentiated Thru Packaging Technology

- **Same 3-axis accelerometer device in 4 package types differentiating performance and cost of MEMS device.**

Sensing Axis	Operating Temperature Range (Deg C)	Performance Spec in g's	Offset Spec Over Temp Range (mg)	Package Type	Package Cost	Application
X,Y,Z (Pitch, Yaw, Roll)	-40 to +85	±16	±100	Over molded LGA 	Low	Consumer & Gaming
X,Y,Z (Pitch, Yaw, Roll)	-40 to +105	±12	±100	Over molded SOIC 	Low	Consumer & Gaming
X,Y,Z (Pitch, Yaw, Roll)	-40 to +125	±5	±60	Cavity SOIC 	High	High-end Consumer, Automotive, Medical
X,Y,Z (Pitch, Yaw, Roll)	-40 to +150	±0.5	±10	Ceramic Cavity Pkg 	Very High	Industrial, Automotive, Medical

Wireless Bandwidth

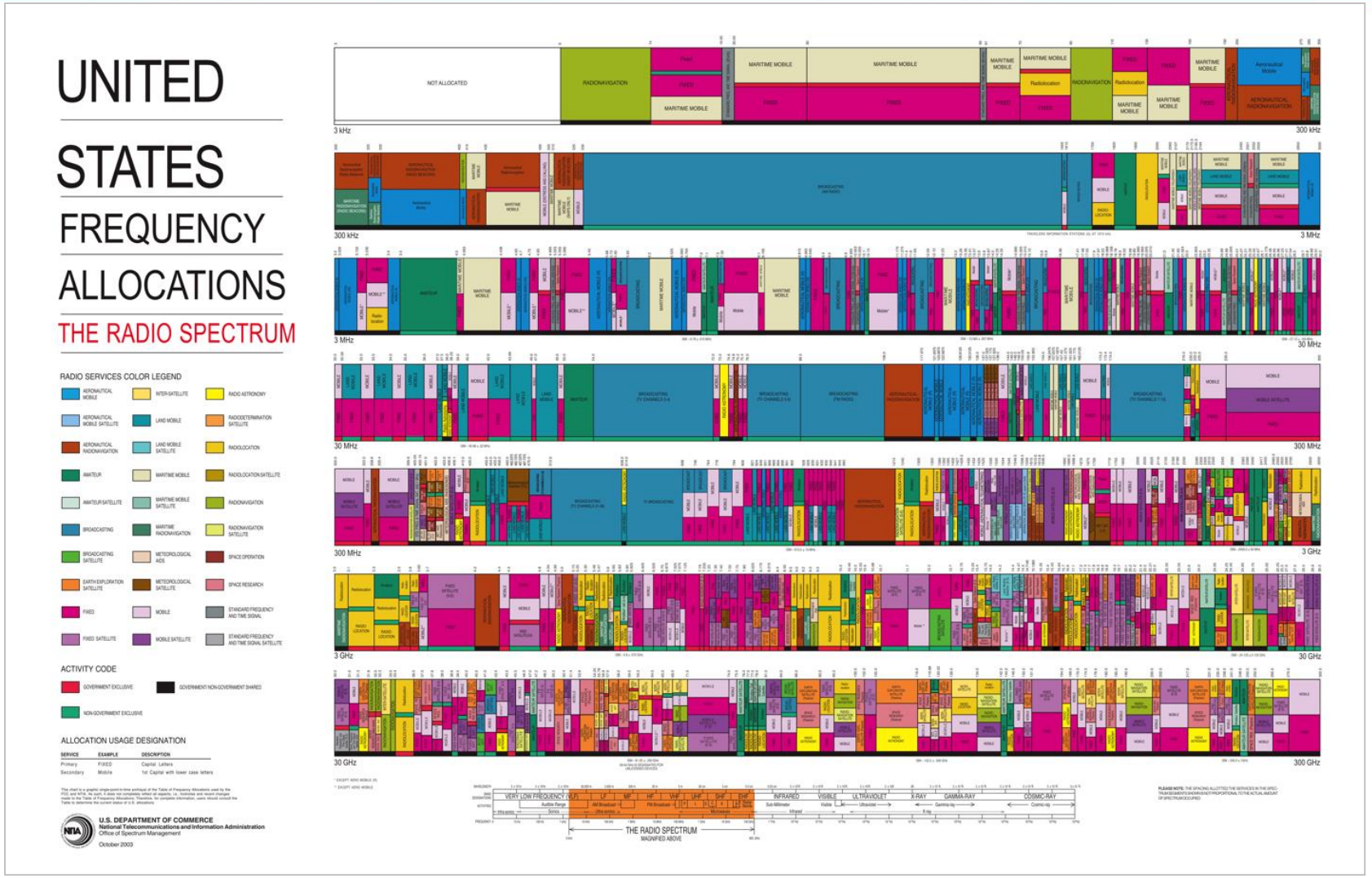


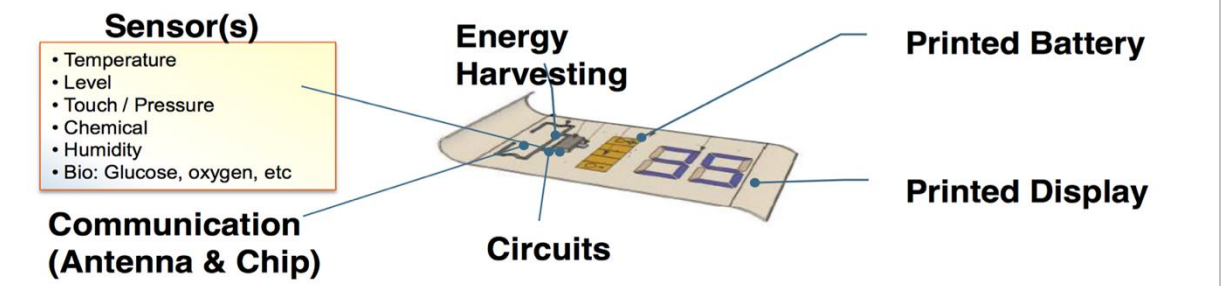
Chart of the US Radio Frequency Allocation Spectrum as of 2011: there is no open spectrum remaining to support the expansion of wireless bandwidth needed for IoT and TSensors.

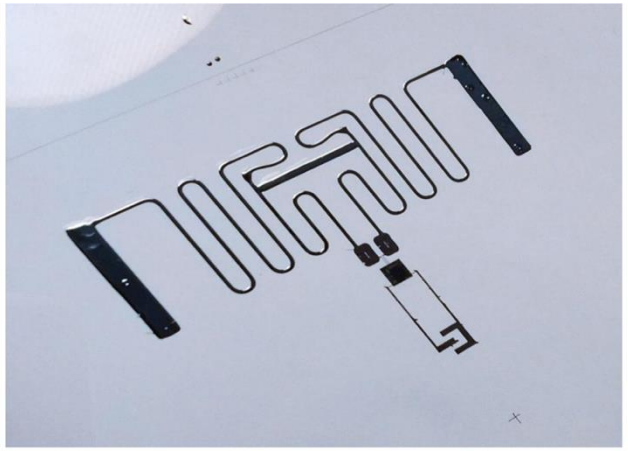
2019 Roadmap: Key Topics/Scope

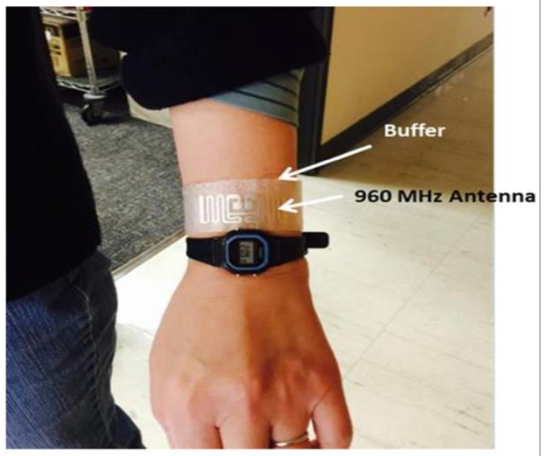
Hybrid Flexible Electronics for MEMS/Sensors Technology

The number of sensors to meet future needs is envisioned to exceed over 10 of trillion units by 2025

- New roll to roll facilities being built but is there support for fabless companies?
- Improving yields and performance of new systems and components
- Sensors/electronics performance under stretching, bending
- Materials characterization and test methods for flexible systems
- Design infrastructure and methodologies and process design kits and design rules



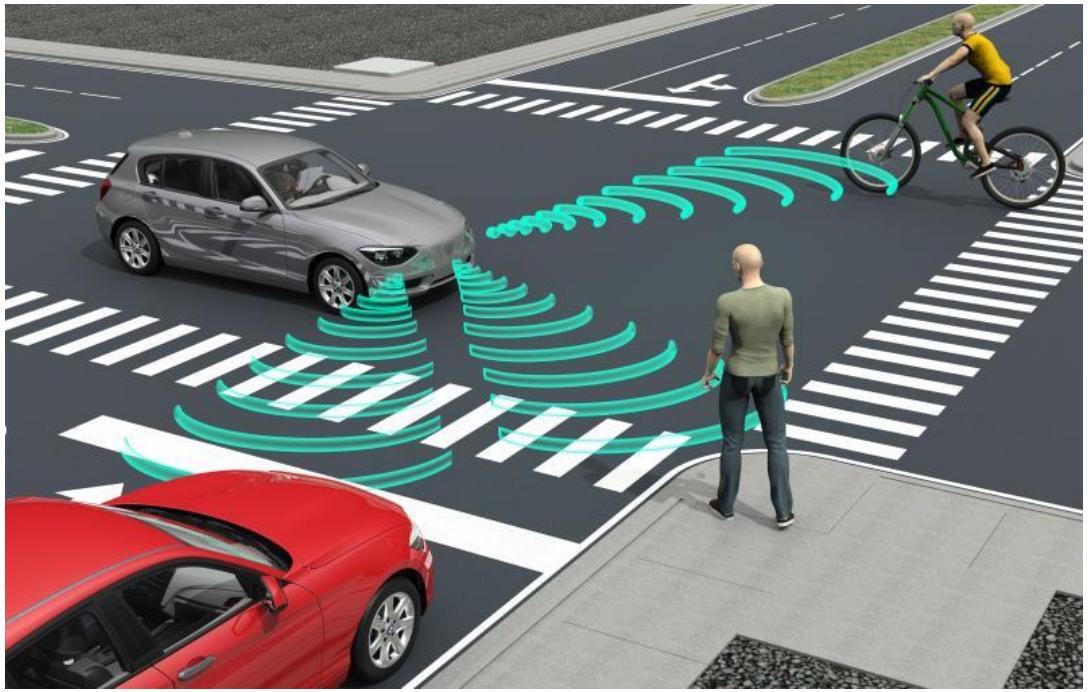




Hybrid Approach, Combining Roll-to-Roll Printing with Silicon-Based Logic
Source: Roger Grace, "Printed / Flexible / Stretchable Sensors: Creative Solutions for Empowering Abundance Realities," Trillion Sensors Summit, Celebration, Florida, November 10, 2015

2019 Roadmap: Key Topics/Scope

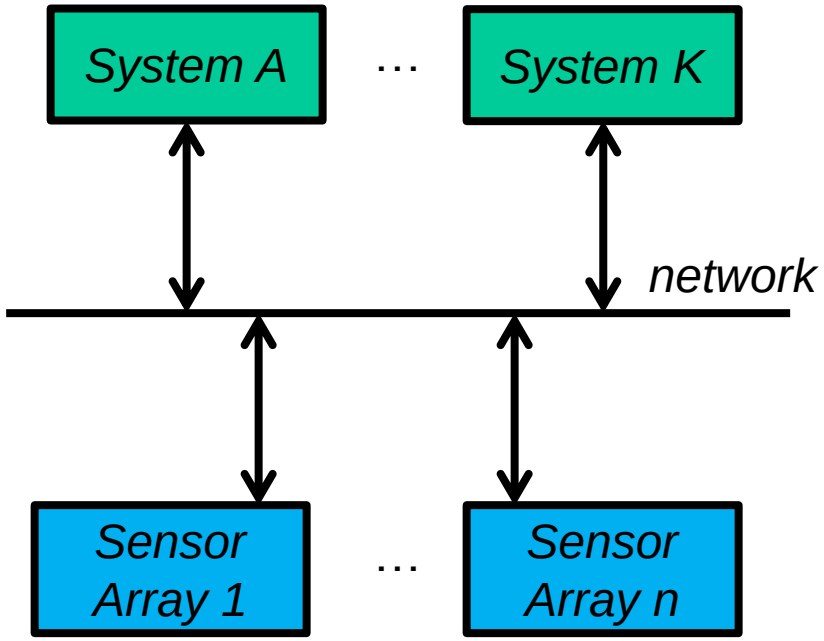
Autonomous Vehicles



From: The Rise of Autonomous Vehicles: Planning for Deployment Not Just Development

- **Autonomous vehicles will undoubtedly require new levels of sensor performance**
- **GPS signals are not always continuously available**
- **Inertial sensors that can provide continuous position information as well as cost requirements will need to advance**
- **Plan to report from the sensor manufacturers perspective on the current state of the art and future needs in manufacturing**

Robust Sensor Networks for IoT



- Future IoT Systems may communicate over multiple networks to multiple sensor arrays
- Sensors may not be dedicated to a single system but instead report to multiple systems
- The sensors must report data over various network infrastructures such as wired, wireless, optical, etc. with accurate time stamps
- New methodologies are needed to classify the accuracy of the data as well as the the measurements reported
- Anomalous behaviors as well as hacking or spoofing of data should be detected
- The IEEE Sensors Society is considering standards, such as using weighting factors, to classify the robustness of the data but how these factors will be determined is not yet defined

2019 MEMS Roadmap Plans

- Continue our review of testing needs and sensor integration path
- Report on the needs of hybrid flexible manufacturing for MEMS/Sensors
- Report on our perspectives for needs autonomous vehicles and the possible needs for international testing standards for digital inertial sensors
- Investigate and report on requirements for robust sensor networks for IoT
- Focus towards documenting needs from the sensor manufacturers perspective

Participation & Access

OPEN TO ALL INDUSTRY EXPERTS AND ORGANIZATIONS!

Contributing Organization's Benefits

- The earliest look at the iNEMI 2019 Roadmap.
- A free copy of the contributors chapter ($500 value) or (if chair/co-chair) the entire iNEMI 2019 Roadmap ($3,500 value)
- The opportunity to help drive the industry over the 10-year horizon of the iNEMI Roadmap and insure your company's needs are represented.

Contributing Team Member's Benefits

- Experience leading an international group of contributors plus building a network of valuable contacts.
- In-depth insights into their subject matter
- Cross-cut perspectives from the other iNEMI roadmaps

- Download Roadmap at iNEMI Web
  http://www.inemi.org/inemi-roadmap
- Follow iNEMI on LinkedIn
  https://www.linkedin.com/company/inemi
- iNEMI LinkedIn Roadmap Group
  https://www.linkedin.com/groups/8554679
- Linda Wilson, iNEMI Roadmap manager

- December, 2018 – Roadmap Ship to Members
- April, 2019 – Global industry roadmap presentations

www.inemi.org

Linda Wilson
linda.wilson@inemi.org

Haley Fu
haley.fu@inemi.org

iNEMI®
Advancing manufacturing technology