TSensors and Exponential Abundance

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American Physical Society
Actualization of the Internet of Things
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Agenda

- Mega Challenges & Opportunities
- TSensors Overview
- Summary/Call to Action
- Q&A

Global Grand Challenges

- Singularity University identified twelve Global Grand Challenges representing the world's biggest problems
- Most will require new sensors in ultrahigh volumes, due to the global scale of solutions

Resource Needs

Energy
Ample, accessible and sustainable energy for the needs of humanity.

Environment
Sustainable and equitable stewardship of Earth's ecosystems for optimal functioning both globally and locally.

Food
Consumption of sufficient, safe, and nutritious food to maintain healthy and active lives for all people at all times.

Shelter
Secure, safe, and sustainable shelter for residence, recreation, and industry for all people at all times.

Space
Safe and equitable use, and stewardship of, space resources and technologies for the benefit of humanity and our future as a multi-planetary species.

Water
Ample and safe water for consumption, sanitation, industry, and recreation for all people at all times.

Societal Needs

Disaster Resilience
Effective and efficient disaster risk reduction, emergency response, and rehabilitation that saves lives and livelihoods, minimizes economic loss, and builds resilience both globally and locally.

Governance
Equitable participation of all people in formal and societal governance in accordance with principles of justice and individual rights; free from discrimination and identity-based prejudices; and able to meet the needs of an exponentially changing world.

Health
Optimal physical and mental health, including access to cost effective prevention, early diagnosis, and personalized therapy for individuals and communities.

Learning
Access to information and experiences that build knowledge and skills for all people at all stages of their lives for personal fulfillment and benefit to society.

Prosperity
Equitable access to economic and other opportunities for self-fulfillment where all people are free from poverty.

Security
Safety of all people from physical and psychological harm, including in virtual worlds; and protection of physical, financial, digital systems.

https://su.org/about/global-grand-challenges/

Mega Challenges by the numbers

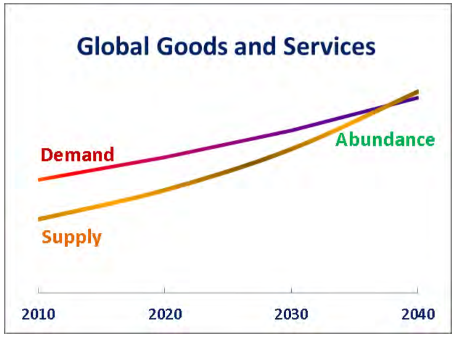
- <u>Food:</u> **842 million** people live with chronic hunger and food insecurity. Population by 2050 projected to be **9.6B** and we need an increase of 70% more food calories to feed them
- <u>Health:</u> **1 billion** people lack access to healthcare services
- <u>Environment:</u> **2.5 billion** people do not have access to proper sanitation. **7 million** deaths each year are caused by air pollution
- <u>Energy:</u> **1.4 billion** people do not have access to electricity

Initiatives to Solve Global Challenges on the Rise

- **IBM's and Xprize Foundation's four-year $5 million Artificial Intelligence Competition to tackle humanity's greatest challenges was launched in 2016**
- **MIT's "Campaign for a Better World", a $5 billion fundraising initiative to advance MIT's work on some of the world's biggest challenges was launched in 2016**
- **Dangote and Bill & Melinda Gates Foundations announced a combined commitment of $100 million over the next five years (2016-2020) towards ending undernutrition in Nigeria**
- **MacArthur Foundation's announced $100 million grant contest "100&Change" for the best proposal and plan for solving a pressing global problem**

http://ai.xprize.org/; https://betterworld.mit.edu/; http://gcgh.grandchallenges.org/grant-opportunities; https://www.philanthropy.com/resources/audio/podcast-inside-macarthur-s-1/6049/;

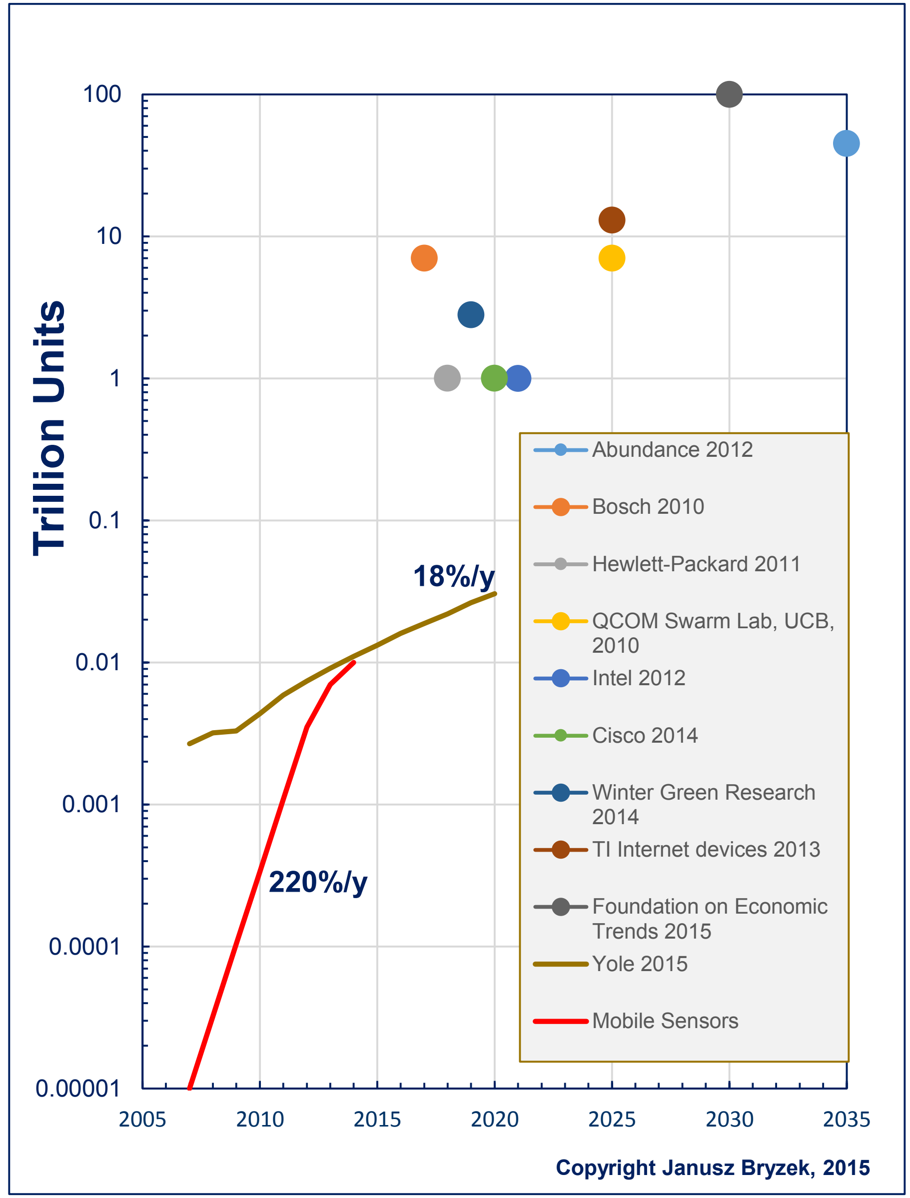
TSensors focused on these challenges



Abundance could be reached in the next 20-25 years.
Will require ~45 Trillion connected devices with multiple sensors

TSensors Initiative

- Major sensor market growth change occurred in 2007 triggered by iPhone introduction
- Janusz Bryzek started TSensors in 2012 to support a path to Abundance
- Multiple trillion sensor (TSensors) visions have emerged
- 7 international TSensors Summits held to date
- Phase 1 TSensors Initiative concluded in 2016



* http://www.huffingtonpost.com/jeremy-rifkin/obamas-climate-change-plan_b_5427656.html

TSensors Phase 1 Selected Findings

- **Trillion Sensors will be economy driven**
  - IOT, Health, Environmental, Food-AgTech, Energy, Automotive…
- **Sensors will need to move from fab to flex & printed**
  - Discrete solutions move to sensor nodes (processing, comms, power source, sensor arrays) and need to be sub $1
- **Exponential Technologies will disrupt**
  - 40% of world largest companies will be displaced by 2025
- **Jobs will be transformed from old to new industries**
  - Robots, AI, UAV's…software and knowledge workers

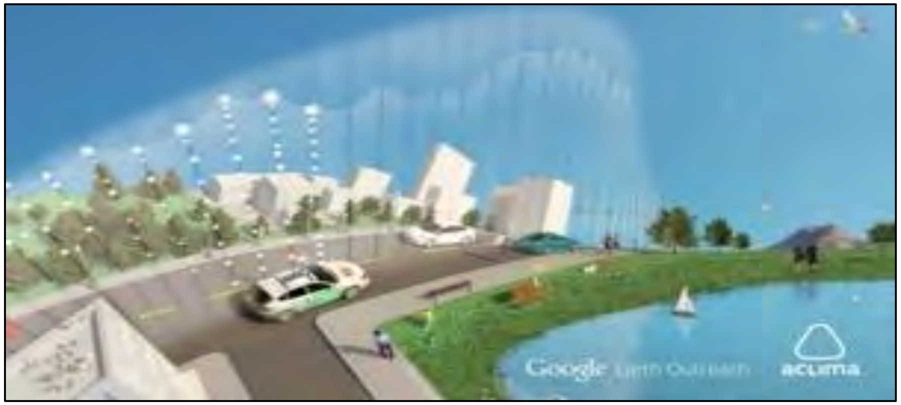
Most Impactful TSensors Applications

- **Phase 1 of TSensors identified five business opportunities with a huge global impact**
  - Environmental Pollution
  - Unobtrusive Personal Health Monitoring
  - Clean, Sustainable Energy & Energy Harvesting
  - Agriculture and Food Delivery
  - Global disasters and Aging Infrastructure Monitoring
- **To meet the target costs of enabling trillions of nodes, solutions need to move to printed electronics**

1. Environmental Pollution Monitoring

- The largest application identified through TSensors Summits is a global pollution monitoring network
- GE showed plans for 10 trillion pollution monitoring printed sensors for 2025
- Global bio-chem-pollutant pollution is largely unknown. US Government agencies track about 1000 chemicals, biological agents and pollutants for air, water and soil pollution. Needs to scale
- Air pollution monitoring deployments by Aclima (supported by Google), showed the benefits of city-wide pollution mapping. With other company efforts in this area a global pollution map is within reach

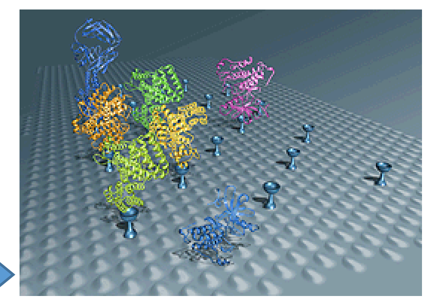
Mission Innovation launched in December 2015, supported by 20 nations and 26 billionaires and is receiving a startup fund of $10 to $20 billion.



2. Unobtrusive Personal Health Monitoring

- mHealth was triggered by wearables reusing sensors developed for mobile devices. Fitness Apps will migrate to Medical Apps
- MEMS technology is already foundational in medical devices and will impact new delivery vehicles and form factors for Personal Vital Sign Monitoring, Implantable's, Protein Panels, Rapid Diagnostics, etc.
- Revolutionary genome sequencing transistor from iNanoBio and other DNA sequencing companies are expected to transform medical, food production and biofuels fields

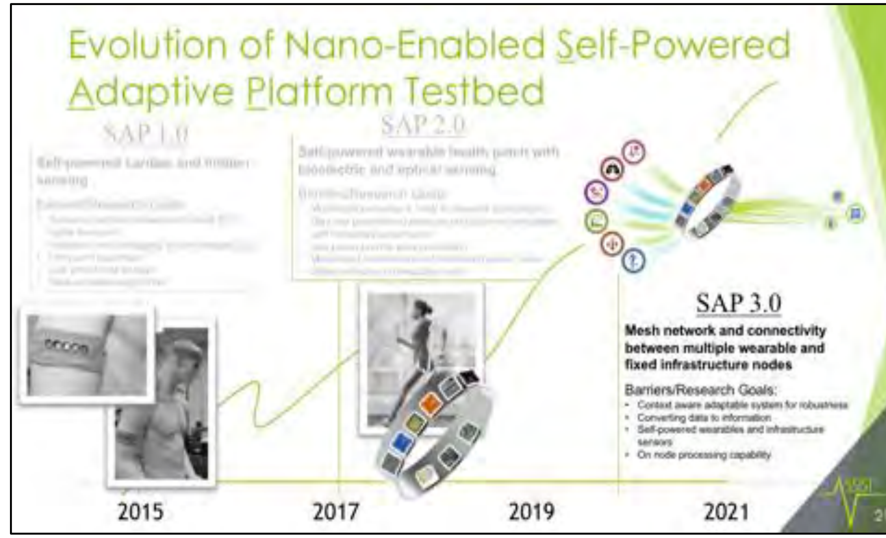
Microfluidics has "grown-up".
It will be required to realize cost-effective protein panels.

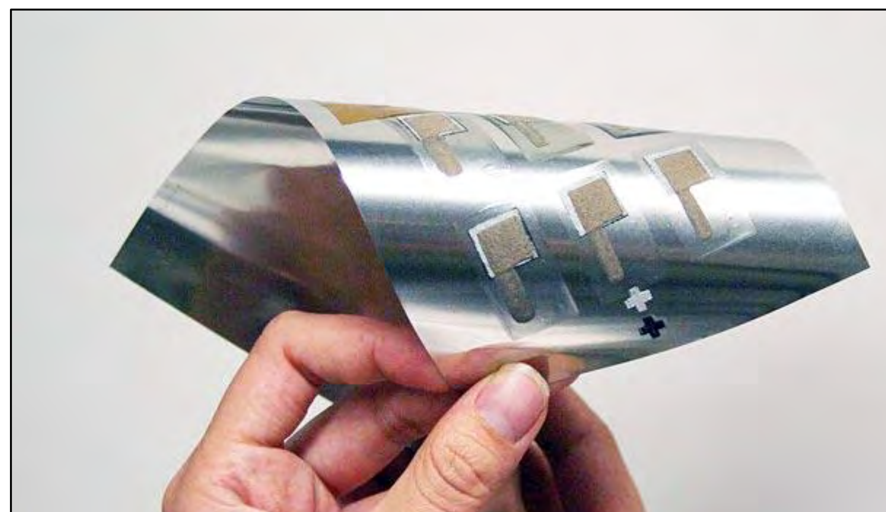


Wireless tattoo temperature sensors and therapeutic heater from MC10 includes transistors, power supply, and an antenna.

3. Clean, Sustainable Energy & Energy Harvesting

- **Energy harvesting technologies are approaching capability to support low power radios, per presentation from University of Utah and many others**
- **The implementations will likely integrate harvesters from multiple energy domains, such as light, kinetic, thermal and RF**
- **Supercaps are emerging**
- **Printed batteries are ready for global deployment according to Applied Materials**





4. The Food-AgTech Demand for Sensors

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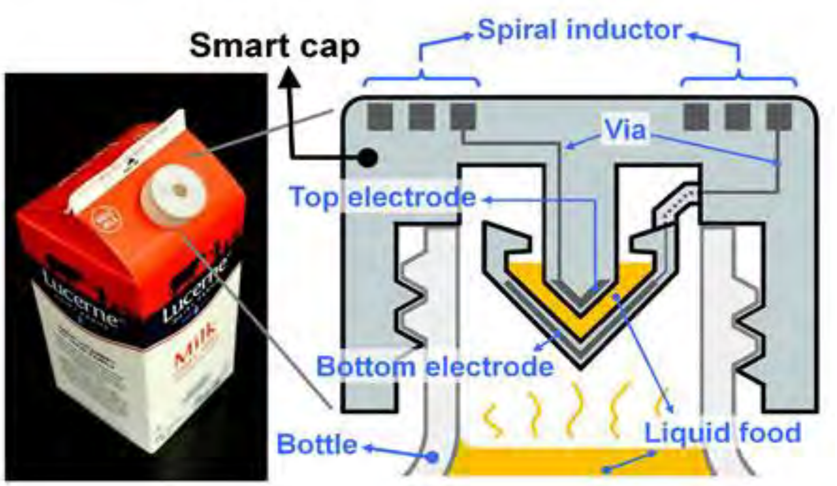
- About 25% of household food is wasted due to "use by" label on trillions of food packages. Additional 10% to 15% of food is spoiled during transportation, all preventable with sensors.
- Sensor-based precision agriculture demonstrated significant crop yield gains.
- Broad range of sensors has been already used, such as thermographic health sensing of livestock, GPS, motion, temperature, humidity, light, color, vision, ultrasound, hyperspectral, nitrogen, moisture, chemical, etc.
- Main issue is cost for scaling
- Printed sensors for such applications were demonstrated at multiple centers, e.g., at UC Berkeley, VTT, and others.

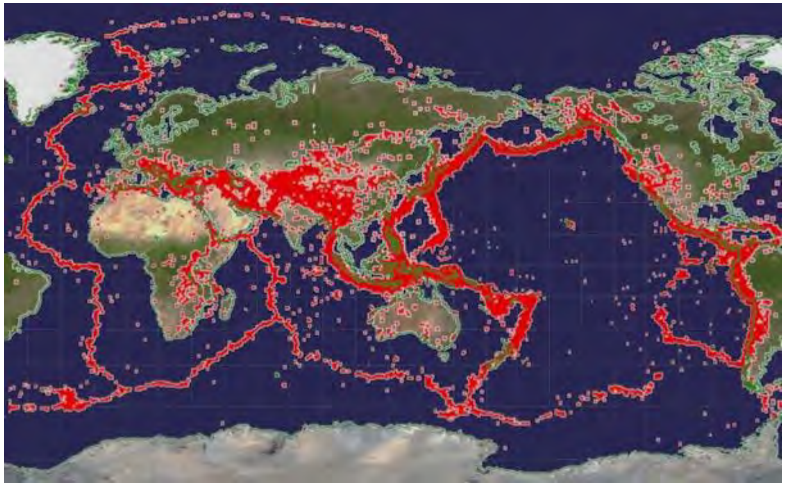
VTT ethanol sensor detects food spoilage in the package. Signal is wirelessly readable by a mobile devices.



UC Berkeley printed sensor monitors milk quality

5. Monitoring of Global Disasters & Infrastructure

- **Natural disasters: earthquakes, hurricanes, tsunamis, landslides, floods, etc. claimed 1.35M lives between 1994 and 2014.**
  - Damage between 2000 and 2014 is estimated at about $3 Trillion.
- **Aging infrastructure" roads, bridges, buildings, etc.**
  - Economic loss in the US alone is estimated at $1.1 Trillion between 2014 and 2020.
- **Global monitoring of all these threats is the foundation for deployment of preventive measures.**
  - 2015 Hitachi's TSensors study estimated the need for 1.4 Trillion sensors by 2025 to support the emerging monitoring needs.



Global earthquake monitoring network would improve predictability, accelerating response and significantly reducing losses (courtesy of Omron)

New growth coming from new companies

- ***Unicorns*: companies rapidly reaching (imaginary) valuation of a billion dollars.**
  - Often overpriced by investors, seldom reaching $Billion sales.
  - Unicorns are imaginary animals…
- ***Narwhals*: companies rapidly reaching $Billion sales**
  - Narwhals are real animals…
- ***Exponential Organizations*: companies scaling at least 10x better than their peers in the same space**.
  - Of the top 100 ExOs, 35 are also Unicorns, and 10 are also Narwhals.
- **Startups have less trouble implementing exponential attributes than large corporations.**
  - Many will likely displace Fortune 500 companies in one decade…

Exponential Organizations follow a 6D Process

- **1D**igitization phase
  - Products or services are digitized, which leads to
- **2D**eceptive phase (currently Printed Electronics and Sensors)
  - New technologies seem not good enough to create competitive threat, which leads to
- **3D**isruptive phase
  - New technologies improve and disrupt existing players, which leads to
- **4D**ematerialization
  - Products or services are distributed as bits, which leads to
- **5D**emonetization
  - Bit based products and services can be freely distributed globally and monetization is derived from an alternative business model, which leads to
- **6D**emocratization
  - Products and services can be distributed to all

MEMS/Sensor improvements and volumes on rise

Item	Honeywell HG1900	Fairchild FIS1100	Improvement
Development start	1980s – 2000s	2010 - 2015	
Gyro	1 axis	3 axes	3x
Gyro bias stability	10^{o}/h	10^{o}/h	1x
Acceleration	1 axis	3 axes	3x
Magnetic	N/A	3 axes (fusion)	
Transistors	1,000	1,000,000	1,000x
Built-in algorithms	None	9DOF Sensor Fusion	100x processor power
Gyro power	3,000 mW/axis	0.7 mW/axis	4,300x
Supply voltage	10 to 30 V	2.4 to 3.0 V	4 to 10x
Package volume, mm^3	540,000	10	54,000x
Weight, grams	460	0.4	1,100x
Cost	$10,000	$1	10,000x
Applications	Defense, Industrial	Mobile, VR	

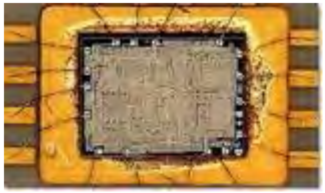
- **Mobile market delivered exponential changes (2 to 3 orders of magnitude) in sensor market in just one decade:**
  - Cost
  - Power consumption
  - Weight
  - Size
  - Height
  - Intelligence
- **Created a foundation for sensor adoption in other industries enabling support of largest economic tides.**

T SENSORS

Deceptive Phase for Printed Electronics/Sensors

<u>1971: Intel 4004</u>

First Si µProc.
10 µm
4 bit
pMOS
-15V Vdd
2300 TOR
108 KHz

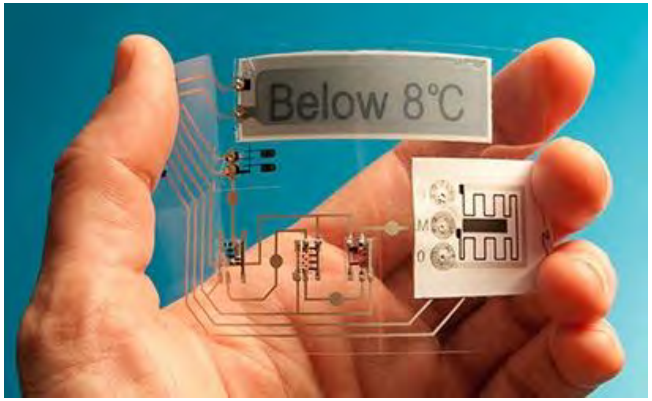


<u>2011: imec & Holst</u>

First plastic µProc.
5 µm
8 bit
pMOS, dual Vt
-10V Vdd
2000 TOR
6 Hz

<u>2015</u>

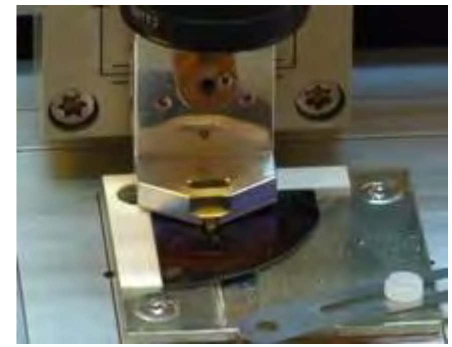
ThinFilm prints 5 µm transistors and sensors, with down to $0.05/tag



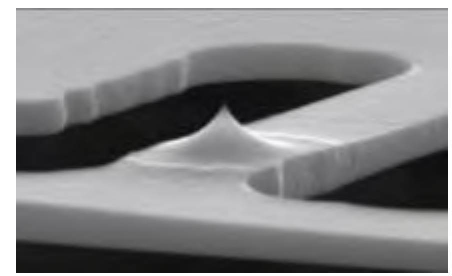
Gap between monolithic and printed transistors: 40 years

Disruptive Phase for Printed Electronics/Sensors

- **IBM Research in Zurich unveiled in 2014 a 3D printer based on MEMS/NEMS and capable of writing 10 nm patterns**
  - Printer outperforms e-beams, but costs around $500k, as opposed to e-beams, $1.5M to $30M
- **IBM hoped to be prototyping tunneling FETs in GaAs and graphene by the end of 2014…**



IBM's mechanism works like an atomic force microscope (AFM) but with a heated tip that can sculpt 3D nanometer resolution patterns. (Source: IBM)



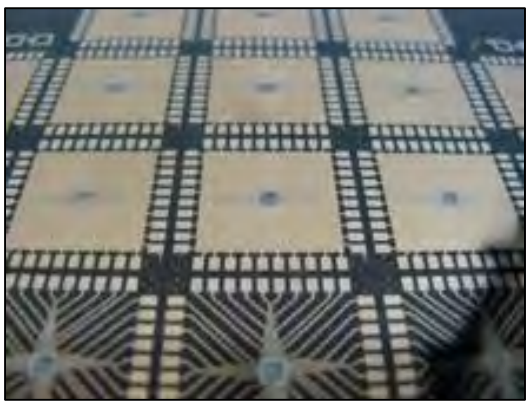
The heated tip of the 3D printing mechanism is 700 nanometers long but just 10 nanometers at its tip and can be positioned with nanometer resolution. (Source: IBM)

http://www.eetimes.com/document.asp?doc_id=1322091

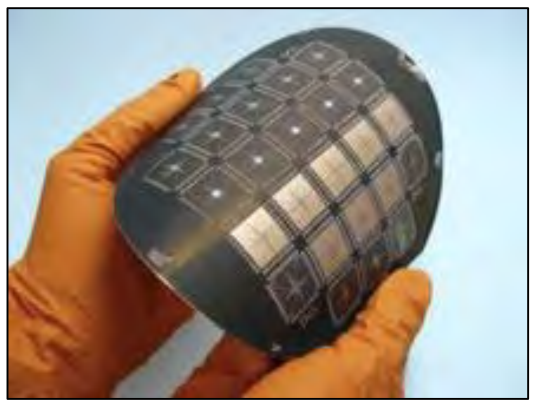
Gap between monolithic and printed transistors: Zero years

Flexible Hybrid Printed Solutions Emerging

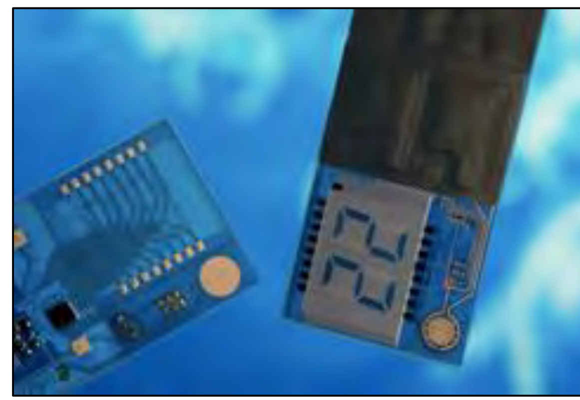
- Hybrid implementations will likely dominate volume applications into the mid 2020's
- Pure printing of electronics alone is not sufficient due to low power challenges that are only addressed by wafer based silicon currently
- Pure printed deployments are servicing niche markets however
- Pure printed volume applications will likely dominate in the second half of 2020's



Thin-Chip-Foil-Package"
for Hybrid Integration



Temperature Tag: Hybrid
Integration on Plastic Films



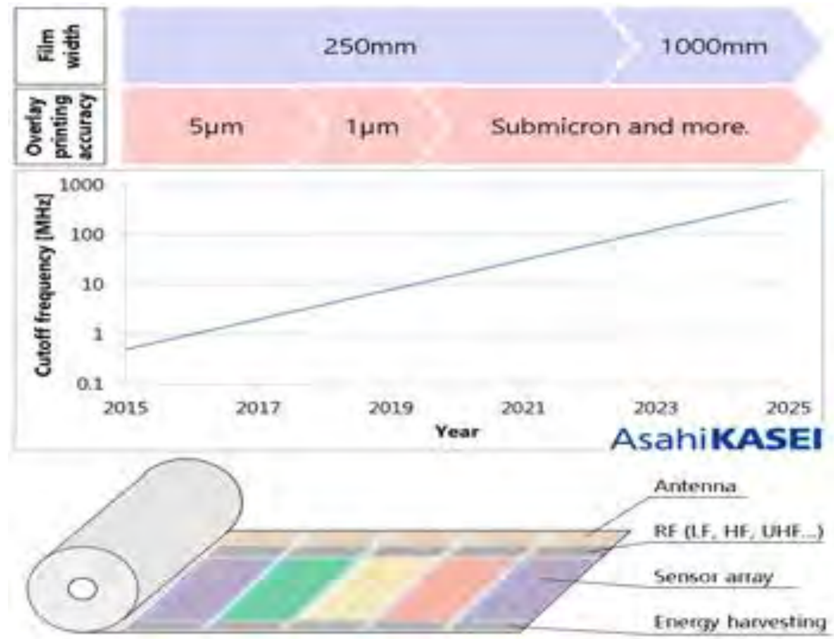
Temperature Tag in Foil

- integrated multilayer foil system
- printed wiring
- thin film batteries
- flexible printed display
- low temperature foil-to-foil and SMD assembly

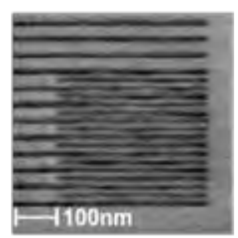
Sensor Examples from Fraunhofer EMFT

Fully Printed Solutions – Needs More Work

- **Many emerging applications need printed electronics and sensors due to:**
  - Large area deployment and sensor arrays
  - Low cost exceeding capability of wafer based electronics and sensors
  - Form Factors: Sensors embedded in walls, furniture, robots skin, fabrics, casings…
- **Printed transistors have reached volume production in RFID and NFC tags with about 2000 transistors in 5um printed process node**
- **Many companies presented at the TSensors Summits a large number of printed transistor and sensor types**
  - e.g. Asahi-Kasei presented a 2015-2025 roadmap for Roll-to-Roll (R2R) manufacturing line enabling production of 1 GHz submicron transistors on 1 meter wide rolls
- **IBM Zurich have printed 10nm lines leading to 10nm transistor process node**



Asahi Kasei Roadmap for printed electronics



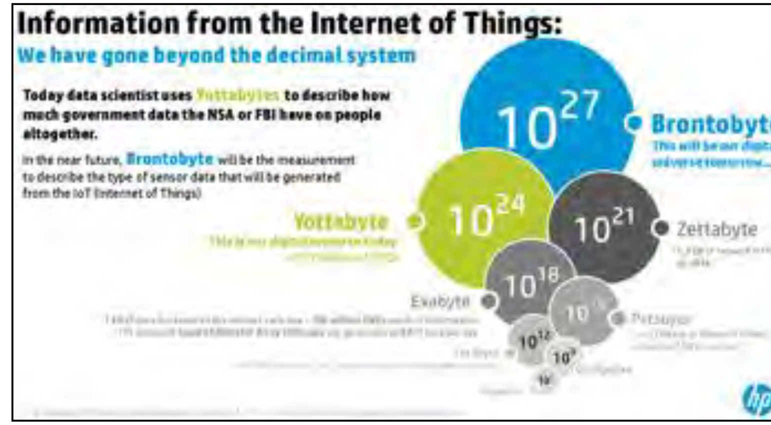
10 nm lines printed by NanoFrazer printer

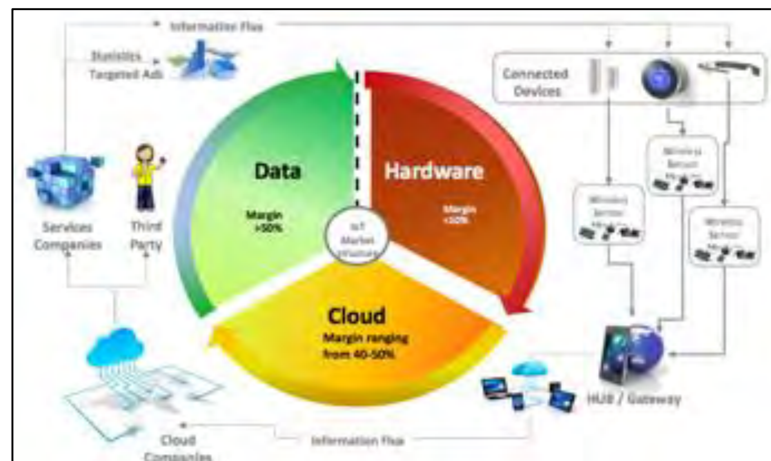
Large Sensor Arrays Showing Promise

- Individual sensors are expected to migrate to Sensor Arrays and Large Area Electronics for certain applications
- Princeton University presentation showed that accurate information for many applications could be derived from a large number of inaccurate (cheap) sensors data in the array, using artificial intelligence (AI) algorithms
- Emerging tool of choice for Big Sensor Array Data Fusion is Deep Learning

Don’t Forget the Data…and Insights

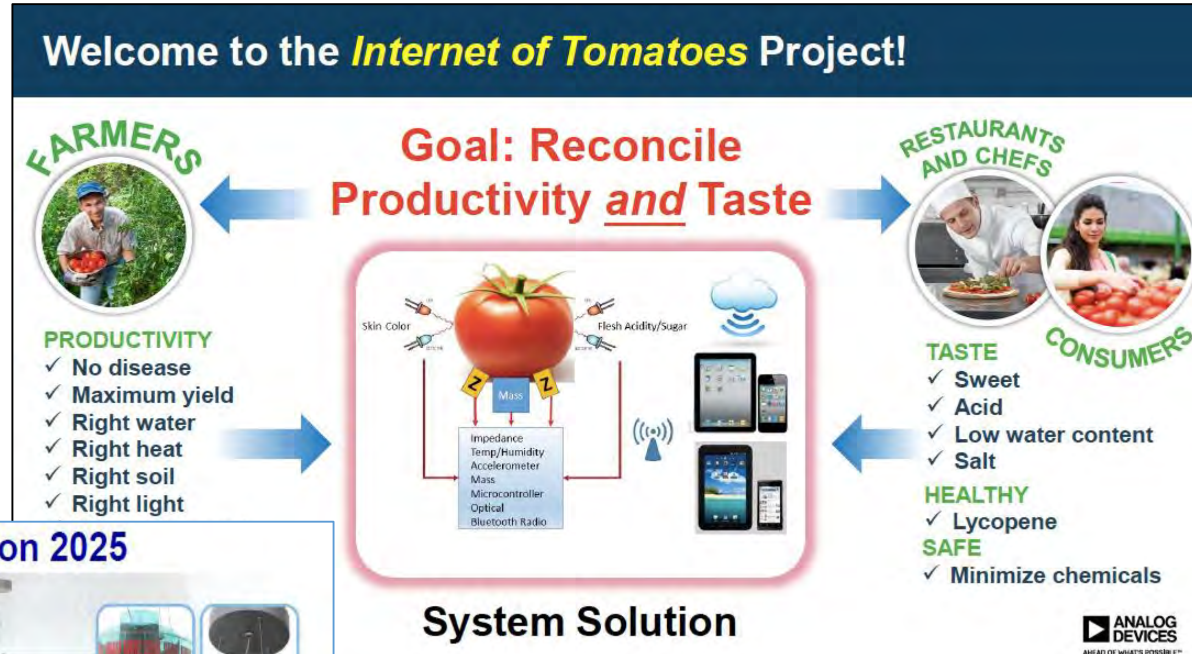
- **Sensors are expected to generate 1BB (10^{27}) Brontobyte of data, perhaps as early as the next decade**
- **Processing of Brontobytes will put the strain on IT infrastructure:**
  - Internet size will need to grow exponentially.
  - There will not be enough programmers to develop algorithms processing Big Data
  - Algorithm development will need to shift to AI/Deep Learning
- **Data Analytics is expected to generate 60% to 90% of profits in the global economy by 2025**





New Business Models Emerging

ADI's Internet of Tomatoes Project is helping to shape their entire IOT strategy



VTT's vision of printed electronics and sensors enabling new business model: Surroundings as a Service

TSensors Phase 2 Plans

- **Building a content database**
  - Past TSensors Summit content, New Whitepapers, Articles
  - Exploring book publication
- **Data to be used to drive projects**
  - Solve challenges, secure funding, and accelerate commercialization of new sensors
- **Feasibility Study to build TSensors pillar demonstrators**
  - Demonstrate Printed technology can meet needs
  - Partner with academic, research and industry organizations
- **Events and workshops under planning**

Summary/Next Steps

- **The worlds mega challenges can drive the largest business opportunities for the sensors and semiconductor industries**
- **Existing and many new companies will exponentially advance printed electronics/sensing in the coming decade. Hybrid approaches are the foundation today**
- **Data analytics will generate the bulk of profits**

We encourage your participation to co-create the future and impact the lives of a Billion people!

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