TSensors Strategic Markets and Technologies Reviews Background Vision

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Reviews of Strategic Markets and Technologies for TSensors are conceived as multiple reports, each focused on one of the most impactful market segments for sensor related industries for the next decade. These technologies were discovered in TSensors Summits and are being updated and added to on an ongoing basis now.

These reviews will include a collection of white papers summarizing advanced developments at leading sensor academic and research organizations, creating a foundation for solutions of global problems characterized later. In parallel, these solutions lead towards Abundance in mid-2030 – a World with healthcare, food, a clean environment and energy for all.

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Introduction

The Trillion Sensors (TSensors) initiative was conceived by and launched in 2012 by Dr. Janusz Bryzek, and focused on identifying TSensors applications helping to accelerate Abundance[1] - the future World with food, medical care, clean energy and a clean environment for all.

Historically, the time cycle for commercialization of new sensor and MEMS technologies has been 28 years to high volumes (billions/year), longer than the expected 20 years to Abundance, which predicts the need for 45 trillion connected nodes, most with sensors.

The first TSensors activity was a TSensors Summit held at Stanford University in October of 2012. Through invitations to present at that event and six subsequent Summits, Dr. Bryzek sought out global sensor technology and market visionaries to present their views on the future. Seven Summits have been held to date: UC Berkeley, Stanford University, UC San Diego, Munich and twice in Tokyo.

The initial motivation behind the TSensors initiative[2] was to accelerate commercialization of new sensor types supporting Abundance through early discovery of demand. With time, it became clear that the same sensors will be needed to support the largest global economic tides, creating the largest business opportunity in history for sensor related industries.

In parallel, Janusz joined the Abundance community run by Peter Diamandis[3] and got connected to visions generated by Peter and by Singularity University[4].

Based on the above, TSensors activities have:

- Extracted global economic tides driving demand for sensors and their impacts on society.
- Concluded that these global tides will be driving a World in the direction of Abundance.
- Selected five most impactful TSensors applications as focus for TSensors Vision Reviews.
- Selected one infrastructure technology enabling TSensors based network nodes deployment as a focus for the 6th TSensors Vision Review.

Reviews of Strategic Markets and Technologies for TSensors are defined here as a fusion of Foresight (a prediction what will be needed in the future) and Feasibility (an evaluation of what could be practical by 2025) for selected applications deemed by TSensors leaders as the biggest business opportunities in history for sensor and related industries.

These opportunities are expected to cumulatively consume trillions of sensor-based network nodes, and possibly bring Abundance by mid-2030's.

We believe that there will be very few emerging sensor-based applications capable of generating the demand for trillions of sensors (TSensors) by 2025. Only applications driven by billions of users or by global infrastructure demand, both supported by global economic tides, will be capable to drive sensor demand to such a level.

Reviews of Strategic Markets and Technologies for TSensors are conceived as a collection of white papers from visionaries in a given field, and summarizing those findings, one application per book. The objective is to increase global awareness enabling accelerated commercialization of these technologies, thus accelerating Abundance.

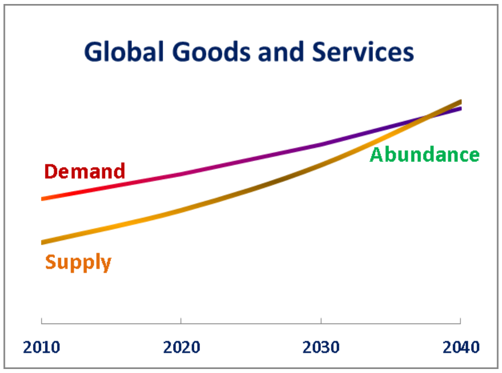
As Reviews will outline technologies supporting extraordinary business opportunities improving the World, the follow up activity accelerating commercialization is currently conceived as follows:

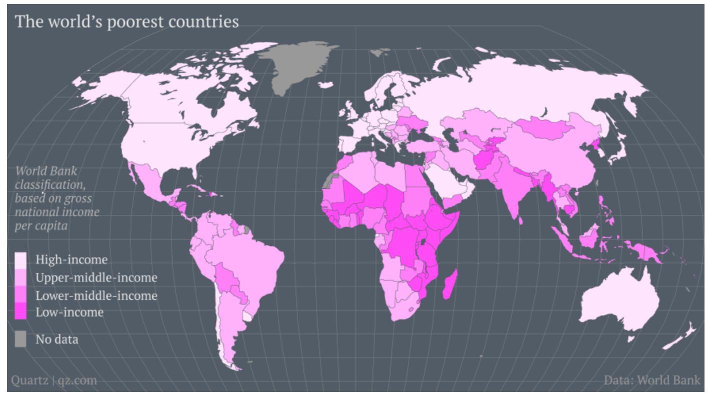
- Forming a Consortium of companies interested and capable of bringing new sensing node technologies to market.
- Defining product architectures for each of the characterized applications enabling a parallel innovation.
    - Similar to a PC architecture, wherein innovation of each system component (such as processor, hard drive, memory, monitor, etc.) could be deployed independently of other components.
- Assigning development responsibilities to interested companies.
- Arranging supporting co- funding from Governments interested in job creation and non-profit organizations interested in improving the World.

- Launching coordinated global development enabling commercialization as soon as a given sensor is developed (plugging into an "awaiting" system socket).

World's Largest Business Opportunities

The World's biggest problems represent the World's largest opportunities[5] which are expected to be solved by Exponential Technologies[6] enabling the World's largest economic tides. This will lead the





World towards Abundance.

Figure 1. Abundance concept is based on matching global demand for goods and services with supply (left), primarily through exponential technologies enabling growth of supply faster than growth of demand. Bill Gates is on the same wavelength, predicting there will be almost no poor countries by 2035[7] (right).

In line with Abundance, the Massachusetts Institute of Technology (MIT) made explicit its goal of making the world a better place with its "Campaign for A Better World[8]", a $5 billion fundraising initiative that will amplify the Institute's distinctive strength in education, research, and innovation, to advance MIT's work on some of the world's biggest challenges.

There are eleven Global Grand Challenges representing the World's biggest problems identified by Singularity University[9] market research. TSensors Vision Reviews will address the emerging sensing technologies supporting solutions for Energy, Environment, Food, Health, Water and Disaster Resilience. The solutions are expected to create demand for billions and trillions of sensor-based connected nodes.

Sample global initiatives supporting such solutions include:

- IBM and XPRIZE Foundation initiated a four year $5M Artificial Intelligence Competition to tackle humanity's greatest challenges[10].
- 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[11].
- Bill & Melinda Gates Foundation's Grand Challenges Initiatives[12] to solve key health and development problems. Most recent included "100&Change": competition for a $100 million grant to fund a single proposal that will make measurable progress toward solving a significant problem.
- In a *Letter of Commitment*[13] presented to President Barack Obama in 2015, more than 120 U.S. engineering schools announced plans to educate a new generation of engineers expressly equipped to tackle some of the most pressing issues facing society in the 21st century.

TSensors Vision plans to address these challenges on the sensor level.

Figure 2. Solutions to eleven Global Grand Challenges identified by Singularity University, most sensor-based, represent the World's largest business opportunities due to their global scale and alignment with economic tides. TSensors Vision Reviews will characterize most impactful emerging sensor technologies addressing these challenges, plus the emerging infrastructure technology, printed electronics and energy sources.

Benefits of Reviews of Strategic Markets and Technologies for TSensors

There are multiple categories of individuals and organizations who/which will benefit from TSensors Reviews:

<u>Authors of white papers</u>

- Create publishing opportunity aiming at improving the World.
- Increased visibility of their research, exposing their developments to potential commercialization and funding partners.
- Provide insights helping to restructure curriculum and advanced R&D programs in line with largest global needs.

<u>Sponsoring organizations</u>

- Advanced access to White Papers.
- Potential for first mover advantage in accessing emerging technologies.
- Satisfaction from improving the World.

<u>Academia</u>

- Insights helping to restructure curriculum and advanced R&D programs in line with largest global needs bettering the World.

<u>R&D organizations</u>

- Insights helping to restructure curriculum and advanced R&D programs in line with largest global needs improving the World.

<u>Sensor industry</u>

- Advanced visibility of emerging largest markets.
- Visibility of potential sources to partner with for access of enabling technologies.
- Potential for improving the World.

<u>Material and tool suppliers and Infrastructure developers</u>

- Advanced visibility of largest needs in emerging ultra-high volume sensor technologies and applications improving the World.

<u>Supply chain</u>

- Find new ultrahigh volume business opportunities adding to the existing maturing markets such as mobile phones.

Takeaways from TSensors Summits and Abundance-360

MEMS market evolution

The MEMS market has followed the growth of semiconductor market, but at a higher growth rate. Between 1970s and 2010s, the MEMS market grew from about 1% to about 4% of the semiconductor market. Figure 3 shows major products along the evolution.

Emerging global tides, such as IoT and mHealth, have potential to drive MEMS market to much higher percentage of the semiconductor market.

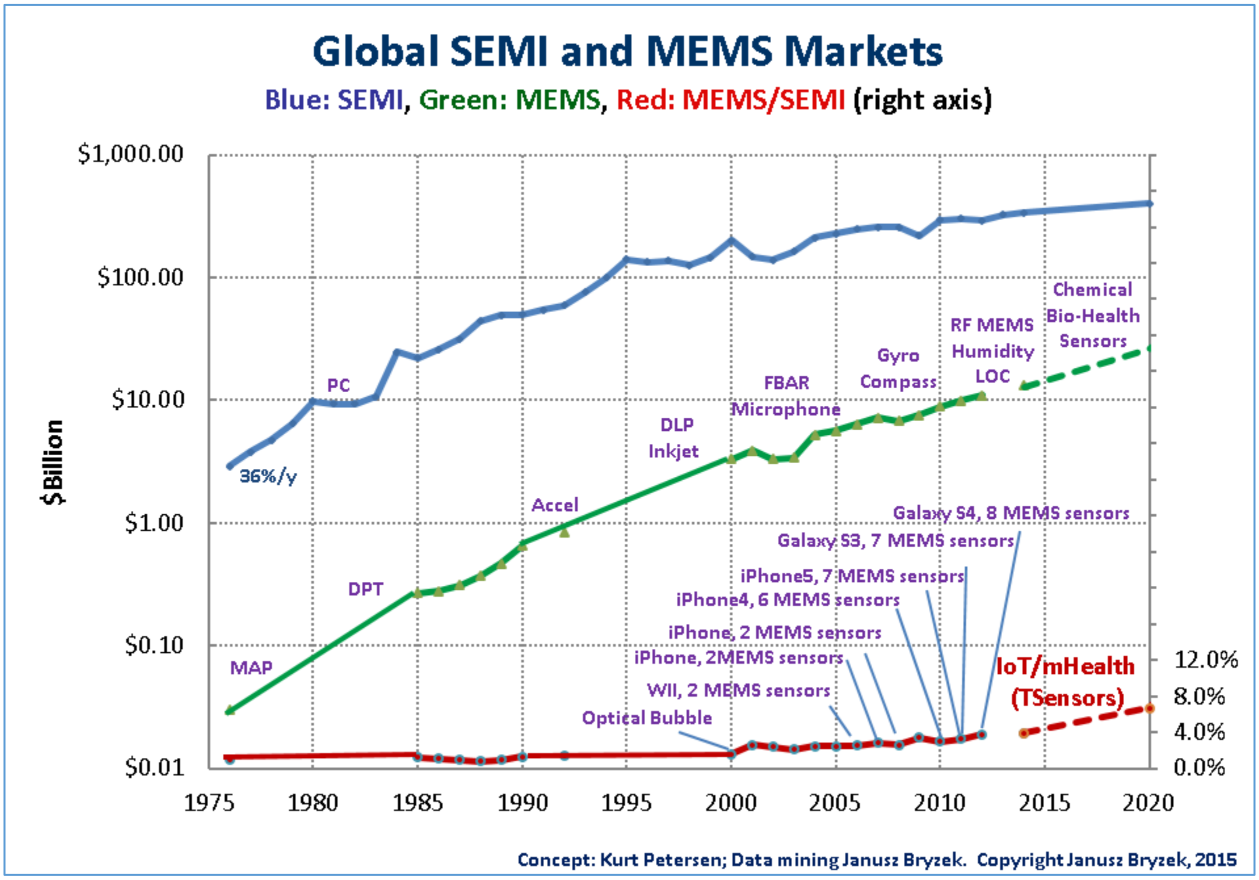


Figure 3. Evolution of MEMS market.

The first volume application for MEMS sensors reached the market in the 1970s, a manifold absolute pressure sensor (MAP) to control car emission. The next one was DPT, a disposable blood pressure sensor entering the market in the 1980s. It was followed by the airbag acceleration sensor, DLP (digital light processor for displays) and inkjet heads for printers in the 1990s. The Mobile market opened high volume sockets for microphones, FBAR (field bulk acoustic resonator), gyro and compass in the mid 2000s. In the current decade, several other applications reached high volume including humidity and chemical sensors. In parallel, optical MEMS driven by the “optical bubble” in the early 2000s failed to reach high volume. In the coming decade, chemical and bio/health sensors supporting IoT and mHealth are likely to emerge in high volumes.

MEMS sensors are a subset of a larger sensor market, represented by a large number of technologies addressing a broad range of markets, characterized by higher ASPs and lower volumes, and estimated to be about 6x larger market than MEMS sensors market (per BCC Research).

TSensors Visions

Historical volume growth of MEMS devices had been about 18%/year. Introduction of the iPhone triggered accelerated growth of MEMS sensors, for mobile applications from 10 million in 2007 to over 10 billion in 2015, representing over 220%/year growth rate.

Visions for growth of sensors to trillions started to emerge. First visions were presented in 2010, with Bosch forecasting 7 trillion sensory swarms by 2017, supported by related visions from the Qualcomm Swarm Lab at UC Berkeley expecting 7 trillion sensors by 2025.

In 2011, the most visible trillion sensor forecast for 2018 was made by Hewlett Packard, as part of the Central Nervous System for Earth (CeNSE).

The 2012 bestseller book Abundance[1] estimated the need for 45 trillion connected nodes around 2035. A large fraction of these nodes is likely to have embedded sensor arrays, consuming trillions of sensors.

Intel envisioned in 2012 a trillion sensors by 2022, and Cisco by 2020.

The most aggressive forecast was made in 2015 by Foundation for Economic Trends at 100 trillion sensors by 2030.

From the TSensors Summits we found that the demand for ultrahigh volume sensors is being generated by emerged and emerging global economic tides:

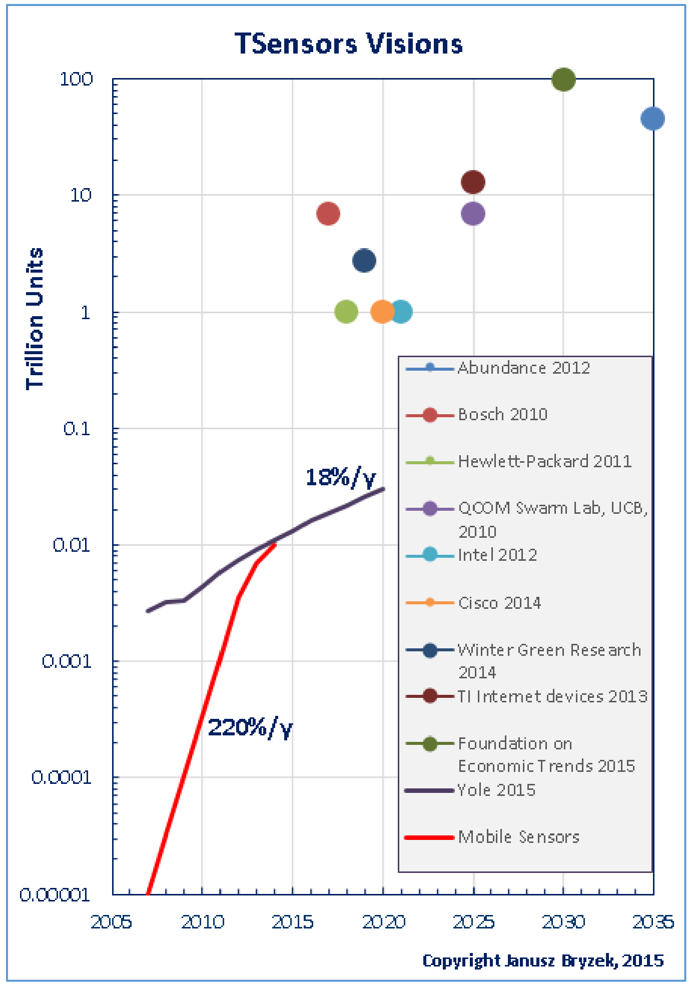


Figure 4. Mobile sensor market explosion from 10 million units in 2007 to 10 billion in 2015 is complemented by a trillion sensor visions.

- **Mobile Market**: which not only created the exponential growth, but also drove multiple technologies to unprecedented price/performance enabling other global tides.
- **Wearable Market**: benefitting from mobile market technologies and creating a foundation for mHealth.
- **mHealth**: an emerging disruptive global health system, leading to Healthcare Abundance, with expected growth from about $1 billion in 2015 to $3.8 trillion 2025 (Peter Diamandis' forecast).
- **Mission Innovation**: an agreement signed in Paris, December 2015 by a large number of countries and 26 billionaires to clean the global environment preventing global warming, leading to Clean Environment and Energy Abundance, with initial funding of $10 to $20 billion.
- **AgTech (Agricultural Technologies)**: the emerging Venture Capital funding trend is increasing funding from $103 million in 2013, to 2.3 billion in 2014 and $4.6 billion in 2015, a stepping stone towards Food Abundance.
- **Internet of Things (IoT)**: emerging tide to connect billions of devices and collecingt related information, leading to IoE. The Internet of Things has the potential to be the engine that powers the global economy for decades to come[14].
- **Internet of Everything (IoE)**: a follow-up tide connecting trillions of things by migrating to disposable products.

- McKinsey forecasts[15] 2025 IoT/IoE at up to $11 trillion,
- GE forecasts[16] that the industrial IoT alone will impact $32.3 trillion of global economy by 2025 (for comparison, 2015 US GDP was $17.4 trillion).

Currently, only about 15 sensor types ship in billions units/year or close to a billion/year. The majority of the trillions of sensors supporting these global tides are expected to be new types, such as:

- 100s of healthcare sensors/person.
- 1000s of sensors in robots' skins.
- 100s of chemical/biological/pollutant sensors in billions of pollution nodes.
- 100s of sensors/person in smart fabrics.
- Trillions of sensors in billions m^2 of eWallpaper.
- Trillions of sensors in disposable packages.
- Trillions of sensors planted with seeds.
- Trillions of sensors in food packages monitoring freshness.

Evolving Sensors Architecture

Individual sensors are expected to evolve to sensor arrays (benefitting from printed sensor technologies), enabling the paradigm shift in defining sensor quality

The current generation of sensors aims at producing accurate data to be transmitting to receiving systems, e.g., 1.5478 g acceleration. Integrated sensor-based systems will have embedded processing, and will be producing information, e.g., "This bridge will collapse in 23 hours". It was shown that accurate information can be derived from inaccurate data when individual accurate sensor is replaced with an array of inexpensive low performance sensors:

- GE showed[17] that an array of printed chemical sensors, each with poor selectivity, can deliver a highly selective chemical sensing information through data processing.
- Princeton University showed[17] that an array of sensors could compensate individual sensor drift, an achievement which is not possible for discrete sensors.

Figure 5. Flir's Boson thermal imaging camera includes a VPU with amazing 2 TFLOPs computational power and 18 Gbps input I/O pipe, enabling to run AI algorithms in real time while consuming only 500 mW.

Implementation of advanced sensor architectures with embedded AI processing is becoming easier, as advanced processors are reaching market. One of the examples could be the Flir Boson[18], Figure 5, the thermal imaging camera, with the Movidius Myriad 2 Vision Processing Unit (VPU), bringing artificial intelligence to thermal imaging products.

Exponential Technologies

Several technologies have been classified by Singularity University as exponential, reflecting their growth. They also have been enabling growth of global goods and services faster than demand, creating a foundation for reaching Abundance in mid 2030s.

Exponential technologies include:

- Computation
- Internet of Things (Sensors & Networks)
- Robotics/Drones
- Artificial Intelligence

- 3D Printing
- Materials Science
- Virtual/Augmented Reality
- Synthetic Biology

Sensors are embedded in most exponential technology applications.

Sampling of cost drop for selected exponential technologies is shows below:

Technology	Cost Drop	Over Time Span of:
Graphene (forecast)	1000x	5 years
DNA Sequencing	10,000x	7 years
DNA Sequencing (forecast)	100x	5 years
Sensors, Lidar	250x	5 years
Sensors, tri-axial Gyroscope	1000x	7 years
Sensors, tri-axial Accelerometer	100x	7 years
Sensors, tri-axial Magnetometer	100x	7 years
Drones	142x	6 years
Neurotechnology	44x	5 years
3D Printing	400x	7 years
Industrial Robots	23x	5 years
Solar Energy	200x	30 years

DNA sequencing is reaching affordability for large group of people, promising to transform medical cure focus into prevention focus. New sensors have enabled markets such as IoT, self-driving cars, robots, drones, solar power. 3D printing is starting its migration into electronics, bringing a potential for unprecedented cost reduction for electronics, enabling e-walls in all buildings.

Solar power could slay the fossil fuel empire by 2030, eliminating the need for combustion engines and all businesses relying on fossils. Superimposed on emergence of new business model car-as-a-service, it is forecasted that global car production will drop 10x (electric only), road and parking utilization will improve 10X, and global pollution will dramatically drop[19]

Emerging graphene promises revolutions in chemical sensing, energy generation and storage.

Computational systems components, such as number of transistors in the CPU, memory size and network speed, are expected to grow 60%/year for the next three decades. Many of new GPUs focus on enabling Deep Learning supporting emerging sensor-enabled AI applications such as self-driving cars, self-flying drones, autonomous robots and complex sensor fusion. For example, Dual NVIDIA Pascal GPUs delivers over 5 TFLOPS and over 24 trillion Deep Learning operations/s[20].

Exponential technologies support solutions to the Global Grand Challenges, and are synergistic with emerging global economic tides such as the Wearable Market, eHealth, Mission Innovation, AgTech, Internet of Things and Internet of Everything.

TSensors Data

Connectivity of “all things” is forecasted to generate a BrontoByte (10^{27}) of sensor data perhaps as soon as 2025[21] (Figure 6).

Such volume creates an unprecedented business opportunity for data analytics, which is forecasted by some to grab between 60% and 90% of global profits in 2025[22], disrupting business models.

Processing of brontobytes will put a strain on IT infrastructure:

- Internet size will need to grow exponentially.
- New localized network layers emerge, Fog and Swarm, enabling offloading Cloud and reduced latency
- There will not be enough programmers to develop algorithms processing Big Data, thus algorithm development will need to shift to Deep Learning.
- Data security will be become one of the critical enablers of growth.
- 5G connectivity brings a promise to connect every spot on Earth.

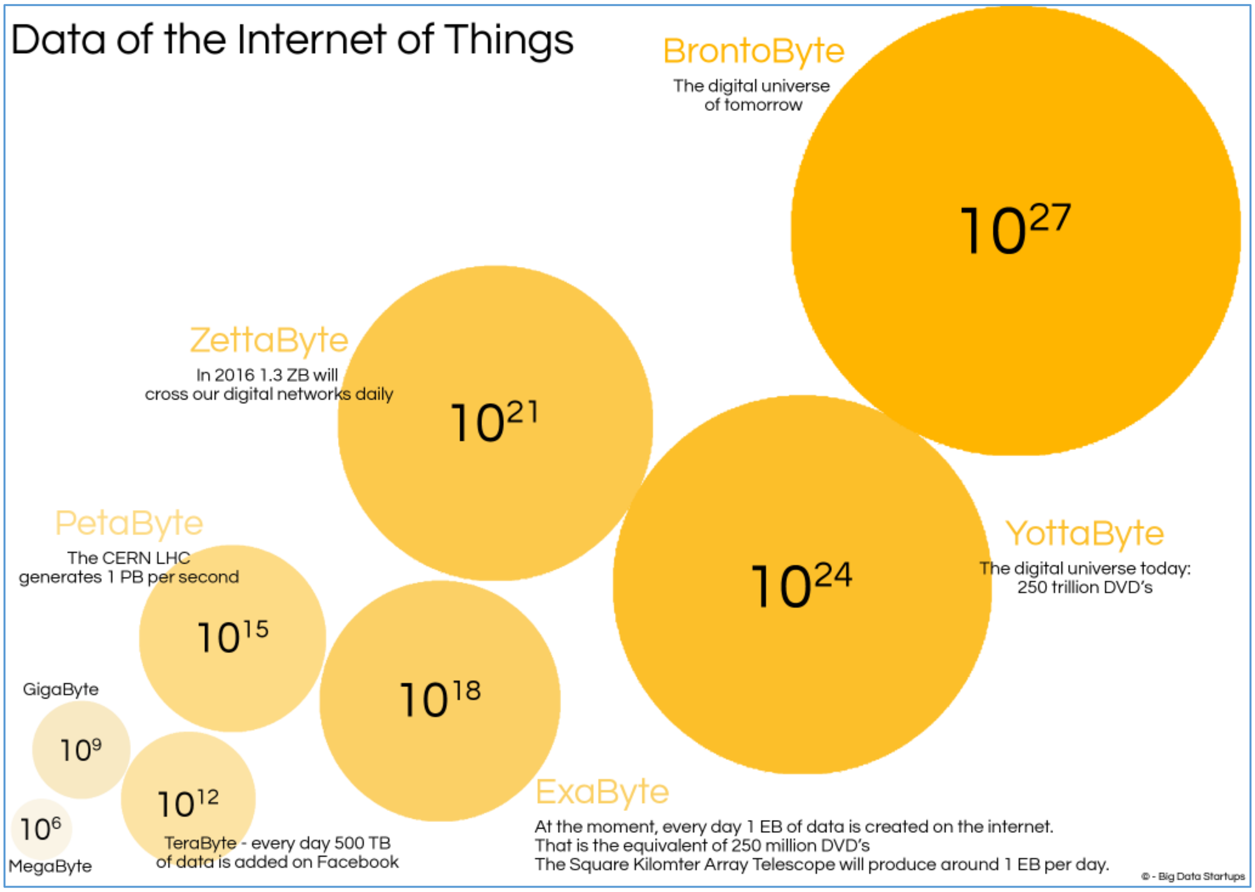


Figure 6. Exponential IoT data scale[21]

One of the biggest concerns in the developed countries with about 2 billion residents is data privacy/security. The recommendation from TSensors Summit is to embed data encryption directly at the sensor, in addition to secondary encryption at the node.

It should be noted that over 5 billion people in less developed countries have not yet been concerned with data privacy/security, potentially enabling a faster path to market for advanced products.

Emerging Organizations Types

Three types of new ultrafast growing organizations for IoT/TSensors economy have emerged:

- Unicorns: fast (1 to 4 years) growth to $1 billion market capitalization.
- Narwhals: fast (1 to 4 years) growth to $1 billion sales.
- Exponential Organizations (ExO), delivering10x faster scaling as compared to their peers.

ExO's are likely winners in the coming decade, and are expected to displace 40% of Fortune 500 companies by 2025.

- Similar to the 2012 Kodak ($28 billion linear photography business) "replacement" by Instagram (13-person exponential photography startup acquired by Facebook for $1 billion).

Growth cycles of exponentially advancing technologies are broken up into the six D phases[23]:

1D - Digitization
2D - Deception
3D - Disruption
4D - Demonetization
5D - Dematerialization
6D - Democratization.

The new business models enabled by such disruption shift revenue and profit generation from hardware to service and information. One of the examples could be a free cellphone in the US, in exchange for a two-year service contract.

The first spectrometric systems analyzing food quality adopted a similar model[24].

Sensor and Surroundings as a Service is another example of emerging business models. VTT presented at the 2015 TSensors Summit a vision of Surrounding as a Service[25], wherein our surroundings such as walls, furniture, beds, cars, etc. will have printed electronics and sensors, enabling the generation of billable information (Figure 7). Such a vision is aligned with the emergence of large area electronics such as eWallpaper and unPad concepts at UC Berkeley[26], with potential demand for trillions of square meters of printed electronics by 2035.

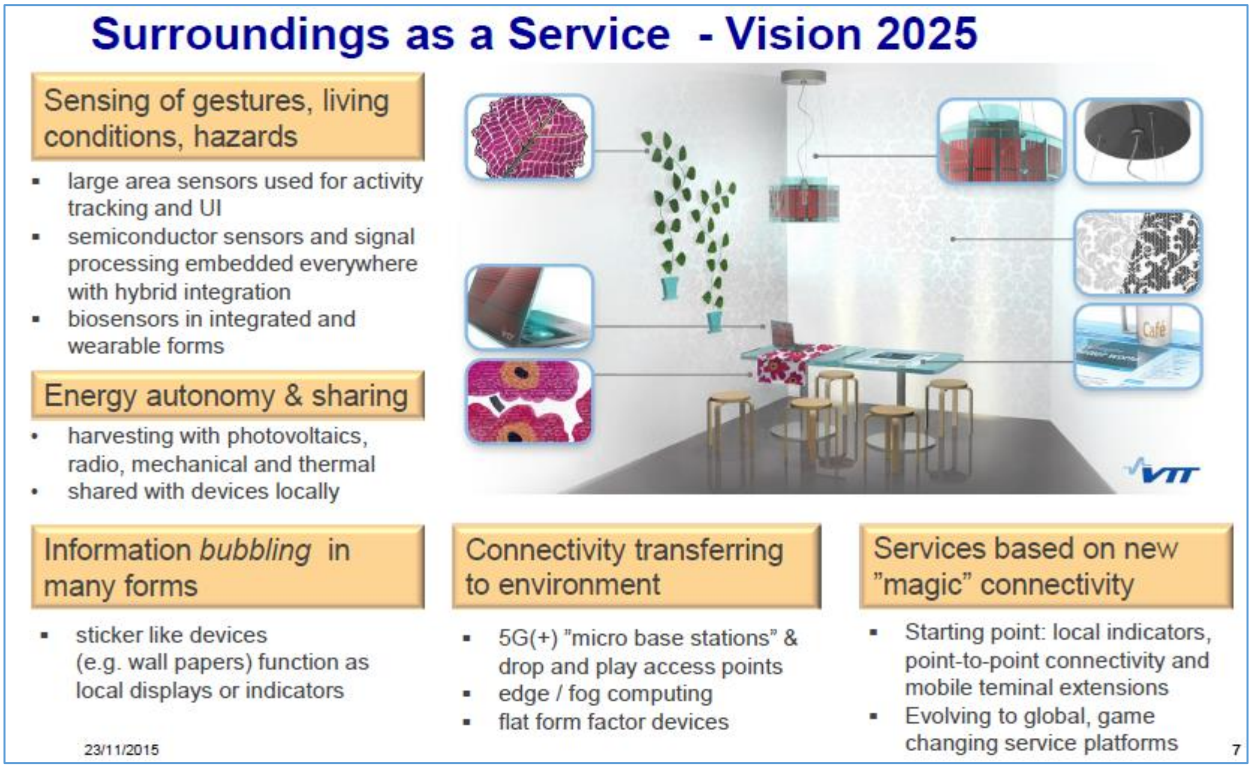


Figure 7. VTT's vision of printed electronics and sensors enabling new business model: surrounding as a service.

Startups can easily adopt new organizational structure. Established linear organization have a much higher level of difficulty to transform their organizations.

- One of strategies deemed successful is a replacement of centralized R&D by a fully autonomous idea lab funded by a linear organization.
- The crazier the ideas the better, with a small percentage of ideas creating potential for big wins, as opposed to focus on every development effort to win in linear organizations.

Security and Privacy

Security and privacy in the connected World becomes an extremely important aspect of deployment of global sensor based systems in developed countries, representing about 2 billion people.

Takeaways from dedicated sessions at TSensors Summits was a message to sensor manufacturers: embed an additional encryption of sensor data before they reach the Internet connected node.

Impact on Jobs

Disruptive economy changes are expected to traumatically affect jobs:

- Robots are forecasted to eliminate 50% of current US jobs by 2025.
- Self-driving cars, trucks, drones, tractors will eliminate millions of jobs.
- Combined with disappearance of 40% of large organizations, the 2025 job loss could reach 100 million in the US, and much more globally.

In parallel, GE forecast for 2025 IoT/IoE at $32.5T, could create 300 million new global jobs, at least 100 million in the US. These jobs, however will be for high tech workers (such as programmers) and thus massive global retraining will be required.

In anticipation of such socially disruptive changes decoupling wages and jobs from growth (Figure 8), new concepts emerge, such as Unconditional Basic Income (UBI)[27], or "money for nothing, or negative tax. In countries as diverse as Brazil, Canada, Finland, the Netherlands and India, local and national governments are experimenting with the idea of introducing some form of basic income as they struggle to overhaul inefficient welfare states and manage the social disruption caused by technological change.

Switzerland voted down in June 2016 the idea of handing out an unconditional basic income of SFr 30,000 ($30,275) a year to every citizen, regardless of work, wealth or their social contribution.

100 People in Oakland will get free money in 2016 as part of a Basic Income Experiment run by Y Combinator[28]. Their tentative plan is to give about 100 people in Oakland between $1,000 and $2,000 per month for between six months and a year, and test its impact. "We're on a trajectory where a lot of jobs are degrading over time in terms of job security and how much jobs are paying. If you extrapolate that going forward, it's going to be a problem. Basic income is a possible solution for those problems." The participants will be selected randomly from across the city but will include people across all economic tiers and will not discriminate between employed and unemployed people.

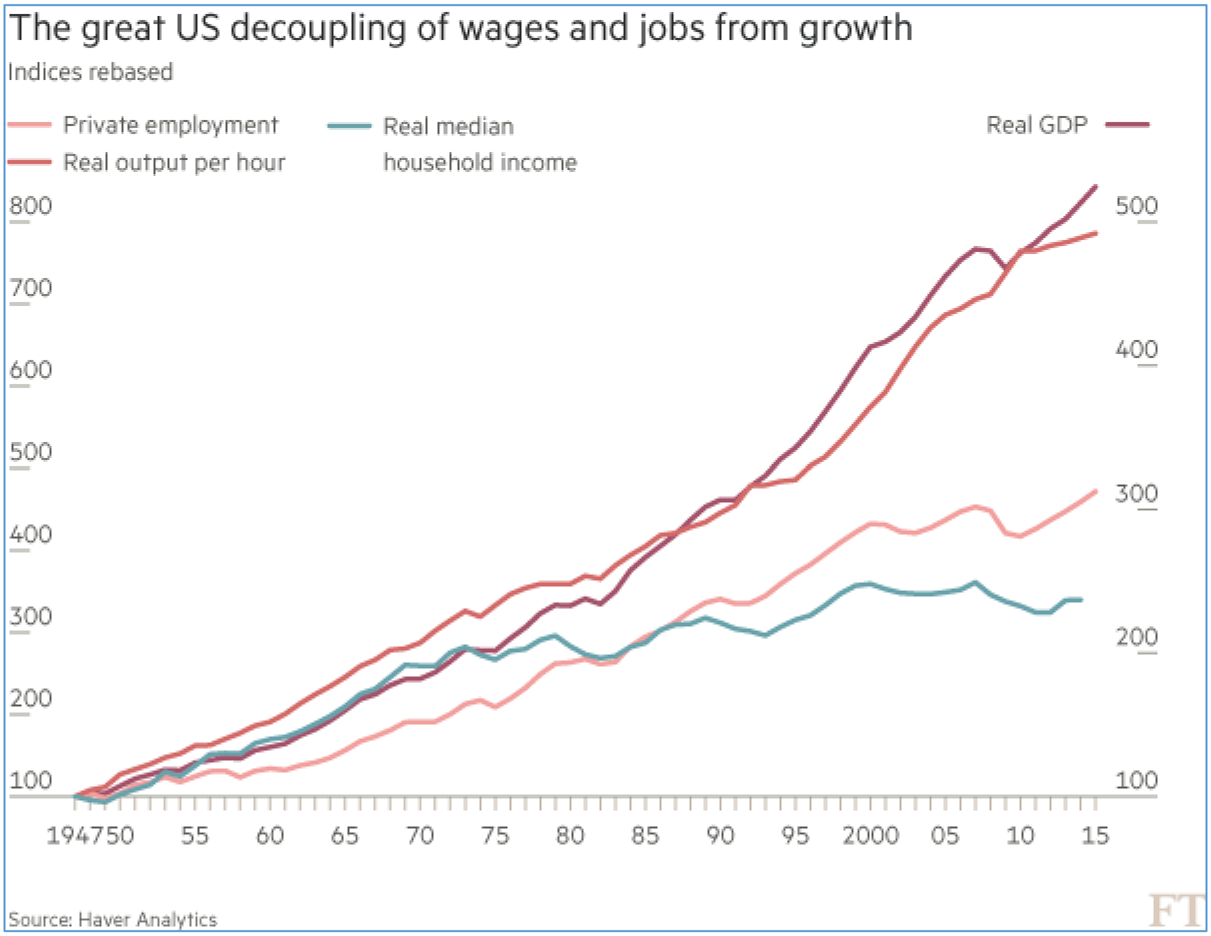


Figure 8. Progress in technology improved workers' productivity and real GDP, but failed to increase real median income over the last two decades[27]. Exponential technologies and emerging global economic tides such as IoT and mHealth will likely compound this trend.

Reviews of Strategic Markets and Technologies for TSensors

Drivers for ultrahigh volume, trillion-unit demand will come from new applications resulting from global economic tides, solving along the way Global Grand Challenges. Many such applications will be launched using disruptive business models, many expected to provide hardware for free, and monetizing from extracting relevant information through Data Analytics.

Reviews of Strategic Markets and Technologies for TSensors will include white papers from global leaders presenting emerging enabling technologies focused on six applications:

- TSensors and MEMS for Energy Generation and Conservation
- Enabling Sustainable Solutions for the Global Environment through Novel Sensing
- Food and AgTech
- Unobtrusive Health Monitoring
- Disaster Resilience: Monitoring of Global Disasters and Aging Infrastructure
- Large Area Electronics: Printed Sensors, Transistors, Displays and Power Sources

The objective of Reviews is to provide an easy introduction to emerging technologies representing a foundation for largest sensor related business opportunities in coming decade. The expectation is that they will accelerate partnerships between developers and commercialization companies.

Overview of the white papers target directions for these Reviews are summarized on the following pages.

TSensors and MEMS for Energy Generation and Conservation

We are facing the lack of energy for all people on Earth, compounded by a growing population and improved global standards of living.

Generation of energy is a major contributor to global pollution and warming. Cleaning the existing energy generating plants requires a massive deployment of distributed closed control loops, based on information from sensors.

An additional global problem is low efficiency of devices receiving energy, as the majority is operating in an open loop. Sensor based closed loop system can significantly improve their efficiency. One example could be the control of the automotive combustion engine, increasing the average car fuel efficiency from 10 mpg in 1974 (open loop), to 27.5 mpg in 1997 (forced by US Government mandate CAFÉ[29]), to forecasted improvements to 54.5 mpg by 2025 (new CAFÉ). Such dramatic efficiency improvement was possible mainly due to massive deployment of new sensors enabling a closed loop system operation.

On a global scale, improved energy efficiency is a major stepping stone towards green environment.

While many sensor-based applications in this sector will not reach trillions, their impact on the Earth justifies including them in TSensors Visions.

Ultrahigh volume sensor/MEMS applications in energy sector include:

- Monitoring energy flow through every power socket (IoE), to enable efficient energy management.
- Monitoring energy grid delivery and disruption prevention.
  - E.g., GE showed a demo system in Canada monitoring 300,000 power transmission line poles, each including 30 sensors (temperature, light, wind speed, snow fall, rain fall, proximity to trees, bending of transmission wires, etc.).
  - GE's Predix software processes sensor data in real time using AI, to early predict potential energy delivery disruptions and their bottom line impact. The outcome: dispatching maintenance crews to fix problems before failure occurs.
- Improving energy efficiency of all processes generating and using energy.
  - There are trillions of energy using and generating devices on Earth, such as engines, compressors, turbines, heaters, etc.
- Monitoring terrorist threats may be an accelerator for deployment a new generation of energy security sensors.
- Energy harvesters and storage devices to power trillions of IoT nodes and billions of wearables and mobile devices.
  - Integrating energy from multiple energy domains, such as light, kinetic, thermal, RF, wind, fuel cells and nuclear.
  - To enable deployment, new more efficient technologies are needed.

TSensors Enabling Sustainable Solutions for the Global Environment through Novel Sensing

Global pollution not only threatens human's future, but also creates massive health problem for the current generation. Global pollution monitoring seems to be positioned for massive adoption of TSensors:

- US Government agencies track pollution by about 1000 sensed chemicals, biological agents and pollutants in air, water and soil.
  - This is a likely target for incorporation in the global pollution monitoring node.
  - There will be a need for billions of such nodes located on buildings, ships, cars, road signs, etc.
- Monitoring terrorist threats may be an accelerator of deployment for global pollution monitoring nodes.

Mission Innovation[30] launched in December 2015, supported by 175 nations and 26 billionaires is receiving a starting fund of $10 to $20 billion to reduce global warming. Such reduction is possible only when the pollution level is monitored and acted on.

One of the first approaches to create a foundation for a global pollution map was undertaken by Aclima and later in cooperation with Google. Aclima's pollution monitoring sensors are located on Google cars driving daily on two Silicon Valley highways, creating a pollution map (Figure 9). A Global pollution map would require perhaps trillions of nodes, each with 100s of pollution sensor types.

It is expected that pollution mapping will include air, water and soil, and will provide a chemical pollution, biological pollution and particulate pollution map

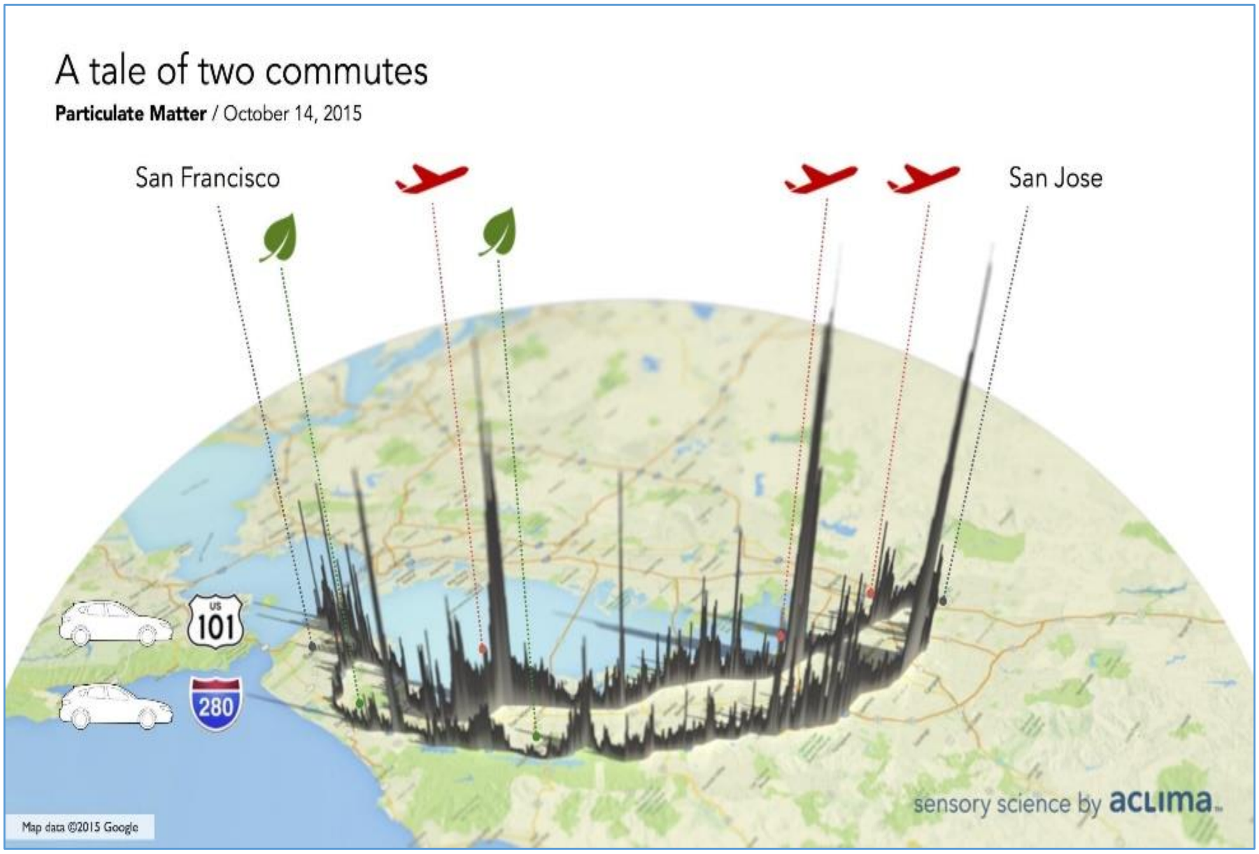


Figure 9. Aclima is generating 500B pollution measurements daily on two highways in Silicon Valley using Google cars, creating a pollution map. Global pollution map would need respectively more data…

TSensors for Food and AgTech

The World's population is projected to grow from 7 billion today to 9 billion by 2050. Hunger is one of the global problems that needs to be solved to reach Abundance.

The United Nations Food and Agriculture Organization estimates that about 795 million people of the 7.3 billion people in the world, or one in nine, were suffering from chronic undernourishment in 2014-2016. Almost all the hungry people, 780 million, live in developing countries, representing 12.9 percent, or one in eight, of the population of developing counties.

Black et.al[31] (2013) estimate that undernutrition in the aggregate—including fetal growth restriction, stunting, wasting, and deficiencies of vitamin A and zinc along with suboptimum breastfeeding—is a cause of 3.1 million child deaths annually or 45% of all child deaths in 2011.

UN believes that food production will have to increase by 70% in the next 35 years to prevent widespread hunger.

Farming is not very efficient. It takes 10 calories of oil to produce 1 calorie of food and uses 70% of the water on the planet. Irrigation systems pumped our reservoirs dry, global warming reduces arable land, creating dust bowls. Toxic herbicides and pesticides destroyed our water ways. Runoff from nitrogen-laden fertilizer turned our coastal waters into dead zones.

Food production per acre increased 2.2 times between 1961 and 2011, but productivity flattened due to lack of new improvements.

Fishing: bottom trawling destroys about 6 million square miles of sea floor every year. At current pace, the world would run out of seafood by 2048.

New farming technologies emerge, such as vertical farming, hydroponics (growing plants in water, 70% more efficient than traditional agriculture), aeoroponics (growing plants in air delivering food through nutrient rich mist, 70% more efficient than hydroponics), and conversion of annual crops to perennials

Cloud farming has emerged, with Big Data analysis of sensor data increasing crop yields by helping famers make better decisions about when to plant, manage and harvest their crops. E.g., Climate Corporation (founded by two ex-Google employees and acquired by Monsanto in 2013 for $1.1B) operates a cloud-based system including:

- Weather measurements from 2.5 million locations every day.
- 150 billion soil observations from hyperspectral sensors on satellites.
- Generating 10 trillion weather simulation data points, to provide temperature, rain and wind forecasts for 200 acre lots, for the forthcoming 24-hour and seven-day periods.
- The system also uses weather data from the past few months and the last 30 growing seasons to provide yield estimates for crops in individual fields.

Nanotechnology is expected to help us grow more food using less energy and water[32].

Wireless sensor arrays monitoring health, feeding and location of poultry, cattle and fish represent another large TSensors market.

In-vitro (Cultured) meat emerged, grown from stem cells, pioneered by NASA in late 1990s.

- Less vulnerable to emerging diseases, 70% of which come from livestock.
- Eliminates fatty acids, thus no contribution to heart disease.
- Eliminates problems and inefficiencies related to livestock.

All these new technologies will need massive deployment of sensors, such as light, moisture, temperature, PH, hyperspectral, chemical, nitrogen, phosphorus, potassium, nutrient flow, soil type, root development, color, plant biology, biosensors, plant genome sequencing, AI, robotics, drones, etc.

One of the emerging ultrahigh volume sensor application is planting seeds with sensors and actuators[33] to monitor temperature, root sizes to optimize watering, nutrients, etc. (Figure 10).

Figure 10. Heating roots to optimum temperature enables dramatically improved crops yield.

New Venture Capital space emerged: AgTech (Agricultural Technology). It attracted $103M in 2013, $2.4B in 2014 and $4.6B funding in 2015.

In parallel, about 25% of household food in developed countries is wasted due to "use by" label on trillions of food packages. Additionally, 10% to 15% of food is spoiled during transportation. This is huge and could be prevented by sensors, if every food package had food freshness and shipping condition monitors. Printed sensors for such applications were demonstrated at multiple centers, e.g., at VTT[34] (Figure 11) and UC Berkeley[35] (Figure 12).

Figure 11. Printed food freshness sensor from VTT, communicating through RFID link.

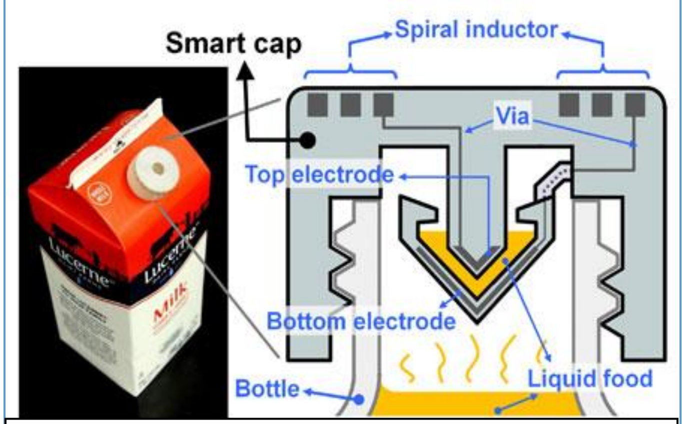


Figure 12. Example of printed sensor monitoring milk quality.

TSensors for Unobtrusive Health Monitoring

The objective of eHealth is to empower billions of people to become CEO's of their own health, democratizing healthcare, improving its quality, enabling the shift of healthcare to prevention, and dramatically reducing healthcare cost. This represents a stepping stone towards Abundance, the future world with healthcare for all.

The experience from health and fitness sensing using wearable devices shows that their use drops sharply in the first months whenever the user needs to perform even one operation a day, such as pushing a button or charging.

Unobtrusive health sensing is defined here as automated collection of person's health data without user's action, supplemented by occasional testing requiring user's involvement (such as medical imaging). The concept is shown in Figure 13.

The focus of this Review is on consumers, not medical professionals. Approximately 2 billion of consumers live in countries with strong medical regulations, and about 5 billion in countries with loose or no medical regulations. As regulatory organizations are slow to approve new technologies, the proposed strategy is to focus on bringing to market advanced health sensors without considering approvals by regulatory organizations, e.g., FDA in the US, to help billions people earlier, then focus on approvals in regulated countries.

This implies a need for manufacturing operation in non-regulated countries for products which require such approvals in regulated countries.

The only easily accessible infrastructure to billions of people is mobile technology supported by Cloud/Fog/Swarm networks. It is envisioned that an array of sensors will be connected to nodes communicating either with mobile devices which will communicate with Cloud/Fog/Swarm networks or directly to Cloud/Fog/Swarm networks (Figure 10).

Sensor output data will need to be in a standardized format to be transferred to such networks, to enable personal health data storage and Data Analytics.

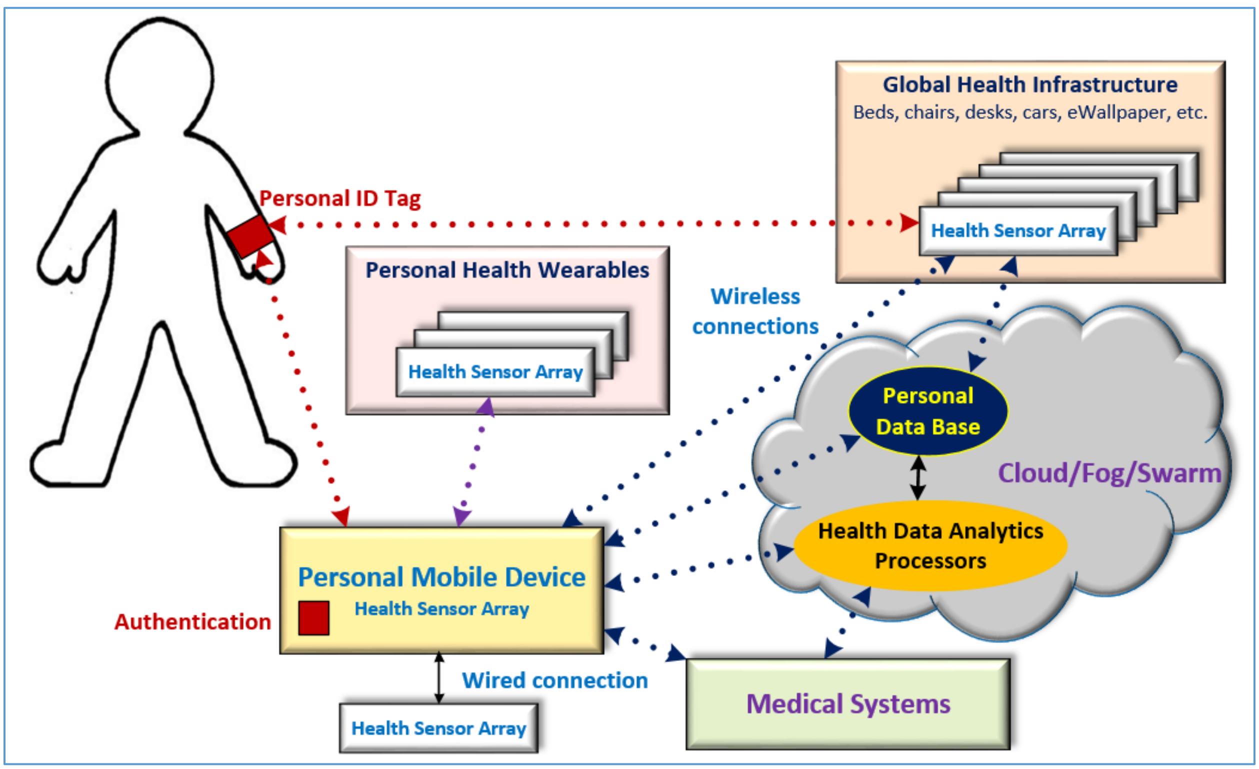


Figure 13. Initial concept of the Unobtrusive Health Monitoring System (UHMS).

- Personal ID tag and/or mobile device's authentication enable access to a Personal Data Base following the person throughout the world.
- Health data could be collected by multiple sensor arrays:
    - Embedded in a personal mobile device
    - Wired to a personal mobile device
    - Deployed in personal wearables wirelessly connected to personal mobile device.
    - Deployed in global health infrastructure (e.g., chairs, walls, cars) wirelessly/Wi-Fi connectable to a personal mobile device and Personal Data Base.
- Health data processing could be in the Cloud/Fog/Swarm, possibly accessing dedicated services such as IBM's Dr. Watson or Samsung's SAMI, with results mirrored on a personal mobile device.
- Processed data would be available to individuals and medical systems (e.g., doctors).

Preliminary list (to be updated by authors) of unobtrusive health sensing categories:

- 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

To enable unobtrusive health monitoring, sensors will need to be embedded in the surrounding environment, such as:

- Wrist watches
- Wearables
- Mobile devices
- Furniture (beds, chairs, tables, desks, etc.)
- Mirrors
- Toilets
- Clothing, shoes
- Walls, floors
- Etc.

This implies a need for strategic partnerships between sensor and smart products manufacturers.

Embedding sensors with surrounding infrastructure mirrors the emerging Large Area Electronics, such as unPad and eWallpaper efforts at UC Berkeley[36].

An example of unobtrusive health monitor could be Waze Mirror under development by eleven European R&D centers (Figure 14).

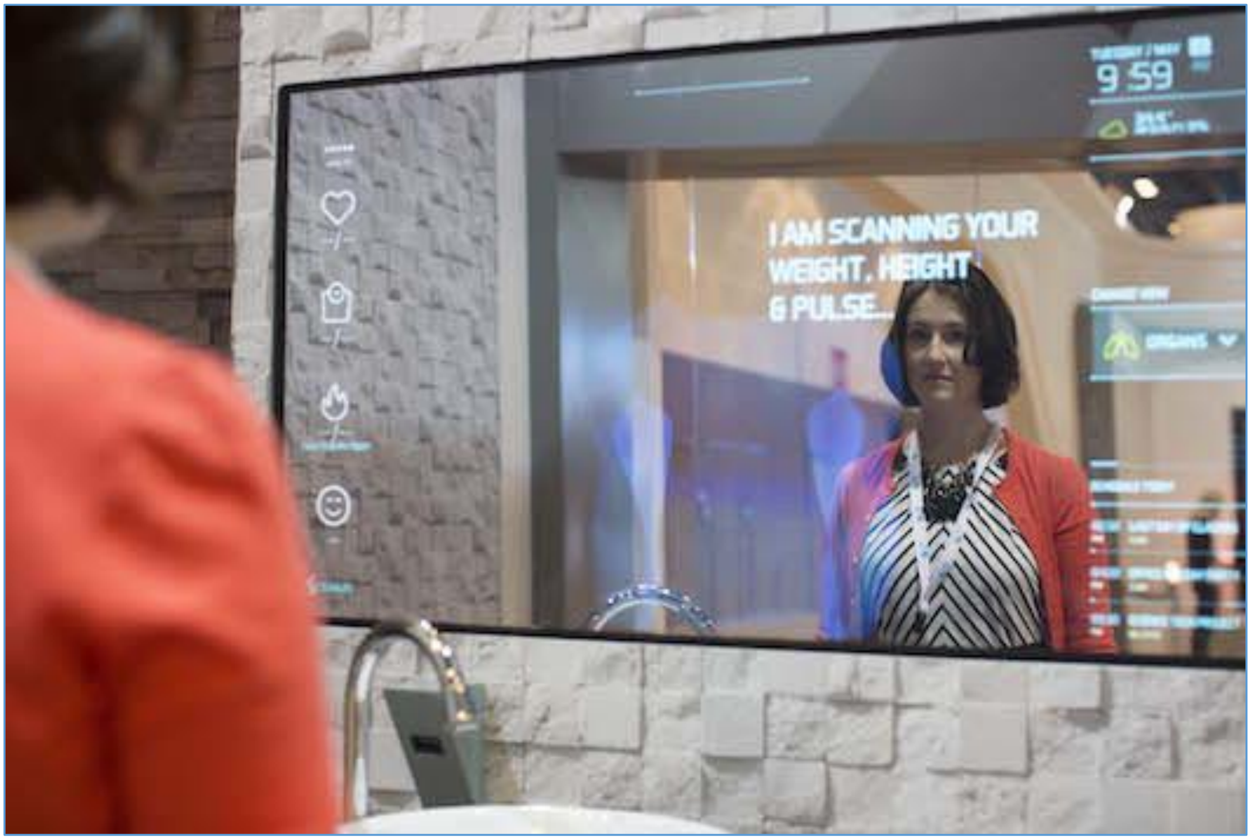


Figure 14. Wize Mirror. Embedded in mirror are 5 hyperspectral cameras, gas sensors and 3D scanners to extract heart rate, hemoglobin, cholesterol, sugar level, weight gain/loss, O2, stress/anxiety and breath gases, and producing daily health score.

TSensors for Disaster Resilience: Monitoring of Global Disasters and Aging Infrastructure

Natural disasters (earthquakes, hurricanes, tsunamis, landslides, etc.) between 1994 and 2014 claimed 1.35 million lives. The cost of global natural disasters since 2000 was about $3 trillion.

Economic loss in the US alone due to aging infrastructure (roads, bridges, buildings, etc.) between 2014 and 2020 is estimated at $1.1 trillion.

Global monitoring of all these threats is the foundation for deployment of preventive measures.

2015 Hitachi's TSensors presentation estimated the need for 1.4 trillion sensors by 2025 to support the emerging global monitoring needs. For such monitoring, large number of existing sensor types could be used, provided their cost would support a trillion node deployment. Selectively, new sensor types will be needed to support new requirements, such as landslide sensing.

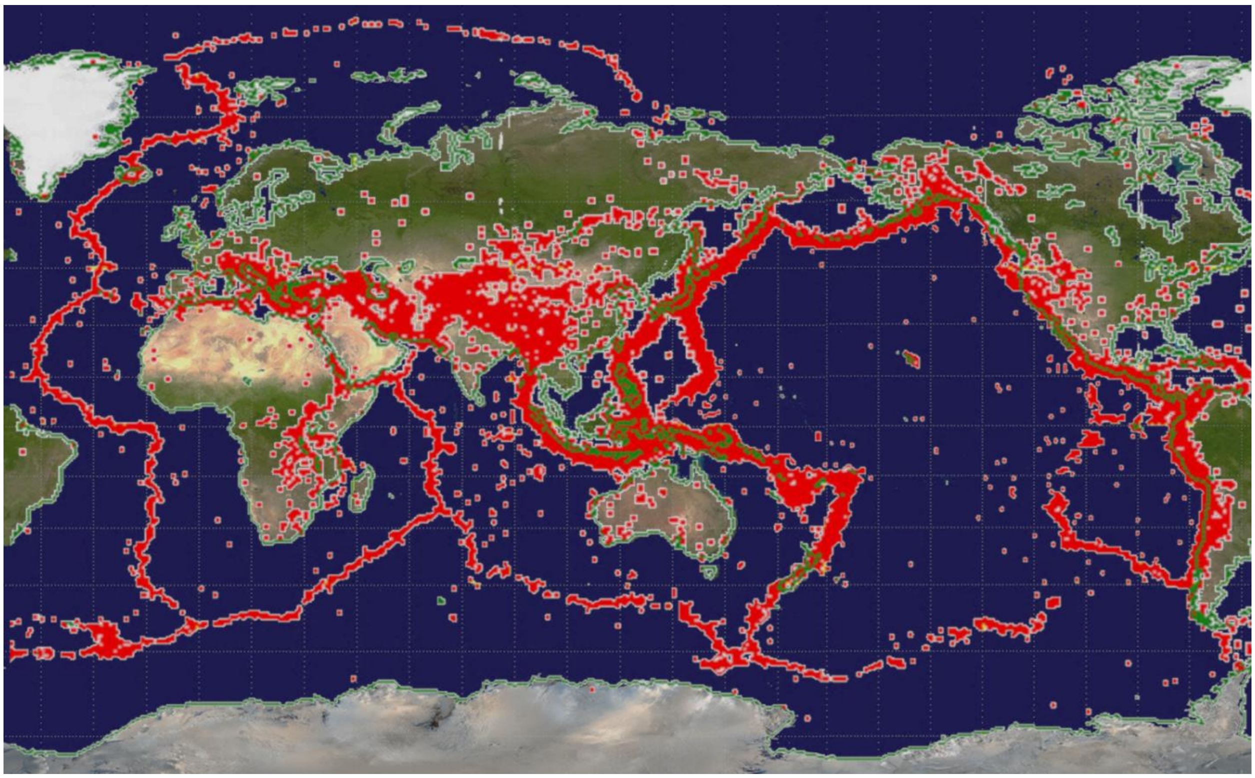


Figure 15. Global map of earthquakes (courtesy of Omron). Deployment of global monitoring systems for earthquakes and other disasters would enable early warning dramatically reducing their destruction.

Large Area Electronics: Printed Sensors, Transistors, Displays and Power Sources

Solutions for Global Grand Challenges are expected to represent extraordinary exponential business opportunities in the coming decade, possibly the largest in history.

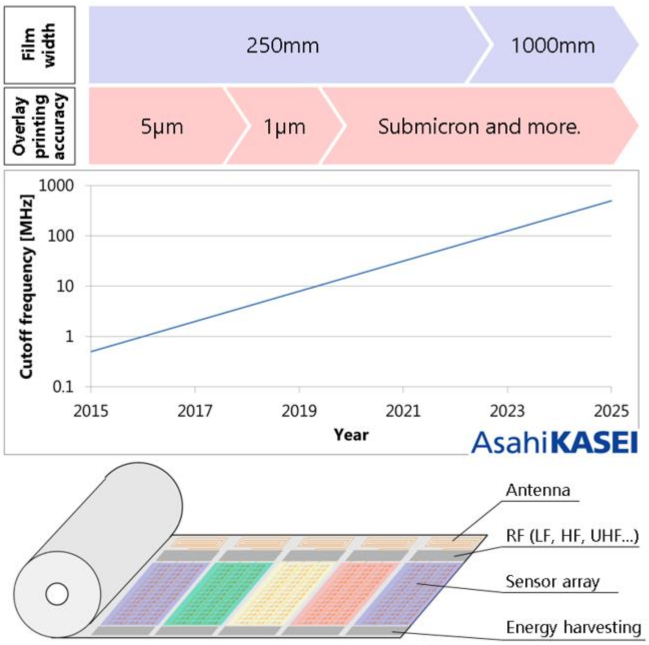
Currently projected GDP for 2035 is around $140 trillion. Assuming that 28 trillion connected nodes will be required to enable solutions for global challenges, and the available budget would be 20% of GDP, or $28 trillion, the cost of a connected node should be about $1. Such nodes may include the array of sensors and actuators, processor, communication, software and energy source.

TSensors Initiative data indicate that the only technology capable of supporting such a level of pricing is printed electronics, wherein all required components would be printed roll-to-roll, similarly to newspapers.

Printed electronics is one of exponential technologies, believed to be currently in a deceptive phase of the 6D process of exponential technologies evolution (the next phase should be a "disruption").

Current commercial printed transistor technology is at the 5um node[37], representing about 40 years lag behind semiconductor transistor technologies. Multiple organizations are now targeting development of submicron roll-to-roll transistor technologies.

One of the most advanced commercial roadmaps for printed electronics was presented by Asahi Kasei at the 2015 TSensors Summit (Figure 16). The company has already demonstrated 250 nm transistor technology, and developed a plan to release by 2025 perhaps 100 nm commercial process node operating at about 1 GHz, integratable with sensors and energy harvesters, printed on 1-meter-wide rolls.



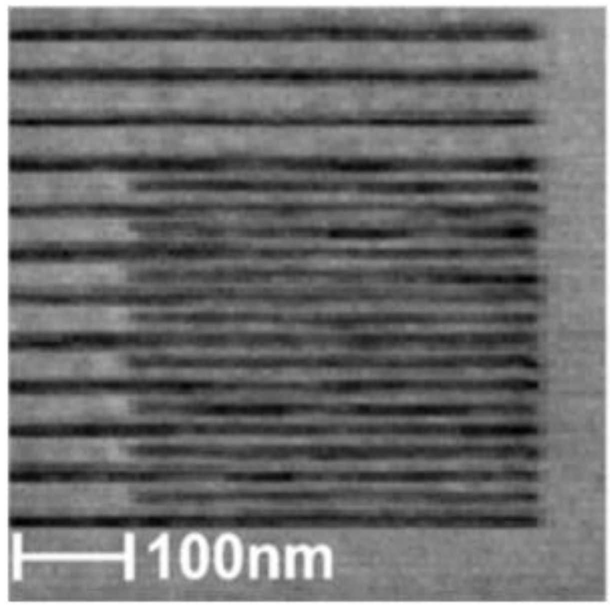


Figure 16. Asahi-Kasei printed electronics roadmap.

Figure 17. 10 nm lines printed by NanoFrazor[38].

The most advanced printed technology was demonstrated by IBM Zurich using Nano Frazor printer from Swiss Litho Ag[38] (Figure 17). IBM planned to demonstrate GaAs and graphene transistors based on this technology in 2015. This development would eliminate the gap between wafer-based and printed transistor technologies.

Multiple organizations are developing printed sensors and energy sources. GE presented (at TSensors Summit Orlando) a plan for 10 trillion roll-to-roll printed chemical and bio sensor arrays in 2025 (Figure 18). GE introduced a novel concept of multivariable sensing, enabling system performance improvement by two orders of magnitude, and disruptively overcoming insufficient reliability of existing printed sensors.

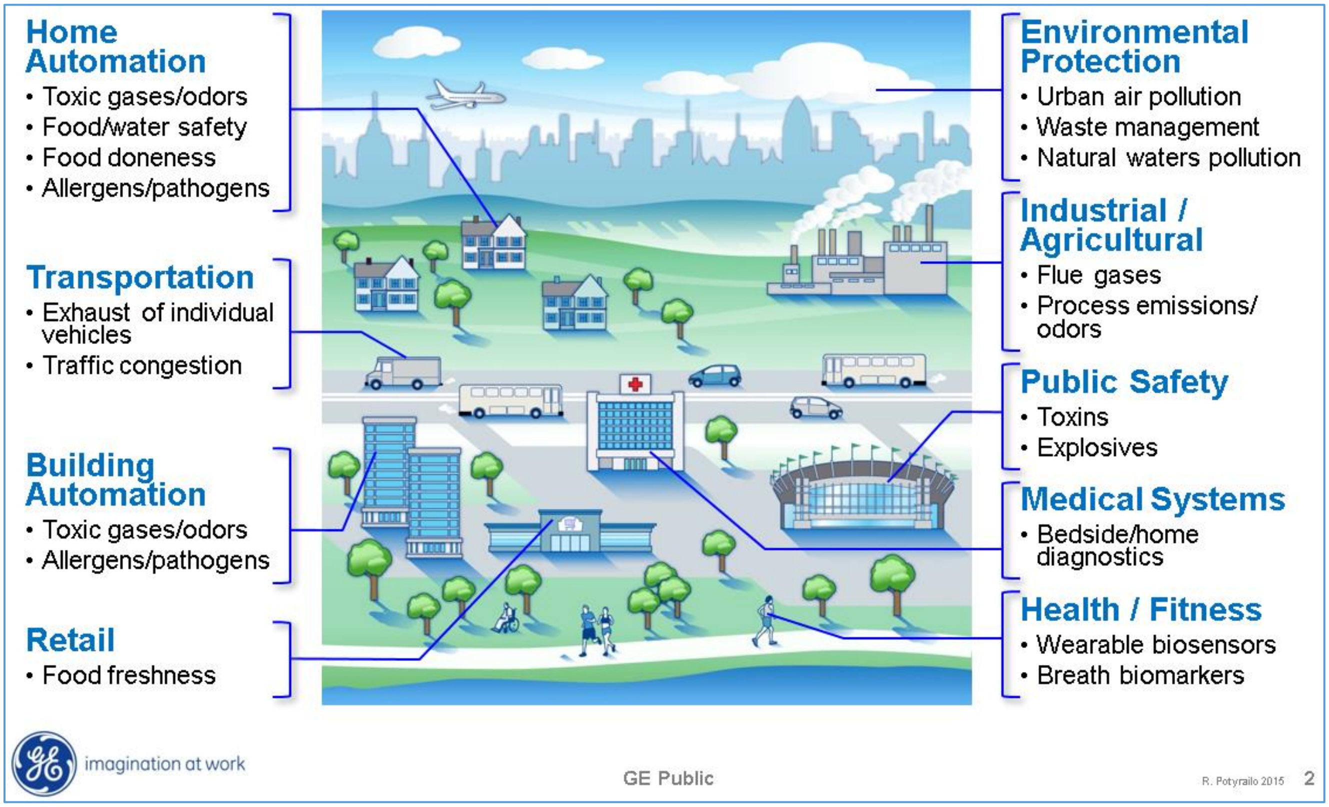


Figure 18. GE's vision for markets capable absorbing 10 trillion printed chemical and biomedical sensor arrays.

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