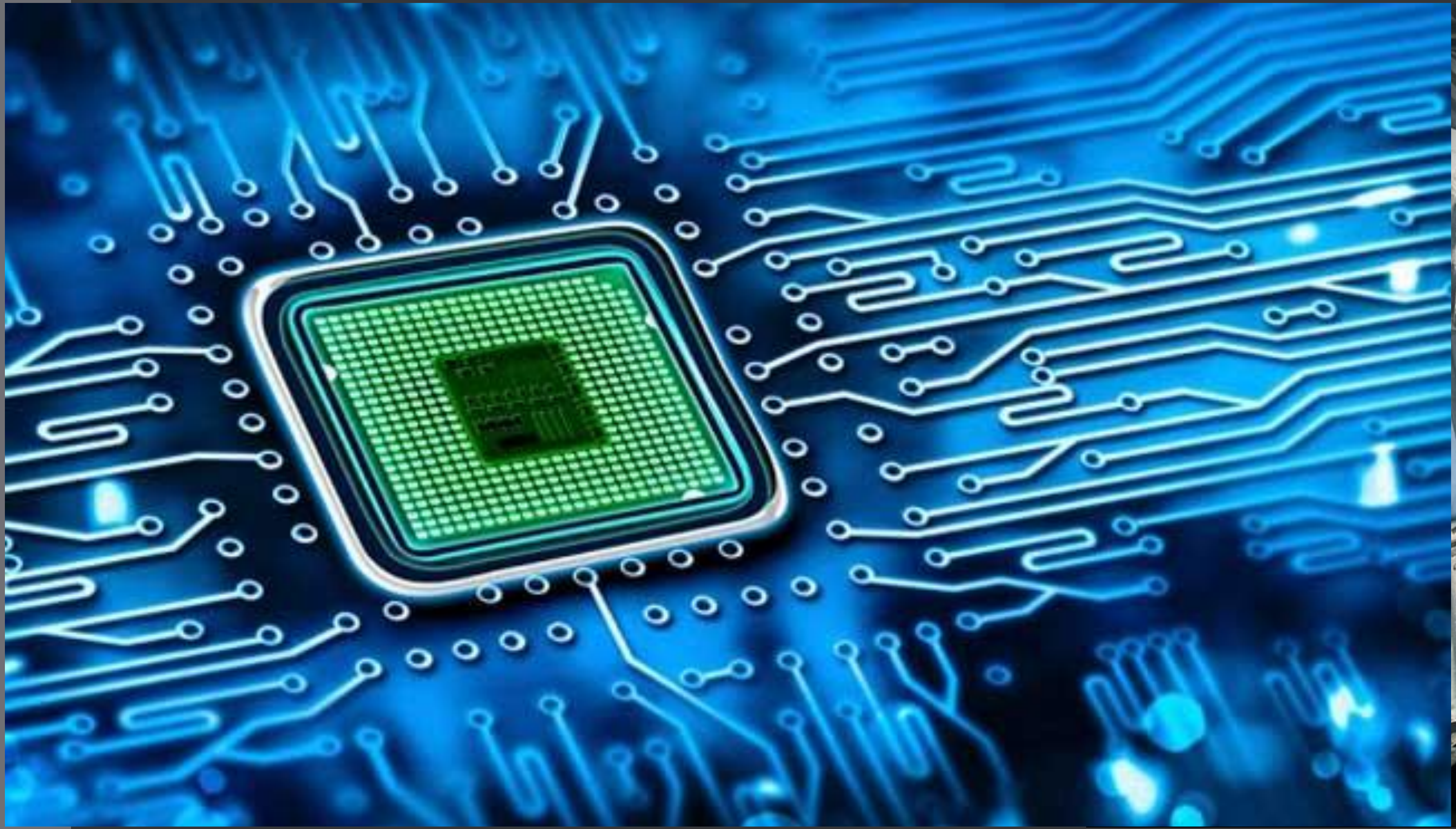
Almost there... what's next?



Adrian M. Ionescu, EPFL, Switzerland @ Euronanoforum, June 12th, 2019

Outline

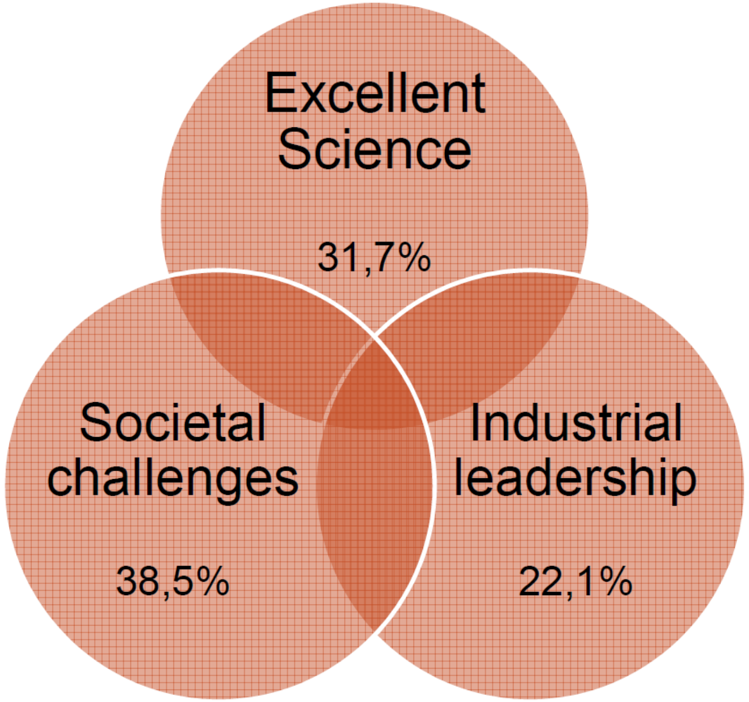
- From H2020 to **Horizon Europe**: Technologies for Global Challenges with Economic & Societal Impact
- **Nanotechnology**, Iphone, Guardian Angels, Energy Efficiency, 3D chips…
- Future technologies for **Edge Artificial Intelligence**
- Health EU initiative: a Revolutionary Integrative Technological Platform for P3 Healthcare to shape future missions in **Digital Healthcare**
- Conclusions

Horizon 2020

- Horizon 2020 is/has been the EU's biggest ever programme for research and innovation.
- 3rd largest programme after Structural Funds and Common Agricultural Policy.
- € 79 BN funding for 2014-2020

Carlos Moedas,
Commissioner for Research,
Science and Innovation.

Robert-Jan Smits,
Director-General,
Directorate-General for Research and Innovation,
European Commission.



Covers the whole value chain :
From blue sky research to near to market innovation activities.

Mid-term evaluation of H2020

KEY STRENGTHS OF HORIZON 2020 AT MID-TERM

- **An attractive, simplified and well-performing programme**, highly relevant for stakeholders and societal needs.
- On track to deliver **value for money** and **to meet its knowledge-creating objectives**.
- Strong **EU Added Value** through unique collaboration opportunities, competition & access to new knowledge.

Yes, almost there!

KEY AREAS FOR IMPROVEMENT IDENTIFIED

- **Underfunding:** Has lower success rates than FP7, especially for high quality proposals, which constitutes a waste of resources for applicants and of good proposals for Europe.
- **Support for market-creating innovation:** Demonstrates potential for breakthrough, market-creating innovation, but it could be strengthened substantially.
- **Outreach to civil society:** Could better communicate the results and impacts of R&I for society, and involve users & citizens more in the agenda-setting & implementation (co-creation).

Features of coming HORIZON EUROPE

Horizon Europe is proposed as the most ambitious research and innovation funding programme ever: a budget of **€100 billion for 2021-2027** for Horizon Europe and the Euratom Research and Training Programme.

- Strengthen EU science and technology thanks to increased investment in highly skilled people and cutting-edge research;
- Foster the EU's industrial competiveness and its innovation performance, notably supporting market-creating innovation via the European Innovation Council and the European Institute of Innovation and Technology;
- Deliver on the EU's strategic priorities, such as the Paris Agreement on climate change, and tackle global challenges that affect the quality of our daily lives.

HORIZON EUROPE: what's new?!

Support breakthrough innovation →	European Innovation Council
Create more impact through mission-orientation and citizens' involvement →	EU-wide R&I missions
Reinforce openness →	Open science policy
Rationalise the funding landscape →	New approach to Partnerships
Reduce administrative burden →	Simpler rules

Pillar 1
Open Science

- European Research Council
- Marie Skłodowska-Curie Actions
- Infrastructures

Pillar 2
Global Challenges and Industrial Competitiveness

Clusters
- Health
- Inclusive and Secure Society
- Digital and Industry
- Climate, Energy and Mobility
- Food and natural resources

Joint Research Centre

Pillar 3
Open Innovation

- European Innovation Council
- European innovation ecosystems
- European Institute of Innovation and Technology

Strengthening the European Research Area

- Sharing excellence
- Reforming and Enhancing the European R&I system

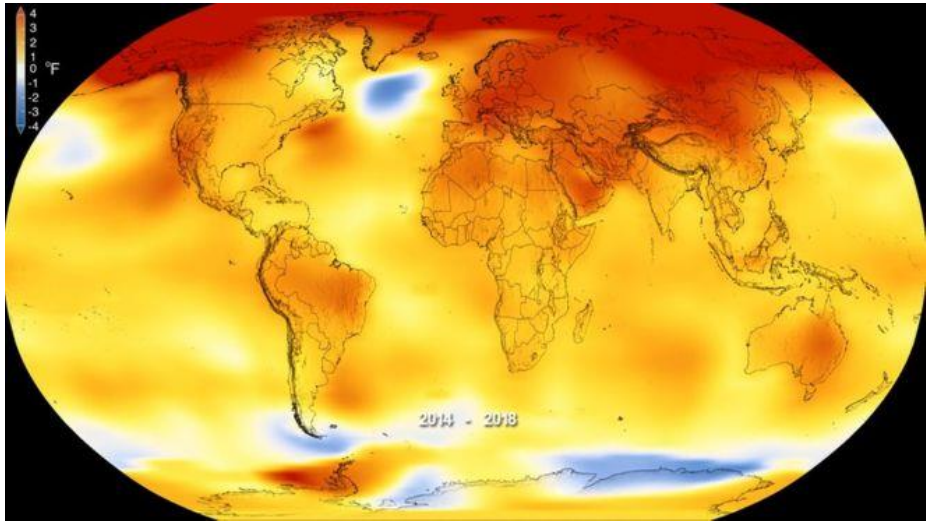
More than almost there!

Missions for global challenges.

Why the European Commission wants missions?

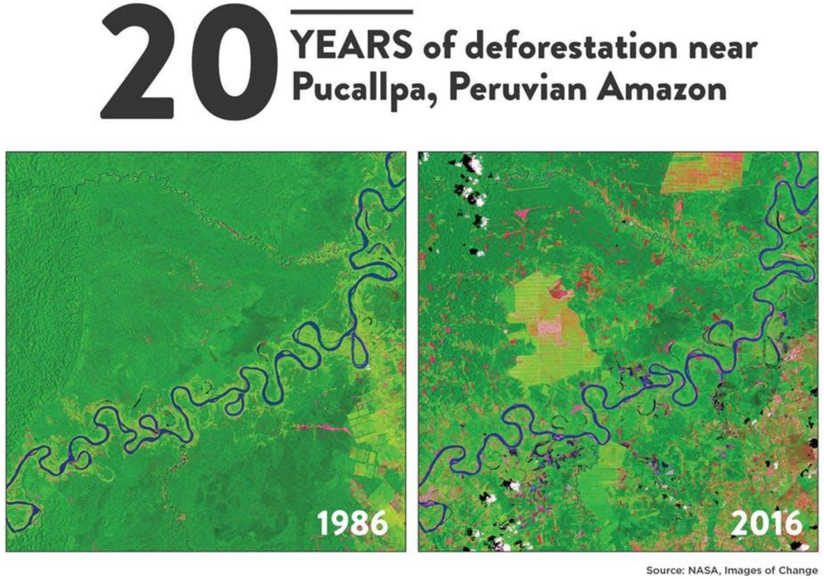
Answer: we need responsible excellent research to better address global challenges for humanity in 21st century.

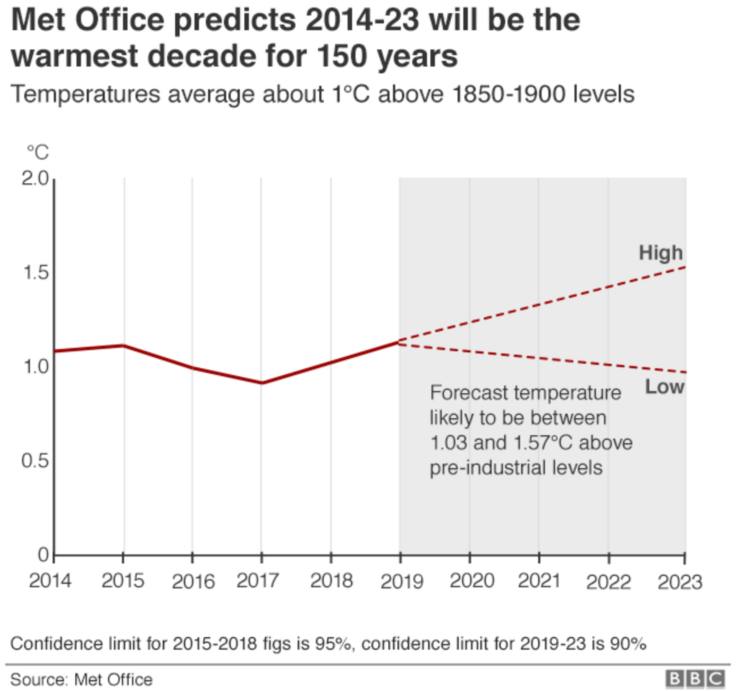
Global Challenges for Humanity in 21st Century



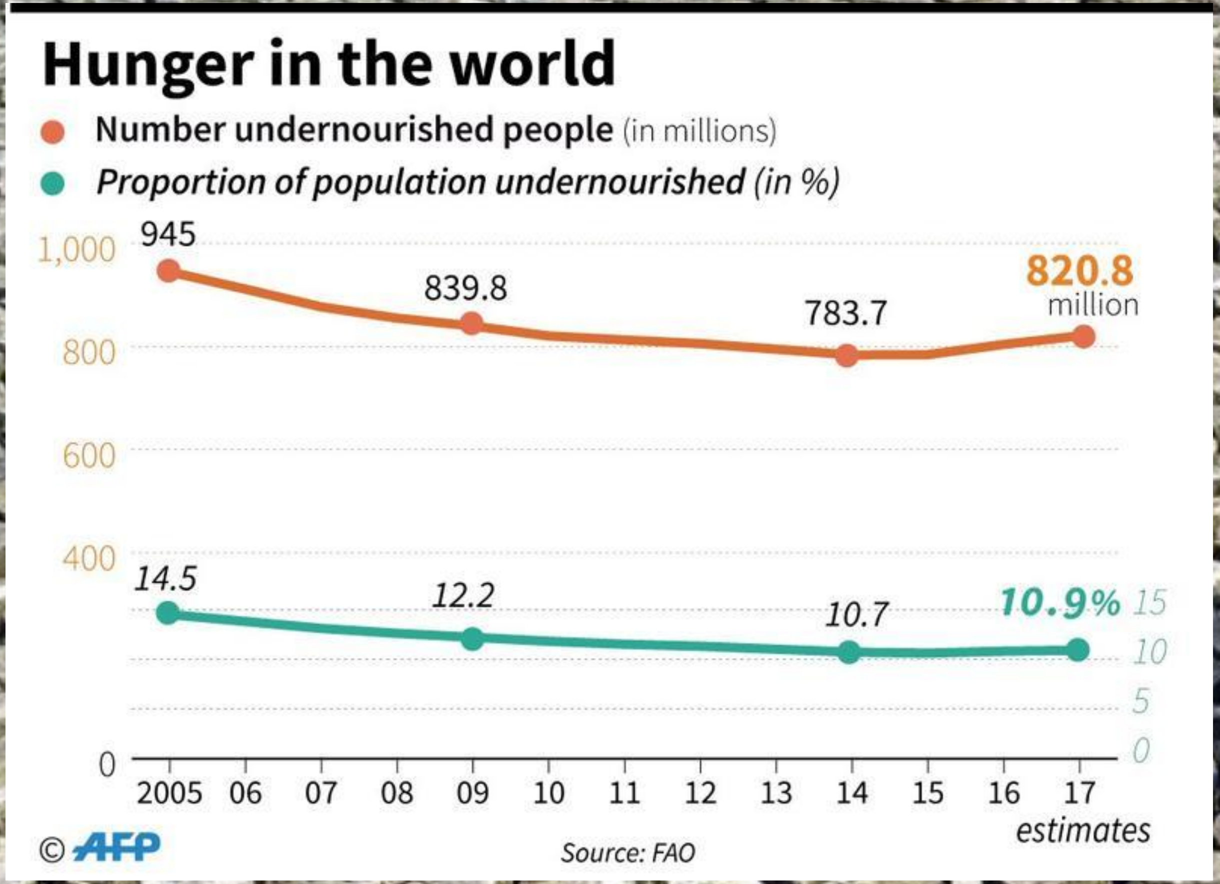
1. Climate Change

Greenhouse gas emissions must be drastically reduced within the next decades to stay within 1.5°C of warming above pre-industrial levels and avert the worst impacts of climate change.





Climate change: amplifier of depleted resources…



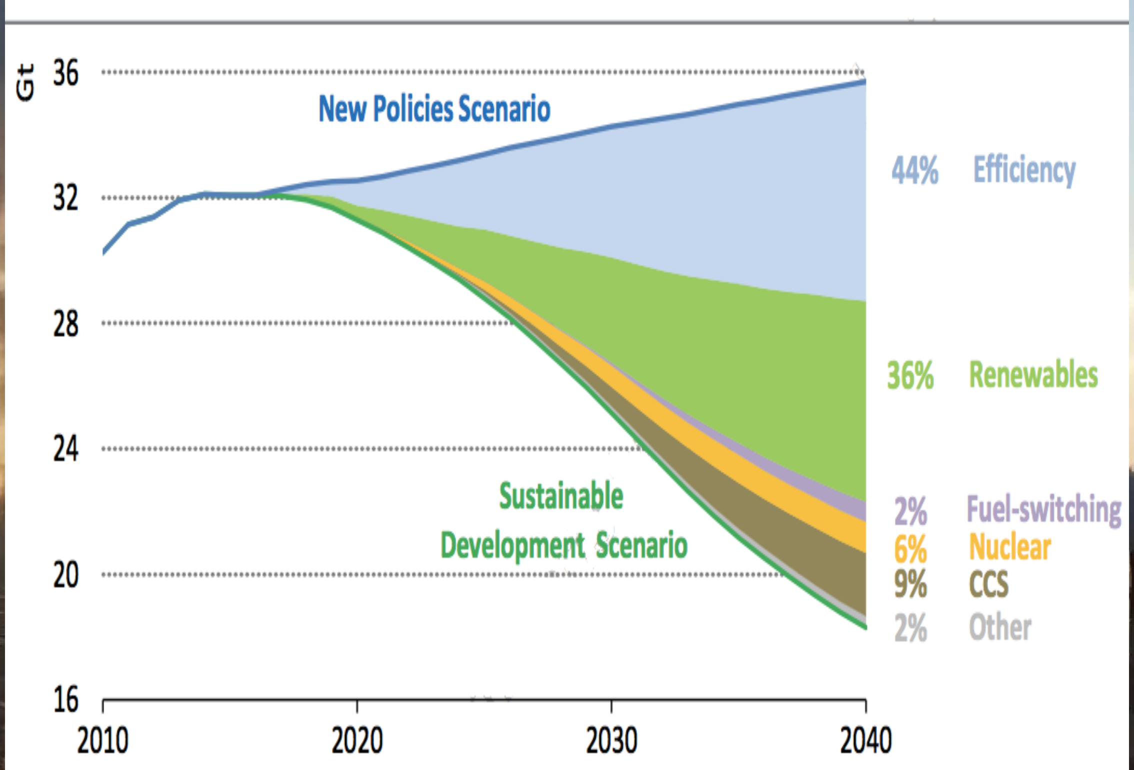
A.M. Ionescu, Euronanoforum, Bucharest, June 2019

New policies, efficiency & renewables…

There is an **enormous gap** between **what we need to do** and what we're **actually doing** to prevent dangerous levels of climate change.

2018 **#EmissionsGap** Report

UN environment

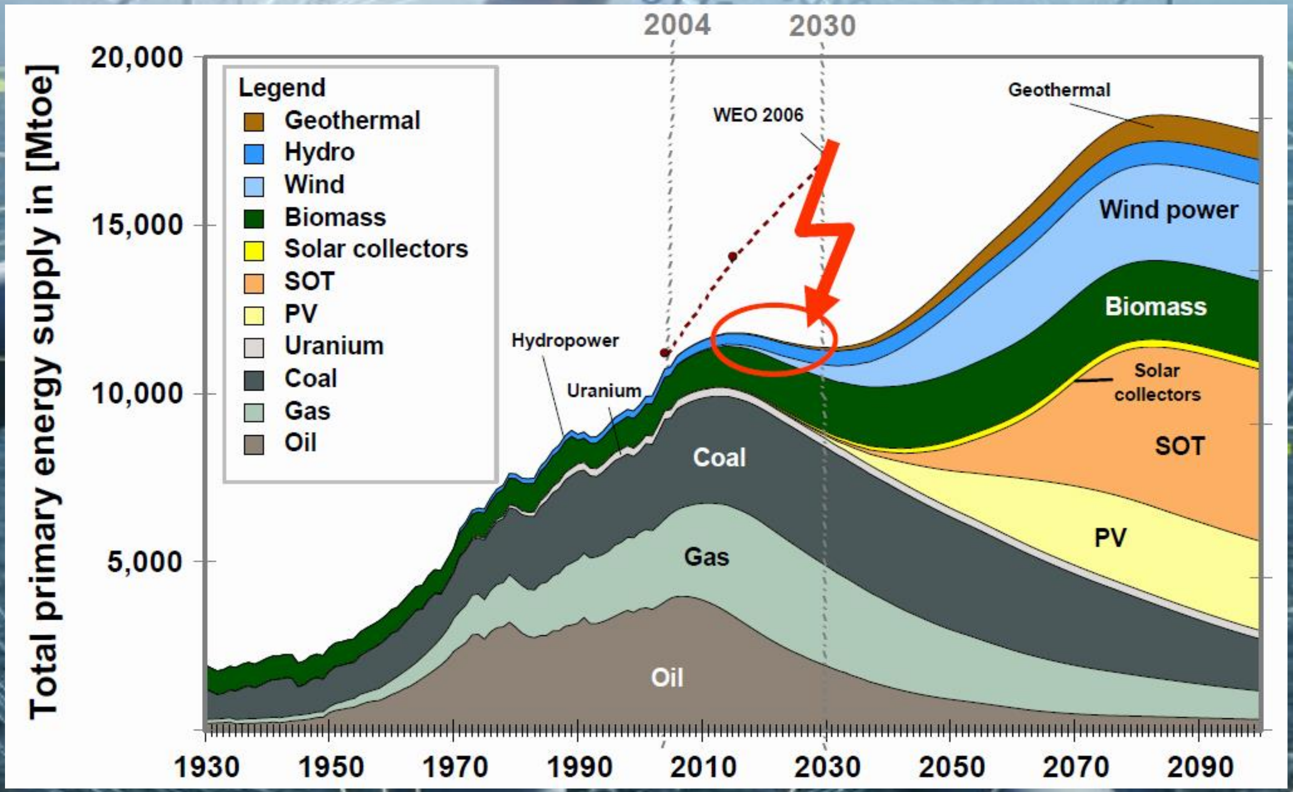


We are not yet almost there!

Global Challenges for Humanity in 21st Century

2. Energy

We are at a crucial point on how we make and use sustainable energy:



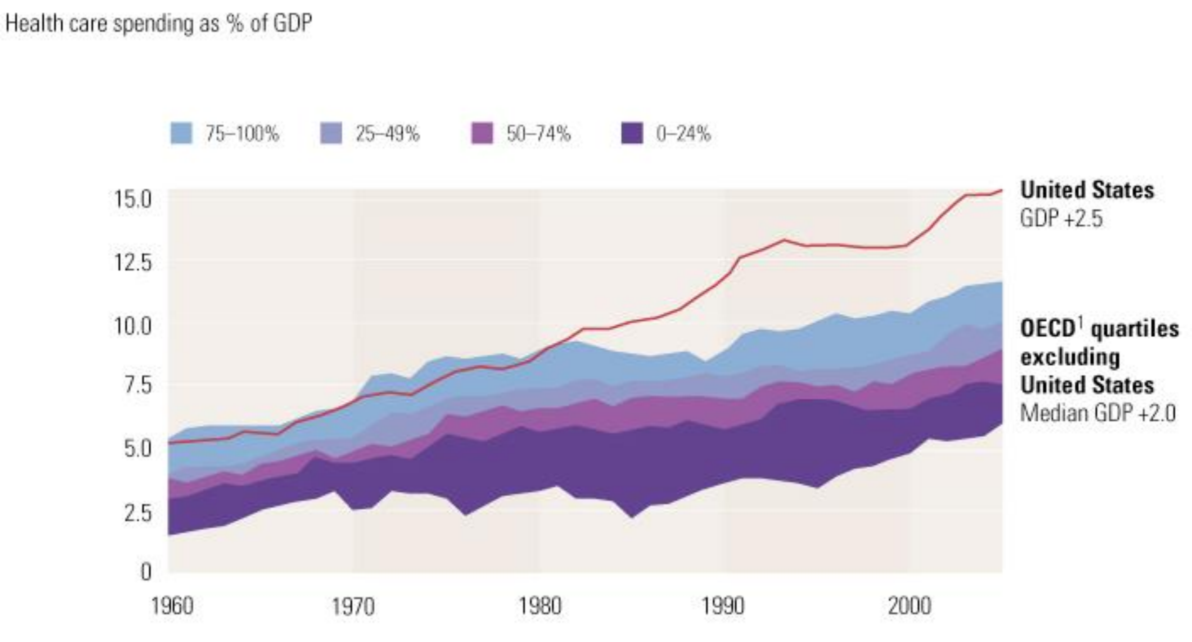
We are not yet almost there!

A.M. Ionescu, Euronanoforum, Bucharest, June 2019

Global Challenges for Humanity in 21st Century

3. Health

The 20th Century reactive healthcare model is unsustainable!



The median increase in health care spending has been 2% points above GDP for nearly 50 years in all OECD countries, with only minor fluctuations. Expectations:

- **30% of GDP in the United States by 2040** (up to 97% in 2100)
- **30% of the median OECD GDP by 2070**

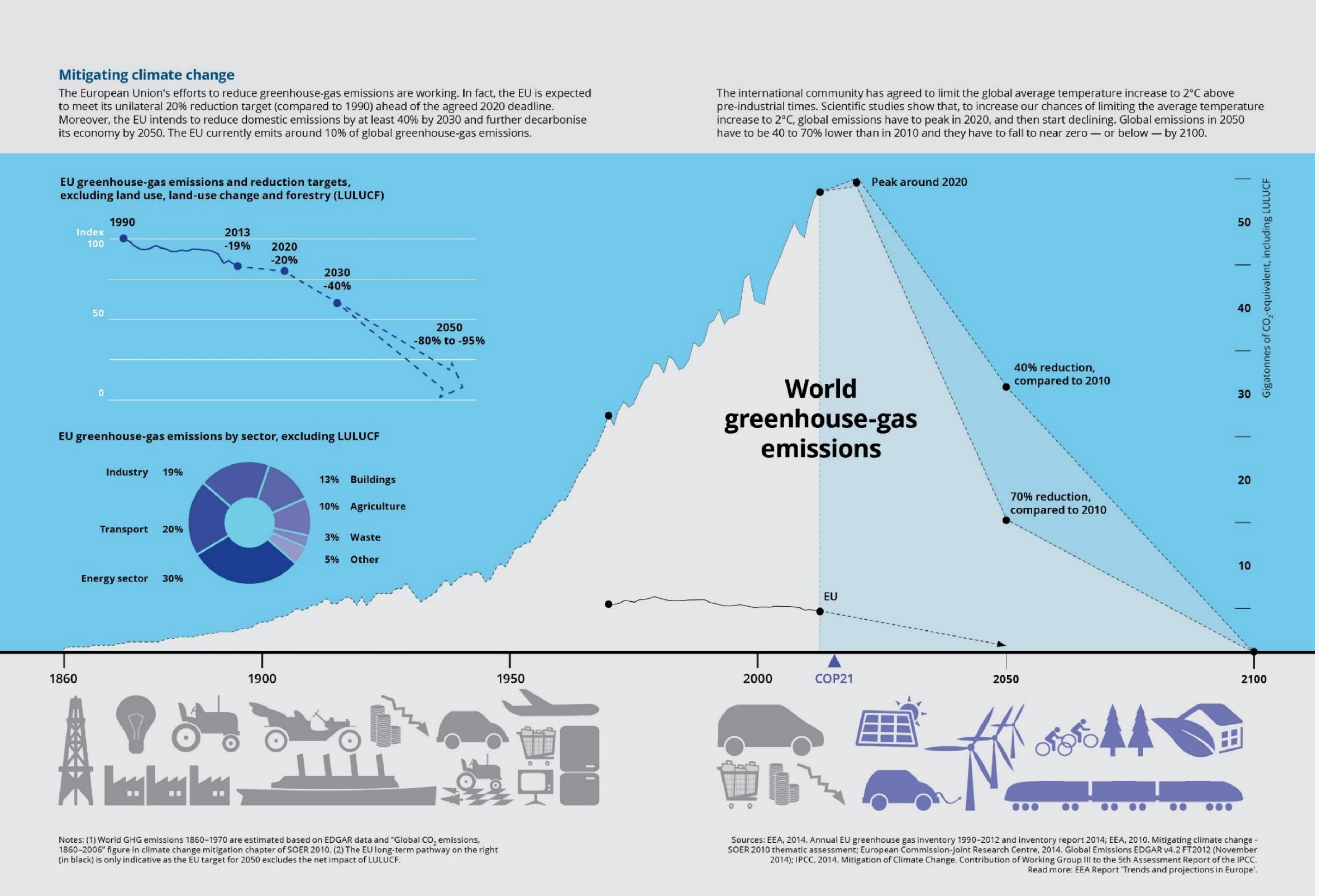
We need a paradigm change: a P3 Digital Healthcare revolution.

We are not yet almost there!

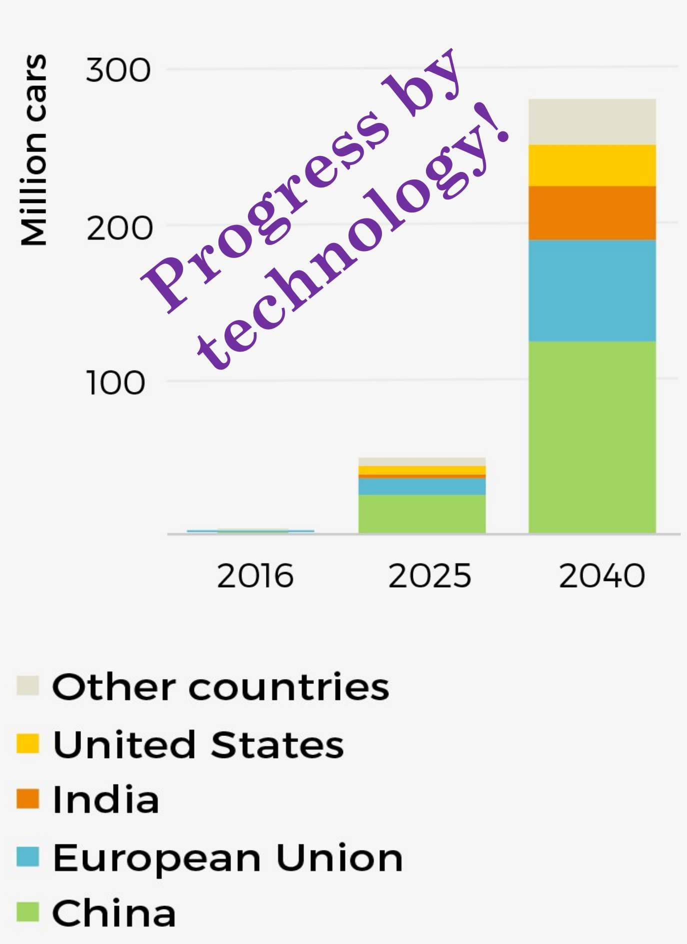
How technology can help to be almost there?

- Every day new evidence of our unsustainable impact on the environment is emerging.
- We have a critical window of opportunity to put in place commitments and actions to reverse the trend of nature loss and ensure the health and well-being of people and our planet.
- **Digital Technology** should play a crucial role in **decoupling development and environmental degradation**.

EU: responsible answer to climate change!



Electric car fleet: 2016 -2040



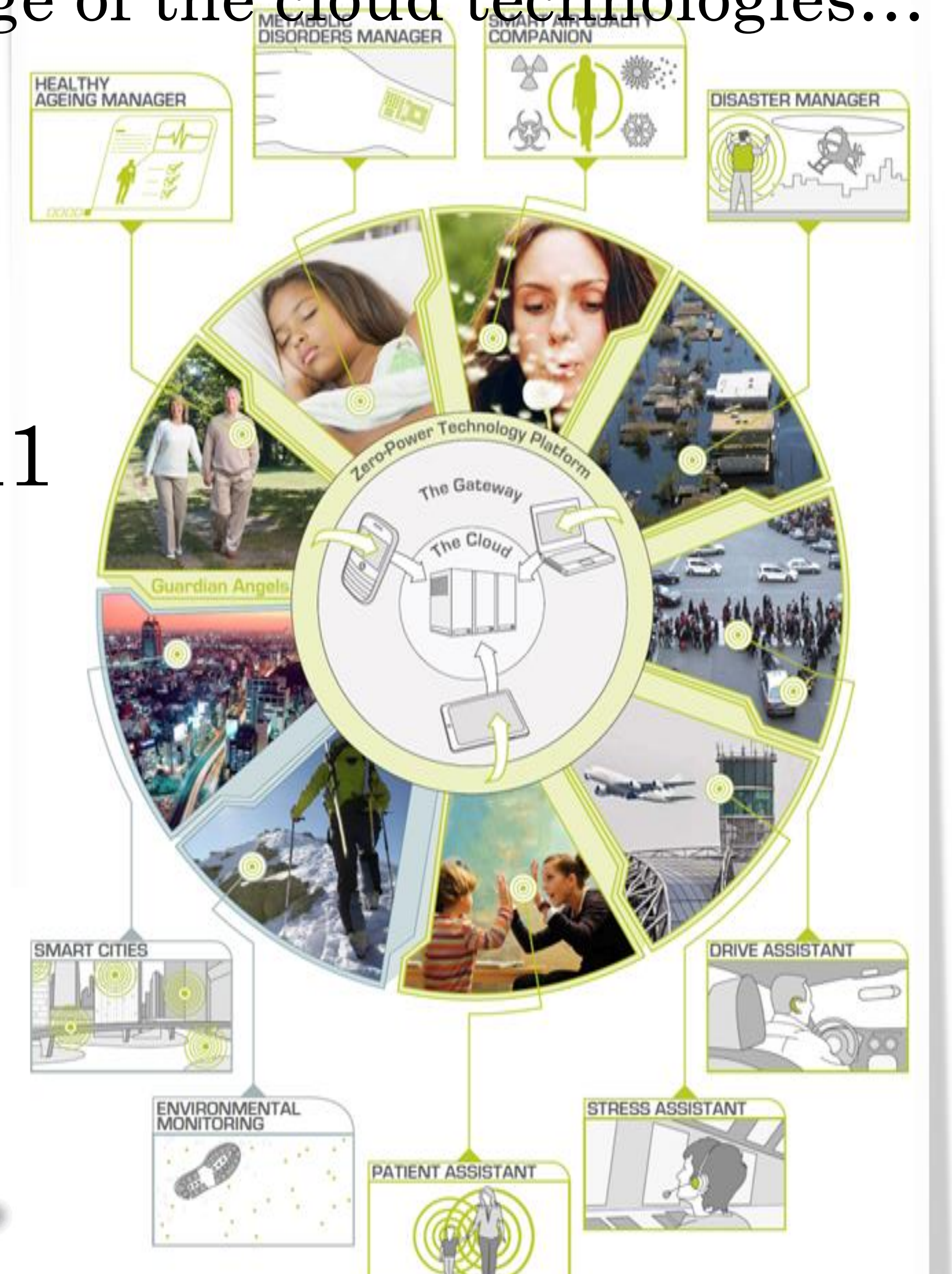
Iphone & Guardian Angels

- First wireless computer with sensors

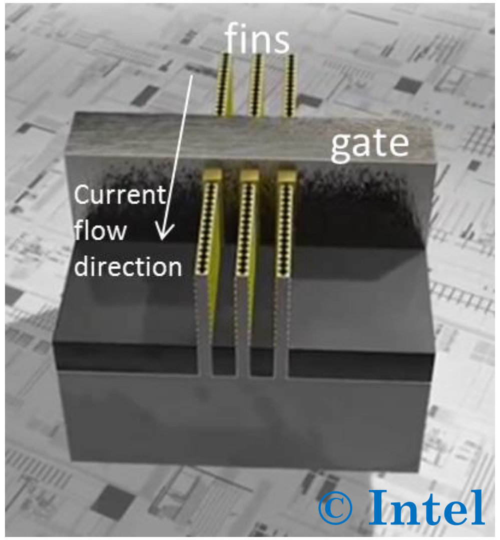
2007

- Edge of the cloud technologies…

2011

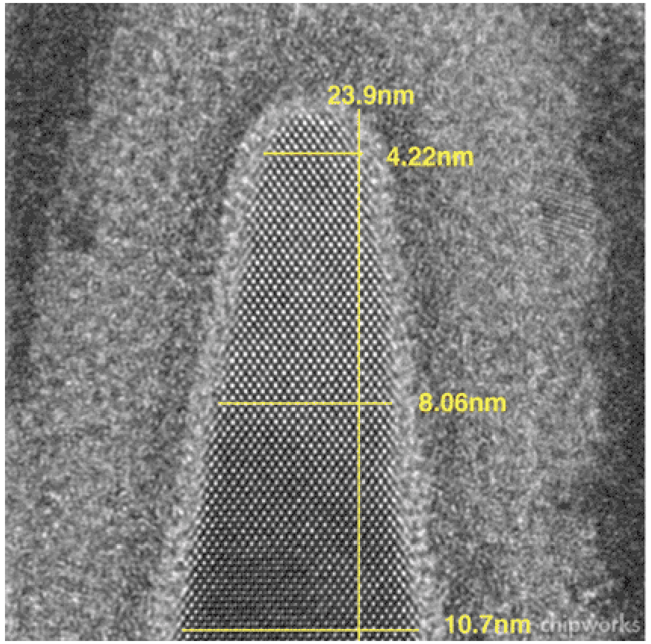


Nanoelectronics: ~10nm 3D transistors

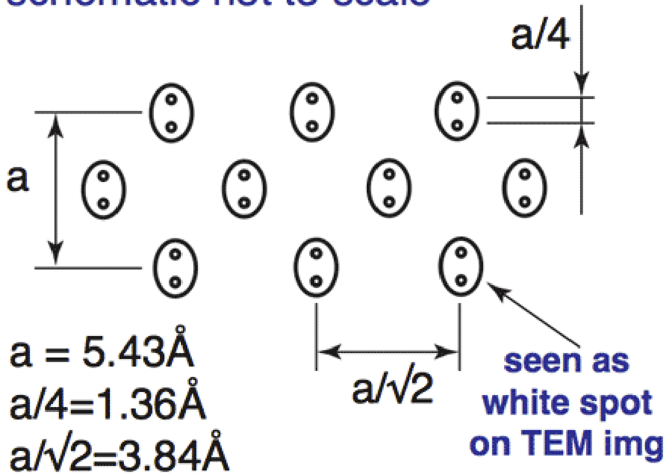


Today: 14 nm:
- ❑ **40 millions transistors/mm²**

2019-2020: 10 nm:
- ❑ **100 millions transistors/mm²**



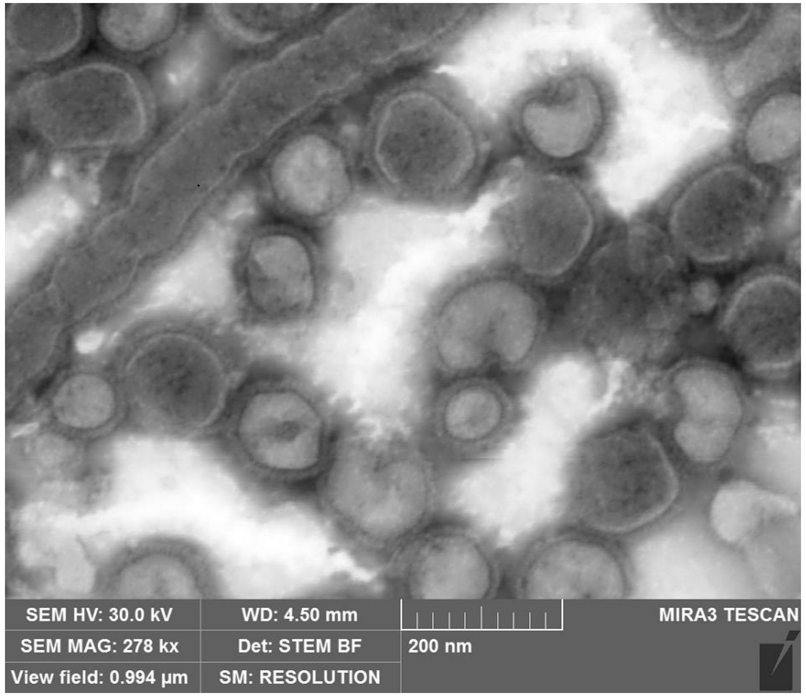
TEM image of Si(110), schematic not to scale



a = 5.43Å
a/4=1.36Å
a/√2=3.84Å

Virus

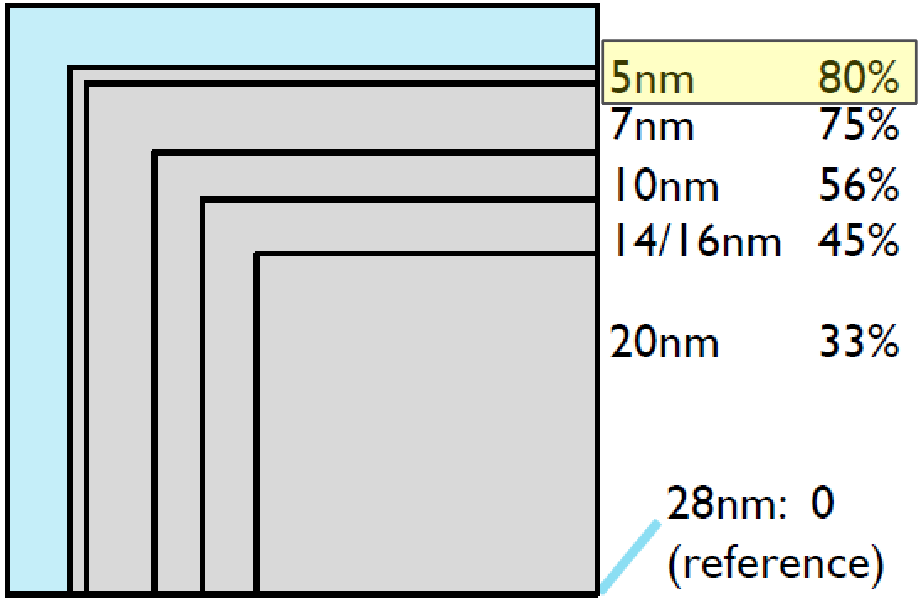
Negatively stained Influenza Virus, usually spherical or ovoid in shape, 80 to 150 nm.



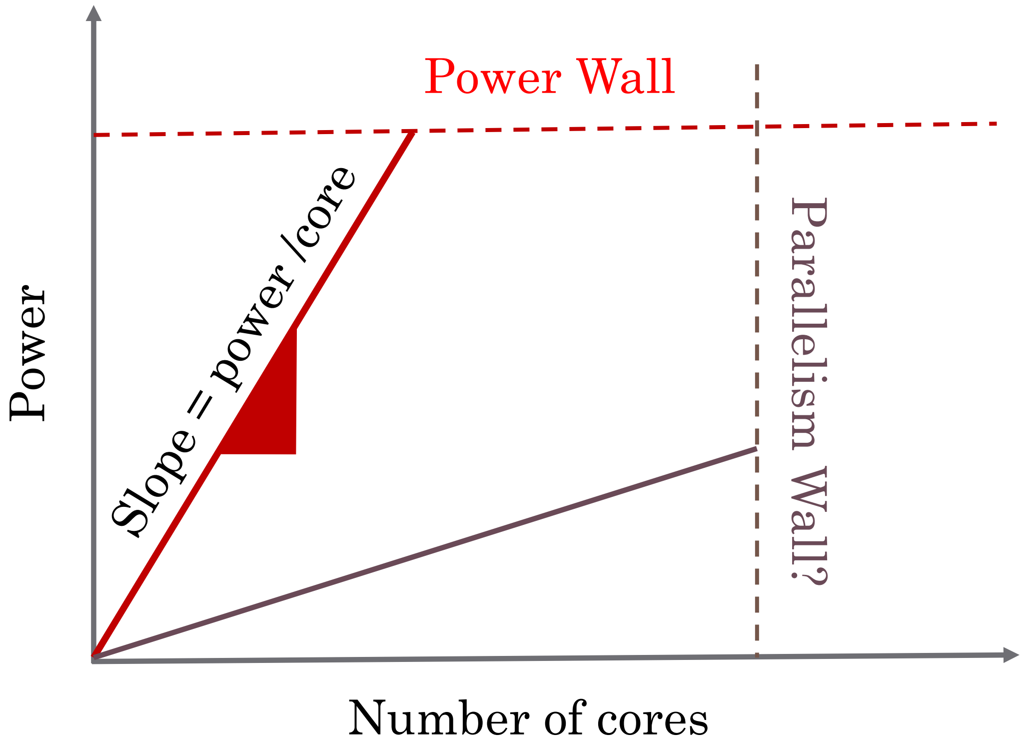
Dark silicon era? Is this so bad?

- ***We get more transistors, we just can't afford to turn them all!***

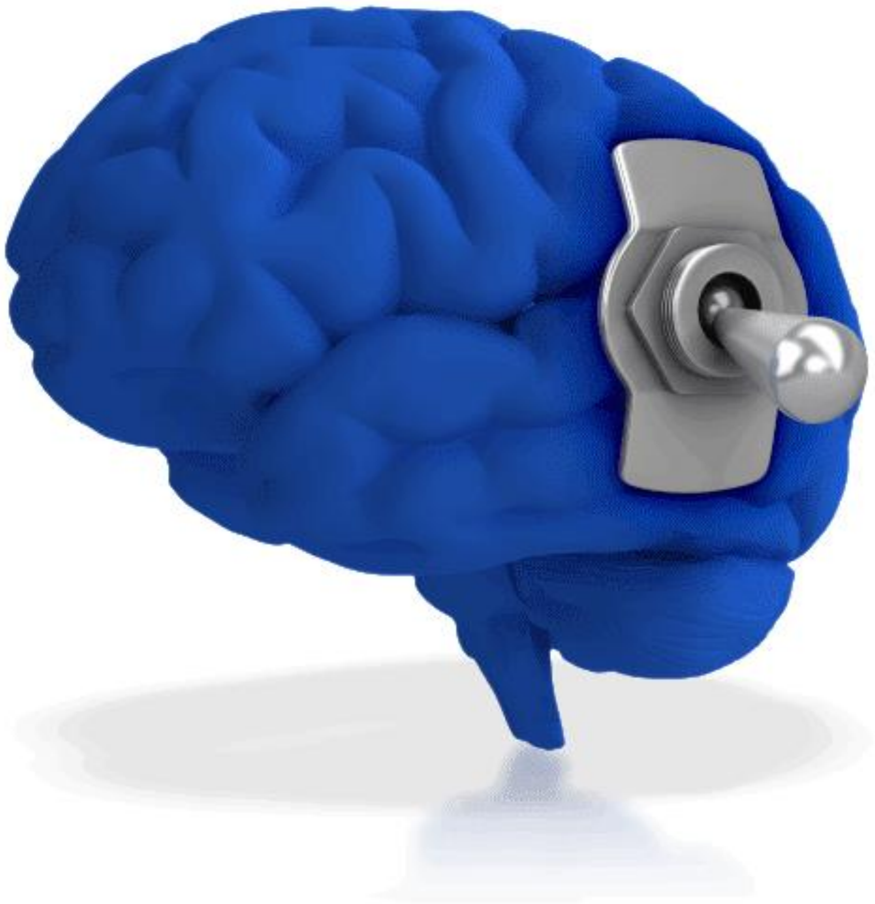
  Greg Yeric, ARM @ IEDM 2015



One or two walls?

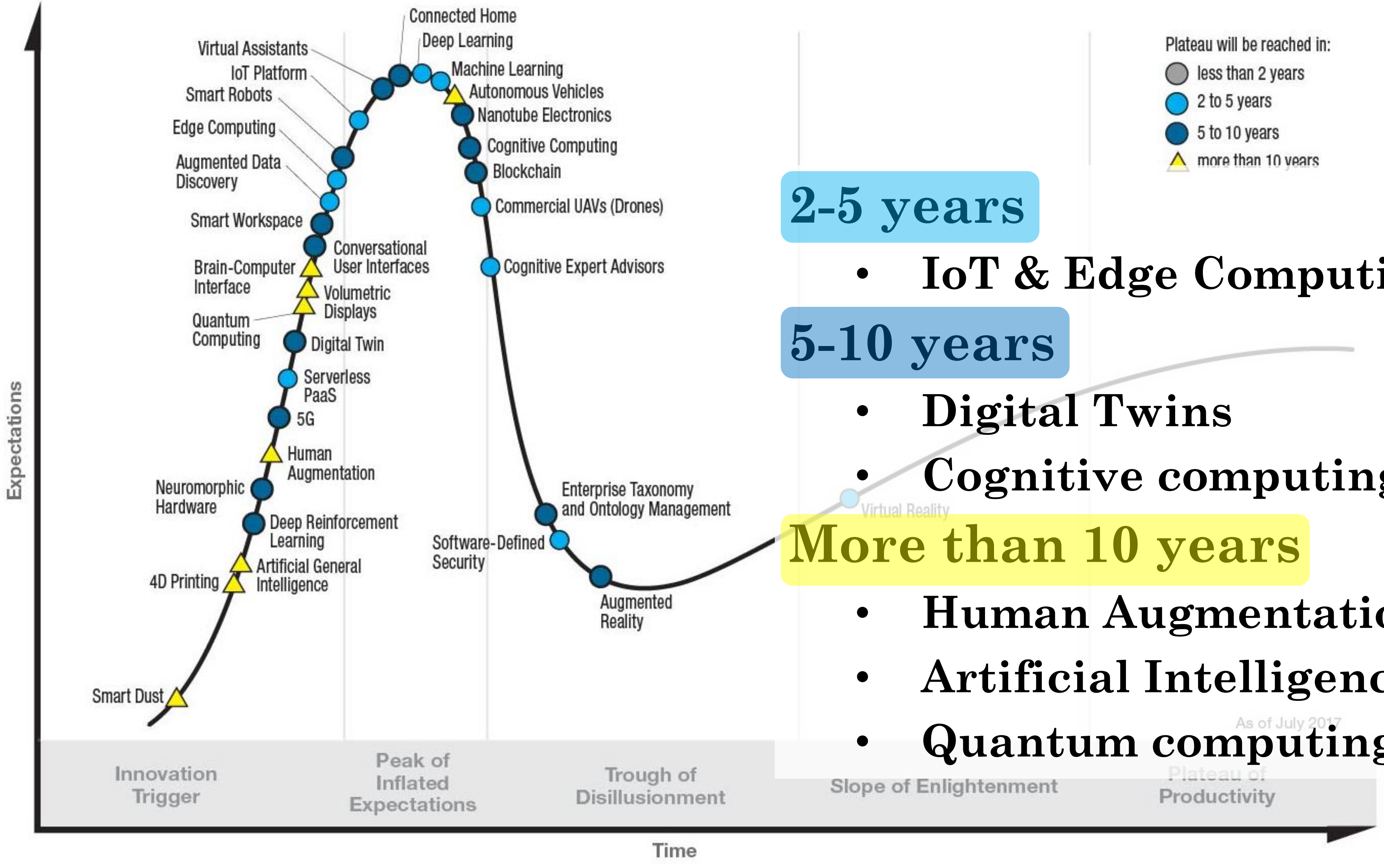


A dark brain?



- only about 3% of the neurons in the brain can be highly active at one time
- *visual processing accounts for 44% of the brain's energy consumption*

P. Lennie, Current Biology, 2003.



2-5 years

- **IoT & Edge Computing**

5-10 years

- **Digital Twins**
- **Cognitive computing**

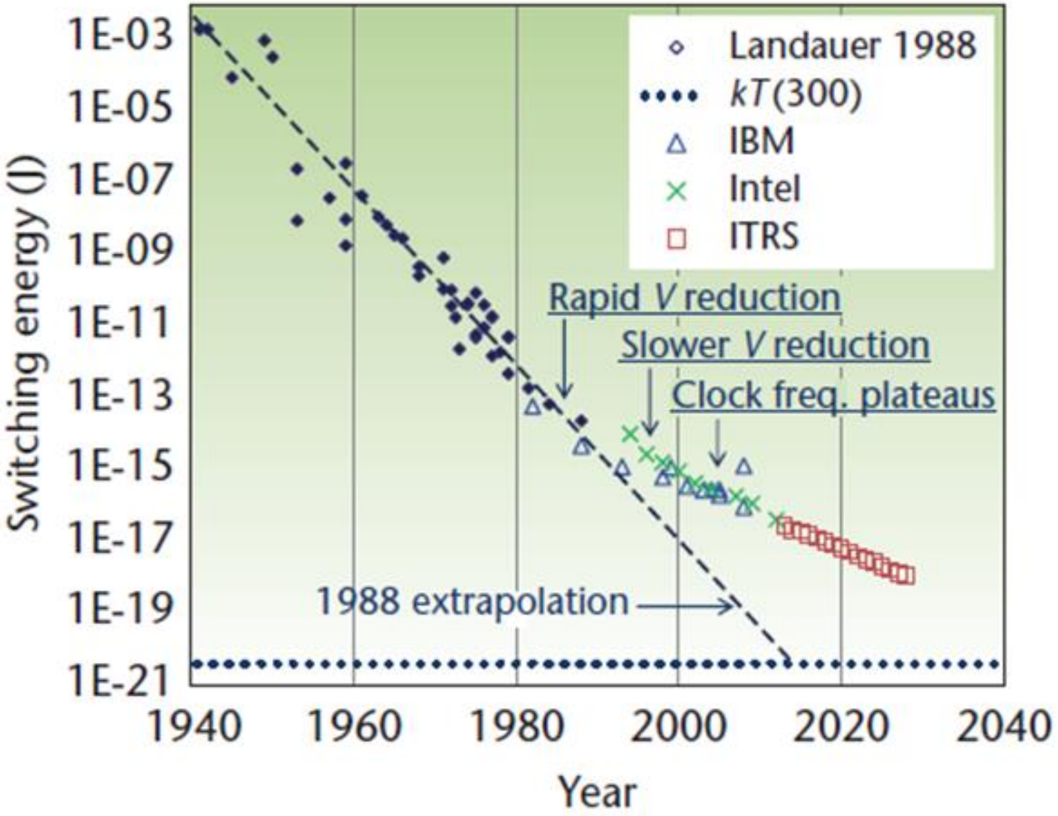
More than 10 years

- **Human Augmentation**
- **Artificial Intelligence**
- **Quantum computing**

Source: gartner.com/SmarterWithGartner

Silicon technology @ end of nano-scaling?

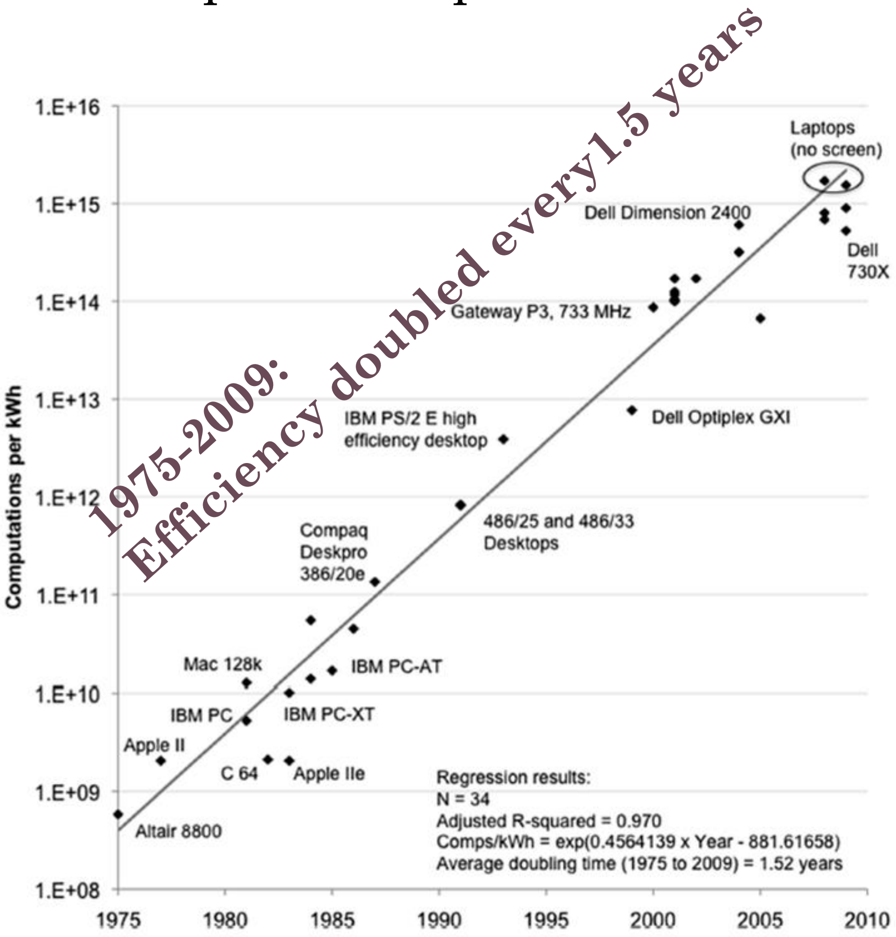
- **Moore's Law**, Dennard's happy scaling
- Silicon is mainstream: 14nm, 7nm, 5nm, … 1nm?



Theis & Wong, Computing in Sci. & Eng., 2017.

Koomey's law:

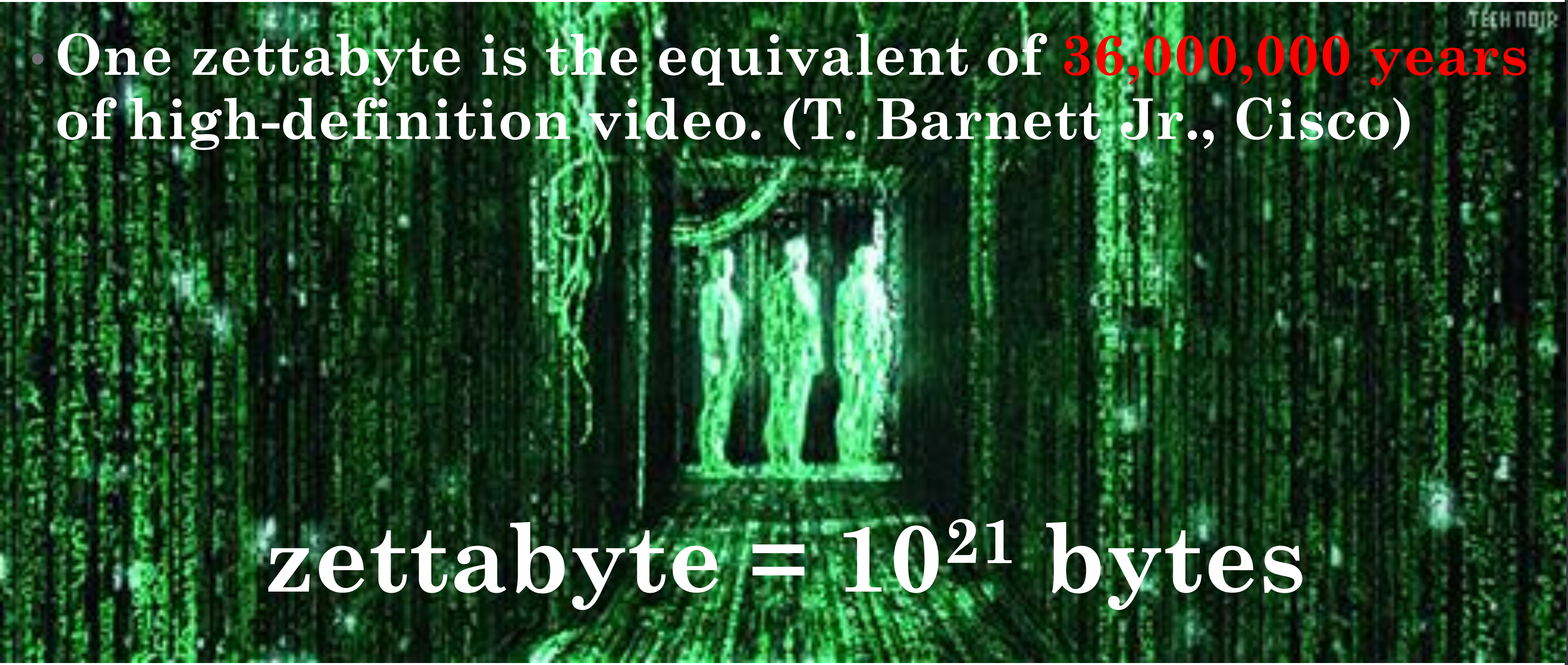
computations per killowatt hour



Koomey et al., IEEE Ann. of History of Comp., 2011.

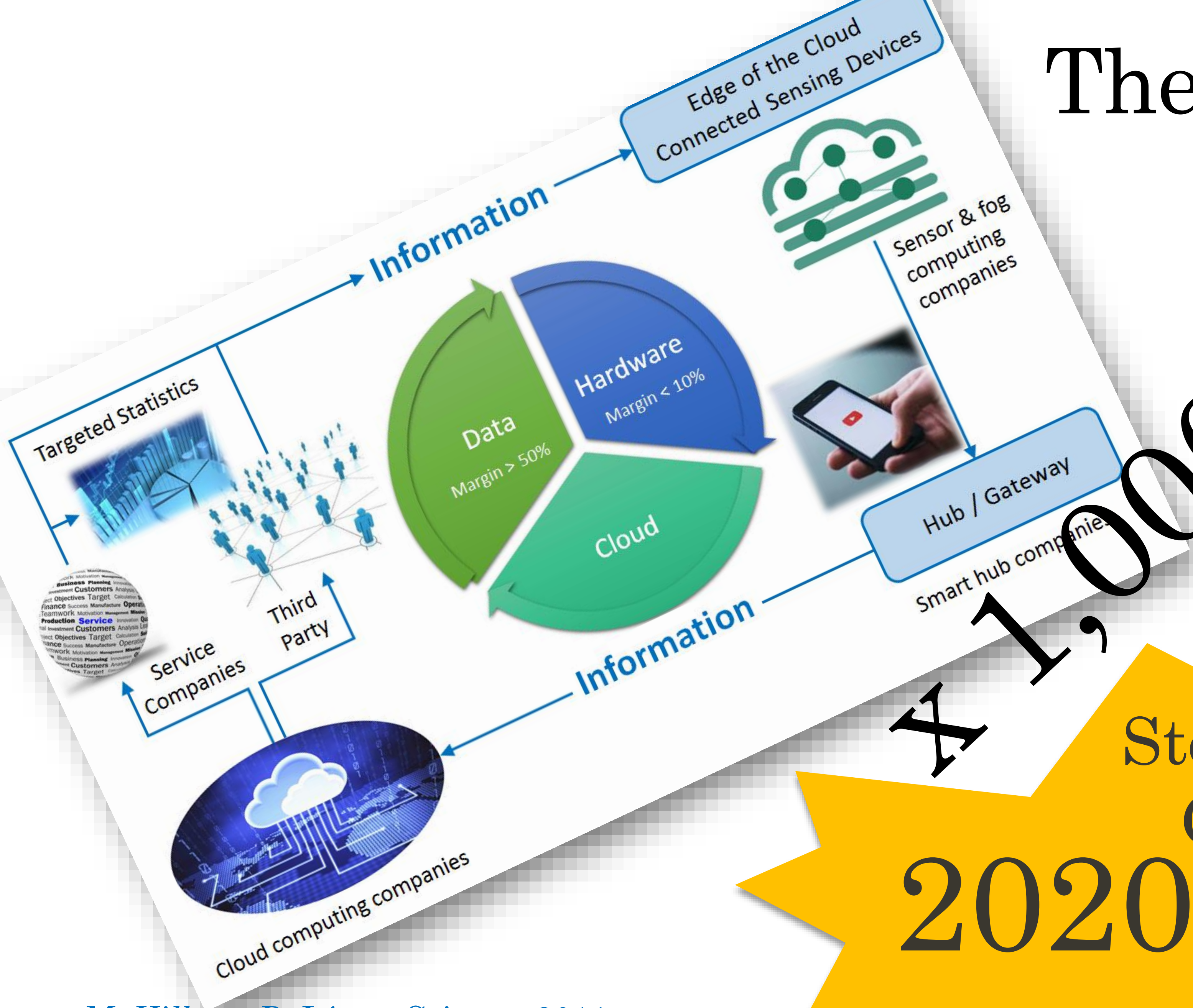
The Zettabyte Era… started in 2010!

- **One zettabyte is the equivalent of 36,000,000 years of high-definition video. (T. Barnett Jr., Cisco)**



zettabyte = 10^{21} bytes

The Zettabyte Era



x 1,000,000

1985
Storage 21PB
Coms 59PB
Comp 0.74PIPS

2007
Storage 277EB
Coms 537EB1
Comp 195PIPS

2020
Storage 140 ZB
Coms 272 ZB
Comp 2'590 ZIPS
Edge IoT >50 ZB

M. Hilbert, P. López, Science, 2011.
Z.-W. Xu, J. of Comp. Sci. and Tech., 2014.

Future: billions of energy efficient IoT edge & fog devices…

CLOUD: Data Centers

Thousands

FOG: Nodes

Millions

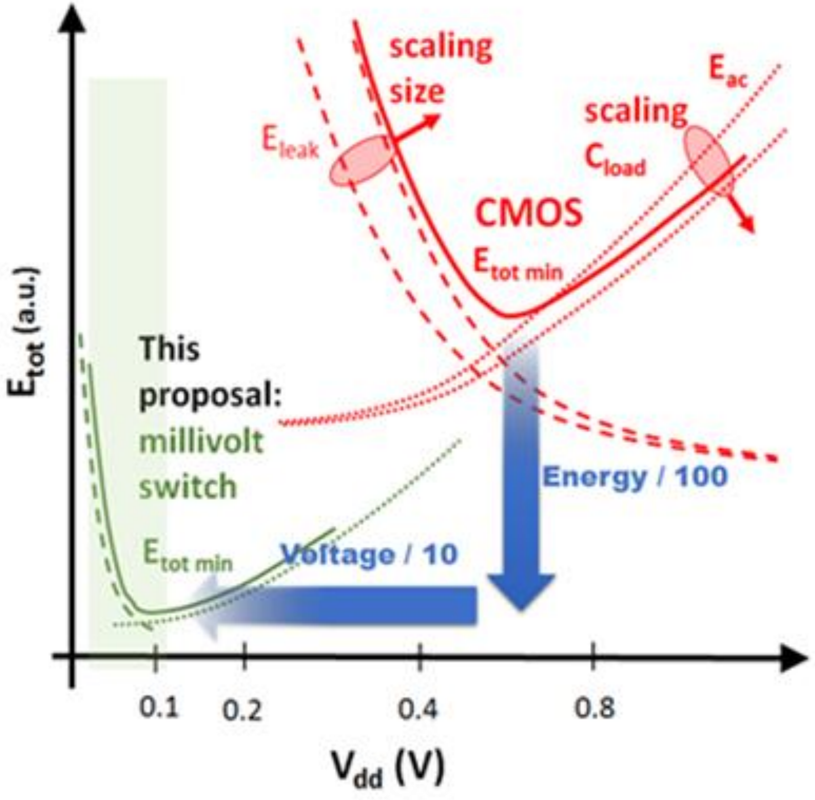
EDGE: Devices

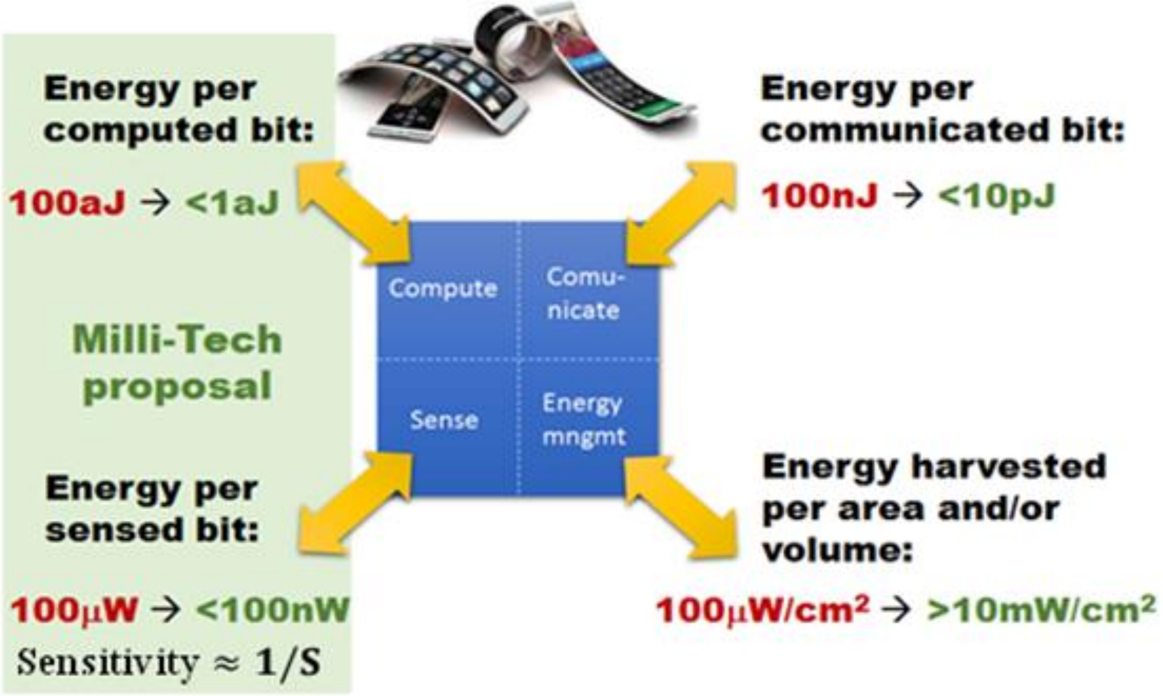
Billions

2020:10% of the world's data (Source: IDC).

Future computing and sensing near 100mV: **energy efficient technologies**

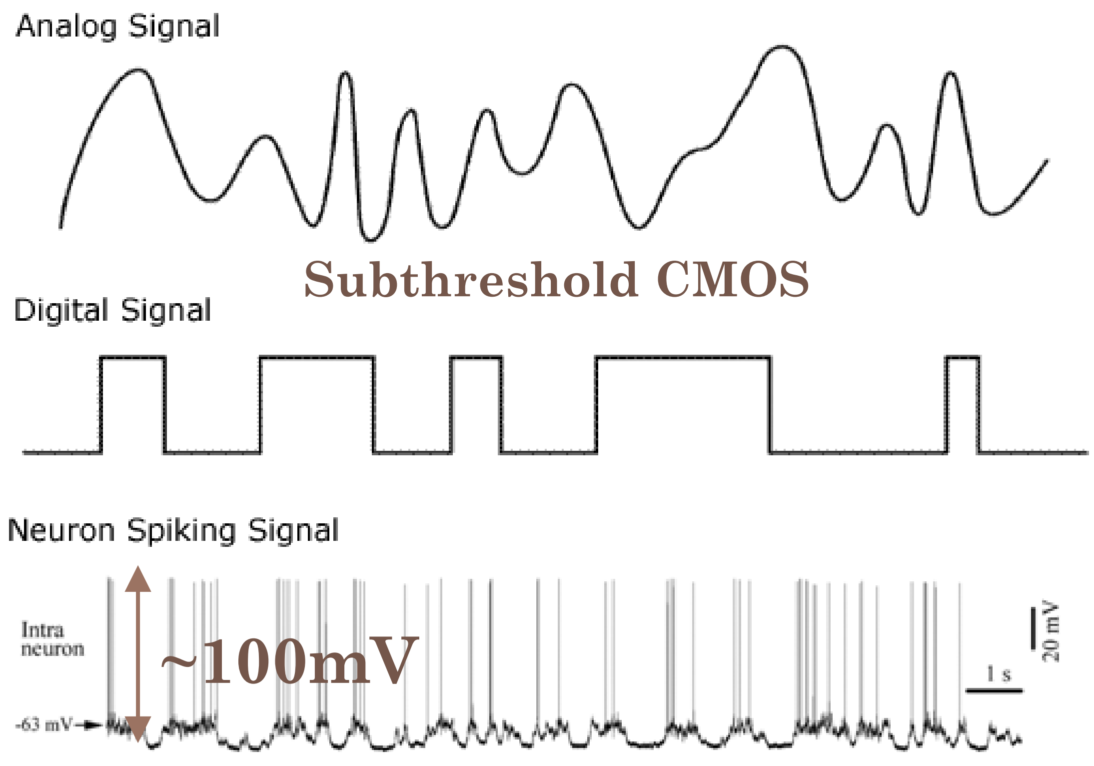
- What is the optimal voltage?





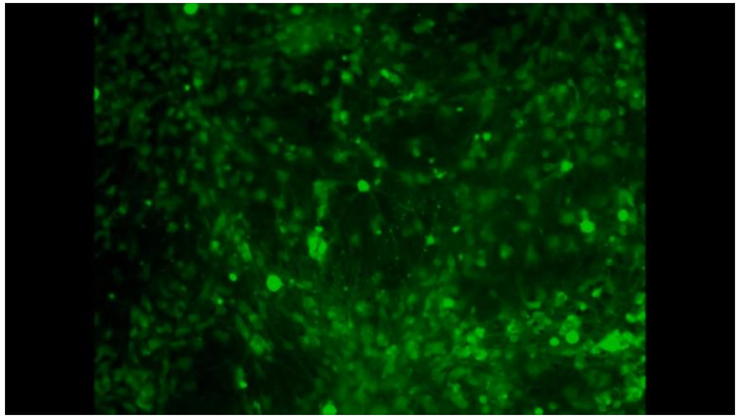
ERC MilliTech

Information processing @ 100mV?

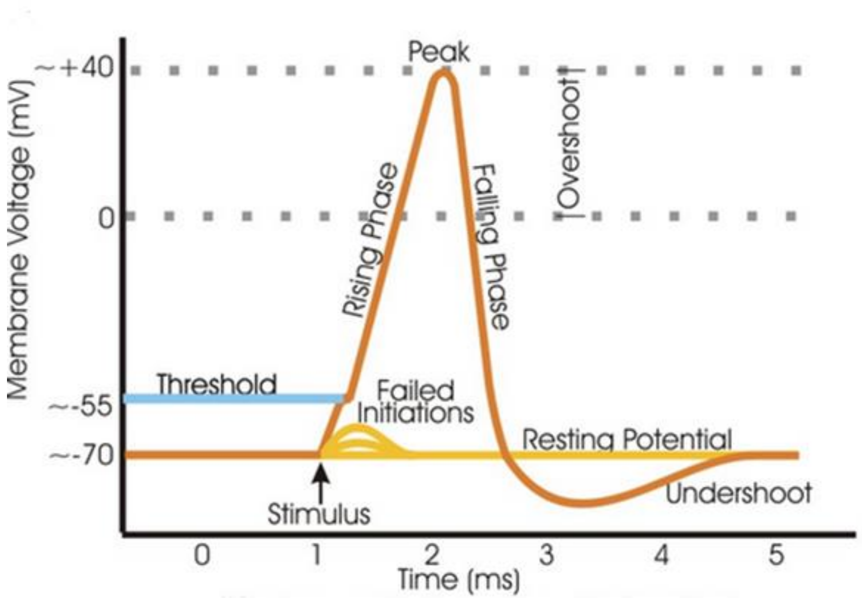


- **Neural activity is very costly, and a little of it has to go a long way.**

The firing of the neuron



Neuron potential by Na+, K+ ion pumps, is in the order of **+40mV to -70mV**

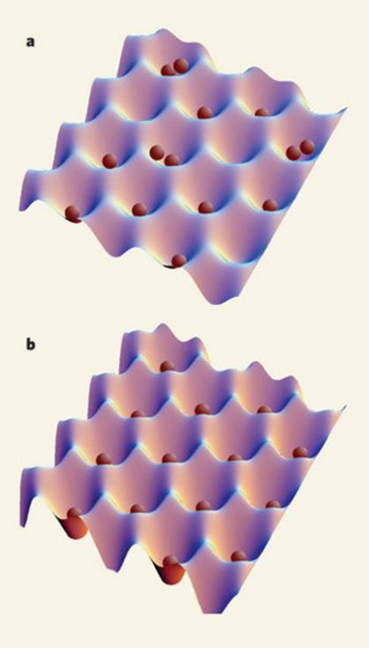


Energy efficient tunable electronics by phase transition materails

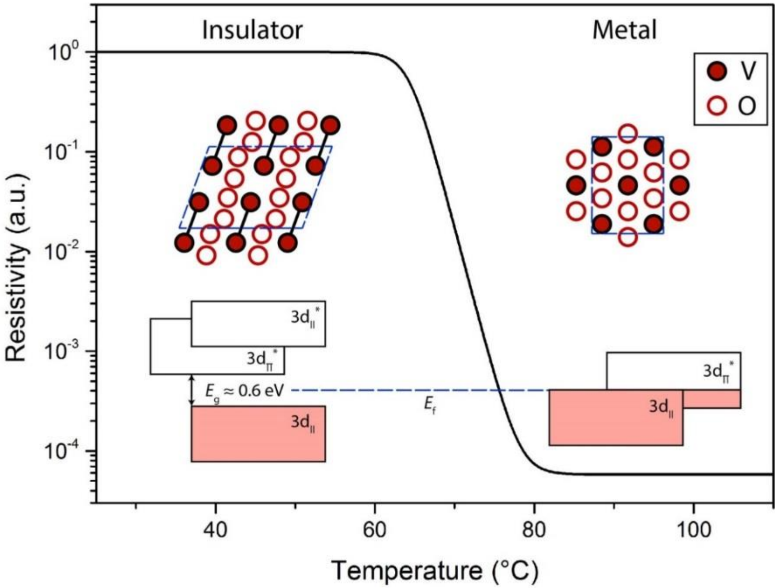
Nobel Prize for Physics in 1977

Revolution by new material properties: correlated oxides and Metal-Insulator-Transition!

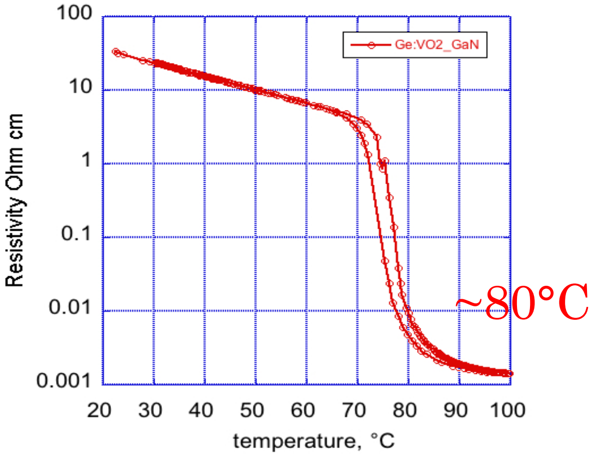
- **Mott insulators**: *Metal that stops conducting under certain conditions (low temperature or high pressure), despite classical theory predicting conduction.* Flaw in central approximation in band theory: *inter-electron forces are not negligible*
- **When is a metal not a metal?** Steven C. Erwin (Nature, Vol. 441, 2006) - *Materials that owe their insulating nature to correlations in the motions of different electrons.*

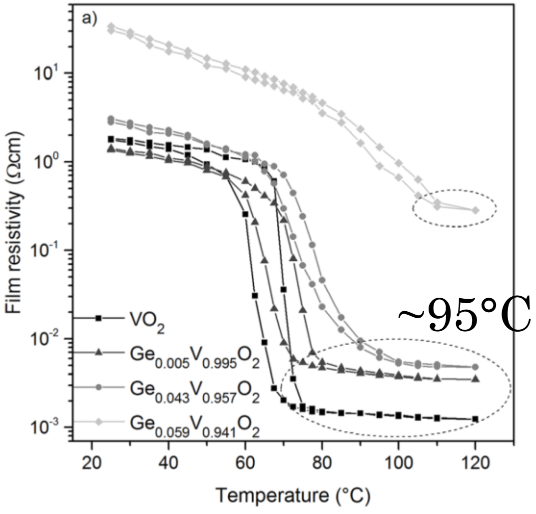


- Vanadium dioxide, VO_2, undergoes a structural phase transition at ~68 °C accompanied by a steep decrease in resistivity.
- The monoclicic phase presents a **bandgap ~0.6 eV.**
- The tetragonal phase presents **metallic behavior.**
- **Fast transition ~ns.**

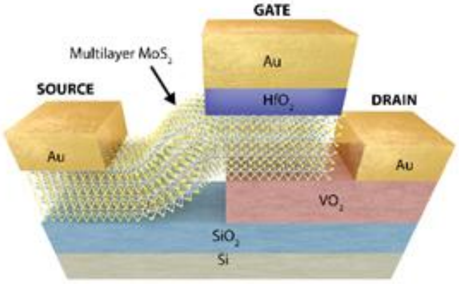


Reconfigurable electronic functions based on MIT in Ge-VO2 (FET Open Phase Change & Millitec ERC)

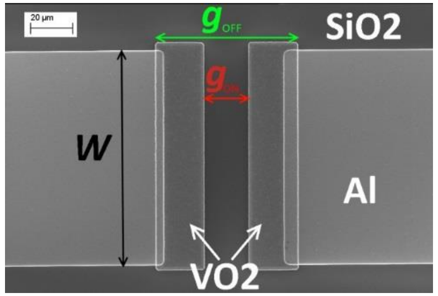


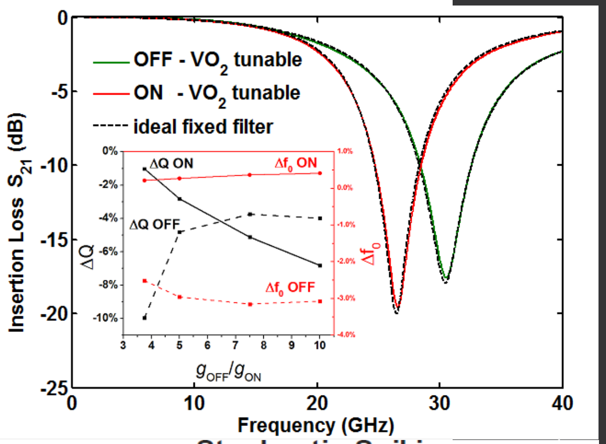


- **Hybrid steep slope switches**

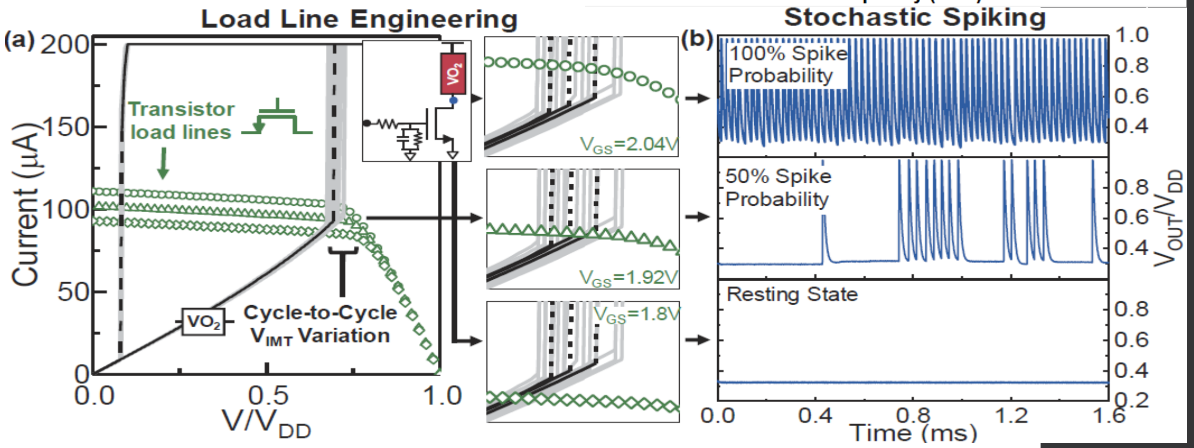


- **RF filters, phase shifters and tunable antennas: 1- 100GHz**



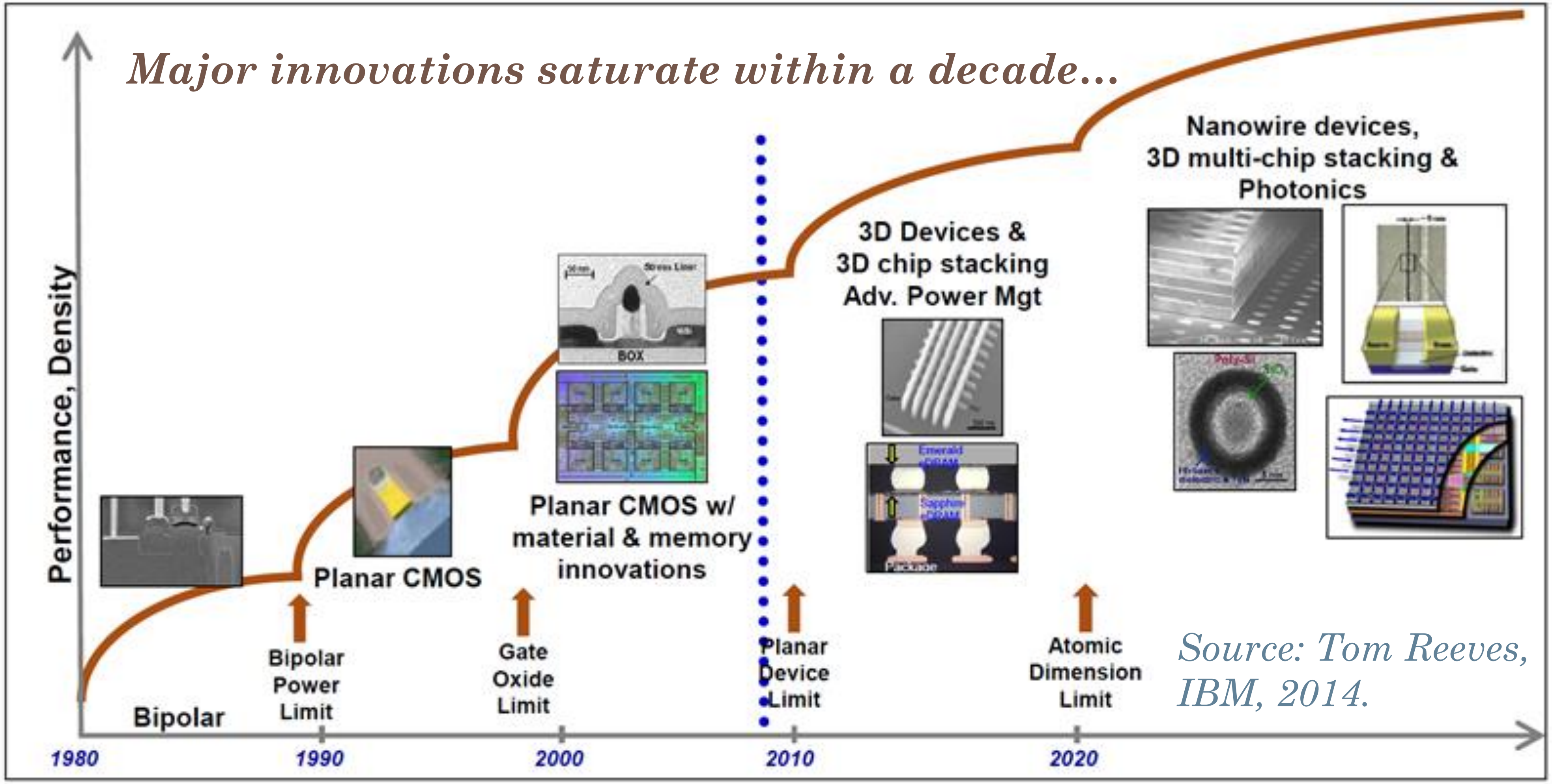


- **Neuromorphic computing:**
- ✓ **Coupled oscillators**
- ✓ **Stochastic ICs**



Silicon Technology: a 3D migration into the future

- High-performance, functionally diversified, 3D integrated # technologies

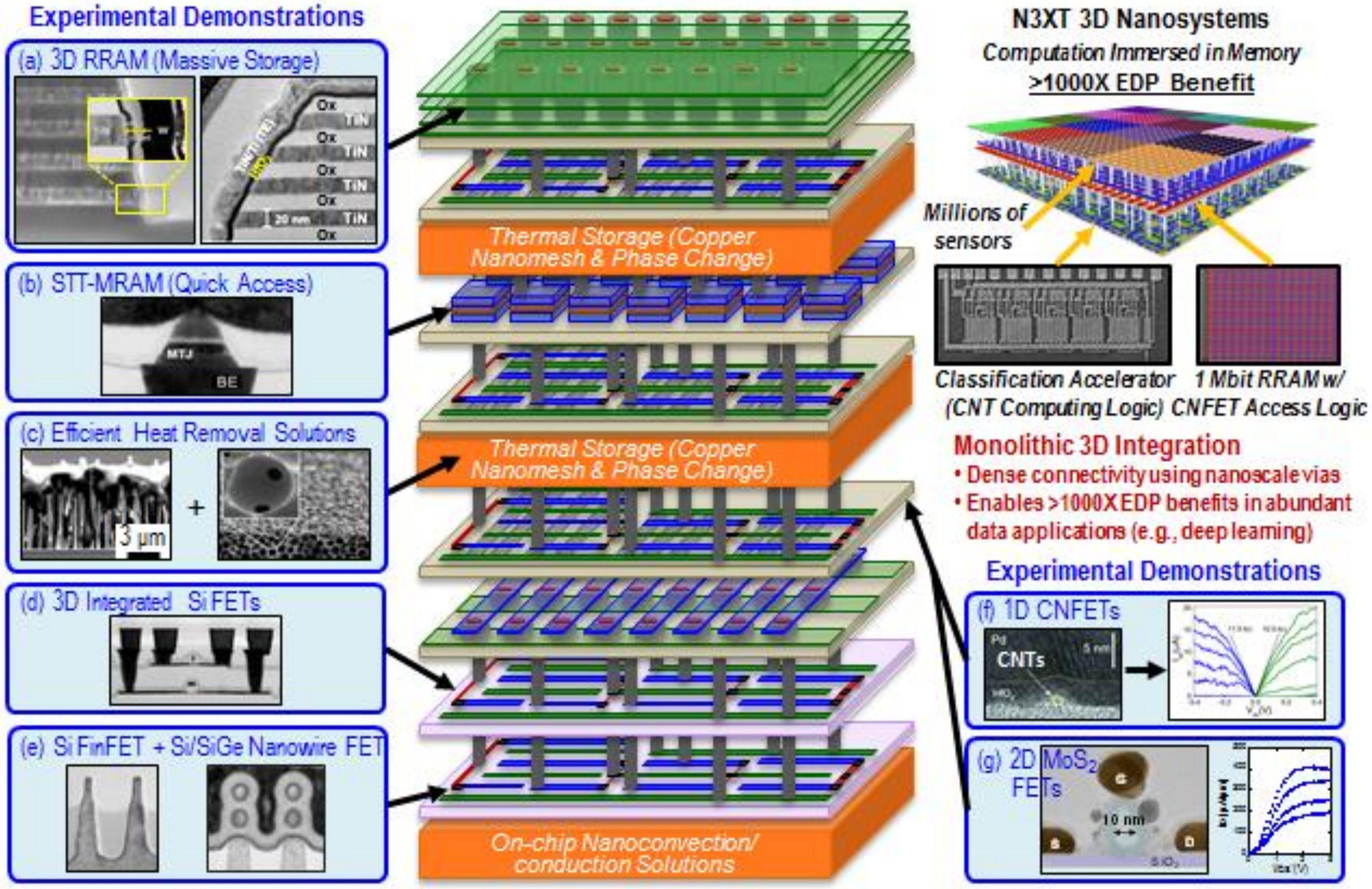


Source: Tom Reeves, IBM, 2014.

3D heterogeneous integration with ultra-dense connectivity: the N3XT concept

Merits

- **Computation Immersed in Memory**
- **Fine-grained connectivity**
- **1000x Energy-Delay Product benefits**
- Energy efficient transistors: CNT & 2D
- Large amounts of NV M RAM & RRAM memory
- Abundant data applications
- Addresses needs in neuromorphic computing



M. Sabry, Ph. Wong, S. Mitra, Computer, 2015.

Neuromorphic computing: what is and what is not?!

Goal: build computers that learn and generalize in broad variety of tasks, much as human brains - *Todd Hylton*

Cognitive computing:

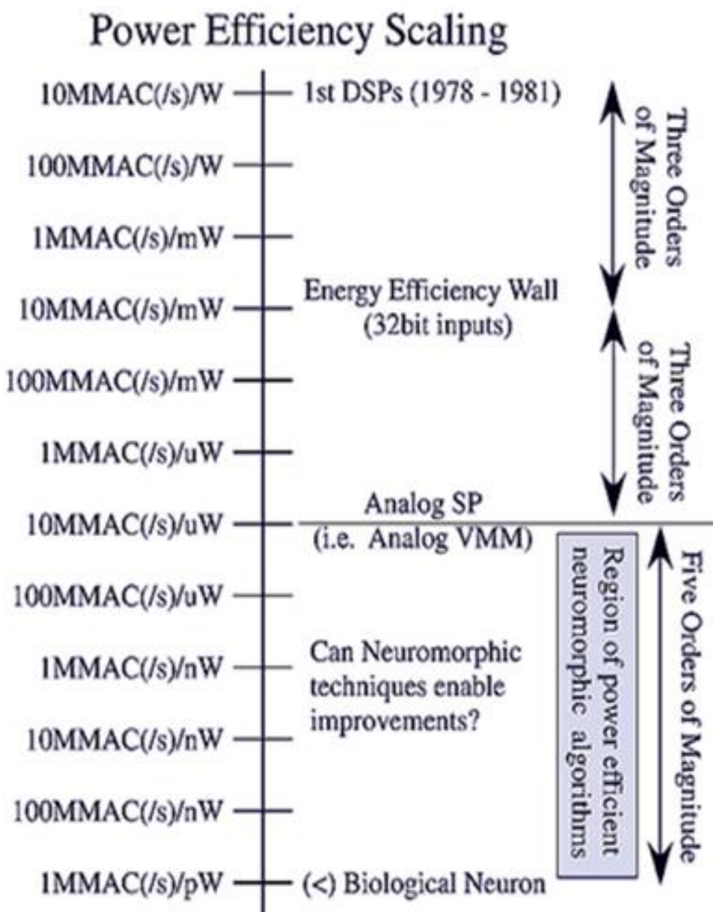
BRAIN = COMPUTER

THINKING = EXECUTION OF ALGORITHMS !

=

A neuromorphic computer is <u>not</u> a brain but **a brain-like energy efficient system** to do machine learning & AI.

Computational efficiency of various technologies



MAC = Multiply-Accumulate Instr.

J. Hasler, B. Marr, "Frt. Neurosc., 2013.

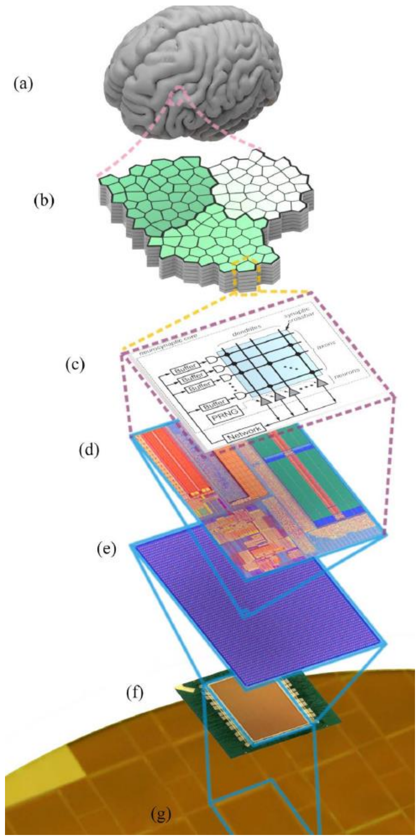
Tremendous recent progress in neuromorphic computers…

- Key feature: fundamental reorganization of memory and processing (co-location).
- **IBM's TrueNorth** (DARPA's SyNAPSE project)

  65 mW real-time neurosynaptic processor, 4096 neurosynaptic cores tiled in 2-D array, ***1 million digital neurons*** and ***256 million synapses,*** with ***computational energy efficiency = 400 GSOPS/Watt.***

- **Intel's Liohi** *(September 2017)*

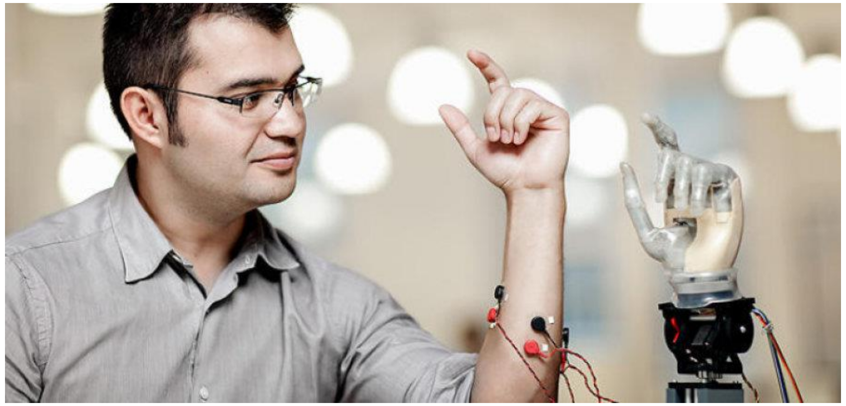
  130000 neurons, 130 million synapses



F. Akopyan et al., IEEE TCAD, 2015

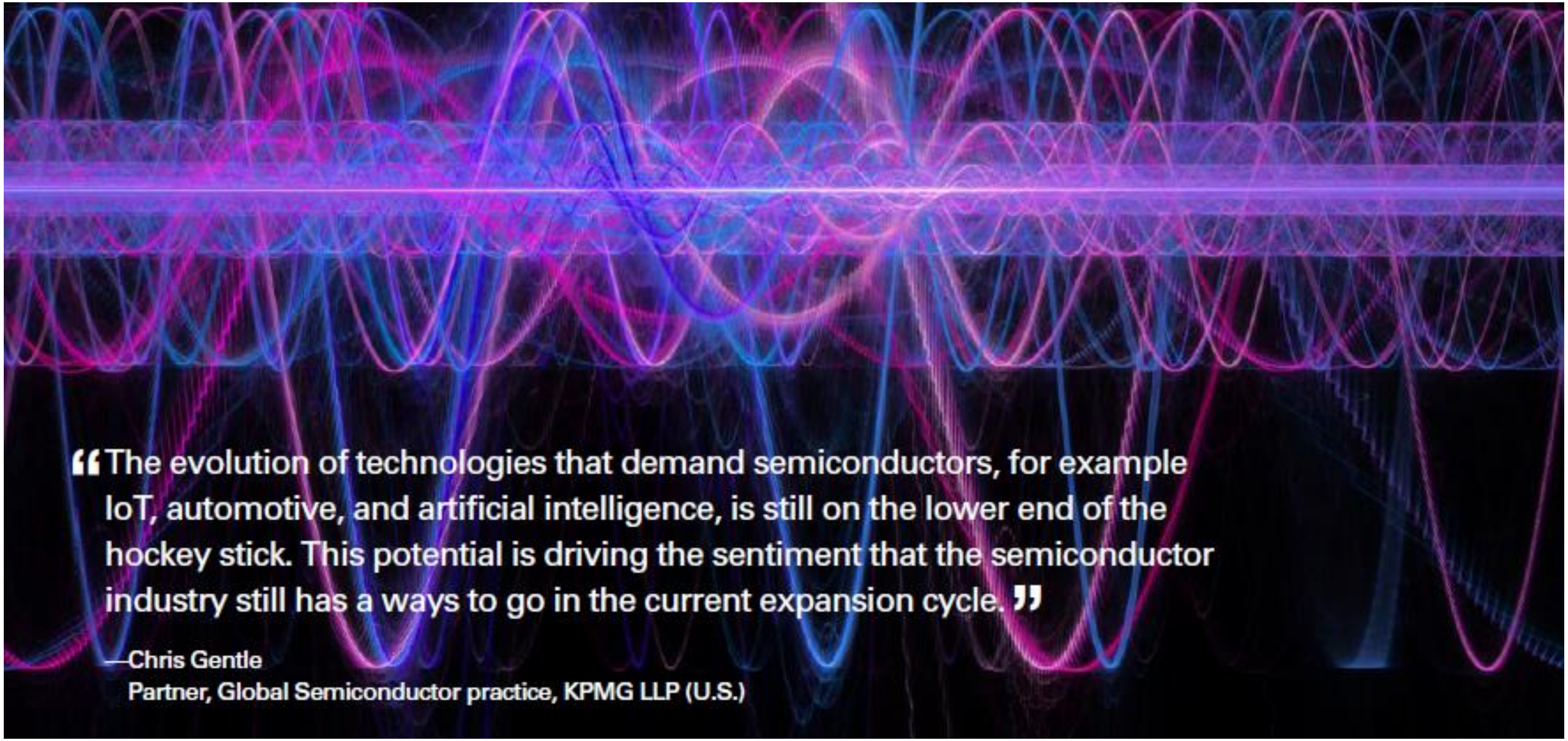
Potential future applications:

cognitive prostetics, BMI, wearables, smart in situ imaging facilities.



The Future of Energy Efficient Computing?
Hybrid: CMOS + Neuromorphic + Quantum

What's next? A deluge of opportunities…



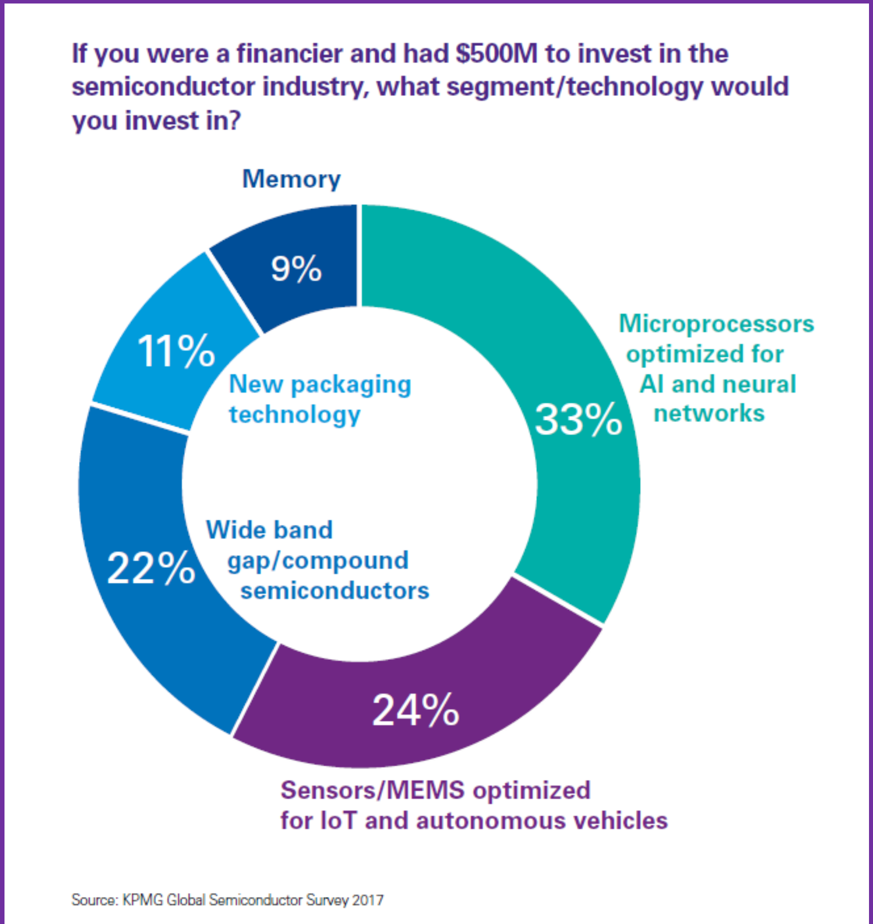
The global semiconductor market was valued at $463.5 billion in 2016 and is projected to reach $831.5 billion by 2024.

Semiconductors are the best performing industry over the past five years

Through 20 August 2018	
Fund / ticker	5-year annualized return (%)
Aerospace & Defense (XAR)	20
Biotech (XBI)	20.1
US Technology Sector Stocks (XLK)	20.2
Health Care Equipment (XHE)	22.4
Semiconductors (XSD)	23

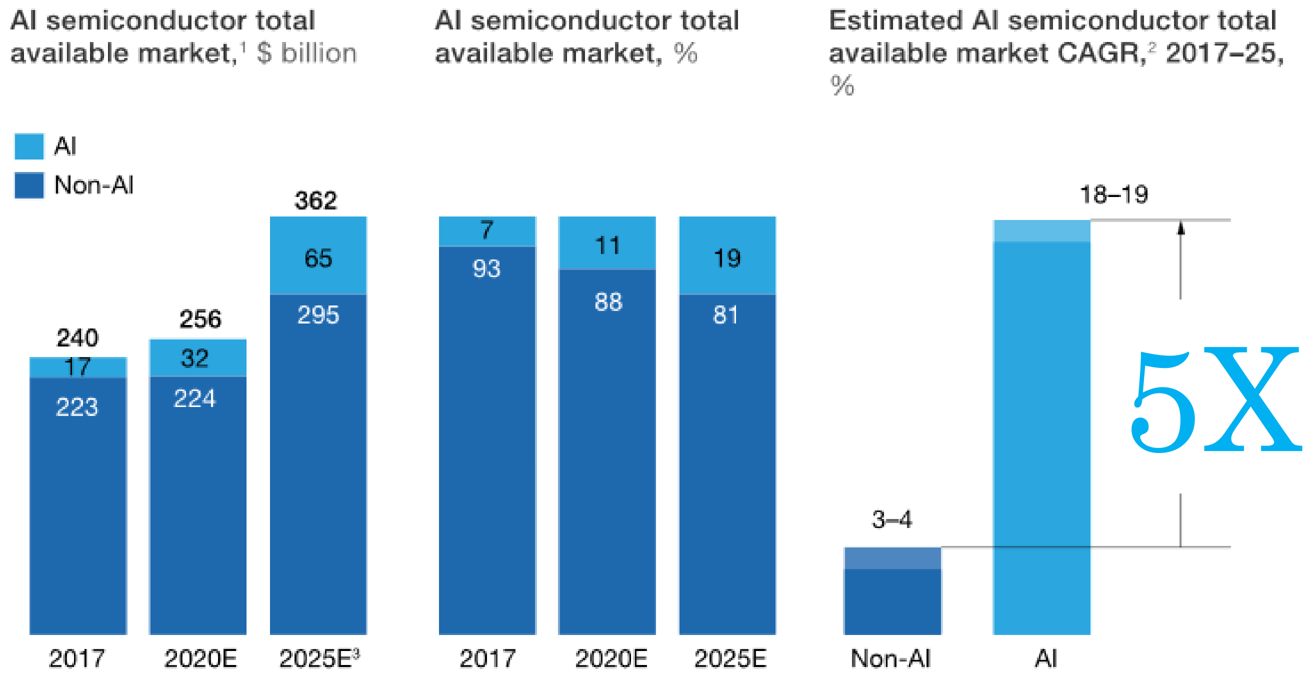
- The industry is evolving to more of a portfolio model — selling chips into many different products, spreading returns across a greater number of assets.

What's next?



2025: AI-related semiconductors will account for 20% percent of all demand, $67 billion in revenue.

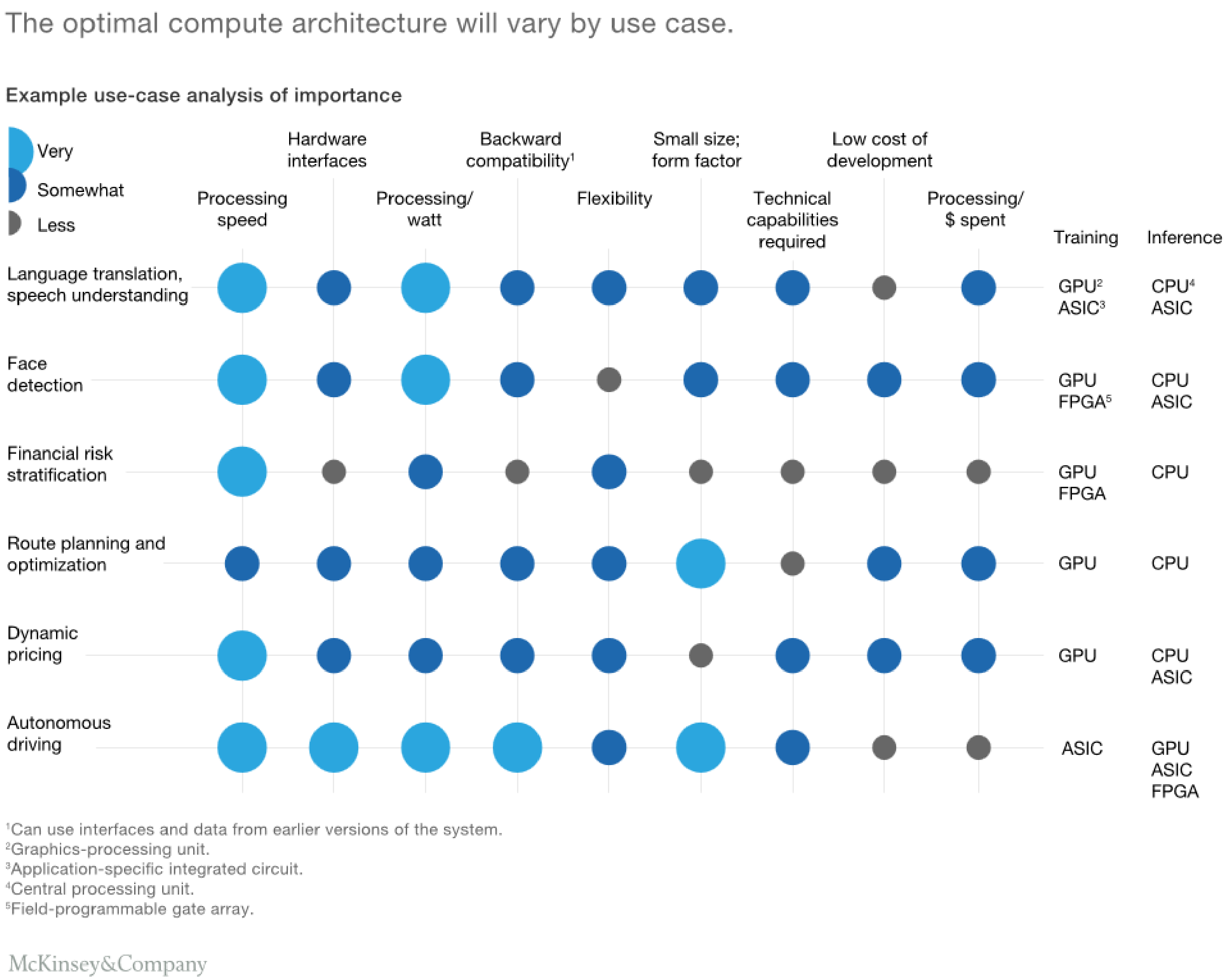
Growth for semiconductors related to artificial intelligence (AI) is expected to be five times greater than growth in the remainder of the market.



[1]Total available market includes processors, memory, and storage; excludes discretes, optical, and micro-electrical-mechanical systems.
[2]Compound annual growth rate.
[3]E = estimated.
Source: Bernstein; Cisco Systems; Gartner; IC Insights; IHS Markit; Machina Research; McKinsey analysis

McKinsey&Company

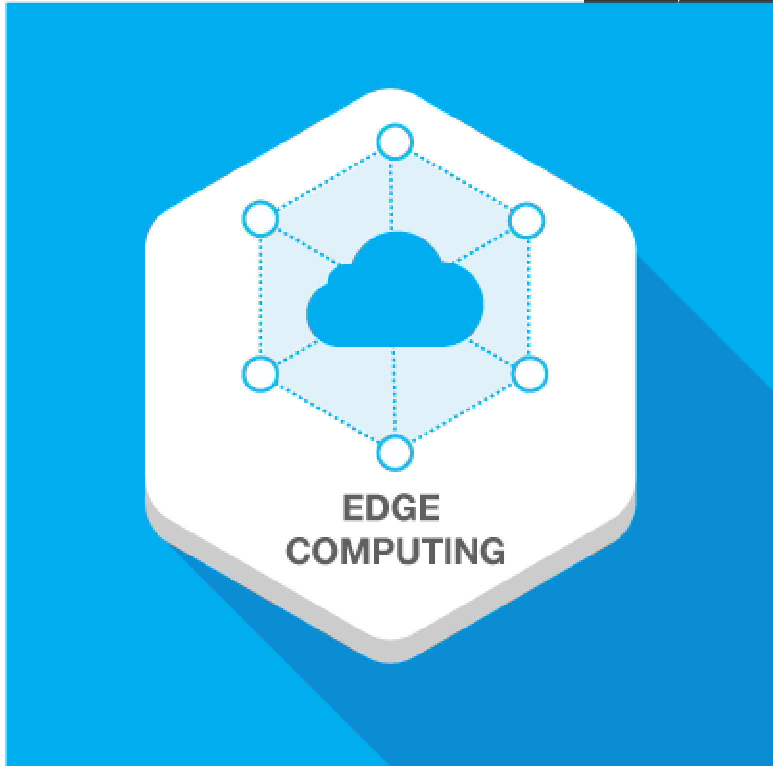
Anticipating (!) future optimal computing



Decentralizing is next.

This is the breathing in and out of the computer industry.

Edge computing is a natural next step from cloud computing.



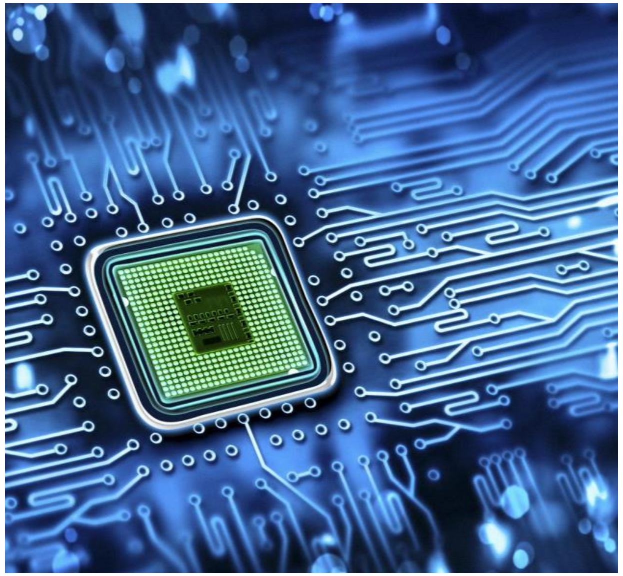
Challenge: creating **next-generation R&D for AI-related semicondutors**!

"Technical or energy constraints make it impossible to stream all that data to the cloud where the AI resides," Rudi Cartuyvels, Imec Smart Electronics & Applications R&D

Anticipating Digital Hardware AI challenges with focus on the Edge

.. for democratized AI verticals

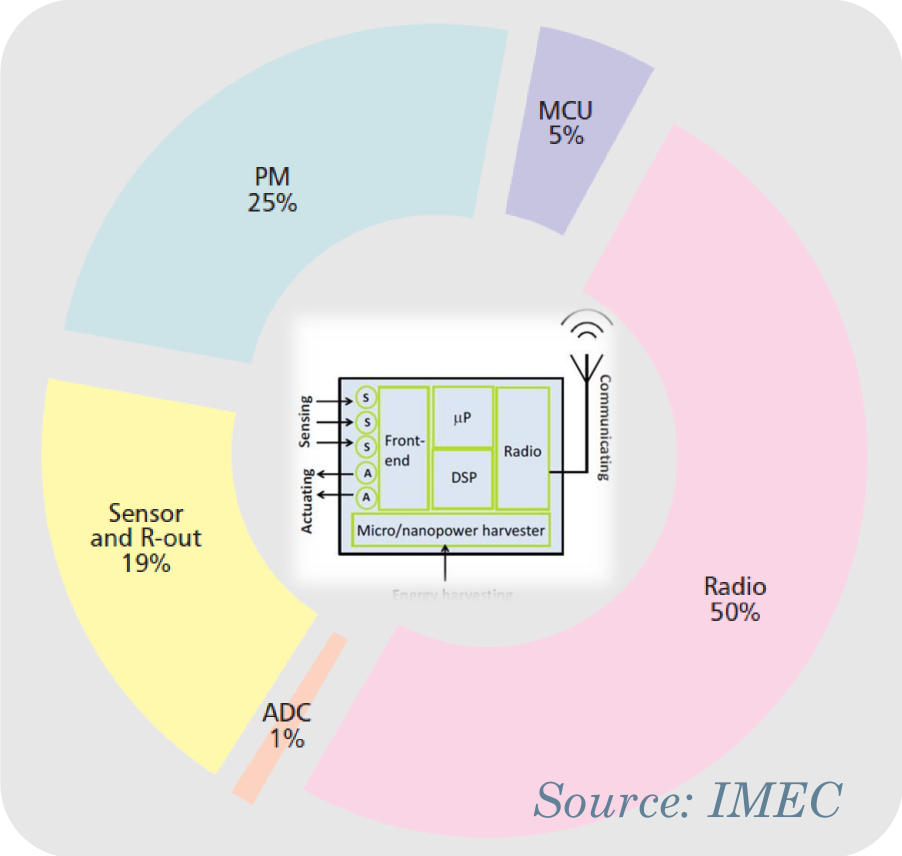
- Computation: from Machine Learning in the Cloud to Machine learning on the Edge
- Energy Efficiency
- Custom Form Factor
- Closer to real-time
- Include enhanced security features
- Self-contained
- Enhanced customer experiences



- Conversational AI
- Bussiness intelligence & analytics
- Cybersecurity
- Automotive
- Healthcare
- Robotics
- Fintech and insurance
- Commerce
- …

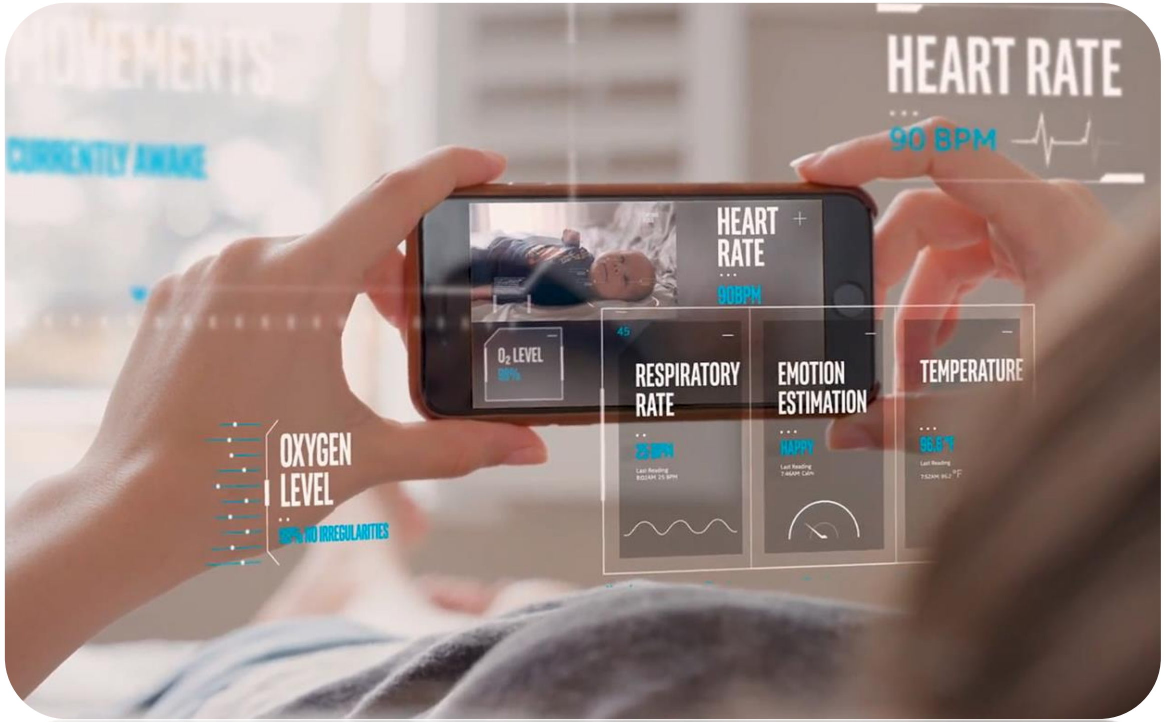
Energy efficient autonomous sensor nodes for Internet of Things

100 microWatt – 10 mW
/ sensor node



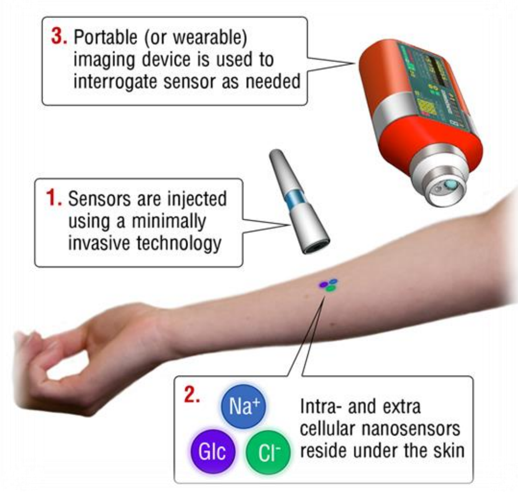
Source: IMEC

Smart hub: 100mW – 10W
(tens of sensors /hub)



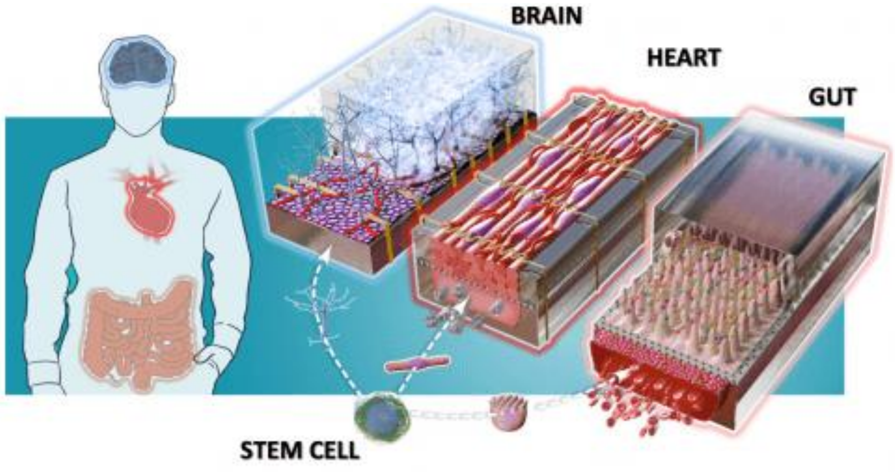
Biosensing as enabler of revolutionary smart sensing & computational systems

- **Wearable** biosensors: ECG, EEG, EMG, SpO2, blood pressure, pH, glucose, various analytes/biomarkers in biofluids, …
- **Implantable** sensors and transducers
- **Organs on Chip** with embedded biosensors!

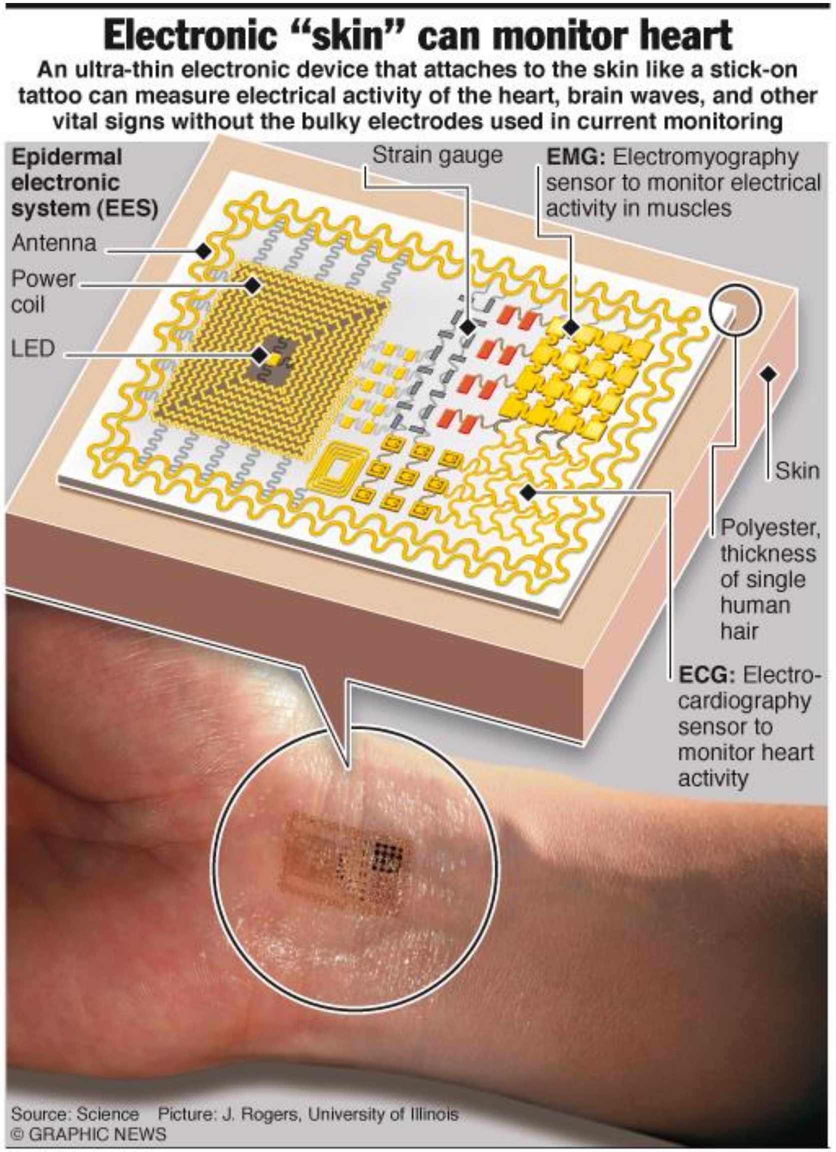


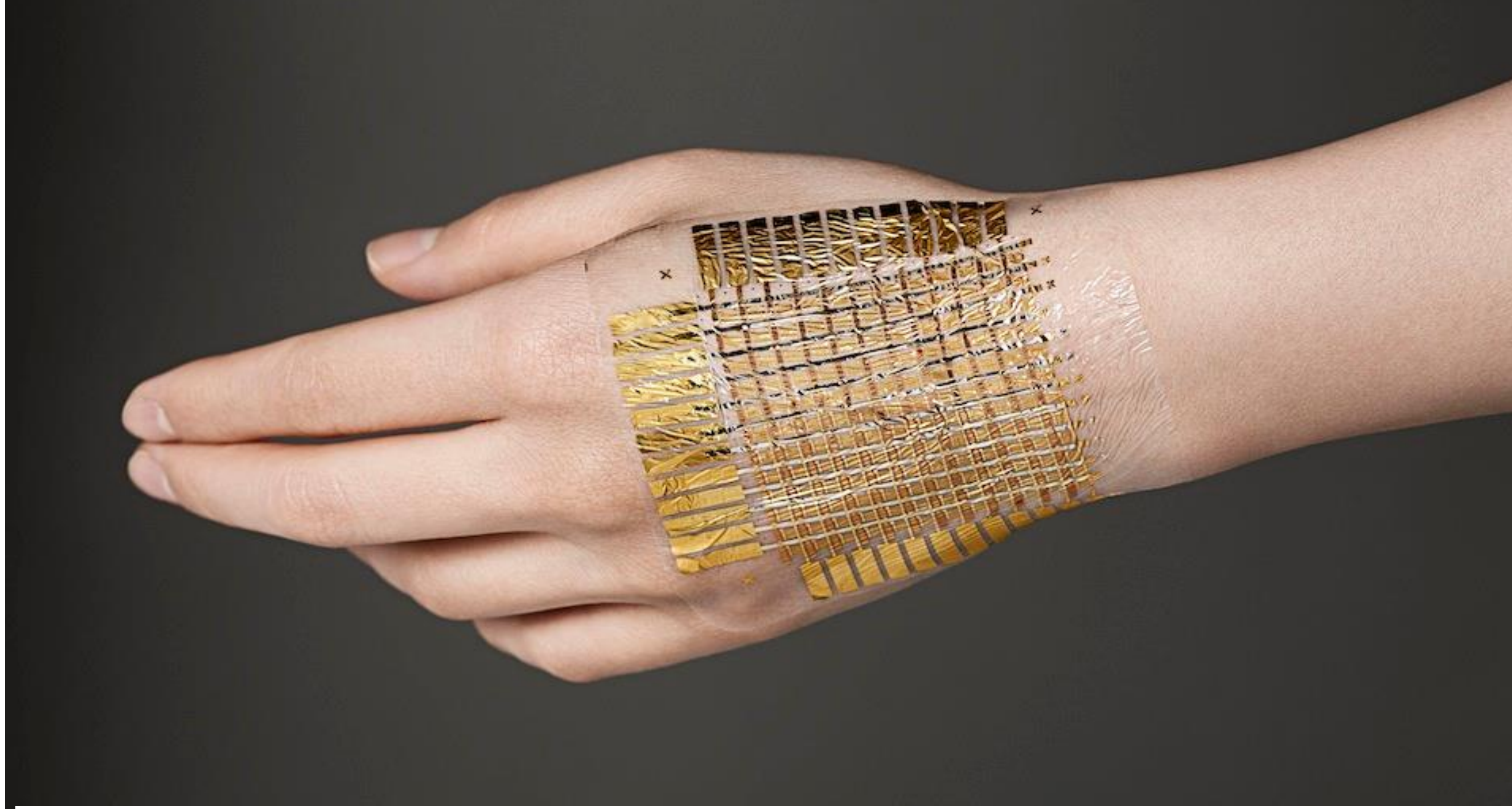
Requirements

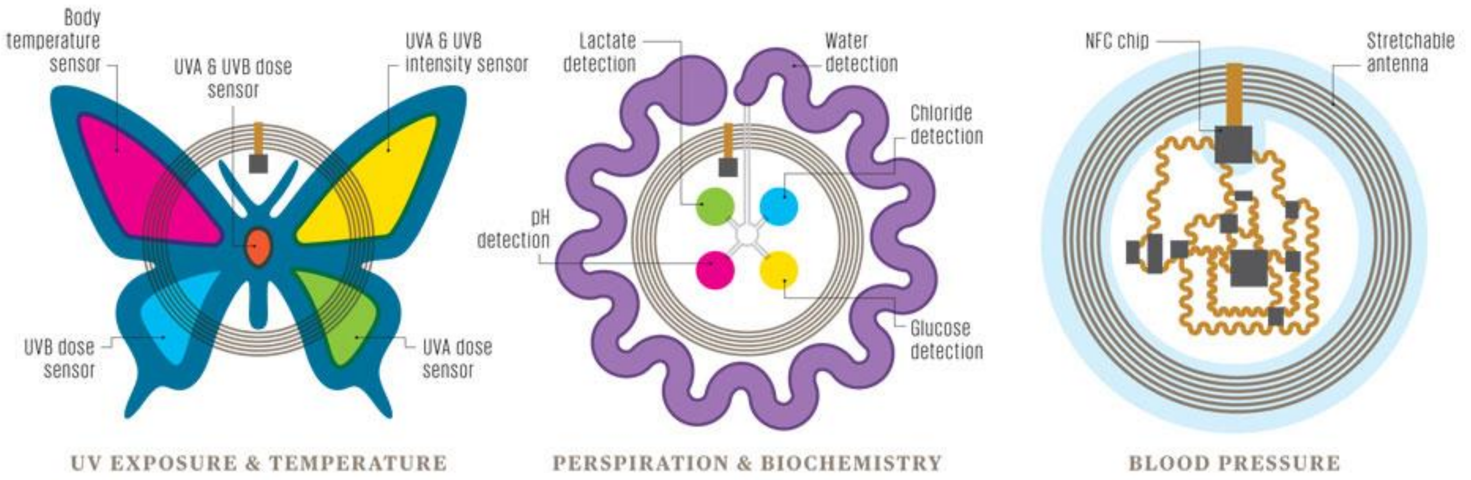
- **High quality data** - multi-parameter sensing
- **Form factor** - frictionless
- **Autonomy** - low power, energy efficiency
- **User acceptance** - data security, privacy
- **Low cost systems** – 3D, on foil integration



Towards sensitive biostamps & tatoos







John A. Rogers, Science, 2011 & IEEE Spectrum. 2015.

Sweat sensing

- An emerging frontier for wearable biosensors

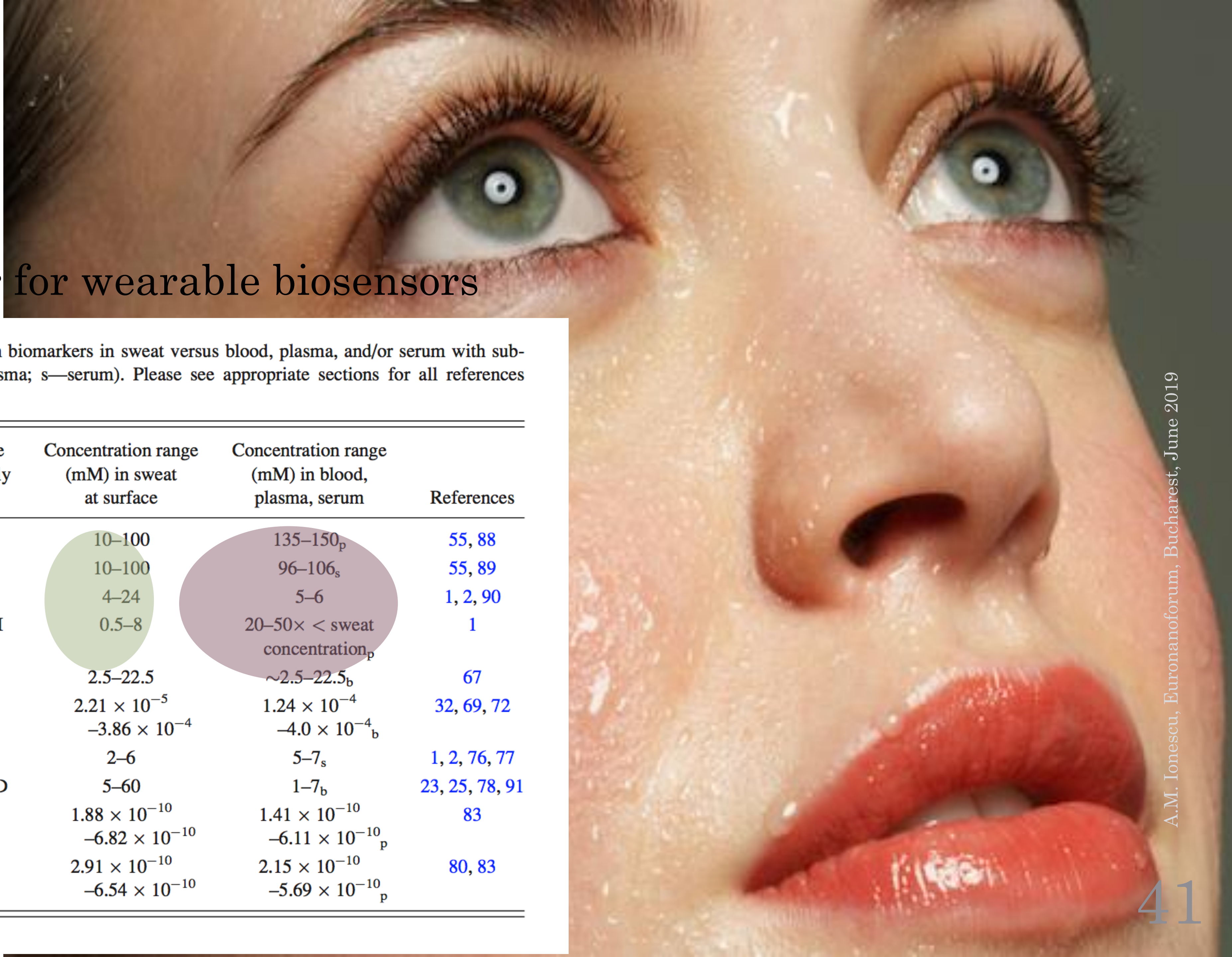
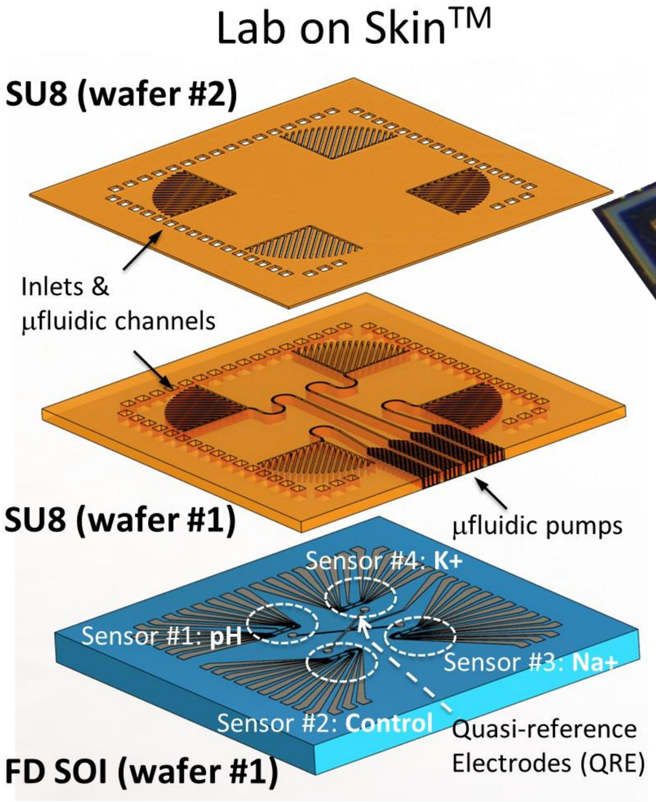


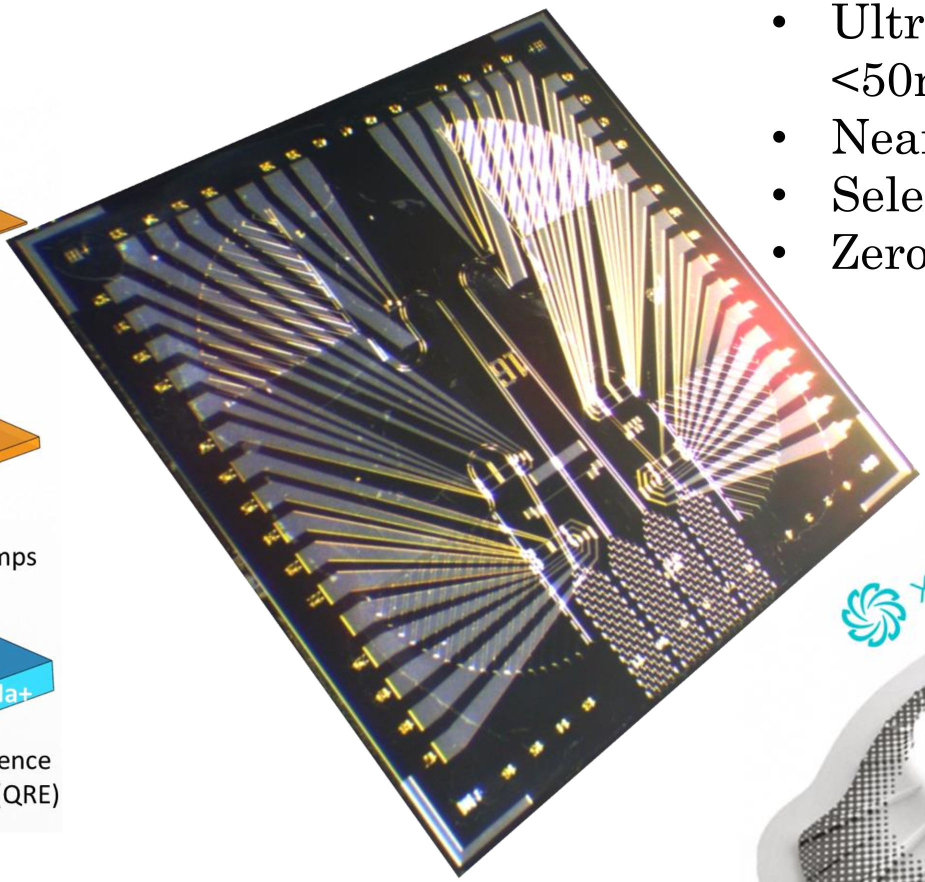
TABLE II. Typical concentration ranges for common biomarkers in sweat versus blood, plasma, and/or serum with subscripts indicating particular fluid (b—blood; p—plasma; s—serum). Please see appropriate sections for all references related to each biomarker.

Biomarker	Partitioning and sweat rate dependent (SWD) or mainly independent (SWI)	Concentration range (mM) in sweat at surface	Concentration range (mM) in blood, plasma, serum	References
Sodium (Na^+)	Active—SWD	10–100	$135–150_p$	55, 88
Chloride (Cl^-)	Active—SWD	10–100	$96–106_s$	55, 89
Potassium (K^+)	Passive—SWI	4–24	5–6	1, 2, 90
Ammonium (NH_4^+)	Passive (amplified)—SWI	0.5–8	20–50× < sweat concentration_p	1
Ethanol	Passive—SWI	2.5–22.5	$\sim 2.5–22.5_b$	67
Cortisol	Passive—likely SWI	2.21×10^{-5} $–3.86 \times 10^{-4}$	1.24×10^{-4} $–4.0 \times 10^{-4}{}_b$	32, 69, 72
Urea	Various, not confirmed	2–6	$5–7_s$	1, 2, 76, 77
Lactate	Generated by gland—SWD	5–60	$1–7_b$	23, 25, 78, 91
Neuropeptide Y (NPY)	Various, not confirmed	1.88×10^{-10} $–6.82 \times 10^{-10}$	1.41×10^{-10} $–6.11 \times 10^{-10}{}_p$	83
Interleukin 6 (IL-6)	Various, not confirmed	2.91×10^{-10} $–6.54 \times 10^{-10}$	2.15×10^{-10} $–5.69 \times 10^{-10}{}_p$	80, 83

Real-time sweat analysis with Lab On Skin™

- Embeddable unique Xsensio's **Lab-On-Skin™ electronic stamp technology**: minute by minute non-invasive multi-biomarker sensing



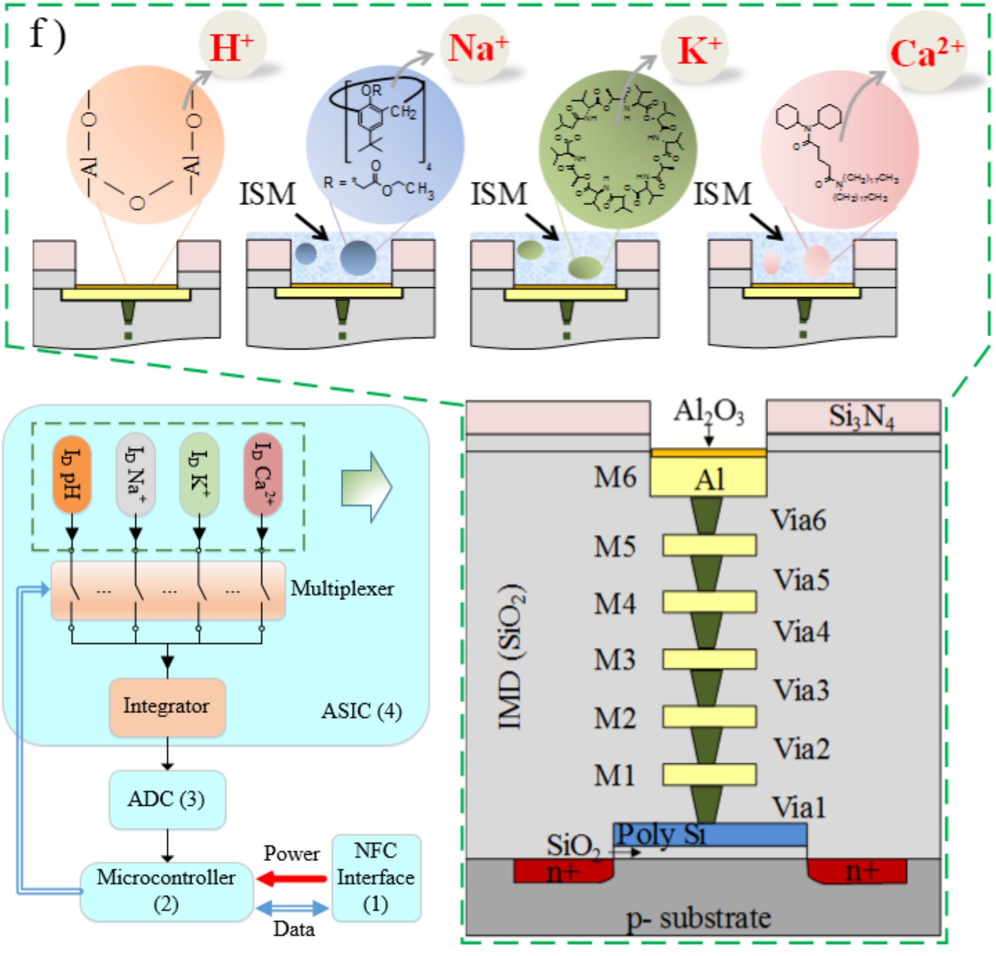


- Ultra-low power UTB SOI ISFETs: <50nWatts/sensor
- Near Nernst limit sensitivity
- Selective
- Zero energy microfludics

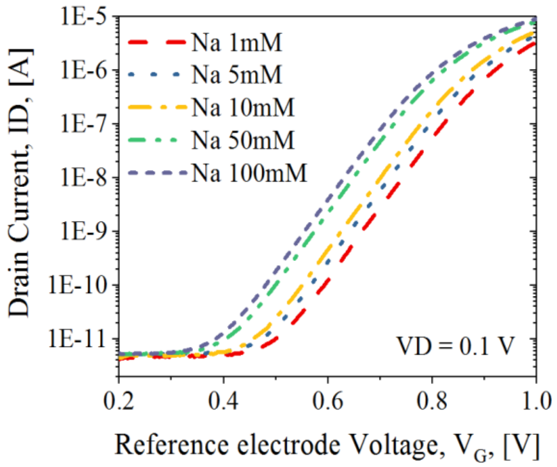
F. Bellando et al., IEDM 2017.

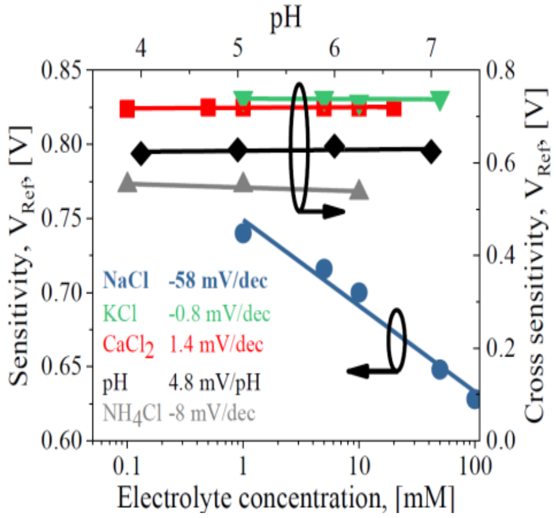
Extended gate ISFETs in CMOS BEOL for pH, Na+, K+ and Ca2+ sensing

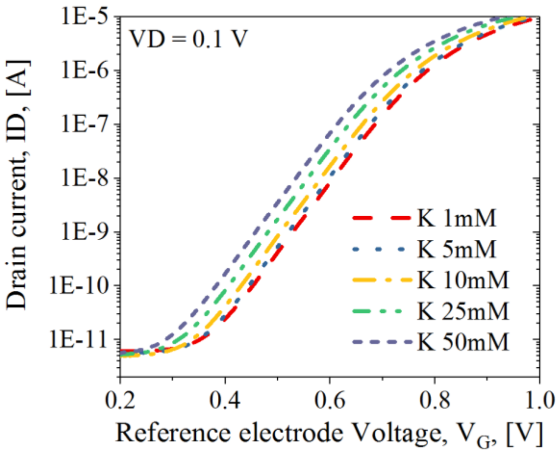
J. Zhang et al., @ IEDM 2018.

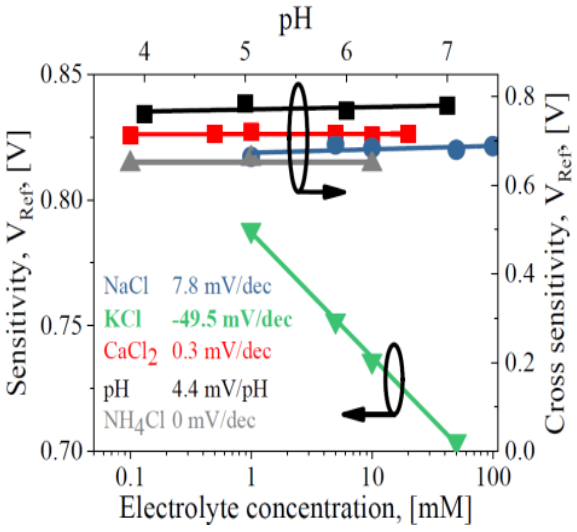


d) e)



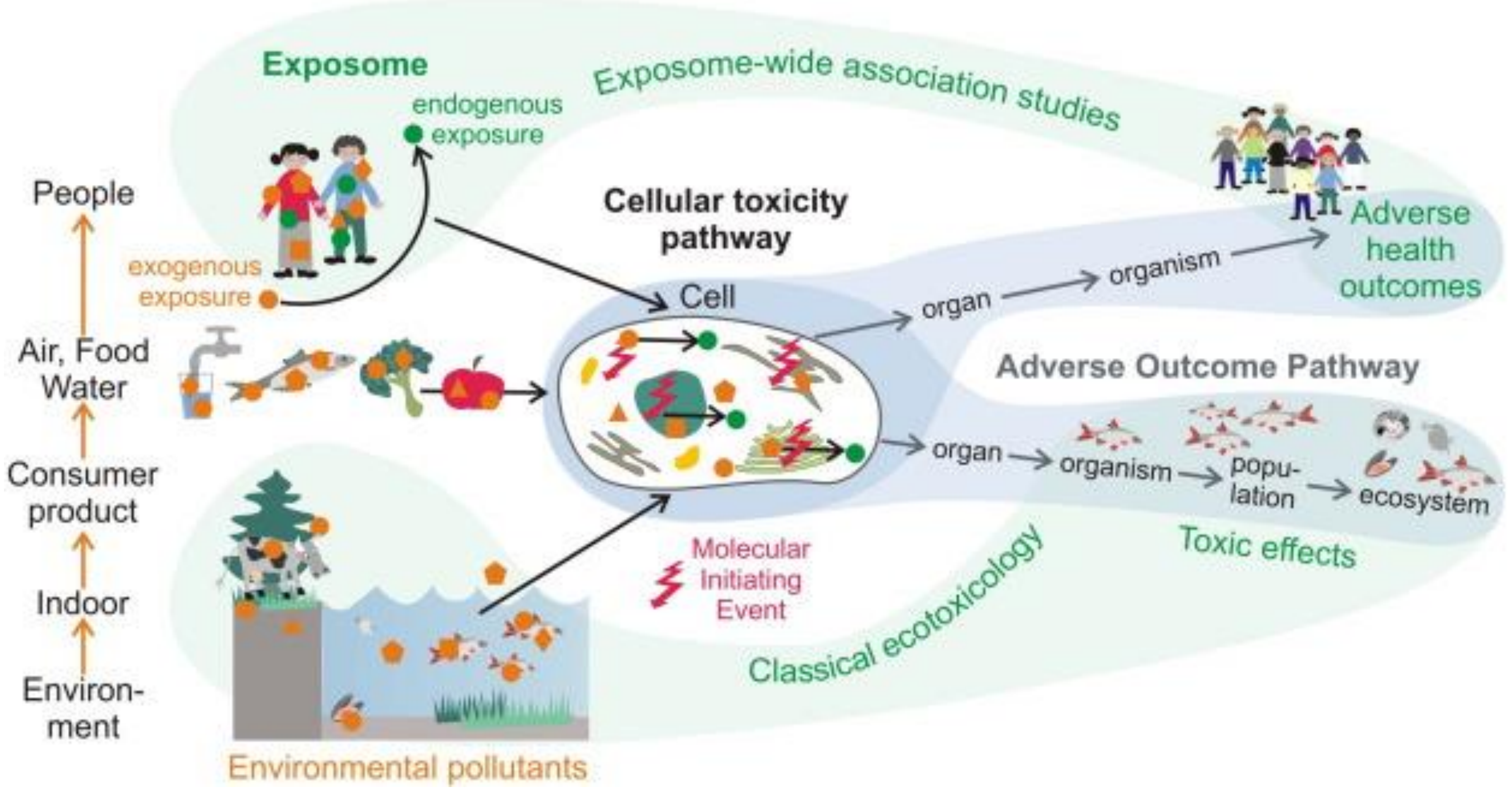






Micro/Nanotechnologies for human exposome

- The **exposome represents a concept that incorporates the complex exposures** we face as humans.
- **Effect of mixtures**: an increasing body of science shows *a neglect of mixture effects can cause underestimated chemical risks*, leading to adverse health outcomes.



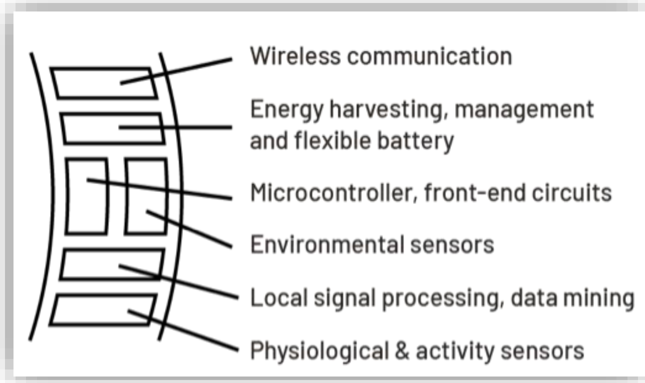
Wearable exposome gas sensors

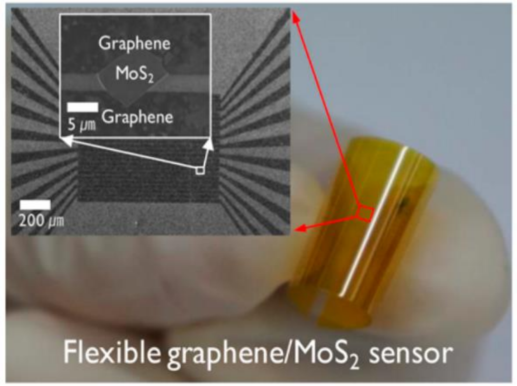
Provide the exposome (environmental) sensing technology that is consistent with the form factor and low energy budget.

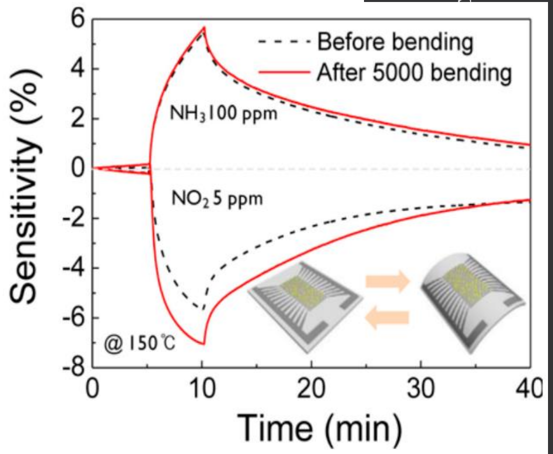
- Exposome: gases (O_3, $NO_{2/x}$, SO_2, CO, CO_2, VOCs), particles (PM2.5, PM10) and relative humidity (R.H.).
- Resolution: EC Standards.
- Power consumption: ~10µW (incl. ROIC).
- Form factor (size): 0.1-1cm.
- Rate: 1-10 Hz.
- Benchmarking

Heterogeneous system integration

On-foil integration

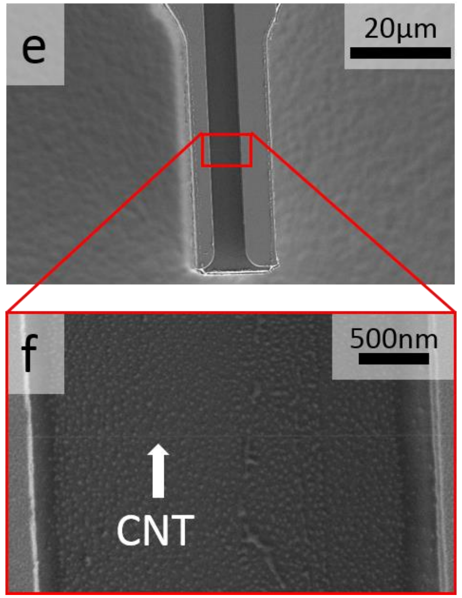


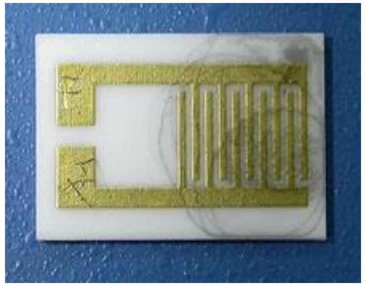




Exposome gas and particle sensors in Flagera CONVERGENCE

Energy-efficient, compatible with on-foil integration and including interface electronics



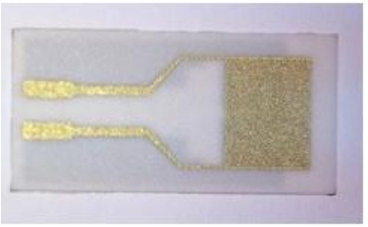


$NO_{2/x}$ sensors

carbon-based (CNT, graphene)

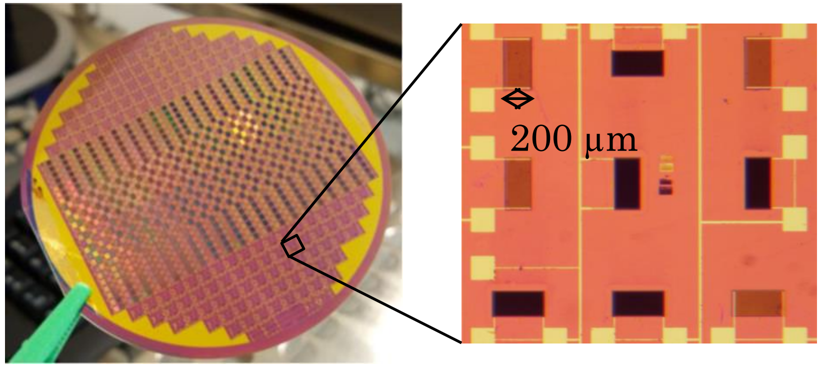
ETHZ **IUNET-BO** **ENEA**

IMT

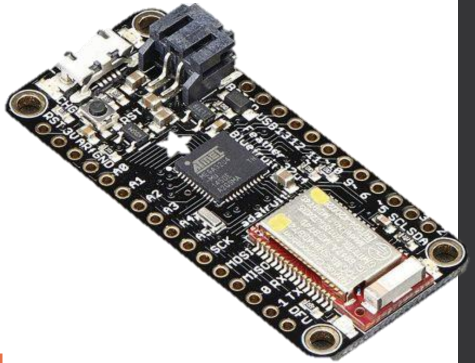


CO, NH_3, VOCs

polymeric layers (Polyaniline, Polypyrrole)



UCL



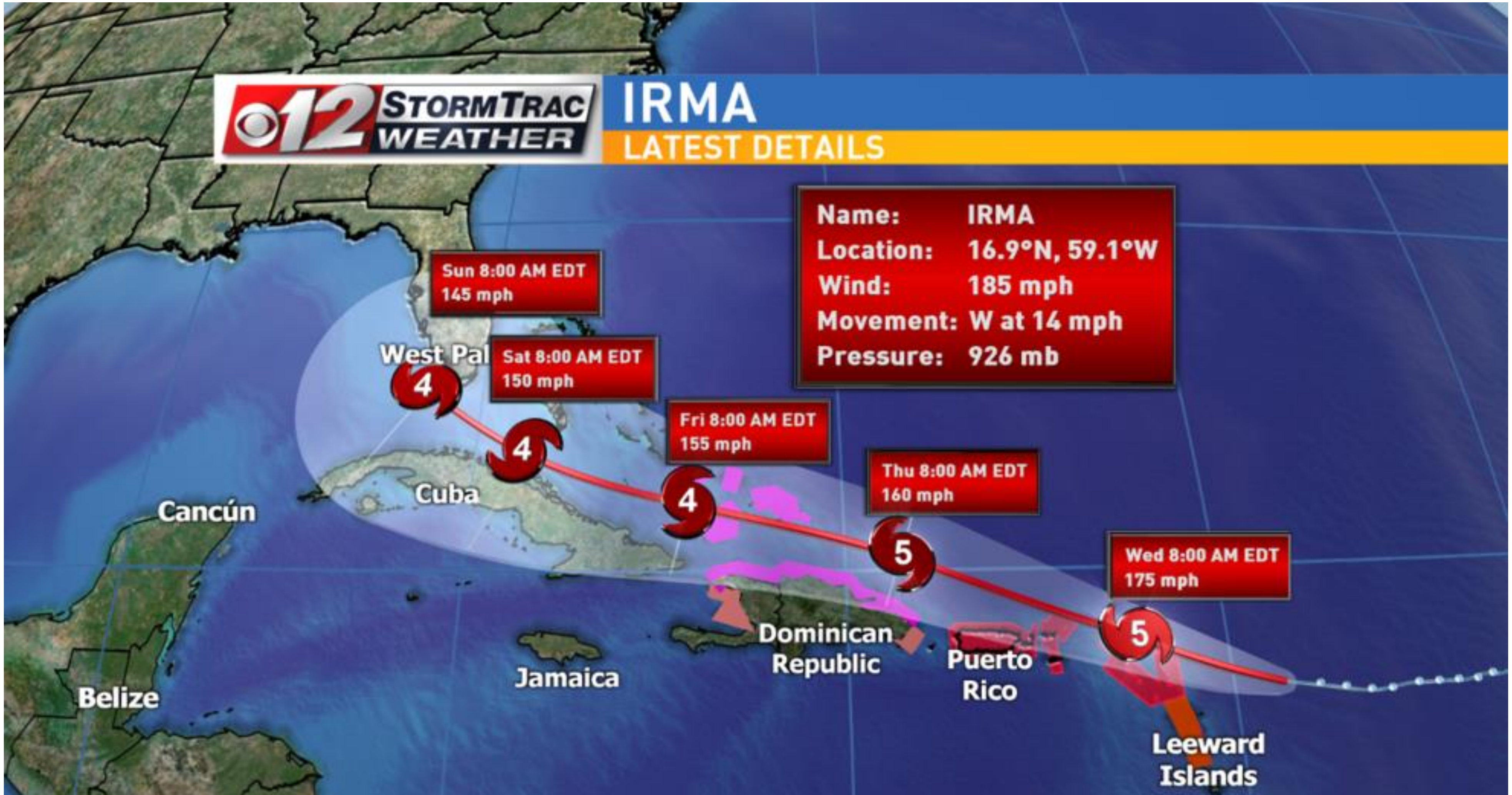
CO_2/O_2

voltammetric sensors

UCBM

What else?
Today our technology can predict weather…

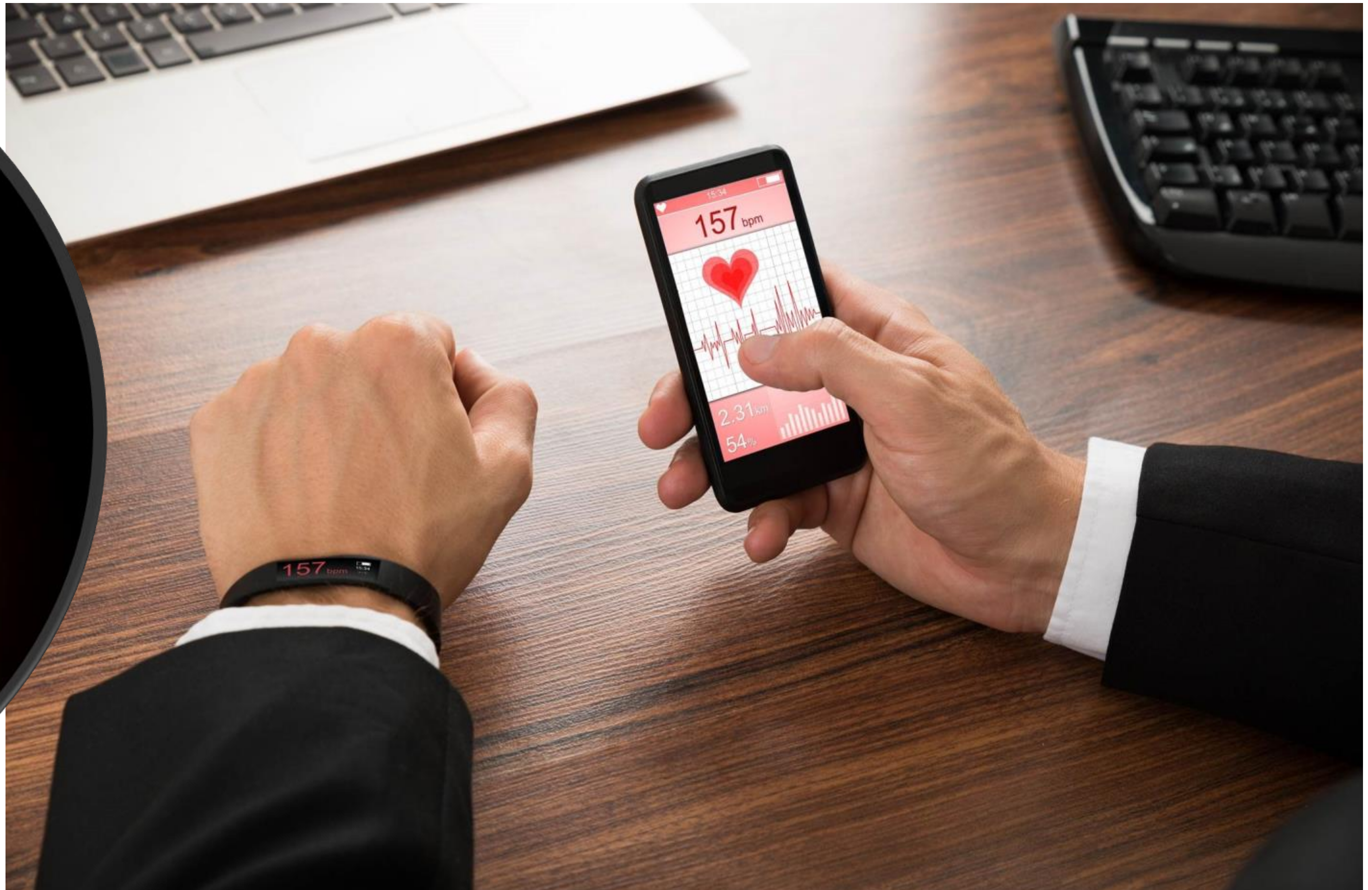
SENSORS → BIG DATA → MODELS → COMPUTING → **WEATHER FORECAST**



… but cannot predict health status

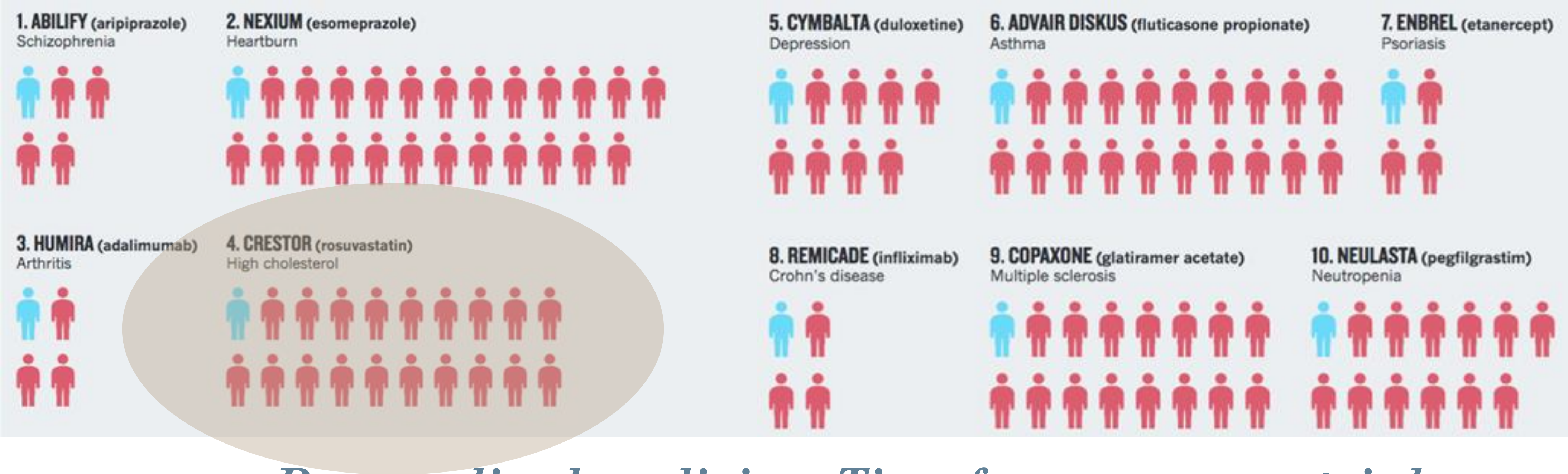
- Goal: turning a stream of information into predictions of outcomes
- **Can a Wearable Fitness Device Predict Your Heart Attack? Value chain!**

SENSORS → BIG DATA → MODELS → COMPUTING → **HEALTH FORECAST**



2018: Imprecision medicine era

For every person they do help (BLUE) the ten highest growing drugs in USA fail to improve the conditions of 3 to 24 people (RED):
IMPRECISION & HIGH COST!



Personalized medicine: Time for one-person trials

N.J. Schork, Nature, 2015.

Severe consequences…

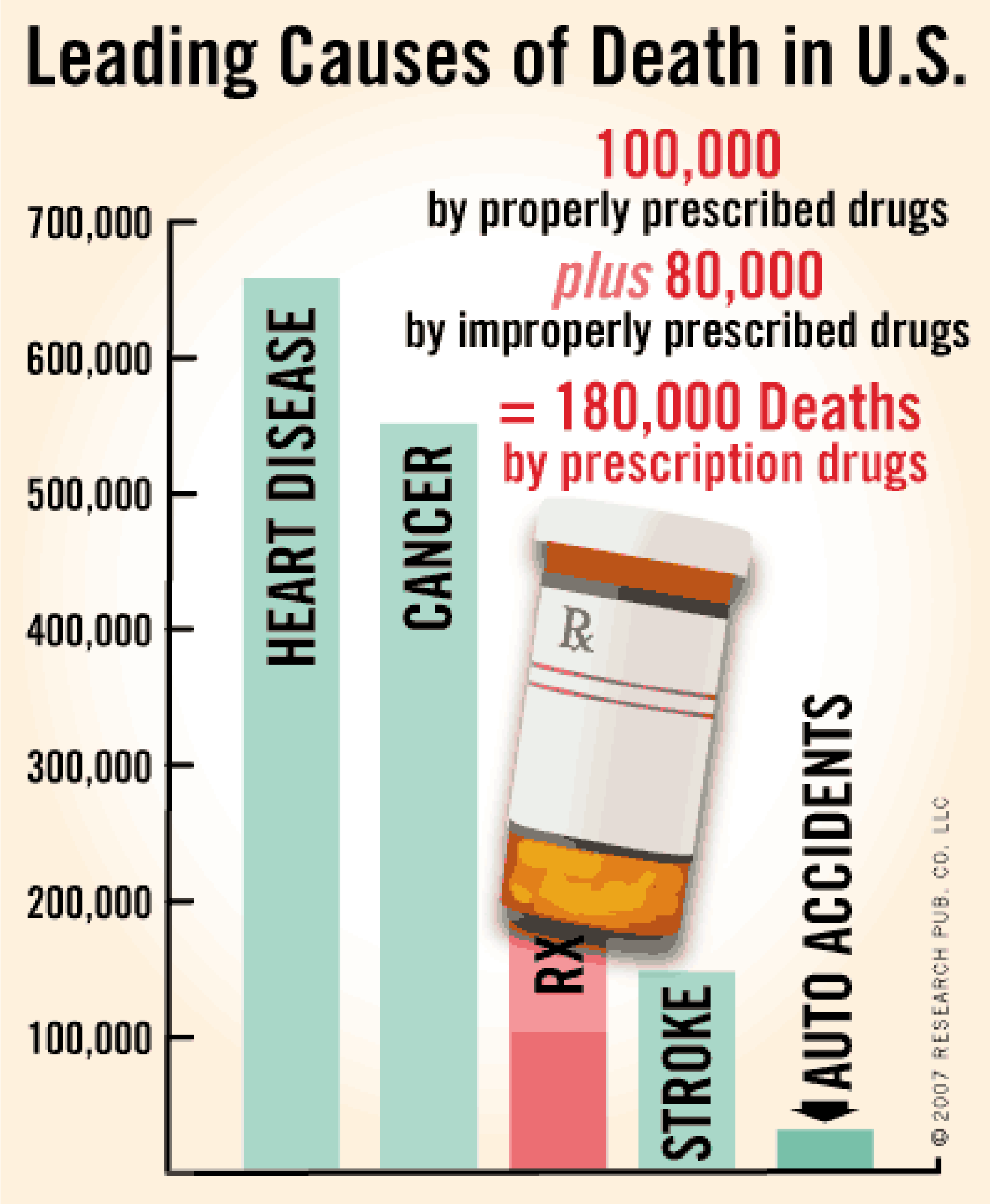
Adverse drug reactions:

kill 197’000 Europeans every year

kill 180’000 Americans every year

This is more than colon cancer!

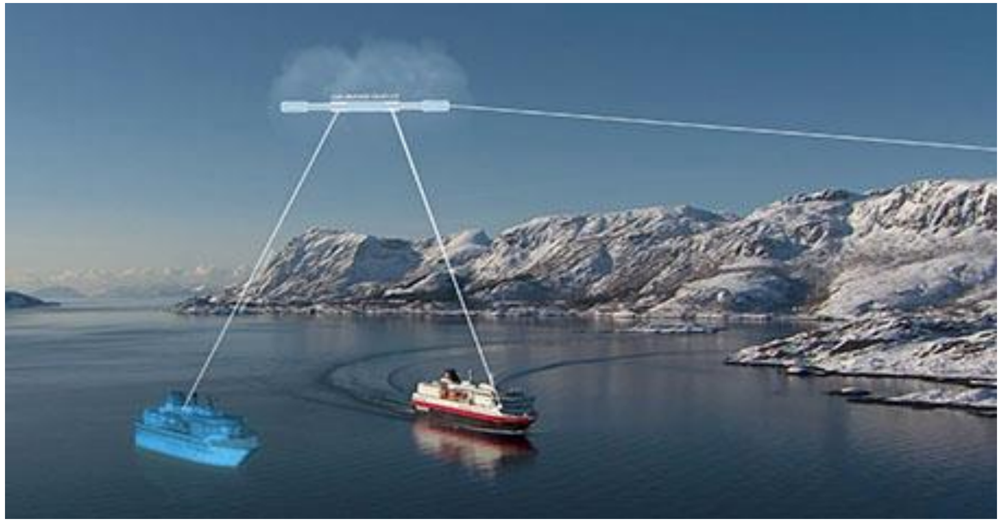
Time to act!

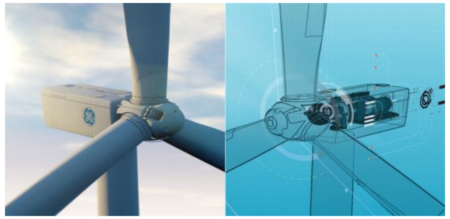


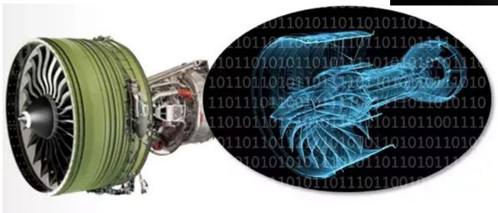
SOURCES of Data: U.S. Centers for Disease Control and Prevention and Journal of the American Medical Association (JAMA).

2030: From Object to Human Digital Twins

Digital Twins of All Objects







Digital Twins of All Humans

A Truly Personalized and Preventive Healthcare System: ***SUSTAINABLE***

Health EU

Healthy You!

Imagine a revolutionary healthcare and disease management system in Europe, built on human avatars aiming at:

Empowering every citizen with a Human Avatar enabling access to comprehensive personalized healthcare, healthy lifestyle and disease prevention

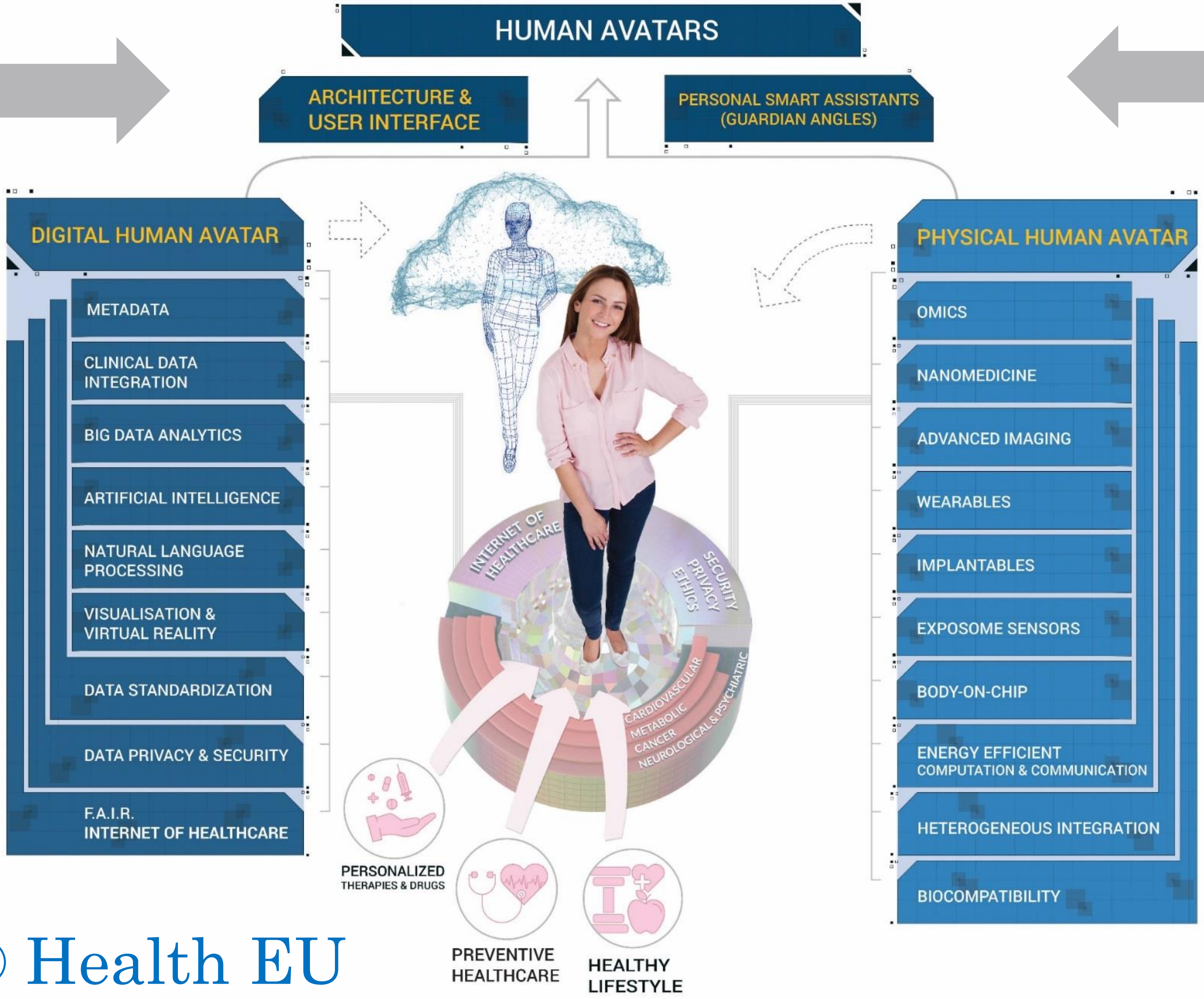
Why Health EU is disruptive?

- **missing link** of the 21st century for **breaking barriers** between Medical Knowledge Creation and Medical Knowledge Application
- **creating the Citizen – Human Avatar – Clinical Professional triangle** for the personalised, preventive and participatory healthcare vision proposed by Health EU.

A.M. Ionescu, Euronanoforum, Bucharest, June 2019

Health EU Integrative Technology Platform: much more than a Digital Twin…

Big
Data
IoH
AI



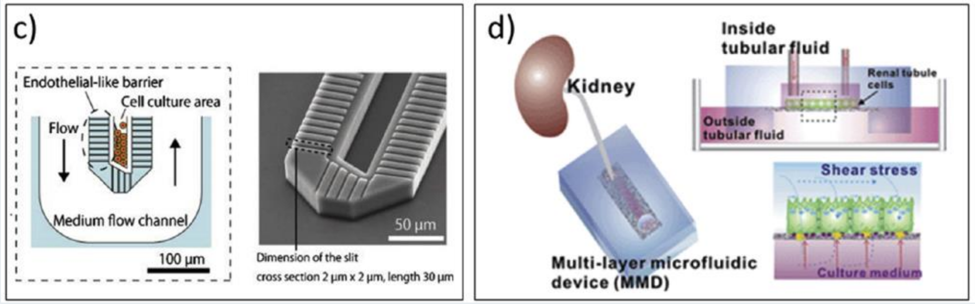
Data
Generator
Technology
Body-On-Chip

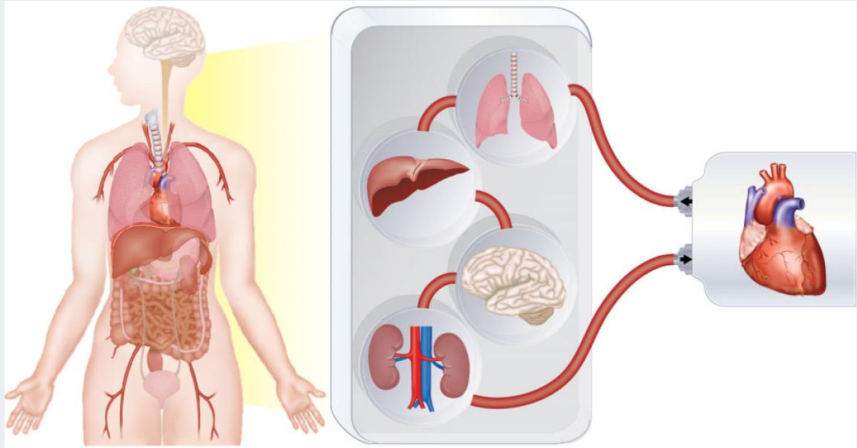
Organ-On-Chip Technology in Health EU

OOC → Body-On-Chip goals

- **Strategic dedicated Roadmap for OOC/BOC**
- **3D biocompatible heterogeneous integration platform: microfluidics + sensors & actuators**
- **Validated realistic, multicellular and physiologically relevant OOC models of any healthy individual or patient**
  - capability to model a unique genetic background
  - used for prediction of disease predisposition and severity
  - serve as test systems for the discovery of new effective treatments (clinical trial-on-chip) and repurposing of drugs
- **Long term: scaled production and standardization of OOC and its development into a Body-on-Chip technology**
  - to create multi-organ/body-on-chip surrogates to study inter-organ communication.
  - gradually replacing animal experimentation

Body-On-Chip systems: future in vitro tools to enable the discovery of new mechanisms underlying diseases





H. Kimura et al, Drug metabolism & Pharmacokinetics, 2017.
D. Bovard et al, Toxicology, 2017.

Health EU expectations

- Delivering on the promises of personalised and preventive medicine in **advancing towards affordable universal healthcare solutions**
- Taking medical sciences and practice to the next level **to promote well-being and improve life expectancy in good health**
- Providing future tools and infrastructure **to accelerate the generation of new data that can further enhance our knowledge** to support prevention and personalised treatment of diseases
- Creating **new business models, financing frameworks and incentive schemes**

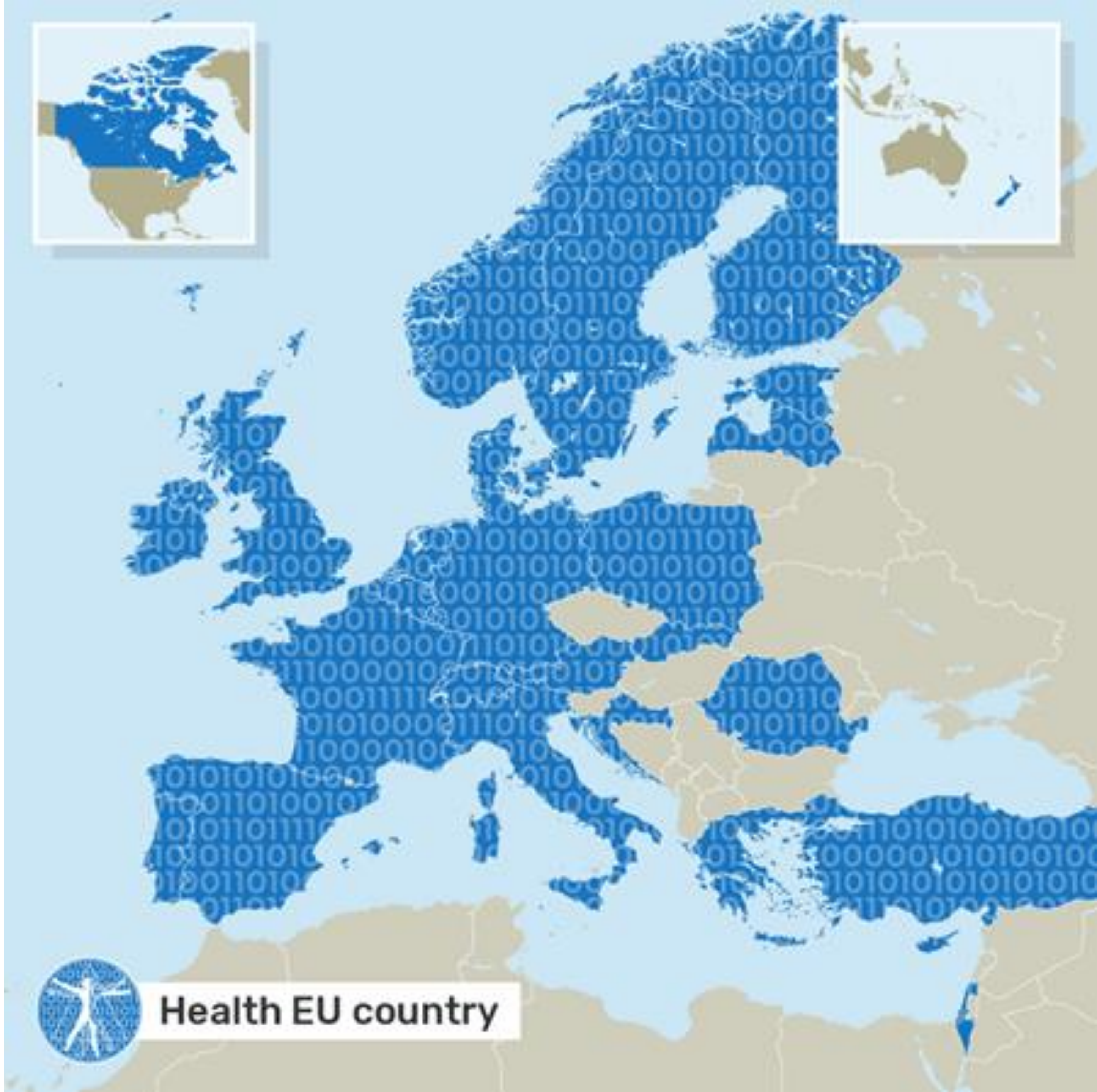
➢ You, Your Human Avatar, Clinical Professional

➢ Up to 80 % of the costs associated to NCDs preventable with Health EU Human Avatars:

- Less chronic diseases (by prevention and monitored avatar-guide healthy living)
- Better Quality of Life
- Less adverse drug effects & medical errors (3rd leading cause of death)
- Cheaper medication by personalized repurposing
- Less need for organ transplantation by prevention
- Less (severe)surgical interventions and less misguided therapies
- Less need for animal testing by Organs on Chip

Health EU Consortium

- 110 participating organisations from 29 countries
- Unifies:
  - 87 ERC grants
  - 308 FP7/H2020 project coordinations
  - 633 large national programme leads



Health EU stakeholders

- **100+ stakeholders**
- **3 chambers**

❖ Chamber A: large industries

❖ Chamber B: patient and professional organizations, hospitals, public and private insurance companies and regulatory bodies.

❖ Chamber C: innovative SME's, start-up companies and start-up investors

(Yves Bayon)

Conclusions

Almost there…

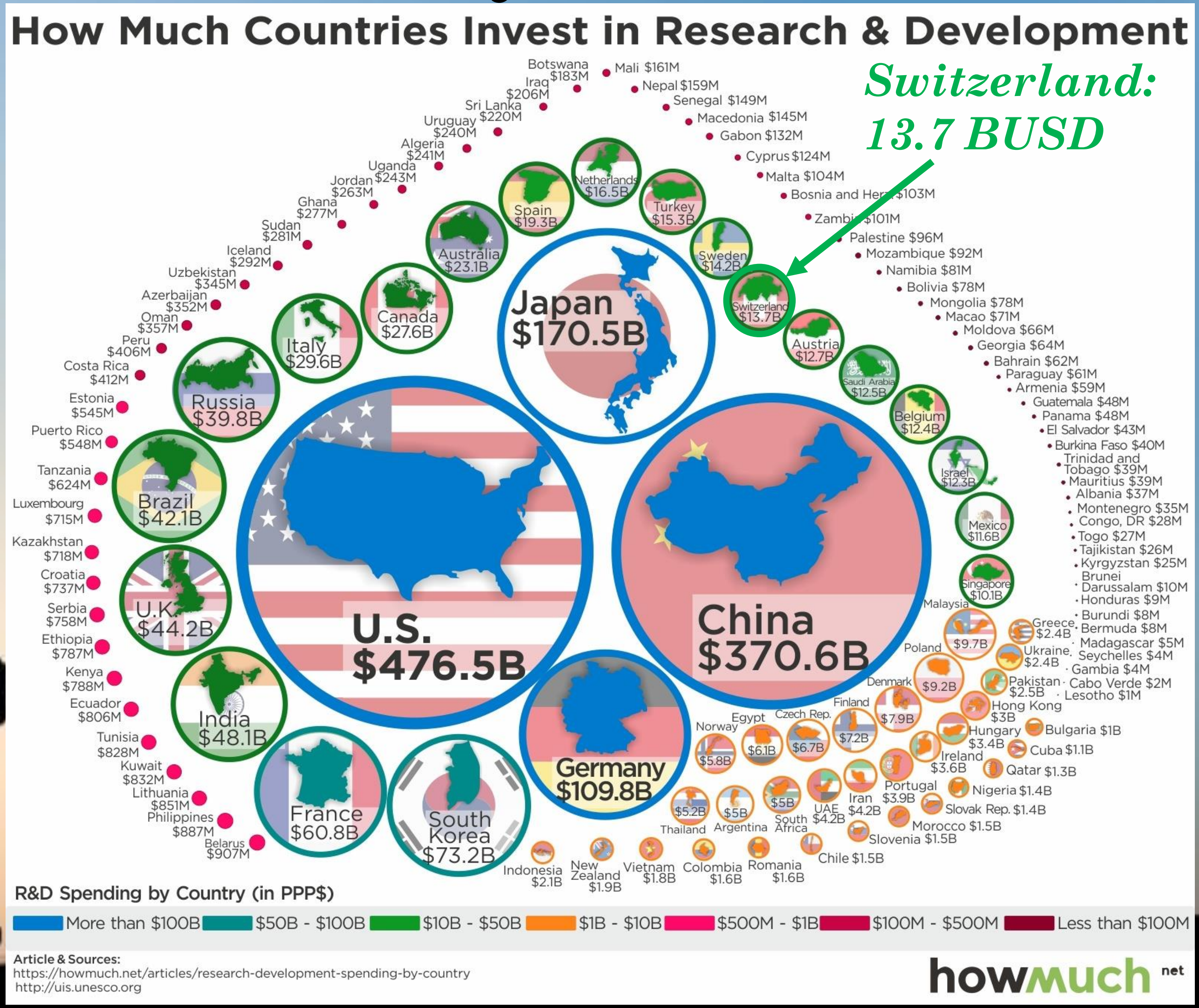
- Extraordinary progress made by R&D in Horizon 2020 EC programme.

What is next?

- High expectations in framework R&D programme Horizon Europe from novel technologies to sustainably solve **Human Great Challenges: Climate Change, Energy and Health!**
- **Energy efficiency** technologies form the next driver in the **zettabyte era**.
- Future innovations: based on **TECHNOLOGY-SYSTEM-DATA** interactions!
- **Democratized Edge Artificial Intelligence**: huge opportunity for semiconductor technology in 21st century – new strategic verticals!
- A revolution in P3 **Digital Healthcare** is possible by **Nanotech & AI: Human Avatars for a Healthy YOU!**

How to effectively ACT?

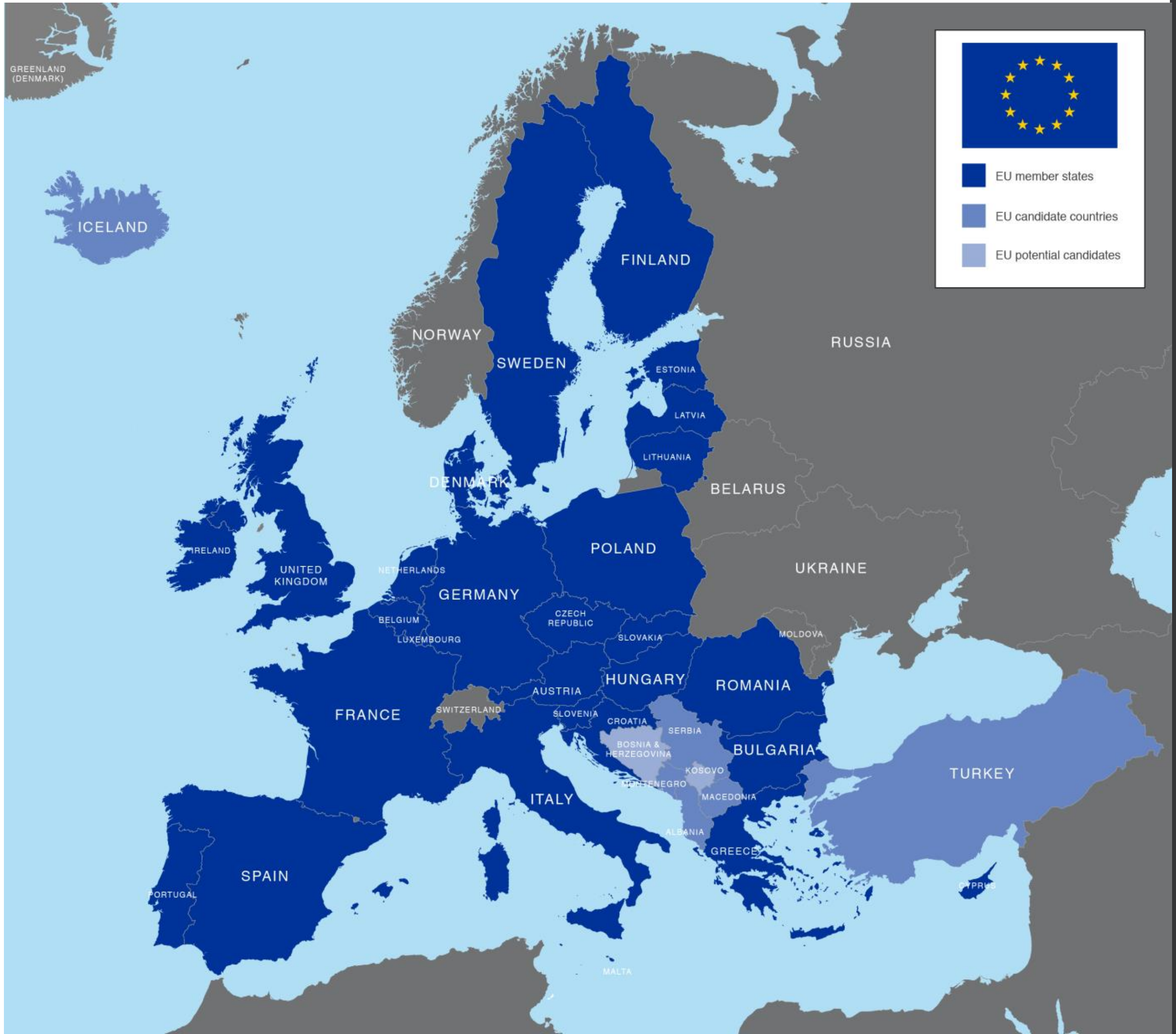
Education, Research, Innovation & Health: are strategic investments in the future of any nation



Europe of Convergence

romania2019.eu

Wealth is WHealth: enabled by Nanotech & future AI!



Thank you!

Questions?