NanoElectronics Roadmap for Europe: Identification and Dissemination

2nd General Workshop

Athens, April 6-7, 2017

WP4/Task.1

HORIZON 2020

Importance of Smart Sensors

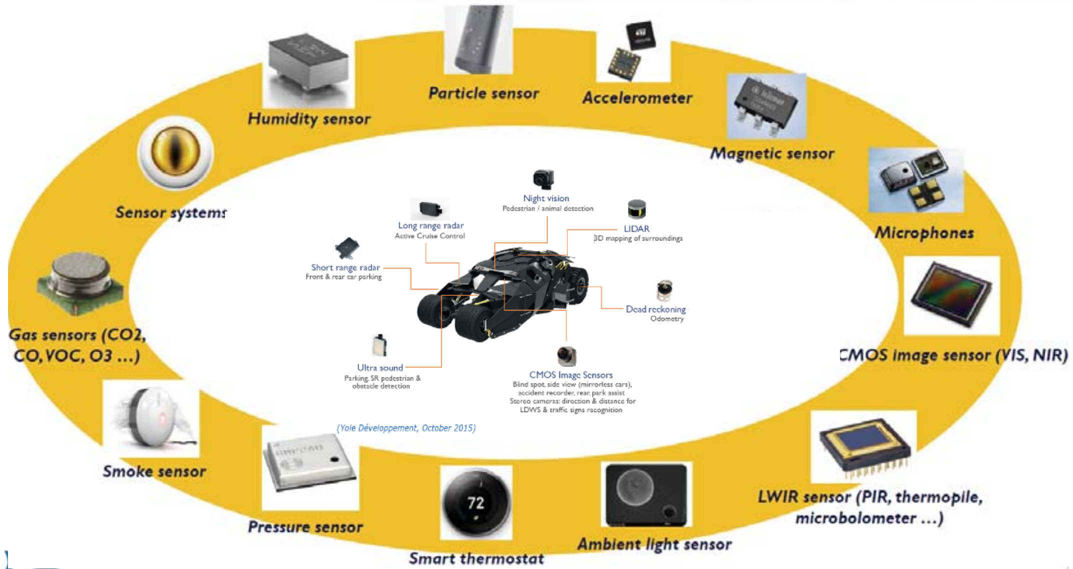
❖ Global Challenges:

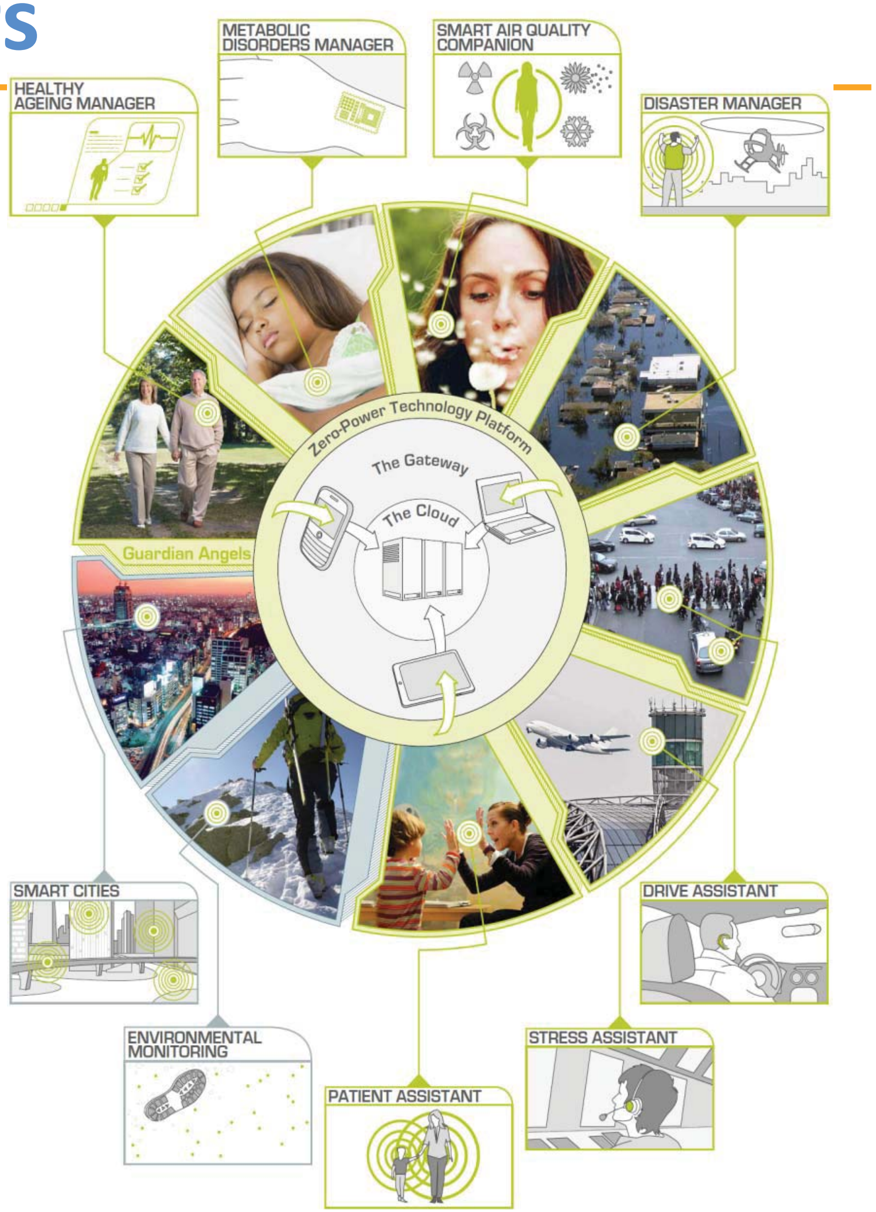
- Healthcare, energy, environment

Much more than infotainment:

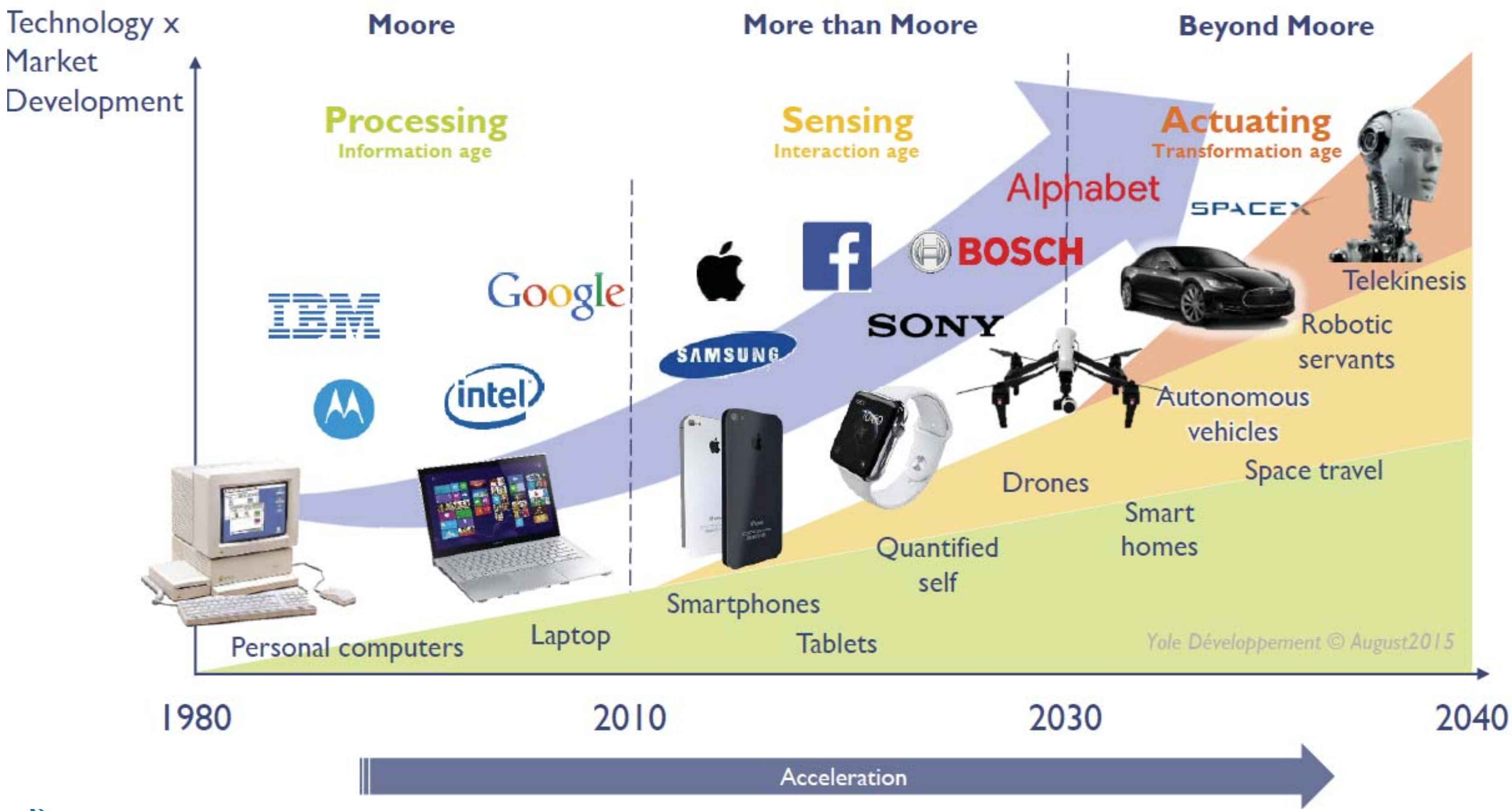
By combined low power sensing, computing, communication and energy management

New **Quality of Life:**





Global technology Roadmap



Outline

- 1. Key Research Directions & Challenges
- 2. Smart Sensor Application needs
- 3. Smart Sensors Technology - Design Challenges
- 4. Smart Sensors Figures of Merit
- 5. Other issues and interaction with other Tasks/WPs

1. Key Research Directions & Challenges

Key Research Directions	Medium term: 5+	Long term: 10+
Multi-parameter sensing	XX	XXX
Autonomous sensor systems	XX	XXX
Role of new materials and nanostructures in sensing (versus mature CMOS sensors)	XX	XX
System-in-Package (SiP) sensors	XXX	XXX
Autocalibration	XXX	XX

Open Challenges (1)

- Energy efficiency: per electronic function needs progress. The enabling zero-power approach will be disruptive overall for efficient autonomous systems.
  - Low power sensing + energy harvesting = most elegant approach
  - Batteries implemented efficiency or environmental friendly solutions

- CMOS integration, compatibility and readout circuitry: with novel hybrid technologies, integration becomes more challenging and reliability less predictible.

- Packaging: required within sensor development (SiP versus SoC). Its optimization is even more important than materials (→ Task 5.2 Heterogenous Integration)

Open Challenges (2)

- **Stability and Reliability:** are important features for the industrialization of the sensors.

- **Assembly Testing, metrology and calibration:** there is a lack of metrology standards, is time consuming and difficult to interpret the results. Self-calibrated sensors does not exist in the market yet apart from CMOS capacitive sensors.

- **Maturity level:** of each sensor technology has to be assessed. TRL correlation with technology performance versus cost, repetability, stability, yield, etc for high volume sensors or niche applications.

2. Smart Sensor Application needs

Potential for application or Application needs and Impact for Europe

Application needs	Medium term: 5+	Long term: 10+
Healthcare & Wellness Application		
- Physiological signals monitoring	XXX	XX
- Biomolecule/particle detection for disease diagnostic	XX	XXX
- Indoor/Outdoor air quality control & monitor	XXX	XX
Automotive Application		
- Sensors for autonomous cars: ultrasonic sensors, vision sensors, radars	XXX	XXX
- Sensors for driver assistance & monitoring (detect allertness, fatigue and drownsiness → physiological signals)	XX	XXX
- Pollution detection (gas and particles)	XXX	XX

Application needs: Healthcare & Wellness

Physiological signals monitoring

in wearable devices to enhance well-being, prevent cardiovascular accidents or dehydratation and to improve management of chronic/ acute diseases

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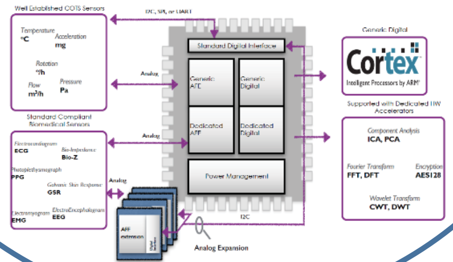
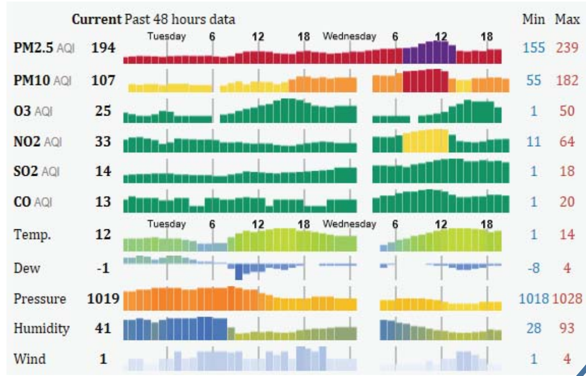


Biomolecule/ particle detection

for virus detection, counting of particle or DNA recognition

Indoor/Outdoor Air quality control & monitoring - Gas Sensors



Healthcare & Wellness

Other sensors

- *Water vapour or relative humidity sensors*
- *Pressure sensors for blood pressure, bladder examination*
- *Displacement and force sensors, tunable resonator or mass balances*
- *Tactic sensors for height and fall detection*
- *Implanted sensors*

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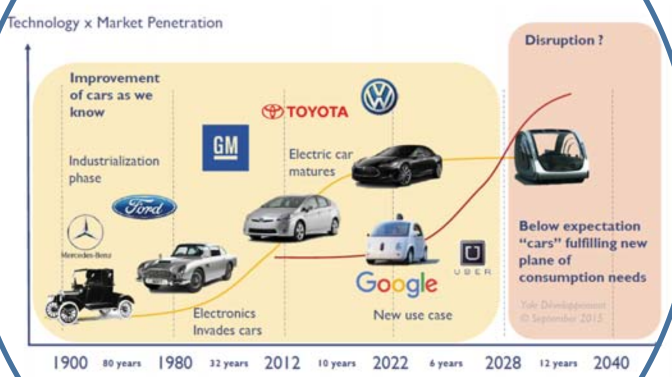
Medical Sensor Technology Requirements

- **Good quality signaly**
- **Frictionless technology**
- **Autonomie** ultra-low-power or enegry harvesting
- **Clinical validation** and **user adoption**
- **Safety/ Security** big data storage & computing power (filter, process)
- **Portable** and **very low power**
- **Miniaturization/weight**
- **Biocompatibility** (implanted/absorbed devices), manufacturability and cost
- **Packaging and reliability**

Application needs: Automotive

Sensors for autonomous cars



Feet off, hands off, eyes off

Pollution detection

(gas & particles) within the car as in-vehicle air quality, emmissions testing & monitoring

Certifications

Sensors for driver assistance & monitoring

towards Internet of things (IoT) in multisensing capabilities with capacitive /optical sensors everywhere in the car (headrest, seatbelt, seat, dashboard, steering wheel) & alchool detection

Contactless/non-intrusive drivers physiological signals monitoring for accurate

Drowsiness detection

Automotive

Other sensors

- *Accelerometers*
- *Tire pressure sensors (TPMS)*
- *Short/long range radars for front/rear car parking & cruise control*
- *Cameras (Visible, NIR, IR, ultrasound, lidar)*

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Automotive Technology Requirements

- **High quality standards** and requirements (high resolution and contrast of the cameras)
- **Safety/ Security** big data storage & computing power (filter, process)
- **Stability** in harsh environment (large T° range)
- **Long life-time,** failsafe and have redundancy
- **Low power**
- **Low cost**
- **Transferable** to all vehicucle types
- **Miniaturization** of all the functions (sensors…)

3. Smart Sensors Technology - Design Challenges

Sensors Technology	Medium term: 5+	Long term: 10+
CMOS sensors (just CMOS and smart CMOS)	XXX	XX
IR and MEMS/NEMS sensors	XX	XXX
Carbon sensors	X	XX
Polymers sensors	X	X
Nanowires sensors	X	XX

- Millions of sensors,
- Arrays of sensors
- Miniaturization
- Ultra-low power consumption
- Combination of optical & chemical sensors
- Complex read-out circuits

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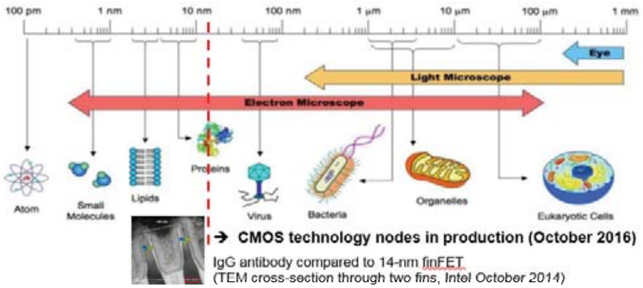
- Nanotechnology
- Self-powered
- Autonomous sensors

Sensor Technologies

CMOS Sensors



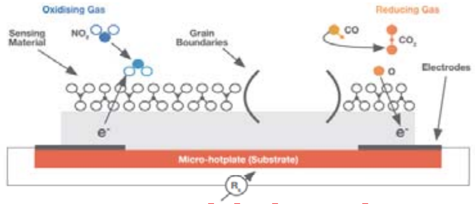
What it can be sensed in CMOS, it will be sensed in CMOS

SOI CMOS

higher performance, ULP, high-RF and resist better to harsh environment (high T° & radiation) than Si bulk

Smart CMOS

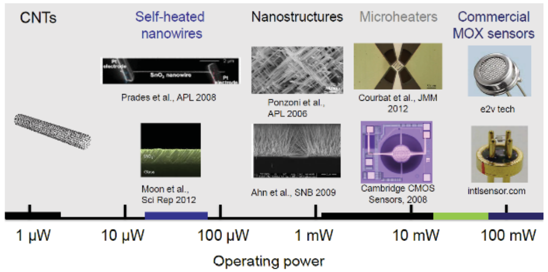
MEMS micro-hotplates MOX gas sensors



Low-cost, high-volume, close proximity

Sensor Technology

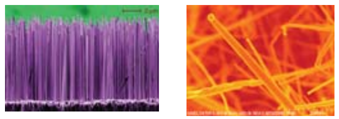
Carbon-based



Low power sensing, better sensitivity, resolution and SNR

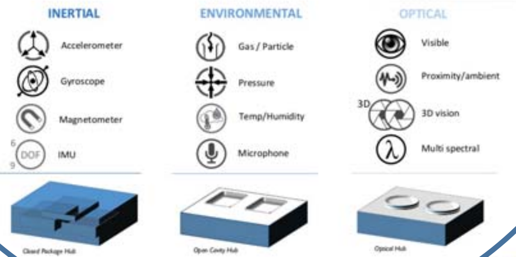
Nanowires

High efficiency, high selectivity



MEMS/NEMS

alone or in hybrid integration with IR, MOEMS, CMOS or other emerging technologies or materials (piezoelectric, polymers…)



Sensor Technologies → open challenges

Sensor Technology

CMOS Sensors
- Power consumption for millions applications
- Sensor sensitivity is poor

SOI CMOS
- Expensive substrate

MOX sensors
- Large & expensive
- High power consumption
- Cross sensitivity & Drift
- Stabilization time
- Expensive & Frequent calibrations & filters

Carbon-based
- **Lack of control over NT material** (diameter, location or orientation)
- **Interfaces** (contacts, oxide)
- **Variability** (distribution I_{on}, V_T)
- **Hysteretic stability**
- **Cross-selectivity** (functionalization)
- **Read-out circuit/Calibration**
- **Noise** (SNR)
- **Co-integration**

Nanowires
- Uncontrol dimension, orientation and defects
- Lack of metrology
- Integration

IR & MEMS/NEMS
- Reduce size→ high volume
- Cost (share manufacturing industry & process CMOS MEMS)
- User case for application/add value
- Fussion different sensors/Software
- Power decrease (chip increases)
- Packaging

4. Smart Sensors Figures of Merit

Definition of FoMs (quantative or qualitative) or planned evolution (based on SoA @ 2017 and evolution vs time)

Figures of Merit (FoMs)	Medium term: 5+	Long term: 10+
Sensitivity, detection limit	XX	X
Energy efficiency - low power sensing	XXX	XXX
Stability and reliability	XXX	XXX
Assembling testing, metrology and calibration	XX	XXX
CMOS integration, compatibility and readout circuit	XXX	XXX
Maturity level	XX	XX
Packaging	XXX	XXX
Safety/Security	X	X
Minituarization/Form factor	XX	X
Biocompatibility	XX	XXX
Computing capacity	XX	XX
Manufacturability/sensing functionality and micro-pumps	X	XX
Energy harvesting	XX	XX

5. Other issues and interaction with other Tasks/WPs

Interaction with other Tasks/WPs	Medium term: 5+	Long term: 10+
Packaging → Task 5.2 Heterogenous integration	XXX	XXX
Zero-power approach → sub Task 4.2 Power for autonomous systems	XX	XXX
Assembling testing, metrology and calibration	XX	XXX
Ecosystem → WP6 Equipment and manufacturing Science	XX	XXX

- Internet of Things (IoT)
- Big Data - Software/Algorithms
- Zero-power/ self-powered
- System-in-package (SiP)
- Ecosystem

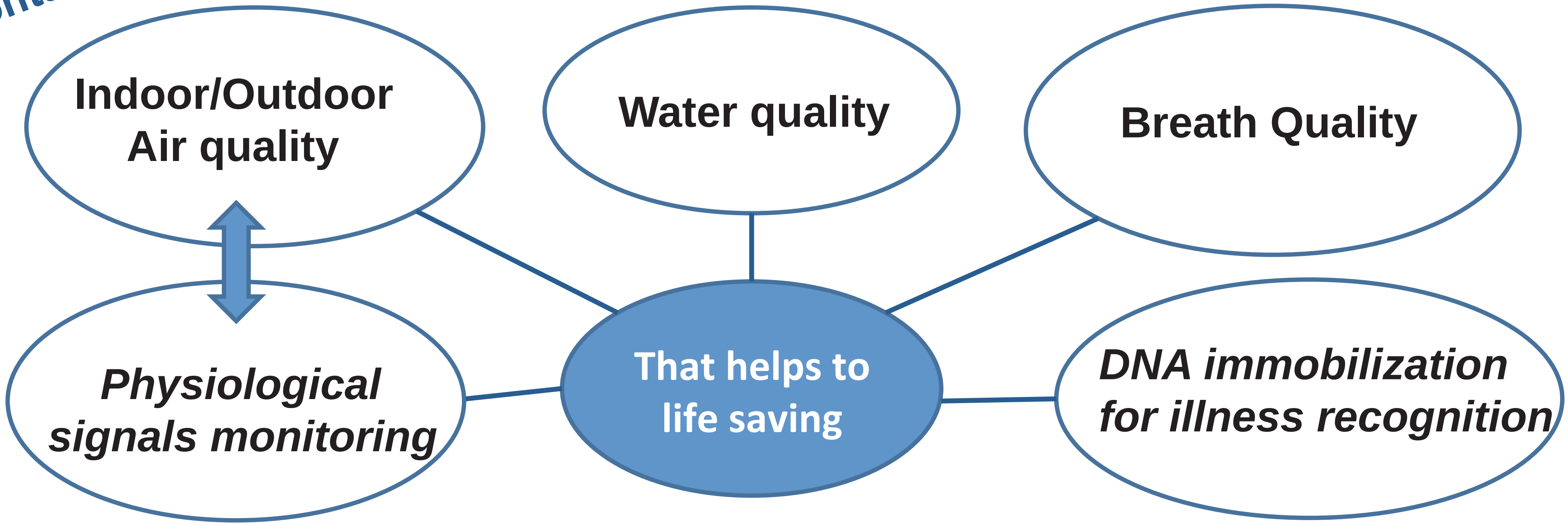
→

- Task 3.2 Connectivity
- *Sub*-Task 4.2 Power for autonomous systems
- Task 5.1 System Design
- Task 5.2 Heterogeneous Integration
- WP6 Equipment and manufacturing Science

Conclusions: Application gap Medical/Health

Contactless/non-invasive

Multisensing Platforms
Qualification/Certification Institutions



Portability **Energy efficiency** **Miniaturization**