The European Sensor Systems Cluster

Roadmap Towards European Leadership in Sensor Systems

SURVEY OF INDUSTRIAL NEEDS

Final 03/10/2016

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Executive Summary

This Survey by the **European Sensor Systems Cluster (ESSC)** of hot-topics related to Sensor Systems is a contribution to define PRIORITIES of a Roadmap for the European Commission (primarily DG Research & Innovation - Directorate *Key Enabling Technologies* - Unit *Advanced Materials and Nanotechnologies*, but also other units) useful to select topics for future H2020 Calls (2018-2020).

Requirements analysis of the European Industry (small medium enterprises, large companies) has been executed by ESSC Steering Committee with support of the ESSC members by interviews (questionnaires, email, phone, telco, webpages, meetings, networking, etc.) in the period 2015-2016.

The Survey has been organized addressing two types of Topics: *Specific Topics* at High Priority for each surveyed industrial sector and *Horizontal Topics* of interest for several sectors with large industrial relevance and high socio-economic impact.

The **ESSC** key technological areas include:

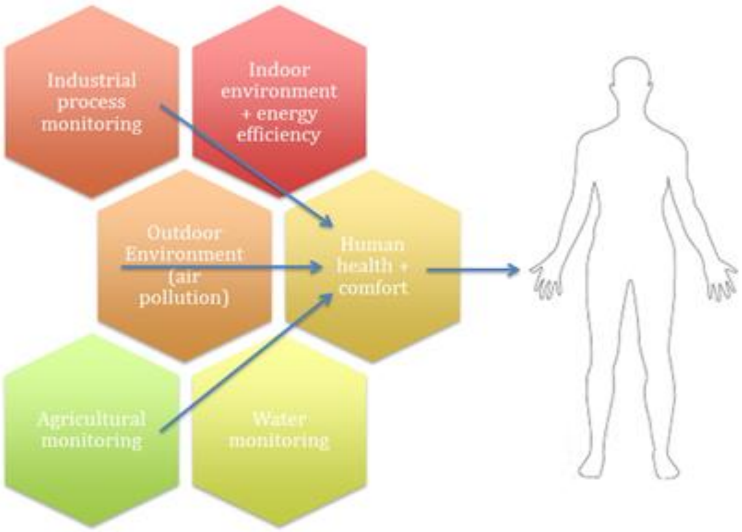
- Environmental Sensors
- Indoor Air Quality Sensors
- Health Monitoring and Comfort Sensors
- Monitoring of Industrial Processes
- Commercialization

ESSC has identified the technical or non-technical challenges of (bio)chemical sensing and highlighted opportunities resulting from functional materials, nanotechnology, microsystems integration, advanced data evaluation, their manufacturing, commercialization and systemic integration. **ESSC** has concentrated on (bio)chemical sensor systems as physical sensing is today already ubiquitous and highly advanced, while sensitivity, selectivity and stability are still largely unsolved for many applications of (bio)chemical sensors due. This is due in part to the higher complexity of the chemical environment and also to the direct chemical interaction required for sensing which prevents, e.g., hermetic sealing.

ESSC mobilizes a *pan-European network*, ready to advise, assist and execute the national or international measures leading to strengthened position of European Research and Innovation in the field (bio)chemical sensing (e.g. analysis, measures proposition, evaluation, reviews).

The key challenge is to dramatically reduce the cost of low-powered, reliable and accurate sensor-systems by at least one order of magnitude, and preferably more, in order to open the way to dramatic improvements in the density of deployments, and the frequency of measurements and usage.

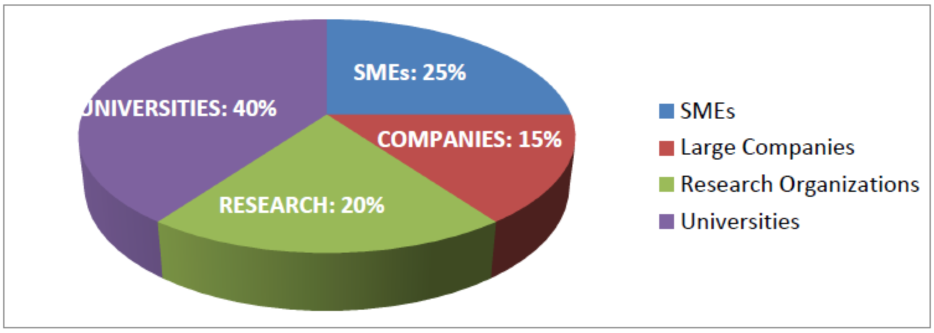
A multifaceted research strategy will be required, targeting both '*evolutionary and revolutionary*' approaches, e.g., by transferring analytical platforms from the lab to the field or via autonomous sensors capable of long-term independent operation with new smart functionalities (e.g., data acquisition/storage, stand-alone operation, data communication, smart miniaturization, system integration) using advanced materials, smart structures and micro-nano-technologies.



Vision of ESSC based on human-centred sensor-system solutions

This document highlights the main objectives for ESSC Working Groups in order to help the EC to prepare priorities for future calls in the field of sensor systems for *environmental monitoring* (air, water and soil quality control), *indoor air quality* (modules, sensors, devices, systems), *health monitoring and comfort* (sensors, systems, technologies), *monitoring of industrial processes* (sensors, devices, systems, standards) as well as *integration and commercialization* (analytical tools, standardization, protocols, metrology, business model and spin-offs).

The ESSC structured survey of more than 100 contributors:



Statistics of international experts involved in ESSC survey for H2020 Calls inputs

ESSC Steering Committee:	9 Members
Experts involved in ESSC:	110 Members (90 registered in webpages)
ESSC Working Groups:	6
ESSC Workshops (Nov. 2014 - Apr. 2016):	10

- **Experts involved from Academia**:
  - Research Bodies: ENEA (IT), IMEC (NL),
  - Universities: Saarland University (DE), Dublin City University (IE), Tyndall National Institute (IE), Graz University of Technology (AT), Brandenburg University of Technology (DE), Denmark Technical University (DK),
- **Experts involved from Industry**:
  - SMEs: Alphasense Ltd (UK), SenseAir AB (SE), Amires Sarl (CH), Eurice GmbH (DE), NanoSense SARL (FR), Efficiency Marketing (FR), NanoAnalytik GmbH (DE), Novasis srl (IT), Bioage srl (IT), Cambridge CMOS Sensors Ltd (UK),

- Large Companies: ST Microelectronics (IT+FR); Analog Devices (IE); Bosch (DE); Infineon Technologies (DE), Mettler Toledo AG (CH), Panasonic Industrial Devices Europe GmbH (DE), ams AG (AT), Siemens AG (DE),
- Industry Associations: AMA Sensorik und Messtechnik (DE, repr. ~ 500 members)

Industry 4.0 is a new paradigm to enhance the efficiency and productivity of the factory of the future. It is based on new and radically changed processes in manufacturing companies (Factory 4.0). In this concept, data is gathered from suppliers, customers and the company itself and evaluated before being linked up with real production. The latter is increasingly using new technologies such as **sensors**, advanced materials, 3D printing, next generation robots, autonomous vehicle, advanced manufacturing systems, cyber-physical systems, cloud computing, big & smart data.
The Industry 4.0 consists in digitalization of production processes based on capillary network of smart objects connected by Internet of Things (IoT). The smart sensor systems are key technologies for a next generation of Internet of Things (IoT). The current trend in smart systems is the linking from Internet of People to Internet of Things with “billions or trillions” of connected smart sensors in the next decades (2030). Industry 4.0 is thus closely linked to novel sensors for industrial processes represented in WG4 of the ESSC, but many paradigms can be transferred to other areas such as medical technology or environmental monitoring.

Particular innovation challenges of ESSC for R&D and commercialization:
- Indoor Sensing
- Environmental Sensing
- Biosensors
- Chemo/Bio Sensors for Liquids
- Modelling and Simulation
- Analytical Tools and Metrology
- Standardization and Regulation
- Business Models and Spin-offs

Some barriers for intensive commercialization of the sensor-systems:
- 3S open questions: Sensitivity, Selectivity, Stability
- Ease of use
- Manufacturing questions
- Low accuracy for specified applications
- Moderate reliability for given applications
- Lack of standards for benchmarking
- Lack of protocols for validation
- Lack of guidelines and regulation
- Maintenance for mass deployment
- Periodical re-calibration
- Specific algorithms for calibration
- Cost reduction for robust and accurate sensors

Several building blocks (sensing, acquisition, transmission, processing, actuating) need for system integration to able cross-cutting applications.

The sensor systems will have a high impact in the following application sectors:
- Medical Devices
- Pharmaceutical Industry
- Industrial Instrumentation and Process Control
- Environment

- Building Technology
- Water Management
- Safety and Security
- City Management
- Agrofood
- Automotive and Transportation
- Consumer
- Cosmetic
- Retail and Logistics
- Sport and Well-being
- Telecom and IT
- Laboratory Equipment

The demand, according to visionary organizations (*Trillion Sensors Summit 2013*, Stanford University, October 23-25, 2013) is expected to be driven by emergence of sensor-based smart systems fusing the computing, communication and sensing. Global GDP is estimated likely around USD 64 trillion in 2013, and USD 128 trillion in 2023. While the cost of individual sensor systems will be low, there impact will be huge due to the leverage effect of sensors for more complex products, e.g. novel ambient sensors will push the next generation of high-end smartphones.

In Europe, the number of sensors is expected to double every five years in the period 2000-2020. The current trend in the sensors and sensor-systems is the miniaturization, low-power consumption, integration and cost-reduction with expansion to chemical quantities in addition to established physical parameters.
Significant and direct benefits for European citizens are as follows:

- Personalised precision healthcare
- Sustainable and managed environment
- Energy saving and efficiency
- Comfort improvement
- Safety and security
- Critical success factors for Industry 4.0, precision agriculture and IoT
- Complex knowledge-based, high-margin products - manufacturing in Europe

The European economy will greatly profit from this development due to its traditional strength in sensors and sensor systems because of their significant economic leverage effect.

Further information on **ESSC** initiatives is regularly uploaded at the dedicated webpages: www.cluster-essc.eu

WG 1 - Environmental Sensors

Chaired by Dermot Diamond (Dublin City University, IE)

Rationale

This document highlights the main objectives for this working group in order to help the EC to prepare priorities for future calls in the field of environmental sensors to address air, water and soil quality control. The latest version has been made consistent with the request to prioritise two initiatives for the period 2018-20120, and two initiatives 2020-2022. It also reflects input from industry, academia and agencies gathered at conferences, workshops and via personal discussions gained over the past months.

Background

Environmental sensing covers a huge range of application scenarios, varying widely in terms sample types, background matrix, analytes of interest, frequency of measurement, and concentration ranges. Coupled with the lack of major commercial driving forces, this had led to a very fragmented market, dominated by small companies selling niche products. Consequently the sector has failed to embrace new technologies compared to, for example, the clinical domain. Conversely, developments in cloud computing and satellite based remote sensing offer tremendous opportunities to create new synergies linking autonomous deployed sensor networks with satellite information, and enhancing citizen participation (as information creators as well as consumers) through cloud-based social media mechanisms. Sample types range across freshwater, drinking /potable water, groundwater, marine/sea water, estuaries, waste water, air quality control in sustainable and resilient cities, green ports/airports, critical urban hot-spots, landfills, wastes, soil monitoring such as leachate, agricultural emissions (e.g., NH_3 and other nitrogen pollution), etc. Parameters of interest vary from physical (e.g. colour, turbidity, particle size, temperature), through chemical (e.g. pH, COD, DO, nutrients, metals, gases, volatile organic compounds, organics, particulate matter (PM_{10}, $PM_{2.5}$, $PM_{1.0}$) and ultrafine particles, black carbon, odorants, pollen) to biological (e.g. algae, E.coli, cryptosporidium, species), covering a huge range of targets and analytical scenarios, each of which can have differing analytical and legal demands. In order to develop a priority listing, it is necessary to cluster the issues/opportunities very broadly. The key challenge is to dramatically reduce the cost of environmental monitoring devices (particularly for water analysis) by at least one order of magnitude, and preferably more, in order to open the way to dramatic improvements in the density of deployments, and the frequency of measurements. A multifaceted research strategy will be required, targeting both 'evolutionary and revolutionary' approaches, and transferring analytical platforms from the lab to the field, via autonomous sensors capable of long-term independent operation with new functionalities (e.g., data acquisition/storage, stand-alone operation, data communication, smart miniaturization, system integration) using advanced materials and micro-nano-technologies. A variety of platform types are required, ranging in sophistication from highly robust autonomous devices for use in the marine environment, to single use, low cost indicator sensors that can be used by the general public and linked to mobile phone apps (consistent with the increasing importance of 'Citizen Science'). The scene is also set for a dramatic increase in the volume of data generated; from citizens using mobile phone based sensors, to distributed sensor networks, to drone/flyover based multi-spectral imaging and atmospheric monitoring, through to satellite based remote sensing. Definition of standards in data handling, including metadata, will be essential for sharing and accessing 'environmental big data'.

Priority Topics

Cross Cutting Topics

Driving Down Costs of In-Situ Analysis

This is a generic challenge across all sensor areas. Key contributors include unit (purchase) cost and cost of ownership (consumables, servicing). Future platforms must increasingly become autonomous in operation and much less expensive to purchase, and research investment must prioritise ways to deliver these improvements. This can be achieved by harnessing the tremendous potential of new materials emerging from fundamental materials research, and coupling this with dramatic improvements in fabrication technologies, for example, through 3D printing, specifically targeting the 'analytical engine' of the analyser. Increasingly, this will be based on microfluidic approaches with fully integrated fluid handing components. Understanding and controlling biofouling is key for reducing the cost of ownership for chemical sensors generically across all aspects of water quality monitoring (freshwater, waste water, marine environment etc.), as biofouling is the most common cause of device failure. Another key challenge related to biosensors is how to perform repeated in-situ measurements over time in remote locations, when the devices are essentially single use (e.g. immunoassays) or at best short term use (enzyme based devices). This will require arrays of sensors that are sequentially switched into use, which in turn will involve more complex yet relatively low cost microfluidics.

Harnessing the Power of Environmental Big Data

Cloud systems will enable information from many sources to be integrated and queried. For example, satellite remote sensing can be correlated with deployed sensor networks to leverage complementary information, and generate a much fuller picture of environmental systems at local and global scales. Environmental data from multiple sources must be accommodated, ranging from single use, disposable colorimetric sensor strips suitable for use by non-specialists will be increasingly linked with mobile phones to provide image based analysis and measurement storage, along with location, date, time and operator information. Data streaming from in-situ sensor networks will be integrated with satellite based data, and complemented by done/flyover multispectral imaging. Such multimodal information will require the adoption of data standards for sensed target species, and for associated metadata to enable the power of environmental 'big data' to be realized. This is also a requirement for the implementation of policies associated with 'open science' across EU research programmes. Coupled with data standards will be the need for ground-truthing of in-situ deployed, relatively low cost sensors for specific analytes through coordinated trials involving more sophisticated reference units and laboratories. For example, while low-cost air quality sensors are currently lower accuracy compared to high-cost reference analyzers, they are nevertheless useful for deployments in urban areas at high spatial-temporal resolution to address real-time and in-situ air quality monitoring at known hot-spots for city managers and policy makers. To explore the characteristics of air quality sensors in real scenarios, intensive long-term experimental campaigns in cities are extremely useful, as their performance can be compared to air quality stations reference analyzers and mobile air quality laboratories. These joint-exercises *sensors-versus-analyzers* are important to benchmark the performance limits of emerging low cost sensors in real deployment scenarios, establish a protocol for data comparisons, and enhance accuracy in order to address the *Indicative Measurements* of the EU Directive Ambient Air Quality 2008/50/EC. These Indicative Measurements are less strict than the *Fixed Measurements*, that are mandatory when important thresholds are regularly exceeded in urban agglomerations. The low-cost sensing platforms addressing *Indicative Measurements* are extremely urgent for urban air quality monitoring at high spatial resolution and potential citizen exposure by means of stationary sensor-nodes and/or mobile nodes (e.g., tramways, buses, bikes, cars, etc.). Furthermore, related environmental informatics could evolve from a *reactive mode* (after the event) to *predictive mode* (prevent or mitigate the event) in a 'chemical weather forecasting' approach for publicly accessible network applications. The same strategy for ground-truthing of air quality can be applied more generically across the entire environmental monitoring sector, integrating the enormous spatial coverage of satellite multispectral sensing of the atmosphere, sea surface and land characteristics, with highly localized sensitive monitoring of specific analytes via in-situ deployed sensor networks, grounded via standardized methods measurements of spot samples by reference laboratories/units.

WG Specific Topics

Improved platforms for Characterising the Marine Environment
The marine environment is arguably the most challenging and hostile for sensor deployments in terms of potential for physical damage, fouling, communication and power management issues, and servicing intervals. Furthermore, analytical specifications can be very challenging, as many key targets require speciation, detection at very low (trace level) concentrations, measurement within very tight ranges, and depth profiling (platforms must perform under wide pressure and temperature ranges). Examples include understanding CO2 partitioning into surface layers (e.g. surface pH), and algae detection and speciation. Consequently monitoring of the marine chemical and biological condition is not well established compared to physical parameters. For example, the Argo project currently has ca. 4,000 networked floats world-wide instrumented with temperature, colour, conductivity, location, and depth; however, only 25 of these are fitted with relatively simple pH sensors, and none have more complex fluidic based analysers (last checked, March 2016). The US-based Alliance for Coastal Technologies currently has an open 'Global Nutrients Challenge' for innovative platforms that can function autonomously with a minimum 3-month service interval, and a purchase price of €5K or less. The goal is to encourage companies to deliver platforms that meet the regulatory analytical requirements for phosphate, nitrate, nitrite and ammonia in coastal, estuarine and freshwater environments.

Autonomous Analysers for Freshwater/Waste Water Analysis
Current platforms are too expensive to purchase and maintain. A key objective could be to reduce the unit cost by at least one order of magnitude, and preferably more (e.g. commercial target price of €1,000). Analytical targets could encompass pH, COD, DO, nutrients, metal ions; these are accessible via reagent based analyser methods and/or electrochemical methods. More challenging is the delivery of instruments for the in-situ detection of specific organic targets, such as endocrine disruptors and carcinogens.

Migrating Analytical Instruments from the Lab to the Field
Related to the above is the need to investigate ways to bring instrumentation from the lab to the field to enable a broader range of analytical measurements for the in-situ detection of specific organic targets, such as endocrine disruptors and carcinogens. This is already happening to some extent with spectroscopic and electrochemical methods, but there is scope to develop this trend further, to encompass information rich techniques like separation methods/chromatography and mass spectroscopy, for example by exploiting micro/nanofabrication approaches.

Integrated Approaches to Air Quality Monitoring

Gas sensing is the most developed and reliable form of environmental chemical sensing. Approaches like IR-based sensing allow long-term, in-situ sensing of targets with appropriate absorbance characteristics like the greenhouse gases CO_2 and CH_4 in a variety of deployment scenarios, whereas electrochemical and silicon-based sensors target gases like O_2, CO, H_2S, SOx, NOx, and NH_3. Likewise, spectroscopic remote sensing using satellite platforms have advanced rapidly, enabling SOx, NOx and O_3 levels to be monitored dynamically on a global basis. A major goal should be the integration of various gas sensing modalities, particularly in-situ deployed sensor networks and satellite based remote sensing to obtain a more comprehensive understanding of cause/effect relationships and trends in air/atmospheric gases. The urban environment is particularly challenging for cost-effective and low-power sensor development to address air pollution monitoring and greenhouse gases reduction by means of deployment in real scenario at micro-scale (street, district) and city-scale (ports, airports, landfills, etc.) using wireless/wired sensor networks in terms of protection for chemical damage to people, environment and cultural heritages, personal exposure of citizens, human health assessment (epidemiological studies, emissions inventory). Furthermore, high-performance, accurate and low-cost sensors based on advanced transducers should be cross-cutting by targets such as selectivity, sensitivity, stability, fast response, detection at lower concentrations (sub-ppm and sub-ppb level). Examples include understanding emission source apportionment of air pollution such as gases (e.g., NO_x, O_3, CO, SO_2, H_2S), volatile organic compounds (e.g, benzene, toluene, xylene), particulate matter (PM_{10}, $PM_{2.5}$, $PM_{1.0}$), black carbon and ultrafine particle (UFP), greenhouse emissions (e.g., CO_2, CH_4, N_2O), nitrogen pollution (e.g., NH_3), non-methanic hydrocarbons, odorants, heavy metals, polycyclic aromatic hydrocarbons (PAH), pollens and other organic pollutants.

Citizens as Consumers and Providers of Environmental Data

Low-cost sensing platforms and portable/wearable sensor-systems of air quality monitoring for mass production and large market are extremely necessary to enhance the usage at global scale for citizen-centred (*now and here*) and personalized environmental services using consumer-electronics like smartphones. Chemical 'weather forecasting', data assimilation and a standardized air quality index (AQI) should be further developed for sustainable environmental services and new business models (e.g. using social media applications to share data) to address the involvement of citizens as *comsumers and providers* of sensor data for improved environmental awareness and personal exposure monitoring. Analytical targets could encompass toxic gases (e.g., NO_2, O_3), volatile organic compounds, particulate matter, UV radiation, noise, odours, greenhouse gases (e.g., CO_2), meteorological and comfort parameters (e.g, temperature, relative humidity). At the lowest end of the cost scale, a variety of devices will become widely available, based initially on versions of existing single use colorimetric test strip sensors. These will be integrated into mobile phones to enable more accurate assessment of colour changes and estimation of analyte concentrations, along with image storage for post-validation, and automatic integration of metadata. Over time, integrated low cost fluidics will enable more sophisticated measurements to be integrated with smartphones. This approach can be extended to encompass *Living Sensors* that combine natural species (e.g., lichens, moss, higher chemical species) and traditional physical transducers (e.g., optical, electrical, capacitive and smartphones) to sense changes in the quality of the local environment. These more citizen centric approaches should be cheap, easy-to-use, with early applications related to mapping urban air, localized water pollution and personal exposure. A key challenge with citizen generated data is how to standardize across a potentially massive variety of heterogeneous sources, so that the data can be validated or scored in terms of quality, and made compatible with emerging standard formats (see 'Environmental Big Data' section above).

Concluding Comments

In the environmental sector, sensing has a huge role to play, for the effective policing of legislative directives, ensuring the quality of our environment is enhanced, and our understanding of human impact is more clearly understood. A particular issue is the need to create a more effective driving force for adoption of innovative technologies across the sector, for example through the effective implementation of regulations and directives, or through global challenges and new business models/competitions. In fact, the effective implementation of environmental legislation and directives can only happen if there is an efficient system for monitoring environmental quality parameters with high temporal frequency and wide spatial coverage; and conversely, effective implementation of the regulatory framework can in turn drive the adoption of innovative sensing technologies!

Title	**ST1&ST2 Improved Platforms for Marine and Freshwater/ Wastewater Monitoring**			
Call timing	2018	2019	2020	2021
Market segment	*Environmental Sensing, Instrument Development, Water Industry, Marine Science*			
Companies interested / **consulted**	***TELLAbs, IBM, INTEL, HACH, HENKEL, VEOLIA***			
Challenge	Current platforms are too expensive to purchase and maintain. A key objective could be to reduce the unit cost by at least one order of magnitude, and preferably more (e.g. commercial target price of €1,000[1]; current systems typically cost €20K+ and for Marine deployments considerably more). A key issue is to maintain system analytical performance in remote deployments, often under hostile conditions. Scalability of deployments depends on reliability and cost of ownership (initial purchase + ongoing recurrent costs). Hence maintenance intervals should be as long as possible. This in turn places significant stability requirements on all reagents employed such as standards for calibration, and reactive reagents for generating specific detectable products from samples.			
Possible solutions	Analytical targets in the initial phase could encompass pH, COD, DO, nutrients, metal ions; these are accessible via reagent based analyser methods and/or electrochemical methods. More challenging is the delivery of instruments for the in-situ detection of specific organic targets, such as endocrine disruptors and carcinogens (see **ST3&HT5 Migrating Analytical Instruments to the Field)**. Microfluidics will be essential for liquid handling associated with regular recalibration to ensure the analytical performance is acceptable, and any shift the characteristics is compensated. Microfluidic systems are advancing rapidly through the introduction of polymer rapid prototyping (e.g. 3D printing technologies) and materials science (e.g. stimuli-responsive polymer actuators). Particularly important			

[1] Nutrient Sensing Challenge currently is targeting a commercial price of $5,000 per unit, see http://www.act-us.info/nutrients-challenge/index.php

	will be low cost, fully integrated, scalable approaches to incorporating components like detectors, pumps and valves.
EU positioning	Europe is quite well positioned to lead this area. There have been multiple EU multipartner projects on this topic and networks of collaborative partners have been established, involving SMEs, research and regulatory agencies and academic teams. However it is critical that the momentum generated via these collaborative activities is maintained and developed, and effective mechanisms implemented to provide an effective route to commercialization and market. The US is much better at this through investment in new spinouts and the use of targeted global challenges; examples include the issuing of global challenges for Nutrient Sensing (Alliance for Coastal Technologies) and the Wendy Schmidt Global Challenge for pH sensing in the Marine Environment ($2 million prize). However, in terms of research knowledge and output, Europe is very well positioned.
Possible impact of topic in H2020	The delivery of effective, low cost analytical platforms incorporating relatively sophisticated sample processing capabilities based on inexpensive integrated fluidic handling will be significantly disruptive within the water industry, and monitoring of the marine/freshwater environment. It represents an essential technology for the effective implementation of environmental legislation, as this depends on the availability of quality data at multiple locations in real time, which can only be delivered through scalable sensor network deployments.

Title	**ST3&HT5 Migrating Analytical Instruments to the Field**			
Call timing	2018	2019	2020	2021
Market segment	*Environmental Sensing, Instrument Development*			
Companies interested / **consulted**	***TELLAbs, IBM, INTEL, HACH, HENKEL, VEOLIA***			
Challenge	Currently, it is not possible to perform in-situ measurements for many species listed under regulatory directives like the WFD. Consequently, enforcement of legislation is difficult, as these targets are not monitored with acceptable temporal frequency and spatial coverage. Chemical and biological selectivity and high sensitivity require the use of expensive centralized laboratory techniques based on separation methods (e.g. LC, GC) coupled with information rich detection schemes (e.g. MS, IR, RAMAN), or parallel sophisticated biodetection schemes (e.g. immunosensor arrays). Enabling these instruments to function will require a significant effort to reduce or eliminate the impact of biofouling; e.g. on sampling units, fluidic channels and sensitive surfaces through developments in fundamental materials science			
Possible solutions	Strategies for meeting this challenge can be sequenced through an initial focus on bringing separation techniques with simpler, more rugged detectors to in-situ deployment (e.g. coupling post-column reagent based detection with a separation capability). The ultimate goal will be to couple more sophisticated, information rich MS and optical (RAMAN/IR)			

	detectors and biodetectors that will become available via breakthroughs in micro/nanofabrication technologies and new materials fabrication technologies (e.g. 3D printing, 2Photon polymerization) to create highly parallel biodetector arrays. Advanced functional materials coupled with emerging fabrication technologies also offer routes to significantly ameliorating the impact of biofouling through control of materials characteristics like surface micro/nanostructure and hydrophobic/hydrophilic nature.
EU positioning	Europe is quite strong in this field, although the US is also very active, particularly in the development of miniaturized MS detectors. Given the global impact of developments in such instrumentation, it could be an excellent topic for 'open science' and collaborative alliances focused on this as a 'global challenge'.
Possible impact of topic in H2020	Migrating instrumentation from the lab to the field will enable a broader range of analytical measurements to be made for the in-situ detection of specific organic targets, such as endocrine disruptors and carcinogens. This is already happening to some extent with spectroscopic and electrochemical methods, but there is scope to develop this trend further, to encompass information rich techniques like separation methods/chromatography and mass spectroscopy, for example by exploiting micro/nanofabrication approaches.

Title	**ST4: Integrated Approaches to Air Quality Monitoring**			
Call timing	2018	2019	2020	2021
Market segment	*Environmental Sensing, Instrument Development, Air Quality, Personal Health, Cloud Computing, Environmental Big Data*			
Companies interested / **consulted**	***IBM, INTEL, AlphaSense, Skytek, Ambisense, SGX, SenseAir***			
Challenge	To develop scalable deployments of low cost accurate in-situ sensor networks targeting specific components in the atmosphere, and to integrate this data with complementary information generated by satellite remote sensing and drone/flyover measurements in particular locations.			
Possible solutions	Gas sensing is the most developed and reliable form of environmental chemical sensing. Approaches like IR-based sensing allow long-term, in-situ sensing of targets with appropriate absorbance characteristics like the greenhouse gases CO_2 and CH_4 in a variety of deployment scenarios, whereas electrochemical and silicon-based sensors target gases like O_2, CO, H_2S, SOx, NOx, and NH_3. Likewise, spectroscopic remote sensing using satellite platforms have advanced rapidly, enabling SOx, NOx and O_3 levels to be monitored dynamically on a global basis. Improved analytical performance in terms of selectivity, sensitivity, stability, fast response, detection at lower concentrations (sub-ppm and sub-ppb level) will contribute to reliable predictive modeling downstream. Examples incl. understanding emission source apportionment of air pollution such as gases (e.g., NO_x, O_3, CO, SO_2, H_2S), volatile organic compounds (e.g, benzene, toluene, xylene), particulate matter (PM_{10}, $PM_{2.5}$, $PM_{1.0}$), black carbon and ultrafine particle (UFP), greenhouse emissions (e.g., CO_2, CH_4, N_2O), nitrogen pollution (e.g., NH_3), non-methanic hydrocarbons, odorants, heavy			

	metals, polycyclic aromatic hydrocarbons (PAH), pollens and other organic pollutants.
EU positioning	Europe has a strong position and has all the elements required to advance this area rapidly. This ranges across gas sensor manufacturers, specialist services providers based on gas sensing, satellite based informatics (e.g. EU SatCen) and research capacity and industry related to geospatial informatics/intelligence/services. However, this area would obviously benefit from ‘open science’ collaboration on a global basis.
Possible impact of topic in H2020	Emergence of global research alliances tacking major global issues (e.g. maintaining/improving urban air quality) perhaps via targeted global challenges; delivery of real-time and ultimately predictive services integrated with networked communications to the citizen, regulatory agencies and industry. Stimulation of clustering of SMEs, multinationals and Academic research networks.

Title	**ST5&HT13 Environmental Sensor Informatics and Forecasting**			
Call timing	2018	2019	2020	2021
Market segment	*Environmental Sensing, Instrument Development, Water Industry, Marine Science, Cloud Computing, Environmental Big Data*			
Companies interested / **consulted**	***IBM, INTEL, HACH,*** *GOOGLE, Health Services e.g. related to allergenic and respiratory issues, travel industry.*			
Challenge	Cloud systems will enable information from many sources to be integrated and queried. For example, satellite remote sensing can be correlated with deployed sensor networks to leverage complementary information, and generate a much fuller picture of environmental systems at local and global scales. Environmental data from multiple sources must be accommodated, ranging from single use, disposable colorimetric sensor strips suitable for use by non-specialists will be increasingly linked with mobile phones to provide image based analysis and measurement storage, along with location, date, time and operator information. Data streaming from in-situ sensor networks will be integrated with satellite based data, and complemented by done/flyover multispectral imaging. Such multimodal information will require the adoption of data standards for sensed target species, and for associated metadata to enable the power of environmental ‘big data’ to be realized. This is also a requirement for the implementation of policies associated with ‘open science’ across EU research programmes.			
Possible solutions	Gas sensing is the most developed and reliable form of environmental chemical sensing. Approaches like IR-based sensing allow long-term, in-situ sensing of targets with appropriate absorbance characteristics like the greenhouse gases CO_2 and CH_4 in a variety of deployment scenarios, whereas electrochemical and silicon-based sensors target gases like O_2, CO, H_2S, SOx, NOx, and NH_3. Likewise, spectroscopic remote sensing using satellite platforms have advanced rapidly, enabling SOx, NOx and O_3 levels to be monitored dynamically on a global basis. A major goal should be the integration of various gas sensing modalities, particularly in-situ deployed sensor networks and satellite based remote sensing to obtain a more comprehensive understanding of cause/effect relationships and trends			

	in air/atmospheric gases. This is an essential prerequisite for the realization of the ultimate vision of predictive environmental modeling. Furthermore, to explore the air quality sensors limits in real scenario, intensive long-term experimental campaigns in city are extremely useful to compare their performance to air quality stations reference analyzers and mobile air quality laboratories. These joint-exercises sensors-versus-analyzers are important to know the limit of performance in real scenario, establish a protocol for data benchmarking, enhance accuracy in order to address the Indicative Measurements of the EU Directive Ambient Air Quality 2008/50/EC.
EU positioning	Europe is well placed to lead advances in environmental big data. Many industry big players in informatics are located in Europe, and there has been significant investment in big data research across the EU, both nationally and through EU consortia. However, Environmental Big Data is an obvious lead contender for ‘open Science’ initiatives with other major global players e.g. USA and China. For example, satellite based remote sensing is already well networked globally through close cooperation between the ESA and NASA, and linking this data with deployed sensor networks will require similar close cooperation to deal effectively with global environmental issues.
Possible impact of topic in H2020	The availability of reliable large environmental data sets for predictive modeling will have enormous impact across multiple industries and society in general. It will form the basis of decision making for environmental legislation, which is centrally important for the future of the global economy. It is also essential for the accurate modeling of environmental status and for effective implementation of environmental legislation.

WG 2 - Indoor air quality

Chaired by Andreas Schütze (Saarland University, GE), Olivier Martimort (NanoSense, FR)

Introduction

This document is to define main objectives for this working group in order to help the EC to prepare future call in the field of sensor systems for Indoor Air Quality (IAQ).

Health concerns connected with Air Quality in general have been emphasized in the 2015 SOER 2015 report[2]: “Air pollution harms human health and the environment. In Europe, emissions of many air pollutants have decreased substantially over the past decades, resulting in improved air quality across the region. However, air pollutant concentrations are still too high, and air quality problems persist. A significant proportion of Europe’s population live in areas, especially cities, where exceedances of air quality standards occur.” As people now spend most of their time (often more than 90%) indoors, Indoor Air Quality has to be considered separately[3]: “Furthermore, it is worth noting that most health-related pollution

[2] European Environmental Agency: SOER 2015 The European environment — state and outlook 2015: an integrated assessment of the European Environment

[3] European Environmental Agency: The European environment | State and outlook 2010

policies are targeted to the outdoor environment. A somewhat neglected area in this regard is the indoor environment — considering that European citizens spend up to 90% of their time indoors. The quality of indoor environment is affected by ambient air quality; building materials and ventilation; consumer products, including furnishings and electrical appliances, cleaning and household products; occupants' behaviour, including smoking; and building maintenance (for example, energy saving measures). Exposure to particulate matter and chemicals, combustion products, and to dampness, moulds and other biological agents has been linked to asthma and allergic symptoms, lung cancer, and other respiratory and cardiovascular diseases."

Background: Indoor air quality

- There are four important and complementary aspects to indoor air quality:
    - **Health**: people spend most of their time indoors, so poor air quality has a great influence on people's health. This can be caused by high concentrations of hazardous or even toxic gases for a brief period, but also by extended or continuous exposure to very low concentrations, especially for carcinogenic compounds. In addition to gases, particulate matter (PM), pollen and mould are of increasing concern also for indoor environments. Eurostat reports that the percentage of total population exposed to mould problems varies between 4.2% (Finland) to 35.7% (Portugal).
    - **Comfort**: many toxic gases, especially VOCs, are not smelly and cannot be detected by humans, while other compounds, e.g. odors like isovaleric acid, are not hazardous but influence the comfort, both awake and during our sleep, greatly. In addition, comfort is a complex aspect not only depending on chemical components, primarily humidity, CO_2 and VOC concentration and "smell", but also physical parameters, i.e. temperature, light and air flow/draft.
    - **Productivity:** increased CO_2 concentration greatly reduces human productivity. Memorization, decision making, cognitive and behavioral responses are strongly affected above 1000 ppm CO_2 (http://www.famcoiaq.com/assets/IAQ-intelligence.pdf). Recent studies indicate that VOCs can have similar effects on cognitive functions (http://dx.doi.org/10.1289/ehp.1510037). Productivity gains in worker and student performance can represent an enormous economic impact based on CO_2 and VOC reduction enabled by low-cost sensors.
    - **Building integrity and value:** Humidity can generate mold growth and deteriorate building structure and decoration. Especially for modern or modernized buildings which are highly insulated to reduce energy consumption this is an increasing hazard and many people are highly aware of the danger of molds and spores on their health and on the building value.

- Indoor air quality covers a great variety of application scenarios
    - Private homes with different rooms (living, sleeping, kitchen, bathroom, …)
    - Public buildings (kindergarten, schools, banks, super markets, sports arenas, …)
    - Work environment (office, industrial, workspaces, …)
    - Cars, busses, trains, airplanes etc.

  The relevance towards health, comfort and productivity is closely related to the time spent in each environment and the concentrations/levels of certain pollutants.

- Indoor air quality in buildings is closely connected to energy consumption:
    - Increased insulation with associated air proofing reduces natural air exchange rate
    - Forced ventilation increases energy consumption of HVAC systems
    - Reduced ventilation leads to increasing concentration of pollutants from indoor sources, e.g. CO_2, humidity and odor (sweat) from human presence, VOCs from building materials, cleaning, cooking etc.

- Sensor systems measuring IAQ can have several purposes
    - Purely informative, i.e. indoor air quality station
    - Prove compliance with regulations on long term average exposure (data logging)
    - Give active feedback and advise to people ("open the window to ventilate")
    - Actively control IAQ as part of a complex system to control dilution with outdoor air and possibly also active air treatment (by recirculation or treatment of incoming air, e.g. filtering, catalytic decomposition, air ionization, …)

Priority topics

Cross cutting topics:

Development of a comprehensive Air Quality Index

As air quality (both indoor and outdoor) is a very complex issue and influenced by many variables, a strategy to integrate all available information into one Air Quality Index for public use needs to be developed to allow easy comparison of locations, causes and effects and to allow abatement strategies like demand controlled ventilation. This index should cover all pollutants, e.g. toxic and carcinogenic gases, PM (ideally differentiated for size, shape, material and composition) as well as comfort aspects and should allow tailoring to set individual priorities.

Odor nuisance monitoring for comprehensive IAQ assessment

Odor measurements today are based on sensory panels, i.e. test persons. For comprehensive IAQ assessment, sensor systems for evaluation of odor should be developed especially for public areas (e.g. restaurants, restrooms, toilets, transport systems) but also for private homes (e.g. kitchen and bathroom). This aspect is not limited to indoor applications, but closely related to outdoor air quality/environmental monitoring, but with different sources and target odors. The challenge will be to discriminate bad and good (perfumes, air freshener...) odors. Odors can be culturally pleasant or unpleasant (mainly related to cooking cultures). Individual odor memory also plays a role because of past related pleasant or unpleasant situations. So an adaptation to user requirements (primarily in domestic applications) should be implemented.

Development of low cost, high performance PM sensor systems

Particulate matter is today only measured as mass concentration and differentiated for different particle sizes. However, besides mass and rough size, the number, shape, material composition and also adsorbed species are contributing heavily to the health impact of PM. Efficient sensor systems are therefore required that can detect and characterize particles to estimate the true effect. This is of increasing interest as emissions from wood burning – both from "green" wood pellet boilers/stoves and from open fireplaces – are strongly increasing. In this context, increase in benz(a)pyren in the environment resulting from wood fires and adsorbed on soot particles is a premier concern of the European Environmental Agency due to the high carcinogenity.

Integrate mobile sensor systems (primarily smartphones and wearables) into IAQ networks

Chemical sensors in mobile phones will become ubiquitous. Thus, not every area, especially in public spaces and transport systems, will need to be equipped with sensor networks. Instead, the data from mobile phones could be used in a way similar to traffic data being generated through mobile phone networks. However, mobile phones will not be very reliable (not turned on due to power consumption; measuring local effects, i.e. perfume of owner; etc.) and accurate, which can be offset by polling several sensors and by correlating mobile phone data with fixed and accurate AQ measurement stations.

Working group specific topics:

IAQ User Interface allowing easy understanding and individual tailoring

IAQ is a very complex issue and the normal end user will have difficulties interpreting the measurement data of several sensors, especially for hazardous gases ("What does 5 ppb Benzene mean for me?"). An optimized IAQ user interface should provide easy understanding at a glance (graphical symbols, e.g. a traffic light) and in depth information of the different IAQ aspects for interested users. The user should be able to tailor the interface to his requirements, i.e. with emphasis on health, comfort, productivity or specific allergies. The system should also indicate what the effect of different measures (i.e. opening a window, reducing temperature, change cleaning product…) would be in understandable terms, especially for health effects (poor air quality reduces life expectancy, but how can this be expressed for the general user without causing unnecessary anxiety?)

Connect Outdoor Air Quality and Indoor Air Quality for development of demand controlled ventilation

The standard approach to poor indoor air quality is increased ventilation which is fine e.g. for human sources like CO_2 caused by (many) people in confined spaces. However, this is only relevant if the outdoor air is "better" than indoor air. Thus, a comprehensive Air Quality Index is required to optimize ventilation strategies and times, in order to ventilate when this actually improves air quality. Systems should be adaptive and ideally predictive, i.e. able to ventilate in advance if outdoor air quality will deteriorate due to onset of traffic etc. Energy optimization could also be part of the optimization by comparing the energy requirement between air dilution (ventilation) and air treatment (filtering, catalytic decomposition, ozone treatment).

Bio-chemical sensor systems for mold detection

An increasing concern connected with air quality and improved building insulation is (hidden) mold formation which has a huge impact on health and on building integrity. Thus, systems to detect mold at an early stage or systems to predict mold formation based on comprehensive air quality data (temperature, humidity, ventilation, etc.) will be very important to make full use of low energy buildings and building renovation. Some spores are known to have a typical VOC signature and could be monitored by VOC monitoring at very low concentrations, but also biosensors could contribute to solving this challenge.

Title	**Integration of mobile sensor systems (primarily smart-phones, wearables and IoT) into IAQ networks (HT11&7)**			
Call timing	2018	2019	2020	2021
TRL	Start: TRL 3/4		End: TRL 5/6	
Market segment	*Environmental sensing, consumer electronics/wearables, Internet of Things (IoT)*			
Companies interested / **consulted**	*Sensor systems:* ***Siemens, ams, Analog Devices, Bosch Sensortec, Infineon,*** *NanoSense, 3S,* ***SGX, CCMOSS****, UST etc.Wearables and IoT:* ***Samsung****, Apple, Microsoft, Google, LG, Jawbone,* ***Panasonic*** *etc. Networks and information services:* ***Worldsensing, Arianet, Siemens*** *etc.*			
Challenge	Gas sensors will be integrated into smartphones and other mobile electronics starting in III/2016 with expected volumes of 200 Mio units in 2017 and fast growth in the following years according to IHS. First applications will be localized monitoring, e.g. for indoor air quality (based on total VOC) and breath alcohol levels. Further applications could include breath odor monitoring, health diagnostics (e.g. for asthma or diabetes patients). So far, all evaluations will be based on the local measurement only. However, one can expect a fast saturation of the technology, thus a new paradigm could be achieved for air quality networks due to ubiquitous sensor systems. For example, a typical meeting or class room would have several sensors, public buildings and transport could have several tens or even hundreds of sensors and large sports arenas several thousand. In addition to environmental monitoring, data could also be used for safety and security applications, e.g. fire detection or explosives warning. Making use of this wealth of information would require standardized data interfaces (e.g. integrated into the major smartphone operating systems) and of course specific regulatory frameworks, but also novel data evaluation and interpretation technologies. At the same time, this technology could be used to improve the performance of the individual sensor systems by using the network for cross-validation and re-calibration. Data exchange at a local level could easily help users to lead a healthier life, e.g. by making them aware of the "canyon effect" in cities or helping them to find "green routes" through the city for jogging, skating and biking[4].			
Possible solutions	Sensor systems could take the next step to Environmental Information (EI) services, e.g. by personalization of AQ information on the basis of crowd sensing and computational intelligence methods. This will require a suitable EI services framework, i.e. a comprehensive data and user interface for environmental sensor networks. Data processing could be realized locally, exchanging (limited) data between mobile phones and wearables within a defined area (local awareness), or centrally, via a backend system which could be offered by mobile network providers or dedicated service providers. The latter could make use of big data analysis to achieve high performance and could also link low-cost sensors with state-of-the-art analytical monitoring stations. Output could be via public websites ("environmental weather forecast") and via individually adapted tailored interfaces.			

[4] The "canyon effect" in city streets refers to the effect that pollution levels on one side of the street are often significantly higher compared to the opposite side due to the wind effect pushing pollutants to one side while clean air is drawn to the other. "Green routes" refers to roads and paths with lower pollution levels as an additional personalized service for navigation systems.

	One current bottleneck is the functional integration and high volume availability at low cost for highly reliable sensor systems. Required building blocks are a combination of volume manufacturing capable micro and nano technologies and the use of physical and chemical detection principles for miniaturized low cost sensor systems, but also suitable calibration schemes. Performance could be assured by intercomparison exercises, i.e. Air Quality joint exercises comparing sensor performance to reference analyzers in standardized measurements.
EU positioning	Europe has a strong commercial position especially in sensor systems for mobile applications but is currently weak in the system integration itself (smartphones, wearables). Also, big data is a challenge where many opportunities exist which can be addressed based on the excellent scientific expertise in Europe in this field. Indeed, the upcoming Internet of Things is expected to strengthen Europe´s competitive situation due to the requirement of integrating not only electronics but also systems know-how for various relevant fields from environmental monitoring, health up to safety and security.
Possible impact of topic in H2020	The consumer and mobile sensor market dominated by smartphone applications has overtaken automotive applications as the largest MEMS sensor market in 2011 and continues to grow at 17.8% CAGR with sales reaching nearly 5 B US$ in 2016 (source: IHS iSuppli). Bosch, the leading supplier reached more than 1 B sensors per year in 2014, expects strong growth for integrated environmental sensor units combining temperature and pressure with humidity and gas sensors. Target areas covering user context and ambient awareness will specifically profit from sensor data fusion. Ubiquitous sensor systems combined with advanced data processing and big data approaches could prove to open the next huge markets not only for gadgets but also for smart services. The first impact is expected for environmental monitoring and awareness of citizens concerning their impact on the environment, but further benefits are expected for health, especially for elderly people (online monitoring of breath), food security (monitoring of food freshness) and secure societies. Initially, the emerging IoT market is expected to be primarily a hardware market, with hardware sales increasing strongly until approx. 2020. Then, however, it is expected to shift to a software and services market, according to Yole Developpment. By the mid 2020s, 75 % of the $400 Billion IoT market is expected to be based on data and services.

Title	**Bio-chemical sensor systems for mold detection (ST8b)**			
Call timing	2018	2019	2020	2021
TRL	Start: TRL 3/4		End: TRL 5/6	
Market segment	*Building and construction, environmental sensing,*			
Companies interested / **consulted**	*Building and construction:* ***Siemens Building Technologies****,* ***Camfil****,* ***CIAT Compagnie Industrielle d'Application thermique****,* ***Systemair****, ALDES Aéraulique, Acciona Infraestructuras,* ***Delos****, Energy Efficient Buildings European Initiative (E2B EI) etc., Sensor systems: Siemens, ams,* ***Samsung****, Panasonic, Analog Devices, Bosch Sensortec****, NanoSense, 3S****, SGX, UST,* ***CCMOSS****,* ***Environmental Monitoring Systems****, etc.*			

Challenge	Humidity can lead to (hidden) mold formation, which has a huge impact on health and can greatly deteriorate building structure and decoration. Especially for modern or modernized buildings which are highly insulated to reduce energy consumption this is an increasing hazard and many people are highly aware of the danger of molds and spores on their health and on the building value. Thus, systems to detect mold at an early stage or systems to predict mold formation based on comprehensive air quality data (temperature, humidity, ventilation, etc.) will be very important to make full use of low energy buildings and building renovation. Current sensor solutions lack sensitivity and selectivity for detecting especially hidden mold; other technologies require lab tests and are not suitable for online use. Symptoms of mold exposure may include: • Nausea • Headache • Fatigue • Asthma • Memory loss • Irritation of the eyes, nose, skin, throat, and lungs • Lung disease • Kidney (renal) failure • Acute idiopathic pulmonary hemorrhage (especially in infants) • Some forms of cancer, including lung and liver cancers • Increased lower respiratory illness and/or viral infections in healthy children
Possible solutions	Some spores are known to have a typical VOC signature and could thus be monitored by VOC sensor systems, however at very low concentrations. These systems could work continuously and could be combined with other monitoring solution, e.g. for air quality or fire detection. Model-based approaches could be suitable solutions based on comprehensive air quality sensor data (temperature, humidity, ventilation, occupancy, etc.) but these need to be verified with direct (biochemical) measurements. These could be enhanced with additional techniques, e.g. low-cost thermal imaging to detect condensation or mobile VOC sensor systems for source localization. Biosensors could contribute to addressing this challenge by developing suitable on-the-spot measurement solutions for fast tests, e.g. during house shopping.
EU positioning	Europe has a strong position in sensor systems for environmental monitoring and especially in biosensor systems. This expertise can be combined with modelling know-how allowing direct and indirect detection solutions for mold formation. The market demand is expected to increase strongly in the near future due to increased refurbishments of existing houses for higher energy efficiency which will, however, exacerbate the problem of mold formation.

Possible impact of topic in H2020	Eurostat reported that the percentage of total population exposed to mould problems varies between 4.2% (Finland) to 35.7% (Portugal). Results from various studies (e.g. DBH and ALLHOME) found strong and consistent associations between moisture related problems indoor and symptoms among children. The risk for symptoms was more than doubled for children living in a home with self reported “dampness” ; this problem can be of similar high importance for elderly and immunological depressed persons, e.g. cancer patients receiving chemotherapy. Sensors for mold detection, both as spot measurements and for continuous monitoring, are one important element for reducing the energy consumption of public buildings and private homes and thus reaching the European targets in terms of reduced energy consumption and CO_2 reduction without endangering the health of Europe´s population.

Title	**High-performance, low-cost particle monitoring systems (ST8a)**			
Call timing	2018	2019	2020	2021
TRL	Start: TRL 2/3		End: TRL 4/5	
Market segment	*Environmental sensing, building and construction*			
Companies interested / **consulted**	*Building and construction: Siemens Building Technologies,* ***Camfil****,* ***CIAT Compagnie Industrielle d‘Application thermique****,* ***Systemair****, ALDES Aéraulique, Acciona Infraestructuras, Delos, Energy Efficient Buildings European Initiative (E2B EI) etc., Sensor systems:* ***Siemens, ams, Samsung, Infineon,*** *Panasonic,* ***Analog Devices****,* ***NanoSense, 3S****, SGX, UST,* ***Alphasense, SenSiC*** *etc.*			
Challenge	Particulate Matter (PM) is recognized today as having the greatest impact on health of all pollutants, both in outdoor and in indoor environments[5]. Ambient fine particulate matter (PM2.5) concentrations have been associated with excess mortality and morbidity at current urban levels and there is also evidence linking particulate air pollution and increases in hospital admissions for respiratory and cardiovascular diseases. Epidemiological studies have consistently shown an association between PM pollution and the number of deaths from cancer and cardiovascular and respiratory diseases. On the other hand, sensor systems today are very bulky and expensive and provide only limited information, at best giving the particle mass concentration for PM10, PM2.5 and PM1 (particles <10, < 2.5 and <1 µm, respectively). However, epidemiological studies show that many factors contribute to the health impact of PM: - The number of the particles (mass concentration favors larger particles over smaller)			

[5] cf. European Environmental Agency: SOER 2015 — The European environment — state and outlook 2015, A comprehensive assessment of the European environment's state, trends and prospects, in a global context. http://www.eea.europa.eu/soer
Quote: “Particulate matter, nitrogen dioxide and ground-level ozone, are now generally recognised as the three pollutants that most significantly affect human health…. For example, fine particulate matter (PM2.5) in air has been estimated to reduce life expectancy in the EU by more than eight months. Benzo(a)pyrene is a carcinogenic pollutant of increasing concern, with concentrations being above the threshold set to protect human health in several urban areas, especially in central and eastern Europe.”

	- The material composition of the particles, i.e. soot vs. inorganic - The shape of the particles (well known for asbestos) - Adsorbates attached to the surface; pure carbon, e.g., seems to have little impact but PAH (polycyclic aromatic hydrocarbons) are highly carcinogenic and are often found on soot particles A specific pollutant of interest is Benzo[a]pyrene primarily stemming from wood fires, both open fireplaces and pellet burners, which are also an increasingly relevant source for PM. Benzo[a]pyrene is highly carcinogenic and one of the few pollutants showing a strong increase in recent years according to the European Environmental Agency[1]. Due to its low vapor pressure it is primarily found adsorbed on PM and thought to contribute strongly to its health impact.
Possible solutions	Sensor systems for PM today are mostly based on optical techniques combined with fluidics to count particles and estimate their size related mass concentration. Existing approaches could be miniaturized and combined with other techniques to assess different PM properties, e.g. by collecting PM on a surface and using impedance spectroscopy, impact measurement or surface ionization to gain additional information on size, weight and shape or using capacitive measurements. Adsorbates could be characterized by heating the samples and subsequent analysis of the released molecules. It is expected that multiparameter sensor systems need to be combined with appropriate data analysis techniques to obtain reliable data. One current bottleneck is the functional integration and high volume availability at low cost for highly reliable sensor systems. Required building blocks are a combination of volume manufacturing capable micro and nano technologies and the use of physical and chemical detection principles for miniaturized low cost sensor systems, but also suitable calibration schemes.
EU positioning	Europe has a strong commercial position in sensor systems for environmental monitoring, both in analytical equipment for scientific use and for low-cost sensors. Combining the expertise in these fields with micro- and nanotechnologies where Europe is also strong for novel multiparameter PM sensors would allow a worldwide leading position for novel PM sensors required for various applications, both indoor and outdoor.
Possible impact of topic in H2020	Sensors for PM are a prerequisite for comprehensive environmental monitoring both indoor and outdoor, which would by the first step to raise awareness for PM sources and effects. In a second step, low-cost sensors could be combined with amelioration strategies (e.g. filtering) and source control (e.g. closed loop control of fire places and wood burners) to address the societal challenges health, environment and clean energy by addressing two main areas of concern today, i.e. PM and Benzo[a]pyrene.

Title	**Comprehensive IAQ User Interface for demand controlled ventilation (ST6&7, HT1)**			
Call timing	2018	2019	2020	2021
TRL	Start: TRL 4/5		End: TRL 6/7	
Market segment	*Environmental sensing, building and construction, energy efficiency*			

Companies interested / **consulted**	*Building and construction:* ***Siemens Building Technologies, CIAT, Compagnie Industrielle d'Application thermique, Systemair****, ALDES Aéraulique, Acciona Infraestructuras,* ***Delos****, Energy Efficient Buildings European Initiative (E2B EI) etc.* *Sensor systems: Siemens,* ***ams, Samsung, Analog Devices, Infineon****, Bosch Sensortec****, NanoSense, 3S****,* ***SGX, UST, SenSiC, Environmental Monitoring Systems*** *etc.*
Challenge	Indoor Air Quality (IAQ) has a strong impact on humans (health, comfort, productivity and sleep quality) as well as on buildings (energy consumption, building integrity). High CO_2 and VOC values strongly affect well-being (sick building syndrome), but also learning ability for children and students and productivity for workers. Hazardous VOCs, Radon & particulate matter (PM) lead to cancer and respiratory diseases, malodors and allergens induce discomfort. To make full use of sensor systems for controlling IAQ several steps need to be addressed: - Development of a comprehensive Air Quality Index including odor nuisance monitoring for comprehensive IAQ assessment - Outdoor and Indoor Air Quality have to be connected to allow optimal demand controlled remediation strategy, e.g. by ventilation, based on the developed AQ index - A dedicated IAQ User Interface is required that raises awareness of the people indoors, allows easy understanding and individual tailoring, e.g. for people with allergies or specific susceptibilities (pregnant women, small children) This approach also requires standardization in IAQ and environmental monitoring (e.g. data format as basis for the AQ index, legal and regulatory frameworks)
Possible solutions	Close collaboration between specialists in sensor systems, building technologies, health experts and user interfaces is required to address this complex field. Displaying numerical concentration values of different pollutants and ambient conditions in combination with energy consumption is insufficient to raise the awareness on the one hand and to allow people to adapt the system according to their requirements. Solutions could range from simple traffic light control (as simple day to day interface) via more complex graphical representations to expert systems with numerical data and adaptive weighting for specific room uses (offices, living room, bedroom etc.) and user groups (elderly, children, people with specific allergies etc.). Specific solutions might be based on existing building control interfaces for HVAC systems or make use of smart home solutions with smart phones and tablets as omnipresent user interface. At the same time, sensors integrated in smartphones could be integrated into the IAQ monitoring system. Viable solutions will also need to address the issue of efficient factory calibration and especially field re-calibration of sensor systems. This could be achieved periodically with specific simple-to-use solutions or automatically over the internet using connected sensor systems (IoT approach).

EU positioning	Europe has a strong commercial position both in sensor systems and in building technologies. A specific challenge for Europe compared to, e.g., Asia is the refurbishment of existing buildings which are far more numerous than newly constructed buildings. Awareness of the impact on indoor pollutants on health has already triggered standards for low pollutant levels in several countries and for reducing emissions of specific hazards (e.g. formaldehyde from building materials). Emphasis on increased energy efficiency, however, threatens to counteract measures to improve air quality inside buildings due to reduced ventilation.
Possible impact of topic in H2020	Improved IAQ will have a huge positive impact on health for many Europeans and will also allow green, energy optimized buildings. Sensor systems combined with a comprehensive user interface for IAQ will find a huge market in Europe and beyond, especially if the systems are intuitive and available at low cost. Sensor system development has progressed to the stage that integration with building control is possible but now data standards und user interfaces are required for smart home solutions. Leading this development will open up international markets for sensor system manufacturers and building control integrators with a huge market potential especially in Asia and North America.

WG 3 - Health Monitoring and Comfort Sensors

Chaired by Paul Galvin (Tyndall National Institute, University College Cork)

Introduction

This document is to define main objectives for this working group in order to help the EC to prepare calls related to sensor systems for Health Monitoring and Comfort Sensors.

Background: Health Monitoring and Comfort Sensors

Advances in the Key Enabling Technologies of nano and microelectronics, advanced materials, photonics and biotechnology are providing new opportunities for the development of smart systems for precision health in areas such as:

- diagnostics,
- connected health,
- theranostic systems,
- cardio and neural interfacing, and
- surgical innovations.

Opportunities are emerging for new generations of sensors, which will lead to several disruptive changes to the way healthcare can be delivered. These include:

- the development of non-invasive or minimally invasive sensor devices to enable early detection and quantification of specific biomarkers for cancer, cardiovascular, neurodegenerative and infectious disease;
- realtime remote monitoring of patients using wearable technologies;
- integrated therapeutic systems with feedback loops informing controlled release of therapeutic agents based on integrated realtime sensing technologies,
- implantable and wearable technologies for monitoring neural signals to facilitate diagnosis and treatment of intellectual disabilities, neurodegenerative disorders and for bidirectional communication with new generations of prostheses.
- augmented reality for surgical procedures to enable tissue identification to ensure sparing during surgery, and for minimizing surgical margins during tumor surgery.

These opportunities require the development and integration of new generation of sensor systems into everyday clinical practice and health monitoring. This has implications not just relating to the sensor functionality of these systems, but also other aspects including biocompatibility, manufacturability, data management, etc.

<u>Priority topics</u>

Cross cutting topics:

Multiparameter sensing
Health monitoring systems typically require integration of multiple data streams, such as details of the position and movement of the individual, a combination of vital signs measurements including body temperature, pulse and blood pressure, and a selection of biochemical measures taken from blood / saliva / urine. Therefore, the integration of these discrete individual sensing systems presents significant challenges and opportunities.

Internet of things / Internet of everything
The anticipated disruptive nature of advancements based on the internet of things will also create opportunities for health monitoring including new wearable sensing systems and integration of sensing systems into implantable devices and surgical tools. These distributed sensing systems will facilitate independent living for the elderly, persons with intellectual disabilities and palliative care, as well as providing opportunities to optimize the patient care pathway.

Energy management / Energy harvesting
Autonomous sensor systems will require systems level designs that take into account available power sources. While reducing power requirements based on sensor design and duty cycling will contribute, there is likely to be a need for energy harvesting technologies which enable sensor systems to operate fully autonomously for extended periods.

Data management and integration into EMRs (Electronic Medical Records)
While the focus of many new sensor systems technologies is to capture additional parameters, the value of this data to making informed clinical decisions. The need for embedded software to enable data fusion and perform analytics that will provide the basis for a “traffic light” type decision support for the responsible clinician. Clinical data storage and use is not just a logistical issue, but most importantly, raises many ethical and regulatory issues, and the full benefits will not be realized unless the data can be seamlessly and appropriately integrated into the patient EMR. The business models for exploiting the additional data also need to be

developed, including the reimbursement codes required to justify the additional costs of the devices with all of the integrated sensing capabilities.

Sensor system design

Human factors need to be considered carefully and early on in the development of sensor systems for health monitoring. While the need for industrial design will be obvious for products focused on health monitoring for consumer markets, such as the various watches and wearable technologies which are currently on the market, human factors considerations are just as critical for the clinical market. Integration of novel sensor systems into medical devices needs to carefully consider how such innovations could impact on the process flow within the clinical environment, the interactions between different members of the clinical team, the ability to train the relevant clinicians on the use of the new device (i.e. need to not only design for manufacture and test, but also for training).

Biocompatibility

Wearable and implantable sensor systems will need to leverage innovative solutions for ensuring their functionality over days, weeks or even months in the presence of complex biological media which typically cause fouling. Conversely, many of the sensing platforms with the greatest levels of sensitivity currently reported in the literature, have been developed using materials which are not biocompatible and could present significant toxicity issues. This is particularly relevant where the sensing platforms require the use of contrast agents that need to be released into the tissues, or systemically delivered.

Working group specific topics:

Sensors for detection and quantification of volatile organic compounds

It has long been known that breath analysis provides opportunities to identify unique chemical signatures, which are diagnostic for specific diseases. The potential for realtime analysis of VOCs (such as from breath) would provide the basis for the ultimate point-of-care diagnostic system. Significant advances in the state of the art are required to enable the levels of sensitivity and complexity required (e.g. emulating what has been reported in the literature using dogs to detect cancer).

Detection of single cells in complex media

While there are now many systems available capable of analyzing nucleic acids, proteins and cells when the samples provided are at appropriate concentrations for the system sample prep module, there is still a significant challenge to enable capture, identification and characterization of very rare biomolecules such as infectious agents or circulating tumor cells which can have concentrations less than one cell per 10ml blood.

Sensors for tissue identification and characterization

Realtime analysis of tissues and cells is required to facilitate intraoperative diagnosis and tissue sparing. While this can be achieved today with very narrow depth of field by some electrochemical and biophotonic methodologies, a new generation of sensors are required that enable augmented reality for surgical procedures which facilitate tissue differentiation and identification of target tissues for resection or tissue sparing.

Non-contact sensing platforms for physiological monitoring

Sensor systems capable of remote monitoring of physiological parameters are needed which can rapidly and non-invasively provide the clinical data needed to support independent living, rapid identification of persons suffering from pathogens in the event of an epidemic, or continuous monitoring of patients from admission to discharge within the hospital context.

Integration of sensors into organ-on-chip systems

As the development of organ-on-chip accelerates, the ability to integrate sensors into the organ scaffolds will provide the opportunity to monitor, and hence modulate stem cell differentiation in the development of individual organs, and also create new artificial systems for toxicity testing, as well as for realtime monitoring of new generations of implants.

Development of disposable imaging systems

The growth of camera based applications for health monitoring is rapidly accelerating due to the growth of the smartphone. However, unlike the smart phone which typically costs between €100-800, there is a need to integrate cameras into wearable and disposable devices for health monitoring, where the camera should be completely disposable. This will require significant innovation to deliver the level of image quality currently achieved by standard CMOS / CCD cameras.

Title	**ST9 – Sensors for detection and quantification of volatile organic compounds**			
Call timing	**2018**	**2019**	2020	2021
Market segment	Healthcare			
Companies interested / **consulted**	Smartphone companies and smart wearable technology companies; medical device companies involved in selling equipment for surgical / ambulatory applications; medical diagnostics companies; pharma and biopharma industry for monitoring safety and efficacy of their products; security industry and agencies. **Discussed under CDA with senior R&D directors from: 10 multinational and two SME medtech companies; four biopharma companies; one smartphone and smart wearable company; senior military representatives from Ireland and US**			
Challenge	It has long been known that breath analysis provides opportunities to identify unique chemical signatures, which are diagnostic for specific diseases. The potential for realtime analysis of VOCs (such as from breath, but also from other sources such as wounds) would provide the basis for the ultimate point-of-care diagnostic system. Similarly, realtime monitoring of plumes during electrosurgery has been demonstrated to enable rapid identification of the tissues at the cutting edge. Significant advances in the state of the art are required to enable the levels of sensitivity and complexity required (e.g. emulating what has been reported in the literature using dogs to detect cancer). Disease-specific VOC signatures require extensive validation due to the many factors which can influence the concentration of VOCs including diet, physiology, etc., and the many different compounds which need to be analysed in parallel to fully characterize specific VOCs. While large lab-scale equipment can currently facilitate such comprehensive analysis, there is a need to miniaturise the required systems and make the analyses available realtime in order to address the various application needs. In practice, this means that the relevant sensors and systems must be fully integrated into wearable technologies, smartphones, surgical tools, etc in order to enable continuous VOC analysis with realtime feedback. Separate to the chemical / biochemical challenge, this also presents a data analytics challenge requiring efficient			

	algorithms to correctly interrogate complex data from multiple sensors.
Possible solutions	The solution is likely to be an array of optical or electrochemical sensors (or some combination of the two), enabling the capture of VOCs into the appropriate media, and using highly sensitive (nanosensor) platforms, enabling very accurate but subtle differentiation between similar compounds even in the presence of interfering elements. Apart from the sensors, the solution will need to enable the appropriate through flow of VOCs without any dead volumes in the device impacting on the speed or accuracy of measurements. The proposed diagnostic systems would need to be designed taking into consideration the need for disposable collector modules, calibration of the sensors, etc.
EU positioning	If successful, VOC diagnostic systems could revolutionise healthcare systems, based on their user friendliness, compatibility with use in the home, in primary healthcare settings, and integrated into wearables. With the exception of alcohol testing, there is currently no significant market for VOC products, so that this will be a very rapid and disruptive technology once developed, which should support many new companies addressing various market segments, ranging from the clinical to the consumer markets.
Possible impact of topic in H2020	Impacts could include remote monitoring for independent living and active and healthy ageing; enabling augmented reality during surgical procedures; early discharge of patients post-operatively; monitoring efficacy of therapeutic programmes as a basis for reimbursement; enabling early diagnosis and treatment of diseases such as cancers. Miniaturisation of the VOC systems will require innovations in photonics / electronics to enable a high degree of multiplexing for up to several hundred different sensors. This could be supported through sensor development within NMPB programme, system integration through supports from DG CONNECT and DG GROW, and validation through DG Health

Title	**ST11 - Non-invasive sensing platforms for health monitoring**			
Call timing	**2018**	**2019**	2020	2021
Market segment	Healthcare			
Companies potentially interested / **companies consulted**	Smartphone companies and smart wearable technology companies; medical device companies involved in selling equipment for surgical / ambulatory applications; medical diagnostics companies; pharma and biopharma industry for monitoring safety and efficacy of their products; security industry and agencies. **Discussed under CDA with senior R&D directors from: 10 multinational and two SME medtech companies; four biopharma companies; one smartphone and smart wearable company; senior military representatives from Ireland and US**			

Challenge	Sensor systems capable of remote monitoring of physiological parameters are needed which can rapidly and non-invasively provide the clinical data needed to support independent living, rapid identification of persons suffering from pathogens in the event of an epidemic, or continuous monitoring of patients from admission to discharge within the hospital context. Implantable and / or in vitro technologies can measure various biochemical and electrophysiological parameters directly from body fluids, and as such, provide the gold standard for accuracy and precision of clinical measurements. However, while continuous monitoring with implantable systems is typically limited to electrophysiological cardiac / neural parameters for cardiac rhythm management or neuromodulation respectively, in vitro analysis is largely restricted to intermittent sampling in acute care scenarios, or through remote analysis taking days or weeks from specimens collected from primary care facilities. In both scenarios, biofluids (blood / urine / saliva /etc.) needs to be extracted from the body, or a device needs to be inserted into the body in direct contact with bodily fluid to measure the required parameters.
Possible solutions	With the advent of IOT-enabled smart buildings, the potential to integrate non-contact sensing platforms into homes, cars, hospitals, and wearable systems to enable health monitoring. These could be based on multispectral biophotonic techniques, ultrawideband radar, or other nano/ICT-enabled sensor platforms as applicable. Significant effort is required to overcome issues with background noise, signal artifacts, low light conditions, etc. in order to ensure reliable data. Vital signs such as pulse, respiration rate, and temperature can already be monitored using non-contact biophotonic and UWB technologies, but ultimately, data from a wide range of electrophysiological and biochemical parameters are required to enable accurate health monitoring.
EU positioning	With the emergence of Industry 4.0 and the rapid convergence of pharma, medical and ICT industries, Europe needs to position itself as a leader in the development and manufacture of smart medtech. Europe has already more than 500,000 medtech companies with a market worth over €100bn. The vast majority of these companies are SMEs. Advanced manufacturing for current medtech and electronics products and components remains one of the largest employers within the EU. The health monitoring market combining both clinical and consumer products is growing rapidly, and EU manufactured products have global leadership due to their high quality and reliability. The opportunities to consolidate the EU leadership in this field require embedding R&D capabilities within companies and facilities based in EU.
Possible impact of topic in H2020	The H2020 support on this topic should operate at two levels: 1. Exciting and highly innovative new concepts with the potential for high impact which already have a preliminary proof of concept (e.g. TRL2-3) should be supported to demonstrate their potential as advanced prototypes (TRL 5-6). 2. Where advanced prototypes have already been advanced through National or previous EC programmes, the manufacture and integration of these devices and systems would need to be supported through advanced manufacturing within pilot lines, clinical validation, integration of the physical and cyber aspects with established products in homes, cars, hospitals etc, to ensure rapid market penetration. As such, support could be envisaged through DG CONNECT, Health, LEIT, GROW, etc.

WG 4 – Industrial Process Monitoring

Chaired by Torsten Mayr (Graz University of Technology)

Rationale

This document highlights the main objectives for this working group in order to help the EC to prepare priorities for future calls in the field of industrial process monitoring with chemical sensors.

Background

Process monitoring and control is essential in chemical, pharmaceutical, food industries and biotechnology. In order to enhance production efficiency and product quality (quality by design) the FDA has introduced in 2011 RTRT (real time release testing),[6] which is based on the former FDA PAT (Process analytical technology) initiative.[7,8] Although, FDA PAT initiative had a strong impact on the development of process instrumentation, the number of chemical parameters that can be monitored with sensors is still limited as indicated in the NAMUR/GMA Technology Roadmap Prozess Sensoren 2015+.[9] Various representatives of the chemical and pharmaceutical industry and process sensor equipment producers in Germany contributed to this guideline. Reason can be found in the special requirements on sensors for process monitoring including long term stability under harsh conditions, selectivity, sensitivity, reliability, calibration stability, explosion prevention, minimized total cost of ownership among others. Process sensors have to show improvements in all these items.

This is underlined by a recent opinion article from Formenti et al. (2014) discussing some of the current challenges of industrial fermentation technology research. One of the challenges is the lack of novel sensors to measure and control insightful process parameters in biotechnology processes. The available sensors for industrial processes measure single physical or chemical parameters at a single position of the reactor. In particular, reactors with large volumes show an inhomogeneous temperature and concentration distribution. At best, the measurement data can be regarded as averages over space and time, but the information on the spatial heterogeneity in the reactor is not available. Alternative analytical methods are still very rare in bio-based and other production processes in a full-scale production environment, as concluded by Cervera et al. (2009).

New topics such as "Industrie 4.0", "Factories of the future", "smart manufacturing" have gained rapid development in the above mentioned industries. These rapid changes require

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6 Regulatory perspective on real time release testing (RTRT), FDA, October 2011, on-line at: http://www.fda.gov/downloads/AboutFDA/CentersOffices/OfficeofMedicalProductsandTobacco/CDER/UCM301055.pdf

7 Guidance for Industry-Process Validation: General principles and practices", FDA, January 2011, on-line at: http://www.fda.gov/downloads/Drugs/GuidanceComplianceRegulatoryInformation/Guidances/UCM070336.pdf

8 Guidance for Industry PAT — A Framework for Innovative Pharmaceutical Development, Manufacturing and Quality Assurance", FDA, September 2004, on-line at : http://www.fda.gov/downloads/drugs/guidancecomplianceregulatoryinformation/guidances/ucm070305.pdf

9 http://www.namur.net/fileadmin/media/News/Prozess-Sensoren_2015.pdf

advances in the state-of-the-art sensor technology as indicated in the recently published new NAMUR roadmap “Prozesssensoren 4.0”.[10]

A smart sensor suitable for advanced PAT

- measures several parameters
- is self-maintained
- is self-calibrated
- is easy to integrate (connectivity)
- has communication features (accessibility to cloud services)
- and can work interactively with other smart sensors in a network

Smart multiparameter and multiposition sensors will generate information of a higher level, meaning data can be stored in cloud systems that will enable information from many sources to be integrated and queried. This will contribute to a flexible and target predicting process control.

Priority Topics

Cross Cutting Topics

Driving Down Costs of Analysis
From WG1: This is a generic challenge across all sensor areas. Key contributors include unit (purchase) cost and cost of ownership (consumables, servicing). Future platforms must increasingly become autonomous in operation and much less expensive to purchase, and research investment must prioritise ways to deliver these improvements. This can be achieved by harnessing the tremendous potential of new materials emerging from fundamental materials research, and coupling this with dramatic improvements in fabrication technologies, for example, through 3D printing, specifically targeting the ‘analytical engine’ of the analyser. Increasingly, this will be based on microfluidic approaches with fully integrated fluid handing components.
In addition to the points of WG1:

- Establish complementary chemical sensor approaches to expensive spectrometric techniques (NIR, MIR)
- Enabling a widespread sensor deployment and multipoint measurements in a reactor

Robust, selective and safe sensor materials for new and established parameters
The number of parameters that can be monitored continuously in chemical and biotechnological process is very limited. In order to monitor and control industrial process better and more reliable more parameters are needed. In many cases monitoring is limited to physical parameters and oxygen, pH and biomass. A specific requirement for sensor applied in process monitoring is that they have to withstand harsh condition of cleaning and sterilization and must possess long-term operational stability.

Ease-of Use
Application of the sensor out the box including calibration free or factory calibrated sensors or calibration routines with minimized effort for the end-user.

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[10] New NAMUR Sensor Roadmap published in November 2015.
http://www.namur.net/fileadmin/media_www/Roadmap_Dateien/Roadmap_Prozesssensoren_4.0.pdf

Understanding and controlling Biofouling
Biofouling affects many sensor applications. It has prevented the early promise of implantable chem/biosensors for personal health monitoring from being realized, and driven up the complexity and cost of analysers across the entire environmental sector.
As in WG1 biofouling is also an issue, in particular in fermentation processes.

Harnessing the Power of Data Analysis and Modelling
Cloud systems will enable information from many sources to be integrated and queried. Data of processes can be collected and stored in the cloud and be access-able. Data on process parameters are stored in the cloud and are accessed by the smart sensors enabling an autonomous decision on the process control. Moreover, information based on raw materials prize predictions, weather forecast, market observations, etc. can be used to plan and operate processes.

WG Specific Topics

Title	**Sensor for single use reactors**			
Call timing	2018	2019	2020	2021
Market segment	Biotechnological and Pharmaceutical processes			
Companies interested / **informed**	GE Healthcare Life Sciences, Merck Millipore, CerCell, Sartorius**, Blue-Sense, Applicon, m2p-labs,**			
Challenge	An ongoing trend in biotechnology and pharmaceutical industry is the introduction of single-use reactors and even whole factories. This results in reduced costs by eliminating cumbersome cleaning and sterilisation procedures. Monitoring and control is essential since these reactors are used for the production of high value pharmaceuticals or biochemicals. Although sensor technology exists, there is a lack in the number of parameters, sensor stability and ease-of-use. Demands on the sensors include cost-efficiency, simple integration to reactors and compatibility with GMP and PAT regulations. Single-use-reactors are pre-sterilized (γ-radiation) and are applied out-of-the-box without further treatment. The sensor system should have self-testing and monitoring capabilities. Compensation of sensors drifts and on-site calibration should to be included. Since the reactors are made for single use, active sensing elements have to be low-priced and non-toxic.			
Possible solutions	The active-sensor element is integrated into the single use reactors and the read-out electronics can be separated. Therefore, the active sensor elements have to possess resistance to sterilization methods (e.g. γ-radiation, ethylenoxide) and sufficient storage stability. The read-out electronics can be combined with communication capabilities to achieve sensor networks.			
EU positioning	Europe has a several companies which are active in the market of disposables reactor technology for biotechnology. The market demand is expected to increase strongly in the near future due to an increase in the use of disposables reactors in biotechnological and pharmaceutical industry.			

Possible impact of topic in H2020	According to the German NAMUR roadmap “Prozess-Sensoren 4.0” the market for disposables an increase of 15-20% is expected (time not specified). MarketsandMarekts reports the global single use bioreactor (SUBs) market is poised to reach \$470.9 million by 2019 from \$202.5 million in 2014, at a CAGR of 18.4% from 2014 to 2019.[11] There is an increasing demand on taylor-made pharmaceuticals and fine chemicals produced in a low quantities, which are with biotechnological processes. Leading this development will open up international markets for sensor system and dispose-able manufacturers with a huge market potential especially in Asia and North America.

Title	**Smart and intelligent process control systems for smart manufacturing and process-intensification**			
Call timing	2018	2019	2020	2021
Market segment	Chemical, Biotechnological, Pharmaceutical processes			
Companies interested / **informed**	**Endress + Hausser, Bayer, BASF, Evonik, Krohne Messtechnik GmbH, Aliseca GmbH, ABB AG, Siemens AG, Verein Deutscher Ingenieure e.V, Bilfinger Maintenance GmbH, Evonik Industries AG, Hamilton, Mettler-Toledo, Metroglass,**			
Challenge	Miniaturized and cheap smart sensor systems based on chemical sensors for widespread deployment in industrial processes for small and large volume reactors are needed in the future These systems enable multipoint measurements to achieve a better view on the actual concentration distributions in a reactor. The optimisation of processes can be shifted from an empirical to a systemic approach. The obtained data and knowledge would lead to models that enable a predicable process. Furthermore, upscaling and downscaling of processes can be facilitated and accelerated by using sensor data. Thereto, sufficient sensors or smart sensors systems have to be developed. Sensors for process monitoring need improved 3S properties to fulfil the requirement of GMP and PAT regulations and be capable to withstand the harsh treatment, e.g. cleaning in place and sterilisation methods. The sensor systems should have self-testing, -monitoring capabilities, and on-site calibration should be included. Moreover, sensor systems have to be capable to be easy integrated in reactors and to work interactively in a network of sensors nodes. The interactive communication with other sensor elements can enable self-calibration, self-correction of sensor drifts and self-maintenance. Therefore, the individual sensor elements have to be equipped with communication features and operate autonomously at low energy consumptions.			
Possible solutions	Miniaturized sensor devices with electrochemical or optical transducing elements. Advanced sensor materials based on the materials research. Sensor modules needs communication interfaces to achieve sensor networks connected to cloud services. This is enabling the “internet of things” for process analytics or the Industrie 4.0 concept for chemical production.			

[11] http://www.marketsandmarkets.com/PressReleases/single-use-bioreactor.asp

EU positioning	Europe has a strong commercial position in sensor systems for process analytical technology because many large companies are established in Europe using these instruments. Process instrumentation and services are strongly covered by European manufacturers (see above). (According to the German NAMUR roadmap "Prozess-Sensoren 2015+" of 2009, the chemical and pharmaceutical industry in Germany employes 400.000 people with annual turnover of €170b and F&E expenditure of €9.5b) However there is a need to speed up standardization[12].
Possible impact of topic in H2020	The recently published NAMUR roadmap "Prozess-sensoren 4.0" documented that new topics such as "Industrie 4.0", "Factories of the future", "smart manufacturing" will influence the future of Process analytics dramatically. These rapid changes require advances in the state-of-the-art sensor technology. Smart sensors are required to enable new and more efficient, more flexible and better-controlled processes. Without any digitalization for sensory units and Information Fusion functionalities (including integral sensor defect detection) strategical goals are definitely not reachable. Europe will lose main impact factors on Industrie 4.0 and related topics in the process industry. On the other hand, leading this development will open up international markets for sensor system manufacturers and building control integrators with a huge market potential especially in Asia and North America. In a societal context intelligent, autonomous sensors in the sense of -Physical systems will definitely change the way we work.[13] Furthermore, they will change many technological possibilities especially in health, Pharma, Life Sciences, etc.[14]

Title	**Sensor platform for multi-parametric process control**		
Call timing	2018	2019	2020	2021
Market segment	Chemical, Biotechnological, Pharmaceutical processes			
Companies interested / **informed**	**Endress + Hausser, Bayer, BASF, Evonik, Krohne Messtechnik GmbH, Aliseca GmbH, ABB AG, Siemens AG, Verein Deutscher Ingenieure e.V, Bilfinger Maintenance GmbH, Evonik Industries AG, Hamilton, Xylem, Mettler-Toledo, Metroglass, m2p-labs,**			
Challenge	Intelligent processes of the future require quantitative information on many different chemical species in order to monitor, control and predict complex systems – the measurement of a single parameter is not sufficient. The information on different parameters should be available online and from the same sample increment, thus clearly pointing towards the need for multi-parameter chemical sensors. Nevertheless, in many cases a certain sensing technology is not capable or at least not optimal for sensing of all the parameters required in a given application. The development of multi-parameter sensors for such applications then requires heterogenic integration of complementary sensor technologies (e.g. electrochemical and optical sensors). These sensors			

[12] http://www.zvei.org/Downloads/Automation/ZVEI-Industrie-40-RAMI-40-English.pdf, http://www.zvei.org/Downloads/Automation/ZVEI-Industrie-40-Component-English.pdf
[13] http://www.bmas.de/SharedDocs/Downloads/DE/PDF-Publikationen/arbeiten-4-0-green-paper.pdf
[14] http://www.hightech-strategie.de/de/Gesundes-Leben-89.php

	should be compatible with GMP and PAT regulations, in particular for the application in the pharmaceutical industry. In addition the sensor must be capable of withstanding cleaning in place (CIP) and sterilisation (e.g. steam, γ-rays, e-beam,) procedures. The sensor systems should have self-testing and monitoring capabilities. Compensation of sensors drifts and on-site calibration should to be included. Such sensor system have communication features and can work interactively with other sensors nodes in a network. Smart, multiparameter sensors will generate information of a higher level, which contribute to a flexible and target predicting process control.
Possible solutions	Research on the development of generic techniques for heterogenic integration of different sensor technologies. This includes methods for the realization of different sensor types on common substrates, using similar materials, packaging and fabrication techniques, as well as electronic readout systems and data treatment. Based on this approach, multi-parameter sensors, enabling to use the ideal sensing mechanism for each analyte and providing a complete, holistic picture of the sample can be realized. Sensor modules need communication interfaces to achieve sensor networks connected to cloud services. This is enabling the "internet of things" for process analytics and the Industrie 4.0 concept for chemical production.
EU positioning	Europe has a strong commercial position in sensor systems for process analytical technology because many large companies are established in Europe using these instruments. Process instrumentation and services are strongly covered by European manufacturers (see above). (According to the German NAMUR roadmap "Prozess-Sensoren 2015+" of 2009, the chemical and pharmaceutical industry in Germany employes 400.000 people with annual turnover of €170b and F&E expenditure of €9.5b) In the direction of multi-sensory systems and Information Fusion for Industrie 4.0 Europe is in a good status. The main threats are coming from China (applications) and US America (Business Models) for Multi-sensory-systems.
Possible impact of topic in H2020	New topics such as "Industrie 4.0", "Factories of the future", "smart manufacturing" have gained rapid development. These rapid changes require advances in the state-of-the-art sensor technology. Smart sensors are required to enable new and more efficient, more flexible and better controlled processes. Leading this development will open up international markets for sensor system manufacturers and building control integrators with a huge market potential especially in Asia and North America. In a societal context intelligent, autonomous sensors in the sense of -Physical systems will definitely change the way we work.[15] Furthermore, they will change many technological possibilities especially in health, Pharma, Life Sciences, etc.[16]

[15] http://www.bmas.de/SharedDocs/Downloads/DE/PDF-Publikationen/arbeiten-4-0-green-paper.pdf
[16] http://www.hightech-strategie.de/de/Gesundes-Leben-89.php

Summary of proposed topics an the suggested call timing

Environmental Sensors	Year
Improved Platforms for Marine and Freshwater/ Wastewater Monitoring	2018-2019
Integrated Approaches to Air Quality Monitoring	2018-2019
Migrating Analytical Instruments to the Field	2020-2021
Environmental Sensor Informatics and Forecasting Integrated Approaches to Air Quality Monitoring	2020-2021
Indoor air quality	
Integration of mobile sensor systems (primarily smart-phones, wearables and IoT) into IAQ networks	2018-2019
Comprehensive IAQ User Interface for demand controlled ventilation Bio-chemical sensor systems for mold detection	2018-2019
Bio-chemical sensor systems for mold detection	2020-2021
High-performance, low-cost particle monitoring systems	2020-2021
Health Monitoring and Comfort Sensors	
Sensors for detection and quantification of volatile organic compounds	2018-2019
Non-invasive sensing platforms for health monitoring	2018-2019
Industrial Process Monitoring	
Sensor for single use reactors	2018
Smart and intelligent process control systems for smart manufacturing and process-intensification	2019-2020
Sensor platform for multi-parametric process control	2019-2020

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