European Nanoelectronics consortium on sustainability (ENCOS)

I. Motivations

A sustainable use of rare raw materials is an economic, social, environmental and major geopolitical stake for the current and next generations. Some key elements considered today in the emerging-electronic devices for expending markets as IoT, transports, connected medicine or energy must be substituted or saved (by orders of decades) in a drastic sustainable way in the near future.

Indeed, the 21st century is the age of mobile communications and the conscious use of natural resources. Communication contributes to reduce distance between people. It is the emergence of new human community, the **wireless social world** with tens of billions of connected objects which will need more and more sustainable design.

Smart objects communicate to each other to deploy an interactive environment (Internet of Things, IoT). People talk about the **digital society**. Everything seems to be fast, clean, reconfigurable, etc. but behind our screens there is an industry which requires, **more than ever, space, energy and matter**. There is an urgent need to revisit the economic, technological, and societal models to develop a sustainable electronic industry with an increasing care about its impact right from the conception of these objects. For example, China provides 95% of the production of rare earths to occidental countries and this monopolistic situation is a major stake for coming years. Another example is the dangerous conditions faced by African workers in cobalt mines that reinforces the attention paid to human rights issues in global supply chains.

However, no clear methodology exists today to design, manufacture and deploy the IoT in a "sustainable way" that preserves enough resources to avoid political, economic, and environmental tensions in the next twenty years. European microelectronics industry depends on rare raw material sourcing. European technology supplies are very fragile, and economy, strategic independence, ethical and environmental considerations are converging into a common requirement: **design differently our technologies at the early stage of the research process.**

Only a few initiatives have been launched in Europe[1, 2] and around the world[3, 4] to address the sustainable use of critical raw materials and none for developing sustainable wireless electronics devices and systems which are going to be massively deployed within the digital society.

Research laboratories in nanoelectronics, which investigate emerging materials, devices, and designs of components and systems, prepare technologies typically 10 years before their production. It is of first importance in this context to anticipate at the early stage of development the possible impact of the proposed technology, link it with societal, economical, regulation, and supply chains long term evolutions.

The consortium aims **to develop methodologies applied to advanced research** integrating the economic analysis, geopolitics issues, acceptability, life cycle, multi-criteria impact evaluation and the durability of new technological solutions. Basically, a systemic approach will be adopted. The established methodology will be opened to academia, research labs and the industry and will help them to take decision by comparing various scenarios to move forward to more sustainable electronic processes, designs and systems.

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[1] FP7, RESET: Sustainable substitution of rare earth elements in photodevices, 2014-04-01 to 2019-03-31.
[2] H2020, SCRREEN will contribute to improve the Critical Raw Materials strategy in Europe, 2016-11-01 to 2019-04-30.
[3] iNEMI, http://www.inemi.org/
[4] The Sustainable Electronics Initiative (SEI) at the Illinois Sustainable Technology Center (ISTC) is dedicated to the development and implementation of a more sustainable system for designing, producing, using, and managing electronic devices. http://www.sustainelectronics.illinois.edu/

Concretely, the consortium aims to analyze and propose **innovative solutions** for the main topics shortly described hereafter and illustrated by a few examples. The recommendations drawn by the consortium will impact the nanoelectronics domain for the next 15 years and induce profound changes which will pave the way to a more sustainable electronics industry.

II. Partnership between research institutes and industries toward sustainable electronics

These last years, several industries, including micro and nanoelectronics, have been engaged in sustainable approaches.

However, advanced research should take into account well in advance sustainable approaches by analyzing additional parameters than traditional cost/performance criteria.

ENCOS must help the nanoelectronics industry to adapt their manufacturing processes of electronic devices for being in phase with the evolution of the society, the economic and environmental constraints, and within the respect of the current and future regulations. In particular, the following considerations could structure specific advanced research actions in nanoelectronics.

- **Reduce the power consumption and industrial waste** during manufacturing electronic devices and their components. Low temperature processes, reduction of heat dissipation in and from the oven, reduction and recycling of chemicals and water cleaning, etc. will be evaluated for each fabrication step of the nanoelectronics devices. Beyond resource efficiency and recycling waste, the transition towards a cost effective **circular economy** should be implemented with the industrial partners of the consortium. As an example, today ST Microelectronics in Malta which is a world-beating IT manufacturing firm acts for a production of innovative products that provide environmental and social benefits. For instance, reducing end-application energy consumption, and thinking through whole life-cycle approaches. They believe in one fundamental truth - products that are more sustainable continue to gain a bigger market support[5]. We can also cite Veolia which is a world leader when it comes to producing ultra-pure water for the microelectronics industry. Drawing on the principles of circular economy, the clients of Veolia have benefitted from their approach of reducing raw water usage by continuously recycling used water and refining treatment processes for optimal energy efficiency. The water management solution implemented onsite not only translated into cost savings for the client, but also reduced the water and carbon footprints of the plant for the benefit of the environment[6].
- **Substitute or decrease the use of toxic, hazardous, and critical raw materials** to greatly reduce the environmental degradation, health issues, geopolitical crises, and avoid future supply disruption of key materials. More precisely, elements such as indium, ruthenium, platinum, gallium, arsenic, gold, are already identified as critical for disruptive devices yielding communicating objects. New technologies and materials are investigated to replace them or to limit drastically their amount in some critical devices (sensors, memories, optoelectronics and spintronics). Design methodologies of materials for sustainable development proposed by Prof. M. Ashby[7] (Cambridge University, UK) who is partner of the consortium and his spin-off company Granta[8] will be revisited and adapted to the specific domain of nanoelectronics. Research will also help industries to adapt to new European and international regulations (like RoHS on lead, EU conflict mineral restriction, DEEE recycling). Today, manufacturers adapt and/or anticipate the evolution toward sustainable electronics. We can cite the following examples in the consortium:
    - Unleaded solutions for micro-components like actuators included in cell phones;

[5] https://ec.europa.eu/commission/commissioners/2014-2019/vella/announcements/spanish-chamber-commerce-circular-economy-role-business-developing-green-economy_en
[6] http://www.veolia.com.sg/our-services/commercial/water-management
[7] Michael F. Ashby, "Materials and Sustainable Development", Butterworth-Heinemann, ISBN-13: 978-0081001769.
[8] Cambridge University spin-off specialising in Materials information management: www.grantadesign.com

- Use of 2D mono-atomic or ultra-thin atomic-deposition layers to reduce up to factor 10^6 the use of some active materials;
- Replacement of Pt by other elements;
- Use of silicon-based substrates such as Silicon-on-Insulator (SOI), manufactured by SOITEC in Bernin, instead of III-V materials for RF technologies

- **Extend the lifetime of electronics devices by design.** Over the past decades, the development of high tech devices has been associated with a scaling down of dimensions and the multiplication of materials in the components with for some of them in extremely small quantity of a few µg only. This leads to new **challenges in recycling**, namely pay for the entropy of mixing, and for the entropy of dispersion. **Modular design of electronic devices** such as proposed by FairPhone[9] and PuzzlePhone[10] paves the way to extend the lifetime of electronics components by either allowing the **device repair, upgrade or reuse** for another functionality. Today, European microelectronic industry (for instance, ST-Microelectronics, ON Semiconductor) and R&D laboratories are designing or fabricating highly reliable components for automotive, energy management, security. This knowledge in highly valued for a vision of a modular, eco-concept based and extended lifetime electronics.
- **Innovative recycling solutions.** When it comes to the end of the electronic devices lifetime, Umicore proposes innovative solutions to recycle several noble and rare earth materials[11]. Umicore Precious Metals Refining operates the world's most sophisticated precious metals recycling facility in Hoboken, Belgium. They recover 20 precious and non-ferrous metals from industrial residues, used electronic scrap, automotive and industrial catalysts and fuel cells. In a more general way, end of life will be anticipated at the early stage of technologies evaluation.
- **Reduce power consumption of electronic**. Several research opportunities exist to develop autonomous systems especially for IoT that will harvest energy from their environment (light, motion, temperature gradients). This will reduce the use of battery or wiring. Several teams in the consortium have a long research record in the field of ultra low voltage – low power design of integrated circuits mainly based on Silicon-on-Insulator (SOI) technology. They have demonstrated the great opportunity in terms of power consumption reduction in designing SOI ICs operating under subthreshold regime. They have demonstrated ICs operating under 0.4 V which leads to a large decrease of the IC static power consumption because it is inversely proportional to the square of the voltage supply. In the industry, ON Semiconductor is driving energy efficient innovations, empowering customers to reduce global energy use. The company is a leading supplier of semiconductor-based solutions, offering a comprehensive portfolio of energy efficient connectivity, sensing, power management, analog, logic, timing, discrete, and custom devices[12].
- **Increase the transparency of the supply chain within the consumer electronics sector**. The goal is to be able to trace every element in electronics devices, from the raw materials to the final parts. Today supply chain is the main short term risk in industries. Geological and ethical aspect are closely linked in this perspective. Nowadays, prime societal concerns require effective traceability, as illustrated by **"ethical care"** label given to laptop computers or smartphones produced by some European companies. Fair Phone for instance proposes reduced consumption of those materials produced in non-ethical conditions. Creating a high-transparency supply chain in microelectronics industry calls for extensive critical analysis of current practices aiming to produce a guideline for the engineering design and a roadmap for new technological developments. More generally, a definitive method to integrate in the design of new IoT technologies, constraints associated with environmental, social and economic changes is missing for the stakeholders.
- **Develop new business models to overcome the planned obsolescence.** Enjoying a good without owning it. For a service provider (transport, home monitoring, health), the **longer the lifetime** is,

[9] https://www.fairphone.com/en/our-goals/
[10] http://www.puzzlephone.com/
[11] www.umicore.com/en/industries/electronics/precious-metals-refining/
[12] http://www.onsemi.com/site/pdf/Corporate_Fact_Sheet.pdf

the lower (in some extend) the cost of components is and the higher benefit you have. The microelectronics business has to move from the conventional manufacturing and sale product to the **service-based model**. At the hardware level we can cite home internet box which is not bought by the client but rented to the internet service provider. When a new generation of internet box comes up on the market, the service provider could take back the former box to remanufacture it in a cost and performance effective way and put it back on the market, giving a second life to the electronic components. Planned obsolescence is also driven by software. Imposed software updates usually lead to a degradation of the device performance and force the consumer to upgrade or most of the time to buy a new smartphone, tablet or personal computer. Open source software must be developed to bring more fairness to software. FairPhone launched several programs that address the transparency, longevity and ownership of software. They released the complete build environment for Fairphone OS on Fairphone 2, which contains the full open source code, all the tools and the binary blobs that will allow users to build their own Fairphone OS.

III. Public, governments and authorities

- ENCOS has the ambition to create a platform where scientists, entrepreneurs and consumers can directly interact, think and build together the up-coming digital society. Environmental, economic, social, and technological issues related to concrete current electronic devices such as smartphones, tablets, personal computers, and so on, will be the vectors to develop together a vision for a more sustainable digital society.
- ENCOS members must be in close contact with the public authorities and governments to anticipate the new laws, labels, norms, regulations, etc. concerning the production of electronics goods, their sale on the market, their remanufacturing, reuse, or recycling, etc. ENCOS will propose to the public authorities research proposals and concrete actions which should help the industry to turn to a more sustainable economy.

IV. Education/universities

Educate differently to think, innovate and act differently.

A main goal of our consortium is to disseminate sustainable thinking for IoT in engineering schools and research laboratories.

- Being convinced that changes in the industry will not come if scientists and engineers are not trained to think differently, Prof. Raskin of UCL established **5 years ago**, in collaboration with the NGO Louvain Cooperation, a lecture named ***IngénieuxSud*** in which **a systemic approach is taught to students** from the Sector of Science and Technology at UCL. The aim of this lecture is to encourage students to open their mind to complexity, to strengthen their capacity to commit themselves individually and collectively to a sustainable transition. This **lecture changes the mindset** of students towards considering parameters related to **sustainable development, appropriable technologies and social justice** in the analysis, design and implementation of projects. Students, privileged actors of transition, must have the capability to **go beyond their areas of expertise**, to embrace the **complexity of the world** and to bring solutions that integrate parameters that go far beyond technical efficiency and economic profitability. *IngénieuxSud* encourages students to reflect on the meaning of their future career as scientists. *IngénieuxSud* initiative recently received the **European Global Education Innovation Award 2017.**
- The recent group called « **Ingénieurs engagés** » that has been developed in the **INSA engineering school in Lyon** is another example of students that aim to succeed in the engineering profession while remaining consistent with the values of the movement: solidarity, social and environmental ethics, integrity, openness, responsibility. This movement is currently growing in France as more

and more students in engineering schools ask themselves the question of **the meaning of their job**.

- **University Grenoble Alpes** launched a multi-institutes and universities project Called "*NEED*" financed by the French Agency for Research (ANR). The ***NEED* project** develops research methods and advanced technological demonstrators for connected objects and their components, integrating an economic analysis that includes the acceptability and sustainability of the proposed new solutions. A main goal of the *NEED* project is to achieve a better understanding **of research practices to facilitate the evolution toward sustainable thinking** and propose new technologies for IoT accordingly. This requires an **interdisciplinary approach** which involves: supply chain studies to develop predictive tools to anticipate strategic evolutions, social science to anticipate and adapt to a rapidly evolving context, materials and engineering sciences to propose new technological solutions for the substitution of materials.