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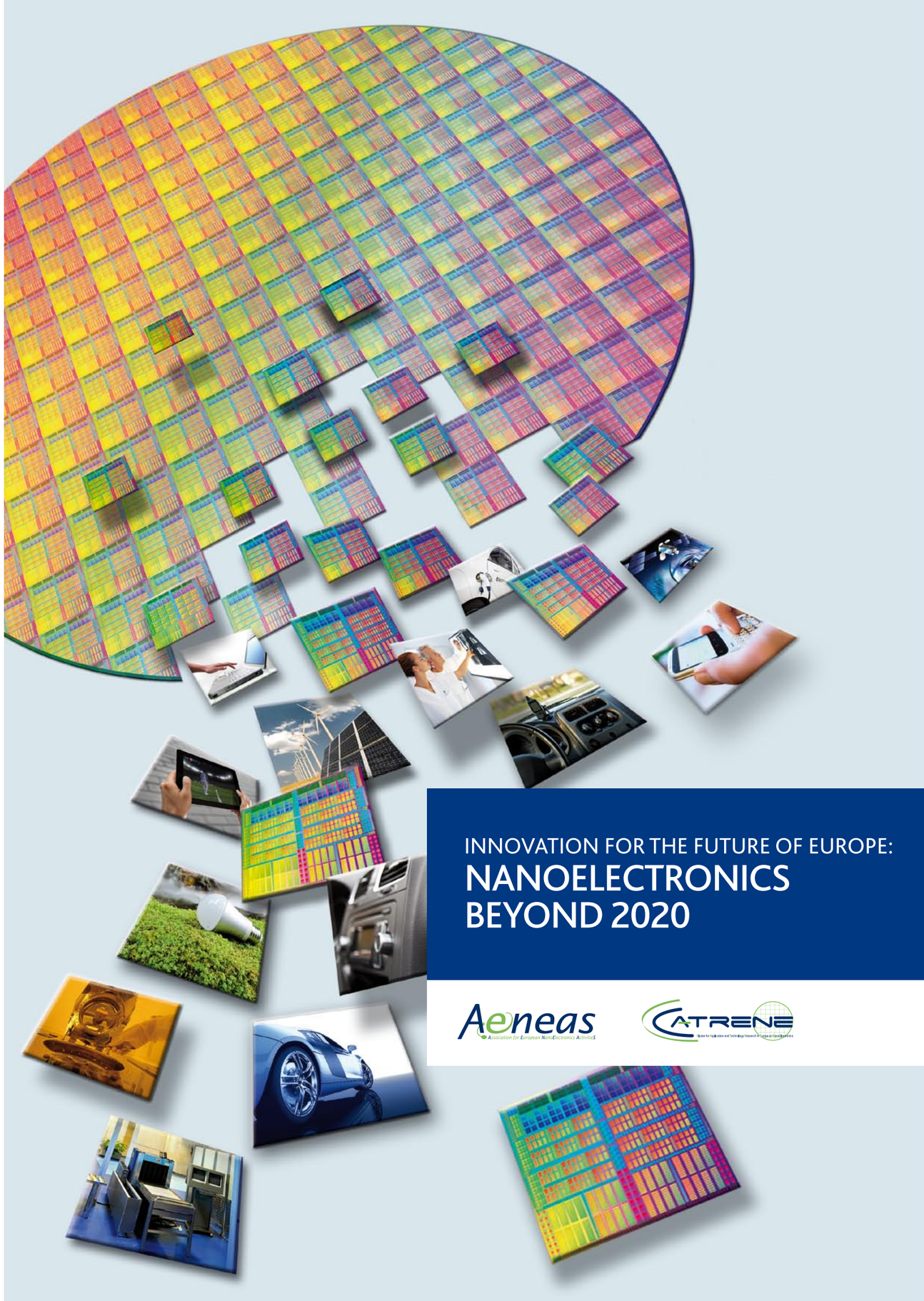

INNOVATION FOR THE FUTURE OF EUROPE:

NANOELECTRONICS BEYOND 2020

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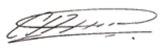

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Executive summary

Europe needs unrestricted access to sustainable solutions for its societal challenges; it needs industrial drive for wealth creation and global competitiveness; and it needs to step up research and innovation. The nanoelectronics industry is key to solving Europe's societal challenges; its products and innovations are essential in all market segments where Europe is a recognized global leader; and the intensity of its industrial research and innovation is among the highest in the world.

The European nanoelectronics value and innovation chain comprises leading research institutes and academia, large and small suppliers of semiconductor manufacturing equipment and materials, designers and manufacturers of semiconductor microchips, and system integrators for microchip end-user applications in segments of European market strength. This ecosystem builds on large-scale semiconductor manufacturing in Europe. Many of the key actors are global leaders in the relevant markets. Europe's nanoelectronics ecosystem is therefore a key asset for European economic growth and wealth creation.

Worldwide, the market for nanoelectronics is growing faster than the industry average. Europe's nanoelectronics industry is also growing, but not as fast as in other parts of the world. Reinforcement is needed throughout the nanoelectronics ecosystem so that Europe can regain its leading position in this highly competitive domain.

To achieve this objective, the companies and institutes in Europe's nanoelectronics ecosystem propose a strategic research and innovation programme with a total investment of 100 billion € up to the year 2020. By 2020, the programme aims to increase Europe's nanoelectronics-based world-wide revenues by over 200 billion € per year, and create an additional 250,000 direct and induced jobs in Europe.

Priorities include: collaboration with research institutes and academia; pilot lines to prove state-of-the-art microchip technologies; enhancement of large-scale semiconductor microchip manufacturing in Europe (150 mm, 200 mm and 300 mm wafer size); dedicated test bed facilities for equipment and materials (450 mm wafer size); and microchip, system and application development that leverages Europe's strengths in solving societal challenges across the entire value chain.

Implementation of this ambitious programme requires a holistic approach, with public and private co-investment. Because of comprehensive incentives outside Europe, the world is not a level playing field. To compete, the European nanoelectronics ecosystem needs a coherent and aligned industrial strategy that is supported by industry, the European Union and the Member States.

Nanoelectronics: European innovation ecosystem of strategic importance

A Key Enabling Technology to address global markets

Since the publication in 2004 of the European vision document 'Vision 2020: nanoelectronics at the centre of change'[1], significant steps forward have been made in terms of a coordinated approach through extension of the EUREKA MEDEA+ programme to the CATRENE programme[2], establishment of the ENIAC Joint Technology Initiative[3] and recognition by the European Union and the Member States of nanoelectronics as a Key Enabling Technology (KET) for Europe[4]. Today, the nanoelectronics ecosystem in Europe encompasses the entire value chain from semiconductor equipment and materials suppliers to designers and manufacturers of semiconductor microchips, and system integrators who integrate microchips into end-user applications. It connects leading research institutes and academia, large companies and small and medium enterprises (SME) throughout the innovation chain.

The exponential increase in semiconductor microchip functionality and affordability, brought about by a continuous process of circuit miniaturization and higher volume manufacturing, is providing sustainable solutions to the societal challenges identified in the Horizon 2020 framework programme for research and innovation[5]. Europe's active involvement in the semiconductor industry gives it access to global markets in major end-user applications. The era of nanoelectronics will extend this functionality through breakthrough innovations, ranging from leading-edge scientific and industrial research to large-scale state-of-the-art manufacturing. The nanoelectronics ecosystem is therefore an essential asset for assuring Europe's future competitiveness.

[1] ftp://ftp.cordis.europa.eu/pub/nanotechnology/docs/e-vision-2020.pdf
[2] http://www.catrene.org
[3] http://www.eniac.eu
[4] COM(2009) 512
[5] COM(2011) 808

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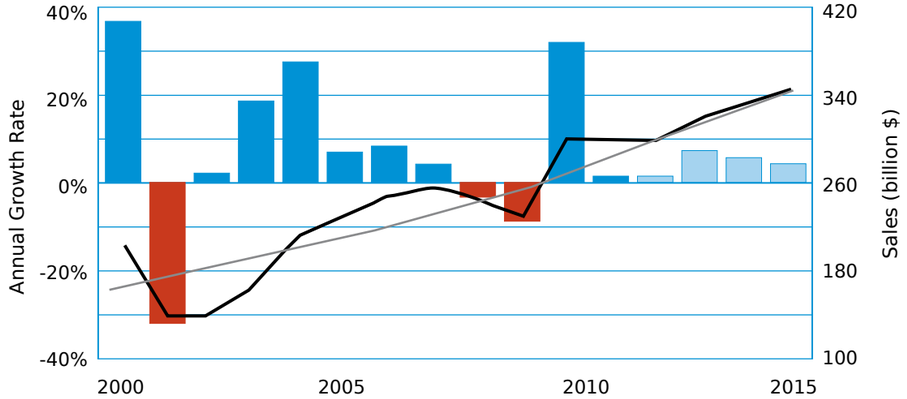
Driving innovation in European strongholds

At least 10% of global GDP (around 70,000 billion $) depends on nanoelectronics products and services. Innovation through nanoelectronics is an essential enabler of growth in the automotive, aerospace, medical, industrial, and telecommunications segments, in which Europe is recognized as a world leader. These segments represent an economic value to Europe in excess of 700 billion €. The innovation they demand is inconceivable without a strong nanoelectronics content.

Despite the recent financial and economic setbacks, the worldwide market for semiconductor microchips has continued to grow by 5% per annum from the beginning of the millennium, as shown in the figure[6].



Worldwide semiconductor market

Further growth of at least the same magnitude has been predicted for the remaining part of the current decade.

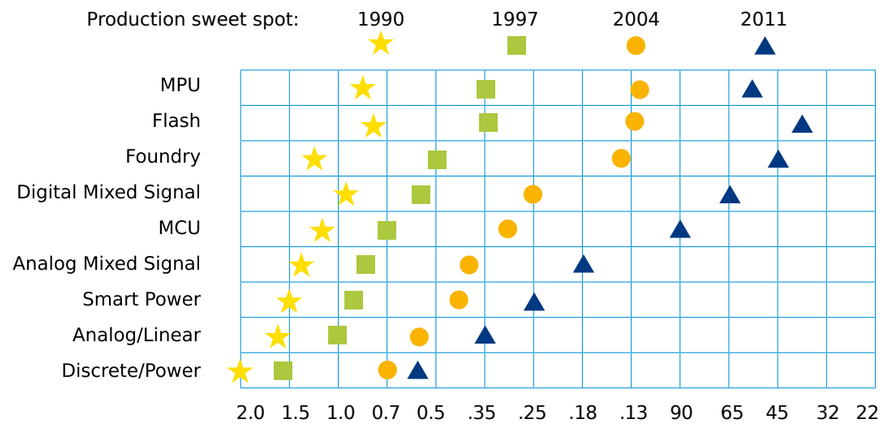
Within Europe's nanoelectronics ecosystem, the European semiconductor industry is estimated to have a worldwide economic value of 30 billion €, and is responsible for 200,000 direct and more than 800,000 induced jobs[7]. European semiconductor companies have dominant global positions in key application areas for Europe, such as transport and security, as well as in equipment and materials for worldwide semiconductor manufacturing, where the European equipment industry continues to gain market share. Their research and innovation investment is among the highest in the world, reaching 20% of total revenues. As such, the semiconductor industry is a major net contributor to the Europe 2020 target of investing 3% of GDP in research and innovation[8].

[6] WSTS forecast 2012Q2; data made available through ESIA (www.eeca.eu/esia)
[7] http://ec.europa.eu/enterprise/sectors/ict/files/kets/hlg_kets_report_en.pdf
[8] COM(2010) 2020

Technology renewal and extended functionality

The digital data processing and storage capacities of semiconductor microchips constitute the 'brains' of electronic systems. To achieve greater capacity for the same overall costs, the density of the electronic circuitry on the microchip is increased by reducing the feature size (the smallest element that can be patterned). However, microchips also need additional functionalities to interact with the application that they are part of. If digital data processing and storage represent the brains, these functionalities are the equivalent of the 'ears, eyes, arms and legs' that add value by allowing the 'digital' brains to interact with the non-digital physical world.

The added-value technologies needed to realize these non-digital functionalities involve more than feature size reduction for sustained cost-effectiveness. In the nanoelectronics era, the differences in the materials and manufacturing processes required to produce a microchip's 'brains' and those required to produce its 'ears, eyes, arms and legs' continually increase. As a result, the range of necessary feature size 'sweet spots' for state-of-the-art microchip production is also increasing, as shown in the figure[9].



Feature size in semiconductor production (micrometer, nanometer)

The cost-effectiveness of microchips is also determined by wafer size (the diameter of the base substrate used in microchip manufacturing). Established wafer sizes today are 150 mm, 200 mm and 300 mm, smaller wafer sizes usually coinciding with the feature size 'sweet spot' for the added-value technologies. 450 mm is emerging as the next wafer size for very high volume manufacturing of microchips for digital data processing such as memories and microprocessors, also requiring the smallest possible feature size. The move to 450 mm wafer processing offers extensive worldwide market opportunities and challenges for Europe's semiconductor manufacturing equipment and materials suppliers.

[9]WSTS and ITRS 2011 data; source: 5th SEMI Brussels Forum 24 May, 2011

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Research and innovation through connected value chains

Disruptive innovation and related efforts in its downstream industrialization, coupled with continuous technology renewal, are essential for maintaining Europe's competitiveness and independence in nanoelectronics. Because of the massive resources required to bring about this innovation and renewal, extended collaboration is required throughout the nanoelectronics ecosystem, addressing the entire value and innovation chain. Such collaboration must bring together leading research institutes and academia, suppliers of semiconductor manufacturing equipment and materials, designers and manufacturers of semiconductor microchips, and system integrators of microchips for end user applications. To ensure the sustainability of innovation, long-term commitments are needed from all research and innovation actors, as well as from the European Union bodies and national and regional public authorities in the Member States.

Safeguarding Europe's independence

Europe needs independent access to nanoelectronics, through hands-on interaction between the semiconductor industry and system integrators in the industry segments where Europe is strong, notably the automotive, aerospace, medical, industrial, and telecommunications segments, all af which are critical to Europe's long-term economic growth and sustainability. Global competition is fierce and the worldwide investment in nanoelectronics is massive, involving both private and public parties. The European semiconductor industry is growing faster than the industry average, and it leads in global markets that are strategic for Europe. Nevertheless, semiconductor industry growth outside Europe is faster, notably in regions where companies benefit from a helpful environment and generous public support.

To ensure that Europe regains its leadership position, Europe's research and innovation efforts within the nanoelectronics ecosystem need to be raised significantly above their current levels. At present, Europe is in danger of losing competitive advantage, not only in nanoelectronics but also in many industries that demand innovation and rely on the ability of nanoelectronics to deliver breakthrough solutions for societal challenges. An increase in the scale of European public-private partnership in nanoelectronics research and innovation is urgently required to maintain ground in this highly competitive domain.

Investing in partnerships for competitive growth

To prepare for Europe beyond 2020, the companies and research institutes within the European nanoelectronics ecosystem propose to increase their overall research and innovation investment through a joint programme with the European Union and the Member States. The objective is to make sure that Europe's growth in the nanoelectronics domain surpasses the worldwide average market growth. The total investment needed between now and 2020 is 85 billion € in operational costs and 15 billion € in capital expenditures (equipment and materials test bed facilities and pilot lines connected with volume manufacturing of microchips). All phases of the innovation cycle will be addressed, from Technology Readiness Level (TRL) 2 (technology concept formulated) to TRL 8 (system complete and qualified). This investment is a prerequisite for safeguarding the long-term amplification and renewal of large-scale semiconductor microchip manufacturing in Europe. Innovative small and medium enterprises (SME) will benefit from access to this ecosystem, gaining scale and competitiveness and fostering European job creation along the value chain.

By 2020, after successful implementation of the programme, annual research and innovation investment in the European nanoelectronics ecosystem will have increased by 50%; over 200 billion € will have been added to the annual global revenues of the European semiconductor industry and strategically important end-user applications segments, and the number of direct and induced jobs in Europe will have increased by more than 250,000.

Investment programme priorities include:

Leading-edge scientific research in collaborating research institutes and academia, guided by industry innovation;

Breakthrough research and development in state-of-the-art digital and added-value technologies, connected with innovation through pilot lines that enhance the renewal and extension of large scale manufacturing in Europe (150 mm, 200 mm and 300 mm wafers);

Accelerated development of advanced equipment and materials for 450 mm wafer processing through dedicated test bed facilities featuring industry-relevant process flows for early learning;

System integration and application development in industry segments where Europe has particular strengths, focusing on sustainable solutions for societal challenges.

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Key recommendations and next steps

The world of nanoelectronics is not a level playing field, as highlighted in the report of the high-level expert group on Key Enabling Technologies[10]. To achieve maximum economic benefit from the proposed programme, the European nanoelectronics ecosystem needs an industrial strategy that is firmly aligned with the objectives of the European Union and the individual Member States. Co-investment by all partners is necessary through a coherent suite of public-private partnerships, with a clear view on the global competitiveness and industry attractiveness of Europe. European regulation needs to be brought in line with Europe's need for global competitiveness in nanoelectronics. Because of the size and scale of the programme, a holistic approach is needed, articulated through complementary and coordinated instruments in order to meet the operational and capital expenditure needs at each Technology Readiness Level.

Project initiatives fitting the scope of the proposed programme are in preparation today. Detailed planning and operational guidance can be provided through the established CATRENE and AENEAS networks[11] (representing large companies, innovative small and medium enterprises (SME), and research institutes and academia) in close cooperation with representatives from the European Union and Member States.

Urgent industrial strategy actions include:

Extension of the dedicated budgets for Key Enabling Technologies to reflect their common dependence on nanoelectronics;

Simplified notification and enlarged eligibility for public funding in nanoelectronics;

Greater focus on European Union funding for regional initiatives to support the proposed programme.

[10] http://ec.europa.eu/enterprise/sectors/ict/files/kets/hlg_kets_report_en.pdf
[11] http://www.aeneas-office.eu

Nanoelectronics: providing sustainable solutions for societal challenges

Health, demographic change and wellbeing

Meeting the health and well-being needs of Europe's ageing society not only poses immense challenges, it also offers valuable opportunities to exploit Europe's strengths in technology innovation, particularly in the area of nanoelectronics. Opportunities lie in all parts of the care cycle - from screening and early diagnosis to treatment, therapy monitoring and aftercare (including the long-term management of chronic diseases such as heart failure, diabetes and arthritis). Innovation in these areas has the ability to both improve patient outcomes and contain healthcare costs.

Nanoelectronics will play a crucial role in this medical revolution. It will enable the development of ultra-sensitive DNA/protein assays that can be used for highly personalized (genome-based) risk assessment, diagnosis, therapy selection and treatment monitoring, or used at a patient's bedside to rapidly identify infections. Nanoelectronics will also facilitate advancements in molecular imaging, layering quantitative functional information onto anatomical data to assist in the early detection and treatment of disease and speed up the (pre-)clinical testing of new drugs.

Telemonitoring networks that employ unobtrusive body sensors to monitor vital body signs will allow patients to return home sooner, freeing up valuable hospital resources and making health care more affordable. Nanoelectronics-based prosthetics will restore sight to the blind, hearing to the deaf and automatically administer drugs.

Achieving these objectives will involve the development of nanoelectronic devices (nanosensors) that interact with molecules and living cells in real time. Achieving the required bio-compatibility, ultra-low power consumption, device miniaturization and safety-critical reliability will pose major challenges.

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Food security and sustainable agriculture

In Europe's food industry, nanoelectronics has the potential to improve the quality, safety and availability of the food that we eat. Nanosensors, similar to those developed for healthcare applications, that can respond to specific genes or proteins will enable the development of plant strains that are resistant to disease and adverse climatic conditions. Embedded into packaging and labeling, nanosensors will provide consumers with an immediate indication of a food's suitability for human consumption. Embedded into production processes, they will ensure the quality, reliability and traceability of food processing operations.

Opportunities also exist in the agrochemical industry. For example, nanoelectronics will allow detection of the presence and degree of biodegradation of pesticides, herbicides and fertilizers, so that they do not enter the food chain or adversely affect biodiversity or the environment.

Developing and implementing such applications will involve the design and fabrication of biologically sensitive nanosensors for the detection of specific chemical/biochemical signals, and micro-/nano- electromechanical actuators that can respond to those signals.

Secure, clean and efficient energy

By the end of the 21st century, at least 70% of the world's energy requirements will need to come from renewable CO_2-free or carbon-neutral energy sources, because non-renewable sources such as coal and gas will either be exhausted or unacceptable because of their detrimental effect on global warming. Nanoelectronics has the potential to address the challenge from both ends, by helping to minimize the world's energy consumption and making renewable energy sources more affordable.

Through the relentless pursuit of nanoscale miniaturization, the semiconductor industry continues to deliver lower-cost higher-performance chips that consume less energy. These nanoelectronic microchips will help to reduce power consumption in many other sectors as well-for example, by bringing greater intelligence to energy distribution (smart grid), public and private spaces (smart lighting, smart buildings), and industrial automation. Devices that convert heat or motion into electrical energy will allow many nanoelectronic solutions to scavenge sufficient power from their surroundings.

At the same time, nanoelectronics will reduce the cost of renewable energy sources such as solar power and increase the viability of clean fuels such as hydrogen (the basis of the so-called hydrogen economy), particularly in (auto)motive applications. It will be at the heart of the energy management systems needed to utilize these new and diversified energy sources.

Smart, green and integrated transport

An integrated transport infrastructure that encompasses all modes of transport (air, rail, road and water) is vital to ensuring Europe's economic prosperity and social cohesion. As the volume of traffic on Europe's roads continues to increase, there will be an ever-increasing demand for drive-by-wire systems that out-perform humans in terms of speed control and collision avoidance. More information will need to be transferred to and from moving vehicles, not only for driver information, navigation and entertainment purposes, but also for vehicle tracking and road toll applications. Greater fuel-efficiency will be required from petrol/diesel powered vehicles and cleaner alternatives such as electric (battery powered) vehicles or fuel-cell powered vehicles will need to be developed well beyond their current state-of-the-art.

The nanoelectronic solutions at the heart of these new developments will have to withstand harsh environments, including high temperatures, humidity, vibration, fluid contamination and electro-magnetic interference without compromising system reliability. Although these problems have largely been solved for conventionally packaged semiconductor microchips, a new set of challenges will have to be faced when the packages also contain integrated sensor, actuator, mechatronic or opto-electronic functions. Some applications will also push the frequency, power and thermal boundaries of existing semiconductor technologies.

The technical hurdles that will need to be overcome will also apply to the aircraft and locomotive industries, although the cost constraints in these industries will be less.

Resource efficiency and climate action

Europe has particular strengths in environmental (green) technology and eco-innovation (the development of products and processes that contribute to sustainable development). It already accounts for approximately one third of the global market in these high growth-rate domains. In addition to being areas where there are attractive research and development opportunities, activity in these areas could also be promoted through complementary measures such as the promotion of energy efficiency, the adoption of green public procurement policies and tax incentives.

The range of applications in which innovation opportunities exist is very broad, ranging from energy generation and energy efficiency to conservation, recycling, waste reduction, emissions control and environmental control. Virtually all of these applications are important in strategic sectors such as construction, transport and agriculture - most of which are also lead markets for nanoelectronics in their own right. Solid-state (LED) lighting is an emerging market where nanoelectronics and energy saving go hand in hand.

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New semiconductor materials (such as SiC and GaN) will provide large efficiency gains in energy conversion for a multitude of end-user applications. Environmental monitoring and control using smart sensor networks is another potentially high-volume market for nanoelectronics-based solutions.

Inclusive, innovative and secure societies

Feeling safe and secure, putting the world around us into context and communicating with friends and loved ones are all basic human needs that technological breakthroughs such as mobile telephony, the internet and smartcard technology have done a great deal to address. Yet there remains a paradox. The more information we can access about the world we live in, especially in relation to issues such as crime and terrorism, the less secure we feel. The more data we communicate, the less comfortable we are about our privacy being respected. 'Cybercrime' and 'cyber terrorism' now figure in our vocabulary as much as their physical counterparts.

Next-generation information, security and communication systems will need to overcome this paradox by embracing the paradigm shift to 'ambient intelligence' - systems that are capable of recognizing individuals and responding to their individual needs in highly personalized ways. Nanoelectronics, through its ability to provide the necessary sensors, actuators and computing power at an affordable cost level, will be the single most important enabler of ambient intelligence. For example, it will enable security systems that use multifaceted biometrics to indentify individual users, communication systems that tunnel data from source to destination without relying on dedicated network infrastructures, and home environments that automatically respond to people's needs in ways that make them feel safe and secure.

Conclusions

Nanoelectronics is one of the fields recognized by the European Union as deserving immediate policy actions given the situation of the European industry in global competition and the challenges stemming from the economic crisis. It is not only of strategic importance in its own right. Nanoelectronics is also key in providing solutions for all of the societal challenges identified in the Horizon 2020 programme.

Disruptive innovation and continuous technology renewal are essential for maintaining Europe's competitiveness and independence in nanoelectronics. To bring about this innovation and renewal, extended collaboration is required throughout the nanoelectronics ecosystem, bringing together leading research institutes and academia, suppliers of semiconductor manufacturing equipment and materials, designers and manufacturers of semiconductor microchips, and system integrators of microchips for end user applications. To ensure the sustainability of innovation, long-term commitments are needed from all parties, including the European Union and the Member States' national and regional public authorities.

To prepare for Europe beyond 2020, the companies and institutes within the European nanoelectronics ecosystem propose to increase their overall research and innovation investment through a joint programme with the European Union and the Member States. By 2020, this programme aims to increase Europe's nanoelectronics-based worldwide revenues by over 200 billion € per year, and create an additional 250,000 direct and induced jobs in Europe.

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Investment priorities identified in the programme:

Collaboration with participating institutes and academia to perform leading-edge nanoelectronics research;

Pilot lines to prove state-of-the-art microchip technologies and enhance the renewal and extension of large-scale semiconductor microchip manufacturing in Europe on 150 mm, 200 mm and 300 mm wafers;

Dedicated test-bed facilities for the equipment and materials needed for 450 mm wafer processing;

System integration and application development in industry segments where Europe has particular strengths (e.g. automotive, aerospace, medical, industrial, and telecommunications), focusing on sustainable solutions for societal challenges.

Urgent industrial strategy actions:

Extension of the dedicated budgets for Key Enabling Technologies to reflect their common dependence on nanoelectronics;

Simplified notification and enlarged eligibility for public funding in nanoelectronics;

Greater focus on European Union funding for regional initiatives to support the proposed programme.