



NanoElectronics Roadmap for Europe: Identification and Dissemination

D8.2	Mapping of International Roadmap Activities		
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1 Executive Summary

NEREID is aiming at creating a useful and internationally valid nanoelectronics roadmapping, with focus on European priorities and realities, capable of attracting strong industrial commitments from the industry and to provide feedback to the European Commission, in terms of technical content and strategic priorities, for the specific calls related to nanoelectronic technologies and applications.

The international mapping of similar activities is important from multiple points of view:

1. **Exchange best experiences** in terms of both methodology and technical/scientific content, between NEREID and other international or European roadmaps;
2. **Contribute directly with NEREID ideas and priorities to other roadmaps**, as a measure of the recognition and impact that NEREID can have beyond its own road-mapping;
3. **Avoid duplication of efforts** and take on board, if relevant for the internally defined priorities and for Europe, content and priorities defined by other initiative,
4. **Take into account the complexity of the nanoelectronics ecosystem in the era of Internet of Things (IoT) and Cyber Physical Systems (CPS)**, with the international dimension of this ecosystem and with a distribution of strengths between USA, Asia and Europe. For instance, NEREID acknowledges that the industrial leaders in advanced processors and memory are not in Europe, while Europe has a very strong potential in highly added value technologies such as **smart systems, analog/RF, sensors, power electronics, communications related with applications and industrial fields such as automotive, healthcare, energy, communications, equipment manufacturing**. This is a very dynamic ecosystem in which new directions of research such as quantum computing, in relation with data security, are emerging and NEREID should take into account the global picture in the roadmap building.
5. It may **serve the visibility and success of NEREID at long term, and of Europe and European Commission, to be active game players and influencers** in both R&D, technology transfer and reinforcement and/or creation of European industrial leadership.

In order to take all these points into account NEREID has concentrated on four points to contribute this deliverable: (i) the feedback of the Advisory Board for priorities in the context of a complex international map of activities, (ii) a particular cooperation with the IRDS groups, that is inheriting many past ITRS contributors (with some of the European members, participants in NEREID, invited to contribute) and where NEREID can find a place to directly influence and contribute international roadmapping, and have exposed to constructive criticism the internal decisions and focus points, (iii) a direct and very close connection with AENEAS Scientific Committee (where many of the NEREID members, including the coordinators, prof. Enrico Sangiorgi and Francis Balestra, as well as some of the workpackages leaders (including WP8), are active members), (iv) a new action with IPWNG that has the goal of mapping (without roadmapping) the initiatives in nanoelectronics in Europe, USA and Japan.

TABLE OF CONTENTS

1	Executive Summary	3
2	International Roadmapping in the Field of Nanoelectronics	5
3	NEREID cooperation with IRDS	6
4	NEREID cooperation with AENEAS	8
5	NEREID cooperation with IPWGN	8
4	Conclusions.....	10

2 International Roadmapping in the Field of Nanoelectronics

Roadmapping in nanoelectronics has been for decades a largely accepted way to push and coordinate efforts related to the extension of Moore's law, targeting the scaling of CMOS with higher performance and less and less costs per transistor. Essentially, between 1998 and 2017, these activities have captured in the so called International Technology Roadmap of Semiconductors (ITRS), which had many successive editions and was an essential vector of progress to unite academic and industry communities working towards common technical goals; the time line of the many editions of ITRS is as it follows below:

- 1998 - First meeting of ITRS: focused on the limits of geometrical scaling
- 1999 - First publication of ITRS
- 2012 - Identified the need to evolve ITRS to the new ecosystem
- 2013 - Last publication of traditional ITRS
- 2014 - ITRS 2.0 restructured with 7 Focus Team and several ITWGs
- 2015 - ITRS 2.0 generated
- 2016 - ITRS 2.0 published on www.itrs2.net

However, as observed in the rationale of starting NEREID in Europe, after 2016 semiconductor industries experience a very particular era of the scaling (near 10nm nodes), where the cost of scaling versus performance can be challenged and it was anticipated that the limits of traditional 2D scaling will potentially create a crisis by 2020+ and, among solutions, 3D monolithic integration was proposed to allow continuation of Moore's Law. It was also acknowledged that having only a focus at technology and device level is limiting and is not anymore corresponding to the reality of an increasingly complex nanoelectronic system, where the systems and the application's diversity play a major role. Moreover, the crisis of the power (density and leakage) made the case even more difficult, together with the emergence of the Internet of Things and visions combining in single system computation functions with communication and sensing (the success of smartphone/iphone). Therefore, today's visions of roadmaps of electronic industries such as IRDS (International Roadmap of Devices and Systems) and NEREID, do consider the full value chain from devices to systems, in connection with specific applications. Some other groups are advocating that the future is about abundant-data energy-efficient architectures (N3XT Architecture) like the one suggested below, with computation embedded in memory, and with sensor integrated in 3D⁵, requiring completely new approaches for roadmapping of technology options.

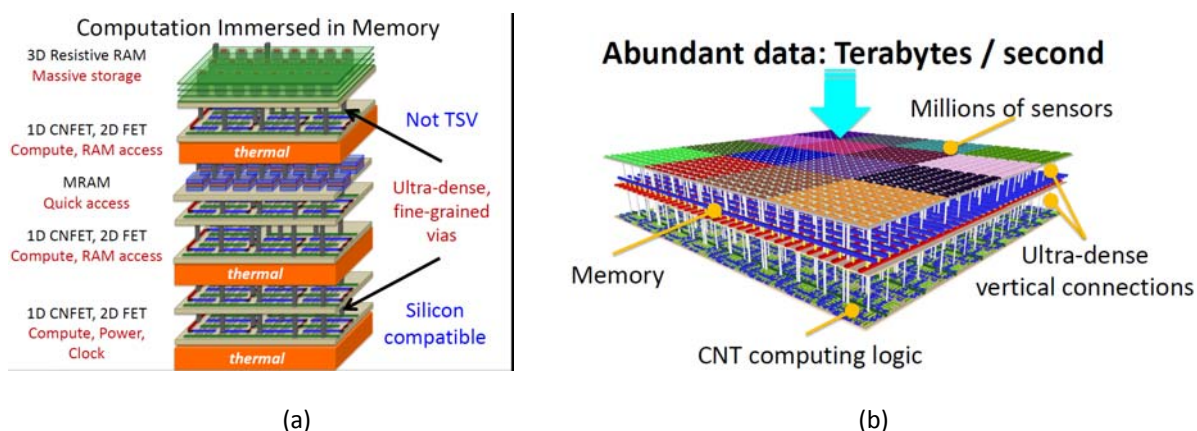


Figure 1: Emerging concept of: (a) computation immersed in memory, (b) abundant data energy efficient architectures with 3D integrated sensors.

⁵ Aly et al., *Energy-Efficient Abundant-Data Computing: The N3XT 1,000x*, IEEE Computer, Volume: 48, Issue: 12, Dec. 2015.

Additionally, Europe proposed and led efforts and new roadmapping along the concept of More than Moore, where functionality is prevailing over scaling and the smartness of the design is providing customized solutions for specific applications at the edge of the cloud or in domains of high added value such as healthcare, automotive, etc.

Concerning international roadmaps in Asia, we refer here to activities related to a public industrial roadmap of devices and systems in the field of information technology and electronics started in Japan under the name System Device Roadmap Committee of Japan (SDRJ), affiliated to the Japan Society of Applied Physics (JSAP). The SDRJ plans roadmapping activities covering the period 2016 - 2030, with emphasis on semiconductor devices and peripherals, as well as packaging and module configurations, all linked with systems and architectures for the applications with identified market drivers. The SDRJ will input their point of views to IRDS (similarly to the cooperation plan between NEREID and IRDS – see next section 3 of this deliverable).

SDRJ is organized in eight focus teams (FT), which are practically mirrored to IRDS:

- FT1: Application Domain Benchmark,
- FT2: System and Architecture,
- FT3: Moore Moore (includes 1D/vertical FET and BEOL evolution),
- FT4: Beyond CMOS (includes ERD/ERM and memristors),
- FT5: Factory integration,
- FT6: Heterogeneous Integration (includes packaging),
- FT7: Heterogeneous Components (includes MEMS and sensors),
- FT8: Outside System Connectivity (includes RF, antenna and optical technologies),

Other roadmapping activities at technology level are dedicated to base process modules needed to support FT's options: lithography, metrology, emerging materials, yield, test and equipment, environment, safety and health.

3 NEREID cooperation with IRDS

On May 4th, 2016, IEEE, the world's largest technical professional organization dedicated to advancing technology for humanity, announced the launch of the International Roadmap for Devices and Systems (IRDS), a new IEEE Standards Association (IEEE-SA) Industry Connections (IC) program to be sponsored by the IEEE Rebooting Computing (IEEE RC) Initiative in consultation with the IEEE Computer Society.

Concerning IRDS operation, the concept of a public-domain-base roadmap originating from ITRS is preserved; the roadmap is open for contributions, everybody having possibility to give feedback and comments for a given edition. The IRDS will be revised every two years. A particular aspect is that typical application domains are selected as the potential market drivers. The performances and functionality will be discussed by the computer/IT system architects, the semiconductor device engineers and the packaging/module engineers, with feedbacks from the process, tool and material engineers. The roadmap will have an International Roadmap Committee (IRC) with members from US, Japan, Europe, Korea and Taiwan) that will manage the international cooperation, and will achieve a world-wide consensus on the roadmap content. The organization of the IRDS is summarized in Fig. 2.

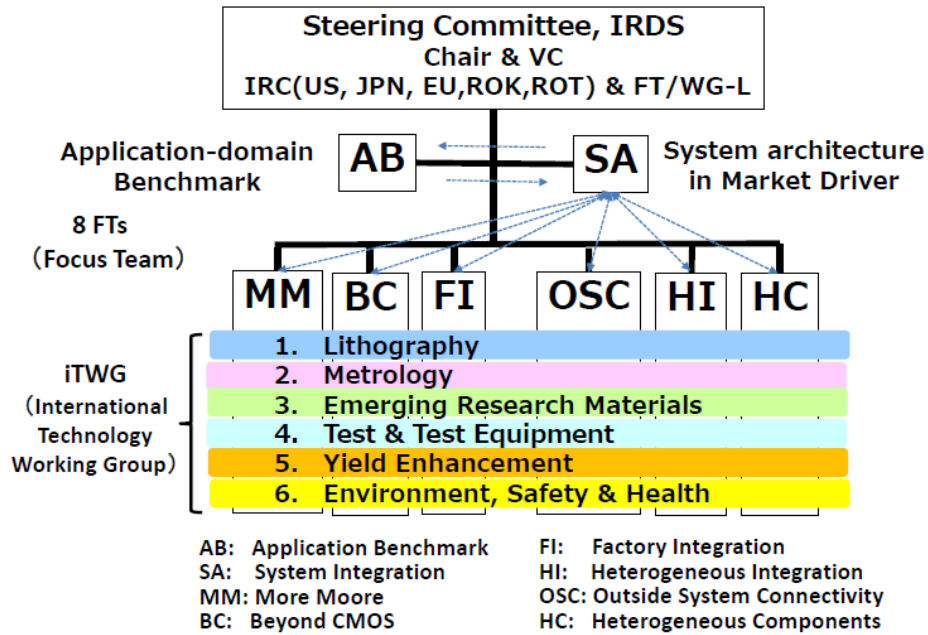


Figure 2: IRDS organization in 8 focused teams. NEREID will have direct contributors in some

The participation of four representatives (F. Balestra, E. Sangiorgi, D. Demarchi and A. Ionescu) of NEREID at the IRDS Meeting, Atlanta, December 1-2, 2016, triggered many interactions and a few topics have been identified for NEREID contributions to the domains of some focused team of IRDS:

- **Systems and Architectures:** Cloud computing, Internet of Things, the Smartphone, Cyber Physical systems.
- **Outside System Connectivity:** RF & Analog & Mixed Signal, Photonic Interconnects.
- **Beyond CMOS:** Emerging memory and storage devices, Emerging information processing and logic devices, Emerging devices for functional diversification, Interface between emerging devices and novel computing architectures/paradigms (steep slope devices for neuromorphic computing). NEREID will also introduce the roadmapping of IoT sensors, which are planned as part of functional diversification under beyond CMOS.
- **Market drivers:** medical diagnosis, medical devices and automotive.

A larger participation of NEREID groups, with many contributors, is expected in 2017, where a specific collaborative event with IRDS will be organized by NEREID in Greece (NEREID General Workshop in Athens, 6-8 April 2017). In any case, the chair of IRDS, Dr. Paolo Gargini, and the coordinators of NEREID, Dr. Francis Balestra and Prof. Enrico Sangiorgi, have agreed in Atlanta to implement this cooperation in a concrete way, with reciprocal benefits from both IRDS and NEREID. This cooperation is following the positive recommendations of the European Commission at the 1st review meeting of NEREID to intensify and make concrete the international cooperation with roadmaps like IRDS.

Finally, internal discussions within the NEREID Consortium pointed out that, while there are clear benefits of the NEREID-IRDS interactions, NEREID reserves the option of having specific European topics and priorities that are defined independently of IRDS and reflect the European point of view and long term nanoelectronics research (for instance, this may specifically apply to the Beyond CMOS domain).

4 NEREID cooperation with AENEAS

Many members of NEREID are also members of the AENEAS Scientific Council. The mission of the AENEAS Scientific Council is to advise the AENEAS Management Committee in all matters related to science and medium- to long-term developments in programmes and projects relevant for the AENEAS Association. NEREID Consortium includes many representatives of universities and RTOs that are members of the Scientific Council, with significant expertise in the scientific and technical fields relevant for AENEAS and in collaborative R&D&I programmes. In this context, of particular importance is that the Scientific Council supports AENEAS with long term vision, focusing on TRL1-3, which also corresponds to the long term roadmapping that is planned in NEREID.

To make the interaction even stronger, Dr. Mart Graef, the Chair of AENEAS Scientific Committee was invited as a member of the Advisory Board of NEREID. Therefore, a bidirectional flux of feedback and contributions is supported, currently: (i) from AENEAS to NEREID, via an Advisory Board member and feedback given on presentations, (ii) from NEREID to AENEAS Scientific Council, via the participation of the NEREID representatives in the AENEAS Scientific Council. Moreover, these members are expected to contribute to the Strategic Research Agenda of AENEAS, which is a guideline for pan-European R&D&I cooperation in the electronics value chain and serves as a basis for the nano/micro-electronics content in the workplans of ECSEL, PENTA, H2020 and national and regional programs.

On November 22nd, 2016, Francis Balestra presented NEREID to the Scientific Council of AENEAS, and a very positive feedback has been received, including a few focused comments:

- Marketing possibilities around the NEREID roadmapping effort should be used.
- The roadmap on zero power sensors needs to be translated into the work programmes of the funding instruments. (the US is taking up this subject very effectively in DARPA projects)
- The NEREID roadmapping effort alignment with IRDS should be continued.

Regular interactions with AENEAS are expected all along the NEREID lifetime. As a measure of success, the NEREID roadmaps are expected to influence the long term Strategic Research Agenda of AENEAS that has a high European specificity.

5 NEREID cooperation with IPWGN

The International Planning Working Group on Nanoelectronics (IPWGN) is an international task force working group for nanoelectronics operating in three regions: United States of America, Europe and Japan, and having representatives of all these regions (<http://www.ipwgn.org/members.html>). The goal of IPWGN is to find ways to stimulate and enhance the inter-regional cooperation in nanoelectronics through information organization exchange. More particularly, it plans to: (i) defining global research needs of nanoelectronics, (ii) understanding the scope and size of regional nanoelectronics research programs, (iii) discussing potential research gaps, and, (iv) identifying areas where collaboration and cooperation between regions will accelerate programs.

NEREID has been invited to provide one or two representatives to IPWGN and become directly active into this working group. NEREID is positively considering this invitation and will assign at least one direct contributor to IPWGN, representing the European community involved in NEREID.

In the past, IPWGN contributed in promoting a global way some of the research vectors needed in nanoelectronics and used the INC series of conferences as a platform to promote the inter-regional cooperations and point-out existing gaps. NEREID will directly contribute to future editions of INC conference, as well as to such survey⁶ results in nanoelectronics research and regional programmes (see Fig. 3) that are regularly published by IPWGN. A more concrete implementation of the cooperation will be discussed in 2017 at the NEREID workshop in Athens, 6-8 April 2017.

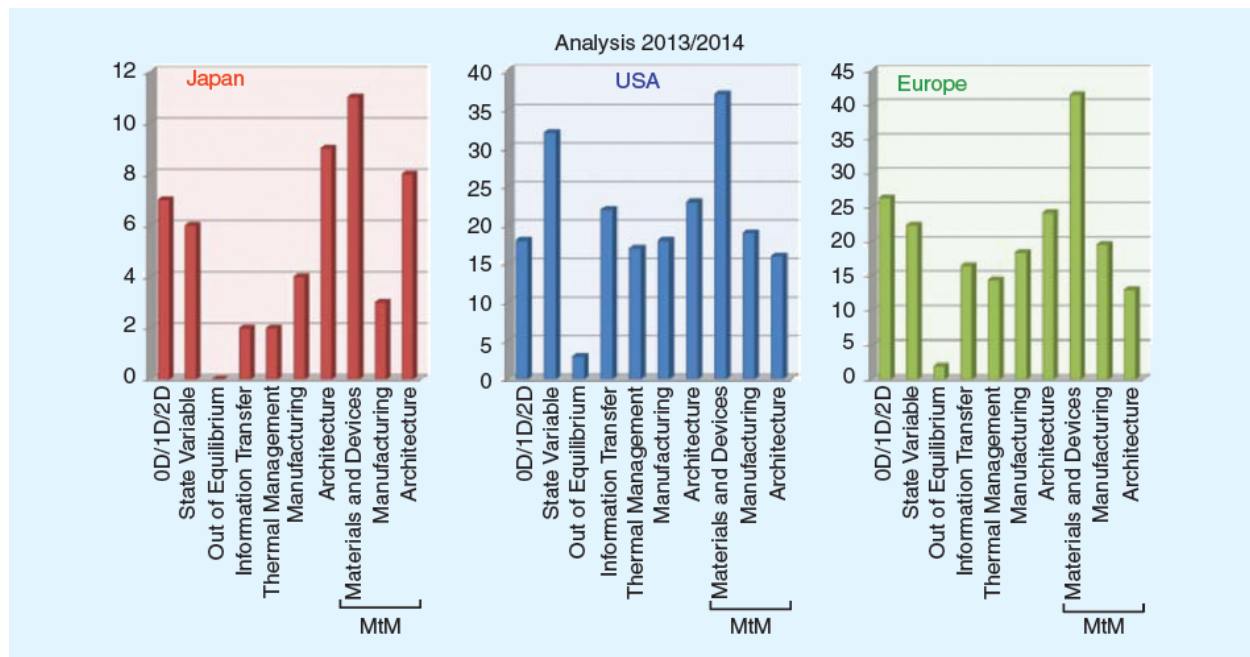


Figure 3: 2013/2014 nanoelectronics surveys per regions published by IPWGN (from [6]).

⁶ K. Galatsis et al., Nanoelectronics Research Gaps and Recommendations: A Report from the International Planning Working Group on Nanoelectronics (IPWGN), IEEE Technology and Society Magazine, Volume: 34, Issue: 2, June 2015.

4 Conclusions

This deliverable mapped and summarized some of the main contributions of NEREID in the global context of nanoelectronics roadmapping, regional and inter-regional initiatives in nanoelectronics. The objectives are to offer some credible paths, with significant benefits, for the future of nanoelectronics in Europe, in a vision resulting from collaborative scheme between universities and industry combining application pull and technology push approaches.

The list of actions includes:

- Cooperation with IRDS – planned, started in Y1 and, now, in progress.
- Cooperation with AENEAS - planned, started in Y1 and, now, in progress.
- Cooperation and contribution to IPWGN – contacts established and start planned in Y2.

NEREID remains open to more interactions at national level, with all the European countries and with the European Commission concerning the nanoelectronics research planning and links with nanoelectronics European ecosystem.