TECH DAYS

INNOVATION FOR INDUSTRY

OCTOBER 15 & 16, 2019
KEIO PLAZA HOTEL, TOKYO

Liten Day

OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

08:55 **Welcoming address,** Mrs. Evelyne Etchebehere, CEA-Tech Japan Representative

09:00 **CEA-Liten, world-class renewable energy R&D organization offering innovative solutions from materials to systems,** Mr. Yohan Souteyrand, Director, Industrial Partnerships, CEA-Liten

09:20 **Towards the Record Efficiency of Si-based Solar Cells**, Dr. Kunihiro Nakano, Manager, PV & Thin Film Device Research Laboratories, **Kaneka Corporation**

09:50 **The road from recent records to the PV industry adoption for competitive LCOE and smart integration,** Dr. Anis Jouini, Head of Solar Technology Division, CEA-Liten & Mrs. Magali Davenet, Industrial Partnerships Director, Solar Technology Division, CEA-Liten

10:20-10:40 Coffee break & networking

10:40 **Honda's Approach towards Sustainable and Carbon Free Mobility with Electrification**, Mr. Eisuke Kimura, Senior Chief Engineer, Technology Development Division 1, Automobile Center, **Honda R&D**

11:10 **Batteries & fuel cells: benchmark, characterization, multi-scale modeling for improvement of performance, durability and safety,** Dr. Didier Jamet, Head of Electrical Architecture, Modeling & Analysis Section; Electricity and Hydrogen for Transportation Division, CEA-Liten

11:40 **High temperature electrolysis and compact methanation reactors: two key technologies for power-to-gas,** Mr. Olivier Lemaire, Head of Thermal and Reactor Components Section; Thermal, Bioresources and Hydrogen Technologies Division, CEA-Liten

12:10 **Advanced material technologies to sustain circular economy for the energy transition,** Mr. Thibaud Fleury, Industrial Partnerships Manager, New Materials Division, CEA-Liten

12:40 **Closing remarks,** Mr. Yohan Souteyrand, Director, Industrial Partnerships, CEA-Liten

12:45-14:00 Buffet lunch & networking

List Day

OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

14:00 **List digital technologies for nuclear dismantling and decontamination,** Mr. Karim Boudergui, Head of Sensors and Instrumentation Section; Metrology, Instrumentation and Information Division, CEA-List

14:15 **Current Status and Challenges of Fuel Debris Retrieval Work at Fukushima Daiichi NPS**, Mr. Shumpei Nakazawa, Deputy Manager, Fuel Debris Strategy Group, Project Planning Department, Fukushima Daiichi D&D Engineering Company, **TEPCO**

14:35 **Innovative sensors and systems for nuclear and dismantling industries,** Mr. Karim Boudergui, Head of Sensors and Instrumentation Section; Metrology, Instrumentation and Information Division, CEA-List

15:05 **Miniaturized gamma imaging,** Mr. Vincent Schoepff, Project Manager for Nuclear Instrumentation; Metrology, Instrumentation and Information Division, CEA-List

15:35 **Tritium detection and quantification system,** Dr. Frédérick Carrel, Sensors and Electronics Architecture Laboratory Manager; Metrology, Instrumentation and Information Division, CEA-List

16:05 **Risk management on piping systems, based on wall thinning monotoring and prediction,** Dr. Christophe Reboud, Head of Electromagnetic Modeling Laboratory; Non-Destructive Testing Division, CEA-List

16:35 **Artificial intelligence for nuclear industry,** Dr. Cédric Auliac, Industrial Partnerships Manager, AI and Innovative Instrumentations; Metrology, Instrumentation and Information Division, CEA-List

17:05 **Closing remarks,** Mr. Karim Boudergui, Head of Sensors and Instrumentation Section; Metrology, Instrumentation and Information Division, CEA-List

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Leti Day

OCTOBER 16, 2019
KEIO PLAZA HOTEL, TOKYO

INTRODUCTION SESSION

09:00 **Introduction to CEA-Leti,** Dr. Emmanuel Sabonnadière, CEO, CEA-Leti

09:20 SEMI Market Outlook — Fab investment, Equipment and Materials Market, Mr. Jim Hamajima, President, **SEMI Japan**

09:45 **Overview of Leti platforms,** Dr. Laurent Clavelier, Head of Technology Platform Division, CEA-Leti

10:10 **Highlights of Leti technologies,** Dr. Jean-René Lequèpeys, CTO and Deputy Director, CEA-Leti

10:35-11:05 Coffee break & networking

QUANTUM COMPUTING SESSION

11:05 **Quantum-Inspired Computing Digital Annealer**, Dr. Toshiyuki Miyazawa, Manager of Digital Annealer Technology Development Project, **Fujitsu Limited**

11:30 **Leti program on Quantum Computing,** Dr. Maud Vinet, Quantum Computing Program Director, CEA-Leti

12:00 **Leti initiative for Startups,** Mr. Philippe Ruffin, Startup Program Manager, CEA-Leti

12:25-13:55 Buffet lunch & networking

EMBEDDED AI SESSION

13:55 **Leti program on Embedded AI,** Dr. Frédéric Heitzmann, Embedded AI Program Director, CEA-Leti

LIDAR SESSION

14:25 **Leti program on LIDAR,** Dr. François Simoens, LIDAR Program Director, CEA-Leti

14:55-15:25 Coffee break & networking

5G SESSION

15:25 **5G Integration of Services and Technologies**, Dr. Yuichi Nakamura, VP Central Research Labs, **NEC Corporation**

15:50 **Leti program on 5G,** Mr. Eric Mercier, 5G Program Manager, CEA-Leti

16:20 **Opportunities of collaboration with Leti through European programs,** Dr. Laurent Hérault, VP, Director of the Europe Division, CEA-Leti

16:45 **Closing remarks,** Dr. Emmanuel Sabonnadière, CEO, CEA-Leti

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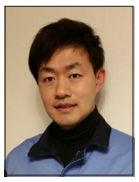
SPEAKERS BIOS

Mr. Yohan Souteyrand

Director, Industrial Partnerships, CEA-Liten

After completing a Master Degree in mechanics (Engineer) at INSA Lyon (1993) as well a Master of Business Administration in Grenoble (1994), he spent 11 years in machine-tool field as General sales manager in various Swiss and German groups, focusing on manufacturing production efficiency. From 2005 to 2016 he was acting as Sales and Marketing General Manager Europe by NTN-SNR ROULEMENTS (Subsidiary of theJapanese bearings manufacturer NTN). He joined CEA in 2016 as VP Sales & Marketing for LITEN institute.



Dr. Kunihiro Nakano

Manager, PV and Thin Film Device Research Laboratories, Kaneka Corporation

Kunihiro NAKANO graduated from Kyoto University in 2007. He received his PhD in magnetic physics at the Institute for Chemical Research, Kyoto University, Japan in 2012. After completing his doctorate, he joined Photovoltaic & Thin Film Device Research Laboratories of KANEKA Corporation. He has worked on research and development of heterojunction silicon PV cells and modules for seven years in Kaneka. His research career in Kaneka includes PV research in Kaneka's European Photovoltaic Research Laboratory at Imec for one year and a collaboration work with Delft University of Technology.

Dr. Anis Jouini

Head of Solar Technology Division, CEA-Liten

Anis Jouini, PhD in Chemistry and Habilitation in Materials Sciences at Claude Bernard Lyon 1 University-France is currently, CEO / Head of Solar Division Technologies at CEA-Liten (Research, Development and Innovation part at the National Institute of Solar Energy, France : 500 engineers working on three main divisions 1) PV-OPV-CPV, 2) Storage, Electrical Systems and Smart grids and 3) Buildings Energy efficiency). He worked as a researcher at Tohoku University in Sendai Japan growing oxides and fluoride materials for optical applications, and he had an industrial experience on Solar Grade Si for photovoltaic applications within CaliSolar (Silicon Materials), both in Germany and California-USA. Dr Jouini's recent research focuses on crystalline silicon for advanced high efficiency solar cell processes and advanced modules assembly technology in close collaboration with industrial partners. He has published more than 50 scientific papers and holds more than 20 patents. He is a committee member for a number of international conferences and workshops in the fields of photovoltaics.

Mrs. Magali Davenet

Industrial Partnerships Director, Solar Technology Division, CEA-Liten

Magali Davenet is Partnerships Director for CEA-Liten Solar Technology Division. She joined CEA-Liten as a business developper in 2015, in charge of International Industrial partnerships for the Solar Technology Division. Graduated in 2000 from Institut d'Optique Graduate School (Paris, France), she completed her education with International Executive MBA (Master of Business Administration) at Grenoble Graduate Schools of Business in 2014 (Innovation and Finances specialization). Before CEA, she built 15 years of expertise in managing collaborative innovation & International partnerships in Industry (Start up company, Alcatel ; Pfeiffer vacuum) especially for semiconductors and PV sectors.

Mr. Eisuke Kimura

Senior Chief Engineer, Technology Development Division 1, Automobile Center, Honda R&D Co., Ltd

Eisuke Kimura graduated from University of Tokyo with a bachelor of precise mechanical engineering in 1988. He started power train engineer at Honda R&D Co., Ltd. from 1988, mainly contributed R&D works for environmental friendly engines and power sources, for example, LEVs, Lean burn, Direct Injection, Integrated PT control, Hybrid system, Fuel Cell, Fuel Reformer, and other advanced power-trains system design, testing and calibration. Recently he led 2018 global ACCORD development project as the head of powertrain area, realized lower GHG emission with enhancing driving fun, resulting in getting lots of world awards for this model. After he had experienced technical managing of powertrain R&D department and division from powertrain testing side long time in Honda, he is currently responsible for building power-train research strategy with energy carrier investigation, targeting sustainable and carbon free mobility, as "Senior Chief Engineer at Automobile center of Honda R&D", that is technical expert leader in Honda, especially in the power-train strategy planning, system design, integrated control and calibration field.

Dr. Didier Jamet

Head of Electrical Architecture, Modeling & Analysis Section; Electricity and Hydrogen for Transportation Division, CEA-Liten

Dr. Didier Jamet graduated from the Ecole Centrale Paris in 1994 in Thermal Sciences. After his PhD, and a Post-doc at the Los Alamos National Laboratory (Theoretical Division), he worked as a research-engineer at the Nuclear Energy Directorate of CEA for more than 10 years. He worked mainly on the physical modeling and numerical simulation of moving interface problems and on the modeling of transport phenomena in porous media. He then became responsible of all the thermal-hydraulics simulation codes developed at the Nuclear Energy Directorate, including the French nuclear safety code, and of the corresponding experimental validation programs. He joined CEA-Liten in 2014 where he is now the head of the electrical Architecture, Modeling and Analysis Department where is developed, in particular, a multi-physics and multi-scale characterization and modeling approach dedicated to batteries and PEM fuel cells.

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SPEAKERS BIOS

Dr. Olivier Lemaire

Head of Thermal Components and Reactors Section; Thermal, Biomass and Hydrogen Division, CEA-Liten

Olivier Lemaire is graduated from the University of Science and Technology of Lille, France. After his PhD in 2001, and a post-doc in the field of water radiolysis at the Nuclear Energy Directorate of CEA, he worked in a private company for the development of gas analysis technologies. Then, he joined CEA-Liten as a research-engineer in the field of hydrogen with proton exchange membrane fuel cells, and managed the laboratory (50 people) from 2010 to 2013 with experimental, nano-characterisation and modeling activities. Since 2014, he is the head of the Thermal Components and Reactors Department with three labs: Heat Exchangers and Reactors lab, Thermal Storage lab and Conception/Assembling Technologies lab.

Mr. Thibaud Fleury

Industrial Partnership Manager, New Materials Division, CEA-Liten

Thibaud Fleury graduated in 2004 from the French engineering school Supélec and completed a Master of Science degree from the Georgia Institute of Technology in Atlanta USA. He started his career in the R&D labs of Sagem Communication in Paris, for which he developed and deployed new digital products for key accounts. After this 1st experience of 3 years, Thibaud held for 11 years various position in Sales & Tendering, Strategic Marketing, Market & Competitive Intelligence for international companies in the field of electrical grid and power generation: Areva T&D, Alstom, General Electric. With a strong focus on Power markets, Renewable and emerging technologies, he developed his expertise in Smart Grids, Solar PV, Wind On & Offshore, stationary battery storage and electrical vehicles. Thibaud joined CEA-Liten in 2018 for developing industrial partnerships for DTNM organization, specialized in new materials, printed electronics and advanced manufacturing processes such as 3D printing.

SPEAKERS BIOS

Mr. Karim Boudergui

Head of Sensors and Instrumentation Section; Metrology, Instrumentation and Information Division, CEA-List

M. Karim Boudergui is a research engineer in CEA-List, head of SCI (Sensor and Instrumentation Service, ~60 people) since the beginning of 2019. He began his career with AREVA as a software engineer and project manager in the field of nuclear measurement systems. He holds a post-graduate diploma in Instrumentation optical signals and optoelectronics (1995), a MS degree in Electronic, Electrotechnic and Automatic (1994). He took part in the design, development, qualification and demonstration tests of the Tagged Neutron Inspection System (TNIS) within UNCOSS EU project. He was also strongly involved in several European Security projects, enabling to develop advanced Radiation Portal Monitors (RPM) or specific systems for contamination monitoring in water.

Mr. Shumpei Nakazawa

Deputy Manager, Fuel Debris Strategy Group, Project Planning Department, Fukushima Daiichi D&D Engineering Company (FDEC), TEPCO

As a Deputy Manager, Shumpei Nakazawa has responsibilities in the Fuel Debris Strategy Group, Project Planning Department, which is focusing on fuel debris retrieval and PCV internal investigation project at Unit 1-3 at Fukushima Daiichi NPS. He joined Tokyo Electric Power Company Holdings (TEPCO) in 2005 after master graduation from Keio University in mechanical engineering. This allowed him to grasp multiple experiences especially in turbine maintenance, nuclear asset management, nuclear power and plant siting and finally project planning since 2017.

Mr. Vincent Schoepff

Project Manager for Nuclear Instrumentation; Metrology, Instrumentation and Information Division, CEA-List

M. Vincent SCHOEPFF is part of the Sensors and Electronic Architectures Laboratory, part of CEA-List Institute. He graduated from the ENSICAEN engineer school in 2009. He is responsible of developments carried out on radiation imaging systems in his laboratory for several years and is part of the GAMPIX development team (industrial name iPIX commercialized by MIRION Technologies). He is now project officer of the Common Innovation Laboratory signed with MIRION Technologies (CANBERRA), mainly working on improvement of the iPIX commercial system and future generations of radiation imagers. Since 2015, he worked on the miniaturization of the GAMPIX gamma imager (Nanopix technology) in collaboration with ORANO team. He is responsible from 2019 of the nuclear measurement section in LCAE.

Dr. Frédérick Carrel

Sensors and Electronics Architecture Laboratory Manager; Metrology, Instrumentation and Information Division, CEA-List

M. Frédérick CARREL graduated from the ENSICAEN engineer school in 2004. His PhD (2007) was dedicated to the characterization of nuclear waste packages using photon or neutron active interrogation and delayed gamma-ray spectrometry. He worked for AREVA CANBERRA in 2008 and has been hired by CEA-List the same year. His research topic is related to nuclear measurements (passive and active neutron measurements, gamma-ray spectrometry using various detectors, use of plastic scintillators, gamma imaging) and associated Monte Carlo simulation (MCNP code). He is part of the development team of the GAMPIX gamma camera. He is CEA senior expert in nuclear measurements from 2017. He is the Head of Sensors and Electronic Architectures Laboratory (LCAE, ~30 people in 2019) from the beginning of 2019.

Dr. Christophe Reboud

Head of Electromagnetic Modeling Laboratory; Non-Destructive Testing Division, CEA-List

M. Christophe Reboud received his Engineering and Master degrees at Ecole Centrale de Nantes in 2003 and defended in 2006 a PhD at University Paris Sud XI. He then joined CEA-List as a permanent researcher in charge of electromagnetic modelling for Non Destructive Testing (NDT) applications. He specialized in semi-analytical methods for efficient simulation of eddy current testing problems, as well as meta-modelling and statistical studies for reliability assessment. Since 2012, he is responsible for the Electromagnetic modelling laboratory inside the NDT department (Département Imagerie Simulation pour le Contrôle) of CEA LIST. This laboratory is in charge of developments related to quasi-static Electromagnetics, X-ray modelling, computed tomography, statistical studies, meta-modelling and model-based inversion for NDT applications. Developed tools are integrated into the multi-physics CIVA software, which is a leading product in the field of NDT. Christophe Reboud is a senior expert of CEA in the fields of NDT techniques, Electromagnetics and modelling. He is currently chairing the Intenational Scientific Committee of the International Workshop on Electromagnetic Nondestructive Evaluation (ENDE).

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SPEAKERS BIOS

Dr. Cédric Auliac

Industrial Partnerships Manager, AI and Innovative Instrumentations; Metrology, Instrumentation and Information Division, CEA-List

M. Cédric Auliac graduated from ORSAY University with an MSc (2003) in computational biology, focusing on the application of data sciences to make sense of rapidly growing biological datasets. During his PhD (2007), in order to support biologists in deciphering gene regulatory networks, he developed new methods to learn complex graphical models from gene expression data with evolutionary computation. He started his career at CEA LIST in 2008 with a Post Doc position aiming at improving the analysis of seismic signals with deep neural networks. The next year, he was hired has a research engineer and started working on various AI research projects mainly linked to the energy and transportation sectors. In 2012, he became a project manager, taking care of the design and implementation of large European and industrial projects for CEA's AI lab. In 2018, he got an MBA from HEC Business School. He took over the position of commercial manager of the DM2I department the next year. He is now the main point of contact for the commercial & industrial activities carried out by the 200 experts working on AI, innovative sensors and nuclear metrology within the department.

SPEAKERS BIOS

Dr. Emmanuel Sabonnadiere
CEO, CEA-Leti

Since November 20th, 2017, Emmanuel Sabonnadiere has been CEO of Leti, institute of CEA Tech. Before, he was in charge of the industrial partnerships of CEA Tech. Previously, he was CEO of the Business Group Professional of Philips Lighting based in Amsterdam (NL). From 2008 till 2014, he was CEO & Chairman of General Cable Europe based in Barcelona (Spain). From 2005 till 2008, he was CEO of NKM Noell at Wurzburg (Germany). He has been vice-president of the Distribution Transformers division of Alstom T&D for 5 years.
He began his career in 1992 with Schneider Electric holding various positions including that of Managing Director of development for equipment units. He has a strong technological background combined with a successful business track record over decades. With 25+ years of executive leadership of large operations, he produced successful operating results and great team building.
He has gained a sound experience of change management in large multi-cultural matrix organizations in order to adapt to the new markets conditions and a strong knowledge of European and international environments. He designed and set-up strategic plans including innovation process. He believes in operational excellence, technology innovation, talent management and enthusiasm in leadership. He obtained a PhD in physics (France), and an engineering degree in Information Technology (France). He holds an MBA (France). He is a member of the Advisory Board of IAC.

Mr. Jim Hamajima
President, SEMI Japan

As President of SEMI Japan, Masahiko (Jim) Hamajima has full responsibility for SEMI operations and oversees development of the association's programs, committees, products, and services in the region. He is responsible for relationships with SEMI members as well as with representatives of industry, government, academia, and other local constituencies. He is additionally charged with supporting SEMI members worldwide who have interests in SEMICON Japan, the region's premier microelectronics event.
Hamajima brings more than 30 years of experience in the semiconductor equipment industry in Japan and the U.S. and a comprehensive understanding of the global industry. Starting at Tokyo Electron Ltd. (TEL) in diffusion, Hamajima later held vice president positions overseeing multiple product lines at Tokyo Electron America and later for Cleaning Systems in Japan. Hamajima's experience includes leading complex integrations as senior vice president at Timbre Technologies and as vice president and general manager at TEL-FSI. Prior to joining SEMI, Hamajima served as vice president and general manager of Corporate Strategy at TEL. Hamajima holds a Bachelor of Science degree in Metallurgy from the Nagoya Institute of Technology.

Dr. Laurent Pain, Head of Partnerships, Technology Division Platform, CEA-Leti

Laurent Pain is graduated from the Ecole Nationale Supérieure de Physique de Grenoble in 1992. After receiving a PhD in 1996, he joined the Optronic Division of CEA-LETI. In 2000, he moved to STMicroelectronics Crolles site to participate to the start of the first 193nm litho cell. From 2001 to 2008, he leaded the E-Beam direct write litho cell in the ST Crolles manufacturing site. The objective of this activity was first to show the integration capabilities of the EBDW lithography in industrial environment.
From 2008 to 2014, Laurent Pain leaded the Lithography Laboratory of the Silicon Technology Division of CEA-LETI back at Grenoble pushing the insertion of innovative lithography techniques : multibeam, DSA and imprint. During this period, he also managed the industrial consortium IMAGINE dedicated to the development of MAPPER multibeam technology.
Since July 2014, still within the LETI Silicon Technologies Division, he is now Head of Partnerships at the Technology Division Platform, and ensures the developments of all the associated business development.

Dr. Jean-René Lequèpeys
CTO and Deputy Director, CEA-Leti

Jean-René Lequèpeys received his engineering degree in 1983 from Supélec and taught physics for 2 years in Ouarzazate, Morocco. He joined CEA in October 1985, in Saclay, within the Central Security Office, in the laboratory for the evaluation of means of detection and intrusion; in 1987, he hold the head of the laboratory. In 1993, he was recruited by DSYS, at LETI in Grenoble, as an R & D engineer, in the field of image processing. He then lead projects in the field of «Telecom» at LETI before getting the head of «Telecom, Communicating Objects and Smart Card» programs in 1999, within the team of Jean-Frédéric Clerc. In 2000, Jean-René Lèquepeys received the famous award from SEE «Grand Prix de l'électronique Général Ferrié» for his work in the telecommunications field. He is the author of about fifteen patents in this field. In 2005, he took in charge the Circuits Design Department at LETI / DSYS, and then created, in partenership with the Ecole des Mines de Saint-Etienne, a laboratory dedicated to electronic components safety analysis located in Gardanne (Paca). In 2010, from the common initiative of both LETI and LIST Directors, he launched DACLE division, relying on original bi-site and bi-institute model, and focusing on Electronic Architectures, Integrated Circuit Design and Embedded Software. He participated to the creation of the Division DCOS (Division of Silicon Components) in 2011, and then lead the division until the end of 2017, when he got back to the head of DACLE division in 2018.
Since 2019 he is Deputy Director & CTO at CEA-Leti.

SPEAKERS BIOS

Dr. Toshiyuki Miyazawa, Manager of Digital Annealer Technology Development Project, Fujitsu Limited

Dr. Toshiyuki Miyazawa is currently the Manager of Digital Annealer Technology Development Project at Fujitsu Laboratories Ltd. He has been leading hardware architecture of Digital Annealer, which was inspired by quantum phenomena, for solving large scale combinatorial optimization problems. He joined Fujitsu Laboratories Ltd. in 2001, where he has been engaged in research and development of single photon generator and quantum bits using semiconductor nanostructure. He contributed quantum dots project in Institute for Nano Quantum Information Electronics, University of Tokyo from 2003 to 2015.
He received his B.S. degree in Physics from Yokohama National University in 1997, and his MS and PhD degrees in Electrical Engineering from University of Tokyo in 1999 and 2011 respectively. He is a member of The Japan Society of Applied Physics and The Physical Society of Japan.

Dr. Maud Vinet

Quantum Computing Program Director, CEA-Leti

Maud Vinet (CEA-Leti, University Grenoble Alpes, France) is currently leading the quantum computing program in Leti. Her team is in charge of developing a silicon based quantum computer and on the other hand, she fosters innovation in quantum technologies through creation of a public-private collaboration ecosystem.
Since she joined in Leti, her research activities have been focused on advanced CMOS integration and they are evolving towards new computing paradigms. She defended her PhD in Physics from University of Grenoble Alps in 2001 and then was hired Leti in 2001 as a CMOS integration and device engineer. From 2009 to 2013, she spent 4 years in Albany, NY as a Leti assignee with IBM Alliance. She took part to the development of Fully Depleted Silicon-on-Insulator technology. In 2015, she joined Globalfoundries for 6 months as an assignee to launch 22FDX technology in Malta, NY, USA. From 2013 to 2018, she managed the Advanced CMOS integration team activities in Leti (~50 people). In 2019, she was appointed project leader for the quantum computing program in Leti. In 2011-12 she took Management of Innovation classes at the MIT Sloan School of Management, Boston, USA. In 2018, she followed the IHEST (French Institute of High Studies for Science and Technology) one-year training cycle, which aims at strengthening the relationship between science and society. She is part of the board of Quantum Engineering Grenoble. She has served in many technical committees; she is currently part of VLSI Symposium TPC. Maud Vinet authored or co-authored about 150 papers, she owns more than 65 patents related to nanotechnology and her Google h-index is 41.

Mr. Philippe Ruffin

Startup Program Manager, CEA-Leti

Philippe joins CEA-LETI in 2013 to set up a new program for aspiring entrepreneurs, Leti Startup Program. This program is dedicated to supporting and accelerating deep-tech startups through technology evaluation and Proof of Concept development, IP portfolio enhancement, business design, access to partners and VCs. Philippe previously served as startup advisor at Grenoble's public accelerator 'Grain', specializing in technology transfer to high tech companies in the fields of bio-technology, energy, microelectronics and ICT. Prior to that he held several marketing positions in the semiconductor and smart card industries, in both startups and large corporations. Philippe holds a Master of Science degree in Information Technology (systems integration) from Napier University, Edinburgh (Scotland).

Dr. Frédéric Heitzmann

Embedded AI Program Director, CEA-Leti

Frederic Heitzmann was born in 1977. He received a master degree from the Ecole Polytechnique (France) in 2000, and a master degree from Telecom Paritech 2002. He started his career in a software development company, with a focus on multimedia contents, database, and rich user interfaces. In 2004, he came to the Mobile Phone Division of Sagem (Safran group), in the OS-driver team. He contributed to the development of several platform (2G, 2.5G, 3G) integrated in dozens of commercial products, then took the lead of the low-level software team in 2005. In 2007, he moved to CEA-Leti, the French leading RTO in semiconductors, micro/nano devices, design and systems. He was part of the digital design research group, and contributed to reduce the gap between software and hardware developments. Notable realizations include: prototype of a programming environment for heterogeneous dataflow multicore SoC, joint algorithm/hardware design of a 60GHz demodulator, leading the development of a full Rx Telecom platform (software model and FPGA IPs), and a common framework for digital simulation/emulation. In 2012, he joined the Embedded Software Research group at CEA-Leti. He developed a compiler backend for asynchronous processor, and was part of the "sensor fusion" team, contributed to several patents and demonstrators. From 2018, he moves to his current position, head of the strategic program "EdgeAI" for CEA-Leti, whose purpose is to design, build, and demonstrate System breakthroughs for Artificial Intelligence at the edge.

Dr. François Simoens

LIDAR Program Director, CEA-Leti

Dr François Simoens carried out seven years of research in the accelerator field at CEA Saclay, before joining CEA-Leti in Grenoble in 2003 with the position of program manager and expert in infrared and THz sensors. From 2015 to 2018, he has been the Marketing and Strategy Manager for the imaging technologies and systems developed at Leti from X-ray to Far-Infrared. Since 2019 he acts as the Director of the LETI strategic program named 'miniaturized LIDAR – CPS'.

SPEAKERS BIOS

Dr. Yuichi Nakamura

VP Central Research Labs, NEC Corporation

Yuichi Nakamura received his B.E. degree in information engineering and M.E. degree in electrical engineering from the Tokyo Institute of Technology in 1986 and 1988, respectively. He received his PhD. from the Graduate School of Information, Production and Systems, Waseda University, in 2007. He joined NEC Corp. in 1988 and he is currently he is currently vice president at Central Research Labs. NEC Corp. He is also a guest professor of National Institute of Informatics. He has more than 25 years of professional experience in electronic design automation, signal processing, optical communication and quantum computing.

Mr. Eric Mercier

5G Program Director, CEA-Leti

Eric MERCIER is at the CEA-Leti in Grenoble since 2006, now in charge of the LETI Technology Line - Connectivity coordination, including 5G and IoT topics. Graduated from the ENSEEIH of Toulouse, France, 1991, and holding a DEA in Microwaves focused on Near-field/ Far-field antenna diagram conversion done at Thales-Alenia Space (formerly Alcatel Space), he had held positions in the Optical Test Equipment with Schlumberger/Wavetek, for physical fiber optical link tests, as Analog & Signal Processing engineer, and had pursued his work in the semiconductor domain, back to RF topics in companies like ST and Atmel as R&D Application & Characterization engineer, as well as Marketing engineer, in the field of low-power RF dedicated to IoT. At CEA-Leti, he has led projects in the scope of ULP RF, with a specific focus on low-power RF transceiver design & implementation, and on embedded resources dedicated to low-power IoT solutions. Amongst these researches, the FOXY solution has been awarded ''Electron D'Or – Golden Electron 2018'' for ''Connected Objects'' in France. He had been the Head Manager of the Laboratory for Architectures & Integrated RF design (LAIR) in the Architecture, IC Design and Embedded Software department (DACLE) for 4 years, the Lab. being in charge of designing RF solutions for ULP, UWB, UNB, mmW, High-Data Rate, RFID, PA & FEM systems, with a common target of addressing the lowest possible power consumption and make use of the most advanced CMOS technologies. He has co-authored some conference papers and participated to a book chapter on Wireless Sensor Network topic.

Dr. Laurent Hérault

VP, Director of the Europe Division, CEA-Leti

Dr. Laurent Hérault was born in Tours, France, in 1964. He received the BS degree in electrical engineering and the MS degree in control engineering from the Institute National Polytechnique de Grenoble, (INPG) in 1987 and a Ph.D. degree in computer science from INPG in 1991. He won the Best Junior Researcher Award from the University of Grenoble, France, in 1990. Since 2004 he is 'International Expert' at CEA. From 2009 to 2011, he has led the Wireless Communications and Security labs.
Since 2011 he is Vice President, Director of the Europe division of CEA-Leti.

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Presentations

TECH DAYS

INNOVATION FOR INDUSTRY

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LITEN DAY

OCTOBER 15, 2019

KEIO PLAZA HOTEL, TOKYO

CEA-LITEN, WORLD-CLASS RENEWABLE ENERGY R&D ORGANIZATION OFFERING INNOVATIVE SOLUTIONS FROM MATERIALS TO SYSTEMS

CEA Tech Days 2019 | Yohan Souteyrand | 15/10/2019

KEY FIGURES 2018

TOP 3 GLOBAL INNOVATORS

Since 8 years, CEA is ranked among the *« **Top 100 Global Innovators** in the **Clarivate 2018»*** for its proactive intellectual property policy.

Source : https://clarivate.com/top100innovators

FIGURES 2018

975 EMPLOYEES

1 612 PATENTS *in the portfolio*

> 250 INDUSTRIAL PARTNERS

BUDGET **138 M€**

RESEARCH CONTRACTS

40% *competitive public funding*

60% *industrial*

13 PLATFORMS

RESEARCH CENTER,

Creator of Solutions, to Address Climate, Energy & Environmental Issues

TARGETS

- Reduction of greenhouse gas emissions
- Energy efficiency
- Anchoring in a “Circular Economy” approach

And creating value when transferring to industry and the economic world.

STRATEGIC RESEARCH AREAS

1 LOW-CARBON POWER GENERATION

Decentralized Renewable Energy

- Utility scale production (PV & CSP)
- High added-value PV solutions (BIPV, autonomous systems).

2 MANAGEMENT OF ENERGY GRIDS

Components & Digital Tools for a « Smart Energy Grid » with **Demand Management**

Solutions for Flexibility

- Storage (thermal, eletrochemical)
- Hydrogen Vector
- Sector coupling

3 IMPROVE ENERGY EFFICIENCY

Energy Efficiency

- In service
- During the product lifetime

Material Ressource Efficiency

- Additive manufacturing

Reducing the Environmental Footprint

- Life-cycle analysis
- Recycling
- Closing the carbon cycle

liten CEA tech

1

LOW-CARBON POWER GENERATION

Decentralized Renewable Energy

- Utility scale production (PV & CSP)
- High added-value PV solutions (BIPV, autonomous systems).

2

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Develop PV Technologies with High Efficiency and Controlled Cost

- *Homojunction*
- *Heterojunction*
- *Tandem Cells*

Large Solar Power Plants

PV Everywhere

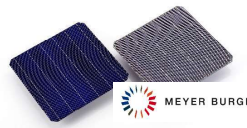
Optimize the Overall Efficiency of Solar Systems

- *PV Inverters*
- *Architecture and Downstream Module Components*
- *Custom Integration*
- *High-level Requirements Solutions*

1

LOW-CARBON POWER GENERATION

Heterojunction :
23,9% of efficiency over the entire surface area.
348 Watts record: power for a nominal module using
120 half-cells with heterojunction



http://www.cea.fr/presse/Pages/actualites-communiques/energies/cellules-solaires-meyer-burger.aspx

Stratobus project : Development of a **flexible and ultra-light PV module** to power stratospheric aircrafts

ThalesAlenia Space

1

LOW-CARBON POWER GENERATION

Decentralized Renewable Energy

- Utility scale production (PV & CSP)
- High added-value PV solutions (BIPV, autonomous systems).

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MANAGEMENT OF ENERGY GRIDS

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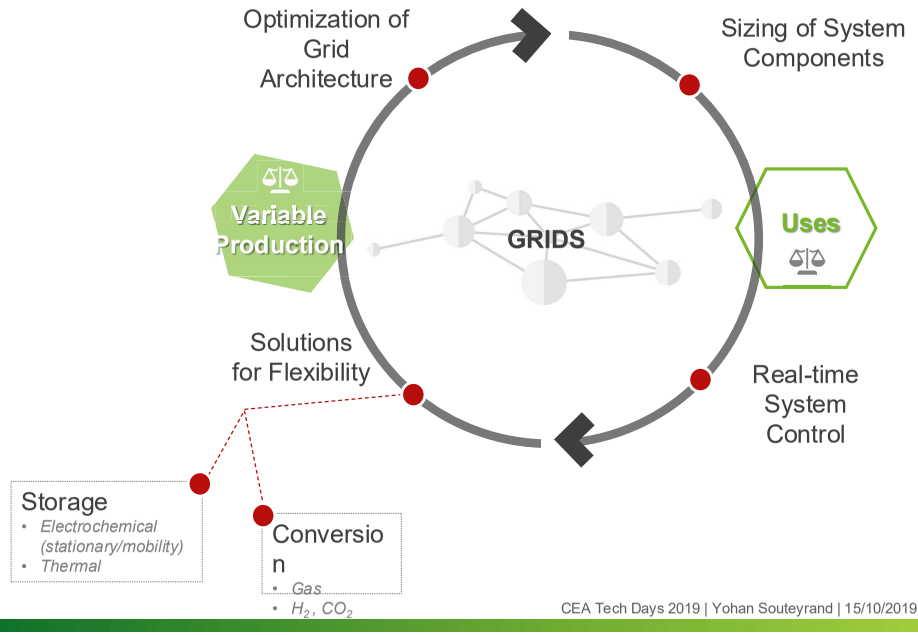


2 MANAGEMENT OF ENERGY GRIDS

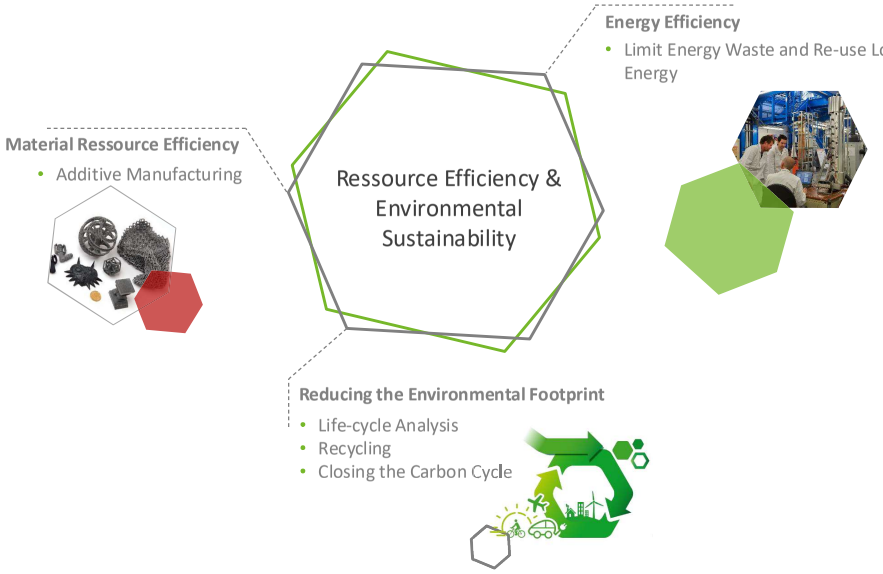
Marie Galante, Caribbean island, is moving towards **100% renewable**

Liten has dimensioned the **PV and battery storage installations** with the grid operator

SOEC Hydrogen Production
Proven system level performance:
87% PCI
Demonstrator **300 kW** in 2022

3 IMPROVE ENERGY EFFICIENCY

Finding the Economic and Environmental Optimum of the Energy Transition



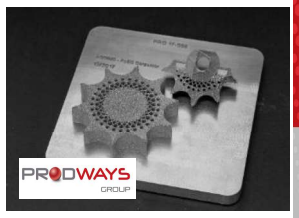
3

IMPROVE ENERGY EFFICIENCY

Development of the hydrometallurgical process for the extraction of precious metals (Ni, Co, Mn, Li)
Pilot scale (5L) validation of a single-step process for the selective extraction of precious metals.

SNAM

Additive Manufacturing :
Extend the fields of application with the manufacture of magnetic parts by laser fusion on a powder bed.



liten cea tech

liten cea tech 3

IMPROVE ENERGY EFFICIENCY

- Contribute to Carbon Neutrality
- Limiting Dependence on Fossil Fuels

POWER TO X

CARBON TO X

1ST DEMONSTRATOR FOR THE PRODUCTION OF OPERATIONAL SYNTHETIC GAS

TAURON POLSKA ENERGIA

Compact reactor technology with a millistructured plate tested by CEA

Demonstrator on a scale of 1 with 4 reactors (in Poland)

Carbon conversion rate > 97%

HYDROTHERMAL CONVERSION OF MICROALGAE

Vasco2

Valorization of CO_2 emitted by manufacturers with the testing of a new biomass production solution based on biological recycling of CO_2

Microalgae culture pool "fed" with factory smoke

Continuous hydrothermal liquefaction pilot of CEA Grenoble

Carbon-rich oil ~ 75%

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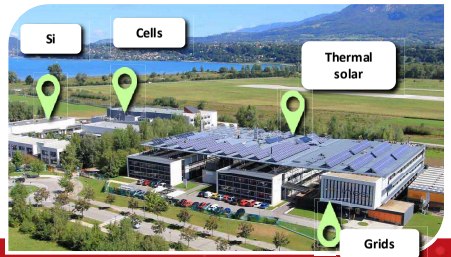
OUR RESEARCH CAMPUSES



ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

Solar & Grids

GreEn GRENOBLEENERGIE

Storage & Energy Efficiency

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OUR TECHNOLOGICAL AND DIGITAL PLATFORMS

THE LITEN DIVISIONS

DTS : SOLAR & GRIDS

≈ 400

A. JOUINI

Chambéry

DTBH : THERMAL ENGINEERING H_2 BIOMASS

≈ 200

P.TOCHON

Grenoble / Chambéry / Cadarache

DEHT : ELECTROMOBILITY

≈ 200

S.JOUANNEAU

Grenoble

DTNM : ADVANCED MATERIALS STRUCTURAL ELECTRONICS

≈ 200

C.DEGUET

Grenoble

INTERNATIONAL REACH

ONGOING COLLABORATIONS/PARTNERSHIPS 2018/19

CEA TECH SERVICE OFFERING

UNRIVALED

Technology Platforms and a real I.P. « heritage »

FULLY CONFIDENTIAL

Strict protocols governing data and client interest

CUSTUMER ORIENTED

- Customized support to facilitate technology integration
- Personalized collaboration (contract, industrial transfer, high quality account management)

MULTI-SECTORIAL

From low-end to high-end technologies

INNOVATIVE & COMPETITIVE

- Key enabling technologies as a driver for innovation
- Internationally renowned for our scientists' expertise

HOW TO COLLABORATE WITH CEA TECH?

Service delivery : Prototyping, qualification, tests **/ Studies made only** CEA
I.P.: Yes
R&D agreement / Licence & royalities (non-exclusive)

Collaboration Agreement 1-3 years

Multiple research needs:
Long-term agreements with extent of the work to be carried out defined
Projects annually defined
I.P.: Yes
Licence & royalities (exclusive or not)

Contract Letter 1-12 months

Industrial with a unique subject:
Punctual agreement made to measure
I.P.: Yes
Licence & royalities (exclusive or not)

Framework Agreement Joint Labo 3-5 years

> Analysis of the specifications / Proposal of a quantified technical program with deliverables / Budget and agreement <

Contact:

Yohan Souteyrand
Email: yohan.souteyrand@cea.fr

THANK YOU
ご清聴ありがとうございました
COME TO VISIT US IN FRANCE !

Commissariat à l'énergie atomique et aux énergies alternatives
17 rue des Martyrs | 38054 Grenoble Cedex
www-liten.cea.fr

Établissement public à caractère industriel et commercial | RCS Paris B 775 685 019

Liten Day
Oct 15, 2019

Towards the Record Efficiency of Si-Based Solar Cells

Kunihiro NAKANO

KANEKA Corporation

kaneka
The Dreamology Company
—Make your dreams come true—

Outline

- Overview of solar photovoltaics;
  Current status and perspectives
- High efficiency crystalline Si solar cells using Si heterojunction technology
- Multi-junction solar cell (HJ & perovskite solar cells)
- Summary

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- **Overview of solar photovoltaics;**
  Current status and perspectives
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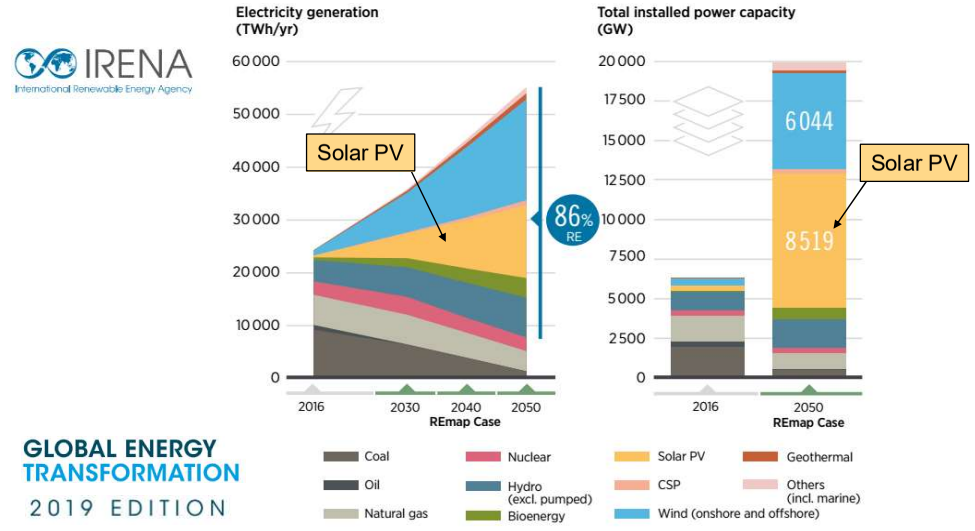
A roadmap to 2030~2050

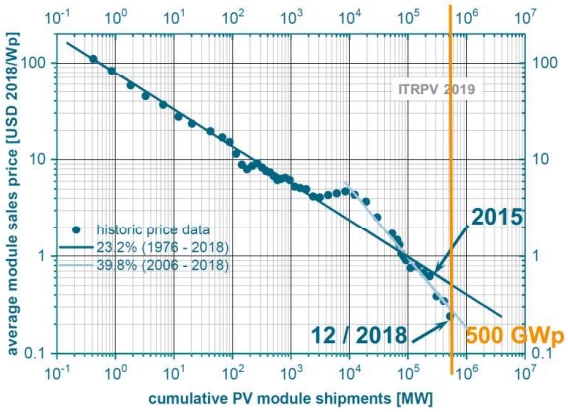
The global energy system needs to be transformed to meet the Paris Agreement.
In IRENA roadmap, capacity of solar PV in 2050 is 8500 GW; currently, still,>500GW.



Learning curve on PV module*

The Dreamology Company —Make your dreams come true—

Year	1980	2010	2011	2012	2013	2014	2015	2016	2017	2018
avg. Module power p- type (ITRPV-data)	147.6	241.5	248	253	262	267.5	278.5	287.5	290	302.5
Module efficency [%], avg. Mod. area: 1.64m²	9 [25]	14.7	15.1	15.4	16	16.3	17	17.5	17.7	18.4
Module price [$2018]	36.57	1.7	1.06	0.75	0.78	0.67	0.62	0.39	0.34	0.24
relative module price reduction [%]		95.34	37.77	28.84	-2.84	13.21	7.83	37.65	11.08	30.27



During 38 years :1980-2018

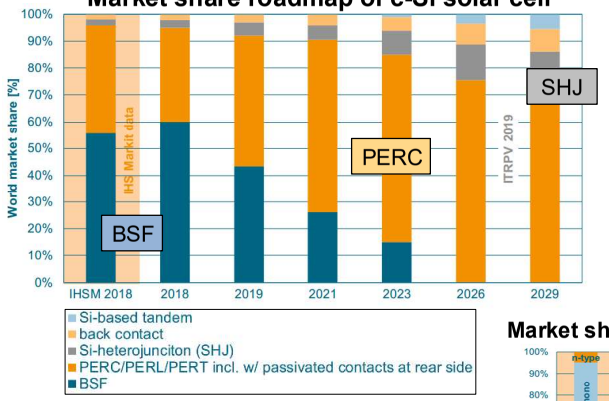
- Module price: 1/150
  Recently, learning rate become larger.
- Module power: double
- Developments of cell and module technologies made them possible besides the scale-up.

* ITRPV 2019

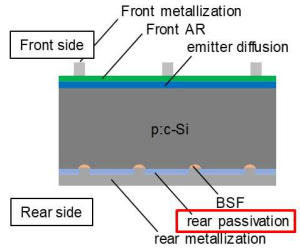
Current industrial solar cell

The Dreamology Company —Make your dreams come true—

Market share roadmap of c-Si solar cell



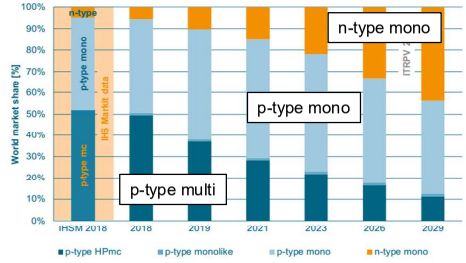
Cross sectional image of PERC



Bifacial type PERC is widely produced.

- Currently, PERC (passivated emitter, rear cell) offers best balancing between cost and power.
- p-type multi-crystalline Si solar cell will reduce market share.
- PERC is expected to be the main player in 2020s.

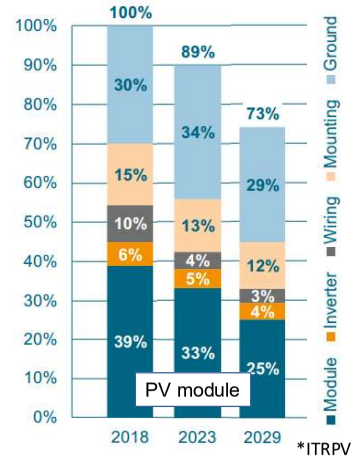
Market share roadmap of different wafer type



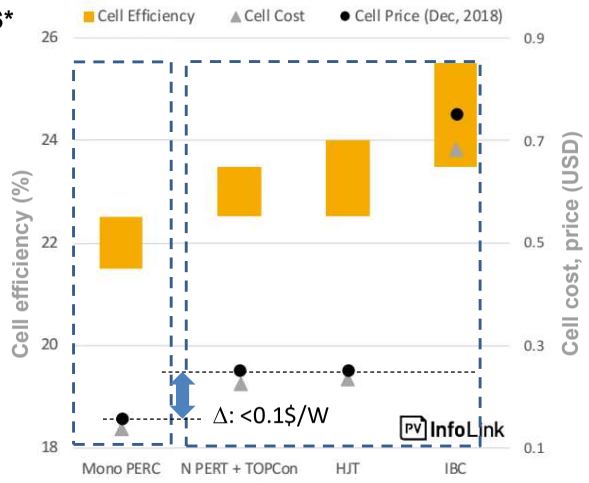
Industrial c-Si solar cells

The Dreamology Company —Make your dreams come true—

Cost structure of PV system in US*



*ITRPV 2019



"New technology"

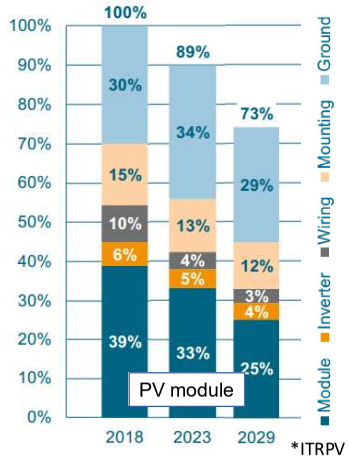
- High efficiency
- Currently higher cost
- Small production capacity

Reduction of production cost is one of the most crucial challenge for new technologies.

Industrial c-Si solar cells

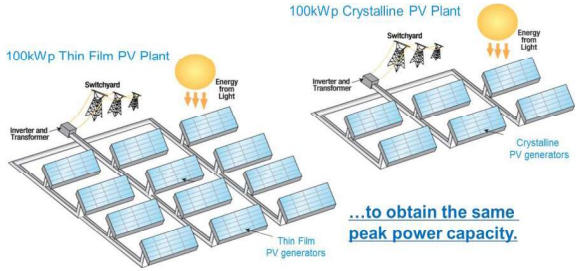
The Dreamology Company —Make your dreams come true—

Cost structure of PV system in US*



*ITRPV 2019

Ratio of module cost in PV system cost is expected to be smaller and smaller;
Higher efficiency is a key to realize the further reduction of system cost.

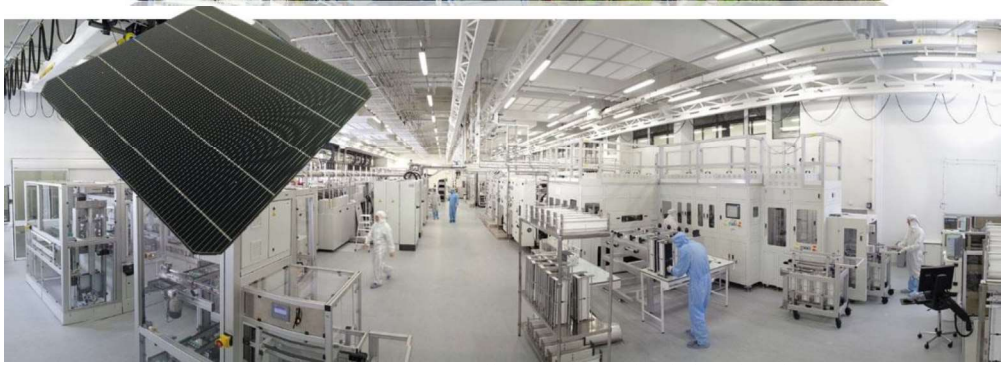


…to obtain the same peak power capacity.

Larger surface means larger costs of installations!!!

C. Gerardi *et al.*, presented in 1st International Workshop on Silicon Heterojunction Solar Cells

Reduction of production cost is one of the most crucial challenge for new technologies.



http://liten.cea.fr/cea-tech/liten/en/Pages/News/heterojunction-technology.aspx

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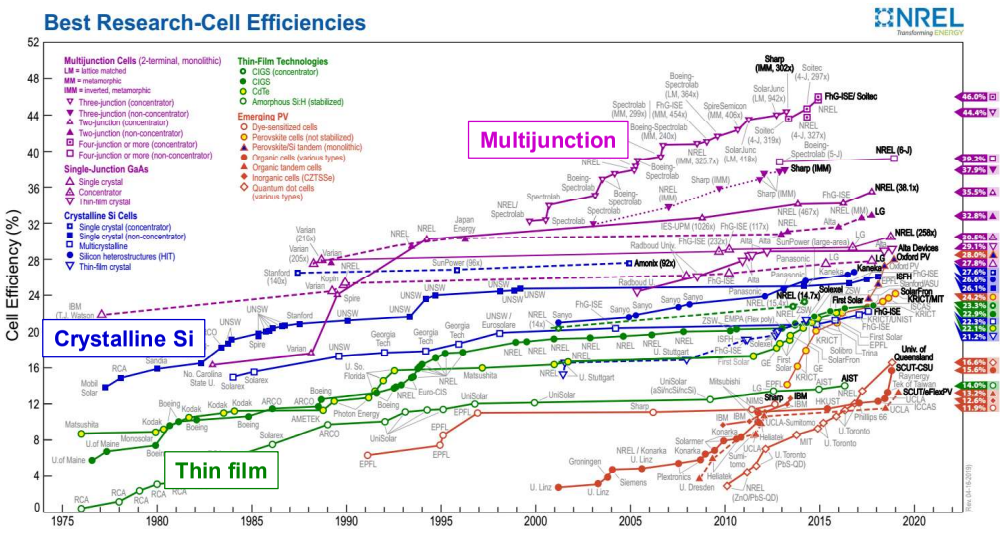
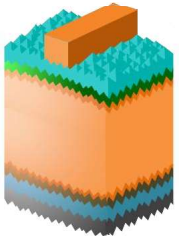
  Current status and perspectives
- **High efficiency crystalline Si solar cells using Si heterojunction technology**
- Multi-junction solar cell (HJ & perovskite solar cells)
- Summary



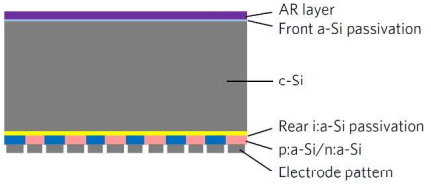
Speed of conversion efficiency improvement of solar cell was increased in 2010s.

Trend of High efficiency Si PV

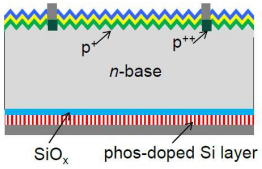
25.1% top/rear-contacted a-Si/c-Si heterojunction
(KANEKA, 2015)[2)]



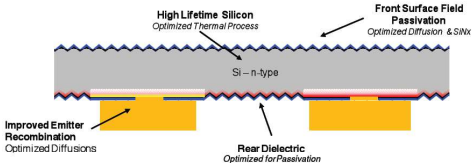
26.7% back-contact Si heterojunction
(KANEKA, 2017) [1)]



25.7% Tunnel oxide passivated contact
(Fraunhofer ISE, 2017) [4)]



25.2% Back-contact
(SunPower, 2015) [3)]



[1)] K. Yamamoto *et al*, Jpn. J. Appl. Phys. **57** 08RB20 (2018) [2)] K. Yamamoto *et al*, Proc. of 31st EUPVSEC (2015), 1003.
[3)]"SunPower 2015 Analyst Day" (2015), [4)]A. Richter *et al*. Sol. Energy Mater. Sol. Cells **173** (2017), 96.

Trend of High efficiency Si PV

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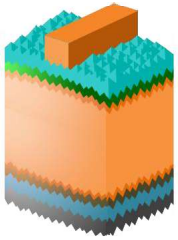

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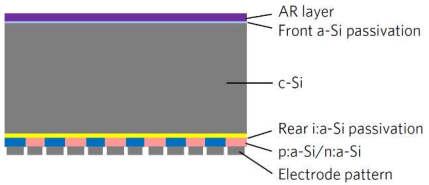


Advantages of a-Si/c-Si heterojunction (HJ) Si solar cell

a-Si/c-Si HJ : High V_{oc} and FF with smaller temperature coefficient of power
by excellent a-Si/c-Si interface
Production process :First process, Low thermal budget (T<200°C)
Si wafer-based: Reasonable production cost

[1)] K. Yamamoto *et al*, Jpn. J. Appl. Phys. **57** 08RB20 (2018) [2)] K. Yamamoto *et al*, Proc. of 31st EUPVSEC (2015), 1003. [3)]"SunPower 2015 Analyst Day" (2015), [4)]A. Richter *et al*. Sol. Energy Mater. Sol. Cells **173** (2017), 96.

Received: 23 May 2019 | Accepted: 31 May 2019
DOI: 10.1002/pip.3171
*M. Green *et al*., Prog. Photovolt: Res. Appl. 27 (2019) 565.
ACCELERATED PUBLICATION
WILEY PROGRESS IN PHOTOVOLTAICS

Solar cell efficiency tables (version 54)

TABLE 1 Confirmed single-junction terrestrial cell and submodule efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at 25°C (IEC 60904-3: 2008, ASTM G-173-03 global)

Classification	Efficiency, %	Area, cm^2	V_{oc}, V	J_{sc}, mA/cm^2	Fill Factor, %	Test Centre (Date)	Description
Silicon							
Si (crystalline cell)	26.7 ± 0.5	79.0 (da)	0.738	42.65[a]	84.9	AIST (3/17)	Kaneka, n-type rear IBC[4]

TABLE 2 "Notable exceptions" for single-junction cells and submodules: "Top dozen" confirmed results, not class records, measured under the global AM1.5 spectrum (1000 Wm^{-2}) at 25°C (IEC 60904-3: 2008, ASTM G-173-03 global)

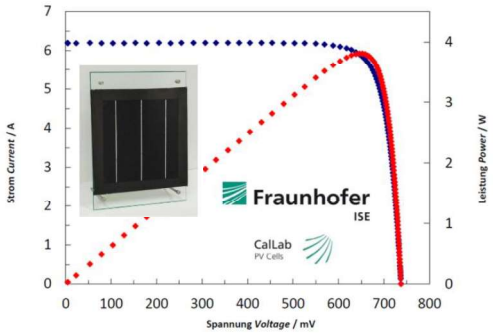
Classification	Efficiency, %	Area, cm^2	V_{oc}, V	J_{sc}, mA/cm^2	Fill Factor, %	Test Centre (Date)	Description
Si (large crystalline)	25.1 ± 0.5	151.88 (ap)	0.7375	40.79[f]	83.5	FhG-ISE (9/15)	Kaneka, n-type top/rear contacts[32]
Si (large crystalline)	26.6 ± 0.5	179.74 (da)	0.7403	42.5[g]	84.7	FhG-ISE (11/16)	Kaneka, n-type rear IBC[4]

TABLE 4 Confirmed terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at a cell temperature of 25°C (IEC 60904-3: 2008, ASTM G-173-03 global)

Classification	Effic., %	Area, cm^2	V_{oc}, V	I_{sc}, A	FF, %	Test Centre (Date)	Description
Si (crystalline)	24.4 ± 0.5	13177 (da)	79.5	5.04[a]	80.1	AIST (9/16)	Kaneka (108 cells)[4]

KANEKA's best R&D HJ c-Si solar cell result (2015)

Area	151.9 cm^2
V_{oc}	738 mV
J_{sc}	40.8 mA/cm^2
FF	83.5%
Eff.	25.1%



K. Yamamoto *et al.*, Proc. of 31st EUPVSEC, p.1003 (2015)
D. Adachi *et al.*, Appl. Phys. Lett. **107**, 233506 (2015) .

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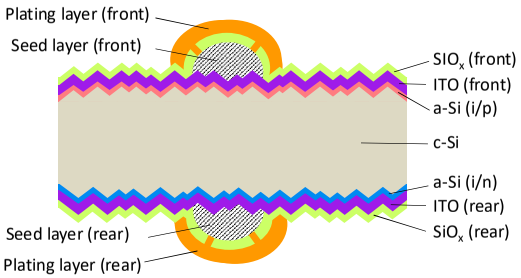
25.1%: Record efficiency in large size top/rear type c-Si solar cell

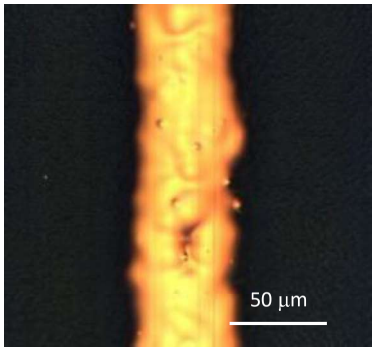
*M. Green *et al.*, Prog. Photovolt: Res. Appl. 27 (2019) 565.

Industrial Cu plating metallization process using PECVD SiO_x barrier layer

Schematic image of HJ c-Si solar cell



Optical microscope image of Finger electrode



D. Adachi, K. Yamamoto *et al.*, Sol. Energy Mater. & Sol. Cells **163,** 204 (2017).

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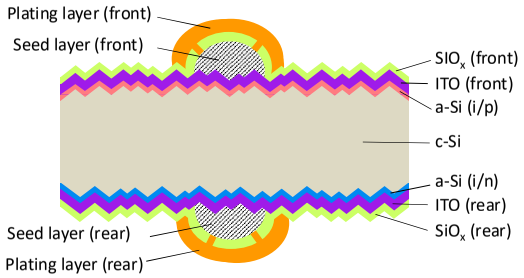


Process Step

(1) Screen-printing of seed layer

(2) SiO_x layer by PECVD method

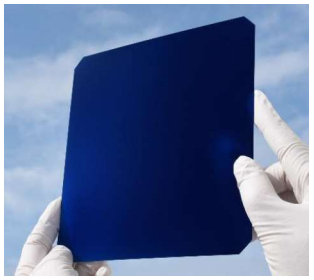
(3) Heating process

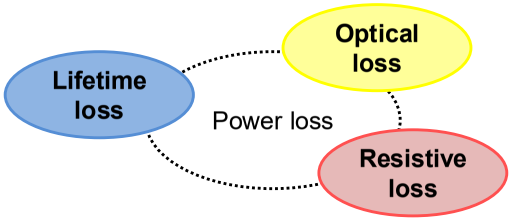
This thermal treatment changes the surface morphology of the seed layer and generates holes (cracks) of the PECVD-SiO_x layer selectively on the seed layer.

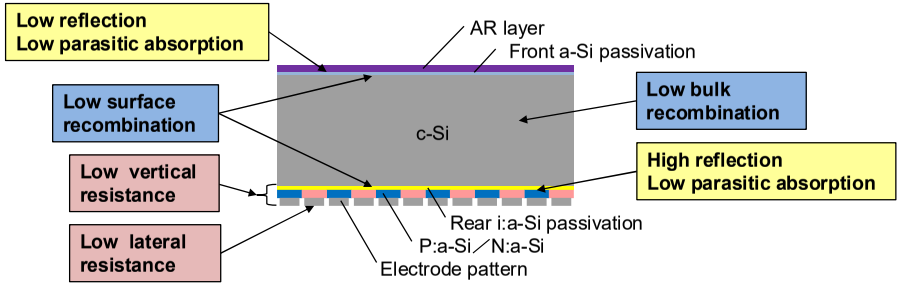
(4) Cu plating

D. Adachi, K. Yamamoto *et al.*, Sol. Energy Mater. & Sol. Cells **163,** 204 (2017).

Development of HJ-IBC cell



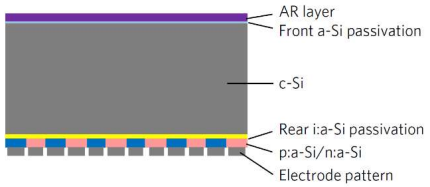




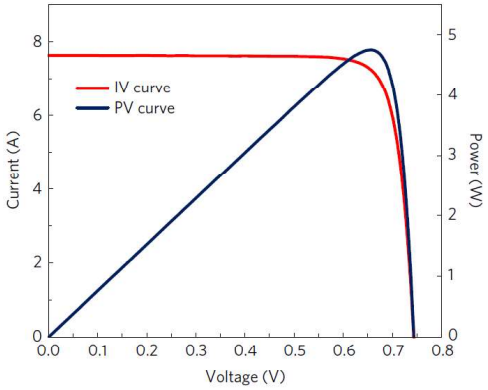
Achievement of 26.3% by HJ-IBC (2016)

nature energy — ARTICLES
PUBLISHED: 20 MARCH 2017 | VOLUME: 2 | ARTICLE NUMBER: 17032

Silicon heterojunction solar cell with interdigitated back contacts for a photoconversion efficiency over 26% (*)



Area	180.43±0.18 cm^2
V_{OC}	743.8 ±2.5 mV
J_{SC}	42.25 ±0.80 mA/cm^2
FF	83.78 ±0.54%
Eff	26.33 ±0.53%

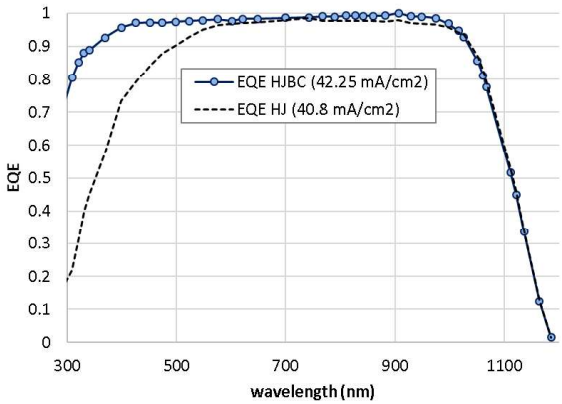


(*) K. Yoshikawa *et al.*, Nat. Energy 2, 17032 (2017).

EQE of HJ-IBC cell

26.33% BC vs 25.1% top/rear

	HJ-IBC	Top/ Rear	Diff.
Eff. (%)	26.3	25.1	4.9%
V_{oc} (mV)	744	738 (741: 24.5% HJ)	0.8% (0.4%)
J_{sc}(mA/cm^2)	42.3	40.8	**3.6%**
F.F. (%)	83.8	83.5	0.3%

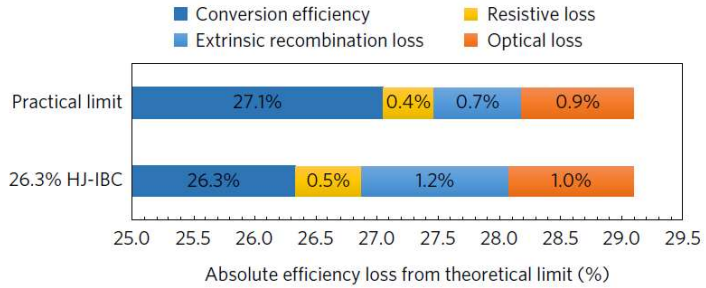


EQE of short wavelength improved due to front optics improvement compared to top/rear HJ record (25.1% Kaneka)

Practical limit efficiency 27.1% and loss elements

Practical limit (3 Ohm.cm, 165 μm)	
Implied V_{OC}	748 mV
Predicted J_{SC}	42.4 mA/cm^2
Implied FF (pFF)	85.6% (86.6%)
Predicted R_S	0.25 Ohm.cm^2
Predicted Eff	27.1%

Practical limit (27.1%) was estimated from characteristic of 26.3% HJ-IBC cell and passivated sample. (*)



(※) K. Yoshikawa *et al.*, Nat. Energy 2, 17032 (2017).

High efficiency c-Si solar cell; PV parameters

*da: designated area *ta: total area *ap: aperture area

	V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)	Eff (%)	Area* (cm^2)	Cell type
Panasonic	0.740	41.8	82.7	25.6	143.7 (da)	HJ-IBC [1]
SunPower	0.737	41.3	82.7	25.2	153.5 (ta)	IBC [2]
Fraunhofer ISE	0.725	42.5	83.3	25.7	4.017(da)	TOPCon [3]
Kaneka	0.738	40.8	83.5	25.1	151.9 (ap)	HJ [4]
Kaneka	0.744	42.3	83.8	26.3	180.4 (da)	HJ-IBC [5]
Kaneka	0.740	42.5	**84.7**	26.6	179.7 (da)	HJ-IBC [6]
Kaneka	0.738	42.7	**84.9**	26.7	79.0 (da)	HJ-IBC
Theoretical limit	0.752	43.7	88.5	29.1		180μm-thick wafer [7]
Ratio (26.7%/limit)	0.981	0.977	**0.959**	0.918		

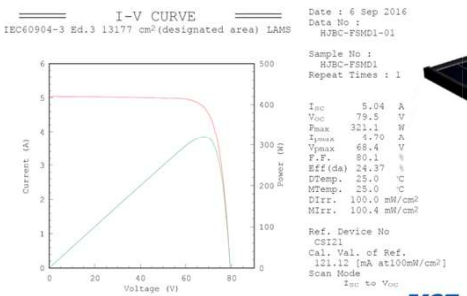
- High V_{oc}, J_{sc} and FF obtained by excellent PECVD passivation and structure design
- Challenge for improvement of FF is a key to achieve >27% efficiency.

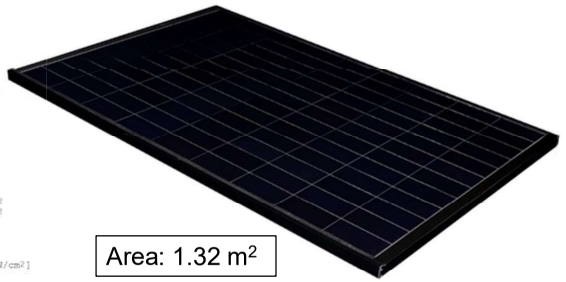
[1] K. Masuko *et al.*, IEEE Journal of Photovoltaics, 4, 1433 (2014), [2] "SunPower 2015 Analyst Day" (2015), [3] A. Richter et al., Silicon PV proceedings (2017). [4] D. Adachi *et al.*, Applied Physics Letters, 107, 233506 (2015), [5] K. Yoshikawa *et al.*, Nat. Energy 2, 17032 (2017) [6] K. Yoshikawa *et al.*, Silicon PV proceedings (2017) [7] A. Richter *et al.*, IEEE J. Photovolt. 3, 1184 (2013).

HJ-IBC module

TABLE 4 Confirmed terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at a cell temperature of 25°C (IEC 60904-3: 2008, ASTM G-173-03 global)

Classification	Effic., %	Area, cm^2	V_{oc}, V	I_{sc}, A	FF, %	Test Centre (Date)	Description
Si (crystalline)	24.4 ± 0.5	13177 (da)	79.5	5.04[a]	80.1	AIST (9/16)	Kaneka (108 cells)[4]
GaAs (thin film)	25.1 ± 0.8	866.45 (ap)	11.08	2.303[b]	85.3	FhG-ISE (11/17)	Alta Devices[55]





Area: 1.32 m^2

AIST

Record efficiency for c-Si solar cell module, 24.37%

*M. Green *et al.*, Prog. Photovolt: Res. Appl. 27 (2019) 565.

KANEKA BIPV module product

BIPV module for Japanese residential market

Roof tile type **VISOLA™**

1000 mm

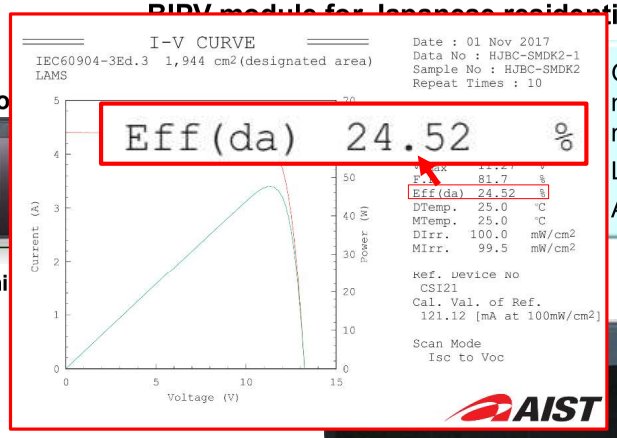
Thin-film Si

- Good performance as roof material (wind- and water-resistance, durability)
- Light-weight
- Aesthetic design

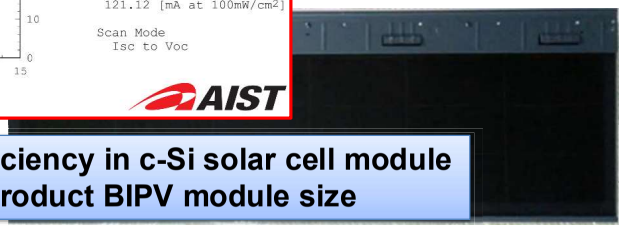
VISOLA™ type HJ-IBC (Prototype)

KANEKA BIPV module product

BIPV module for Japanese residential market



- Good performance as roof material (wind- and water-resistance, durability)
- Light-weight
- Aesthetic design



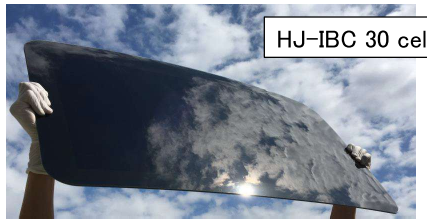
Record efficiency in c-Si solar cell module by product BIPV module size

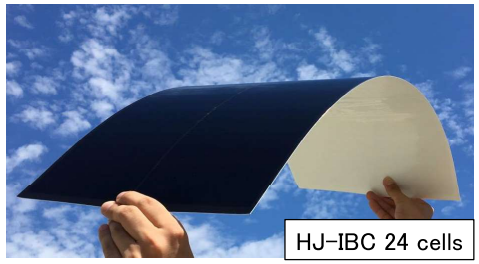
*)Kenji Yamamoto *et al*, Jpn. J. Appl. Phys. **57** 08RB20 (2018)

Aesthetic HJ-IBC Module

Outdoor installation

Curved module





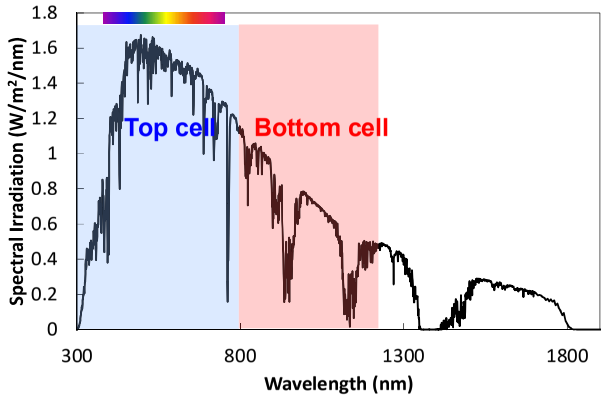
Outline

- Overview of solar photovoltaics: current status and perspectives
- High efficiency crystalline Si solar cells using Si heterojunction technology
- **Multi-junction solar cell (HJ & perovskite solar cells)**
- Summary

Multi-junction solar cell

Single-junction c-Si solar cell:
Theoretical limit: 29.4%
Practically achieved: 26.7%

Multi-junction solar cell

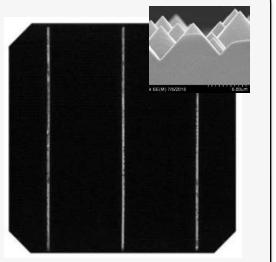


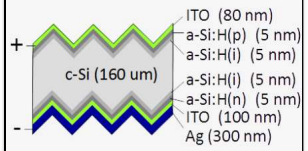
Multi-junction solar cell needed to increase efficiency
-> Optical management of solar spectrum

Monolithic perovskite/c-Si tandem

The Dreamology Company
—Make your dreams come true—

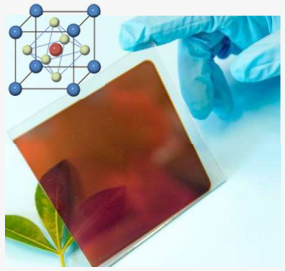
c-Si heterojunction

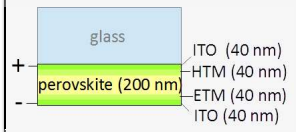




Demonstrated: η >26%

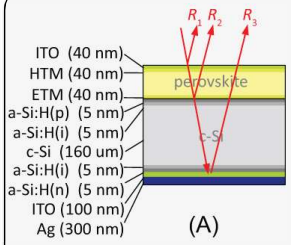
perovskite





Demonstrated: η >24%

Tandem



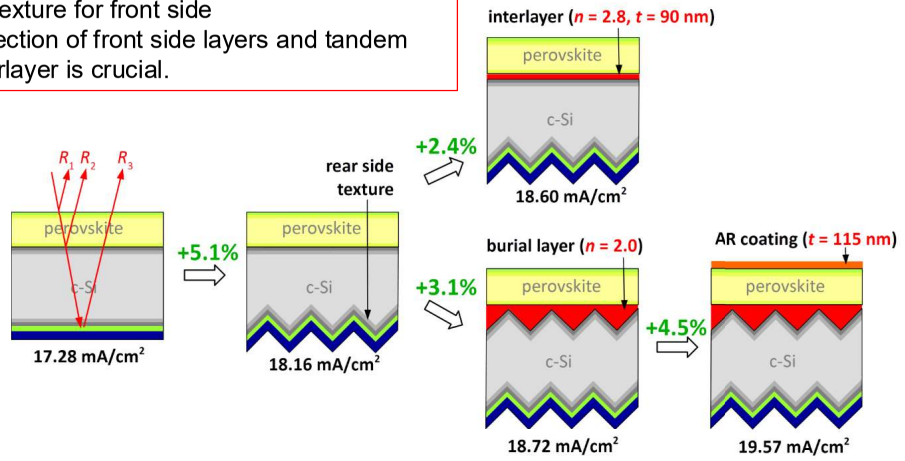
Perovskite sola cell on c-Si solar cell

Demonstrated: η = 28%
(Potentially η > 30%)

Approaches for high current; texturing and front-side optics

- Highest current can be obtained by pyramid texturing for both side
- Optical interlayer is effective in the case of no texture for front side
- Selection of front side layers and tandem interlayer is crucial.

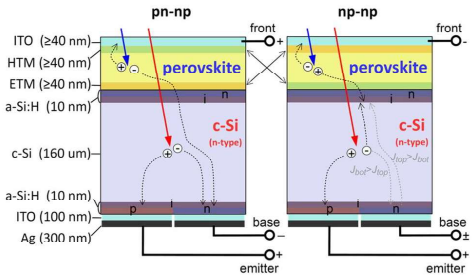
Two-terminal tandem



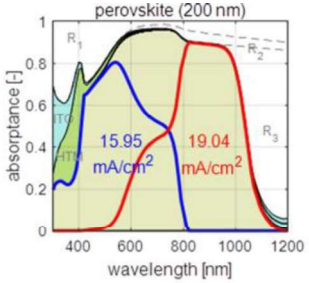
R. Santbergen, K. Yamamoto *et al.*, *Optics Express* **24**, A1288 (2016)

Back-contact/Perovskite 3-terminal tandem solar cell

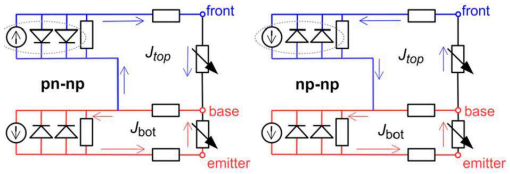
Cross-sectional image



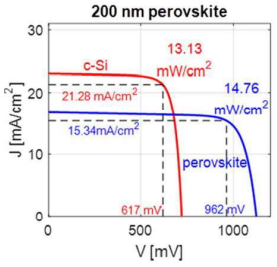
Optical simulation



Equivalent circuit



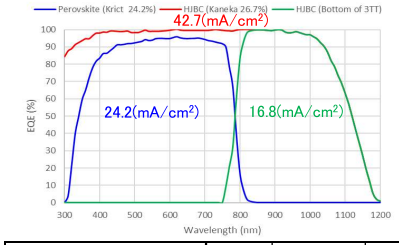
Electrical circuit simulation

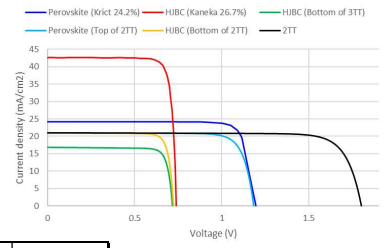


R. Santbergen, K. Yamamoto *et al.*, IEEE J. Photovoltaics 9, 446 (2019).

Possibility of over 35% efficiency

Simulation result under some assumptions is shown below.





cell		Voc(V)	Jsc(mA/cm2)	FF(%)	Eff(%)	
Single cell	Perovskite(Krict)	1.195	24.16	84.0	24.2	
	HJBC(Kaneka)	0.738	42.65	84.9	26.7	
2TT(概算)	Top/Bottom	1.800	21.00	78.1	**29.5**	
3TT(概算)	Top	1.195	24.16	84.0	24.2	**34.2**
	Bottom	0.716	16.78	83.4	10.0	

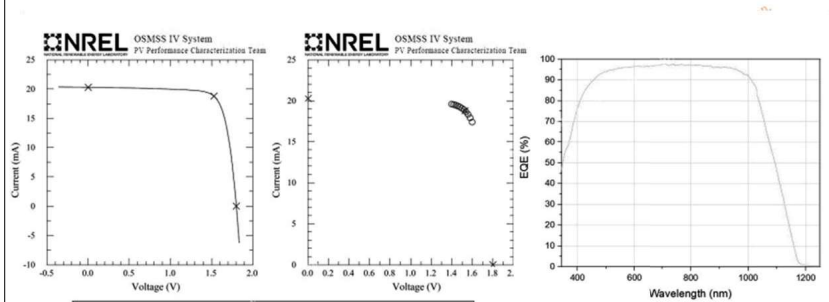
This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO.

The **over 35% efficiency** can be achievable with the 3TT cell which consists of highest efficiency perovskite cell and HJ-IBC cell.

1) M. A. Green *et al.*, "Solar cell efficiency tables (version 54)," Prog. Photovolt., Res. Appl., vol. 27, pp. 565–575, 2019.
2) M. A. Green *et al.*, "Solar cell efficiency tables (version 50)," Prog. Photovolt., Res. Appl., vol. 25, pp. 668–676, 2017.

Progress - 28% certified 1 cm² monolithic tandem

December 2018



V_{oc} = 1.8009 V ± 1.7%	I_{max} = 18.794 mA ± 1.3%
I_{sc} = 20.287 mA ± 1.3%	V_{max} = 1.5292 V ± 1.7%
J_{sc} = 19.767 mA/cm² ± 1.3%	P_{max} = 28.740 mW ± 2.0%
Fill Factor = 78.7 ± 0.7%	Efficiency = 28.00 ± 0.7%

OXFORD PV™ The Perovskite Company

*C.Case, Heterojunction and thin film solar cell forum (2019)

kaneka

The Dreamology Company
—Make your dreams come true—

SUMMARY

- PV market is growing rapidly in this 10 years. Further growth is expected. Currently, dominant solar cell structure is PERC cell with ~22%-efficiency.
- Efficiency of 25.1% reached for top/bottom contacted HJ solar cell
- World record efficiency for c-Si solar cell of 26.7% and module of 24.5% using back contact HJ solar cell
- Perovskite-HJ tandem structure is expected towards conversion efficiency > 30%. Cell structure candidate: 2-terminal, 3-terminal, 4-terminal
- Technology improvement for high-efficiency is a key to reduce the electricity cost of PV.

ACKNOWLEDGEMENT
This work was supported in part by the New Energy and Industrial Technology Development Organization (NEDO) under the Ministry of Economy, Trade and Industry of Japan.

TECH DAYS

INNOVATION FOR INDUSTRY

—

LITEN DAY

OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

TTHE ROAD FROM RECENT RECORDS TO THE PV INDUSTRY ADOPTION FOR COMPETITIVE LCOE & SMART INTEGRATION

CEA Tech Days | Anis JOUINI | CEO INES | 15/10/2019
| Head of Solar Technologies Department – CEA/LITEN

SOME INFORMATION ABOUT LITEN…

F. LAMBERT

SOLAR & GRIDS

ELECTROMOBILITY

THERMAL ENGINEERING H2 BIOMASS

ADVANCED MATERIALS STRUCTURAL ELECTRONICS

FIGURES 2018

975 EMPLOYEES
1 612 PATENTS *in the portfolio*
250 INDUSTRIAL PARTNERS
240 *patents/year*
BUDGET **138 M€**
RESEARCH CONTRACTS
40% *competitive public funding*
60% *industrial*
13 PLATFORMS

TARGETS

REDUCTION OF GREENHOUSE GAS EMISSIONS

ENERGY EFFICIENCY

ANCHORING IN A "CIRCULAR ECONOMY" APPROACH

INNOVATION FOR INDUSTRY ON THE COMPLETE VALUE CHAIN

From the heart of the French alps : 1h by car from Lyon or Geneva

A. JOUINI

Budget 45 M€, 400 E&T, 150 M€ Equipments, 80 Patents/Year

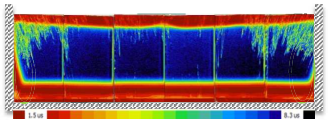
CHALLENGES FOR 2019 AND AFTERWARDS

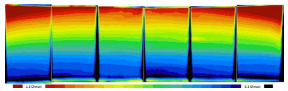
W_{peak} ↑ and W_{hour} ↑

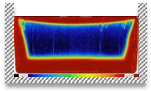
$C_{apacity}$ ↑ (200 GW) and C_{ost} ↓ (Btw 2-5 ¢$/kWh)

$S_{tandardization}$ (M2-M12…) and $S_{ustainability}$ ($...)

CM-SI KEY DATES







- Upscaling to G6
- Process optimization
- Wafer quality improvement

- Upscaling to G5
- Loading process optimization

- Furnace concept redesign
- Dislocation analysis/reduction
- Efficiency improvement through cell processes

- Design furnace optimization
- Seeding arrangement
- Process improvement

- Competitive LCOE
- Field data test
- Compatibility with n-type high efficiency cell processes

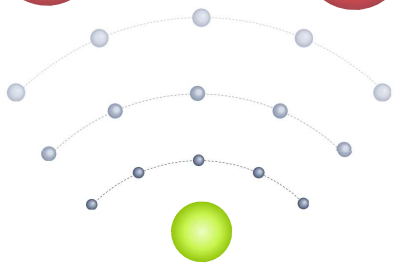
Gen2 | 2010
Proof of concept

Gen5 | 2012
Pilot Line 450 kg

Gen6 | 2014
Pilot Line 800 kg
Technology Transfer

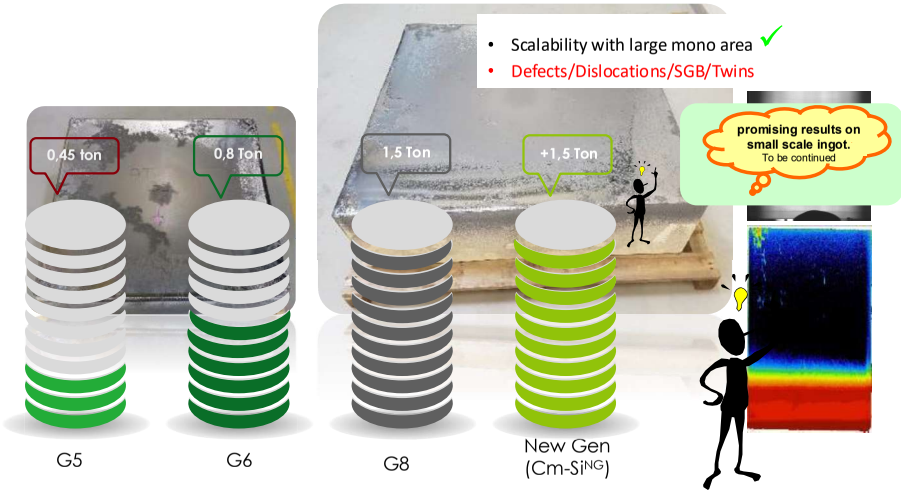
Gen8 | 2018
Pilot Line 1500 kg

2019-2020
Towards multi GW Ecosystem

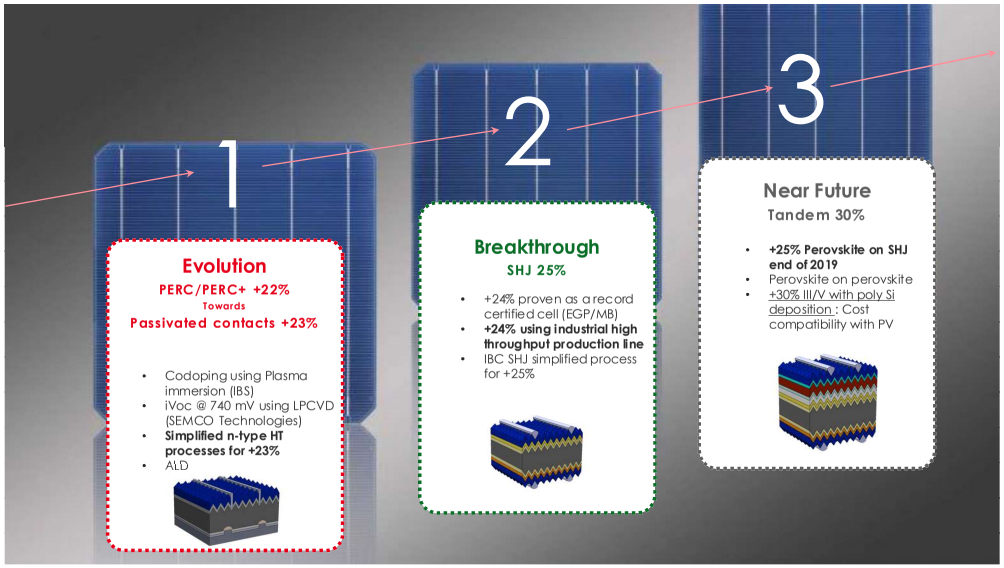


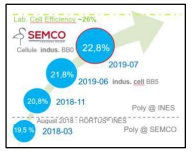
CM-SI^{NG} : QUALITY MATTERS

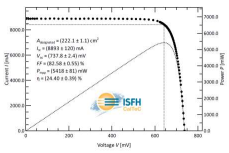
- Scalability with large mono area ✓
- Defects/Dislocations/SGB/Twins

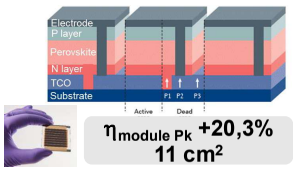


WAFER DEVELOPMENT = CAST MONO (MONOLIKE)









$\eta_{module\ Pk}$ +20,3%
11 cm²

PASSIVATED CONTACT BIFACIAL

- **DESCRIPTION**
  - Passivated contact technology using polycrystalline silicon layers deposited on ultra-thin oxide films
  - In the roadmap evolution of existing PERC manufacturer

- **KEY FIGURES**
  - **Record Efficiency 22.8% with industrial processes**
  - Efficiency potential of 26%
  - Compatible with all kinds of silicon wafers (n&p, Cz, cast mono, …)
  - Compatible with multi-junction devices (30% efficiency already obtained)

- **WHAT'S NEXT?**
  - Integration into multi-junction devices for efficiencies above 30%.

BIFACIAL HETEROJUNCTION SHJ @ 24.4%

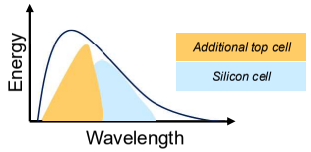
- **DESCRIPTION**
  - Silicon heterojunction solar cell (SHJ) based on n-type monocrystalline silicon wafer and amorphous silicon with busbar or busbarless metallization
  - A good solution for new comers or new facilities in the production of photovoltaic cells

- **KEY FIGURES**
  - CEA Record Efficiency **24.4% in production**
  - >90% of bifaciality without front efficiency loss
  - Stable efficiency down to 100µm wafer thickness

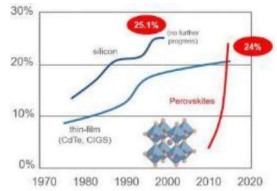
- **WHAT'S NEXT?**
  - Silicon heterojunction cells with efficiency 25%-26% and low carbon footprint and positive life cycle compatible with tandem integration to reach >30%

WHY PEROVSKITE/SILICON TANDEM TECHNOLOGY

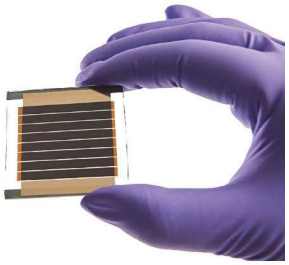
- **Most Si technologies are converging to their limit ~25%**
- **Tandem architectures are needed to absorb and convert more photons → increasing efficiencies >30%**
- **Direct and tunable bandgap Perovskite materials offer new opportunity for very high efficiency (theotical limit at 33% for single junction)**
- **Perovskite is a unique material and technology that reached:**
  - > 23% in single junction in 5 years time
  - > 27% in tandem in 3 years time
- **Perovskite is Low cost technology** (cheap material, lower cost equipment)



Perovskite - ABX_3



PEROVSKITE THIN FILM @ 20.3%



- **DESCRIPTION**
  - Thin film Photovoltaic module based on Perovski materials
  - Disruptive technology for Photovoltaic cells manufacturer

- **KEY FIGURES**
  - Record CEA Efficiency 20.3% / Active area 10 cm² / Geometrical Fill Factor > 93%
  - Performances >16.5 µW/cm² @ 200 Lux (low light illumination for indoor application)
  - Low temperature process & Low carbon footprint, lightweight, conformability

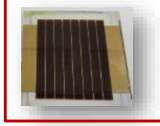
- **WHAT'S NEXT?**
  - Larger area (>240cm²) thin film perovskite modules with high performances > 20%

CEA'S EXPERTISE ON PEROVSKITE

- Expertise in Perovskite PV cells & Modules
- Expertise in Silicon Cells & Modules
- Best in class platforms:
  - Processes
  - Characterization
  - Monitoring
- Complete value chain

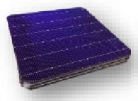
➔ Reduced time to industrialization

Perovskite technology

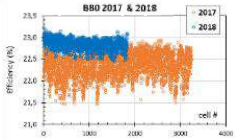


- High performance Perovskite cells and modules 16%
- Stability assessment by specific encapsulation materials
- Printing platform

Silicon technology

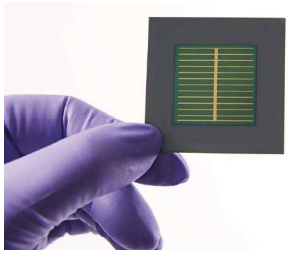


- High efficiency of HJT cells 23%
- High performance modules HJT 60 cells module > 330 Wc
- Certification according to IEC-61215 & 61730



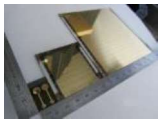
> 8000 cells on labfab equipment

TANDEM PEROVSKITE ON SILICON SHJ @ 20.17%



- **DESCRIPTION**
  - Photovoltaic cell in 2-terminal architecture based on perovskite and silicon heterojunction technologies
  - Disruptive technology compatible with existing SHJ manufacturer
- **KEY FIGURES**
  - Record CEA Efficiency 20.17% (without any shading, metallization to be optimized) / Active area 9cm²
  - Open circuit voltage 1.8 V
- **WHAT'S NEXT?**
  - Perovskite on silicon architecture should led to premium PV cells with very high efficiencies >30%

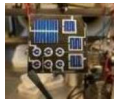
CEA'S ROADMAP TOWARDS TANDEM



Perovskite :
18%, 12 mm²
16% 10cm², 1000h 1SUN

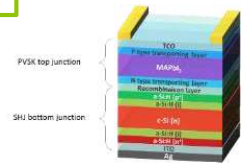
Silicon technologies :
HMJ 21%
HJT 23%

2018



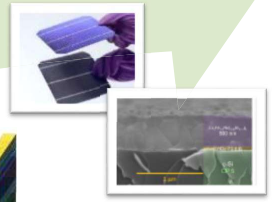
Tandem Si/PK :
> 25%, 25 cm²
Module BOM development

Tandem Si/PK :
> 27%, 243 cm²
Modules IEC qualification



2020

Tandem Si/PK :
Cells > 30%, 243 cm²
Modules: P > 500W – 72 cells
Qualification = 3xIEC



2024

PV CELLS RECORD RESULTS !

Passivated contacts bifacial

Record Efficiency

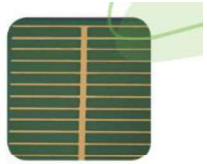
- **22.8%**
- with industrial processes

Bifacial heterojunction (SHJ)

- **24.4%**
- in production

Perovskite thin film

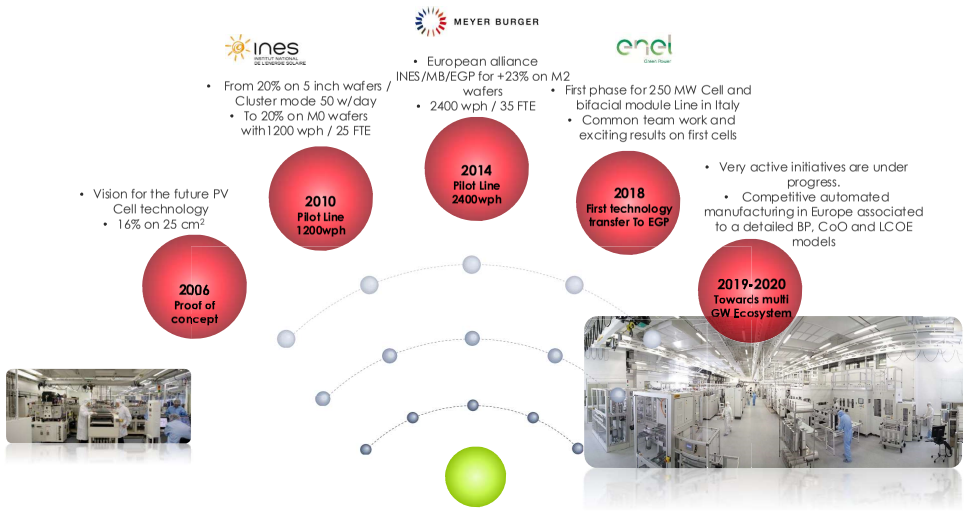
- **20.3%**
- Active area 10 cm² / Geometrical Fill Factor > 93%



Tandem perovskite on silicon SHJ

- **20.17%**
- without any shading, metallization to be optimized / Active area 9cm²

FOCUS ON SHJ KEY DATES

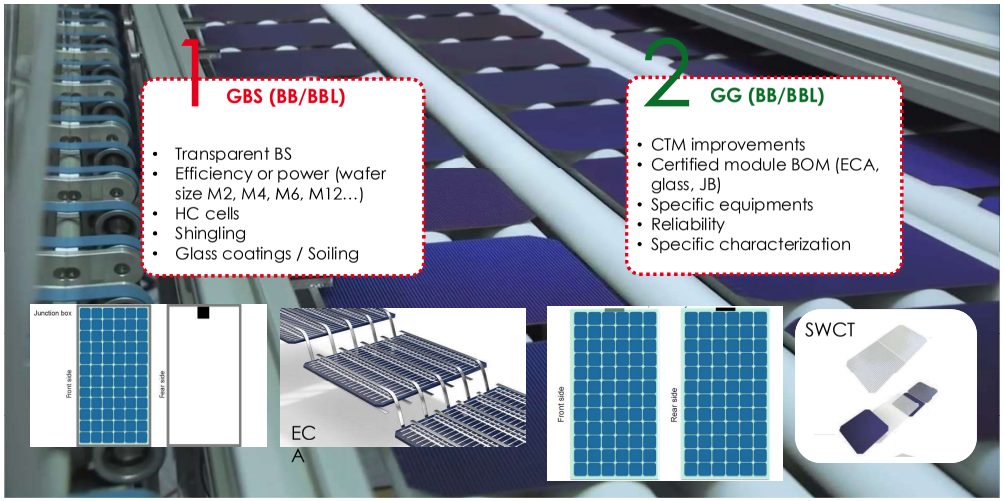


CEA/LITEN-INES

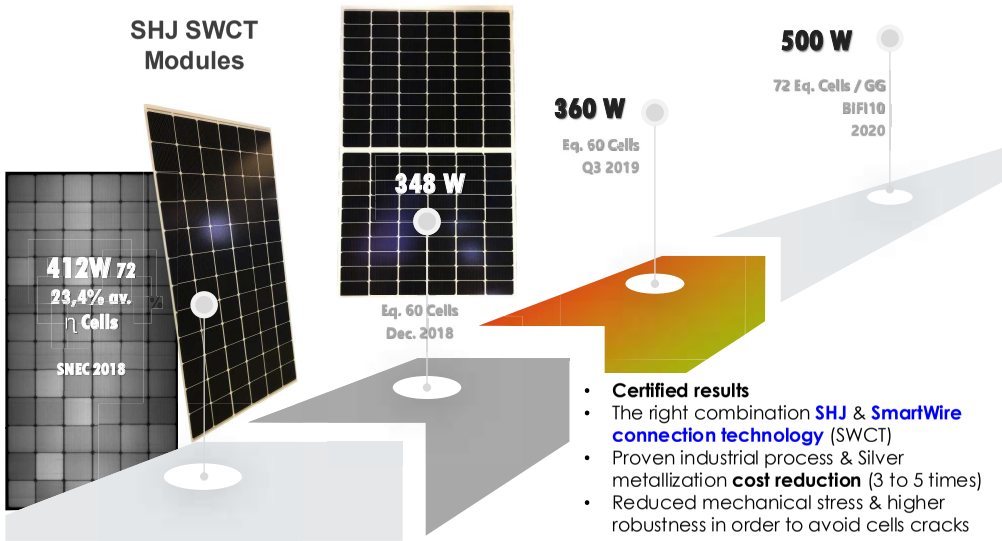
The European R&D center of reference for PV SHJ and Tandem development : Lets join forces

PV MODULES CHANGING THE GAME

SHJ Moduling : for simple integration



SHJ MODULES TOWARDS 500 W



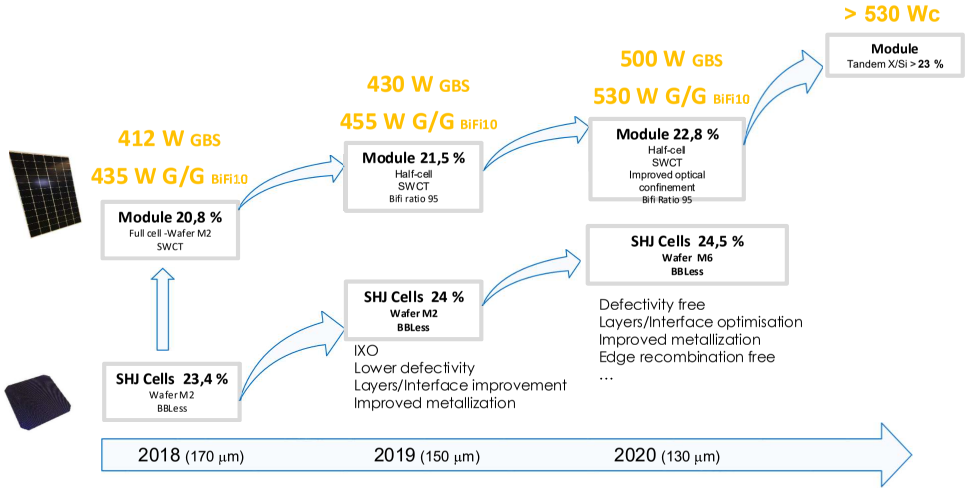
- **Certified results**
- The right combination **SHJ** & **SmartWire connection technology** (SWCT)
- Proven industrial process & Silver metallization **cost reduction** (3 to 5 times)
- Reduced mechanical stress & higher robustness in order to avoid cells cracks

enel MEYER BURGER

CHALLENGING ROADMAP BEYOND IRTPV

SHJ : Our Roadmap Towards 24.5% and 500 W

(associated to an accurate economic modelling BP, CoO, LCOE...)



PV SOLAR CELLS INNOVATIVE TECHNOLOGIES A NICE BRIDGE FOR LOWER LCOE PV INSTALLATIONS

❶ HJT technology combines several key benefits for a new European eco-system

1. Power potential well above announced public roadmaps
2. Improved energy yield due to T coefficient and bifaciality
3. Adapted to thin wafer leading to cost reduction and LCA benefit

❷ ENEL GREEN POWER-3SUN
PANASONIC-GS SOLAR
PANASONIC-TESLA
HEVEL SOLAR
ECOSOLIFER
JINERGY
REC
CIE
...

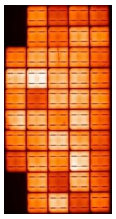
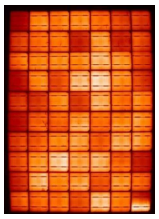
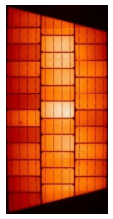
❸ Industrialization of HJT technology at GW scale associated to a development Roadmap towards Tandem for 30% and Collecting additional data regarding SHJ production yield benefits at the MW scale including new features like tracking, cleaning...

VIPV INTEGRATION C-ZEN CAR

Final integration on the C-Zen car

VIPV INTEGRATION C-ZEN CAR

Electrical and imaging characterization

	Back Roof	Front Roof	Hood
Electroluminescence			
Power STC	54 W	85 W	73 W

- Total peak power: > 210 Wp STC.
- Active area: 1,3 m²

⇒ Global efficiency: 16 %

⇒ Estimated PV gain: > 1 600 km / year in Chambéry[1]

[1]Static estimation based on PVGIS 5 simulation tool, including all losses

LIGHTWEIGHT AND FLEXIBLE PANELS

- Flight design including all electrical and mechanical interfaces (4 EQMs realized):

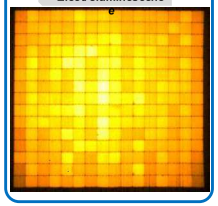
Standard lamination process

240 IBC cells
240 by-pass diodes
4,2 m²

822 Wc (STC) => η = 19,1%
960 Wc (calculated AM0; 40°C)

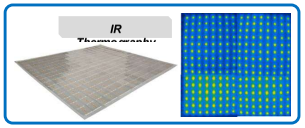
Performances (AM0; 40°C; BOL)	Objective	EQMs
Mass (g/m²)	<800	790
W/m²	>220	228
W/kg	>275	288

Electroluminescenc

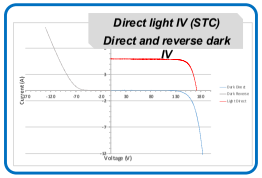


Glued mechanical and electrical interfaces

IR



Direct light IV (STC)
Direct and reverse dark IV



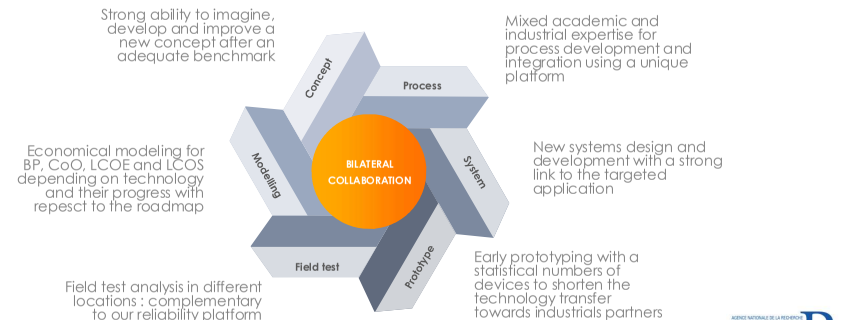
STRATOBUS : NEXT STEPS

- Successful development of a specific module designed for the Stratobus™ airship:
  - Lightweight **<800 gm/m²**
  - High efficiency **>220 W/m² (AM0; 40°C)**
  - Large scale **>4m²** with 1 by-pass diode per cell.
  - Integrated electrical and mechanical interfaces.
  - Terrestrial and low cost fabrication processes.
  - Resistance to stratospheric conditions: temperature, UV, Ozone, wind….

- PVA EQMs flight tests scheduled in 2020 on a small scale airship.
- Further developments will focus on the PVA/envelop interface.
- Integration of this technology on the Stratobus™ PFM for its first flight in 2022/2023.

Our rich eco system with more than 100 industrial partners
AND YOU ?

VALUE CHAIN INTEGRATED OFFER



KEEP IN MIND

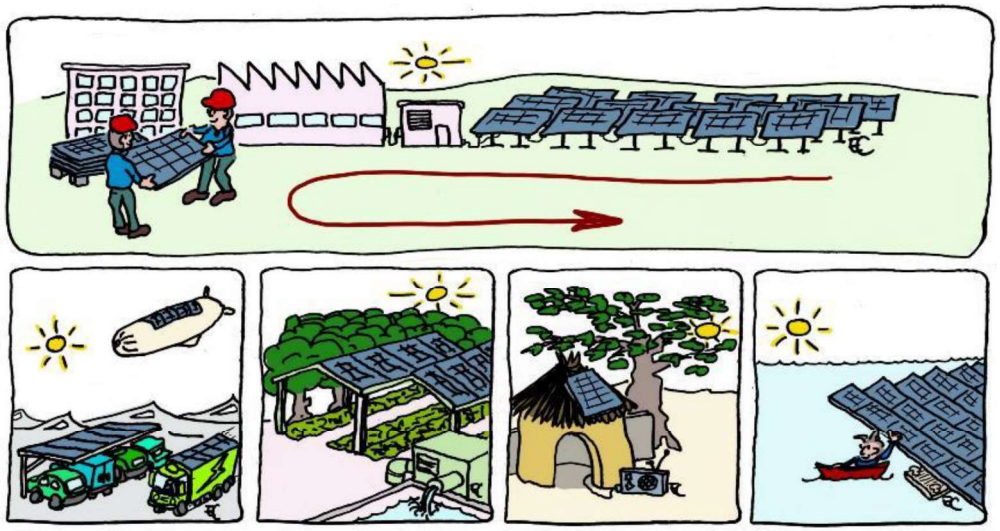
500 W, 72 Cells Modules by 2020
Light, Flexible and Colorful

200 GW Annual Capacity by 2023

kWh

Stars are aligned to bring the missing peace back : standard, sustainable and competitive worldwide SHJ PV manufacturing

SOLAR FOR ALL, EVERYWHERE AND FOREVER



Honda's Approach towards Sustainable and Carbon Free Mobility with Electrification

Honda R&D Co., Ltd. Automobile Center

Eisuke Kimura

15th October, 2019

Encounting Issues and challenge for Automotive Industry

Electrification R&D is key to challenge to the future for automotive industry

Global warming Urban air pollution

Reducing GHG and pollutant emission

Energy & resource issue

Defossilization / Sustainable energy development

Traffic accident

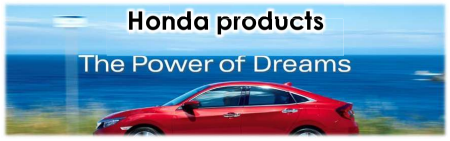
ADAS Autonomous

Connected
Autonomous
Service
Electric + "energy"

Honda Vision for 2030

Serve people worldwide with the "joy of expanding their life's potential"

- Lead the advancement of mobility and enable people everywhere in the world to improve their daily lives -



Motorcycle

Automobile

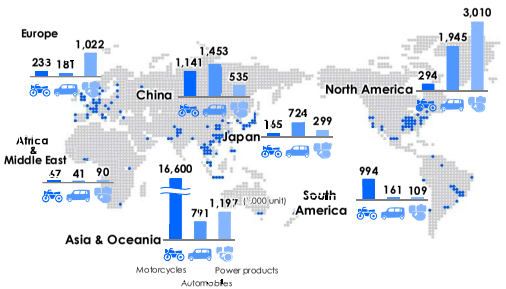
Marine

Power products

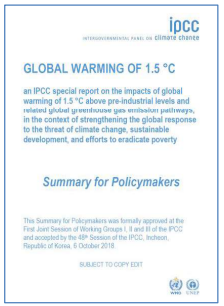
Honda Jet/Aircraft engine

Robotics

Global unit sales (Motorcycles・Automobiles・Power products) **32 mil. units**



Global requirement of GHG Reduction for Climate Change Mitigation

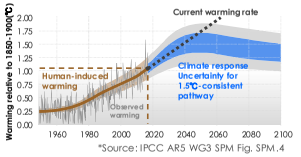


IPCC CO2 reduction target

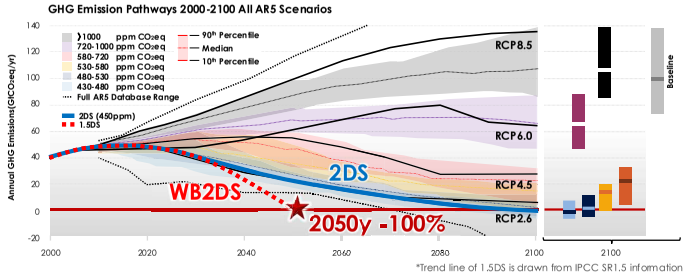
2DS Scenario

Go shifting to **WB2DS**

※WB2DS=Well Below 2 Degree Scenario
(Scenario to hold increase in global temperature to well below 2° C)



*Source: IPCC AR5 WG3 SPM Fig. SPM.4

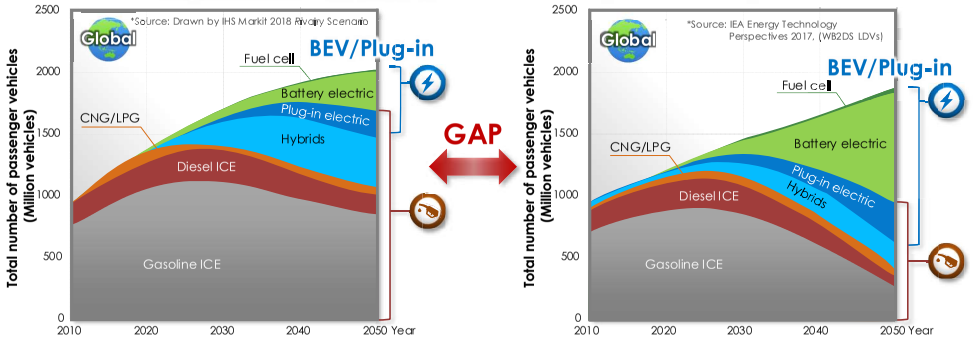


*Trend line of 1.5DS is drawn from IPCC SR1.5 information

To Hold Increase in Global Temperature to Well Below 2°C

HONDA The Power of Dreams

The expansion of use of BEV/PHEVs necessary for the realization of the environmental requirements scenario, but far from acceptable to the public



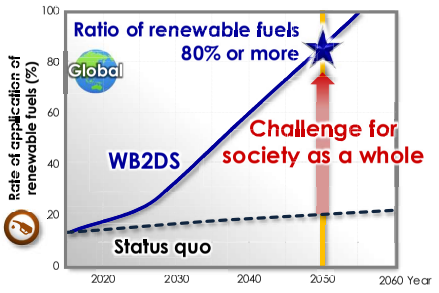
Standard scenario:
Technological progress and social change
<IHS Markit Rivalry Scenario>

BEV/PHEV-based environmental requirements scenario
<IEA : WB2DS>

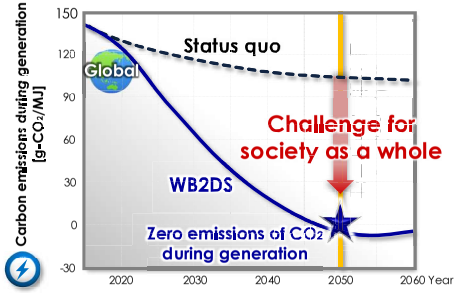
To Hold Increase in Global Temperature to Well Below 2°C

HONDA The Power of Dreams

The realization of WB2DS is a high hurdle no matter the scenario



Necessary ratio of renewable fuels for achievement of WB2DS in standard scenario



Necessary reduction in CO_2 emissions for achievement of WB2DS in BEV/PHEV-based environmental requirement scenario

*Source: This analysis is based on the Mobility model developed by the International Energy Agency, ©OECA/IEA2017, but the resulting analysis has been prepared by Honda and does not necessarily reflect the views of the International Energy Agency

Honda's approach : "Multi-Pathways" for Society Challenges

HONDA The Power of Dreams

Scenario 1 **Electrified Mobility Society (BEV)**

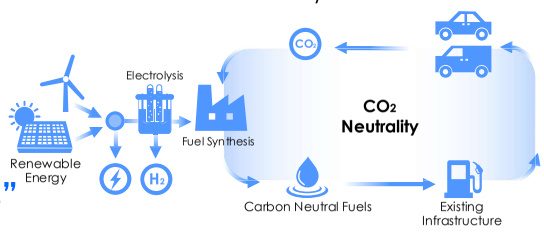
→ Significant rapid transformation of the social structure
(Charging infrastructure, Sharing, Shift to public transport, MaaS)

Scenario 2 **Mobility Society by utilizing renewable energy**

→ Enhancing usage of Biofuel, e-fuel, hydrogen, and others
(Challenge to secure enough production amount to meet demand)

Scenario 3

Mixed scenario of "1" and " 2"

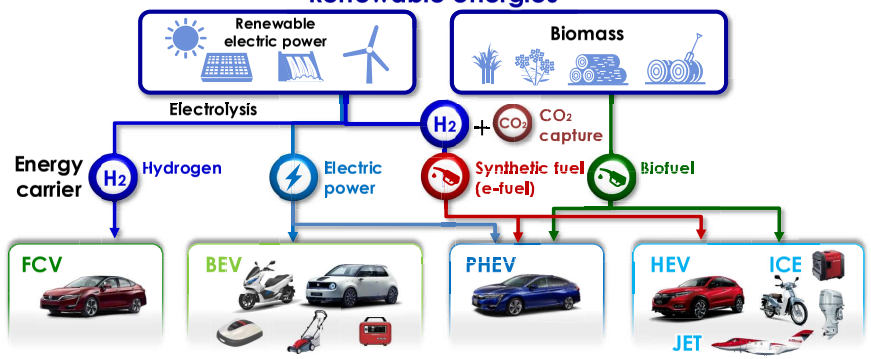


Honda draws "Multi-Pathways"
with various renewable energy carriers
to provide carbon-free mobility to all customers for sustainable society

Maximizing Use of Renewable Energy with Electrified Power Unit

HONDA The Power of Dreams

"Connect electrified powertrain product with renewable energy carriers"



Right product (power unit) in the Right place for the Right application by providing the Right energy carrier

Key Points for the Designing Multi-pathways*

prepare and map the right power units for each application,
from the perspectives of the different people, societies and energy in each region.

Energy policy / Regional characteristics	Mobility Sector/ Power Density & Package	Characteristics and roles of power units	Customer preferences and Use Case
Coal Nuclear Wind Solar Water Biomass	Ship Aviation Automobiles Motorcycles Power Products	Long drive / City USE BEV base ICE base HEV base FC base	1st CAR / 2nd CAR Top speed / Towing Comfort / Sport

* Multi-pathways = a concept to maximize the usage of renewable energy not only by direct use of electricity, but also by conversion use to fuels such as hydrogen or e-fuel

Energy: Regional Characteristics

Preparation of Powertrain MIX suiting regional energy characteristics

EU
- Leads world in CO_2 reduction policy
- Policies promoting use of renewable energies

HEV PHEV BEV FCV

China
- Policies promoting expansion of NEVs strongly
- Reduce oil import dependency
- Coal remains as main source, while NG and RE expands

HEV PHEV BEV

US
- High ratio of large vehicles whose electrification is difficult
- Strict ZEV/GHG regulations in California

ICE HEV PHEV BEV FCV

India
- Reduction of environmental pollution by electrification
- Policy of overcoming dependence on crude oil imports

HEV Motor cycle

Japan
- Diverse sources for generation of primary energy
- Government aiming towards hydrogen-based society

HEV BEV FCV

Thailand
- Inducement towards use of alcohol fuels (E85)
- Incentive for use of hybrid technologies

E85 HEV

Brazi
- Inducement towards use of alcohol fuels (E100)
- Sufficient electricity generated from renewable energy

FFV

Energy Policy / Regional characteristics

Main sources for generation of primary energy

Power Source in Various Products vs. Renewable Fuels

Power units to provide suitable energy carriers for each of sectors

Sector	Automobiles	Motorcycles	Aircraft	Power products
Mobility	City type / Long-distance	Commuter / Tool for daily life		
Energy carrier				
Characteristics	➢ Battery EV could be used. ➢ Necessary to select energy carriers with consideration of use scenarios (distances traveled, use for towing, etc.) and status of establishment of charging infrastructure	➢ Battery EV could be used as short-distance commuters ➢ Based on considerations of driving distance and cost, liquid fuel will be the main focus for motorcycles and scooters used as tools for daily life in developing countries	➢ Liquid fuel is essential for jets, for which maximum energy density is demanded ➢ CO_2 reductions are expected through the use of renewable fuels	➢ Small products could be electrified ➢ Liquid fuel is necessary for high-power products and emergency power supplies

Mobility Sector/ Power Density & Package

Right Electrified Powertrain Type in the Right Place

Transportation between Cities/Rural regions
(LONG drive, Journey to resort region)

FHEV ICE

FCV

FC Truck/Bus

Last One Mile Mobility

74Mil/y world sales@2025
including 1.7Mil/y of E-motorcycle
*Forecasted by Yano Research Institute Ltd.

PHEV
EV Drive In the city

Near Zero EM

BEV
(Long range between cities and in city driving)

Motorcycle
(Rural/Long drive at developing countries)

Commuter E-Motorcycle

ICE drive prohibited

Commuter BEV
In city commuter
(No Emission / Short range drive)

Carbon Free Mobility

Characteristics and roles of power units

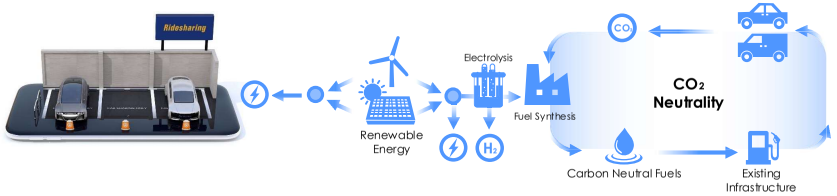
Customers' Preference & Use Case

Realizing Multi-pathways

HONDA The Power of Dreams

Electrified mobility society

Mobility society by utilizing renewable fuel



- Challenge for society as a whole

Invest to renewable energy infrastructure

Cooperation with energy sector

- Challenge for Honda

Provide electrified power units

Honda Environmental Initiatives

HONDA The Power of Dreams

We will continue meeting the demand for
"the joy and freedom of mobility"
For that purpose, we will realize
"sustainable ways of life"

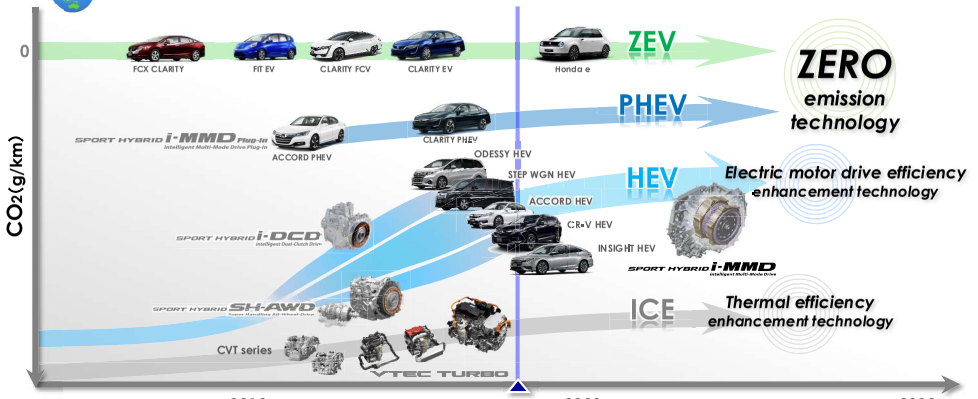
"Zero environmental impact society"

Environmental Vehicle Initiatives at Honda for Worldwide

HONDA The Power of Dreams

Focus our efforts on further enhancing HEV performance as well as on PHEV and zero emission vehicles

Global



ZERO *emission technology*

Electric motor drive efficiency enhancement technology

Thermal efficiency enhancement technology

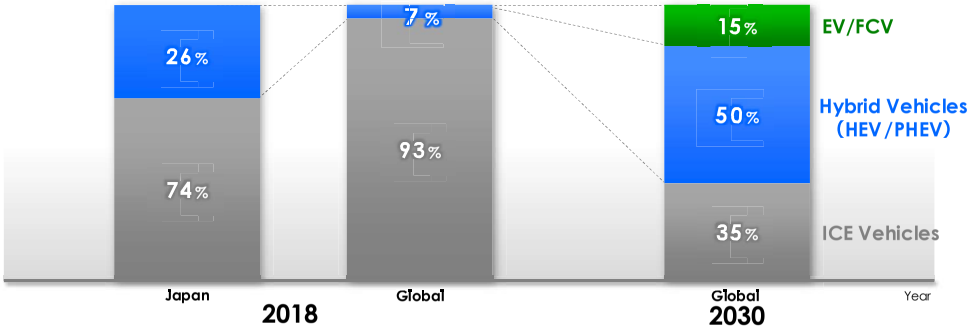
Honda's Electrification Initiatives of Automobile

HONDA The Power of Dreams

Moving towards electrification rate of two-thirds or greater in 2030

Global

- Battery electric vehicle (BEV) and fuel cell vehicle (FCV) make up: **15%**
- HEV and PHEV are main factors: **50%**



Honda i-MMD System: Provide with "Enjoy the Drive"

HONDA The Power of Dreams

Sophisticated and light driving feel with motor drive

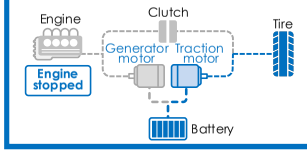
Light acceleration and response by high power motor

Enjoy the Drive

Series Hybrid

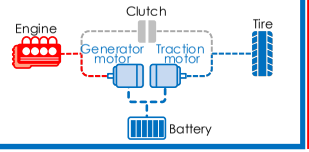
EV DRIVE

Operates as an EV when driving in urban areas



HYBRID DRIVE

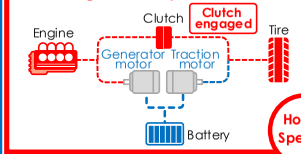
Realizes strong acceleration by driving the generator motor using engine power



Parallel Hybrid

ENGINE DRIVE

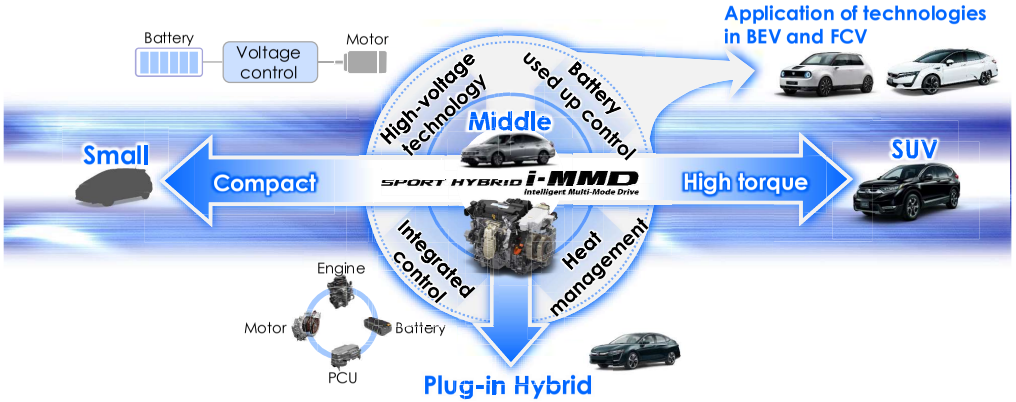
During high-speed cruising, the engine directly drives the tires



Expanded Deployment of the i-MMD System

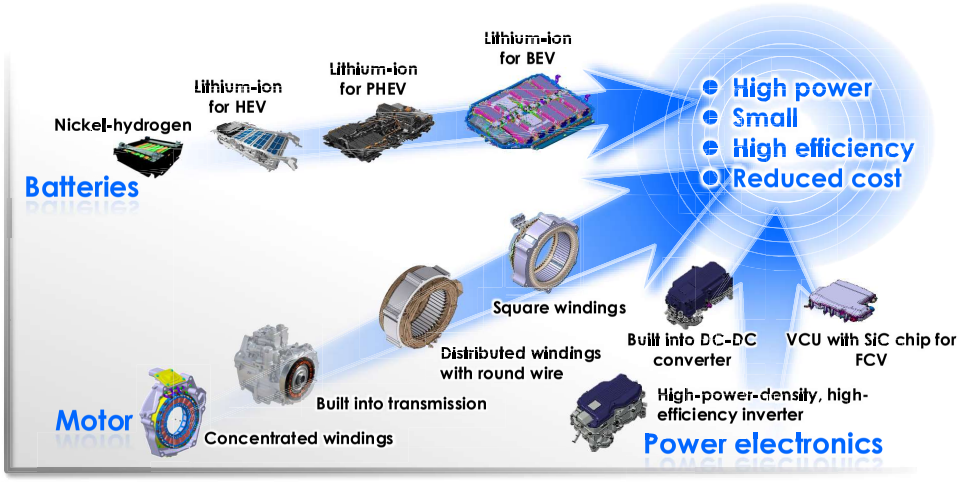
HONDA The Power of Dreams

- ✓ **Model expansion of i-MMD system, compatible both for HEV and PHEV**
- ✓ **Key electrification technologies applied in BEV and FCV**



Evolution of Electrified Components

HONDA The Power of Dreams



Deployment of BEV

HONDA The Power of Dreams

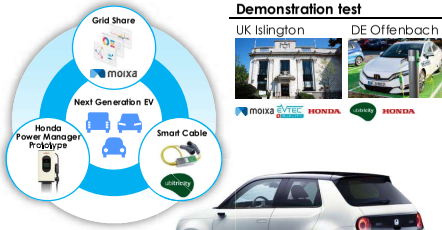
Honda e and Energy Management Business

Honda e : SOP in 2020 for Europe & Japan

- Complete electrification in Europe by 2025
- Develop energy management business in Europe by 2025

The integrated concept for a carbon free society

Honda Energy Management Project



Demonstration test

UK Islington

DE Offenbach

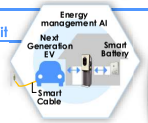
moixa EVTEC HONDA HONDA

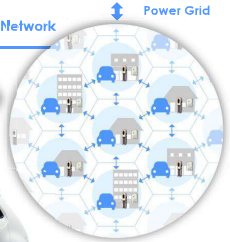
Honda's energy management

Honda Energy Service Platform

Energy Management Network

Smart Unit





Honda Fuel Cell Vehicle History

2002

- World's first FCV for commercial use (U.S.-certified)

2003 FCX

- Operation (starts) in sub-zero temperatures
- World's first FCV leased to individual customers

2005 FCX

2008

- Leased to individual customers (U.S. and Japan)

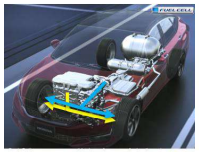
FCX Clarity

2016

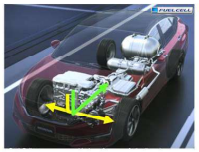
CLARITY FUEL CELL

Development of H_2 infrastructure

Clarity Fuel Cell : Packaging & Energy Management and Range



Acceleration (FC power+Battery)



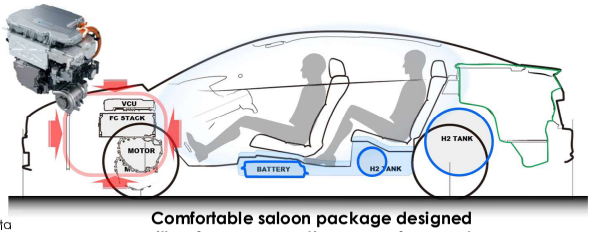
Cruising (FC power only)

Deceleration (Battery recharge by regeneration)

Idling (Battery recharge by FC power)

Driving range per charge

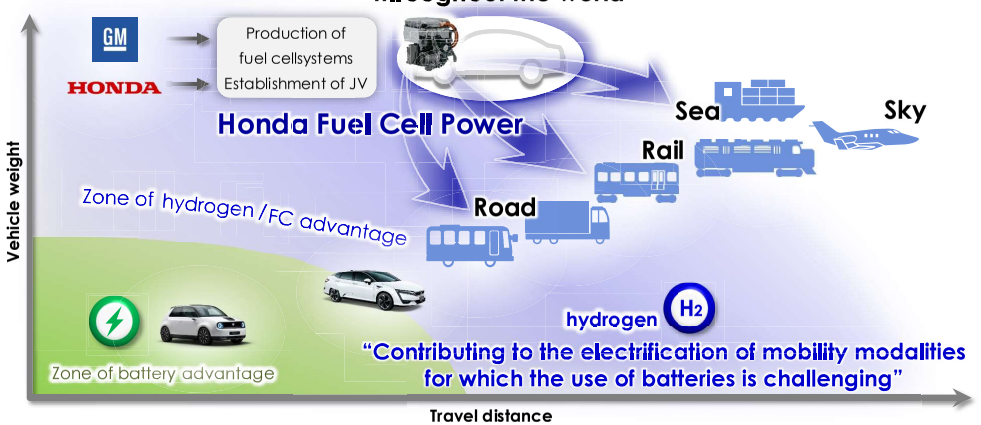
Approx.*650km *Honda internal data based on NEDC consumption



Comfortable saloon package designed with a focus on creating space for people

Fuel Cell System Application Road Map

Building a new ecosystem together and delivering joy to customers throughout the world



Honda Mobile Power Pack

HONDA The Power of Dreams

Use the standardized battery pack as an exchangeable power source to resolve charging issues

Generate
electricity using natural energy
Renewable Energy
"Local Production for Local Consumption" makes use of energy that can be harvested at that location

Use
electricity for compact mobility, household appliances, and so on
Honda Mobile Power Pack
Mobile Power Pack with electric-powered mobility = Travel by clean energy

Get Connected
with electricity anytime, anywhere
Honda Mobile Power Pack Exchanger Concept
You can exchange it right away, without waiting, when you need it and where you need it


Mobile Power Pack Exchanger Concept


Field test at Miyakojima @ Japan

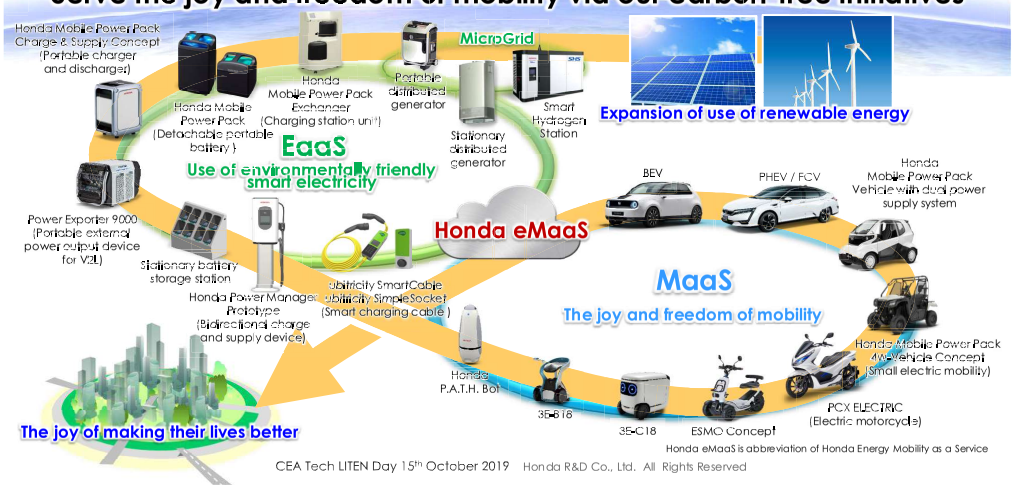
Honda Mobile Power Pack Charge & Supply Concept
You can use electricity when you need it and where you need it, without having to worry about power outages


Mobile Power Pack Charge and Supply Expandable Concept

Honda's ideal future mobility

HONDA The Power of Dreams

Serve the joy and freedom of mobility via our carbon-free initiatives



Honda eMaaS is abbreviation of Honda Energy Mobility as a Service

HONDA
The Power of Dreams

TECH DAYS

INNOVATION FOR INDUSTRY

—

LITEN DAY

OCTOBER 15, 2019

KEIO PLAZA HOTEL, TOKYO

BATTERIES & FUEL CELLS: BENCHMARK, CHARACTERIZATION, MULTI-SCALE MODELING FOR IMPROVEMENT OF PERFORMANCE, DURABILITY AND SAFETY

CEA Tech Days | Didier Jamet | 15/10/2019

OBJECTIVES & APPROACH

General objectives

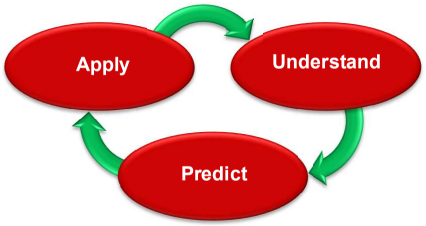
- Improve the technologies
- Provide the best of the existing technologies to the applications

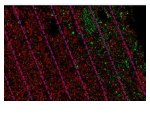
Performance

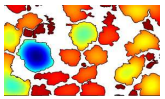
Durability

Safety

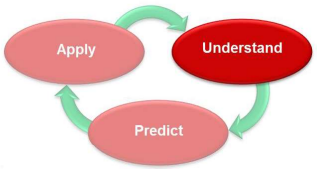
General approach







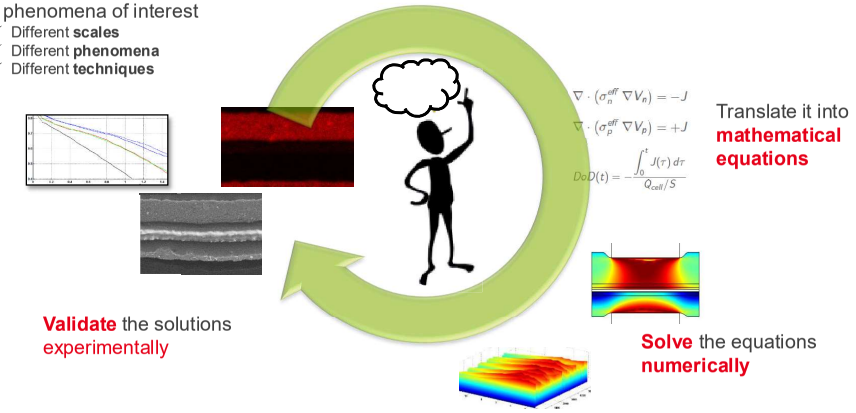
GENERAL APPROACH



Observe experimentally the phenomena of interest

- ✓ Different **scales**
- ✓ Different **phenomena**
- ✓ Different **techniques**

Construct a **mental representation** of what happens



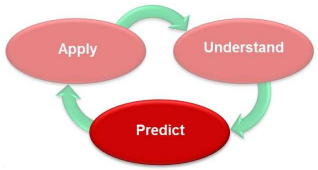
Translate it into **mathematical equations**

Validate the solutions experimentally

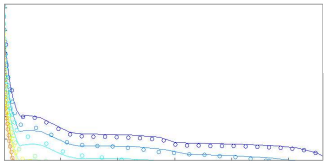
Solve the equations **numerically**

Consolidate our knowledge and **expertise**
Get **predictive models**

GENERAL APPROACH



Known conditions

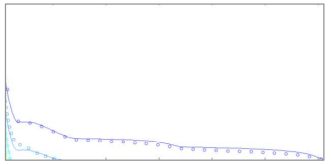


Predictive model

$\nabla \cdot (\sigma_n^{eff} \nabla V_n) = -J$

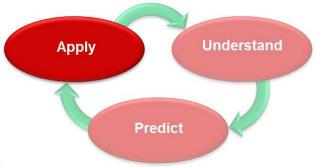
$\nabla \cdot (\sigma_p^{eff} \nabla V_p) = +J$

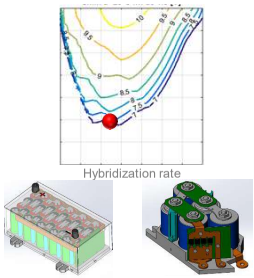
Unknown conditions of interest



Get the response of a system in **unknown conditions**
Accelerate the developments

GENERAL APPROACH

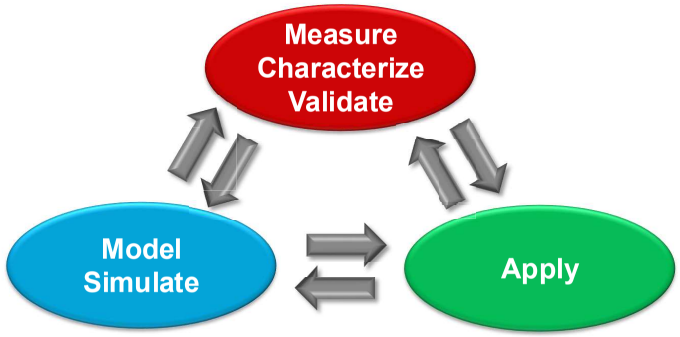


Problem to be solved	Study of several possible solutions through modeling / simulation	Development of the real system & validation of the solution
Example Design an optimal battery / supercapacitor hybrid system		

Assess more possible conditions
Optimize the solution

A MULTI-SCALE AND MULTI-PHYSICS CHARACTERIZATION AND SIMULATION PLATFORM

3 main pillars



EXPERIMENTAL CHARACTERIZATION

Performance evaluation

- ✓ Of all the electro-chemical storage technologies
- ✓ With client-specific experimental protocols
- ✓ With standardized experimental protocols for inter-comparison purposes
- ✓ Put into perspective into a CEA-LITEN data base
- ✓ Added value thanks to advanced analyses and modeling

EXPERIMENTAL CHARACTERIZATION

- **Battery test platform**

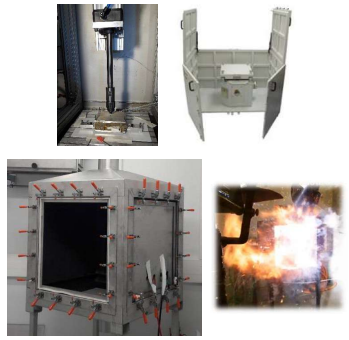
Performance

~700 test lines dedicated to Li-ion batteries

- ✓ *From cells to large-scale battery packs*
- ✓ *Performance at BoL*
- ✓ *Ageing: calendar & cycling*

Durability

Safety



All types of abusive tests on any energy battery

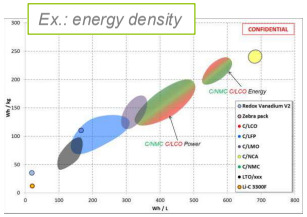
- ✓ *Mechanical*
- ✓ *Electrical*
- ✓ *Thermal*

EXPERIMENTAL CHARACTERIZATION

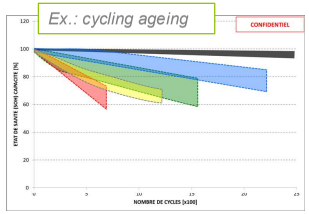
- **Battery data base**

Performance **Durability** **Safety**

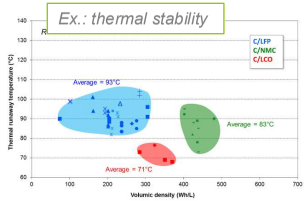
Ex.: energy density



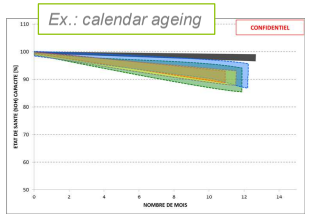
Ex.: cycling ageing



Ex.: thermal stability



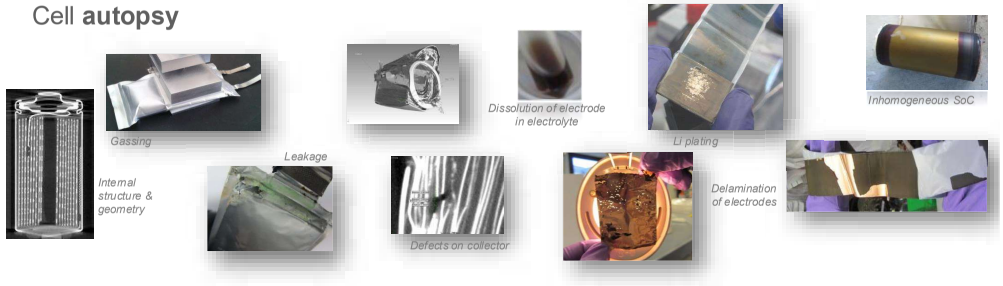
Ex.: calendar ageing



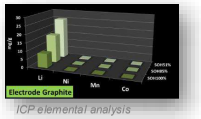
EXPERIMENTAL CHARACTERIZATION

- **Battery advanced analyses**

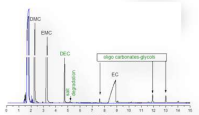
Cell **autopsy**



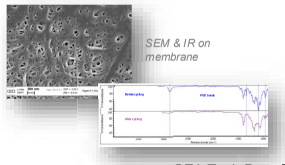
Physico-chemical and electrochemical analyses of **internal components**



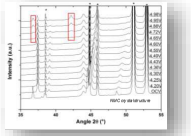
ICP elemental analysis



GCMS on volatile electrolyte products



SEM & IR on membrane

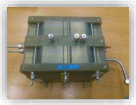


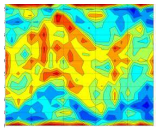
In-situ XRD in overcharge test

EXPERIMENTAL CHARACTERIZATION

- **PEM Fuel Cells**

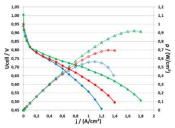
Performance **Durability**





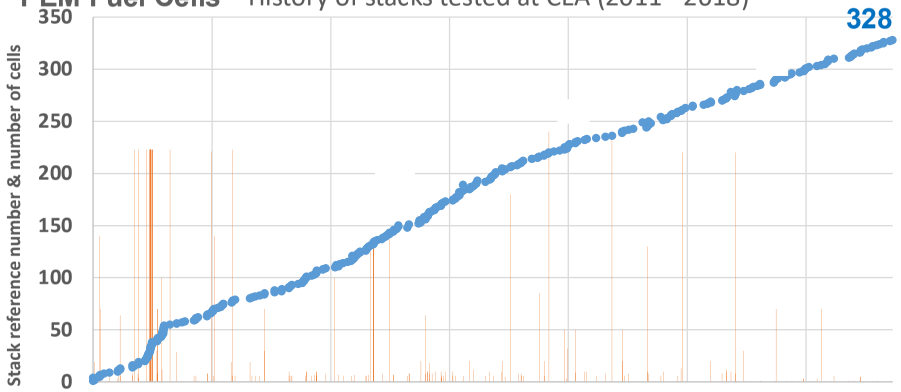
~20 test benches from 0.1 to 100 kW

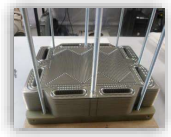
- ✓ *Performance at BoL*
- ✓ *Durability tests*
- ✓ *Advanced characterizations*



EXPERIMENTAL CHARACTERIZATION

- **PEM Fuel Cells** History of stacks tested at CEA (2011 - 2018)

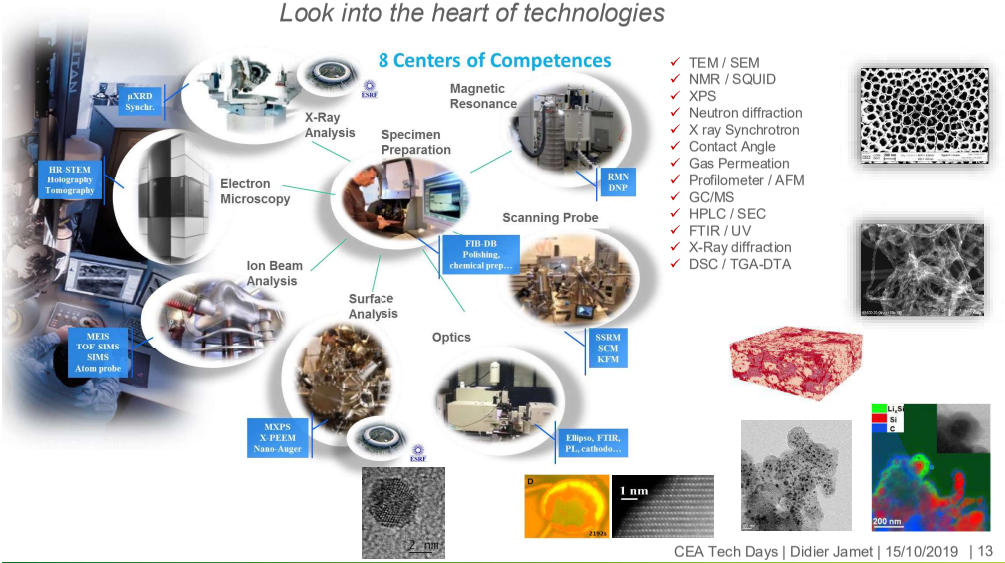




EXPERIMENTAL CHARACTERIZATION

- **Nano-characterization platform: cutting-edge capabilities**

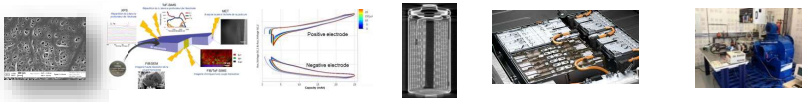
Look into the heart of technologies



- ✓ TEM / SEM
- ✓ NMR / SQUID
- ✓ XPS
- ✓ Neutron diffraction
- ✓ X ray Synchrotron
- ✓ Contact Angle
- ✓ Gas Permeation
- ✓ Profilometer / AFM
- ✓ GC/MS
- ✓ HPLC / SEC
- ✓ FTIR / UV
- ✓ X-Ray diffraction
- ✓ DSC / TGA-DTA

SIMULATION PLATFORM

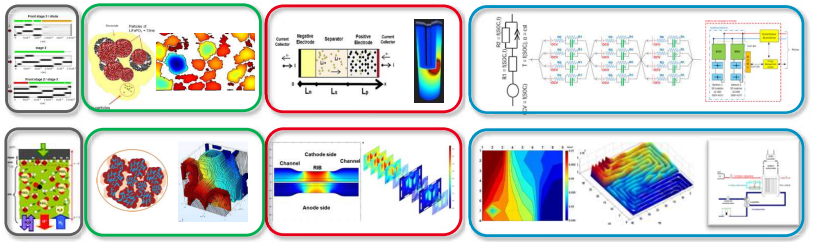
Battery
Experimental characterization platform



Strong and close coupling

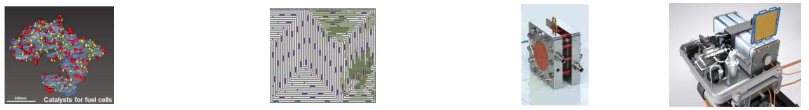
MUSES

Simulation platform



Strong and close coupling

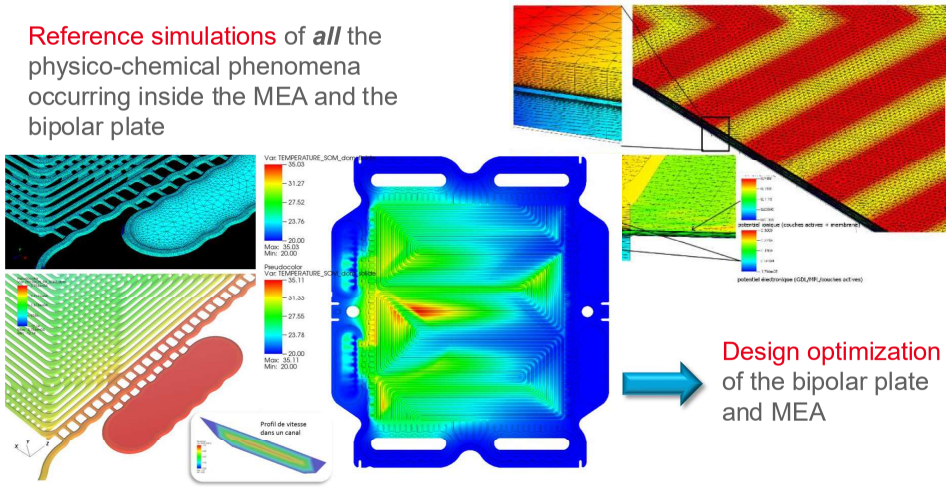
PEMFC
Experimental characterization platform



EXAMPLES OF APPLICATIONS

- **Technology improvement**

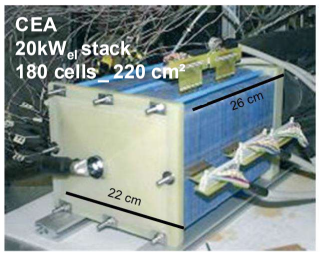
Reference simulations of ***all*** the physico-chemical phenomena occurring inside the MEA and the bipolar plate

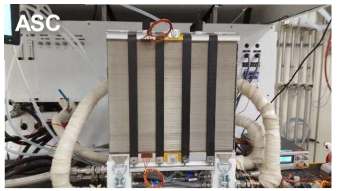


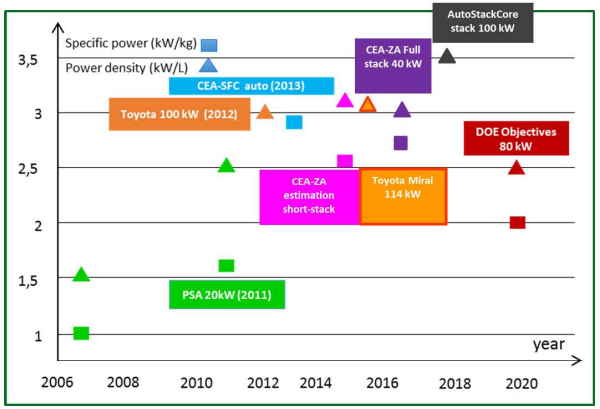
Design optimization of the bipolar plate and MEA

EXPERIMENTAL CHARACTERIZATION

- **PEM Fuel Cells**







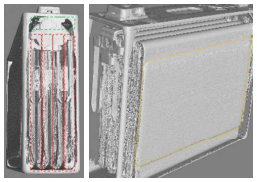
- ✓Optimisation of MEA performances
- ✓Optimisation of bipolar plates performances
- ✓Decrease of the mass and volume of bipolar plates

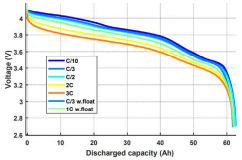
EXAMPLES OF APPLICATIONS

- **Solution optimization**

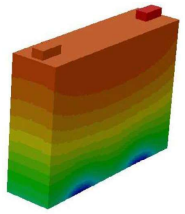
Given a cell, optimize the battery pack architecture and thermal management to increase its life time

1. Electro-thermal characterization of the cell





2. Detailed electro-thermal model of the cell

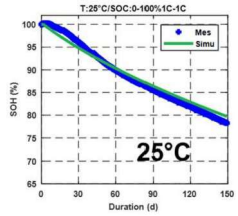


EXAMPLES OF APPLICATIONS

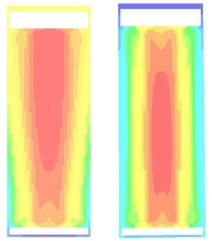
- **Solution optimization**

Given a cell, optimize the battery pack architecture and thermal management to increase its life time

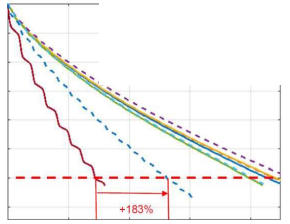
3. Ageing characterization of the cell



4. Simulation of different thermal architectures and managements

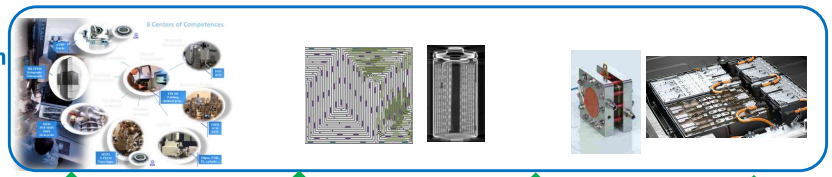


5. Increase the battery life time

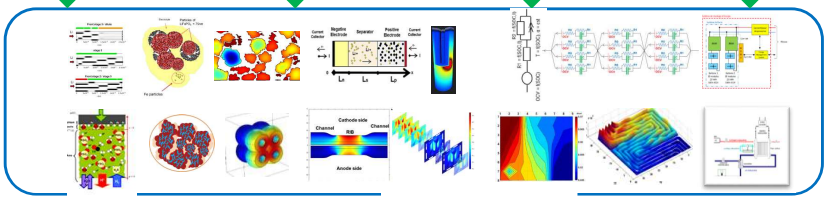


THE ONLY INSTITUTE TO COVER THE ENTIRE DEVELOPMENT PROCESS

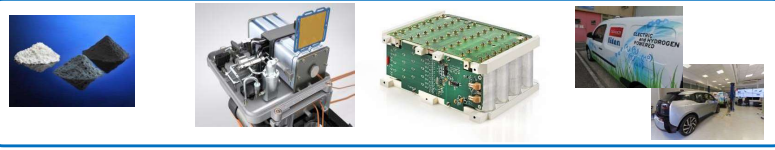
Characterization & post-mortem analysis



Multi-scale & Multi-physics modeling



Applications



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THANK YOU

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TECH DAYS

INNOVATION FOR INDUSTRY

—

LITEN DAY

OCTOBER 15, 2019

KEIO PLAZA HOTEL, TOKYO

HIGH TEMPERATURE ELECTROLYSIS AND COMPACT METHANATION REACTORS: TWO KEY TECHNOLOGIES FOR POWER-TO-GAS

CEA Tech Days | Dr. Olivier Lemaire | 15/10/2019

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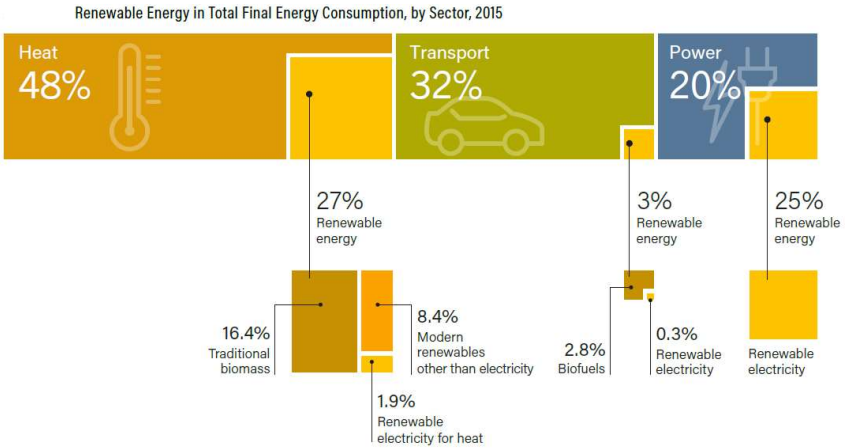
LITEN ➔ FOR DECARBONIZING ENERGY SECTORS

▶ Decarbonizing the electric power sector is necessary but not sufficient

Renewable energy in global final energy consumption by sector, in 2015 (REN21, 2018)



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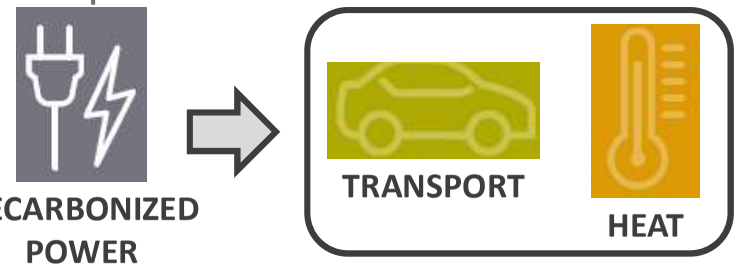
LITEN ➔ FOR DECARBONIZING ENERGY SECTORS

▶ Technologies coupling (power-to-X) is key to decarbonize the transport and heat sectors



DECARBONIZING THE TRANSPORT SECTOR

- power-to-mobility (batteries), power-to-hydrogen, power-to-fuels
- biofuels

DECARBONIZING THE HEAT SECTOR

- power-to-heat (heat pumps), power-to-hydrogen, power-to-gas
- biogas, solid biomass, solar thermal energy

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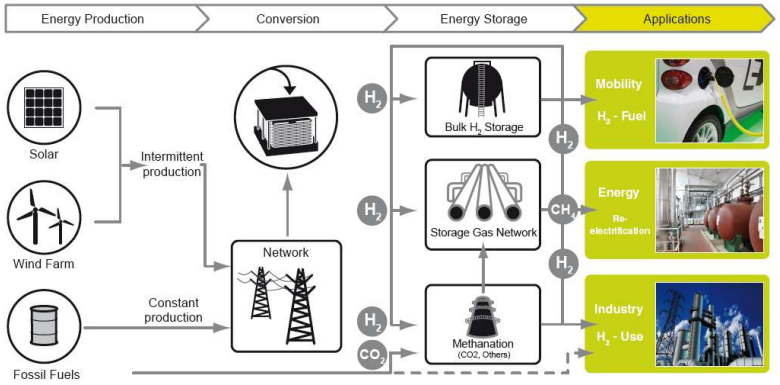
LITEN ➔ FOR ENERGY STORAGE

▶ Evolution of the energy mix: growth of renewable energies and local productions

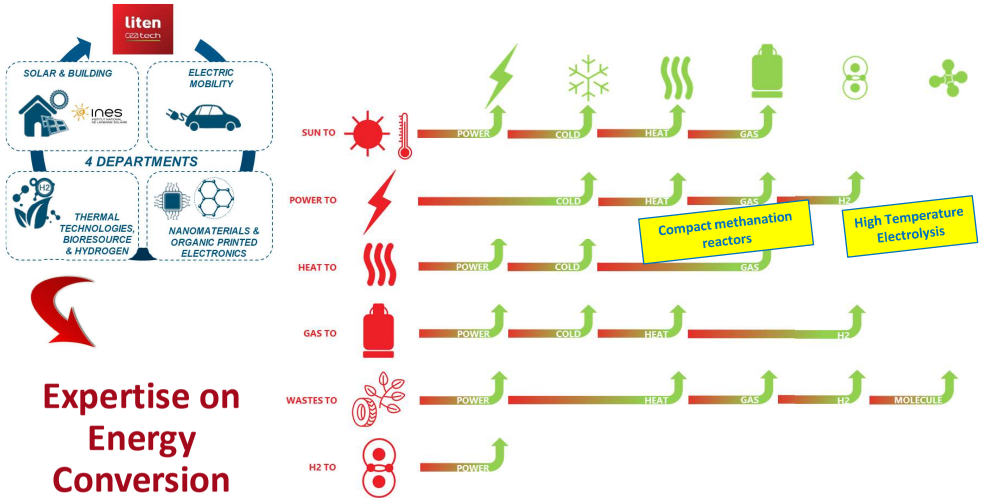
▶ Need of electricity storage solutions



▶ Technologies coupling is key to store energy in different sectors (heat, transport and power)

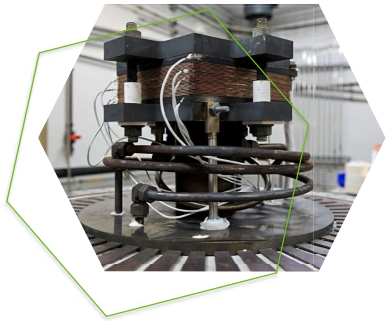
▶ H_2 and methanation can play a role

LITEN ➔ FOR DECARBONIZING ENERGY SECTORS & ENERGY STORAGE



Expertise on Energy Conversion

▶Two key technologies for power-to-gas

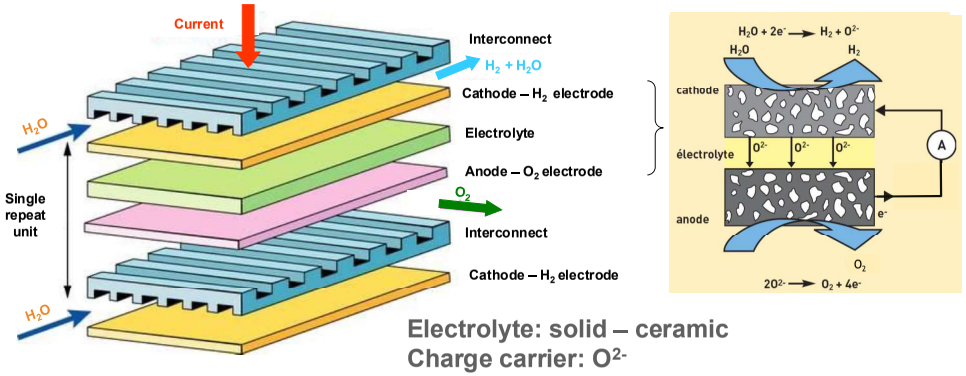


High Temperature Electrolysis

LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS ➔ HIGH TEMPERATURE ELECTROLYSIS

TECHNOLOGY PRESENTATION

- High Temperature Electrolysis (HTE)
- Solid Oxide Electrolysis Cell (SOEC) Technology

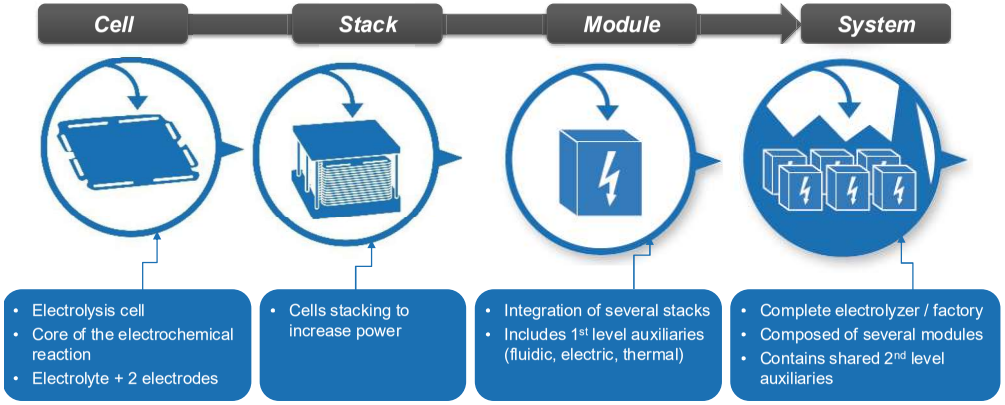


Electrolyte: solid – ceramic
Charge carrier: O^{2-}

Operating temperature: 700-850°C
Pressure: atmospheric (30 bar under development)

LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS ➔ HIGH TEMPERATURE ELECTROLYSIS

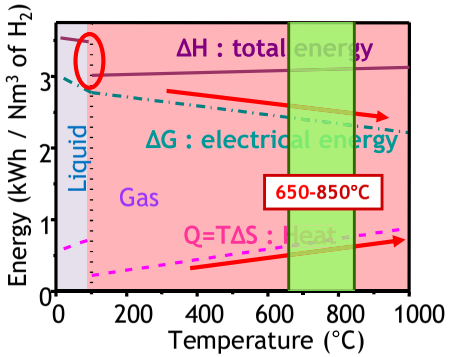
TECHNOLOGY PRESENTATION

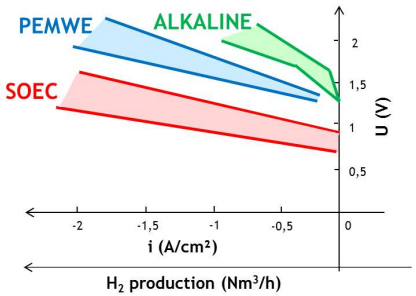


Modular technology:

- A stack can contain a variable number of cells depending on the target power
- Cells can have different sizes depending on the targeted power
- To increase the power, the stack size can be adjusted
- Possibility to have several stacks in a module and several modules in a system: flexibility

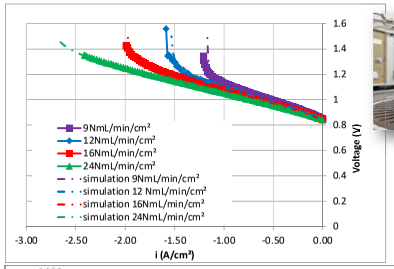
LOW-TEMPERATURE VS. HIGH TEMPERATURE WATER ELECTROLYSIS





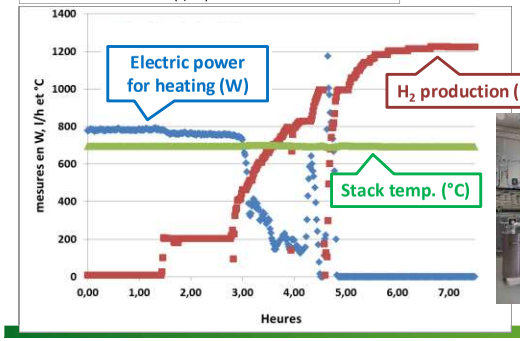
- Low-temperature electrolysis (liquid water): alkaline & PEMWE
  - ➔ 50%-65% LHV efficiency
- High-temperature electrolysis (water vapor): solid-oxide electrolysis cell (SOEC)
  - ➔ 87% LHV efficiency (if waste heat is used for steam generation)
- Other key advantage of SOEC: reversible technology (SOEC / SOFC)

SOME RESULTS: PERFORMANCES. Stack and system levels



Good performance at stack level:

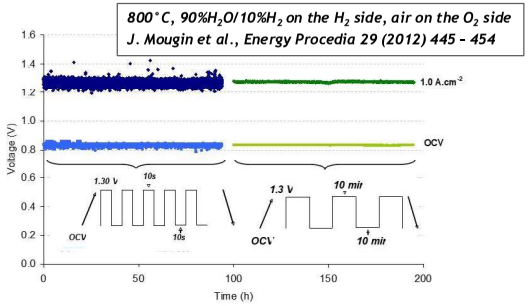
- May exceed -2 A/cm² at 1.3V
- 100% recovery rate of produced H_2
- Ability to operate with high conversion rates of water vapor (~80%)
- 1.7 Nm^3/h of H_2 produced for a 25-cells stack



Good performance at system level:

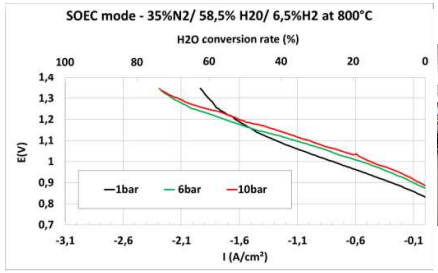
- 1.2 Nm^3/h H_2 produced at 700°C with a 25-cells stack
- Good efficiency of heat exchangers for preheating input gases
- A 87% LHV electrolysis efficiency is measured at the system level

SOME RESULTS: PERFORMANCES. Operating strategy



- Ability to follow very fast current transients
- No degradation related to these transients

➔ Coupling to intermittent renewable energies is possible



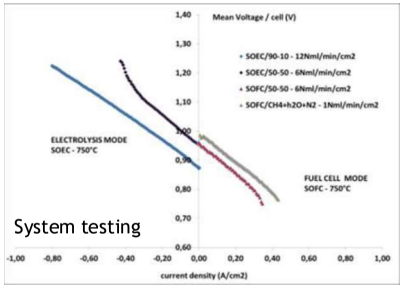
Possibility to operate under pressure at 10-30 bar

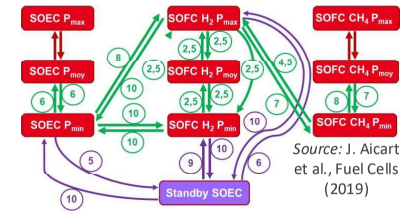
Double gain:

- At system level: avoiding a compression stage
- At stack level: limiting current shifted = possibility to operate at higher currents and steam conversion

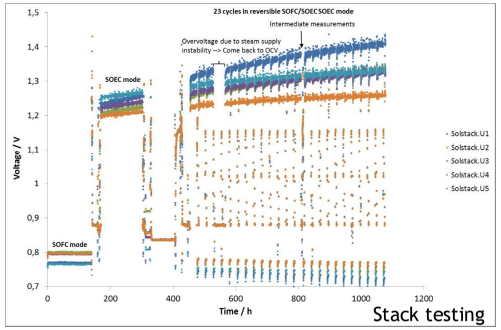
SOME SPECIFICITIES: REVERSIBLE OPERATION SOEC/SOFC ➔ rSOC

- Better CAPEX: only one system
- Better return on investment: system running 100% of the time



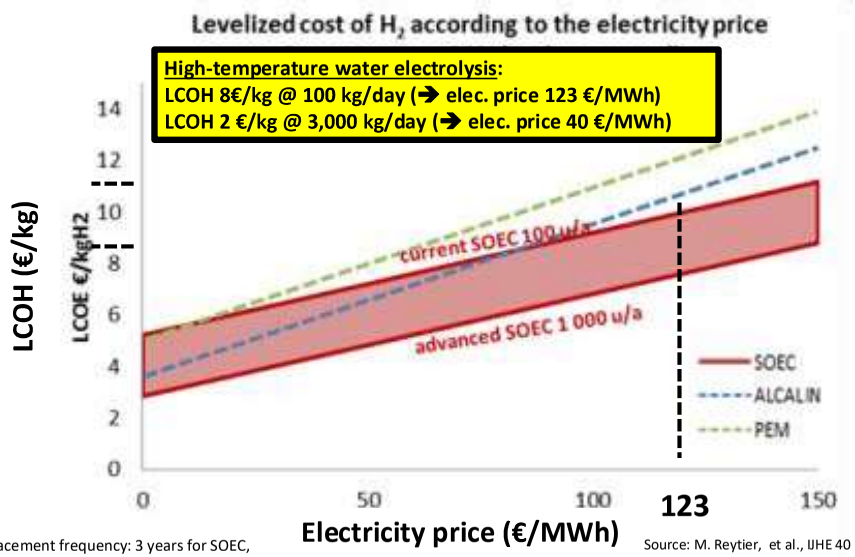


Source: J. Aicart et al., Fuel Cells (2019)



- Similar operation in both modes
- Cycling between SOEC and SOFC possible, no further degradation
- Relatively fast transitions (<10 min)

COST ANALYSIS: LEVELIZED COST OF HYDROGEN (LCOH)



Replacement frequency: 3 years for SOEC, 10 years for alkaline, 6 years for PEMWE

Source: M. Reytier, et al., IJHE 40 (2015) 11370

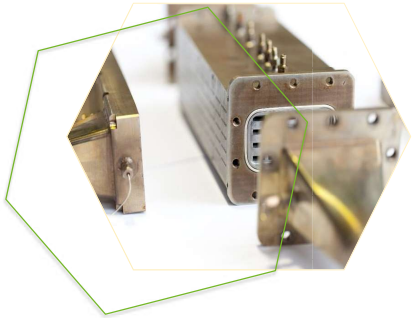
DEVELOPMENT STATUS

- **Examples of realization**
  - 2014: 1st SOEC system set up by CEA
    - 1 stack – 1 Nm^3/h H_2 produced at 700°C
    - Energy efficiency 99%HHV
  - 2017: Grinhy system set up by Sunfire
    - steelmaking site in Germany
    - 150 kW - 40 Nm^3/h of H_2 produced
  - 2019: start of Grinhy 2.0 project:
    - 720 kW
    - Production of 100t of H_2 by the end of 2022
  - 2019: call EU FCH-JU
    - SOEC of >2 MW
- **French roadmap**
  - 2022: 300 kW
  - 2024: 2 MW
  - 2027 and beyond: ~100 MW

Table 1: RSOFC System Efficiencies

Operation	LHV_{AC}	HHV_{AC}
SOEC	60.5	71.1
SOEC (No Steam Generator)	72.0	84.4
SOEC (No Steam Gen or Compressor)	84.5	99.3

▶Two key technologies for power-to-gas



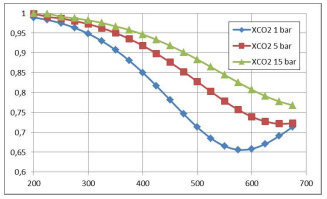
Compact methanation reactors

SOME REMINDERS ON Thermodynamics and Kinetics…

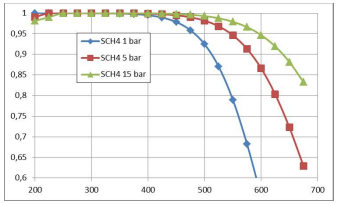
- **Sabatier reaction (1902) :** $CO_2 + 4H_2 \Leftrightarrow 2H_2O + CH_4 \quad (\Delta_r H_{298} = -165 KJ/mol)$
- Carbon dioxide Methanation (Xu and Froment 1989)

$$\begin{cases} CO_2 + 4H_2 \Leftrightarrow CH_4 + 2H_2O \quad (1) \quad (\Delta_r H_{298} = -165 KJ/mol) \quad (methanation \ \ CO2) \\ CO + 3H_2 \Leftrightarrow CH_4 + H_2O \quad (2) \quad (\Delta_r H_{298} = -206 KJ/mol) \quad (methanation \ \ CO) \\ CO_2 + H_2 \Leftrightarrow CO + H_2O \quad (3) \quad (\Delta_r H_{298} = +41 KJ/mol) \quad (RWGS) \end{cases}$$

- Thermodynamic : promoted at low T and high P



CO_2 Conversion



CH_4 Selectivity

✓ **Favored by high pressure and low temperature**
✓ **Yield > 95% for T<350°C @ 5 bar**

LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS ➔ COMPACT METHANATION REACTORS

METHANATION REACTORS: different technologies

	Adiabatic fixed-bed	Cooled fixed-bed	Fluidized bed	Milli-structured
Operation mode	Adiabatic	Polytropic	Isothermal	Polytropic
Process complexity	High	Low	Low	Low
Catalyst	Packing	Packing	Fluidized	Packing
Particle size	Millimeters	Millimeters	100-500 µm	< 1 mm
GHSV	Medium-high	High	Low	High
TRL	9	7	7	5-7

(Modified from Rönsch 2016)

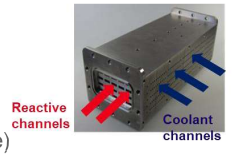
Optimization of known concepts ➔ Milli-structured reactors

- ✓ Enhancement of temperature control
- ✓ Flexibility to hydrogen flow
- ✓ Modularity

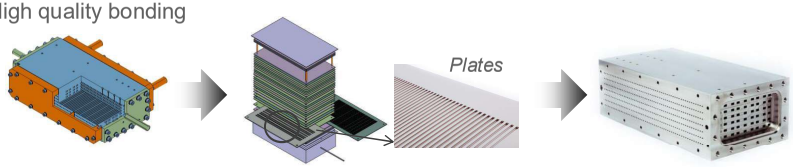
LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS ➔ COMPACT METHANATION REACTORS

MILLI-STRUCTURED REACTOR DEVELOPMENT

▶ **Prototype milli-structured reactor**
- Keep small scale channels for intensification of heat and mass transfer
- Use of millimeter-scale catalyst particles (high catalyst density and easy loading)
- Scale-up by numbering-up reactive channels and coolant channels



▶ **Manufacturing by HIP (CEA nuclear background)**
- Machining of metallic plates (reactive and coolant channels)
- Stacking of machined and non-machined plates
- Bonding by Hot Isostatic Pressure (high temperature, high pressure)
- High quality bonding

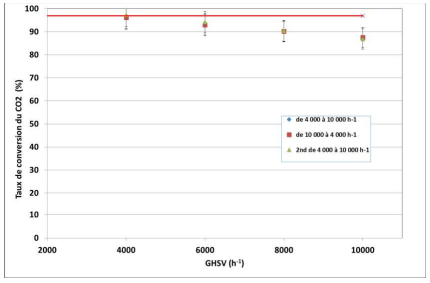


▶ **Qualification**
- High methane yield for high GHSV (>95% @4000 h-1)
- Flexibility : Adaptation to flowrates 20%-100%
- Ageing : >90% CO2 conversion sustained for 700 h (& more)

LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS ➔ COMPACT METHANATION REACTORS

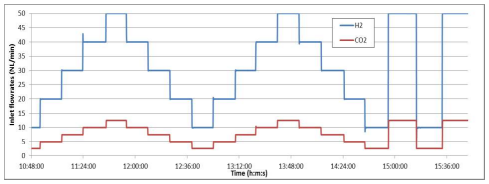
SOME RESULTS: PERFORMANCES

CO_2 Conversion rate vs GHSV

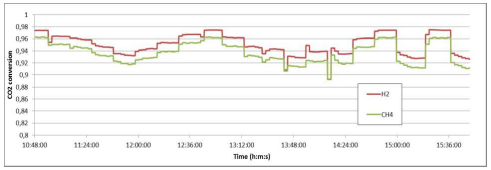


2,5 bar and cooling fluid at 290°C
(Conversion rate at the equilibrium 96.9%)

Flowrate flexibility



Inlet flowrates, P = 2.5 bar, T = 290°C, flowrates from 20% to 100%

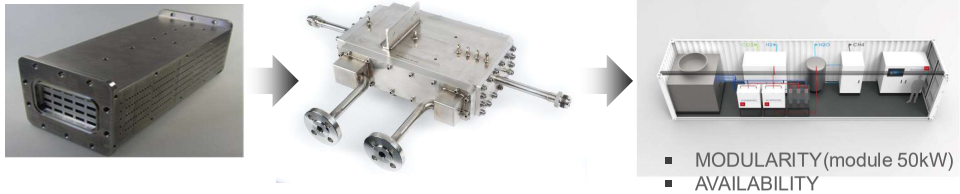


CO_2 conversion, P = 2.5 bar, T = 290°C, flowrates from 20% to 100%

Good performance:
- ➔ Technology validated
- ➔ Upscaling of module and integration into a methanation unit

LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS ➔ COMPACT METHANATION REACTORS

A SPECIFIC AGREEMENT



- MODULARITY (module 50kW)
- AVAILABILITY
- FLEXIBILITY
- COMPACTNESS

Compact reactor (~30m² / MWe / unit)

Agreement with ATMOSTAT company located nearby Paris

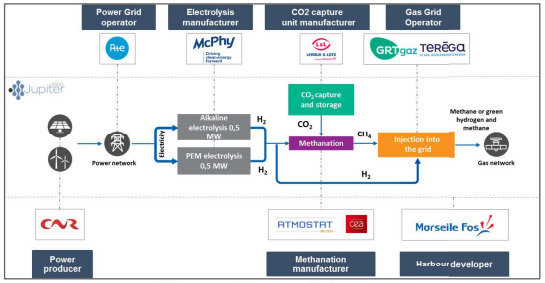
ATMOSTAT ALCEN

LACRE FROM RESEARCH TO BUSINESS

http://www.hex-reactor-lacre.com

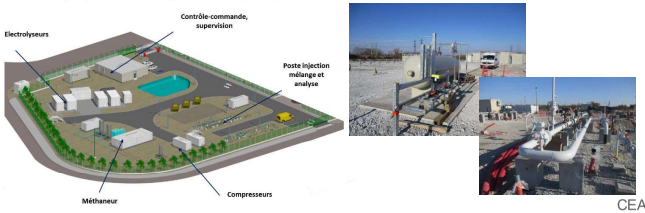
DEVELOPMENT STATUS. Projects in France

▶ JUPITER 1000: 1 MWel plant led by GRTgaz company



Upscaling of one reference module of reactor and tested at CEA.

Manufacturing of the methanation unit in progress



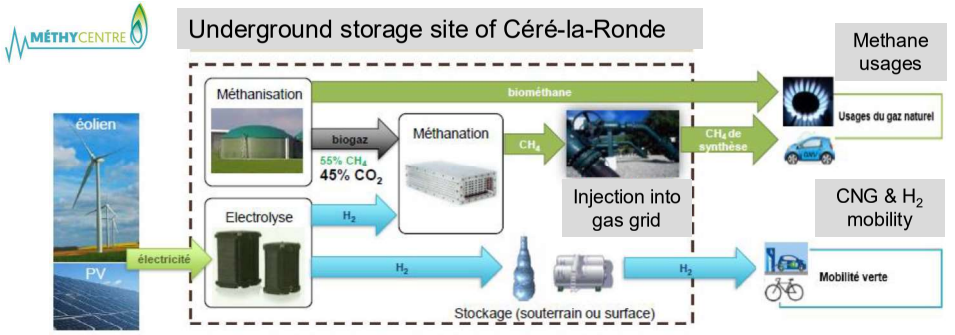
Schedule:
Start of the H_2 chain: August 2019
Start of the SNG chain: Early 2020

www.jupiter1000.com

LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS
➔ COMPACT METHANATION REACTORS

DEVELOPMENT STATUS. Projects in France

▶ METHYCENTRE: methanization-methanation plant led by STORENGY company



Schedule:
Start of the H_2 chain: 2020 ➔ Start of the SNG chain: 2021 ➔ Start of the whole system: 2021

https://methycentre.eu/

LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS
➔ COMPACT METHANATION REACTORS

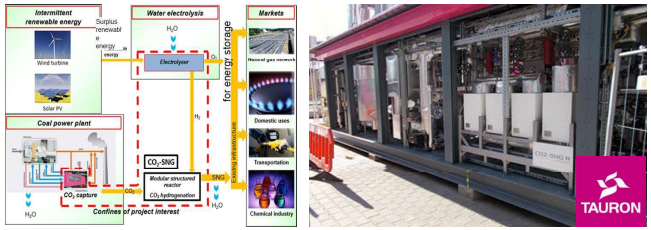
DEVELOPMENT STATUS. Projects in Europe

Power to gas demo plant in Troia

- Capturing of CO_2 from ambient air
- Modular millistructured-reactor based methanation concept
- A "small-scale" liquefaction to supply LNG to a dedicated cryogenic tank

STORE&GO

H2020 project including 3 demo P2G plants



- **SNG quality**: the plant can produce SNG with the quality required, the conversion rate of CO_2 has reached 98,5%.
- **Control of methanation temperature**: as expected with the innovative technology of the methanation reactors, the control of the reaction temperature is efficient.
- **Flexibility**: the plant can produce SNG from 20% to 100% in a few minutes.
- **Long run with stable parameters** in progress, to confirm stabilization of catalyst.

CO2-SNG: Upscaling of module and tests at CEA.
SNG with a good quality and high conversion rate (for mobility)
A KIC Inno Energy project located in Poland

LITEN ➔ TWO KEY TECHNOLOGIES FOR POWER-TO-GAS

CONCLUSIONS and PERSPECTIVES

▶ **Development of two promising power-to-gas technologies for DECARBONIZING and STORAGE ENERGY**
- Advanced development of the two technologies (high temperature electrolysis and compact reactors for methanation)
- Good performances at laboratory level and also at system level
- Starting of industrialization with partners

▶ **High temperature electrolysis**
- Continue/speed up demonstration projects
- Upscaling
- Diversification with co-electrolysis for producing syngas or other molecules

▶ **Compact methanation reactors**
- Demonstration projects on-going to gather Return of Experience (JUPITER1000, CO2-SNG, STORE&GO, METHYCENTRE)
- Durability and upscaling
- Diversification to other reactions (in progress): methanol, FT, other molecules

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THANK YOU
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TECH DAYS
INNOVATION FOR INDUSTRY
—
LITEN DAY
OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

ADVANCED MATERIAL TECHNOLOGIES TO SUSTAIN THE ENERGY TRANSITION WITH CIRCULAR ECONOMY FOCUS

Thibaud FLEURY, Industrial Partnership Manager, New Materials Division DTNM, CEA-Liten

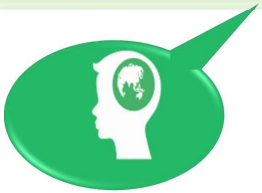
CURRENT ENVIRONMENTAL ISSUES

Raw materials limitation

Impact of environmental degradation on health

Environmental regulations

INNOVATION OPPORTUNITIES FOR MATERIALS & PROCESSES WITH **CIRCULAR ECONOMY** FOCUS



Collective awareness

Climate change

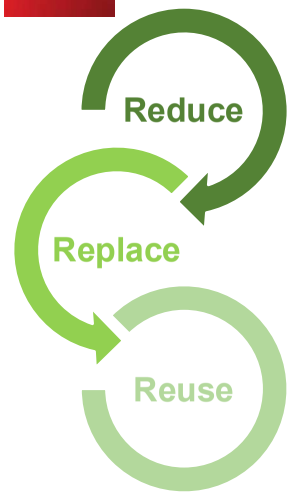
FROM MATERIAL TO COMPONENTS TO APPLICATIONS

ANTICIPATE / SUSTAIN THE ENERGY TRANSITION

Our mission:

Develop high-performance
materials, processes and components
for industry in accordance
with the concept of **material and energy savings**

CIRCULAR ECONOMY: « 3 R » STRATEGY



Use less materials

Decrease the environmental footprint of materials

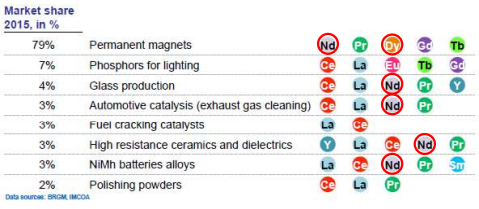
Integrate recycled materials

Material: Rare-earth permanent & Temporary magnets
Process: Additive Manufacturing
Application: Structural Electronics

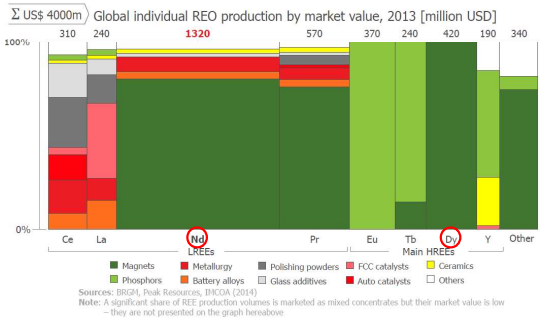
MATERIAL: RARE-EARTH MAGNETS

- **Context**

  - ✓ REE is a family of 14-16 elements, needed by different rapidly evolving markets for high-technology applications

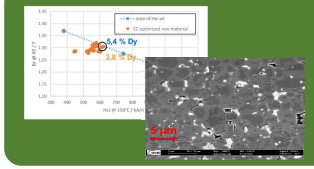


  - ✓ As the main REE constituent of NdFeB magnets, **Nd** is the single most valuable REO that should be targeted for **"Reuse"**
  - ✓ As one of the HREEs in highest demand, **Dy** prices have witnesses the highest increase and should be targeted for **"Reduce"** and/or **"Replace"**



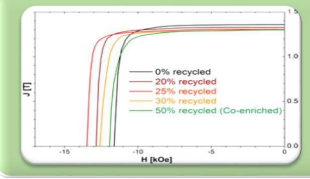
MATERIAL: RARE-EARTH MAGNETS

- **"3 R" strategy: how do we optimize REE in permanent magnets?**



REDUCE
- Control of microstructure, phases's nature and stability
- Dy location in grain boundaries
- Less material thanks to additive manufacturing

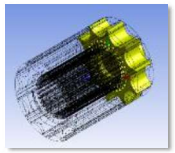
REPLACE
- Use new phases to reduce/replace REE (Ce instead of Dy)

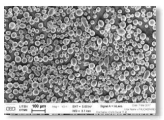


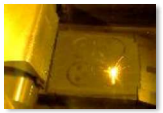
REUSE
- Magnets recycling (by chemical treatment, powder, fusion)
- The recycled powder alone does not densify (cause: 9000 ppm 02 contamination)
- When mixing with standard NdFeB powder, 30% blend achieved
- When mixing with Co-enriched powder, 50% blend achieved

MATERIAL: TEMPORARY MAGNETS

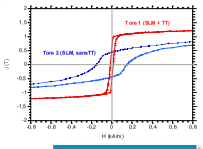
Using temporary magnet cores (FeSi and FeCo) for performances improvement:
- Manufacturing of **lightweight rotor** with less material
- Integration of new geometries allowing **cooling** closer to magnets
- Magnets dimension & cost **reduction** and cooling optimization


Conception of complex geometries by simulation

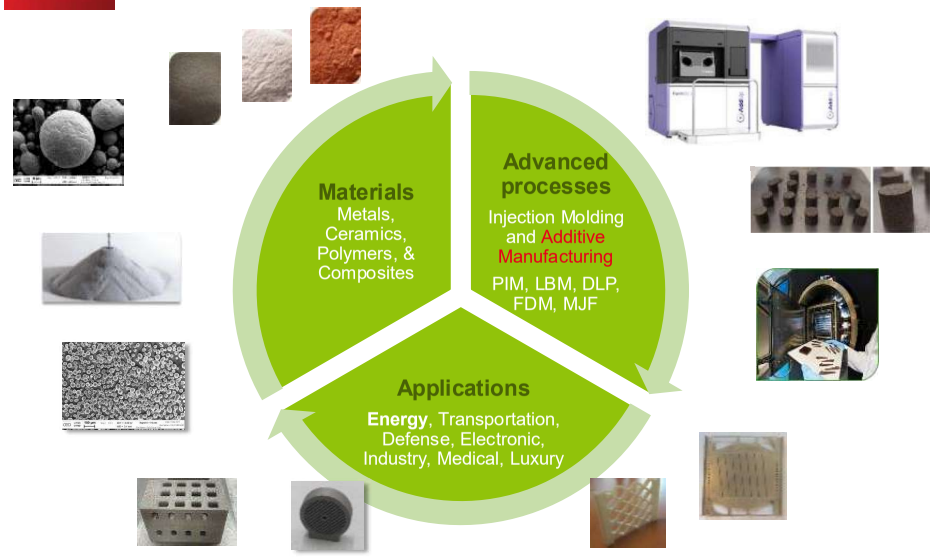

Material selection


Manufacturing process fine tuning & optimization


Manufacturing


Thermal post-treatment

PROCESS: ADDITIVE MANUFACTURING



Additive manufacturing: Advanced processes at the heart of our circular economy approach

PROCESS: ADDITIVE MANUFACTURING

2012 — PIM : Powder Injection Molding

SPS : Spark Plasma Sintering

2014 — SLA : Stereo Lithography Apparatus

2016 — LBM or SLM : Laser Beam Melting

2018 — MJF : Multi Jet Fusion

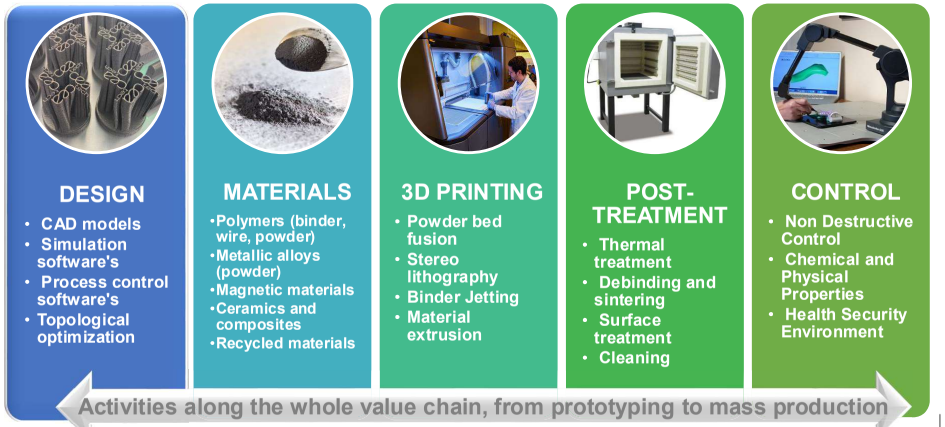
FDM : Fused Deposition Modeling

Recently Installed

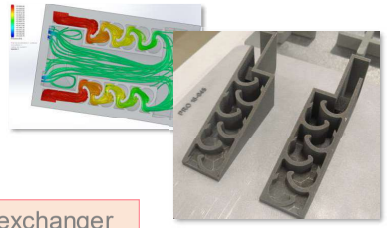
A large range of technologies and competencies to operate/evaluate them

PROCESS: ADDITIVE MANUFACTURING

- **Create an ecosystem** developing technological breakthroughs, including equipment suppliers to facilitate new technology transfers
- **Some key figures**
  - ✓ 60+ people
  - ✓ 1 400 m² of dedicated platform
  - ✓ ~ 100 equipment



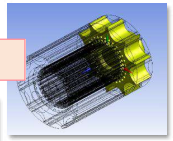
PROCESS: ADDITIVE MANUFACTURING

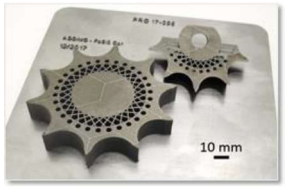


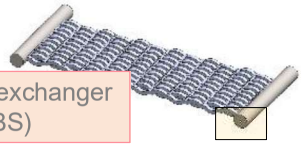
H_2 phase separator for PEM technology (AlSi)

Helicoidal heat exchanger (AlSi, 316L)

Magnetic rotor (FeSi)







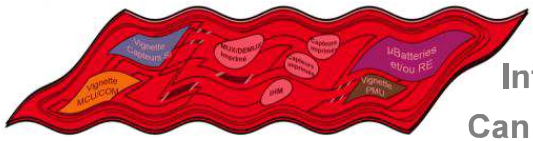
Polymer heat exchanger (PA, ABS)

Net shape magnets (NdFeB)

APPLICATION: STRUCTURAL ELECTRONICS

Integration of the electronics on or in the structure of the object

Add a functional layer, in order to:

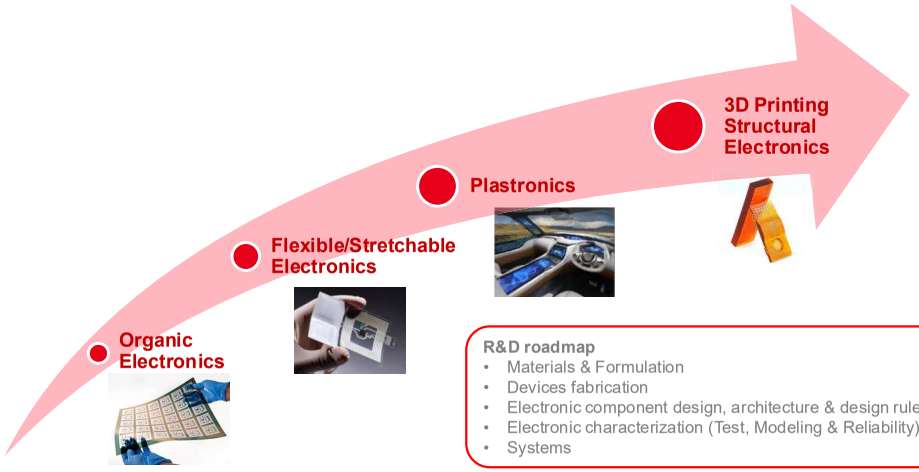


Activate / Operate
Interface / Communicate
Can be an autonomous layer

With more than 10 years expertise, CEA could bring you value on:
- Material & formulation
- Electronic component design, architecture & design rules
- Electronic characterization (Test, Modeling & Reliability)
- Systems

APPLICATION: STRUCTURAL ELECTRONICS

Integration of the electronics on or in the structure of the object



R&D roadmap
- Materials & Formulation
- Devices fabrication
- Electronic component design, architecture & design rules
- Electronic characterization (Test, Modeling & Reliability)
- Systems

Key drivers: weight / cost / congestion reduction, customization, design, usages

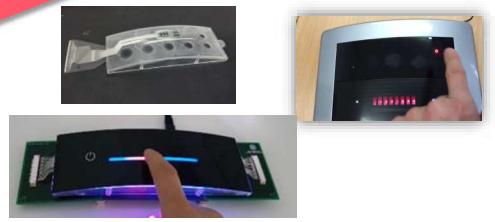
TOWARDS STRUCTURAL ELECTRONICS: STRETCHABLE ELECTRONICS

Towards 3D Printing, 2 complementary technologies: Injection and/or Thermoforming

Functionalize with electronics thanks to In Mold Decoration

- **Targeted products:** sensors (capacitive, actuators, SMD, …) printed in 2D, then inserted into plastic parts via injection and/or thermoforming
- **Main industrial challenge**: large volumes of products used in automotive, automation, home appliances …
- **Key differentiators:** integration into 3D parts, customization, design

Applications



TOWARDS STRUCTURAL ELECTRONICS: PLASTRONICS

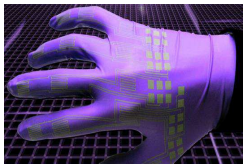
Towards 3D Printing, 2 complementary technologies: Injection and/or Thermoforming

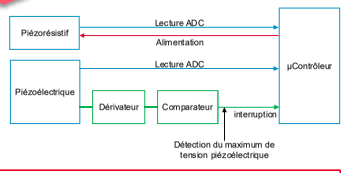
Development of strain sensors, generic and relevant for a wide range of applications such as batteries monitoring, robotics, wearable devices, etc…

Main challenges: sensors, multiplexer, energy generation/harvesting

Key differentiators: integration on stretchable substrates, low consumption, compatible with traditional electronics (SMD, ASICS, etc…) to create hybrid devices

Applications





Piezo-E & piezo-R printed sensors – Low consumption pressure measurement

Contact:

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THANK YOU

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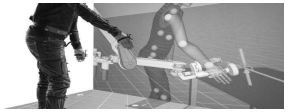
List Day Presentations

TECH DAYS
INNOVATION FOR INDUSTRY

LIST DAY
OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

LIST, CEA TECH INSTITUTE

INTEGRATED SYSTEMS AND TECHNOLOGIES INSTITUTE



CEA Tech Days | Karim BOUDERGUI | 15/10/2019

CEA, A HIGH LEVEL PUBLIC RESEARCH ORGANISM

The CEA is ranked the most innovative in Europe and second in the world in the "Top 25 Global Innovators - Government"

REUTERS

TOP INSTITUTIONS | 2017 RANKINGS

1	Health & Human Services Laboratories	USA
2	Alternative Energies and Atomic Energy Commission	France
3	Fraunhofer Society	Germany
4	Japan Science & Technology Agency	Japan
5	National Institute of Advanced Industrial Science & Technology	Japan
6	Korea Institute of Science & Technology	South Korea
7	Medical Research Council	UK
8	National Center for Scientific Research	France

16000 people

4 billion euros budget

750 Priority patents /year

600 Industrial partners

4800 Scientific publications

CEA, FROM FUNDAMENTAL TO TECHNOLOGY RESEARCH

1 Defence & national security

2 France's energy independence

3 Economic competitiveness of French industry

DRF Fundamental research

DAM Defence & Security

DEN Nuclear & renewable energies

Technological research for industry

leti — Micro & nano-technologies

liten — New energy technologies

list — Smart digital systems

MORE THAN 200 START-UP CREATED IN 20 YEARS

200th Start-up in 2017

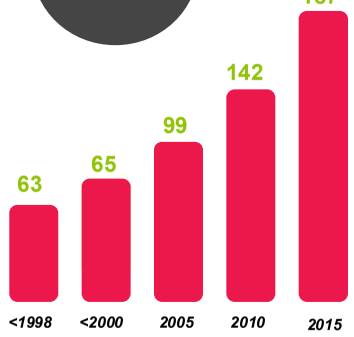
202 Start-up since 1972

93% always active in the last 5 years

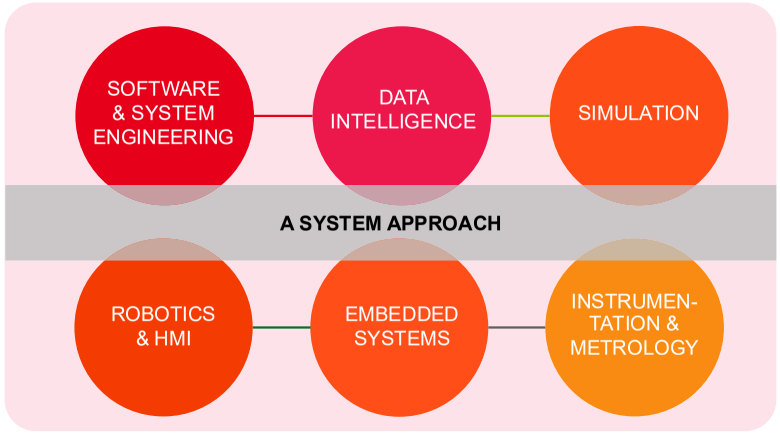
51 Created in 5 years, 21 in Paris area

37 supported byCEA

158 By spinning



CEA LIST'S AREAS OF EXPERTISE



CEA LIST'S DNA

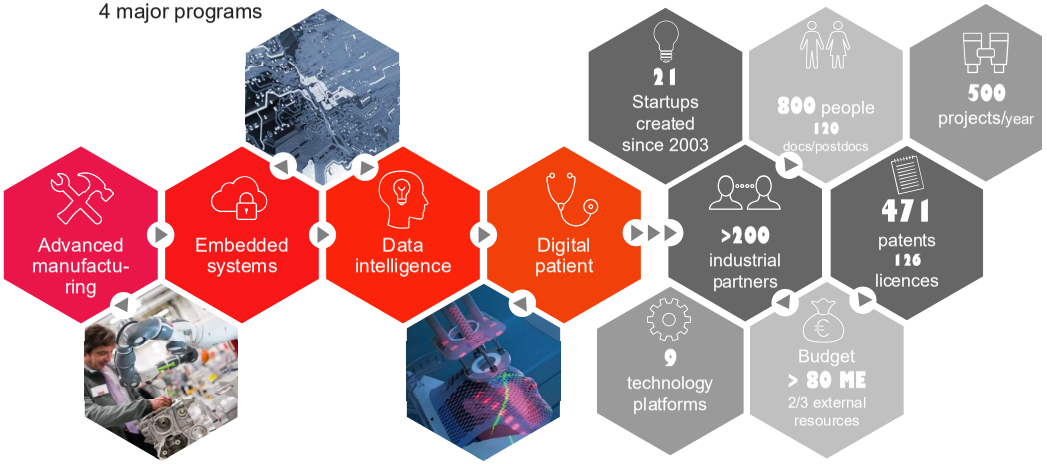
Laboratoire d'**I**ntégration des **S**ystèmes et des **T**echnologies

TECHNOLOGIES → **INTEGRATION** → **SYSTEMS**

- High level of mastery of basic technological bricks
- System approach combining SW / SW & SW / HW
- Upstream software engineering of artificial intelligences

LAB FOR INTEGRATION OF SYSTEMS & TECHNOLOGIES

4 major programs



OUR STARTUPS, VECTORS OF INTERNATIONAL influence

ありがとうございました

Commissariat à l'énergie atomique et aux énergies alternatives
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www-list.cea.fr

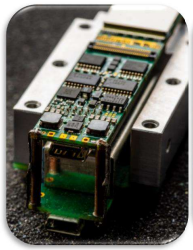
TECH DAYS
INNOVATION FOR INDUSTRY

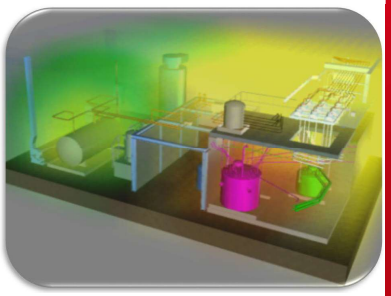
LIST DAY
OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

CEA-LIST INNOVATIVE SENSORS AND SYSTEMS

FOR NUCLEAR AND DISMANTLING INDUSTRIES

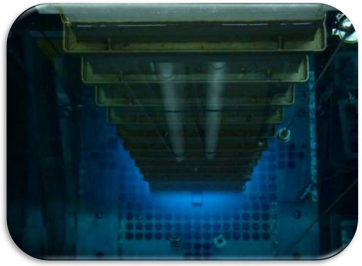
CEA Tech Days | Karim BOUDERGUI | 15/10/2019





OUTLINE

- CEA-LIST in the Nuclear industry
- Sensors and electronic architectures
- Measurements systems and metrology
- Robotics and teleoperation
- Software validation, simulation and virtual Reality
- Systems test and validation facilities



CEA-LIST
IN THE NUCLEAR INDUSTRY

CEA-LIST *IN THE NUCLEAR INDUSTRY*

- *Unified measurement chain*
- *Current neutron flux Pre-amplifier*
- *Fuel pin cladding failure*
- *Advanced NDT*

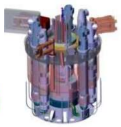
- *Fission chamber design*
- *High immunity cables*
- *Neutron monitoring (Campbell mode)*

3/3G+ Reactors

Nuclear propulsion

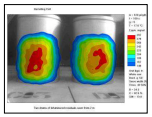
LIST

4G Reactors



- *SHM of vessel reactor*
- *Na leakage monitoring*
- *Fission chamber design*
- *High dynamic electronics for neutron monitoring*

- *Photofission*
- *Neutron interrogation*
- *Gamma Imaging*
- *Robotics*



Waste management

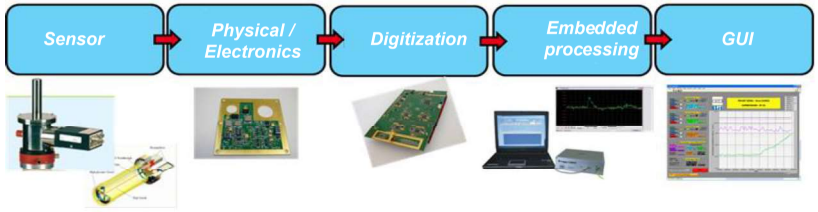
Dismantling

- *γ–α–n imaging*
- *Multi-channel electronics*
- *Enhanced spectrometry algorithms*
- *Robotics and AR/VR*

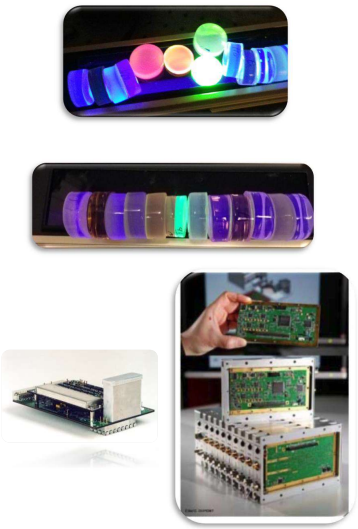
Various needs to address by developing innovative and versatile systems

CEA-LIST *IN THE NUCLEAR INDUSTRY*

- To develop instrumentation systems for nuclear Industry



Design	Simulation	Testing	Prototyping	…
▪ Sensors ▪ Electronics ▪ Robotics	▪ Sensors and signal process. ▪ Decommissioning in VR ▪ Robotics ▪ Training	▪ Sensors ▪ Electronics	▪ Sensors ▪ Electronics ▪ Robotics	



SENSORS AND ELECTRONIC ARCHITECTURES

DEVELOPING INNOVATIVE SENSORS: *LUMINESCENT MATERIALS*

- Synthesis of luminescent materials

Collaborations

Academics: UNICAEN, LCP, CNRS CACHAN, CNRS

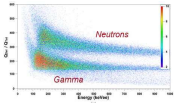
Industrials: NUVIA, AREVA, SAINT-GOBAIN

Publications & proceedings
≈ 60 from 2007

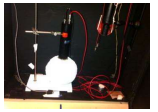
Patents
≈ 19 from 2007

DEVELOPING INNOVATIVE SENSORS : *LUMINESCENT MATERIALS*

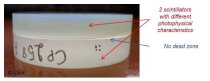
- **Fast neutrons detection**
  - Chemically optimized and nanostructured plastic scintillators
  - Pulse Shape Discrimination



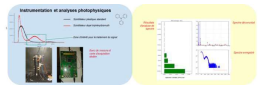
- **Thermal neutrons detection**
  - Use of neutron capture with loaded elements inside the plastic scintillator (Gadosphere)



- **Beta/Gamma discrimination**
  - Molecular coupling of scintillators having different photophysics properties

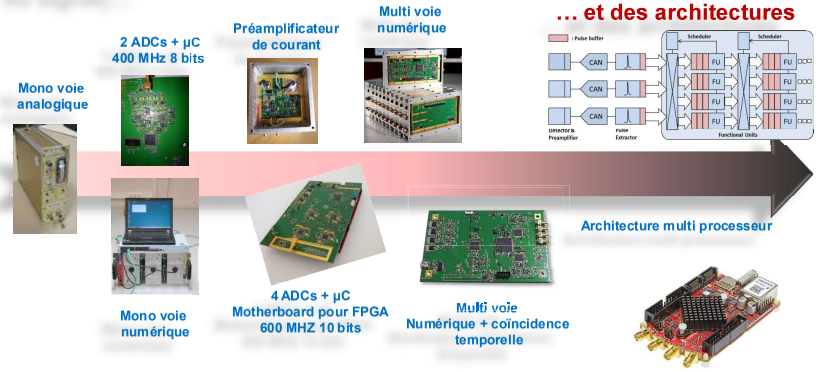


- **Pseudo-gamma spectrometry**
  - Plastic scintillators loading with heavy elements (Pb, Bi, Sn)
  - Algorithms: Non-parametric Bayesian approach



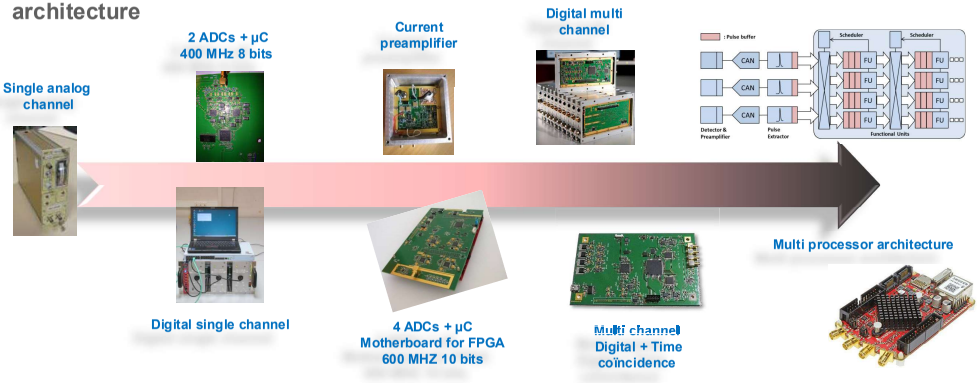
Architecture Electronique pour la mesure nucléaire

Evolution permanente des cartes d'acquisitions (numérisation précoce du signal)…



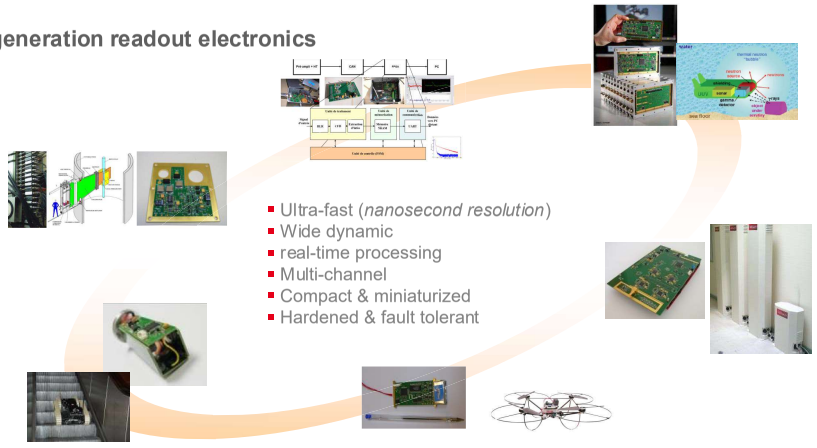
ELECTRONIC ARCHITECTURE

- Permanent evolution of acquisition cards (early numerization of the signal) ... And architecture



ELECTRONIC ARCHITECTURES

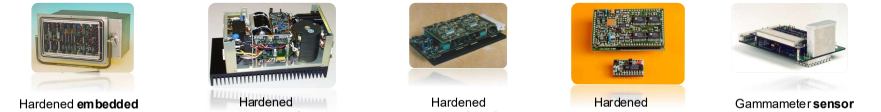
- New generation readout electronics



- Ultra-fast (*nanosecond resolution*)
- Wide dynamic
- real-time processing
- Multi-channel
- Compact & miniaturized
- Hardened & fault tolerant

ELECTRONIC ARCHITECTURES: *HARDENED TECHNOLOGIES*

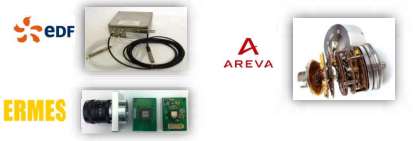
- Strong experience in design and realization of hardened systems

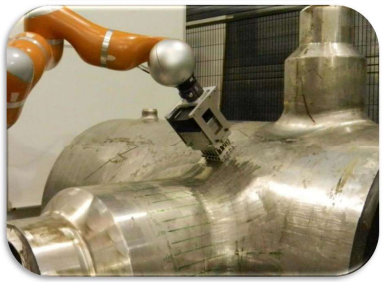


Hardened **embedded computer** — Hardened **power supply** — Hardened **variator** for DC current motor — Hardened **converter** — Gammameter **sensor**

Quality assurance | **COTS design** | **Redundancy** | **Regeneration**

- COTS / Component Knowledge Library ➡ Quick and cost-effective
- Harsh environments applications using COTS
  - Datalogger (3kGy – 3Mrad)
  - Absolute coder (1 MGy – 100 Mrad)
  - Hardened camera





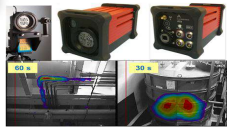
MEASUREMENTS SYSTEMS AND METROLOGY

MEASUREMENTS SYSTEMS

- **Smart Gamma Probe**
  - Sensor : Geiger-Müller (energy compensated)
  - Sensing range : 0.1 µSv/h – 100 mSv/h and 0.1 mSv/h – 10 Sv/h
  - Size : ø3.2 x 8.9 cm, 90 g

- **Miniature Gamma Spectrometer**
  - Sensors : CdZnTe crystals of 60mm3 to 500 mm
  - Size : 75 mm x 40 mm
  - Weight : 20 g

- **Gamma camera**
  - Low weight : m~2 kg
  - Wide energy range: 241Am to 60Co
  - Plug-and-play system



- **n/g Radioactive Portal Monitor**
  - Standard scintillator
  - Multi-channel electronics
  - Coincidence measurement

NDT (NON DESTRUCTIVE TESTING) INSTRUMENTATION

Advanced sensors (GMR, flexible arrays)

Robotized NDT, real time processing
Pre-pilot advanced NDT methods

800 m² Platform

METROLOGY : *THE FRENCH NATIONAL METROLOGY INSTITUTE (LNHB)*

- **Access to metrological standards in the field of Ionizing Radiation in the frame of a well-established traceability**

Development and maintenance of reference standards Precision instrumentation and measurement methods	International consistency of standards Consistency and excellence of the national metrological chain	Transfer to end user QA, ISO 17025 External accreditation by COFRAC (French accreditation body)

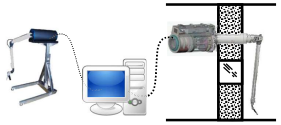
- **Dosimetry** : absorbed dose and kerma (**gray**) ; Dose equivalent (**sievert**)
- **Radioactivity** : activity (**becquerel**) ; emission rate (**s-1**)

ROBOTICS AND TELEOPERATION

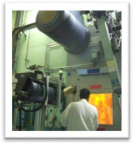
STRONG BACKGROUND ON ROBOTICS FOR NUCLEAR INDUSTRY

- Historical activity : Remote handling for nuclear industry

1970's



1990's computer assisted remote handling



2000's Industrial transfer

AREVA

Daily operations in remote / teleoperated robotics

Intervention and decommissioning

Simulation and mission preparation

THE MAESTRO NUCLEAR ARM

- Maestro : Hydraulic Force-feedback Arm
  - 6 axes, robust / titanium (MTBF > 1000 h)
  - High quality force-feedback TAO V2 software
  - 100 kg load capacity
  - 2,4 m working area
  - Up to 104 Gray with specific hardened embedded controller
  - Industrial transfert by Cybernetix

cybernétix

- Maestro integrated in systems

Integrated on gantry crane (/w embedded hydraulic system)

Integrated on a BROKK mobile platform

STANDARD REMOTE FORCE FEEDBACK HANDLING MASTER-SLAVE

- TAO CONTROL : Flexible framework for robotics teleoperation

ISO 17874-3" Remote handling devices for radioactive materials - Part 3: Electrical master-slave manipulators"

GETINGE La Calhène

AREVA

Nuclear and Industrial Robots

cybernétix

Force Feedback Master Device

POSITION FORCE CONTROLLER

XM_D

XM_M

MULTILATERAL MASTER/SLAVE CONTROLLER

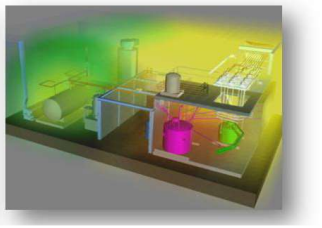
XM_D

XM_M

POSITION FORCE CONTROLLER

TEMIS

Real-time Physics simulation



SOFTWARE VALIDATION,
SIMULATION AND VIRTUAL REALITY

FORMAL VALIDATION OF SAFETY AND SECURITY CRITICAL SOFTWARE

Operational deployment and support of Frama-C tool

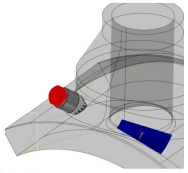
Nuclear
- Runtime error detection
- Functional and temporal properties
- Applied on Operating system validation
- EDF
- ISO 60880
- ISO 61513

Avionics
- Unit proof
- Control and data flow verification
- Applied on Cockpit alarm system
- AIRBUS GROUP
- DO-178C
- DO-333

Cybersecurity
- Exhaustive detection of the 16 "Common Weakness Vulnerabilities"
- Specification and verification of APIs
- Applied on PolarSSL (cryptographic protocol)
- Cryptography libraries
- THALES

NDT (NON-DESTRUCTIVE TESTING) SIMULATION SOFTWARE

- Ultrasonic models, Electromagnetic, X-Ray models
- Imaging and reconstruction
- Analysis and Statistics
- Design of new probes, methods, procedures
- NDT performance, Qualification of methods
- Interpretation of results: analysis, diagnosis



- CIVA : Multi-technique platform for NDT modeling

CIVA NDE 2016

World Leader for NDT simulation & expertize
Multi-technique platform: UT, ET, RT/CT

International and national Academic community

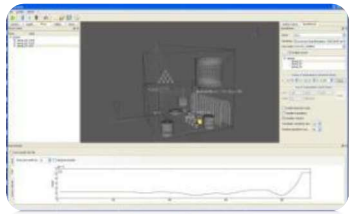
VALUE PROPOSITION FOR THE DISMANTLING AND DECOMMISSIONING

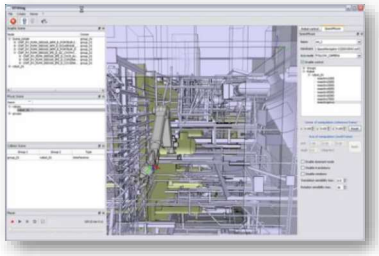
Life cycle management of decommissioning: from design to implementation and monitoring

Topics	Mastery of the environment	Design, simulation and scenario tests	Supervision	Waste management	Data management	Standards
Actions	Instrumentation, digitalization and site planning	Deploy on-site custom equipment	Real-time site monitoring with advanced digital tools	Waste characterization in situ	Data management over a long period	Valorization of the methodology with ASN
Results	Optimization of the contractors work	Increased efficiency in time and cost	Continuous measurement of the drift / forecasts	Reducing the cost of waste	information accumulated over 30 years Regulatory monitoring	Simplification of procedures

ROBOTICS, PHYSICS AND RADIOLOGY SIMULATION IN VR

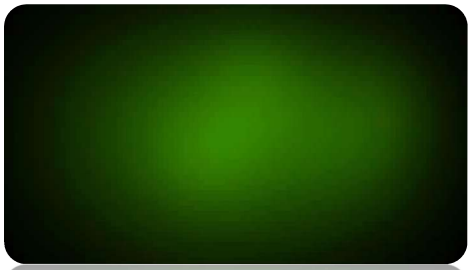
- **Precise interactive simulation of complex scenario in desktop, immersive VR and training environment**
  - Complex geometries (no simplification required)
  - Realistic radiologic computation (Monte-Carlo volumic sources)
  - Force feedback for robotics simulation
  - Virtual Human operator simulation (radiologic impact and training)

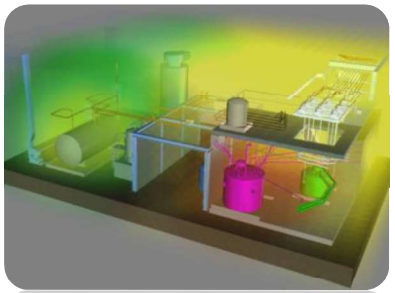




DEMPlus SOFTWARE FOR DECOMMISSIONING

- **Global scenario management**
  - Planning, costs, waste management
  - Simplified and ergonomic input
  - Simplified radiologic simulation (point sources)
  - Desktop usage





SYSTEMS TEST
AND VALIDATION FACILITIES

SYSTEMS TEST *AND VALIDATION FACILITIES*

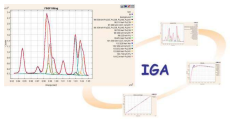
- **Test and validation of sensors and systems**
  - Photophysics and nuclear characterization facilities
  - Validation of full systems
  - Fabrication of dedicated test benches
  - Representative conditions

- **Irradiation facilities**
  - Varieties of radioactive sources
  - Irradiators of TID (Total Ionizing Dose) testing :
    - 1 Gy/h < Dose Rate < 10 kGy/h
    - D < 1 MGy
  - Nuclear reactors for thermal neutrons tests
    - 10^9 n·cm^{-2}·s^{-1} < neutron flux < 10^{14} n·cm^{-2}·s^{-1}
  - LINACs Accelerators for electrons / photons / neutrons irradiation modes
  - High energy imaging

A LARGE OFFER OF INSTRUMENTATION AND SOFTWARE TOOLS FOR DISMANTLING

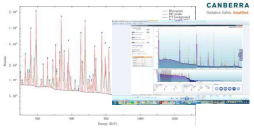
IGA

Analysis tool for actinide measurment



SINBAD

New approach for gamma spectrum analysis



Nanopix

Miniature gamma camera

SIGALE

Software for CZT spectrum analysis

Multichannels System

New approach for gamma spectrum analysis

Active shielding

Spectrometry system with Compton subtraction

Contact:

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Email: karim.boudergui@cea.fr
Phone: +33.1.69.08.96.86

THANK YOU

COME TO VISIT US IN FRANCE !

Commissariat à l'énergie atomique et aux énergies alternatives
Institut List | CEA SACLAY NANO-INNOV | BAT. 861 – PC142
91191 Gif-sur-Yvette Cedex - FRANCE
www-list.cea.fr

Établissement public à caractère industriel et commercial | RCS Paris B 775 685 019

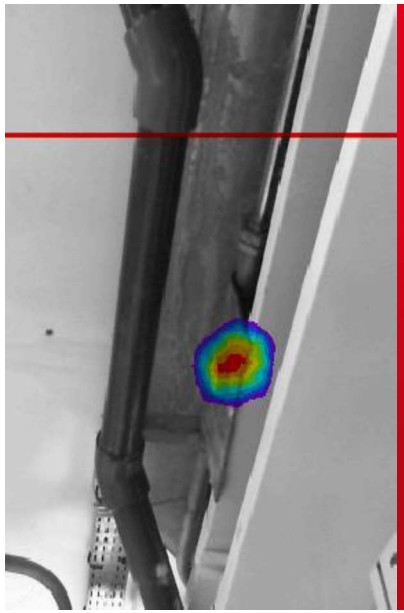
TECH DAYS
INNOVATION FOR INDUSTRY

LIST DAY
OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

MINIATURIZED GAMMA IMAGING

ULTRA COMPACT, REMOTELY CONTROLLED AND INTEGRATED GAMMA CAMERA

CEA Tech Days | Vincent SCHOEPFF | 15/10/2019



01

VISUALIZE RADIOACTIVITY

WHAT IS GAMMA IMAGING?

VISUALIZE RADIOACTIVITY…

… A CHALLENGE FOR NUMEROUS APPLICATIONS

Operational Radiation Protection

Dismantling & decommissioning

Nuclear waste disposal

Accidental situations

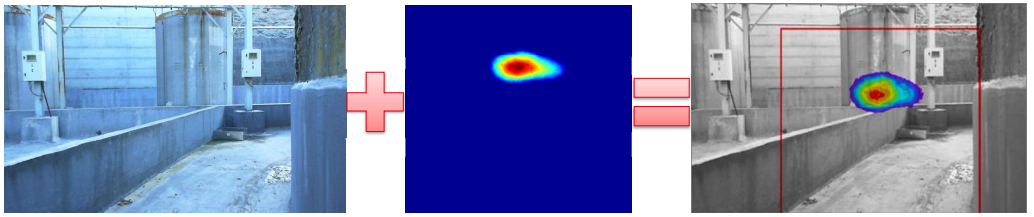
Homeland Security

Border monitoring

Medical radiophysics

VISUALIZE RADIOACTIVITY…

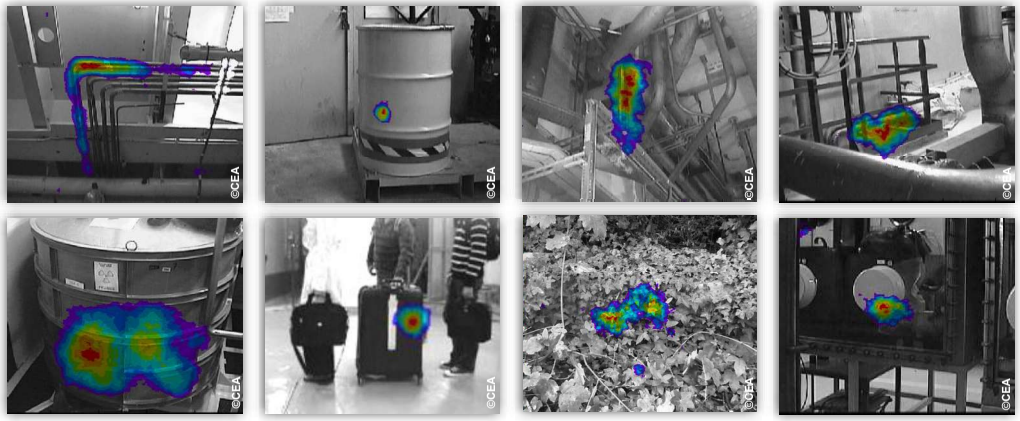
… THE OBJECTIVE OF GAMMA IMAGING



- **Superimposition** of a **gamma** image on a **visible** image
- **Remote visualization** of hot spots
- Information on **intensity / dose rate**

VISUALIZE RADIOACTIVITY…

… A METHOD VALIDATED IN FIELD SITUATIONS



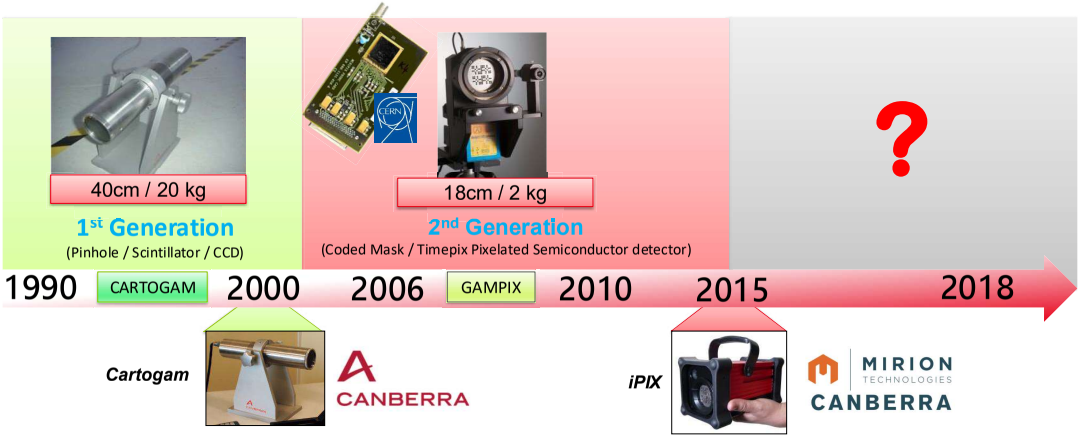
02

FROM CARTOGAM TO NANOPIX

A LONG (HI)STORY OF GAMMA IMAGING AT CEA

FROM CARTOGAM TO NANOPIX…

… ALMOST 30 YEARS OF GAMMA IMAGER DEVELOPMENTS @ CEA LIST

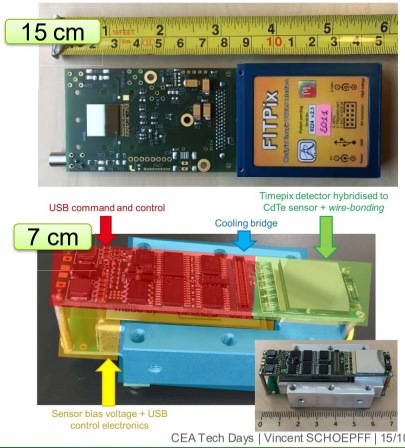


FROM CARTOGAM TO NANOPIX…

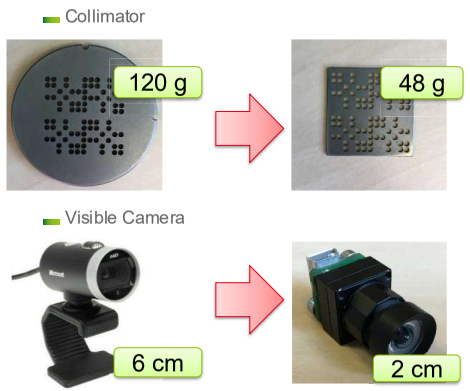
… MINIATURIZE ALL TECHNOLOGICAL BLOCKS

orano · X-RAY IMAGING EUROPE · IEAP CTU in Prague

Miniaturization of detector

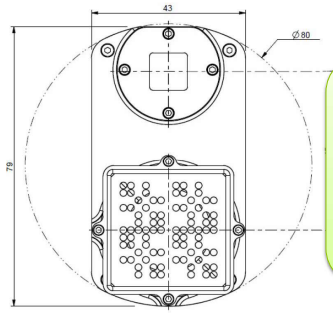


Miniaturization of other building blocks



FROM CARTOGAM TO NANOPIX…

… THE SMALLEST GAMMA CAMERA



8 cm x
5,1 cm x
4,3 cm
268 g!

orano

03

***Augmented*-NANOPIX**

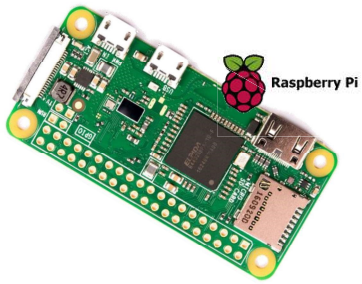
A CONCENTRATE OF INTELLIGENCE

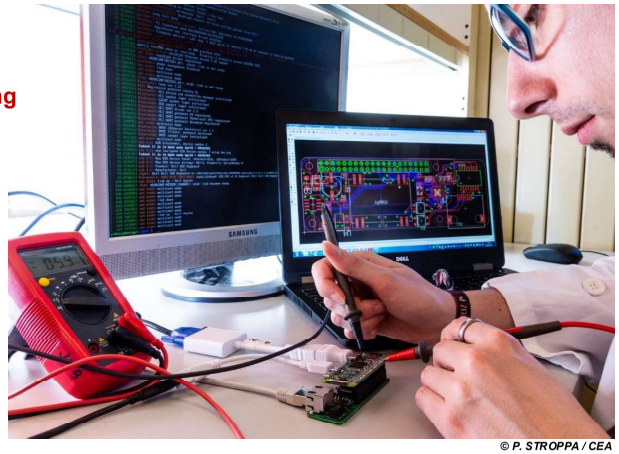
Augmented-NANOPIX…

… INTELLIGENCE CLOSE TO SENSOR

orano XIE X-RAY IMAGING EUROPE IEAP CTU in Prague

- Integration of **on-board computing** capabilities for **embedded preprocessing**



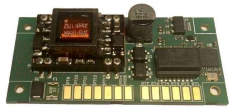


© P. STROPPA / CEA

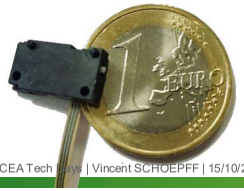
Augmented-NANOPIX…

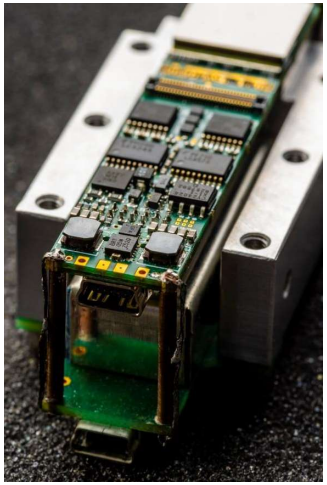
… Integrated State-of-the-Art Technologies

- **Advanced bias and communication electronics** (Power-over-Ethernet)

- Mini piezoelectric motor for **remote mask rotation**

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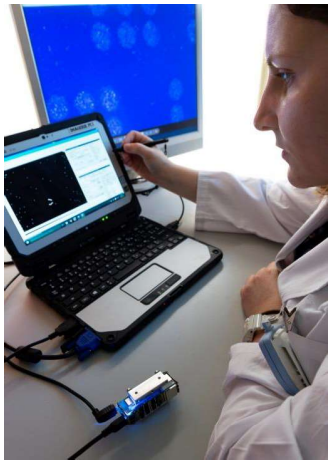
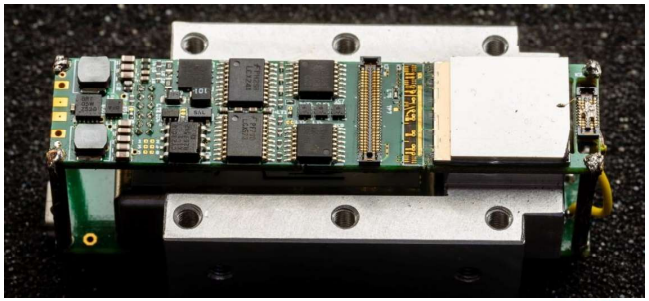
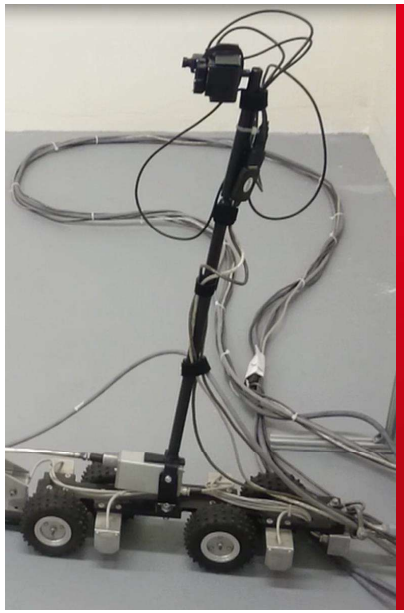
Augmented-NANOPIX…

… High Level Calibration of Sensor



- **Fine tuning and calibration** of the detector with **metrological** sources from **Henry Becquerel National Laboratory**
  (Attached to the French Metrological National Lab)
  ensuring **enhanced detection accuracy**


© P. STROPPA / CEA



04

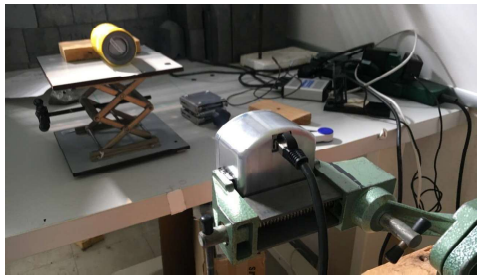
VALIDATION RESULTS

IN-LAB & ON-SITE MEASUREMENTS

Augmented-NANOPIX…

… Characterized in Laboratory

Same technology as GAMPIX → **SAME PERFORMANCES**



Angular Resolution: 6°

Field of View: 50°

Spectroscopy capability: Yes

Dose Rate info possible: Yes

RN	Activité	Sensitivity @ 1 m
^{241}Am	74 MBq	< 1s
^{137}Cs	33 MBq	60 s
^{60}Co	4,6 MBq	1200 s

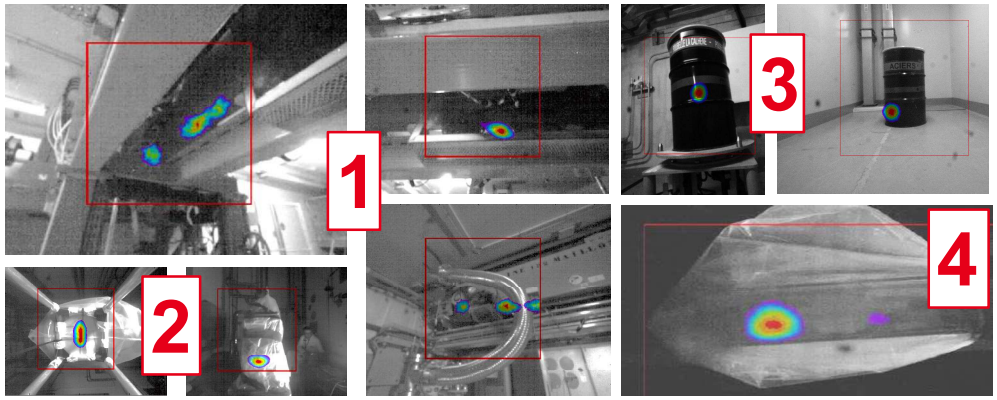
Dose rate range:
25 nGy.h^{-1} to > 30 Gy.h^{-1}

Energy range:
8 keV to 1.5 MeV

Augmented-NANOPIX…

… Validated On-Site (@ ORANO La Hague Fuel Processing Plant)

orano



1 | Contamination on guide rail
3 | Hot spots in drums

2 | Localized contamination due to liquid effluent
4 | Contaminated filter [2 hot spots with ¼ activity ratio]

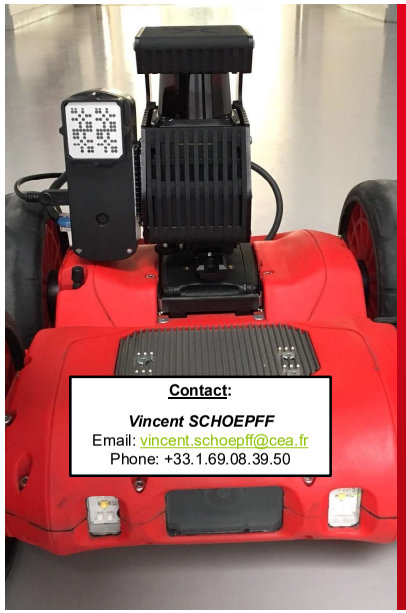
TERRIFFIC
ACCELERATED CBRNE RESPONSE

As part of a European Commission funded Research Program :

Embedment of NANOPIX miniaturized gamma camera **on robot** (UGV) **and drones** (UAV) for **area assessment**

nexter ROBOTICS

aeraccess airborne engineering research



Contact:

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Email: vincent.schoepff@cea.fr
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THANK YOU

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Commissariat à l'énergie atomique et aux énergies alternatives
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www-list.cea.fr

Établissement public à caractère industriel et commercial | RCS Paris B 775 685 019

TECH DAYS
INNOVATION FOR INDUSTRY
—
LIST DAY
OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

SYSTEMS FOR ONLINE MONITORING OF RADIOLOGICAL WATER CONTAMINATION

CEA Tech Days | Frédérick CARREL | 15/10/2019

OUTLINE

I. SAFEWATER SYSTEM FOR HOMELAND SECURITY PURPOSES

II. SAFEWATER OPTIMIZATION FOR D&D APPLICATIONS AND ONLINE TRITIUM MONITORING

III. CONCLUSIONS AND FUTURE DEVELOPMENTS

Commissariat à l'énergie atomique et aux énergies alternatives
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MAIN REQUIREMENTS FOR HOMELAND SECURITY APPLICATIONS

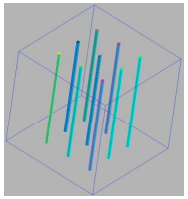
- New system to detect a **Beta and alpha contamination** threat in drinking water
- **Online** measurement (max 10 mn)
- **No influence**:
  - Temperature
  - Turbidity
  - Organic materials
  - High concentration of chlorine

PROJECT REQUIREMENTS – CHALLENGES

- For **beta** particles with an energy from 50 keV to 2 MeV the free path is from **43 µm to 1 cm**.
- For **alpha** particles with an energy from 3 MeV to 7 MeV the free path is from **18 µm to 62 µm**

Energy (MeV)	Range of Alpha		Range of Electron	
	Air 0,001204 g.cm⁻³	Water 1 g.cm⁻³	Air 0,001204 g.cm⁻³	Water 1 g.cm⁻³
5 keV	93,4 µm	989 Å	0,4 mm	450 nm
20 keV	313 µm	3775 Å	8 mm	8,5 µm
50 keV	660 µm	8150 Å	4 cm	43 µm
100 keV	1,1 mm	1,3 µm	13,5 cm	0,14 mm
500 keV	3,1 mm	3,6 µm	1,6 m	0,2 cm
1	5,2 mm	5,9 µm	4,1 m	0,4 cm
2	1 cm	11,4 µm	9 m	1 cm
3	1,7 cm	18,4 µm	13,7 m	1,5 cm
5	3,5 cm	37,3 µm	23 m	2,5 cm
7	5,9 cm	62 µm	31,2 m	3,5 cm
10	10,4 cm	110 µm	43 m[a]	5 cm
15	20,5 cm	215 µm	61,5 m	7,2 cm
20	33,6 cm	353 µm	78,4 m	9,3 cm
50	1,7 m	1,8 mm	161 m	19,8 cm
100	5,83 m	6,3 mm	263 m[b]	32,5 cm

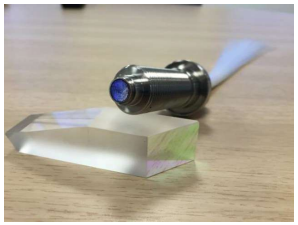
SAFEWATER: SENSOR DESIGN



MCNP calculation

Measurement volume is directly linked to the scintillating optical fibers

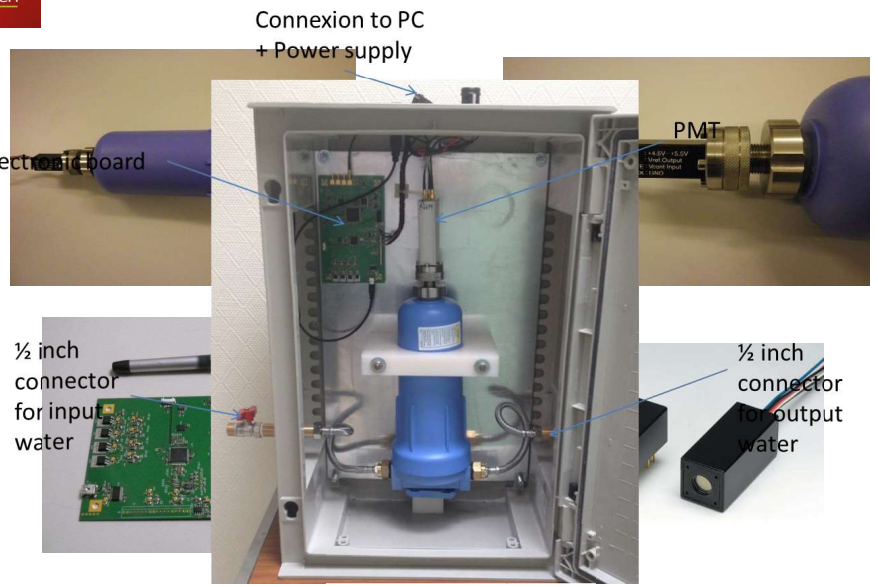
$$V_m = \pi * L * N * r * (r + d)$$



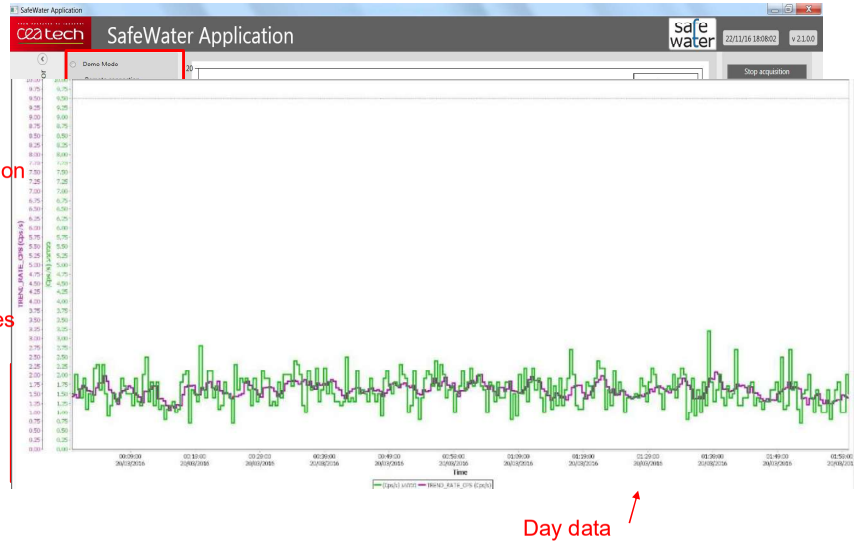
With :

- L length of the scintillating optical fibers,
- N number of fibers
- r the particle free path in water
- d diameter of fibers

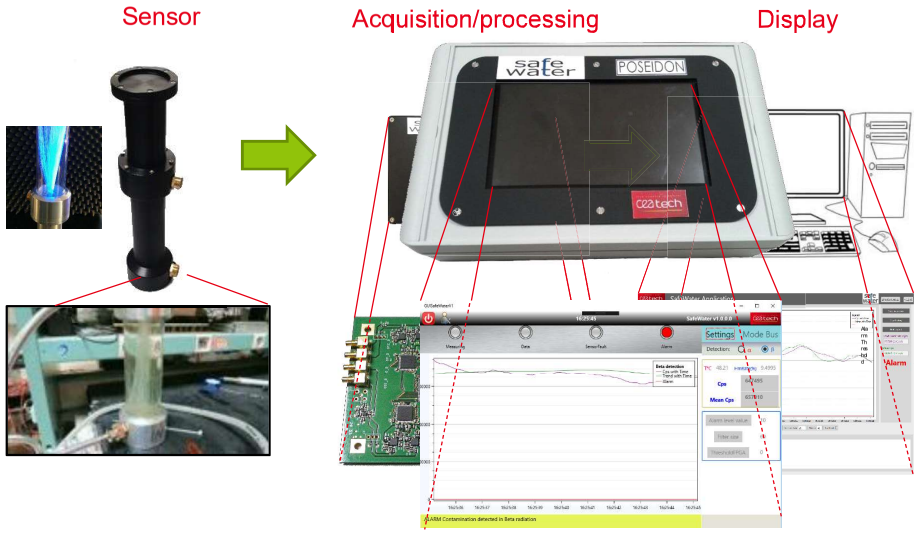
SYSTEM DESIGN – RELEASE 1



SOFTWARE DEVELOPMENT WITH SCADA DIALOG



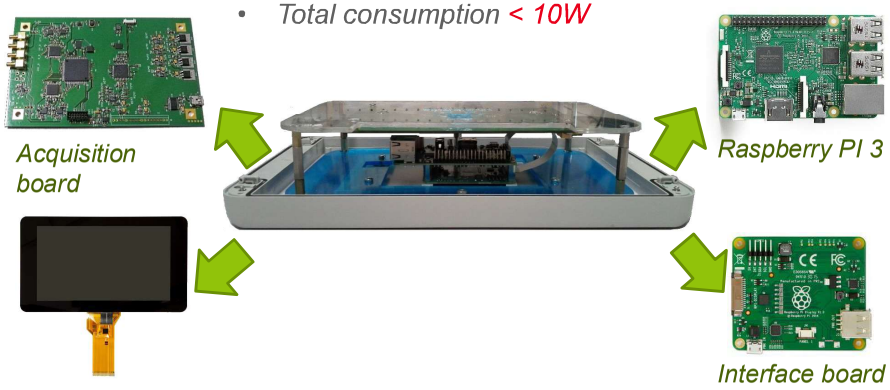
SYSTEM DESIGN – RELEASE 2



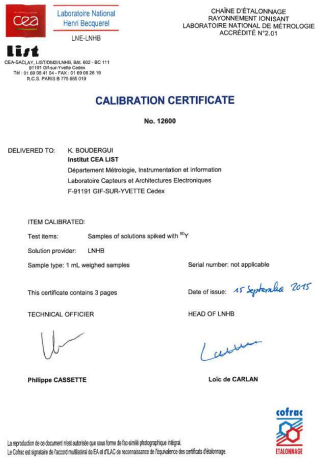
SYSTEM DESIGN – RELEASE 2

Acquisition and analyzes box:

- *Low power supply 5V/2A (standard)*
- *Total consumption < 10W*



MAIN RESULTS – LNHB CERTIFICATION



Laboratoire National Henri Becquerel
LNE-LNHB

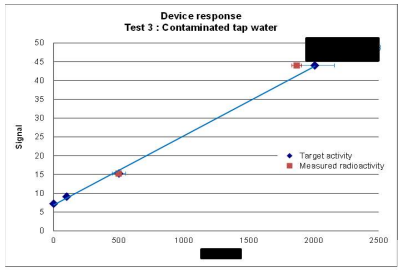
CHAÎNE D'ÉTALONNAGE
RAYONNEMENT IONISANT
LABORATOIRE NATIONAL DE MÉTROLOGIE
ACCREDITÉ N°2.01

CALIBRATION CERTIFICATE

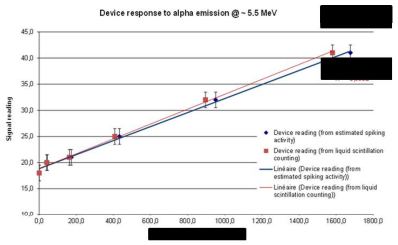
No. 12600

DELIVERED TO: K. BOUDERGUI
Institut CEA LIST
Département Métrologie, Instrumentation et Information
Laboratoire Capteurs et Architectures Electroniques
F-91191 GIF-SUR-YVETTE Cedex

ITEM CALIBRATED:
Test items: Samples of solutions spiked with ^{90}Y
Solution provider: LNHB
Sample type: 1 mL weighed samples
Serial number: not applicable
This certificate contains 3 pages
Date of issue: 15 September 2015
TECHNICAL OFFICIER: Philippe CASSETTE
HEAD OF LNHB: Loïc de CARLAN



Beta



Alpha

INFLUENCE OF NON RADIOACTIVE MATERIALS

- During **in-situ measurements** in HAGIHON (Israel), **variable conditions** with different water sources and contaminants (other than radioactive materials) have been evaluated:
  - Temperature
  - Turbidity
  - Organic materials
  - High concentration of chlorine

The sensor was **not influenced** by changes in water

SAFEWATER – SUMMARY OF THE MAIN CHARACTERISTICS

Physics:

Online measurements with 1s sample with a 60s smoothing buffer

- β detection efficiency:
  - 5,8 % for β with an energy <100keV
- Sensor detection volume:
  - 0.9 liter
- Detection limits:
  - α : ^{241}Am <200 Bq/l
  - β : ^{90}Sr <300 Bq/l et ^{131}I ≤400 Bq/l

Mechanical:

- Sensor cylinder: L = 427 mm, ø = 98mm,
- Weight: 1kg
- Electronic box:
  - 280 x 170 x 60 mm
  - Poids : 0,5 kg

Electric:

- 230V- 50Hz (or 110V- 60Hz), 40VA
- Total cconsumption <10W

Environmental:

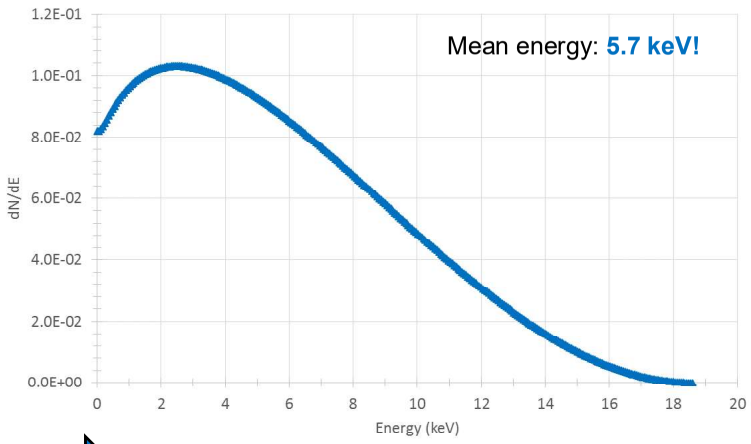
Temperature: 5°C à 45°C

Interface:

- Modbus protocol from Ethernet connection

TRITIUM ENERGY SPECTRUM

- **Energy spectrum of beta particles emitted by tritium**



Tritium is a real challenge because of the **very low energy** of emitted beta particles

SAFEWATER TRITIUM: MAIN DEVELOPMENTS

❑ SAFEWATER – Modified version

Simulation step → **Development step** →

Compatible with SAFEWATER design

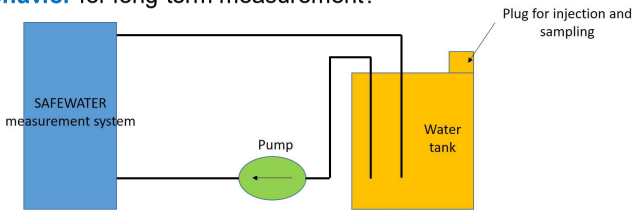
- **Replacement** of scintillating fibers by **ZnS:Ag sheets**
- **ZnS:Ag**: initially dedicated to the detection of **α particles**
- Also working for **β detection** using **homemade data processing**
- **Supply chain** compatible with the current action plan

Experimental validation is required

EXPERIMENTAL CONFIGURATION

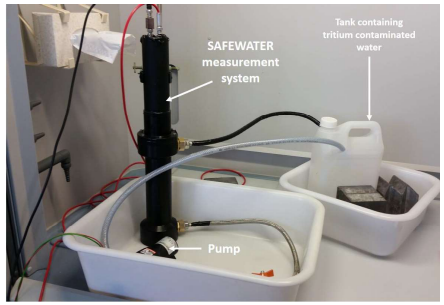
❑ Main characteristics of the experimental protocol

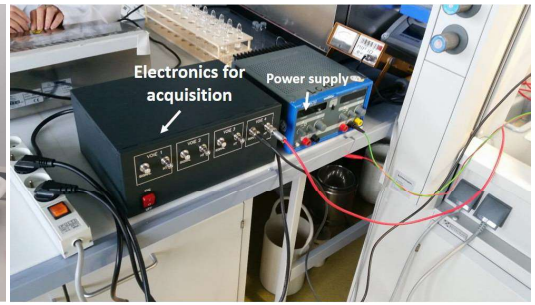
- Water flow rate controlled by a dedicated **pump**
- Controlled **tritium quantity** injected step by step
- Tritium level: 1 kBq.L^{-1}; 1.5 kBq.L^{-1}; 2 kBq.L^{-1}; 4 kBq.L^{-1}; 8 kBq.L^{-1}; 16 kBq.L^{-1}
- **Long time acquisition** for each tritium contamination level
- **Sequential acquisition** carried out for monitoring the behavior of the sensor in water
  - ✓ **Sensitivity** of the system according to the tritium level?
  - ✓ **Behavior** for long-term measurement?



EXPERIMENTAL CONFIGURATION

❑ SAFEWATER detection head and dedicated electronics





- ✓ Experimental set-up **rapidly deployable**
- ✓ **No water leak or failure** during the whole measurement campaign/Fully operational

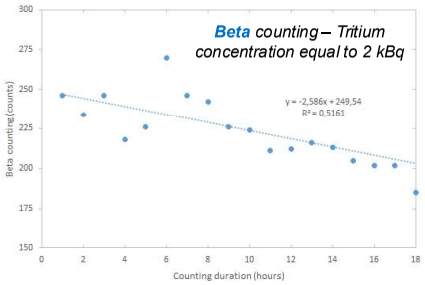
QUANTITATIVE RESULTS

❑ Evolution of the counting rate during tritium injection

- **Unexpected loss of sensitivity** of the system needs to be taken into account
- Study of the counting rate evolution **during tritium injection** from one level to another

Measurement time	Tritium concentration ($kBq.L^{-1}$)	Counting ($counts.h^{-1}$)
T=0 h	2	250 ± 16
T=6 h	2	234 ± 15
T=12 h	2	219 ± 15
T=18 h	2	203 ± 14
T=24 h*	2	187 ± 14
T= 0 h	4	287 ± 17
T= 6 h	4	253 ± 16

^3H injection



Increase of the counting rate statistically significant after tritium injection from **2 $kBq.L^{-1}$ to 4 $kBq.L^{-1}$**

** Extrapolated counting rate according to the fitting procedure*

MAIN CONCLUSIONS AND FUTURE DEVELOPMENTS

❑ Main conclusions

- ✓ SAFEWATER prototype: from the **idea** to the **optimized prototype** deployed during **in-situ measurements** (one year of operations in Israel without any failure)
- ✓ Design, **prototyping**, algorithms and software, **metrological characterization** using LNHB facilities and in-situ measurements
- ✓ SAFEWATER upgraded prototype for **tritium detection**: upgrade of the current prototype in a short period of time and first successful **experimental validation**

❑ Future developments

- ✓ **Optimize** the SAFEWATER prototype for tritium detection: improved sensitivity and robustness (main purposes of Phase 2)
- ✓ Prepare the **industrial transfer** of the different SAFEWATER prototypes

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TECH DAYS

INNOVATION FOR INDUSTRY

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LIST DAY

OCTOBER 15, 2019

KEIO PLAZA HOTEL, TOKYO

SIMULATION TOOLS FOR NONDESTRUCTIVE TESTING APPLICATIONS

CEA Tech Days | Christophe Reboud | 15/10/2019

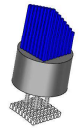
R&D ACTIVITIES AT THE NDT DEPARTMENT OF CEA LIST INSTITUTE

Embedding simulation tools in NDT devices

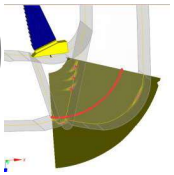
Real time imaging and post-processing

Sensors design

Flexible array probes

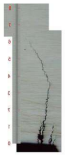


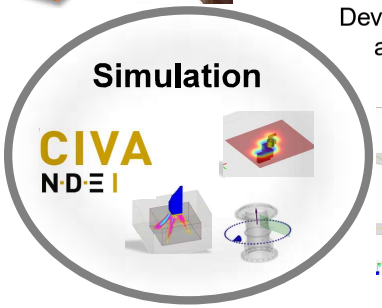
Development of imaging and reconstruction techniques



Characterization and diagnosis

Inversion, image processing, artificial intelligence techniques

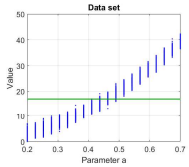


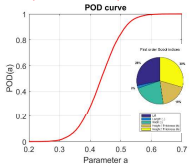


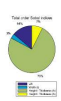
Reliability assessment

Management of uncertainties

Model assisted POD (MAPOD)







New NDT methods

Robotized NDT

Inspection of complex materials

KEY CHALLENGES IN THE FIELD OF NON DESTRUCTIVE TESTING

Enhancement of NDT techniques

- Modeling for designing new sensors and test new procedures

Flaw detection and characterization

- Sizing
- Shape / type (criticality)
- Confidence bounds on the estimation
- Well-posedness of the problem
- Fast inversion (online diagnosis)

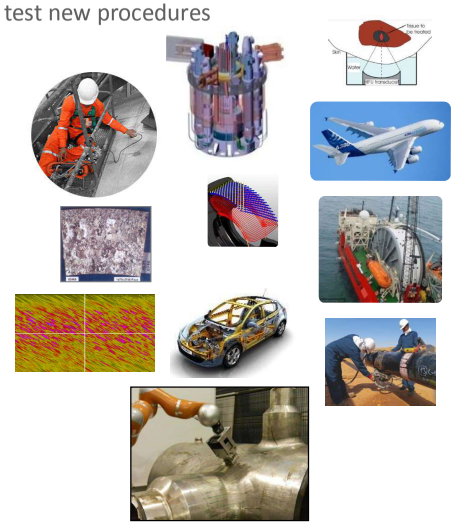
Material characterization

- Material ageing or in production
- New techniques (additive manufacturing)

Inputs for diagnosis, lifetime prediction

- (Structural Health Monitoring)

Demonstration of performance



OUTLINE

The CIVA simulation platform: collaborative R&D for technological transfer

Physical models for ultrasonic testing, electromagnetic testing, X-ray testing and infrared thermography

Metamodeling and learning techniques for optimization, characterization and management of uncertainty

Focus on the PYRAMID project: a French and Japanese collaboration to support decommissioning

CIVA FOR ACADEMIC COLLABORATION AND TECHNOLOGICAL TRANSFER

- Distributor in Japan: Insight k.k. company (insightkk.co.jp)
- Integration of codes developed by partners
- Collaborative platform in R&D projects
- Transfer of simulation / data processing tools to industry

National and international academic community : « **CIVAMONT** »

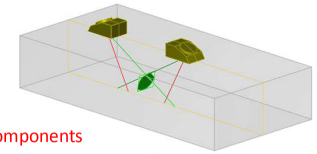
SIMULATION FOR NDT: ULTRASONIC INSPECTIONS

Pencil method model

1. Emitting probe:
Computation of the incident beam on the defect : ray model

2. Beam defect interaction:
Computation of the beam diffracted by the defect using dedicated model (including numerical ones) according to the defect and inspection configuration

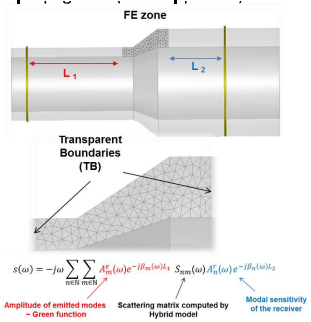
3. Echo in reception:
Received signal synthesis using Auld reciprocity principle



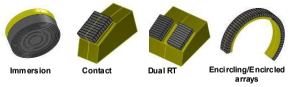
Components

FEM techniques dedicated to guided waves modelling

Coupling with semi analytical propagators (SAFE approach)

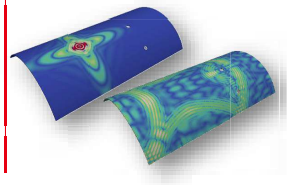


Probes



Spectral FEM in transient regime

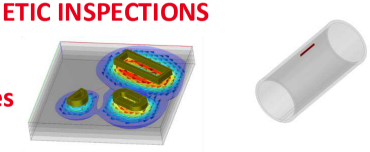
Applications :
- SHM in composite structures
- Bulk waves modelling in stratified composites
- ADVISE : account for microstructural effects



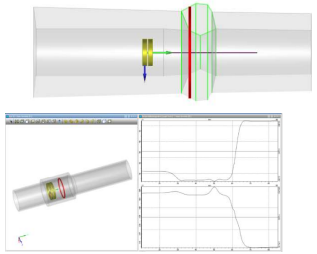
Defects

SIMULATION FOR NDT: ELECTROMAGNETIC INSPECTIONS

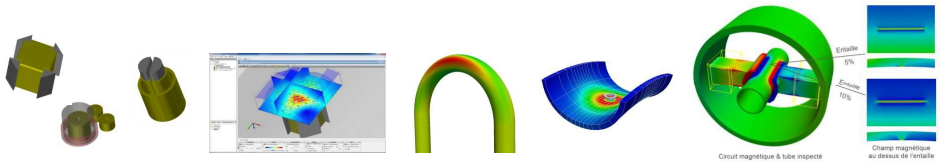
1. **Semi-analytical models for canonical geometries**
   Modal methods, Green dyads and integral methods for flaw interaction, reciprocity



2. **2D solver based on Finite Integration Technique**
   Numerical method, extension to symmetric 3D configurations (coupling with modal method)
   3D solver in Magnetostatics

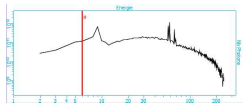


3. **3D solver based on Surface Integral Equation**
   Boundary element method



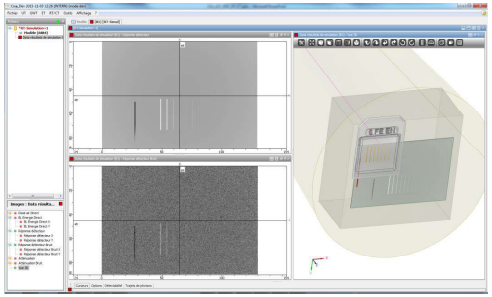
SIMULATION FOR NDT: RADIOGRAPHIC INSPECTIONS AND COMPUTED TOMOGRAPHY

- **Ray based** model (Beer Lambert law)
- Computation of **scattered field** (MODERATO code developed by EDF, Monte Carlo approach)
- **Sources** : X, gamma, linear accelerator
- **Detectors** : Radiographic film or DR (MTF, sensitive material, resolution, DQE…)
- **Flaws**, image quality indicators (**IQI**)



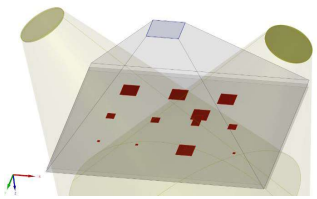
Computed tomography:

- 3D FDK algorithm (CPU/GPU),
- 3D iterative algorithms (SIRT/SART)
- 2D algorithm based on compressed sensing (PixTV)



SIMULATION FOR NDT: INFRARED THERMOGRAPHY (NOT YET RELEASED)

1. **Semi-analytical models for canonical geometries**
2. **2D solver based on Finite Integration Technique**



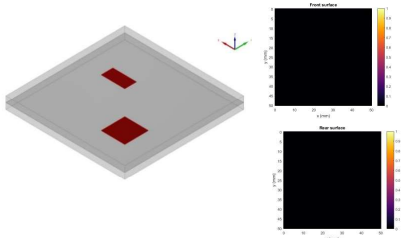
Challenges:

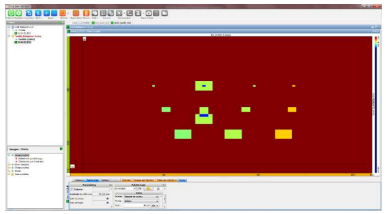
1/ Inspection of composite structures

Anisotropy, heterogeneity, delamination

2/ Inspection of metallic parts

Detection of small cracks, alternative to liquid penetrant testing, optimization of the induction heating

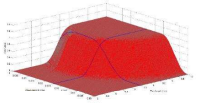


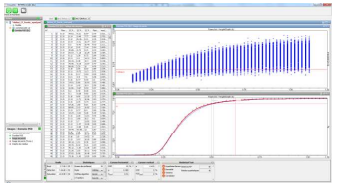


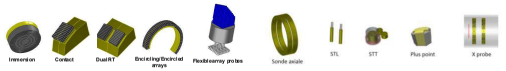
METAMODELING AND LEARNING TECHNIQUES FOR OPTIMIZATION, CHARACTERIZATION AND MANAGEMENT OF UNCERTAINTY

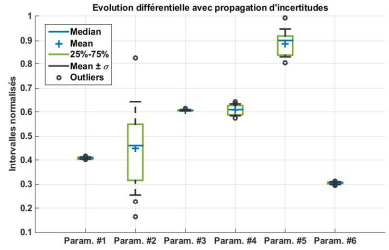
3 main applications requiring (almost) real time simulation tools

- Reliability assessment of NDT processes
- Flaw characterization and help to the diagnostic
- Sensors optimization



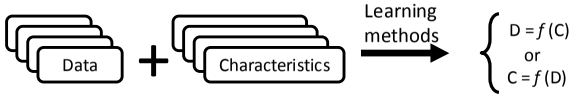






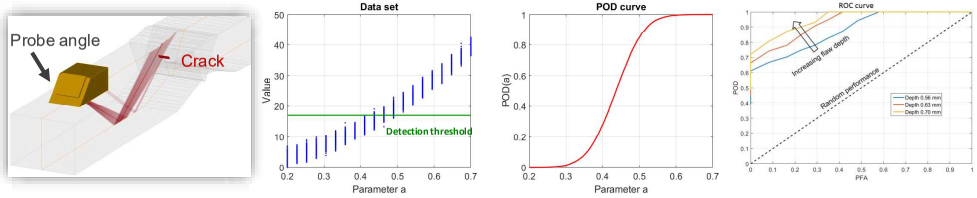
Solution proposed: replace the physical model with a metamodel

- Step 1: building the database
- Step 2: fitting an interpolator on the database

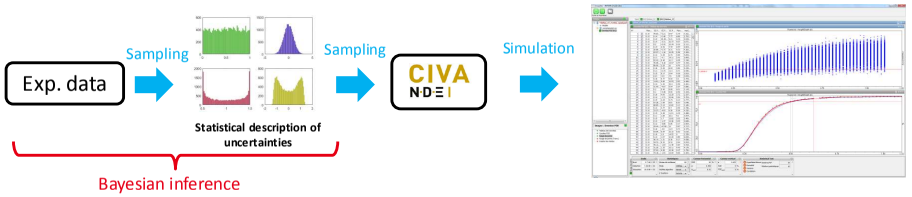


RELIABILITY ASSESSMENT OF NDT TECHNIQUES

- **Probability of Detection as a quantitative indicator of detection capability**



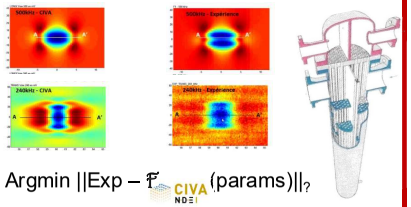
- **Model based POD calculations with uncertainty propagation**



MODEL BASED CHARACTERIZATION: SOLVING INVERSE PROBLEMS

Iterative methods

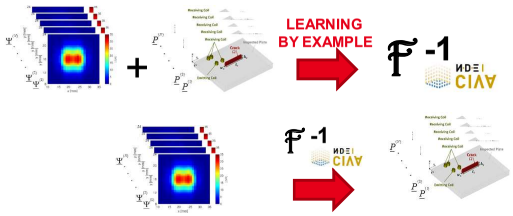
- Optimization of a cost function
- Minimizing the "distance" between simulations and observations



Argmin $||Exp - \mathcal{F}_{CIVA\ NDE}(params)||_2$

Construction of inverse operators

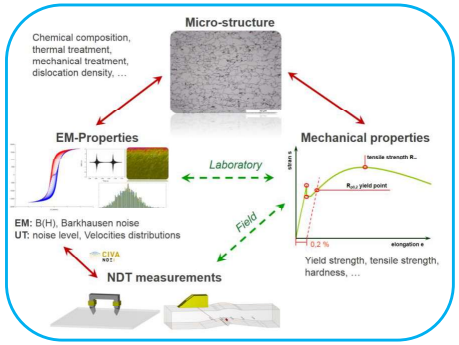
- Fitting of a regressor onto a training set of signals/parameters couples
- Robustness to noise (SVM)



- **Limitations: computational time, dimensionality, optimal training set, accuracy/robustness?**

MODELLING FOR CHARACTERIZATION OF MATERIALS

- Mechanical properties directly accessible through destructive tests
- Indirect link between them and macroscopic EM and UT properties (accessible in laboratory)
- Strategy of monitoring with NDT techniques:



1. **Use materials models** to describe EM and UT properties
2. **Simulate** NDT processes Characterize variability
3. **Learn** offline the correlation between Mech. Properties and NDT signals with a set of expertized samples
4. **Estimate online mechanical properties** from NDT signals

FOCUS ON THE PYRAMID PROJECT

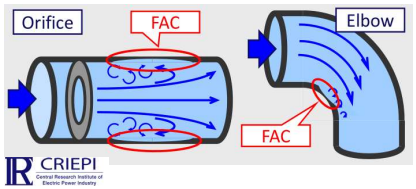
Piping sYstem, Risk management based on wAll thinning MonItoring and preDiction (Started in Nov. 2017)
http://pyramid.cfrend.tohoku.ac.jp/

Project Objective: develop new tools and techniques to detect and quantify wall thinning due to Slurry Flow induced Corrosion (SFC) in piping systems

Context: Strong demand of industry for corrosion monitoring solutions, Fukushima Dai-ichi nuclear plant decommissioning

FOCUS ON THE PYRAMID PROJECT

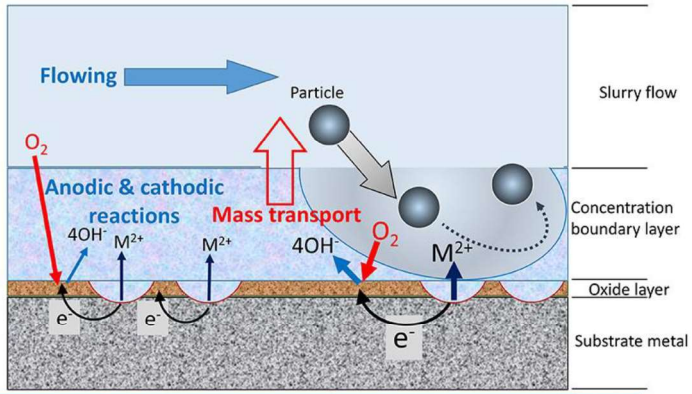
- Slurry Flow induced Corrosion (SFC) is a special case of Flow Accelerated Corrosion (FAC) in presence of a flow with a high concentration of debris of various kinds (concrete, corrosion, metallic…)



- Prediction of corrosion modes in elbows by numerical simulations
- Validation by electrochemical experiments under controlled mass transfer coefficient
- Model assisted design of Ultrasonic Non Destructive Testing (UT) methods to detect and characterize SFC
- Bayesian techniques and risk management assessment based on prediction-monitoring of wall thinning due to SFC

FOCUS ON THE PYRAMID PROJECT

Pipe wall thinning phenomena induced by flowing solid particles.



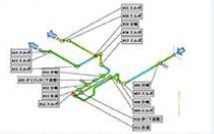
Possible mechanisms of enhanced corrosion due to interactions between surface and particle;
1. Disturbance of concentration boundary layer by particles
2. Direct mechanical effect of particles on oxide film

FOCUS ON THE PYRAMID PROJECT

ANR-MEXT Bilateral Program
Basic and Fundamental Technologies for Fukushima Decommissioning

PYRAMID (Piping sYstem, Risk management based on wAll thinning MonItoring and preDiction)

Modeling of solid-water phase flow and prediction of wall thinning



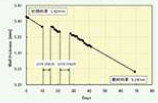
Evaluation of mass-transfer coefficient by numerical simulation and experiment.
【CRIEPI, Tohoku U.】

Electrochemical evaluaiton of corrosion under slurry flow. Mechanistic understanding of wall wastage phenomena.
【Tohoku U., INSA】

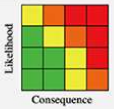
Distribution of mass-transfer coefficient
⇨ Indentify locations of monitoring

Development of EMAT monitoring system
【Tohoku U., INSA, CEA】

Monitoring of FAC wall thinning



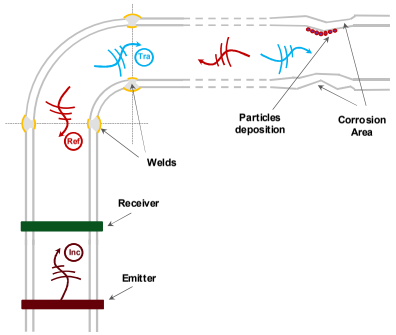
Engineering risk management system
【Gunma U., CEA】



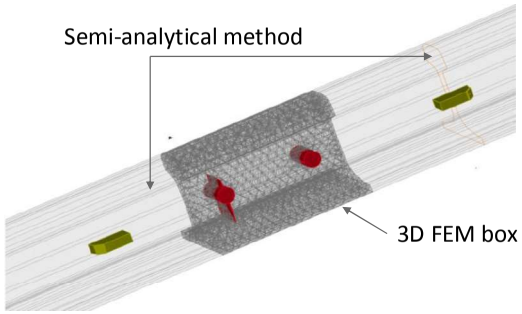
Engineering risk evaluation technique for piping system with combination of prediction and monitoring

CONTRIBUTIONS OF CEA LIST TO THE PYRAMID PROJECT

- Simulation of inspection by means of ultrasonic guided waves generated with an EMAT probe

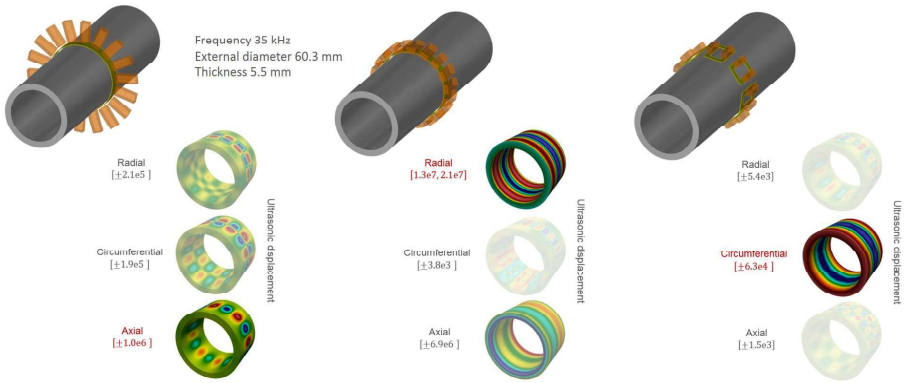


Hybrid modelling strategy: SAFE and FEM



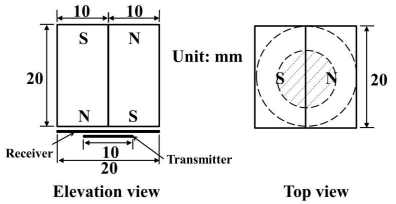
CONTRIBUTIONS OF CEA LIST TO THE PYRAMID PROJECT

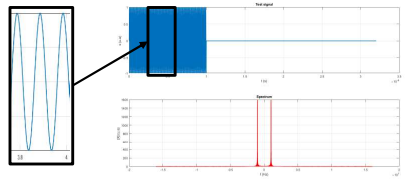
- **EMAT**: **E**lectro**M**agnetic **A**coustic **T**ransducer, generation of ultrasonic waves using an transient electromagnetic excitation
- Simulation of guided waves generated by different probe arrangements



CONTRIBUTIONS OF CEA LIST TO THE PYRAMID PROJECT

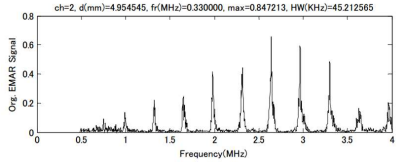
- Simulation of **local** thickness measurement with the electromagnetic acoustic resonance (**EMAR**) technique
- Generation of shear waves in a range of frequencies





Frequency sweep of the sinus part in the investigated range of frequencies

- Representation of the received signal amplitude w.r.t frequency sweep
- Resonance peaks observed correspond to frequencies verifying the relation



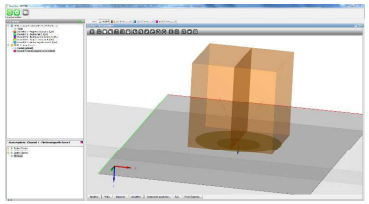
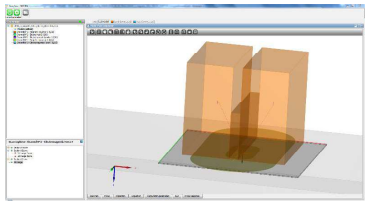
$$f \propto \frac{c}{2t}$$

c: shear wave speed
t: piece thickness
f: excitation frequency

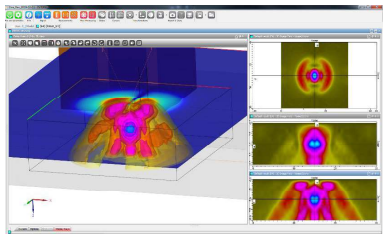
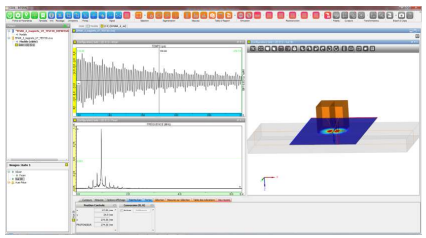
Indirect measurement of the piece thickness

CONTRIBUTIONS OF CEA LIST TO THE PYRAMID PROJECT

- Step 1: computation of electromagnetic source terms in the electromagnetic module

- Step 2: computation of emitted UT field and EMAR signals in the ultrasonic module

CONTRIBUTIONS OF CEA LIST TO THE PYRAMID PROJECT

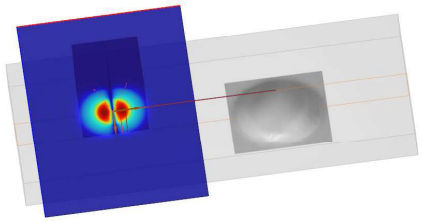
- Typical simulation result obtained with CIVA NDE

Resonance peaks carry information about the local thickness below the probe

CONTRIBUTIONS OF CEA LIST TO THE PYRAMID PROJECT

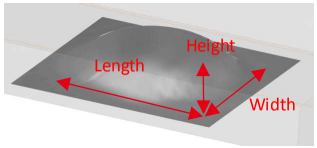
- Possibility to account for wall thinning by adding deformations to the piece

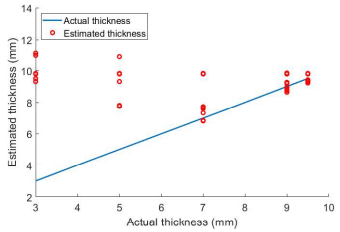
Illustration of the simulated UT paths in a corroded part



- Example of parametric study: effect of the deformation shape

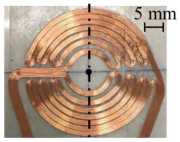
Length ∈ [4, 8, 12, 16, 20, 24, 28, 32, 36, 40] mm
Width = Length
Height ∈ [0.5, 1, 3, 5, 7] mm
50 simulations

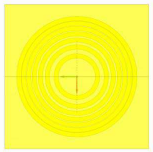




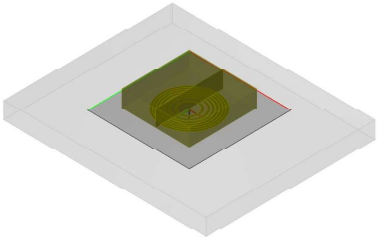
CONTRIBUTIONS OF CEA LIST TO THE PYRAMID PROJECT

- Simulation of specific probes arrangements developed at Tohoku Univ.

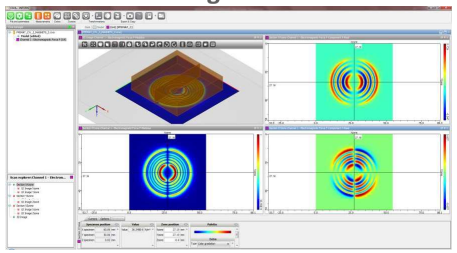




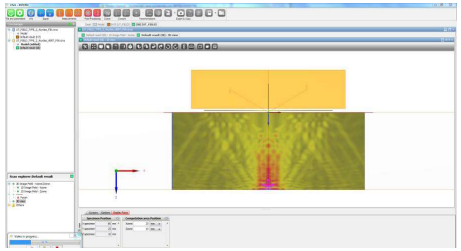
Type 2 (two coils)



Electromagnetic excitation



Ultrasonic propagation



CONCLUSIONS

- CIVA : multi-physics simulation platform aiming at federating the developments in the NDT community
- Great vector of technological transfer to industry
- Complex physical models made simple to use in ultrasounds, Xray, electromagnetics and (soon) thermography
- Data processing, machine learning tools for intensive simulation, inversion and management of uncertainty
- Focus on the PYRAMID project, aiming at develop new tools and techniques to detect and quantify wall thinning due to Slurry Flow induced Corrosion (SFC) in piping systems

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THANK YOU

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TECH DAYS

INNOVATION FOR INDUSTRY

—

LIST DAY

OCTOBER 15, 2019
KEIO PLAZA HOTEL, TOKYO

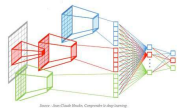
Artificial Intelligence : Opportunities for the Nuclear Industry

CEA Tech Days | Cédric Auliac | 15/10/2019

AGENDA

1. Bridging the gap between innovative sensors and data-sciences
   → The PACT software

2. Solving classical nuclear data mining problems with Machine Learning
   → From IGA to Deep Learning, new methods for Spectroscopy



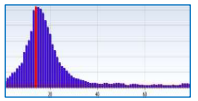
3. Leveraging nuclear experts knowledge with symbolic AI (ExpressIF™)
   → Crisis management & Non Destructive Testing

A Software for Seamless Integration of Radiological Sensors and Data-Science

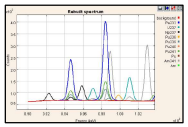
GOAL = Putting Sensors Expertise & Data-Science Together

Sensor → Data → Processing → Decision

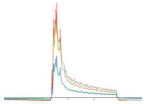

CZT Spectrometer

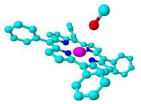

Spectrum

- Spectrum Analysis
- Signal Processing
- Image Analysis
- Machine Learning
- Optimisation
- …

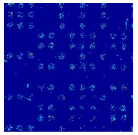

Nuclide Identification

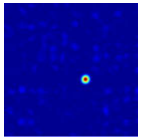

SAW Sensors


Signal


Compound Identification


Gamma Camera

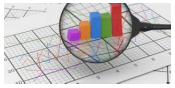
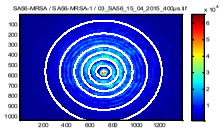
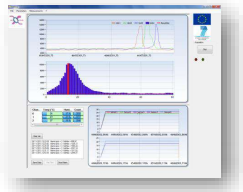

Raw Image


Final Image

SOLUTION = Sensors & Data-Processing Access Platform (PACT)

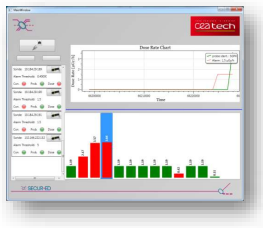
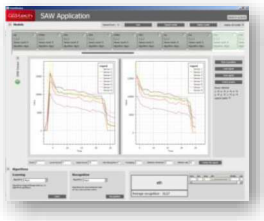


PACT

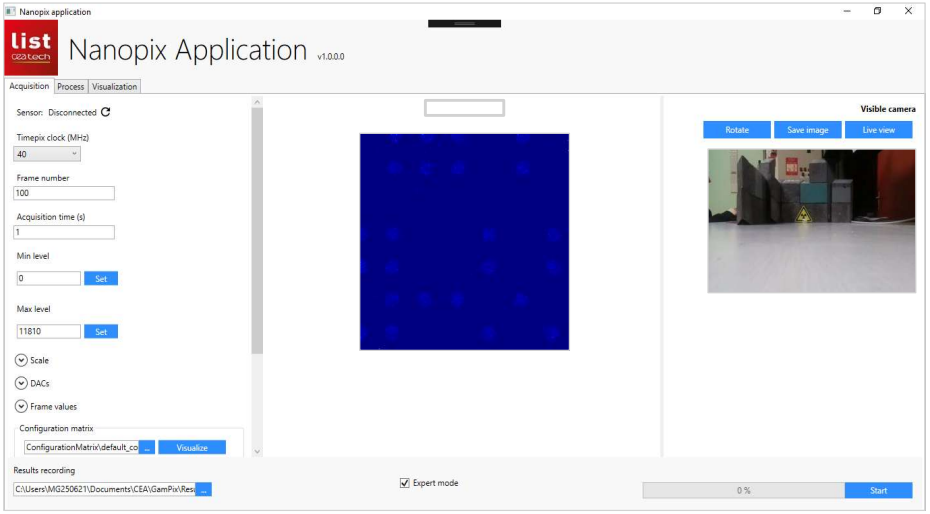
Key Features

- Genericity → 1 Sensor = 1 class that takes a data stream as input
- General purpose libraries
  - PACT.MATHS
  - PACT.SIGNAL
  - PACT.IMAGE
  - PACT.SPECTRUM
  - PACT.OPTIMIZATION
  - PACT.LEARNING
  - PACT.CONTROLS
- ~30 Specific algorithms
  - Gamma Camera
  - SAW
- 

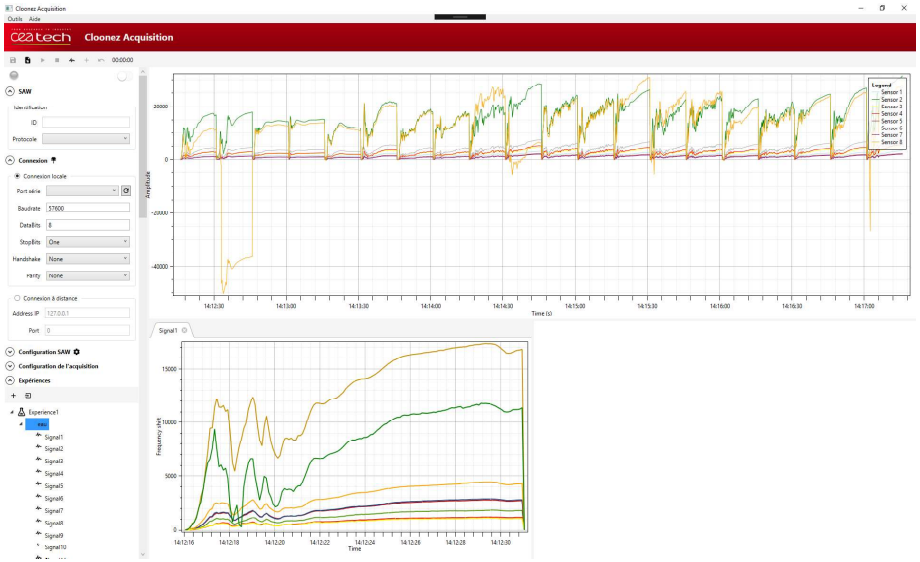



Example 1 : MONACO V2

Example 2 : NANOPIX V2



Example 3 : ESSAIM



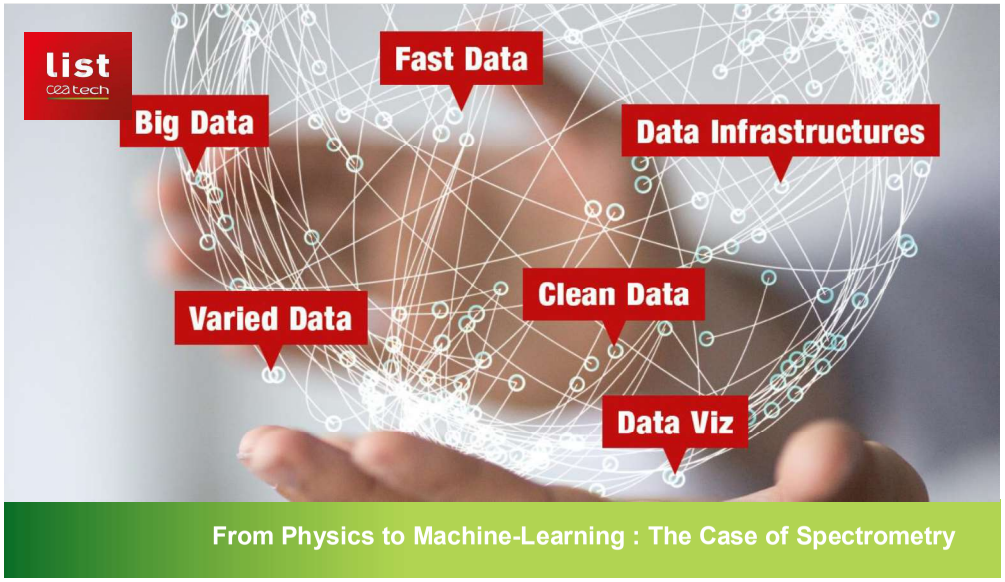
KEY FIGURES

10
Proprietary Sensors

12
Proprietary Algorithms

5
Projects in 2019

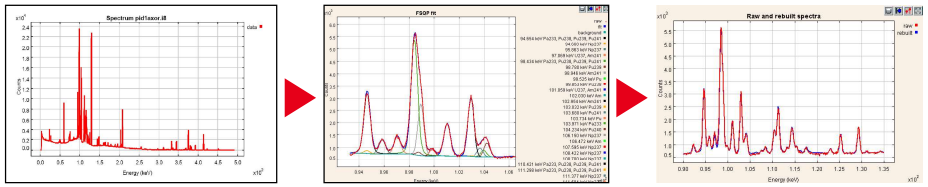
20 librairies / ~62000 lignes of code in C#



From Physics to Machine-Learning : The Case of Spectrometry

The Road so far : the IGA Software

- **IGA** (i.e. Actinides Gamma Isotopy) is a professional **software** dedicated at **characterizing** the **isotopic composition** from a Ge-HP γ/X spectrum



- Key principles
  - Formalizing and generalizing the reasoning of physicists (wrt spectra analysis)
  - Systematic exploitation of atomic and nuclear databases (ToRI & LARA)
- **Developed** by **CEA** LIST, with the support of **AREVA** NC (ORANO)
- **Commercialized** by **CANBERRA** (MIRION) and integrated within **GENIE 2000™**

Still a Complex Procedure

Peaks Area = Atomic & Nuclear Data X Efficiency X Mass Fraction

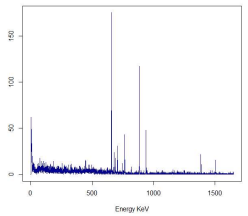
Measure (Spectrum γ/X)	Data	Unknown	Unknown $\left(\frac{m_{Pu238}}{m_{Pu\,tot}}, \frac{m_{Pu239}}{m_{Pu\,tot}}, \ldots\right)$

- Spectrum Type & Isotopes Identification
- Calibration (Energy & Resolution Estimation)
- Efficiency & Mass Fraction Estimation
- Consistency Tests

Isotopes	Fractions (%)	
	LD	IGA
Pa233	8.8e-010	8e-007
U237	7.3e-010	3.2e-008
Np237	1.1	23.6 ± 2.5
Pu238	0.039	0.12
Pu239	5	82.3 ± 1.9
Pu240	2.3	16.5 ± 1.8
Pu241	0.095	1.1
Pu242	.	0.48
Pu	7.5e-018	3.7e-018 ± 3.7e-018 *
Am241	0.0031	1.9
Am	6.8e-018	3.4e-018 ± 3.4e-018 *
Σ (normalized isos)	.	100

Nuclide Identification as a Machine Learning Problem

- **GOAL : Challenging IGA = Detecting** candidate **nuclides** in a Gamma spectrum (acquired Ge detector) **without human intervention or nuclear database**

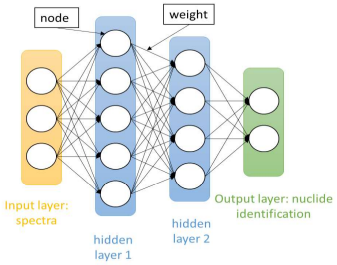


Nb-95?

- **Working assumptions :**
  - 200 nuclide candidates
  - Experimental conditions are stable & data points are abundant → Simulated spectra
- **Resulting Database:**
  - For each nuclide = a balanced database with 10 000 spectra (Train = 80%, Test = 20%)
  - Each spectra contains 30-60 different nuclides

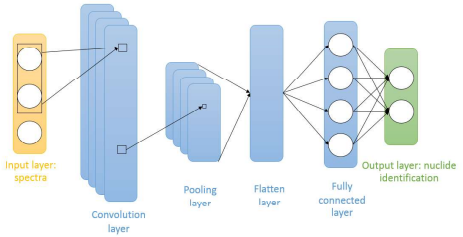
Building Detection Models from Data with Deep Learning

Artificial Neural Network **(ANN)**



Selection of:
- Number of fully connected layers
- Number of neurons per layer
- Activation functions of the neurons

Convolutional Neural Network **(CNN)**



Selection of:
- Number of layers
- Number of neurons per layer
- Activation functions of the neurons
- # Kernels, Kernel size, …

Example of Tests Results for Different Configurations

- **CNN with a preliminary configuration A**

F-scores (%)	60-70	70-79	80-89	90-100
# of nuclides	17	34	79	70
% of nuclides	9%	17%	40%	35%

- **CNN with an improved configuration B**

F-scores (%)	60-70	70-79	80-89	90-100
# of nuclides	-	9	36	155
% of nuclides	0%	5%	18%	78%

Execution time (on a regular desktop)
- **3 hours to train** a model over 8000 spectra
- **30 seconds to** charge and **apply** the model over the test set of 2000 spectra

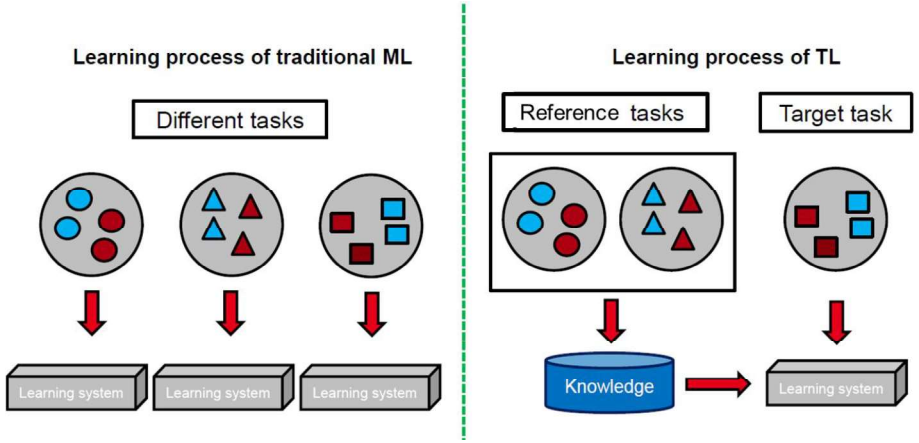
NEXT STEPS

QUESTION 1 = Can we use the model with different experimental set ups?

- STEP 1 = Assessing the **performances** of the **current models** against
  - new simulated spectra generated with ≠ configurations (e.g. geometries, filters)
  - real spectra generated through laboratory experiments
- STEP 2 = Comparing with **state of the art algorithm** (i.e. IGA)
- STEP 3 = Adjusting the model through **transfer learning**
  - A model has been learned in a reference configuration R
  - Can we use part of the knowledge, acquired in configuration R to tackle a new, but "similar" problem, in a new, target configuration T?

QUESTION 2 = Can we use this technology within embedded systems?

QUESTION 1 → Transfer Learning Concept

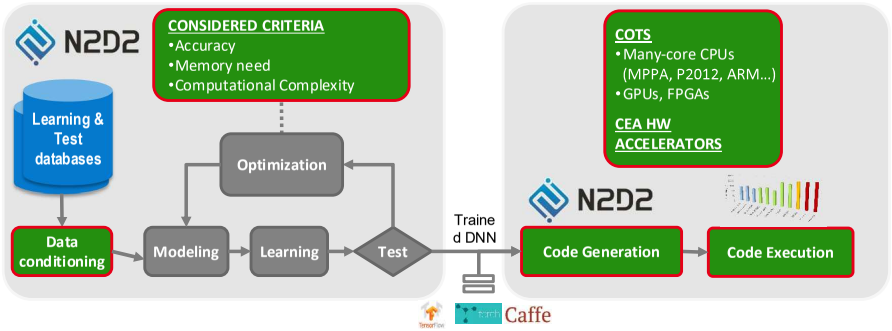


Pan, Sinno; Yang, Qiang; A Survey on Transfer Learning
IEEE Transactions on Knowledge and Data Engineering 22(10):1345 - 1359 · November 2010

QUESTION 2 → Tools for Accelerating/Embedding DNN

N2D2, CEA's Deep Learning Platform to address Embedded Systems' Challenges

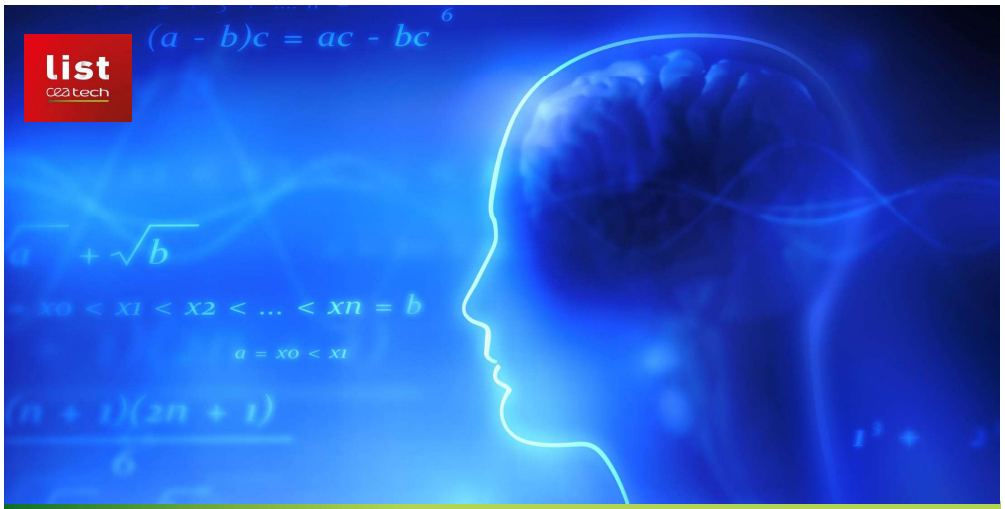
- Easy database access to facilitate the learning step
- Automatic code generation on various hardware targets
- Multiple comparison criteria : latency, HW cost, memory need, power consumption…



Try N2D2 now!

- Free download @ https://github.com/CEA-LIST/N2D2/

AppObjectRecognition/	AppFaceDetection/	AppRoadDetection/
Live object recognition application *based on ILSVRC2012 (ImageNet) dataset*	**Live face detection application, with gender recognition** *based on the IMDB-WIKI dataset*	**Simple road segmentation application** *based on the KITTI Road dataset*
		

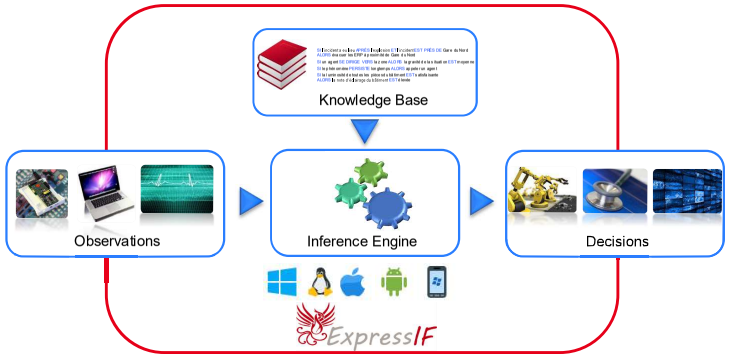


EXPRESSIF™

- Knowledge Modelling
- Automated Reasonning
- Decision Making

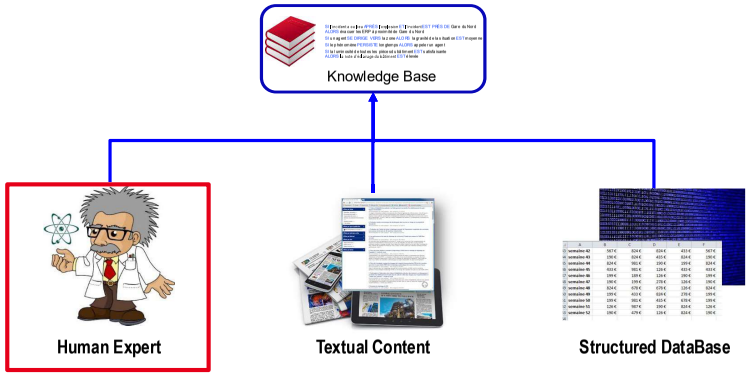
The Software Platform : EXPRESSIF™

- Portable & embeddable **software** library,
- for **real time « reasoning »** over real life observations,
- based on (expert) **knowledge** that is **formalised & capitalised** within a knowledge base.



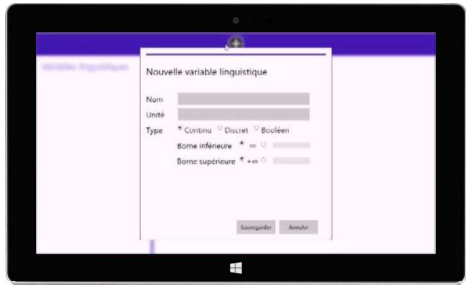
Building a Knowledge Base

Easing and **Automating Knowledge Extraction** from ≠ sources



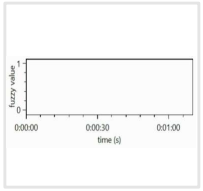
Buiding on top of human expertise (1)

Fostering Knowledge Modelling through the development of adapted HMI and logics to ease the translation of expert knowledge **into computational rules**



Buiding on top of human expertise (2)

Designing rich & **intuitive operators**
to **express naturally** complex **temporal & spatial behaviors** (e.g. reasoning over maps)

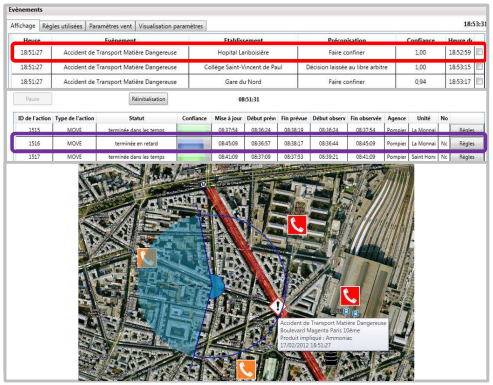


Application Example : Crisis Management

Scenario : **Monitoring** & supporting SAR **operations** in case of a **radiological accident**

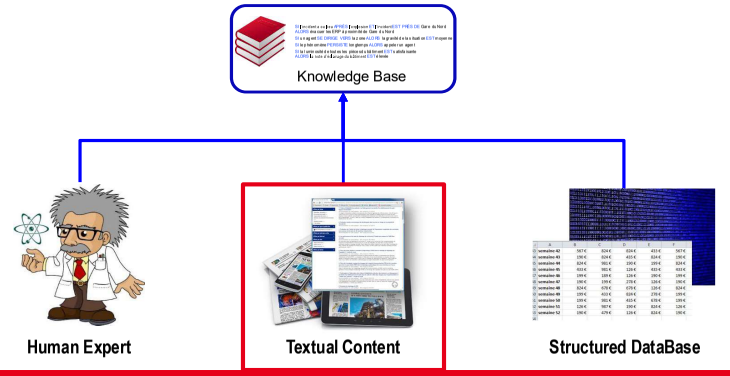
Event-processing platform using
- rule-based **expert system**
- spatial & temporal operators

1. Threats evolution
   → context (impact) monitoring
2. Decision support
   → mitigation recommendation
3. Operations monitoring



Building a Knowledge Base

Easing and **automating knowledge extraction** from ≠ sources



Using our LIMA technology to access the wisdom within experts reports or articles

LIMA
LIst Multilingual Analyzer

11 Languages

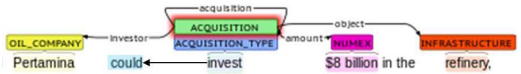
Multiple Industries

NLP tool of list

Natural Language Processing

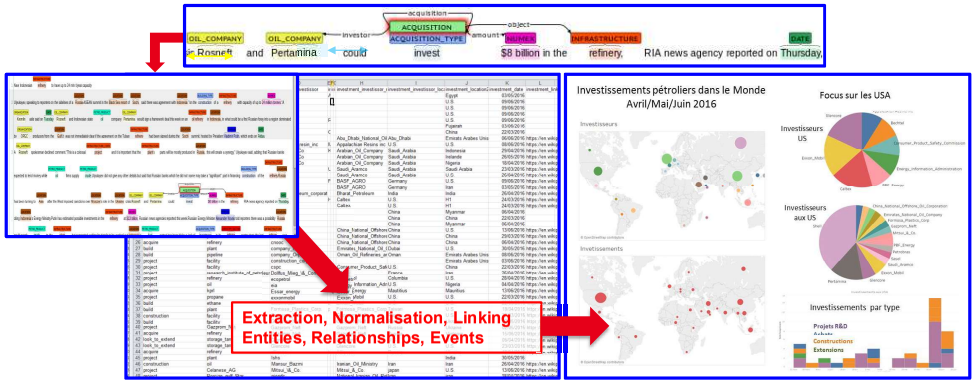
Use Cases :
- *Mining Textual Data*
- *Sophisticated Search Engine*
- *Chatbots*

- 10 years of developments
- Generic & Configurable
- State of the Art (Deep Learning)
- Open Source & Proprietary Tech,



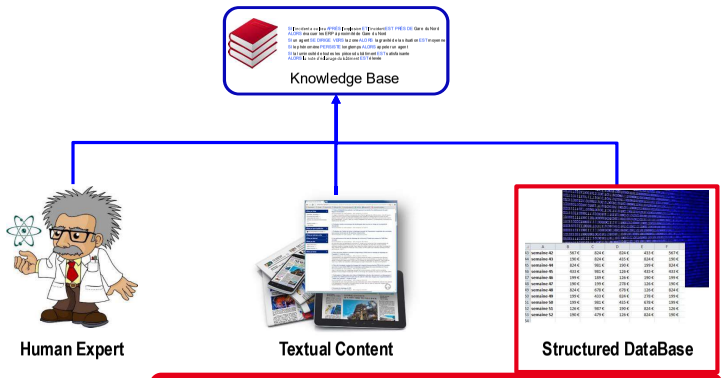
LIMA
Functionality Example = Information Extraction

Quantifying « oil & gas investments » **events**, all over the world, **based on press articles**



Building a Knowledge Base

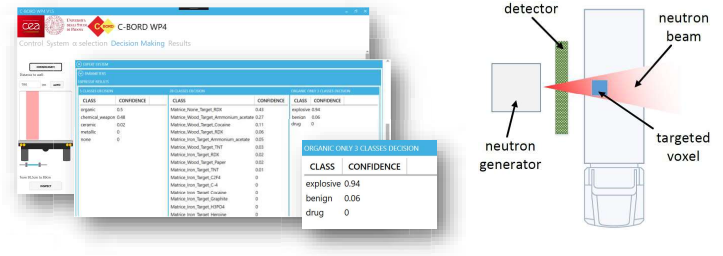
Easing and automating knowledge extraction from ≠ sources



Extracting knowledge directly from structured data thanks to new symbolic learning tools

Application Example : Blind Shipping Container Inspections

Learning the identification rules of a target compound using active neutron interrogation



- **Input**
  - 28 compounds
  - **7 examples per compound**
- **Output**
  - Compound detection/classification
  - → **Precision > 89%**

KEY FIGURES

4	8	20	550k
Patents	Projects in 2019	Publications	Rules/sec.

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THANK YOU

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LETI DAY TOKYO 2019

Emmanuel Sabonnadière
CEA-Leti CEO

leti
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LETI: A CEA TECHNOLOGY RESEARCH INSTITUTE

CEA,
#1 Innovative
Public Research
Organization
in Europe

Clarivate
Analytics

TOP 100 GLOBAL INNOVATORS SINCE 2011

"CEA is a key player in research, development
and innovation in four main areas:

defense and security,
nuclear and renewable energies,
technological research for industry,
fundamental research in the physical sciences and life sciences.

Drawing on its widely acknowledged expertise, the CEA actively
participates in collaborative projects with a large number of
academic and industrial partners"

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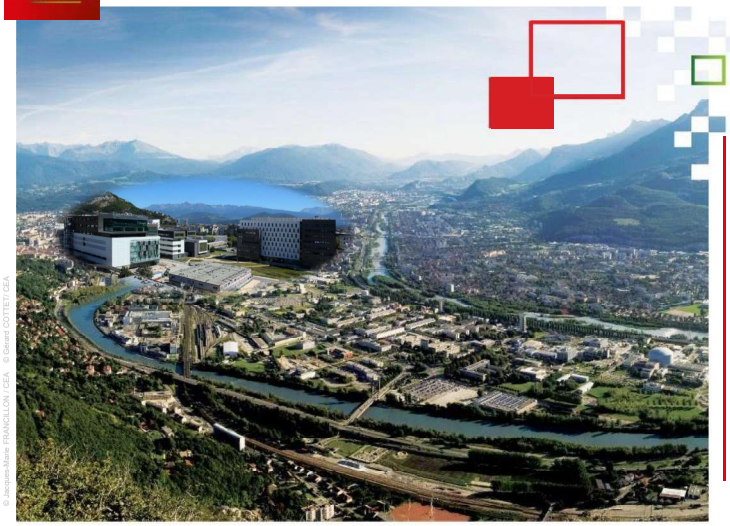
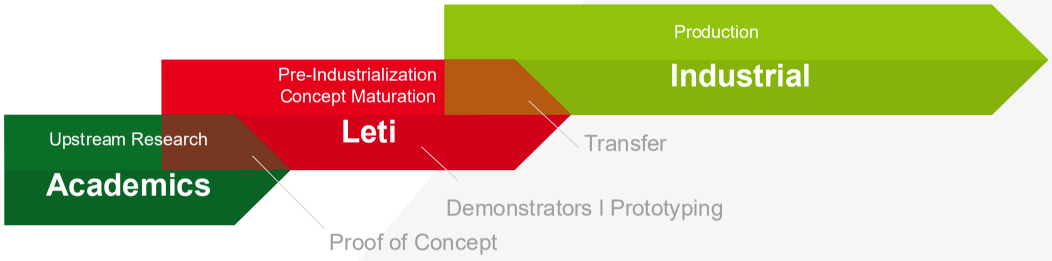


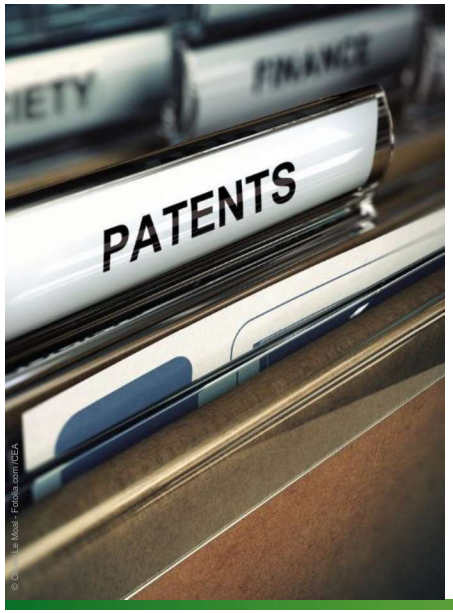
- Since **1967**
- France, USA, Japan
- **2,000** People
- **> 2,760** Patents in Portfolio
- **350** Industrial Partners
- **> 65** Startups Created
- **10,000 m²** Cleanroom 200-300mm
- **315 M€** Budget
  (**85%** from R&D contracts)

Committed to innovation,
Leti 's teams pioneer micro-& nanotechnologies
enabling smart, energy-efficient and secure solutions for industry

Bridging the Gap Between Academia and the Semiconductor Industry



- **Long-term partnerships**
- **Milestones-oriented** projects
- Highly available and flexible teams



Leti, 50+ Years of Expertise & IPs

2,760 Patents

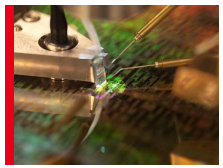
> 40% Under License Agreement

350 Patents Granted per Year

Clear IP policy

World-class infrastructures and platforms

Nanoelectronics Micro & Nanosystems



Photonics

Nano-biotechnology

Clinatec

IC & Embedded System Design

Nano-characterization

Leti's Silicon Platform

1	CMOS / FDSOI
2	BEYOND CMOS
3	POWER
4	MEMS
5	EMBEDDED MEMORIES
6	MEMORIES
7	IMAGERS
8	DISPLAY/LED
9	Si PHOTONIC
10	3D
11	SOI SUBSTRATE

300 mm 200 mm

Anytime, Anywhere, Any Devices

World Digitalization | Mobility | Digital Life | e-Health

A Cornerstone for your Semiconductor and ICT Innovations

Circuits & Systems
- Circuit Design
- System Integration
- Architecture Development

Hardware Technologies
- **More Moore (Scaling) – HPC & servers**
  FDSOI, Stacked GAA Nanowires, CoolCube™
- **More than Moore – Diversification**
  MEMS Sensors & Actuators, 3D integration
  Imagers & Displays, Si Photonics
  RF
  Power electronics

Hardware: Key Partners

st life.augmented · soitec · GLOBAL FOUNDRIES · intel · APPLIED MATERIALS · Lam RESEARCH

Equipment | Electronics | Energy | Communication 5G, RF

Systems: Key Partners

AIRBUS · Air Liquide creative oxygen · esa · SAFRAN · THALES · RENAULT · Valeo · Schneider Electric

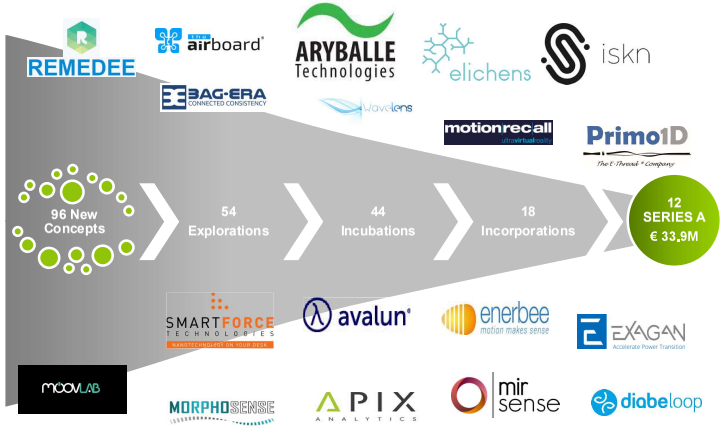
Multi-sensors | Interface | Energy | Digital platform | Cyber-security | Communication 5G, RF

Spin-Off: Another Way to bring Leti's deep tech solutions to market

LAST 5 YEARS
ALL STARTUPS COMBINED
€ 148.5M

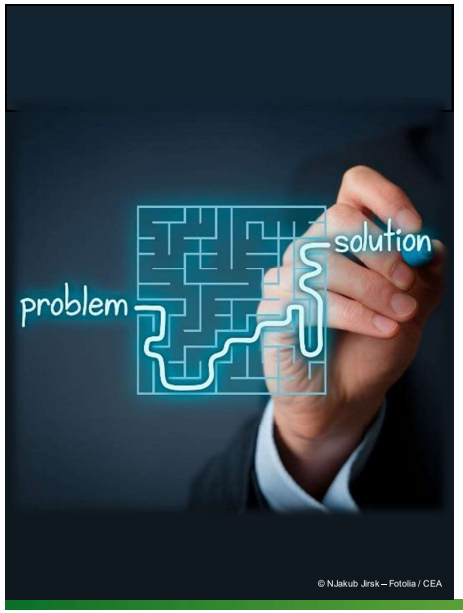
- € 2.2M – SERIES A
- € 7.8M – SERIES B
- € 13.7M – SERIES B
- € 30M – SERIES C
- € 23.6M – SERIES D

Start-up Program: 2013-2018 Key Figures



Latest rounds Last 12 months

REMEDEE	2.5 M€
DIABE loop	13.7 M€
APIX	7.8 M€
mir sense	2.2 M€
Aledia	30 M€
KALRAY	23.6 M€
elichens	7 M€
KALRAY	IPO

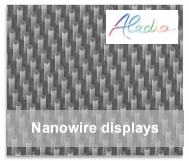


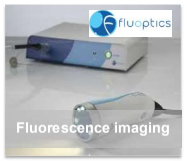
Client's Value at a Glance

- ✓ **PROOF OF CONCEPT AND PROTOTYPING CAPABILITY**
  including mass production constraints for fast technology transfer and reduced time to market.
- ✓ **KEEP CONTROL OF THE TECHNOLOGY**
  future transfer and negotiation with manufacturers
- ✓ **MASS PRODUCTION SOLUTIONS**
  Innovative breakthroughs that meets mass-market requirements
- ✓ **TRUST: LONG TERM BILATERAL PARTNERSHIPS**
  with year after years results and client satisfaction

R&D Program: 6 Major Steps

Example of Leti's innovations available on the market

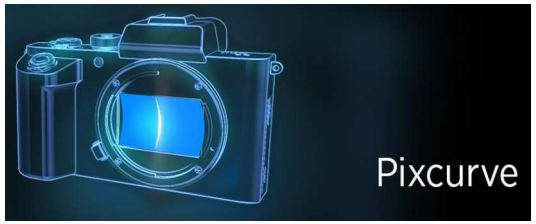




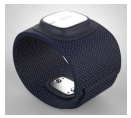
Leti @ CES

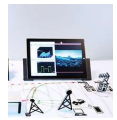
Demonstrators 2019

From research to industry… and consumers



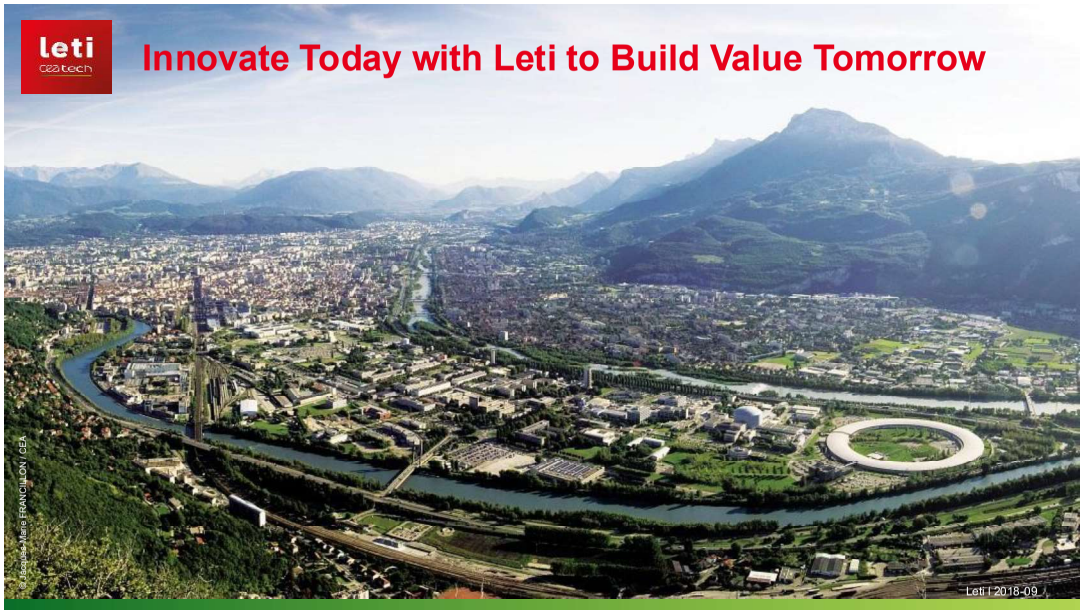
Demonstrators unveiled for the last 3 years





Worldwide Research Ecosystem

Innovate Today with Leti to Build Value Tomorrow



LETI DAY 2019
SEMI Market Outlook

Jim Hamajima, SEMI Japan
October 16th 2019

semi CONNECT - COLLABORATE - INNOVATE

Outline

- **SEMI Outline**
- **SEMI Industry Reports**
- **Industrial trends**
- **Trade War & Supply Chain**

SEMI Outline

SEMI *speeds the time to better business results* for its members across the global electronics manufacturing supply chain.

SEMI BRINGS THE WORLD TO YOU

- 1,000+ STANDARDS
- 20+ TECHNOLOGY COMMUNITIES
- 170+ PROGRAMS
- 2,260+ MEMBER COMPANIES
- 1.3 MIL PEOPLE SERVED
- 2,300+ PROGRAM HOURS
- 5,000+ VOLUNTEERS
- 7 SEMICONS

GLOBAL ADVOCACY
WORKFORCE DEVELOPMENT
TECH COMMUNITIES
MARKET INTELLIGENCE
STANDARDS/EHS
THOUGHT LEADERSHIP
EXPOSITIONS/CONFERENCES

semi

FROM MONOLITHIC DEMAND DRIVERS TO AN

EXPLOSION IN APPLICATIONS

Mainframe Computers	Personal Computers	Internet "The Web"	Mobile & Social Networking	IoT, Big Data &...
1970s	1980s	1990s	2000s	2010s

This is the ***most interesting*** time to be in the electronics manufacturing industry

- IoT/wearables
- Big Data
- Quantum Computing
- New Memory/Server Farms
- Virtual and Augmented Reality
- Autonomous Vehicles
- Artificial Intelligence
- Smart Manufacturing
- Digital Medicine
- …

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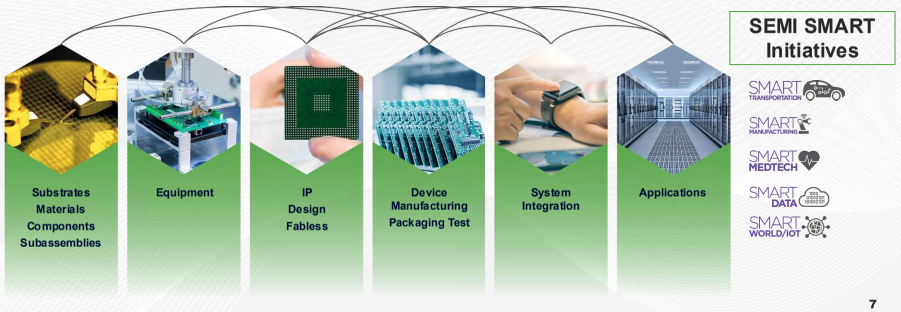
SEMI CONNECTS THE GLOBAL ELECTRONICS DESIGN & MANUFACTURING SUPPLY CHAIN

CONVERGENCE AND NEW DISRUPTIONS ARE ENABLING TRANSFORMATION OF MANY NEW COMPANIES TO DIGITAL ERA

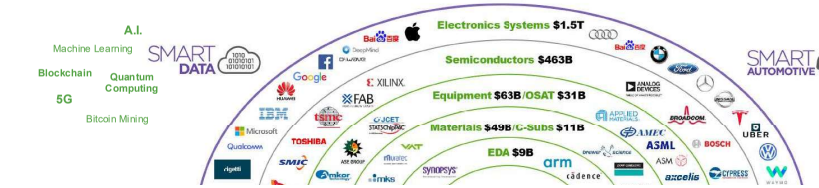


SEMI SMART Initiatives

- SMART TRANSPORTATION
- SMART MANUFACTURING
- SMART MEDTECH
- SMART DATA
- SMART WORLD/IOT

semi

BRINGING THE SUPPLY CHAIN TOGETHER IN 5 VERTICALS



A.I.
Machine Learning
Blockchain
Quantum Computing
5G
Bitcoin Mining
SMART DATA

Autonomous Vehicles
Fleet
Driver Assitance
Trucking
Drones
SMART AUTOMOTIVE

SEMI...Your Gateway to the $2T+ Electronics Supply Chain

Realtime Configuration
Robots
3D Printing
Industry 4.0
SMART MANUFACTURING
Adaptive Manufacturing

Smart City
AR/VR
Wearables
Fitness Tracking
IOT
Smart Home
Voice Assistant
CPS
Gaming
Agriculture

Human Performance Monitoring
CRISPR
Dosage Monitoring
SMART MEDTECH
Biometrics
Digital Health

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SEMI

VERTICALS

SMART TRANSPORTATION

ADAS market worth $67.4B by 2025.
Source: Grand View Research (2/18)

- Autonomous Vehicles
- Tracking
- Fleet
- Drones
- Driver Assistance

SMART DATA

AI direct revenue $36B, enabled areas $59B, in 2025.
Source: Grand View Research (5/17)

- AI
- Machine Learning
- Blockchain
- 5G
- Bitcoin Mining
- Quantum Computing

SMART MEDTECH

Wireless health market worth $315B in 2025.
Source: Global Market Insights (4/18)

- Human Performance Monitoring
- CRISPR
- Biometrics
- Digital Health
- Dosage Monitoring

SMART MANUFACTURING

Industrial IoT work $834B in 2025.
Source: Grand View Research (4/17)

- 3D Printing
- IIoT
- Industry 4.0
- Realtime Configuration
- Robots
- Adaptive Manufacturing

IOT

IOT annual economic impact of $3.9T to $11.1T by 2025.
Source: McKinsey Global Institute

- Smart City/Home
- AR/VR
- Gaming
- GPS
- Fitness Tracking
- Voice Assistant
- Wearables
- Agriculture

semi | FlexTech =170B*

*2017 revenue for semiconductor EDA, IP, Materials, Critical Sub-Systems, and Equipment

SEMI Standards

SEMI Standards Publishes Its 1000th Document

1000 SEMI STANDARDS & COUNTING

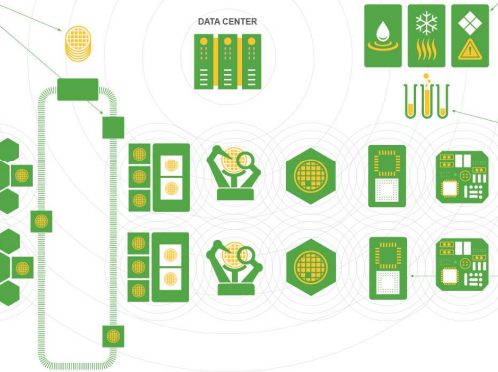
SEMI Standards

Standards Families for Electronics Manufacturing

Wafers & Substrates
- Wafer & Substrate sizes & specifications
- Wafer ID, ID reader/writer
- Wafer edge profiling
- Photomask registration marking
- Defects classification
- Substrate tracking
- Specs for GaA wafers
- Specs for Indium Phosphide wafers
- Silicon on insulator
- Shipping boxes

Equipment & Communications
- SECS-II and GEM
- Carriers and physical interfaces
- CIM framework
- Clustertools
- Recipe management
- Sensor & actuator networks
- I/O interfaces
- Equipment process control
- Human-machine interfaces
- Mass flow controllers
- Minienvironments
- Equipment training

Microlithography
- Lithography
- Photomask & Resist
- Defect inspection
- Design data exchange
- Reticle pads



Safety, Ergonomics & Facilities
- S2 Safety guidelines
- Chemical & gas distribution
- Chemical & gas testing
- Facilities – electrical
- Facilities – atmospheric
- Ultra-pure water specs
- Fluorocarbon compoents
- Stainless steel compenents
- Chemical hazards
- Fire safety

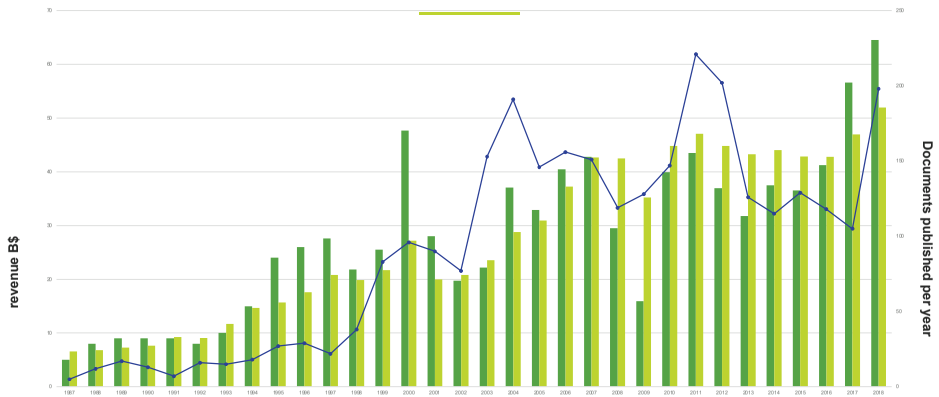
Chemicals & Gases
- Chemical & gas testing
- Gas particle specifications
- Processes for gases & specialty gases
- Water systems

Traceability
- Substrate and device tracking
- Device & wafer marking
- Carriers

Packaging
- Ball grid arrays & lead frames
- Automated test equipment & probers
- Molding compounds
- Package & chip carrier tooling
- Package specifications
- 3DS-IC packaging

1000 SEMI STANDARDS & COUNTING

Equipment, Materials Revenue and SEMI Standards Published each year



SEMI INDUSTY REPORTS & STATISTICS

SEMI

MARKET DATA REPORTS

Fab Forecast
Semiconductor, MEMS & Sensors, LED, Power Devices

- World Fab Forecast
- World Fab Watch
- Global 200mm Fab Outlook to 2022 New
- Global 300mm Fab Outlook to 2022 Q2 19
- Power and Compound Semiconductor Database

Equipment & Component Market

- Equipment Market Data Subscription
- North American Billing Report
- Semiconductor Equipment Market Statistics (WWSEMS)
- New Equipment Forecast
- Mass Flow Controller Report

Material Market
Semiconductor Materials

- Material Market Data Subscription
- Photomask Characterization Report
- Silicon Reclaim Wafer Characterization
- Global Semiconductor Silicon Report Q4 19

Packaging Materials/ Assembly & Test

- Global Semiconductor Packaging Materials Outlook
- China Semiconductor Packaging Market Outlook
- OSAT Manufacturing Sites Database

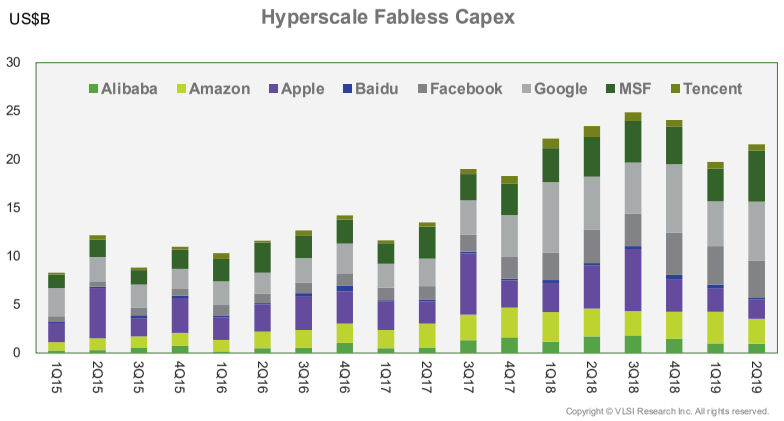
Regional/ Specialty Reports

- Global Semiconductor Packaging Materials Outlook
- China Semiconductor Packaging Market Outlook
- OSAT Manufacturing Sites Database

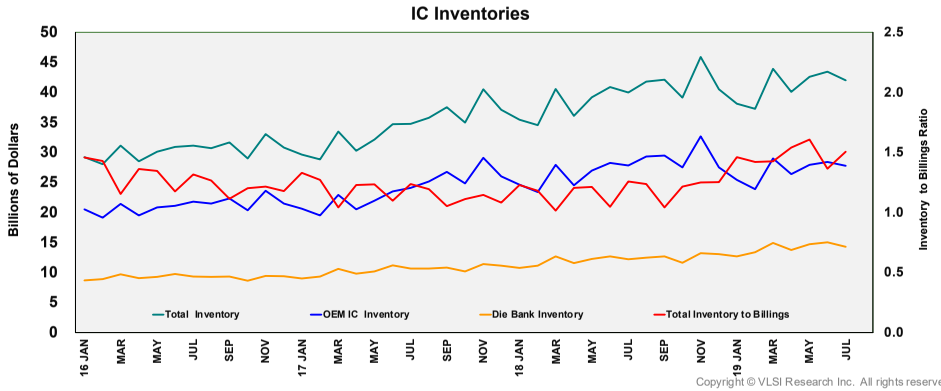
www1.semi.org/en/store

Year-to-Date Trend & Industry Headwinds

Weak Cloud Capex in 1H19 but @ another level of stage



Inventory Level Remains a Concern



2019 Year-to-Date Trends

Year-to-Date Equipment Trends

$Billion	2019 YTD (July)	2018 YTD (July)	Year/Year %
Europe	1.55	2.68	-42%
Japan	3.44	5.15	-33%
North America	4.03	3.06	32%
Korea	6.19	12.03	-48%
Taiwan	7.80	5.22	49%
China	6.77	7.89	-14%
Rest of the World	1.42	2.50	-43%
Total	**31.22**	**38.56**	**-19%**

Source: SEMI/SEAJ Worldwide Semiconductor Equipment Market Statistics Report, August 2019

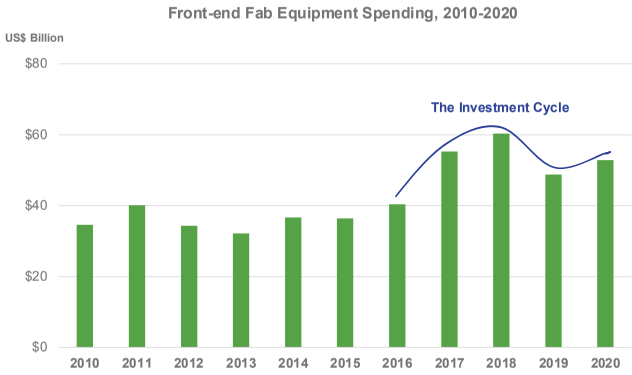
Year-to-Date Device Trends

$Billion	2019 YTD (July)	2018 YTD (July)	Year/Year %
Americas	41.7	57.47	-27.4%
Europe	23.29	25.14	-7.4%
Japan	20.39	23.14	-11.9%
China	79.35	90.00	-11.8%
Asia Pacific/ All Other	63.92	71.49	-10.6%
Total	**228.66**	**267.25**	**-14.4%**

Source: WSTS Blue Books

Fab Investment Outlook

Fab Investment – *Deep Correction in 2019*

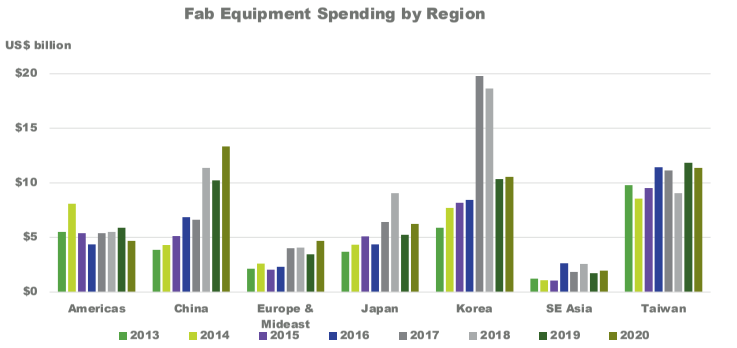


Source: Prelim. World Fab Forecast Report, August 2019, SEMI

- 2019 investment correction is deeper than previously expected
- 2019 will see spending correction by ~20% due to near-term demand weakness and excess inventory throughout the supply chain
- 2020 recovery may be smaller than previously anticipated with close to 10% increase supported by memory capex and China projects

Fab Investment by Region

Strong Taiwan Investment, Sharp Decline in Korea

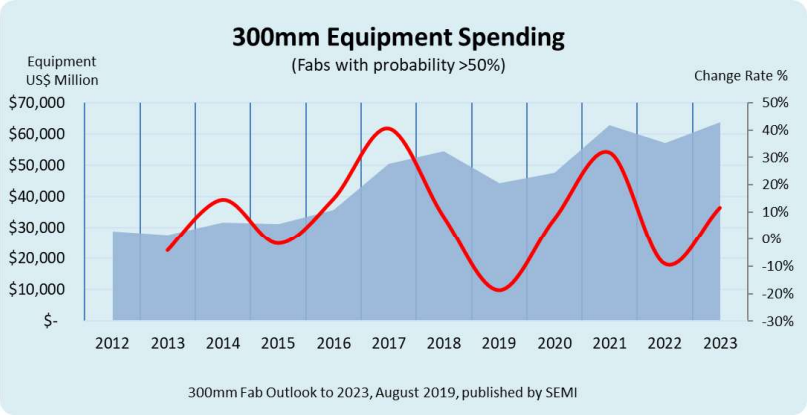


Source: Prelim. World Fab Forecast Report, August 2019, SEMI

YoY Change	2018 to 2019 (%)	2019 to 2020 (%)
Taiwan	+30%	-4%
America	+7%	-20%
China	-10%	30%
Europe	-15%	35%
SEA/ROW	-33%	14%
Japan	-42%	19%
Korea	-45%	2%

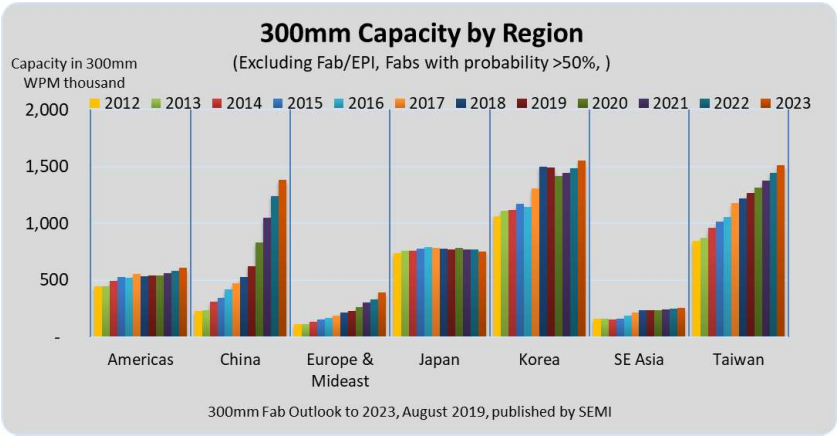
300mm Fab Outlook

300mm Equipment Spending Forecast



Source, SEMI August 2019

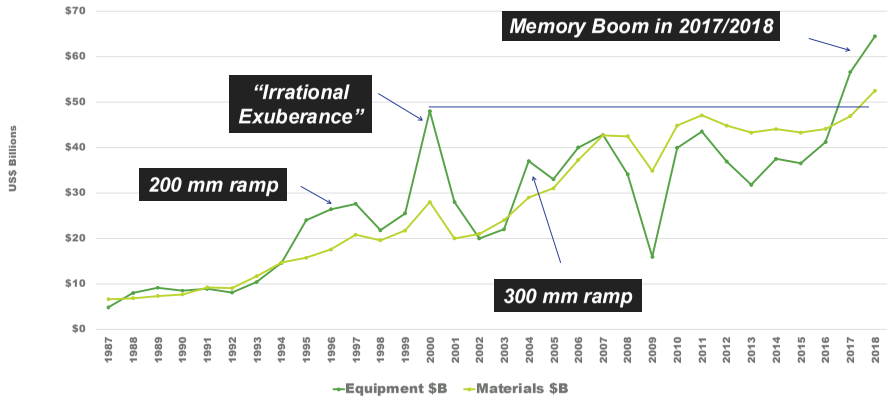
300mm Fab Capacity by Region



Source, SEMI August 2019

Equipment and Materials Forecasts

Total Equipment Revenue vs. Total Material Revenue Trends



Source: Equipment: SEMI/SEAJ
Materials: Rose and Associates 1987-1999, SEMI 2000-present

Worldwide Wafer Fab Materials Forecast

	Actual			Forecast	
	2016 US$ B	2017 US$ B	2018 US$ B	2019F US$ B	2020 US$ B
Silicon Wafers[1]	$7.65	$9.25	$12.10	$11.84	$11.99
Photomasks[2]	3.32	3.75	4.04	4.14	4.29
Photoresist	1.45	1.60	1.73	1.71	1.73
Photoresist Ancillaries[3]	1.91	2.11	2.28	2.27	2.29
Wet Chemicals[4]	1.59	1.88	2.16	2.20	2.35
Gases	3.63	3.87	4.27	4.25	4.29
Sputter Targets[4]	0.67	0.74	0.78	0.75	0.79
CMP Slurry & Pads[4]	1.67	1.85	2.17	2.13	2.34
Other/New Materials[5]	2.96	3.14	3.49	3.48	3.68
Total	$24.84	$28.19	33.02	32.77	33.76
Y-o-Y % Growth	4%	13%	17%	-1%	3%

Totals may not add due to rounding

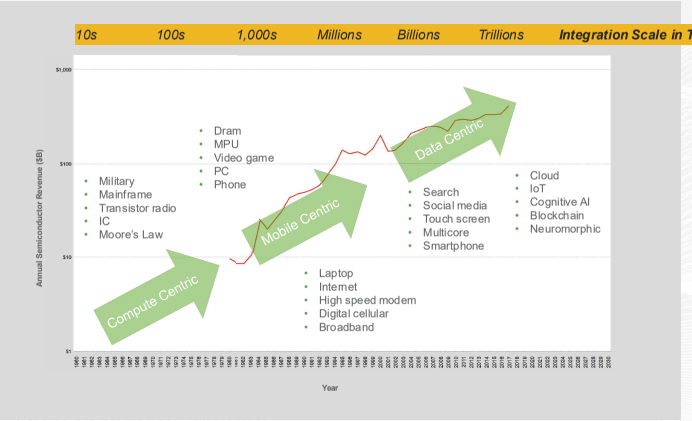
Source: Materials Market Data Subscription, August 2019, SEMI

Annual Trends Snapshot

	2018	2019F	2020F	2018 Y/Y %	2019 Y/Y %	2020 Y/Y %
Device (WSTS, June 2019)	$469 B	$412 B	$434 B	14%	-12%	5%
Equipment (SEAJ/SEMI; SEMI Forecast Sept. 2019)	$64.5 B	$52.1 B	$55.8 B	14%	-19%	7%
Total Materials (SEMI, August 2019)	$52.7 B	$52.5 B	$53.8 B	11%	0%	3%
Wafer Fab Materials	$33.0 B	$32.8 B	$33.8 B	17%	-1%	3%
Packaging Materials	$19.7 B	$19.7 B	$20.1 B	3%	0%	2%

Industrial Trends

NEW DISRUPTIONS ARE DRIVING EXPONENTIAL GROWTH IN IC INDUSTRY



$500 Billion
in 50 years

$1 Trillion
in the next 10-15 years

Sources: IC Insights & VLSI Research

30

MEGATRENDS

- 5G
- AI/ML
- Autonomous driving
- Energy
- MedTech
- Broader view
  - The workforce of the future
  - Automation & robotics
  - Circular economy
  - Education in technology
  - Open source

31

OUR NEW DIGITAL & CONNECTED WORLD

~30B
connected devices today

200M+
connected devices every day

500B – 1T
connected devices is expected to more than double by 2030

ECONOMIC GROWTH

CONNECTIVITY IS DRIVING
$13T → **DIGITAL ECONOMY IN 2025**
$23T

Source: Statistica

8

DIGITAL ECONOMY DISRUPTIONS…

WHAT IF WE COULD HAVE FORSEEN?

Streaming for Everything
(entertainment to home repair)

Digital-Powered Sharing Economy

Genome Sequencing
(CRISPR gene editing)

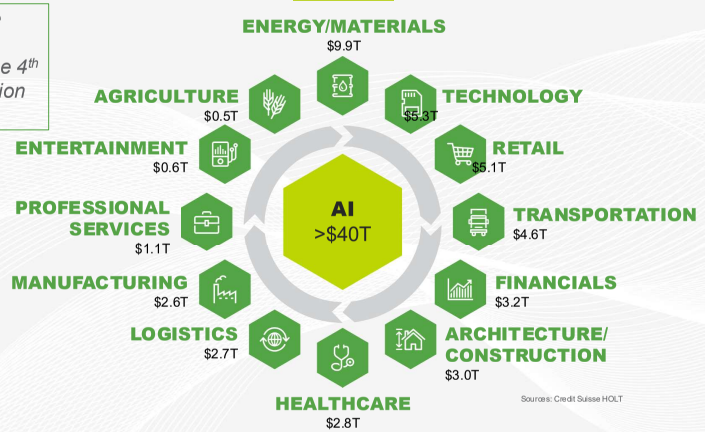
Social Media as Policy Platform

AR/VR Assistant &Visualization

Navigation & "Nearby"

AI IS INTERSECTING VIRTUALLY ALL INDUSTRIES

AI, 5G/6G are *the most promising catalysts to put the 4th Industrial Revolution on a fast track*



Sources: Credit Suisse HOLT

Trade Wars & Supply Chain

Trade wars

- Historically political has impacted long term positioning of the industry
  - US / Japan
- Trade war creates uncertainty for the industry
  - US / China
  - Korea / Japan : limited impact but maybe long- term issue

- Global supply chain is a key for the growth
- Opportunity for fair development competition
- Challenges with innovation

ITPC (International Technology Partners Conference) - Long-term SEMI's activity for easing trade tension -

- Industry experts and leading executives from around the world will gather at ITPC to share unique insights into the global ecosystem, business opportunities and technology collaboration in the semiconductor supply chain.
- This year's ITPC conference theme, "Industry Futures,"
- Particular focus on the growing economic tensions and geopolitical concerns, such as the U.S.-China trade war and the Japan-Korea dispute, which have emerged in the past year. All of this will directly impact operations for semiconductor companies.

Summary

- **Semiconductor Industry Outlook**
  - Headwind continues into 2H19, rebound expected in 2020
  - Weakness is memory and trade tensions impacting near term
  - Longer term prospects are very positive and promising as technology innovation advances
- **Fab Investment & Equipment Market**
  - Memory weakness continues into 2H 2019
  - Foundry and Logic spending robust in 2019/2020 driven by strong 10nm/7nm/5nm build-up
  - Rebound in 2020 may be smaller than anticipated; though memory segment and China investment shall recover some
- **Materials Market**
  - Wafer pricing under pressure in 2H19 as demand weakens
  - Fab materials market flat to slightly decline in 2019, +4% in 2020

Thank you!

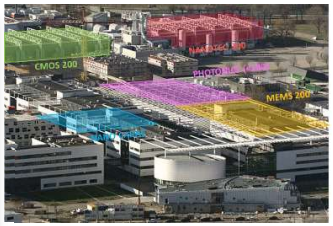
Questions about SEMI Market Research and Market Data?
Contact us at mktstats@semi.org
For more information, please visit us at http://www.semi.org/en/MarketInfo

LETI DAY TOKYO 2019

Laurent Pain
Head of Partnerships,Technology Platform Division, CEA-Leti

ABOUT THE MICRO, NANO-ELECTRONICS & PHOTONICS PLATFORMS

- **300mm & 200mm Si components Platforms**
  - **~270**@200mm equipments
  - **~105**@300mm equipments
  - 5600 square meters Cleanroom - ISO3-5
  - 24/6 operations
- **200mm MEMS Platform**
  - **~130**@200 mm equipments
  - 2200 square meters - ISO 4-5
  - 24/6 operations
- **Substrates <200 mm, III-V and II-VI Platform**
  - **~230** @ various diameter equipments
  - 1000+1000 square meters - ISO 4-5
  - 1shift/day
- **Nano-CHARACTERIZATION Platform**
  - **~40** huge equipments
  - 2200 square meters
  - 8 centers of competences



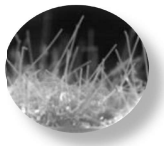
PLATFORM ID CARD :

- >700 equipments on 10000m2 of clean room >500 talented people including international experts
- >150 scientific papers published per year
- ~50 patents filed per year
- 24/6 operations

OUR COLLABORATION OFFER

New products & applications

- Collaboration thru LETI's application Divisions
- Maturity increase of product
- Industrial transfer



New Materials & Process Development

- Collaborative bilateral research on specific project
- Common laboratories
- Affiliation program

New Equipement Engineering

- Specific Joint Development Program
- Your equipment in new integration scheme of near future product

Internal and external start up incubator

- Time to market developments
- Complexity handling
- Leti covers the all food chain in a one stop shop

A full range of business models to meet our partner's needs

A worldwide ecosystem on components

Equipment | Electronics | Energy | Communication 5G, RF

<200mm, 200mm & 300mm PLATFORMS

300mm
1. Imager
2. µController/eNVM
3. Photonic on Si
4. 3D Integration
5. FDSOI & Quantuum
6. SOI substrates

200mm
1. Power GaN and RF
2. Sensor
3. Display
4. Lighting
5. Photonic on Si
6. 3D Integration
7. SOI substrates

< 200mm
1. II-VI material
2. II-VI componants
3. III-V material
4. III-V components
5. X-OI substrates

EVOLUTION OF THE 300mm TOOL SET

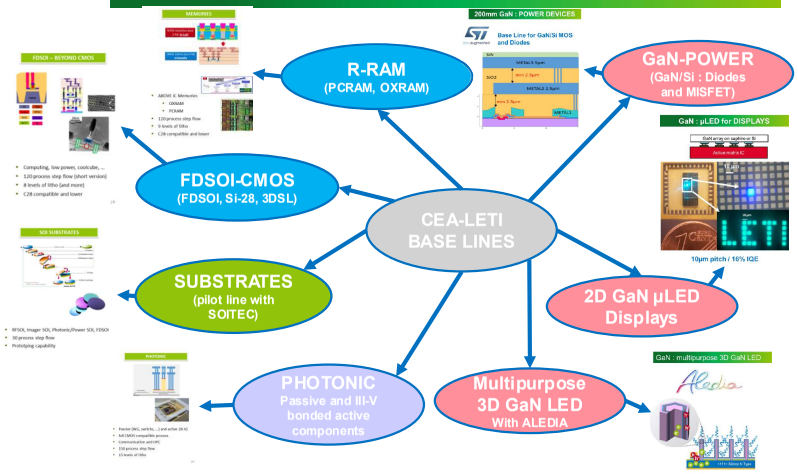
Scatterometry ASML Yieldstar	Scanner ASML NXT	Track SCREEN DUO	Scatterometry eKLA Archer 600	Scrubber for thick Epi Si	Cluster DIEL3 filters / BEnd- AMAT Producer	Cluster DIEL2 FEnd AMAT Producer	Stripping FEnd MATTSON SUPREMA XP	TXRF + VPD RIGAKU V310	Etching Imagers TEL TACTRAS VIGUS	Surfscan (SP3) KLA	Reactor PVD Ta/TaN AMAT pour Endura 300B
04- 2018	05- 2018	05- 2018	06- 2018	09- 2018	11- 2018	12 - 2018	02- 2019	02 - 2019	03 - 2019	04 - 2019	04 -2019

Low Temperature epitaxy	Stripping Imagers DNS SU3 100B	Contact etch/ Bevel deposition LAM Versys4	multi-cathode PCRAM Chamber	CMP bevel	Cdour filters track RGB TEL ACT12	Inspection & Defectivity platform AMAT	Raquare Measurement Napson	Molecular bonding	FIB / SEM	PLD piezo	CMP Cu BEOL / bonding
08- 2019	09- 2019	09- 2019	09- 2019	09- 2019	10- 2019	11- 2019	12- 2019	03-2020	03-2020	03-2020	03-2020

wet SiN etch	Cluster Diel1 FEND	Wet etch Si	Ellipsometer
03-2020	10-2020	2021	2021

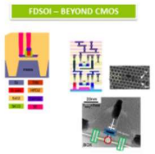
→ State of the art 300mm line for FDSOI, Memories, imagers, photonic, substrats and 3D

Main base lines at LETI

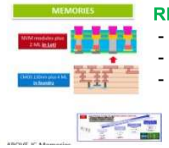


GOAL : stabilize, increase maturity and reduce cycle time of CEA-LETI strategic technologies for time-to-market industrial transfer with lowered risks and MPW and collaborative programs

High Recurrent Batches (HRB) – 300mm

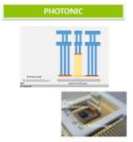


FDSOI HRB ID Card
- 300mm
- 28nm node
- Families
  - Edge IA,
  - Quantic (Si_{28}),
  - coolcube™



RRAM HRB ID Card
- OXRAM : 200-300mm
- PCRAM : 300mm
- 28nm node

PHOTONIC HRB ID Card
- 300mm
- passive components and III-V components co-integration by molecular bonding of III-V chip
- « Si like » process (CMOS foundry compatible)



SUBSTRATE HRB ID Card
- (200 and) 300mm
- FDSOI, HRSOI, …
- In the frame of SOITEC-CEA Substrate Innovation Center
- Prototyping capability

100-300mm SUBSTRATES PROTOTYPING LINE WITH SOITEC

soitec

R&D comon lab

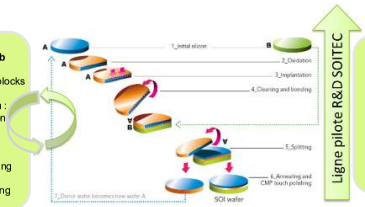
Derivatives techno blocks

Epitaxy trap rich : Functionalization

Thick top Si

Thick BOX bonding

Disruptive finishing & uniformities



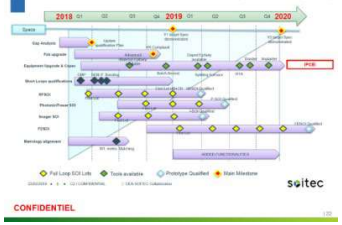
1 – R&D technology modules validation

2 – Prototyping possibility

3 – Acceleration & transfer to SOITEC for large scale ramp up

30033 SOI equipments localization

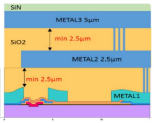
R&D Pilot Line Chart and Milestones (Soitec Request)



High Recurrent Batches (HRB) – 200mm

200mm GaN : POWER DEVICES

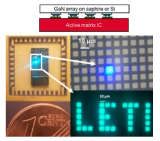
Base Line for GaN/Si MOS and Diodes



GaN Power HRB ID Card

- 200mm
- GaN EPI on Silicon
- Diodes
- MISFETs
- with ST

GaN : µLED for DISPLAYS

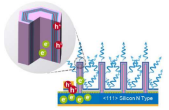


GaN µLED HRB ID Card

- 200mm
- GaN on ASIC by molecular bonding
- less than 10µm pixel pitch

GaN : multipurpose 3D GaN LED

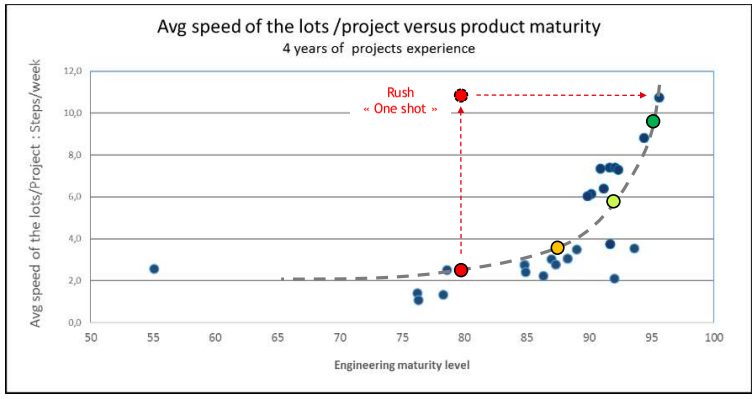
Aledia



GaN multipurpose 3D LED HRB ID Card

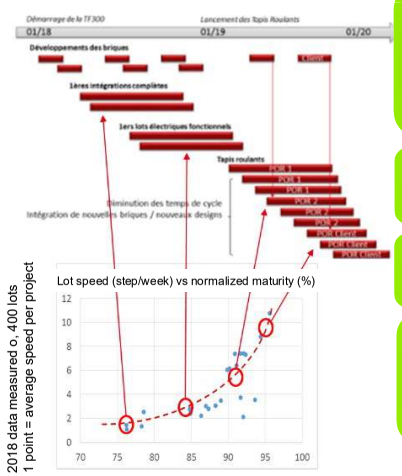
- 200mm (300mm)
- 3D nanowire GaN LED epitaxy on Si
- Multipurpose (dispalys, lighting, …)

FAB PERFORMANCE PLAN 2018-2020



Data measured on more than 400 lots -Year 2018

PERFORMANCE PLAN 2018-2020



Strengths of Recurrent batches

- Reduced engineering / lot (Eng mat > 93%)
- More lots with POR in WIP
- Reduced process steps (In line control)
- Improved cycle time

Concept already operationnal
→ FDSOI baseline
→ it works !

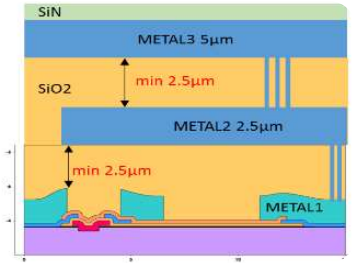
Approach compatible for fast R&D cycle time
Increase of publication number & quality

Strategy deployed in 2019 on
→ Photonic
→ Power device
→ Substrate
Other to come in 2020

200mm GaN : POWER DEVICES

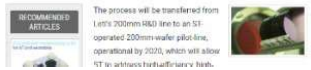
life.augmented

Base Line for GaN/Si MOS and Diodes



ST and Leti to make GaN-on-Si power transistors

STMicroelectronics to manufacture GaN-on-Si power transistors, based on a process developed by French research lab Leti. ST and IRT Nanoelec.

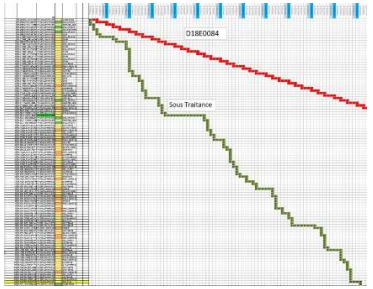


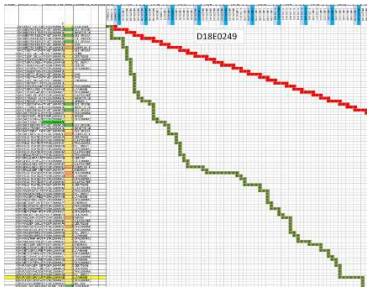
The process will be transferred from Leti's 200mm R&D line to an ST-operated 200mm-wafer pilot-line, operational by 2020, which will allow ST to address high-efficiency high-

PERFORMANCE PLAN 2018-2020

POWER-GaN base line example with ST

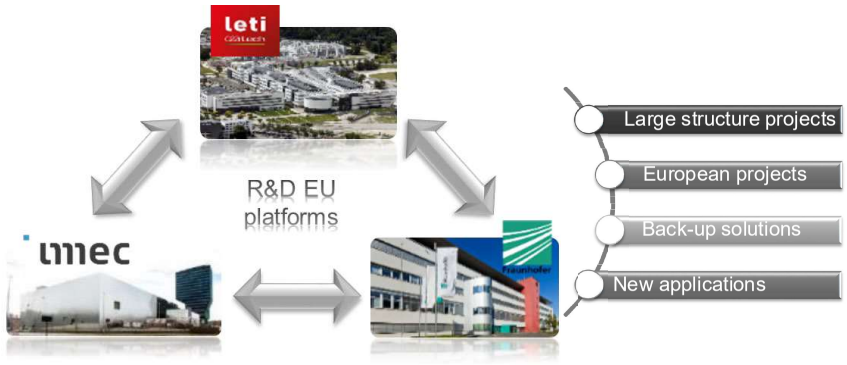
life.augmented





10 step/w in average → 9-10 week cycle time
with recurrent batches approach implemented
Full compatible with MPW approach

A COMPLETE SYNERGIE AT EUROPEAN LEVEL



CONCLUSIONS

- State of the art 100-200-300mm tool set & technologies in « one stop shop »
- From R&D to Instsutrial Transfer thanks to Highly skilled teams comming from both words
- Full compatible with all Fab requirements (flying wafers)
- Access to the SOITEC-CEA « substrate innovation center »
- Access to
  - Specific device developments for your needs

  or
  - Access to our recurent batches (MPW, tool and material assessment)
    - FDSOI CMOS and cool cube
    - R-RAM memories
    - GaN power devices
    - Substrates (Substrate Innovation Center)
    - III-V photonic on Si
    - 3D
    - …
- Confidentility management & IP protection

QUESTIONS ?

Leti, technology research institute
Commissariat à l'énergie atomique et aux énergies alternatives
Minatec Campus | 17 rue des Martyrs | 38054 Grenoble Cedex | France
www.leti-cea.com

LETI DAY TOKYO 2019

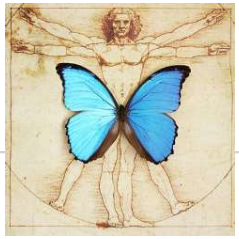
Jean-René Lèquepeys
CEA-Leti CTO

LETI'S TECHNOS HIGHLIGHTS

Jean-René Lèquepeys

October 16, 2019

WORLD BELONGS TO DREAMERS



Production
Industrial
Pre-Industrialization
Concept Maturation
Leti
Upstream Research
Academics
Demonstrators I Prototyping
Proof of Concept

WORLD BELONGS TO DREAMERS

Reuters RTO ranking (2016) : CEA #1

1. Alternative Energies and Atomic Energy Commission (France)
2. Fraunhofer Society (Allemagne)
3. Japan Science & Technology Agency (Japon)
4. 4 U.S. Department of Health & Human (USA)
5. National Center for Scientific Research (France)

Reuters RTO ranking (2017) : CEA #2

1. Health & Human Services Services Laboratories (USA)
2. Alternative Energies and Atomic Energy Commission (France)
3. Fraunhofer Society (Allemagne)
4. Japan Science & Technology Agency (Japon)
5. National Institute of Advanced Science & Technology (Japon)

Clarivate Analytics

TOP 100 GLOBAL INNOVATORS SINCE 2011

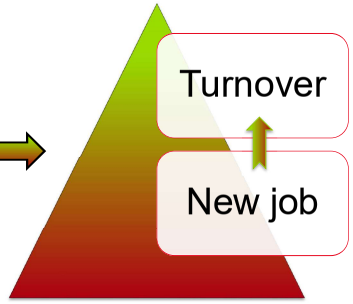
"CEA is a key player in research, development and innovation in four main areas:

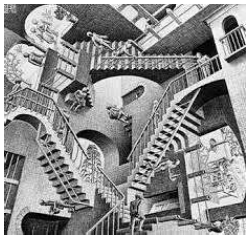
defense and security,
nuclear and renewable energies,
technological research for industry,
fundamental research in the physical sciences and life sciences.

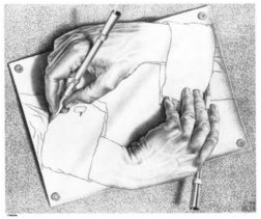
Drawing on its widely acknowledged expertise, the CEA actively participates in collaborative projects with a large number of academic and industrial partners"

BUT WE HAVE TO BE REALISTIC & HAVE STRONG INDUSTRIAL IMPACT

- New product
- Increase market share







We need to bring innovation for our industrial customers

TECHNOLOGIES ARE TRANSFORMING SOCIETY & HUMAN BEHAVIOR

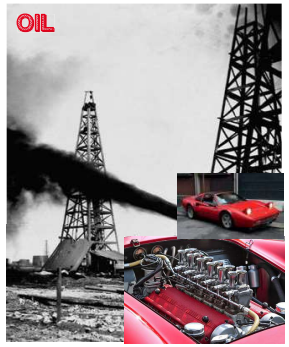
COMMUNICATION
CITIES way of living WORK Business TRANSPORTATION

THREE MAIN REVOLUTIONS

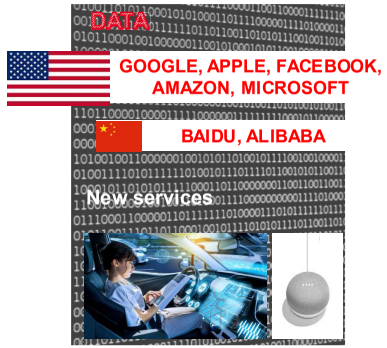
XVIII century | 1858 | 2010+

COAL

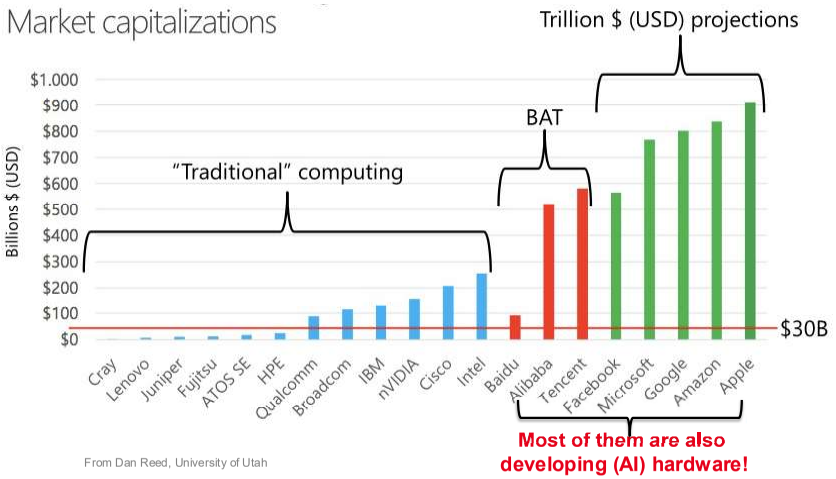
OIL (Pennsylvania Rush)



New Eldorado : DATAs

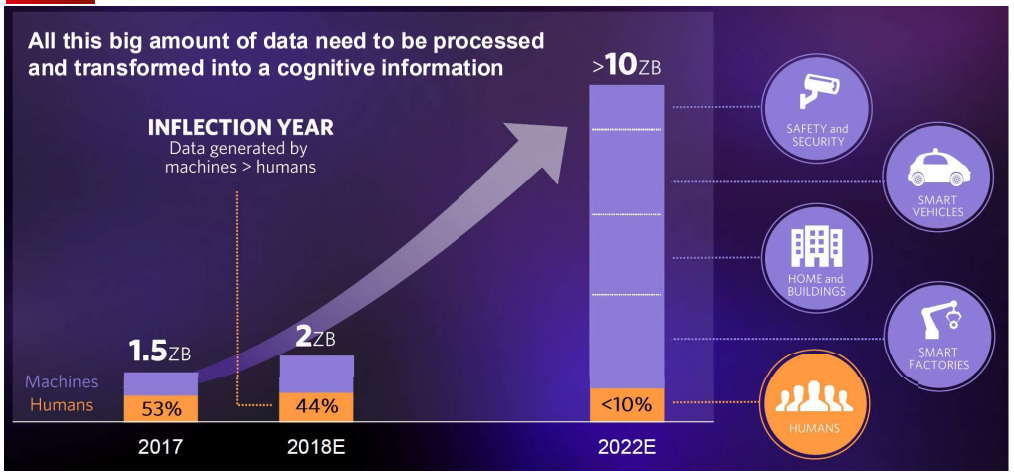


EVOLUTION OF SOCIETY: DATA (INFORMATION) IS THE NEW FUELMARKET CAP LEADER



From Dan Reed, University of Utah

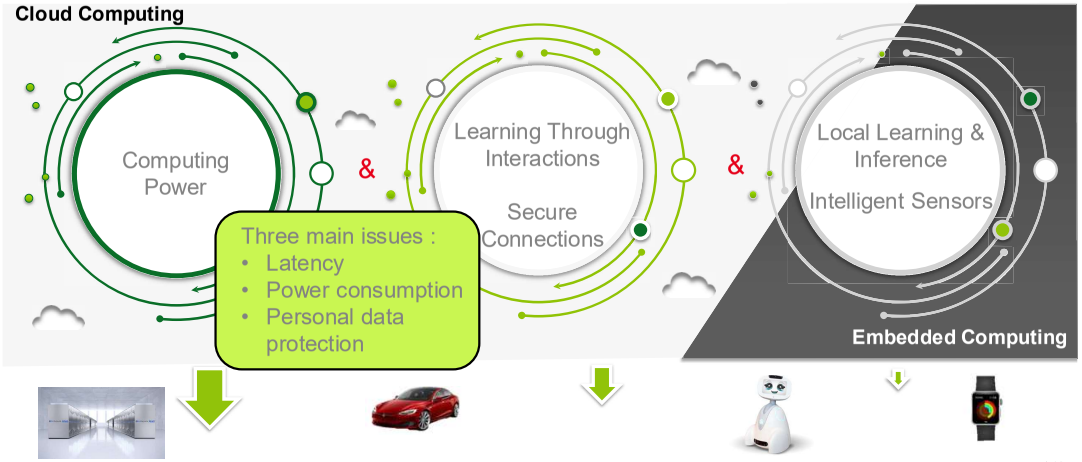
DATA DELUGE AREA



Source: Applied Materials, SEMICON West July 2018

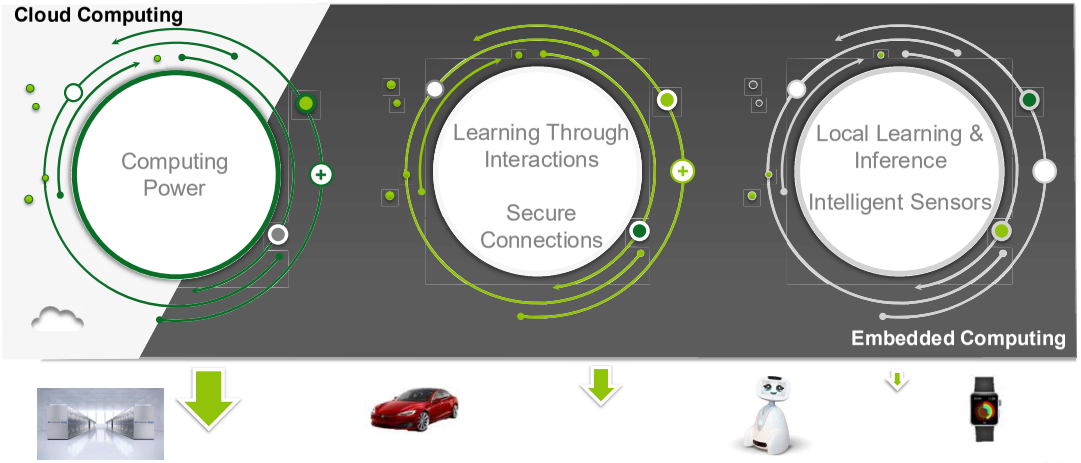
TOWARD A PERVASIVE INTELLIGENCE FOR MANAGING ALL GENERATED DATA

TODAY 80% OF DATA ARE PROCESSED IN THE CLOUD

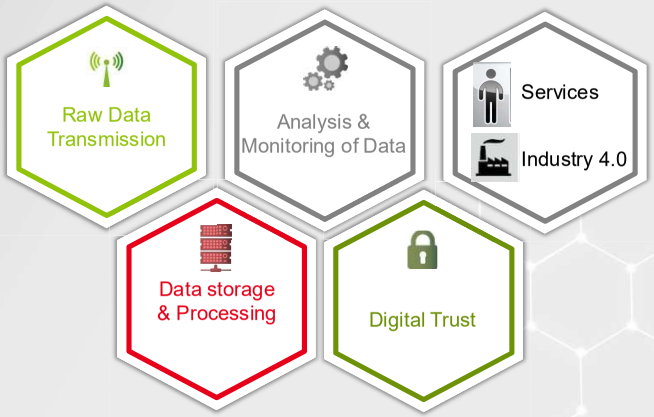


TOWARD A PERVASIVE INTELLIGENCE FOR MANAGING ALL GENERATED DATA

TOMORROW MORE & MORE EMBEDDED INTELLIGENCE

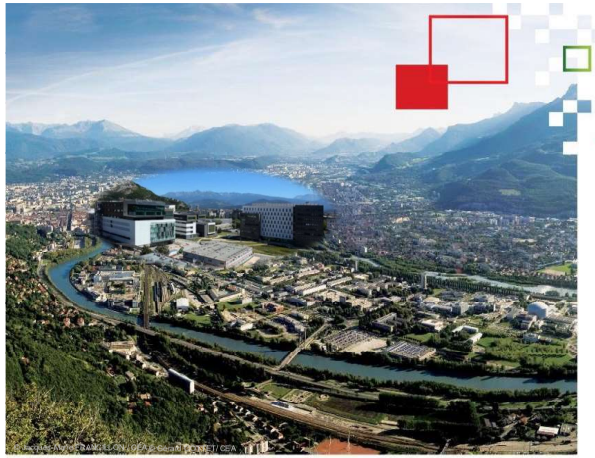


KEY TECHNOLOGIES TO ADDRESS BIG DATA CHALLENGES



WHAT DOES LETI BRING IN THIS AREA ?

KEY R&D PARTNER TO BUILD YOUR NEXT BEST TECH INNOVATIONS



- Since **1967**
- France, USA, Japan
- **2,000** People
- **> 2,760** Patents in Portfolio
- **350** Industrial Partners
- **> 65** Startups Created
- **10,000 m²** Cleanroom 200-300mm
- **315 M€** Budget (**85%** from R&D contracts)

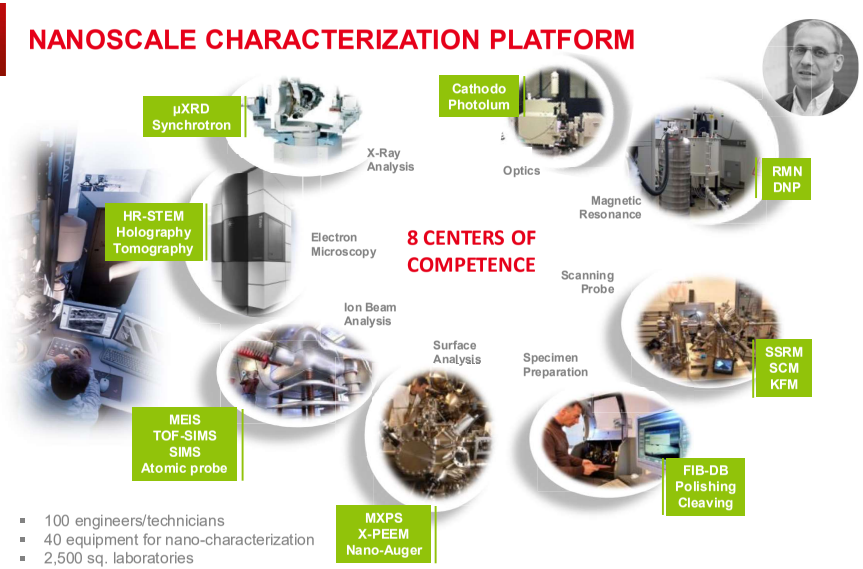
LETI'S SILICON PLATFORM

300 mm 200 mm

1. CMOS / FDSOI
2. BEYOND CMOS
3. POWER
4. MEMS
5. MEMORIES
6. IMAGERS
7. DISPLAY/LED
8. Si PHOTONIC
9. 3D
10. SOI SUBSTRATE

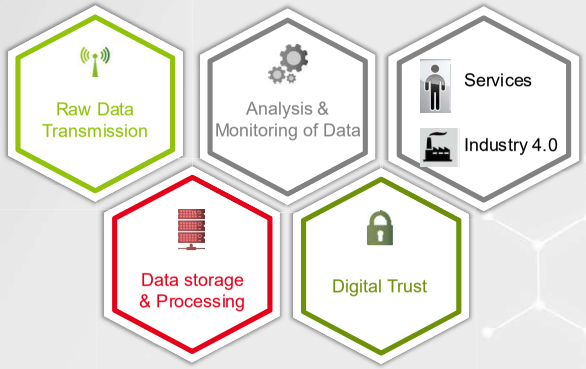
600 people **10,000 m² Cleanroom 200-300mm** **500 equipments**

NANOSCALE CHARACTERIZATION PLATFORM



- 100 engineers/technicians
- 40 equipment for nano-characterization
- 2,500 sq. laboratories

KEY TECHNOLOGIES TO ADDRESS BIG DATA CHALLENGES



Thanks to smart embedded computing coupled with advanced new technologies (FDSOI, RRAM, 3D, …),

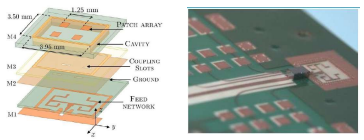
Leti is strongly committed to ensure:

- Better protection of our personal data
- Low latency
- Lower power consumption
- For bringing new services to users

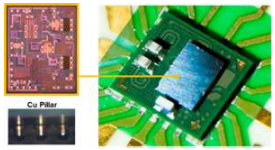
2019 MAIN ACHIEVEMENT IN THE FIELD OF CONNECTIVITY

Raw Data Transmission

BEYOND 5G FULLY-INTEGRATED ANTENNA FRONT-END SOLUTION AT 140 GHZ



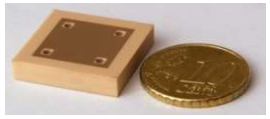
5G WIDEBAND PA AT 2.5GHZ HIGH POWER / HIGH LINEARITY IN RFSOI



CONNECTIVITY

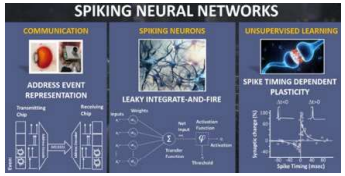
SHORT-RANGE / LOW POWER SOLUTION FOR 5 GBPS AT 60 GHZ

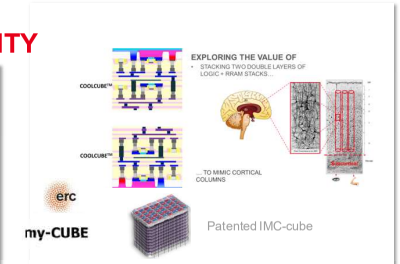
BEYOND 5G SMALL FORM FACTOR 300GHZ INTEGRATED ANTENNA



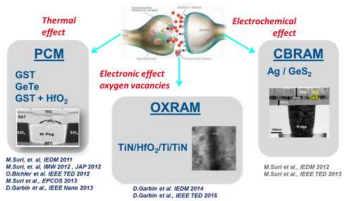
2019 MAIN ACHIEVEMENT IN THE FIELD OF CONNECTIVITY

Analysis & Monitoring of Data

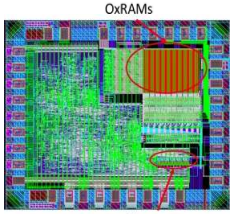




NEUROMORPHIC & ARTIFICIAL INTELLIGENCE

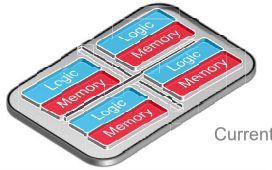


Spirit
Handwritten Signs recognition circuit



2019 MAIN ACHIEVEMENT IN THE FIELD OF COMPUTING AND STORAGE

Analysis & Monitoring of Data

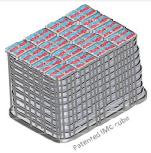


Current Architecture

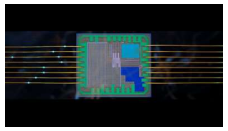
REDUCE THE AMOUNT OF ENERGY PER OPERATION

Memory Stacking on top of processor

Non Volatile Memory Stacking



In Memory Computing ERC my-CUBE

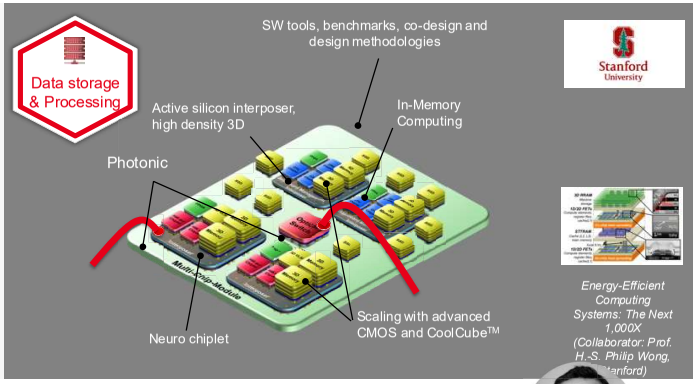


Analog Computing with Spikes

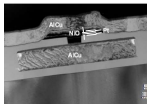
HPC ROADMAP

HETEROGENEITY & EVERYTHING CLOSE

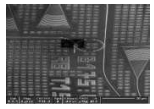
Data storage & Processing



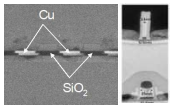
QUANTUM



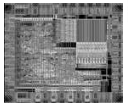
NEW MEMORY TECHNOLOGIES



PHOTONICS



HIGH DENSITY 3D INTEGRATION



ADVANCED ARCHITECTURES

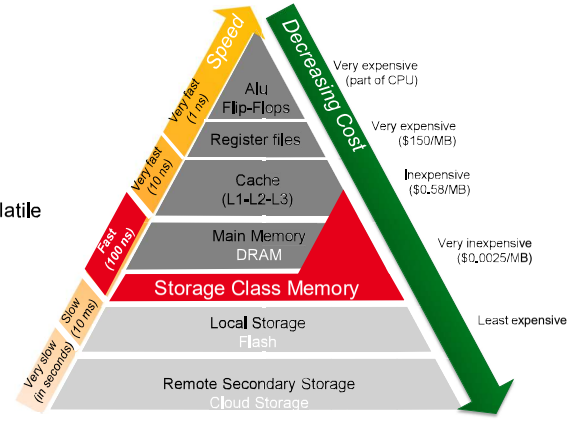
NEUROMORPHIC

ADVANCED MEMORIES, NOVEL ARCHITECTURES

STANDALONE | EMBEDDED

Volatile

Non-volatile



Data storage & Processing

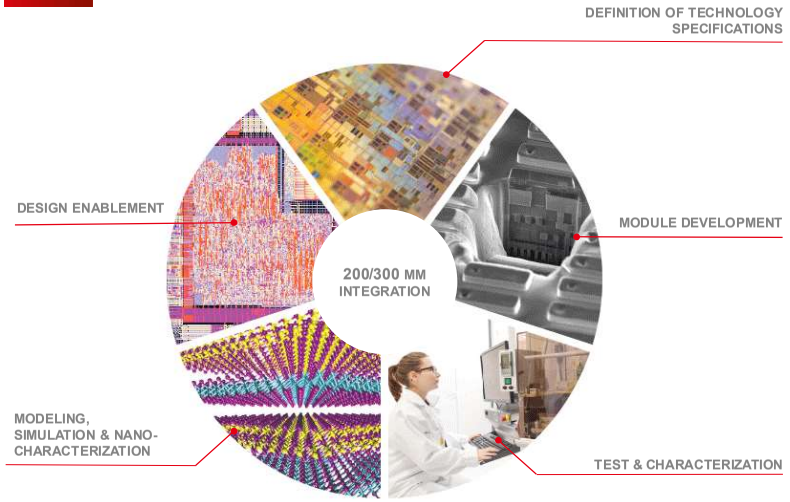
MAIN RESEARCH FOCUS:

MATERIAL STACKS
SELECTOR
ARCHITECTURES
HW ACCELERATORS
IC DESIGN

SPECIFICATIONS:

SPEED
POWER CONSUMPTION
ENDURANCE
HIGH TEMPERATURE
COST
SCALING

MEMORY A UNIQUE VALUE PROPOSITION



Data storage & Processing

Large variety of materials available

GeSbTe
SiOx
TaOx
ZrO2
AlOx
VOx
HfAlxOy

GeAsSbTe

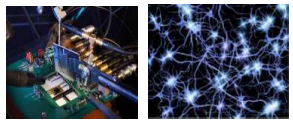
Large variety of Memories available

spintec
pSTT-Magnetic RAM
Conductive Bridge RAM
Oxide Resistive RAM
Ferro-electric RAM
Phase – Change Memory

2019 MAIN ACHIEVEMENT IN THE FIELD OF CYBERSECURITY

Digital Trust

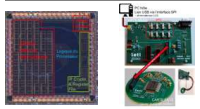
CONVOLUTIONAL NEURAL NETWORKS AGAINST SECURITY COMPONENTS CONTERMEASURES



CRITICAL FUNCTIONS SECURITY IMPROVMENT AGAINST HACKING

CYBERSECURITY

TECHNOLOGICAL BRICK OF ASYMETRIC CRYPTOGRAPHY FOR IOT

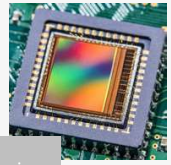


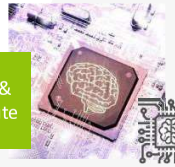
AUTOMATED SECURITY TEST TOOLS FOR CONNECTED OBJECTS

NEW FINGERPRINT TECHNOLOGY IN PRINTED ELECTRONICS FOR BANKING APPLICATIONS

PORTFOLIO OF OUR ACTIVITIES

AI is everywhere





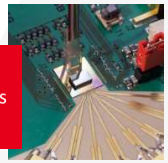
Store & Compute

Imaging Systems

5G & Beyond

Sensors & Actuators

Photonics



Cyber Security

Display

Power Devices

Medical Devices

SCIENTIFIC DIMENSION

Advanced Materials

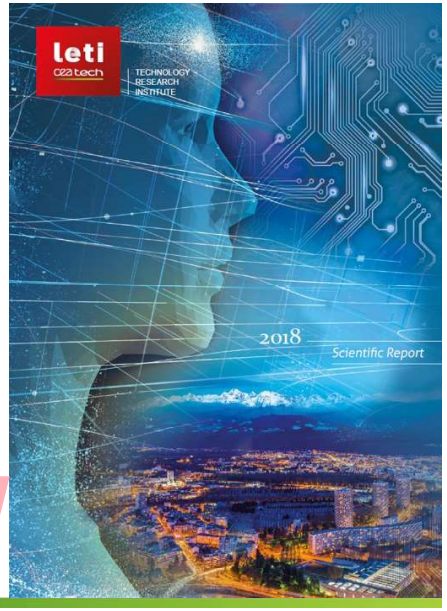
Virtues of Photons

Complex Systems

Power Efficiency

Human Health

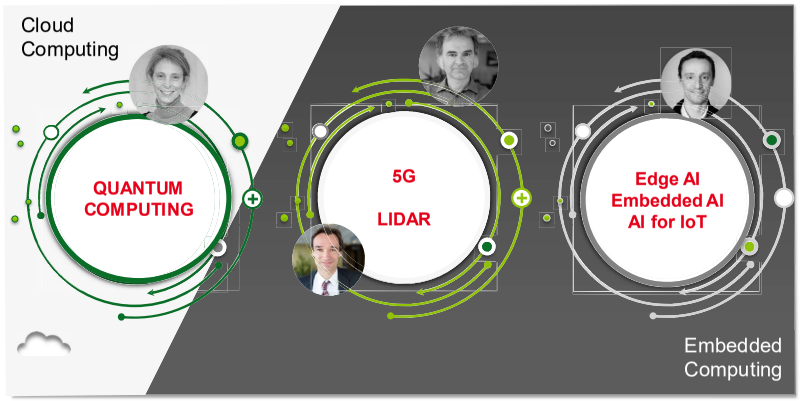
FOR MORE INFORMATION
DOWNLOAD OUR SCIENTIFIC REPORT
https://portail.intra.cea.fr/drt/leti/Pages/LETI/6-Communication/Actualites/2019/02-Fevrier-2019/Rapport-Scientifique.aspx



WORLDWIDE RESEARCH ECOSYSTEM TO FOSTER INNOVATION

TOWARD A PERVASIVE INTELLIGENCE

LETI'S KEY STRATEGIC PROGRAMS HIGHLIGHTED TODAY



Thank you for your attention

Questions are welcome

CEA Tech Days 2019

FUJITSU

Quantum-Inspired Computing Digital Annealer

Toshiyuki Miyazawa
Manager of Digital Annealer Unit
FUJITSU LABORATORIES LTD.

Agenda

FUJITSU

- Background
  - Domain specific computing
  - Hardware architecture for solving combinatorial optimization problems
- Digital Annealer
  - Technology
  - Applications

Reaching the Limit of Moore's Law

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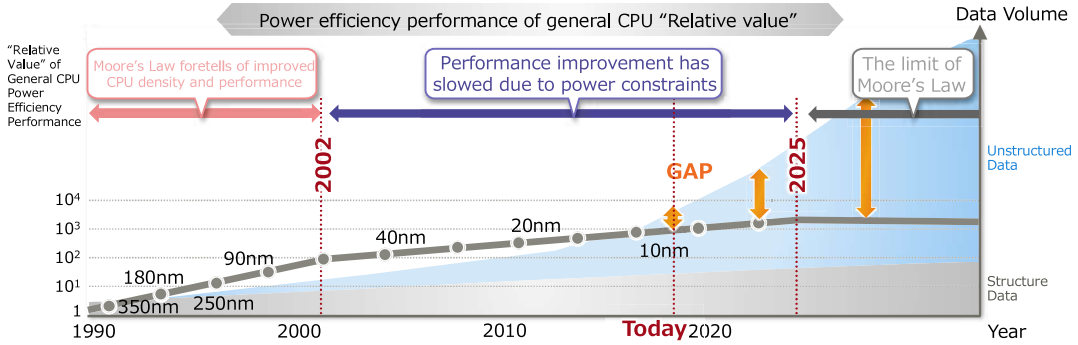
- As we approach the scaling limits of Moore's Law advances in performance of ordinary computing devices have begun to slow.
- Attention is turning to domain-specific computing, which achieves performance increases using hardware specialized for a particular domain.



*Moore's Law: An empirical rule in the semiconductor industry stating that the number of transistors in a dense integrated circuit doubles every 18~24 months.

Combinatorial Optimization Problem

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- Decision-making problems in which the optimal solution has to be found from a given set of combinations within a finite amount of time.

Finding materials with similar structures

Route optimization to alleviate traffic congestion

Optimization portfolio of assets

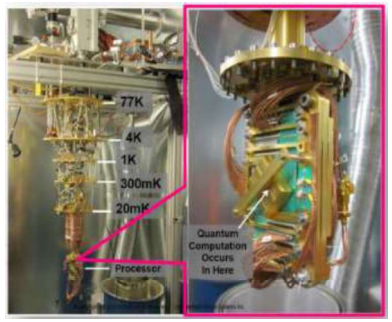
Most combinatorial optimization problems belong to the class of NP-hard.

Agenda

- Background
  - Domain specific computing
  - Hardware architecture for solving combinatorial optimization problems
- Digital Annealer
  - Technology
  - Applications

Quantum Annealer for combinatorial optimization

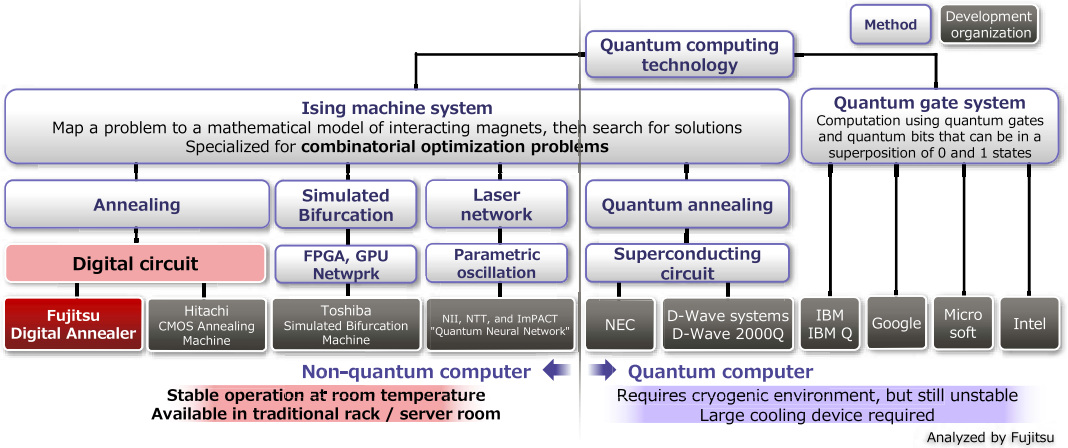
- The first dedicated quantum hardware for combinatorial optimization problem
  - 3×3×3m magnetic shield and 15-mk refrigerator (~15mk)
  - 25kW power consumption including the cryogenic system



*D-Wave Systems Inc. (Burnaby, BC, Canada)

Hardware architecture for combinatorial optimization

- Digital Annealer makes use of the annealing method, specialized for combinatorial optimization.



New Computing Perspective : Digital Annealer

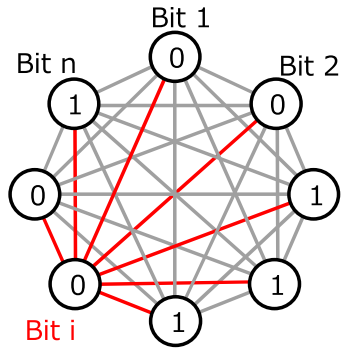
- A new digital circuit inspired by quantum phenomena
- Specialized in combinatorial optimization problems

Agenda

- Background
  - Domain specific computing
  - Hardware architecture for solving combinatorial optimization problems
- Digital Annealer
  - Technology
  - Applications

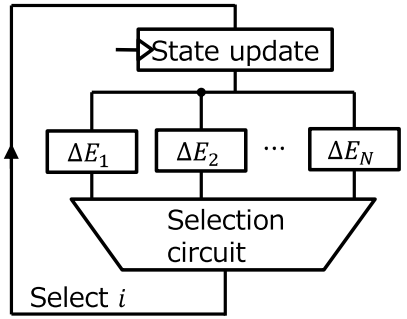
Design policy

Fully-connected structure



Easy problem mapping to Ising model

Parallel search of update candidate



Select one update bit according to the acceptance probability of MCMC search

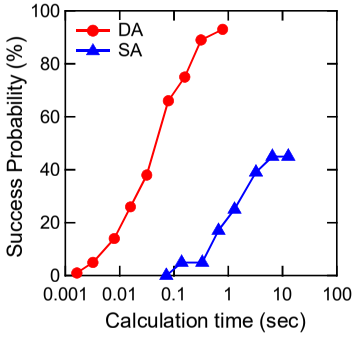
Performance Examples for the 1st Gen. DA

Comparison between 1st Gen. DA and Optimized simulated annealing (SA)*

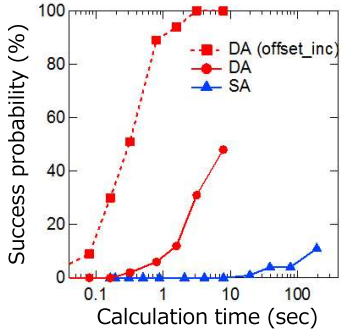
*Isakov *et al.*, Computer Physics Communications **192** (2015) 265–271.

Optimized SA is widely used software-based solver as a reference heuristic in the field of statistical physics area.

Fully-connected 1,024 node MAXCUT



24-city Travelling Salesman Problem

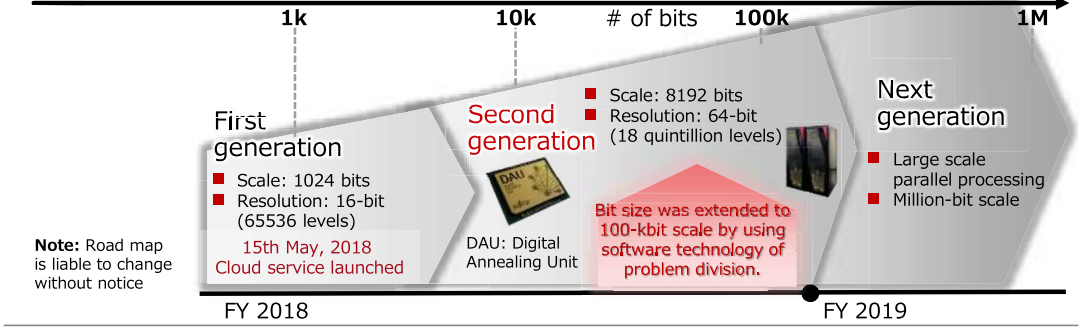


Processor used in SA: 3.5-GHz Xeon E5

Load map of Digital Annealer

- Application

Drug discovery (Finding stable structure)	Small molecule	Middle molecule	Large molecule
Manufacturing (component picking)	One floor	Multiple floors	Entire factory
Traffic (Traffic optimization)	Tokyo bay area	Tokyo city	Entire Tokyo metropolitan area



Note: Road map is liable to change without notice

Technology to handle large-scale problem with DA

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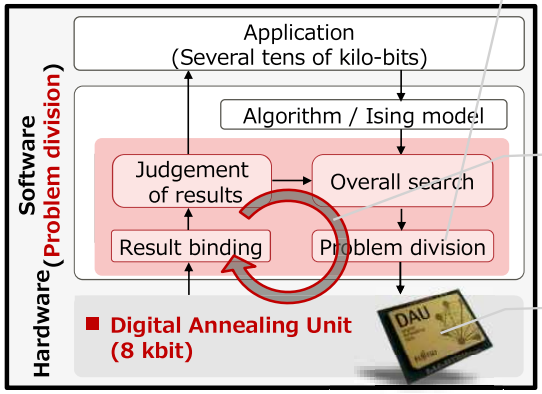
- Process flow of problem division technique with 8-kbit DA



Best dividing method according to problem characteristics
・Improve convergence by dividing the problem based on the problem characteristic

Optimization by HW/SW cooperation
・Efficiently searching the broad problem space through combined search of HW (local search) and SW (global search)

2nd generation DA(DAU)
・High-speed search by dedicated HW engine supporting 8 Kbits

Agenda

FUJITSU

- Background
  - Domain specific computing
  - Hardware architecture for solving combinatorial optimization problems
- Digital Annealer
  - Technology
  - Applications

Drug discovery

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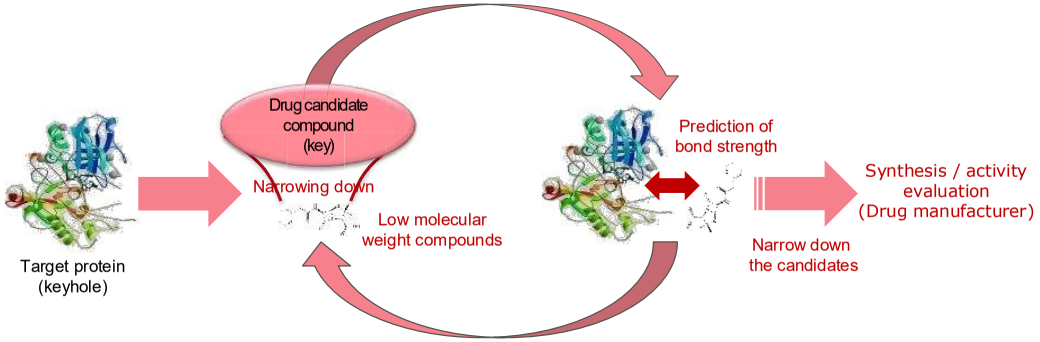
- Designing drug candidate compounds on a computer
- Efficacy can be estimated very accurately by predicting the bond strength between target proteins and drug candidate compounds



Creating drug candidates with high probability is available now (mostly low molecular weight).

Finding larger drug candidate with the Digital Annealer

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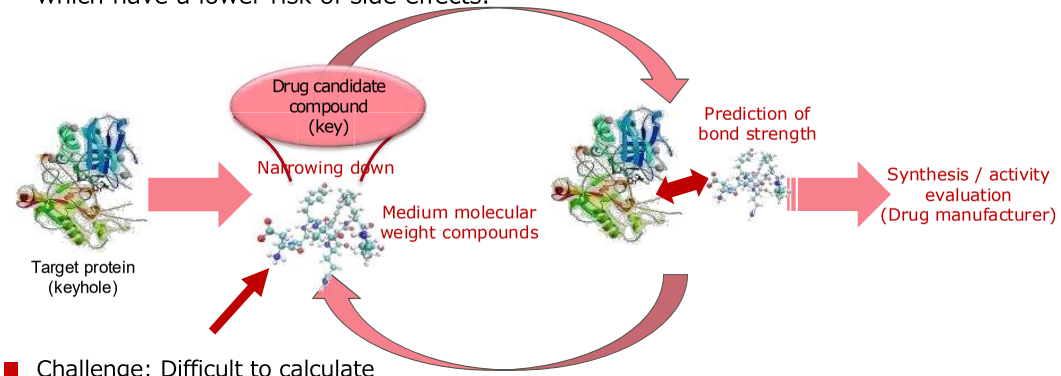
- The development of medicines is shifting from low molecular compounds (with two to four amino acids) to medium molecular compounds (with five to fifty amino acids), which have a lower risk of side effects.



- Challenge: Difficult to calculate stable structures in an exhaustive search of all atoms

⇨ Use DA to design drug candidate compounds

Drug Discovery by Digital Annealer

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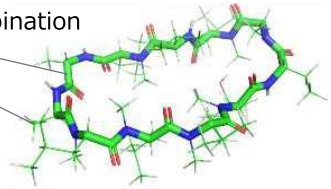
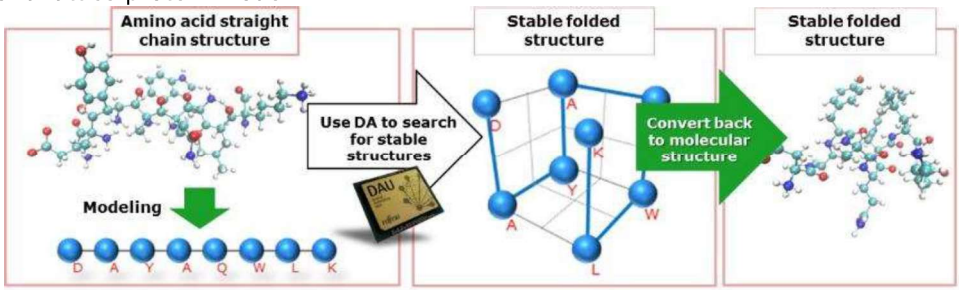
- Issue: Find the stable structure of side chains of a peptide
- Solve the stable rotation state by optimizing rotamers combination (main chain structure is provided)



- Issue: Find the stable structure of main chains of a peptide
- Solve the stable state by optimizing stable folded structure of a lattice protein model



Drug discovery by DA demo (48 amino acid; 31 kbits)

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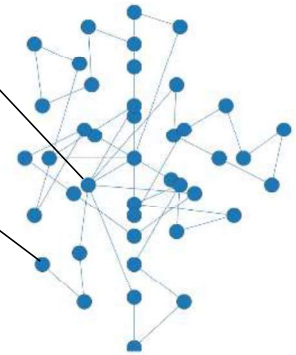
Annealing early stage 1

Amino acids are piled up

Too many amino acids



A lot of violation of constraints are seen in this structure.

Drug discovery by DA demo (48 amino acid; 31 kbits)

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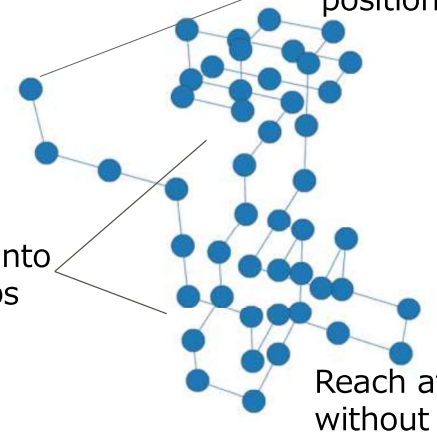
Annealing early stage 2

Some amino acid are in the position without interaction

Energy: - 898



Separate into two groups

Reach at a local solution without violation of constraints

Drug discovery by DA demo (48 amino acid; 31 kbits)

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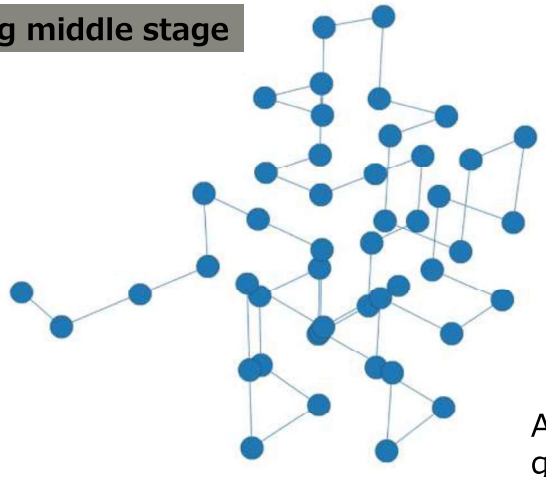
Annealing middle stage

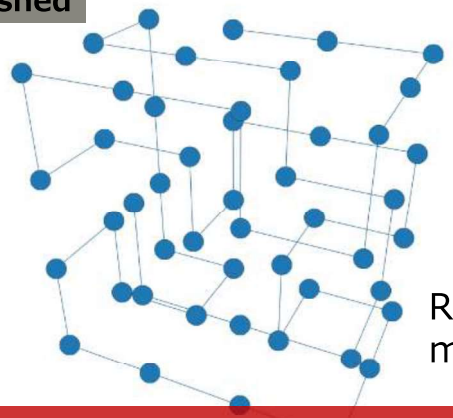


Energy: - 1593

Amino acids chain is gradually folding

Drug discovery by DA demo (48 amino acid; 31 kbits)

Annealing finished



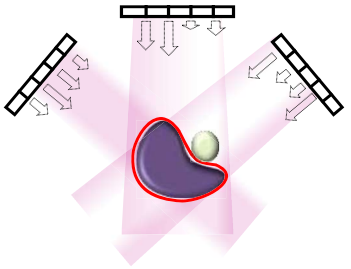
Energy: - 2615

Reach at the
most stable structure

Total calculation time of ~60s is about 100 times faster than the previous result using simulated annealing for the same chain of amino acids.

Radiation Therapy

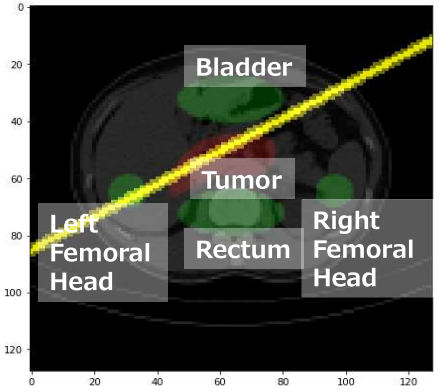
- Intensity Modulated Radiotherapy (IMRT)
  is now becoming an increasingly popular cancer treatments.
  IMRT uses several beams onto the cancers without or minimizing damage to normal organs.
  - Adequate treatment, by optimizing patterns and intensity of radiation
- Large amount of calculation is required for optimization
  - Usually up to several days are required

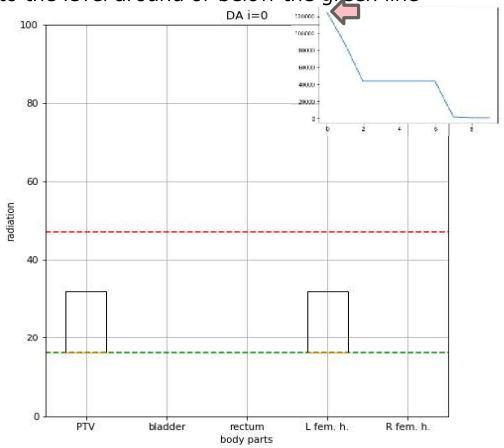


Optimized Radiation Therapy Sequence with DA (1)

Goal: to damage the tumor at the level around the red line and limit the damage to the other organs to the level around or below the green line

Initial State

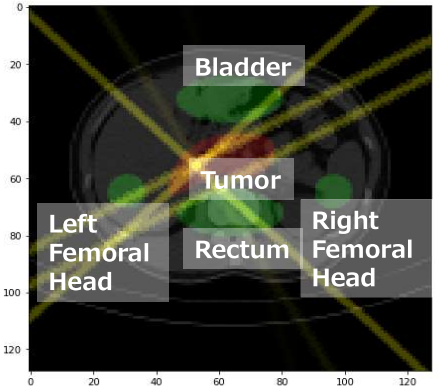


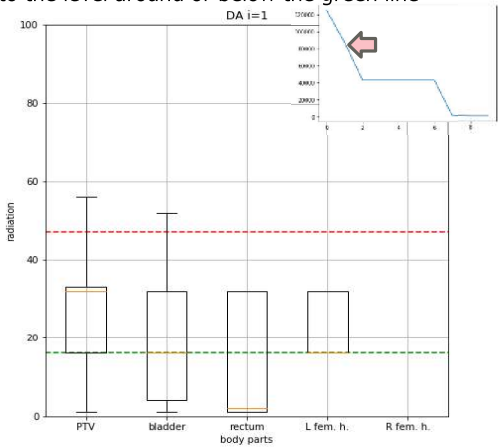


Optimized Radiation Therapy Sequence with DA (2)

Goal: to damage the tumor at the level around the red line and limit the damage to the other organs to the level around or below the green line

Early stage

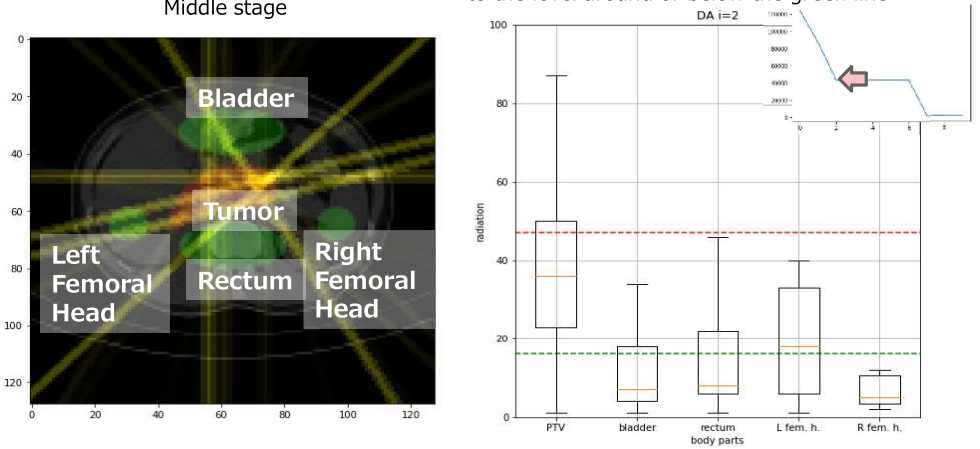




Optimized Radiation Therapy Sequence with DA (3)

Goal: to damage the tumor at the level around the red line and limit the damage to the other organs to the level around or below the green line

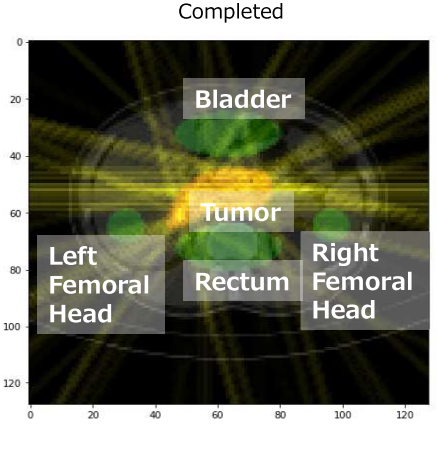
Middle stage

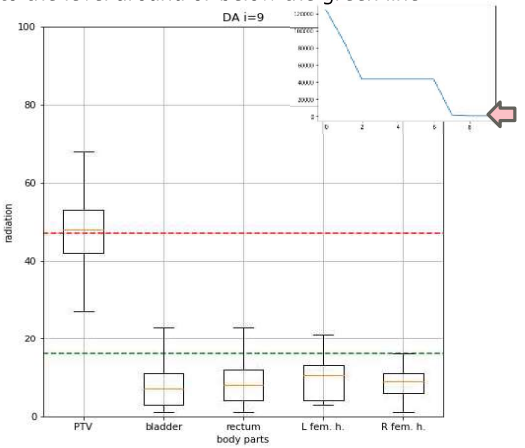


Optimized Radiation Therapy Sequence with DA (4)

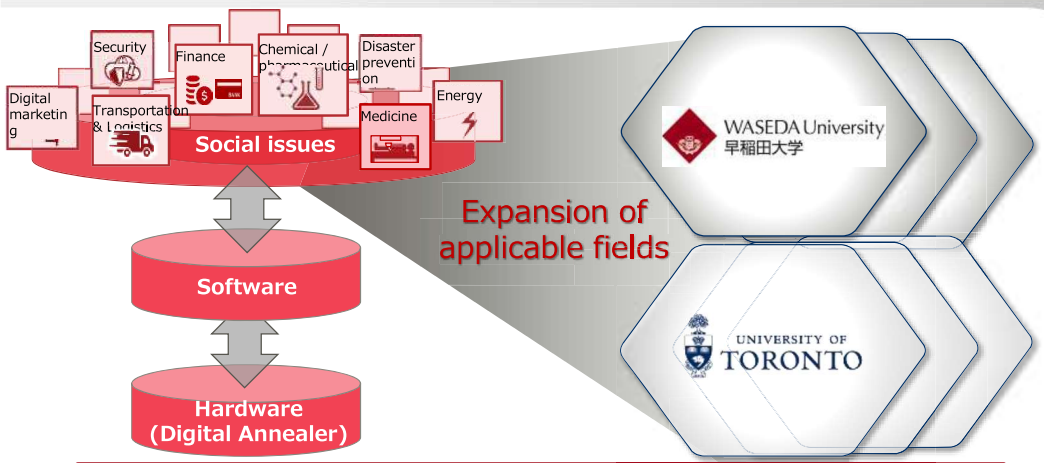
Goal: to damage the tumor at the level around the red line and limit the damage to the other organs to the level around or below the green line

Completed





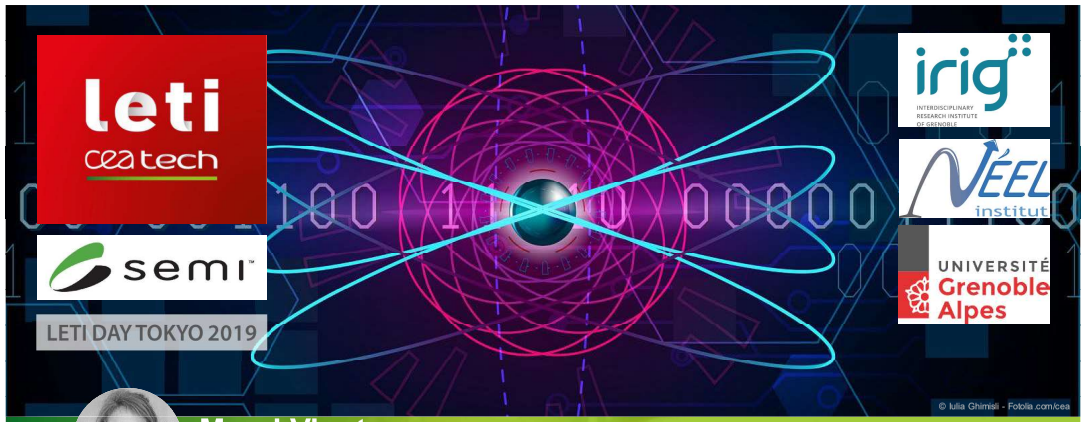
Community formation / utilization



We are forming user and application developer communities to expand the applicable fields of Digital Annealer.

FUJITSU

shaping tomorrow with you



Maud Vinet
Quantum Computing Program Manager, CEA-Leti

LETI PROGRAM ON QUANTUM COMPUTING

European Research Council
Established by the European Commission

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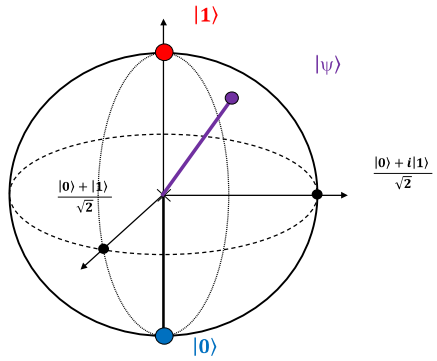
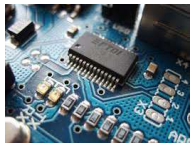
USE CASES

PRINCIPLE

$$|\psi\rangle = cos\frac{\theta}{2}|0\rangle + e^{i\varphi}sin\frac{\theta}{2}|1\rangle$$



QUANTUM COMPUTING MACHINE



3 bits …

You can count to 7!

$s_0 = 000$
$s_1 = 001$
$s_2 = 010$
$s_3 = 011$
$s_4 = 100$
$s_5 = 101$
$s_6 = 110$
$s_7 = 111$

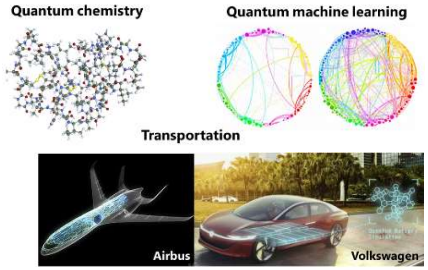
3 quantum bits

$$\varphi = \begin{matrix} +|000\rangle \\ -|001\rangle \\ +|010\rangle \\ -i|011\rangle \\ +|100\rangle \\ +i|101\rangle \\ -|110\rangle \\ +|111\rangle \end{matrix} \xrightarrow{e^{i\pi/4}} \begin{matrix} +e^{i\pi/4}|000\rangle \\ -e^{i\pi/4}|001\rangle \\ +e^{i\pi/4}|010\rangle \\ -ie^{i\pi/4}|011\rangle \\ +e^{i\pi/4}|100\rangle \\ +ie^{i\pi/4}|101\rangle \\ -e^{i\pi/4}|110\rangle \\ +e^{i\pi/4}|111\rangle \end{matrix}$$

Operations on coherent superposition of states
Superpolynomial/Exponential speedup

Entanglement at distance
Quantum teleportation

HOW TO REACH THE PROMISE OF QUANTUM COMPUTING?



>>

Hundreds of qubits

Millions of errorless quantum operations

WORLDWIDE EFFORT ON QUANTUM COMPUTING

National initiatives

QUANTUM FLAGSHIP

EU initiative 1B€ over 10 years

10B$

Big companies

IBM, intel, Google, Microsoft, NEC, FUJITSU

Start up companies

D-Wave, IONQ, SILICON QUANTUM COMPUTING, XANADU, universität innsbruck, Quantum Motion Technologies, TUNDRA SYSTEMS GLOBAL, OXFORD QUANTUM, rigetti, MDR, PSIQUANTUM, BraneCell, TURING, qci, EeroQ, MDR

Multidisciplinary academic centers

CENTRE FOR QUANTUM COMPUTATION & COMMUNICATION TECHNOLOGY, QuTech, NQIT Networked Quantum Information Technologies, IQC Institute for Quantum Computing, QuantumSilicon Grenoble

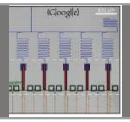
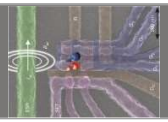
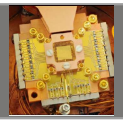
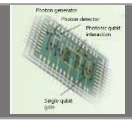
WHERE DOES QUANTUM COMPUTING STAND?

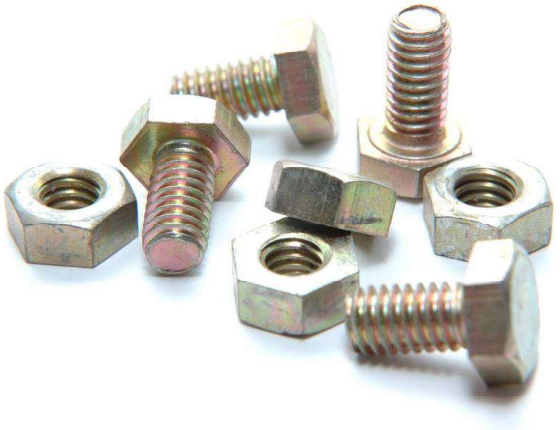
Software makes the assumption that hardware will arrive

Q^Branch, ANYON, STRANGE WORKS, QC WARE, ZAPATA, QILIMANJARO, NQCG, Q-CTRL, ProteinQure, HORIZON, Artiste-qb.net, ENTROPICA LABS, 1QBit, CQC, qb quantum benchmark, Tokyo Quantum Computing, HORIZON, QBITLOGIC

WHERE DOES QUANTUM COMPUTING STAND?

Hardware is at its infancy

	Superconductor	Spin silicon	Ion trap	Photons
Key platforms				
Entangled qubits	20	2	20	18



WHERE DOES QUANTUM COMPUTING STAND?

Hardware is at its infancy

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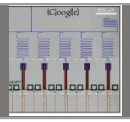
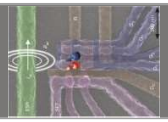
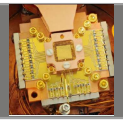
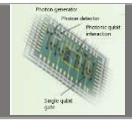
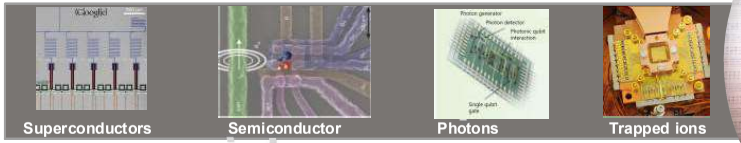
Key platforms				
Entangled qubits	20	2	20	18
Size	(100µm)²	(100nm)²	(1mm)²	1 mm2
Fidelity	99.3%	98%	99.9%	50% (mesure) 98% (portes)
Speed	100 ns	5 µs	100 µs	1 ms

How to go to large scale?

- Variability
- Controlability
- Tuning
- Cross talk
- Large scale coherence

IMPACT OF VLSI TECHNOLOGY: ENABLE SCALE UP IN TERMS OF QUANTITY AND QUALITY OF THE QUBITS

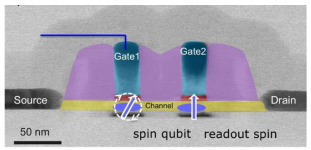
Integration of discrete components (form factor reduction & SNR improvement)
Better interface control
Better thickness control
Better chemical composition control
Better critical dimensions control



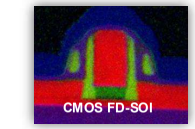
LEVERAGE CMOS PLATFORM TO DESIGN QUANTUM BITS

- Perturbative approach: leverage existing flows to build on actual technology
  - Scientific objectives: few qubits optimization (quality axis)
  - Materials and modules validation

Silicon Spin Qbit

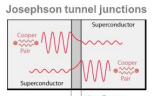


- Linear array demonstration
- Si qubit in-deth understanding

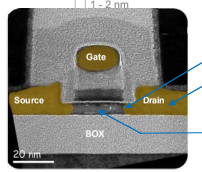


Perturbative branches

Superconducting QBit (GATEMON)



- Gate tunable semiconductor
- Superconducting S/D contacts



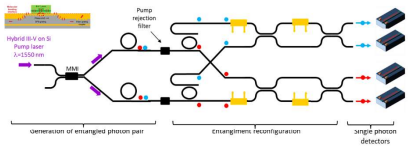
High quality interface
Superconducting reservoirs
Low decoherence
Defect free material

LEVERAGE SILICON PHOTONICS PLATFORM FOR QUANTUM COMMUNICATIONS

Toward a quantum internet & connected computers

- Strategy to provide unconditional security
  - Silicon photonics technology developed for classical telecom / datacom will be extended to build integrated transmitters and receivers for quantum com
- Q-grade PICs based on a versatile Si quantum photonics platform
  - Technological developments & design of key components to generate, manipulate and detect single photons

Example of circuit for advanced protocols based on entangled photon pairs



irig femto-st III-V lab DTU University of BRISTOL SQUARE

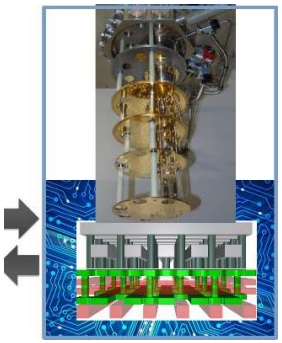
- Partnerships for quantum characterization and implementation of Quantum Key Distribution protocols

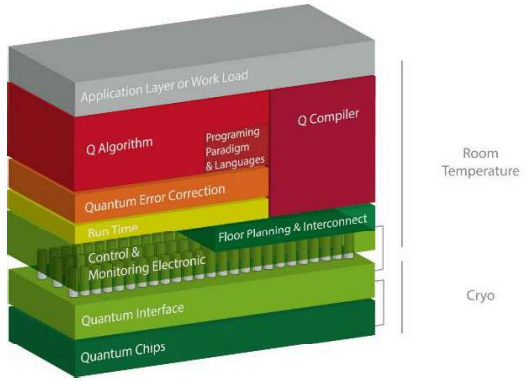
Terrestrial Q network
Ex : 1st demo in the UK in 2018

Terrestrial/Satellite Q network
Ex : chinese demo with satellite Micius in 2017

EFFORT ON SI SPIN QC: OBJECTIVE

Design and fabricate a quantum accelerator encoding quantum information in silicon spins and develop low level software allowing its use to solve useful problems.





SI SPIN QC ROADMAP

QuantumSilicon Grenoble

Technological challenges
- Development of technological modules for a million of qubits
- First 2D array of 100 to 256 interconnected qubits

Technology and biz
- Demonstration of all the modules together
- Architecture yield
- Fabrication of a million of qubits
- Value chain consolidation
- Cloud accesss

Gen0 Application processor

2030

Error correction

Tackle scientific questions
- 2 qubits gate
- Fidelity increase
- 2D tile for large scale
- Large scale coherence
- Quantum error correction

100 qubits prototype

System development

6 entangled qubits

2D array geometry

1 qubit

Linear geometry

2024

Quantum simulation algorithm
Logical qubit demonstration

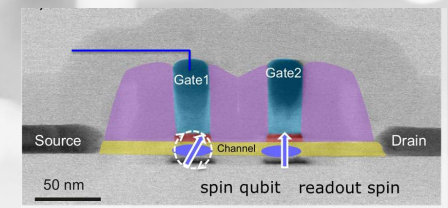
2021

2018

EFFORT ON SI SPIN QC: STRATEGY

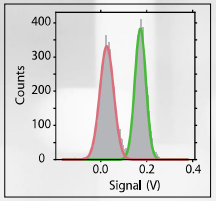
1. Definition of single and few qubits
2. 2D array definition
3. Long distance quantum information transfer
4. Cryogenic large scale compatible architecture

1 Definition of single and few qubits

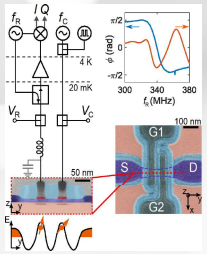


First CMOS spin qubits
2016

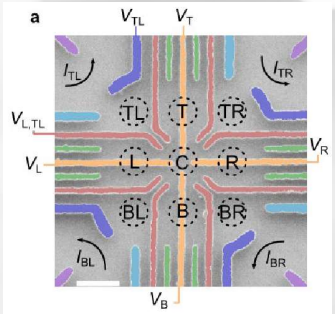
1 qubit
Fidelity > 99%
2018



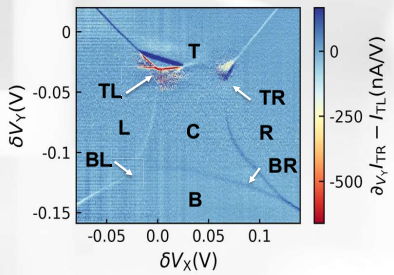
First one qubit with manipulation and scalable read out co-integrated
2019



2 2D array definition



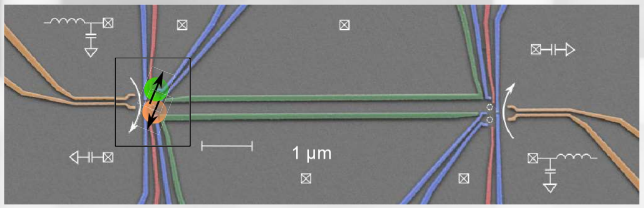
Controlling an array of tunnel coupled quantum dots in III-V (2DEG)

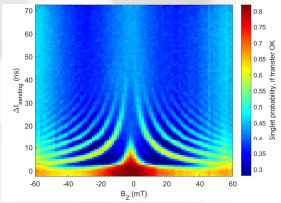


PA Mortemousque, ArXiv (2018)

3 Long distance quantum information transfer

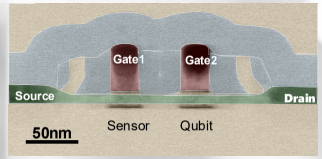
Fast spin coherent link
and spin entanglement at distance

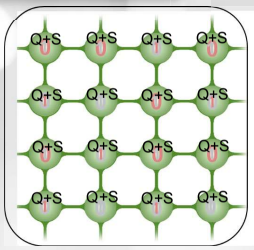


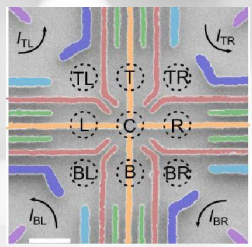


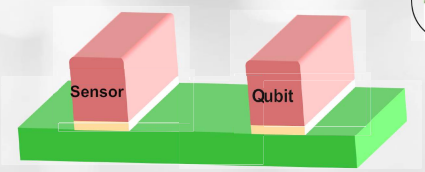
B. Jadot (Grenoble)
Unpublished 2018

4 Cryogenic large scale compatible architecture

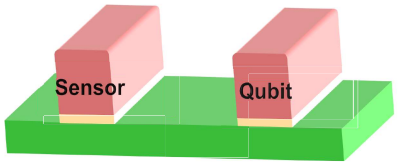




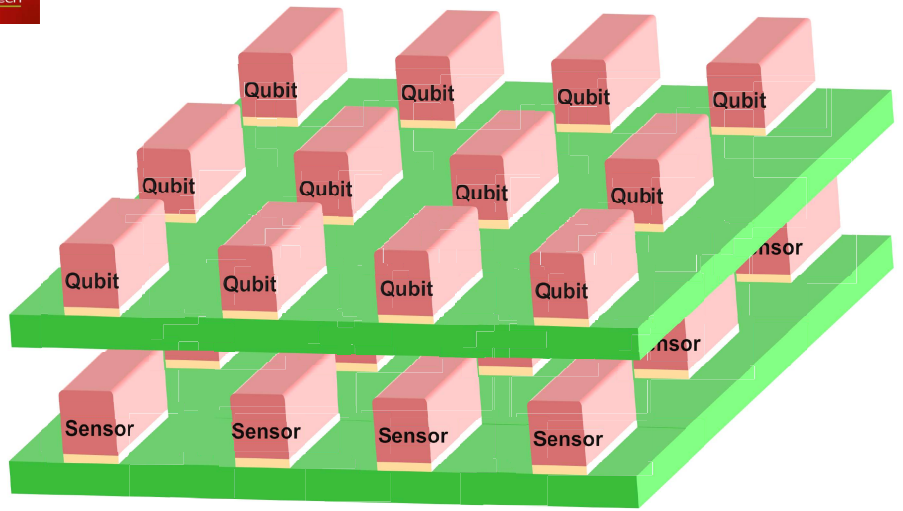




SCALABILITY

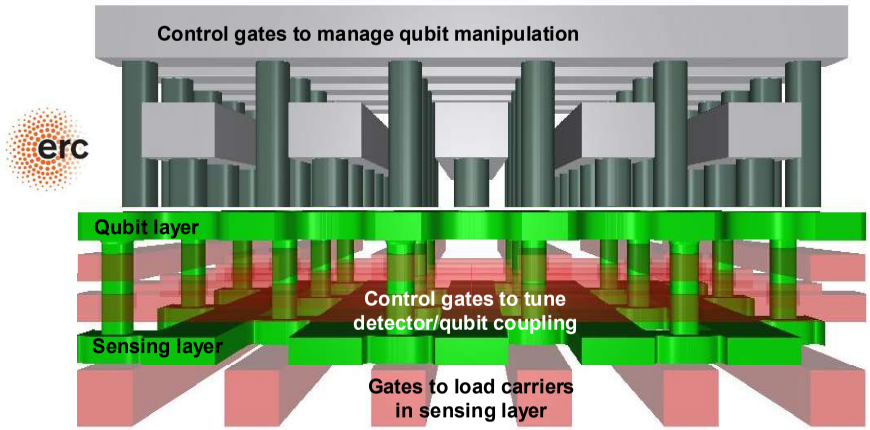


SCALABILITY

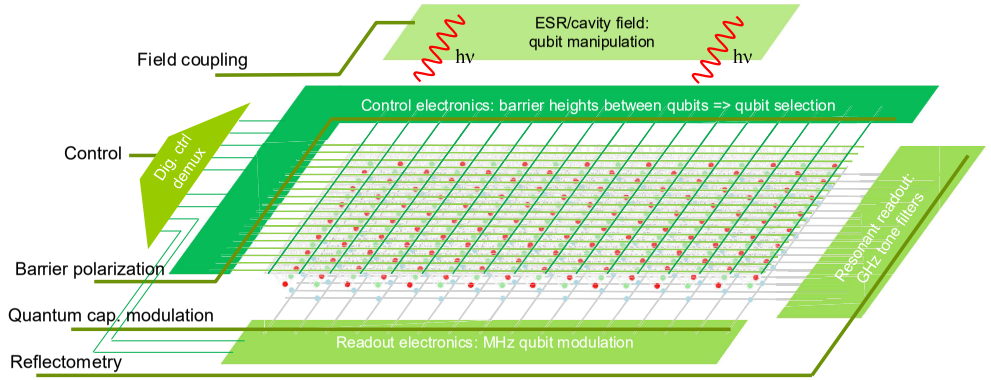


ARRAY ARCHITECTURE

Meunier, De Franceschi, Vinet, Hutin (2017)



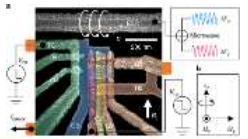
CONTROL ELECTRONICS AND CHIP ARCHITECTURE



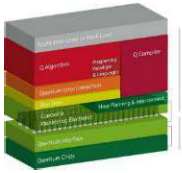
Conclusion

Quantum computing is a **disruptive innovation** in computing.
French industrial and research ecosystem is **at the state-of-the-art.**

State of the art



Grenoble quantum program



Motivation and positioning

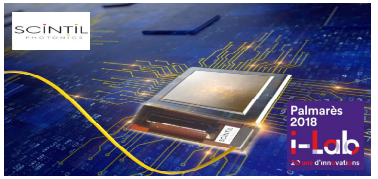
- Become the hardware leader in terms of qubits quality and quantity
- Interlock with users ecosystem to optimize usage-hardware design

Philippe Ruffin
Startup Program Manager, CEA-Leti

leti ceatech

LETI STARTUPS – 65 COMPANIES TO DATE

Augmented Interaction Tech Company Iskn Raises €10.5M



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A MATURE SPIN-OFF PROCESS

- **Nurturing**
  - Internal incubation process
  - Technology maturation
  - => Strong background IP
  - Customer Development
- **Enabling**
  - License Agreements
  - Equity as co-founder
- **Supporting**
  - Joint development labs
  - Hosting and access to facilities
  - Seed investment

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A MATURE INCUBATION AND ACCELERATION PROCESS

ceatech

SUPER NOVA INVEST

Incubation → Acceleration

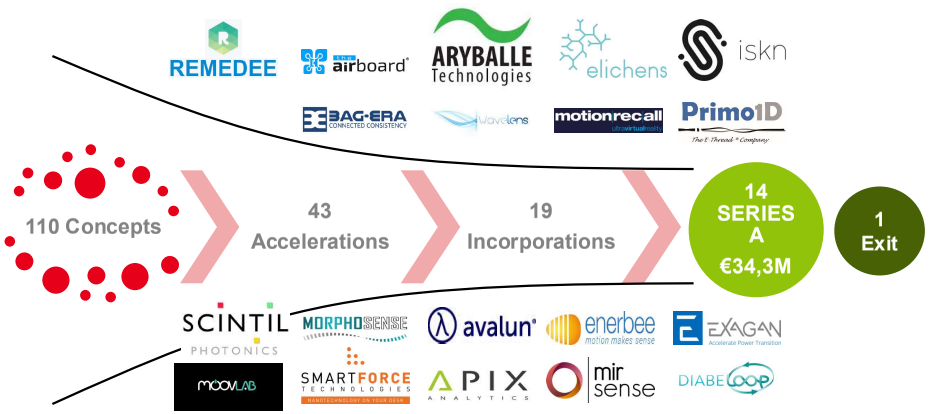
S6: Ideation → S5: Problem Validation (BUILD – LEARN – MEASURE) → S4: Solution Proposal (BUILD – LEARN – MEASURE) → S3: Product/Market Fit (BUILD – LEARN – MEASURE) → S2: Go to Market → S1: Scale

A dedicated support team

A dedicated mentor program

LETI Startup Program: from Concept to Series A

LETI STARTUP PROGRAM SINCE 2013



LETI STARTUPS - FINANCING ROUNDS 2018 (105,5 M€ TOTAL)

SERIE A

SERIE B

SERIE C

IPO

Latest rounds
Last 12 months

REMEDEE	2.5 M€
Primo1D	5 M€
mir sense	2,2 M€
Aledia	30 M€
KALRAY	43,5 M€ (IPO)
elichens	7 M€
iskn	10.5M€
enerbee	2,5 M€
MORPHOSENSE	1,5 M€
moovLAB	0,5 M€

A STRONG LOCAL INNOVATION ECOSYSTEM

VC ECOSYSTEM

DEALFLOW: CURRENTLY INCUBATED

ANTENEO CUTTING-EDGE DESIGNS FOR INTEGRATED COMPACT GNSS ANTENNAS	TELECOM AUTOMOTIVE
WORMS WE EQUIP SPACES AND OBJECTS WITH TACTILE FUNCTIONS WHILE PRESERVING DESIGN AND ERGONOMICS FOR A BETTER USER EXPERIENCE	AUTOMOTIVE CONSUMER ELECTRONICS
WISE INTEGRATION INNOVATIVE GAN IC TO REACH ULTIMATE POWER SUPPLY EFFICIENCY AND COMPACTNESS	CONSUMER ELECTRONICS
MAG-4-HEALTH DEMOCRATIZE MEG, IMPROVE DIAGNOSIS OF NEURONAL DISORDERS	MEDICAL DIAGNOSIS
DIRECT FOOD TESTING TOOL FOR FAST ON SITE PATHOGENIC BACTERIA DETECTION	AGTECH
KENTYOU CREATE VALUE OUT OF DATA FOR SMARTER CITIES	SMART CITY

LETI STARTUP PROGRAM: WHAT'S NEXT?

INCUBATION

FIRST STEP

Supporting the creation of startups with an 18-month program for researchers-entrepreneurs

ACCELERATION

GROWTH

Supporting startup growth with dedicated IP bundles at Series B and C level

MICRO NANO VENTURE STUDIO

Micro Nano Venture Studio

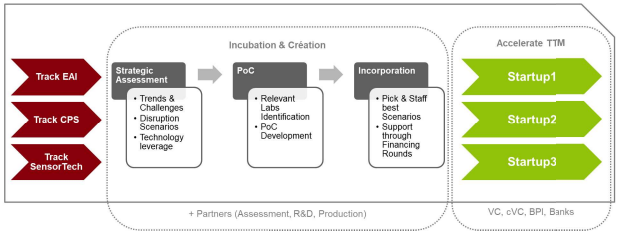
build Ambitious Companies based on Transformative Technologies

- A « Venture-Studio » dedicated to building micro and nano technology-based companies, through the establishment of Proof of Concepts in stealth mode, in partnership with leading RTOs
- Tracks: Edge AI, Cyber Physical Systems, Sensor Technologies
- Currently building a €20M financing round, to ensure 5 years of operations, and the creation of up to 10 companies
- Partners: CEA-LETI, BPI, Corporate Partners

MICRO NANO VENTURE STUDIO

- MNV Studio will take up to 40-45% of NewCos.

Equity for providing:
Strategic positionning;
Development of relevant PoCs;
Strong IP portfolio;
Sourcing of Management Teams;
Access to Ecosystem;



- « One-time investment » only: no follow-up investment.
- Board seat and actively involved – at least through first 2 rounds.
- Exit Strategy: IPOs and Acquisition.

LETI STARTUP PROGRAM - SUMMARY

- **65 startups to date :**
  - 3 IPO's (Soitec, Karlay, Tronics)
  - 10 acquisitions (Movea, SmartForce,….)

- **> 100M€ raised in 2018**

- **High selectivity**
  - 110 projects assessed
  - 19 start-ups
  - 14 series A
  - 1 exit

- **A new approach for creating disruptive startup companies**

Micro Nano Venture Studio
build Ambitious Companies based on Transformative Technologies

THANK YOU!

PLEASE GET IN TOUCH FOR MORE INFORMATION

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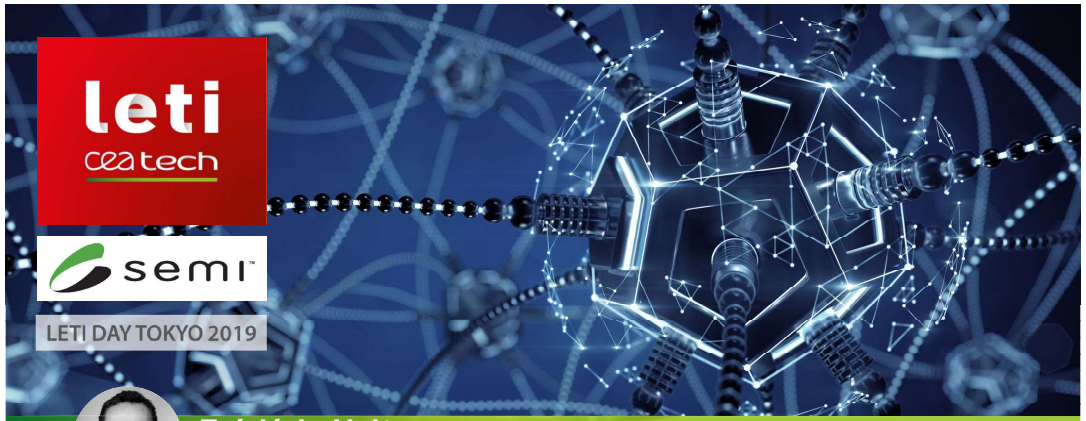
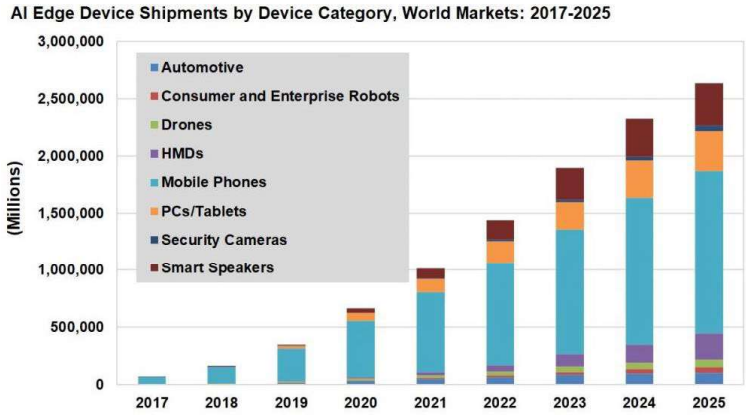
Leti, technology research institute
Commissariat à l'énergie atomique et aux énergies alternatives
Minatec Campus | 17 rue des Martyrs | 38054 Grenoble Cedex | France
www.leti-cea.com



LETI DAY TOKYO 2019

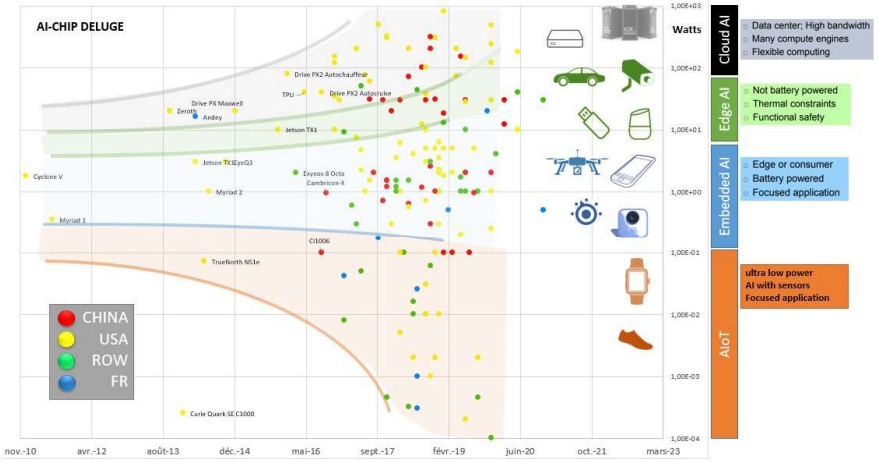
Frédéric Heitzmann
Embedded AI Program Director, CEA-Leti

THE NEED FOR AI AT THE EDGE



Source: Tractica - Sept 2018

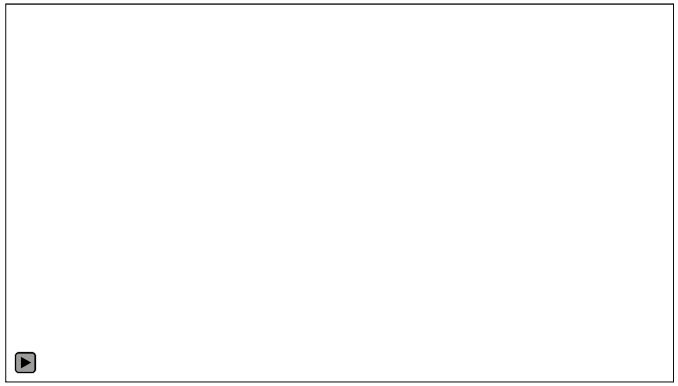
WHO WANTS AN AI-CHIP?



AI APPLIES TO … EVERYTHING !

AI FOR CONSUMER MARKET
SMART DIGITAL SIGNAGE

Real Time Faces Detection, Gender Recognition, Emotion measurement
Quickly realized thanks to N2D2, hardware-optimized

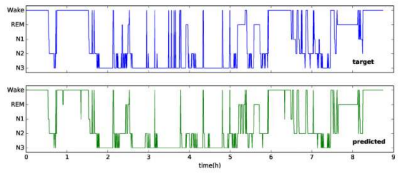


AI FOR HEALTHCARE
SLEEP STAGING

- **Data from the Sleep Heart Health Study: 5,793 PolySomnoGraphy (PSG) records**
- **Deep Learning architecture**
  - Input = 30-s epoch single-channel EEG data
  - Output = 5 classes Wake, N1, N2, N3, REM
  - 14 CNN layers
  - Multiclass cross-entropy cost function
  - Mini-batch training for stochastic optimization of the weights and biases
- Generate artificial inputs that maximize the output activation of each of the 5 output neurons, corresponding to the 5 sleep stages

Medical expertise

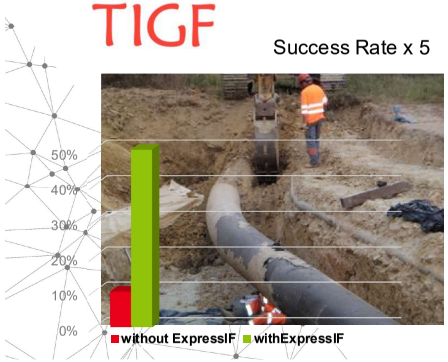
Machine predictions



AI FOR PREDICTIVE MAINTENANCE &
INSPECTION REPORTS ANALYSIS

AI for gas maintenance

Gathering your experts knowledge in a single decision support tool to quickly make the best choice



#Challenge

- 5 000km gas pipeline network
- 50% without accurate sensors
- High cost of intervention
- Various and uncomplete data
- <10% success

#CEA Solution

- Fuzzy rules logics
- 3 patents

ExpressIF

➔ **Explicit AI**

FROM AI ALGORITHM TO INDUSTRIAL APPLICATION

EXAMPLE 1 : DEEPMANTA, AI FOR VISION PROCESSING WITH AUTOMOTIVE CONSTRAINTS

EXPERIENCES

- Computing power: 7.25 TFLOPS
- Power consumption (+300W on original GPU) down to 80 W

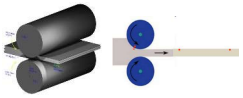
Valeo

CES2018

EXAMPLE 2: AI FOR MANUFACTURING, FROM ALGORITHM TO HARDWARE

THANKS TO N2D2 SOFTWARE FRAMEWORK

EXPERIENCES



CONSTRAINTS

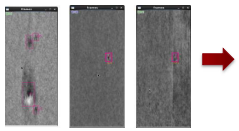
Real time with very high throughput (20m/s)
Tiny defect (~mm) with low contrast
Complex environment (oil vapor, few room for inspection..)

SOLUTION

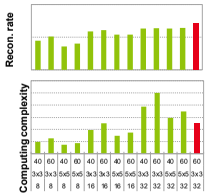
Database labelling and Processing
Fast NN topology Exploration
Performance vs complexity analysis

➔ Real time performance achievable on FPGA (direct code generation with N2D2)

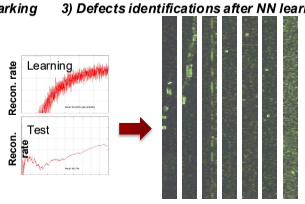
1) Defects labeling and visualization



2) NN Exploration and benchmarking

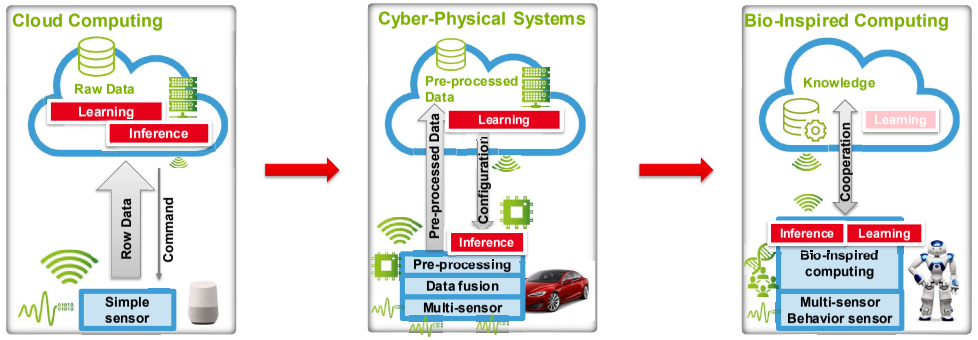


3) Defects identifications after NN learning



AI, NOT ONLY IN THE CLOUD

"ARTIFICIAL INTELLIGENCE, EXTEND OUT OF THE CLOUD!"



What is needed to get from a "Cloud-centric" AI to a "Edge/Embedded/IoT" AI

CHALLENGES FOR EDGE/EMBEDDED AI

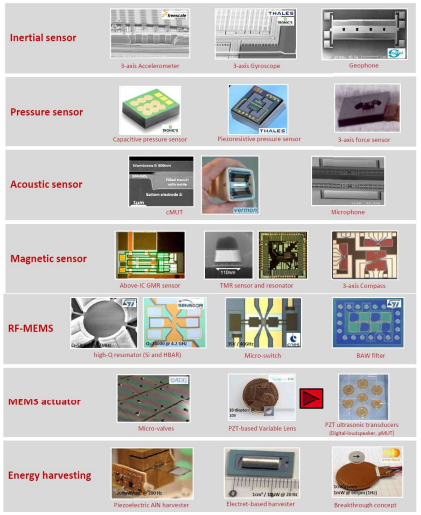
- **Challenges for Edge/Embedded/IoT systems (no only AI)**
  - Low power consumption
  - System Integration, from sensing to computing to acting
  - Autonomy for decision, i.e. do not rely on communications
  - Reduced latency (manufacturing, transportations, critical systems)
- **Make AI easier to develop/deploy**
  - System exploration tools for hardware designers and software developpers
  - Ressource constrained algorithms, e.g. « hardware-aware » learning
- **Make AI easier to use**
  - Adaptation to the environment
  - Customization to the user
  - Workload sharing between the cloud/edge/embedded/IoT

EDGE AI MEANS DEDICATED HARDWARE

« Frugal as a sensor »:

- Technology powered,
- Integrated from sensor to decision,
- 1-100mW range

➔ **Targets ultra low power sensors**

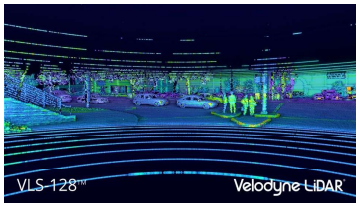


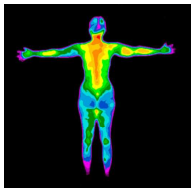
EDGE AI MEANS DEDICATED HARDWARE (CONT'D)

« Versatile as the cloud » :

- Generates information from raw measurements,
- Supports always-evolving algorithms,
- 10^{13} to 10^{15} operations/s/W

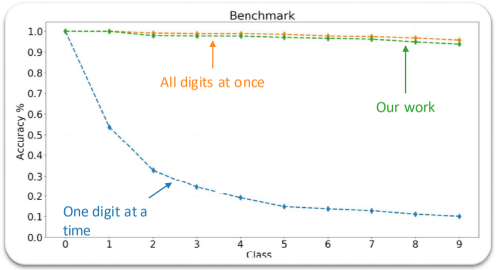
➔ **Target high-thoughput sensors**





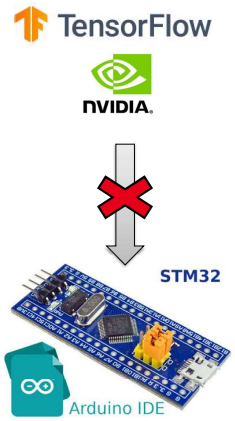
EDGE AI MEANS DEDICATED ALGORITHMS

- **Incremental learning**
  - Must handle real-world data as they come
- **Online learning**
  - Do it locally, keep my private data … private!
  - Enforce the GDPR (General Data Protection Regulation)
- **Security resilience & detection of unknown**
  - When data are not under control
- **Federative learning**
  - Learn locally, share globally
- **Ressource-constrained learning**



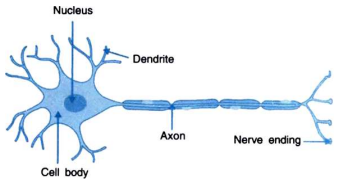
EDGE AI MEANS DEDICATED TOOLS

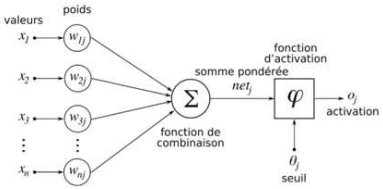
- **Tensorflow is the de facto standard**
  - Supports GPU, Python, SW libraries for neural networks…
- **Tensorflow does not target ressource-constrained hardware**
  - Only GPU and common CPU
- **What is missing (at least)**
  - Hardware-aware learning
  - Fine-tuning of application accuracy *versus* system cost
  - Explore system architecture
  - Generate optimized Software/Hardware combination



WHICH TECHNOLOGY FOR EDGE AI ?

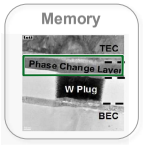
Theory



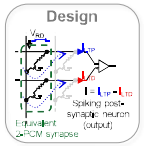


WHICH TECHNOLOGY FOR EDGE AI ?

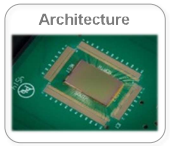
Practice



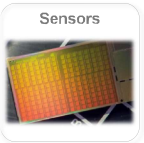
Resistive RAM
- OxRAM, PCRAM
- Multivalue
- Drift compensation
- BE selector



Digital/Analog
- Spikes/Formal
- Frequency coding
- Temporal coding



3D
- Fine/coarse
- Interposer
- Sequential



Sensor integration
- Spike-based processing
- Compressed sensing
- Feature extraction

Complete Framework
- Learn-and-run
- Export models to HW
- Design-space exploration
- Compatible with standards (ONNX)

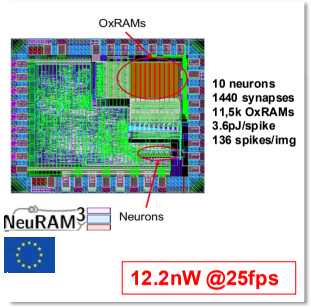
SPIKE-CODING FOR DEEP NEURAL NETWORKS

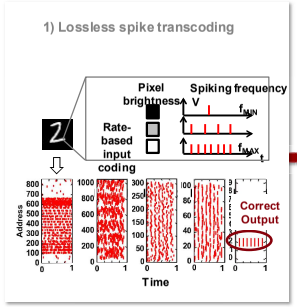
Spike-coding Neural Network (SNN) for ultra low power systems

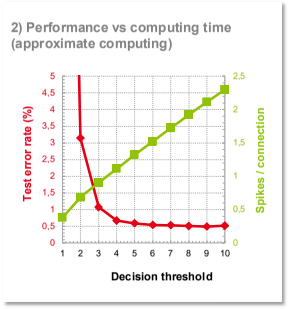
- Spiking NN best exploit NVMs such as RRAM, for massively parallel synaptic memory
- Simple and efficient performance tunability capabilities
- Analog computing

➔ **Demonstration figure classification (MNIST database)**

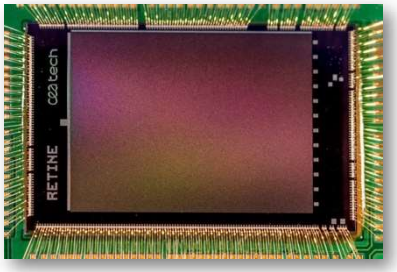
➔ **Published at IEDM 2019**







3D STACKING FOR FOR SMART IMAGER



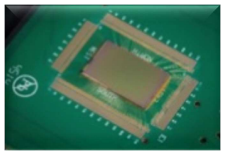
L1@130 nm / L2@130 nm; Die size : 160 mm²
Image sensor:
192x256 @ 5500 fps or 768x1024 @ 60 fps
12 µm pixel, 75% fill factor,

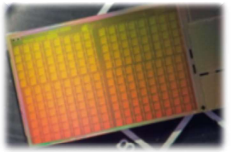
192 processors (3072 PE):
- Processing : 72 GOPS, 11.7 MOPS/mW
1 k instructions / pixel @ 1000 fps
Distributed memory
Each processor can execute a different code in a set

x100 computing power,

x10 energy efficiency,

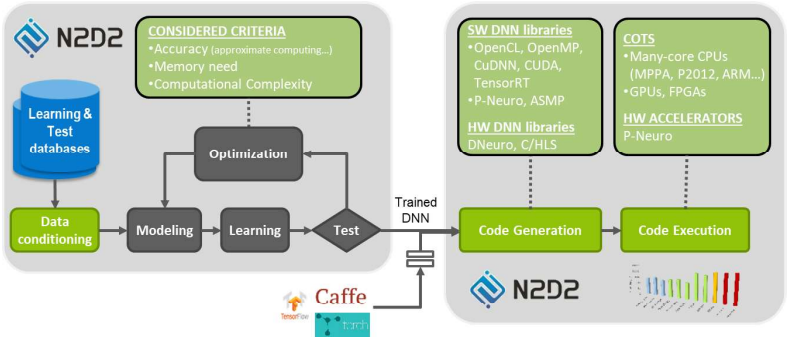
/15 processing latency


BSI sensor die

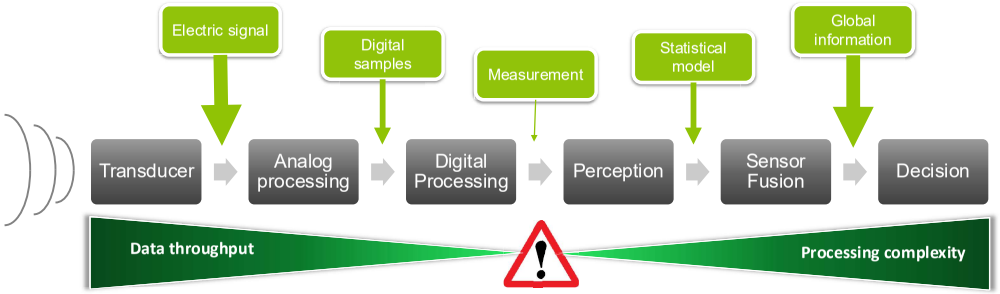

Processor array die

N2D2: NEURAL NETWORK DESIGN & DEPLOYMENT

- A platform for the design and exploration of Deep Neural Networks applications
- N2D2 is available at HTTPS://GITHUB.COM/CEA-LIST/N2D2/



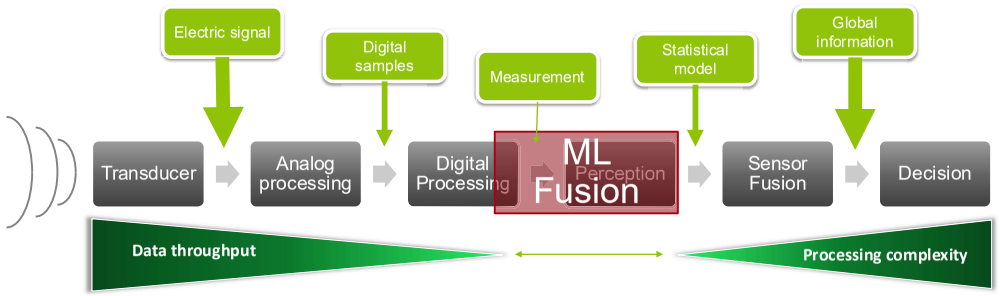
WHAT ABOUT SENSORS: FROM ACQUISITION TO DECISION



➔ Information bottleneck between the sensor (acquisition) and the processor (decision)

➔ AI opens new opportunities to optimize at system level

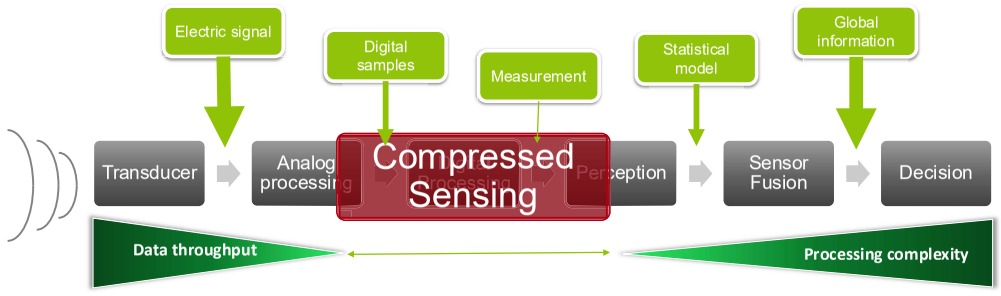
EXAMPLE 1: AI-POWERED SENSOR FUSION



➔ **Improve perception model with Machine Learning**

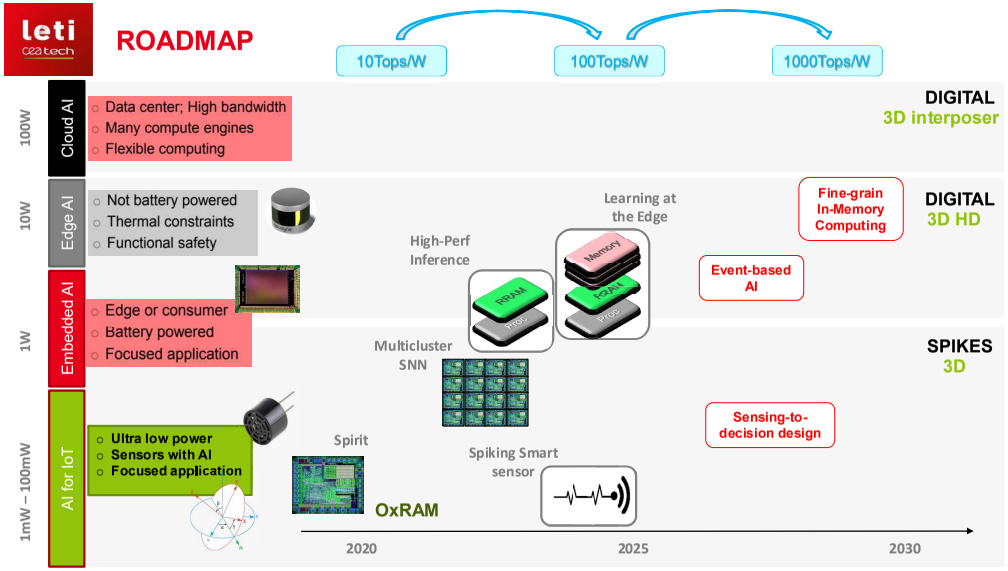
- PhD thesis ongoing with multi-target sensors (radar, ultrasound)

EXAMPLE 2: AI-POWERED PERCEPTION

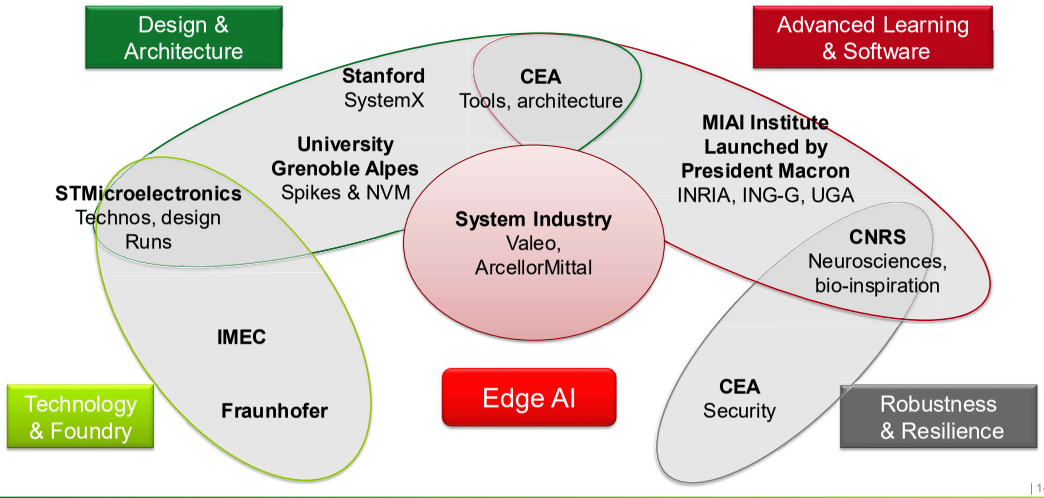


➔ Reduce data rate with compressed sensing and Machine Learning in compressed space

ROADMAP



A REGIONAL-TO-CONTINENTAL ECOSYSTEM



MIAI @ GRENOBLE ALPES

"INTERDISCIPLINARY INSTITUTE FOR ARTIFICIAL INTELLIGENCE"

Institute to support the development of education, research and transfer in AI, at the service of human beings and the environment

- Develop a world-class interdisciplinary research in AI and AI for the human beings and the environment
- Offer attractive courses in AI and its applications for students of all levels and all ages and professionals
- Sustain innovation in AI and develop AI in major companies, SMEs and start-ups
- Inform and interact with citizens on all aspects of AI

NEXT STAGE AI	AI FOR HUMAN BEINGS AND THE ENVIRONMENT
Axis 1. Machine learning and reasoning (8)	Axis 4. AI and society (4)
Axis 2. Embedded AI & hardware architecture for AI (3)	Axis 5. Health (4)
Axis 3. Perception and interaction (7)	Axis 6. Environment and energy (4)
	Axis 7. Industry 4.0 (2)

MIAI @ Grenoble Alpes – Public Partners

MIAI @ GRENOBLE ALPES – INTER DISCIPLINARY INSTITUTE ON AI

Industrial partners

23 big companies

Google, orange, THALES, criteo, Atos, Hewlett Packard Enterprise, ArcelorMittal, Schneider Electric, SIEMENS, LABS, AFP, IBM, TOTAL, ENEDIS, Constellium, Medtronic, facebook, RENAULT, NOKIA, STMicroelectronics, Mentor Graphics, HUAWEI

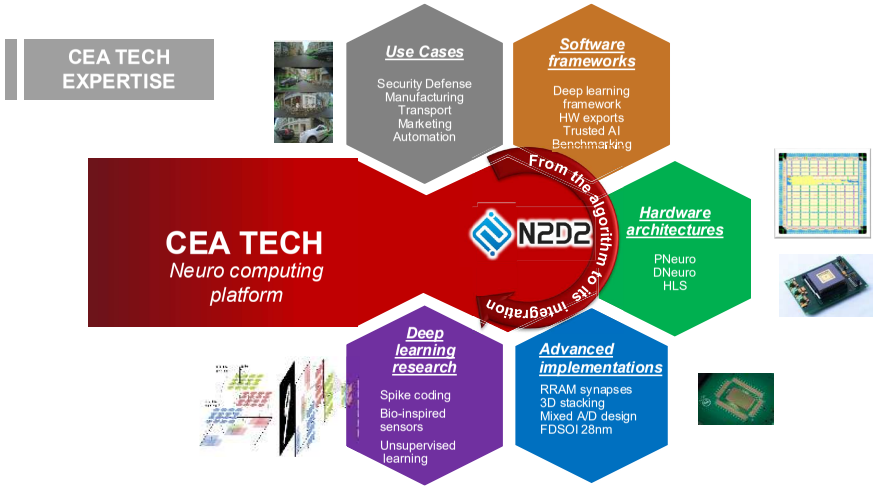
21 SME

genOway, COSMOTECH, Energy Pool, ProbaYes, neovision, TexiSense, PIXYL, hurence, kelkoo, iexec, ARYBALLE Technologies, coservit, QARNOT COMPUTING, eBikeLabs, Quantmetry, Skopai, Seqone, INCOM, Carbon Bee, KOELIS

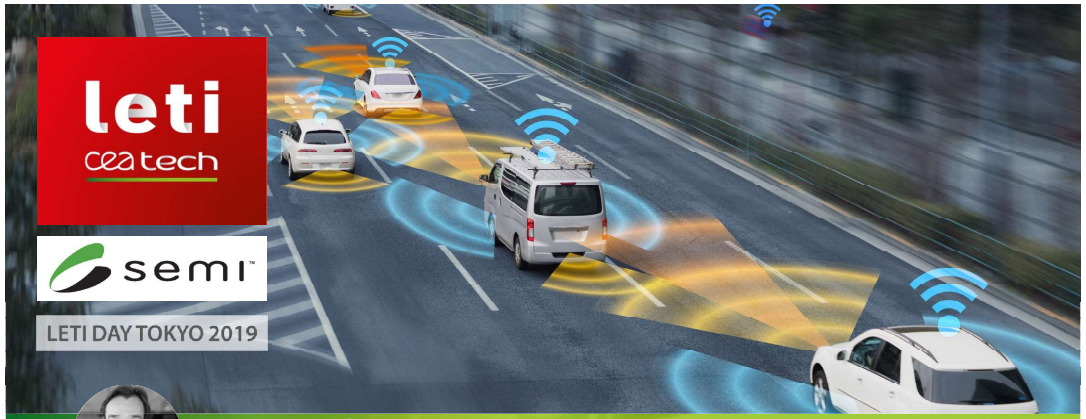
11 very small companies

SurgiQual, THEIA, COMONGO, ryax, microlight3D, P2LINK, Efisense, Oditeo, neoma LABS, SentinHealth

A FULL OFFER: FROM ALGORITHMS TO AI AT THE EDGE



THANK YOU

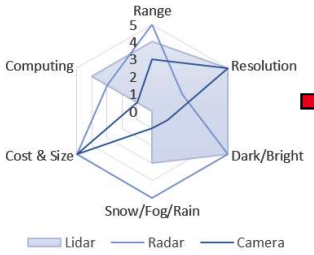


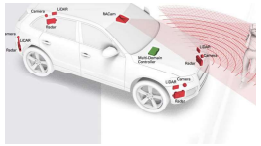
François Simoens
LiDAR Program Director, CEA-Leti

leti ceatech

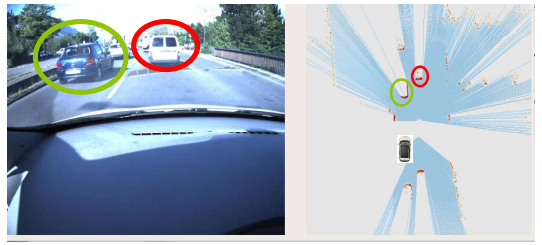
CHIP-SCALE LIDAR IN CPS

- PERCEPTION IS PROVIDED BY COMPLEMENTARY SENSORS





LIDARS PROVIDE HIGH-RESOLUTION & REAL-TIME 3D SENSING



- **All obstacles** in the surroundings are detected in a unique environment model (in red)
- **Free space** is also detected (in blue)

leti ceatech

CHIP-SCALE LIDAR IN CPS

- A WIDE RANGE OF APPLICATIONS

COST & SIZE REDUCTION

CONSUMER

1D RANGE FINDER
LOW COST

INDUSTRY

fetch ROBOTICS
REAL-TIME

MOBILITY

SELF-DRIVING
REAL-TIME & SENSITIVITY

ENGINEERING

3D MAPPING
ACCURACY

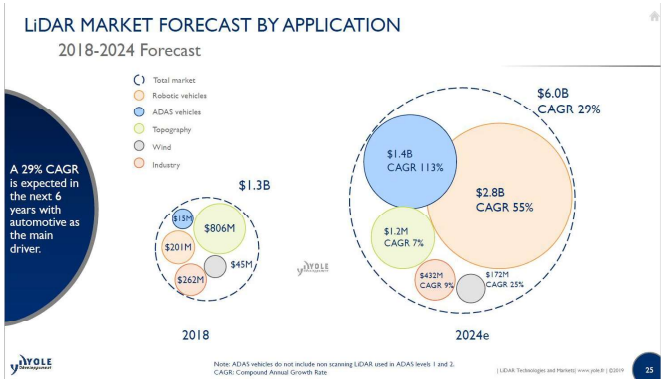
SPACE/SCIENCE

REMOTE SENSING
PERFORMANCE

leti ceatech

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- WITH PERSPECTIVES OF HIGH GROWTH



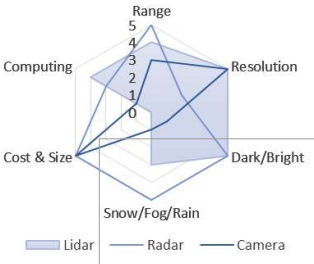
CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- STILL 2 MAJOR OBSTACLES TO LARGE MARKET ADOPTION: COST & SIZE

Price
Scalability / Availability
- Product or Power

Computing
Manufacturability
Maintenance

Form factor
- Size
- Mass



Performances
- Range
- Angular resolution (H / V)
- Spatial resolution
- Spatial accuracy – any 'blooming' artifacts etc…
- Scan rate / frame rate (per sec, in Hz)
- Range repeatability
- **Immunity to other LiDARs**

Environmental conditions
- Environment variability (temperature range, peak sun, fog-snow-rain…)
- Functionality amidst window obstruction
- Quality reliability
  - Shock : Vibe / Jitter
  - Thermal range & cycling
  - Corrosion

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- 3 MAJOR GUIDELINES FOR THE LETI PROGRAM

Chip-scale LIDAR in CPS Program

Miniaturized

Infrared chip-scale LiDAR

Low cost

Fully CMOS-compatible technologies

Agile

driven by embedded computing that processes data fusion

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

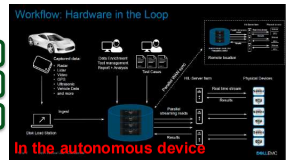
- CEA-LETI HAS THE CAPABILITY TO MAP THIS STRATEGY

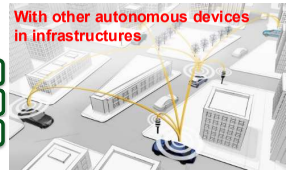
TECHNOLOGIES — SYSTEM — CPS

VCSEL	Laser diode	Fiber laser
Rotating mirror	Optical phased array	MEMs mirror
Lens	MEMs mirror	
SPADs - Gm	PiN	APDs	SiPM
Si	SiGe / Ge	InGaAs	HgCdTe
Analog IC	Time to Digital C	Pulse averaging	Heterodyne detection
Sigma fusion	Sensor fusion	Feedback loops	Embedded AI

Optical source
Beam steering
Optics (Tx, Rx)
3D Sensor
System integration
Data processing

AI
RF
SLAM
V2I
V2V
…





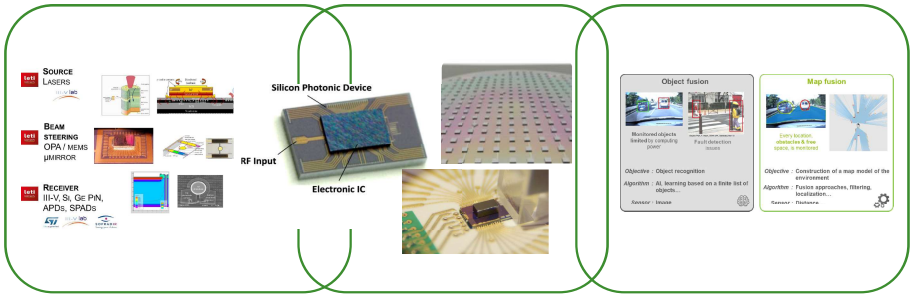
CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- LETI HAS THE KEYS TO CRACK THE CODE OF A LOW COST CHIP-SCALE LIDAR

PHOTONICS
LOW COST TECHNOLOGIES & INTEGRATED ON CHIP

ELECTRONICS
HETEROGENEOUS INTEGRATION & 3D ASSEMBLY WITH ELECTRONICS

SOFTWARE
OPERATION DERIVED FROM DATA FUSION & AI

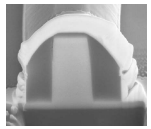


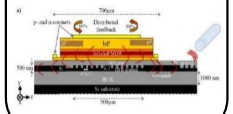
CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- LETI'S KEY PHOTONICS TECHNOLOGIES FOR CHIP-SCALE LIDAR

OPTICAL EMITTER

CMOS-COMPATIBLE HYBRID III-V ON SI LASER



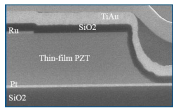


BEAM STEERING

OPTICAL PHASED ARRAYS

1D ±10° BEAM STEERING AT 900NM USING AN INTEGRATED OPA

MEMS MIRRORS

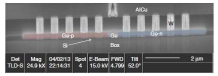


8" THIN-FILM PIEZOELECTRIC MATERIAL & TECHNOLOGY

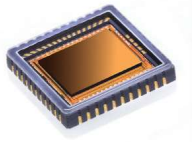
RESONANT ASYMMETRIC MICRO-MIRROR WITH PZT ACTUATION

OPTICAL RECEIVER

SIGE / SI PHOTODIODES



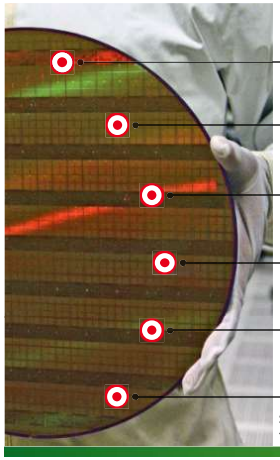
INGAAS PHOTODIODES



SOFRADIR — III-V lab

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- LETI'S KEY PHOTONICS TECHNOLOGIES :
  STATE-OF-THE-ART INTEGRATED SILICON PHOTONICS PLATFORM



FIBER GRATING COUPLER

SI-SIN TRANSITION

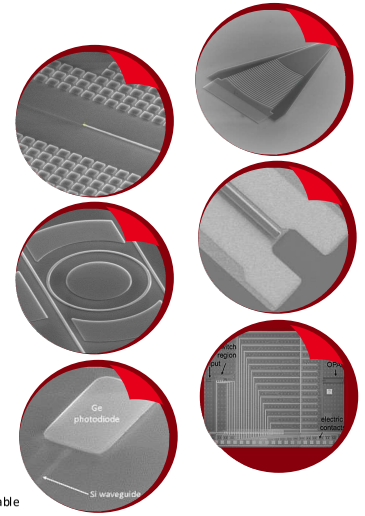
HYBRID INP/SI LASER

MODULATOR

OPTICAL PHASED ARRAY

PHOTODETECTOR

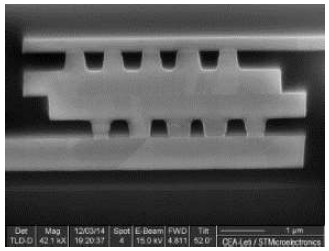
Szelag et al., " CMOS compatible 200mm silicon photonic platform suitable for high bandwidth applications" SSDM, 2017



CHIP-SCALE LIDAR IN CPS LETI PROGRAM

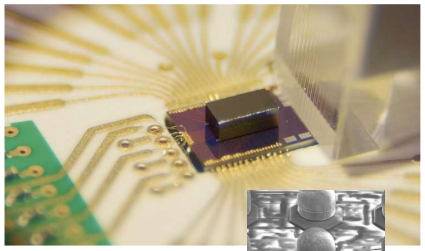
- LETI'S KEY INTEGRATION TECHNOLOGIES FOR CHIP-SCALE LIDAR

ELECTRONICS 3D-STACKING



High density hybrid bonding
Towards smaller pitch and multi layers

SI-PHOTONICS 3D ASSEMBLY WITH ELECTRONICS

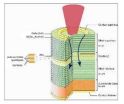


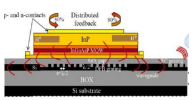
Flip-chip assembly
with copper pillars

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

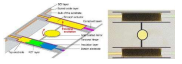
- LETI HAS KEY TECHNOLOGIES + HETEROGENEOUS INTEGRATION KNOW-HOW

SOURCE
LASERS
III-V lab

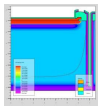


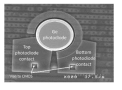


BEAM STEERING
OPA / MEMS µMIRROR

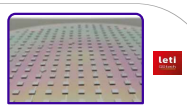


RECEIVER
III-V, SI, GE PIN, APDS, SPADS
III-V lab — SOFRADIR

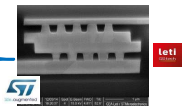




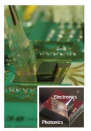
HETEROGENEOUS INTEGRATION



3D-STACKING



SI-PHOTONICS



LIDAR-ON CHIP

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- FOCUS ON BEAM STEERING WITH NO MECHANICAL ELEMENTS

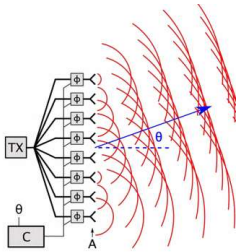
Mechanical scanning RADAR

Mechanical scanning LIDAR

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

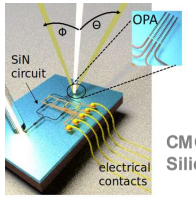
- FOCUS ON BEAM STEERING WITH NO MECHANICAL ELEMENTS

NO MECHANICAL ELEMENTS



Phased array RADAR

Optical Phased array- based LIDAR

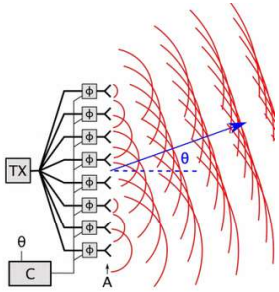


OPA

CMOS compatible Silicon photonics

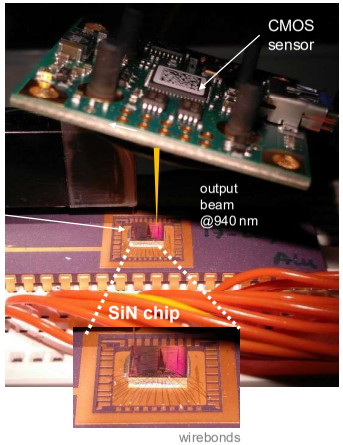
CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- FOCUS ON OPTICAL PHASED ARRAY FOR BEAM STEERING



Silicon photonics:

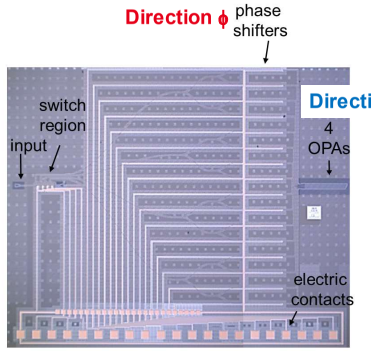
- Operating λ=0,5-4µm
- Suited to high component density
- CMOS compatible for high-volume/low cost production

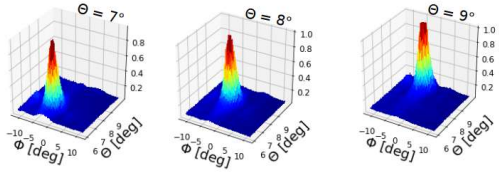


DEMONSTRATOR OF 1D ±10° BEAM STEERING AT 900NM

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- FOCUS ON OPTICAL PHASED ARRAY FOR BEAM STEERING: DEMONSTRATION OF 2D SCANNING OPA





- 905nm OPA based on SiN waveguides/devices

N. A. Tyler *et al. Optics Express*, Feb. 2019.
Tyler, N. A., et al. CPMT Symposium **BEST PAPER AWARD**

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- LETI'S KEY KNOW-HOW IN PERCEPTION COMPUTING: COMPLEMENTARY APPROACHES

Object fusion

Monitored objects limited by computing power

Fault detection issues

Objective : Object recognition

Algorithm : AI, learning based on a finite list of objects…

Sensor : Image

SigmaFusion™

Map fusion

Every location, **obstacles & free** space, is monitored

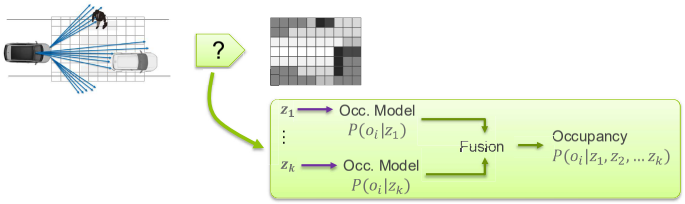
Objective : Construction of a map model of the environment

Algorithm : Fusion approaches, filtering, localization…

Sensor : Distance…

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- LETI'S KEY KNOW-HOW IN PERCEPTION COMPUTING: SIGMAFUSION™ BUILD THE OCCUPANCY GRID FROM DIFFERENT MEASUREMENTS



- Use Bayesian Fusion
  - only **integer arithmetic**
  - Compatible with **µC hardware (no Floating-Point Unit)**
  - Suitable for **embedded SW** or HW implementations

→ Rethink arithmetic!

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- LETI'S KEY KNOW-HOW IN PERCEPTION COMPUTING: SIGMAFUSIONTM DEMO

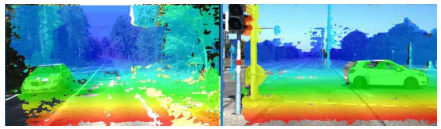
- Perception for autonomous vehicles
  - 2x Velodyne VLP 16 LIDARs
    - 600000 data points per sec
    - 16 Mbits/sec data bandwidth (Ethernet)
  - 77GHz IFX Radar prototype
  - Environment model
    - ~1M cells
    - real-time computing (40 ms)
  - Hardware used: World First
    - **Infineon AURIX TriCore TC29x & TC39x**
    - **Ready for ISO26262 ASIL-D certification**

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- LETI'S KEY KNOW-HOW IN PERCEPTION COMPUTING: STEREOVISION IN AUTOMOTIVE EMBEDDED SYSTEM

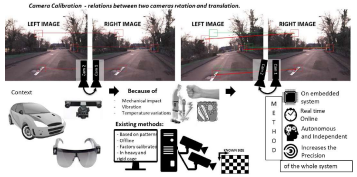
Depth extraction from stereovision camera

Low latency hardware accelerator
Integrated in Blaxtair Cameras for pedestrian detection
Extraction of road plane and obstacles



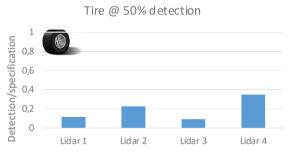
Online Stereo camera self calibration

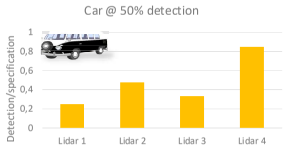
Enhance stereovision camera robustness
Calibration Monitoring and calculation
Based on extracted features for the application pipeline

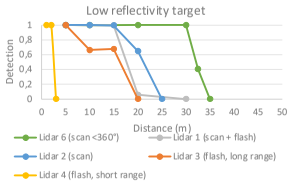


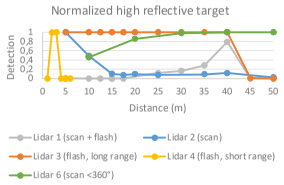
CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- LETI DEVELOPS METROLOGY FOR LIDAR BENCHMARKING & ASSESMENT







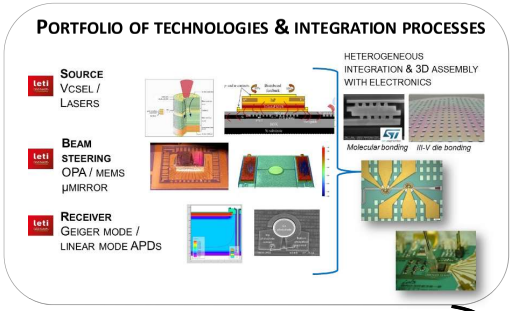


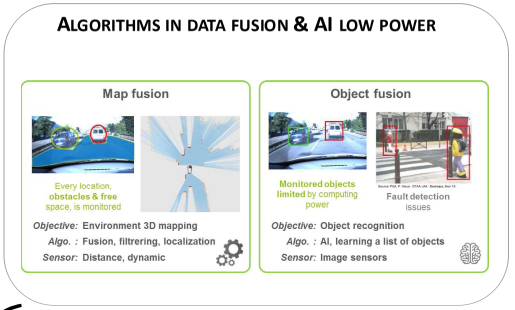
http://www.leti-cea.com/cea-tech/leti/english/Pages/Whats-On/Press%20releaseLeti-Transdev-IRT-Nanoceleo-Announce-Pilot-Program-To-Assess-New-Perception-Sensors-For-Autonomous-Vehicles.aspx

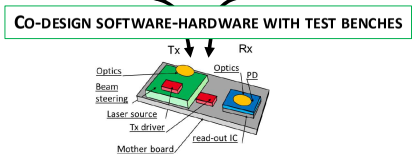
http://www.cea-tech.fr/cea-tech/english/Pages/ec_2018/evaluating-perception-sensors-autonomous-vehicles.aspx

CHIP-SCALE LIDAR IN CPS LETI PROGRAM

- TAKEAWAY: LETI HAS THE KEYS TO CRACK THE CODE OF AN INTEGRATION STRATEGY







\Orchestrating a brighter world NEC

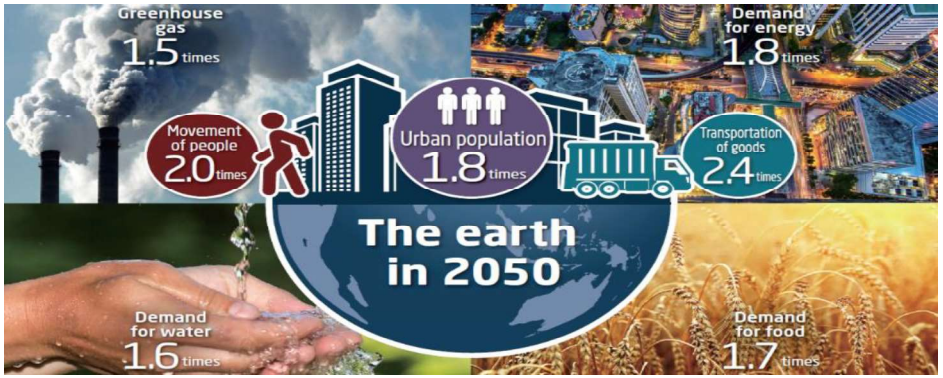
5G Integrations of Services and Technologies

Yuichi Nakamura, PhD.
Vice President, R&D, NEC Corp.

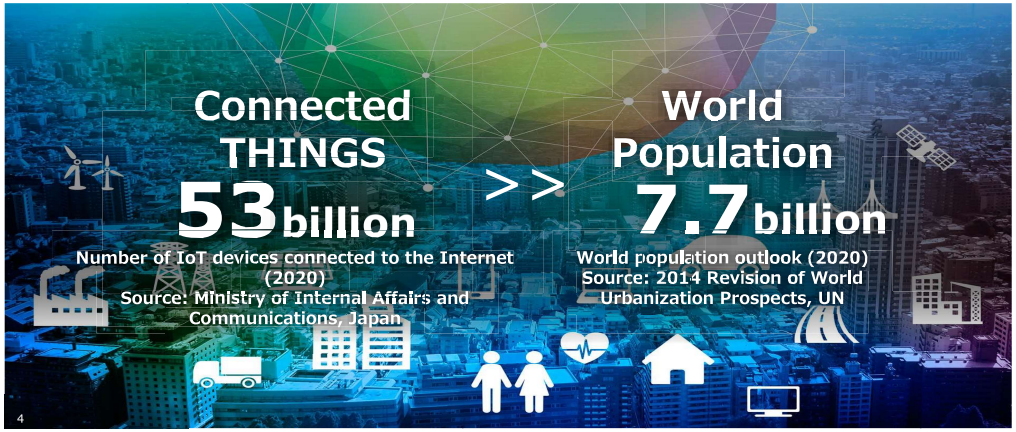
\Orchestrating a brighter world NEC

Social Environment And Technology Outlook

Global Megatrends: Urban Life is Very Good!, but



Future Outlook – Connectivity



Social Value Creation and SDGs

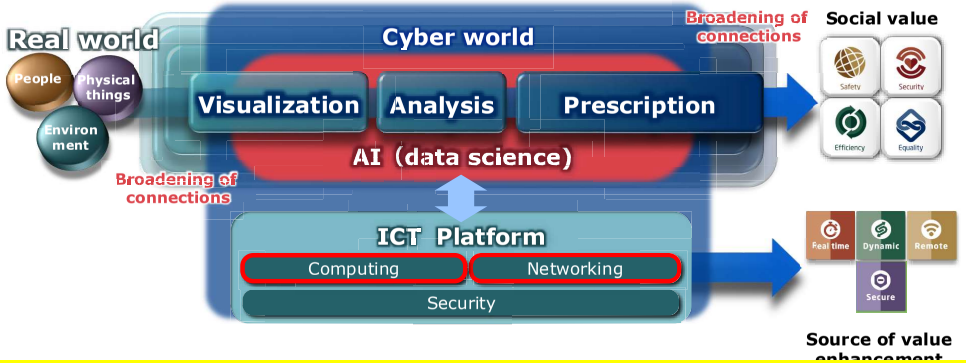
NEC's 7 Themes for Social Value Creation

SDGs
Sustainable Development Goals

AI and ICT can support !

AI and ICT Platform

AI cannot create new social value without high efficiency ICT platform



EX: ICT can contribute transmit huge data, process huge data, or etc.

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5G : From Roadmap to Integration

Customers Trends are Changed

What are CS/Customer Satisfaction and CX/Customer Experience

- Customers were surprised with technical words.
  Up to AI, 100Mbps, LTE, super, hyper, and etc.

Technologies are going to complicated. ⇩ Some cases, they cannot feel them

- Customers recognize new technologies via their satisfaction and experience
  - They have no interest in mechanism or technologies.
  - Amazing, Cool, Lovely, Sakusaku(Japanese),

Impressive technologies are good!

Technologies Trends are also Changed.

During roadmap age, we can easy to present "Impressive", but

Roadmap → **Integration**

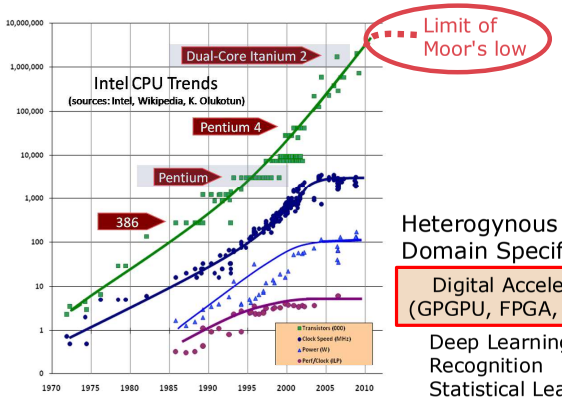
- Silicon Process
  (130nm,28nm,…,7nm)
- Clock Speed
  (100MHz, …,1GHz,…3GHz)
- Speed of Optical Fiber
  (1Gbps, 10Gbps…, 400G)
- Speed of Wireless
  (256Kbps,…, 150Mbps)

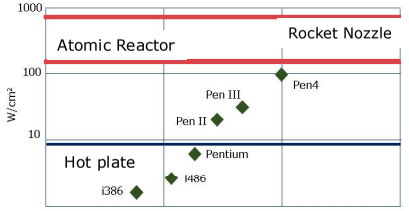
- Using Accelerator
  GPGPU, FPGA,…
- Estimation of real performance
- MIMO / Beam Forming
  - Focusing resources to terminals
- Machine Learning
  - A good result is good!

Key Words : Integration all technologies for customer experiences

Computing : Integration of Heterogeneous Cores

Heat at Chips makes "Heterogeneous Domain Specific Computing"





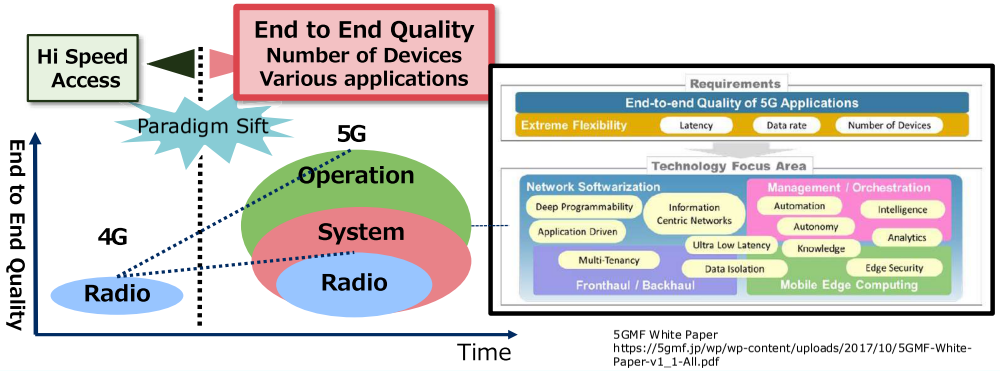
Heterogynous
Domain Specific Computing

Digital Accelerator (GPGPU, FPGA, Vector)	Quantum computing	Brain Morphic
Deep Learning Recognition Statistical Learning	Combinational Optimization Security	Human like decision

http://www.gotw.ca/publications/concurrency-ddj.htm

5G : From Radio Technologies to System Architecture

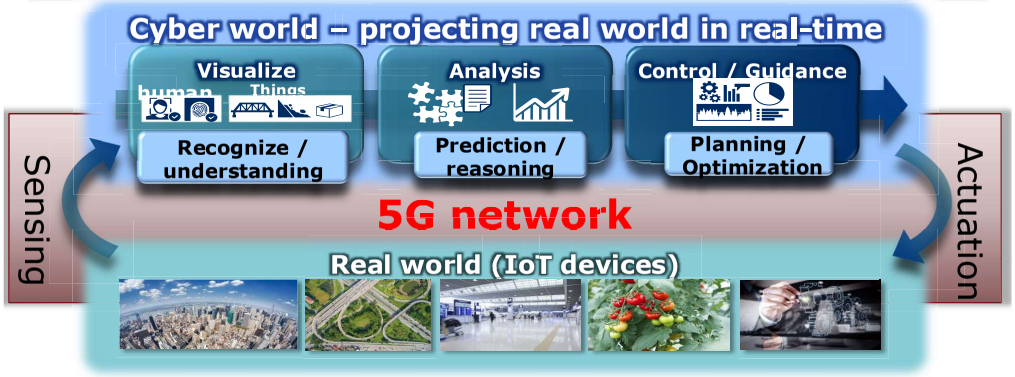
Technological development is important to improve a performance of an entire system and "customer experiences/CX or CS".



5GMF White Paper
https://5gmf.jp/wp/wp-content/uploads/2017/10/5GMF-White-Paper-v1_1-All.pdf

5G Works as Bridge among IoT devices

What is CX/CS on IoT systems by using 5G?
-> communication between sensing and acutuation



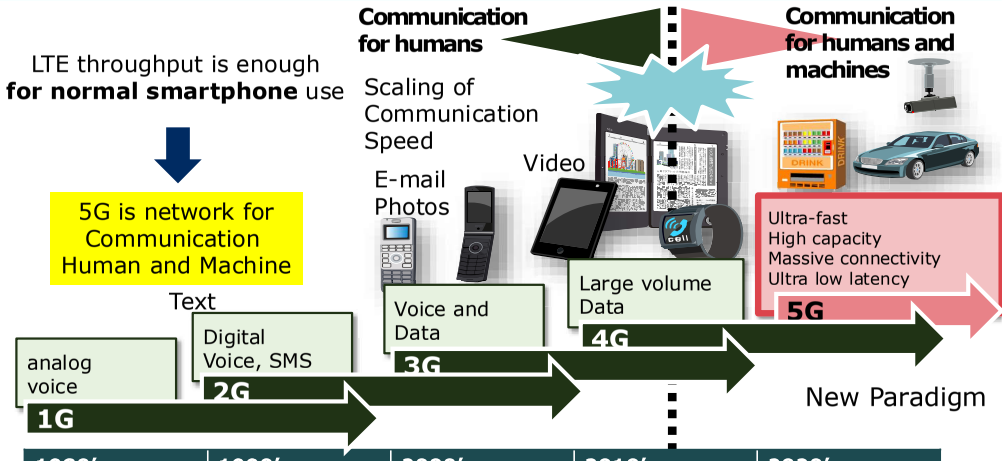
\Orchestrating a brighter world NEC

5G Technologies
What are different points from 3G/LTE

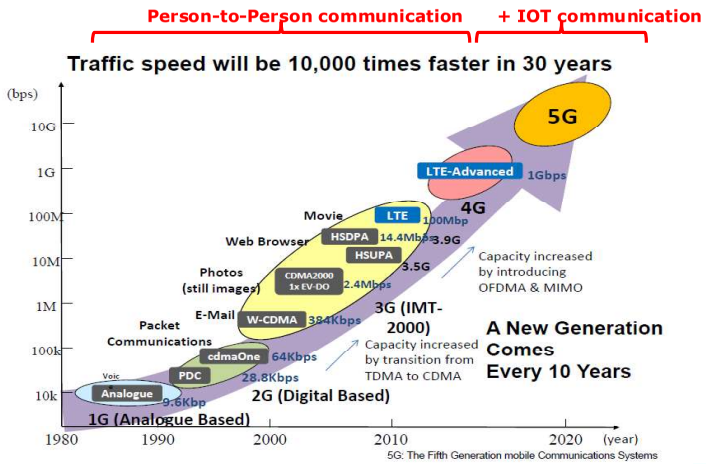
Mobile Network Evolution toward 5G

LTE throughput is enough **for normal smartphone** use

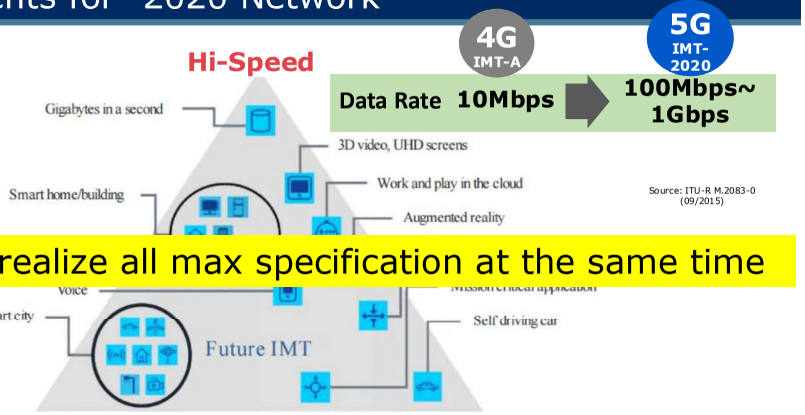
5G is network for Communication Human and Machine



5G Trend Mobile Access Evolution



Requirements for "2020 Network"



We cannot realize all max specification at the same time

Massive connections

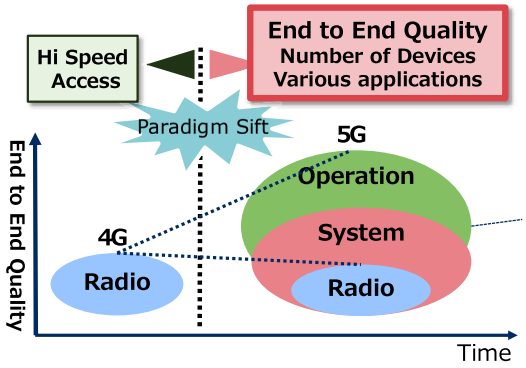
Number of Terminals	100	10000

Low latency

Latency (Access)	10ms	1ms

Technology Trends for 5G (System)

Technological development is important to improve a performance of an entire system

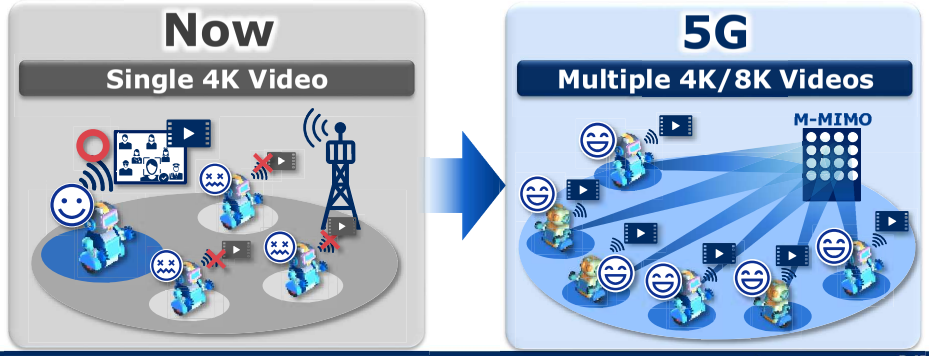


Tech area	Technology
Operation	・Automatic design ・Failure analysis
System	・MEC ・Network Slicing ・SDN/NFV ・IoT Service Enabler ・C-RAN
Radio	・Massive MIMO ・Multi-RAT/Multi-band Coordination

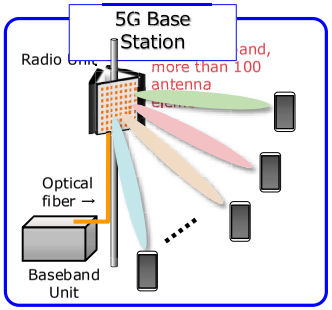
Technical case1 : Radio: Massive MIMO

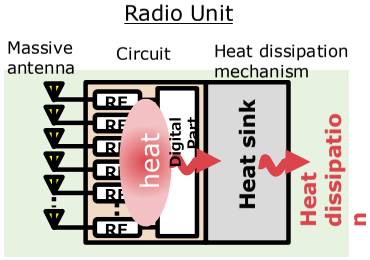
High speed & Capacity

Individual beam is allocated to each device to send multiple high resolution videos at the same time.



Deployment Challenges of 5G Massive MIMO Radio Units

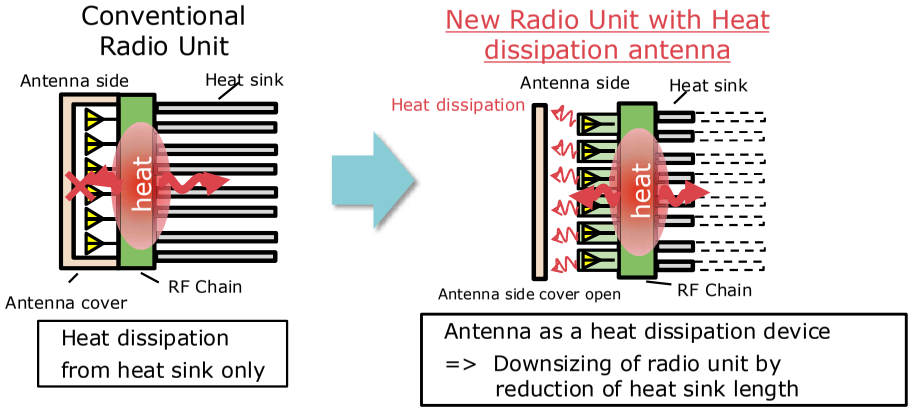




・RF chain generates a lot of heat
・Large heat sink is required

The installation location is restricted due to the increased radio unit's size

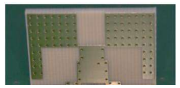
New Concept: Heat Dissipation from Antenna

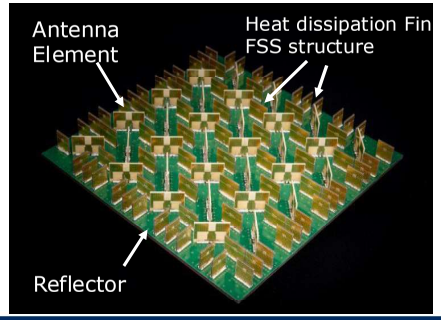


Heat Dissipation Antenna Array

- The antenna element is configured as a 3-D form and used as a heat dissipation fin
- Many metal plates with (Frequency-Selective Surface (FSS) structure are also added as heat dissipation fin on the reflector

32 elements（4×4×2pol.）

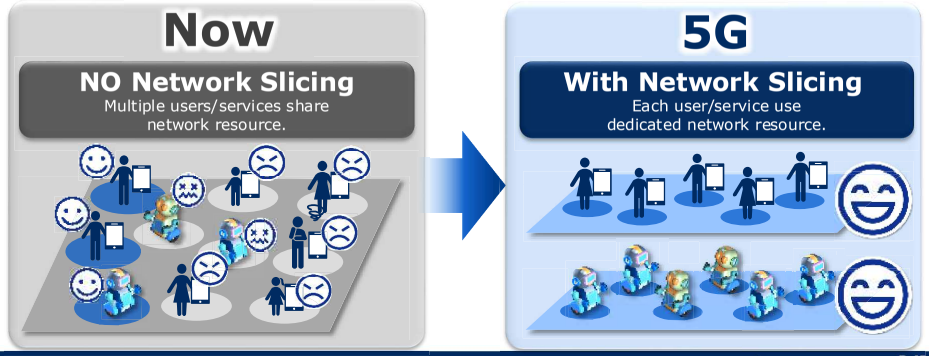




Technical case2 : System: Network Slicing

Service Diversity

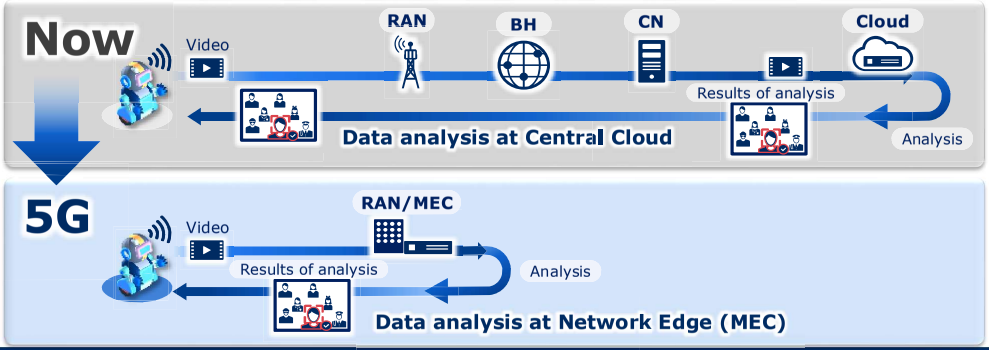
Sufficient network resource is allocated for each user/service by network slicing on virtualization base.



Technical case3 : System: Mobile Edge Computing

Low Latency

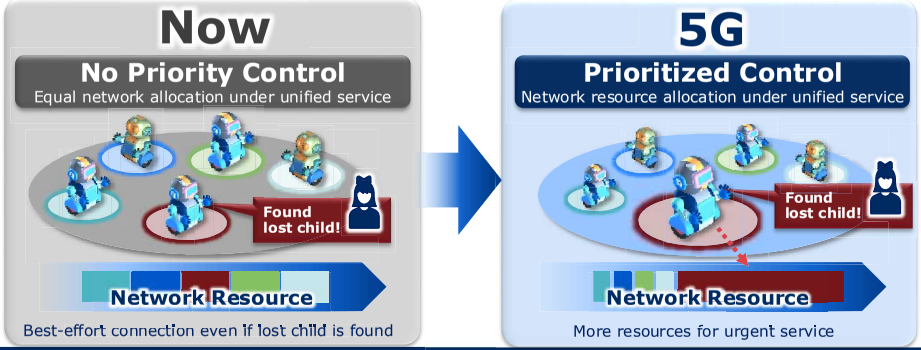
Data analysis is performed at Network Edge (nearby data source) to realize low latency.



Technical case4 : System: IoT Service Enabler (ISE)

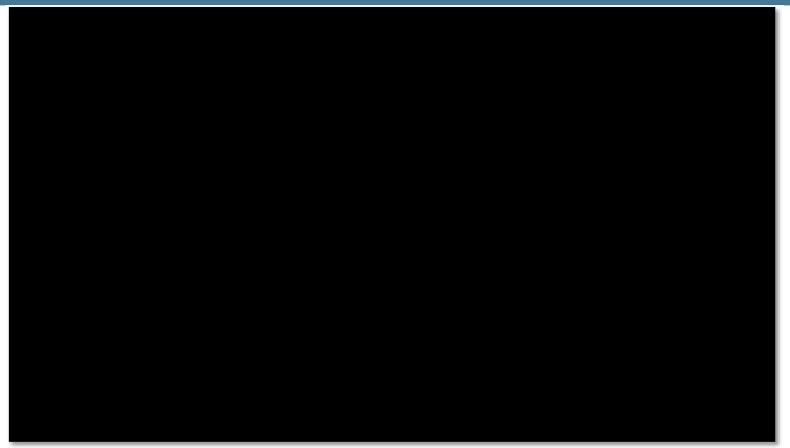
High Reliability

Necessary network resource can be secured by ISE when service priority is required by critical and urgent moments.



5G Use Cases :Video

5G Demo Video 1 : Advanced Security Services

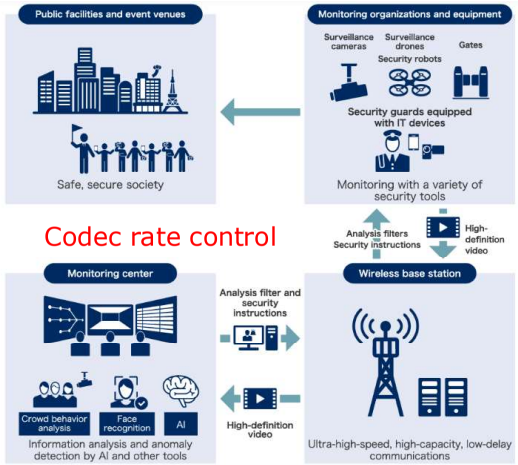


NEC HP : NEC, NTT DOCOMO, ALSOK, Field trial to achieve advanced security services ALSOC
https://www.nec.com/en/global/onlinetv/en/5gtrial2.html

5G Demo Video 1 : Advanced security services

This trial will verify the implementation of security for preventing crimes and accidents in combination with featuring image analysis and AI-based security, as well as the advantages of 5G.

NEC HP : Trial to achieve advanced security services leveraging 5G
https://www.nec.com/en/global/about/vision/case/20.html

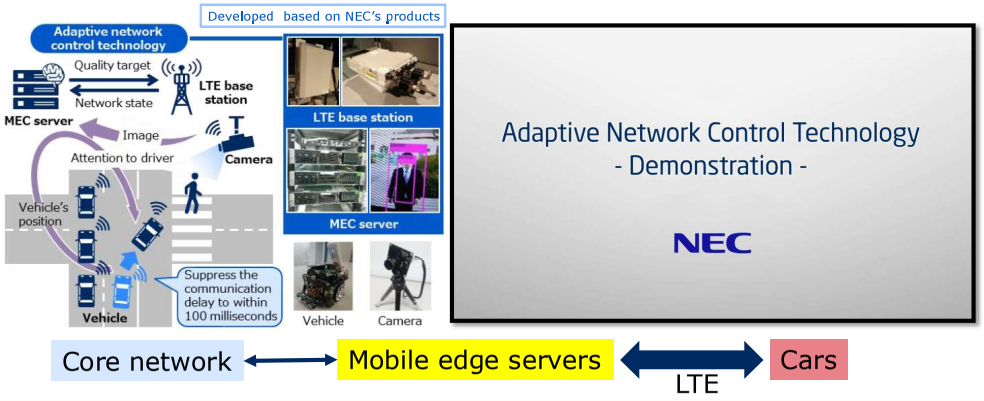


5G Demo Video 2 : Remote-controlled Construction

NEC HP : NEC, KDDI, Obayashi conducts remote construction trial using 5G
https://www.nec.com/en/global/onlinetv/en/5gtrial1.html

5G Demo Video 4 : Adaptive Network Control Technology by Mobile Edge Servers

- NEC confirmed that its adaptive network control technology helps to improve the safety of automated driving in the experiment.



Conclusions

- 5G and Social Value Creation
  - Customer's sense is changed. Technology trends is changed.
  - Roadmap style research cannot be adopted for IoT age.
- 5G = Integration of Various technologies
  - One point improvement cannot achieve
  - Diversity of technologies makes cool 5G
- Use cases
  - Realize social value creations
- Machine Learning can support cool 5G systems

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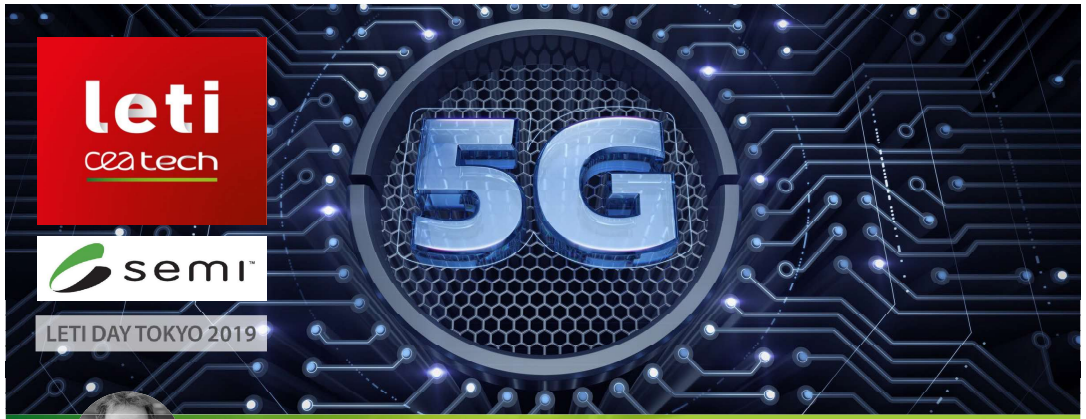
NEC



Eric Mercier
5G Program Manager, CEA-Leti

leti ceatech

RF & MMW TRENDS IN 5G

Main topics of interest in RF & mmW

More throughput & Higher Frequency
- Race for **higher data rate**: 1Gbps, 10 Gbps, 100 Gbps …
- Address WorldWide solutions: **28 GHz, 40 GHz**, 70 GHz, 81 GHz, **140 GHz** …

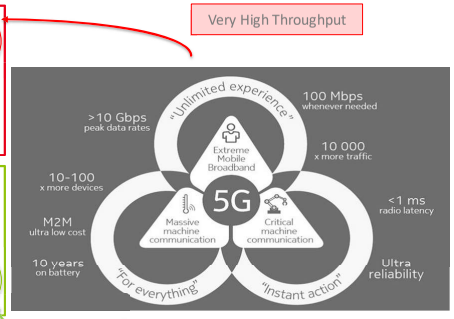
eMBB

RF connectivity for the IoT market
- Standards get more & more maturity: LTE-M, **NB-IoT** as flagships
- Emerging stand-alone solutions: LoRa, SIGFOX

mMTC

New features for 5G :
- ultra-Reliable **Low Latency** Communications / uRLLC
- massive Machine Type Communications / mMTC

uRLLC



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RF & MMW TRENDS IN 5G

Connecting Objects, Machine, People – Deploying Infra-structures

CONNECTED ASSET long lasting energy autonomy
- **Low-cost** solution drawing few energy from battery
- Performance versus cost, implying high-degree of integration

10 BUnits

USER TERMINAL increase the connectivity capacity & data rates
- Miniaturization for mmW modules
- Expand throughput capacity of mmW to low-cost, **small form factor**

1 BUnits

ACESS POINT bridging infra-structures / back-haul with users
- **High-performance** medium-range communications
- Specific requirements on the Front-End Module

10 MUnits

INFRASTRUCTURE high capacity
- High-power transmission associated with **high data rate**
- Few constraints on the form factor

100 kUnits

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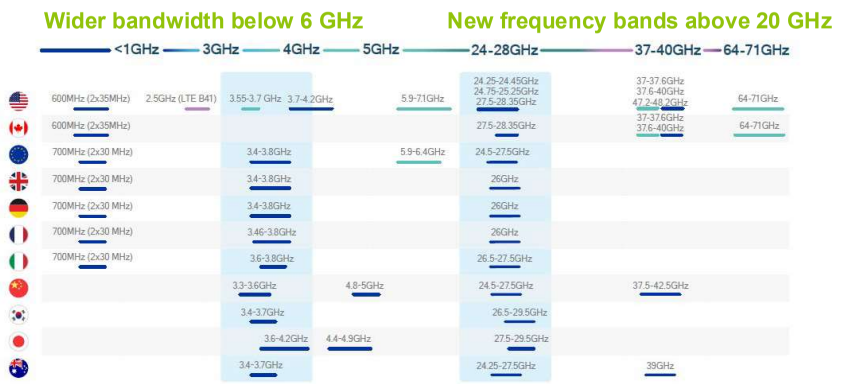
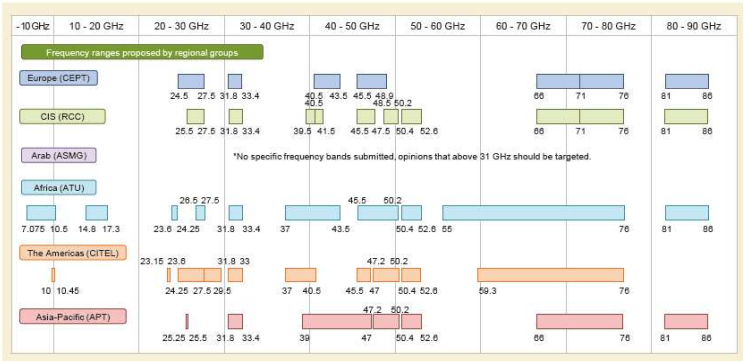
RF & MMW TRENDS IN 5G – MAIN ALLOCATED BANDS



RF & MMW TRENDS IN 5G – MAIN ALLOCATED BANDS

Aggregation of frequency bands to get very wide bandwidth



BEYOND 100GHz

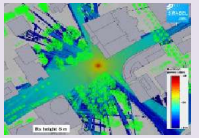
Scenarios

Ultra-high capacity xHaul

100+ Gbps transport, for
- Dense massive MIMO networks
- Cell-free network architecture
- Massive cloud & edge computing
- Enhanced broadband fixed access
- Casual drone-based xHaul
- ...

Enhanced hospot

100+ Gbps per cell,
Multi-user access
Few meters range,
Low mobility, for
- Kiosk (high speed download)
- Enhanced immersive experience
- ...



Ultra-fast short-range communications

100+ Gbps P2P or P2MP, for
- Server farm
- Inter-chip
- Intra-chip
- ...

bit/s/Hz/J → bit/s/Hz/J

Frequency of interest
92- 94 GHz,
94.1-100 GHz,
102-109.5 GHz,
111.8-114.25 GHz,
122.25-123 GHz,
130-134 GHz,
141-148.5 GHz,
151.5-164 GHz,
167-174.5 GHz,
174.5-174.8 GHz,
191.8-200 GHz

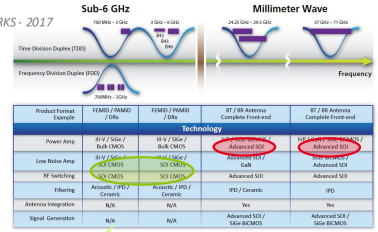
Source ANFR

5G NEW CHALLENGES – CMOS BRIGHT FUTURE

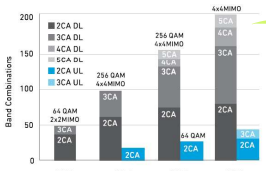
5G vision for eMBB

- **Below 6 GHz :**
  - Extending bandwidth : carrier frequency intended to be up to 6 GHz
  - **Carrier Aggregation**, More Channels, More Filtering ….
  - Better energy efficiency requirement for longer battery life-time
- **Above 6 GHz – mmW Bands**
  - Natural Wider Bandwith / Much **Higher Operating Frequencies**
  - 28 GHz / 39 GHz as 5G objectives, then 140 GHz …. up to 285 GHz for future 6G

SKYWORKS - 2017

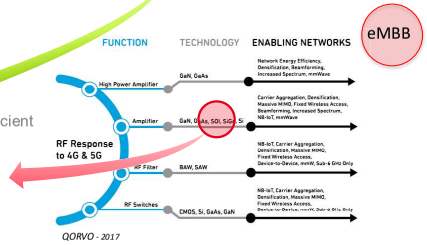


eMBB



QORVO - 2017

- Wider Bandwidth / More Efficient
- CMOS SOI technologies as a solution for more integration



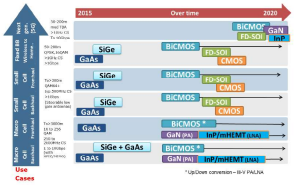
QORVO - 2017

TECHNOLOGY PERSPECTIVES – CMOS versus III-V

5G mmW communications - Trends in publication

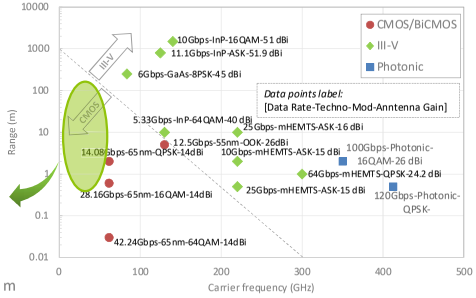
- **Output Power$_{DIRECTED}$ (dBi) / Range (m) versus Carrier frequency (GHz)**

eMBB



ETSI - 2018

Recent multi-Gb/s transceivers



- Connected Asset : 2.4 GHz / 100 m
- User Terminal : 28 GHz / 20 m
- Access Point : 28 & 60 GHz / 30 m

mmW communication will make massive use of directivity (Beam-Forming / Beam-Steering), maintaining long-range/high-performance

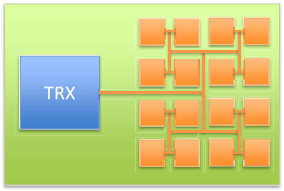
CMOS technology relevant for Low-Cost / High-Integration

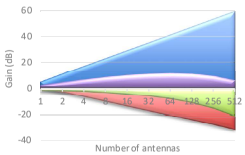
MMW IC AND SYSTEMS FOR 5G BEAM-FORMING/BEAM-STEERING

5G Access point module architecture

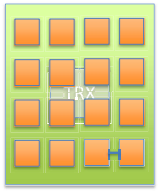
eMBB

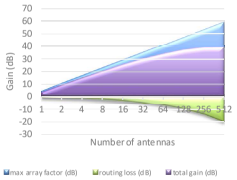
Fixed beam antenna array



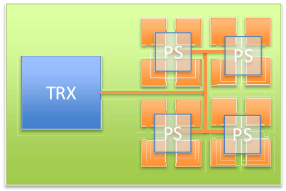


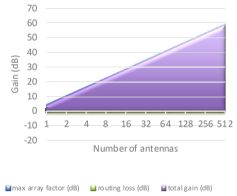
Compact monochip





Satellite phase shifters





MMW SILICON POWER AMPLIFIER CHALLENGES

5G-New Radio opportunity : from 33dBm to 63dBm EIRP

Indoor Hotspot
Dense Urban
Urban Macro
User Equipment (UE) to Base Station (BS)

Source: Accton

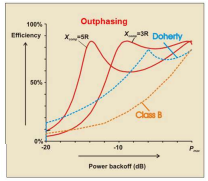
Considering a MIMO, with a panel unit of 256 antenna elements array, and split into 4 sub-panels of 64 elements each, thus the required output power could be:

33dBm EIRP : 64 elements with P_{1dB} = 3dBm for each PA
43dBm EIRP : 64 elements with **P_{1dB} = 13dBm** for each PA
53dBm EIRP : 64 elements with **P_{1dB} = 23dBm** for each PA → Challenging for CMOS but to be considered FD-SOI and RFSOI are candidates
63dBm EIRP : 64 elements with P_{1dB} = 33dBm for each PA → III-V / GaN technology must be considered

RF FRONT-END MODULES FOR WIDEBAND 5G

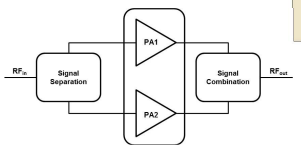
Architecture trends in Power Amplifier

Advanced PA architectures for improved linear efficiency
- Load modulation
- Supply modulation

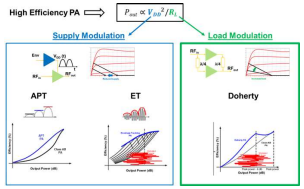


eMBB

Concepts for next generation
- Doherty (DPA)
- Outphasing (OPA)
- Envelope Tracking (ET)



These new concepts will help to deploy CMOS for PA
- **LDMOS available** for PDSOI technologies
- **High-gain / high-efficiency** made possible

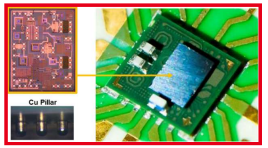


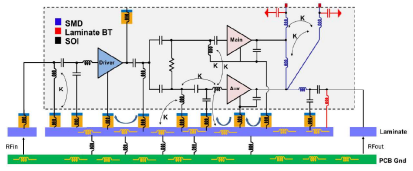
HIGH EFFICIENCY PA/FEM FRONT-END MODULES

eMBB

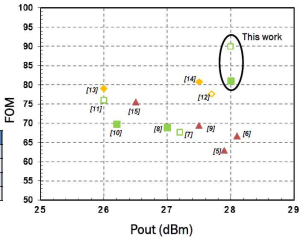
5G Sub-6GHz Wideband PA / 2.5GHz – Low cost RFSOI now demonstrated !

- A Broadband High-Efficiency SOI-CMOS PA Module - **RFIC 2019** (Boston)
  - Linear Doherty Power Amplifier (DPA) for LTE/LTE-A
  - **CMOS 130nm RFSOI** technology
  - Packaged using flip-chip on a laminate substrate
  - **PAE ~ 45%** at 2.5 GHz for 4.5 dB back-off
  - POUT = **+28 dBm**
  - Maximum FOM (PAE+|ACLR|) : **80** (w/o. DPD)
  - Maximum FOM : **90** (w. DPD)





BW (MHz)	60MHz
MPR (dB)	3
PAPR (dB)	9.59
Pout (dBm)	24.93
PAE (%)	29.8



HIGH EFFICIENCY PA/FEM FRONT-END MODULES

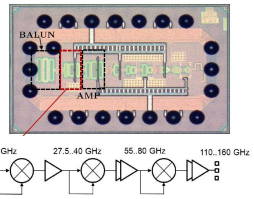
eMBB

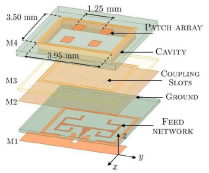
5G-NR Fully-integrated Antenna Front-End solution at 140 GHz

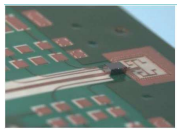
Demonstration of the high potential of co-design / IC & Antenna

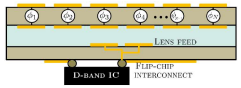
High-Gain Antenna Module for D-Band - RFIC 2019 (Boston)

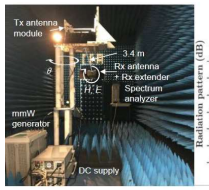
- Compact D-band antenna module – flat & low profile
- Targeting ultra-fast short-range communications
- **Multi-layer PCB** antenna
- Antenna-in-Package with a 28 nm bulk CMOS frequency multiplier
- Focal distance = 32 mm
- **$Gain_{PEAK}$ = 29.5 dBi** in D-Band

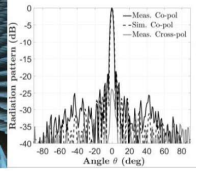












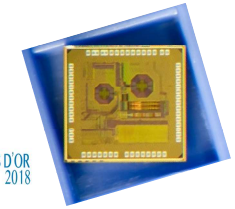
ULP RF - SIGFOX COMPLIANT SOC

SIGFOX-compliant ULP RF SoC

ULP RF SoC transceiver for Ultra-Narrow Band (UNB) applications - FOXY

mMTC

- Sub-GHz ISM Frequency Bands
- Low Data Rate / Narrow-Band receiver 100 bps to 1 kbps
- Low-Power RX target : **15 mW** / Very-High sensitivity at **-136 dBm**
- Low-Power TX target : **5 mW / 0 dBm** - Integration of a **+10dBm / 24mA PA**
- Low-Cost target for very high volume applications
- Very low leakage current target for very long battery life
- Technology : **TSMC 65 nm / 3.8 mm²**
- 7 x 7mm² in QFN48 package



ELECTRONS D'OR 2018

Functionalities

- Ready to use IC : integrated digital process / application features
- Fully compatible with Sigfox protocol WorldWide

D. Lachartre, & altri, "7.5 A TCXO-less 100Hz-minimum-bandwidth transceiver for ul-tra-narrow-band sub-GHz IoT cellular networks," 2017 IEEE ISSCC, San Francisco, CA, 2017, pp. 134-135

sigfox

ULP RF – SATELLITE COMM. COMPLIANT SOC

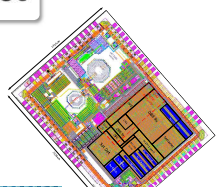
mMTC

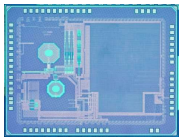
Satellite IOT compliant ULP RF SoC

ULP RF SoC transceiver for IoT sat. comm. - LEO

astrocast

- L- Frequency Bands : 1.5 to 1.7 GHz
- Medium Data Rate receiver : 20 ksymbol/s.
- Low Data Rate transmitter : 400 symbol/s
- Low-Power RX target : **15 mW** / Very-High sensitivity at **-119 dBm**
- Low-Power TX target : **10 mW / 0 dBm** - Integration of a **+12dBm / 22mA PA**
- Low-Cost target for very high volume applications
- Very low leakage current target for very long battery life
- Technology : **TSMC 65 nm / 4.9mm²**
- Digital core : 1.2mm²
- 0.5mm² for the framing/deframing with TurboCoder
- Analog core of 1.8mm² with only 2 inductors
- 7 x 7mm² in QFN48 package





L, Ouvry & altri, "An Ultra Low Power 4.7mA-Rx 22.4mA-Tx Transceiver Circuit in 65nm CMOS for M2M Satellite Communications" 2018 IEEE TCAS, Firenze, Italy

NEXT STEPS FOR SMART RADIO DEDICATED TO ULP IOT

Extraction of information from the RF signal : 5G and beyond …

mMTC

Improve IoT network performance **expanding applications**

- Increasingly crowded Licence-Free bands, plaguing LPWA by increased levels of interference
- Identify PHY layers and statistical characteristics of ISM transmissions
  - Mitigating interference, either **by changing bands/channel, PHY-layer or Link-Layer characteristics**

Improve link bandwidth **highly demanding**

- IoT links have limited data bandwidth, especially in a crowded network context
- **Trade excess** SNR for more data bandwidth using **adaptive modulation & coding rate**

Save energy **crucial**

- IOT links frequently operate under excessive SNR conditions
- **Trade excess SNR** for **lower energy transmissions** - exponential savings !

Develop a new applications **RF software sensor for free**

- Mobility detector of the node itself or in its immediate environment, node displacement detector
  - Propagation environment detector : industrial / outdoor / indoor / deep indoor …
- **Interference-type** detector (e.g. Sigfox, LoRa, BlueTooth…)

CONCLUSION ON 5G SYSTEMS & TECHNOLOGIES

5G - New Challenges, new Constraints, new Vision …

Forthcoming Digital & RF Co-Design perspectives

Software-Design Radio	Right partitioning on D-FE, D-BB, Processing Agnostic approach on Over-the-Air RF signals
Mission Critical	Real-Time sensing, RF channel availability Optimal **Output Power for High QoS**
mmW Beam-Steering	Digital processing for **beam forming**

Technology considerations

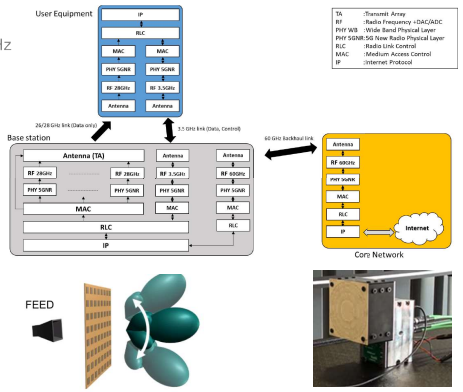
Benefits from CMOS process	FD-SOI for the best trade-off RF Perf. / Consumption / Integration / Cost Alleviate power handling
Hybrid approach	Mixing GaN / SiGe RF chip with CMOS digital chip Challenge put on the packaging / **3D process**
Architecture optimization	Making use of the available technologies for better implementations

CEA-LETI 5G STRATEGIC PROGRAM – TECHNICAL OVERVIEW

Integrated 5G-NR mmWave platform

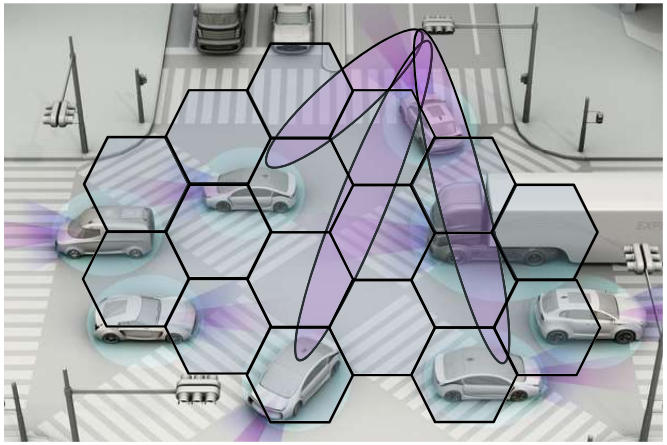
5G-NR Release-15 compliant (up to 400MHz), Non Stand-Alone (NSA) mode

Comm. RF in **3.5GHz** / **26GHz** / **60 GHz** bands
Backhaul considered at 26 GHz / 60 GHz
Comm. RF bi-directional at 3.5GHz / downlink at 26GHz



CEA-LETI 5G STRATEGIC PROGRAM – POTENTIAL USE CASE

Mobile Beam-Forming and Tracking making use of various modalities



TOWARDS 6G ….

New frequency bands

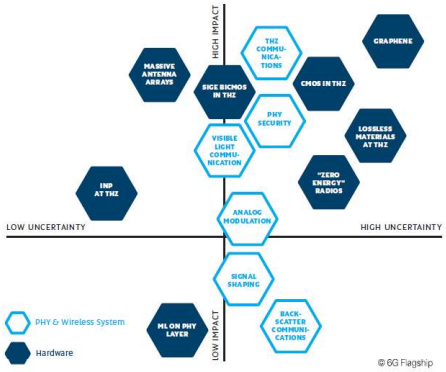
Above 50GHz
Above 92 GHz – W Band
Above **120 GHz – D-Band**

New architectures

Push further on RF system co-integration
- Antenna-in-package
- Maintain efficiency & compactness

Consider **Visible Light Communication**
…. or **IR light**

RF-over-fiber
- Alleviates cost & deployment
- Technology convergence



New paradigm

Machine Learning
- for Network Scheduling
- for **Pre-Distorsion Generation & Compensation**
- for Signal Shaping

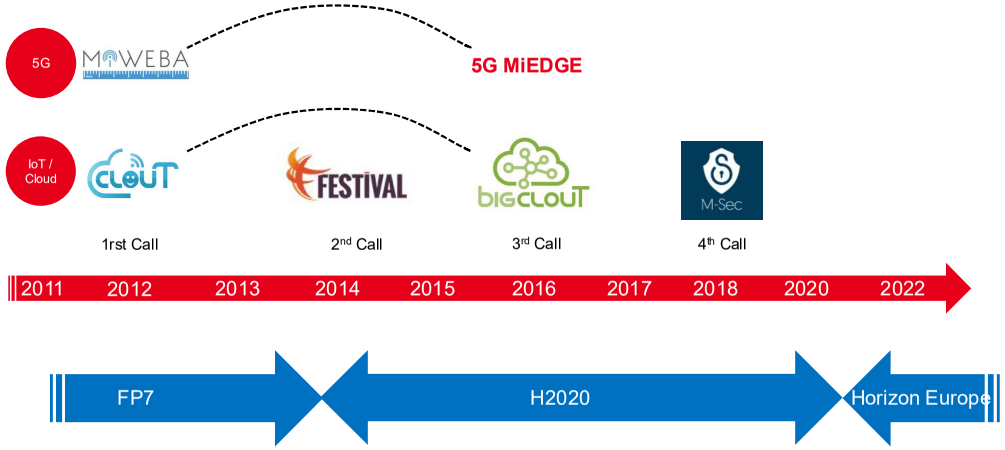
A JOURNEY STARTED IN 2011

"Senior officials from the EU and Japan have agreed on a common area for research in **Future Internet** and **New Generation Networks**. This will be the subject of the first ever EU-Japan coordinated calls for ICT research proposals in 2012-13. "

EU-JAPAN

Brussels, 20 June 2011

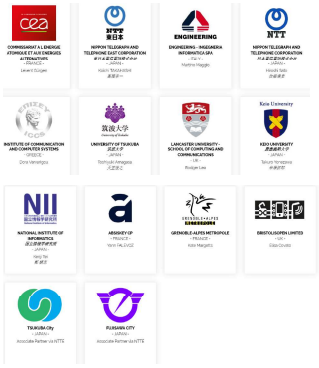
LETI'S ROADMAP IN EU-JAPAN COOPERATION



BIG-CLOUT

http://bigclout.eu/

Big data meeting Cloud and IoT for empowering the citizen clout in smart cities



M-SEC

https://www.msecproject.eu

The main goal of M-Sec project is to research, develop, deploy and demonstrate multi-layered Security technologies to ensure hyper connected smart cities and empower IoT stakeholders with an innovative platform which leverages blockchain, BigData, Cloud and IoT security, upon which they can build innovative smart city applications.

Santander & Fujisawa

Uses cases: well-being, environment monitoring, citizen care, citizen as sensor, etc.

URBAN TECHNOLOGY ALLIANCE

It's time to move forward!

Urban Technology Alliance

CITIES NEED TO FACE CURRENT AND FUTURE SOCIAL, ECONOMIC AND ENVIRONMENTAL CHALLENGES

More than half of the world's population live in cities

Taking up only 2% of the earth's surface, cities use 75% of the world's resources

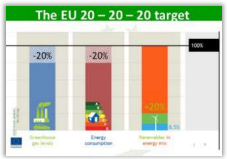
WATER

60%

Worldwide, up to of water is lost due to leaky pipes—to the tune of **US$14 billion every year.**'

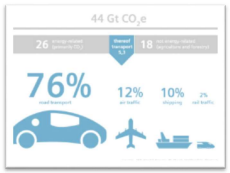
IBM

ENERGY



In Europe, **50%** of energy consumed today is imported – expected to reach **70%** by **2030**

TRANSPORT



In Europe and US, drivers spend **from 5 to 10 working days** per year **stuck in traffic**

Urban resources must be efficiently shared by the increasing population in a sustainable manner

IT'S TIME TO MOVE FORWARD

> Technology is ready IOT AI BIG DATA

> IoT, Cloud/Edge Computing, Big Data, Artificial Intelligence have great potential to prepare cities for the future

> **Cities are excited,** looking for innovative solutions and neutral guidance

> What is **the missing piece?**

Testing and validation in real-life conditions, in order to ensure

- No techno-push solutions, focus on city and citizen-requirements
- No just rapid prototyping, focus on sustainable and adaptive solutions
- Validation of not only technical but also non-technical issues: social acceptance, business models, ethical issues, etc.

Urban Technology Alliance

Worldwide testing environment for smart city solutions

UTA provides city scale tesbeds

Smart city solutions need technical, economic, social validation before large scale deployment

UTA provides a matchmaking platform

Cities need neutral guidance, industry needs testing environment, researchers need real requirements

UTA provides best practices among cities all around the globe

Yes, each city is unique; yet, today's wordwide urban challenges are very similar

A VIBRANT COMMUNITY OF SMART CITY STAKEHOLDERS

NEW FP: HORIZON EUROPE 2021-2027

Horizon Europe: evolution not revolution

Specific objectives of the Programme

- Support the creation and diffusion of high-quality knowledge
- Strengthen the impact of R&I in supporting EU policies
- Foster all forms of innovation and strengthen market deployment

Optimise the Programme's delivery for impact in a strengthened ERA

Pillar 1 Open Science
- European Research Council
- Marie Sklodowska-Curie Actions
- Research Infrastructures

Pillar 2 Global Challenges and Industrial Competitiveness
- Clusters: Health; Inclusive and Secure Society; Digital and Industry; Climate, Energy and Mobility; Food and natural resources
- Joint Research Centre

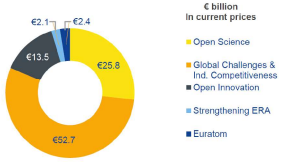
Pillar 3 Open Innovation
- European Innovation Council
- European innovation ecosystems
- European Institute of Innovation and Technology

Strengthening the European Research Area
- Sharing excellence
- Reforming and Enhancing the European R&I system

International Cooperation

International Cooperation: Tackling together global societal challenges; access to the world's best talents, expertise and resources; enhanced supply and demand of innovative solutions

Budget: €100 billion* (2021-2027)



NEW OPPORTUNITY HEALTH, DEMOGRAPHIC CHANGE AND WELLBEING (H2020)

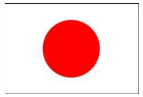
International cooperation in smart living environments for ageing people (SC1-DTH-04-2020)

With Japan: "… use of generalized infrastructures such as cloud system and open sources"
Proposals are expected to contribute to help ageing people remain active and healthy inside and outside their home, by providing action guidance and decision support derived from personal information such as memories and action histories through progress beyond the state of the art in interaction technology and ICT.
The proposed solutions on an open-platform where data collection by sensors, data analysis by artificial intelligence and user-friendly user interfaces cooperatively work are expected to be naturally integrated into ageing people's daily life and provide emotional support to ageing people.

Opening: 19 November 2019
Deadline for proposals: 22 April 2020

Overall EU budget for one project with Japan: 4 M€
Funding of Japanese partners by MIC / NICT
Instrument type: RIA (Research and Innovation Action)

CONCLUSIONS



EU and Japan have successfully demonstrated an excellent collaboration in collaborative projects on 5G and IoT/Cloud

LETI in 6 cooperative projects with Japanese partners

Creation of a global open Alliance jointly with Japanese partners: Urban Technology Alliance

New opportunities for collaboration on IoT/Cloud platforms is in place in 2020

Ongoing dialogue for collaboration from 2021 in Horizon Europe

ありがとう
ございます

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CEA Tech is the CEA's technology research unit. CEA Tech's three labs—Leti, Liten, and List—develop a broad portfolio of technologies for ICTs, energy, and healthcare.

CEA Tech leverages a unique innovation-driven culture and unrivalled expertise to develop and disseminate new technologies for industry, effectively bridging the gap between the worlds of research and business.