ABSTRACT ENEA

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1. Introduction

ENEA is a public body with the aim of pursuing research and technological innovation, as well as providing enterprises, public administration and citizens with advanced services in the sectors of energy, environment and sustainable economic development.

ENEA activities in the field of renewable energy sources are mainly centered upon research, innovation, and technology transfer. The Agency also provides advanced services contributing to both decreasing CO_2 emissions and the national energy dependence on fossil sources, and increasing Italy's economic competitiveness.

In particular clean energy technologies represent a key R&D topic for ENEA, an organization that fosters innovation in this field as well as in many sectors of renewable energy sources, such as thermal and concentrated solar with storage systems, photovoltaics, hydrogen, CCUS (carbon capture, utilisation and storage), bioenergies, smart grids, integrated energy networks, etc.

In such a context, ENEA also coordinates the National Technological Energy Cluster, funded by the Italian Ministry of University and Research, which aims to promote scientific and technological research in Italy to foster participation, coordination and launching of national and international initiatives and projects concerning the energy sector, paying particular attention to clean energy solutions.

Regarding the national energy policy, Italy's pathway towards sustainability follows in the footsteps of the Energy Union strategy, aimed at decarbonisation (including renewables), energy efficiency, energy security, a fully integrated energy market, research, innovation and competitiveness.

In particular the Italian national energy and climate plan (PNIEC – Piano Integrato Energia e Clima), which is the result of the collaboration between three ministries, Environment, Economic Development and Infrastructure and Transport, aims to achieve specific objectives in 5 sectors: decarbonisation, energy efficiency, energy security, internal energy market, research, innovation and competitiveness, through an integrated approach. This plan, closely coordinated with the European Strategic Energy Technology Plan (SET Plan), defines the national energy objectives to drive the energy transition towards ambitious policy targets.

In particular it intends to implement a vision of broad transformation of the economy, in which de-carbonization, circular economy, efficiency and the rational and equitable use of natural resources represent goals and tools for a sustainable economy and future.

Furthermore, Italy is part of the EU SET-Plan and is a promoter of Mission Innovation launched at COP21 to boost frontier projects for clean energy technologies and committed to double public funds for R&D for clean energy (from 222 Million Euro in 2013 to 444 Million Euro in 2021).

PNIEC sets the energy scenario towards 2030, fostering a wide-ranging transformation of the energy system as a whole in view of a strong decarbonisation. In line with this vision, the main objectives that Italy wants to achieve are:

- accelerating the decarbonisation process, considering 2030 as an intermediate step towards a deep decarbonisation of the energy sector by 2050;

- putting citizens and (especially small and medium-sized) businesses at the centre, so that they are protagonists and beneficiaries of the energy transition by promoting self-consumption and renewable energy communities;
- favouring the evolution of the energy system, in particular in the electricity sector, from a centralized to a distributed structure based mainly on renewable sources;
- promoting energy efficiency in all sectors, as a tool towards protecting the environment, improving energy security and reducing energy expenditure for families and businesses;
- promoting the electrification of consumption, in particular in the civil sector and in transport, as a tool to improve also the quality of the air and the environment as a whole;
- fostering the use of hydrogen in the different sectors: energy, industrial, transport and residential.

In particular, with an expected energy consumption of 111 Mtoe by 2030, the target for renewable energy production is approximately 33 Mtoe, distributed between the various sectors of applications as below:

- 55.4% renewables share in the electricity sector;
- 33.0% renewables share in the heating sector (for heating and cooling);
- 21.6% renewables share in the transport sector.

2. R&D activities related to clean energy technology

ENEA, through the Department for Energy Technologies and Renewables(500 researchers and technicians organized in six Divisions), fosters innovation in the development of new energy technologies and in the following sectors of renewable energy: thermal and concentrated solar with storage systems, photovoltaics, CCUS (carbon capture, utilization and storage), bioenergies, biorefining for production of energy and biofuels, hydrogen and fuel cells.

R&D activities in the field of clean energies, supported by testing and validation on relevant-scale experimental platforms (Fig. 1), are aimed at the reduction of greenhouse emissions and fossil-sourced energy dependency, development of a low-carbon economy, also by optimizing energy use, medium-to-long-term diversification of energy sources, enhancement of the competitiveness of the Italian industry by reducing energy costs.

The priorities of research activities take into account the PNIEC, the programme agreement with the Italian Ministry of Economic Development for Electric System Research and for Mission Innovation, and the vision embodied by the European SET Plan, EERA (European Energy Research Alliance), BIC (Bio-based Industries Consortium), SERIT (Security Energy in Italy) and the Horizon 2020 and Horizon Europe programmes.

3. Specific research activities in renewable energies, next-generation energy management systems with batteries, hydrogen, CCUS, and related technologies

ENEA supports a value chain approach to promote hydrogen as a clean energy vector, dealing with the development of process and components in the sector of hydrogen production, storage and final uses including Fuel Cell systems. In particular ENEA has been operating in the field of hydrogen production technologies from renewable sources (mainly solar) since the early 2000s, with research on reactive materials and plant components, working on the development of processes from the basic concept to the experimental validation of technical feasibility on pre-pilot scale. Over the years, various pathways and methods for the production of hydrogen have been explored, both thermochemical and electrochemical, with carbonaceous matter or water as feedstock.

Currently the research is focused on advanced alkaline electrolysis, high-temperature electrolysis, solar-assisted thermo-catalytic conversion of biogas, dry and steam reforming of natural gas, the water gas shift (WGS) reaction and thermochemical water splitting. Indeed, even if current state-of-the-art shows water electrolysis as the most mature approach, particularly promising in a Power-to-Gas perspective, in view of diversification of sources and technologies that could match local availabilities and applications, and taking into account the scale-up issue, ENEA has been developing alternative and complementary production routes, still with minimal or neutral CO_2 emissions, like solar-assisted reforming of methane (Natural Gas or biogas), biomass gasification, and WGS coupled with carbon capture process. As far as final uses are concerned, ENEA has intensively worked on the development of fuel cell technology, playing a significant role in the sector, having built a profitable network of scientific collaborations in the academic and industrial fields, at national and international level. Furthermore, again with reference to the uses of hydrogen, ENEA carries out research on gas turbine systems oriented towards fuel flexibility (H_2/NG blends), the objective of which is the de-carbonization of back-up services of the electricity grid in scenarios with a high penetration of non-programmable RESs.

The demonstration at relevant scale of hydrogen production, storage and utilization technologies is considered as the key factor to foster market penetration of hydrogen systems. In this context, ENEA represents a link between research, innovation, technology transfer and industrial development, through the realization of pilot plants and implementation of experimental activities.

Regarding the CCUS technology, ENEA's activities on sustainable processes for CO_2 capture are supported by validation on the ZECOMIX pilot plant (Zero emission of Carbon with mixed technologies), which has been positively evaluated by the European Research Infrastructure Coordination Committee to be part of the ECCSEL (European Carbon Dioxide Capture and Storage Laboratory Infrastructure) consortium. The carbon capture process which is being tested in the ZECOMIX research infrastructure is based on a highly regenerable calcium-based material that reacts with CO_2 producing inert media as calcium carbonate. This process, known as calcium looping (CaL), can be integrated with methane reforming providing a robust high-temperature route for CO_2 capture, leading to a step-change in efficiency of carbon removal and producing low-carbon hydrogen. This process makes use of relatively abundant cheap materials with several outlet markets for spent materials (iron, steel, road aggregation and cement industries). Considerable efforts are made in ENEA to develop and demonstrate the CaL process as an environmentally benign and cost-effective technology option to reduce the emission of CO_2 and produce H_2 in carbon-intensive industries (e.g. iron and steel making process).

The current activities regarding the utilisation of carbon are mainly focused on hydrogenation of CO_2 via catalytic processes. Alternative routes for carbon utilisation is the production of inert materials (mainly $CaCO_3$) via the reaction of CO_2 and residues produced in industrial sectors (e.g. steelmaking and incineration plants). The main objectives of this process, known as

carbonation, are: (i) permanent sequestration of CO_2; (ii) production of marketable materials such as bricks or tiles; (iii) reduction of the impact related to the generation of hazardous waste.

Furthermore ENEA has worked for the last 20 years on the development of high-temperature concentrated solar power technologies (CSP) to produce dispatchable electricity and process heat for centralized and distributed applications. The research activity, both at the component and at the system level, has led particularly to the implementation of significant innovations in the Parabolic Trough (PT) technology, achieving a relevant improvement of the overall plant efficiency. The core of the innovation introduced by ENEA consists of the use of molten salt mixtures both as heat transfer fluid and thermal storage material, replacing conventional diathermic oil, and in the development of high-performance selective coatings for the PT receiver, producing a series of patents whose licenses have been acquired by a national industry in the sector. Currently, research is mainly focused on the development of new materials for reliable and cost-effective components, new system configurations for multipurpose CSP plants applications (heat and power), and innovative concepts of heat storage to be integrated with CSP plants to enhance the energy storage capacity and reduce the LCoE (levelised cost of energy).

Additionally, regarding the development of photovoltaics as a key technology to build a secure and sustainable energy system for the future and to favour the energy transition, ENEA is developing materials and device architecture for highly efficient solar cells. In particular we are studying tandem solar cells realized with a bottom cell made with a silicon heterojunction and a front cell obtained with perovskite or kesterite films. The development of thin-film innovative materials but also our knowledge on more standard absorbers such us silicon-based thin films are also applied in the Building Integrated PV (BIPV) and agricultural PV (agriPV) by studying spectrally selective solar cells. Furthermore at the system level we are designing new or renovated greenhouses with roofs equipped with different customized photovoltaic glasses in order to test the effects on test species (plants and microalgae).

Finally, research activities have recently been started on the eco-design of new PV modules with polymers alternative to conventional encapsulants and backsheets, looking also to the possibility to recover valuable materials, such as glass, metals and the new polymers introduced into the eco-designed panels.

Beyond the R&D activities with reference to single clean energy technologies, from hydrogen to CCUS and concentrated solar, ENEA is fully committed within research activities regarding their integration through solutions as smart grids/microgrids and integrated energy networks. In this regard, the lab's activities mainly focus on the development of technologies, components, systems and management and control strategies for local and renewable energy communities, and technologies, tools and devices for applications in the field of smart grids and energy networks and microgrids in the presence of poly-generation and distributed cogeneration and energy storage.

Some of the main national and international programmes/projects conducted by ENEA on the topics addressed above are reported below.

- **National Fund for Electric System Research (RdS) ENEA-MiSE**: development of innovative hydrogen production technologies based on electrochemical and thermochemical routes (e.g. dry reforming of natural gas, water gas shift, steam methane reforming, intensified with calcium looping for the decarbonisation of industry); uses of hydrogen for transport (fuel cell electric vehicles), industry (process gas, chemical and metallurgical industry) and residential (CHP) applications, and power to gas for network flexibility; renewable technologies to increase the flexibility of the grid; technologies and system for energy storage (electrical and thermal), high-efficiency solar cells and innovative materials for PV applications, development of smart grids, etc. (2019-2021). Project Funding 170.0 M€ - ENEA Funding ~66.0 M€.
- **H2020 AMPERE**: the project has the objective to set-up an innovative 200 MW_p full-scale

automated pilot line for bifacial silicon heterojunction cells and modules at the 3SUN fab in Catania (Italy). (2017-2020) - Project Funding: 15,0 M€ - ENEA Funding: 560.0 k€.

- **H2020 CUSTOM-ART**: the project is starting with the aim to develop a new generation of flexible thin film PV modules based on kesterites to be used for BIPV. (2020-2024) - Project Funding: 7.0 M€ - ENEA Funding: 216.0 k€.
- **National Project MINERVA**, funded by Italian Ministry of Economic Development: this project is starting with the objective to optimize the performance of silicon-based PV modules by implementing non-conventional materials and innovative processes in the production line. (2020-2024) - Project Funding: 4.6 M€- ENEA Funding: 551.0 k€.
- **H2020 INTERPLAN**: design and development of an integrated operation planning tool towards the Pan-European Network (2017-2020) – Project Funding: 2.9 M€ - ENEA Funding: 556.0 k€.
- **H2020 eNeuron**: development of innovative tools for the optimal design and operation of Local Energy Communities integrating distributed generation and multiple energy carriers at different scales (2020-2023) - Project Funding: 5.7 M€ - ENEA Funding: 487.0 k€.
- **H2020 AMBIENCE**: methodologies for extending the concept of energy performance contracting for active building and making the model available and attractive to a wider range of building typologies (2019-2021) - Project Funding: 2.0 M€ - ENEA Funding: 196.0 k€.
- **ComESto** national project funded by the Italian Ministry of Education, University and Research: creation of an Energy Storage Community integrating distributed generation and storage systems at different scales by managing all the resources as a whole to increase the potential benefits for the different actors involved. (2018-2021) - Project Funding: 10.0 M€ - ENEA Funding: 1.0 M€.
- **IPCEI- Batteries**: the “German-led Important project of Common European Interest” (or “Winter IPCEI”) has many Member States involved and ENEA is one of the Italian participants. Our role is to develop new-concept batteries suitable for being transformed into an industrial product and to optimize recycling in line with a circular economy approach. The aim is to fill the gap between the lab-scale and the installation and production problems at a pilot plant level to assist the industry upon the first industrial deployment stage.
- **H2020 3BeLiEVe**: aimed at the strengthening the position of the European battery and automotive industry in the future xEV market by delivering the next generation of battery cells, designed and made in Europe, for the electrified vehicles market of 2025 and beyond - Project Funding: 10.8 M€ - ENEA Funding: 298.0 k€.
- **H2020 BATTERY2030PLUS**: lies along the pathway started by the long-term research initiative “Battery 2030+” and the related roadmap. It is a newly started CSA with the aim to coordinate and monitor research activities contributing to the large-scale research initiative on Future Battery Technologies, BATTERY 2030+. The project, coordinated by University of Uppsala (Sweden) will update continuously the BATTERY 2030+ roadmap, contributing to competence building and strengthening the battery community by facilitating communication, dialogue and cooperation on cross-cutting topics. The consortium is built on the most active European research organizations and universities - Project Funding: 2.0 M€ - ENEA Funding: 21.0 k€.
- **H2020 IN POWER**: development of advanced materials solution for Concentrated Solar Power Plants (CSP) to increase overall efficiency while decreasing the energy production cost – Project Funding: 4.99 M€ - ENEA Funding: 0.57 M€.
- **H2020 ORC_PLUS**: development of an optimized combination of innovative Thermal Energy Storage (TES), small CSP plants, and Organic Rankine Cycle systems to produce electricity from solar source – Project Funding: 6.33 M€ - ENEA Funding: 1.25 M€.
- **H2020 SFERA III**: supporting the European advanced Solar Facilities to ensure their long-

term sustainability through networking, transnational access and joint research activities - Project funding: 9.10 M€ - ENEA funding: 0.85 M€.

- **H2020 RESLAG**: valorization of steel slag, currently not recycled, and reuse as a raw material for Thermal Storage application, particularly in the CSP sector – Project Funding: 8.02 M€, ENEA Funding: 1.08 M€.
- **European FP7 SOCTESQA (2014-2017):** realization of uniform and industry wide test procedures for SOC cell/stack assembly. Project Funding: 1.6 € - ENEA Funding: 285.0 k€.
- **European FP7 NELLHI (2014-2017)**: development of a novel 1 kW SOFC stack of unprecedented performance, together with the proof of concept of a 10 kWe SOFC stack. Project Funding: 2.0 M€ - ENEA Funding: 356.0 k€.
- **European FP7 SCoRed 2.0 (2013-2017)**: production of coated steel components for SOFC systems showing markedly improved properties with regard to chromium release, electrical resistivity and scale growth. Project Funding: 2.8 M€ - ENEA Funding: 335.0 k€.
- **H2020 BALANCE (2017-2019)**: development of reversible high temperature electrolysers to support the integration of wind and solar energy with the electricity grid; Project Funding: 2.5M€ - ENEA Funding: 301.0 k€.
- **H2020 AD ASTRA (2019-2021)**: development of accelerated test protocols for high-temperature electrolysers and fuel cells; Project Funding: 3.0 M€ - ENEA Funding: 400.0 k€.
- **H2020 qSOFC (2017-2020)**: reduction of production costs and improvement of the production process quality for high temperature fuel cell systems; Project Funding: 2.0 M€ - ENEA Funding: 240.0 k€.
- **H2020 WASTE2WATTS (2019-2021) and BLAZE (2019-2022)**: use of biogas and syngas (from biomass) for fuel cell supply; WASTE2WATTS: Project Funding: 1.6 M€ - ENEA Funding: 155.0 k€; BLAZE: Project Funding: 4.2 M€ - ENEA Funding: 210.0 k€.
- **H2020 INNOSOFC (2016-2019)**: development, validation and demonstration of a 50 kW high efficiency cogeneration system based on high-temperature fuel cells; Project Funding:4.0 M€ - ENEA Funding: 259.0 k€.
- **H2020 SO-FREE (2021-2023)**: development of a fully future-ready solid oxide fuel cell (SOFC)-based system for combined heat and power (CHP) generation for efficient, near-zero-emission, fuel-flexible and truly modular power and heat supply. Project Funding: 2.7 M€ - ENEA Funding: 324.0 k€.
- **H2020 REACTT (2021-2023):** realize a Monitoring, Diagnostic, Prognostic and Control Tool (MDPC) for Solid Oxide Electrolysers and Reversible SOC stacks and systems. Project Funding: 2.7 M€ - ENEA Funding: 128.0 k€.
- **H2020 PROMETEO (2021-2023):** producing green hydrogen from renewable heat & power sources by high temperature electrolysis in areas of low electricity prices associated to photovoltaic or wind. Project Funding: 2.5 M€ - ENEA Funding: 416.0 k€.
- **European FP7 ASCENT**: addressing the need for innovative sorbent materials for capturing CO_2 to produce low-carbon H_2 with advanced solid cycles.
- **H2020 GICO**: testing of plasma technologies at TRL5 for the valorization of CO_2 captured in sorption enhanced gasification of biomass wastes. Project Funding 3.9 M€ - ENEA Funding: 532.0 k€.
- **EIT Raw Material Platform SISAL**: CO_2 capture process will be studied for the recovery of silicon and aluminium - rom industrial waste. Project Funding 4.7 M€ - ENEA Funding: 464.0 k€.
- **National fund by Italian Ministry of Economic Development for Mission Innovation, HYDROGEN demo VALLEY:** realization, at CR ENEA Casaccia, of a multifunctional platform to create a hydrogen ecosystem (hydrogen production, injection in the methane

pipeline for transport and storage, utilization in mobility, residential and energy sector**).** Project Funding 17.5 M€ - ENEA Funding: 13.8 M€.

- **H2020 ECCSELERATE**: development and upgrading of European research infrastructure for carbon capture and valorization (TRL 7). Project Funding: 3.5 M€ - ENEA will be funded with 0.23 k€ per each 5-day experimental test.
- **H2020 CHEMPGM**: optimization of the reuse of exhausted materials used as advanced catalytic systems for the valorization of CO_2 and the production of H_2. Project Funding: 736.0 k€ - ENEA Funding 101.0 k€.

4. International collaboration

4-1 International alliance/networking development

ENEA is present in the clean energies sector as a highly qualified player dealing with key national, EU and international initiatives. Furthermore ENEA has concluded a number of comprehensive and specific cooperation agreements and MOUs with research institutes, universities and industrial stake-holders to promote research and technology transfer to industry aimed at the energy system de-carbonization.

As an example, within the EU-funded project SFERA III, ENEA is involved in: (i) networking activities to develop the cooperation between research infrastructures, the scientific community, industries and other stakeholders in the field of CSP technology; (ii) transnational access activities aiming at providing access to all European researchers from both academia and industry to singular scientific and technological solar research infrastructures; and (iii) joint research activities whose purpose is to improve the integrated services provided by the infrastructure.

ENEA is present, as Italian representative, in numerous intergovernmental bodies, regulatory bodies and international initiatives aimed at promoting the development of clean energies.

Regarding the photovoltaics topic, ENEA is involved in:

- Technology Collaboration Programme (TCP) “Photovoltaic Power System” (PVPS) of IEA with activities in several tasks (task 1 “Strategic PV analysis & outreach, task 15 “Enabling framework for BIPV acceleration”, task 12 “PV sustainability”).
- European Energy Research Alliance Joint Programme Photovoltaic Solar Energy (EERA JP PV) that has the objective to accelerate the development of Photovoltaic Solar Energy towards an energy technology that can be implemented at a very large scale through Joint Programming activities by key research institutes in Europe.
- all the working groups of the European Technology and Innovation Platform for Photovoltaics (ETIP PV).

Regarding the Concentrated Solar Plants topic ENEA participates to: IEA-SolarPACES TCP, IEA-ECES (Energy Conservation and Energy storage), IEA-Industrial Energy-Related Technologies and Systems, EERA JP on CSP (with coordination of the SP3 - Thermal Energy Storage for CSP plants).

ENEA is also involved in several European and International initiatives in the field of Smart Grids:

- IEA (International Energy Agency) Task 11 “PV Hybrid systems within mini-grids”
- IEA Task 14 “High penetration of PV systems in electricity grids”.
- IEA Task 18 “Off-Grid and Edge-of-Grid Photovoltaic Systems”.
- IEC (International Electro-technical Commission), TC 82 “Solar photovoltaic energy systems”.

- IEEE IES Industrial Energy Society TC on Smart Grids.
- Working Group (WG) EU PV Technology Platform (EUPVTP), Grid Integration (www.eupvplatform.org/about-pv-platform/ad-hoc-working-group-4.html).
- Joint Programme “Smart Grid” in EERA - European Energy Research Alliance. ENEA is the vice coordinator of Joint Programme on Smart Grids within the European Energy Research Alliance.

Additionally ENEA is member of the EERA JP on Energy Storage (Electrochemical Energy Storage and Thermal Storage Sub-Programmes) and participates in all the working groups of the European Technology and Innovation Platform (ETIP) Batteries Europe, with a role in the managing board and secretariat key roles.

Regarding hydrogen technologies ENEA participates in: IEA-Hydrogen, IEA-FC, Hydrogen Europe Research and the EERA Fuel Cells and Hydrogen Joint Program, IEC-TC 105.

4-2 International joint R&D activities

ENEA covers a key role within the International Initiative of Mission Innovation (MI), which is a global initiative of 24 countries and the European Union aiming to dramatically accelerate global clean energy innovation. As part of the initiative, participating countries have committed to double their governments’ clean energy research and development investments over five years, while encouraging greater levels of private sector investment in clean energy technologies. The MI actions are based on eight Innovation Challenges (IC), which consist of a global network of policymakers, scientists and innovators working towards a common objective, and cover the entire spectrum of R&D, from early-stage research to technology demonstration projects. Italy has endorsed all the ICs and ENEA is going to receive funds from the national government in the following sectors:

- Smart Grid Innovation Challenge (#1) aiming at enabling future grids that are powered by affordable, reliable, decentralised renewable electricity systems.
- Clean Energy Materials Innovation Challenge (#6) aiming at accelerate the advanced energy materials discovery by integrating high-throughput methods with artificial intelligence.
- Renewable and Clean Hydrogen Innovation Challenge (#8) aiming at accelerating the development of a global hydrogen market by identifying and overcoming key technology barriers to the production, distribution, storage, and use of hydrogen at gigawatt scale.

ENEA is involved in numerous European Projects in cooperation with several countries.

- Regarding the PV activities, a joint research is being carried out with Joint Research Centre (JRC) and several other international institutes (SUPSI- Switserland, AIT -Austria, Photovoltaic Technology Laboratory-Cyprus, CENER-Spain, Photovoltaik Institut Berlin - Germany, PV Lab Germany GmbH-Germany) on the inter comparison between different laboratories with the main objective to harmonize measurements and instruments calibration techniques. Furthermore, additional international collaborations are underway with several countries including CEA (France) and Fraunhofer - ISE (H2020 AMPERE project- Automated photovoltaic cell and Module industrial Production to regain and secure European Renewable Energy market; H2020).
- In the topic of the Energy Management System, ENEA carries out activities inside H2020 INTERPLAN project (design and development of an integrated operation planning tool

towards the Pan-European Network), with the following partners: AIT Austrian Institute of Technology, GMBH, European Distributed Energy Resources Laboratories e.V. (DERLab), University of Cyprus, FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V., INSTYTUT ENERGETYKI.

- In the batteries research field ENEA is involved in the project H2020 BATTERY2030PLUS: a network of European top institutes among which CNRS, CEA and Fraunhofer are taking part in RD20. ENEA is also well connected with most universities, research groups and companies working on this field in Europe throughout the participation at European projects (e.g. 3beLiEVe - Delivering the 3b generation of LNMO cells for the xEV market of 2025 and beyond) and bilateral collaborations: Austria, Swiss, Spain, Portugal, France, Germany, Belgium, The Netherlands, Poland, Slovenia, Ireland, Norway, Sweden, Finland.
- Regarding CSP technology, ENEA, among numerous joint research activities, is involved in the H2020 SFERAIII Project, whose specific objective is to ensure the long-term sustainability of the European most advanced solar laboratories (ENEA, CNRS, CIEMAT, DLR, ETH, Fraunhofer Institute), supporting Europe as a global leader in solar research infrastructures, through networking activities between the research infrastructures, the scientific community, the industries and other stakeholders. Additionally, within the proposal H2020 SoSuCy, which addresses the Horizon 2020 Call Topic "LC-SC3-RES-25-2020: International cooperation with Japan for Research and Innovation on advanced biofuels and alternative renewable fuels", a research collaboration with Kumamoto University (KU), Japan Atomic Energy Agency (JAEA), National University Corporation Tokyo University Of Agriculture And Technology (TUAT), has just been started to develop an innovative thermochemical process, powered by solar energy, to produce an alternative renewable energy carrier (elemental Sulphur), that can be employed as an additional contributor to a future diversified energy portfolio.
- On the topic of hydrogen and fuel cells, ENEA is involved on several H2020 projects:
  - SOCTESQA (Solid Oxide Cell and Stack Testing, Safety and Quality Assurance)
  - AD ASTRA (HArnessing Degradation mechanisms to prescribe Accelerated Stress Tests for the Realization of SOC lifetime prediction Algorithms),
  - SO-FREE (Solid oxide fuel cell combined heat and power: Future-ready Energy)

  On the above projects ENEA cooperate with CEA, Commissariat à l'Énergie Atomique et aux Energies Alternatives - Research Institute – France, Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V. – Germany, JRC -Joint Research Centre-European Commission Research Institute – Belgium, DTU, Danmarks Tekniske Universitet – Denmark, EIFER, European Institute for Energy Research – Germany, EPFL, École Politechnique Federale de Lausanne – Switzerland, IEES, Institute of Electrochemistry and Energy Systems – Bulgaria, VTT: Teknologian tutkimuskeskus - Finland
- With regards to CCUS technologies, ENEA is in charge of a pilot plant ZECOMIX (Zero Emissions of CarbOn with MIXed technologies) composed of innovative reactors for the production of H_2 from biomass or methane. As member of ECCSEL consortium ZECOMIX offers: (i) top quality scientific and technological performance and support recognized as being of European relevance; (ii) access visiting scientists from Europe and beyond through a transparent selection and admission process on the basis of scientific merit; (iii) training for PhD and Master students. In particular, within the H2020 project ECCSELERATE which addresses the Call H2020-INFRADEV-2018-2020 for the development of research infrastructures, ENEA will collaborate in the field of CCUS technologies with (i) Sintef Energi AS (Norway); (ii) Bureau De Recherches Geologiques

Et Minieres (France); (iii) Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek TNO (The Netherlands); (iv) Norges Teknisk-Naturvitenskapelige Universitet NTNU, (Norway); (v) Sintef AS (Norway); (vi) The University Of Edinburgh (UK); Istituto Nazionale Di Oceanografia E Di Geofisica Sperimentale (IT).

5. Future perspectives (beyond 2030)

As previously discussed, Italy is aiming to increase the share of RES by paying the highest attention to the electricity sector, with a 55.4% share of RES power generation to be reached by 2030.

However, variability of power generation is a serious issue for introducing renewable energy at large scale as at times it may lead to unused excess power generation. For that, R&D of more efficient, durable, and affordable technologies to use renewable energy with “anytime-anywhere” application flexibility is needed. Therefore, integration of conversion, transportation and storage technologies is inevitable for introducing renewable energy at large scale.

In such a perspective, R&D activities play a fundamental role in the implementation of the national energy strategies. In particular, two main research objectives have been identified in PNIEC:

- to monitor and develop product and process technologies vital to the energy transition;
- to promote the introduction of technologies, organizational and operational models and systems fostering security of electricity supply.

With specific reference to a smart grid context which is expected to play a key role in the future Italian electricity system, the following key innovation challenges are identified to be addressed in the near future from an R&D perspective:

- observability and control at transmission and distribution level to be achieved in a cost-effective way;
- integration of all forms of energy storage to increase RES penetration while improving security of supply;
- implementation of integrated energy systems based on the integration of the power network with other energy vectors’ systems (heating and cooling, natural gas, hydrogen, biogas, water) to increase flexibility and security of the energy system;
- distributed control vs. centralized control of the electricity system;
- integration of demand side management and ancillary network services at distribution system level and integration on the transmission operation;
- new electricity-markets design, based on the exploitation of flexibility potential coming from distributed energy resources.

Moreover, the power generated from renewables such as solar and wind could be used to produce hydrogen. ENEA is also promoting “Power to X” approaches by converting the excess power form RES to commodity fuels such as through methanation technology and thus enabling the storage of the excess power

It must be said that ENEA is putting great efforts into developing new, next-generation technologies addressing the key R&D challenges defined above. The latter are not only addressed in the various laboratories that make up the Agency, but represent also the most important objectives of the various international collaborations that ENEA has established in the last years.

Short CV

Dr. Eng. Giorgio Graditi - PhD in Electrical Engineering / Director of the Department of Energy Technologies and Renewable Sources of ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Rome, Italy.

He received the doctoral degree and the Laurea degree (cum laude) in Electrical Engineering from the University of Palermo (Italy). Since July 2020, he is the Director of the Department of Energy Technologies and Renewable Sources of ENEA. Since 2000, he is a Researcher at ENEA. From 2011 to 2017, he was the head of the Photovoltaic Systems and Smart Grid Unit of ENEA, whereas from 2018 to 2019 he was the head of Solar Thermal and Smart Network Division of ENEA. From April 2019, he is the President of MEDENER, Mediterranean Association of National Agencies for Energy Management for energy efficiency and the development of renewable energy sources, and from May 2019 is the Coordinator of the Scientific Technical Committee of National Energy Technological Cluster funded by the Italian Ministry of Education, University and Research. He is a member of IEA task 11 “PV Hybrid systems within mini-grids” and task 14 “High penetration of PV systems in electricity grids” and of Italian Electrotechnical Committee (CEI) CT 82 “Solar photovoltaic”, CT 316 “Connection to LV, MV and HV distribution networks” and CT 313 “Smart grids”.

In 2017, he received the Italian National Scientific Qualification as Full Professor in the sector of electrical energy engineering. He is operating as Italian member for Mission Innovation Challenge 1 “Smart Grids” and Challenge 2 “Off-grid access to electricity”, and he is a member of the H2020 National Steering Board for the "Safe, Clean and Efficient Energy" Cluster, and member of the working group of the thematic area "Industrial Energy” for the “Climate, Energy and Sustainable Mobility” area set up by the Italian Ministry of University and Research within the drafting of the national research plan 2020-2027. He is the vice-coordinator of the Joint Programme on Smart Grid (JP SG) within European Energy Research Alliance (EERA) and the responsible of many National and European (FP7, H2020) projects on the topics of RES, integrated energy networks and smart grid.

His main research interests are in: design, modelling and tools development for the control and management of Smart Grids and microgrids in the presence of DER; energy conversion components and systems design and characterization; performance analysis of integrated energy networks by multi-objective techniques; design, modelling, and analysis of multi-energy hubs; management and operation optimization of local and renewable energy communities; design, characterization and testing of concentrated solar power and photovoltaic components and plants; RES production and demand forecasting based on artificial intelligence techniques (machine learning).

He has supervised several MSc and PhD theses. He is also peer review, associated editor, member of editorial and advisory board of scientific journals, and chairman in international conference. He is also responsible of many R&D contract and agreement in the energy sector with international and national stakeholders. He is author of more than 250 scientific papers (with Scopus H-index 32) published in international journals and proceedings of international conference most of them awarded as highly-cited papers.