PROT. ENEA/2019/45143/DTE-STSN

ABSTRACT ENEA

Dr. Giorgio Graditi
Vice Director of Energy Technologies Department
Italian National Agency for New Technologies, Energy and Sustainable Economic Development – ENEA

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, which fosters innovation in diverse sectors of renewable energy sources, such as thermal and thermodynamic solar with storage systems, photovoltaic, bioenergies, smart grids, integrated energy networks, etc.

In such a context, ENEA also coordinates the National Technological Energy Cluster, which aims to promote scientific and technological research to foster participation, coordination and launching of national and international initiatives and projects concerning the energy sector, by giving particular attention to clean energy solutions.
Regarding the national energy policy, Italy's path towards sustainability follows in the tracks of the Energy Union strategy, aimed at decarbonisation (including renewables), energy efficiency, energy security, fully integrated energy market, research, innovation and competitiveness.
In particular the National Energy Strategy (SEN, issued in 2017), which is the ten-year plan published by the Ministry of the Economic Development (MiSE), closely coordinated with the European Strategic Energy Technology Plan (SET Plan), defines the national energy objectives to drive the energy transition toward the policy targets. The SEN is complemented by the Integrated National Energy and Climate Plan (PNIEC). The plan 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 businesses (especially small and medium-sized ones) at the center, so that they are protagonists and beneficiaries of energy transition by promoting self-consumption and renewable energy communities;
- favoring the evolution of the energy system, in particular in the electricity sector, from a centralized structure to a distributed one based mainly on renewable sources;
- promoting energy efficiency in all sectors, as a tool for 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.

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% 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 Energy Technologies Department (500 researchers and technicians organised in six Divisions), fosters innovation in the following sectors of renewable energy sources: thermal and thermodynamic solar with accumulation systems, photovoltaic, 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 green-house 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 Italian industry by reducing energy costs.

The priorities of the research activities take into account the SEN, the programme agreement with the Italian Ministry of Economic Development for power system research, and the vision embodied by the European SET (Strategic Energy Technology) Plan, EERA (European Energy Research Alliance), BIC (Bio-based Industries Consortium), SERIT (Security Energy in Italy) and the Horizon 2020 programme.

3. Specific Research activities in 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, 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 aided 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 turbogas systems oriented to fuel flexibility (H_2/NG blends) whose objective is the decarbonisation of the back-up services of the electricity grid in scenarios with 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 high regenerable calcium based material which 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 plant 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 thermal technologies (CST) to produce dispatchable electricity and process heat for centralized and distributed applications. Particularly the research activity, both at the component and at the system level, has led 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 in the use of molten salt mixtures both as heat transfer fluid and thermal storage material, replacing the 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 the research is mainly focused on the development of

new materials for reliable and costly 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 cost.

Beyond the R&D activities regarding the single clean energy technology, from hydrogen to CCUS and concentrated solar, ENEA is fully committed in 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 technologies, methodologies 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 national and international programs/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 (eg. dry reforming of natural gas, water gas shift, steam methane reforming, intensified with calcium looping process 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), etc..

BALANCE: development of reversible high temperature electrolysers to support the integration of wind and solar energy with the electricity grid;

AD ASTRA: development of accelerated test protocols for electrolysers and high temperature fuel cells;

qSOFC: reduction of production costs and improvement of the production process quality for high temperature fuel cell systems;

WASTE2WATTS and BLAZE: use of biogas and syngas (from biomass) for fuel cell supply;

INNOSOFC: development, validation and demonstration of a 50kW high efficiency cogeneration system based on high temperature fuel cells;

GAS: P2G: production of biomethane for transport;

E-CO_2: production of H2 through innovative electrolysers and subsequent conversion to methane and other fuels (DME) for transport;

IN POWER: development of advanced materials solution for Concentrated Solar Power Plants (CSP) to increase overall efficiency while decreasing the energy production cost;

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;

SFERA III: supporting the European advanced Solar Facilities to ensure their long-term sustainability through networking, transnational access and joint research activities;

RESLAG: valorization of steel slag, currently not recycled, and reuse as a raw material for Thermal Storage application, particularly in the CSP sector;

ASCENT: addressing the need for innovative sorbent materials for capturing CO2 to produce low-carbon H_2 with advanced solid cycles;

National Fund for Electric System Research (RdS) ENEA-MiSE: development of smart grids - integration of distributed generation, energy storage, active distribution network control, automation and related communication needs and technologies, power electronics, user network integration and system aspects of demand response, DC transmission and distribution, measuring and metering, modelling.

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 decarbonization.

As an example, within the EU funded project SFERA III, ENEA is involved in: (i) networking activities to develop the cooperation between the 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 (IEA-Hydrogen, IEA-FC, IEA-SolarPACES TCP, IEA-ECES (Energy Conservation and Energy storage), IEA-Industrial Energy-Related Technologies and Systems, Fuel Cells and Hydrogen Joint Undertaking and EERA-NET Hydrogen Joint Program, IEC-TC 105, European Turbine Network).

ENEA is also member of the EERA JP on Energy Storage (Electrochemical Energy Storage and Thermal Storage Sub-Programmes) and EERA JP on CSP (with coordination of the SP3 - Thermal Energy Storage for CSP plants).

Furthermore ENEA is involved in several European and International initiatives in the field of Smart Grids. In detail, ENEA coordinates with RSE the European Energy Research Alliance – Joint Programme on Smart Grids.

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 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 IC and ENEA is involved in *IC1-Smart Grids* aimed at enabling future grids that are powered by affordable, reliable, decentralised renewable electricity systems; *IC3-Carbon Capture*, targeted to enable near-zero CO_2 emissions from power plants and carbon intensive industries; *IC5-Converting Sunlight*, focused on the development of affordable ways to convert sunlight into storable solar fuels; *IC8-Renewable and clean hydrogen*, aimed 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.

5. Future perspectives

As previously discussed, Italy is aiming to increase the share of RES by giving 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 large scale introduction of renewable energy.

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:

monitor and develop product and process technologies vital to the energy transition;

promote the introduction of technologies, organizational and operational models and systems fostering security of electricity supply.

With specific reference to 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. central 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 H2. ENEA is also promoting "Power to X" approach by converting the excess power form RES to liquid fuels such as methanation technology and thus enabling the storage of the excess power

It must be said that ENEA is putting great efforts to develop new next generation technologies addressing the R&D key challenges defined above. These latter are not only addressed in the various laboratories composing the Agency, but represent also the most important objects of the various international collaborations that ENEA has established in the last years.

Dr. Giorgio Graditi - PhD (male). He received the doctoral degree and the Laurea degree (cum laude) in electrical engineering from the University of Palermo (Italy). Since 2000, he is a Researcher at ENEA, Italian National agency for new technologies, Energy and sustainable economic development. Since October 2011 until August 2018, he is the head of Photovoltaic Systems and Smart Grid Unit of ENEA; since September 2018 is leading the Solar Thermal and Smart Network Division of ENEA, and since June 2019 is also the Vice Director of Energy Technologies Department of ENEA. He is also the president of MEDENER - Mediterranean Association of National Agencies for Energy Management, energy efficiency and the development of renewable energy sources.

In 2017, he received the Italian National Scientific Qualification as Full Professor in the sector of electrical energy engineering. His main research interests are in: power systems design and control; power system conversion; PV, CSP electrical and thermal design, characterization and testing; microgrids and smart grids modelling and analysis; design, management and control of multi-energy hub systems by multi-objective optimization approach. 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". He is operating as Italian member for Mission Innovation Challenge 1 "Smart Grids" and Challenge 2 "Off-grid access to electricity", and as a member of national board of director of H2020 for "Secure, Clean and Efficient Energy".

He is the responsible of National and European (FP7, H2020) projects within renewable energy and smart grid topics. He is the vice-coordinator of Joint Programme on Smart Grid (JP SG) within European energy Research Alliance (EERA). He has supervised several MSc and PhD theses. He is also peer review, member of editorial and advisor board of scientific journals, and chairman in international conference. He is author of more 230 scientific papers published in the proceedings of international conferences and journals.