WHITE PAPER AP17
LOW EMISSION ENERGY TECHNOLOGIES

EXECUTIVE SUMMARY

The current Italian and European policy on energy suggests to re-position research activities on power generation within the context of a renewable energy future.
Europe is benefitting from a rapid increase of renewable power resulting in a severe change in the energy mix. However, the main renewable energy resources (wind, solar, tidal power) are inherently intermittent and non-programmable: their production can be insufficient and asynchronous with demand, thus generating great problems to the grid stability.
In the mid-term, in order to secure the energy supply, conventional power plants, designed for steady full load operation, will be used intermittently to balance the grid. This means that the research activities on fossil fuels will aim to emission control and CO_2 capture processes both effective and economically under intermittent operation mode.
Another important research topic will be the development of energy storage alternatives: fuel cells and chemical energy vectors are investigated within this context.
The future of research in the field of energy technologies for the longer term is most likely in an integrated approach to power, thermal, chemical and materials production, an effort that requires combining expertise in combustion, chemical engineering, mechanical engineering, chemistry, materials science, biotechnology, IT, geology, social science, and economics. In the long-term, the digitization (i.e., the utilization of sensors, big data approaches, automation and artificial intelligence, cybersecurity, etc.) will be another fundamental aspect of the energy production as a consequence of the fourth industrial revolution, similarly to the other industrial processes.
Within this frame, the Department, with its broad spectrum of activities and expertise, is the ideal "environment" to carry out interdisciplinary projects at national and international level. All these aspects are discussed in the document.

1. STATE OF THE ART OF THE RELEVANT SCIENTIFIC AREA

The scenario designed by the SET-Plan

The EU has the ambition to become the world number one in renewable energy. To meet this goal, the EU must lead the development of the next generation of renewable energy technologies. A key aim of the Energy Union is also to increase the number of citizens as active players in a decentralised and digitalised energy system – with a direct role in a cleaner energy production and adjusting their consumption patterns to market signals. Buildings, districts and cities will also need to become smarter to reach 'zero energy' levels. The overall goal is to have a more flexible and highly-efficient energy system that incorporates storage capabilities, is better integrated with local heating and cooling networks and that puts consumers at the centre. These challenges call for innovative R&I solutions as the SET Plan sets out to achieve.

Photovoltaic solar energy (PV)

All major future energy scenarios forecast a key role for photovoltaic solar energy. PV currently covers approximately 3% of total EU electricity demand and 2% of the global demand. The PV industry has changed dramatically over the last few years. Italy can play a crucial role in this effort as it hosts 3Sun, the largest European manufacturing industry covering the crucial upstream segments apart from Si feedstock production. Italy identified two major flagship activities (*Flagship 1: BIPV*; *Flagship 2: Utility Scale PV*) and is looking to launch a national network of R&I labs in order to maximise the effects of the tecnology-trasfer projects and contribute to the "N.1 in renewables" objective of the SET Plan.

Concentrated Solar Power (CSP)

Coupled with thermal energy storage, CSP can make a significant contribution to the transformation of the European energy system by providing an important share of dispatchable renewable electricity. CSP can facilitate the integration of variable output renewables such as PV or wind energy, thereby contributing to the reliability of the transmission grid. CSP could account for up to 11% of the electricity generated worldwide and up to 4% of the electricity generated in Europe by 2050. The agreed Strategic Targets on CSP concern a significant cost reduction (> 40% by 2020) and the development of the next generation of CSP/STE technology (introduction of new cycles including supercritical ones).

Off-shore Wind

Wind energy is expected to provide the largest contribution to the RE targets for 2020 and beyond. By 2020 total installed wind energy capacity could reach 210 GW (14% of electricity demand), and by 2030 it could reach 350 GW (i.e. supplying between 21% and 24% of demand). In order to maintain European leadership, the competitiveness of the offshore wind energy sector must increase further. Two key issues need to be tackled: the reduction of the offshore wind costs through the increase of performance and reliability and the need to develop (floating) substructures or integrated floating wind energy systems for deeper waters and wind energy systems for use in other marine climatic conditions.

Biofuels

In the EU, agricultural biomass is the main feedstock for biofuels. However, the request of renewable biofuel production avoiding competition with food resources, stimulate technologies and research in the direction of second and third biofuels generation (including biofuel production from algae and hydrogen produced from biomass). Biofuels are expected to make a significant contribution in passenger car and urban transport markets as of 2030. New technology developments, such as hydrogenation, could help to match the predicted growth in demand for bio-diesel by diversifying the feedstock used as raw material. Biogas, or 'green' natural gas, could see increased use in the transport sector in the future. The production of high quality biogas is one of the most stimulating challenges of the next future.

CCS and CCU

CCS is one of the key promising technologies that can reduce CO_2 emissions in the power generation sector and the only pathway for very stringent GHG emission reductions from specific energy and/or carbon intensive industries that generate CO_2 as part of their production processes. In order to achieve the greenhouse gas emission reductions agreed at COP21 in Paris, CCS will need to be deployed as soon as possible. In order to realise its potential, CCS needs to become a cost-competitive technology and gain public acceptance (mainly regarding storage safety), so that it could start to be commercially deployed and thus contribute to the low-carbon transition of the European economy.

Ocean Energy

Ocean energy is abundant, geographically diverse and renewable. It could meet 10 % of the European Union's power demand by 2050. Ocean energy comprises five distinct technologies: wave energy, tidal stream energy, tidal range energy, ocean energy thermal conversion (OTEC) and salinity gradient power generation. In order to speed up the time to market of ocean energy technologies it is important to prioritise and concentrate efforts for a limited number of technologies. Priority will be given to tidal stream and wave energy, which have a high market potential for Europe and sufficient scale on a European level. It should be noted that OTEC and other technologies could form part of future considerations.

E-Storage

The Implementation Plan of the SET Plan comes at a crucial moment for European Industry. Its scope is batteries for e-mobility and stationary energy storage applications. It is imperative that European industry masters the development, manufacturing, application and recycling of advanced batteries to become competitive in the global battery sector. The Implementation Plan has identified five Flagship R&I initiatives: *Materials Flagship*; *Manufacturing flagship*; *Fast-charge flagship*; *Second-use flagship*; *Recycling flagship*).

Resilient and secure European energy system
The goals of the SET-Plan are the development and operation of energy systems showing an appropriate level of resilience, reliability, energy and economic efficiency, leveraging the use and integration of bulk and local resources, with special reference to integrating variable renewables. The variability of renewables, the stochastic nature of loads, the necessity to integrate different energy vectors according to different energy scenarios raise the necessity to develop a strong flexibility. This requires innovative technologies enhancing customer participation, storage, connections between electricity grids and other networks (gas, heat and cold, transport), optimising the use of flexible sustainable combined power and heat generation and the centralization/decentralization of thermal power generation.

Cross cutting heating and cooling technologies for buildings
The total EU28 energy demand for heating and cooling (H/C) equals 51% of the total final energy. With the exception of biomass (12%), the use of renewables for H/C is marginal. The use of renewable energy sources for heating and cooling, such as biomass, solar thermal, geothermal hydrothermal and aerothermal offer a safe, reliable and increasingly cost-competitive solution to all heating and cooling needs. Small and large scale Heat Pumps, District Heating and Cooling (DHC), Micro CHP/CCHP and Thermal Energy Storage (TES) all fit the above definition very well, can be used in buildings, and represent the technology focus of this action.

2. CONTRIBUTION TO THE RELEVANT SCIENTIFIC AREA

1: RENEWABLE ENERGY
Wind energy
Research activities concern floating offshore wind turbines for deep-sea applications as regards platform/turbine integration. Offshore and onshore turbines are investigated by means of aerodynamic and aeroelastic modeling in order to predict aeroloads (wind shear, yaw misalignment, floater motion), response and hub loads. Integration with hydroelastic solvers and control tools is used for preliminary design. Wind turbines noise is predicted by the Acoustic Analogy formulation coupled with suitable CFD aerodynamic solvers, assessing the effect of blades elasticity on the radiated noise.
Ocean Energy
Hydrokinetic turbines for the conversion of ocean and tidal currents represent the most mature technology in the marine renewables sector, while great interest is given to Oscillating Water Column (OWC) as a cost-effective technology to harvest wave energy from coastal infrastructures. Conditions relevant for operation at sea are addressed through computational modeling and tests on lab-scale models. Research addresses the effects of onset flow turbulence, wave/current interactions, seabed flow confinement in shallow waters, interactions among devices in arrays, PTO control strategies, device response to extreme conditions.
Solar energy
A novel concept of indirectly irradiated solar receiver for CHP generation consisting of a compartmented dense gas fluidized bed has been proved. This configuration permits higher operating temperatures, more efficient thermodynamic cycles, endothermic thermochemical reversible reactions for energy storage. A new approach for photoelectrochemical splitting of water into H2 and O2 is investigated with metal oxide electrodes. High efficiency tandem solar cells resulting from the combinations of the Silicon-heterojunction technology are investigated.

2. FLEXIBILITY AND SUSTAINABILITY OF ENERGY AND POWER
Revamping of conventional plants
Scientific topics under investigation regard the behavior of burners and boilers upon dynamic operation modes (switch from oxygen lean to oxygen rich conditions, fuel switch, cold start). Activities address also the conversion of fossil fuels plants into reactors for gas and fuel synthesis.
Emission control
The research concerns the formation of pollutants, in situ, on-line and off line advanced diagnostics of pollutants and ultrafine particles; flame instabilities; Ox, SCR; NOx and particulate reduction; sea water scrubbing with NH3-SCR for marine application; NOx storage-decomposition for automotive application; PM

reduction through water vapor condensation; Hg capture from flue gases; purification of CO2 streams; tar and VOC abatement.

Energy storage and carriers

Research addresses electrochemical storage for stationary and transportation applications by means of state-of-the-art batteries, highly reversible and low-cost materials for high battery performances. Energy storage of renewable energy is achieved producing H2 for fuel cells by water photo-electrolysis, by CO2-H2 co-electrolysis, by solar thermochemical splitting of water and CO2. Application of ammonia, a no-carbon energy carrier, to mild combustion is also investigated.

Fuel cells

Activities aim to develop new materials and improved membrane electrode assemblies to reduce costs and increase performance and lifetime. High temperature solid oxide fuel cells are developed for direct feed of biofuels (no intermediate reforming step) and to improve the tolerance to redox and thermal cycles. In the transition period, solid oxide fuel cells can operate efficiently with natural gas.

Integrated Systems

Integrated paths (e.g., fossil+renewables, etc.) are explored to overcome the inherent limitations of renewable energy sources and reduce the cost of energy. Co-combustion of fossil and fuels from wastes is adopted to reduce the CO2 emissions. A new approach couples thermochemical conversion processes with Solar or Wind Power (CSP). Fluidized bed CSP is integrated with thermochemcial conversion of biomass to obtain a micro-CHP generator. CSP and wind or photovoltaic electricity is also integrated with the methanation processes of CO2.

Energy harvesting

Specific topics addressed are devices containing cantilevers or polymers in reverse electro-wetting configuration that exploit mechanical or environmental vibrations, devices based on Spin-Seebeck effect or in magneto-caloric transitions to obtain electrical energy from temperature gradients, new devices for micro-generation applied to powering sensors or in general IOT devices using oscillating loads due to waves, wind or vibrations, based on embedding PZT devices.

Power grids

Activities focus on the design and the prototyping of electronic power converters with high dynamic performance and high efficiency for interfacing the smart micro-grid with the main power network, renewables sources, storage systems (batteries, supercapacitors), and loads. The activities concern the development of new control and observations techniques; new maximum power point tracking techniques (MPPTs), for PV/wind/marine current generators; new architectures for the electric energy distribution in smart micro-grids; energy management systems (EMS).

Micro-cogeneration

The studies are aimed at developing high efficiency, low cost, microcogeneration systems (MCHP) for smart-grid use, provided with electrical and thermal storage and powered by renewable and conventional fuels. The objectives concern: the development of single house MCHP (3.0 kW, high efficiency and low vibration), the industrial development of a low cost 10 kWe MCHP, the development of a turbocharged super high electric efficiency 25 kWe prototype (> 35%) and the development of a super low cost 25 kWe system (<1000 €/kWe).

3. BIO AND ALTERNATIVE FUELS

The activity addresses the valorization of biomass, agro-wastes, wastes from industry, end-of-life consumer goods. A key topic is the production of gaseous and liquid fuels by thermochemical processes: pyrolysis yields solid (biochar) and liquid fuels (bio-oil), gasification converts waste into syngas. Upgrade of syngas and biooils is pursued by biotechnological and biorefinery processes: green diesel and gen III bio jet fuels from hydrogenation/cracking of microalgae; biodiesel by enzymatic lipase or from estherification of bio oils and bioethanol. Small-scale demonstrative units for reforming of biogas into a hydrogen-rich mixture are investigated and integrated with Fuel Cell. Other topics include biogas cleaning by functionalized carbon sorbents; catalytic (Rh based) reforming of biogas with residual H_2S, H_2S/siloxanes adsorption. The combustion properties of biofuels are assessed in lab-scale tests replicating real-life conditions; optimized solutions are defined for the utilization in i.c. engines (reciprocating and turbines). MILD combustion of torrefied biomass and biofuels is investigated targeting negative CO_2 emissions. Other topics include the

combustion properties and kinetics of gen II and III biofuels, their frame of knowledge being far from exhaustive. This frame includes the research on the production of micro-emulsions through micro-fluidic systems, and bio-slurry (dispersion of bio-char in bio or fossil oils), and the study of their combustion properties for the utilization in CHP systems.

4. CO2 CAPTURE AND USE

Research activities concern catalytic combustion of methanol, IGCC, oxycombustion, chemical looping, CLOU, chemical looping reforming, mild combustion, new catalysts and chemical carriers. Activities span from fundamental aspects to modeling, prototype development, and safety issues. Extensive research is carried out on CO2 capture: calcium looping, enzymatic capture, innovative CO2 sorbents for acoustic fluidized beds (MOF, GRM and magnetic materials). Activities aiming at post capture utilization of CO2 include purification of flue gases, enzymatic and catalytic conversion to methane or methanol. Advanced compact reactors for small-scale application are investigated, as well as integration with hydrogen coming from renewable solar source (Power to Gas concept). A simple scheme of integrated CaL-CSP process is suggested for the integration of CCUS in the energy grid. Other Integrated systems to be developed in the future activities are CO2 capture +solar and biorefinery and CO2 capture+chemicals production.

5 COOLING AND HEATING

HVAC&R

The activities concern: dynamic modeling of heat exchange processes and analysis and optimization of the air-side performances by experimental thermo-fluid dynamics; control of components and remote monitoring for operation; optimization of the overall efficiency of the electric drive moving the compressor; techniques for the minimization of motor's electric losses (ELMT); pulsewidth modulation techniques (PWM) for the power converter; working fluids in HAVACR applications and PCMs for energy storage, also added with nanoparticles or nanoencapsulated.

Diagnostics, energy saving and eco-sustainability in buildings

Infrared thermography is used to measure thermal performances of building envelops. Photocatalytic degradation of pollutants in air and in water is investigated. Energy management systems (EMS) targeting maximum efficiency of the building power plant are developed. Magnetic refrigeration is under development: it is a solid state technology based on easily recyclable magnetocaloric alloys and permanent magnets and uses water based fluids as heat vectors. The reverse operation allows for harvesting wasted heat.

Solar cooling and heating

Solar cooling and heating is studied for small-size residential and industrial buildings, based on an adsorption chiller and an electric heat pump. Innovative hybrid storage concepts for the Mediterranean and Continental climate are investigated, combining innovative adsorbent material for the surface heat exchanger with high density latent storage through an aluminum micro-channel heat exchanger with additional PCM layers.

3. IMPACT

Impact 1: Expected impact of national and EU Set Plans

DIITET research program contributes to realize the broader National and European energy and climate policy to achieve a European integrated and flexible energy system. Responding to the vision of a low carbon society, while at the same time safeguarding energy supply for all societal stakeholders, DIITET supports the development of technologies that enhance the share of renewable power (solar, wind, biomass etc), includes the use of clean fossil-based energy, in support of renewable energy sources and decarbonised industries. It includes a range of power generation technology sectors and ensures efficient CCUS (Carbon Capture Utilization and Storage).

Impact 2: Developing critical mass of research capacity in Italy

Putting together institutes of CNR with different expertise and funding opportunities, DIITET develops a critical mass and unique research capacity in Italy in the field of Energy technologies. This means to have the capability for solving the challenges facing the complex integration aspects in the current energy systems.

Impact 3: Affirming CNR role
Exploitation, dissemination and communication of results through third mission initiatives will increase the reputation and public perception of CNR and Italian Research in general. DIITET can be the interlocutor of National Public authorities and policy makers as regards energy issues.

Impact 4: Internationalization
Communication and transfer of the results in more academic contexts, through research publications and conferences, are the drive to foster national and international collaboration. Researchers of DIITET are already involved directly in several EU projects as well as active members of the European Energy Research Alliance's Joint Programmes and national representative in international institutions (e.g., Mission Innovation, etc.). The projects carried out within the Department also explicitly sets out to bring on board a broader international energy R&D environment.

Impact 5: Identifying gaps within national programmes/activities
DIITET has already started to identify gaps within national programmes and activities. Currently, certain topics to be put in focus in the next 5-10 years have been identified:
VALUE CHAINS: Focus on value chains would be positive because it would allow to adjust and carry out the research in a way that will benefit individual components and whole process system and its integration into a wider system for production of energy, fuels, chemicals.
ENERGY SYSTEM LINKING RENEWABLES AND FOSSIL FUELS: Renewable dominated electricity production is key to realise the climate targets, but according to the Eurostat data of 2014 only 27% of the energy mix in Europe is based on renewables. The share of fossil fuel will be reduced further in the coming years, but the amount of CO2 emitted is still significant. Low cost and low carbon CCUS technologies and integrated value chains for CO2tutilization can reduce the CO2 footprint of the European energy system, making sure the EU meet the COP targets and facilitate the needed security of supply.
FLEXIBILITY IN THE ENERGY INFRASTRUCTURE:
Renewable production of electricity is based on more and different power sources and due to the dependency on wind, solar and or tidal, it produces a non-programmable electricity output. Thus, fossil fuel utilization is a reliable back-up source of energy and CCUS technologies will be designed to generate this low-carbon flexible back-up power. DIITET will increase national and European focus on the mentioned topics, in close dialogue with relevant stakeholders. This will help to release CNR potential to becoming excellent in this field of energy research.

Impact 6: Fund Raising
EU calls:
Numerous calls in the field of energy are available in several funding frameworks as Secure, clean and efficient energy of Horizon 2020, or under the Programme Research Fund for Coal and Steel. They offer an efficient way for the funding projects in all the research areas covered by DIITET.
Other funding opportunities
DIITET has already undertaken initiatives to foster international collaboration and catch funding opportunities in other counties. Of particular interest the fast growing countries of China and Korea, as regards the development of clean coal combustion technologies, and South America countries for biothecnological processes. CNR could look with particular attention the opportunities of international collaboration coming from the huge Chinese funding from the One Belt one Road.

Impact 7. National Economy
Italy is a country characterized by an economy based on the transformation industry. The development of technologies for efficient and clean energy production from renewable sources has a double positive impact. Firstly, the increase of energy production from renewable sources lowers the import of energy sources, with a positive impact on the commercial balance. Secondly, if the capability to harvest and use larger shares of renewable energy at low cost will be increased, thus improving the competitiveness of the Italian products on the international markets. Not secondary is the impact on the national energy grid system: a target of the new generation energy production systems from renewable source is the increase of dispatchability levels.

Finally, not less important is the capability to maintain a technological leadership in the sector of renewable energy, a prerequisite to sustain the growth of the companies that operates in this emerging sector of renewable energy, a task where the CNR can play a major role.

Impact 8. Societal impact

The diffusion of advanced energy systems can have several impacts on the society. Italy has been already subject to infraction procedures from the EU because of too high level of pollutant emissions. Ensuring a cleaner production of energy and ensuring lower consumption of fossil fuels is clearly a priority dictated not only by the undersigned agreements (Horizon 202020 and COP21), but especially to avoid the costly damage on public health.

Other costs in the use of renewable energy are being considered, as those associated with the grid imbalance, the need to shutdown conventional power plants with the negative effects on the employment levels in the large utility companies. Furthermore, it is emerging that not all renewable energy sources are equivalent to clean energy sources: proper processes are required to avoid the emission of pollutants or the disposal of end life wastes coming from devices for low carbon energy production.

Not less important is the sustainability of the sources that has already guided the introduction of rules for the production of bio-fuels.

These considerations clearly indicate the need of a correct strategy and the involvement of multidisciplinary research organizations, as the CNR, in the development of programs that sustain the transition to a low carbon economy.

4. EMERGING RESEARCH CHALLENGES

The priority challenge in the energy field is to meet increasing demand for energy while reducing emissions. This can be achieved by combining two technological issues: to use energy as efficiently as possible and replace primary sources with low carbon energies (including fossil-fuels power integrated with efficient CCSU operation). The efficient utilization of renewable non-programmable energy (wind, PV, etc.) places the additional challenges of the storage of energy and the management of the energy fluxes and their integration in hybrid energy grids. This aspect opens to the challenge of the new millennium, e.g., the digitization of energy. According to the BP Technology Outlook 2018, the digitization (sensors, big data, artificial intelligence, cybersecurity, etc.) could reduce energy demand and costs by 20-30% by 2050. The AP-LCT will promote a greater integration of the expertise inside the DIITET in order to face properly this stimulating multidisciplinary challenge.

5. CONCLUSIONS

The world is undergoing a radical transformation in the way energy is produced and used, shifting to a cleaner, consumer-centric and more efficient energy system. European countries, the industry, research organisations and the European Commission are working together to speed up this transformation. The goal is to facilitate the achievement of the EU climate and energy goals and to strengthen industrial competitiveness. This is being done by better coordinating national R&I agendas on low-carbon energy and mobilising the associated resources required.

The CNR and in particular the AP Low emission energy technologies (“Tecnologie energetiche a basse emissioni”) of DIITET are contributing to achieve the target that the national and European policies have fixed for a Secure, clean and efficient energy.

The research activities developed in the AP span from basic to applied science, from numerical modeling to complex experimental systems, with the aim of increasing the knowledge in the field of energy, energy transformation, energy systems. The numerous publications and participations in national and international projects, as well as in national and European networks and Institutions permits to DITTET to be a privileged observatory.

In the energy field the challenge to face in the next future is to meet increasing demand for energy at the same time as reducing emissions. The answer to such a dilemma is in the combination of two technological issues: to use energy as efficiently as possible and substitute the primary sources with low carbon energies. The research and the development of technologies able to contribute to the achievement of such issues will

emerge as challenges in the future. In the next years, the decarbonization of the power sector will require a delicate transition passing through an integrated approach based on the use efficient and controlled of different and complementary primary energy sources. Such an effort requires combining expertise in chemical and mechanical engineering, chemistry, physics, materials science, biotechnology, information and communication technology, etc. The Department, with its broad spectrum of activities and expertise, is the ideal “environment” to carry out projects interdisciplinary at national and international level. The AP Low emission energy technologies could represent the core of expertise to stimulate and promote such initiative inside the DIITET and transversally to other Departments of CNR.

PROJECT AREA 17: LOW EMISSION ENERGY TECHNOLOGIES

Editorial team and Contact person (CP)	**Institute**	**Email**
BAGLIO VINCENZO	ITAE	vincenzo.baglio@itae.cnr.it
DE JULIAN FERNANDEZ CESAR	IMEM	cesar.dejulian@imem.cnr.it
DE LORENZI ANTONIO	IGI	antonio.delorenzi@igi.cnr.it
DI PIAZZA MARIA CARMELA	ISSIA	dipiazza@pa.issia.cnr.it
SALVATORE FRANCESCO	INM	francesco.salvatore@cnr.it
MUSCARI ROBERTO	INM	roberto.muscari@cnr.it
MARINETTI SERGIO	ITC	s.marinetti@itc.cnr.it
MASSOLI PATRIZIO (**CP**)	IM	p.massoli@im.cnr.it
MAZZER MASSIMO	IMEM	mazzer@imem.cnr.it
MEROLA SIMONA	IM	s.merola@im.cnr.it
MOCCIA VINCENZO	IM	v.moccia@im.cnr.it
PUCCI MARCELLO,	ISSIA	marcello.pucci@cnr.it
SENNECA OSVALDA (**CP**)	IRC	o.senneca@irc.cnr.it