WHITE PAPER AP20
CONTROLLED THERMONUCLEAR FUSION

EXECUTIVE SUMMARY

CNR research activities in the area of Controlled Thermonuclear Fusion (CTF) are aimed at the realization by the mid of next decade of the experimental prototype of fusion reactor ITER, under construction in France;its scientific exploitation in the next twenty years;the construction of the demonstrator reactor, DEMO, which will feed the grid with the first fusion electricity around the mid of the century.
The Institute for Ionized Gases (IGI, acting in the frame of the Consortium RFX, CRFX) and the Institute for Plasma Physics "P. Caldirola" (IFP) participate, with ENEA, INFN and several universities, to the EU fusion programme in the frame of several EU and international collaborations.
The scientific and technological activities carried out by IGI and IFP are supported mainly by the EURATOM, via the EUROfusion Grant Agreement "Implementation of activities described in the Roadmap to Fusion during H-2020", for R&D and including the participation to experimental campaigns in EU fusion facilities, and the agency Fusion for Energy (F4E), managing the procurements of the EU in-kind contributions to ITER.CRFX is responsible of the construction in Padua of the prototype of the Neutral Beam injector for ITER, in collaboration with Japan and India.IFP and IGI also benefit of contracts directly issued by the ITER Organization (IO) for integration activities and collaborate with Japan under the Broader Approach agreement.
In 2018 CRFX with a pool of private companies obtained funds under the POR-FESR EU scheme for regional development to upgrade the experimental fusion device RFX-mod, operative in Padua.
In 2017 the Italian Government approved the construction of a new fusion facility, the Divertor Tokamak Test (DTT), proposed by ENEA, CNR, INFN, and the consortia CRFX and CREATE.DTT is considered a key device in the "Roadmap to the realization of fusion energy" to investigate the system of power exhaust to be implemented in DEMO, to mitigate the enormous thermal loads onto the walls due to the burning plasma.IGI and IFP contributed to the DTT proposal and are presently working to the definition of the design of the device.
IFP and IGI participation to the fusion programme ensures CNR to develop strategic skills in Physics and Technologies of CTF and support the national industries in the procurement of ITER components.
IGI and IFP are deeply committed in formation and training of young scientists and engineers to adequately prepare the ITER- and DEMO-generation.

1. STATE OF THE ART OF THE RELEVANT SCIENTIFIC AREA

In 2013 the long-term programme of the European fusion community has been drawn up in the Roadmap to the realization of fusion energy covering a multi-decade period and aimed at the scientific exploitation of ITER and the construction of the demonstrator reactor DEMO by the mid of the century.
The implementation of the missions of the Roadmap has been assigned by EURATOM to the European Consortium EUROfusion via the multi-annual Grant Agreement "Implementation of activities described in the Roadmap to Fusion during Horizon 2020 through a Joint programme of the members of the EUROfusion consortium", supporting the R&D activities organized in projects and experimental campaigns on a number of devices. EUROfusion consists of 30 research organisations and universities from 26 EU member states plus Switzerland and Ukraine. ENEA is the Italian member of EUROfusion, and CNR (coordinated by IFP) and CRFX (including IGI personnel) participate to the programme as two linked Third Parties of ENEA.
The programme includes several lines of scientific and technological research activities characterized by a high level of innovation as the development of new materials which can stand the thermal loads produced by a burning plasma, comparable with those on the surface of the Sun, and intense neutron fluxes; the superconducting magnets under construction for ITER, the largest ever realized; the remote handling systems

necessary for the manipulation of reactor components activated by neutrons; the advanced control systems necessary for the integrated functioning of all systems and sub-systems essential for the full operations; the multi-MW auxiliary heating systems consisting of neutral atom injectors with energies around 1 MV and of millimeter-wave sources (gyrotrons).
Besides the technological challenges, also Physics and modeling of fusion plasmas have an important role in the Roadmap, from the implementation of an integrated tokamak modeling tool to realize a 'numerical tokamak' with high predictive capabilities, to the EU contribution to the Research Plan of JT-60SA, from the development of diagnostics of burning plasmas to the modeling activities supporting the experimental campaigns aimed at the preparation of the operational scenarios in ITER.
Indeed, the European fusion strategy under the EUROfusion Grant includes a robust experimental programme carried out in several European and international magnetic fusion devices. The largest operating tokamak in the world is the European facility JET (UK), which is also the only fusion device where the radioactive isotope of Hydrogen, Tritium (T), an essential ingredient of the nuclear fuel (together with Deuterium, D), can be used. In 1997 16 MW of fusion thermal power were produced in JET for ~1 second against 22MW of auxiliary heating power in the form of neutral beam and radiofrequency injection, achieving an amplification factor of Q~0.6. In 2020 a new experimental campaign in DT is planned in JET, which should demonstrate the fusion energy production in stationary conditions, still for Q<1, while Q>1 will be one of the missions of ITER.
In parallel to the JET programme, a coordinated set of experimental campaigns is carried out on the so-called Medium Size Tokamaks, Asdex-Upgrade (IPP, D), TCV (SPC, CH), MAST-Upgrade (CCFE, UK), and WEST (CEA, F), while for specific projects, other magnetic confinement devices are also exploited, the tokamaks Compass (IPP, CZ) and FTU (ENEA, I), the stellarator Wendelstein-7X (IPP, D), the reversal field pinch RFX (CRFX, I), the linear plasma devices MAGNUM- and PILOT-PSI (DIFFER, NL), and GyM (IFP, I).
An international programme has also been established among some of the ITER parties, that foresees the participation of European Researchers to the experimental campaigns in DIII-D (GA, USA), EAST (ASIPP, C), JT-60 (QST, J), K-STAR (NFRI, SK).
Finally, new devices are under construction with an important involvement of the Italian community. The Broader Approach (BA) agreement between EU and Japan, which accompanies the experiments on ITER towards a future fusion reactor, envisages a voluntary contribution of some EU countries, including Italy, to the construction of the tokamak JT-60SA in Naka, and the successive share of experimental time. In the frame of the BA, CRFX is committed to procure the power supplies of the control systems (already delivered and installed in 2015) and of the protection circuits of JT-60SA.
The new Italian tokamak DTT, proposed by ENEA, CNR, INFN, and the consortia CRFX and CREATE, is presently in the design phase. Its first operations are envisaged in 2025, and its main aim will be addressing the problem of power exhaust for DEMO. Around 2022-23 EUROfusion will identify, on the basis of the outcome of an ongoing multi-machine investigation, the divertor concept most suitable to mitigate the large thermal loads expected in the reactor and will support the installation of such an optimized divertor in DTT.
In 2012 in the frame of an international agreement among ITER IO, F4E, CRFX and the Indian and Japanese Domestic Agencies, CRFX started the realization in the CNR Research Campus in Padua of the prototype of the neutral beam injector which will be installed in ITER for plasma heating. The facility consists of the SPIDER negative ion source with an acceleration voltage of 100 keV, and of MITICA, the full size neutral atom injector with energy of 1 MeV for ITER. SPIDER will start its commissioning and operations in 2018, while first operations of MITICA are expected in 2023.
Since 2016 the RFX-mod experiment has been shut down in order to implement several upgrades, including substantial modifications of the magnetic front-end and improvements of the diagnostic systems , which will empower the experimental capabilities of the device. The modified RFX-mod2 first operations are expected in early 2020.
The long-term character of the fusion programme requires in parallel an intense activity of formation and training of new generations of scientists and engineers who should inherit and further develop the skills grown in the European national fusion labs. A training fellowship scheme for physicists and engineers has then been implemented by EUROfusion in close collaboration with several national Universities and Polytechnics.

There is also a strong effort to involve industries in the fusion programme. The Fusion Industry Innovation Forum (FIIF) has been implemented by the European Commission in 2010, and later with the Roadmap to Fusion Energy the fusion programme has been re-oriented towards the design and construction of the prototype reactor DEMO, that should integrate the requirements and the principles that nuclear industry requires.
Moreover, the EU fusion labs have developed and are repository of the skills in science and technology of magnetic fusion, which are necessary to support the national industries in answering the calls for tender issued by F4E for the construction of the ITER components in charge to EU. Due to the productive cooperation between Italian research centers and the industry, in the last ten years the Italian high-tech companies have been awarder of European contracts by F4E for about 1 billion € out of 2 B€ granted to European companies. EU industries will be also involved in the construction of DTT.
Fusion turns not only out to be a unique scientific and technological challenge, but also to open a new “market” for high-tech industry.

2. CONTRIBUTION TO THE RELEVANT SCIENTIFIC AREA

Since their birth in the early 70's, IGI and IFP were focused on plasma physics and engineering studies, joining the Association of Italy with EURATOM to investigate plasma applications to fusion.
In the 80's IFP started a close collaboration, still going on, with ENEA-Frascati, with the responsibility of implementation and of operations of the ECRH system on the FTU tokamak.
Since 1996 IGI’s activities are fully integrated in CRFX, as its principal partner, providing 60% of the manpower;other partners are ENEA, INFN, Padova University and Acciaierie Venete SpA.
Both IGI and IFP are strongly committed in the activities on the EU Tokamaks, and in developments for future devices:IGI/CRFX being responsible of the construction of the ITER Neutral Beam Test facility (NBTF), IFP with a strong involvement in the development of ECRH systems for ITER, DEMO, DTT.
At IGI/CRFX is also located the RFX-mod facility, exploiting the magnetic configuration Reversed Field Pinch to confine the plasma, alternative to Tokamak.IGI/CRFX is involved in BA activities for power supply provision for JT60-SA.
Collaboration to the ITER project:
IGI/CRFX hosts inside the CNR Research Campus in Padua the ITER NBTF set up to develop and optimize the prototype of the neutral beam injectors, one of the most important and critical components of ITER. NBTF comprises two experiments:SPIDER negative ion source with an acceleration voltage of 100keV, and MITICA, the full size ITER neutral atom injector with energy of 1MeV, both with 40A accelerated D-beam. SPIDER is starting the operation in 2018, while MITICA components are under construction, operation being planned from 2023. NBTF is a large facility with a total investment of 200 M€ from F4E, CNR and the Japanese and Indian ITER Agencies. About 50% of IGI personnel is involved in NBTF through F4E grants. IGI/CRFX is managing the facility, has designed, followed up the construction and commissioned the subsystems:vacuum vessel, RF beam source, accelerator grids, beamline components, vacuum and gas injection plant, cooling plant and cryogenics, diagnostics and data acquisition and control systems, source and accelerator power supplies. Physics studies of the accelerator and of the Cesium effect support the design.
R&D on NBTF is accompanied by an extensive programme on local flexible test facilities to study the High Voltage holding up to 1MV, RF voltage hold off, Cs deposition (required for negative deuterium ions generation), and on the NIO1 small experiment to optimize source and accelerator. This is complemented by participation to R&D programmes on ion sources and beam injectors at NIFS and QST Japanese laboratories and at IPP-Garching in Germany. Collaborations for specific activities are setup with laboratories including CNR-Nanotech in Bari and IFP, which provides the neutron diagnostic.
IGI/CRFX works through direct contracts with IO on electromagnetic modeling of ITER passive structures and on design of the ITER core Thomson scattering and magnetic sensors.
IFP contributes to the ITER project with the design, optimization and realization of different components of the Electron Cyclotron Resonant Heating (ECRH) system, the first heating system which will operate on ITER in 2025. Up to 20 MW of millimeter-wave electromagnetic (EM) radiation at a frequency of 170 GHz will be

injected in the plasma to assist breakdown, plasma current ramp-up and ramp-down, plasma heating, localized non-inductive plasma current generation to control MHD instabilities and for disruption mitigation.
Under F4E Grants, IFP is responsible for the Physics and optimization of the ECRH Upper Launcher and for the procurement of the bolometric dummy load needed to dissipate MW-level EM radiation produced by the gyrotron sources. This technology, developed at IFP during two decades, is at the basis of the provision of several dummy loads to different international labs hosting fusion devices, as ENEA, IPP-D, SPC-CH, QST-Japan.
IFP participates also to the design of ITER diagnostics, the Plasma Position Reflectometer and the Gamma-ray Spectrometry system of the Radial Neutron Camera.
IFP has been beneficiary of contracts by ITER IO for the optimization of the Equatorial Launcher, for Physics-based transport modelling of plasma particles and energy, and for the design of the EC first Plasma Protection components.
For their expertize in plasma diagnostics, CRFX and IFP, in Consortium with two private companies, have been also awarded of a longstanding ITER Framework Contract for “Diagnostic Systems Engineering Services”.
Collaboration to EUROfusion:
Both IGI/CRFX and IFP are deeply involved in the EUROfusion R&D programme, supporting the Physics activities aimed at the preparation of ITER operations and the development of technologies in view of the prototype reactor DEMO. This programme is carried out in a wide European collaboration. The IFP and IGI/CRFX involvement in EUROfusion Physics areas includes the exploitation of EU tokamaks, with a strong commitment in terms of resources both on-site and at IFP and IGI premises. Such collaboration, including data interpretation by advanced modeling tools for particle, energy and momentum transport studies, covers the fields of control of disruptions and runaway electrons;impurity transport;preparation of next D-T campaign in JET;power exhaust; magnetic equilibria reconstruction; development of data access layers to support the data model of the infrastructure.
IGI/CRFX also collaborates to the Stellarator W7-X experiment by contributing to data acquisition and with the procurement of an innovative probe to diagnose the edge plasma.
The spectrum of IFP activities under EUROfusion extends to theoretical and modeling studies of electromagnetic radiation propagation in magnetized plasmas and of MHD plasma instabilities in tokamaks, as well as to data interpretation. The realization of the 'numerical tokamak' tool to support future devices design is being pursued in this context.
IFP also participates to the upgrade of nuclear diagnostics systems in JET, like neutron and gamma-ray spectrometers, crucial for the next DT campaign.
IFP also develops experimental studies on W erosion, material redeposition, ammonia formation in N seeded D-plasmas, dust formation, migration and interactions, due to high plasma fluences, which are carried out on JET and other tokamaks, and on the linear plasma machines MAGNUM-PSI, Pilot-PSI (NL), and GyM at IFP. Dust dynamics in the plasma is investigated by means of different numerical codes and compared with experimental data in JET. Plasma interaction at high fluences with liquid metals is also investigated experimentally in view of their possible use in the DTT divertor.
A relevant activity, carried out both by IFP and IGI/CRFX, is the contribution to the preparation of experiments for the JT-60SA tokamak in the design of the ECRH and MHD control systems (IFP), in the procurement of the power supply for RWM instability control system and protection circuits (IGI), scenario developments, diagnostic design, database management (IGI).
The collaboration in laying the foundation for DEMO is carried out through the EUROfusion Power Plant Physics and Technologies Work Projects.
IGI/CRFX contribution is focused on: conceptual design of the DEMO Neutral Beam Injector; advanced diagnostic design; studies on the Plant Electrical System; optimization of the design of the toroidal field circuit topologies; design of large non evaporable getter pumps; studies on the role of fusion in long term energy scenarios and fusion power plant assessment.
In this frame, IFP coordinates activities aimed at defining the conceptual design of the ECR Heating & Current Drive system for DEMO.

In collaboration with ICMATE, IFP is involved in the mechanical and thermo-physical characterization of existing materials and alloys for structural applications in DEMO.
In past years, the experiments carried out on the fusion device RFX-mod led to the discovery of enhanced plasma regimes dubbed Single Helicity. This was possible thanks to a state-of-art real time system for the control of magnetic instabilities developed at IGI/CRFX. At present the device is being upgraded to further optimise the magnetic field error control and improve the plasma performance. The modifications are also intended to contribute to the scientific program of JT-60 SA for the magnetic unstable mode control.
All the experimental activities, both by IFP and IGI/CRFX, are supported by theoretical and modelling studies.
The Divertor Tokamk Test (DTT) facility will be a large strategic research infrastructure, to be built in Italy in the next decade, with a financial contribution from EURATOM. It will operate for 30 years, in parallel to ITER and in view of DEMO. The main objective is to identify the most effective way to handle the huge amount of thermal power which will be produced in DEMO from fusion reactions. Due to the relatively low thermal power density hitting the walls, no fusion device presently operating or under construction, not even ITER, can face this issue.
CNR participated to the definition of the Project Proposal in 2015, and of its Business Plan in 2016, and presently is contributing to the pre-conceptual design of the machine. The skills grown up at IGI and IFP turn out to be of the utmost importance, mainly in (a) Physics and technology of plasma heating systems, by the injection of energetic neutral beams (IGI) and powerful millimeter-wave EM radiation (IFP); (b) design and realization of crucial plasma diagnostics (IFP & IGI) and (c) development of plasma active control systems, either via in-vessel magnetic coils (IGI) or by a local non-inductive drive of plasma current by means of ECRH (IFP).
Additional involvements of CNR in the project are in the preparation of operational scenarios, in the study of the edge and divertor physics, in the ELM and disruption mitigation strategies.

3. IMPACT

IGI/CRFX and IFP are among the major contributors to the international fusion programme, as host of the relevant ITER NBTF and of the upgraded RFX, as key parties in the DTT project, as participants, in collaboration with other EU fusion centers, to the development of several component and sub-systems of ITER, as leading contributors to Physics and engineering topics within a worldwide network of collaborations.

Two test bed experiments of the ITER most powerful heating system, the Neutral Beam Injector, are being realized in Padua under the leadership of IGI/CRFX, which is therefore responsible of one of the key systems of ITER, whose performance will critically depend on the reliability of such components. The construction of the two facilities involves several companies, Italian and international, and is carried out in strict collaboration with Japan and India.
Integration of several competences has been essential to the success of this project: thermo-mechanical and vacuum engineering, power electronics, in particular with RF and High Voltage expertise, IT and control systems engineering, modeling physics of the RF source and of the beam, diagnostics physics and engineering.
The mission of the NBTF facility extends beyond the development of ITER injectors, as it is meant to optimize the injector performance throughout the ITER lifetime and it represents the best environment to test new technologies, especially towards the future experimental reactor DEMO.
As far as the Physics activities are concerned, they are focused on critical aspects for future fusion devices, ranging from power exhaust to real time control, particle and energy transport studies, disruption control, MHD, edge physics, beam modeling, diagnostic implementation. They are aimed at preparing the operation of future devices: JT60-SA in Japan, DTT in Italy, ITER, and on the long-term DEMO. This regards naturally the activities related to NBTF and the involvement in the experimental campaigns in Tokamaks, but also the experiments on RFX-mod2, which will impact on key issues relevant for future devices, besides progressing

the understanding of the RFP configuration fusion potentialities. IGI/CRFX pursues fusion power plant assessment studies through simulations of an RFP reactor and of an RFP based Fusion-Fission reactor.
The ongoing RFX-mod2 modifications have been funded (2M€ over a total cost of about 4M€) as a joint project by Consorzio RFX and a pool of three local companies under the POR-FESR European scheme, thus contributing to industrial innovation.
A great effort is devoted to the education of young scientists. Padua University and Consorzio RFX coordinate an International doctorate in Fusion Science among Padua University, Lisbon University, Ghent University. Master/Bachelor students, internships of master students summer stages of high school students are supervised by IGI/CRFX researchers.
Several outreach and communication activities are coordinated at IGI/CRFX within a science and society programme including tours and visits to the facilities, round tables, open days and events, which got a significant public response. Great effort continued to be dedicated to schools: as an example, 1008 students visited the laboratory in 2017, receiving a preliminary introduction into energy scenarios and fusion as a possible energy option for the future.

In the Eighties, IFP was given the responsibility to design and install the ECRH system, still operating on FTU (ENEA, Frascati), delivering 1.6 MW of EM radiation at 140 GHz for 0.5 sec, the most advanced ECRH system operating at that time. In the first decade of this century, still under IFP responsibility, this heating system has allowed to achieve in FTU several scientific results of high impact for the fusion community: record Te value of 14 KeV, development of ECRH modulation techniques for power deposition profile measurements, demonstration of plasma MHD instability feed-back control, proof-of-principle of the collective Thomson scattering diagnostic of Ti , demonstration of plasma disruption suppression, of saw-tooth period control, of EC-assisted plasma start-up, and of MHD real time control.
As a side product of the implementation of the ECRH system in FTU, IFP personnel started to develop a key technology for such plant, a bolometer load of new type capable of absorb and dissipate MW-level millimeter-wave radiation, and to give a measurement of the total amount of power generated by the gyrotron source by means of bolometric techniques. Over the years, in collaboration with an engineering design company, IFP, under EFDA and F4E supports, has developed several prototypes of bolometric loads, matched with the different technical specifications (frequencies, pulse duration, power) of the operating ECRH systems in the world, where they have been purchased and installed: in AUG in Garching, in TCV and the EU gyrotron test-bed in Lausanne, in JT-60SA in Naka.
Relevant scientific advancements in fusion plasma theory and modeling have been achieved mainly in two areas. The Physics of propagation and interaction of electron cyclotron waves in a magnetized toroidal plasma has been for many years a subject of theoretical investigation at IFP. A numerical code to describe the propagation and absorption of EC wave Gaussian beams in a magnetized plasma in tokamak geometry has been developed by IFP researchers and is presently recognized by the EU community as a benchmarking reference code for other models under development and is used in the optimization and design activities in the frame of EUROfusion and F4E ECRH-related activities on ITER.
A long-standing commitment of IFP Researchers in advanced numerical modeling and interpretation of discharges carried out in JET and other EU and extra-EU Tokamaks has allowed to deepen our understanding of the Physics underlying the processes of transport of plasma particles, energy, momentum, and impurities in the extremely complex system as a magnetically confinement fusion plasma, including turbulent processes. IFP maintains a key role in the international fusion community in this area.
An other area of excellence of IFP is the development of fusion plasma diagnostics. The expertize of IFP in millimeter-wave Physics and technologies has made possible to develop and install a prototype collective Thomson scattering diagnostic of the ion temperature in FTU, to design and install the Oblique ECE diagnostic in JET, to contribute under F4E to the design of the Plasma Position Reflectometry for ITER. The low-frequency instrument installed in the satellite Planck, to measure the CMB radiation, has been tested at IFP millimeter-wave laboratory.
IFP is a main center of competences in the development of neutron and gamma-ray diagnostics for fusion plasmas.
IFP in collaboration with ISM has developed a 12-pixels diamond based neutron spectrometer matrix. The first application of the diamond matrix will be the measurements of the 14 MeV neutron spectrum in the

next DT campaign in JET. In JET IFP has designed and installed the gamma-ray spectroscopy and has the responsibility for the upgrade of the gamma-ray camera. IFP is responsible for the design of the gamma-ray diagnostic system in ITER and collaborates to the design and implementation of the neutron diagnostics for the NBTF in Padua and of a neutron spectrometer in EAST (in China).
IFP is putting a lot of efforts in dissemination of plasma and fusion science. During the years of activities under EURATOM programmes, IFP has begun collaborations with the University of Milano-Bicocca (UniMiB), with Polytecnic of Milan (PoliMi), and with the University of Milan.
Reseracher of IFP are delivering courses on Plasma Physics, Fusion science and Plasma diagnostics at UniMiB, and students attend laboratory course using IFP facilities.
IFP has a traditional collaboration with UniMiB on neutron diagnostic development, and with PoliMi on investigations on plasma-material interaction. IFP has had and still have a key role in the increase of students in Physics and Nuclear and Material Engineering which are attracted by Fusion Science.
IFP organizes two Open-Days every year, which attract almost one hundreds students from the Universities and Polytechnic of Milan; is receives ten students per year from high-school in the so-called "*Alternanza scuola-lavoro*" project; participates to the "European Researchers Night" events in collaboration with the University of Milano-Bicocca and with then Polytechnic of Milan.
In 2019 IFP, in collaboration with the University of Milano-Bicocca, will organize the "46th European Physical Society Conference on Plasma Physics" (EPS2019), Milan, 8-12/7/2019, which will convene almost 700-800 scientists from all over the world.

4. EMERGING RESEARCH CHALLENGES

Being fusion at the forefront of Physics and of technological research, several emerging challenges are faced towards the realization of the reactor.As for Physics of burning plasmas, a coordinated set of experimental campaigns on the most performing fusion devices is carried out, accompanied by strong efforts in plasma modeling using high-power super-computers and as far as possible first-principle based numerical codes.The main technological challenge is represented by the enormous thermal energy fluxes produced by the nuclear reactions in the burning chamber. The aim of the construction of DTT is to develop and test the power exhaust system to be used in DEMO.IFP and IGI are deeply involved in the design of DTT.
Powerful heating systems are needed for ITER and DEMO.IGI/CRFX is building the PRIMA facility to test the 33MW 1MeV neutral injection system for ITER.IFP is working at the design and optimization of the ECRH system aimed at injecting 20 MW of radiation power in ITER plasma.

5. CONCLUSIONS

Controlled Thermonuclear Fusion (CTF) is considered by the most industrialized Countries and by those with the fastest economical growth as one of the most promising options to guarantee a long term, environmentally sustainable, almost inexhaustible base-load energy source to integrate the intrinsically intermittent renewable sources.
In H-2020 the EU research programme on CTF has been profoundly re-oriented towards the realization and scientific exploitation of ITER and to the design and construction of the prototype reactor DEMO,a strategic plan covering the first half of the century and described in the "Roadmap to the realization of fusion energy".
Italy is a leading actor at EU level since joining EURATOM almost 60 years ago.In the 70's CNR started to be involved in fusion research via its Institute for Plasma Physics (IFP) and Institute for Ionized Gases (IGI), later entering the CRFX, investing important resources in personnel and in construction and operation of a number of facilities that have produced important scientific results at international level, and on which hundreds of scientists and engineers have been formed, many pursuing brilliant careers in national and international research centers.

Due to the cross-cutting nature of fusion, other CNR Institutes have been later involved in EU programme, ICMATE, ISC, NANOTEC, SPIN, INO.
The increasing complexity of the fusion facilities and the decision taken in the first decade of the century of building ITER have motivated a closer and closer involvement of high-tech and innovative industries.
The Italian research-education-industry system in CTF has grown including the main public research bodies, several Universities and Polytechnics, establishing a number of new plasma physics and fusion science courses. In 2016 EUROfusion has listed more than 40 CTF-related PhD Thesis in progress in Italian Academic and research centers.
This community has successfully supported the national industry, which has proved to be the undisputed champion in the construction of ITER components.
The construction by CRFX of the SPIDER negative ion source and the procurements of JT-60SA components under the Broader Approach are a demonstration of the successful cooperation between national industry and research centers.
The next challenge for the community will be the construction of DTT, which will represent the most advanced operating European tokamak in the next thirty years, in parallel to ITER, and in view of DEMO.

PROJECT AREA 20: CONTROLLED THERMONUCLEAR FUSION

Editorial team and Contact person (CP)	Institute	Email
LONTANO MAURIZIO (**CP**)	IFP	lontano@ifp.cnr.it
MORO ALESSANDRO	IFP	moro@ifp.cnr.it
PASQUALOTTO ROBERTO	IGI	roberto.pasqualotto@igi.cnr.it
PUIATTI MARIA ESTER	IGI	mariaester.puiatti@igi.cnr.it