

 One of the ITER vacuum vessels being manufactured in Italy. Courtesy of ITER Organization.

"Advances made in various disciplines, from physics and computational science to engineering and materials science are steadily transitioning fusion energy from vision to reality."

IAEA Director General Rafael Mariano Grossi



Fusion Energy: Present and Future

By Rafael Mariano Grossi, IAEA Director General

1ST EDITION

Fusion energy promises a potentially unlimited, low carbon source of clean energy.



A significant step forward in December 2022 was the first ever achievement of scientific energy gain (a controlled fusion reaction generating more energy output than invested energy input) by the Lawrence Livermore National Laboratory's National Ignition Facility (NIF) in the United States of America. Courtesy of Lawrence Livermore National Laboratory.

I am proud to introduce the first issue of the IAEA World Fusion Outlook, convinced that this publication will become the global reference for authoritative information and updates on a truly fascinating and promising, potentially unlimited, low carbon source of clean energy: fusion energy.

Scientific and technological advances combined with growing demand for clean energy to power economies, mitigate climate change and protect our planet, plus recent significant capital investment in the fusion industry sector, are stimulating international efforts towards achieving the first economically viable energy producing fusion power plant. Private companies have attracted billions of US dollars from venture capital companies, private equity and sovereign funds, and other corporate investors. As the challenges associated with fusion science and technology are formidable, increased private funding combined with State commitment is needed to drive fusion energy forward.

This year has witnessed several new government initiatives that include fusion in response to the climate change urgency, such as UK Industrial Fusion Solutions Ltd, the Fusion Industry Council of Japan, the European Commission's Net-Zero Industry Act, which includes promotion of fusion technology investments, and Germany's Fusion Research Position Paper, as well as the United States Department of Energy's Milestone-Based Fusion Development Program allocation of US \$46 million to eight commercial fusion companies.

Fuelling the future of fusion

Some of the biggest remaining challenges facing fusion have to do with achieving the conditions for a fusion reaction to sustain itself in a hot, dense ionic gas or plasma, the same sort of reaction that powers the stars. The challenges include extremely high temperatures, exceeding 100 million degrees Celsius; long lasting confinement of the hot plasma inside the chamber core; a fusion machine first wall able to withstand the extreme conditions; closing the fuel cycle; and extracting and harnessing the enormous amount of energy produced. There have been three important advances in 2023 that help surmount these challenges. The first is China's EAST tokamak, which demonstrated a tokamak operation mode that improves energy confinement or long term plasma retention while avoiding accumulation of impurities. The second is the record breaking performance of the most advanced and recently upgraded stellarator W7-X in Germany, which achieved a long plasma discharge with high energy turnover, thus demonstrating the

> private sector companies in different parts of the world.

possibility of continuously coupling large amounts of energy in the plasma and removing heat in a controlled way. Finally, NIF in the United States of America achieved even greater scientific energy gain in July 2023 than announced last year. Advancements in a different fusion challenge brought a boost to regulatory certainty for the growing fusion industry with the announcement by the United States Nuclear Regulatory Commission that their national fusion regulatory framework will be different from existing nuclear fission power plant regulation.

The IAEA: a hub for fusion research & development

The IAEA has been promoting fusion energy research and development for over 60 years, and it continues to strongly support research and development and future deployment by bringing the fusion community together to create solutions for both scientific and technological challenges. In recent years, the IAEA has increased its fusion activities in a multidisciplinary effort. This includes addressing fusion energy facilities in a holistic manner, integrating best practices and lessons learned from successful fission energy generating plants into efforts to achieve fusion energy production, where applicable. Fusion science research and technology - including plasma and materials sciences, fundamental fusion process data, regulatory frameworks, licensing, nuclear safety, nuclear waste management, nuclear liability issues, and economic aspects of nuclear fusion facilities - span all the IAEA's technical Departments and organizational units. Fusion related programmatic activities in the IAEA are coordinated by its internal cross-cutting Nuclear Fusion Coordination Committee, established in 2019. The International Fusion Research Council and the IAEA's Standing Advisory Groups on Nuclear Energy and on Nuclear Applications provide advice on a range of key activities the IAEA conducts to strengthen international cooperation on fusion research and development and to enhance the present state of the art.

Making fusion energy accessible to all

IAEA support to its Member States in accelerating fusion energy development is delivered using a broad portfolio of tools and processes. This includes providing various fusion related forums such as the biennial Fusion Energy Conference, DEMO Programme Workshops, and periodic consultative and technical meetings and workshops, where experts can exchange knowledge and experience.



billion invested in fusion

The IAEA is stepping up its support to Member States by accelerating the research and development of fusion energy generation to meet



"International collaboration is vital in achieving this grand engineering challenge of the 21st century."

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The IAEA also hosts the Fusion Portal and numerous databases and codes including the Fusion Device Information System; facilitates access to radiation and analytical services through partner organizations and facilities; manages coordinated research projects; delivers education and training activities; and fosters strategic partnerships, often through formal - typically bilateral - cooperation agreements, such as long-standing cooperation with the ITER Organization since its conception and more recently with organizations in the United States of America and China. Last year the IAEA was instrumental in forming Women in Fusion, a non-profit organization aimed at promoting gender parity in the fusion community and establishing a welcoming work environment for everyone. The progress made through these activities is published in IAEA technical documents and publications, in peer reviewed journals, on the Fusion Portal and via social media and outreach channels.

Meeting tomorrow's energy demands



years of promoting fusion energy research and development at the IAEA.

tomorrow's energy demands and mitigate carbon emissions. International collaboration is vital to achieving this grand engineering challenge of the twenty-first century. As an international organization, the IAEA will continue to work together with countries, other organizations and the fast growing fusion industry across the globe to tackle the scientific and technological challenges and help deliver the talent pipeline, nurture the supply chain, establish best knowledge management practices and engage with the public to make fusion energy a reality.

Forthcoming: the IAEA WORLD FUSION OUTLOOK 2023. Scan to find out more.



