

CONFERENCE PRE-PRINT**CONTROLLED NUCLEAR FUSION FOR A SUSTAINABLE FUTURE:
ADVANCING ENERGY, HEALTH, AND INDUSTRY IN ARGENTINA AND
URUGUAY**

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Abstract

Nuclear fusion has emerged as a promising solution to the global energy crisis, offering a perspective of clean, safe, and virtually limitless source of power. While large-scale international projects such as ITER and public and private ventures in the United States and Europe dominate the headlines, regional efforts in South America—particularly in Argentina and Uruguay—are contributing to the advancement of nuclear fusion science and its applications. This paper explores the current state of approaches related to nuclear fusion in both countries, highlighting institutional initiatives, academic programs, research and developments. It also examines the use of fusion-related technologies in medical diagnostics, radiation therapy, and industrial processes. By analysing these regional efforts within the context of global trends, this study underscores the importance of inclusive, collaborative approaches towards achieving fusion energy's full potential.

1. INTRODUCTION

Nuclear fusion—the process of combining atomic nuclei to release energy—has long been heralded as “the holy grail of clean energy”. It certainly could be deemed the most relevant energy source for life since it fires up stars. In terms of artificially made fusion, that definition must be constantly challenged in order to push towards the permanent reduction of the carbon footprint. In 1920 Eddington, at Cambridge, proposed fusion as the source of energy of stars. In 1938 Ruhlig, at Michigan, reported results inferring large cross-sections (at relatively low energies) for DT reaction. In 1943, Baker, Holloway and collaborators, at Purdue, performed experiments to deliberately measure them [1]. It is interesting to note that, in the context of these “fusion” experiments, the word “barn” was coined for the cross-section unit meaning 10^{-24} cm² [2, 3, 4]. Given its large cross-sections at low energies, DT reactions are currently of highest relevance for fast-track energy and neutron production projects. Nevertheless, there is still a diverse family of reactions that, despite their more exigent conditioning, have very interesting features and potential advantages.

Although there are different approaches to fusion science and technology, most experimental achievements in the field of neutronic fusion, such as that from DT reaction, present aspects that should be thoroughly studied. Metallographic and alloy developments, new technologies in high temperature superconductivity, and technologies for the construction and cooling of critical parts of neutron systems are constantly being considered by companies and governments involved in the field. Experimental developments in aneutronic fusion systems and others based on plasma pre-ignition systems enrich the menu of experimental and commercial options, especially in the private sector. All options remain open despite considerations regarding the sustainable production of the initial fuel in the required quantity and the maintenance of its purity during nuclear fusion reactions, which, unlike nuclear fission, are not chain reactions but rather a succession of pulsed ignitions. This ensures the most suitable treatment of the internal walls and blankets, microwave injectors and the necessary

control instrumentation, as well as the design and manufacture of superconducting magnets to optimize costs with proven technologies.

Unlike fission, fusion produces no long-lived radioactive waste and carries no risk of meltdown, making it an attractive alternative to other energy sources once design, engineering and manufacture standards are appropriate. After decades of theoretical development and experimental challenges, the global fusion industry is now experiencing unprecedented momentum, with the appearance of diverse commercial and government actors interested in the topic [5] due to an estimated decrease of hydrocarbon resources, increment of their prospection and exploitation complexity and consequences of the whole carbon footprint. In recent years, private fusion companies and public institutions have raised billions in investment, and major experimental breakthroughs—such as ignition at the National Ignition Facility (NIF) and sustained plasma confinement at China’s EAST tokamak—have validated key scientific principles and accelerated the race towards a future practical implementation and eventually its commercialization [6].

Governments and corporations alike are responding to this surge in optimism. The United Kingdom has committed substantial funding to fusion research, while technological giants have signed historic power purchase agreements with fusion start-ups. Regulatory frameworks are evolving, with countries like the United States developing distinct pathways for fusion reactors that differ from traditional nuclear regulation. According to market forecasts, the global demand for fusion-generated electricity could exceed \$1 trillion by 2050, driven by a projected 79% increase in worldwide energy consumption.

While much of the attention centers on large-scale international projects such as ITER in France or Commonwealth Fusion Systems in the U.S., regional efforts in South America are quietly contributing to the fusion ecosystem. Argentina and Uruguay, though not traditionally viewed as fusion powerhouses, have cultivated scientific communities and technological infrastructures that support nuclear research and its applications. From plasma physics and reactor modeling to medical diagnostics and industrial uses, both countries demonstrate strategic engagement with nuclear-based technologies (depending on fuel cycle types) and particularly with those related to fusion.

This paper examines the current state of nuclear fusion research and application in Argentina and Uruguay, two countries connected by Río Uruguay and Río de la Plata and historical culture. Some of their most neuralgic scientific and technological areas are found within 1000 km (Figs. 1 and 2) what seems logistically advantageous for collaboration development. Specifically, the paper explores institutional initiatives, academic programs, and the integration of fusion-derived technologies in medicine and industry. By situating these regional efforts within the broader global context, the study aims to highlight the importance of inclusive, decentralized contributions to the future of fusion energy.

2. NUCLEAR FUSION ACTIVITY IN ARGENTINA

Argentina has a long and complex history with nuclear science and technology, including early attempts at fusion energy. A milestone was established by renowned physicists Enrique Gaviola and Guido Beck in 1943 when they joined in the Córdoba Astronomical Observatory to launch the founding actions of Argentine nuclear science and technology, including creation of the Argentine Physics Association (1944), fostering integral education-science-technology programs and mentoring future leaders, being José Balseiro one of them [7, 8]. Notable documents from those days are two 1946 local publications on applications of nuclear energy and opportunities for Argentina in the new atomic era [9, 10].



FIG. 1. Maps of Argentina and Uruguay containing the main continental lands. Google Maps, 25 September 2025.

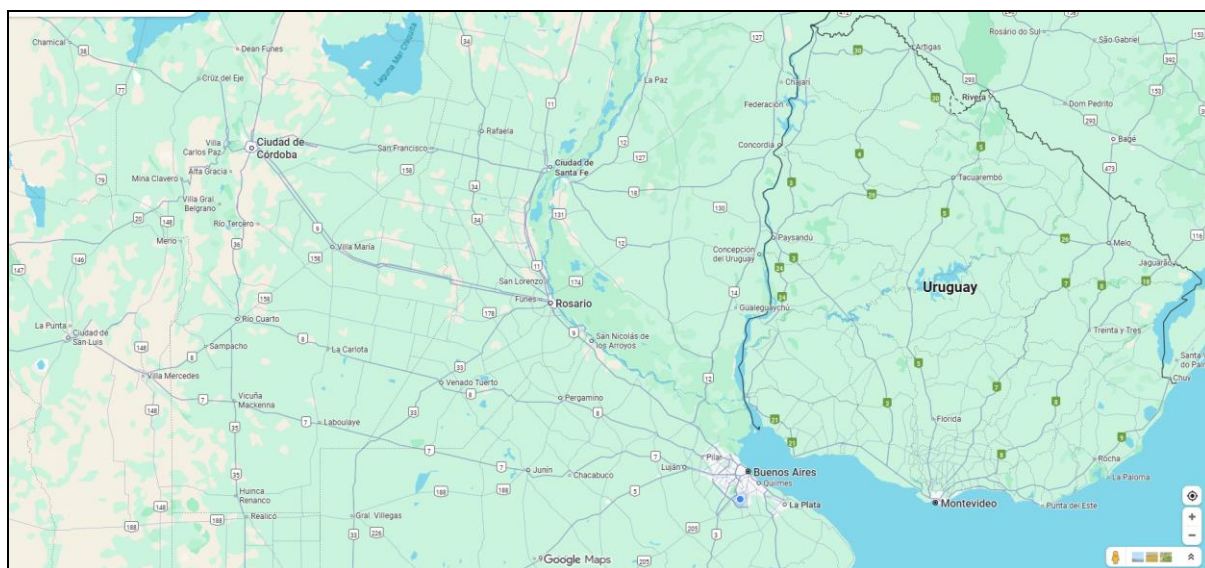


FIG. 2. Maps of Argentina and Uruguay highlighting key urban centers and regional proximity. It provides geographic context for the scientific and industrial activities discussed throughout the paper. Google Maps, 25 September 2025.

Concerning fusion, one of the most notable episodes was the Huemul Project during 1948-1952, which aimed to achieve controlled nuclear fusion on Huemul Island in Patagonia. It was led by Austrian physicist Ronald Richter, with sound support from Argentina's Government and in disagreement with local physics community due to the poorly grounded rationale of the project. Despite initial claims of success in 1951, the project was later discredited and terminated in 1952 following scientific scrutiny and allegations of fraud. José Balseiro was the scientific leader of the commission for investigating the project development. While the Huemul Project failed to deliver viable fusion technology, it marked Argentina's early ambition in the field and triggered a strengthened interest of international researchers in fusion for energy production [8, 11].

Today, Argentina's fusion research is centered in the synergy of two major institutions: National Atomic Energy Commission (CNEA) and National Council of Science and Technology Research (CONICET). This includes CNEA's atomic centers and some laboratories and institutes hosted in and with a series of universities [10, 12]. These centers host advanced research groups working on plasma physics, magnetic confinement, diverse fusion applications and materials science relevant to fusion reactors. There is a local nuclear ecosystem currently driven by fission endeavors or involving them, such research/production and power reactors, which could provide substantial support to fusion development. This includes CNEA, the Nuclear Regulatory Agency (ARN), and a conglomerate of companies like Nucleoeléctrica Argentina (NA-SA) or INVAP.

Argentina also contributes to fusion research through academic programs and international collaboration. Undergraduate and graduate students are trained in nuclear engineering, plasma physics, radiation physics and fusion applications, often participating in joint projects with institutions abroad. Although Argentina does not host a tokamak or stellarator facility, its theoretical and computational contributions are recognized within the Latin American fusion community. Argentina is also exploring the design of hybrid fusion-fission reactors, which combine the advantages of both technologies to enhance energy output and fuel sustainability.

Argentina plays a sustained and strategic role in nuclear fusion research, driven by its nuclear scaffold and strong theoretical foundations, interdisciplinary academic programs, and applied technological development. Despite the absence of large-scale experimental facilities such as tokamaks or stellarators, the country has cultivated a robust ecosystem of plasma physics and fusion-adjacent innovation that positions it as a valuable contributor to both regional and global efforts.

CNEA leads national research in energetic particle dynamics, plasma and particle transport calculations, and magnetic confinement systems and applications. Its teams focus on modeling the interaction of magnetohydrodynamic (MHD) perturbations with suprathermal particles—such as high-energy ions and alpha particles—and on developing control strategies for magnetic and kinetic plasma profiles. These studies are essential for improving reactor stability and confinement efficiency. CNEA, CONICET and Universidad Nacional del Centro de la Provincia de Buenos Aires host the Laboratory for Dense Magnetized Plasmas (PLADEMA) which contributes to the understanding of high-density plasma behavior and its potential applications. Complementing this work, the Institute of Plasma Physics (INFIP)—a joint initiative of the University of Buenos Aires and CONICET—conducts both theoretical and experimental research on laboratory, astrophysical, and space plasmas. INFIP actively participates in national programs such as PIPAD (Dense Plasma Research Program). CNEA also counts on experience related to physical metallurgy of steel for structural components of fusion reactors, materials applicable to hybrid reactors, tritium breeders and lithium compounds, and heavy water production [12].

In addition to energy-focused research, fusion-related technologies have found applications in Argentina's medical and industrial sectors. There are approaches concerning fusion-based neutrons generators for applications in Boron Neutron Capture Therapy (BNCT), a promising treatment for radioresistant tumors [12, 13], and radioisotope production as well as for neutron interrogation for oil and mining industry [12, 14, 15]. These initiatives reflect Argentina's ability to translate fusion science into practical technologies with societal

impact. Techniques derived from plasma physics are also used, for example, in improving of seeds [16]. In general, these spin-off applications demonstrate the broader utility of fusion science beyond power generation.

Academic development plays a central role in sustaining this research landscape. Argentine institutions supervise undergraduate and graduate theses in physics, nuclear engineering, and medical physics engineering, fostering a new generation of fusion scientists. Research teams employ high-performance computing resources, including GPU/CPU clusters and parallel processing systems, to simulate plasma behavior, mixed radiation field distributions and reactor conditions with precision.

Concerning nuclear background that could support fusion developments, it is worth noting the extensive experience developed in areas such as neutronics, nuclear detection, instrumentation and control, mixed-field radiation dosimetry, radioprotection and nuclear safety, special alloys manufacture, and metal-mechanic and electricity industries. In these cases, the scaffold scales range from scientific bench to industry application.

3. NUCLEAR FUSION ACTIVITY IN URUGUAY

Uruguay's relationship with nuclear science is shaped by a unique legal and cultural context. Since the passage of Law 16.832 in 1997 [17], the use of nuclear energy for electricity generation has been explicitly prohibited. However, nuclear technologies—including those related to fusion—are actively employed in medicine, agriculture, and industrial diagnostics. This duality reflects Uruguay's cautious but pragmatic approach to nuclear science: while large-scale energy applications are restricted, scientific research and technological development continue in specialized domains.

Historically, Uruguay operated a small research reactor donated by the United States in 1964 through a tripartite agreement with the International Atomic Energy Agency (IAEA) through the “Atoms for Peace” Program. The reactor was installed at the Centro de Investigaciones Nucleares (CIN) in Montevideo and functioned until 1985, when it was shut down due to corrosion. The reactor's fuel was safely returned to the U.S. under IAEA safeguards in 1998 [18]. Although the reactor is no longer operational, the CIN remains a hub for nuclear-related research, particularly in radiation safety, medical physics, and environmental studies.

In recent years, Uruguay has taken steps to reengage with the global nuclear research community. In October 2024, the country signed a landmark cooperation agreement with the European Organization for Nuclear Research (CERN) [19], one of the world's leading institutions in high-energy physics. This agreement enables Uruguayan scientists, engineers, and students to participate in CERN-led projects, including those related to particle acceleration and plasma behavior—fields that intersect with fusion science. The partnership also opens doors for training and technology transfer, strengthening Uruguay's scientific capacity.

While Uruguay does not currently conduct direct fusion energy research, its involvement in high-energy physics and its use of fusion-adjacent technologies in medicine and industry position it as a potential contributor to regional fusion initiatives. Applications include radiation therapy, imaging techniques, and agricultural studies using isotopic tracing such as in Uruguayan Center for Molecular Imaging (CUDIM) and CIN, respectively. These activities demonstrate Uruguay's commitment to leveraging nuclear science for societal benefit, even within the constraints of its legal framework. Uruguay's stance on nuclear fission energy reflects broader public concerns and historical debates, but its scientific institutions continue to evolve. Through international collaboration and targeted applications, the country maintains a meaningful presence in the nuclear research landscape of Latin America, while the developed world focuses on the growth of figures of nuclear power generation, which became a necessity in front of demands of reliability, safety, continuous generation, life of facilities of up to 60 years, low fuel cost, and negligible carbon footprint in its construction and operation. One can find more than 800 global installations, between land and sea applications, with a significant growth rate in China, South Korea, India, Russian Federation, Eastern European countries, MENA (Middle East and

North Africa), and countries that are reversing their generation policies such as Great Britain, United States of America, Canada, South Africa, Japan, among others.

4. MEDICAL AND INDUSTRIAL APPLICATIONS OF NUCLEAR FUSION

Although nuclear fusion is primarily pursued as a future energy source, its technologies and by-products have found valuable applications in fields such as aeronautics and space defence, space shuttle development, hypersonic vehicles, stockpile control and military design and optimization in medicine and industry [5, 12, 15]. In Argentina and Uruguay, fusion-related innovations are being adapted to address public health challenges, such as in CNEA and CUDIM, improve diagnostic capabilities, and enhance industrial processes.

Argentina has made significant strides in applying fusion-derived technologies to medical treatment. The National Atomic Energy Commission (CNEA) has developed approaches of neutron irradiation facilities based on controlled nuclear fusion for use in Boron Neutron Capture Therapy (BNCT) —a cutting-edge cancer treatment that targets infiltrative and radioresistant tumours. BNCT offers a highly selective alternative to conventional radiotherapy, especially for tumours that are difficult to treat with photon or proton beams [13]. This type of facilities is intended for in-hospital use. One of the approaches is based on neutron generators which would allow for building a thermal-column like facility enabling localized neutron irradiation of explanted organs and tissues [20]. Another approach is considering a compact accelerator-based neutron source for building an external beam BNCT facility [21]. For this case, the approach considers one of the low energy prototypes of devices developed in the Accelerator Technology Laboratory, which includes “Accelerators for Life” program and is pioneering the development of particle accelerators for BNCT [13, 15]. These devices are entirely designed and manufactured in Argentina, with one modular accelerator already installed and another exported to South Korea’s KIRAMS institute. This family of devices and facilities are also consider for small scale radioisotope production [5, 12].

For and beyond oncology, fusion-based neutron sources are being explored for: radiopharmaceutical production for diagnostic imaging and therapy, e.g. utilizing reactions like (n,g) or $(n,2n)$; interdisciplinary engagement; neutron interrogation for material characterization, e.g. through neutron scattering and/or activation analysis [12, 22]. These applications demonstrate Argentina’s capacity to translate fusion science into practical industrial and healthcare solutions.

Uruguay, despite its legal prohibition on nuclear power generation, actively employs nuclear technologies in medicine and environmental safety. The CUDIM produces radiopharmaceuticals used in the diagnosis and treatment of diseases such as prostate cancer and neurodegenerative disorders [23]. With support from the IAEA, Uruguay has acquired isotopes like Lutetium-177 for advanced nuclear medicine and produced in research, contribute to public safety and environmental stewardship. While Uruguay does not currently utilize fusion-specific technologies, its infrastructure and expertise in nuclear medicine and radiological safety position it to benefit from future fusion innovations.

5. CHALLENGES AND OPPORTUNITIES

Despite growing global interest in nuclear fusion, countries like Argentina and Uruguay face distinct challenges in advancing fusion-related research and applications. Both nations also present unique opportunities to contribute meaningfully to the fusion ecosystem through specialized expertise, international partnerships, and strategic applications in medicine and industry. Technological developed areas of both countries are geographically accessible to each other, both share cultural and fraternal roots with frequent migration and commuting in between both countries. This fact represents an important logistical asset which already benefits binational groups working on nuclear medicine and BNCT radiobiology approaches.

Argentina's main challenge lies in scaling its theoretical and computational research into experimental platforms. The absence of a domestic tokamak or stellarator limits hands-on development. Nevertheless, Argentina's legacy in nuclear science, its skilled workforce, and its leadership in medical applications like BNCT or radioisotope production position it as a regional innovator. The country's ability to design and export compact particle accelerators demonstrates its potential to contribute niche technologies to the global fusion supply chain.

Category	Argentina	Uruguay
Scientific Research	Active programs in plasma physics, reactor modeling, and neutron interactions.	Emerging interest in plasma studies and theoretical modeling.
Human Resources	Specialized training programs; fusion topics integrated into university curricula; participation in international networks.	Growing academic engagement; early-stage training and outreach initiatives.
Medical Applications	Use of nuclear technologies in diagnostics and radiotherapy; potential synergies with fusion-based isotopes.	Applications in medical imaging and diagnostics; exploring fusion-related potential.
Industrial Applications	Collaboration with nuclear, metallurgy, and electronics sectors; development of support infrastructure for fusion tech.	Initial links with energy and electronics industries; interest in scalable technologies.

TABLE 1. COMPARATIVE DATA ARGENTINA and URUGUAY IN NUCLEAR FUSION.

On the other hand, Uruguay's legal prohibition on nuclear power generation presents a structural barrier to direct fusion energy development. However, the country has embraced nuclear technologies in medicine, environmental monitoring, and high-energy physics. Its recent agreement with CERN opens new pathways for collaboration, training, and access to fusion-adjacent research. Its opportunity lies in becoming a hub for fusion related diagnostics, radiological safety, and scientific diplomacy.

Global fusion development is currently going through a window of opportunities: science and technology is advancing and beginning to provide revolutionary breakthroughs while fusion community is still relatively open to share and cooperate. It is difficult to think this window will remain open after large projects get commercially established.

Oil industry activity is currently very active in South America. Argentina particularly has a convergence centre for national and international oil companies in the Vaca Muerta oil field, which is attracting considerable investments and producing even larger profits. Although main focus is now oil, these energy-based hubs are sensitive to fusion new developments as can be seen, for example, in the list of investors of the Fusion Industry Association.

6. CONCLUSIONS

As global efforts to develop nuclear fusion intensify, the contributions of smaller nations and regional actors are becoming increasingly significant. Argentina and Uruguay—despite differing legal frameworks and infrastructure—demonstrate strategic engagement with fusion-related science and technology. Argentina's deep-rooted expertise in nuclear research, combined with its pioneering medical applications such as Boron Neutron

Capture Therapy (BNCT), positions it as a regional leader in fusion-adjacent innovation. Uruguay, while legally restricted from nuclear power generation, has built a strong presence in diagnostics, radiological safety, and international collaboration, notably through its agreement with CERN.

Both countries face challenges: limited funding, absence of medium /large-scale experimental facilities, and the need for sustained policy support. Yet these constraints are offset by opportunities for specialization, export of niche technologies, and integration into global research networks. Their efforts affirm a broader truth: the future of fusion energy will not be shaped solely by megaprojects and global powers, but also by decentralized innovation, interdisciplinary applications, and inclusive scientific cooperation.

To advance fusion-related science and technology, Argentina and Uruguay can pursue a series of strategic measures:

- **Political and Institutional Commitment** Embed fusion-related activities into national science and technology agendas, and strengthen institutional support for emerging initiatives.
- **Human Capital Development** Train professionals and technicians, integrate fusion topics into academic curricula, promote outreach, and assess long-term human resource needs.
- **Focused Research Agenda** Prioritize high-impact areas such as energy generation, medical and industrial applications, neutron interaction studies, tritium breeding systems, advanced detection and control technologies, compact fusion designs, and fuel injection in high-temperature plasmas.
- **Leveraging Infrastructure and International Partnerships** Utilize Argentina's established nuclear sector and Uruguay's collaborative platforms to engage with global institutions like the IAEA, fostering scientific, technological, and financial cooperation.
- **Deployment of Accessible Fusion Devices** Promote the installation of versatile, cost-effective fusion systems tailored for diagnostics, education, and applied research.
- **Industry Integration and Support Infrastructure** Adapt laboratories and build links with nuclear, energy, metallurgy, electrical, and electronics industries, strengthening the supply chain as both users and providers.
- **Public Engagement and Communication** Despite the absence of specialized media on fusion, Argentina and Uruguay are working to raise public awareness through active information exchange. This initiative fosters dialogue among institutions, policymakers, and society, bridging communication gaps and reinforcing the strategic relevance of fusion technologies.

By examining the fusion landscape in Argentina and Uruguay, this paper highlights the importance of regional contributions in shaping a diverse and resilient global fusion ecosystem

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