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Proposal for a global licensing and regulation framework for fusion energy

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ABSTRACT

If fusion energy is commercialized and deployed by 2040 and then scaled up quickly, it has the potential to significantly mitigate the effects of climate change and meet the growing global energy demand. One of the key factors in the speed of deployment is the licensing and regulatory framework, which can accelerate or impede deployment. Fortunately, this is a factor that can be addressed well in advance, but the time to do so is now. In fact, the United States, Germany, Japan, and the United Kingdom have realized this and are planning to regulate fusion power plants differently from fission power plants, outside of nuclear law. As is the case in other areas of licensing and regulation, this process will begin with national frameworks and progress through a phase of harmonization, potentially culminating in a global framework. However, if the destination is clear, why take the long way around? This paper argues for starting with a global licensing and regulation framework for fusion energy now. It shows examples from other fields that demonstrate the feasibility of this approach and develops a seven-step plan for such a framework.

1. Introduction

If fusion energy is commercialized and deployed by 2040 and then scaled up quickly, it has the potential to significantly mitigate the effects of climate change and meet the growing global energy demand. One of the key factors in the speed of deployment is the licensing and regulatory framework, which can accelerate or impede deployment.

The official U.S. Fusion Energy Strategy [1] aims to build a fusion pilot plant in the 2030s and scale up to commercial production in the 2040s. Japan's official policy is to demonstrate fusion-powered electricity generation in the 2030s. The 2025 edition of the Fusion Industry Association survey found that 38 out of 45 private companies expect to deliver electricity to the grid from fusion in the 2030s. Not only do the involved companies expect the first fusion power plant to produce electricity in the 2030s, but it is also government policy and is backed by contracts, such as the recent agreement between Commonwealth Fusion Systems and the state of Virginia.

Fusion power plant designs based on magnetic confinement share essential components with particle accelerators. These designs include superconducting magnets with high magnetic fields, radio-frequency acceleration or heating structures, vacuum vessels, and cryogenics. However, they do not include the essential components of nuclear fission reactors; notably, they do not contain any fissile material. Laser-based fusion power plant designs do not create particle beams; they only create radiation as part of the fusion reaction. Regulating fusion power plants like fission power plants only demonstrates helplessness in the face of something new. A more plausible approach would be to use particle accelerators and large laser installations as a starting point.

By now, most major economies have established programmes to support the development of fusion energy. Recent programmes have been set up through public-private partnerships in the US, Germany, Japan and the UK. It is expected that North America and Europe will require more energy over the next few decades. The advent of AI alone will increase energy demand. So too will the need for air conditioning in areas where this was not previously commonplace. However, a much larger increase in energy demand is expected in China, India and the developing world in general. Currently, none of the countries in Africa, Latin America or South East Asia (except India) have access to fusion technology. To meet growing electricity demand and socio-economic development aspirations while mitigating climate change emissions, fusion energy should be deployed quickly and on a large scale in these countries. This will only be possible if the developing world is offered

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more than just the sale of fusion power plants; it must also be supported with licensing and regulation. In our post-colonial, multipolar world, this requires the developing world to be included in the process from the outset.

This paper argues for the establishment of a Global Licensing and Regulation Framework for Fusion Energy. It provides examples from other fields to demonstrate the feasibility of this approach and sets out a seven-point plan for such a framework. Key components of the plan include the establishment of a Global Organisation for Fusion Energy (GOFE), a core agreement alongside a global network of agreements, a global regulator, and global safeguards. This is not the 'natural' way in which such a framework would develop, starting with national frameworks and progressing through a process of international harmonisation. In a world heading towards a climate crisis, this process would be too slow. The paper presents the seven-point plan and demonstrates how the different elements work together to accelerate the global deployment of fusion energy.

2. Current approaches to licensing and regulation

All countries currently developing fusion power plants realise that licensing and regulatory frameworks are required for them to be legally built and operated. While this is a new area of regulation, decades of research and research installations have paved the way. Therefore, reference points for a regulatory framework are available. Most private fusion companies are based in the US, with others in the UK, Germany and other EU countries, as well as Japan. In addition, China has a substantial fusion programme focused on developing fusion technology. The following overview will therefore focus on these six countries.

In the United States, the US Nuclear Regulatory Commission (US NRC) has jurisdiction over commercial fusion devices. This decision was made in 2009. In 2018, the US Congress passed the Nuclear Energy Innovation and Modernization Act (NEIMA), requiring the NRC to develop and implement the regulatory framework necessary for advanced reactors, including fusion power plants, by the end of 2027. Since 2020, frameworks for fusion and advanced fission reactors have been developed separately. In January 2023, the NRC published a paper recommending an approach that would result in fusion regulation in the US being based on Title 10 of the Code of Federal Regulations (10 CFR), specifically Part 30: 'Rules of General Applicability to Domestic Licensing of Byproduct Material'. The NRC is currently developing a new volume of NUREG-1556, 'Consolidated Guidance About Materials Licences', dedicated to fusion systems, which is expected to be published by 2025. This process clearly shows that the US is focusing primarily on the radioactive materials used in, and produced as by-products of, fusion power plants. This approach is based on existing regulations and will remain separate from the regulation of advanced fission reactors. The process is progressing swiftly, in line with the timelines of US private fusion companies.

In 2021, the UK published its first fusion strategy, together with proposals for a regulatory framework for fusion energy [2]. This framework's key approach is to regulate fusion as a radioactive substance activity, with the Environment Agency (EA) and the Health and Safety Executive (HSE) responsible for regulating fusion facilities. Fusion plants would not require a nuclear site licence, nor would they be regulated by the Office for Nuclear Regulation (ONR). Item 156 of the UK Energy Act 2023 states that “the restriction of certain nuclear installations to licensed sites does not apply to a fusion energy facility”. The Act came into force in October 2023, making the UK the first country where fusion technology is not officially regulated in the same way as nuclear fission.

In China, the Ministry of Ecology and Environment (MEE) is responsible for the management and licensing of fusion experimental devices. The relevant legislation is the Law on the Prevention and Control of Radioactive Pollution (Decree No 6 of the President of the People's Republic of China) and the State Council's Regulations on the Safety and Protection of Radioisotopes and Radiation-Emitting Devices (Decree No 449). Classification is carried out on a case-by-case basis, with most fusion devices falling within Category III of radiation-emitting devices. The MEE is currently developing a regulatory pathway for fusion power plants, but this is less advanced than those in the UK and US. However, it seems that they favour treating fusion power plants similarly to high-power proton accelerators.

Japan also appears to be following a similar approach to the US and the UK. The Japan Fusion Energy Council, 'J-Fusion', recently published a white paper recommending the application of the Radiation Hazards Prevention Law (RI Law) to fusion machines instead of the Act governing fission reactors [3].

A recent German government paper on fusion [4] suggests a unified European framework but does not specify what this should look like, while the recent coalition contract of the current German government coalition simply states that fusion will be regulated 'outside of nuclear law' [5].

The fusion landscape in the European Union is complex. Both the Directorate-General for Research and Innovation (DG RTD) and the Directorate-General for Energy (DG ENER) are involved, as are national governments. In 2021, DG ENER commissioned a study focusing on magnetic confinement tritium fusion devices [6]. More recently, in 2024, a EUROfusion working group published a paper entitled 'Recommendations for the Future Regulation of Fusion Power Plants' [7]. Both documents are written in the context of the official European Fusion Roadmap [8] and thus focus on ITER and DEMO. The recommendations are based on the safety principles developed by the International Atomic Energy Agency (IAEA) for nuclear fission power plants. The recommendations do not propose following the examples of the US and the UK. Nor do they take into account the recent development of private fusion companies. The fact that the EU has a strong investment in ITER, which has been licensed as a nuclear installation in France, further complicates the issue. Creating a European regulator for fusion power plants would elegantly sidestep possible conflicts between France, Germany, and other EU countries.

3. The case for regulating fusion power plants like particle accelerators

In a nuclear fission reactor, heavy nuclei split into two smaller nuclei, releasing energy in the form of heat and radiation, as well as one or more neutrons. These neutrons can then split other nuclei, releasing more neutrons, and so on. This process, known as a 'chain reaction', is fundamental to the operation of a fission reactor. If the reaction is not controlled, however, it can lead to a catastrophic meltdown or even an explosion, usually due to the build-up of hydrogen. The combination of large quantities of fissile radioactive material, the associated proliferation risk and high levels of radiation during and after operation are the basis for the strict regulation and licensing of nuclear fission reactors around the world.

A fusion power plant based on magnetic confinement typically comprises strong magnets, radiofrequency electromagnetic wave emitters, cryogenics and large-volume vacuum vessels. Inertial confinement designs typically incorporate high-power lasers. Fusion power plants do not include any fissile material and do not undergo a chain reaction. Metaphorically speaking, in a 'fission car', you have to keep your foot on the brake at all times, whereas in a 'fusion car', you have to keep your foot on the accelerator; otherwise, the car stops. A fusion reactor's start-up tritium inventory is of the order of a few kg, whereas a typical fission reactor has a uranium inventory of around 100 tonnes, 3–5 tonnes of which is ^{235}U

The key components of magnetic confinement fusion power plant designs are in fact the same as those of a modern particle accelerator. Therefore, particle accelerators rather than fission power plants are the natural starting point for the regulation and licensing of fusion power plants.

The most frequent argument against this view is that neutrons from a fusion plant can be used to produce fissile material, particularly ^{239}Pu and ^{233}U This has been recognised for a long time [9], and applies in the same way to any other neutron source, e.g. high-power proton accelerators [10]. The existence of such a proliferation risk means that some kind of safeguards inspections will likely be required, although these may differ from those for fission reactors. Currently, high-power accelerators are not subject to any non-proliferation regulations or safeguards. Proliferation risks and the corresponding safeguards procedures could be developed and tested using blanket modules at ITER [11].

4. An example of international licensing and regulation

Ideally, an example of international licensing and regulation comparable to fusion power plants would be a technology of similar cost and complexity. Although there are no international standards for coal or gas power plants, there are ISO standards for gas turbines (ISO 21,789:2022), which are a central part of gas power plants. Ultimately, ISO standards for fusion power plant components will likely emerge.

Another area to consider is the global aircraft industry. Large passenger aircraft cost about one-third to one-tenth as much as small fusion power plants will cost, and their designs are similarly complex. The global aircraft industry produces about 1400 large passenger jets per year and is similar in size to what the fusion power plant industry will become.

Licensing and regulation of large passenger aircraft began with national authorities. The United Kingdom introduced early aviation safety regulations with the Aerial Navigation Act of 1911 and the British Air Navigation Regulations of 1919, marking the beginning of European national aircraft licensing and regulatory efforts. A harmonization and centralization process then took place in Europe, starting with the European Civil Aviation Conference (ECAC) in 1955, continuing with the Joint Airworthiness Authorities (JAA) in 1970, and culminating in the creation of the European Union Aviation Safety Agency (EASA), which became fully operational in 2008. In 2011, the US and the EU signed the Agreement on Cooperation in the Regulation of Civil Aviation Safety [12], which effectively establishes a global licensing process for aircraft. As early as 1944, the International Civil Aviation Organisation (ICAO) was formed as a United Nations Agency. ICAO develops policies and standards and builds capacity, but it does not act as a global licensing and regulatory authority. In principle, the U.S. and the E.U. could combine their agreement with the ICAO and add an opt-in process for licensing aircraft in ICAO member states. This would establish a global licensing and regulatory framework for large civil aircraft. Overall, $>$100 years will have passed from the first national regulation to the global regulatory framework.

If the licensing and regulation of fusion power plants follows a similar path to that of the aircraft industry, it will start with national legislation and regulatory bodies, conferences to promote harmonisation, and an international agency to support the development of regulatory expertise and capacity. Ultimately, the national regulatory agencies of countries manufacturing the majority of fusion power plants may reach an agreement similar to that between the EU and US regarding commercial passenger aircraft. However, this harmonisation process will take longer than it will take for the first commercial fusion power plants to reach the market. In such a scenario, many potential buyers and operators of fusion power plants, particularly those likely to build most of them over the next few decades, will not be ready to licence and regulate them. While these countries would still build the power plants they need, they would predominantly be fossil fuel based. Consequently, the absence of adequate licensing and regulatory capacity for fusion power plants would directly contribute to increased greenhouse gas emissions and exacerbate the climate crisis.

To have the greatest positive impact on meeting growing energy demand and mitigating climate change, large-scale deployment of fusion energy should take place as soon as possible. Therefore, we propose turning this process on its head and starting immediately with an international regulatory approach. If the destination is known, why take the long road to get there, especially when time is of the essence?

From a rapid deployment perspective, a single global licensing and regulatory authority would be ideal. However, in a multipolar world, the next best thing is an international agency with some global mandates and simple opt-in mechanisms, which is also easier to implement. This proposal for international licensing and regulation draws inspiration from a 2020 policy brief on nuclear energy for the G20 [13] and the US NRC Agreement State Programme.

5. 7-Point plan for a global framework

The following infographic and accompanying text outline our proposal for a seven-point plan to establish a global licensing and regulatory framework for fusion energy. The plan aims to accelerate the global deployment of fusion energy by creating a framework that encompasses all future plant designs and operators, as well as manufacturers. This framework would eliminate regulation as a factor delaying deployment, while providing safety through safeguards and encouraging public involvement through outreach.

The visualisation shows the Global Organisation for Fusion Energy (GOFE) at the centre, with the other points representing its tasks. This structure can therefore be mapped directly onto the GOFE's departmental structure (Fig. 1).

5.1. Global organisation for fusion energy (GOFE)

The GOFE will include governmental representation from all countries of origin of the manufacturers, actual and potential operator countries, and the fusion industry. GOFE can either be a new international organisation or an existing organisation can take on the GOFE role. Some organisational options are outlined below. New international organisations are usually established when there is a need for them and a host government is willing to support them. Recent examples include the International Renewable Energy Agency (IRENA) in Abu Dhabi in 2010 and Sustainable Energy for All (SE4ALL) in Vienna in 2011.

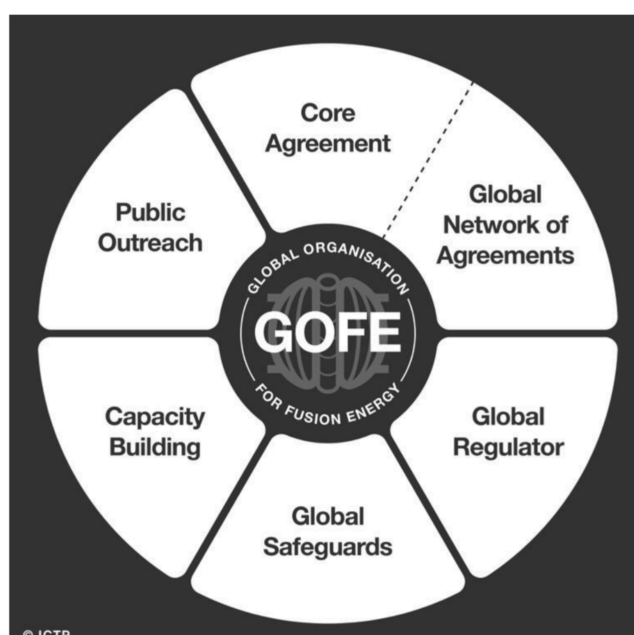

Fig. 1. 7-Point plan for a global framework.

5.2. Core agreement

International organisations are often established to implement specific international agreements. In the case of the GOFE, the initial agreement will be a core agreement on the reciprocal acceptance of certification for fusion power plants. This initial agreement could be between the US, the EU and the UK, with Canada and China potentially included. Other manufacturing countries could then join this agreement as their fusion designs approach commercial feasibility.

As with other international organisations, this core agreement will lead to the formation of the GOFE in a similar way to how the Comprehensive Nuclear-Test-Ban Treaty led to the formation of the CTBTO. The GOFE will comprise the secretariat of the core agreement.

5.3. Global network of agreements

Any GOFE member that is, or plans to become, an operator country can unilaterally join the Core Agreement by accepting the licensing of all members of the Core Agreement. Additionally, any operator country can have licensing agreements with individual manufacturing countries. However, the GOFE will monitor all such agreements and act as their repository. Over time, these networks will merge into a single network of agreements.

GOFE membership should not be limited to manufacturer and operator countries but should be open to all countries. However, the level of representation and access to GOFE services will depend on the agreements

5.4. Global regulator

The GOFE will act as a global regulator for fusion facilities, particularly fusion power plants, on an opt-in basis. Unlike international organisations in other fields, such as aviation, this means that countries without their own regulator can outsource the regulation of fusion power plants to the GOFE. This is important because it will enable countries to deploy fusion plants immediately while they are still developing their domestic regulatory capacity. In other words, a lack of regulatory capacity will not delay the deployment of fusion energy.

Once a country has developed its own regulatory capacity, it can opt out of the GOFE's regulatory function. However, its regulatory standards should continue to align with those of the GOFE. Indeed, it would be simpler and more coherent if the GOFE were to continue acting as the global regulator for all fusion facilities.

5.5. Global safeguards

The GOFE acts as a global safeguards inspector for fusion power plants and facilities to ensure that no undeclared fissile material is produced. This should be a necessary condition for becoming a GOFE Member, not an optional extra.

However, safeguards for fusion power plants will differ from those for fission power plants because material that can be bred into fissionable material is not part of their regular fuel cycle, and tritium is not currently subject to safeguards. Research into safeguards for fusion energy that are distinct from those for fission should form part of the GOFE's initial mandate.

5.6. Capacity building

The GOFE will be mandated to assist all Member States without domestic fusion capacities in developing and building them. In the case of developing countries, this should be funded through a Fusion Capacity Building Fund managed by the GOFE and funded by fusion-manufacturing countries and industry.

Capacity building for fusion energy should include a peacebuilding component, for which the GOFE could cooperate with other organisations, such as the Pugwash Conferences on Science and World Affairs (https://pugwash.org).

5.7. Public outreach

As a new technology, fusion is not yet well understood by the public. It is therefore vital to raise awareness and communicate effectively, in order to avoid the acceptance issues encountered with nuclear fission. The GOFE will therefore also be responsible for public outreach.

Public opinion is an important factor in the deployment of new technologies and should not be underestimated. The social acceptance of fusion energy has already been the subject of studies [14–16], albeit mostly at the level of individual countries. The GOFE's public outreach activities can build on this research. GOFE's remit would be not only to inform the global public, but also to create positive images and memes for fusion energy. Examples could include an 'International Year of Fusion Energy' and a 'dome of light' on a fusion power plant that illuminates when the plant produces electricity from fusion. Currently, a positive vision of the future is gaining momentum under the banner of 'Abundance' [17], and this could be capitalised on.

6. Organisational options for realising the global framework

The International Atomic Energy Agency (IAEA) in Vienna is the most obvious candidate to take over the role of GOFE. The IAEA already has an established fusion programme, publishes the leading journal Nuclear Fusion and organises the largest conferences in the field: the Fusion Energy Conference series. Almost all countries are already IAEA Member States. The IAEA has begun to expand its fusion activities and published its first World Fusion Outlook in 2023. However, fusion energy has not yet been recognised in the IAEA's organisational structure, with its activities spread across several departments. Point 5, Global Safeguards, would clearly benefit from the IAEA's existing expertise. The biggest challenge for the IAEA in taking on the role of the GOFE could be cultural resistance to fusion from nuclear fission organisations, companies, and individuals. While this could make this option more difficult than establishing a new organisation, it could also be overcome politically through pressure from the Member States.

The second obvious candidate is the ITER Organisation. It already includes almost all of the countries that could potentially manufacture it: the USA, Russia, the EU, China, Japan, South Korea and India. Initial negotiations on the core agreement could take place within ITER, taking advantage of its limited membership, before opening it up more widely. However, ITER has traditionally focused solely on the construction of the ITER reactor, and the ITER Organisation lacks a straightforward process for admitting new members. This would need to change, as would the size of the ITER Organisation's secretariat. The projected timetable for DT fusion at ITER now exceeds the likely timeframe for the success of a prototype fusion power plant elsewhere. This also suggests that shifting the focus of the ITER Organisation could be appealing to the Organisation and its Member States. In such a scenario, the ITER reactor itself could play an important role in training scientists from developing countries. Indeed, shifting the ITER Organisation's focus to include developing countries could establish it as the main organisational vehicle for fusion training and outreach in the developing world.

Another approach to establishing a global focal point for fusion energy would be to set up a Global Commission backed by the International Energy Agency (IEA) [18]. Such a commission could be a practical first step towards establishing a GOFE as a new organisation, particularly if neither the IAEA nor ITER are interested in taking on the role.

7. Conclusion

Fusion energy is set to become a reality soon. The most recent timelines suggest that fusion-generated electricity will be available in the 2030s. That's only around 10 years away! As a clean, dispatchable energy source, fusion could help mitigate the climate crisis. For fusion to play this role, it is crucial to overcome remaining technical hurdles and remove regulatory barriers that could delay deployment — or better yet, prevent these barriers from arising in the first place.

The establishment of an international licensing and regulatory framework, along with a Global Organization for Fusion Energy, could facilitate this process. We acknowledge that our proposal deviates from the traditional approach of developing regulations and licensing agreements. However, the typical approach may not be the most appropriate one.

Glossary

ARC The ARC fusion reactor (affordable, robust, compact) is a compact fusion reactor developed by the Massachusetts Institute of Technology (MIT)
UNFCCC United Nations Framework Convention on Climate Change
BEIS United Kingdom Department for Business, Energy and Industrial Strategy, until 2023
DESNZ United Kingdom Department for Energy Security and Net Zero, since 2023
D-T Fusion Deuterium-Tritium Fusion
EASA European Union Aviation Safety Agency
FAA United States Federal Aviation Administration
GOFE Global Organisation for Fusion Energy
IAEA International Atomic Energy Agency
ICAO International Civil Aviation Organization
IPCC Intergovernmental Panel on Climate Change
IRENA International Renewable Energy Agency
ITER International Thermonuclear Experimental Reactor
JAA Joint Airworthiness Authorities
Lawson criterionFigure of merit used in fusion research that compares the rate of Figure of merit used in fusion research that compares the rate ofenergy being generated by fusion reactions within the fusion fuel to the rate of energy losses to the environment.
MWh Megawatt-hour – an amount of energy that corresponds to a power output of one million Watts for one hour
SE4ALL Sustainable Energy for All

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CRediT authorship contribution statement

Ralf B. Kaiser: Writing – original draft, Methodology, Conceptualization. **H.-Holger Rogner:** Writing – review & editing, Validation. **Adnan Shihab-Eldin:** Writing – review & editing, Supervision, Conceptualization. **Sehila M. Gonzalez de Vicente:** Writing – review & editing, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ralf B. Kaiser reports a relationship with Renaissance Fusion SAS that includes: board membership. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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