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Global Licensing and Regulation Framework to accelerate the development and deployment of fusion energy

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ABSTRACT

Fusion energy, the energy that powers the stars, is now almost within our grasp. Most recent timelines agree on the second half of the 2030s for the realisation of a Fusion Energy pilot plant. For this clean, virtually carbon-neutral energy source to contribute to the mitigation of the climate crisis and contribute to meeting the growing energy demand, fusion energy will have to be deployed quickly – more quickly than was the case for solar and wind power. There are numerous factors that have to be considered, but licensing and regulation is a key factor. This paper introduces the basic facts on fusion energy, makes the case for an International Licensing and Regulation Framework for Fusion Energy, shows examples from other fields that demonstrate that this is feasible and develops a 7-point plan for such a framework. In technical aspects the paper focuses on magnetic confinement fusion, but the general aspects and the 7-point plan apply to fusion energy in general.

1. Introduction

On December 5th, 2023, at the COP28 conference in Dubai, US special envoy John Kerry announced that “We are edging ever-closer to a fusion-powered reality.” Fusion energy is not yet here, but we can already see that it will be soon. The new official US Fusion Energy Strategy [1] is to ‘realize a commercially relevant, private sector-led fusion pilot plant in the 2030s, followed by commercial fusion deployment scale-up throughout the 2040s’. A recent report by the US Commission on the Scaling of Fusion Energy explicitly calls for the operation of fusion power plants in the US by the early 2030s [2]. In Germany, the coalition contract of the new government states the goal of building the first fusion plant worldwide in Germany [3]. Japan has revised its policy in 2024 to include power generation demonstration from fusion in the 2030s. A survey by the Fusion Industry Association indicated that 26 of the 37 private fusion companies surveyed believe that the first fusion plant will start delivering electricity to the grid by 2035 [4]. In fact, one company, Helion Energy in Everett, Washington State, announced a power purchase agreement with Microsoft in May 2023 that targets the delivery of 50 MW of electrical power by 2029 [5]. Most recently, Commonwealth Fusion Systems announced an agreement with Dominion Energy Virginia to build its ARC fusion power plant in Virginia in the early 2030s [6].

Researchers from fusion laboratories frequently state longer timelines for the commercialization of fusion than private companies, emphasising the technological challenges that still have to be overcome. However, considering that each group of experts may have secondary motives, like investment into their companies or continued relevance of their research facilities, the timelines in the US Fusion Energy Strategy offer a reasonable baseline for expectation. We will therefore use the second half of the 2030s, i.e. 10–15 years from now, as the feasible timeline for the first fusion pilot plant to produce electricity.

The Paris Agreement on Climate Action [7] has established the objective of limiting the increase in global temperature from anthropogenic emissions to 1.5 °C. The extrapolation of current trends by the International Panel on Climate Change (IPCC) indicates that greenhouse gas (GHG) emissions must be reduced to net-zero by 2050 to reach this goal [8]. This sets the timeframe for meaningful intervention. To achieve this objective a technology must be deployed at scale well before 2050. Time is of the essence. Beyond the 2050 timeline of the Paris Agreement, it is clear that socio-economic development and growth will continue, which requires a significant increase in energy demand, and the

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sustainability paradigm requires sustainable energy.

There are many factors that contribute to how quickly a new technology can be introduced and scaled up: technology readiness, public policy, the availability of funding, the workforce, the competitiveness of the technology, public perception, the availability of materials, the existence of a supply chain and the legal and organisational framework of licensing and regulation – all of these factors matter, and any one of them can impede the development progress. This paper will focus on the role of licensing and regulation of fusion energy in accelerating its global market entry.

All major economies have established programmes to support the development of fusion energy. Recent public-private partnerships have been set up in the US, Germany, Japan and the UK. However, with the exception of China and India, none of the developing countries, where significant growth in energy use is projected in the coming decades, have any access to fusion technology. This is a paramount factor that must be addressed for the fast global deployment of fusion energy.

This paper does not attempt to provide a comprehensive roadmap covering all aspects of introducing fusion technology as a major energy source. Instead, following a very brief introduction to basic concepts in fusion science and technology, it focuses on licensing and regulation and presents a proposal for a global approach to accelerate the development and deployment of fusion energy. This approach is based on international structures and agreements that also takes the needs and requirements of developing countries into account.

2. Fusion energy

In a fusion reaction two light atomic nuclei, such as hydrogen, combine to one heavier nucleus, sometimes producing neutrons in the reaction at the same time. The new, heavier nucleus has a slightly lower mass than the sum of the two original light nuclei. Fusion is the opposite reaction to nuclear fission. In a fission reaction a heavy atomic nucleus, like uranium, is split into two, also producing neutrons at the same time. These neutrons lead to new fission reactions, and a chain reaction is the result. In this case the resulting fragments have less mass than the original nucleus. In both cases the difference in mass is transformed into energy according to Einstein's formula $E = mc^2$. The factor c^2 is very large, the square of the speed of light, and therefore the resulting energy is very large. The resulting energies are truly vast: for each kilogram of fuel, fusion and fission produce millions of times more energy than fossil fuels.

Fusion reactions power the stars and also our sun. The mass of the sun is approximately 333,000 times that of the Earth. The gravity of this enormous mass preserves the sun's integrity and compresses the light elements that constitute the sun, primarily hydrogen and helium, to incredibly high densities and temperatures. These conditions enable continuous fusion reactions to take place. To utilize fusion energy on Earth, such an extreme environment needs to be confined to the size of a power plant. Fortunately, electromagnetism is a much stronger force than gravity, and therefore electromagnetic fields can be used instead of gravity to confine the fusion reactions.

The viability of an ongoing fusion reaction is determined by the so-called triple product of density, temperature and confinement time. If this product exceeds a certain limit, the so-called Lawson criterion, a fusion reaction can 'burn' continuously. Most fusion experiments and power plant designs utilize a plasma, i.e. a fully ionised gas with a density below that of our atmosphere. Consequently, the temperatures have to exceed those at the centre of the sun to meet the Lawson criterion. Different fusion reactions have different Lawson criteria. The deuterium-tritium (DT) fusion reaction has the lowest Lawson criterion and is therefore the preferred reaction for many fusion power plant designs. Other reactions include D-D fusion which has no fuel issue and proton-Boron (p-B) fusion, which produces no neutrons. While the majority of current private fusion companies are pursuing D-T fusion, some companies pursue different approaches: Helion Energy is planning to utilize a combination of D-D and D-3He, while TAE Technologies (formerly Tri Alpha Energy) is planning to apply p-B fusion.

Fusion power plant designs are about different approaches to reach the Lawson criterion by confining a plasma that is hot enough and dense enough for a sufficiently long enough time. Most designs fall into one of three categories – magnetic, inertial or magneto-inertial. The most common magnetic confinement designs are toroidal, i.e., Tokamak or Stellarator configurations. The most common inertial confinement setups use high power lasers to compress a small pellet of fusion fuel, while magneto-inertial setups use a combination of magnetic fields and other compression techniques. A comprehensive taxonomy of approaches can be found in the IAEA World Fusion Outlook 2023 [9] and there are others summary papers on fusion commercialization activities, e.g. Refs. [10,11], which give also an overview of non-electricity applications. However, the field is developing rapidly and a paper that is only two or three years old is already missing important developments. This is why regularly updated reports, such as the ones from the IAEA [12] and the FIA [4] play an important role.

Every technology interacts with the environment and therefore can cause negative consequences. Scaled to a world population of 8.2 billion people, these negative effects become quite significant. This applies to all methods of energy conversion and power generation. While known fossil fuel resources are expected to last at least through this century at current consumption levels [13], the combustion of these resources is the primary source of greenhouse gas emissions, especially carbon dioxide. Solar and wind power require a lot of space. They are intermittent and non-dispatchable which means that they cannot be relied upon exclusively to provide power at all times. Nuclear fission carries a built-in proliferation risk: The fuel is the same material that, following further processing, can also be used to manufacture nuclear weapons. Fission also produces long-lived highly radioactive waste and it has a history of accidents such as the events at Chernobyl and Fukushima.

Compared to all the energy sources mentioned above, fusion has essentially none of these drawbacks. As mentioned earlier, fusion energy is dispatchable, virtually net-zero, compact and safe. However, it has its own specific negative side effects. Tritium is a radioactive substance with a half-life of 12.3 years, difficult to handle and contain. The neutron radiation associated with D-T fusion will activate materials and internal structures of the power plant resulting in low-level and intermediate-level radioactive waste [14]. The same neutrons could be misused in a manipulated fusion machine to produce not only more tritium fuel, but also fissionable material. Some fusion power plant designs therefore also have a potential proliferation risk, which we will detail in a later section. However, the main drawback of fusion energy is that it is not yet a commercial reality – it will still take another 10–15 years to get there. Looking ahead, eventually fusion energy will fuel our civilisation, just like it powers the stars. Fusion energy is destined to become the mainstay of the world's deep future energy system.

The potential economic competitiveness of fusion energy based on magnetic confinement has been investigated recently by Prost and Volpe [15], showing that a cost of electricity in the range of $30-$60 per MWh should be possible for fusion. This illustrates that fusion can be economically competitive with solar and wind. Other studies, for example, by Lindley et al. [16] lead to higher estimated generating costs of about $150 per MWh. Compared to other energy sources the uncertainties of these estimates are still relatively large. In any case, if fusion plants are not considered as individual projects, but rather as integral parts of the energy system, deployed in large numbers via programmes with international standardisation and cooperation, competitive economics can be reached. Fusion energy is dispatchable, i.e. it can be dispatched when required. Indeed, a virtually zero-carbon dispatchable energy source is precisely what is needed to complement non-dispatchable zero-carbon energy sources wind and solar to achieve an overall net-zero-carbon grid [17].

3. A potential deployment scenario

The desirable timeline for the deployment of fusion energy is given by the timelines in the Paris Agreement [7] and the IPCC reports [8]. By 2050 our global economy should be carbon neutral. This means that fusion energy should make a substantial contribution on this timescale, or at the very least have started to penetrate the market with a visible and rapidly rising market share.

The successful adoption of a new technology follows a predictable pattern. In essence, it follows a logistic curve. After the initial proof of principle and prototype demonstration, there is an exponential growth phase characterised by a product and market specific doubling time, followed by a linear growth phase and finally, after passing the point of inflection an exponentially declining rate as the technology approaches a 100 % market share or a new competitor enters the scene [18,19]. The doubling time for the last three successful newcomer energy technologies was similar – for nuclear fission, photovoltaic solar and wind energy the doubling time was about 2.5 years. This means that it takes about 30 years from the first power plant to the supply of about 1 % of world energy demand, and about 40 years to provide about 10 % [20]. It is reasonable to assume that the deployment of fusion energy will follow a similar pattern as nuclear fission, solar and wind. If the first fusion power plant is ready and operating in the 2030s, this would mean that it takes until the 2060s for fusion to reach 1 % of world energy demand and until the 2070s to make a sizeable contribution of the order of 10 %. A recent study by the MIT Energy Initiative [21] provides the first global projections on the potential impact of fusion energy on electricity generation by 2100, considering different pricing scenarios.

New technologies may face a 'valley of death', where public funding is drying up, while private sector funding is not yet sufficient [22,23]. This can be overcome by political will to continue support, involvement of early adopters as well as engagement with regulators and the public [24]. In particular, public outreach about fusion energy is crucial but currently it is still sorely lacking.

Technologies that are seen as attractive either from a market perspective, or those that receive significant government support in times of crisis or for strategic reasons, or both, can experience much shorter periods of market penetration. Examples include the sales of iPhones, the number of rocket launches by SpaceX, the production of fighter aircraft in the United States during World War II, and the production of vaccines in the context of the recent COVID pandemic. Fusion energy presents itself as a highly attractive proposition for governments to address climate change mitigation and energy security concerns, as well as for the operational stability of the energy market. With the necessary political will and concerted efforts by governments and private industry, an optimistic scenario with a shorter doubling time is a realistic possibility.

The global aircraft industry can serve as a model for production capacity. A large, modern passenger aircraft from Airbus or Boeing costs about $300 million which is of a similar order of magnitude as the cost of a 300 MW fusion power plant, which can cost about $1 billion. It is estimated that there are currently 12,000 large passenger aircraft in service. In 2023 Airbus delivered 735 commercial aircraft and Boeing delivered 528 –a total of 1263 aircraft or approximately 3.5 per day. This is in the order of magnitude of the production capacity that will be required for fusion power plants.

The year 2050 is an important target for climate action, while the world's energy needs are expected to continue to grow after that date. Continued efforts to achieve and ultimately maintain net-zero greenhouse gas emissions may require the removal of CO_2 from the atmosphere. This will require even more energy, as will adapting to new and more challenging climate scenarios. A 24/7 dispatchable energy source with a negligible environmental footprint will still be needed as soon as possible.

4. A global approach

Climate change is an inherently global problem; the atmosphere and the oceans do not respect borders. Global energy demand will increase, especially in the Global South [25]. There is a direct correlation between energy use and quality of life, e.g. as measured by the Human Development Index [26]. Developing countries will want to achieve a better standard of living for their citizens and thus will drive global energy demand. In developed countries the growing use of technologies such as artificial intelligence and the data centres that support it will also further contribute to rising energy demand. At the same, AI is set to facilitate the advancement of fusion energy [27]. Ultimately, the reason for future growth in energy demand is the same in developed and developing countries – better standards of living.

It is safe to say that the first fusion power plant that to generate electricity and feed it into the grid will be located in one of the ITER Member States. This is not a difficult statement to make, since ITER membership is, in essence, tantamount to having access to the technology and, thus, to building a fusion power plant. Given the different levels of public and private funding in the different ITER Member States it seems likely that the first ever fusion power plant will be located in the United States, China or potentially in Europe.

India and China are the countries where most new power plants will be built between now and 2050 [25]. In addition, countries in Southeast Asia, such as Indonesia, and African countries, such as Nigeria, will see a significant increase in new power plant construction. By 2050 fusion plants could be the leading candidate for new power plants in these countries.

The global nature of the challenges and opportunities we face would benefit significantly from a global approach to their resolution.

5. The importance of licensing and regulation

With only about 15 years or less between the first fusion power plant expected to generate electricity in the 2030s and the 2050 goal of the Paris Agreement, the time to deploy of fusion technology at scale is short. If licensing and regulation take up a significant part of this time, they will have a direct impact on the feasibility of the deployment of fusion energy on a large scale before 2050.

It is reasonable to assume that the licensing process for a fusion power plant could take as long as the licensing process for other complex industrial facilities and products, such as nuclear power plants and passenger aircraft. The average time for the licensing process for a new nuclear reactor ranges from 1 ½ years (Hungary) to 11 years (Switzerland) [28], some of which may overlap with construction. The IAEA gives a typical timeframe of 5 years from project start to construction start, of which 2 ½ years are for licensing [29]. By comparison, the airworthiness certification process for a new passenger aircraft model is takes a similar timeframe of 5–9 years [30].

If the licensing process for fusion power plants takes a similar amount of time in every country, it will be impossible for fusion to tangibly impact greenhouse gas emissions within the Paris Agreement timeframe. Clear guidelines that can de-facto provide harmonisation for international licensing and regulation in all countries deploying fusion power plants would be a prerequisite for high rates of technology learning, so that the technology holders, i.e. companies from the ITER countries, can start mass production, export fusion plants and benefit from the cost reductions of the economy of multiples. This can be directly deduced from the analogy with small modular fission reactors [31].

6. The case for regulating fusion like particle accelerators

In a nuclear fission reactor, heavy nuclei are split into two smaller ones, releasing energy (heat and radiation) and one or more neutrons. These neutrons can in turn split other nuclei, releasing more neutrons, and so on. This so-called 'chain reaction' is fundamental to the operation of a fission reactor. If this reaction is not controlled, it can lead to a catastrophic meltdown or even an explosion, usually due to the build-up of hydrogen.

Every nuclear engineering student learns that the essential parts of a nuclear fission reactor are fissile material, a moderator, control rods and a cooling system. The fissile material is usually the uranium isotope ^{235}U or the plutonium isotope ^{239}Pu. These are the same materials used in nuclear weapons. Most reactors use nuclear fuel that is enriched, i.e. it has a higher concentration of ^{235}U than the 0.7 % in natural uranium ^{238}U, typically around 3–5 %. The neutrons that are produced in the fission reaction are fast and have a higher energy than is optimal for the next reaction. The moderator is a material that slows down the neutrons to a more optimal energy for a sustained chain reaction. Typical moderators are water and graphite. The chain reaction is controlled by control rods made of a material, such as boron, that captures the neutrons and removes them from the reaction. By capturing the neutrons, the control rods can also stop the chain reaction and therefore the reactor altogether. Finally, the cooling system not only removes heat and prevents materials from melting, it also transfers the heat to the turbines that in turn generate electricity. Nuclear fission reactors produce high levels of radiation both when they are operating and when they are not (caused by the decay of fission products after reactor shutdown), and they have a large inventory of highly radioactive material.

The combination of a large quantities of fissile, radioactive material and the associated proliferation risk, as well as 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 has none of the critical parts of a fission reactor just described. Taking a modern design of a magnetic confinement fusion device, such as a tokamak or stellarator, as an example, the critical parts of a fusion power plant are strong magnets, radiofrequency electromagnetic wave emitters, cryogenics and large-volume vacuum vessels. During operation, a fusion plant produces a high level of radiation, but after operation the residual radiation level is very low, as is the inventory of radioactive material. The start-up tritium inventory of the Commonwealth Fusion Systems ARC design is expected to be 327 g [32], whereas a typical fission reactor contains about 100 t of uranium, of which about 3–5 t is ^{235}U. This means that a fusion plant contains several hundred thousand times less radioactive material than a fission reactor, and none of it is fissile.

There is no chain reaction in a fusion power plant. Whereas a fission reactor must be constantly controlled to operate safely, a fusion power plant must be constantly controlled to keep the reaction going. To use a car as a metaphor - in a 'fission car' the foot must always be on the brake to prevent the vehicle from crashing, whereas in a 'fusion car', the foot must always be on the accelerator to prevent the vehicle from stopping. Therefore, a fusion power plant is inherently safe.

The key components of a magnetic confinement fusion power plant are the same as those of a modern particle accelerator (see Fig. 1). It therefore makes very perfect sense to regulate fusion power plants like particle accelerators, rather than like fission reactors. Inertial fusion and magneto-inertial fusion are slightly different and may utilize powerful lasers instead of large magnets. However, also they do not contain any of the basic components of fission reactors.

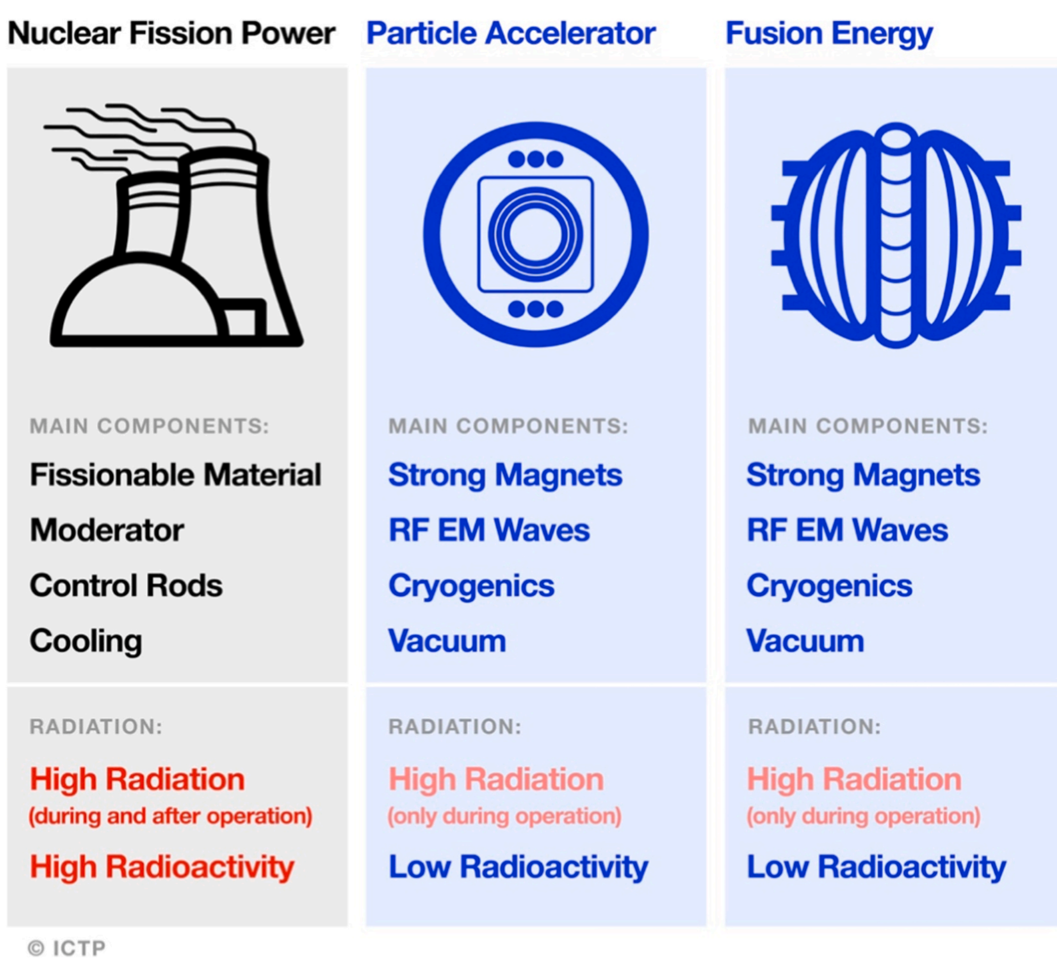

Fig. 1. Key components of nuclear fission reactors, particle accelerators and magnetic confinement fusion power plants.

7. Proliferation risks of fusion energy

The most frequent argument against the view that fusion power plants should be regulated like particle accelerators points at the fact that neutrons from a fusion plant can be used to breed fissile material, in particular ^{239}Pu and ^{233}U. This is well known [33]. In fact, any large neutron source can in principle be used to breed fissile material. This is the reason why at least some fusion power plant designs will need to be controlled and inspected for proliferation. If in any of the steps in a fusion reaction fissile material is present this would constitute a malevolent use of a fusion power plant. This proliferation risk should be taken into account in the design of fusion power plants from the beginning.

The case for a proliferation risk associated with the ARC machine has been investigated in detail recently [34]. This paper also includes a comprehensive review of other studies on this topic. The study finds that a significant quantity of fissile material could be produced in less than six months, representing a non-negligible breakout proliferation risk. A significant quantity in this case is defined by the IAEA as 8 kg of ^{239}Pu or ^{233}U [35], and a breakout proliferation risk implies the intentional misuse of the fusion reactor. Their study also shows that ^{6}Li enrichment in the blanket material lowers the proliferation risk.

Goldston and Glaser have investigated the proliferation risk for both magnetic and inertial confinement fusion power plant designs [36,37]. They find that the proliferation risk from fusion systems 'can be much lower than the equivalent risk from fission systems, if the fusion system is designed to accommodate appropriate safeguards.' Also, this study suggests including the potential proliferation risk in the design early on. These proliferation risks could usefully be studied using blankets at ITER [38].

Unlike a fission reactor, where the proliferation risk is inherent to the fuel cycle and fissile material is always present, this is not the case in a fusion power plant. In this regard, fusion power plants are more like particle accelerators. High power proton accelerators also can in principle be used to produce fissile material [39] but are currently not subject to non-proliferation regulations or safeguards.

Many fusion plant designs will include breeding blankets to produce tritium fuel by splitting ^{6}Li. Consequently, these plants will have a larger inventory of tritium and a complex tritium system. This is not comparable to the nuclear inventory of a fission reactor. The inventory of nuclear fuel in a fission reactor is in the order of 100 tonnes, whereas for fusion it is in the order of kilograms of tritium on the site. In addition, any setup to breed fissile material in a fusion plant will be easy to detect during an inspection.

8. Current approaches to licensing and regulation

All countries currently developing fusion power plants have recognised that licensing and regulation is an issue that needs to be addressed soonest, simply to allow a completed design to be legally built and then legally operate. Most private fusion companies are based in the US, with some in the UK, the EU and Japan. In addition, China has a large fusion programme aimed at the development of fusion technology. The following overview will therefore focus on these five.

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), which requires the NRC to develop and implement the necessary regulatory framework for advanced reactors, including fusion power plants, by the end of 2027.

From 2020, the frameworks for fusion and advanced fission reactors were developed separately. In January 2023, the NRC published a paper [40] presenting three options for the regulation of fusion energy systems: (1) a utilisation facility approach, (2) a byproduct material approach and (3) a hybrid framework based on potential hazards. The paper recommends the hybrid approach, which would introduce decision criteria for licensing and regulating fusion energy systems under either a byproduct material or utilisation facility regulatory approach, based on an assessment of potential hazards. If adopted, this approach will result in fusion regulation in the US being based on Title 10 of the Code of Federal Regulations (10 CFR) Part 30, Rules of General Applicability to Domestic Licensing of Byproduct Material.

The NRC is currently preparing a new volume of NUREG-1556 "Consolidated Guidance About Materials Licenses," dedicated to fusion systems, which is expected to be published by 2025. It is clear from this process that the US has adopted an approach that focuses primarily on radioactive materials used in and produced as byproducts of a fusion power plant. The regulation will be based on existing regulations, will be kept separate from the regulation of advanced fission reactors, and the process is moving quickly and on a schedule compatible with the plans of US private fusion companies. It is interesting to note that representatives of UK organisations have been involved in public stakeholder meetings of the US NRC on this issue. Documents and information on the process are available online at https://www.nrc.gov/materials/fusion-energy-systems.html. The US NRC has an Agreement State Programme, under which 39 US states regulate about 17,000 radioactive material licences or 86 % of all US licences. This internal US programme is an interesting example with a basic idea that could be applied to an international programme.

The UK published its first fusion strategy in 2021, together with proposals for a regulatory framework for fusion energy [41]. The key approach in this framework is to regulate fusion as a radioactive substance activity and that the Environment Agency (EA) and the Health and Safety Executive (HSE) will be responsible for regulating fusion facilities. Fusion plants would not need a nuclear site licence and would not be regulated by the Office for Nuclear Regulation (ONR). The UK government has undertaken a consultation process and published an updated version of the UK fusion strategy in 2023 [42]. The UK Energy Act 2023 (item 156) states that the "restriction of certain nuclear installations to licensed sites … does not apply to a fusion energy facility". The Act entered into force in October 2023, and the UK is now the first country where fusion technology is not officially regulated in the manner as nuclear fission. However, this is not the same as an existing regulatory framework for fusion power plants, but it indicates that the UK HSE is now engaged in the process of developing such a framework.

In China, the management and licencing of fusion experimental devices is carried out by the Ministry of Ecology and Environment (MEE). The pertinent 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 Regulations on the Safety and Protection of Radioisotopes and Radiation-Emitting Devices (State Council Decree No. 449). Classification is made on a case-by-case basis, with the majority of fusion devices falling within Category III of radiation-emitting devices. The MEE is currently working on a regulatory pathway for fusion power plants but is not as far advanced as the UK or the US. However, their approach seems to favour treating fusion power plants in a manner similar to high power proton accelerators.

Also, Japan appears to follow a similar approach as the US and the UK. The Japan Fusion Energy Council 'J-Fusion' has recently published a whitepaper that recommends the application of the Radiation Hazards Prevention Law (RI Law) to fusion machines, instead of the Act governing fission reactors [43].

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 [44]. More recently, in 2024, a EUROfusion working group published a paper on 'Recommendations for the Future Regulation of Fusion Power Plants' [45]. Both documents are written in the context of the official European Fusion Roadmap [46] and thus focus on ITER and DEMO. They are based on IAEA Safety Principles developed for nuclear fission power plants. The recommendations do not contain a clear proposal to follow the examples of the US and the UK. Nor do they take account of the recent development of private fusion companies. The recent German government paper on fusion [47] 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 regulations 'outside of nuclear law' [3].

9. A proposal for international licensing and regulation

We have already seen that the global aircraft industry is a good approximation of what the global fusion industry is likely to become, similar in size and complexity. The licensing and regulation of large aircraft is therefore an obvious place to look for inspiration for the licensing and regulation of fusion power plants.

The Joint Airworthiness Authorities (JAA) was an organisation founded in 1970, initially to establish common certification codes in Europe for large aircraft and engines. The European Union Aviation Safety Agency (EASA) is an agency of the European Union that has assumed the functions previously performed by the JAA. The concept of the EASA dates back to 1996, it was legally established in 2002, started its work in 2003 and attained full operationality in 2008. As an agency of the European Union, EASA is responsible for the certification of aircraft in all EU Member States. It has taken over this responsibility from the various national authorities that previously held it.

In 2011, the US and the EU signed the Agreement on Cooperation in the Regulation of Civil Aviation Safety [48]. This agreement essentially means that aircraft type certifications are mutually recognised by the US and the EU. Aircraft built in the US are certified by the Federal Aviation Administration (FAA) and this certification is validated by the European Aviation Safety Agency (EASA) without any technical involvement by EASA. The reverse is the case for aircraft built in the EU. As the market for large passenger aircraft is dominated by Airbus and Boeing, this effectively establishes a global certification (licensing) process for aircraft.

The International Civil Aviation Organization (ICAO) is a United Nations agency that fosters cooperation among its 193 Member States. It was established in 1944 as a global forum for civil aviation. It develops policies and standards and builds aviation capacity. It does not act as a global licensing and regulatory authority. Aircraft in countries outside the US and the EU typically have to go through a national certification process. Given the political will, the US and the EU could now move to combine their agreement with ICAO and implement an opt-in process for licensing aircraft in ICAO Member States. In practice, this would cover almost all large civil aircraft in the world.

Of the around 45 private fusion companies in 2024, 25 are located in the US, 6 in the EU, and 3 each in the UK, Japan and China. Of the 8 largest private fusion companies, with a capitalisation of more than $200 million, 5 are in the US and one each in the UK, Canada and China [4].

If the licensing and regulation of fusion power plants follows the historical example of the aircraft industry, i.e. it develops from the bottom up starting in nation states, there will eventually be a need for the creation of an international organisation for regulatory capacity building. In such a scenario, national regulatory agencies in the US, EU and UK would certify most fusion power plant designs. Eventually these national licensing and regulatory processes would lead to an agreement between the US, EU and UK (and perhaps also Canada and China) to mutually accept the national certifications. It could well take a decade or more for these agreements and organisation to be established. In such a scenario, each country outside this circle would still have to establish its own regulatory infrastructure before fusion power plants could be deployed in the country. This would take another decade or more and access to fusion power for developing countries would be difficult or impossible.

To have the greatest positive impact on meeting the growing energy demand and mitigating climate change, the large-scale deployment of fusion energy should begin 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?

The process of negotiating international agreements takes years. For example, the average time to negotiate a regional trade agreement is 28 months [49]. Multilateral agreements take longer than bilateral agreements ones. The good news is that there is likely to be sufficient time to negotiate such an agreement before the construction of the first fusion power plant starts.

From the point of view of rapid deployment, a single global licensing and regulatory authority would be ideal. However, in a multipolar world, an international agency with some global mandates and simple opt-in mechanisms is the next best thing and easier to implement. The proposal for international licensing and regulation draws some inspiration from a policy brief on nuclear energy for the G20 in 2020 [50] and from the US NRC Agreement State Programme. The specifics of the proposal are outlined below.

10. 7-Point plan for a Global Framework

The following infographic (Fig. 2) and the accompanying text outline our proposal for a 7-Point Plan to establish a Global Licensing and Regulation Framework for Fusion Energy (GOFE). The visualisation shows GOFE at the centre, with the other points representing its tasks. This structure can therefore be mapped directly onto the GOFE's departmental structure.

10.1. Point 1. Global Organisation for Fusion Energy (GOFE)

The GOFE will either be a new international body or an existing international organisation with additional functions and responsibilities. In any case, it will be imperative to include, from the outset, representation from industry, in particular fusion power plant manufacturers, as well as from developing countries, which constitute a substantial proportion of the potential customer base. Options for the formation of the GOFE are outlined in the following section.

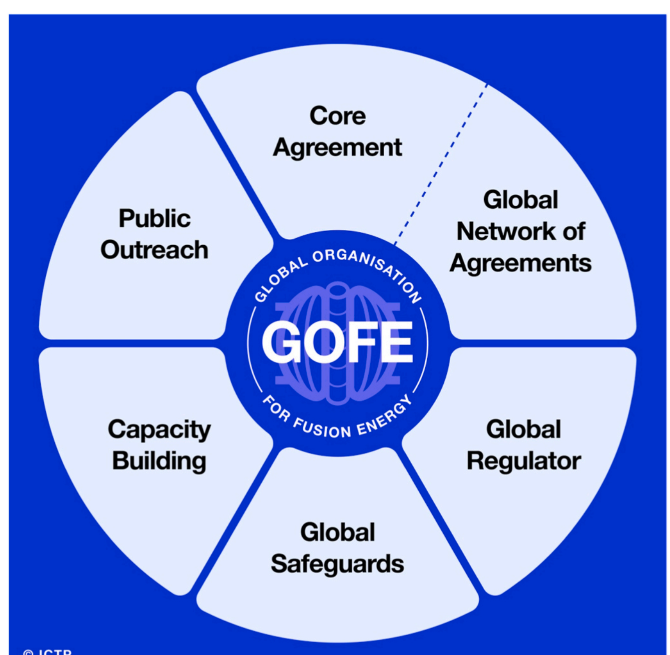

Fig. 2. 7-Point plan for a global framework for fusion energy.

10.2. Point 2. core agreement

The GOFE will act as a depository for unidirectional or reciprocal certification agreements operating on a network basis. The initial core agreement is expected to be a reciprocal agreement between the US, the EU and the UK, with the potential inclusion of Canada and China. Mutual extension agreements can be negotiated with other countries also manufacturing fusion power plants, but these should be extensions of the Core Agreement.

As is the case with other international organisations, this Core Agreement is the treaty that will lead to the formation of the GOFE, in a similar way as the Comprehensive Nuclear Test Ban Treaty led to the formation of the CTBTO. The GOFE will include the secretariat of the core agreement.

10.3. Point 3. global network of agreements

Each Member of the GOFE shall have the right to unidirectionally opt-in to the Core Agreement and any mutual or unilateral agreement, i.e. to accept certifications from the members of the Core Agreement, the mutual agreement or the sole certifying member of a unilateral agreement. This will lead to the formation of opt-in networks that will eventual will merge into a single network of agreements.

Membership of the GOFE should not be limited to the signatories of the Core Agreement, or even the signatories of the unilateral agreements, but to all countries. However, the level of representation and the access to services of GOFE will depend on the agreements.

10.4. Point 4. global regulator

The GOFE will act as a global regulator for fusion facilities, in particular fusion power plants, on an opt-in basis. This means that countries that do not have their own regulator can outsource the regulation of fusion power plants to the GOFE. This is crucial, as it will ensure that countries can deploy fusion plants immediately while they are still building their domestic fusion regulatory capacity.

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. In fact, it would be simpler and more coherent if the GOFE continued to act as the global regulator for all fusion facilities.

10.5. Point 5. global safeguards

The GOFE acts as a global safeguards inspector for fusion power plants (fusion facilities at large) to ensure that no undeclared fissionable material is produced.

Safeguards for fusion power plants will have to be different from safeguards for fission power plants, because material that can be bred into fissionable material is not part of their regular fuel cycle and tritium is currently not subject to safeguards. Research on safeguards approaches for fusion energy, distinct from safeguards for fission, should be part of the initial mandate of the GOFE.

10.6. Point 6. capacity building

The GOFE will be an active player for fusion capacity building in all Member States that do not yet have their own fusion capacity. In the case of developing countries, this will be through a Fusion Capacity Building Fund to be managed by GOFE that is funded by the fusion plant manufacturing countries and industry.

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

10.7. Point 7. public outreach

Fusion is a new technology and as such is not yet well understood by the public. It is therefore vital to raise awareness and communicate effectively with the public, so as to avoid the acceptance problems experienced with nuclear fission. The GOFE will therefore also have a mandate for public outreach.

Public opinion is an important factor for the deployment of a new technology that should not be underestimated. The social acceptance of fusion energy has already become the subject of studies [51–53]), albeit mostly at the level of individual countries. The public outreach activities of the GOFE can build on this. The mandate of GOFE would not only be to inform the global public, but also to create positive images and memes for fusion. One example could be an 'International Year of Fusion Energy', another one a 'dome of light' on a fusion power plant that turns on when the plant produces electricity from fusion. Currently, an optimistic vision of the future is gaining some momentum under the label of 'Abundance' [54] and one could try and connect to this as well.

11. Organisational options for the realisation of the Global Licensing and Regulation Framework

New international (intergovernmental) organisations are established when the need arises, and with the agreement of Member States. Recent examples include the International Renewable Energy Agency (IRENA) in Abu Dhabi in 2010 and Sustainable Energy for All (SE4ALL) in Vienna in 2011. Given the novel nature of fusion technology, which differs significantly from both renewables and nuclear fission in key aspects, the establishment of a GOFE appears to be the most logical and adequate option.

However, the creation of a new international organisation is a complicated piece of international diplomatic negotiation and as such takes time. Since he whole point of international licensing and regulation of fusion is to accelerate its deployment, it might be more efficient to use one of the existing international organisations, at least initially.

The most obvious candidate could be the International Atomic Energy Agency (IAEA) in Vienna. The IAEA has a long existing 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 Members States. The IAEA has begun to expand its fusion activities and published its first World Fusion Outlook in 2023. However, the IAEA has not yet recognised fusion energy in its organisational structure and fusion activities are spread across several departments. Point 5, Global Safeguards, would obviously benefit from the expertise already present at the IAEA. The largest challenge with the IAEA taking on the role of the GOFE could be the cultural resistance to fusion from nuclear fission organisations, companies and protagonists. This could prove to make this option more difficult than a new organisation, but it also could be overcome politically through pressure from the Member States.

The second organisation that comes to mind is the ITER Organisation. It already includes all potential producer countries with the technical capability to develop fusion power plants: USA, Russia, EU, China, Japan, South Korea and India. Initial negotiations on the core agreement (point 2) could take place within ITER, taking advantage of its limited membership, before opening it up more widely. However, the ITER organisation was set up by its member states for the specific purpose of constructing the ITER reactor. ITER does not currently have a mechanism for admitting new members. Any change to the ITER statutes would require the agreement of all current member states, which is politically difficult and challenging. The projected timetable for DT fusion at ITER is now later than the likely success of a prototype fusion power plant elsewhere. This also means that a shift in the focus of the ITER Organisation could be attractive to the Organisation and its Member States. In such a scenario, the ITER reactor itself could play an important role as a training facility for scientists from developing countries. Indeed, an overall shift in the structure of the ITER Organisation to include developing countries could establish it as the main organisational vehicle for fusion training and outreach in the developing world.

A different approach toward establishing a global focal point for fusion energy is the proposal of an IEA-backed Global Commission [55]. Such a commission could be a practical step towards a GOFE, particularly if neither the IAEA nor ITER are interested or able in taking on the role and the GOFE is created as a new global organization.

The most significant challenge for any organisational setup is that fusion power plants should be regulated like accelerators, not like nuclear fission power plants. This is the approach adopted by the US and the UK, which are currently furthest along the route to fusion regulation. For the IAEA, this would require an internal cultural change and new relationships with non-nuclear regulators in Member States. For ITER, this would mean transitioning from a regulated organisation to an international regulator. In our assessment, the creation of a new organisation may be the best option, but the IAEA taking over this role may be the most likely option, while ITER may provide the best platform to prepare a new organisation.

12. Conclusions

Fusion energy will soon be a reality. Most recent timelines converge on the 2030s for the first fusion-generated electricity, some 10–15 years from now. As a clean, virtually carbon-neutral, dispatchable energy source, fusion can be an integral part of any solution, if not the solution, to mitigating the climate crisis.

However, fusion energy can only play a real role if it can be deployed at scale quickly enough. If it follows the same pattern as nuclear fission, solar and wind energy, fusion energy will not be deployed at scale, i.e. reaching a market share of 1 % of the world's energy supply by the 2060s. This will still be very important, but it would mean that fusion energy would not make a significant contribution to meeting the Paris goals.

If fusion energy is to contribute on a timescale of the 2050s, special, concerted efforts will be necessary. This includes removing regulatory barriers that could delay the deployment. The establishment of an international licensing and regulatory framework, along with a GOFE, could facilitate this. Such a framework and organisation will also be instrumental for the deployment of fusion power plants in those countries where the majority of new power plants will be built in the next 30 years and beyond. The necessary capacity building and public outreach will also be part of GOFE's mandate.

As mentioned earlier, we are aware of the typical path that the development of regulations and licensing agreements will take. However, the global climate crisis should prompt us to consider how this process can be accelerated.

This paper makes the case for a global licensing and regulatory framework for fusion energy, together with a Global Organisation for Fusion Energy, and presents a 7-point plan for what such a framework could look like. We believe that such an approach could accelerate the realisation and deployment of fusion energy. It is our hope that this paper will help to make this a reality.

Author contributions

Ralf B. Kaiser: Conceptualization, Methodology, Writing – Original Draft. H.-Holger Rogner: Writing - Review & Editing, Validation. Adnan Shihab-Eldin: Supervision, Conceptualization, Writing - Review & Editing. Sehila M. Gonzalez de Vicente: Data Curation, Writing - Review & Editing.

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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 criterion	Figure of merit used in fusion research that compares the rate of energy 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 1 h
SE4ALL	Sustainable Energy for All

Data availability

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

References

[1] Fusion Energy Strategy 2024. Washington, DC 20024: U.S. Department of Energy, Available at: https://www.energy.gov/sites/default/files/2024-06/fusion-energy-strategy-2024.pdf. (Accessed 5 November 2025).

[2] Fusion power - enabling 21st century American dominance, Commission on the scaling of fusion energy. https://www.scsp.ai/wp-content/uploads/2025/02/Final-Fusion-Power_-Enabling-21st-Century-American-Dominance.pdf, 2025. (Accessed 5 November 2025).

[3] Verantwortung für Deutschland, German government coalition contract. https://www.spd.de/fileadmin/Dokumente/Koalitionsvertrag2025_bf.pdf, 2025. (Accessed 5 November 2025).

[4] The global fusion industry in 2024. Washington, DC 20024: Fusion Industry Association, Available at: https://www.fusionindustryassociation.org/fusion-industry-reports/. (Accessed 5 November 2025).

[5] Helion announces world's first fusion energy purchase agreement with Microsoft, 2023, Available at: https://www.helionenergy.com/articles/helion-announces-worlds-first-fusion-ppa-with-microsoft/. (Accessed 5 November 2025).
[6] A breakthrough for commercial fusion energy, Commonwealth Fusion Systems, Available at: https://cfs.energy/news-and-media/commonwealth-fusion-systems-to-build-worlds-first-commercial-fusion-power-plant-in-virgina, 2024. (Accessed 5 November 2025).
[7] Paris Agreement', Paris climate change conference, Available at: https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf, 2015. (Accessed 5 November 2025).
[8] Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. Geneva, Switzerland. Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647, last accessed 5.November.2025.
[9] IAEA world fusion outlook, Vienna, Austria: International Atomic Energy Agency, https://doi.org/10.61092/iaea.ehyw-jq1g, 2023. (Accessed 5 November 2025).
[10] S. Meschini, et al., Review of commercial nuclear fusion projects, Front. Energy Res. 11 (2023) 1157394, https://doi.org/10.3389/fenrg.2023.1157394.
[11] T. Griffiths, et al., The commercialisation of fusion for the energy market: a review of socio-economic studies, Prog. Energy 4 (2022) 042008.
[12] IAEA world fusion outlook, Vienna, Austria: International Atomic Energy Agency, https://doi.org/10.61092/iaea.es3t-vz6q, 2024. (Accessed 5 November 2025).
[13] Fossil fuel reserves aren't running out, Gapminder (2024). Available at: https://www.gapminder.org/facts/fossil-fuel-reserves-arent-running-out/. (Accessed 5 November 2025).
[14] S. Gonzalez de Vicente, et al., 'Overview on the management of radioactive waste from fusion facilities: ITER, demonstration machines and power plants', Nucl. Fusion 62 (2022) 085001.
[15] Economically optimized design point of high-field stellarator power-plant, Victor Prost and Francesco A. Volpe, 2024 026007. Nucl. Fusion 64.
[16] B. Lindley, et al., Can fusion energy be cost-competitive and commercially viable? An analysis of magnetically confined reactors, Energy Policy 177 (2023) 113511, https://doi.org/10.1016/j.enpol.2023.113511. (Accessed 5 November 2025).
[17] Miklos Dietz, et al., Will Fusion Energy Help Decarbonize the Power System? McKinsey & Company, 2022. Available at: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/will-fusion-energy-help-decarbonize-the-power-system#/. (Accessed 5 November 2025).
[18] C. Marchetti, N. Nakicenovic, The dynamics of energy systems and the logistic substitution model. Research Report RR 79-13, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, 1979. Available at: https://pure.iiasa.ac.at/id/eprint/1024/1/RR-79-013.pdf. (Accessed 5 November 2025).
[19] P.D. Lund, Fast market penetration of energy technologies in retrospect with application to clean energy futures, Appl. Energy 87 (2010) 3575–3583.
[20] N.J.L. Cardozo, Economic aspects of the deployment of fusion energy: the valley of death and the innovation cycle, Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 377 (2141) (2019) 20170444, https://doi.org/10.1098/rsta.2017.0444. (Accessed 5 November 2025).
[21] MIT Energy Initiative, The role of fusion energy in a decarbonised electricity system. https://energy.mit.edu/publication/the-role-of-fusion-energy-in-a-decarbonized-electricity-system/, 2024. (Accessed 5 November 2025).
[22] C. Frank, et al., Surviving the "valley of death": a comparative analysis, J. Technol. Tran. 21 (1–2) (1996) 61–69, https://doi.org/10.1007/BF02220308. (Accessed 5 November 2025).
[23] P.R. Hartley, K.B. Medlock, The Valley of death for new energy technologies, Energy J. 38 (3) (2017) 33–62, https://doi.org/10.5547/01956574.38.3.phar. (Accessed 5 November 2025).
[24] A.E. Finan, Fusion innovation and the valley of death—lessons from fission, J. Fusion Energy 42 (1) (2023), https://doi.org/10.1007/s10894-023-00352-0. (Accessed 5 November 2025).
[25] International Energy Outlook, U.S. Energy Information Administration, Washington, DC 20585, 2023. Available at: https://www.eia.gov/outlooks/ieo/. (Accessed 5 November 2025).
[26] D.M. Martínez, B.W. Ebenhack, Understanding the role of energy consumption in human development through the use of saturation phenomena, Energy Policy 36 (4) (2008) 1430–1435, https://doi.org/10.1016/j.enpol.2007.12.016. (Accessed 5 November 2025).
[27] S. Gonzalez de Vicente, et al., A survey of artificial intelligence and high performance computing applications to fusion commercialization, Clean Air Task Force (CATF) (2024). Available at: https://cdn.catf.us/wp-content/uploads/2024/11/04152245/fusion-ai-executive-summary.pdf. (Accessed 5 November 2025).
[28] Summary Report on the Licensing Process of New Reactor Applications, 2021. NEA/CNRA/R(2020)1. Paris, France: Nuclear Energy Agency (NEA). Available at: https://www.oecd-nea.org/upload/docs/application/pdf/2021-10/nea_cnra_r_2020_1.pdf, last accessed 5.November.2025.
[29] Project Management in Nuclear Power Plant Construction: Guidelines and Experience, International Atomic Energy Agency (IAEA), Vienna, 2012 (IAEA nuclear energy series, NP-T-2.7).
[30] How does the FAA certify aircraft?, aircraft certification. https://www.faa.gov/aircraft/air_cert/airworthiness_certification. (Accessed 5 November 2025).
[31] H.-H. Rogner, et al., Keeping the nuclear energy option open, SSRN Electron. J. (2021), https://doi.org/10.2139/ssrn.3778835. (Accessed 5 November 2025).
[32] C. Malone, et al., Approach to startup inventory for viable commercial fusion power plant, Fusion Eng. Des. 206 (2024) 114563.
[33] A.A. Harms, C.W. Gordon, Fissile fuel breeding potential with paired fusion-fission reactors, Ann. Nucl. Energy 3 (9–10) (1976) 411–420, https://doi.org/10.1016/0306-4549(76)90025-6. (Accessed 5 November 2025).
[34] J.L. Ball, Assessing the risk of proliferation via fissile breeding in ARC-class fusion power plants, Nucl. Fusion 65 (2025) 036038.
[35] IAEA, IAEA Safeguards Glossary (Number 3 in International Nuclear Verification Series), International Atomic Energy Agency, 2022. Available at: https://www-pub.iaea.org/MTCD/Publications/PDF/PUB2003_web.pdf. (Accessed 5 November 2025).
[36] R.J. Goldston, A. Glaser, Inertial confinement fusion energy R&D and nuclear proliferation: the need for direct and transparent review, Bull. At. Sci. 67 (3) (2011) 59–66, https://doi.org/10.1177/0096340211407562.
[37] A. Glaser, R.J. Goldston, Proliferation risks of magnetic fusion energy: clandestine production, covert production and breakout, Nucl. Fusion 52 (2012) 043004, https://doi.org/10.1088/0029-5515/52/4/043004.
[38] G. Franceschini, et al., Nuclear fusion power for weapons purposes, Nonproliferation Rev. 20 (3) (2013) 525–544, https://doi.org/10.1080/10736700.2013.852876.
[39] R.S. Kemp, Nuclear proliferation with particle accelerators, Sci. Global Secur. 13 (3) (2005) 183–207, https://doi.org/10.1080/08929880500357708.
[40] 'OPTIONS for licensing and regulating fusion energy systems', U.S. Nuclear Regulatory Commission (NRC) - SECY-23-0001Available at: https://www.nrc.gov/docs/ML2227/ML22273A163.pdf, 2023. (Accessed 5 November 2025).
[41] Towards Fusion Energy: The UK Government's Proposals for a Regulatory Framework for Fusion Energy, Department for Business, Energy & Industrial Strategy, UK Government, 2021. Available at: https://www.gov.uk/government/consultations/towards-fusion-energy-proposals-for-a-regulatory-framework. (Accessed 5 November 2025).
[42] Towards Fusion Energy 2023 - The next Stage of the Uk's Fusion Energy Strategy, Department for Energy Security & Net Zero, UK Government, 2023. Available at: www.gov.uk/government/publications/towards-fusion-energy-the-uk-fusion-strategy. (Accessed 5 November 2025).
[43] Japan Fusion Energy Council 'J-Fusion, White Paper, June 2025. https://jfusion.jp/news/2025/0630501/. (Accessed 5 November 2025).
[44] Study on the applicability of the regulatory framework for nuclear facilities to fusion facilities, in: LU: Directorate General for Energy (European Commission), 2021. Available at: https://data.europa.eu/doi/10.2833/787609. (Accessed 5 November 2025).
[45] J. Elbez-Uzan, et al., Recommendations for the future regulation of fusion power plants, Nucl. Fusion 64 (3) (2024) 037001, https://doi.org/10.1088/1741-4326/ad13ad. (Accessed 5 November 2025).
[46] European research roadmap to the realisation of fusion energy, 2018. EUROfusion, Available at: https://euro-fusion.org/wp-content/uploads/2022/10/2018_Research_roadmap_long_version_01.pdf. (Accessed 5 November 2025).
[47] Position Paper Fusion Research', Federal Ministry of Education and Research, BMBF, 2023. Available at: https://www.bmbf.de/SharedDocs/Publikationen/DE/FS/815284_Positionspapier_Fusionsforschung_en.html. (Accessed 5 November 2025).
[48] Agreement between the United States of America and the European Community on cooperation in the regulation of civil aviation safety, Off. J. Eur. Union (2011). Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:64d9e1a2-633c-4e91-bbf5-053e5ab1b432.0010.02/DOC_2&format=PDF. (Accessed 5 November 2025).
[49] C. Moser, A.K. Rose, Why do trade negotiations take so long? J. Econ. Integrat. 27 (2) (June 2012) 280–290.
[50] A. Shihab-Eldin, et al., Does a climate constrained world need nuclear energy?, in: T20 Task Force 2 Policy Brief, Saudi-Arabia, 2020.
[51] T. Griffiths, et al., The commercialisation of fusion for the energy market: a review of socio-economic studies', Prog. Energy 4 (2022) 042008.
[52] C.R. Jones, et al., The social acceptance of fusion: critically examining public perceptions of uranium-based fuel storage for nuclear fusion in Europe, Energy Res. Social Sci. 52 (2019) 192–203.
[53] C. Turcanu, et al., Fusion energy: a deeper look into attitudes among the general public, Fusion Eng. Des. 161 (2020) 111891.
[54] E. Klein, D. Thompson, Abundance, 2025. ISBN 9781668023488.
[55] E.G. Carayannis, et al., Democratic engagement in sustainable energy innovation: applying the quintuple innovation helix to manage accelerating fusion energy through an IEA-Backed Global Commission, IEEE Trans. Eng. Manag. 71 (2024) 14293–14306, https://doi.org/10.1109/TEM.2024.3428975, 2024.