Fusion in 10 years – Is this 'the real thing' or 'here-we-go-again'?

Can fusion energy become a significant contributor towards net zero by 2050?

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Introduction

Fusion energy is increasingly making headlines as an energy source which is ready to help mitigate the impacts of climate change. It has been long sought after as the "holy grail" of energy sources touting an almost endless source of fuel, its high energy density, no runaway reaction, and no long-lived radioactive waste streams. Research on fusion has been going on for almost 70 years, with breakthrough always "just another 20 years away". So, what is making the difference today? This article examines the following questions: 1. Is fusion ready to become a viable commercial energy source? 2. What are the challenges the technology faces to reach that viability?

This article is the second in a 3-part series by NECG in atw – International Journal for Nuclear Power, to explore the role that new technology in nuclear fission and in fusion can have in a New Energy System, and what challenges they will need to overcome.

PART 2/3

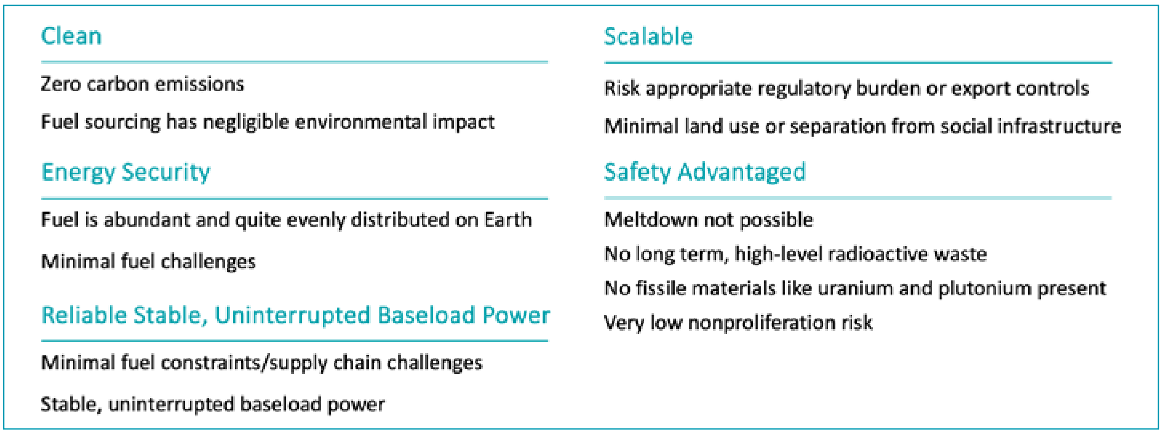
In the first article in this series[1] we addressed what needs to facilitate Small Modular Reactor and advanced fission deployment at scale:

Issue 1: The scale and profile of financial support for technology deployment
Issue 2: The capacity and agility of the technology Supply Chain
Issue 3: Modifications to Energy Market Design to accommodate technology advantages
Issue 4: The technology implementation risk in technology designs still not eliminated
Issue 5: Alignment of technology design and siting licensing systems
Issue 6: Successful technology deployment will encompass significantly more nuclear sites
Issue 7: (Nuclear) industry culture is driven by excess risk aversion could spill over to Fusion
Issue 8: Competition from other technologies

In this article, we will refer to these in the context of the fusion sector, by highlighting with a reference to the particular issue number. In the third article, we will explore in more detail how these challenges may impact the future relative growth of fusion and SMR technologies.

From the outset, the authors would like to make clear that we acknowledge and agree that fusion technology is being developed distinctly separate from fission technology – its industry, its stakeholders, the public see fusion as pure, clean, peaceful, and exciting and want to see it untouched by the negative attributes of "nuclear".

However, there are lessons to be learned, there are skills and capabilities to be shared, and from a pragmatic business perspective the two represent competing pathways to an equitable global energy supply and a net zero new energy system.



Clean

Zero carbon emissions

Fuel sourcing has negligible environmental impact

Energy Security

Fuel is abundant and quite evenly distributed on Earth

Minimal fuel challenges

Reliable Stable, Uninterrupted Baseload Power

Minimal fuel constraints/supply chain challenges

Stable, uninterrupted baseload power

Scalable

Risk appropriate regulatory burden or export controls

Minimal land use or separation from social infrastructure

Safety Advantaged

Meltdown not possible

No long term, high-level radioactive waste

No fissile materials like uranium and plutonium present

Very low nonproliferation risk

Fig. 1
Benefits of fusion energy.

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[1] atw – International Journal for Nuclear Power, 4-23, June 2023, https://kernd.de/wp-content/uploads/2023/07/Article_From_Smart_Marketing_to_Building_a_New_Energy_System-Challenges_for_SMR_Global_Adoption_John_Warden_Ruediger_Koenig_atw_-2023-04.pdf

Fusion energy

Fusion can uniquely benefit the world. It is a technology that can satisfy all the real-world economic, social, and political constraints of energy. Here are some of the noted benefits of fusion energy **(Figure 1)**. The figure also highlights some of the noted differences between fusion and fission – no long-term high-level waste, no possibility of a meltdown or runaway reaction, and very low proliferation risk.

What is fusion?

Fusion is the process by which two light atoms fuse to form a single heavier atom releasing large amounts of energy as a byproduct. As depicted in **Figure 2**, the most common approach to fusion energy uses two isotopes of hydrogen, deuterium, and tritium as fuel for fusion. Deuterium can be distilled from water, while tritium will be produced during the fusion reaction as fusion neutrons interact with lithium. A noted critical challenge is how to breed and recover tritium reliably in a fusion machine.

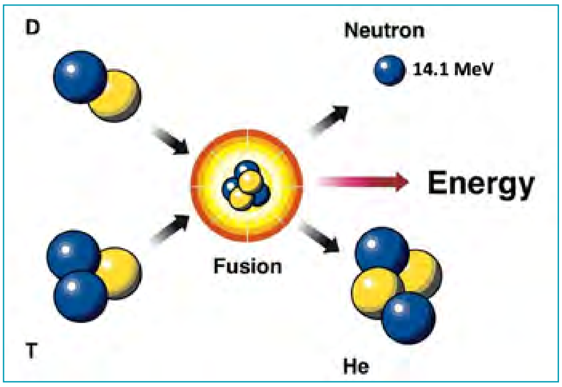

Fig. 2
What is Fusion? [I]

Fusion is what powers the sun and the stars. The gravity of the stars creates the tremendous pressure and heat which enables lighter nuclei to fuse together into heavy nuclei releasing enormous amounts of energy. Scientists and engineers are working, as some put it, “to create the power of the sun in a bottle” here on earth. Part of their challenge is to create the conditions provided at the centre of stars to cause the fusion reaction to occur. The result of the fusion reaction is the creation of Helium and a very high energy neutron. These high energy neutrons are the source to provide the heat necessary to create electrical energy from fusion energy. Just like a conventional power plant, a fusion power plant will use this heat to produce steam and then electricity by way of turbines and generators.

Background: Why Fusion? Why Now? What is Different?

Recent years have seen a significant, quickly accelerating dynamic on the path towards making fusion a real option[2]. Various international and national Government funded programs are progressing the development of the technology with a longer-term deployment window. Private fusion technology developers are attempting to commercialize fusion powered electricity over the next decade with near-term demonstration projects underway. Governments have recognized the private dynamic and are establishing enabling programs to help progress these endeavours in parallel to the traditional public R&D programs. Lastly, momentum is progressing regulatory frameworks in order to de-risk technology deployment by eliminating regulatory uncertainty, but work is needed to achieve global harmonization of regulations.

Technology development of fusion is accelerating from R&D towards commercial applications based on advances in three important areas:

1) Maturing fusion science:

- Plasma physics knowledge
- Advanced simulation codes and modelling
- Experimental confirmation of fusion theory
- Movement from research to engineering delivery

Fusion research has been ongoing for almost 7 decades. Until recently, this was carried out exclusively in large national and international programmes, and these continue.[3] Such Government funded programs like ITER tend to advance with longer delivery horizons. More recently, there is a movement in fusion, led by the private sector to commercialize fusion technology in the next decade. This is best typified by a half a dozen private fusion companies in the UK, Canada and the United States working on proof-of-concept fusion machines today with operations slated to begin as early as 2024. Research is still required and ongoing, and the sector is evolving. New fusion challenges are moving towards engineering and operations challenges as private designs move forward for near term fusion demonstration machines.

2) New enabling technologies:

- Additive and advanced manufacturing (3D printing)
- Computational power and big data analytics

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[2] We play with the expression: the option is becoming ”real” but its value is still a game theory ”real option”.

[3] The authors are familiar with and recognize the importance of these programs, but this article will skip discussion since well documented elsewhere, including the present Issue of atw – International Journal for Nuclear Power.

- High speed digital control systems
- High temperature superconducting magnets

The ability to deliver technology with these enabling technologies is another reason fusion is advancing at a different rate today. Advanced manufacturing allows developers to deliver complex components for fusion machines cost effectively and rapidly – with the ability to quickly deliver a modified component. The latest simulation codes are by new high-speed computers delivering greater details in their analysis. And advancements in magnet technology is allowing fusion machines to be designed and developed more cost effectively to deliver better performance on a smaller scale.

3) Private investment in fusion development (Issue 1)

There has been a marked uptick in private investment in the private fusion sector as shown in **Figure 3**. This investment is being driven by the game-changing nature of fusion technology to the existing electricity generation sector and the aggregate impact of the potential benefits of carbon free generation from fusion technology, advancements in science and engineering, new enabling technologies, results from private and public fusion programs, and a multi-Trillion-dollar electricity market opportunity between now and 2050 to support decarbonization (Issue 7). This funding is promoting the rapid expansion of the private fusion sector.

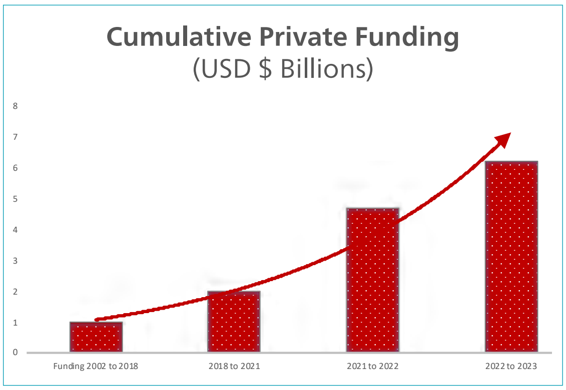


Fig. 3
Cumulative private fusion funding. [III]

The U.S. based, international Fusion Industry Association ("FIA") released its third global fusion industry survey in June 2023.[IV] Some noted points from this survey are:

- 8 private companies have **each raised in excess of $ 200 M USD** (1 > $ 2 B, 1> $ 1 B)
- When asked when your company will **deliver power to the grid**, of the 30 responders, half said 2030–2035
- There are now **over 40 private fusion companies globally** developing fusion technology to supply clean energy to the grid.

US: 25	**Italy: 1**
UK: 3	**Israel: 1**
Canada: 1	**China: 2**
France: 1	**Japan: 3**
Sweden: 1	**Australia: 1**
Germany: 3	**New Zealand: 1**

Governments are also starting to support the development of private fusion companies. One example is the recent public private partnership milestone program put in place by the United States Department of Energy. Eight private fusion companies were selected as participants in this new program.
The factors above are advancing fusion technology with varying approaches to fusion energy delivering demonstration machines in the mid-2020s and projected first power plants early in the 2030s. Internationally and national government funded programs are continuing to progress fusion technology in parallel with the private developers.

Why is this significant? – it multiplies by a factor of 40 the different approaches addressing the science and technology challenges and speeds up dramatically the learning-by-doing curve towards achieving breakthrough(s), hence the probability of breakthrough and success. More on this later in this article.

What very broadly are the challenges to commercializing fusion?

Fusion has been demonstrated on a small scale by scientists, with a noted demonstration of a first scientific energy break even, meaning it produced more energy from fusion than the laser energy used to drive it, at Lawrence Livermore National Laboratory in December 2022 and repeated in July 2023. And, given the momentum in development the technology will scale up in the next few years lead by the private sector's demonstration machines. It is the scaling up of the process that presents some well documented challenges to commercialization of fusion technology. These common challenges are similarly noted by multiple governmental agencies and engineering organizations around the world such as US Department of Energy, National Academy of Engineering, ITER, National Academy of Science, and the UKAEA to name a few.

Technical Challenges (Issue 4)

The UKAEA sums up the technical challenges quite well in the emphasis of their ongoing research focus for fusion [V] **(Table 1)**.

CHALLENGE AREA	RESEARCH FOCUS
Materials Science	Developing materials that can withstand the demanding conditions inside a fusion machine.
Robotic Maintenance	Maintaining the reactor entirely with robotics and remote maintenance techniques.
Plasma Exhaust	Designing an exhaust system to deal with the intense heat from the plasma.
Plasma Science	Confining fusion fuel in a plasma at temperatures ten times hotter than the sun's core.
Innovative Engineering	Taking advantage of new engineering and manufacturing techniques to advance fusion development.
Fuel Handling	Breeding and handling tritium fuel to power commercial fusion machines.

Tab. 1
Fusion Challenges and Research Focus.

Materials will be needed that can withstand the assaults from products of the fusion reaction. Deuterium-fusion reactions produce helium, which can provide some of the energy to keep the plasma heated. But the main source of energy to be extracted from the reaction comes from the high energy neutrons produced in the fusion reaction. These neutrons will pass through the reactor chamber wall into a blanket of material surrounding the reactor, depositing their energy and heat that can then be used to produce power. (In advanced fusion machine designs, the neutrons would also be used to initiate reactions converting lithium to tritium.) Not only will the neutrons deposit energy in the blanket material, but their impact will convert atoms in the wall and blanket into radioactive forms. Materials will be needed that can extract heat effectively while surviving the neutron-induced structural weakening for extended periods of time.

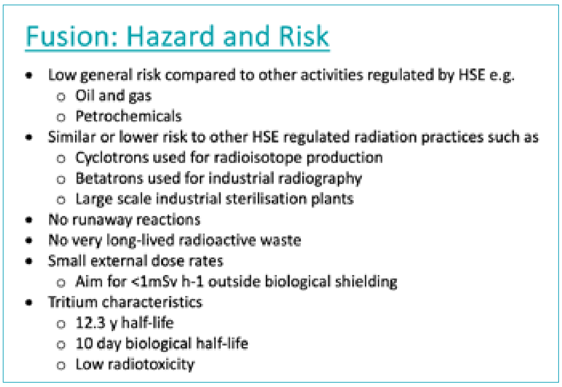
Methods also will be needed for confining the radioactivity induced by neutrons as well as preventing releases of the radioactive tritium fuel. In addition, interaction of the plasma with reactor materials will produce radioactive dust that needs to be removed. Building full-scale fusion generating facilities will require engineering advances to meet all of these challenges, including better superconducting magnets and advanced vacuum systems. The European Union and Japan are designing the International Fusion Materials Irradiation Facility, where possible materials for fusion plant purposes will be developed and tested. Robotic methods for maintenance and repair will also have to be developed. [VI]

The UKAEA is leading efforts to incorporate robotics. The Remote Applications in Challenging Environments (RACE) center is developing robotic and remote handling technology. The remote handling system on the European JET tokamak at Culham has undertaken over 30,000 hours of complex maintenance and upgrade tasks. This has enabled RACE to work with industry on robotics and autonomous maintenance systems for future fusion devices. [VII]

Regulatory and Other Challenges (Issue 5)

In addition to the technological challenges, regulatory uncertainty and public acceptance will also need to be addressed. The recent advancements of the private fusion companies have spurred regulators to structure regulatory frameworks for the delivery of fusion technology. The UK and the US have taken the lead in this effort with frameworks established and plans to refine as fusion technology is deployed.

A key point in the newly announced fusion regulation frameworks is that the technology will not be regulated like fission. Regulators are adopting existing regulation used to regulate particle accelerators or other industrial processes to safely regulate the radiological hazard present in the current private fusion machine designs. Supporting this approach is an example in **Figure 4**, from the Health and Safety Executive (HSE) in the UK presentation in August of 2021 at the British Regulatory Horizons Council Fusion Event. [VIII]



Fusion: Hazard and Risk

- Low general risk compared to other activities regulated by HSE e.g.
  - Oil and gas
  - Petrochemicals
- Similar or lower risk to other HSE regulated radiation practices such as
  - Cyclotrons used for radioisotope production
  - Betatrons used for industrial radiography
  - Large scale industrial sterilisation plants
- No runaway reactions
- No very long-lived radioactive waste
- Small external dose rates
  - Aim for <1mSv h-1 outside biological shielding
- Tritium characteristics
  - 12.3 y half-life
  - 10 day biological half-life
  - Low radiotoxicity

Fig. 4
Fusion Hazard and Risk.

These fusion regulatory structures will address the siting and licensing requirements for fusion power plants and, as they are based on less onerous requirements than for fission installations, may allow more flexible deployment. Other countries are beginning to take similar steps as fusion technology begins to develop in their borders. The bigger opportunity and future effort on the regulatory front is the need and chance to develop a global harmonized set of fusion

SUMMARY TABLE ON THE PATH FORWARD FOR FUSION

Challenges confronting the fusion industry	How is the fusion industry approaching these challenges?	Which "Issue" from the article does this relate to?
1. There's the unique, revolutionary scientific achievement to generate energy at scale – a positive energy harvest through atomic fusion – which has no precedent, and to make this function in a sustained process over extended periods of time.	The industry is covering a variety of fusion techniques, and a diversity of engineering and materials solutions, across upwards of 40 commercial developers pursuing 25 different approaches, as well as government mega-projects. The aim and hope is that this leads to steep learning curve with at least one of these players able to pass break-even consistently, to produce energy from fusion at scale.	4
2. There are large technical and materials challenges to produce, capture and transfer the energy produced, e.g.: how to contain plasma at 100 M °C; the effects on materials of high energy neutron irradiation; how to remove the energy created.		
3. The methods and technologies to capture and process the fusion energy and convert that to electrical energy must be made commercially viable.	Most developers are primarily concentrating on demonstration of their chosen fusion concept; however, the leading private developers are also working on their first-of-a-kind power plant designs in parallel. Governments are also funding the development of preconceptual power plant designs – to be delivered in the next 5 years.	2, 4, 5
4. The new kinds of facilities must be constructed and operated safely, reliably, and efficiently.	Relevant regulatory regimes are being put in place, especially in the US and UK. Modern engineering and material techniques are being built to emerging designs to maximise reliability and efficiency. Nevertheless, many other technologies have failed – or taken long learning curves – to transition from basic design ("paper plants") to real world implementation.	5, 6, 7
5. A new supply chain with fusion centric materials and technologies must be grown and established, including suitable skills.	Fusion facilities require a highly specialised supply chain that is being developed. For example, there is no robust global supply of the large superconducting components for fleet production of tokomak plants; this will need to be developed at pace once the concept has been demonstrated and scaling up commences. Similarly, the skills needed to design and manufacture a fusion plant are at present contained in only a few centres.	2
6. This must all be done within acceptable budget and quality parameters.	The pace of development over the next decade will first challenge the developers' ability to constrain cost while maintaining quality, through breakthrough, to commercial viability. It is also important to note that if net energy gain is demonstrated it is highly probable that significant investor interest will follow that achievement. This however will likely be a different investor class, with business models that will require successful EPC performance on a large scale.	1, 6

In the third article in our atw series, we will build on this assessment in the setting of different options the global market can pursue to achieve net zero goals.

regulations to spur deployment in a global market. This is a very similar challenge to what SMR technologies face. The core regulatory constructs that address safety, codes and standards, security, emergency planning, non-proliferation, radioactive waste and decommissioning are nationalized and there is not a supported international agency in place to align and implement a globally accepted set of protocols and regulatory frameworks.

Public acceptance will need to be better understood. The IAEA has done some preliminary polling [IV] in this space. The UK has also published some preliminary polling on the technology as seen in **Figur 5** [X], but much more needs to be done globally to get a solid foundation established to address the public's view of fusion close current knowledge gaps.

Supply Chain Development (Issue 2)

Fusion presents another supply chain dilemma. Fusion technology will require highly specialized and precision manufactured components. A robust supply chain will have to deliver components such as high-powered magnets, lasers, power electronics and semiconductors, ultra-efficient heat management technologies, and materials that can withstand the extreme conditions in a fusion vessel.

And it will need to supply the fuel that powers the technology. The FIA published [XI] its first supply

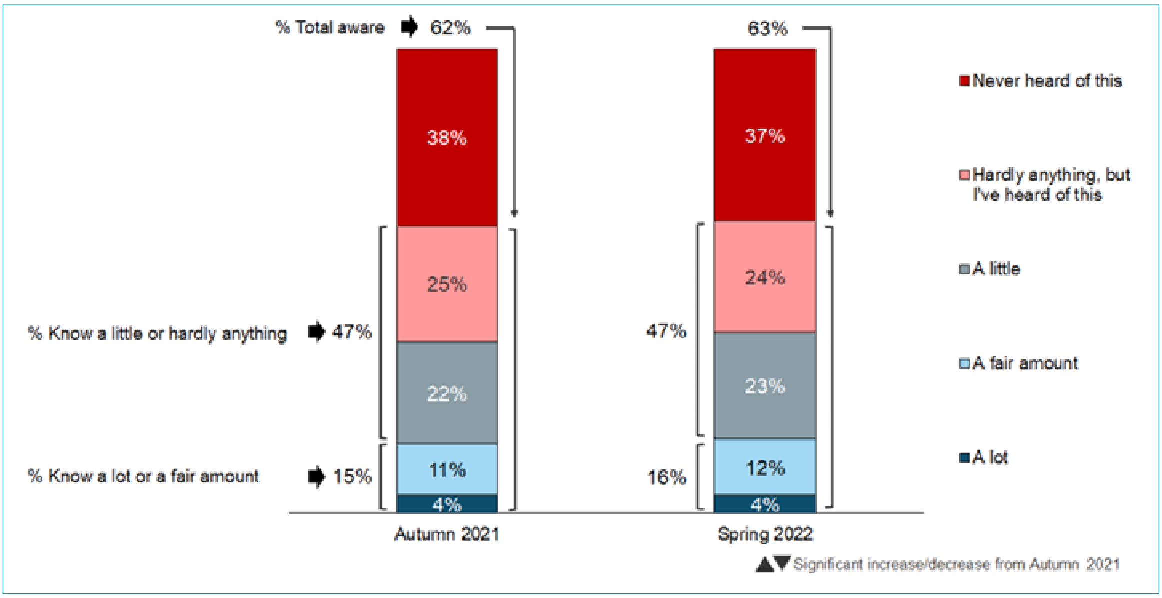


Fig. 5
Awareness of fusion energy (based on all people), Autumn 2021 and Spring 2022.

chain analysis earlier this year. Some key supply chain opportunities and challenges relayed in that report are:

- Fusion developers spent over $500m on their supply chain in 2022.
- Spending by fusion developers is set to grow to over $7bn by the time they build their "First of a Kind" power plant, and potentially trillions in a mature fusion industry (timescales for this range from 2035–2050).
- Contrary to widespread belief outside the industry, there was limited concern about geopolitical supply risk. No critical parts or materials face insufficient global supply or come solely from unstable countries. Where such risks exist, it is considered manageable with foresight and planning.
- Recommendations focused on increased investment, both public and private into fusion to build confidence about the necessity of supplier scale, new lines of communication between the industry and its suppliers, and standardization of regulation to eliminate regulatory uncertainty to increase confidence in long-term investments.

Globally, research and engineering efforts are continuing to address all of these challenges, in the developing supply chain, national laboratories, academia and in the efforts of the private fusion developers.

What will fusion energy cost? (Issue 1)

It is challenging to understand with limited information available on the economics of the technology. One noted publicly available study on fusion economics by ARPA-E in the United States was updated in 2020. [XII] The results of that updated study estimated construction costs between $2,400/kW and $3,300/kW, and an average cost of electricity in the $50/MWh range for an ~500 MWe power plant. If these are indicative of where the sector can deliver the technology, it could be an attractive set of economics for fusion energy. Interestingly, these capital cost estimates are similar to those that were made for GEN-III+ nuclear power plants in 2000–2009. These NPP estimates were based on substantial industry experience – but what they did not predict were the enormous cost overrides due to complexity and general implementation problems with (nearly) all megaprojects in OECD countries. This experience points to one of the major challenges still ahead for fusion plants. (Issue 4, Issue 6)

In our judgement therefore, a critical success factor for fusion implementation projects will be how to judge and incorporate the necessary learning curve from technological feasibility, through industrial application, practical implementation, to commercial operation and performance optimization.

How do privately funded fusion developers contrast with public mega-projects (ITER)?

Fusion technology is advancing in government funded and privately funded approaches. **Figure 6** provides a high-level summary of three primary fusion technology approaches and some examples of entities developing each approach.

Speed of business vs. speed of government

The seven decades of research in the development of fusion has historically been led by Government funded programs around the world. The emergence of private developers in the fusion sector in the last five to ten years has significantly changed the technology development landscape. Both private and federally

MAGNETIC CONFINEMENT FUSION	MAGNETIZED TARGET FUSION	INERTIAL CONFINEMENT FUSION
• Strong magnets are used to confine the plasma	• An array of lasers or other drivers drive a pressure wave into a plasma target (or sphere), compressing the plasma to fusion conditions.	• Powerful lasers or ion beams compress a pellet of fusion fuel to the right temperatures and pressures
• **Plasma Density:** Low density • **Duration:** Continuous operation • **Public Examples:** Tokamaks, stellarators (ITER, Wendelstein 7-X) • **Private Examples:** Commonwealth Fusion Systems, Tokamak Energy, Thea Energy, ENN, Type One Energy	• **Plasma Density:** Medium density • **Duration:** Microsecond (pulsed) • **Public Examples:** FRX-L, FRCHX • **Private Examples:** General Fusion, Helion, Zap Energy, TAE Technologies	• **Plasma Density:** Extremely high density • **Duration:** Nanosecond (pulsed) • **Public Examples:** National Ignition Facility • **Private Examples:** First Light, Marvel Fusion

Fig. 6
Fusion technology approaches and developers.

funded programs work toward the same goal of delivering fusion technology, but the programs progress at different rates. One at the speed of government which represents a very methodical and risk averse approach and another at the speed of business that is entrepreneurial and has a higher risk tolerance. There are different drivers behind the approaches as well. The private sector has investors that are expecting a return on investment whereas government programs are steadily advancing the science to commercialize the technology.

A great example of how this has worked is SpaceX and NASA in the United States. The entities were focused on a common desired outcome, however SpaceX was able to “move fast and break things” implementing the now famous start up focused quote attributed to Facebook’s Mark Zuckerberg. SpaceX had three Falcon 1 initial launch failures before getting it right and eventually reaching a 99 % success rate with Falcon 9. NASA as a taxpayer funded agency could not take that kind of approach.

This analogy is a good parallel to how fusion technology is being developed globally with government and privately funded programs – risk averse and risk tolerant. In football parlance the world is taking multiple shots on goal in anticipation of someone scoring. Who and when and how many that will be is yet to be determined, but everyone is on the field trying to make it happen.

At the same time, this also explains why all this activity is happening now:
Whether Space X or commercial fusion ventures: none of these private risk takers would be on the field taking shots if the 70 years of large Government programs hadn’t brought the technology close enough to the goal. Of course, what is important in an industrial, business context: if you aren’t on the field now, you’ll likely miss the game. But it is not necessarily the first to score a goal that will win the game.

What needs to happen for fusion to be an investment grade meaningful contribution to global energy supply?

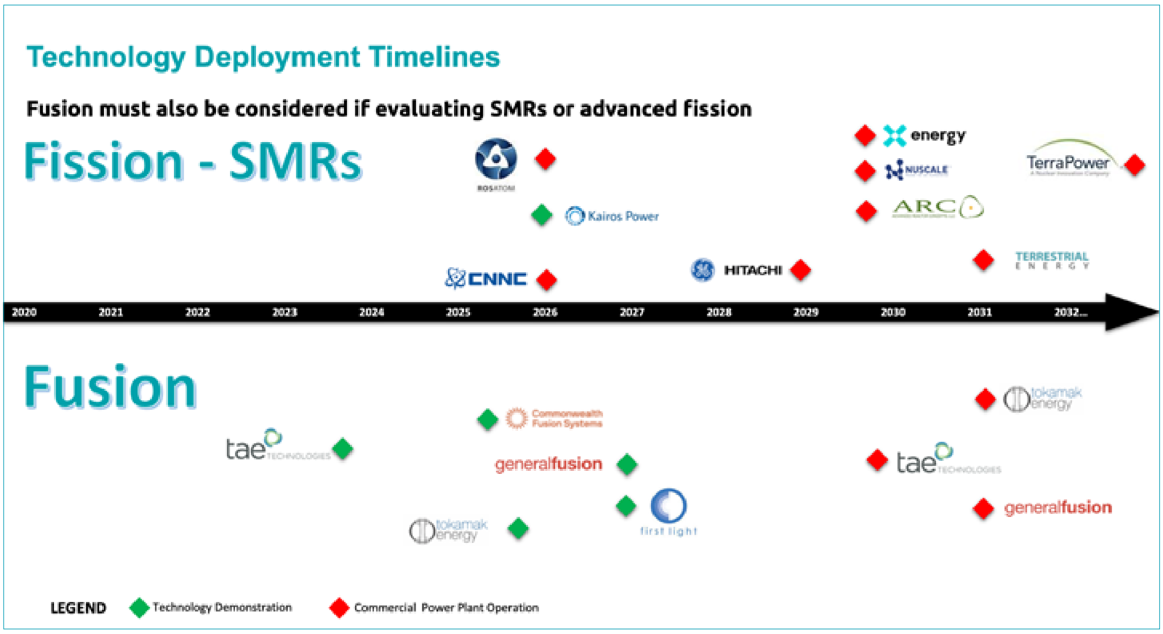
The short game

Private development of fusion is moving forward more rapidly with the noted increase in private funding. Several are moving ahead on a parallel path of building demonstration machines as well as developing commercial prototypes. The first step is a demonstration machine that will validate proof of concept. Most of these machines will not produce electricity. The major milestone to be achieved in demonstration is Net Energy Gain – Producing more energy with fusion that is put into the reaction to make it happen. In addition to Net Energy Gain, one developer is working on a concept to prove a direct energy conversion process (fusion to electrical energy). In parallel the developers are designing their power producing machines. These designs will be influenced heavily by the outcomes of the respective demonstration machines.

Several of the leading private fusion companies – 2 in the UK, 2 in the US and 1 in Canada – have technology demonstration machines under development planned for operation between 2024 and 2027, and most have also published plans to have operational power plants connected to the grid in the early to mid 2030’s. Further private endeavours, including 3 in Germany, are working to similar ambitious goals.

The demonstration machines are being designed, developed, and delivered in parallel with the designs for fusion power plants. As noted in the FIA survey most of these designs have a stated goal to go operational in the early 2030’s with some as early as 2028. [XIII]

Demonstration of technology will be a game changing milestone for the developers. Those with



| **Fig. 7**
Fission and Fusion technology timelines.

successful demonstration (net energy gain) will most likely reap the reward of increased private investment to further to development of the technology. The market will make the decision on which technology and approach will be successful. This will also support the delivery timelines of the early 2030's. It is the "move the deployment timeline to the left" for a more rapid delivery of the technology that increases the potential impact of fusion technology to make a marked difference in combating climate change. The success of demonstration should also trickle down to the supply chain for the sector. Long-term confidence in the sector will be bolstered with proof of concept of fusion technology driving suppliers to increase engagement to advance technology delivery.

It is worth noting, and as depicted on the figure above, that the deployment timelines projected by the private fusion companies are very similar to those forecast by the SMR technology developers. It will be interesting to see how the future market responds to an ability to decide on a fusion or a fission technology. (Issue 8)

Fusion technology is also similar to SMRs with respect to the needed changes to energy market design. Current energy market designs do not always compensate best use of proposed fusion technology characteristics such as load following and load shedding. In order to encourage and support fusion technology deployment at scale, energy market mechanisms will have to be revised to recognise such advantages. (Issue 3)

The long game

PAs noted, governments and industry are also supporting and taking an increased interest in fusion technology development. They are also looking at timelines that deliver technology in the 2040 to 2050 timeline. Evidence of this can be relayed in how the UK and the United States governments are supporting private fusion technology commercialization.

US DOE Cost Share Program

In March 2022 the Biden administration announced at the White House its "Bold Decadal Vision" for the development of fusion energy. In this vision the US DOE will launch an agency-wide initiative, coordinating across program offices, to develop a decadal strategy to accelerate the viability of commercial fusion energy in partnership with the private sector. This is supported further with the passing of the Energy Policy Act of 2020 that created a milestone based cost share program (public private partnership) for the development of fusion technology. In May 2023 the US Department of Energy announced funding awards totaling $46 M USD to 8 companies to initiate the program with a goal of producing a preconceptual fusion power plant design before the end of this decade.

STEP in the UK

In 2019 the UK government committed £ 220 M to the development of the conceptual design of a fusion power station – the Spherical Tokamak for Energy Production (STEP). The program has been steadily advancing with a site located and plans to deliver the program in three phases:

FUSION IN GERMANY – A TURNING POINT

As reported e.g. in the recent KTG-Fachinfo 13/2023 (also in this publication, see page 63) the German federal research Ministry, Bundesministerium für Bildung und Forschung – BMBF, has announced a strategic initiative to advance and diversify the development of fusion technology in Germany with a goal of bringing a technology to market sooner than current plans aligned to ITER and DEMO deployment. Specifically, BMBF has published a Recommendation by an international expert committee and a ministerial Position Paper, as the basis for a consultation process to be conducted with industry and science[FN1].

Compared to the US and UK programs mentioned above, this German initiative appears to differ in two ways:

(1) as an initiative by BMBF this does not yet reflect a robust national strategy and policy; the breadth of support for this initiative is not yet fully assimilated across the German Government and across political party lines; and, certainly partly as a result:

(2) the approach seeks to create and extend the necessary ecosystem, more like an R&D support program rather than an end-result focused vision/mission. It is noted that the Max Plank Institute in support of this BMBF initiative has stated a longer-term view of commercialization of fusion energy (mid-century).

Nevertheless, the BMBF initiative sets and highlights a bigger stage for fusion. Beyond traditional science programs it creates a bigger platform for 3 private German fusion developers who have in aggregate over $200 M USD in funding and each pursuing a different approach to deliver fusion energy (Laser, pB11, and Stellarator approaches) and, significantly, for industrial interests along the specialized supply chain. In a recent announcement, one of these private companies stated they would pursue the advancement of their technology in a public private partnership in the United States. Therefore, it is a prudent first step for the German government to move forward to provide additional support for the development of fusion technology in Germany. The existing capabilities and infrastructure with additional support can further research, create platforms for public private partnerships and shorten the timeline to commercialized fusion energy in Germany.

Germany will face many if not all the same challenges identified for the fusion sector as a whole. However, given the existing fusion technology infrastructure in the country, the broader high tech supply chain capabilities, and the phase out of carbon free fission produced electricity in the country, a replacement carbon free base load/load following source like fusion energy needs to be deployed to diversify Germany's generation portfolio and support the weather dependent generation in the country. These decisions need to be made in the context of where the global fusion sector sits, its noted near-term performance milestones and level of investment supporting federal and privately funded programs.

Hence, this will be a real turning point for Germany in deciding if it will or won't be supporting the development of new carbon free generation source for the country and an opportunity to be a part of a global supply chain to address global warming with clean fusion energy.

[FN1] BMBF Positionspapier Fusionsforschung (06/23, German): https://www.bmbf.de/SharedDocs/Publikationen/de/bmbf/7/775804_Positionspapier_Fusionsforschung.html and international experts MEMORANDUM LASER INERTIAL FUSION ENERGY (05/23, English): https://www.bmbf.de/SharedDocs/Downloads/de/2023/230522-memorandum-laser-inertial-fusion-energy.html

Phase 1: The aim for this first phase of work is to produce a 'concept design' by 2024. This means an outline of the power plant, with a clear view on how we will design each of the major systems.

Phase 2: Through phase 2 the design will be developed through detailed engineering design, while all consents and permissions to build the plant will be sought.

Phase 3: Construction of the prototype power plant will begin in phase 3, targeting completion around 2040. [XIV]

Diverse Interest in Technology Deployment

There is a broad and diverse global interest in the development of fusion technology. Sample investors in the sector include large oil and gas companies like Chevron Technology Ventures, ENI, Equinor and Shell Ventures. Investors also include Jeff Bezos' Bezos Expeditions, Bill Gate's Breakthrough Energy Ventures and sovereign wealth funds Temasek and GIC from Singapore.

Fusion is also migrating to the list of innovative technologies large utilities are monitoring to help them meet their long-term generation decarbonization goals. This includes utilities Duke Energy, Southern Company and the Tennessee Valley Authority in the United States, E.ON in the UK, Bruce Power in Canada [XV], and Engie [XVI] in the EU to name a few.

Conclusions

The potential for development of fusion energy seems more probable today than at any point in history. Private investment in the sector now surpasses ongoing government funding. That has allowed private companies to move "at the speed of business" and fusion demonstration machines will be going online within 2 years. The "speed of government" programs are still present and methodically working on de-risking the commercialization of the technology. This is a great parallel approach that is mutually beneficial. Commercial fusion is coming, but increased momentum does not guarantee success – especially individual develop success – and significant challenges are still faced by the sector. Materials challenges, plasma confinement and control challenges, and energy conversion systems challenges that are not required for demonstration machines will need to be tackled to deliver a viable fusion power plant. These are not easy obstacles to solve, and we will have to wait and see if large investment continues so they can be addressed to support deployment of fusion power plants in the early 2030s.

So, as we conclude this second article in our series, we see an emerging fusion energy sector facing many of the same issues as the SMR sector. The nuance here is that fission technology is proven, and just needs confirmation of concept in the variety of SMR designs being brought to market. Fusion technology does not have that advantage. However the fission sector is burdened with historical performance in construction and cost overruns for large scale nuclear fission projects, as well as an image problem, that are that are not being applied to fusion technology. Governments and investors are faced with a unique decision – do I start building advanced fission technology or do I wait for delivery of a game changing carbon free fusion technology. We will address this question in our final article in this series in atw – International Journal for Nuclear Power.

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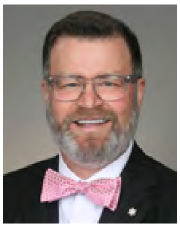

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