Written Evidence Submitted by Tokamak Energy Ltd (SPA0087)

Tokamak Energy is a fusion energy development business with exciting new technology and bold ambitions. Our goal is plentiful, economic fusion on earth, but our technology – particularly our high temperature superconducting magnets – may have many applications in space

1. The Government's approach to a space strategy must be holistic. Some of the bold new technologies required for the UK to successfully implement and execute this strategy already exist in a number of different sectors, including commercial fusion development. There will be great benefits to the UK in realising the synergies between different areas of scientific research.

2. We agree that the satellite industry is one of the fastest growing in the world and Britain has had a strong position in the research, development and manufacture of satellites and the systems that make use of them. If the UK is to be a leading force, we agree the need to develop and execute a space strategy which builds on our strengths and equips us for the future.

3. We regard it as essential that the UK space strategy should not be limited to research, development and manufacture of satellites and the systems that make use of them, but should also encourage technology development, based on existing strengths, that gives the UK options for longer term opportunities including travel to Mars, the asteroids and beyond.

4. We offer the Tokamak Energy technologies of high temperature superconducting (HTS) magnets and compact fusion power plants as examples of technology options that could be nurtured within an effective UK space strategy.

5. Our HTS magnet technology has been developed with assistance from CERN with magnet design and test. The magnets are robust, compact, lightweight, easy to cool, high field and low energy consumption, making them ideal for space applications where magnetic fields higher than available from permanent magnets are required. They have near term applications for plasma thrusters for satellite manoeuvring and longer-term applications for magnetic shielding.

6. On 15 June 2021, I made an invited presentation to the ASCENDx event of the American Institute of Aeronautics and Astronautics on the subject of fusion and fusion-related technologies for space power and propulsion. These subjects may seem too futuristic for a UK space strategy, but the pace of innovation in space technologies, driven by the rapid increase in private investment, means that the future may arrive much sooner than expected.

7. It will be important to include space in the remit of ARIA so that early stage, but potentially high impact, technologies can be encouraged to develop.

We have other observations that may be helpful in the context of this inquiry

8. It is crucial to encourage private investment in R&D intensive SMEs capable of expanding fast and developing and delivering the technology of the future. Enhancing R&D tax credits for SMEs will achieve this goal.

9. Enhancing R&D tax credits can help make the UK a scientific superpower. Enhanced R&D tax credits are particularly important at this moment of economic recovery and before the new ARIA agency is up and running.

10. Fusion energy is the best possible example of the ambition of a scientific superpower and the UK has the right starting position of world leading fusion energy research at UKAEA Culham Laboratory and at many of the country's leading universities. Tokamak Energy and other ventures have shown that it is possible to attract substantial amounts of private investment for development of fusion energy, despite the relatively long timescales before fusion power plants will be ready for widespread deployment.

11. Fusion power from compact tokamaks is a technology that can be developed for global deployment in the 2030s and beyond, fast enough and at large enough scale to make a major contribution to achievement of net zero carbon emissions by 2050. Or we could do too little, too late.

12. Spin-off technologies from development of fusion energy such as high temperature superconducting magnets, high heat load materials and robotics for remote handling can reinforce the UK's position as a scientific superpower and can spawn new clusters of science-based businesses.

13. High temperature superconducting (HTS) magnets have huge potential to transform other industries in the medium to long term. The UK already has a globally competitive cluster of superconducting magnet businesses. The new technology of HTS magnets can stimulate further growth of this cluster.

Specific Policy Suggestions

14. The best government support mechanisms are those that directly encourage private investment in highly desirable technology development.

Improvements to R&D tax credits

15. In the short term the Government should announce an increased rate of payable R&D tax credits for SME radical innovators tackling grand challenges including space technologies. Using the established and trusted mechanism of R&D tax credits is the surest way of achieving rapid impact.

16. R&D tax credits play to the strengths of the UK economy (scientific excellence, entrepreneurial spirit and a history of bold innovation). We now need these strengths more than ever.

17. R&D tax credits are well targeted at robust R&D intensive SMEs that are well placed to attract private investment and deliver future economic growth.

18. Such improvement to the rate of R&D tax credits could be reserved for businesses able to tackle major challenges and opportunities for the future – such as climate change, space or medical emergencies - to ensure that the UK has as wide a range of "technology options" as possible. Given how difficult it is to predict what will be needed to deal with future crises or opportunities it is important to have such technology options available. This will ensure that the UK will benefit economically as these technology options are deployed. It will also send an important signal that the Government is not just learning lessons from the Covid-19 crisis, but is actively improving policy measures in response.

Learning lessons from US policy

19. Tokamak Energy has participated in a series of ARPA-E workshops on fusion energy since 2017 at the invitation of the US Department of Energy. These workshops are valuable because they bring together innovators, entrepreneurs and investors interested in tackling the same challenge in different ways.

20. ARPA-E has several programs that can support fusion energy development with a total budget of some $110m just for commercially viable fusion energy.

21. We welcome the news of the ARIA – Advanced Research and Invention Agency - modelled on the US DARPA programme. However, ARIA will not have an impact in the short-term and it is certainly not an alternative to R&D tax credits.

22. The UK can learn from other examples of programmes that work well in the US.

23. For example, US Department of Energy has a program known as the Innovation Network for Fusion Energy, or INFUSE, to encourage private-public research partnerships to tackle challenges in fusion energy development. Tokamak Energy Inc, a wholly owned subsidiary of Tokamak Energy Ltd, has won 5 grants under the INFUSE program. They are valuable because they give access to unique knowledge and technology. The UK Government could use a programme like INFUSE to allow UK companies better access to Government Laboratories in fusion and in other areas of radical technology development. The programme could be extended to University-business collaboration.

24. US DOE has also held a formal consultation on a "cost share" program for fusion power prototype devices. This is very timely as it resembles the NASA COTS program that helped finance the early years of Space-X and resulted in major US successes with commercial space launchers. We expect further developments on this US Cost Share Program for Fusion Energy in the next 12 months. ARIA could take a similar approach of competitive cost-share programmes to encourage private co-investment in radical innovation.

25. ARIA could consider new bilateral agreements – eg with the US which has a far better track record of technological innovation and commercial success than the EU or the UK. Such agreements could have joint calls for proposals open to companies in both countries and could allow ARIA to learn quickly from US experience.

About Tokamak Energy

26. Tokamak Energy Ltd is a private company that aims to accelerate the development and deployment of commercial fusion energy. The company is a spin-out from UKAEA Culham Laboratory near Oxford which is currently the world-leading centre for magnetic confinement fusion energy research. Fusion research is one of the very few areas today with enormous long term global economic potential where the UK has a distinctive global lead. We are seizing the moment when private investment in fusion energy around the world is beginning to accelerate.

27. Our approach at Tokamak Energy is to combine the new technology of high field strength, high temperature superconducting (HTS) magnets with the efficiency advantages of the spherical tokamak as pioneered at Culham Laboratory in the 1990s. The result is a better, stronger, smaller magnetic "bottle" to confine a plasma at high density and pressure for a long time with no energy dissipation in the magnets.

28. Fusion energy from tokamaks will be clean and safe. There is no emission of carbon from combustion, no long-lived radioactive waste and no risk of meltdown or proliferation. There is plentiful fuel for mankind's total energy needs for millennia (deuterium is abundant in sea water; tritium can be bred in situ from lithium) and the energy density of the fuel is several million times greater than coal or oil.

29. Tokamak Energy has received investment totalling over £117m to date, mainly from private investors such as David Harding and Legal and General Capital, and including the UK Innovation and Science Seed Fund (UKI2S) and the Institution of Mechanical Engineers. In addition, Tokamak Energy has received grants from the Government's Advanced Modular Reactor competition, the Energy Entrepreneurs Fund and the UKI2S Accelerator Programme for Technology Development from Innovate UK.

30. Tokamak Energy partner organisations in the US, Princeton and Oak Ridge National Laboratories, have received $4m from US Department of Energy to assist with scientific progress on Tokamak Energy's latest prototype, ST40. Tokamak Energy Inc (a wholly owned subsidiary) has won five grants worth $1m from the US Department of Energy INFUSE program for technology development projects at Princeton, Los Alamos and Oak Ridge National Laboratories.

31. Our total UK Government grant funding to date is £12.5m, so we have been able to achieve exceptional leverage of private investment compared to grant funding. This is important as bold ventures that become too dependent on grant funding too soon are less likely to attract more private investment and achieve commercial success.

32. Tokamak Energy has built three prototype tokamak devices, the latest of which has already achieved plasma temperatures hotter that the centre of the sun. The second pioneering device had all its magnets made from high temperature superconductor and was on display at the Science Museum from October 2018 to May 2019. The third device, the ST40, has been successfully upgraded and is scheduled to reach 100 million degrees, the temperature threshold required for commercial fusion on earth, by the end of 2021.

33. Tokamak Energy consultants and staff published a paper in Nuclear Fusion in 2015 "On the power and size of tokamak fusion pilot plants and reactors" showing that tokamaks do not have to be huge to produce power and that low-power, high-gain compact

tokamaks are feasible. This paper has become the most downloaded ever from the journal's web site.

34. More recently our consultants and staff published a paper in Plasma Physics and Controlled Fusion "Fusion performance of spherical and conventional tokamaks: implications for compact pilot plants and reactors" showing that spherical tokamaks have a huge efficiency advantage compared to conventional tokamaks. This efficiency advantage translates directly into commercial advantage.

35. Members of the Tokamak Energy Scientific Advisory Board were prominent in organising a Royal Society meeting in March 2018 entitled "Fusion energy from Tokamaks, can development be accelerated?". Acceleration is possible now because of: better scientific understanding of the efficiency of tokamaks; the availability of new, reliable, high temperature superconductors suitable for high field magnets; and a range of other new technologies including AI and 3-D printing of complex materials that can speed up both R&D and deployment.

36. If UK companies such as Tokamak Energy can indeed develop and deploy new technologies to deliver clean power at large scale then the whole world can benefit from reduced carbon emissions, while the UK can capture many of the economic benefits through high value supply chains.

37. There is now increasing international competition among privately funded fusion ventures, with some 25 members of the international Fusion Industry Association – which held its first meeting outside the US in London in early March 2020. Tokamak Energy is well placed to win the competitive race due to its solid scientific foundations, track record of delivering record-breaking prototypes, robust and commercially viable fusion power plant concept design, strong IP portfolio, outstanding engineering and business leadership team and its fund-raising to date – raising £100m since early 2018. However, there are serious and well-funded competitors in the US, Canada and now in China. These competitors are benefitting from rapidly increasing support from their governments.

38. The Fusion Industry Association has a sub-group of companies developing technology for space, including fusion propulsion systems for future missions to Mars, the asteroids and beyond.

39. Tokamak Energy is the world leader, by far, in the engineering of robust high field HTS magnets, a technology that is essential for commercially viable fusion energy. Our record breaking HTS magnet demonstrator was recently tested at CERN. HTS magnets have many attractive applications outside fusion including: space propulsion and shielding; motors and generators for wind turbines and electric aircraft; inductive heating for energy efficient industrial processes; proton/hadron beam cancer therapy; particle accelerator magnets; chemical analysis and high value scientific instruments.

40. The Oxford area already has a globally competitive cluster of high field superconducting magnet businesses. The local human capital and supply chain mean that it is quite feasible for HTS magnets for all these exciting and challenging applications to be developed and manufactured in the UK. Tokamak Energy would be pleased to play its part in encouraging and enabling the development of these additional applications, so long as this does not detract from its main mission of fusion energy.

41. The balance of risk and reward in fusion energy is changing quickly. The reward is getting closer in time and larger in magnitude, especially in view of the deep decarbonisation necessary in the 2030s. Meanwhile the risk is reducing as technologies such as high temperature superconducting magnets are developed, enabling more compact systems and better strategies for rapid innovation. The risk for the UK of not pursuing fusion energy in private companies and of missing the opportunity is increasing.

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