Written Evidence Submitted by Tokamak Energy Ltd (RFA0076)

If there was a new safe, clean energy technology, based on world-leading expertise in the UK, that could have a major global impact on carbon emissions by the 2030s and be an important source of clean energy for centuries to come…

…then we would make every effort to develop the technology quickly in the UK, even if there are great challenges in the technology development, wouldn't we?

The good news is that there is such a technology – fusion energy from compact spherical tokamaks with high temperature superconducting magnets.

Summary

- Fusion can have a huge impact on 2050 carbon targets and can be the main source of safe, clean energy for millennia into the future. The UK has an immediate opportunity to build on its world-leading position in fusion energy research and win the race to deploy the technology
- Government backing for fusion research remains strong as the commercial opportunities emerge
- A new UK research funding agency could address the UK's chronic problem of failing to turn world-leading research into commercial and economic success.
- Tokamak Energy is building on world-class UK strengths in Fusion Research and Superconducting Magnets
- Tokamak Energy faces increasing international competition, but is well-placed to maintain and extend its lead
- Speed of execution is important in radical innovation. We present a new idea, ARPA-BOOST, which can be delivered rapidly and have immediate effect ahead of establishment of a new agency

Introduction

1. Tokamak Energy Ltd is a private company that aims to accelerate the development and deployment of fusion energy. The company is a spin-out from UKAEA Culham Laboratory near Oxford, the world-leading centre for 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.

2. 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, 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.

3. 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 produced in the device from lithium) and the energy density of the fuel is several million times greater than coal or oil.

4. 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 BEIS Advanced Modular Reactor competition, the BEIS Energy Entrepreneurs Fund and the UKI2S Accelerator Programme for Technology Development from Innovate UK. Tokamak Energy partner organisations in the US, Princeton and Oak Ridge National Laboratories, have received $4m from US Department of Energy to collaborate with Tokamak Energy on our latest device, ST40.

5. Our total UK Government grant funding to date is £12.5m, so we have been able to achieve about 10 to 1 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.

6. 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 was the world's first tokamak to have 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, is now being upgraded to reach 100 million degrees, the temperature needed for commercial fusion power, within the next year. Our next device, the ST-F1, will be an investment of many hundreds of millions of pounds. It is to be constructed by 2025 and will demonstrate efficient fusion power on an industrial scale.

7. We would like to build the ST-F1 in the UK.

8. 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.

9. 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.

10. 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.

11. Fusion has particular promise as a source of industrial heat that could also be used to produce hydrogen or carbon neutral fuel for transport and for domestic heating.

12. There is now increasing international competition among privately funded fusion ventures, with some 20 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.

13. 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 has now been shipped to CERN for tests that could achieve even higher field strengths and break new records. HTS magnets have many attractive applications outside fusion including: motors and generators for wind turbines and electric aircraft; inductive heating for energy efficient industrial processes; proton/hadron beam cancer therapy; accelerator magnets; chemical analysis; medical imaging and high value scientific instruments.

14. 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.

15. 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.

16. The balance between the role of public and private sectors in fusion energy is also changing rapidly. UK Government announced a new "Spherical Tokamak for Energy Production" (STEP) project in January 2019. The concept of STEP is similar to the Tokamak Energy approach to fusion power and provides important additional scientific validation. The Government should recognise that its own scientific research establishments work cautiously and are not are not configured for accelerated innovation, development and deployment of new technology. If the UK is to win the race for commercial deployment of fusion energy then it needs to enable innovators, engineers and private investors to pursue technological innovation as rapidly as possible.

17. The March 2020 budget made large commitments to increase scientific research expenditure; to establish an advanced projects agency and to increase funding for fusion and other clean energy technologies. These commitments are welcome and they do reinforce the positive message of investing in economically purposeful science and technology for the future.

18. R&D tax credits also have a valuable role to play in ensuring that private investors have a fair balance of risk and reward when investing in some of the most important future technologies for the UK economy and for society at large.

19. We are pleased to present responses to several of the specific points raised in the call for evidence.

What gaps in the current UK research and development system might be addressed by an ARPA style approach?

20. UKRI invests heavily in basic research and has an excellent track record in this type of research that may lead to applications in 20 to 30 years' time. An ARPA style approach should focus on radical new ideas with huge potential impact that emerge from this basic research, rather than focussing on incremental innovation arising from applied research.

What should be the focus be of the new research funding agency and how should it be structured?

21. The focus of the new agency should be on the high-risk approaches to major challenges with global economic impact – creating the technology and economic options for the future. The new agency should certainly focus a significant proportion of its resources on the challenges of climate change, including radical new technologies for energy production.

22. The structure could be modelled on the DARPA and ARPA-E agencies in the US which employ technically knowledgeable programme managers who are empowered to fund high-risk, high-reward research based on solid scientific foundations.

What funding should ARPA receive, and how should it distribute this funding to maximise effectiveness?

23. Government should allocate funding which is appropriate to the size of the economic goals and is large enough to leverage major private funding.

24. The funding should be distributed to projects which have the potential to be transformational for UK business and economics. There is a risk of spreading capital very thinly across many small low impact projects.

25. To maximise effectiveness, UK ARPA should act quickly. There can be long delays in getting any new agency started, but we have a specific proposal, ARPA-BOOST, to have an immediate – and highly desirable – impact.

ARPA-BOOST

26. In the short term the Government should announce an "ARPA-BOOST", an increased rate of R&D tax credits for SME radical innovators tackling grand challenges. Using the established and trusted mechanism of R&D tax credits is the surest way of achieving rapid impact.

27. 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.

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

29. Such improvement to the rate of R&D tax credits could be reserved for businesses able to tackle major challenges for the future – such as climate change 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 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.

30. One approach would be to offer enhanced payable R&D tax credits for all R&D expenditure from now for one year (this only costs money in 2021, only helps companies that continue to do R&D and should help those companies to raise more private investment to spend quickly on R&D).

31. Another approach would be to offer enhanced payable R&D tax credits for all R&D resulting from investment received from now until the end of 2021 – again this would focus the benefit on those R&D companies best able to attract private investment and therefore best equipped to succeed and deliver long term economic benefits. In this case companies might raise, say, £20m now and spend it on R&D over 2 or 3 years getting the higher payable credit for all that time.

What can be learned from ARPA equivalents in other countries?

32. 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.

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

34. In addition the US DOE 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. A UK ARPA agency might use a program like INFUSE to allow UK companies better access to Government Laboratories in fusion and in other areas of radical technology development.

35. DOE has also launched 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 2020. A UK ARPA agency could take a similar approach of competitive cost-share programmes to encourage private co-investment in radical innovation.

36. The UK ARPA agency 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. Such agreements could have joint calls for proposals open to companies in both countries and could allow the UK ARPA agency to learn quickly from US experience.

What benefits might be gained from basing UK ARPA outside of the 'Golden Triangle' (London, Oxford and Cambridge)?

37. The focus of UK ARPA funding should be on the best ideas and proposals, wherever in the UK they are located. However, applicants should be encouraged to consider how they can deliver maximum economic benefit to the UK as their radical innovations come to fruition. This should include evidence of early engagement with a UK supply chain and of the potential for advanced manufacturing in the UK.

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