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GUEST EDITORIAL

The Changing Political Economy of Fusion

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Fusion: The First 50 Years

Before looking to the future, it can be helpful to reflect on the past. The human species demonstrated the ability to liberate vast amounts of fusion energy roughly 70 years ago in the early 1950s. The Ivy Mike device detonated at Enewetak Atoll, part of the Marshall Islands in the Pacific Ocean had a yield equivalent to more than 10 million tonnes of TNT explosive. The story of humanity's development of nuclear fission had started ten years earlier. In that case the development of a controllable reactor predated the development of nuclear explosives. While fission technology started with a stable reactor, fusion researchers have been a very long journey to demonstrate and establish the possibility of controlling a proven and vast energy source for peaceful purposes. It is a journey that is ongoing. Journeys pass milestones. In December 2022 scientists at the National Ignition Facility in Livermore, California announced that they had achieved controlled fusion ignition for the first time. The announcement was more incremental than it might sound and indeed the definition of ignition can be debated, but it was most definitely a major step on the journey towards fusion as a future energy source.

With the first demonstration of human initiated fusion at the Ivy-Mike test having had an unambiguously military orientation, the early decades of fusion development were set against the backdrop of the Cold War. Indeed the National Ignition Facility has its origins in the history of the Cold War. In the 1990s with the Cold War seemingly over, nuclear weapons testing was out of favour. The United States developed NIF as part of a portfolio of activities to underpin the science of thermonuclear weapons in an era without testing. Although developed with a nuclear weapons mission, part of the research agenda was always protected for civilian science.

Not all fusion research has scientific links to the Cold War arms race, in fact it was through the development of magnetically confined fusion science and technology that an opportunity for utterly peaceful science and engineering collaboration presented itself. The ITER large research facility, currently under construction in Cadarache, France, has its origins in a joint communique from US President Ronald Reagan and Soviet General Secretary Mikhael Gorbachev from their summit held in Geneva in 1985 which stated: *"The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentially inexhaustible, for the benefit for all mankind."* [1].

The peaceful development of fusion energy in the late twentieth century was a large state-funded enterprise governed by the realities of political-economy. There was little or no private sector leadership and the way ahead, as the technological challenges were revealed and overcome, was to partner between nation states. European countries came together to develop the JET fusion research reactor constructed in Oxfordshire, England and then a global collaboration was formed for the ITER facility.

Parallels with Space Exploration

Just as peaceful fusion energy research emerged against the backdrop of the early Cold War of the 1950s and grew strongly through the 1960s so did manned spaceflight. From Yuri Gagarin orbiting the Earth in 1961 to Neil Armstrong and Buzz Aldrin walking on the Moon in 1969, the early years of space exploration involved an expensive, technologically challenging activity. Meeting the challenge was a task led by governments. In the United States NASA was the agency responsible for civilian space activity and its

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successes were a source of enormous national pride and global admiration in the late twentieth century.

By the second decade of the twenty-first century something has started to change for both civilian space flight and the peaceful application of fusion energy. Private entities have started to seize the initiative developing ideas and technologies that in some cases had been rejected by governments decades earlier. In both space exploration and fusion developments, we have seen the emergence of new private actors. In the case of fusion these include companies such as Commonwealth Fusion Systems, First Light Fusion, General Fusion, TAE Energy, Tokamak Energy and many more. Melanie Windridge pointed to such issues in a 2020 article in Forbes entitled: The New Space Race Is Fusion Energy [2].

For a fuller elaboration of the historical emergence of fusion as an entrepreneurial endeavour see [3].

Innovation in the Twenty-First Century

It is interesting to pause and reflect as to the causes of the shift away from state-led endeavour towards private agency in both space exploration and the quest for commercial fusion energy. However, we shall restrict what follows to a consideration of fusion energy, but arguably similar drivers have also applied to the space experience. Innovation is perhaps the part of economic activity least governed by economic rationality. One can point to serendipity of invention and discovery, but there is also a strong role played by virtues such as enthusiasm and tenacity. In this author's opinion it is relevant that today's technology billionaires are in their 50s and 60s. Bill Gates, born in 1955, and Jeff Bezos, born in 1964, are each prominent investors in private fusion start-ups. These men, and their peers investing in private space flight, are children of the Cold War. While the digital revolution has brought them enormous personal wealth, technology in their childhood was very different. They grew up in a world of space rockets and nuclear reactors. A thorough examination of the nature of fusion innovation is available at [4]. For a sense of the UK's attitudes to science and technology in the Cold War period the reader is referred to [5].

Writing in 2022 the post-Cold War geopolitical landscape is increasingly hard to assess in the context of the ongoing war prompted by the Russian invasion of Ukraine in February. One other major driver of 21st Century energy innovation is simpler in its message, while being enormously challenging in its implied requirements. That driver is anthropogenic climate change and the need to shift to low greenhouse gas emission energy technologies.

The physics of fusion, and humanity's demonstrated ability to make it happen, point to the promise of fusion as the energy source of the future. We have the prospect of a controllable, low-carbon and relatively compact energy source with the potential to boost economic and social progress for millennia.

It is orthodox to speak of 'fusion power', however this author has long argued that the greatest early contribution of fusion technology will probably not be in the area of low carbon electricity generation, but rather it might relate to the hard to decarbonise sectors. In many cases, and for diverse reasons, the way ahead may be via the commercial production of hydrogen using fusion energy ([3] and references therein). In addition, there are other process heat applications of fusion energy that might be useful in industrial contexts where other low carbon options might prove to be problematic. For example, the natural variability of solar thermal energy might be incompatible with some continuous industrial processes and other processes might present safety issues that militate against the deployment of fission nuclear technology for process heat applications. It is clear that fusion energy technology has the potential to contribute significantly to the Net Zero future. In looking at the long-term history of energy system decarbonisation one can argue that it represents a 60-year journey from 1990-2050. The pioneering Kyoto Protocol of 1997 pointed to the start of the journey being the year 1990. At present much of the world focusses on 2050 as the date by which Net Zero must be achieved. Hence, we can see the decarbonisation story as having two parts of roughly equal duration. The first part is a 30-year journey from 1990 in which thought leadership and motivation mostly came from intellectuals, politicians, governments and think tanks. The tools for progress were fundamental understanding linking to changes in policy and regulation. Now, however, we are in the second 30-year period taking us to 2050. The actors from the first phase remain powerful and important, but the impetus for progress is increasingly coming from industry and a private sector concerned for "ESG[1]" performance and "scope emissions". Increasingly the Business-As-Usual scenario for business strategic planning is a low carbon scenario. Climate change mitigation has moved from option to axiom (in the sense of a self-evident consensus).

Finally, it is important to note that some of the most attractive commercial opportunities for fusion may lie entirely outside the energy industry. For example, fusion based neutron sources have commercial potential in areas such as industrial testing and medical isotope production. Prominent companies in this space have included NSD Gradel in Luxembourg and SHINE in the United States

[1] Environmental, Social and Governance standards, as applied in business management and as described at [6].

among others. In 2021 SHINE merged with like-minded US technology company Phoenix LLC strengthening their joint position in this emerging technology area.

The Role of Private Investors

While private money is starting to accelerate action across the entire economy towards a low carbon future, for fusion the issues remain somewhat special. Fusion is a very high risk and high return prospect. As a commercial proposition fusion is in its infancy. While key aspects of science and technology are being demonstrated, significant business risks remain. Many of these risks still relate to advanced science and technology. While the core science has arguably been demonstrated, depending on the fusion reactor approach in question, the engineering challenges are in every case still significant. Plasma physics remains important, but increasingly materials science, cryogenics and instrumentation are key to engineering success. The journey ahead will require the development of module manufacturing facilities, the building of supply chains and the development of a skilled workforce. Some of these tasks have barely started.

Given the risks, and given the importance of investor psychology, one can argue that fusion requires something more than the usual hierarchy of investors, namely: initial funding from friends-and-family, moving to support from business angels, and then venture capital, towards an Initial Public Offering until finally entering into public-private partnerships for large scale infrastructure deployment. It is interesting to note that investment banks are starting to offer their professional services to fusion start-ups. In January 2023 it was reported that Tokamak Energy had hired JP Morgan to provide assistance in the company's next funding round [7].

For many years fusion was regarded as being simply too risky to gain traction with the usual sequential set of investors. In recent years we have seen that the initial stage of fusion technology development can be accelerated, and indeed made possible, by the personal wealth of an enthusiastic investor acting almost in a spirit of technological philanthropy. Later in the innovation pathway large information technology companies that have grown rich over the last 30 years have the potential to provide start up capital at the level of billions of dollars, even *on balance sheet* if they so wish. Of course, as public companies, these enterprises have an obligation to protect, and grow, shareholder value, but they are so large and so rich that they might argue that the risks are mitigated through a portfolio approach to high technology investing.

There are investors comfortable with the significant downside risks in fusion innovation and indeed comfortable with the very notion that the company that they seek to support is engaged in ambitious technological ideas. Careful investors can recognise the possibility of an overall attractive balance between downside risk and upside opportunity. With that said, there are signs that market interest in fusion commercialisation may have become overheated. In that vein, Daniel Jassby has coined the term Voodoo Fusion to describe fusion ventures that have "never produced any fusion neutrons, but whose promoters claim will put net electrical power on the grid or serve as a portable electric power generator within a decade or so" [8]. Whether or not the sector is now overheated, it would be unfortunate if excessive hubris from either technologists or investors were to undermine the prospects for what could be one of the most important technologies of the late 21st Century.

As we consider future investments into the emerging fusion economy it is important to pause and reflect that the issues extend beyond the usual considerations of financial investment. Indeed, fusion can be analysed as a prospective investment from a five-capitals perspective [9]. Rather than undertaking such a task here, we simply close with a comment that the investment of human capital is as interesting as the investment of financial capital. Young scientists and engineers face a choice as to the sectors in which they will build their skills and pursue their careers. If fusion is to have a prosperous future in the twenty-first century, then it needs to attract such investment of talent. The good news is that this indeed appears to be happening. The new private start-ups provide a working environment and culture quite unlike that in the large government laboratories that dominated fusion R&D over many decades. Those long-established laboratories with their codified and tacit knowledge and their continuing innovative momentum will remain hugely important for fusion's success for many years to come, but increasingly the new start-ups are bringing new money, new talent, new approaches and new resources into the sector and this can only be a good thing.

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