Whitepaper on proposed strategic element for U.S. magnetic fusion research

Importance of an "Alternate Fusion Energy Concepts" program element

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Executive summary of proposed strategic element: The proposed strategic element is a strong research program in "alternate fusion energy concepts" that enables the potential for transformational breakthroughs, with sound, scientific metrics to determine initiation, "graduation" to the next stage of development, and termination. This is consistent with Action B-4 from *Rising Above the Gathering Storm* [1], which states: "Allocate at least 8% of the budgets of federal research agencies to discretionary funding that would be managed by technical program managers in the agencies and be focused on catalyzing high-risk, high-payoff research of the type that often suffers in today's increasingly risk-averse environment." The U.S. Fusion Energy Sciences (FES) program should be no different, especially when the primary ITER-centric program is unlikely to "provide economical fusion energy within the next several decades" (quotation from the NAS charge). For most of its history, the FES program and its predecessors included, in one form another, alternate concepts research, as embodied most recently by the Exploratory Plasma Research (EPR) and Innovative Confinement Concepts (ICC) research portfolios. The EPR/ICC portfolios included, but were not limited to, research on spheromaks, field-reversed configurations (FRC), reversed field pinches (RFP), mirrors, stellarators, spherical tokamaks, Z-pinches, magneto-inertial fusion (MIF), inertial-electrostatic approaches, and dipoles. These were distributed nationally among universities (e.g., Wisconsin, Washington, MIT) and national laboratories (e.g., LLNL, LANL, PPPL). Since about 2012 when FES ended support for nearly all alternate fusion energy concept development, except for spherical tokamaks and stellarators, a very few remnants of this line of work survive only with privately funded companies (e.g., Tri Alpha Energy and General Fusion) and ARPA-E projects.

Scientific and/or engineering opportunity: Key scientific and engineering opportunities provided by a vigorous alternate fusion energy concepts program are (1) continued advancement of the most promising alternate fusion concepts to enable game-changing advances that could potentially lower the cost and shorten the timeline to a fusion DEMO, and (2) exploration of and validation within parameter regimes different from tokamaks, in support of broad predictive capability for fusion plasma physics. Concomitantly, an alternate program, with its smaller-scale facilities and hands-on opportunities, provides a fertile environment for recruiting and training the next generation of fusion scientists. Finally, the potential for breakthroughs that may lead to timely, economically viable fusion power will help keep the overall FES program healthy, socially relevant, and scientifically vibrant.

1. Ensuring U.S. leadership in a field of plasma physics and/or fusion development

Because worldwide fusion energy research is focusing strongly on the ITER-centric development path, it is an opportune/critical time for the U.S. to aggressively (re)establish itself as the clear worldwide leader in alternate fusion energy concept development, as it arguably has been throughout the history of controlled-fusion research. At some point in the next decade, assuming continued progress toward ITER first plasma, the center of tokamak plasma and fusion research will move to ITER. Since the early 1980s, U.S. scientists have led the world in spheromak and FRC research beginning with the CTX spheromak program at LANL [2] and the LSX FRC program at Washington [3], respectively. World-class spheromak and FRC research continues in the U.S. at the University of Washington [4] and Tri Alpha Energy [5, 6], respectively. World-class Z-pinch-based and/or MIF research (supported by NNSA and/or ARPA-E) continues at Sandia National Laboratories [7] and several other universities [e.g., 8]. Finally, until the recent termination of the Madison Symmetric Torus (MST), world-class RFP research occurred at the University of Wisconsin [9].

2. Impact on present and future international activities and collaborations by U.S. scientists

Over the next 20 years, U.S. fusion scientists will migrate to ITER in order to participate in tokamak fusion experiments and to W7-X for stellarator research. If a vibrant research program in alternate concepts can be maintained in the U.S., world scientists will collaborate with the U.S. on this program.

3. Impact on the health of domestic fusion research at universities, national labs, and industry
Healthy research in alternate fusion energy concept development contributes to the overall health of the U.S. FES program via several effects: (1) it provides the potential for disruptive breakthroughs and, ultimately, a more-attractive fusion power reactor, (2) the science and technology developed in the course of pursuing alternate concept research can be and are applied toward solving problems within the mainline efforts and other scientific disciplines (e.g., space physics and astrophysics), (3) research efforts are spread nationally among many universities, national laboratories, and private companies, leading to broad visibility and stakeholder support of fusion energy research, and (4) attracts new students and postdocs to fusion research and provides excitement and a tangible sense of purpose for the existing workforce. One example is the MST (RFP) at Wisconsin, which has been a top fusion science facility for decades [9]; it has produced a continuous string of fundamental plasma science advances with strong connections to space and astrophysical plasmas, and has been the training ground for dozens of Ph.D. plasma physicists. Another example is that a traditionally strong alternate concepts research program in the U.S. (and notably not the mainline tokamak-based program) enabled and attracted private investments (e.g., Tri Alpha Energy and General Fusion) and sponsorship by a new federal agency (i.e., ARPA-E) to fusion energy development. Companies have been formed and are now supported under the auspices of the ARPA-E ALPHA program (Helion, Numerex, MIFTI, HyperV Technologies, ZAP Energy). Others (CT Fusion, Fusion One, EMC2, LPP, HyperJet Fusion) have also emerged.

4. Impact of/from unanticipated events or innovations requiring programmatic re-direction
Over the past 35 years, numerous discoveries and innovations have come from alternate concepts research. For example, helicity-injection current drive was first discovered and developed on a spheromak [10], before it was implemented on NSTX. Tokamak refueling and current drive by spheromak injection was first demonstrated on a university device [11]; this type of technology may ultimately be required on a DEMO-scale tokamak. Other innovative techniques such as steady inductive helicity injection [12] and rotating magnetic field current drive in FRCs [13] have no counterpart in the conventional magnetic confinement community. Much of the initial 3D MHD modeling (e.g., NIMROD) was fostered/motivated by alternate concepts. Of course, the potential for disruptive breakthroughs for enabling timely fusion-energy development via less-complex, lower-cost concepts is the primary, ultimate objective of this proposed SE.

Additional Considerations: The EPR/ICC research portfolio was redirected by FES over the past decade, with little community input, to focus on tokamaks and stellarators, despite clearly articulated research gaps and objectives for other magnetic configurations during "the ITER era" [14, 15]. The fusion community should have a serious discussion recognizing these events and the damage done both to the health of the community and the degraded ability for the program to benefit from innovations.

References:

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