Perspective on Magnetic Fusion Energy Directions from Early Career Fusion Scientists

February 22, 2018

1 Introduction

This report will present the results from a survey of Early Career Fusion Scientists (ECFSs) regarding the direction and strategic plan of the US fusion science program. The group is self-organized and composed of scientists who have received a doctorate within approximately the last 15 years, and who are currently working in Magnetic Fusion Energy (MFE) in the United States.

Motivation for forming a group of ECFS came from discussions following the US Magnetic Fusion Research Strategic Directions community workshop held in Madison, where it was noted that participation from early career scientists was lower than expected. This group was organized to spur participation among the ECFS community to become more engaged in strategic planning activities, and to provide a platform for gathering input to the NAS panel. Because many of the ECFS hope to be involved in magnetic fusion energy research in the coming decades, it is important for the ECFS community to provide input into the planning process.

An initial organizing group was formed during the 2017 APS meeting in Milwaukee that represents a diversity of institutions and universities across the MFE community. The Organizers identified approximately 200 researchers who satisfied the ECFS criteria. Four ECFSs who are senior managers were not included to avoid potential conflicts of interest. The primary method of collaboration was an online forum. 146 members of the ECFS community registered for the forum. The main method of data gathering was a series of polls conducted through the forum with accompanying discussion threads, where discussion was encouraged. Poll questions were both generated by the Organizers and solicited from the general community, with the Organizers deciding on the final poll questions as a group. In total, there were four rounds of polls, each consisting of 6–10 questions. Poll questions typically received between 65 and 85 responses. Section 2 presents an overview of the major findings. The raw poll results data are presented in Appendix A. The Organizers are listed in Appendix B, and ECFS participants who consented to co-signing are listed in Appendix C.

2 Overview of major findings

This section will provide an overview of the major findings. The full poll results are presented in Appendix A.

2.1 Terminology

Many of the questions were asked using the Likert scale, where respondents are presented with a statement and asked to choose from strongly agree, agree, neutral, disagree and strongly disagree. We use the following terms to indicate our level of agreement for Likert scale questions. We **strongly agree** if the total number of respondents who agree or strongly agree is over 80% and the total number of respondents who disagree or strongly disagree is less than 10%. We **agree** if over 70% of respondents agree and less than 20% disagree. We **lean towards** a statement if over 60% of respondents agree and less than 40% disagree. To provide additional information on our level of agreement/disagreement, we also provide the percentage of people who (agree / disagree) in parenthesis after each statement. Note that "neutral" was also an option in most polls. Furthermore, if you are reading the document electronically, the agreement statement also serves as an internal hyperlink to the relevant poll.

The same breakdowns are appropriate with reverse percentages for **strongly disagree**, **disagree**, and **lean against**. On any other combination we describe ourselves using terms such as **neutral** or **split**, depending on the specific distribution of responses.

2.2 Current state of fusion energy

We asked several questions asking respondents to gauge their opinion on the current state of fusion energy research, and their relation to it.

- We **strongly agree** (91 / 1) that our primary motivation for participating in MFE research is the goal of a fusion power plant, and we **agree** (70 / 8) that timely progress toward fusion energy is a necessary condition for keeping us in the field. We **lean towards** (68 / 14) the statement that the US fusion community should focus on energy production (even at the expense of the science). We are **neutral** (15 / 42) on whether the DOE fusion program presently encourages finding innovative solutions to problems, although no respondent strongly agreed with the above statement.

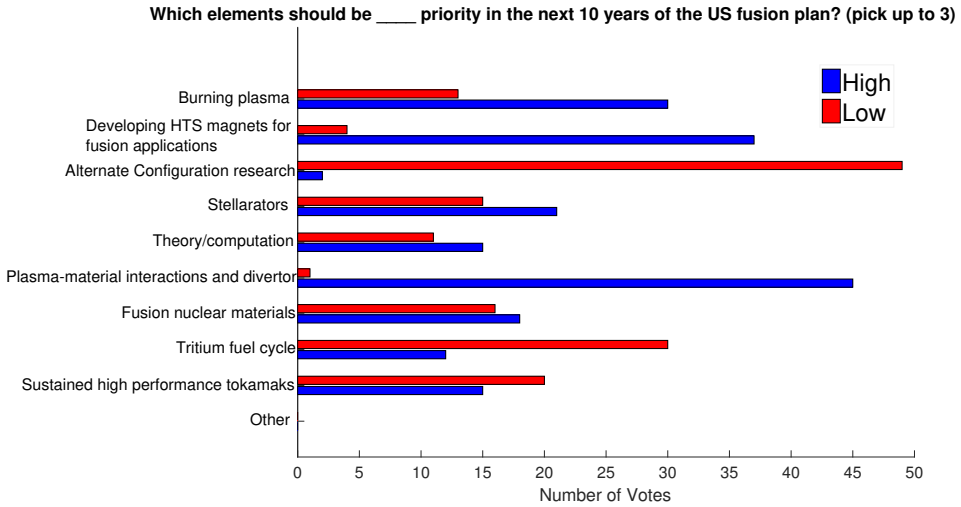
  An underlying theme of these discussions was the lack of urgency in the current US fusion program, and that a more vigorous research program is needed in order to meet the NAS panel's charge that "*economical fusion energy within the next several decades is a U.S. strategic interest*." The fundamental energy mission of fusion science is the overwhelming motivation for the ECFS community, and the rate of progress towards realizing this mission in the near future will play a large role in determining how much of the current ECFS community remains in the US program.

- Regarding the current direction and vision of the field, there was **strong agreement** (90 / 6) that access to a burning plasma should be a major focus of the US fusion program. Regarding the role of ITER specifically and US leadership, we **lean towards** (60 / 17) the proposition that US participation in ITER is important to retaining US leadership in fusion science. However, the ECFS community is **split** (46 / 37) on the question of whether we endorse ITER participation even if it risks the health of the US domestic program. On this question specifically, nearly equal numbers of respondents agreed and disagreed with the proposition, with significantly fewer indicating neutrality.

2.3 Short to mid-term focuses

Polling of the ECFS community identified a series of near-term goals and objectives with broad support.

- The ECFSs were asked to prioritize possible elements of a US strategic plan:



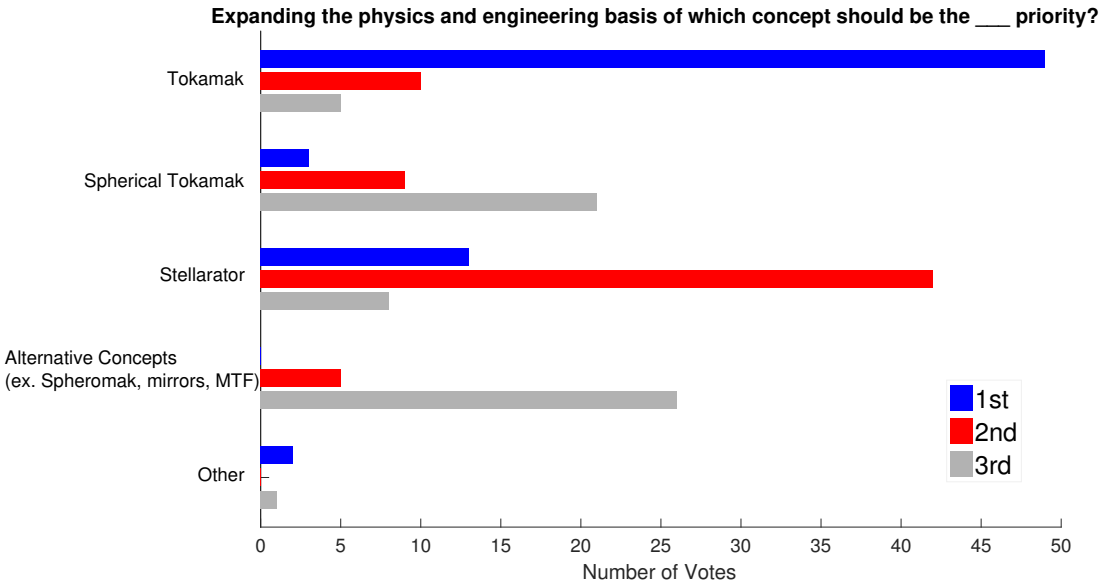
  As shown above, a focus on PMI interactions & divertor studies received the most support. HTS development, and burning plasma research also received significant support as near term priorities. Alternate configuration research was voted to have lowest prioritization. The tritium fuel cycle also was voted to have low prioritization in the near-term. In a separate question, the ECFS community **strongly agreed** (84 / 3) that HTS development should be an immediate high-priority element of a US strategic plan, given its potential to significantly change the state of magnetic fusion research.

- The ECFS community **strongly agrees** (88 / 4) that a new major domestic facility is a necessary component of a US strategic plan. The ECFS community **agrees** (73 / 11) that a redistribution of current funding is expected to support a new national fusion facility, and **agrees** (71 / 13) that reducing funding for current user facilities (NSTX-U and DIII-D) would be acceptable to fund a new national facility. The ECFS community was **neutral** (56 / 13) as to whether decreased funding for their own institution was acceptable for funding a new national facility, although we note that less than 15% of the respondents disagreed with this proposition. However, ECFS community **leans towards** (62 / 7) the statement that maintaining workforce and program continuity should be a priority with any redistribution of funding.

- The ECFS community was asked to pick the top 3 possible research missions for a new, major US fusion facility. The missions of $Q > 1$, PMI, and Divertors received the most support in this poll. However, some voters indicated that more information on what different facilities would cost, and how they would fit into a broader strategic plan, was needed before a decision could be made. The ECFS community did **agree** (78 / 6) that additional design studies of prospective major facilities should be part of the near-term US strategic plan, in order to better inform such choices.

- The ECFS community **leans towards** (69 / 17) the idea that a near-term goal of the US fusion program should be the demonstration of significant progress towards a fusion energy-relevant milestone such as $Q > 1$. Although, we note that 69% of respondents agreed (less than 1% from the criteria for a designation as an "agree" statement) while only 17% disagreed. The ECFSs were also **neutral** as to what the appropriate milestone should be, or what milestone(s) were most likely to improve program perception and resources. More information is needed from both inside and outside the fusion community.

- The ECFS community was asked to prioritize the development of physics and engineering bases for different configurations, and voted as follows:



  The ECFS community thus considers **tokamak research to be the top priority**, and identifies stellarator research as the second highest priority. ECFSs were split as to whether spherical tokamaks (STs) or alternate (non-tokamak, non-stellarator) configurations should be the third priority.

- Although stellarators were ranked second in terms of overall development priority amongst various configurations, there is **support** for continued domestic investment in stellarator research by the ECFS community. In particular 71% of respondents supported the proposition that design and construction of a domestic mid-size quasi-symmetric stellarator (as recommended by the national Stellcon report) should be an important part of near-to-midterm domestic stellarator research plans, in addition to continued international collaboration.

2.4 Mid to long-term fusion goals

We also posed several questions asking members to decide on the mid to long-term priority goals for fusion energy.

- There was **strong agreement** (81 / 6) that the 30-year vision for the US program should be to develop the science and technology basis needed to stimulate sufficient industry involvement to bring fusion to market.

- The ECFS community discussed three possible options for new domestic facilities whose operation would be a long-term (20+ year) strategic goal including options for whether the US remains in ITER, or does not remain in ITER. The ECFS community is generally split between whether this facility should be a net electric Pilot Plant ($Q_{eng} > 1$, tritium breeding ratio TBR > 1, but low cumulative dpa), fusion nuclear science facility (FNSF) (10's-100 dpa fluence, likely TBR > 1, but no constraint on plasma performance), or a net electric Pilot Plant that could be upgraded to a FNSF-like facility.

- When asked what confinement approach the long term vision of a pilot plant/DEMO/FNSF would likely be based on, 45% of ECFS votes chose high field, compact tokamak, 25% of votes chose standard tokamak (ITER or EU-DEMO-like design), with the remaining votes split among ST, stellarator, and "other". A number of voters chose "other" to indicate that more information on the mission, plan, and timeline was needed or a hybrid between the other configuration choices.

2.5 Program composition and balance

- The ECFS community **leans towards** (66 / 14) the proposition that university-based experiments are essential to the US fusion program. On this topic there are recommendations to examine both the approaches used in other scientific fields with large and expensive experiments, and the approaches used in other countries regarding partnership projects between universities and government funded labs.

- The ECFS community is **neutral** (43 / 37) on whether a meaningful part of the US program should be spent developing alternate (non-tokamak, non-stellarator) concepts. Discussion of this issue focused on issues such as possibilities for private industry leadership, as well as opportunities for critical supporting missions such as materials development and qualification rather than direct confinement and energy production.

- Regarding the current breakdown between theory research and computer simulation, 46% of the ECFS community **favor** keeping the current balance, with a roughly even split between proponents of increasing either side. We note that there were fewer respondents to this poll than to most others.

A Full Survey Results

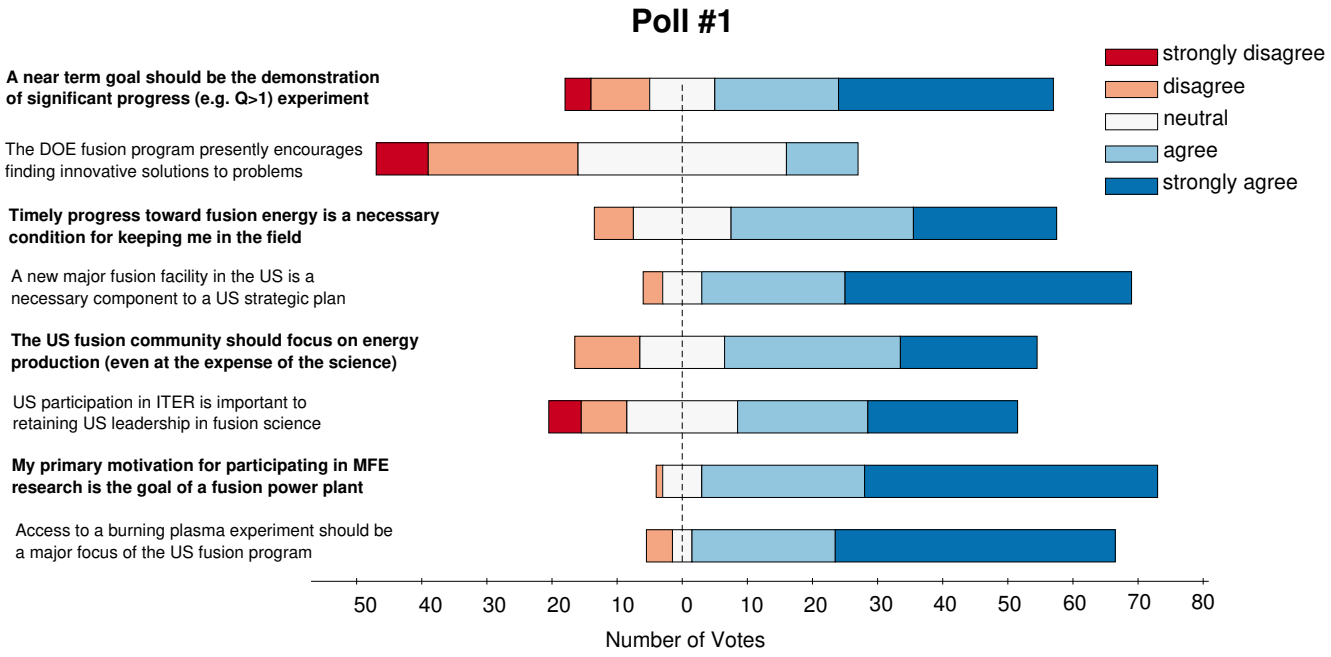


Figure 1: Summary of Likert scale poll results from Poll #1

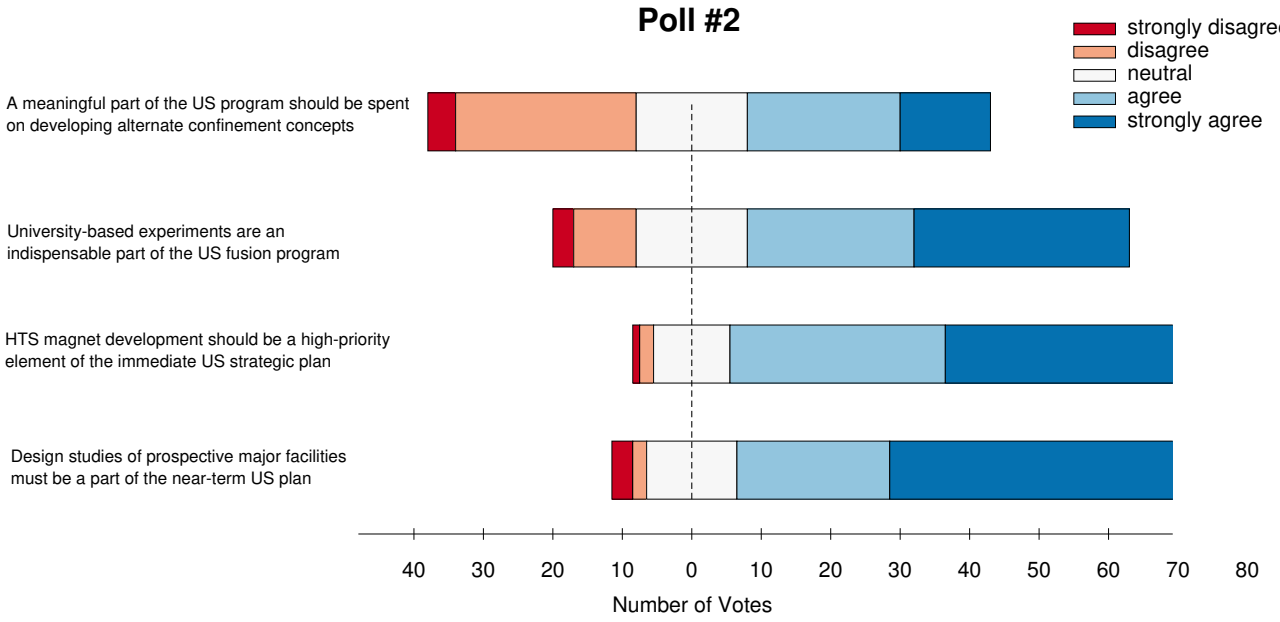


Figure 2: Summary of Likert scale poll results from Poll #2

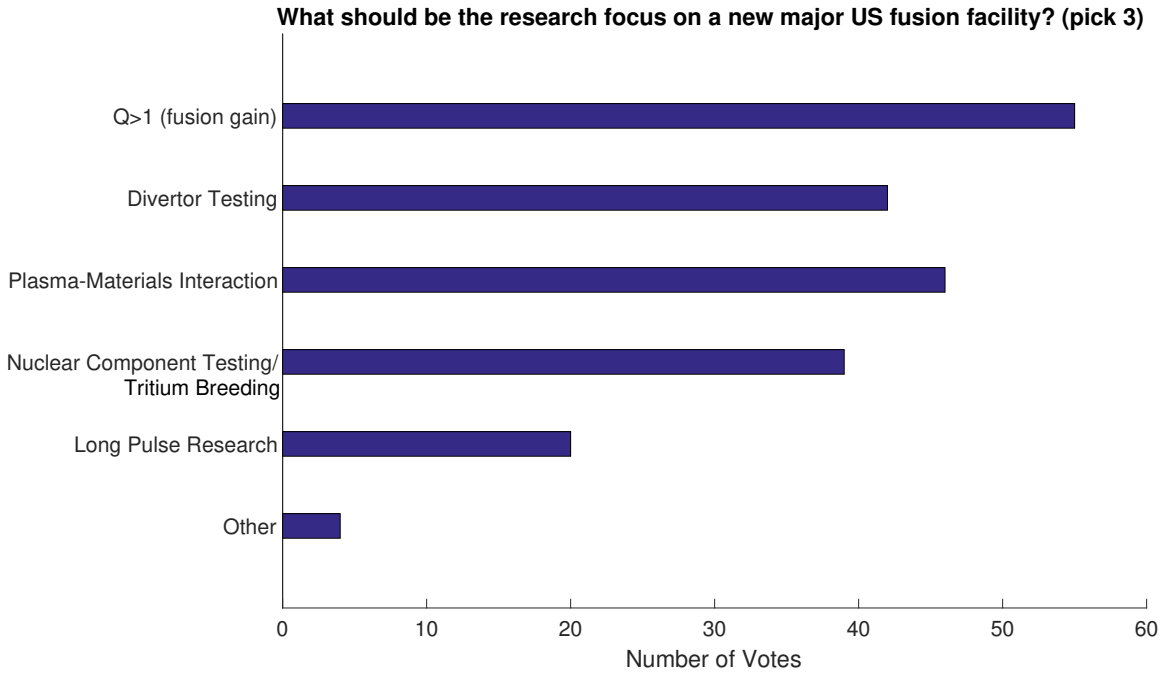


Figure 3: Opinions on research focus of a new major US facility from Poll #2

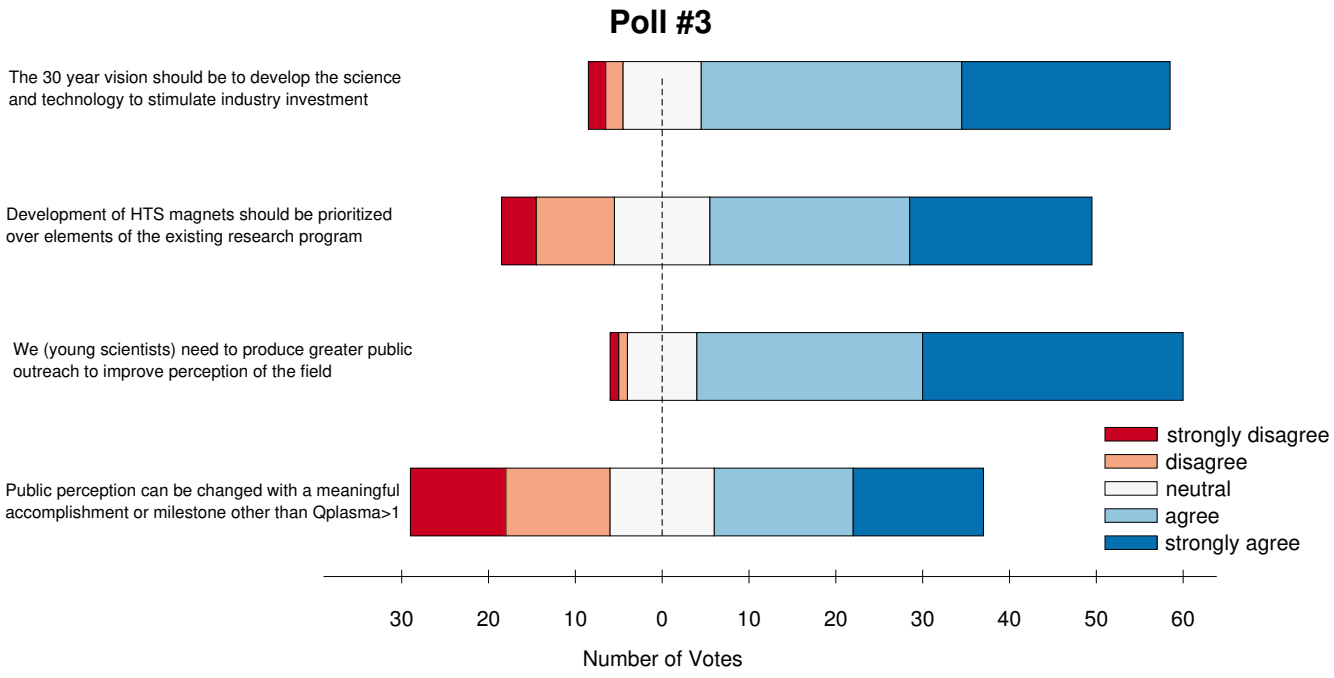


Figure 4: Summary of Likert scale poll results from Poll #3

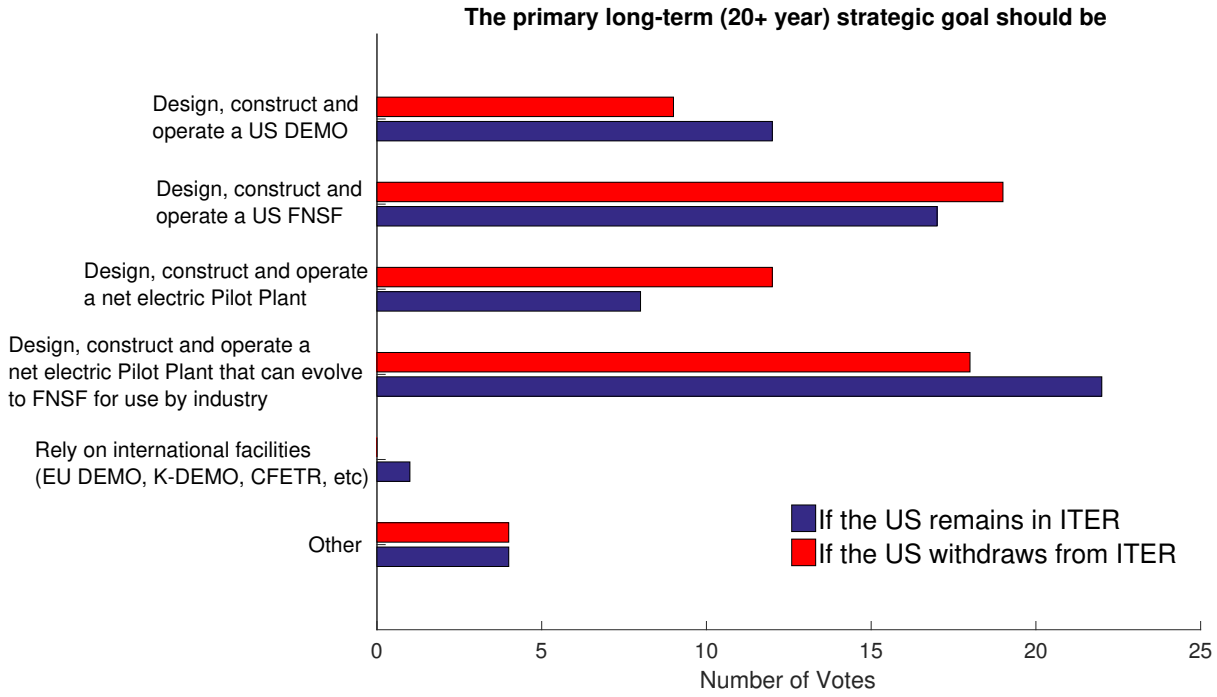


Figure 5: Opinions on long term strategic goals given ITER involvement from Poll #3

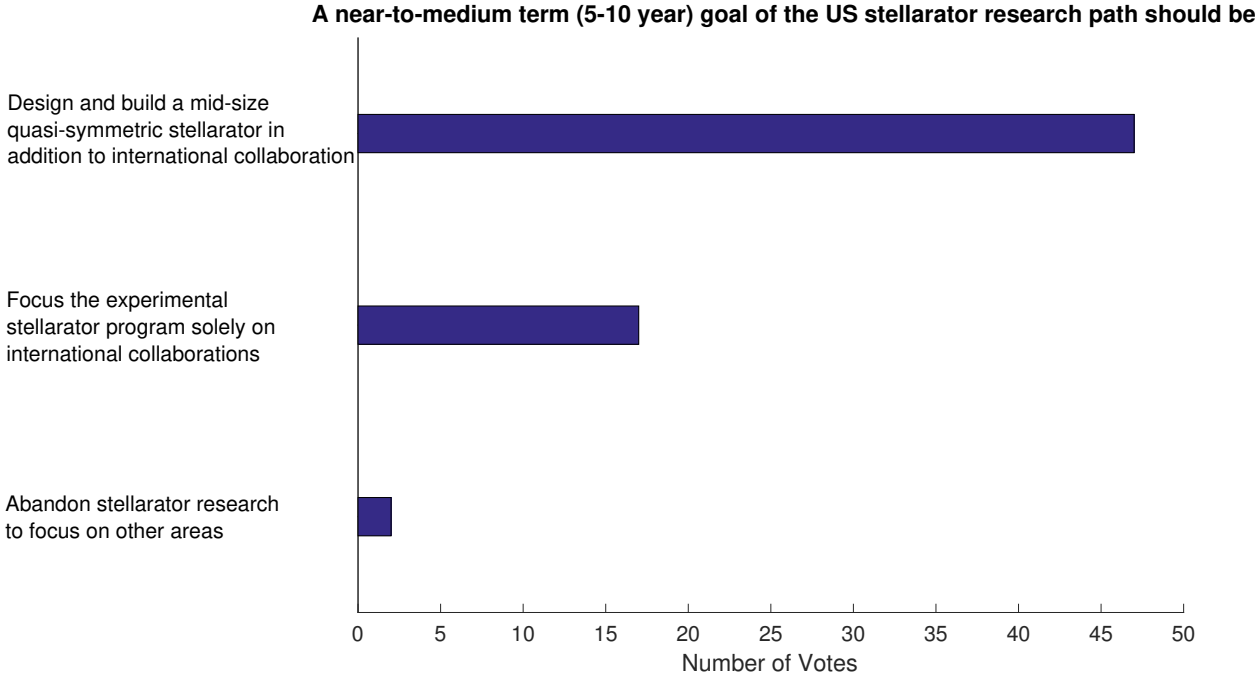


Figure 6: Opinions on a near to medium term research path for stellarators from Poll #3

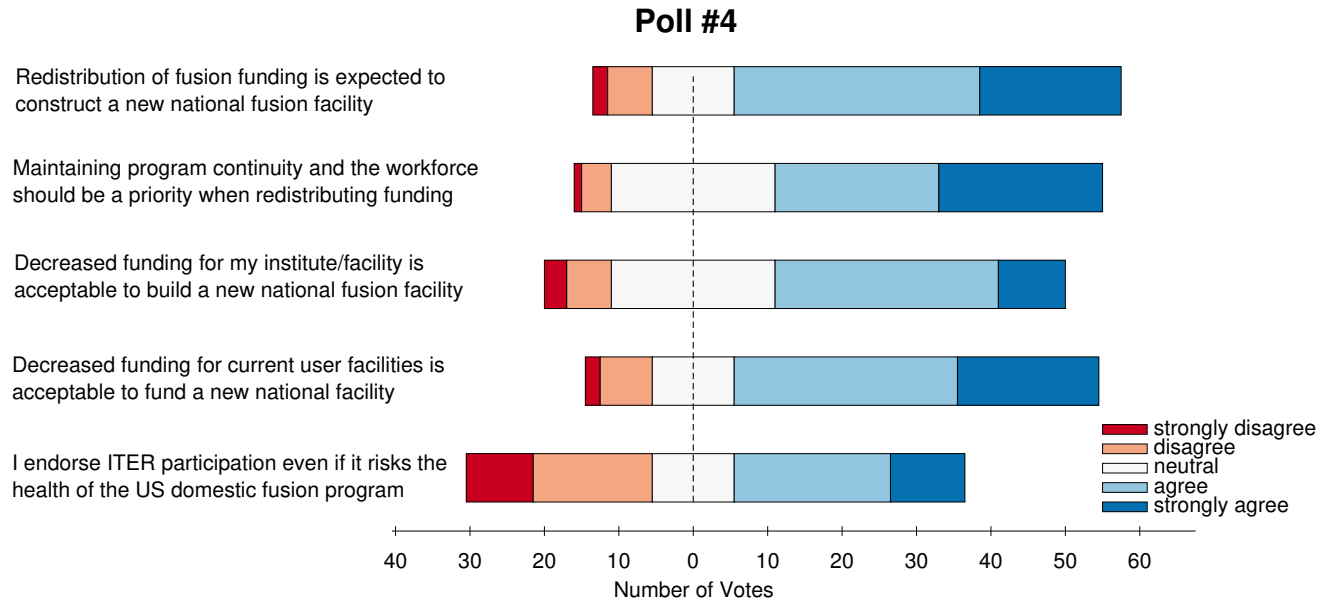


Figure 7: Summary of Likert scale poll results from Poll #4

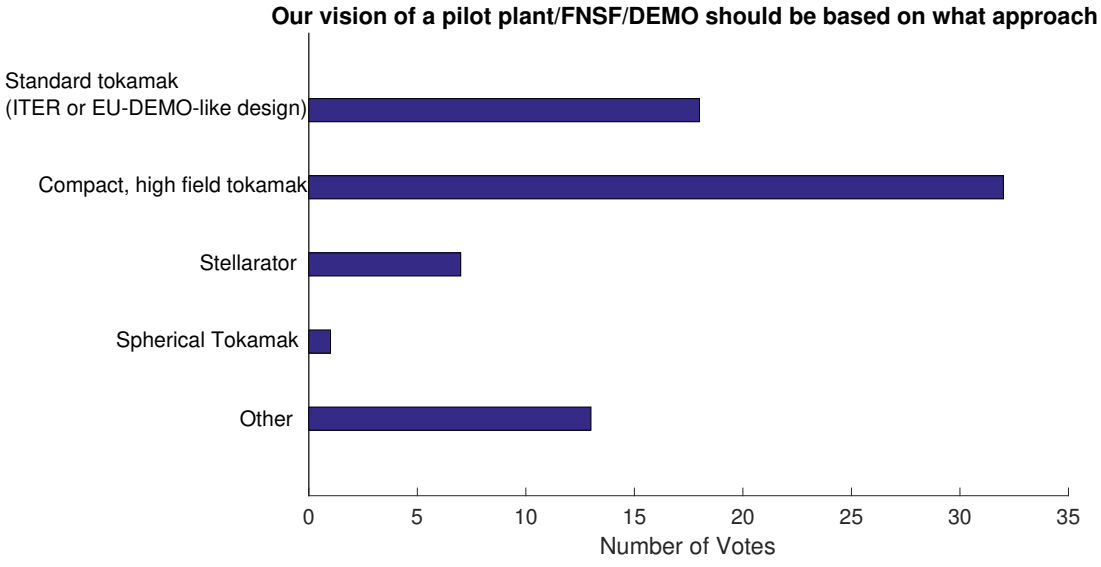


Figure 8: Preference on approach for pilot plant from Poll #4

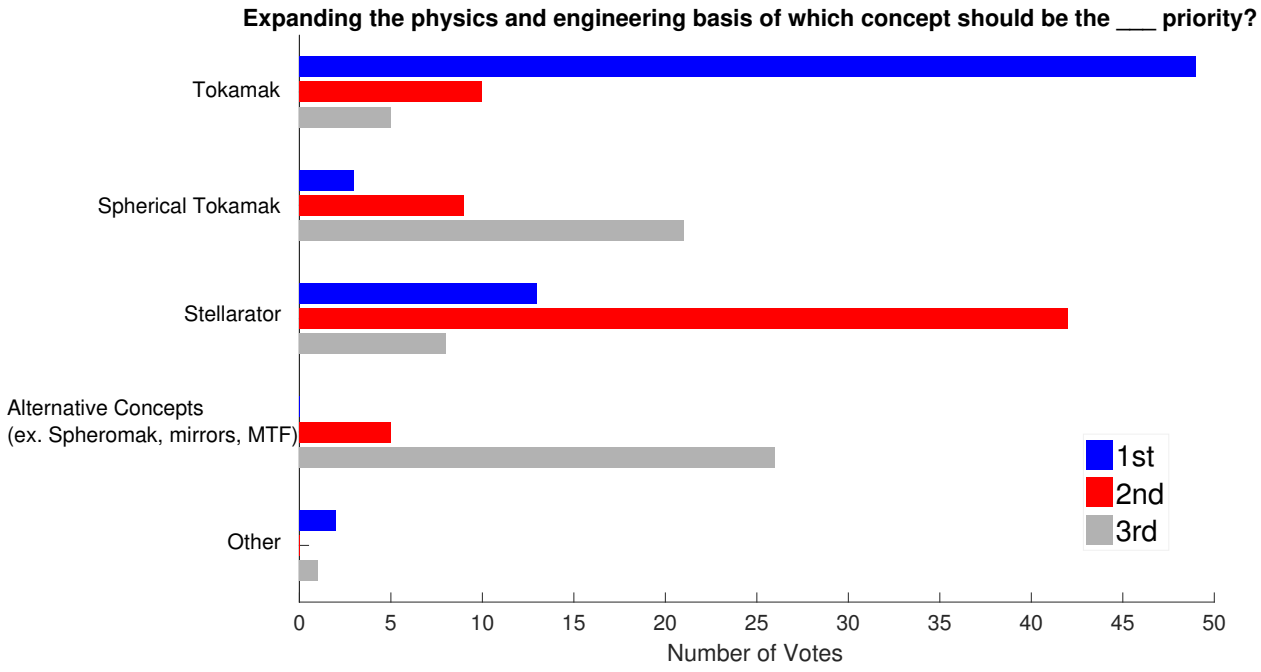


Figure 9: Opinions on prioritization of resources allocated for improving the physics and engineering basis of various confinement concepts from Poll #4

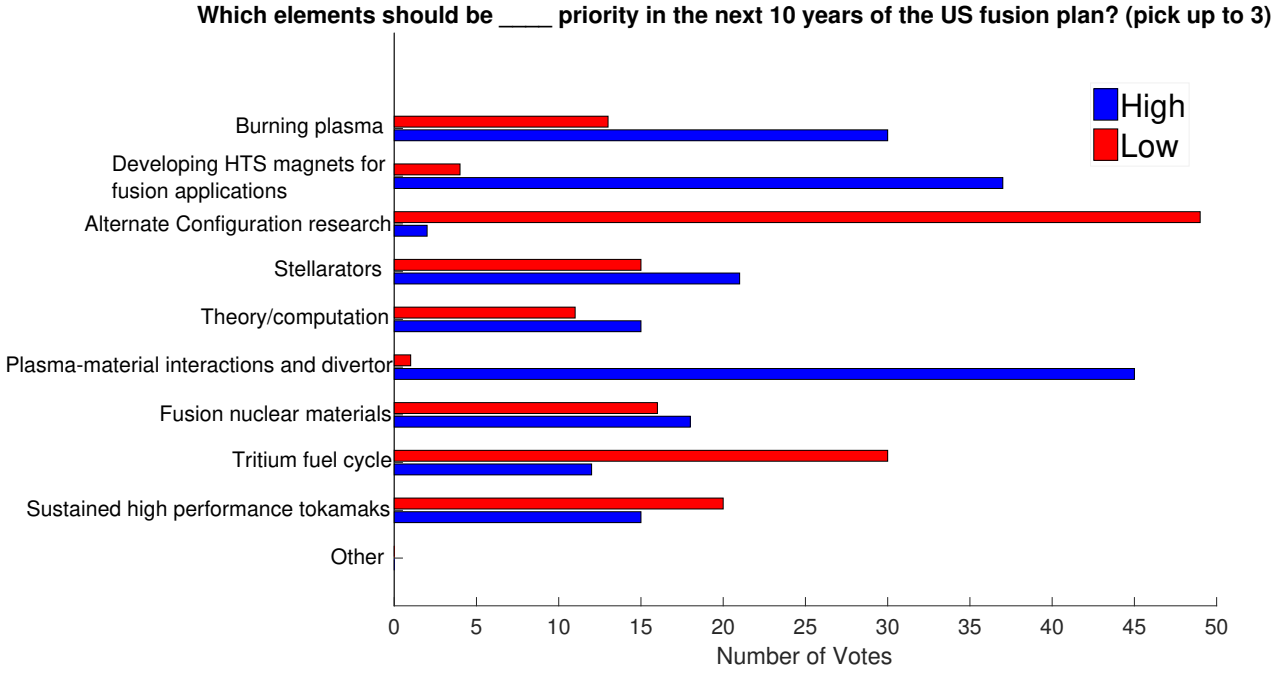


Figure 10: Opinions on prioritization of various strategic elements for fusion technology from Poll #4

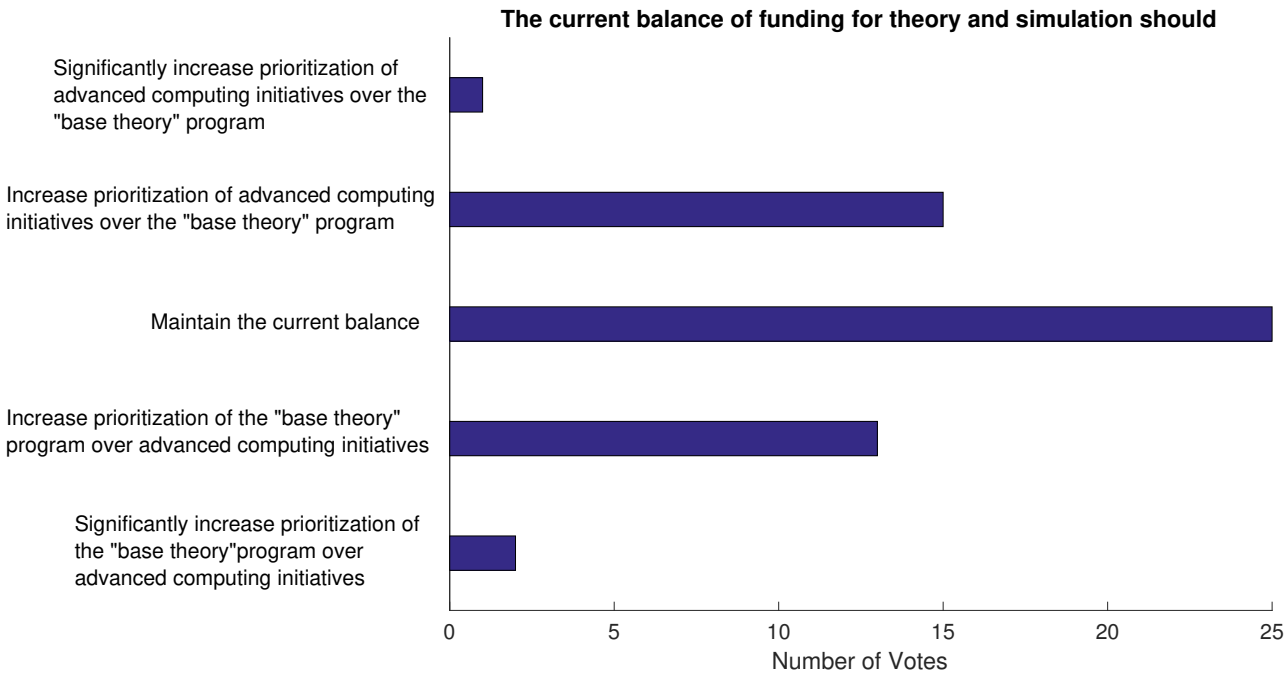


Figure 11: Opinions on the balance of theory funding from Poll #4

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The following individuals together organized the online forum, selected the poll questions, and wrote this white paper:
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