

FUSION ENERGY SCIENCES ADVISORY COMMITTEE

U.S. DEPARTMENT OF ENERGY

PUBLIC MEETING MINUTES

**Virtual Meeting via ZOOM
December 7, 8, and 10, 2020**

**Fusion Energy Sciences Advisory Committee Meeting
December 7, 8, and 10, 2020**

The U.S. Department of Energy (DOE) Fusion Energy Sciences Advisory Committee (FESAC) convened on Monday, Tuesday, and Thursday (December 7, 8, and 10, 2020) via videoconference from 11:00 a.m. – 5:30 p.m. Eastern Time (ET). The meeting was open to the public and conducted in accordance with the requirements of the Federal Advisory Committee Act. Information about FESAC and this meeting can be found at <https://science.osti.gov/fes/fesac>.

Committee Members Present:

Dr. Don Rej (Chair), Los Alamos National Laboratory (LANL)	Dr. Scott Parker, University of Colorado
Dr. Troy Carter, University of California, Los Angeles	Dr. Gertrude Patello, Pacific Northwest National Laboratory (PNNL)
Dr. Ralph Izzo, Public Service Enterprise Group (PSEG)	Dr. Susana Reyes, SLAC National Accelerator Laboratory
Dr. Charles Kessel, Oak Ridge National Laboratory (ORNL)	Dr. Fred Skiff, University of Iowa
Dr. Stephen Knowlton (Vice-Chair), Auburn University	Dr. Philip Snyder, General Atomics
Dr. Carolyn Kuranz, University of Michigan	Dr. Thomas Sunn Pedersen, Max-Planck Institute of Plasma Physics
Dr. Tammy Ma, Lawrence Livermore National Laboratory (LLNL)	Dr. Paul Terry, University of Wisconsin
Dr. Rajesh Maingi, Princeton Plasma Physics Laboratory (PPPL)	Dr. Erik Trask, TAE Technologies, Inc.
Dr. Lorin Matthews, Baylor University	Dr. Mitchell Walker, Georgia Institute of Technology
Dr. Simona Murph, Savannah River National Laboratory	Dr. Anne White, Massachusetts Institute of Technology (MIT)
	Dr. Brian Wirth, University of Tennessee

Committee Members Absent:

None

Ex Officio Members Present:

Prof. Michael Brown, American Physical Society, Division of Plasma Physics, Swarthmore College
Prof. John Verboncoeur, IEEE Nuclear and Plasma Sciences Society (NPSS), Michigan State University
Prof. Paul Wilson, American Nuclear Society (ANS), Oak Ridge National Laboratory

DOE Personnel:

Dr. James Van Dam, Associate Director, Fusion Energy Sciences (FES), DOE Office of Science
Dr. Chris Fall, Director, DOE Office of Science
Dr. Samuel Barish, Designated Federal Officer for FESAC, FES, DOE Office of Science

Approximately 190 FES and fusion community members attended the meeting.

Welcome and Opening Remarks, Dr. Donald Rej, FESAC Chair

Dr. Rej provided an overview of the agenda for all three days of the meeting, noting that there will be no meeting on December 9, but it will resume on December 10, the final day.

FES Perspective, Dr. Van Dam, Associate Director for Fusion Energy Sciences

The DOE Office of Science (SC) has implemented plans to address delays caused by COVID-19, including a three-phase “return to work” plan, virtual meetings and conferences, and accommodations in awards management. An SC internal task group is identifying impacts of COVID-19, and there is a voluntary survey for Principal Investigators (PIs) concerning negative impacts on their research caused by the pandemic.

The FES FY21 budget request includes initiatives on quantum information science, artificial intelligence and machine learning, microelectronics, and fusion acceleration. There are five planned FY21 FES Funding Opportunity Announcements. FES made three university awards and three laboratory awards as part of the FY20 Early Career Research Awards. There is new DIII-D leadership, and the NSTX-U recovery project is proceeding. Status updates were provided for the Materials Plasma Exposure eXperiment (MPEX), Innovation Network for Fusion Energy (INFUSE), Galvanizing Advances in Market-aligned fusion for an Overabundance of Watts (GAMOW) program, four ARPA-E BETHE awards, LaserNetUS, Matter in Extreme Conditions (MEC) Petawatt Laser Facility Upgrade (MEC-U), and ITER. The Nuclear Regulatory Commission (NRC), FES, and the Fusion Industry Association (FIA) hosted the DOE-NRC Public Forum on Regulatory Framework for Fusion Energy on October 6, 2020.

Dr. Van Dam closed by reminding FESAC of the long-range strategic planning activities over the past two years, noting that the culmination of the work is the FESAC Subcommittee’s Long-Range Plan report, issued in December 2020, that will be discussed at this meeting.

Discussion

Dr. Sunn Pedersen asked about funding stability in FY21. **Dr. Van Dam** replied that in previous years there has been bipartisan support for SC and FES.

Dr. Verboncoeur asked about expanding partnerships. **Dr. Van Dam** replied that there is a signed Memorandum of Understanding with the National Aeronautics and Space Administration (NASA) for plasma energy. Two years ago, the National Institutes of Health were interested in opportunities in plasma medicine. The Decadal Assessment of Plasma Science had seven federal sponsors, including the National Nuclear Security Administration (NNSA), National Science Foundation (NSF), ARPA-E and FES, and the Air Force and Navy research offices, as well as private industry colleagues; ITER is a grand example of an international partnership. **Dr. Kuranz** asked about the speed of budget impacts if the FESAC report is approved. **Dr. Van Dam** replied that it is not unheard of that FES is allowed to do something that was not included in the budget request. The INFUSE program, for example, was not in the FES budget request, but Congress allocated funding for DOE to pursue this opportunity.

Update from the Office of Science, Dr. Chris Fall, Director, Office of Science

Dr. Fall provided an overview of advancements in recent years, including Ultra-fast Lasers in 2017, Burning Plasma in 2019, Brightest Light in 2019, Community Planning Process (CPP) in March of 2020, and the Decadal Assessment in May 2020. There is a lot of interest in what FES

is doing. This long-range plan is especially valuable because it puts forth a complete array of needs across the entire FES program and critically prioritizes them; it had robust community input and involvement, and speaks with one voice. The number of ideas in the plan are most surely more than the DOE can pay for in any reasonable budget scenario.

The plan does assume that the U.S. is going to continue to support ITER. That is a strong assumption, and every Administration in the U.S. has the choice to continue participating. The total cost of ITER is unknown, but it should become clearer once there is first plasma. The cost of “phase 2” of ITER is also unknown, and Congress would like to understand those costs better. Supporting ITER has to be balanced by the responsibility to support, domestically, the future of fusion power and private sector investment. DOE asked for permission from Congress to start a public-private partnership (PPP) program similar to NASA’s Commercial Orbiter Transportation Services (COTS) program that allows DOE to co-fund projects with commercial entities to grow the commercial fusion sector.

Dr. Fall thanked FESAC and the Subcommittee for their exceptional work. He suggested exploring the long-range plan through an international prism in terms of FES partnerships on future initiatives in basic, pre-competitive research that DOE might not be able to afford alone. Dr. Fall stated that if he does not have a chance to be with FESAC again in this role, he would like to thank Dr. Van Dam and his team in FES, the labs, and the wider community.

Discussion

Dr. Carter thanked Dr. Fall for his interest and support. **Dr. Maingi** asked Dr. Fall if there is a balancing activity between PPP and the U.S. domestic fusion industry. **Dr. Fall** replied that it is a consideration. Private industry is heavily investing in fusion. There is a responsibility to support an innovative group of technologies and companies. **Dr. Steven Cowley** thanked Dr. Fall and expressed that the long-range plan shows his influence on the fusion community.

Report of the FESAC Subcommittee to Develop a Long-Range Plan for the FES Program, Professor Troy Carter, FESAC Subcommittee Chair, University of California, Los Angeles

Dr. Rej discussed conflicts of interests for the recommendations to be discussed in Dr. Carter’s presentation. Six FESAC members are recused on three of the recommendations.

Dr. Carter provided a presentation on the two-year process that culminated in the Subcommittee report called “Powering the Future”. The 2018 FESAC Charge was to cover the entire FES portfolio in two phases: a community-driven phase, CPP, and a FESAC-led phase under three budget scenarios: constant level of effort, modest growth, and unconstrained but prioritized, and under the assumption that ITER will continue. The Executive Summary of the report emphasizes that now is the time for fusion and plasmas, plasmas transform society, and fusion and plasmas are inextricably linked. The Fusion Science and Technology area should focus on establishing the scientific and technical basis for a Fusion Pilot Plant (FPP) by the 2040s by sustaining a burning plasma, engineering for extreme conditions, and harnessing fusion power. The Plasma Science and Technology area should focus on new opportunities to advance fundamental understanding, and in turn translate these advances into technologies that benefit society. During the CPP process, the research community developed a set of consensus prioritization criteria and guidance for prioritization within program areas. The guidance and feedback were used to develop criteria for whole-portfolio prioritization and include the following: Alignment, Urgency, Innovation, Impact, Leadership, and Stewardship.

Presentation on Overarching Recommendations

Dr. Christopher Holland of the FESAC subcommittee explained that the recommendations fall into two categories: Overarching recommendations which are program/facility independent but essential to successful execution of the FES research program, and project and program specific recommendations, which are divided into three subcategories: Fusion Science and Technology (FST), Plasma Science and Technology (PST), and Cross-cutting recommendations, applicable to all programs.

Dr. Holland outlined the overarching recommendations which discuss the technology and science drivers for a FPP by the 2040s, repeating the long-range planning process, resources for design and construction of new facilities, new experimental capabilities, maturation of designs, scope and costing for new facilities, PPPs, formal coordination between funding agencies, policy changes to improve diversity, equity, and inclusion (DEI), and discipline-specific workforce development.

Presentation on FST Recommendations

Dr. Wayne Solomon of the FESAC subcommittee presented the FST recommendations which focused on closing critical gaps for a FPP, pivoting towards fusion materials and technology (FM&T), establishing mission need for a Fusion Prototypic Neutron Source (FPNS) facility, developing infrastructure for the study of plasma materials interactions, expanding the blanket and tritium programs, closing FPP design gaps utilizing DIII-D and NSTX-U, ensuring full engagement with ITER via a research team, forming the mission need for EXCITE, and strengthening research for fusion energy commercialization.

Discussion

Dr. Wirth asked about the prioritization of facilities in the recommendations. **Dr. Carter** replied that the prioritization is expressed in the scenarios. He added that the facilities are targeting different essential science and technology areas.

Dr. Reyes asked about the separation of facilities that could potentially be combined into a single facility (e.g. blanket component test facility (BCTF), volumetric neutron source (VNS)). **Dr. Carter** explained that the approach was consistent with the CPP structure. The subcommittee did not want to be too specific about how to execute the needs of the program. **Dr. Solomon** added that if there are too many missions or too many activities in a single facility the cost becomes prohibitive. **Dr. Humrickhouse** of the FESAC subcommittee said that the BCTF is an aneutronic facility. The VNS, while less well developed, would be a nuclear facility for atomic scale testing. One explicit recommendation is that a more coherent strategy about component scale blanket testing needs to be developed.

Dr. Snyder inquired if the subcommittee considered having competing design teams rather than a single design effort for FPP. **Dr. Carter** explained that the notion of competing teams was not discussed at length, but coordination is important. **Dr. Holland** added that there are a range of opinions in the community concerning how cohesive, tight, and coordinated this should be. The subcommittee strove to achieve balance. **Dr. Trask** clarified that the recommendation is to have the capability of building a FPP with both the broad infrastructure and knowledge base.

Dr. Terry asked if there is consensus on the mission for the FPP. **Dr. Carter** explained that is a community driven effort that needs to be a follow-on of this activity.

Presentation on PST Recommendations

Dr. Ma of the subcommittee provided an overview of the PST recommendations which focused on supporting fundamental plasma science, the MEC-U, establishing a plasma-based technology research program, coordinating a High Intensity Laser Research Initiative, pursuing a multi-petawatt (multi-PW) laser facility and a high-repetition rate (HRR) high-intensity laser facility, supporting networks to coordinate research, strengthening support of lab-based research for astrophysics and space plasmas, ensuring robust support for foundational research activities, and supporting research that supplies fundamental data.

Discussion

Dr. Kuranz asked if the recommendation for the High Intensity Laser Research Initiative is for FES to partner with other agencies for the U.S. to maintain or reestablish leadership in the field, and asked if the recommendation on the Solar Wind Facility is to build or to design a facility. **Dr. Carter** replied that it is to coordinate and collaborate, and for FES to take ownership. For solar wind, the recommendation is to develop the idea leading into design.

Dr. Brown noted that there are facility projects supported by NSF, NNSA, and NASA on Zeus, multi-PW, and solar wind and asked who might take the lead. **Dr. Carter** replied that the scenarios assume that FES will take the lead on everything recommended. However, the idea of partnering is strongly threaded throughout on the entire portfolio.

Dr. Terry asked for clarification on the types of activities that are envisioned as “foundational.” **Dr. Carter** replied that the term is the embodiment of recommendations in the CPP report about cross-cuts in the program, such as fundamental theory, computation, diagnostics, and control techniques – enabling technologies. **Dr. Holland** added that doing fundamental theoretical research on both the FST and PST areas and for the basic plasma experiments is important.

Presentation on Budget Scenarios

Dr. Carter presented the three budget scenarios as described in the Charge. The scenarios are considered starting from the FY19 budget, specifically focusing on the non-ITER construction project portion. In the two scenarios, constant level of effort and modest growth, any new construction is funded by redirecting resources from current facility operations and research programs. These constrained scenarios are constructed to represent a balanced program with prioritization and emphasis on critical elements that advance the fusion energy mission and sustain scientific impact and technological progress. The constrained scenarios do not provide sufficient resources to confidently prepare for an FPP by the 2040s. Large projects in the PST area are unfunded, including MEC-U.

In the constant level of effort scenario, pivoting and redirection of funds enables the program to undertake a number of exciting and vital new activities. However, the new initiatives and pivoting of program elements are only achieved at great cost to existing and future areas of U.S. strength, innovation, impact, and leadership. In the constant level of effort scenario, the only viable way to redirect sufficient funds for new FM&T priorities and facility construction is to reduce existing domestic tokamak operations at a pace which enables total tokamak research funding to continue at a stable level. With more robust funding for PST programs, technology and science drivers are advanced. However, there are still costs incurred and opportunities missed in the modest growth scenario.

In the unconstrained (but prioritized) scenario, FPNS is accelerated. The prioritization of facilities and their supporting research programs was determined by factoring in the timeliness and urgency of the activities in supporting the strategic plan. A prioritized list of new and expanded programs was also developed. The unconstrained scenario would include several prioritized facilities (EXCITE, MEC-U, Mid-Scale Stellarator, BCTF, Solar Wind, High-Heat Flux, multi-PW laser, HRR laser, and a mid-scale Z-Pinch). The unconstrained scenario also includes prioritized programs (e.g., FM&T, PST, plasma-based technology, FST, LaserNetUS, Inertial Fusion Energy (IFE), volumetric neutron irradiation, etc.).

Discussion

Dr. Reyes sought clarification on the passage “IFE program, focus on enabling technology.” **Dr. Carter** replied that this means laser technologies and other drivers that enable new directions (e.g. broadband lasers that help impact and reduce laser plasma instabilities).

Dr. Reyes asked if there is a level of dollars increased at Δ as situated to the level of the unconstrained scenario and about the graph shown at the last FESAC meeting on the unconstrained scenario. **Dr. Carter** emphasized that there are no budgets in this report. The subcommittee did a lot of work to establish the programs and used their own approach to amplify those programs to what was needed. He urged FESAC to keep in mind staging, utilizing partnerships, and pivoting within the program to make resources available. As to the graphic, he explained that it was provided to give FESAC a sense of where the subcommittee was headed. The value is a flexible plan focused on recommendations that set fusion in the right direction.

Dr. Kuranz inquired about addressing the balance between PST and FST. **Dr. Carter** reiterated the approach and expanded on it. Because FES has a fixed budget with no construction resources, the decision was made to redirect funds within the current budget. The unconstrained scenario provides a prioritized list giving one a sense of where PST and FST projects fall.

Dr. Kuranz asked if, in the unconstrained scenario, FES will fully fund the quest for the multi-PW laser. **Dr. Carter** reiterated that for every facility, partnerships should be exploited. Coordination is very important for large scale facilities. For PST, the resources are split among many agencies. The subcommittee assumed that FES would fund the entire cost because it is a role that FES could play, an opportunity for FES to lead, and it is unclear that another agency has a more pressing need to take the lead.

Dr. Sunn Pedersen stated that the word “unconstrained” is a big one. It is the most important and in some sense the most dangerous of the three scenarios. He asked for Dr. Carter’s perspective on the symbolic value of the term. **Dr. Carter** explained that the subcommittee thought that the “unconstrained” budget was different from blue sky; it mirrors the Particle Physics Project Prioritization Panel (P5) report. P5 picked three things to focus on; however, the focus of this report is on getting resources into things in the next five years that will set the community on the right path. **Dr. Sunn Pedersen** advised that the subcommittee be very explicit in explaining the “unconstrained” term in the document; i.e., it is rapid growth, but it is not a blue sky scenario. **Dr. Trask** said that even the modest growth scenario is unlikely to achieve the goal of a FPP capability in a time frame that matters – the urgent need for climate, energy security, and pollution. “Unconstrained” is something more than modest growth. **Dr. Carter** noted that the unconstrained scenario is what the community thinks is needed to get to the FPP by the 2040s. However, there are PST needs that open up many new directions. Things the CPP called out as important are in the unconstrained scenario.

Dr. Knowlton asked about the two key goals for FST – to field the long-term research team for ITER and to plan for an FPP in the 2040s. Specifically he questioned the amount of investment needed just for that particular mission element and if the subcommittee discussed the rationale for the 2040 timescale. **Dr. Carter** replied that the subcommittee believed the necessary budget to be more than \$1B. The input on the 2040s timescale came from the Burning Plasma report and competition with other carbon neutral sources. This report focuses on setting fusion on a path heading towards the 2040s.

Dr. Kuranz inquired about the multi-PW laser facility stating that NSF is funding a multi-PW construction facility, Zeus. She expressed disappointment about MEC-U and the cost of that project, and hoped that the importance of the critical decision (CD) process can be emphasized to the community. **Dr. Carter** replied that NSF could contribute to such a facility, but it is distinct from Zeus. MEC-U is the top priority, and it needs new resources. There is Congressional language in the stimulus bill for funding for MEC-U and MPEX. **Dr. Trask** commented that a main reason to use the CD process is to gain information for planning.

Dr. Skiff expressed a concern about multi-parameter prioritization in the budget scenarios. He asked how much auxiliary information will be available concerning the way in which the prioritization was performed. **Dr. Carter** explained that the unconstrained scenario was constructed like the CPP report, and it is all included. Cost was not the primary driver for prioritization; all the criteria were used.

Dr. Sunn Pedersen requested more explicit language about assumptions and pointed out that SPARC is not mentioned. For example, there is a focus on the integration of the exhaust and core performance, the ITEP gap. But, the disruption challenge, low recirculating power, and current drive efficiency have been deemphasized. **Dr. Carter** stated that the recommendation about DIII-D and NSTX-U was about closing those gaps. The strategy is based on community input. The stellarator and low recirculating power are in the report. The intention was that issues raised have to be worked on using existing facilities. The stated goal of SPARC is $Q > 2$, not burning. **Dr. Sunn Pedersen** added that it is also relevant because EXCITE is listed as a high-field device, and it will solve the core edge challenge; a lot of this is also true for SPARC. **Dr. Carter** explained that the subcommittee's point-of-view was to set the process in motion for the ITEP gap. SPARC is going forward, and the U.S. needs to find a way to join that. There are questions about SPARC solving the core integration issue because of the size. **Dr. Sunn Pedersen** asked if community consensus is that it is realistic that the disruption challenge is going to be solved without a new facility. **Dr. Carter** argued that the top priority need for the facility is ITEP. However, building such a facility will address multiple issues.

Dr. Wilson noted that specific comments in one budget scenario state that in order to accomplish the mission, funds will need to be ramped down or redirected. However, in another budget scenario, that was vague. He pointed out that was the kind of prioritization people are seeking. **Dr. Carter** said that the resources are available in the modest growth scenario, but are consumed quickly when bringing on new facilities. That is part of the reason for calling out what to enhance. **Dr. Wilson** asked at what point, when it is affordable to bring on the next facility, will the decision be made that the new facility/experiment is more valuable than something currently operating. **Dr. Carter** said that the general principle that the timeline for facility construction in five years is ambitious, but zero activity in an area, while waiting for something else to happen, is a problem. The goal is to set something in motion now; to provide a sensible, yet flexible, sequence, especially on partnerships and cost. **Dr. Maingi** said that the CD process creates a narrower, more realistic, cost range, and that is the kind of rigor articulated in the

report. **Dr. Trask** explained that the P5 report was more straightforward because of the wealth of costing information. **Dr. Carter** added that the fusion community needs to utilize the CD process to get more accurate costing information.

Dr. Wirth suggested adding the basis for the facility costs to provide perspective on the balance between FST and PST. He also speculated, that in relation to Dr. Fall's comments, there should be additional consideration of the opportunities for international collaboration. **Dr. Carter** indicated that there are no specific call-outs on the international issue, rather it is a generic idea that partnering is desirable. On the costing issue, the hope is that Congress will see that MEC-U is almost at CD-1, and EXCITE needs to establish mission need and will put this in motion.

Dr. Kuranz commented that she was concerned about this report being a snapshot in time as the budget scenarios are based on FY19 dollars. She asked if the conditions under which the scenarios are cast could be clearer. **Dr. Carter** noted that the recommendation, to complete MEC-U, is the message. **Dr. Wilson** did not think numbers were necessary, but something that lays out the scale might help support the PST program.

Dr. Wilson stated that both the constant level of effort and modest growth scenarios address the difficulty in achieving the mission of an FPP by the 2040s, and he asked that if that is not feasible, does that impact the priorities. **Dr. Carter** said that the budget scenarios were required, and a set of recommendations was required, and there are far more in the CPP report. The focus of this report was on having impact in the right way and keeping the audience in mind with a goal of influencing change in budget and policy. **Dr. Skiff** said that the task of the subcommittee was to be faithful to the CPP and to have consensus. This report is measured and reflects that consensus; therefore, it will help the fusion community. The budget scenarios have a rhetorical value to help people understand the situation, and he hoped that the constant level of effort budget communicates existential pain.

Dr. Parker stated his concern that the fusion community will pivot to FM&T without a burning plasma in hand. The U.S. may need to provide innovation via tokamak research programs to come up with solutions that allow ITER to achieve its mission. **Dr. Carter** reiterated that the Charge specifically states to assume ITER will continue. **Dr. Matthews** added that the U.S. can leverage ITER and the other partners, and invest in other things, such as materials and the FPP. **Dr. Maingi** noted that private programs are aimed at burning plasma. **Dr. Rej** added that Dr. Fall stated that public-private collaborations are unique to the U.S. **Dr. Snyder** said that the U.S. analog of the China Fusion Engineering Test Reactor (CFETR) is the FPP, but in many ways the FPP is meant to be more ambitious than CFETR.

Dr. Trask said that the subcommittee chose to keep the text general for the tokamak gap, to call out the need without identifying how to solve the problem. SPARC is the nearest term high-temperature tokamak to be built in the U.S. However, adding that specific language was deemed too detailed and could be read as choosing a winner. **Dr. Solomon** said that the disruption challenge needs to be addressed in the very near term using existing facilities, but there is also a timeline for doing that. ITER will be operating, and ITER needs to address the disruption challenge. He was unsure if there was an expectation of building a new facility to address the tokamak disruption challenge. **Dr. Sunn Pedersen** reiterated that too many things are implicit. The report will be read by people outside the field. He suggested writing that the community assumes that this issue must be solved on the timeline of ITER going into operation.

Dr. Snyder addressed Dr. Parker's comment on the U.S. needing a burning plasma. Referring to the National Academies Burning Plasma report, the plan for a burning plasma

experiment in the U.S. is the FPP. But, the FPP is more than a burning plasma experiment; it is the embodiment of the combination of advanced technology and advanced physics that goes into this unique U.S. vision that tries to reduce capital costs and optimize the system. It should achieve burning, but also go all the way to net-electric, not just demonstrate the science, but also combine it with the technology. That FPP goal inspires the pivot for FM&T to address the key materials and technology issues. On the science side, the core edge mission needs to be addressed in order to proceed with the FPP. In this report, the subcommittee is trying to stay broad in order to consider a range of possibilities.

Dr. Terry brought up sunset language concerning closing experiments to bring others forward, the strict adherence to the timeline for achieving a goal, and the hand-off to ITER. Specifically, he asked if DIII-D and NSTX-U are not completed by the mid-2020s, will they continue or be closed – is the sun setting negotiable? He mentioned the hand-off to ITER rather than EXCITE. **Dr. Carter** remarked that there are no recommendations in the scenarios, and there are no proposals to sunset anything. However, EXCITE cannot happen in the constant level of effort scenario.

Dr. Parker raised caution about the underlying assumption for ITER’s burning plasma experiment, pointing out that the FES experimental tokamak program supports improved confinement and a better performing tokamak. **Dr. Carter** replied that the goal was to both pivot and maintain strength, which means reductions in that scenario. The scenario descriptions are a good balance between embracing new opportunities and preserving strength. The message of this report is an increase in funding.

Dr. Parker addressed comments from the public discussion, namely about identifying the assumption about ITER, pivoting away from tokamak science, and the Office of Advanced Scientific Computing Research (ASCR). Regarding ITER, to say that the U.S. will pivot away from tokamak science toward technology without burning plasma seems short-sighted and risky. **Dr. Sunn Pedersen** responded to comments about starting the engineering side of a reactor. His perspective was that the proposed high priority projects must be done regardless of the details of the scenario. Given the constrained scenarios, hard choices had to be made, and the assumption is that ITER will work. In that scenario, the U.S. should be doing things that ITER is not doing.

Dr. Parker strongly expressed that not pivoting away from the tokamak science of confinement would be an improvement. **Dr. Snyder** pointed out that the report contains the EXCITE program as well as strong support for theory and computation. EXCITE is aimed firmly at addressing the science coupled with the edge; it is a non-nuclear facility, and if it achieves the densities approaching what is needed for an FPP, then the models can be tested and provide the deep understanding of the physics necessary to design the best, most cost-effective FPP. **Dr. Parker** articulated that his concern that in the constant level of effort scenario, there was a reduction in the confinement program by 50%, and he noted that EXCITE does not come up until the unconstrained budget scenario.

Dr. Verboncoeur felt that making progress on burning plasma would inform what is needed in terms of engineering. Nonetheless, he acknowledged that there are some engineering aspects that could be addressed regardless of the path. The path to burning plasma might be the critical path and not the engineering components.

Dr. Barish said that the Charge stated that “within each of the three scenarios assume that the U.S. contribution to the ITER project will continue through this entire period”. The Charge requested a 10-year plan under three budget scenarios.

Dr. Parker referred to the slide on Pivoting Tokamak Effort, noting the reference to a significant reduction of ~50% in the mid-2020s, and he feared that the community will actually get what it asked for. **Dr. Carter** said that there is no recommendation that says a tokamak should be shut down. The question is can we address the budget scenario if we do not do this. **Dr. Parker** pointed out that the presentation mentions about a 50% reduction. In a flat budget, there is a proposal to cut the two existing experiments. **Dr. Trask** said that the report is not recommending shutting anything down; however, if budgets do not increase, there must be some guidance on likely scenarios.

On the recommendation of closing FPP design gaps, **Dr. Wirth** reminded FESAC of an earlier comment that existing tokamaks do not provide sufficient insight into runaway electron problems. **Dr. Holland** voiced that even in the pre-fusion phase, there is a lot of international collaboration to advance the tokamak physics space. But private tokamak efforts also have to solve the disruption issue. The recommendation is to take full advantage of all of those opportunities across the world.

Regarding the recommendation: “ensure full engagement of the U.S. fusion community in ITER....” **Dr. Parker** noted that if ITER is delayed or unsuccessful, this plan has to be reconsidered. **Dr. Carter** agreed expressing that he supposed ITER’s success or delay will be known by the next iteration of this process. He said that this recommendation is about the ITER research team only. **Dr. Barish** stated that if ITER is delayed, FES will use good judgement and delay formation of the ITER research team.

Presentation on Appendix A: Public-Private Partnerships

Dr. Maingi of the subcommittee said that PPPs are highly recommended to rapidly and efficiently enhance scientific and technological capabilities. FST PPP programs include: Low Technical Readiness Level (TRL), milestone-based facility programs (new), mature stage programs (new), and facility design collaboration (new). Low TRL maturation programs should be expanded to enhance the scope and scale for the closure of key technology gaps. The subcommittee supported the concept of a milestone-based cost share program aimed at the demonstration of integrated facilities. These have the potential for rapid and cost-effective technological gap closures, executed as a parallel investment to augment the public long-range plan, and “Multiple shots on goal.” New mature stage PPP programs to further aid in the commercialization of fusion energy should be considered. Private entities can help develop new experimental facilities that are needed to close the FST program gaps in a timely fashion. Finally, FES-funded programs should strive to make information available between public and private sectors (e.g., access to ITER design information should be provided to U.S. companies by FES).

Discussion

Dr. Walker asked for more information on the PPP intellectual property (IP) model. **Dr. Maingi** said that the subcommittee did not talk in great depth about the IP aspect of the issues.

Dr. Sunn Pedersen asked about legal obstacles to having close collaborations with private company sites. **Dr. Maingi** explained that the programs mentioned in the report are not directly looking for expertise from one company or another. Proposals will be reviewed and awarded; the process will be competitive. **Dr. Trask** stated that the onus of maintaining a fair, competitive process will fall to review committees who look at proposals. There is a mission need to have stronger partnerships that bridge the gap between the academy, the lab, and the private side. **Dr.**

Verboncoeur stated that in his experience, it is rare that a large, well-funded company will jump into a partnership that concedes any kind of IP if there is a fair degree of certainty. However, if they feel the goal is sufficiently far out, they might enter into a PPP, but in that case, they are not actually building the FPP or the IP, rather they are advancing the science. He suggested capping the amount of cost-share a university can bring in to any PPP. He added that any partnership must recognize that starting the path to translation is an important process. Trust must be built between researchers and industry to make that translation, to understand it, learn a language, and build all of the financial processes so that can happen smoothly.

Dr. John Foster said that there is a lot to be learned from the NSF partnerships and innovations. They have multiple layers, whether it is a single investigator who develops a startup based on a technology, or a partnership with a larger company to take on a component that is too complicated for a single investigator. **Dr. Skiff** asked about the NSF/DOE partnership in basic plasma science and participation by universities. **Dr. Carter** said that program needs to be scaled up. In the modest growth scenario, there is an augmentation. It is part of the PST research program. There is also a comment in the report that there is an urgency to renew that partnership.

Dr. Patello asked which of the facilities listed are most helpful to industry. **Dr. Carter** responded that the sense is that every facility should be looking at this opportunity. Some facilities are more likely than others to have a connection to the industry plan. FIA provided input on activities that might align with the CPP strategic plan.

Dr. Skiff stated that the cost of the facilities coming online later will not help the private sector much. **Dr. Maingi** replied that if the timescales do not match, that is a lost opportunity. But it does not have to remain lost if there is alignment, a way to partner with the company that wants to make the facility move more quickly. **Dr. Trask** added that the timescale also hurts the public program because it makes it unlikely that the community will get to the design capability for FPP by the 2040s. **Dr. Parker** suggested making the private sector reference more specific in the recommendation to expand and establish new PPPs because of the speculation of doing burning plasma in the private sector. U.S. leadership could be in the private sector or PPPs.

Dr. Reyes referred to the slide “Unconstrained: Prioritized Facilities” pointing out that items 7 and 8 have the phrase “with partnerships,” suggesting that 1-6 do not need any partnerships. **Dr. Carter** said that every item on the list should be pursued with partnerships where possible. However, for items 7 and 8, HRR laser and mid-scale Z-Pinch, there is potential interest from the Office of High Energy Physics and NNSA, respectively.

Dr. Kuranz strongly suggested that the multi-PW laser facility be “with partnerships” because of current discussions with NNSA and NSF. **Dr. Carter** explained that “with partnerships” language is used throughout the PST recommendations. To avoid unintended consequences, the subcommittee did not want to signal this as somehow FES’s territory. **Dr. Maingi** said that concerning partnerships, the lesson going forward is to include PPPs in the scenarios. There are practical difficulties in doing this. In essence, how should PPPs be taken into account in such a way that they affect the scenarios? He suggested that thought be given to metrics for this.

Dr. Brown said that the issue is money. FES funding has been stable and growing for the last 30 years; however, there has not been explosive funding since the oil crisis in the 1970s. **Dr. Carter** said that determining the specificity of potential partnerships is difficult, but the report must make sure that the opportunities are called out.

Presentation on Appendix B: Developing a Diverse, Equitable, and Inclusive Workforce

Dr. Ane Lasa of the subcommittee presented Appendix B of the report on DEI, workforce, and outreach. The success of this strategic plan requires innovation, creativity, and a talented, multidisciplinary, and diverse workforce. The subcommittee recommended that FES support outreach efforts to promote plasma science, pre-college outreach, and the development of a new public-facing website for plasma science and fusion. Institutions and agencies funded by, or working in, fields of FES should engage DEI experts for advice, expand recruitment pools and identify underrepresented areas, adopt or update Policies and Codes of Conduct and training, create an accessible environment for all members of the community, work with institutions on family leave policies, develop flexible post-undergraduate education options, and facilitate employment of, and establish development programs for, BS/MS scientists and engineers.

Discussion

Dr. Patello asked for more information on the “double blind” review process and if the PI might be revealed in the references or curriculum vitae. **Dr. Lasa** explained that in a two-step double blind process, the actual scientific content would be reviewed blindly, and the second step would reveal the name of the PIs, or other relevant information. **Dr. Carter** added that details must be worked out, but other agencies have used this process with success. **Dr. Terry** was concerned about the double blind reviewing and questions about infrastructure, renewal, previous funding, productivity level, or capability to deliver. He asked for examples of this type of implementation in reviewing. **Dr. Kuranz** responded that NASA has had success with double blind reviewing. With the Hubble Space Telescope, they received a number of proposals by female PIs (~50%). **Dr. Wilson** illustrated that in double blind reviews, the technical narrative could not identify institutions – they were referred to as institution 1 or institution 2. In the review process, there are two phases. The technical merit is reviewed in one phase, with the blinding, and later, there is an assessment of the institution’s capability of following through on the proposed activity. **Dr. Wirth** asked about language concerning the two-step reviewing process. He noted that the DOE’s two-step process allows one to first review the proposal without identifying the PI or Institution, while the second phase allows one to know those details.

Dr. Wilson asked about the opportunity for FES to provide funding to do new curriculum development and initiate programs separately, and that there should be a clear recommendation. **Dr. Lasa** said that the subcommittee put this in because it needs to happen.

Dr. Knowlton asked about workforce development. The P5 report looked at the skills needed for the existing and envisioned program and identified a lack of skill in one area. He asked if the subcommittee’s comments about the Office of Management and Budget (OMB) restrictions apply to workforce development in specific fields. **Dr. Carter** replied that the subcommittee targeted the main recommendation of the OMB limitation. The policy was meant to reduce duplication of effort, but it had other impacts. The P5 recommendations were targeted at programs that would enable a workforce. **Dr. Wilson** stated that there is more room for discussion of workforce in the budget scenarios, and only in the constant level of effort scenario is there an expression of concern for what the workforce implications might be from pivoting. He added that there may be real workforce constraints depending on the budget scenario. Particularly in the unconstrained scenario, there should be thought given to developing the workforce to keep pace with the needed actions.

Dr. Kuranz asked about engaging DEI experts and if “actionable by other stakeholders” applies to FES or is stating that both FES and other agencies should do this. **Dr. Carter** said that

the sense from the CPP was that this would be a good item for FES funding. It is important to target the advice towards a broader audience. The suggestion is that there should be more institutional ownership than just FES. She stated that DEI should be woven more into the report. Bringing in DEI experts needs to be done at other institutions as well as FES. **Dr. Brown** emphasized the role that undergraduate and graduate institutions can play in introducing, training, and promoting young scientists, especially women and underrepresented minorities, and he recommended more effort be placed at that level.

Dr. Barish said that there has been a lot of discussion by the subcommittee about DEI and workforce, but it was not part of the Charge. An Appendix placement for DEI and workforce is appropriate.

Overall Comments about the Report

Dr. Patello asked what was excluded from the CPP report or added by the subcommittee. **Dr. Carter** replied that one example is a discussion about the additional High-Heat Flux Testing Facility. This was discussed but not called out explicitly in the CPP report. The subcommittee viewed that as an important addition to the program areas. The CPP report is a companion to this report. **Dr. Terry** added that this report needs to articulate that the CPP is a companion report which contains proposals that are not discussed in the FESAC report, and that there was a decision made to focus on a subset.

Dr. Terry asked about a recommendation to explore and implement mechanisms for formal coordination between funding agencies. **Dr. Carter** replied that this report amplifies messages that are in the Decadal Assessment of Plasma Science.

Dr. Knowlton noted that in Chapter 1, there is a reference to a gap in knowledge. The 2007 Greenwald Panel Report listed a complete set of gaps. The recommendation was to incorporate a gap analysis, or list of priorities, into a strategic plan. He suggested that the subcommittee reexamine the listed gaps to see if any have been closed, addressed, or progressed, noting that SPARC as a gap that is progressing. **Dr. Carter** stated that documents similar to the Greenwald Report were utilized by the CPP. The CPP considered gaps and what is needed to close them. ITER is an important part of SC. SPARC may burn plasma, but that is not its mission. The worry was that putting SPARC next to ITER would create unintended consequences.

Dr. Parker was concerned about FES expanding into new areas such as the Solar Wind Facility, space science and space physics, and the mid-scale Z pinch. He said that these areas are central to NASA, NSF, and NNSA, but not FES. **Dr. Carter** explained that NASA does not fund lab experiments, but will construct part of a solar probe. FES's strength is in the lab experiments on fundamental plasma physics that addresses issues elsewhere. Fundamental science around lasers is enabled using facilities like Z pinches and high-energy-density physics (HEDP) experiments. The subcommittee called out the Z pinch as a specific target because NNSA is likely to be interested.

Dr. Sunn Pedersen called attention to Dr. Fall's emphasis on international collaborations. He felt that the focus of those collaborations should be on saving time, not saving money. **Dr. Maingi** noted that the subcommittee did not investigate opportunities overseas or conduct technical analysis on what is strategic and sensible. **Dr. Terry** commented that in terms of selling the plasma science program to the greater world, that sales pitch is largely geared to engineering and technology. His colleagues would be more excited to hear about the science.

Dr. Terry requested that the vague terms (foundational, understand nature) be defined in terms of the opportunities. He highlighted that the criteria used for prioritization did not include

“value to science”. And he noted that in Chapter 1, simulation and computation are mostly described in the context of the biggest, most grandiose, most integrated, and most computer-intensive terms. It is important to clarify that the vision is for a hierarchy of models rather than the fanciest, most state-of-the-art computation.

Dr. Trask was glad to see the energy mission embraced and was pleased that the report suggests a direction of constructing actual tests; these are tools to help produce electricity.

Dr. Moret said that the CPP and subcommittee members seem to be living up to the community agreements and honoring those. FESAC’s comments have highlighted the complexities of meeting the needs of all stakeholder groups. She asked that FESAC layer onto the conversation about boldness which constituents, within which time frame, assuming which budget, and which workforce issues. Thinking of this community as one community is very new, and bringing everyone together is requiring a real culture change. She asked that FESAC remember the strengths of the report, to think carefully about the solutions being recommended, how, in particular, these will be implemented within the time period the Charge offers, and how to make the report inspiring and realistic without breaking consensus. She hoped that everyone would spend time being clear about what they liked, appreciated, and are excited about in the report.

Dr. Wilson noted that the report does not tie FST and PST together. The FST mission has a clear goal to have an FPP in the 2040s, whereas the PST program has great science but no single vision. He asked how the resources would be balanced between the two programs, or if achieving an FPP would dominate the choices. **Dr. Carter** said that in the constrained scenarios the subcommittee decided to redirect within each program because there is no headroom for construction. **Dr. Wilson** thought that the report adequately lays out the shared vision from the CPP; however, he was concerned that the PST area is not well defended – there is not a vision articulated for PST.

Public Comment

Dr. Rej invited public comments and recognized Dr. Amitava Bhattacharjee (PPPL), Dr. Bob Mumgaard (Commonwealth Fusion Systems), Dr. Earl Marmor (MIT), Dr. Allen Boozer (Columbia University), Dr. Nick Murphy (Harvard-Smithsonian Center for Astrophysics), Dr. Sterling Smith (General Atomics), Dr. Mike Campbell (University of Rochester Laboratory for Laser Energetics), Dr. Lauren Garrison (ORNL), Dr. Royce James (Air Force Institute of Technologies), Dr. Hantao Ji (PPPL), Dr. Pierre-Alexandre Gourdain (University of Rochester), and Dr. Andrew Holland (FIA).

Dr. Bhattacharjee said that his comments address great opportunities for the FES-ASCR collaboration, namely a whole device modelling (WDM) hierarchy. The WDM requires a fidelity hierarchy of computational models visualized as a pyramid structure. The computer infrastructure needed depends on the level of the hierarchy – from exascale computing (and beyond) at the highest fidelity to capacity computing for reduced models. An omission that has gradually occurred since the National Academies Final Report of the Committee on a Strategic Plan for U.S. Burning Plasma Research (2019) is one that has found its way into the subcommittee report as well. In the Burning Plasma Report, a special point was made that the largest project in the Office of Science, the DOE Exascale Computing Project (ECP), surpasses ITER in terms of funding, and has provided the “realization of a high-fidelity [WDM] of fusion plasma...” The ECP funds a leading project in FES as well as throughout SC. There is bipartisan agreement that this area should continue to receive significant funding. ITER was designed based

on scaling laws; however, facilities such as EXCITE should be based on WDM, exploiting the power of the pre-exascale and the exascale.

Dr. Mumgaard applauded the unifying of different parts of the portfolio and the recognition that fusion is not attracting the best and brightest from a diverse background due to structural flaws. He highlighted three deficiencies of this consensus report. First, one cannot tell what is in the plan, or what is and is not included in the scenarios. Second, it is clear that anything close to the current budget levels leads to more of the status quo. Third, this plan glaringly leaves the community open to the conclusion that less support could be better for the world. His advice for FESAC was, first, write down the actual numbers for budget proposals. Second, change the plan on a constrained budget that sacrifices more to get more. Third, show the unconstrained budget and that it is not so high. Then, use that to reframe the dialogue with Congress from one that points out how all is lost if they do not appropriate more funds, to one that focuses on the opportunity just ahead, and that is not that far out of reach.

Dr. Earl Marmor discussed three points: (1) PPPs will be a key component of any successful effort to bring commercially viable fusion to fruition, and an explicit plan for moving forward on these is needed; (2) SPARC offers a unique, world-leading opportunity for the U.S. program in burning plasma science; and (3) it is critically important that the fruits of all the investments in ITER are shared among all U.S. participants, including in the private sector.

Dr. Allen Boozer stated that the standard time scale for addressing the CO₂ issue is 30 years, the approximate doubling time for atmospheric CO₂. He asked that if the country is more interested in speed than cost, is there nothing fusion can contribute? It is a dangerous message to imply that fusion cannot be developed on the 30-year time scale. Secondly, he said that to imply that DIII-D and NSTX will retire the disruption issue implies that the subcommittee is unfamiliar with the physics. In any rapid plasma cooling, these machines are in a very different physics regime from a fusion system. In particular, they are off by more than twelve orders of magnitude in the drive for runaway electrons.

Dr. Jonathan Zuegel suggested two changes to the text: (1) on page 23, to “explore and implement mechanisms for formal coordination between funding agencies that support fusion and plasma science research” should be echoed throughout the report, and (2) on page 32, change the statement to “...in operation internationally. The U.S. can stay competitive by leveraging decades-long investments ...” and modify the recommendation to “...high-intensity laser facility in the U.S. in partnership with other interested funding agencies, including other SC offices, NSF, NNSA, and DOD.”

Dr. Nick Murphy spoke as a member of the APS DPP Diversity, Equity, and Inclusion Organizing Collective Committee (OCC) and as a member of the PlasmaPy project. The OCC is encouraged that our community is recognizing that in order to realize a return on scientific goals, we absolutely must improve the DEI culture and our community’s climate. The OCC believes that DEI should be more strongly infused throughout the report. He listed specific changes that were forthcoming in written comments from the OCC focused on DEI, specifically making DEI stronger, removing the suggestion that DEI be a tie-breaker for proposals, engaging DEI experts, and using “double anonymous” rather than “double blind.” As a member of the PlasmaPy project, he had one comment about the recommendation on page 33 which was to address interoperability between “computational tools” and suggested the phrase “research software infrastructure.”

Dr. Sterling Smith pointed out a near-term win, in which the U.S. can prepare for ITER operations: modifying the serving of experimental data for existing tokamaks and the integrated

modeling analysis and predictive workflows so that they are compatible with the Integrated Maintenance System. The benefits to the U.S. are having a single data schema for all of its tokamak data and of acquainting U.S. researchers with the form in which ITER data will be provided. The benefits to the ITER community will be bringing to bear U.S. leadership in integrated modeling and analysis on this topic and stress testing the data schema.

Dr. Mike Campbell made comments on the challenge of fusion environmentally and economically and working with the Office of Nuclear Energy; fourth generation nuclear reactors; the political world's alignment with fusion; prioritizing HEDP; the mortgage for operations in any new facility; and the impact of the fusion program.

Dr. Lauren Garrison expressed her pleasure that the subcommittee was faithful to the CPP; requested that the gap analysis be more obvious in the final report; and asked for a more specific roadmap, sequencing diagram, or detailed timeline. She suggested finding a more elegant and explanatory term than "unconstrained;" indicated that the PST name is a great way to elevate that program and give credit for the technology they develop; and recommended focusing on a milestone-based, competitive process open to all industries rather than specific companies for PPPs. She said including the DEI efforts was groundbreaking for the field, and she was happy to see materials science technology as a high priority.

Dr. Royce James stated that DEI needs to become entrenched into the day-to-day operations, and suggested that the same type of organizational management as in the CPP could be applied to Division diversity as well as other types of diversity (race, sex, age, LGBTQIP+). He said that DEI is not just a mechanism to bring in a full workforce; it is a way in which we will diversify our ideology to solve problems yet to be solved. The strategic plan was a definite step in the right direction, but it needs to be spread out through all the diversity categories.

Dr. Hantao Ji said that a credible plan exists, and the community has reached consensus in Phase 1. However, there are no specific recommendations to address critical issues such as proposed frontier centers, ideas, or extended or super network ideas. He was happy to see that prioritization was done; however, something has to be said about key assumptions. He suggested making the assumptions and leverages, and the definition of unconstrained, very clear.

Dr. Pierre-Alexandre Gourdain would have liked to see more in the report on cross-cutting science, how HEDP can help magnetic fusion energy (MFE) and vice versa. He was disappointed in the priorities in the scenarios; for example, in the constant level of effort scenario, the subcommittee chose to get rid of some basic science facilities and replace them with material testing facilities. He wondered why the drivers are to reduce plasma, and then the consensus is towards a fusion reactor. He suggested restructuring the prioritization and assigning different levels of scientific effort to each budget scenario. He said materials testing should be offloaded to the materials science community that has domain expertise. He would like to see a forum to advocate for the creation of a flexible materials testing facility that can satisfy the needs of multiple agencies, including the private sector. He thought that a facility that includes fusion and a multi-pronged approach to study materials would be more successful and more useful.

Dr. Andrew Holland commented that FIA commends the report for transitioning government fusion research from a science goal toward a goal of developing fusion energy and towards the domestic energy industry. It is true that the U.S. is poised to lead in the private sector fusion energy industry, but this opportunity will be lost without strong support. Private industry and private capital go to the areas of the world that support it the best. That is why now is the time to take up the call from the report to implement a milestone-based cost-share program. Now is the time for U.S. leadership in the emerging global race for commercial fusion power.

International competitors have not waited. Although U.S. companies are world leading, no one would say that the U.S. program would be the world leader.

Overall Comments about the Report, continued

Following the public comments, FESAC engaged in discussions on the topics of boldness of the report, structural changes to the report, and tritium and a BCTF.

Boldness

Dr. Patello asked for FESAC's perspective on the report's level of boldness. **Dr. Sunn Pedersen** explained that if the budget were going to be unconstrained, then the report is too modest; however, there is not consensus for a very bold mission. Consensus is the most important thing, but the report should include a statement that a more aggressive, faster plan needs time to develop. The report needs to clarify that a bold plan could have been developed, and it will be done next time. **Dr. Trask** speculated that even with a tripled budget, the same programs and facilities recommended, in their ranked order, would still be followed. The timeline is set by the budget Congress allocates to FES. Hopefully, the vision and the importance of the mission to get to clean energy will be sufficient. **Dr. Snyder** appreciated the balance of boldness and realism, and was comfortable with the choice made to constrain the unconstrained scenario and to fit it into a realistic budget envelope. **Dr. Terry** stated that the subcommittee provided a well-reasoned scenario with the constant level of effort budget, but that there are significant losses. Only the unconstrained budget has room to be bold. To some, boldness means 10x or 20x the budget; the sky is the limit. He speculated that ballpark numbers can be provided to help the discussion. **Dr. Knowlton** commented that the report must hit the mark on consensus, engaging private partnerships, and addressing the Charge. The P5 report had well defined areas and initiatives; however, FES has two initiatives that are describable, defined initiatives with clear goals. Other initiatives are aspirational, and that limits the ability to be super bold, but there is boldness in this report, especially in terms of PPPs. It is clear that this process needs to be reviewed in less than five years. **Dr. Reyes** said that the report opens with the bold statement of building a fusion pilot plant by the 2040s. Then, it loses its boldness. **Dr. Kessel** articulated various elements that showcased boldness: redirection towards energy, pivot from the tokamak physics, a multipronged activity towards the FPP that pushes parallel activities, moving all of the programs simultaneously towards critical operations, and a strong message tying science, engineering, and technology together. **Dr. Maingi** reminded FESAC that while some are saying that the plan is not bold enough from a science perspective, Dr. Fall said that he had the opposite reaction – there is much more here than DOE will be able to do.

Dr. Barish mentioned that as far as boldness is concerned, people have various opinions on how bold it is; but as boldness is added consensus is threatened. The P5 report was so successful because of consensus with about 2,200 signatures endorsing the report.

Structure

Dr. Matthews said that the plan spelled everything out in detail, was flexible, and adaptable, and that it was good to state the science objectives prior to showing any budget numbers; she appreciated the recommendation to revisit this at least every five years. She proposed that the report lead with the unconstrained scenario and then discuss what will be missed; this proposal was supported by several FESAC members. **Dr. Carter** explained that there is a reason for the order of the scenarios as the Charge reads that “additional items [are] prioritized” in the

unconstrained scenario. **Dr. Barish** said that the Charge from SC specifies, for the unconstrained scenario, to list prioritized activities beyond those in the constrained scenarios.

Dr. Maingi added that in the beginning part of the Charge, the three scenarios are listed in the following order: constant level of effort, modest growth, and the important wording for this unconstrained scenario says, “Please list, in priority order, specific activities beyond those mentioned in the previous budget scenarios”. It was difficult to make an inversion of that workable. The recommendations are the enticing part of the plan and what is needed to execute the full plan; de facto, that is the most aggressive scenario. **Dr. Wirth** expressed his appreciation for that explanation about the unconstrained budget scenario and presenting that first. He asked if it would make sense to provide the modest growth scenario before the constant level of effort scenario. **Dr. Wilson** asked if it would make sense to make a plain statement in the preamble to this section that says the only way to implement these recommendations is with the unconstrained budget. The report currently says the negative version of that. It reads “we cannot prepare for construction by the 2040s within these constrained scenarios.” **Dr. Wirth** suggested writing that it would require a budget with significant growth, rather than specifying unconstrained.

Tritium and a BCTF

Dr. Reyes pointed out gaps in the storyline for construction of a FPP by the 2040s, including stakeholder engagement, licensing preparation, tritium inventories, and blanket designs. The technologies ITER will use for tritium handling yield hundreds of kilograms of tritium. She asked about the effort to move from the current tritium blanket technologies, at a very low TRL, to final plant readiness. **Dr. Carter** said that the activities for an FPP appear in the CPP report, but this report focuses on the near-term. This plan does not get to fusion by 2040. **Dr. Humrickhouse** noted that this report addresses technologies to help reduce the size of the tritium plant. The list of facilities comes directly from the CPP. **Dr. Reyes** asked if consideration was given to having a BCTF do integrated testing with tritium or neutrons. **Dr. Humrickhouse** explained that the description attempts to integrate everything except for radioactive materials and neutrons.

Dr. Patello commented that the tritium testing question is better planned for the next decade. She requested that that assumption be included in the report to address nuclear versus non-nuclear operations. **Dr. Rej** remarked that tritium only shows up once in the Executive Summary and one other time in the report.

Dr. Reyes asked if a BCTF will handle tritium, about international partnerships for fuel cycle and blankets, and the timeline of ITER in relation to FPP designs. **Dr. Humrickhouse** responded that as a non-nuclear facility, a BCTF is using hydrogen and deuterium. He said that there is not a specific comment about international collaboration. And, he suspected that some design work will occur in parallel with ITER activities.

Dr. Wirth suggested conveying a sense of excitement that new and important facilities are necessary to achieve the energy mission. He expressed a strong technical reservation that the report contains too little on tritium and on a BCTF. He took umbrage with the statement about the test facility not having neutrons or radioactive materials, because using hydrogen and deuterium will go far enough; testing in nuclear environments is needed. He advocated for making the test facility specifics more general and stating that community-driven workshops and analysis need to be done to define a BCTF.

Dr. Verboncoeur said that if the fundamental physics is in the system, an opportunity arises to revisit things with new tools and techniques to overcome instabilities, suggesting keeping that in mind as it is a moderate cost.

The wording for the tritium topic was discussed at length. **Dr. Wirth** suggested changing the description of the BCTF. **Dr. Humrickhouse** responded that the nuclear/non-nuclear facilities issue came out of the CPP process. A strategy that would eventually include nuclear testing for component scale blanket testing is necessary.

Dr. Reyes added that the report sounds like the U.S. is going to use ITER technologies for the FPP. **Dr. Kessel** responded that the text recognizes that there is R&D to minimize cost, size, and the tritium inventory of the FPP. That comes from using ITER to the fullest extent, but recognizing that there are modernizations to take advantage of. **Dr. Maingi** explained that the subcommittee focused on the non-nuclear side of the tritium discussion to stay true to the CPP. **Dr. Wirth** indicated that while he appreciated the concern, he could not vote yes if it is a non-nuclear facility.

Overall Comments about the Report, continued on Day 3

Discussion on the last day of the meeting focused on reviewing the recommendations, the suggested changes document, and hearing comments from all members of FESAC in a “round robin” fashion.

Dr. Moret clarified the expectations for the third day: that the discussion will continue, and then FESAC will vote on the recommendations and the entire report; she stated that the votes are critical, and it is also critical that the community maintains its unity. Another important aspect is that the audience of this report is primarily geared towards Congress. She reiterated that the CPP report is the companion document, the blueprint that contains all the technical detail, and it was adopted in its entirety in this report. She hoped that today FESAC members offer feedback and stay focused on completing the review of the recommendations and other text to ensure that there is a shared understanding about the changes made. It is critical that feedback takes the broader context from the community spirit into account. Also, feedback on the entire report should include elements that are liked and valued.

Dr. Rej thanked Dr. Moret and called on Dr. Carter to move forward with his presentation of the recommendations. He stated that the goal is for FESAC members, with consensus, to build upon the subcommittee report.

Recommendations Discussion, Dr. Troy Carter

Dr. Carter began the discussion on each recommendation in turn. The discussion focused on specific wording changes with the exception of one FST, two PST, and two Cross-cutting recommendations.

Dr. Carter explained that the FST Recommendation on Innovations captures stellarators, liquid metal plasma-facing components, IFE, and alternate concepts. He said these four elements were vetted through the CPP carefully, and the order is related to the prioritization from the community regarding the need to mitigate risks and address vulnerabilities of following a mainstream solid plasma-facing components tokamak path. **Dr. Barish** added that the audience for the report includes policymakers, and it should be clear that there are economic impacts beyond the program itself.

Dr. Scott Baalrud said that the point in the PST: Consistent Support recommendation is that consistency is important. **Dr. Verboncoeur** commented that it is only possible to legislate a

steady stream of support for generating ideas and talent. Further, he said that the constant level of funding does not achieve the goal because it is possible to contract or expand the time scale while maintaining support for the fundamental personnel so that the talent is not lost. He speculated that the spirit of this recommendation is intended to keep the talent pipeline filled, and that suggests some outcomes like innovations, but it does not assure them.

Dr. Carter said that the PST: Lab Astro & Space Plasmas recommendation is meant to reinforce FES's strength in laboratory experiments, exploit the recent partnership with NASA, and include the need for new experimental capabilities. **Dr. Verboncoeur** suggested calling out the NSF-DOE partnership as a potential target. **Dr. Carter** responded that the main action was to strengthen the activities with partnerships. FES can enhance investments, especially in new facilities, and the subcommittee wanted that message to come through.

Dr. Carter said that the Cross-cutting: Foundational Research recommendation calls out the need for important activities for the FST and PST portfolio and is meant to raise awareness. **Dr. Verboncoeur** suggested making prioritizing cross-cutting activities explicit. **Dr. Parker** said that the point needs to be relayed that the community wants to maintain international leadership in theory and computation. He added that this is an opportunity to say that the U.S. leads in analytic theory, and it is imperative to maintain that leadership. **Dr. Holland** said that this is an area of historic leadership, and the U.S. needs to maintain investments across these things.

Dr. Verboncoeur clarified that the Cross-cutting: Fundamental Data recommendation is focused on acquiring data. It is very different than a statement of how the data could be managed, disseminated, and supported. It is a science gathering device rather than a process management device.

Dr. Carter opened the floor on three recommendations that FESAC had requested to revisit (focus on FM&T, visibility of theory, and DEI). He reminded FESAC that the conversation on the recommendation concerning increasing the focus on materials and technology was to change the language. **Dr. Wirth** explained that the original words were associated with "pivoting" towards research and FM&T, and that caused some concerns. Discussion ensued as to the definition of "pivot," its boldness, intentionality, and implications of the term. Other terms were suggested ("strengthen" and "increase," "prioritize and strengthen," "expand and prioritize," "strengthen and prioritize," "accelerate," "pivot and prioritize") as possible options to convey the message. **Drs. Kuranz** and **Maingi** read statements in the CPP report that contributed to the discussion on intentionality. The passages were "to rapidly expand the Fusion Materials and Technology Program" and "given the possibility of constrained budgets, there is significant support among the community to pivot resources from existing facilities to fund new program facilities." The sense of "pivot" in the CPP report is tied to those constrained scenarios (constant level of effort and modest growth) which the report is staying true to.

Dr. Carter pointed out that there were concerns about the visibility of theory and computation in the FPP design recommendation. **Dr. Snyder** noted that the change pulls language from the text into the recommendation to highlight theory and computation, and is meant to bring in the sense of the U.S.'s world-leading capabilities and importance in theory and computation that underlies development of an optimal FPP.

Dr. Kuranz explained that the language in the DEI Overarching Recommendation came from the CPP and was modified by additional discussion. **Dr. Verboncoeur** asked if it is appropriate for FESAC to make recommendations to DOE rather than FES. **Dr. Carter** clarified that the report is to DOE-SC. There are also recommendations that are targeted to different places with the idea that this will be read by the Office of Science and Technology Policy

(OSTP), OMB, and Congress. **Dr. Kuranz** suggested that DEI experts be engaged to provide recommendations, stating that accountability and transparency need to be part of that process. She reminded FESAC that the CPP report stated that “FES and relevant institutions engage DEI experts to study the social climate within the community, within the fusion science plasma fields, and take action on those recommendations.” **Dr. Carter** said that what was lost was engaging experts from outside the fusion community, and suggested adding that the unique need is to seek advice from the right people. **Dr. Wilson** said that FES only needs to take advice; there is no action involved. He suggested making the statement: “should seek to implement policy changes in consultation with DEI experts.” **Dr. Walker** recommended adding the word “metrics” to ensure that FES is tracking.

Dr. Carter suggested that FESAC review the recommended changes document (23 suggestions) together and determine if these capture the sense of the recommendations. The changes included emphasizing the plan, clarifying the unconstrained budget, including new phrasing and adding explicit text on partnerships, de-emphasizing the intense laser example, accessing burning plasmas and SPARC, deleting “double blind,” altering text on DEI and workforce improvements, nodding to specific partnerships on high intensity lasers, acknowledging the need for a growing workforce, clarifying that multiple facilities match MPEX/ PMI capabilities, ensuring consistency between the findings and the unconstrained scenario, referencing the spinoffs report, and adding the term “optimize” in the accelerator finding.

Dr. Carter asked FESAC for any additional changes. **Drs. Baalrud** and **Terry** asked about changes to computational capabilities and language indicating that the CPP report should be considered a companion document. **Dr. Carter** confirmed that there was language addressing both of these topics.

Round Robin Discussion, Dr. Donald Rej

Dr. Rej engaged FESAC in a round robin session and asked each FESAC member to make comments on the report or the process. The statements focused on appreciation and impressions, tritium, tokamak physics, and DEI.

Dr. Kessel said that he was very happy with the evolution of the document and thought that the suggestions were excellent. **Dr. Kuranz** noted that she was excited to be a part of this and was impressed with the discussions. **Dr. Wilson** said that he was extremely impressed by the work the subcommittee had done in the last four days responding to the conversations. **Dr. Reyes** valued the fact that this is a consensus report and expressed her appreciation for the effort.

Drs. Knowlton and **Walker** were comfortable with the report, and **Dr. Walker** supported the concept of leaning forward with an aggressive budget. **Dr. Skiff** shared the concern that the constrained scenarios really represent lost opportunities. **Dr. Trask** thought that this report would move the bar and reshape the program in tangible and beneficial ways.

Dr. Maingi thanked everyone for making improvements, noting that people tend to focus on the budget scenarios, particularly the difficult ones. He and **Drs. Skiff** and **Snyder** recognized that it is imperative to emphasize the strength of, and excitement around, the entire set of recommendations, and that it must be clear that the consensus recommendation is the unconstrained budget, the full program, the complete set of recommendations, and an ambitious goal for an FPP by the 2040s.

Drs. Ma, Matthews, and Murph indicated that the report represents a tremendous effort, excellent teamwork, and the result is a great document. **Drs. Patello, Sunn Pedersen, Walker,**

White, and **Wilson** indicated that their concerns had been addressed and thanked Dr. Carter and the subcommittee as well as the CPP process. **Dr. Terry** conveyed his appreciation to the subcommittee for their hard work saying that they have taken the CPP consensus and carried it into this report, and the last three days have provided refinement. **Dr. Parker** expressed his gratitude for the CPP process, the FESAC subcommittee, and Dr. Carter's efforts. **Dr. Wirth** echoed others' appreciation for the work of the subcommittee and their willingness and responsiveness this week for making changes. He complimented the subcommittee for building a consensus strategy. **Dr. Brown** said that on behalf of the DPP, he would like to thank the subcommittee, and Dr. Carter especially, for their hard work. This is going to be a very important report. He stated that FESAC should be proud and pleased to be part of this because we will be referring back to the "Carter report" for a decade or more to come.

Dr. Sunn Pedersen appreciated that the process involved everyone, but thought it would have been nice to have gotten involved earlier as most were left out of the community effort and work on the subcommittee, by design.

Dr. Parker stated that while he trusts the CPP process and that the FESAC draft reflects the CPP findings, he was concerned about being responsible for advising the DOE on the fusion program. The magnetic fusion program is in a holding pattern due to the deuterium-tritium operation timeline on ITER starting around 2035. In his view, the U.S. plan should be more ambitious and include initiation of a FPP. China is doing this; they are very serious with CFETR. There is construction, and they have delicately scheduled the CFETR timelines so as not to supersede any ITER timeline in any way. His hope is that in five years, through the next CPP, the community will be ready for a FPP and be more ambitious. **Dr. Reyes** stated that she did not think the report was ambitious enough, mostly in the area of fusion science for delivery of an FPP. Things that will help move the country towards an FPP were missing from the roadmap, such as licensing, waste management, disposal innovations, and remote handling for very hot, activated components.

Dr. Parker stated that there is a cut being proposed for the constant level of effort, and the modest growth scenarios that involve cutting tokamak physics programs. Tokamak physics is excellent science, and it is critical for the success of ITER; the cut proposed is basically shutting down one of the tokamaks. He said that he genuinely worries that the budget recommendations in this report are damaging to the U.S. MFE program. **Dr. Parker** explained that there is a bullet that explicitly says that we are going to cut the tokamak physics by 50%, and he did not think the report should explicitly make that statement. **Dr. Verboncoeur** had similar misgivings that Dr. Parker expressed over the potential cuts in some of the scenarios. However, he thought that it was necessary to recognize that this is the consensus of what the community is willing to live with.

Dr. Wirth stated that the Nuclear Energy University Program (NEUP) has no process for reviewing projects that are successful. That is a critical part of an assessment for a renewal proposal. **Dr. Wilson** added that the NEUP review process did that for a time, but it has moved away from it. The reason could be that the community is so small that it is impossible to fully anonymize, and that might be true in this case.

Dr. Rej asked Dr. Moret to share her thoughts on what has been happening in the work that has been done. He thanked her and everyone else who worked on this for the past two years.

Dr. Moret encouraged FESAC to reflect on this journey. Some have been on it longer than others, but it has been two years of really thoughtful conversations across hundreds of people. That is extraordinary. The responsiveness to feedback over the past two years, the amount of

people that have been involved and shared their thoughts and feelings about things has been considerable. Everyone has shown such patience and respect for one another, really acting like one united community even where there are real areas of difference, and living up to those community agreements that were introduced in the CPP. It has been beautiful to witness. We started talking today about the critical nature of the report, the critical nature of the vote, so that the community continues to stand as one, and how much more powerful that will be after the vote. She hoped that everyone felt they were able to be heard, the points were able to be incorporated in a thoughtful way, and there was understanding even if not everything was included. She hoped that people were able to vote with good conscience on behalf of the community, recognizing that the report is really directional. It is time limited. There is a recommendation to do this again, and next time everyone will be prepared. She hoped that everyone felt good about it and that whatever compromises were made, were made in the spirit of community, recognizing the sum total of the report is quite extraordinary, and that it could not have happened without the extensive level of compromise and understanding.

Voting on the Recommendations and the Report, Dr. Donald Rej and Dr. Sam Barish

At the end of Day 3, **Dr. Rej** initiated the voting process on the 27 recommendations and the report as a whole. Using Robert's Rules of Order, **Dr. Barish** asked for motions to accept each recommendation in turn. Upon conclusion of the voting, he shared that each of the 27 recommendations had been passed unanimously; three of them were passed 19-0 because of recusals on each of those three, and the remaining 24 were passed 21-0.

Approval of the Report

Dr. Barish noted that the last thing to do was to approve the entire report. Discussion continued about Dr. Parker's concerns on the language in Table 1 about the reduction in tokamak science. He said that there was a stated preference for the CPP language on the topic and to make an implicit, rather than explicit, statement about reducing tokamak science. The change requested was to delete the words "but reduce" or the words "but reduce modestly," and to add the exact words that were in the CPP report regarding the pivot towards materials and away from the tokamak physics program. Adding that to the report will be consistent with the community consensus, but it will not present a negative picture. **Dr. Carter** clarified that Table 1 is meant to be a reflection of the text. The text goes through the discussion of enabling new programs under the two constrained scenarios. That includes language that mentions needing to redirect resources. The content in Table 1 would go away in the Table if "but reduce" is removed. It is meant to convey the scenarios and what has to happen.

Dr. Parker made a motion to add the wording from the CPP report and remove the wording in Table 1 "but reduce" or "reduce modestly," saying that his offers the community consensus takes the place of the negative wording in terms of budgets, preferring not to do one without the other. **Dr. Barish** shared the passage that Dr. Parker was referring to: "given the possibility of constrained budgets, there is significant support among the community to pivot resources from existing facilities to fund new programs and facilities if necessary, so that new facilities can be operational within ten years or less." **Drs. Skiff** and **Sunn Pedersen** were amenable to this change. After much discussion, **Dr. Parker** withdrew his original motion and moved to simply delete "reduce" or "modestly reduce." He explained that he was attempting to avoid showing a negative picture to the funding agencies, the Federal government, and to OMB. His concern was that it is unclear where fusion will fit if the new Administration focuses on renewable energy

sources. **Dr. Skiff** followed saying that the unfortunate consequences in these restricted budgets are precisely the message to communicate. It needs to come through that without significant increases and construction of new things, the program will be devastated. **Dr. Snyder** stated that with either the constant level of effort or the modest growth budget, U.S. tokamak operations and research will be reduced. He pointed out that Table 1 has already appeared in news articles, and **Dr. White** asked if there was a way to make the table prominently represent what FESAC recommends.

Dr. Parker withdrew his motion. He said that Dr. White is emphasizing the importance of Table 1 in her comments that it cannot be changed; that it is prominent and important. **Drs. Matthews, Sunn Pedersen, Parker, and Kuranz** suggested adding a phrase to Table 1, beside each scenario. The proposed phrases were “not recommended, loss of U.S. leadership,” “loss of U.S. leadership,” and “negative impacts on U.S. leadership,” where appropriate. The rationale being that a number of people will see Table 1 but not the rest of the report. The matter was settled, and the recommended modifications were entered into the “suggested changes” document for the subcommittee to address.

Dr. Barish asked if anyone had further concerns and then asked for a motion to accept the entire report as modified by the suggested changes. **Dr. Kuranz** so moved and **Dr. Kessel** seconded. **Dr. Van Dam** interjected that he had received an E-mail message from Dr. Izzo, timestamped at 4:56 p.m., that indicated his “yes” vote for the report. **Dr. Barish** took a roll call vote. All FESAC members voted to approve the report. The motion passed 21-0.

Closing Remarks, Dr. Van Dam

Dr. Van Dam shared closing remarks, saying “previously, I had expressed sincere appreciation for the APS DPP and the CPP process and for the work of the FESAC subcommittee, and I repeat that appreciation in spades. Now, let me thank FESAC. During this three-day meeting, spread over four days, I think that you have operated exactly as a federal advisory committee should operate. You have represented the community and not just narrow interests, and your questions and comments have been thoughtful, professional, and constructive. Now, by approving this report, you and the entire community have demonstrated that we have gotten over the hump of being able to arrive at consensus. I know that at the last minute there was a discussion. I think that FESAC handled it well. That is what a federal advisory committee does. So, if I am asked now is the FES community fractious, I will point to this report as solid, up-to-date, counter evidence. You can be proud that we got to this point. It is a milestone report in so many ways. It is not the last such strategic report. We all need to keep our eye on the ball and keep strategizing, keep racking up various significant R&D accomplishments. Now, some of you may have heard me use this quotation before, but I think it applies here very well. In one of his inspiring speeches during World War II, Sir Winston Churchill said, “Now this is not the end. It is not even the beginning of the end, but it is perhaps the end of the beginning.” And I think that this FESAC report is a very good beginning. We now have consensus, a long-range plan for the entire program, and I encourage all of you to speak about the plan and speak for the plan with a single voice. You should be very proud of achieving the plan in this report, and I encourage all of you to brag about it. I, personally, am very proud of this community, almost to the point that I am emotional. Our office is extremely grateful for this successful, tremendous effort, and to FESAC and the entire community, thank you very much. Don, thank you.”

Dr. Wirth added his appreciation and thanks to Dr. Carter and the subcommittee. He thanked Dr. Moret who has demonstrated how helpful she has been throughout the process,

community planning, and reaching consensus. **Dr. Parker** said that this has been a wonderful group to work with and expressed his delight with the way everyone was able to work together. **Dr. Carter** added his thanks.

Dr. Moret expressed her pleasure that everyone is taking time to pause and reflect because FESAC has done an extraordinary amount of work. Everyone participating today represents many people in diverse subject areas. Because no one spoke on behalf of their own area, everyone will be able to represent this report, own it, and defend it.

Dr. Rej adjourned the meeting at 5:15 p.m. on Thursday, December 10, 2020.

Respectfully submitted February 6, 2021

T. Reneau Conner, PhD, PMP, AHIP and Jim Malone, PhD, MSIS
ORISE/ ORAU

Certified as Correct by:



Dr. Donald J. Rej, FESAC Chair

Date

March 17, 2021