

**FUSION ENERGY SCIENCES ADVISORY COMMITTEE
to the
U.S. DEPARTMENT OF ENERGY**

PUBLIC MEETING MINUTES

**Virtual Meeting via ZOOM
August 24, 2020**

**Fusion Energy Sciences Advisory Committee Meeting
August 24, 2020**

The U.S. Department of Energy (DOE) Fusion Energy Sciences Advisory Committee (FESAC) convened on Monday, August 24, 2020 via teleconference 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. Donald Rej (Chair), Los Alamos
National Laboratory
Prof. Troy Carter, University of California,
Los Angeles
Dr. Ralph Izzo, Public Service Enterprise
Group (PSEG)
Dr. Charles Kessel, Oak Ridge National
Laboratory
Prof. Stephen Knowlton (Vice-Chair),
Auburn University
Prof. Carolyn Kuranz, University of
Michigan
Dr. Tammy Ma, Lawrence Livermore
National Laboratory
Dr. Rajesh Maingi, Princeton Plasma
Physics Laboratory
Prof. Lorin Matthews, Baylor University

Dr. Simona Murph, Savannah River
National Laboratory, University of
Georgia
Prof. Scott Parker, University of Colorado
Dr. Gertrude Patello, Pacific Northwest
National Laboratory
Dr. Susanna Reyes, SLAC National
Accelerator Laboratory
Prof. Fred Skiff, University of Iowa
Dr. Philip Snyder, General Atomics
Prof. Thomas Sunn Pedersen, University of
Greifswald
Prof. Paul Terry, University of Wisconsin
Dr. Erik Trask, TAE Technologies, Inc.
Prof. Anne White, Massachusetts Institute of
Technology
Dr. Mitchell Walker, Georgia Institute of
Technology
Prof. Brian Wirth, University of Tennessee

Ex Officio Members Present:

Prof. John Verboncoeur, IEEE Nuclear Plasma Sciences Society (NPSS), Michigan State
University
Prof. Paul Wilson, American Nuclear Society (ANS), Oak Ridge National Laboratory
Prof. Ellen Zweibel, American Physical Society (APS) Division of Plasma Physics (DPP),
University of Wisconsin

DOE Personnel

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

184 FES and fusion community members attended the meeting.

Welcome and Opening Remarks, Dr. Donald Rej, FESAC Chair, Los Alamos National Laboratory

Dr. Rej reviewed the agenda and requested those wishing to make a public comment in the meeting to contact Dr. Barish.

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

In July 10, 2020, three co-chairs of the Community Planning Process (CPP) of the APS/DPP gave a presentation to the High Energy Physics Advisory Panel (HEPAP). On August 20, the FESAC subcommittee held a workshop for the fusion community to discuss the fusion and plasma science merged vision, mission, synergies, and strategies for the entire FES portfolio. Dr. Van Dam thanked the three CPP leaders for representing FES and welcomed the two new FESAC members.

The ITER Start of the Machine Assembly was celebrated on July 28 in a hybrid meeting and live streamed worldwide. The video is archived on YouTube, and there has been widespread media coverage.

All Funding Opportunity Announcement decisions have been completed, except Quantum Information Science (QIS) Research for FES, and QIS Research Centers. The first round of the Innovation Network for Fusion Energy (INFUSE) award selections has been completed yielding 10 awards. Connected to INFUSE, FES put forward a Request for Information on “Cost-sharing Partnerships with the Private Sector in Fusion Energy.”

The Department of Energy/Nuclear Regulatory Commission/Fusion Industry Association Public Forum on a Regulatory Framework for Fusion has been rescheduled to October 6, 2020. The first meeting for the Update on the National Academies of Science, Engineering, and Medicine (NASEM) Fusion Pilot Plant study will be held on August 26, 2020. The deadline for nominations for the 2020 E.O. Lawrence Awards for mid-career scientists and engineers is October 1, 2020.

Dr. Van Dam extended congratulations to the new leaders at the Princeton Plasma Physics Laboratory, Professors David Graves and William Dorland, and shared that FES has three program manager positions open, as well as opportunities for Intergovernmental Personnel Act (IPA) personnel and Detailee assignments.

Discussion

Dr. Knowlton asked about the expected timeline of the NASEM study on the Fusion Pilot Plant. **Dr. Van Dam** explained that this is a committee consensus fast track study with a charge to finish within eight months.

Dr. Kuranz inquired about the potential impact that an Administration change might have on the long-range plan (LRP). **Dr. Van Dam** indicated that when Administrations change, there is often a hiring freeze and the political appointee process takes place. Upon confirmation, the DOE conducts briefings with the new appointees, and the LRP will be a significant part of those briefings. The plan is expected to be a lasting, solid contribution to FES.

Dr. Sunn Pedersen questioned the discussion protocol voiced at the August 20 workshop. **Dr. Van Dam** stated that FESAC will have an opportunity at its December meeting to approve or change the report. The subcommittee discussions are currently private, and thus they did not speak at the August 20 workshop. The request that FESAC refrain from interjecting was because it will approve the report and thus will have an allotted time to discuss it.

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

The 2018 charge was to identify and prioritize the research required to advance both Discovery Plasma Science (DPS) and Fusion Science and Technology (FST). The two-part process included gathering community input through the American Physical Society's Division of Plasma Physics CPP and the current FESAC Subcommittee. Community consensus is a goal, and the activity is based on the success of both High Energy Physics and Nuclear Physics LRPs.

The 2019 enacted budget acts as the basis for the three budget scenarios in the LRP, which focuses on the entire FES program except ITER. Project experts and cost estimators are providing costing information for projects. Estimates are informed by existing projects and historical information. Most FES facilities are pre-conceptual, and the subcommittee is building in flexibility to accommodate that uncertainty.

The draft unconstrained budget estimate is awaiting refinement. A significant fraction of the unconstrained budget is facility construction. The subcommittee is currently addressing prioritization and constrained scenarios. Utilizing all guidance from the CPP report, the subcommittee will produce a tiered system (such as essential, integral, and aspirational) to maintain flexibility in the plan. The subcommittee has had several external guests talk about partnering and is looking for additional opportunities for public-private partnerships. Merging the DPS and FST plans is being decided.

In June, July, and August 2020, the subcommittee gathered information via focus groups and a virtual workshop. These events concluded with information concerning the task, goals, portfolio, cross-cuts, process, tradeoffs and risks, and budget scenarios.

The LRP will be a concise and compelling report with clearly articulated items of importance to the community. While there will not be a detailed budget in the report, it will contain a number of suggestions and express clear prioritization. The subcommittee will begin writing the report soon and is on track to have a draft report in October. If possible, there will be a NASEM-like external review, but the ultimate authority for the report lies with FESAC.

Discussion

Several FESAC members extended their thanks to Dr. Carter and the subcommittee for their excellent work. Others expressed their comfort with the process and the subcommittee's progress.

Dr. Carter reiterated the importance of obtaining consensus with the broader community, stating that both DPS and FST are intellectually diverse, thus justifying a visible focus on that multiplicity. Dr. Carter informed FESAC that there are limitations on what can be shared concerning the subcommittee's actions and deliberations at this point.

Dr. Walker asked about increases in DOE staffing to manage new activities laid out in the LRP. **Dr. Carter** thought that would be necessary, especially in the aspirational, blue sky budget.

Dr. Murph requested suggestions on how these LRP findings can be implemented and how the fusion community might share the plan with other communities. **Dr. Carter** explained that officially FESAC passes the report on to FES as advice; it is up to FES to implement the LRP. FESAC could possibly monitor the progress on the plan, but FESAC also needs to consider what happens after the report is available. The ultimate goal is to make the plan something the community supports, to make it worth FESAC's backing, and then make the case for the LRP broadly. As the report comes out, the subcommittee is willing to hold seminars, webinars, and

discussions to share the report, take questions, and openly communicate the plan. Based on the Particle Physics Project Prioritization Panel (P5) experience, FESAC also needs to provide materials to the media to advertise the report.

Dr. Snyder appreciated the comments on the different budget scenarios, particularly the constrained budget scenarios, and speculated that these scenarios may be used to make the case for a pilot plant. He suggested thinking of the constrained budgets in terms of the key elements necessary to make the case for a pilot plant.

Dr. Knowlton inquired if program balance and DPS having base-level funding was discussed at the workshop. **Dr. Wilson** proposed a hybrid model of base-level and percentage funding – a funding floor and a percentage above that floor. **Dr. Carter** said that base-level funding for DPS was discussed and that many at the August workshop advocated for a funding floor. **Dr. Knowlton** added that the separate base-level funding for DPS should not be considered a ceiling. DPS is a fundamental area of research and an essential part of the program. Ignoring or picking away at DPS funding will have long-term consequences. **Dr. Wirth** expressed support for Dr. Knowlton's comment about needing base-level funding to maintain support of DPS. **Dr. Carter** stated that like plasma scientists at universities, funding across federal agencies is spread out, and there is no coordination across the funding agencies. That means support has to be won in different venues.

Dr. Terry asked if there are efforts to bring the community to consensus on the budget distribution given the time constraints, and suggested that the subcommittee clearly articulate the consensus as it currently exists with the stated principles used for budget allocations. **Dr. Carter** responded that DOE leadership has indicated this is not a zero-sum game. DPS and FST have their own reasons for growth – those can be conveyed in compelling ways in the report while at the same time acknowledging that his topic needs more development. The LRP will lay out a certain path forward, but course correction can occur based on future information.

Dr. Trask expressed concern about the Office of Science's 20% guidance for new facilities and the proposals in the LRP. **Dr. Carter** mentioned that P5 recommended an increase to 25% which is above the Office of Science guidance; he cautioned against conservatism in the proposed percentage. While FES has been investing in construction, such as ITER, new facilities are needed to meet the emerging directions in the program.

Dr. Kuranz noted that the community understands that balance does not mean equal; however, the balance should be equitable. **Dr. Carter** confirmed that there are many misconceptions about equal versus balance and argued that the various communities in fusion must interact to understand each other better.

Dr. Kuranz expressed that the discussions at the August workshop appeared to be unfinished and asked if there will be additional webinars for more discussion. She also inquired about budget prioritization, cost scenarios, and public access to the costing information. **Dr. Carter** said that while the conversation must continue, it is limited by time. The costing experts were assisted by the CPP co-chairs and program committee members. The costing information should be used to consider possibilities and alternatives, but choosing a direction needs to be based on a clear mission need, and the critical decision (CD) process addresses alternate routes to meet a mission need. **Dr. Rej** pointed out that alternatives for facilities occur at CD-1.

Dr. Terry asked if there was a difference in the quality of information being obtained by DPS and FST, which DPS projects the cost experts are considering, and if the historical approach is providing the necessary information to effectively address the DPS side. **Dr. Carter** explained that a cut-off line in the estimated size of a project was established to best utilize the costing

experts. While the experts may have costed the smaller projects differently, the facilities are all pre-conceptual; thus, it is unclear if different estimates would cause a change in the prioritization approach. However, the report will mention specific types of facilities to be built, and opportunities for these types.

Dr. Patello asked if the costing reports will be made available to FESAC, and **Dr. Kuranz** asked if the notes from the August workshop will be made public. **Dr. Barish** replied that the response to the request for the costing reports will be made later, and that there is no restriction, from the Federal Advisory Committee Act (FACA) rules, on what notes can be shared.

Dr. Wirth requested that FESAC be informed of the subcommittee's assumptions that were used for the costing exercise and the costing values. **Dr. Carter** noted that all facilities mentioned in the CPP report were costed. The subcommittee is attempting to use information from many sources and determine at what point a facility becomes too costly, even in the unconstrained scenario.

Dr. Wilson stated that there are accumulated facilities across many universities and inquired how these factored into the costing. **Dr. Carter** explained that the subcommittee is accommodating the costs for any existing facilities as well as potential needs for upgrades and additional staffing. However, new facilities have been handled differently; for example, by using a multiplier or cost equivalents.

Dr. Sunn Pedersen asked when an external review might take place. **Dr. Wirth** expressed concern about waiting until the December FESAC meeting to address the parallel path of external reviews. **Dr. Carter** stated that while it is ideal for FESAC members to have as much time as possible to review the LRP report, it might be possible to have a simultaneous or staged approach to an external review. He also stated that he has shared ideas for that process with Dr. Barish and Dr. Rej and may also reach out to individual FESAC members for further discussion.

Dr. Walker asked about the impact holding virtual meetings had on the process. **Dr. Carter** said that while personal interactions and the ability to have offline conversations were missed, the quantity of meetings possible and the ease of impromptu discussions was gained. **Dr. Kuranz** offered that being in the comfort of one's home and having to wait to be called upon by the moderator contributed to a much more open conversation than would have been conducted in a hotel ballroom setting. **Dr. Carter** speculated that the inability to see people's reactions may have been helpful to the openness of the conversation.

Dr. Kuranz stated that during the CPP, there was confusion on terminology and overlap, as well as the level of specificity versus conceptualization of a fusion pilot plant. **Dr. Carter** indicated that there are many issues and misconceptions which require communication. Bringing all the diverse voices together to support the fusion mission is important and is part of the larger goal to convince the broader scientific community that the science is excellent and that the applications and the fusion mission are worth significant investment. **Dr. Rej** added that the August 2020 workshop discussions illustrated wide-spread agreement on the importance of the community speaking with one voice. **Dr. Kuranz** suggested framing fundamental science in terms of its relationship and contribution to fusion energy sciences to address the misunderstandings. **Dr. Carter** agreed stating that there is cause to be careful with word choices.

Dr. Matthews asked about the differences between the grouped types of activities (essential, integral, aspirational) and making budget reductions by tier rather than across the board. **Dr. Carter** noted that while there are different interpretations of the tiers, they are more

flexible than a ranked list, and the tiers ensure that the list can represent the unique prioritization between DPS and FST. The terms essential, integral, and aspirational are not absolutes.

Dr. Sunn Pedersen suggested creating a process to address the unconstrained scenario, noting that addressing that scenario will require resources for costing, staging, and scheduling. He also advised that external evaluation and feedback be sought in tandem with FESAC's review of the LRP report. **Dr. Carter** responded that a process must be set in motion and be flexible enough to transition when new information becomes available. He agreed that having a tandem review is desirable and assured FESAC that the subcommittee is working with Dr. Barish, Dr. Rej, and the General Counsel's Office to determine what is feasible.

Dr. Wirth added that it is important to utilize the unconstrained budget to think about staging, especially if the goal is to reach a pilot plant. He recommended that FESAC consider not only the cost, but the staging and the risk associated with modifications and delays. **Dr. Carter** stated that in terms of staging, the most important part of the 10-year plan is the first 5 years, and added that the subcommittee welcomed input from FESAC members on the impact of the constrained scenarios.

Dr. Skiff asked about the role of universities and the preparation of the workforce given the changing landscape in FST and DPS. **Dr. Carter** referred to the CPP report that discusses university roles; universities should be part of the entire program as a source for innovation. In terms of preparing the future workforce, there are many opportunities such as those laid out in the Plasma 2020 report and the recent NSF Physics Frontier Centers FES has the ability to pursue these opportunities. Universities should contribute to every part of the portfolio; they need to be fully engaged to ensure that there is a future workforce. **Dr. Skiff** suggested that because of the interdisciplinary nature of the discipline, the importance of Centers should be emphasized in the report. He speculated that FES's support of interdisciplinary centers might be important for academic vitality.

Dr. Snyder asked Dr. Carter to elaborate on the merged mission and vision for FST and DPS. **Dr. Carter** stated that the subcommittee is considering many ideas that were shared at the August workshop and explained that the mission statement is meant to express what FES is about. The subcommittee does not want to detract from the individual mission and vision statements for FST and DPS that were crafted in the CPP.

Dr. Skiff recommended that the subcommittee make it clear that the merged mission and vision includes consideration of the drivers for both FST and DPS, arguing that the need for a core workforce and academic development of that workforce must be integrated into the equation. **Dr. Carter** explained that the balance is between FST and DPS, but also between small versus large research, and universities versus labs. Flexibility is key, but there is a core budget line that needs to continue. All the elements of the budget must be considered when talking about balancing the whole portfolio.

Dr. Ma asked FESAC to give the subcommittee feedback on what they want to see in the report, what they envision the report will look like, and what advice they have to make the LRP the most useful and actionable plan possible. Below are the suggestions articulated by the FESAC members.

Dr. Patello suggested adding well-developed graphics to communicate the message.

Dr. Zweibel requested that the implicit balance between large and small projects, theory, and experiment be made explicit, stating that including the rules used for decision making will provide flexibility and agility to address scientific and technological breakthroughs and the changing international landscape. **Dr. Carter** clarified that in the CPP report there are a range of

scales of facilities and clear expressions of values about theory and computation and fundamental theory. He added that it is essential to provide new directions on process improvements in the report.

Dr. Knowlton explained that although it is premature to prescribe major facilities, those called out in the CPP report are part of the vision, and he recommended that the report map the science drivers, technical drivers, industrial drivers, and social drivers to those facilities. **Dr. Carter** assured FESAC that the subcommittee will tie the facilities back to drivers of many sorts (science, technical, mission). **Dr. Terry** added that the report should also include statements about the fundamental driver of the exciting science that fusion offers to society, stating that the report should appeal to those who are amazed by discovery as well as those who feel science should serve society.

Dr. Matthews requested the costing data be included in the report, specifically individual projects and their associated costs as those will help with future revisions. **Dr. Sunn Pedersen** said that the blue sky scenario budget should continue to grow past 2028, and the report should explain that the ideas and rough plans require more details. The report needs to be a bold plan that indicates that the community is not afraid of change or changes in direction. Additionally, there needs to be a clear articulation of what will be lost if a flat budget continues. **Dr. Carter** stated that the subcommittee wants to avoid providing rough costing on any project to prevent future cost expectations. He explained that the current downturn in the blue sky budget also appears in the P5 report. The roll-over of the budget is due to facilities being completed or being shifted out to the next decade. This is what makes the 5-year check-in critical, to allow the community to change direction as needed and as opportunities present themselves.

Dr. Snyder said that the report should express excitement and urgency, contain concrete ways to make progress on the fusion goal in 5-7 years, and offer a coherent vision showcasing that advances in the science feed the development of attractive technology.

Dr. Terry requested the report be inclusive of the breadth of contributions from the national labs, universities, and industry. **Dr. Carter** added that to develop a workforce that is engaged across the entire portfolio, universities and national labs have to be part of that portfolio.

Dr. Wirth asked for roadmaps that articulate the timing of facilities, both construction and completion dates, as well as alternatives. The argument of why new facilities are required to push the science and the technology forward should be in the report; he referred to the National Academies' Burning Plasma report as a resource for the science case.

Dr. Wilson wished that the philosophical question of the role of government funded research versus private venture capital funded research would be woven into the report. **Dr. Carter** confirmed that the topic of blending government research and venture capital research to lead to a thriving fusion industry is being considered.

Dr. Verboncoeur requested a framework that appreciates the contributions from the entire community, provides evaluation and decision processes that enable flexibility as new developments arise, and utilizes entrepreneurial elements (e.g., if we are going to fail, fail quickly, learn, and do better next time) in the opportunities for public/private partnerships. **Dr. Carter** commented that the report must stand that test of time and be flexible. He assured FESAC that the subcommittee is thinking carefully about engaging private industry in both FST and DPS opportunities. **Dr. Carter** emphasized that when there is a mission need, the community must push the idea into the CD process. That will provide both alternatives and future facility ideas for the next LRP activity.

Dr. Kuranz recommended that the report include the subcommittee's rationale for its decisions. **Dr. Carter** appreciated the advice and pointed out that the subcommittee must justify the decisions laid out in the LRP to ensure that the community supports the plan. **Dr. Knowlton** amplified Dr. Carter's comment about gaining the backing of the community, explaining that reports from the public power industry are used to gain acceptance by the stakeholders. Having an integrated resource plan that meets the criteria simplifies every action, risky or not. It will be in FESAC's interest to review the report every five years; how well this plan accommodates risk and uncertainty will be useful.

Overview of Power Generation Investment Considerations, Dr. Ralph Izzo, Chairman and CEO, Public Service Enterprise Group (PSEG)

Dr. Izzo provided information about PSEG, illustrated how PSEG views potential investments, and discussed the future of fusion power. PSEG is both a regulated electric and gas utility, and an unregulated power generation company. PSEG is #8 in the nation in terms of energy output; over 60% of PSEG's output is nuclear fission, and the remainder is natural gas. PSEG has a minor asset in solar and is considering a significant investment in offshore wind.

Energy is the price one gets paid for every kilowatt hour of electricity generated. Capacity is a payment given to certain power plants in some markets. The leading costs for most power plants are fuel prices, but for nuclear the leading cost is operations and maintenance. Emission cost is the second most important expense associated with any fossil fuels plant.

Dr. Izzo highlighted three of the five valuation metrics methods – discounted cash flow (DCF) analysis over 30-40 years, DCF analysis over 5-10 years, and free cash flow yield. PSEG, as a long-term investor, uses DCF analysis where assumptions about revenue and cost are made over a 30-40 year period. Purely financial investors use the DCF analysis over 5-10 years, the key being an exit strategy in a relatively near term. Increasingly, investors are modeling their purchases based upon implied free cash flow yield, which is a short-term investment in a relatively new power plant where the revenue generated greatly exceeds the cost of operation.

Challenges and opportunities for fusion power include the levelized price of energy, public support for renewables, dispatchability, external factors from other energy sources, complexity versus simplicity, and the motivation to be carbon-free by 2050.

The levelized price of fusion energy is (\$117 - \$160)/ MWh which makes fusion non-competitive with offshore wind (~\$98/MWh) or onshore wind (\$20-\$30/MWh). Fusion's leveling price is less than rooftop solar, which is still at (\$300-\$400)/MWh, but the public is overwhelming in support of renewable energy, especially solar and wind.

Dispatchability and being able to supply power year-round is an advantage for fusion because many renewables require significant storage solutions. Externalities such as a carbon price or waste from fission can play to fusion's benefit. Additionally, the cost of habitat may be in fusion's favor because of the acreage that is required for solar and wind.

Fusion plants are complex and will require a different workforce in terms of number and expertise. A natural gas combined cycle power plant is operated by 15-20 people. PSEG's solar farms are maintained by one mechanic who ensures that everything is working and a herd of sheep to keep the grounds.

The electric power industry is under substantial motivation and incentives to be carbon-free by 2050. This means that a tremendous amount of capital will be deployed to put in place carbon-free sources of energy and address the storage requirement that will be essential to dispatch electricity around the clock.

An important comparison to make is how fusion stacks up against other carbon-free sources that are coming to market. These carbon-free sources will attract investor interest, dominate the energy supplies, and freeze out fusion because of the simplicity and cost.

Discussion

Dr. Kessler asked if PSEG invests in new technologies or only proven technologies. **Dr. Izzo** stated that PSEG waits until the technology is proven. While PSEG previously had a vibrant research program, it was reduced when the supply sector was deregulated. Some companies will put some money towards research, but nothing of the scale required for fusion to move ahead.

Dr. Wilson was curious about the benefits and liabilities of fusion being base-load supply, given that storage can mitigate the need for load-following. **Dr. Verboncoeur** inquired about storing the produced oversupply in chemical form (augmented liquid fuels). **Dr. Izzo** said that the challenge, whether to be base-load or load-following, is the distortion created by subsidized renewables. He expected that using fuels will be the most likely solution for the seasonal mismatch.

Dr. Knowlton referred to carbon pricing, and asked if there is a credible model for initiatives to electrify the transportation and home and industrial heating industries. **Dr. Izzo** said that currently the #1 source of carbon in the nation is transportation. Increased electrification should be commensurate with the decarbonization of the power supply stack. PSEG has advocated for a 5-part program: 1) national carbon price, 2) increased investment in energy efficiency, 3) preservation of the existing nuclear fleet, 4) investments in new carbon-free sources of energy (renewables and fusion), and 5) further electrification of the economy, beginning with transportation. **Dr. Wilson** added that many studies show that grid-powered electric vehicles are lower carbon than internal combustion engines.

Dr. Parker commented that a more technical staff will be required to run a fusion facility, and that scientific experiments that produce excitement within society will lead to continued research and possible deployment of fusion power.

Dr. Trask asked what an attractive price for a fusion power plant would be. **Dr. Izzo** explained that if all of PSEG's assumptions about operating and maintenance costs were accurate, the price would have to be between \$3,000/kWh - \$3500/kWh. **Dr. Izzo** stated that when a carbon price comes to fruition in the future, he thinks the public will support fusion.

Advancing Fusion with Machine Learning 2019 Workshop, Dr. David Humphreys, Principal Scientist, General Atomics

Artificial Intelligence and Machine Learning (AI/ML) are rapidly growing fields. In the last 2-3 years, DOE has held assessments and workshops on this topic. The goals of the April/May workshop were to identify priority research opportunities (PROs) in transformative AI/ML, gaps for AI/ML applicability to FES areas, and research principles for effective use of AI/ML for fusion.

Seven PROs were identified: science discovery with AI/ML, ML-boosted diagnostics, model extraction and reduction, control augmentation with ML, extreme data algorithms, data-enhanced prediction, and fusion ML data platforms. Foundational activities and resources include experimental fusion facilities and programs, theory and high-performance computing, exascale computing resources, and connections among domain experts (fusion, computer science, and statistical inference mathematics). The seven PROs collectively focused on three areas: accelerating science (1, 2, 3), enabling fusion energy (4, 5, 6) and cross-cutting (7).

Guidelines for how to maximize the effectiveness of AI/ML uncovered some overarching topics. The goals are extracting maximum knowledge and bridging gaps in fusion's knowledge with data. Real-time control has unique requirements of AI/ML for predicting quantities for control, output parameters, and well-behaved models with defined validity and extrapolability. Models for control design demand the same kinds of quantified validity. All of this depends on DOE's fusion experimental facilities and programs, theory programs and computational resources, and the support of robust connections among domain experts.

Discussion

Dr. Snyder extended his thanks to those who worked on the AI for Science report and stated that FESAC members' response comments have been forwarded to the Chair. **Dr. Rej** expressed his thanks as well, and acknowledged those FESAC members who provided comments. He added that such contributions aid in future partnerships.

Dr. Ma requested information on the role of accelerated and unique hardware in keeping up with the data rates and ML rates. **Dr. Humphreys** stated that this topic received minimal discussion because it is covered by other areas, especially in the forthcoming Advanced Scientific Computing Research (ASCR) report on AI for Science. Data handling and the fusion data platform were not emphasized in the deliberations.

Dr. Wilson inquired about the discussion on AI/ML applications in the engineering and technology aspects of a fusion power plant. **Dr. Humphreys** replied that there was a broader analysis of operational issues in control augmentation. For example, the notion of fault monitoring and interpretation is currently a very active area of research; ITER needs a solution in about two years. The fault monitoring and interpretation application for the whole plant must begin and be integrated up to the plasma. Those are being developed on operating devices towards a scalable approach for solving fusion problems for a fusion power plant.

Dr. Parker asked how physical and dimensional parameters would be handled with AI/ML and data science in the absence of an operating fusion reactor. **Dr. Humphreys** stated that is the most essential point illustrating the kind of research that needs to be done to advance AI/ML. Research is currently focused on the fundamental ability to extrapolate beyond the experience in dimensional quantities. In fusion, this has not been successful yet. The entire application mechanism should involve incremental advancement of the data. ITER in particular is developing a plan to grow the use of AI/ML methods as the machine physics program advances.

Public Comment, Dr. Donald Rej

Dr. Lauren Garrison pushed Dr. Carter and the subcommittee to be transparent and share as much information as possible on the cost estimates, arguing that they will be key to reassuring and getting the community excited about the LRP. Second, even if it is impossible to release all of the costing details, she asked that the subcommittee create groups of projects and explain how those projects were categorized; be very forthcoming on the assumptions that were used. And third, she requested a roadmap for the FST part of the program.

Dr. Barish remarked that Dr. Carter answered questions about FACA rules, transparency, and openness. The CPP did a fabulous job in holding a completely transparent process over a year of seeking community input, involving hundreds of people, and producing an excellent report. Two of the seven CPP co-chairs are on the FESAC subcommittee. While the Phase 2 subcommittee would like to share as much information as possible, FESAC, as a DOE

committee, has to follow FACA rules. If there is a lack of information provided, the responsibility for that is with DOE.

Dr. Rej adjourned the FESAC meeting at 5:26 p.m.

Respectfully submitted September 15, 2020
T. Reneau Conner, PhD, PMP, AHIP
ORISE/ ORAU

Certified as Correct by:

A handwritten signature in black ink that reads "Donald J. Rej". The signature is written in a cursive style with a large initial "D" and "R".

Dr. Donald J. Rej,
FESAC Chair
Date November 9, 2020