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

# PUBLIC MEETING MINUTES

**Virtual Meeting via ZOOM**
**August 30 and 31, 2021**

**Fusion Energy Sciences Advisory Committee Meeting**
**August 30 and 31, 2021**

The U.S. Department of Energy (DOE) Fusion Energy Sciences Advisory Committee (FESAC) convened on Monday and Tuesday (August 30 and 31, 2021) 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 (FACA). 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. Troy Carter, University of California, Los Angeles
Dr. Stephanie Hansen, Sandia National Laboratories (SNL)
Dr. Paul Humrickhouse, Idaho National Laboratory (INL)
Dr. Charles Kessel, Oak Ridge National Laboratory (ORNL)
Dr. Stephen Knowlton (Vice-Chair), Auburn University, Professor Emeritus
Dr. Carolyn Kuranz, University of Michigan
Dr. Tammy Ma, Lawrence Livermore National Laboratory (LLNL)
Dr. Richard Magee, TAE Technologies
Dr. Rajesh Maingi, Princeton Plasma Physics Laboratory (PPPL)
Dr. Lorin Matthews, Baylor University
Dr. Simona Murph, Savannah River National Laboratory (SRNL)
Dr. Scott Parker, University of Colorado
Dr. Susana Reyes, SLAC National Accelerator Laboratory
Dr. Fred Skiff, University of Iowa
Dr. Philip Snyder, ORNL
Dr. Thomas Sunn Pedersen, University of Greifswald
Dr. Paul Terry, University of Wisconsin
Dr. Mitchell Walker, Georgia Institute of Technology
Dr. Anne White, Massachusetts Institute of Technology (MIT)
Dr. Brian Wirth, University of Tennessee

**Committee Members Absent**

Dr. Ralph Izzo, Public Service Enterprise Group, Inc. (PSEG)

**Ex Officio Members Present**

Dr. John Verboncoeur, Institute of Electrical and Electronics Engineers - Nuclear and Plasma Sciences Society (IEEE - NPSS), Michigan State University
Dr. Michael Brown, American Physical Society Division of Plasma Physics (APS DPP), Swarthmore College

**Ex Officio Members Absent**

Dr. Paul Wilson, American Nuclear Society (ANS), University of Wisconsin

**DOE Personnel:**

Dr. Stephen Binkley, Acting Director, DOE Office of Science (DOE SC)
Dr. James Van Dam, Associate Director, Fusion Energy Sciences (FES), DOE SC

Dr. Sam Barish, Designated Federal Officer, FES, DOE SC

Approximately 287 fusion community members were present for all or part of the meeting.

## Monday, August 30, 2021

**Dr. Rej** convened the meeting at 11:00 a.m. and introduced Dr. Binkley.

**News from the Office of Science,** Dr. Stephen Binkley, Acting Director, Office of Science

Dr. Binkley reviewed the status of political appointees, program organization and the FY22 budget. Dr. Binkley is currently serving as the SC Acting Director and will return to the SC Principal Deputy Director role after all new nominees are confirmed. Secretary Jennifer Granholm and Deputy Secretary David Turk have been sworn in and are implementing the administration's vision. Geraldine Richmond and Asmeret Berhe are the nominees for Under Secretary for Science and SC Director, respectively. Both await confirmation by the full Senate. Tanya Das is the new SC Chief of Staff and Natalie Tham is a new Special Assistant.

Under the Biden Administration, the DOE Applied Energy Programs have been returned to the purview of the Under Secretary for Science. Closer proximity of SC programs to Applied Energy Programs will facilitate collaboration.

The FY2022 President's Budget Request (PBR) seeks $7.44B for SC, which is a 5.9% ($414M) increase over the FY2021 level. The House Energy and Water Development Subcommittee issued a lower mark of $7.32B, and the Senate mark is higher at $7.49B. Notably, once the budget is finalized, the percentage funding increase will not be the same for every SC program.

**Discussion**

**Dr. Kuranz** asked how the FES Long Range Plan (LRP) that emerged from the two-year community planning process (CPP) factored into this year's budget, and how future budgets will take it into account. Much time was devoted to convincing people that the plan was worth their effort using guidance from SC and the former Secretary of Energy. **Dr. Binkley** appreciated the community's work. The LRP has impacted budgeting and gotten traction with certain Congressional committees, most notably the House Committee on Science, Space and Technology. There are active discussions about implementing major features of the LRP.

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

**Dr. Rej**, FESAC Chair, reviewed the meeting agenda and instructions for public comment. On behalf of FESAC, he thanked and bid farewell to Gert Patello (PNNL) and Erik Trask (TAE Technologies), whose terms ended in 2021 and welcomed new members with terms running through June 2024: Stephanie Hansen (SNL), Paul Humrickhouse (INL) and Richard Magee (TAE Technologies).

**FES Perspective,** Dr. James Van Dam, Associate Director for the Office of Fusion Energy Sciences

The FY2022 FES Request seeks $675M, which is $3M greater than the FY2021 Enacted Budget. The FY2022 Request includes, for Burning Plasma Science, $296M for Foundations, $86M for Long Pulse and $2M for High Power, and $65M for Discovery Plasma Science. Under the FY2022 Request, construction projects are funded at $226M, ($31M less than FY2021 Enacted). FY2022 requested funds are distributed as follows: 44% to Research, 18.6% to Facility Operations and 37.2% for Projects. FES is formulating the FY2023 budget.

The FY2022 Request falls within the "modest growth scenario" outlined in the LRP. Under this paradigm, funding for Research, Operations and Small Scale Construction items is as follows: the Fusion Materials and Technology (FM&T) programs increase by $7.6M; U.S. Tokamak Operations and Research, primarily directed to the DIII-D National Fusion Facility and the National Spherical Torus Experiment Upgrade (NSTX-U), decreases by $3.9M; Stellarator and Alternates Operations and Research remain constant; Inertial Fusion Energy (IFE) program funding is limited, although a basic research needs (BRN) workshop is planned for the spring of FY2022; the Fusion Pilot Plant (FPP) Design Effort will initiate Future Facilities Studies at $3M; the General Plasma Science (GPS) program increases by $5M; the High-Energy-Density Physics (HEDP) program increases by $4.3M; the Plasma-Based Technology program remains constant, but includes $5M for Microelectronics; and Theory and Computation increases by $11M, although this line incorporates Quantum Information Science (QIS) and Artificial Intelligence/ Machine Learning (AI/ML) initiatives that were not included in the comparable line from the FY2021 Enacted Budget. Funding for New Construction of Midscale Facilities is as follows: the Material Plasma Exposure eXperiment (MPEX) increases by $4M; a Fusion Prototypic Neutron Source (FPNS) will receive some Materials funds to study target options; and the Matter in Extreme Conditions Upgrade (MEC-U) decreases by $12M, although MEC may access $30M in reserved Total Estimated Cost (TEC) funds once it attains CD-1. Funding for Collaborations and Networks is as follows: the ITER Research Team will be initiated with $2M following a workshop to discuss priority research topics and engagement opportunities regarding team formation and governance; and private fusion collaborations increase by $2M administered via the Innovation Network for Fusion Energy (INFUSE) program; International Fusion Collaborations remain constant; and LaserNetUS, Znet, and MagNetUS are limited. The Congressional line item for ITER is down by $21M. FES requested a total of $35M to participate in all seven of SC's cross-cutting initiatives, an increase over the FY2021 Enacted Budget of ~$21M when FES participated in three of the initiatives.

ORNL is constructing a Shattered Pellet Injection (SPI) testbed to support ITER. MPEX achieved Critical Decision-1 (CD-1) in January 2020 and CD-3 in October 2020. Long-lead procurements were awarded for magnets, gyrotrons and high-voltage power supplies. MEC-U is projected to attain CD-1 in September 2021. Operations at DIII-D continued with the majority of scientific staff working remotely. DIII-D completed a ~19-week runtime campaign in FY2021 with a high system availability (88%) and has entered a six-month maintenance period. The NSTX Upgrade Recovery is ~70% complete. Due to COVID-19 delays, a new cost and schedule baseline will be reviewed in FY2022. The Super-X divertor reduced the heat flux by more than an order of magnitude for the Mega Amp Spherical Tokamak Upgrade (MAST-U).

FES issued awards for several FY2020 and FY2021 solicitations, including seven awards for Collaborative Research in Magnetic Fusion Energy Sciences on Long-Pulse International Stellarator Facilities; 21 awards for High-Energy-Density Laboratory Plasma (HEDLP) Science, a joint program with the National Nuclear Security Administration (NNSA); ten awards for QIS Research for FES; seven awards for the SC Early Career Research Program; and ten awards to DOE national laboratories for Co-Design Microelectronics R&D Centers, an SC-wide program. FES supplied $3.1M in FY2021 to the HEDLP program and is supporting three of the Microelectronics Co-design awards. FES provided $7.9M to the NSF-DOE Partnership in Basic Plasma Science and Engineering in FY2021, and the program's memorandum of understanding (MOU) is being renewed for FY2022. Fourteen Galvanizing Advances in Market-aligned Fusion for an Overabundance of Watts (GAMOW) awards were issued in FY2020 with +$15M supplied by Advanced Research Projects Agency-Energy (ARPA-E). FES is supplying $5M for FY2021. FES has increased use of the SC Open Funding Opportunity Announcement (FOA), with 18 awards made since 2020. Awards for the Opportunities in Frontier Plasma Sciences Lab Call are forthcoming. The DOE Office of Science Graduate Student Research program issued two FES awards for the 2020 Solicitation-2 cycle. Awards for the 2021 Solicitation-1 cycle are in progress, and applications for the Solicitation-2 cycle are due November 10, 2021. The call for 2021 E. O. Lawrence Awards is open through September 21, 2021.

Nine FES Scientific Discovery through Advanced Computing (SciDAC) partnerships are entering their final year. FES and ASCR have begun re-competition planning. Following the joint 2019 FES-ASCR workshop on Advancing Fusion with Machine Learning, five teams were funded under the FY2020 FOA. In FY2021, six pilot studies were identified from the FY2020 solicitation in the areas of randomized methods for real-time plasma control, ML models for plasma pulse design optimization and validation, data-driven stellarator optimization, surrogate models for detached divertor control, optimization of inertial confinement fusion experiments, and physics-informed neural networks for disruption prediction and avoidance.

FES and HEP are collaborating to develop a unique, world class High-Field Vertical Test Stand. The first External Oversight Committee meeting was held in January 2021, LBNL will begin coil fabrication in 2022 and the project's estimated completion is June 2025.

Ten international research teams are addressing gaps in long pulse tokamak physics at international facilities. At the Joint European Torus (JET), the U.S. is supporting the Deuterium-Tritium Experiments 2 (DTE2) campaign. The Korea Supercharging Tokamak Advanced Research (KSTAR) facility is conducting dual SPI studies with DIII-D and JET to support ITER. Two new teams are preparing for the installation of diagnostics at the Super Advanced Japanese Tokamak 60 (JT-60SA) experiment during a planned 26-month vent after first plasma startup. Research continues for the ASDEX-Upgrade (AUG), Variable Configuration Tokamak (TCV), Experimental Advanced Superconducting Tokamak (EAST) project, Tungsten Environment in Steady-state Tokamak (WEST) project and the COMPact ASSembly Upgrade (COMPASS-U).

ORNL is leading an international team in the assembly of a continuous, high-speed pellet system to fuel Wendelstein 7-X (W7-X) plasmas; the system will be fully tested in the fall of 2021. Helically Symmetric eXperiment (HSX) operations will resume by December 2021.

FES materials characterization is being advanced by the High Flux Isotope Reactor (HFIR) and National Synchrotron Light Source II (NSLS-II).

The Energy Science Network (ESnet) comprehensively surveyed FES stakeholders to determine needs during the 2021 Network Requirements Review.

Over 450 participants from 123 institutions worldwide attended the LaserNetUS Second Annual meeting in August 2021. The Advanced Laser Light Source in Canada joined the network in FY2020, and LaserNetUS renewed nine awards. In FY2021, 86 proposals involving more than130 students were awarded experimental time. An MOU with LaserLab Europe is in progress.

The 2021 Plasma and Fusion Undergraduate Research Opportunity (PFURO) program began in June. Undergraduates will conduct ten weeks of remote research at U.S. institutions, and most students will present their research at a national topical conference. The MIT Plasma Science and Fusion Center is hosting the Second Computational Physics School for Fusion Research from August 30 to September 3, 2021. Over 260 individuals are participating virtually from the U.S. and abroad.

FES posted a program manager position in Theory and Simulation. A second program manager position in Magnetic Fusion Energy (MFE) is anticipated.

**Discussion**

**Dr. Carter** asked about DOE and SC leadership's reception to the LRP. **Dr. Van Dam** thanked Dr. Carter for delivering briefings and suggested he brief Drs. Das, Berhe and Richmond. The FY2022 Request's budget narrative references the LRP, and the plan has been well-received. **Dr. Binkley** reiterated thanks to the FES community. SC is embracing the LRP and is serious about working with the administration and the Office of Management and Budget (OMB) to implement the plan's recommendations. However, the DOE is a large ship, and changing directions is a slow process. There is significant congressional interest in the LRP, especially by the House Committee on Science, Space and Technology staff. Meetings will be held with appropriations staff soon. **Dr. Van Dam** emphasized that Congress wants to see community consensus.

**Dr. Sunn Pedersen** asked when the LRP might impact the budget. **Dr. Binkley** said the High Energy Physics (HEP) budget had equilibrated at ~$700M in 2014 when the Particle Physics Project Prioritization Panel (P5) report was issued, but it exceeds $1B today. The FES budget may or may not grow as much, but it will require support from OMB and appropriations committees. **Dr. Harriet Kung** (SC-3) reflected that programmatic balance is important. Prior to P5, HEP had neither robust facilities nor construction upgrades. P5 successfully inserted new directions while balancing existing capabilities. There are parallels in the FES LRP. **Dr. Van Dam** reiterated the need for community consensus. The FY2022 PBR offers a good cash contribution for ITER, designates more funds for Subproject-1 (SP-1) and increases the overall ITER program.

**Dr. Kuranz** recognized the importance of patience, but registered disappointment that the FES budget request did not increase by a larger amount, especially since there were increases for other SC offices. The community, which has been traditionally divided, made hard decisions to reach consensus. Maintaining this consensus may be difficult in the absence of hoped for results.

**Dr. Maingi** asked about the timeline for the ITER Research Team workshop and associated community input. **Dr. Van Dam** relayed that the workshop will be held in FY2022. The community has contributed thoughts through a recent report from the U.S. Burning Plasma Organization (USBPO). ITER periodically updates a document specifying research needs. The International Tokamak Physics Activity will publish chapters on these needs in Nuclear Fusion. The workshop will differ from other BRNs because it will also address team formation, governance and interactions like data sharing. The workshop will involve the ITER Organization (IO) and likely engage Dr. Tim Luce, an ITER chief scientist from the U.S.

**Dr. Kuranz** asked if QIS is included in the $4.3M increase to the FY2022 HEDP budget. **Dr. Van Dam** replied that the FY2021 Budget Request incorporated QIS in HEDLP as well as Theory and Simulation. AI/ML was in Theory and Simulation. In the FY2021 Enacted Budget, QIS and AI/ML were pulled out of these programs as separate lines. The FY2022 Budget Request uses the same format where the QIS and AI/ML lines are visible. Other initiatives are not necessarily seen but may become visible later. **Mr. Gene Nardella** (SC-FES) added that the FY2021 request for SciDAC and HEDLP contained QIS funds at ~$5M and $4.3M, respectively. QIS numbers were extracted to a separate line in the FY2021 Enacted Budget. For FY2022, FES placed $20M aside for HEDLP. QIS is funded out of a separate line. Likewise, the $5M allocated for Microelectronics in the FY2021 GPS request was extracted to a separate line in the FY2021 Enacted Budget. The GPS line in the FY2022 request allocates $20M. **Dr. Van Dam** clarified that the basic answer is yes.

**Dr. Terry** returned to the LRP budget discussion. Before the next planning process in 5-10 years, what can the community do, besides maintaining consensus, to help policy makers keep the plan's goals in mind? After noting that HEP and Nuclear Physics (NP) usually conduct a mid-term assessment of progress made against their long-range plans, **Dr. Van Dam** remarked that when speaking with representatives on the Hill, starting with the big picture and then narrowing down to an individual group's contributions has been effective. A one-pager is annually produced for Fusion Day, presenting the opportunity to feature the LRP and the community's consensus.

**Dr. Reyes** inquired about coordinating activities for an FPP design. **Dr. Van Dam** said the process is at an early stage. FES is waiting for FY2022 appropriations.

Referencing National Academies of Science, Engineering and Medicine (NASEM) reports and the LRP report, **Dr. Snyder** sought guidance on how to poise the community to take immediate advantage of facility funds when available. There does not appear to be urgency in beginning the FPP design process or in attaining CD-0 for FNPS or EXCITE. **Dr. Van Dam** clarified that the plan's recommendation for EXCITE was to get involved in conceptual design and then construction design. It is unclear if EXCITE requires a new facility or if it can be done on existing machines with upgrades. This requires further community discussion. FES has several facilities underway: MPEX, MEC, and ITER. FPNS is high priority, and SC is moving in that direction. An existing FNPS workshop report could position the community for CD-0.

**Dr. Maingi** reframed Dr. Snyder's question as an exhortation to move towards CD-0 for projects. Part of the CD-0 process requires examining options. The CPP was the foundation of the LRP and indicates that this is important to the community. How international collaborations and public-private partnerships (PPPs) will be integrated with the LRP must be determined. A prior committee reviewed international relationships over a decade ago, and much has changed. Are new charges forthcoming? **Dr. Van Dam** agreed that considering updated information on international collaborations and PPPs, as well as fusion materials, is important. FES developed a charge, but leadership advised taking additional steps before launching the full charge. Notably, Advanced Scientific Computing Research (ASCR) and Basic Energy Sciences (BES) recently directed subcommittees to write reports addressing International Benchmarking charges.

**Dr. Terry** asked about AI/ML pilots and how their utility is being assessed. **Dr. Van Dam** remarked that AI/ML are being proven and used. For example, TAE Technologies is using an AI algorithm called the Optimist to improve machine performance. FES pilots are one-year high-risk, high-return studies. AI/ML is having a broad impact in several areas, like data-driven stellarator optimization; detached diverter control; and inertial confinement. There is high demand in this area; if the budget were doubled, there would be enough proposals to fund.

**Dr. Rej** dismissed the meeting at 12:45 p.m. for lunch and reconvened at 1:45 p.m.

**Update on the FESAC Long Range Planning Report,** Dr. Troy Carter, University of California, Los Angeles, Subcommittee Chair

In 2018, FESAC was charged with identifying and prioritizing the research required to advance the scientific foundation needed to develop a fusion energy source, as well as the broader FES mission to steward plasma science. FESAC engaged the community through the

APS DPP platform to produce a consensus CPP report. The subsequent LRP, *Powering the Future: Fusions and Plasmas*, was unanimously approved during the December 2020 FESAC meeting and released in February 2020.

The LRP was presented to domestic and international plasma/fusion institutions and community groups, Chevron, the Energy Sciences Coalition, the OMB and Congressional staffers from House and Senate authorization or appropriation committees. The plan was also presented at the Fusion Congressional Briefing. Staffers expressed enthusiasm and gratitude for the delivery of a community consensus report that met the charge with clear prioritizations and unanimous FESAC approval.

The PBR cites the LRP and makes changes relative to the FY2021 Enacted Budget consistent with select recommended priorities. However, the total FY2022 PBR of $675M is only $3M greater than the FY2021 Enacted Budget. Although shifts in construction spending mean this represents a ~$14M increase over the LRP's modest growth scenario starting point, this is not consistent with developing an FPP by the 2040s. Notably, the PBR increases the overall DOE SC budget by 5%, leaving no headroom for a significant FES increase. The LRP also landed during the transition in administrations. The increase to HEP's budget was realized over several years after the P5 report's release, underscoring the importance of the community's continued consensus. Indeed, the LRP has gained traction. The DOE Science for the Future Act, which passed the House in June 2021, cites the LRP and increases FES authorization levels. The reauthorization is currently with the Senate. Representative Eddie Bernice Johnson from the House Committee on Science, Space and Technology sent a letter of support to the Chairwoman of the House Appropriations Committee. Representative Don Beyer is chairing the new House Fusion Caucus; he cited the LRP in a Scientific American opinion article.

To further the LRP's progress, the community can advocate for the plan and fully define needed initiatives, such as conducting the FPP design activity, developing the ITER Research Team, and stewarding a Plasma Technology Program. Additionally, FESAC can aid in the development of new PPP models, especially for purposes of realizing new facilities.

**Discussion**

**Dr. Knowlton** asked if policy makers offered feedback on desired community actions. **Dr. Carter** shared that Congressional staffers felt FES met the initial ask and has attractive authorization levels. More discussion is needed to determine how to get the PBR to approach LRP numbers. The community is willing to take on needed activities.

**Dr. Kuranz** posed questions about advocacy strategies. **Dr. Carter** commented that he will have follow-up meetings with the OMB and staffers to discuss alignment with the PBR. Community members should take every advantage to advocate for the LRP in the near term, such as writing letters to their representatives. Community consensus is important.

**Dr. Maingi** asked how to maintain consensus. **Dr. Carter** encouraged everyone to reach out to their institutions with the message that a process is underway and to remember P5. There is reason to be disappointed but not to give up hope. The community must be ready to replace the LRP as events transpire and leverage support when it arrives.

**Dr. Humrickhouse** asked about the new House Fusion Caucus. **Dr. Carter** remarked that the caucus is bipartisan. Rep. Don Byer wrote a letter to the Secretary of Energy asking for information regarding the DOE response to the LRP and NASEM reports.

**Dr. Hansen** commented that recent National Ignition Facility (NIF) results present advocacy opportunities. Since things change quickly, how can the community maintain consensus without overlooking important developments? Should new priority be given to interagency coordination? **Dr. Carter** replied that the LRP gives strong priority to restarting interagency partnership programs. Determining how to respond to changes while advocating in unity requires further discussions.

**Dr. Kessel** asked about LRP advertising strategies**. Dr. Carter** said the LRP's release was advertised via social media. Community members can highlight LRP connections when presenting their research and connect with Government Affairs staff at their institutions. **Dr. Kessel** replied that referring to the LRP, even for small items like hardware, offers a future vision that can get young people excited.

**Dr. Verboncoeur** suggested creating a list of core talking points to aid uniform communication and adding an appendix to the LRP that shows the impact of increasing funds to the recommended level. **Dr. Carter** agreed.

**Dr. Parker** asked how FES can connect with the renewable energy initiative which is receiving increased funds. The goals from both programs align. **Dr. Carter** observed that the current administration is focused on applied offices because it is seeking near-term impact. Helping administrators realize that a long-term fusion strategy is also needed is important. **Dr. Parker** remarked that FES is just as applied. Both parties are interested in green energy and advancing an FPP; FES should be part of this administration's renewables effort.

**Dr. White** inquired about intra-community outreach to organizations like APS, American Nuclear Society (ANS) and USBPO. **Dr. Carter** agreed that involving these organizations and others like the IEEE is important. **Dr. Reyes** agreed with Dr. White's comments. The ANS Fusion Energy Division could update its position paper to align with the LRP.

**Dr. Brown** said that APS DPP is very interested in connecting with other communities. At this year's meeting, APS DPP may hold a letter writing campaign incorporating language about the LRP and encourage its members to send letters to their representatives. The meeting will also have a town hall to brainstorm next community steps.

**NASEM Report: Bringing Fusion to the U.S. Grid,** Dr. Richard Hawryluk, Princeton Plasma Physics Laboratory; Dr. Kathryn McCarthy, Oak Ridge National Laboratory; Dr. David Roop, DWR Associates, LLC; Dr. Brian Wirth, University of Tennessee, Knoxville; and Dr. Dennis Whyte, Massachusetts Institute of Technology

NASEM was charged with establishing the key goals; identifying the principal innovations needed; seeking input from potential future owners and manufacturers; and characterizing the energy market to provide guidance to the DOE, and others, that are aligned with constructing a U.S. FPP to produce electricity at the lowest possible capital cost. The 2021 NASEM report, *Bringing Fusion to the U.S. Grid*, catalogues findings related to FPP commercialization, goals, required innovations and key research, PPPs, and a strategic roadmap. The report has been well received in briefings to stakeholders and the fusion community.

Overall, the report recommends that the DOE and the private sector produce net electricity in a U.S. FPP in the 2035-2040 timeframe; that the DOE should foster the creation of national teams, including PPPs, to develop conceptual FPP designs and technology roadmaps without delay; and urgent investments be made by DOE and private industry to resolve remaining issues and construct an FPP. More specifically, the report recommends using market policy and incentives to encourage diverse energy sources, including non-carbon emission fusion; conducting three FPP operation phases and engaging energy experts to provide the technical and economic information needed for future plants; and constructing an FPP with a generating power of >50MWe and an operation life of ≥40 years for <\$5-6B. Additional report recommendations address innovations in fusion confinement concepts and technology to extract fusion power and close the fusion fuel cycle; the role of modeling and simulation; DOE support for new projects, including linear devices for testing plasma facing components (PFCs) and a non-plasma flux testing platform; the low technology readiness level (TRL) of many FPP elements; diversity, equity and inclusion (DEI); industry access to experts at labs and universities; access to ITER information; and DOE expansion of PPP programs. The FPP technology roadmap outlines a bold but achievable timetable to be enacted by national design teams. The U.S. can either take the lead in this technology or let other countries take the lead.

**Discussion**

**Dr. Parker** suggested that FESAC make a recommendation on the NASEM report, since it recommends FPP actions and a timeline with more urgency than do the CPP or LRP.

**Dr. Parker** inquired how the 50MWe at a total cost of $5-6B figures were determined. **Dr. Hawryluk** explained that the FPP need not be economically attractive. Rather, for lowest possible cost, it must provide the information needed to build a commercial plant that will be economically attractive. **Dr. Sunn Pedersen** expanded on this topic, asking why the figure of merit is not the cost of the produced electricity. Why not build a $10B FPP that can provide 5-10 times as much energy? **Dr. Hawryluk** relayed that many U.S. utilities have modest capitalizations. Asking them to build systems >$5B puts them under financial strain. The fission industry also faces this issue, and few corporations are able to build fission plants. **Dr. Whyte** added that the $5B figure is a reflection of the U.S. marketplace; even that figure is risky for utilities. **Dr. Hawryluk** commented that other countries with state-produced electricity or larger corporations may have different optimizations.

**Dr. Maingi** asked about strategies for reducing the risk in core edge integration in the NASEM timeline. **Dr. Wirth** conceded that while the timeline does not explicitly call out intermediate facilities, it does not exclude them. Many research innovations are needed, and their technological solutions must be demonstrated. To have serious progress, construction projects are needed. EXCITE should be designed now as a risk mitigation strategy.

**Dr. Walker** inquired about FPP security and citizenship considerations. **Dr. Hawryluk** stated that U.S. MFE has been traditionally open since 1958, and certain technologies like tritium will need export control. **Dr. Whyte** added that large portions of the FPP may be executed through PPPs and will require attention to intellectual property (IP) concerns in addition to commercial and national information security considerations.

**Dr. Humrickhouse** observed that funding may increase over a 2-5-year timescale. Given the report's urgency, what is the compatibility of the funding profile with the recommended timeline? **Dr. Hawryluk** advised focusing on actions like creating design teams and determining how to work together efficiently, how to leverage consensus and how to take advantage of PPPs. **Dr. Whyte** noted that FES's situation is not identical to prior P5 conditions. Having compelling PPPs in place will bring new resources to the table while preparing for commercialization.

**Dr. Terry** asked how far into the LRP unconstrained budget scenario this effort goes. If the budget increases in a few years, as seen with P5, which projects should be done now and which ones later? **Dr. Hawryluk** commented that this project probably falls in the unconstrained scenario. However, it is difficult to make a one-to-one comparison. The LRP covered many topics that were beyond NASEM's mandate and did not explicitly leverage financial resources from PPPs. While it is clear funding is needed, there is no financial plan. The technology roadmaps developed by different national teams will be key in defining this depending on the concepts.

**Dr. White** inquired if FNPS and EXCITE fall under the report's recommendation of methods to rapidly advance TRLs. **Dr. Hawryluk** stated the report recommended FPNS for testing material properties. The tokamak community will need to determine if EXCITE is needed. **Dr. Whyte** suggested that these projects are possible targets for PPPs. To generate a technology roadmap, national teams will be necessary; multiple teams advocating for a needed technology will add urgency and clarity to next steps.

**Dr. Reyes** questioned whether coordinated leadership across the national teams will be needed to set priorities, track milestones and maintain good community communication. **Dr. Hawryluk** agreed that a stellarator team would need management, but tokamak and IFE teams would be independent. If all teams are managed in a combined way, the effort may turn into a program, rather than operate as projects that move towards a conceptual design. **Dr. Whyte** added that the private sector has different standards and practices that must be discussed.

**Dr. Maingi** asked if the FPP will be able to learn about tritium plant capabilities from ITER given its scheduled deuterium-tritium (D-T) operation in 2035+. **Dr. McCarthy** remarked that all information obtained between first plasma and D-T operations will be transmitted to the FPP. The FPP has an aggressive schedule, but ITER was designed to reduce risk.

**Dr. Maingi** asked about free flow of ITER information regarding Test Blanket Modules (TBMs). **Dr. McCarthy** stated that the U.S. is not currently participating in the TBMs, although the U.S. reserves the right to do so.

Commenting on overlap between the LRP's and the NASEM report's recommendation to assemble design teams, **Dr. Maingi** asked what NASEM's estimate was for such a fully resourced effort. **Dr. Hawryluk** relayed that budgets and priorities were not discussed due to limited time. **Dr. Wirth** said that the report was concept agnostic, and therefore there are no specific recommendations about projects like EXCITE. The report does highlight the need to assemble national design teams and address 2-4 concepts to start laying out the technology roadmap that will ultimately lead to FPP construction.

**Taming Plasmas and Controlling Laser Beams for Grand Challenge Applications,**
Dr. Dustin Froula, University of Rochester

The University of Rochester's (Rochester's) Laboratory for Laser Energetics (LLE) operates the world's largest lasers in an academic setting and consists of the OMEGA, OMEGA Extended Performance (EP) Optical Parametric Amplifier Line (OPAL) and Multi-TeraWatt (MTW) lasers and facilities. The Fourth generation Laser for Ultrabroadband eXperiments (FLUX) is scheduled for first light in 2023, and OMEGA EP OPAL is under construction. The Omega lasers support a national user program where >60 participating institutions participate in 60% of the experiments. The Plasma & Ultrafast Laser Science & Engineering (PULSE) Division at Rochester is a center for laser-plasma physics, technology, education and collaboration.

Laser-plasma instabilities (LPIs) remain one of the greatest obstacles to using high-power lasers in grand challenge applications. Thomson scattering enables decoupling of hydrodynamic uncertainties from LPI physics, allowing measurement of plasma conditions and opening the design space for applications. Technologies that control laser beams, such as third-harmonic frequency generation, chirped-pulse amplification, smoothing by spectral dispersion and spatiotemporal control of laser intensity, also have advanced applications. More recently, Raman

Amplification has the potential to achieve intensities above $10^{24}$W/cm$^2$, presenting opportunities to study quantum electrodynamics (QED). A multidisciplinary team has proposed a high-temperature amplifier to improve laser beam propagation; this proof-of-principle system would demonstrate energy transfer efficiencies >30%, intensity gains >10, and output intensities >100x the pump intensity. Fourth generation inertial confinement fusion (ICF) lasers must mitigate LPIs to achieve high-yield implosions. A series of Thomson scattering experiments have developed predictive models for ICF designs, and high-bandwidth lasers provide a path for expanding the ICF design space. FLUX will use the OMEGA LPI Platform to validate bandwidth modeling; if successful, FLUX will lead to the design for an upgraded OMEGA FLUX-60 with ultra-wide bandwidth ultra-violet (UV) tripling. Dephasingless Laser Wakefield Acceleration, through spatiotemporal pulse shaping, offers the opportunity to accelerate electrons to TeV energies in few-meter single-stage plasma without the need for a guiding structure. Finally, improved sources for high-energy density (HED) measurements with ultrashort pulse lasers will provide time resolution for access to novel physics. Nonlinear Thomson "Compton" scattering has the potential to produce high-energy photon beams from high-power lasers while spatiotemporal pulse shaping can control the ponderomotive force, significantly improving the power scattered, the scattered photon energies and the scattered emittance.

**Discussion**

**Dr. Carter** requested more information about Raman Amplification and the route to the nonlinear QED regime. **Dr. Froula** observed that Raman Amplification physics is understood but achieving laser propagation is challenging. Additional time will be needed to scale systems up to 100 PW. Researchers may be closer to QED, because high-power lasers are coming online and can be coupled to flying focus and spatiotemporal controls. A recent paper shows how advanced light sources can lower the thresholds for QED processes without requiring traditionally high intensities. QED may be possible on near term lasers or on existing lasers.

**Dr. Terry** asked about validation of codes. **Dr. Froula** explained that laser plasma stability codes have been evolving over 20 years. It took ten years to get ignition with indirect drive through tuning the cross-beam energy transfer. Today, the models in the integrated codes are very good, but there are challenges in deciphering either the LPI physics or the hydrodynamic plasma conditions. Work from the last ten years suggests it is the hydrodynamic part, though the two are interconnected. This is a reason to move forward with bandwidth. The bandwidth is expected to behave as predicted but designing a laser has taken a long time. The lab is also measuring electron distribution functions over many orders of magnitude for heat flux and is developing new models.

**Dr. Hansen** asked about benchmarking plasma science predictive modeling needed for an FPP. **Dr. Froula** commented that this challenging fundamental work requires tying the macroscopic plasma conditions across millimeter scales to the microscopic electron distribution functions and understanding how they interact with LPIs and heat transport. His lab is adding magnetic fields and hopes to measure the fields as a function of time to better understand how the plasma is moving the fields around. Additionally, the lab is examining how the electron distribution functions affect atomic physics.

**Public Reusable Research (PuRe) Data Resources**, Dr. Michael Cooke, Senior Technical Advisor, Office of the Deputy Director for Science Programs.

Community Data Sets, along with Research Funding and User Facilities, comprise the three pillars of the DOE SC Community Research Enterprise. The Public Reusable Research (PuRe) Data Resources effort consists of data repositories, knowledge bases, analysis platforms and other activities that aim to make data publicly available. To qualify, PuRe data resources must receive sustained funding from an SC program; be considered an authoritative provider of data or capabilities in its subject area; be publicly available and use digital object identifiers (DOIs); and be recognized for strategic impact on the SC mission. Additionally, PuRe data sources should have or strive towards providing a plan for long-term sustainability; clear user guidance; metadata; and mechanisms for curation, quality assurance and tracking data provenance. Designating PuRe Data Resources benefits the SC's ability to articulate the products of its investments; preserve records; and facilitate science by making data findable, accessible, interoperable and reusable (FAIR).

To attain a PuRe designation, candidate resources provide a data management plan and a metrics and science highlights collection plan along with assurance of management buy-in to their program office. The program office generates an oversight plan with peer review. The SC Working Group on Digital Data reviews all these documents and makes an official recommendation to the program's associate director. Data sets from the Atmospheric Radiation Measurement Data Center, Joint Genome Institute, Materials Project, National Nuclear Data Center, Particle Data Group, and Systems Biology Knowledgebase are the initial recipients of the PuRe Data Resource designation.

The Office of Scientific and Technical Information (OSTI) Resources platform also enables open science and houses DOE-funded research and development (R&D) results. All R&D results, researchers and pilot projects are documented with searchable persistent identifiers.

Data management plans (DMPs) are required by and reviewed as a part of the overall SC research proposal merit review process. Proposals may request funding to implement a DMP.

**Discussion**

**Dr. Verboncoeur** asked about links between OSTI and similar resources created by professional societies that show citation trees. **Dr. Cooke** responded that OSTI uses DOIs to allow researchers to reference and track data use, that the network allows for research contribution recognitions and career support, and that OSTI houses tools for creating links.

**Dr. Matthews** remarked that fusion/plasma sciences do not yet have a PuRe Data Resource designation. **Dr. Cooke** replied that while the fusion community does not have a designation at this time, there are efforts that could be candidates. SC is working to identify and create more designations and can assist with the designation process. The SC aspires to attain FAIR principles and other desirable characteristics for PuRe Data Resources, but these are not necessarily upfront requirements.

**Recent Inertial Confinement Fusion Results from the National Ignition Facility,**
Dr. Mark Herrmann, Deputy Program Director for Fundamental Weapons Physics

The August 8, 2021 shot on NIF, experiment N210808, yielded 1.35MJ and marks a significant advance in ICF research. This is the first shot to achieve a capsule gain of ~5+/ $E_{abs}$ ~230kJ (yield/ absorbed energy). Nuclear data show high ion temperature, short burn width and increased volume. X-ray diagnostics also reveal larger size and higher temperature. All data are consistent with self-heating and burn propagating into the ice.

NIF is working to create the hottest, most dense and biggest mass of D-T possible by improving compression and energy coupling. Fall 2020 and early spring 2021 experiments improved compression significantly, and initial assessment suggests that N210808 closed much of the ignition gap to burn propagation, with results surpassing simulated yields. Several advances in target designs, diagnostics targets and the NIF laser have led to these results. Repeat experiments are planned for October-November 2021. The longer-term goal is to further increase yield to create even more extreme environments for stewardship applications.

**Discussion**

**Dr. Hansen** inquired about improving ignition metrics, characterizing materials damage and the 1-D clean yield. **Dr. Hermann** replied that identifying the key parameters for ignition will take time. However, the simulations redeemed themselves, providing the opportunity for bolder explorations. The facility obtained a lot of information about harsh environments, and there is a lot to understand. The 1-D clean calculation was $6 \times 10^{17}$ and is very sensitive to $\rho R$.

**Dr. Rej** dismissed the meeting for the day at 5:30 p.m.

## Tuesday, August 31, 2021

**Dr. Rej** convened the meeting at 11:02 a.m.

**HEP Program Overview and Organization and Operations of the Large Hadron Collider Experiments**, Dr. James Siegrist, Associate Director of Science for High Energy Physics

The 2014 HEP P5 report guides U.S. agency investments in particle physics. The Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) is vital to achieving P5's vision. DOE participates in the Compact Muon Solenoid (CMS) and A Toroidal LHC ApparatuS (ATLAS) experiments at the LHC. CERN's model for hosting the LHC separates infrastructural governance (Host Lab or Facility) via the CERN Council from that of experiments, which are flexibly mediated through MOUs. The Council is run by 23 Member States and is the highest governing authority of the CERN Organization. The Council defines strategic programs, sets annual goals, reviews expenditures, and adopts CERN's annual budget. Under this model, the Host Lab is responsible for ~75% of facility construction or upgrade costs while the remaining ~25% is contributed by non-Member States via international cooperative agreements, including the fraction contributed by DOE. In contrast, ~75% of experiments' costs are secured through international partnerships and ~25% by the Host Lab. The Council is assisted by the Scientific Policy Committee (SPC) and Finance Committee (FC). The CERN Director-General, appointed by the Council, manages CERN Laboratory.

From CERN's perspective, experiments are composed of international collaborators and are not a legal entity, nor are they owned by the Host Lab. The Host Lab does, however, maintain oversight through the LHC Resources Review Board (RRB) and provides services, such as electricity and office space. Collaborators must also abide by Host Lab rules. An Executive Committee, consisting of the experiment's Spokesperson, Resource and Technical Coordinators and the Chair of the Institutional Board (IB), directs experimental execution. The IB is a policy and decision-making body of the Collaboration. Additional committees/groups assist CERN and the LHC experiments in program planning, including the LHC experiments

Committee (LHCC), the Maintenance and Operations (M&O) Resources Scrutiny Group and the Computing Resources Scrutiny Group.

CERN's experimental phases correspond to DOE's CD System. Groups of interest form for project systems and subsystems, each with their own internal organization. A multilateral MOU, prepared through a bottom-up process, relies on a matrix (tabular) structure to record all deliverables. The Host Lab is an MOU signatory with each partner. This MOU approach has been successful for the installation and commissioning of the CMS and ATLAS detectors.

DOE supports LHC research though the HEP research program. Detector operations are nationally coordinated through the U.S. ATLAS and CMS Operations program, jointly run by DOE and NSF. Program scope is funded separately by each agency. Overall, U.S. funds are directed to three areas: Operations Program Management, Detector M&O and Software & Computing. Notably, while project and operations tend to be nationally coordinated, physics research is coordinated directly with the international collaboration. U.S. CMS and U.S. ATLAS each have dedicated facilities at DOE laboratories to advance a cohesive research effort by the U.S. universities and labs.

**Discussion**

**Dr. Rej** asked if the ITER and LHC international partnership models are learning from each other. **Dr. Siegrist** said some aspects of the CERN model could likely be mapped onto ITER's future, such as an international approach for core research. Shift work to cover basic operations will likely be necessary as will coordinated access to diagnostic probes and data reduction through a computing system.

**Dr. Carter** asked about coordination among domestic agencies for solicitations. **Dr. Siegrist** said agencies may coordinate joint solicitations but more often release side-by-side solicitations and then decide how to partition scope and funding. DOE and NSF commonly use this behind-the-scenes approach to fund LHC operations and construction. The process is seamless from the applicants' point of view.

**Dr. Terry** inquired about adjudication for when U.S. and international LHC priorities do not align. **Dr. Siegrist** explained that such issues are resolved through the RRB and other oversight bodies. DOE is brutally honest about U.S. team and funding capabilities. When unable to make a desired contribution, the U.S. offers an explanation and encourages other countries to step forward. Sometimes other agencies are able to accept projects with higher risk profiles.

**Dr. Kuranz** asked what steps HEP and the community took to leverage the P5 report. **Dr. Siegrist** replied that HEP encouraged the community to generate detailed plans for the LHC High Luminosity Upgrade and move towards a series of reviews. The Panel also reformulated the neutrino program effort to involve international partners following the CERN model. European collaborators have since heavily contributed.

**Innovation Network for Fusion Energy: Past Performance, Future Plans and Lessons Learned,** Dr. Dennis Youchison, INFUSE Director Oak Ridge National Laboratory; and Dr. Ahmed Diallo, INFUSE Deputy Director, Princeton Plasma Physics Laboratory

The INFUSE program is a PPP first-of-a-kind program within SC started by FES. INFUSE was initiated due to the recent surge in private sector investment in fusion energy. The program focuses on providing streamlined access to DOE national laboratory capabilities and senior scientists. INFUSE is implemented by a point-of-contact (POC) panel with members from each participating laboratory. The panel interfaces with SC-FES, each laboratory's Strategic

Partnership Projects (SPP) office, the DOE site office, company primary investigators (PIs) and chief executive officers (CEOs, and lab PIs. Two Request for Assistance (RFA) calls are issued per year. The panel organizes the merit review process with input provided to FES for final selection. Upon selection, requestors must accept one of two standardized Cooperative Research and Develop Agreements (CRADAs) and provide the required 20% cost-share.

Since its 2019 pilot year, INFUSE has funded a total of 40 projects involving nine national laboratories as well as PPPL and 17 U.S. companies from nine states at a value of ~$9.9M, with ~$7.8M contributed by the DOE. Overall, two awards have been issued in Magnetic Fusion Experimental Capabilities, three in Plasma Diagnostics, ten in Materials Science, ten in Enabling Technologies including magnets, and 15 in Theory and Simulation. There is a ~50% average proposal success rate across all cycles with awards to a diverse portfolio of companies.

Two INFUSE workshops have been held to provide feedback. Several lessons have been learned, addressing navigation of the U.S. government by outside parties, eligibility issues and cost sharing, the field work proposal (FWP) cycle, the limited bandwidth of senior scientists at participating laboratories, conflict of interest mitigations and the INFUSE POCs, CRADA processing and amendments, and INFUSE supplementals. Universities will be eligible for participation in FY2022. FES is actively exploring involvement of other state- or university-funded labs in INFUSE and creating additional PPP programs for engaging industry directly via milestone-driven programs and larger FOAs.

**Discussion**

**Dr. Ma** invited comment about the testing of risky ideas via INFUSE and whether risk is being encouraged by the program. **Dr. Youchison** remarked that there has been good diversity in awards for topics and company sizes. The program has entertained IFE and MFE projects and supported small businesses. Applications with milestones, venture capital and a business plan, and that need DOE assistance generally perform well.

**Dr. Carter** requested that FESAC be briefed about future FES PPP plans. He suggested that INFUSE consider allowing postdocs to conduct work, as senior scientists have limited bandwidth.

**Dr. Maingi** asked what changes will make this program most valuable to industry. **Dr. Youchison** deferred to an earlier presentation of potential FES PPP programs to benefit industries. The national laboratories are not service organizations. INFUSE requires that 25% of any project’s time goes to a senior staff lab member. FES must decide whether the requirements should be changed, and FESAC might consider making a recommendation. Regardless of changes, INFUSE would still expect senior scientist involvement at some level. **Dr. Maingi** agreed. Senior scientist involvement is critical but having them guide others through the work is often the most cost-effective approach.

**Dr. Brown** asked about possible procedures for creating university POCs. **Dr. Diallo** said various models are being considered. One approach is to create a panel of select universities, taking industry feedback into account, to coordinate discussion with all university participants. Additionally, INFUSE is leveraging ARPA-E’s expertise, which may become another point of entry for industry.

**Dr. Rej** dismissed the meeting for lunch at 12:45 p.m. and reconvened at 2:00 p.m.

**Status of U.S. ITER,** Dr. Kathryn McCarthy, Associate Laboratory Director for the Fusion and Fission Energy and Science Directorate, Oak Ridge National Laboratory

The ITER project is ~78% complete for First Plasma site construction and components. Tokamak assembly began in May 2020. The cryostat base and cryostat lower cylinder were installed, the first magnet was installed in the tokamak pit and the first vacuum vessel sector successfully docked. Toroidal field coils were installed for sector assembly in August 2021. Central Solenoid (CS) Module 1 will arrive at the ITER facility on ~September 9, 2021. CS 2 is currently at the Port of Houston after extra transit precautions were taken due to Hurricane Ida.

The U.S. contributes a total of 9% to ITER's hardware construction costs but has access to 100% of the project's scientific discoveries. Hardware delivery by the U.S. ITER Project is divided into two subprojects: SP-1 includes design of all hardware and delivery of hardware for first plasma; and SP-2 includes delivery of the remaining hardware. SP-1 was baselined in 2017. Appropriations for hardware were lower than the baseline early on, but higher in recent years. However, there is a cumulative deficit of $97M relative to the baseline figure. Thus, priority has been given to hardware needed for first plasma. With the larger appropriations, activities that were put on hold have restarted. Finished U.S. hardware projects include the toroidal field coil conductor (U.S. share 8%) and the steady state electrical network (U.S. share 75%). Hardware projects in fabrication include the vacuum system roughing pumps, tokamak cooling water system, central solenoid, electron cyclotron heating transmission lines, and instrumentation and controls. Prototypes in fabrication include diagnostics (U.S. share 14%) and ion cyclotron heating transmission lines. A disruption mitigation system is in design. DOE will supply a full construction baseline report for SP-1 and SP-2 to Congress in December 2022.

Most ITER funding remains in the U.S., and as of June 2021, ~$1.3B has been awarded to U.S. industry, universities and obligated to DOE national laboratories in 46 states as well as the District of Columbia. ITER is creating a transparent, streamlined process for accessing information to support public and private development of fusion energy.

**Discussion**

**Dr. Reyes** asked if the U.S. participates in the development of plans for installation, testing and commissioning of the hardware once it is in France. **Dr. McCarthy** explained that the U.S. is obligated to deliver hardware but is not typically involved in assembly. The IO determines whether an associated operating manual or other information is required.

**Dr. Carter** inquired about the timeline and vision for the ITER Research Team. **Dr. McCarthy** relayed that those discussions are underway; operations teams will likely be involved at later stages of installation and/or for commissioning. Other discussions address the need for a control room simulator. Tax laws must be addressed if the U.S. wants to second scientists to ITER, or else scientists will be limited in their stay. **Dr. Carter** asked whether secondment is preferred to having visiting scientists. **Dr. McCarthy** explained that this has not been decided and might be a combination of both.

**Dr. Maingi** asked about the simulator. **Dr. McCarthy** clarified that nuclear power plants all have control room simulators, some simple and some complex, for training operators. The IO is currently tendering bids, and the important question is what the IO's specifications will be.

**Dr. McCarthy** concluded that it is an exciting time for fusion, and coordination internationally and nationally is key.

**X-ray Light Sources Driven by Laser-plasma Accelerators for High Energy Density Science,** Dr. Félicie Albert, Presidential Early Career Award for Scientists and Engineers Winner, Lawrence Livermore National Laboratory

HED experiments create extreme, transient conditions of temperature and pressure that can be diagnosed with x-ray techniques. Fourth generation x-ray light sources are located at billion-dollar-scale national facilities, and laser plasma accelerators offer a compact alternative to these big machines. Laser Wakefield Acceleration (LWFA) presents novel approaches to produce x-rays with unique properties; they are broadband (keV-MeV), ultrafast (fs-ps), small in source size (µm), collimated (mrad) and synchronized with the drive laser. Researchers are using large KJ-class picosecond lasers to create new platforms for generating x-rays from the self-modulated LWFA (SMLWFA) or blowout LWFA regimes at several facilities.

Selected studies at the LLNL Titan laser show that electrons accelerated into the SMLWFA regime give rise to betatron x-rays, with optimized radiation producing the most photons at energies <40 keV. Compton scattering allows for increased photon flux up to ~300 keV. However, LWFA-driven bremsstrahlung produces the most photons at MeV energies. Combining several processes allows control of x-ray flux and energy, permitting spectral tuning. Studies have also been able to reproduce a test object radiograph using an x-ray tracing code named HADES. When examining a test object with high areal density, betatron x-rays from SMLWFA improved radiography resolution. Using a blowout LWFA regime via the Linac Coherent Light Source-MEC instrument, researchers demonstrated betatron x-ray absorption spectroscopy with sub-picosecond resolution to study ultrafast non-thermal melting in $SiO_2$. Additional experiments are exploring applications for phase contrast imaging of laser-driven shocks, micrometer-resolution imaging of hydrodynamic instabilities without motion blue and opacity in HED matter.

**Discussion**

**Dr. Hansen** asked about source temporal behavior, how intensity scales with the driving laser energy and about monochromatic sources. **Dr. Albert** said the source duration ties directly to the laser pulse duration. Monochromatic studies are possible but not through betatron or bremsstrahlung radiation in this configuration; groups at LBNL and in China are addressing this with X-ray free-electron lasers (XFELs). Compton scattering can be used for some monochromatic sources, but the results are not as coherent as those from XFELs.

**Dr. Terry** inquired if self-modulated wave breaking becomes coherent or turbulent. **Dr. Albert** replied that it is not coherent. The timescales are likely not long enough for turbulence.

**Office of Science User Facilities: Lessons Learned from the COVID Era and Visions for the Future,** Dr. Lijuan Ruan, Co-spokesperson RHIC's STAR Experiment, Brookhaven National Laboratory

The COVID-19 pandemic directly impacted the 28 SC user facilities, causing a shift to remote operations. An SC roundtable was chartered by the Office of the Deputy Director for Science Programs, in collaboration with the Science Programs Associate Directors and Office Directors across programs to capture lessons learned and to strengthen future operations.

The roundtable was held virtually from December 2-15, 2020. The ~50 participants representing perspectives across all facilities were divided into six panels based on themes derived from responses to a facilities questionnaire that was circulated before the workshop: User research in virtual contexts; User research in physically distanced contexts; Facility operations in physically distanced or virtual contexts; User training/engagement; Computation, data and network resources; and Crosscutting Issues. A letter report was delivered in January 2021 and a full report in July 2021.

During the pandemic, most facilities switched to full or predominantly remote operations with limited onsite users and functioned under new controls. In general, facility scientific productivity has been reduced, and early career researchers and staff have been severely affected. Virtual collaboration tools have substituted for on-site presence, but gaps remain: new user training modalities have had to be implemented; user outreach has become limited in some instances; lack of onsite presence has impacted the concept of what " a user" means; higher-complexity, higher-payoff experiments have been deferred; staff have faced additional burdens; creative interactions have been hampered; the loss of community built on physical presence has put mentoring, training, workforce development and other interpersonal activities at risk; and cyber security and cyber productivity issues have emerged.

On the other hand, remote operations have removed physical location and equity constraints leading to several opportunities to share lessons learned and best practices amongst facilities; develop new tools to engage and support broader communities; federate data management tools and processes; reduce the environmental impact of travel and devote travel resources to other priorities; consider more efficient configurations for facilities and operations that confer better work/life balance; create and capture digital products from training sessions and other learning opportunities; free staff to focus on science by capitalizing on automation and virtualization; build and support more diverse and inclusive user communities and staffing paradigms; and support early career staff and users to ensure that they can succeed.

Virtual access is a double-edged sword, with costs and benefits differing for each facility. There are opportunities to capitalize on the rapid shifts necessitated by COVID-19 to move towards a new normal that might have been coming regardless.

**Discussion**

**Dr. Matthews** thanked Dr. Ruan and remarked that virtual meetings obviate travel. **Dr. Ruan** observed that with major conferences going remote, many people who previously lacked the funds necessary to attend are now able to present. Recordings allow people to watch sessions that they could not attend.

**Dr. Van Dam** asked about changes implemented at BNL due to the roundtable. **Dr. Ruan** said staff will likely continue working on site part-time and remotely part-time. Experimental operation modes have also changed. For the Solenoidal Tracker (STAR), two people instead of four are required in the control room, and a 24/7 zoom link has been implemented to facilitate communication between those on shift and experts. These changes will be kept going forward.

**Dr. Hansen** inquired about supporting young people. **Dr. Ruan** has personally found frequent communication helpful as well as making accommodations for students' work environment needs. Post-docs are under huge pressure. It is important to be more understanding compared with before COVID-19 because it is hard to know what is happening in individuals' lives. Students' needs must be considered on a case-by-case basis.

Concerning how much facility time was lost for user research last year, **Dr. Ruan** replied that it varies by facility. RHIC has been able to operate with minimal user impact, albeit staff have faced greater pressures. DOE deemed the RHIC mission to be critical, and users have been able to get permission to go onsite this year. At other facilities, users have not had site access, and some studies cannot be done.

**Dr. Ma** asked about facility breakouts, DOE COVID-19 guidance and whether SC will be mandating vaccines. **Dr. Ruan** replied that each facility developed its own protocols based on guidance from DOE and the local state. Thus far, SC has not mandated vaccination. LANL has mandated the vaccine. BNL has not. **Dr. Snyder** shared that ORNL has mandated vaccinations.

**Dr. Snyder** requested more details about future facility operations. **Dr. Ruan** said COVID-19 has taught facilities how to work with users remotely. The new tools that make this process more efficient will continue to be used after COVID-19. COVID-19 has also highlighted the need to reconsider flexibility in work schedules and locations.

**Public Comment**

**Andrew Holland** (Fusion Industry Association, FIA) stated that many of the FIA's 23 member companies, including CFS, TAE, Helion Energy and General Fusion, have made recent announcements about their fundraising, scientific results and next steps to build fusion facilities. The FIA is excited to participate in PPPs called for in the FES LRP, NASEM report and the Energy Act of 2020. However, the government is not acting with urgency. The FY2022 budget does not include funding to move towards commercial fusion energy, nor does it create the programs and partnerships called for. Rather than waiting for the OMB, DOE can begin planning for PPPs by hiring a coordinator as well as initiate a new IFE program or an alternative program as required by Congress. DOE can also expand existing PPPs to include universities. The climate crisis is getting worse, and public policy is moving fast. If U.S. fusion research programs do not evolve to meet this demand, the U.S. will be left behind by international competitors and could lose this new industry. The UK government plans to create a pilot fusion plant by 2040 and has attracted Canadian company General Fusion to build a demonstration plant via a PPP. China is investing billions of dollars, and there have already been efforts to bring FIA technology or IP to China. The FIA is working with the Fusion Energy Caucus to argue that fusion energy must be included in infrastructure legislation. The FIA has proposed $1B in PPPs to the upcoming reconciliation infrastructure climate plan to build U.S. scientific demonstration facilities. DOE and FESAC can generate a new sense of urgency by pushing the fusion program forward. Private industry wants to work with government programs but will not wait forever. DOE should use PPPs to leverage public investment with private dollars to catalyze a new industry and to meet the goals outlined by the LRP and NASEM.

**Francois Waelbroeck** (University Fusion Association, UFA) commented that realizing a fusion pilot plant will require the joint effort of universities, the private sector and the national labs. While the UFA welcomes INFUSE's inclusion of universities, the program's exclusion of students and postdocs is a serious flaw. This exclusion asks faculty to perform tasks in a way that is incompatible with their academic responsibilities while preventing them from training future members of the fusion workforce. The result will be low participation limited to universities with non-academic research personnel. The UFA urges FES to work with universities to find an arrangement that makes full use of universities' potential contributions.

**Tyler Ellis** (Commonwealth Fusion Systems) said that the fusion community's recommendations, endorsed by Congress's legislative authorizations, are achievable and necessary to keep the U.S. as an international player. The entire fusion community must work together to implement recommended directives. Yet, the UK has committed >$561M to support fusion, and China is spending hundreds of millions of dollars annually. In comparison, the most recent FES budget proposal for INFUSE, the only fusion PPP program, is only \$6M. Without a significant course correction, the U.S. risks not only wasting two years of fusion community efforts by allowing the recommendations to become outdated, but also being left behind internationally. The ball is in DOE's and FES's court; when will FES act to implement directives to support a globally relevant fusion program and regain leadership in this critical industry? The fusion community needs to push harder and reach out to senators and representatives on an individual basis to make fusion more relevant and timelier. Private industry is ready to work with DOE, FES and the rest of the community. Together, we hope to establish fusion energy as a viable energy source by the early 2030s to start addressing climate change.

**Dr. Verboncoeur** observed that an economic argument must be made for fusion. As projects approach technical milestones, it is important to learn the cost to manufacture, ship and assemble, as well as how projects will scale economically. Without an understanding of the supply chain and production level pricing, fusion will be at a significant disadvantage.

**Dr. Carter** thanked the public commenters and requested that future FESAC meetings provide updates on PPP expansion plans, IFE processes and the FPP design activity. **Dr. Brown** agreed and invited next steps from Dr. Van Dam. **Dr. Van Dam** replied that the FY2023 budget is in embargo.

**Dr. Maingi** reemphasized the need to move forward with high priority items from the LRP and NASEM reports. This includes formation of the ITER Research Team. **Dr. Wirth** agreed; FES needs to move aggressively, even to meet the timeline of the 2019 Burning Plasma report. **Dr. Snyder** concurred; FESAC should offer advice and guidance to maintain a sense of urgency. If FESAC feels it should be charged, can it seek guidance from the Chair? **Dr. Rej** said he can mediate dialogue between FES and FESAC.

**Dr. Kuranz** agreed with prior remarks but also stressed the report's excellent fundamental science and its potential to excite young community members. This aspect must also be emphasized going forward. **Dr. White** added resonance to earlier comments and to Dr. Kuranz's remarks; early career scientists are ready to be bold, but they need a stable career path.

**Dr. Rej** adjourned the meeting at 4:44 p.m.

Respectfully submitted on September 17, 2021
Holly Holt, PhD
ORISE/ORAU

**Certified as Correct by:**

Dr. Donald J. Rej, FESAC Chair

Date
October 10, 2021