Draft Strategic Plan
for MFE and FM&T

Prelude

This document has been constructed through the APS-DPP community planning process (DPP-CPP) that has identified scientific and technological opportunities in the fields of Plasma Physics and Fusion Energy Science. The magnetic fusion energy (MFE) and fusion materials and technology (FM&T) groups have joined to produce a strategic plan with the goal of enabling the development of fusion energy in the US. Input from the community has been gathered through a continuous and wide ranging set of opportunities and venues including public submission of initiatives and white papers, regular meetings of topical science expert groups, a dedicated DPP-CPP joint MFE/FM&T workshop, webinars and town halls at major meetings. In addition, an important input to this process has been the 2018 National Academies of Sciences, Engineering, and Medicine (NAS) Final Report of the Committee on a Strategic Plan for U.S. Burning Plasma Research, which has served as an important starting point for the community's discussion. This process has now advanced to the stage that a draft strategic plan, contained in this document, has been formulated incorporating common objectives of the community with broad community support.

The structure of this document has a familiar organization for strategic planning, beginning with the vision and mission statements, followed by overarching objectives and recommendations and then strategic objectives and recommendations. Science drivers are provided for narrative description and interconnections. Continued discussion and refinement of this strategic plan will occur at the second DPP-CPP joint MFE/FM&T workshop in Knoxville with preliminary conclusions and goals for Knoxville provided at the end of this document.

Vision Statement

We embrace the ambitious goal of developing practical fusion energy, which can produce safe, clean, and environmentally sustainable energy for everyone, for the foreseeable future. (*Taken from Austin 2017 Working Group #1.*)

Mission Statement

Develop the innovative science and technology needed to enable construction of a pilot plant that produces electricity from fusion at the lowest possible capital cost. The goal is to demonstrate that fusion energy has the promise to be economically viable in the US energy market.

Definition of a Fusion Pilot Plant

The following deliverables are likely required to demonstrate that fusion has the potential to be a safe, economical energy source in the US, and therefore define the minimum mission scope for a Pilot Plant. These deliverables are consistent with the recommendations of the recent 2018 NAS BP report.

- D1: Produce fusion power comparable to ITER but at significantly lower cost
- D2: Produce net electricity
- D3: Establish the capability of high duty factor operation
- D4: Demonstrate the safe production and handling of the tritium fuel required for sustained power generation

Principles

There are a few principles that embody the strategic planning effort for the US fusion community. These were articulated by the 2017 Austin Working Group #1 and refined following discussion during the 2017 Austin workshop. (Most of these principles were identified by the community in previous activities, e.g. the 1996 FEAC report on restructuring the fusion program). These include: (1) Scientific Basis, (2) Timeliness, (3) US leadership, (4) International context, (5) Robustness, (6) Culture of Innovation, (7) Boldness.

Of these, perhaps the principle that most distinguishes the US fusion program from many others (as noted by the 2018 NAS BP report) is embracing and aggressively pursuing the development of innovations and potentially disruptive technologies that are needed to enable an economical fusion energy solution suited to the US energy market. Embracing these innovations in a timely manner, while maintaining flexibility to evolve, represents an opportunity to realize the boldness of the US fusion vision.

List of Overarching and Strategic Objectives

Overarching Objectives

A. Establish an interdisciplinary project within DOE to coordinate and drive the necessary scientific and technological advancements enabling the design and construction of a Fusion Pilot Plant
B. Develop a licensing framework and safety strategy for fusion
C. Develop validated models for predictive integrated modeling
D. Determine and develop the diagnostics needed to design, operate, and control a FPP
E. Develop the workforce needed for fusion physics, engineering & technology
F. Utilize public-private partnerships to movetowards fusion commercialization

Strategic Objectives

A. Complete the tokamak physics basis necessary to design a fusion pilot plant
B. Advance the stellarator physics basis to the point of readiness for D-T
C. Innovate the magnet and H&CD technology needed to reduce the pilot plant capital cost
D. Demonstrate solutions for managing high heat and particle loads sufficient to design plasma-facing components for the fusion pilot plant
E. Determine the structural and functional materials that will survive under fusion reactor conditions
F. Develop the foundational science and technology necessary to design and build a tritium breeding blanket
G. Develop the capability to test breeding blankets at progressively integral scales
H. Advance tritium management, fueling, and pumping technology necessary for a FPP
I. Establish remote maintenance capabilities and the balance of plant equipment needed for a FPP

Overarching Objectives and Recommendations

Overarching Objective A: Establish an interdisciplinary project within DOE to coordinate and drive the necessary scientific and technological advancements enabling the design and construction of a Fusion Pilot Plant.

In order to establish the scientific and technical readiness for a pilot plant, it will be necessary to conduct increasingly detailed design of the confinement device, auxiliary systems and balance of plant equipment in an organized manner that sustains the knowledge into the construction of a Fusion Pilot Plant. Within DOE, these activities can be connected by the "Program and Project Management for the Acquisition of Capital Assets" under DOE O 413.3b. This Objective lays out an on-ramp for the FPP as a formal DOE project, under which cost, schedule and project performance will be tracked, but which also unlocks significant design resources and establishes goals for technical readiness. A down-selection process, formalized within the pathway to CD-1[1] *to "define, analyze, and refine project concepts and alternatives" will be used for the objective evaluation of multiple confinement concepts, with a target of making a decision by the mid/late-2030s. Although the government typically does not build pilot plants, we are envisioning this facility to be designed and constructed as a DOE acquisition of a capital asset. However, the intent is not to eliminate the possibility of an alternative through private-public partnerships, such as the use of modified Cooperative Agreements or Technology Investment Agreements via peer-reviewed competition of proposals. The first two Recommendations*

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[1] https://opss.fnal.gov/critical-decision-overview/

should be agnostic, and the second two Recommendations would need to be adjusted based on the specifics of the activities private industry are willing to undertake and how DOE decides to implement support. Regardless, this Objective allows the broader set of Recommendations to connect with a formal Fusion Pilot Plant project however that is realized.

Recommendations

1. Expand the integration of predictive plasma physics models with commercial engineering design tools that will be required to support FPP design, ensuring a pathway to incorporate innovations in science and technology outlined in this strategic plan.
2. Conduct FPP mission scoping, engaging public and private stakeholders to provide feedback on the optimal set of deliverables for the fusion pilot plant (such as D1-D4), considering multiple confinement concepts.
3. Using input from FPP mission scoping, establish Mission Need for a capability to demonstrate the integrated science and technology necessary for the future commercialization of fusion energy, forming project-linked design teams to start conceptual designs for at least one tokamak-based FPP and at least one stellarator-based FPP.
4. Following key results from new U.S. confinement facilities, ITER operation, output from international tokamak and stellarator facilities, and advances in the necessary fusion technology conduct a community-wide review to provide input to DOE to approve CD-1 for either moving forward with a tokamak FPP or pivoting to a stellarator FPP.

Overarching Objective B: Develop a licensing framework and safety strategy for fusion

An electricity-producing fusion nuclear device such as the FPP will need to be licensed. This requires the development of an appropriate licensing framework and design rules for fusion reactors and their components. Initiating this activity in the near term is required to avoid delays on the construction and operation of a FPP.

Recommendations

1. Develop suitable plant-wide tritium control and radioactive material containment strategies
2. Develop appropriate component classifications and design rules for fusion reactors
3. Identify criteria for selection of licensing basis events
4. Outline a methodology for determination of source terms
5. Identify gaps in software, sensors and integrated data acquisition for safety analysis, remote maintenance, and integrated plasma core and plant control, and embark on any necessary development efforts to address these
6. Develop a radioactive waste management strategy for fusion

7. Develop and demonstrate power conversion, remote maintenance and plant control systems for a FPP
8. Establish a materials surveillance program to validate lifetime models and ensure safe operation over the life of the reactor.

Overarching Objective C: Develop validated models for predictive integrated modeling

Advancing multi-scale, multi-physics theory and modeling capabilities in a diversity of topical areas will improve the capability to predict the complex interaction between numerous plasma, material and engineering processes. These advances in multi-scale, multi-physics theory and modeling capabilities are required to extrapolate with confidence from present experiments to the fundamentally new physics regimes typical of a fusion power plant. These fundamental advancements also form the basis for the models needed to be integrated into the engineering and physics tools used to develop pilot plant designs in PO-A. There is a hierarchy of approaches spanning whole plasma modeling from the core to the first wall, whole device modeling adding the divertor, wall and blankets, and whole-facility including balance of plant and economics to the site boundary.

Recommendations

1. Support improving fundamental scientific understanding of fusion-relevant plasma and material physics through theoretical and computational exploration to enable innovation and new conceptual solutions
2. Continue development of validated predictive models hierarchies
3. Develop physically rigorous and computationally robust model integration methods to enable predictive whole-facility modeling and optimization of FPP concepts
4. Invest in computational infrastructure and software engineering needs to enable optimal utilization of current and future high performance computing platforms

Overarching Objective D: Determine and develop the diagnostics needed to design, operate, and control a FPP

Advancements in diagnostics, instrumentation, data handling and interpretation are broadly needed for plasma science, fusion materials, power plant operation and control. Development and implementation of plasma science diagnostics are needed to provide adequate data for model validation and prediction of burning plasma behavior. Diagnostics advancements for fusion materials studies are needed to improve scientific productivity and understanding of the interaction of the fusion environment with materials at a fundamental level. Power plant operation and control includes diagnostics and instrumentation to monitor and confirm proper operation of plasma, in-vessel and ex-vessel systems and sensors, and logistics for data processing and automated real-time decision making. These sets of plasma diagnostics and *engineering instrumentation may differ for the stages of operation of an FPP. For example, some systems may be needed in the early phase to confirm adequate operation during commissioning of the plant. Others will need the robustness to survive in the nuclear environment during extended operation. The intent of this Community Objective is to accelerate progress and increase readiness for this cross-cutting area.*

Recommendations

1. Develop critical in-situ and combined effect diagnostics for fusion materials and plasma science needed to validate models, which includes new capabilities on existing confinement devices as well as lab-scale testing (SO-A.3, SO-A.6, SO-D.4).
2. Develop plasma diagnostics and engineering instrumentation deemed incompatible with the fusion environment and benchmark these new instruments on existing devices (OO-A.3, SO-A.2, SO-A.4)
3. Initiate the R&D needed to solve diagnostic survivability challenges (materials & electronics) imposed by the nuclear conditions expected throughout a fusion pilot plant facility (SO-E.1)

Overarching Objective E: Develop the workforce needed for fusion physics, engineering & technology

The fusion community is preparing to enter a dramatic new phase of expansion and development, which will require significant growth in our workforce. The increase in job opportunities presented by private enterprises can provide a powerful new tool for enticing new entrants to the fusion community as well as new avenues to retain our experienced personnel. Obtaining trained personnel to carry out the development of new facilities and technology programs will require expanded focus beyond the typical plasma physics development path and into a wider array of engineering/technology disciplines. Increasing diversity and inclusion in the fusion community are essential components of any workforce development program, and these advancements will only be made possible through deliberate effort to reach out to and engage underrepresented groups. A comprehensive workforce development program is required that begins with encouraging students to enter into a fusion path of study and then ensuring opportunities for engagement with the community through internships, apprenticeships, and academic projects.

Recommendations

1. Expand the fusion workforce in preparation for the realization of commercial fusion energy through a myriad of elements: Undergraduate student design competitions, flexible post-undergraduate education options, identify job opportunities for BS/MS degree holders, post-BS fusion workforce training program, and private-public DOE FES graduate student fellowships.

2. Increase paid summer internship program opportunities for undergraduate students at national laboratories, university labs, and the expanding array of private companies.
3. Enable support for the creation and maintenance of a new public-facing website that would serve as a one-stop URL for US fusion resources and opportunities for students (K-grad), teachers, postdocs, scientists, and the general public.
4. Hold annual or biannual workshops or conferences on equity and inclusion in our field.
5. Establish flexible, fast-track funding approval for U.S. institutions to take advantage of the ITER Project Associates (https://www.iter.org/jobs/IPA) scheme.

Overarching Objective F: Utilize public-private partnerships to move towards fusion commercialization

Partnering with private industry to advance fusion development is a necessary step on the path to commercialization of fusion energy within the US. Building off examples in commercial space, fission, and other industries, public-private partnerships will provide private capital to augment public research through cost-shares, facilities and capabilities that may not otherwise be developed within the public program, a means to transfer technology to the private sector, and a drive to commercial solutions.

Recommendations

1. Develop, utilize, and expand programs for public/private partnerships that leverage lessons learned from DOE and other areas of the federal government

Strategic Objectives and Recommendations

Strategic Objective A: Complete the tokamak physics basis necessary to design a fusion pilot plant

The Mission of the strategic plan requires innovative new approaches to optimize the tokamak in order to reduce the capital cost of a fusion pilot plant. By pivoting our focus to compact size, as recommended by the 2018 NAS Report, we presently have unique gaps in the tokamak physics basis that need to be closed in order to confidently design the FPP. This includes advancing our knowledge of transport and confinement, energetic particles, macrostability, pedestal and SOL/divertor physics as well the critical issues related to integrating this improved understanding into operational scenarios for the FPP. Achieving this objective will require a comprehensive, multidisciplinary science program that uses existing domestic and international facilities, takes full advantage of our ITER partnership, advances theory and modeling, and recommends a key investment in a new tokamak facility to be operational no later than 2030.

The suggested capabilities of this facility are specified to allow timely closure of all physics gaps related to planned FPP operating scenarios and enable FPP design.

Science Drivers: Control, Sustain, and Predict Burning Plasmas, Handle Reactor Relevant Conditions
Expert Groups: MFE-Boundary and Divertor Plasma Physics, MFE-Plasma and Material Interaction, MFE-Transport and Confinement, MFE-Energetic Particles, MFE-Transients, MFE-Scenarios, MFE-Global Context and US Leadership, FM&T-Plasma Material Interaction and High Heat Flux, FM&T-Magnets and Technology, FM&T-Measurements and Diagnostics

Recommendations

1. Design and construct a new intermediate-scale pre-pilot plant tokamak facility referred to here as the "new tokamak user facility" (NTUF), that in conjunction with ITER and other facilities, enables timely closure of all physics gaps related to planned FPP operating scenarios.
2. Leverage all opportunities to access and study burning plasma physics.
3. Utilize existing facilities and funding models to develop candidate scenarios for NTUF/FPP that have the potential for core-edge integration and project to high-average-power. Continue this work at least until NTUF operation (~2030) to ensure continuity of experience and knowledge.
4. Utilize existing facilities and funding models to support ITER readiness through start of PFPO (~2028), the completion of NTUF design (~2025) and innovations needed for FPP decision making (early 2030s).
5. Establish new multi-institution research teams via competed, open FOAs to advance multiple methods for disruption prediction, avoidance, and mitigation to inform the decision on the FPP confinement concept in the mid-2030s.
6. Leveraging the unique features of NTUF and utilizing national research teams established through open FOAs, develop and demonstrate plasma exhaust solutions for FPP-relevant conditions integrated with FPP-relevant tokamak scenarios. Prioritization should be for studies to help inform FPP confinement concept decision in the mid-2030s, coordinating with the FPP conceptual design team on appropriate metrics.
7. Develop and validate the additional fundamental theory and advanced computational modeling tools necessary to predict NTUF and tokamak pilot plant behavior (OO-C).

Strategic Objective B: Advance the stellarator physics basis to the point of readiness for D-T

The stellarator is an inherently steady-state concept that avoids potential sources of instabilities and transient events. Through optimization for both neoclassical (collisional) and turbulent transport, the stellarator has the potential to achieve confinement comparable to that observed in tokamaks. Moreover, the quasi-symmetric stellarator has unique strengths among the classes of optimized stellarators. Recent advances in understanding how to use 3D shaping to *improve plasma confinement, improvements in coil design, and the availability of advanced manufacturing enables a significantly expanded US presence in the world stellarator program.*

Science Drivers: Control, Sustain, and Predict Burning Plasmas
Expert Groups: MFE-Boundary and Divertor Plasma Physics, MFE-Transport and Confinement, MFE-Energetic Particles, MFE-Transients, MFE-Scenarios, MFE-Global Context and US Leadership

Recommendations

1. Develop the tools to enable simultaneous optimization of neoclassical transport, turbulent transport, EP losses, MHD limits, divertor configuration, and magnet design simplicity in stellarator geometry
2. Design, construct, and operate a stellarator to validate whether innovative optimizations enable stellarator performance that projects to an economically competitive pilot plant
3. Continue international collaboration on international stellarators including W7-X to gain experience operating, designing diagnostics for, and developing validated modeling capabilities for a large, optimized, superconducting stellarator

Strategic Objective C: Innovate the magnet and H&CD technology needed to reduce the pilot plant capital cost

Innovations in magnet technology have opened the pathway to achieving high magnetic field that have the potential to reduce the size of confinement devices and eventually a fusion pilot plant. Development of joints for superconducting magnets could radically alter how plants are designed and maintained by enabling access to coils inside the toroidal field coils and vertical remote maintenance. Radiofrequency (RF) power provides practical solutions for high-efficiency heating, current drive, and control of plasma profiles and stability in order to access and sustain burning plasma conditions in future experiments and in a reactor. Innovations in magnets, and optimizations of RF sources, transmission, and power absorption benefit multiple confinement concepts including tokamaks, stellarators, alternate configurations.

Science Drivers: Control, Sustain, and Predict Burning Plasmas
Expert Groups: MFE-Energetic Particles, MFE-Scenarios, FMT - Magnets and Technology

Recommendations

1. Develop the experimental capabilities required to develop and test high field magnets and cables, coordinating with industry and other DOE/SC offices
2. Integrate magnet achievements and limitations into FPP multiphysics design tools for new LTS and HTS magnets.

3. Develop and test high-current, high-field prototype cable technology during the FPP conceptual design phase.
4. Establish a new RF test facility to prototype and test the feasibility of RF antenna concepts in a non-confinement device
5. Establish a new RF source R&D center to develop the RF technology needed for a fusion power plant
6. Develop methods to reduce requirements on central solenoid in start-up/ramp-up
7. Support development of compact, high-field solenoids that enable pulsed tokamak operation with a very long flat-top
8. Investigate possibilities of developing nNBI as a complement to RF actuators
9. Support modeling and validation to define RF requirements for a reactor scenario that optimally controls EP heating and transport. This effort should be coordinated with similar activities in model validation (OO-C).

Strategic Objective D: Demonstrate solutions for managing high heat and particle loads sufficient to design plasma-facing components for the fusion pilot plant

The unmitigated power and particle exhaust expected in a fusion pilot plant cannot be sustained by present materials used in confinement devices. Presently operating or planned facilities can produce heat and particle fluxes prototypical of mitigated levels planned for FPP scenarios, allowing off-line development of candidate materials sufficient to warrant testing in existing or future confinement facilities. This can be complemented by predictive capability which also must be sufficiently matured to assist in showing solutions that extrapolate to a fusion pilot plant. A conservative path will advance the technological readiness level (TRL) of the heat and particle flux handling of solid PFCs, the present leading candidate, and work to improve the TRL of liquid metal PFC solutions. A decision point to proceed with either solid PFCs or LM PFCs for the baseline operational phase of FPP is targeted between the conceptual and detailed design stage (>2035) and drives the need for continued and staged research of both concepts.

Science Drivers: Handle Reactor Relevant Conditions
Expert Groups: FM&T-Plasma Material Interaction and High Heat Flux, FM&T-Fusion Materials, MFE-Boundary and Divertor Plasma Physics, Plasma and Material Interaction

Recommendations

1. Expand our fundamental understanding of the science of plasma material interactions and support demonstrations of material options for new plasma facing components.
2. Re-establish a solid PFC materials development program to use qualified materials in testing of PFC prototypes for new confinement facilities.
3. Build and utilize single-effect laboratory scale experiments to raise the TRL of liquid metal plasma facing materials sufficient to be able to test slow-flow and/or fast-flow concepts on existing and/or new U.S. facilities.

4. Emphasize *in-situ* and *ex-situ* materials characterization tools as a priority in regular, open Measurement Innovations and facility/test-stand linked diagnostic enhancement funding calls (OO-D.1).

Strategic Objective E: Determine the structural and functional materials that will survive under fusion reactor conditions

Materials design and the scientific understanding of materials degradation under fusion conditions must be advanced for designing and operating any fusion power plant. Many of the conditions are more harsh in a reactor than in today's experiments, and those conditions include the neutron fluxes, neutron energy spectrum, neutron dose, operating temperatures, heat flux, working fluids, stress, and magnetic field. Materials for all in-vessel and ex-vessel structural and functional materials need to be designed to handle their respective reactor conditions. A program is needed to gather data necessary for high temperature design and licensing of a reactor, and in some cases this requires new experiments or facilities. There are numerous opportunities to innovate in materials to allow advanced pilot plant designs, such as additive manufacturing and modern computational thermodynamics.

Science Drivers: Handle Reactor Relevant Conditions
Expert Groups: MFE-Boundary and Divertor Plasma Physics, MFE-Plasma and Material Interaction, FM&T-Fusion Materials, FM&T-Blanket, Tritium, and Systems, FM&T-Plasma Material Interaction and High Heat Flux, FM&T-Measurements and Diagnostics

Recommendations

1. Establish a fusion-relevant materials program to develop structural and functional materials that will survive the conditions in a fusion reactor including radiation, corrosion, and temperature.
2. Carry out in-pile fission irradiation testing of fusion relevant materials.
3. Design, procure, and operate a near-term Fusion Prototypic Neutron Source (FPNS).
4. Initiate a near-term activity that determines the strategy for a volumetric neutron source (VNS) for integral scale irradiation testing facility (SO-G.1)
5. Develop high-temperature nuclear structural design (HTNSD) criteria that builds on the ITER Structural Design Criteria (ISDC) (especially regarding safety & licensing)
6. Initiate a near term activity that determines the strategy for a cryogenic neutron irradiation experiment for magnet materials.
7. Integrate the fusion pilot plant design (SO-A.3) and materials development with the remote maintenance equipment and strategy. (SO-I.1)

Strategic Objective F: Develop the foundational science and technology necessary to design and build a tritium breeding blanket

A breeding blanket is required for achieving tritium self-sufficiency in a FPP. At present, the technology to breed tritium is at a low TRL and needs to be raised through foundational developments prior to design and tests of potential breeding solutions. Several possible blanket concepts have the potential to satisfy breeding requirements and near-term developments are required to raise the TRL to a downselection of potential solutions.
Science Drivers: Harness Fusion Power
Expert Groups: FM&T-Blanket, Tritium, and Systems, FM&T-Fusion Materials

Recommendation

1. Initiate small-scale tests for a variety of functional breeder blanket materials to advance blanket concept designs
2. Initiate support to verify the compatibility between breeder and structural materials required to ensure compatibility with the blanket solution
3. Construct bench-scale experiments to test tritium extraction concepts and transport in breeder and structural blanket materials
4. Develop models and a multiphysics modeling capability to enable integrated blanket designs into (OO-C)

Strategic Objective G: Develop the capability to test breeding blankets at progressively integral scales

Integration of a breeding blanket into a FPP requires the blanket to be constructed out of fusion irradiation resistant materials, and qualified while fully operational in a fusion neutron test facility capable of irradiating large components and demonstrating tritium breeding and extraction. A sequence of activities are required to achieve high confidence in the operation of the blanket. The blanket materials need to be defined. Non-nuclear testing in a blanket component test facility (BCTF) is needed for numerous functional requirements such as integrating fluid dynamics, MHD, structural mechanics, heat transfer and surrogate tritium transport analysis. Once a prototype solution is developed, nuclear testing in a volumetric neutron source (VNS) can commence to fully qualify the blanket for installation in a FPP.

Science Drivers: Harness Fusion Power, Handle Reactor Relevant Conditions
Expert Groups: FM&T-Blanket, Tritium, and Systems, FM&T-Fusion Materials

Recommendation

1. Initiate a near-term activity that determines the strategy for a volumetric neutron source (VNS) for integral scale irradiation testing facility (SO-E.4)
2. Establish pre-conceptual designs for a non-nuclear integrated component testing facility (BCTF) to obtain integral effects
3. Commence blanket prototype design and fabrication in preparation for both non-nuclear and irradiation testing
4. Design, construct, and operate a volumetric neutron source to perform integrated component testing

Strategic Objective H: Advance tritium management, fueling, and pumping technology necessary for a FPP

The flux of fuel into and out of a fusion reactor greatly exceeds any experiment today. A FPP requires continuous operation over long time periods, which is not compatible with present cryopumping technology, so new solutions must be sought. Moreover, any fueling and pumping system is intricately tied to the ELM and disruption mitigation system, so a self-consistent solution must be found.

Science Drivers: Harness Fusion Power
Expert Groups: FM&T-Blanket, Tritium, and Systems, FM&T-Magnets and Technology, FM&T-Measurements and Diagnostics

Recommendation

1. Initiate bench-scale tests of plasma exhaust pumping technologies that enable continuous operation
2. Validate the technique to separate D and T from other exhaust gases and re-form it directly into fuel pellets and injection gases
3. Support innovation for measuring tritium inventory
4. Advance beyond the proof of principle stage to deploy DT pellet technology for long pulse operation
5. Develop and demonstrate high speed pellet injection.

Strategic Objective I: Establish remote maintenance capabilities and the balance of plant equipment needed for a FPP

When moving from plasma experiments of today to a fusion pilot plant, there are numerous challenges beyond the plasma and the device itself. In a fusion pilot plant, almost all maintenance must be performed remotely using robotic systems. These robotic components must function in a high background of difficult to shield gamma rays, and accompanied by significant decay heat, and work with components that are contaminated with tritium, activated dust and debris, and component near-surface and bulk deposits.
Although inspiration for balance of plant equipment can be taken from non-nuclear applications and fission reactors, the fusion conditions are unique and must be addressed. Fusion has higher operating temperatures, different working fluids, and unique considerations like tritium safety. Heat exchange, turbine, and other balance of plant equipment must be developed specific for a fusion pilot plant to use the leading heat transfer fluids of helium (He) and lead lithium (PbLi).

Science Drivers: Harness Fusion Power
Expert Groups: FM&T-Magnets and Technology

Recommendation

1. Establish strategies for remote calibration, alignment, maintenance, and replacement of components
2. Develop new, specialized sensors and diagnostics for in- and ex-vessel survey
3. Develop autonomous and intelligent robotic systems for fusion facility
4. Carry out conceptual design and small scale tests of balance of plant equipment

Science Drivers

SD1: Control, Sustain, and Predict Burning Plasmas

A critical need in the quest for fusion energy production will be the control and sustainment of a burning plasma. This requires establishing scenarios for maintaining high performance in a burning regime, which avoids damage associated with transient events. Key to this is the development of theory and modeling tools, carefully validated against experiments, that are capable of predicting all the important aspects of plasma behavior. This also requires making advances in diagnostic techniques to measure the relevant plasma quantities with the needed spatial and temporal resolution.

SD2: Handle Reactor Relevant Conditions

A fusion pilot plant will produce heat and particle fluxes that significantly exceed that in present confinement facilities, and new innovative approaches to managing this challenge are required. In a fusion pilot plant, high fluxes of 14 MeV neutrons produce unique effects in materials which are presently poorly understood.

SD3: Harness Fusion Power

Interlinked with having a burning plasma and materials that can withstand fusion reactor conditions are all the key systems required to capture the power, breed more fuel, and ensure the safe operation of the reactor. Before a device is constructed, this includes the qualification of materials for licensing, a qualification program for components, and the system design to bring all the pieces together. Just as the plasma and materials in a fusion reactor will need to advance beyond today's capabilities, the balance of plant equipment, remote handling, tritium breeding, and safety systems will also require significant advances. Connected to all of these systems will be the measurement and diagnostic systems needed to ensure the safe operation of the device and safe work environment for the site personnel, including surveillance program for materials, stress and motion detectors for components, tritium detectors, and radiation detectors.

Preliminary Conclusions and Goals for Knoxville

The Community Planning Process has identified many important and interconnected objectives combining the MFE and FM&T communities together towards the goal of developing practical fusion energy. We have drafted this preliminary strategic plan to contain objectives necessary to reach our common mission of demonstrating that fusion energy has the promise to be economically viable in the US energy market. Recommendations that appear to have broad community consensus have been provided to form a common guide for the community to achieve our objectives.

The goals of the upcoming workshop in Knoxville will be to solidify community consensus on areas that have broad support, and refine objectives and recommendations where needed. Through guided discussions and breakout sessions we can achieve a refined long-range strategic plan, resolving conflicts, make progress on prioritization, speak with one voice and forge our path together.

As a member of this community, we ask that you consider the content of this preliminary strategic plan both from the perspective of your Expert Group and as a community member at large. We continue to seek feedback and engagement from the community, and ask that you provide constructive suggestions on how to improve this plan. Expert Groups are meeting this week and we suggest that you engage in that process to provide your feedback.

- The Co-Chairs and Program Committee for the DPP-CPP