The National Academies of SCIENCES ENGINEERING MEDICINE

Bringing Fusion to the U.S. Grid

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Presented to:

PCAST

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Key Takeaways

Recommendation: For the United States to be a leader in fusion and to make an impact on the transition to a low-carbon emission electrical system by 2050, the Department of Energy and the private sector should produce net electricity in a fusion pilot plant in the United States in the 2035—2040 timeframe.

Recommendation: DOE should move forward now to foster the creation of national teams, including public-private partnerships, that will develop conceptual pilot plant designs and technology roadmaps that will lead to an engineering design of a pilot plant that will bring fusion to commercial viability.

Conclusion: Successful operation of a pilot plant in the 2035—2040 timeframe requires urgent investments by DOE and private industry — both to resolve the remaining technical and scientific issues, and to design, construct, and commission a pilot plant.

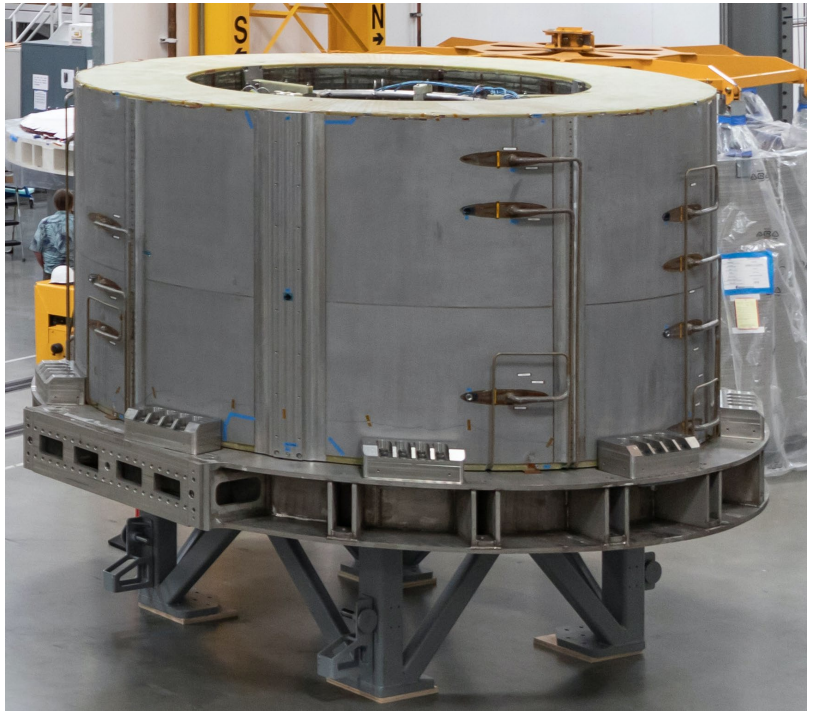
Recent NASEM Study Was Motivated by Previous Study Recommendation plus Advancements due to Private Industry Investments

Key Recommendations:

First, the United States should remain an ITER partner as the most cost-effective way to gain experience with a burning plasma at the scale of a power plant.

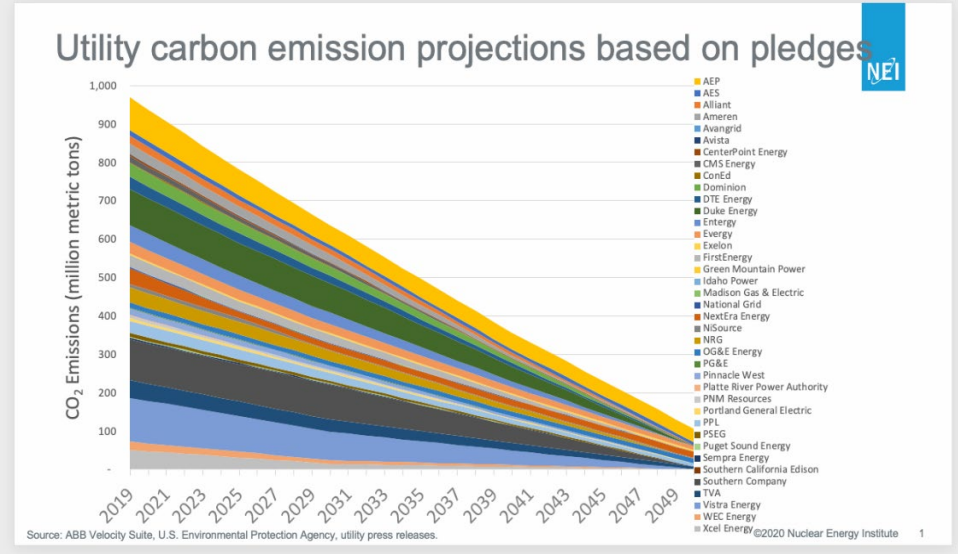
Second, the United States should start a national program of accompanying research and technology leading to the construction of a compact pilot plant that produces electricity from fusion at the lowest possible capital cost.

Significant developments, since NASEM report was published, are highlighted in a blue box.

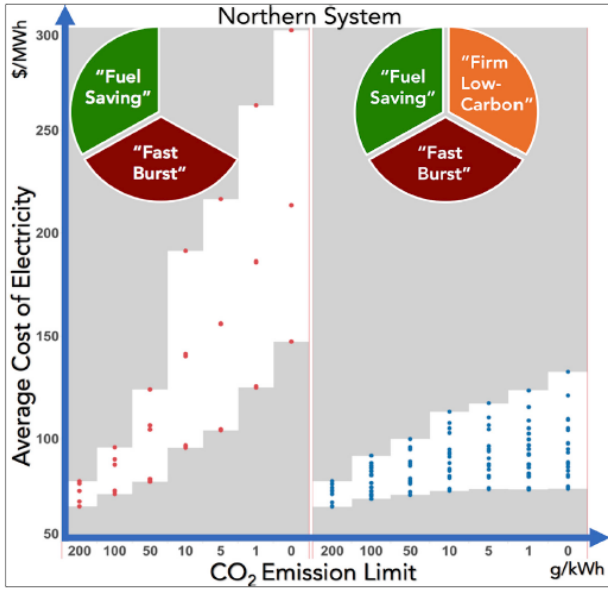


U.S. has recently delivered central solenoid module to ITER

Role of the Pilot Plant:
Future Electricity Generation Market



Utilities foresee a transition to low-carbon electrical generation by 2050.

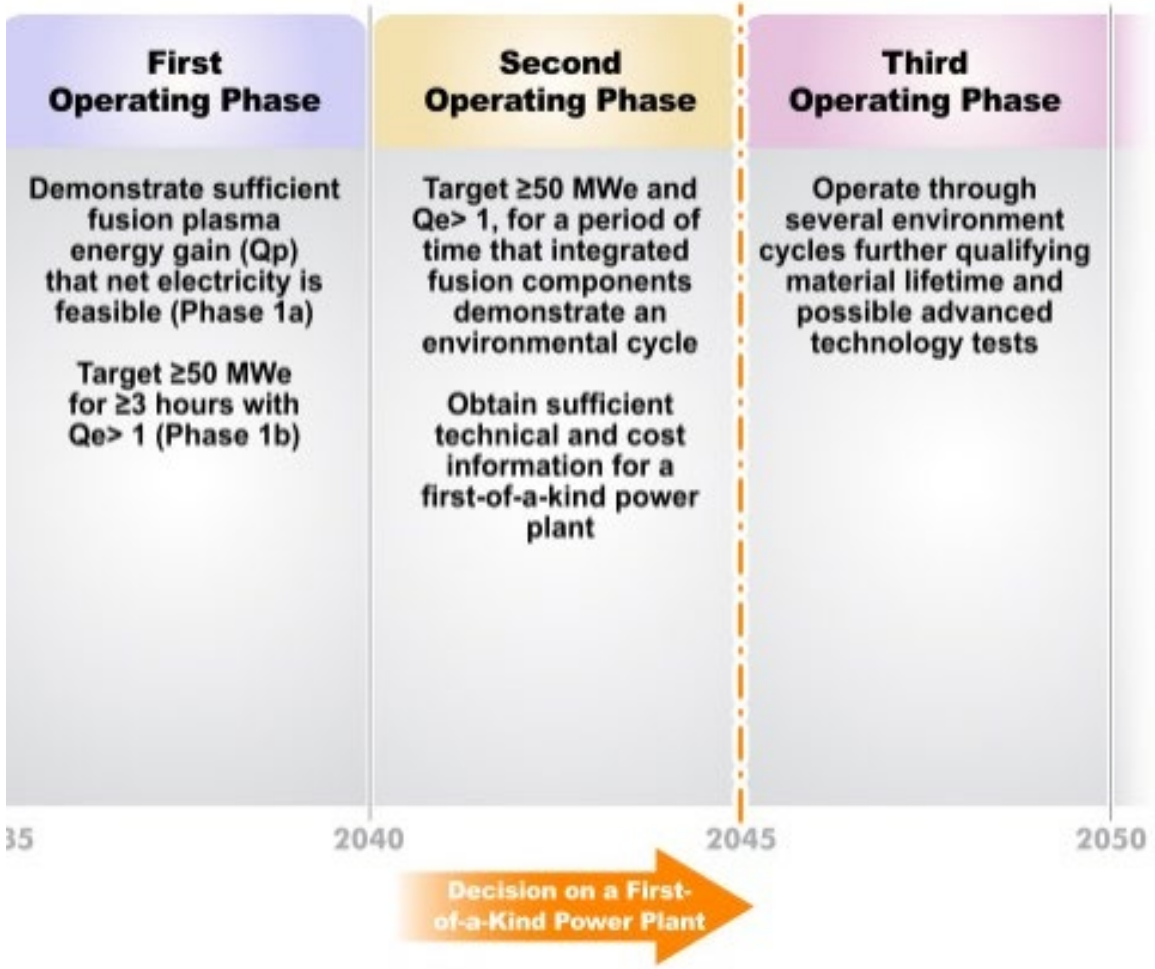


Firm low-carbon/non-carbon electrical energy generation will be needed to decrease the cost.

A pilot plant must provide the technical and economic information needed for utilities to operate future plants.

Goals for a Fusion Pilot Plant:
Recommended Path to Increase TRL for Fusion

Conclusion: A pilot must produce an amount of fusion power and energy that is sufficiently representative of the market needs in order to meet the pilot's goal of demonstrated integrated performance and cost, while also demonstrating net electricity gain Qe > 1 and produce peak net electrical power ≥ 50 MWe.



NASEM Report Provides a National Strategy for a Fusion Pilot Plant

- Integrated fusion and electric power performance
- Materials and manufactured components
- Fuel and Ash
  - D-T fuel cycle – need for tritium breeding
  - Alternative fuel cycles to D-T
- Reliability and availability
- Environmental and safety consideration
  - Regulatory framework is required

UK is moving ahead rapidly in developing a regulatory framework.

Goals for a Fusion Pilot Plant:
Economic Considerations

Finding: On the basis of today's energy market and costs, the fusion First-of-a-Kind power plant will need to have a total overnight construction cost less than $5 billion to $6 billion in order to be viable in the present U.S. electrical marketplace with a projected operation life of at least 40 years for the plant.

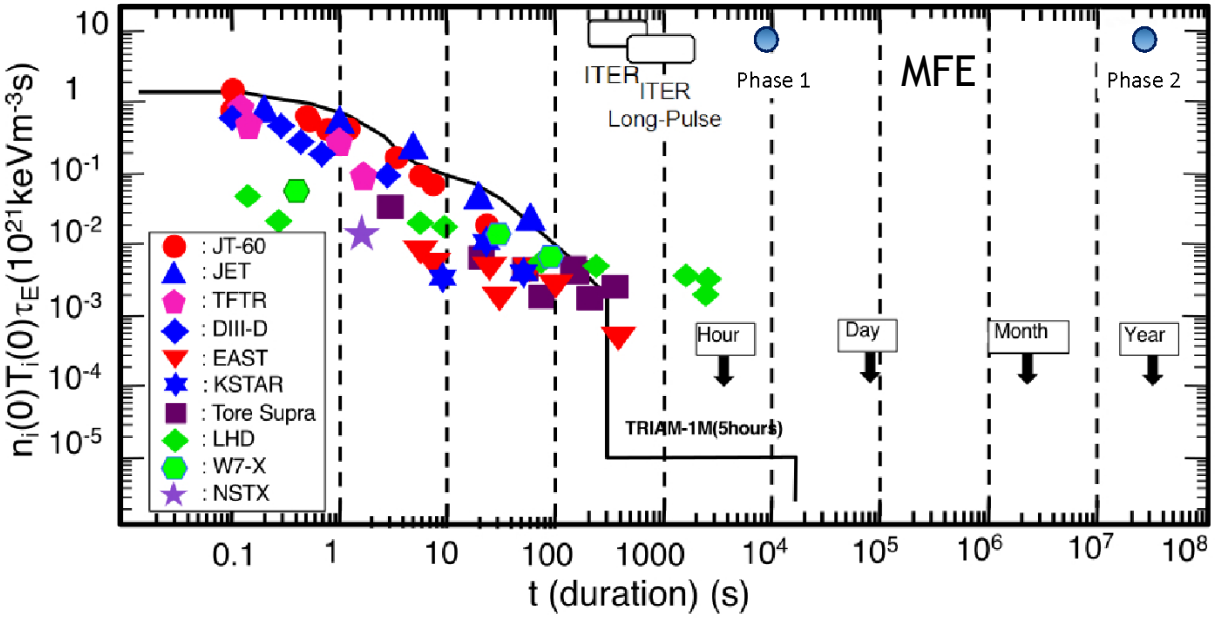
Conclusion: A fusion pilot plant should have a generating power >50 MWe and total overnight construction cost <5-6 B$.

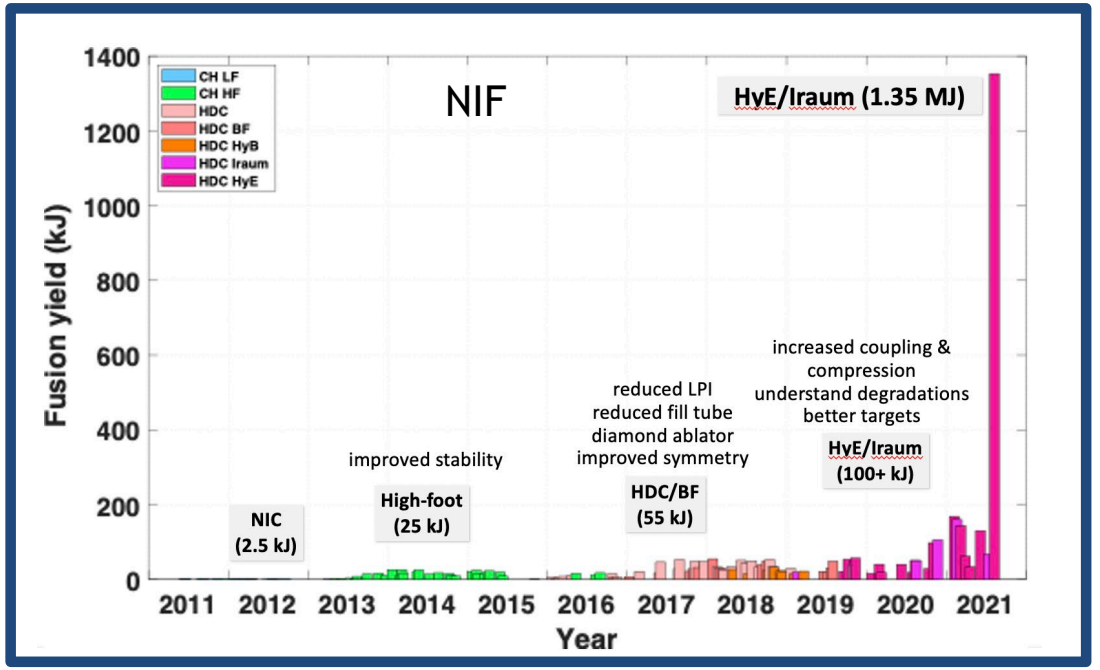
Innovation and Research Investments are Targeted to Meet Technical and Economic Goals

- We need to:
  - Reduce the cost of the pilot plant and accelerate the schedule
  - Improve the economics of a First-of-a-Kind power plant
- ***Recommendation:*** To meet the challenge of having a viable design by 2028 and initial pilot plant operation in 2035-2040, innovations in fusion confinement concepts and technology to extract fusion power and close the fusion fuel cycle should be developed in parallel. This will enable the engineering design of a pilot plant and the construction decisions to be accelerated by a combination of government and private funding.

Innovation and Research in Fusion Plasma Confinement

The pilot plant design will need to be based on a vetted, well-established confinement physics basis for achieving net plasma gain well in excess of unity.





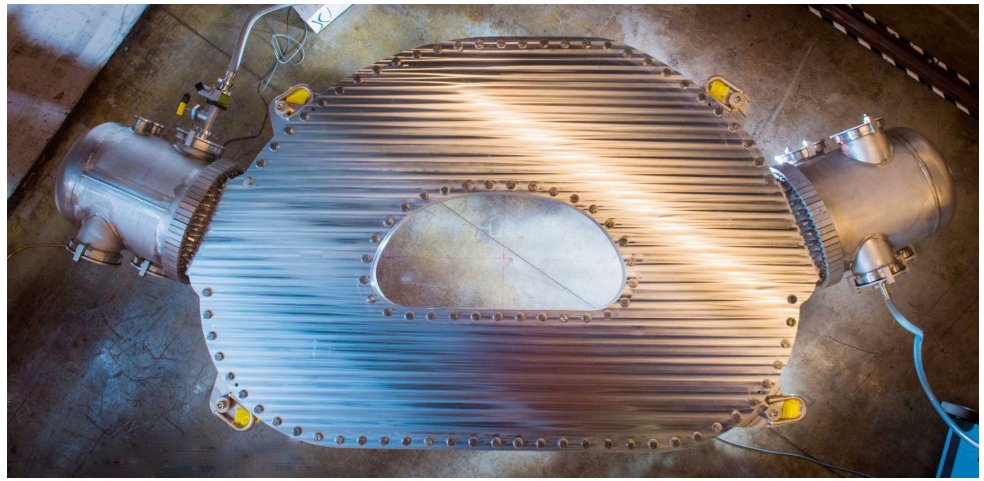
Both MFE and ICF (NIF) have achieved energy gain ~0.6 relative to heating power to the plasma

Computer simulations coupled to experiment are driving performance improvement and design

Technical Innovations and Research Opportunities

- Important examples include:
  - High temperature superconducting magnets
  - Structural and function materials: neutron degradation assessment
  - Plasma heating systems and actuators
  - Closing the fuel cycle: tritium processing, developing a breeding blanket

- Many elements are at a low level of technical readiness
  - But appropriate investment can result in rapid advancement



Commonwealth Fusion Systems and MIT announced achievement of 20T large bore HTSC coil

Diverse Participation Needed for Developing a Pilot Plant

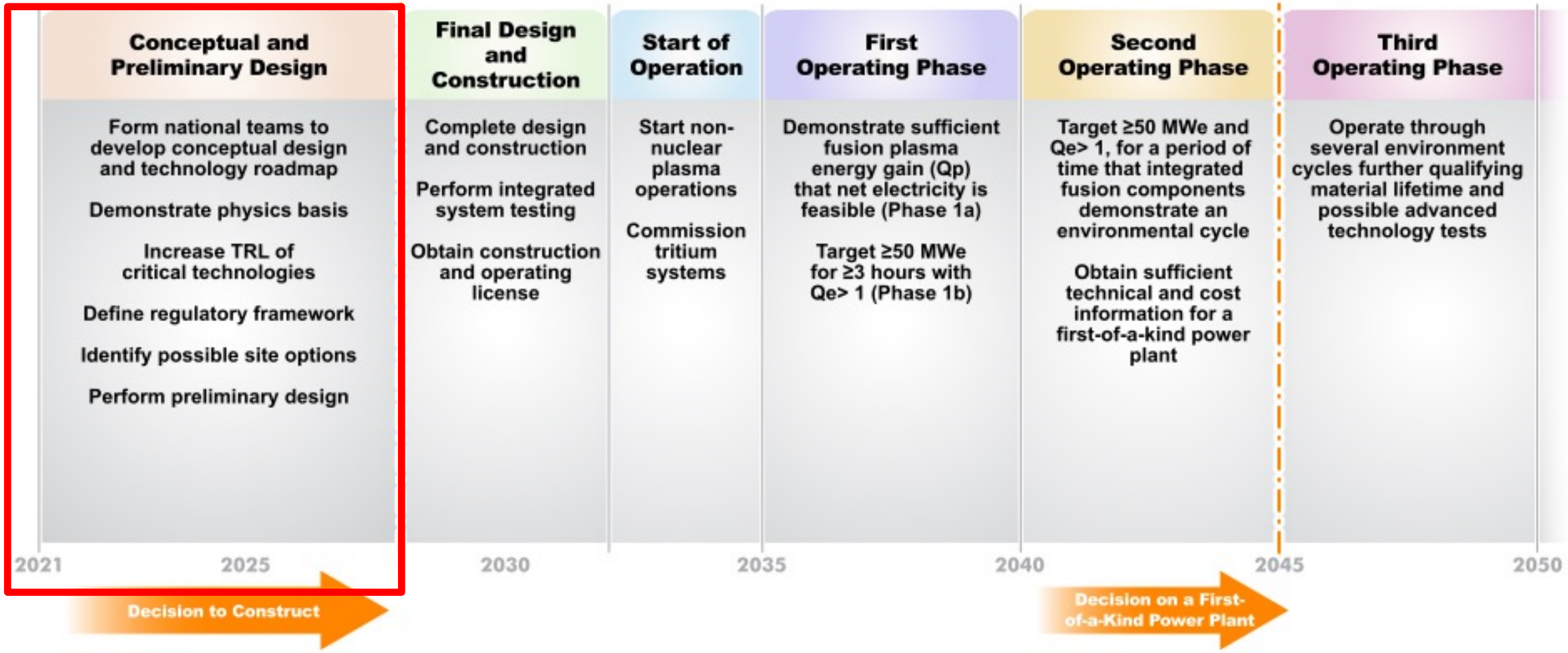
- **Recommendation:** The participants in the development of the pilot plant should execute the recommendation of the Community Planning Process to "Embrace diversity, equity, and inclusion, and develop the multidisciplinary workforce required to solve the challenges in fusion and plasma science."

- ***Finding:*** Teams made up of private industries, national labs, and universities bring together important strengths: industry brings the focus on deploying a usable product on a timeframe that will meet market needs, and national labs and universities bring innovation and deep technical expertise.

Need for DOE to Develop Public-Private Partnership Model for Fusion

- ***Finding:*** The NASA COTS program achieved remarkable success in developing new commercially competitive space transportation capabilities at significantly less cost to the government and with an accelerated schedule using a payment-for-milestones public-private partnership.
- ***Finding:*** While the NASA COTS model holds promise, in general the TRL for space transportation systems is substantially higher than the TRL for major fusion energy systems. …
- ***Recommendation:*** The Department of Energy should evaluate and identify the best model for public-private partnerships to accelerate development and reduce government cost for a fusion pilot plant. Note that the different phases of the development, including conceptual design and technology roadmap, detailed engineering design, construction and operation, may involve different or incremental public private partnership models, including fixed-price payment for milestones.

Strategy and Roadmap Identifies Immediate Actions



Strategic Risks, Opportunities and Mitigations

Risks

- Schedule risk due to level of scientific and technological readiness
- Schedule will not support the electricity transition
- U.K. or China will be first to put fusion on the grid
- Obtaining public and private funding

Opportunities

- Engagement of the private sector
- Impact the transition to low-carbon emission electricity
- Be a leader in the development of fusion energy

Mitigations

- Perform R&D in parallel with design
- Decision points to evaluate progress

Fusion to Power the Grid: The Path is Clear

- The goals, innovations and a timeline has been identified
- Plan is bold and achievable
- U.S. has played a major role in the development of fundamental science for fusion
  - U.S. can take the lead in this technology or
  - Let other countries take the lead

Committee Members

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Savannah River National Laboratory

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For more information, please visit the study website at

http://nas.edu/fusion

The National Academies of SCIENCES ENGINEERING MEDICINE

Statement of Task

The National Academies of Sciences, Engineering, and Medicine (NASEM) shall assemble a committee to provide guidance to the U.S. Department of Energy, and others, that are aligned with the objective of constructing a pilot plant in the United States that produces electricity from fusion at the lowest possible capital cost ("Pilot Plant").
The committee shall provide a concise report that addresses the following points:

- Establish key goals for all critical aspects of the Pilot Plant, independent of confinement concept and during each of the plant's anticipated phases of operation.
- Identify the principal innovations needed from both the private sector and government to meet those key goals.
- Seek input from potential "future owners" of power plants and potential manufacturers of fusion power plant components.
- Characterize the energy market for fusion and provide input on how a fusion pilot plant could contribute to national energy needs.

NOTE: TASK STATEMENT PARAPHRASED TO FIT ON SLIDE

Study Input

- Technical input from NASEM Burning Plasma and APS Community Planning Process reports
  - Solicited additional input on website
  - Workforce issues from NASEM Diversity, Equity and Inclusion reports
- Presentations by DOE and Congressional staff
- Panel discussions with groups from
  - Power Plant Owners/Utilities
  - Developers of fusion power plants
  - National Laboratories
  - Universities
  - Manufacturers of components
  - Regulatory bodies