REPORT OF THE FESAC PANEL ON PRIORITIES AND BALANCE

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Report of the FESAC Panel on Priorities and Balance

Finalized at FESAC meeting
Gaithersburg, Maryland
September 8, 1999

REPORT OUTLINE

Approach

This report presents the results and recommendations of the deliberations of the FESAC Panel on Priorities and Balance for the DOE's Fusion Energy Sciences Program. **The panel consisted of 36 people drawn from 23 different institutions** representing the spectrum of scientific and engineering disciplines involved in fusion energy research, including all key elements of magnetic fusion energy (MFE) and inertial fusion energy (IFE). The panel conducted most of its deliberations by working in four subpanels focused on the principal features of DOE's charge to FESAC on program balance and priorities:

- **Balance between MFE and IFE.**
- **Balance within MFE.**
- **Balance within IFE.**
- **Proof-of Principle (PoP) Priorities.**

Approach (cont)

Prior to the meeting of the FESAC Panel and the final FESAC meeting of FY 1999, there were a number of important related activities.

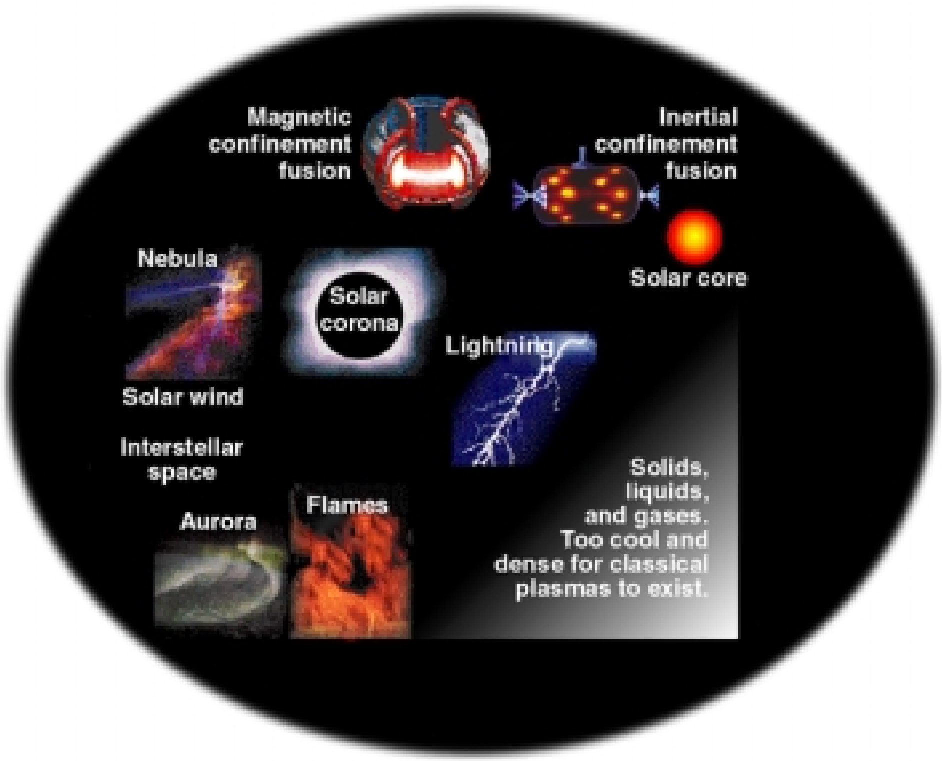
- The FESAC visited a number of fusion laboratories and heard presentations on the majority of the program.

- A process was initiated in October 1999 to produce an Opportunities Document, describing all opportunities for exciting work in the Fusion Energy Sciences Program. Over 120 people in the program contributed material for the document. It was distributed in May to FESAC and other committees – SEAB and NRC – that were also reviewing the program, and put on the Web in June.

- A separate FESAC Panel was constituted to prepare a draft set of goals and metrics for consideration by the program review panel. Aspects of this report were used in the review.

- The FESAC Panel took into account the findings in the draft SEAB report and the deliberations of the fusion community at the July Snowmass Panel meeting.

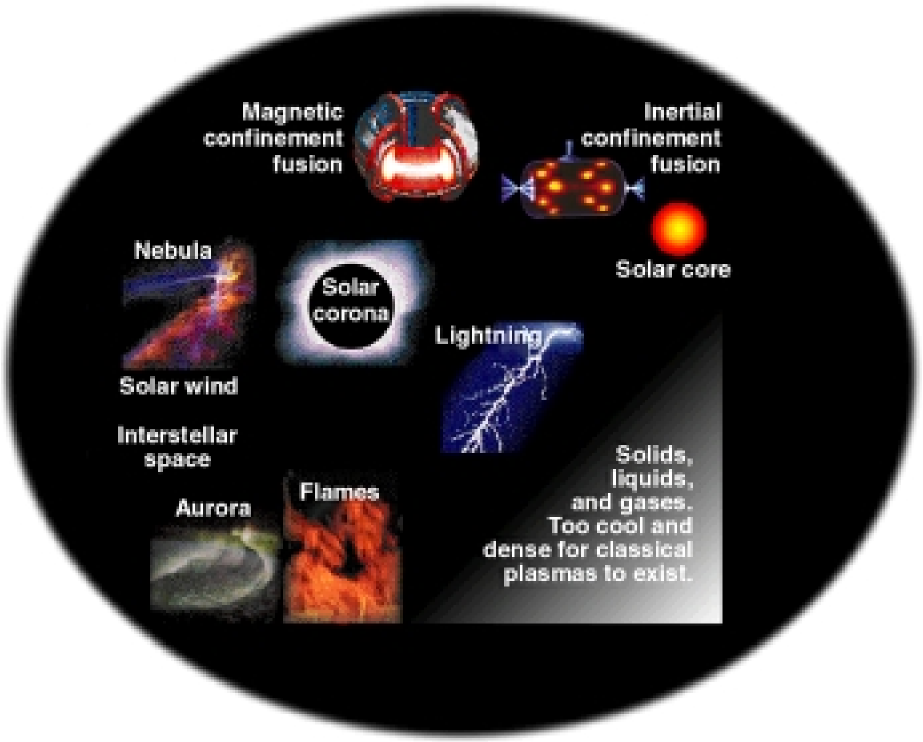
Opportunities in the Fusion Energy Sciences Program



Prepared by the
Fusion Energy Sciences Advisory Committee
for the
Office of Science of the U.S. Department of Energy

Opportunities in the Fusion Energy Sciences Program

Appendix C
Topical Areas Characterization



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SEAB COMMENTS

In addressing the relative balance and priorities, the Panel reaffirms the national custodial responsibility of OFES for the health and vitality of the discipline of plasma science. The well-established value of plasma science for near-term technological spin-offs is also noted by the Panel. With regard to fusion, the Panel endorses and takes as a starting point the following findings and recommendations by the 1999 SEAB Fusion Task Force:

- "OFES should be expected to use its program to leverage activities undertaken elsewhere (in the world and in DOE Defense Programs) to assure effective collaboration and coordination and to establish world leadership in selected niche areas."
- "It should not be anticipated that the restructured MFE program will be fully successful in all of its energy missions – simultaneously pursuing new concepts, supporting tokamak experimentation, and shepherding plasma science – unless some increment in funding is forthcoming."
- "Given the large DP (DOE Defense Programs) program in inertial fusion, only a modest increase in the OFES budget is needed to support the IFE activities that should be funded by the OFES program -- endeavors which address issues of significance to the energy objective and which are not supported by DP."
- "Since the present funding is barely adequate to sustain the restructured MFE program, and since OFES is the sole steward for MFE, any significant increase in IFE funding within OFES should come from an increment to the present budget."
- "Moreover, DP should dedicate funds to dual-purpose activities, consistent with DP's mission statement, that exploit the synergy between the defense work and IFE science. For example, DP might appropriately take the lead in the development of high-average-power lasers because of DP's very significant involvement and accomplishments in the laser field."

Balance between MFE and IFE

The Panel has identified the achievement of a more integrated national program in MFE and IFE as a major programmatic and policy goal in the years ahead.

It should be based on the following guiding principles:

(1) The MFE and IFE programs should be consistent with their respective time frames, set in part by
- MFE opportunities to participate in major international experiments;
- IFE opportunities to leverage the DP funded ICF program.

(2) Specific elements of science and technology critical for evaluating the ultimate energy potential of IFE and MFE, such as interaction of the plasma with chamber walls, should be brought to comparable levels of maturity.

(3) The dramatic advances in the predictive power of modern theory and simulation make these tools essential elements of a cost-effective program.

(4) A common peer review process for MFE, IFE, and cross-cutting activities should be implemented wherever possible.

(5) Cross-cutting science and technology, with application to both MFE and IFE, deserves special encouragement.

(6) Attracting and maintaining a talent pool of creative young scientists in the combined program, for example through research with broad scientific or technological implications, is crucial to fusion progress.

Balance between MFE and IFE (cont)

The Panel considered three budget cases with a total annual funding of $300M, $260M and $222M. To position the U.S. to execute the combined MFE/IFE research program within the timeframes set by the worldwide MFE program and DOE's Defense Program (DP)-funded inertial confinement program.

The Panel strongly endorses a funding level of $300M for the fusion energy sciences program. The Panel further recommends that the funding allocation at this level be $250M for MFE and $50M for IFE.

$260M Case: This case corresponds to the $250M OFES plus $10M DP funding level recommended by the House Energy and Water Appropriations Subcommittee for FY2000.

Balance between MFE and IFE (cont)

At an annual funding level of $260M, it will not be possible to have a combined MFE/IFE program consistent with the timeframes noted above, but it will be possible to augment modestly the four principal MFE thrust areas described in this report and develop at least one IFE driver (heavy-ions) for an integrated research experiment (IRE) and associated chamber technology. **The recommended allocation is $230M for MFE and $30M for IFE.**

At a FY2000 funding level of $222M, both MFE and IFE are sub-critical for meeting program objectives. The Panel recommends an FY2000 funding allocation of $207M for MFE and $15M for IFE.

Budget Case ($)	MFE ($)	IFE ($)
300M	250M	50M
260M	230M	30M
222M	207M	15M

Balance within MFE

The MFE research plan is motivated by three considerations central to the restructured fusion energy sciences program: the continued development of fundamental scientific understanding and innovative technologies, the advancement of innovative magnetic concepts, and the time frame of the international fusion effort.

In the five-year time frame, the international fusion community will be making construction decisions for major next-step experiments. The MFE plan assures that the U.S. remains actively engaged with the international community and is able to participate in a meaningful way with the worldwide development of magnetic fusion energy. Also on approximately a five-year time scale, our understanding of some of the new magnetic fusion concepts can be sufficiently advanced to warrant consideration for study at the larger scales which more closely resemble fusion conditions.

In regard to participation in a burning plasma experiment, the report of the 1999 Fusion Summer Study at Snowmass[5] says that the U.S. should actively seek opportunities to explore burning plasma physics including:
• Pursuing burning plasma physics through collaboration on potential international facilities (JET Upgrade, Ignitor, and ITER-RC); and
• Seeking a partnership position, should ITER-RC construction proceed.

Balance within MFE (cont)

With regard to overall balance and priorities within the MFE program, the Panel believes that at present the program is reasonably well-balanced given the available resources and the ongoing restructuring of the program since 1996. **The Panel recommends funding increases to accomplish the following**:

(1) **Strengthen theory and computation** as very cost effective means to advance fusion and plasma science, taking advantage of advances in computation science and technology. Strengthen activities in general plasma science and encourage research on near-term applications of plasma science and technology.

(2) **Pursue an aggressive portfolio of confinement concepts** through increased effort in the Proof of Principle area, and through strengthening of the Concept Exploration program.

(3) **Focus the moderate-pulse advanced tokamak program,** including U.S. collaboration on leading international facilities, and to a lesser degree the spherical torus program, towards a 5-year assessment point; and prepare for participation in a burning plasma experiment.

(4) **Revitalize the technology program** to provide for continued innovation in this area because of its overall importance to the success of fusion science and fusion energy and applications. Utilize systems studies to identify attractive fusion energy concepts and affordable development paths.

Approximately two-thirds of additional resources (relative to the Administration's request for FY2000) should be divided about equally between recommendations (2) and (3) above. However, it is high priority to increase support for (1) and (4), with a somewhat greater emphasis on (4), especially under small budget increases.

Balance within IFE

In the IFE program, the two central objectives are:

(1) to advance the understanding of high-energy density plasmas, and

(2) to develop an attractive rep-rated IFE power system. Since the DP program addresses critical target issues in single-shot experiments, **the OFES program focuses on high-pulse rate, efficient and affordable drivers and associated fusion chamber and target technology.**

Balance within IFE (cont)

The IFE research plan is motivated to enable the initiation of an Integrated Research Experiment (IRE) program which could be optimized and iterated as results are obtained on NIF and which is consistent with the expected completion of the direct-drive target physics programs on Omega and Nike, and the initiation of ignition experiments on NIF. One essential feature of the IFE program is an emphasis on chamber technology, including beam propagation. The IFE plan aims at making an IRE decision on a five-year time frame, and permits an effective interaction and leverage between a balanced IFE research program and the NIF program in target physics.

The recommended IFE program of $50M per year ($300M case) would prepare three driver candidates for an IRE stage, develop the necessary chamber and target technology and pursue some limited efforts at the concept exploration level.

At a funding of $30M ($260M case), the emphasis would be on the heavy-ion driver option and associated chamber/target technology, while maintaining reduced efforts on advanced laser options.

Balance within IFE (cont)

The ultimate goal of the NIF is to achieve gain in the range of ten, where gain is defined as the ratio of the thermonuclear yield to the laser energy delivered to the target. Indirect-drive targets have been the most thoroughly explored for testing on the NIF. However, the NIF target chamber is being constructed with additional beam ports so that direct-drive targets may also be tested.

The IRE objective for the heavy ion beam driver approach is a completely integrated ion accelerator from injector to beam focus in the target chamber center. The size and characteristics of the accelerator will be chosen so that the performance and cost of a driver, for the fusion engineering development stage Engineering Test Facility (ETF), can be accurately projected.

For lasers, the IRE plan is to develop and optimize one complete laser beam line that would be prototypical of the ETF driver. Presently, both diode-pumped solid-state and KrF lasers are being developed.

Proof-of Principle (PoP) Priorities

The Reversed Field Pinch (RFP), Compact Stellarator (CS) and Magnetized Target Fusion (MTF) concepts were reviewed by an OFES technical review panel last year. Its conclusion was that each concept had a sufficient technical base to be considered for designation as a Proof of Principle (PoP) program. The task of the FESAC PoP subpanel was to determine the actual readiness of each concept for PoP designation and to make recommendations concerning implementation or additional work. The conclusions of the subpanel are as follows:

(1) **The RFP is ready for PoP designation but a more focused sequential approach should be implemented.** The modified budget levels generated in response to the original review are viewed as appropriate. Specifically, this calls for a budget increment of $2M in FY2000 and $3.5M in FY2001.

Proof-of Principle (PoP) Priorities (cont)

(2) **The CS is not ready at this time for PoP designation because of one important technical concern about the NCSX.** The subpanel believes that this concern will likely be addressed in the near future. The subpanel also believes that **in the long run the NCSX promises a high probability of success** and that a FESAC subpanel participate in the Conceptual Design Review (CDR) of the NCSX project to complete the evaluation of readiness to proceed as an approved PoP program. The subpanel further recommends that the design effort and supporting theory and modeling on NCSX be adequately funded to permit expeditious completion of an optimized design and a successful CDR. This is expected to entail an increment of $1M in FY2000 and $1.5M in FY2001.

(3) **The MTF is not ready at this time for PoP designation.** There are a number of important technical issues that must be resolved. **The subpanel recommends a three-year continuation of the MTF concept exploration program** at approximately the present level of effort to produce and translate the required target plasma for the experiment.

Appendix A
FESAC Priorities and Balance Panel Membership

Charles Baker (Chair)
University of California, San Diego

MFE Balance	PoP Balance	IFE Balance	Overall MFE/IFE Balance
Stephen Dean* *(Fusion Power Assoc)*	Jeffrey Freidberg* *(MIT)*	John Sheffield* *(ORNL)*	Ronald Davidson* *(PPPL)*
Raymond Fonck *(Univ. of Wisc.)*	Thomas Jarboe *(Univ. of Wash.)*	Roger Bangerter *(LBNL)*	Charles Baker *(UCSD)*
David Hill *(LLNL)*	Joseph Johnson, III *(Florida A&M Univ.)*	Gerald Kulcinski *(Univ. of Wisc.)*	David Baldwin *(General Atomics)*
Wayne Houlberg *(ORNL)*	Gerald Navratil *(Columbia Univ.)*	John Lindl *(LLNL)*	Richard Briggs *(SAIC)*
Kathryn McCarthy *(INEEL)*	David Newman *(Univ. of Alaska)*	Craig Olson *(Sandia Nat'l Lab)*	E. Michael Campbell *(LLNL)*
Cynthia Phillips *(PPPL)*	Tony Peebles *(UCLA)*	John Soures *(Univ. of Rochester))*	Jill Dahlburg *(NRL)*
Miklos Porkolab *(PSFC/MIT)*	Don Steiner *(Rensselaer)*		Rob Goldston *(PPPL)*
Ned Sauthoff *(PPPL)*	Tony Taylor *(General Atomics)*		Richard Hazeltine *(Univ. of Texas)*
Kurt Schoenberg *(LANL)*	Harold Weitzner *(New York Univ.)*		Michael Mauel *(Columbia Univ.)*
Clement Wong *(General Atomics)*			Marshall Rosenbluth *(UCSD)*
Michael Zarnstorff *(PPPL)*			

***Subpanel Chair**

OPTIONS FOR VERY LARGE POWER PLANTS

- Fusion power plant studies show an economy of scale.
  e.g., if the COE were 8c/kWe for a 1 GWe plant,
  it might be 4.5 - 5c/kWe for a 4 GWe plant.

- However, these numbers do not take into account extra utility costs for handling such a large unit.
  Extra costs include:
  - Increased spinning reserves to handle outages typically, half of largest unit + 200 MWe;
  - Strengthening of local transmission system for reliability and fluctuation minimization;
  - Incremental operating costs; and,
  - Cost of purchased electricity during down time.

- Typically, a utility can easily handle a largest unit of up to 8% of its capacity. So, to handle readily a 4 GWe unit would require a utility with ≥ 30 GWe total.

OPTIONS FOR VERY LARGE POWER PLANTS – COST OF ELECTRICITY

- The estimated extra spinning reserve for a 4 GWe unit is, for a utility having a 1.3 GWe unit (spinning reserve of 0.75 GWe), approximately an extra 1.35 GWe. At a cost of $300/kW this would take a capital cost of $405 M.
  At 10% payback per year for 20 years, assuming 85% unit capacity factor, this would add about 0.14c/kWe.

- Incremental site costs are estimated at about $160 M. With the same payback, adding about 0.05 c/kWe.

- Incremental operating costs are estimated to be about $60 M per year, leading to an extra 0.2 c/kWe.

- Cost of electricity purchased at 5 c/kWe for half the unscheduled downtime of 5% of the , about $44 M per year. Additional cost of electricity 0.17 c/kWe.

- **Incremental COE about 0.56 c/kWe.**

- **Total COE 5 - 5.6 c/kWe.**

OPTIONS FOR VERY LARGE POWER PLANTS – COGENERATION OF HYDROGEN

- The co-generation of hydrogen would give great flexibility in the deployment of very large power plants. e.g., It would allow a 4 GWe plant to operate at full power, while providing around 2 GWe to the grid and the rest for electrolytic hydrogen production. Thus, within say ± 500 MWe it might load follow.

- Because the nominal power to the grid would only be about 2 GWe, the incremental costs would be moderate, Typically, < 0.2 c/kWe, and the total COE ~ 5 c/kWe.

- An improved efficiency of electrolysis can be obtained by heating the water. The trade off between electricity and heat use should be optimized.

- For hydrogen production, off-peak times would be used when possible while, for electricity sales, peak power times would be emphasized.

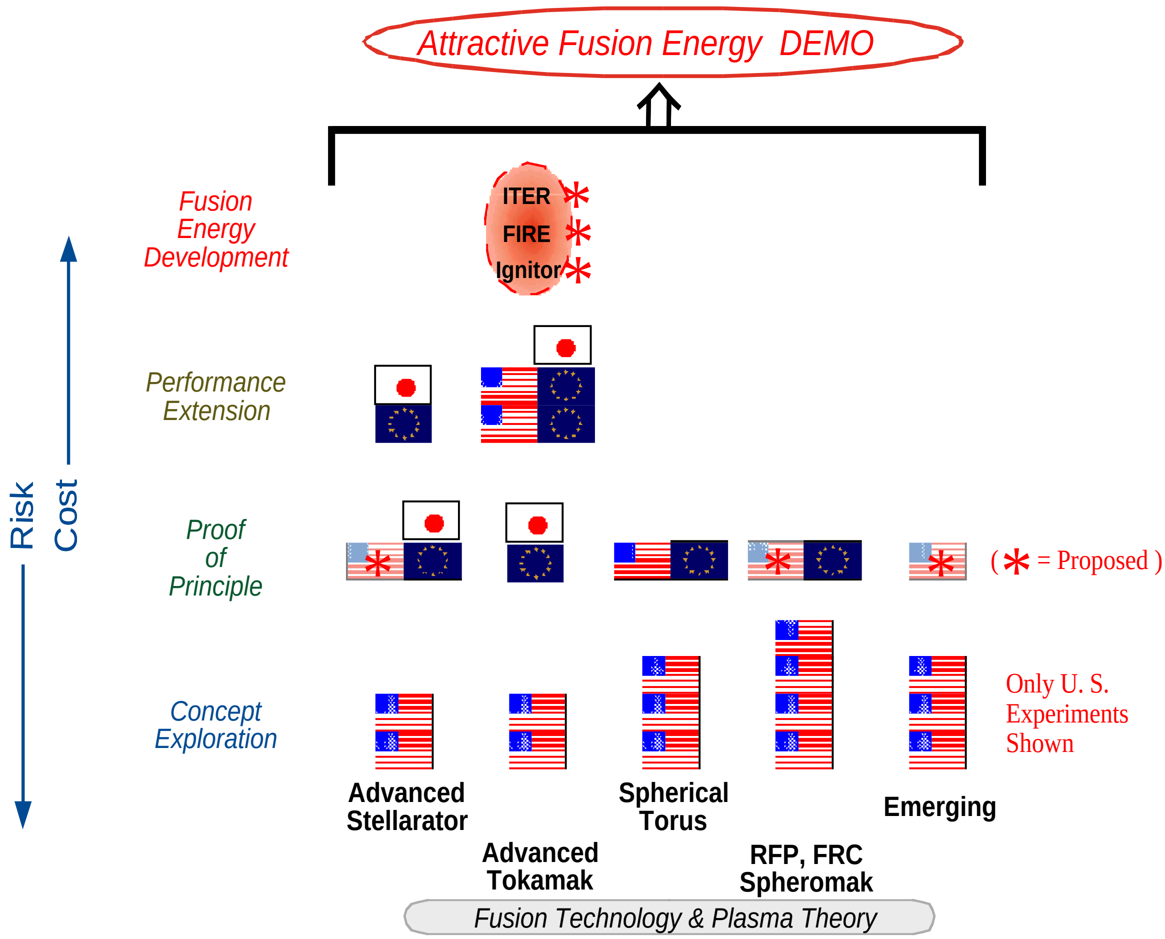
- At around 5 c/kWe, hydrogen costs would exceed those from methane reforming, but would still be low for use in fuel cell systems and would not involve CO_2 production.

FUTURE COSTS OF ELECTRICITY

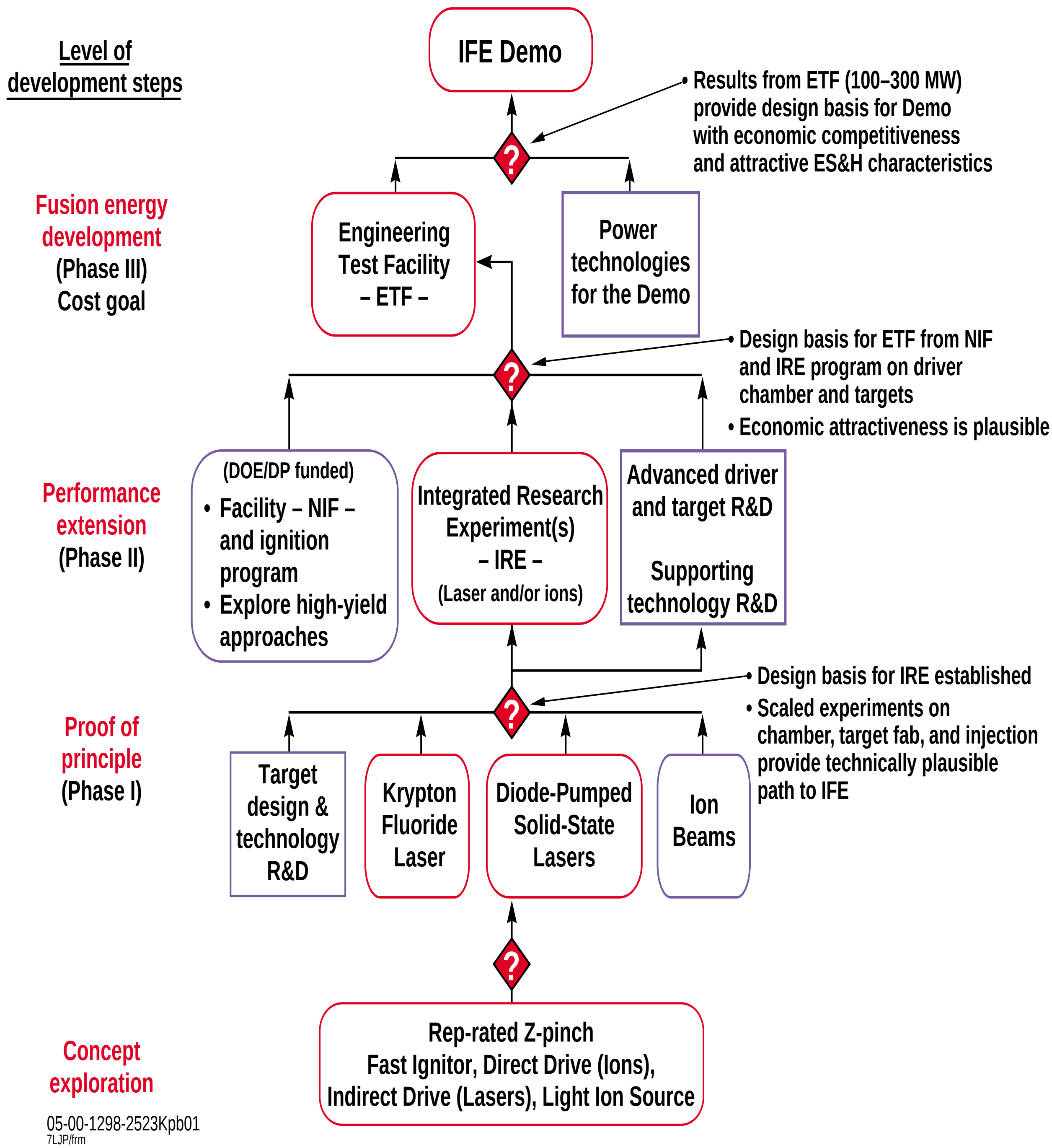
- Today's electricity costs, for economic new plants that are still paying off their capital costs, range from around 3.5 c/kWe to 6 c/kWe – coal, gas, nuclear, wind power - with a typical COE of about 4.5 c/kWe at the plant.

- Future costs of electricity for these systems may be expected to decrease because of higher efficiency and other technology improvements. However, costs will increase if fuel costs increase, energy storage is needed for intermittent systems and environmental requirements lead to more stringent pollution control measures.

- Studies suggest that this price range will still apply in 50 years time because of the offsetting pluses and minuses. These results should be taken into account in setting goals for fusion power plants.



Attractive Fusion Energy DEMO
Fusion Energy Development
ITER
FIRE
Ignitor
Performance Extension
Proof of Principle
(* = Proposed)
Concept Exploration
Only U. S. Experiments Shown
Risk
Cost
Advanced Stellarator
Advanced Tokamak
Spherical Torus
RFP, FRC Spheromak
Emerging
Fusion Technology & Plasma Theory


Level of development steps
Fusion energy development (Phase III) Cost goal
Performance extension (Phase II)
Proof of principle (Phase I)
Concept exploration
IFE Demo
Results from ETF (100–300 MW) provide design basis for Demo with economic competitiveness and attractive ES&H characteristics
Engineering Test Facility – ETF –
Power technologies for the Demo
Design basis for ETF from NIF and IRE program on driver chamber and targets
Economic attractiveness is plausible
(DOE/DP funded)
Facility – NIF – and ignition program
Explore high-yield approaches
Integrated Research Experiment(s) – IRE – (Laser and/or ions)
Advanced driver and target R&D
Supporting technology R&D
Design basis for IRE established
Scaled experiments on chamber, target fab, and injection provide technically plausible path to IFE
Target design & technology R&D
Krypton Fluoride Laser
Diode-Pumped Solid-State Lasers
Ion Beams
Rep-rated Z-pinch Fast Ignitor, Direct Drive (Ions), Indirect Drive (Lasers), Light Ion Source
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Roadmap to Attractive Fusion Power
– A Portfolio Approach –