



**HISTORICAL PERSPECTIVE
ON THE
U. S. FUSION PROGRAM**

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TOPICS

- **1950s - Classified Beginnings**
- **1960s - Beginnings of Inertial Fusion; Emergence of the Tokamak**
- **1970s - Energy Crisis; Budget Growth; New Construction; Planning**
- **1980s - MFE Narrowing to Tokamak; ITER Beginnings**
- **1990s - NIF Authorizaton; MFE Budget Cut and Restructuring towards Science**
- **1999 - Comeback Attempts: SEAB, Snowmass, FESAC**
- **2000s - MFE Focus on Burning Plasmas; IFE Focus on Driver Development; Fusion Technology “Killed”**
- **Policy Reviews, Legislation, Budget History, Progress and Projections, Opinions**



1950s - Classified Beginnings

Most MFE concepts were conceived, at least in rudimentary, form by 1960:

Pinch; Stellarator; Mirror; Cusp; Colliding Beams; Electron Rings; Impact Fusion

References:

Amasa S. Bishop, Project Sherwood, Addison-Wesley Publishing Company, 1958

Glasstone and Lovberg, Controlled Thermonuclear Reactions, D. Van Nostrand Company, 1960

World effort was declassified in 1958



1960s - Beginning of Inertial Fusion

Invention of the laser at the beginning of the decade

Weapons scientists and others quickly began to imagine how lasers could be used for inertial confinement fusion (“microexplosions”).

Energy and power available from lasers and other pulsed power sources was too small for ignition but some fusion neutrons were observed in experiments.

Classification in U. S. hampered development

References:

Basov and Krokhin, Soviet Physics - JETP Vol. 19, p. 123, 1964

Nuckolls et al., Nature, Vol. 239, p. 139, 1972

Brueckner et al., Rev. of Modern Physics, Vol. 46, 1974



1960s - Emergence of Tokamak

MFE Focus on Heating and Confinement

Many heating techniques demonstrated: ohmic, magnetic compression, neutral beams, ECH, ICH

Problems with Confinement but:

Tokamak results in USSR in late 1960s resulted in subsequent transformation and focus of world fusion effort in this direction

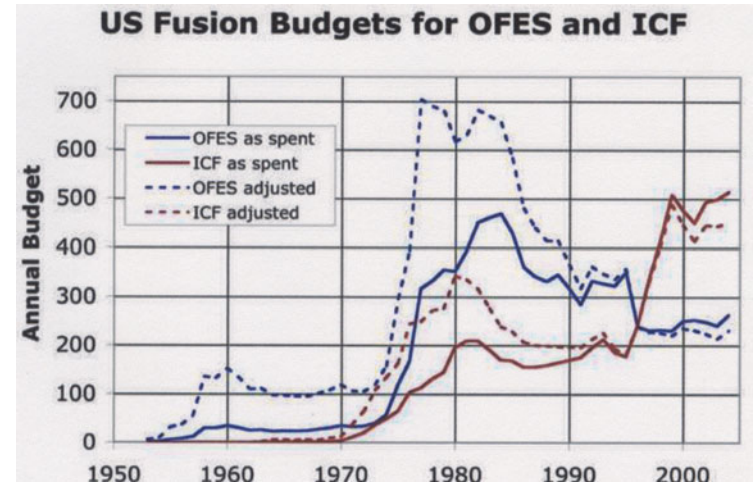
Efforts on Mirrors and Theta Pinch maintained as primary backups



1970s - Energy Crisis; Budget Growth

Beginning around 1972 and continuing through the decade, response to the energy crisis resulted in rapidly rising fusion budgets.

Construction began on many new facilities, including Doublet, TFTR, JET, JT-60, PBFA and Shiva.



1970s - Planning

In 1976 a detailed MFE program plan was completed calling for the construction of a sequence of advanced test facilities aiming at operation of a fusion demonstration power plant around 2000 for a development cost of approximately \$15 B.

This plan was signed into law by President Carter on October 7, 1980 but the required facilities and funding were not subsequently provided.

References:

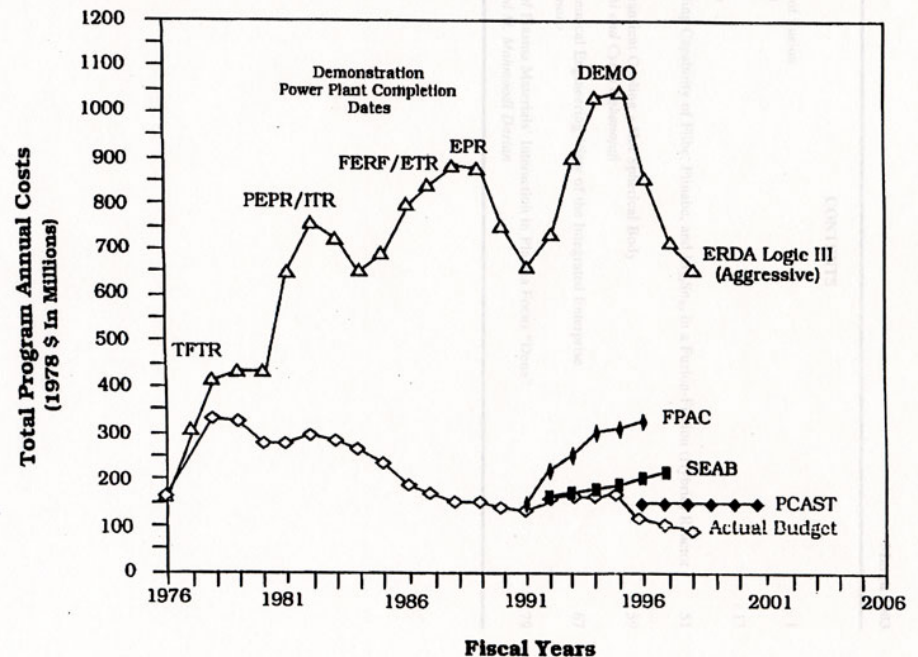
Dean et al., Fusion Power by Magnetic Confinement Program Plan, ERDA-76/110, 1976, published in J. of Fusion Energy, December 1998 and posted in library section of <http://fire.pppl.gov>



1970s - Planning (2)

Although there have been several planning studies since 1976, and the names of facilities have varied, all have the same basic structure or logic: a core science and technology effort, with appropriate test facilities and a sequence of mainline devices: physics test facilities, engineering test facilities, demonstration power plant.

Fusion Program Budget History Compared with Fusion Program Plans



Actual funding provided has been far less than needed and no test facilities beyond TFTR were ever provided



REVIEWS AND POLICY LEGISLATION

June 1980 Report of the Fusion Review Panel of the DOE Energy Research Advisory Board (ERAB):

“As a result of progress, the U.S. is now ready to embark on the next step toward the goal of achieving economic fusion power: exploration of the engineering feasibility of fusion. The engineering program should augment the continuing basic work in fusion research and related technology. Such work is indispensable to the success of the fusion program.”

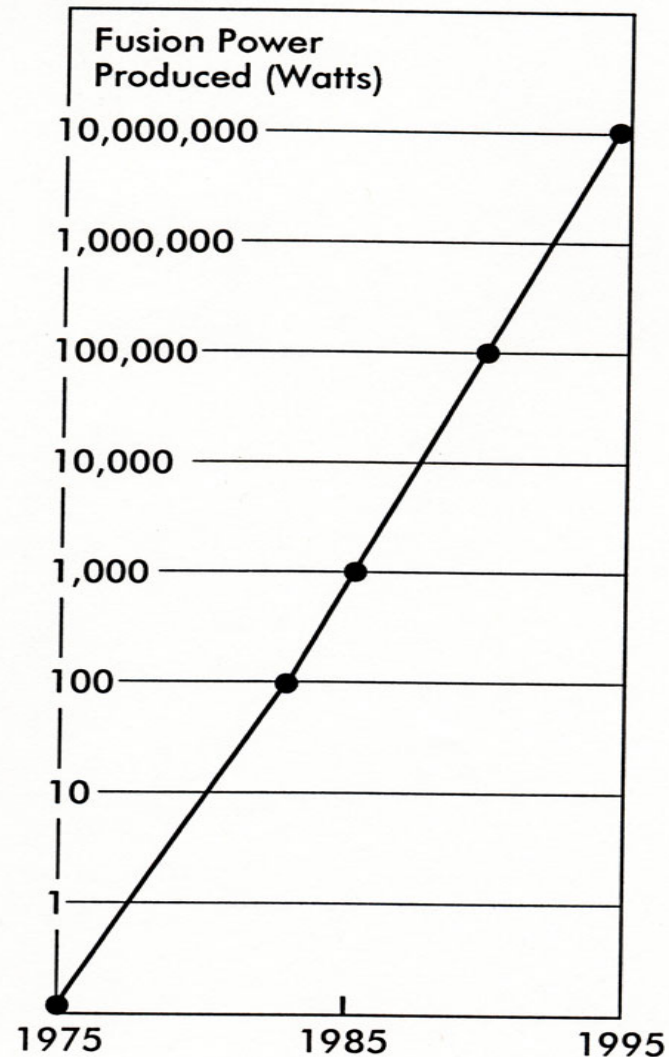
October 7, 1980: President Carter signed the Magnetic Fusion Energy Engineering Act of 1980, which states “The Secretary of Energy shall initiate the design activities on a fusion engineering device using the best available confinement concept to ensure operation of such a device at the earliest possible time, but not later than the year 1990 . . . (and) shall initiate a the earliest practical time each activity he deems necessary to achieve the national goal for operation of a commercial demonstration plant a the turn of the twentieth century.”



1980s - MFE Narrowing to Tokamak

Throughout the 1980s and into the 1990s, the new tokamak facilities yielded impressive results, with fusion power achieved increasing 100 million-fold.

In the face of steadily declining budgets, this progress came at the expense of the elimination of most magnetic alternate concepts.



1980s - MFE Narrowing to Tokamak (2)

The ITER project was initiated following the Reagan-Gorbachev Summit in December 1985.

In February 1987 the DOE proposed, and Congress approved, construction of the Compact Ignition Tokamak (CIT).

In May 1989 the National Academy Committee on Magnetic Fusion in Energy Policy recommended “an increase over current fusion program funding of about 20% ... to permit construction and operation of the Compact Ignition Tokamak.”

However, in June 1989, in a classic Executive Branch management fiasco, DOE cancelled the CIT project.

If CIT had been constructed, very likely MFE ignition would have been achieved by now.



REVIEWS AND POLICY LEGISLATION

September 1990 Report of the Secretary of Energy Fusion Policy Advisory Committee (FPAC):

“The fusion energy program should have two distinct and separate approaches, magnetic fusion energy (MFE) and inertial fusion energy (IFE), both aimed at the same goal of fusion energy production. Both MFE and IFE should increase industrial participation to permit an orderly transition to an energy development program **with strong emphasis on technology development.**”

October 24, 1992: President Bush signed the **Energy Policy Act of 1992**, which directs the Secretary of Energy to “conduct a fusion energy 5-year program . . . that by the year 2010 will result in **a technology demonstration which verifies the practicality of commercial electric power production.**”



1990s - In like a lion; Out like a lamb

In the early 1990s, the U.S. was actively involved in the ITER collaboration and, after cancellation of CIT, was planning to construct the \$1B Tokamak Physics Experiment (TPX).

On October 21, 1994, the DOE approved construction of the inertial confinement National Ignition Facility (NIF).

In late 1994, 10 MW of fusion power was produced in TFTR.

Both MFE and ICF were at technical highpoints when ...

In November 1995, the Congress massively cut the OFES budget from \$363M (FY1995) to \$244M (FY1996) and then to \$233M (FY1997); TPX cancelled.

In January 1996, DOE “restructured” the fusion program to focus on “the science and technology foundations.”

Late 1997, TFTR is shut down; July 1999, U.S. withdraws from ITER collaboration

FY 1999 OFES Budget: \$223 M



1999 Comeback Attempts

In **March 1999**, a Secretary of Energy Advisory Board (SEAB) Task Force on Fusion Energy began a review.

In **May 1999**, a NRC “Assessment of the Fusion Energy Sciences Program” began a review of “the scientific quality of the fusion program.”

In **July 1999**, the first Fusion Summer Study was held in Snowmass.

In **August 1999**, the SEAB endorsed the fusion effort saying, “In light of the promise of fusion, the Task Force concludes that the funding for fusion energy is now subcritical” and saying “The fusion energy program must be led by strong management, capable of directing the program towards its goals at a reasonable pace, and with a sufficient budget, on the order of \$300 million per year.”

In **September 1999**, Congress increased the OFES budget from \$223M (FY 1999) to \$250M (FY2000) and also added funds for high average power laser development for IFE.

In **September 1999**, the FESAC issued a report on Priorities and Balance, recommending an increase in IFE funding within OFES from \$10M to \$30M in a \$260M case and “revitalizing” the technology program.



The New Millennium

During FY 2000 through 2004, the Executive Branch has requested nearly flat budgets for OFES, while the Congress has provided modest increases. **FY 2004: \$264M.**

In December 2000, FESAC stated, “We find that the priorities and thrust areas of the (September 1999) Priorities and Balance report are still valid and that its strategic vision regarding the next 5 years is still appropriate for the program.”

However, under OMB pressure and contrary to FESAC recommendations, OFES has cut IFE and fusion technologies in order to fund plasma science.

Since FY 1999, Congress began adding money to the Defense Programs budget for High Average Power Lasers (HAPL), petawatt lasers for fast ignition, and in FY 2004 also for Z-Pinch IFE.



BURNING PLASMAS

Beginning in December 2000 and continuing into 2001, a series of Burning Plasma Science workshops were held.

In July 2002, a second fusion Summer Study was held in Snowmass, Colorado, focusing on burning plasmas, recommending U.S. rejoin ITER and maintain FIRE as backup.

In October 2002, a FESAC panel began preparation of a 35-year plan for achieving fusion electricity demonstration plant.

In December 2002, the NIF began operation of the first 4 of 192 laser beam lines.

On January 30, 2003, the U.S. rejoined the ITER effort as a ten percent partner.



BURNING PLASMAS (2)

In March 2003, FESAC sent to DOE a 35-year plan for achieving fusion power, based on maintaining a broad portfolio of approaches for the next 15 years at a cost of \$10 B, followed by selection of a single approach and construction of a single Demonstration Power Plant. This report was shelved by the Executive Branch.

In late 2003, the NRC Burning Plasma Assessment Committee endorsed “a burning plasma experiment” but said **“undertaking a burning plasma experiment cannot be done on a flat budget.”**



ITER

On October 23, 2003, DOE Office of Science Director Ray Orbach asked FESAC to do a “prioritized balancing of the program” which assumes ITER as an integral part. Report due in December 2004.

On December 20, 2003 and again on June 18, 2004 the ministers from the ITER parties were unable to agree on a site.

On February 2, 2004, the President sent Congress his FY 2005 budget request of \$264M for fusion, shifting funds to support plasma science and ITER and terminating all IFE and MFE fusion technology, contrary to FESAC recommendations.



IFE

On March 5, 2003, FESAC sent a strong letter to DOE criticizing cuts in IFE and fusion technology programs in FY 2004 budget submission to Congress saying, “In summary, FESAC finds the Presidential request for fusion research funding in FY 2004 to be not only meager but also harmfully distorted. It terminates components of the program that are truly essential.”

In April 2003, Sandia reported successfully compressing a fusion pellet using x-rays from a z-pinch, opening up a possible new technical approach to IFE based on “high-yield” implosions spaced approximately ten seconds apart. Congress then added \$4M to the ICF budget for Z-pinch IFE.



IFE (2)

On March 29, 2004, the FESAC urged DOE “to carry out a coordinated (IFE) program with some level of research on all of the key components (targets, drivers, and chambers), always keeping the end product and its explicit requirements in mind.”

However, the President’s FY 2005 budget, submitted to Congress February 20, 2004, indicated plans to terminate all work on IFE targets, drivers and chambers, while maintaining some effort on “high energy density physics.”



EXECUTIVE BRANCH POLICY

On October 19, 1999, speaking to Fusion Power Associates annual meeting, OMB fusion budget examiner (and now staff at OSTP) Mike Holland said: “From OMB’s view, I’d like to emphasize that **we see fusion as a science program and not an energy technology program.**” He added, “So, if the technology aspects of the fusion sciences program are connected to the science that you are trying to advance, then I think that’s a wise investment. I guess that’s the only way I would imagine doing that part of the budget.”

This remains the basis of Executive Branch fusion policy.

In a March 2004 letter to John Lindl (LLNL), DOE Office of Science Director Ray Orbach said, “While focusing on IFE science, we are bringing the IFE and the MFE long range fusion technology program elements to conclusion this year, using the Congressional supplement to our budget request to complete those activities in an orderly way.”



ACADEMY REVIEWS

Three recent Academy reports have emphasized the importance of plasma science. **These studies were not charged to review fusion technology or the optimized path to fusion energy.**

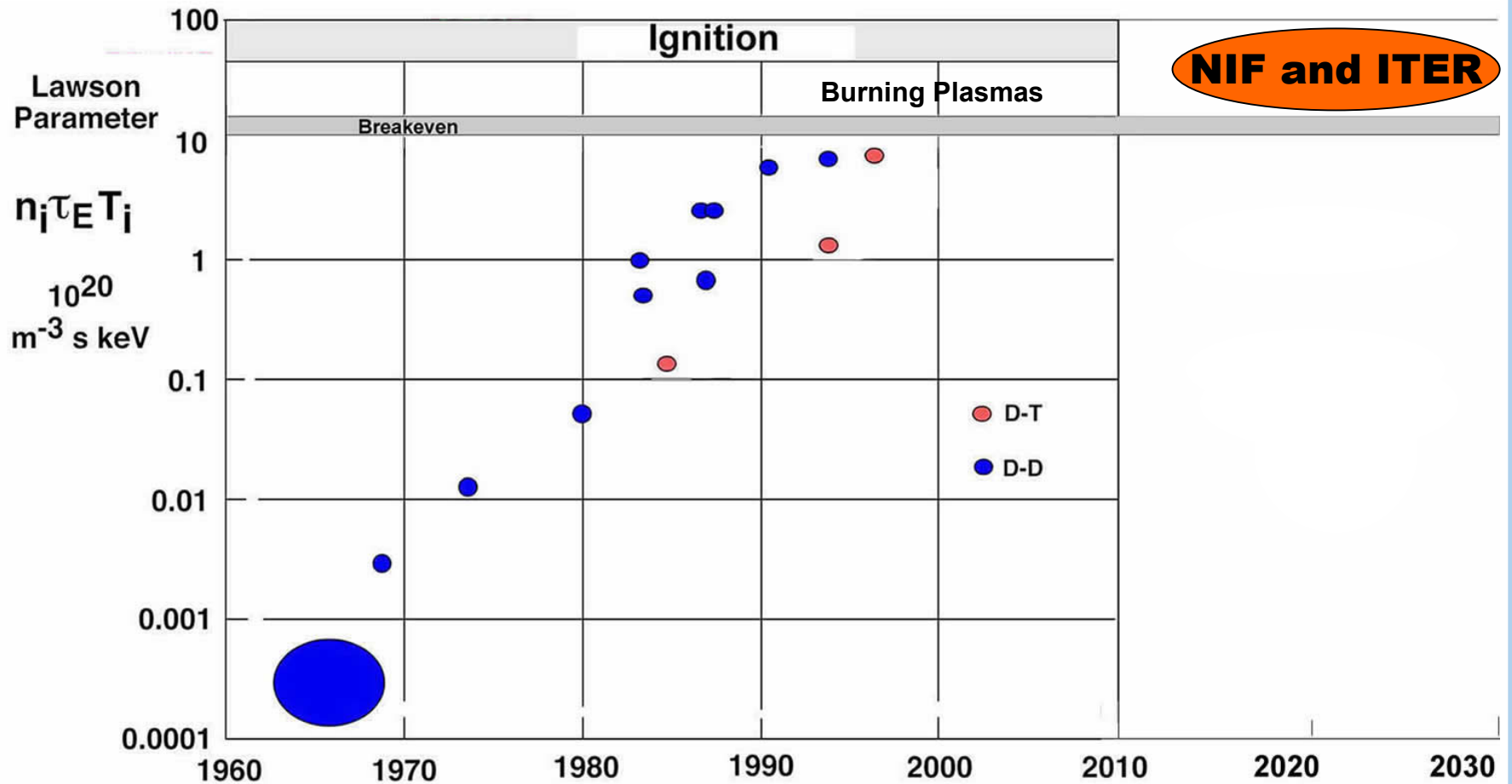
Nevertheless, the Executive Branch is using these reports as justification for focusing the program on plasma science and terminating fusion technology efforts.

These actions of the Executive Branch are not consistent with the recommendations of FESAC or the consensus of the fusion community as developed at the Snowmass meetings.

If the Executive Branch continues on this path, the carefully crafted consensus unity within the U.S. fusion community is likely to fracture as it did in the late 1980s after the DOE terminated work on alternate concepts to support the tokamak.



Fusion Progress and Projections



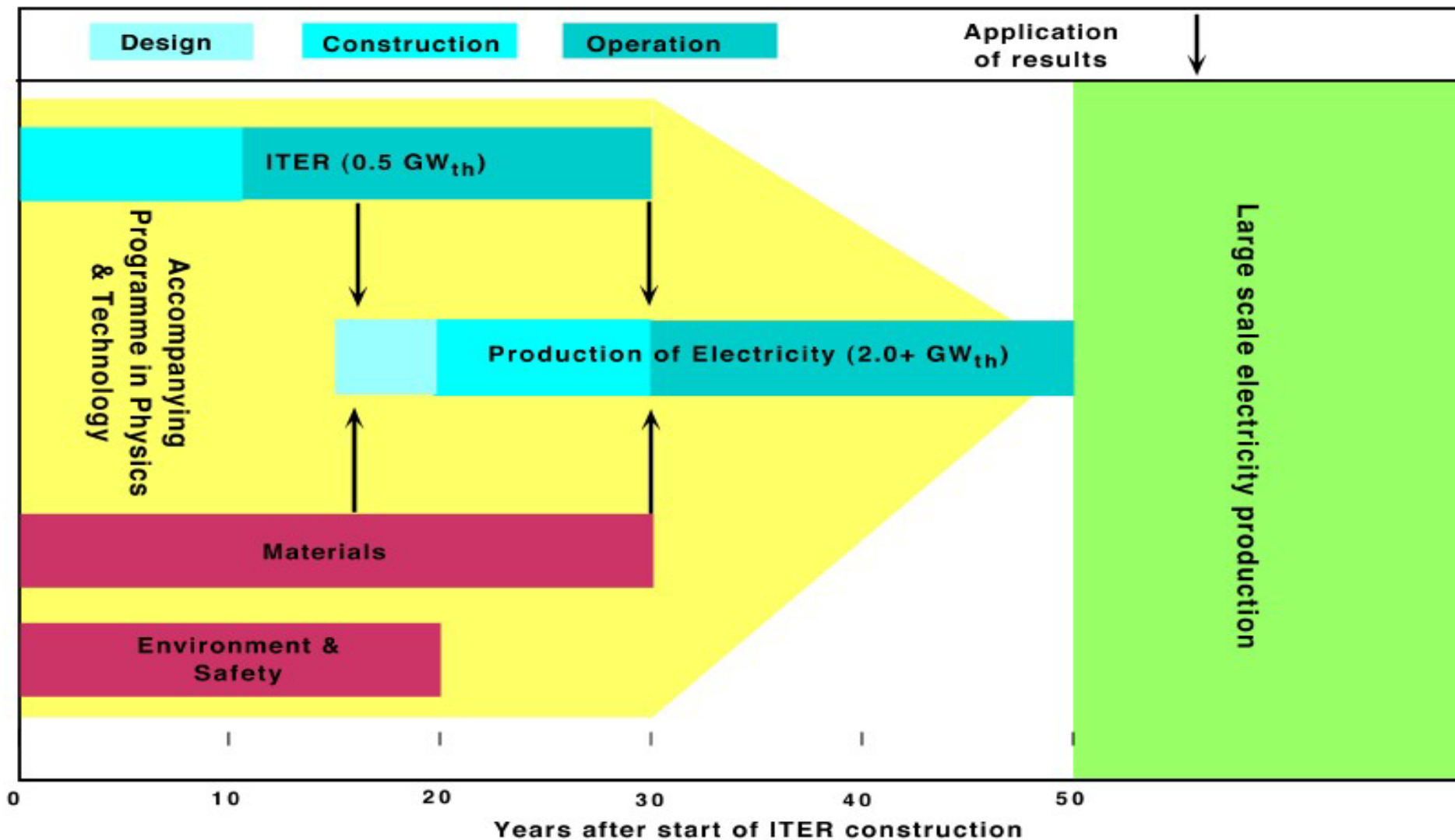
Beyond NIF and ITER

- A number of projections to power plant operation have been made, though there is no official government timetable for fusion.
- There are large uncertainties in these projections due to technical unknowns and to lack of firm funding commitments.
- The projections range from 15 to 50 years, with a mean around 30-35 years.



ITER Project Office Magnetic Fusion Roadmap

December 2003



The Path to Develop Laser Fusion Energy USNRL - 2003

Phase I: 1999-2005

Basic laser fusion technology

- Krypton fluoride laser
- Diode-pumped solid-state laser
- Target fabrication and injection
- Chamber materials and optics

Target design & physics

- 2D/3D simulations
- 1-30 kJ laser-target exp.

Phase II 2006-2014

Develop full-size components

- Power plant laser beamline
- Target fab/injection facility
- Power plant design

Ignition physics validation

- MJ pellet implosions (NIF)
- Calibrated 3D simulations

Phase III ETF operating ~2020

Engineering Test Facility (ETF)

- 2-3 MJ laser-driven implosions @ 5-10 Hz
- Optimize chamber materials & components
- Generate net electricity from fusion



2038

Z-Pinch IFE Road Map

2024

2018

2012

2008

2004

1999

Year

Z-Pinch IFE DEMO

Z-Pinch ETF
Δ ~ \$1B

Laser indirect-drive Ignition

Z-Pinch High Yield
↑
Z-Pinch Ignition

HY

Z-Pinch IRE
~ \$150M (TPC)
+op/year

Z-Pinch IFE target design
~ \$5M /year

Z-Pinch IFE target fab., power plant technologies
~ \$5M /year

NIF

FI
ZR

Z

Z-Pinch IFE PoP
~ \$10M /year

Z-Pinch IFE target design
~ \$2M /year

Z-Pinch IFE target fab., power plant technologies
~ \$2M /year

Z-Pinch IFE CE
~ \$400k /year
(SNL LDRD +)

Single-shot, NNSA/DP

Repetitive for IFE, OFES/VOIFE

ISSUES

For **Magnetic Fusion**, the primary issues are optimizing the configuration for effective confinement of the fuel and extending from pulsed to steady-state operation.

For **Inertial Fusion**, the primary issues are optimizing the techniques for compressing the fuel in a stable manner and extending from single pulse to repetitive pulse operation.

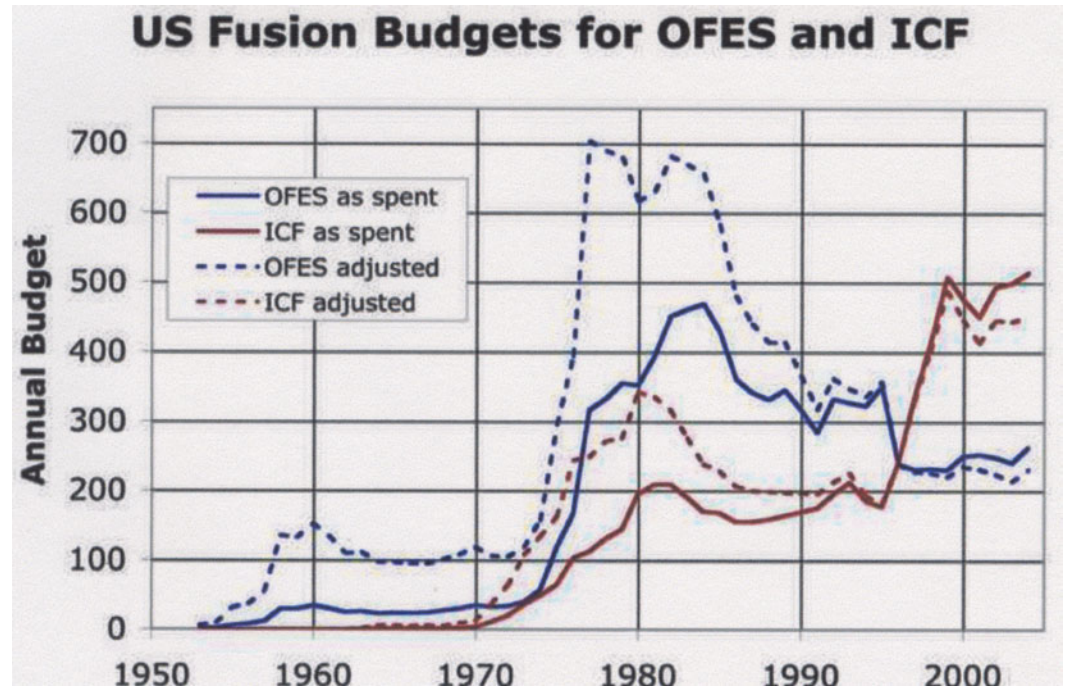
For both, identifying materials that provide long life and low induced radioactivity in a harsh, neutron-rich environment.

For both, optimizing the total system to reduce projected development and capital cost and demonstrating methods for ensuring reliability and cost-effective maintenance.



The budget and policy high point for MFE came around 1980, with the construction of TFTR and the passage of the Magnetic Fusion Energy Engineering Act of 1980.

The budget and policy low point for MFE came in the late 1990s, with the termination of TFTR and the U.S. withdrawal from ITER.



The budget and policy for inertial confinement is currently at a high point, with the construction of NIF and with Congressional add-ons for driver development.



OPINIONS

Since 2000, the budget and policy for OFES has been inconsistent with the recommendations of FESAC for a **balanced** science/technology and MFE/IFE effort.

Under present U. S. budgets and policy, the prospects of achieving commercially competitive electricity generation from **magnetic fusion** are extremely low in the lifetime of anyone living today unless ITER proceeds and the power plant development is done outside the U. S. **This policy needs to change to re-establish a strong fusion technology effort.**

The prospects for **inertial fusion** energy are somewhat better, based on anticipated NIF results and Congressional funding for IFE technologies but **the Executive Branch needs to become supportive of driver development for IFE.**



OPINIONS (2)

The prospects for both MFE and IFE would be markedly improved if the Executive Branch recognized that **engineering sciences, technology development, systems analysis and not just plasma science are all essential elements of a balanced fusion effort,**

and that innovative ideas that reduce costs or accelerate knowledge must be expeditiously pursued in **all** aspects of the fusion program.



FPA PURPOSE AND GOALS

The **purpose** of Fusion Power Associates is to ensure the timely development and acceptance of fusion as a socially, environmentally and economically attractive source of energy.

To fulfill this purpose, we have adopted **four primary goals**:

To bring about a smooth, timely transition from research on fusion science and technology to engineering development and practical applications.

To foster cooperation among all public and private organizations, including government, universities, national laboratories and industry.

To establish increased public awareness and understanding of the potential applications of fusion science and technology.

To foster the use of fusion science and technology in both commercial and government applications, including such areas as energy, space and national security.



FPA INSTITUTIONAL PARTICIPANTS

	1979	1982	1996	2004
Industries	10	39	30	8
Utilities	0	11	2	0
Laboratories	0	1	4	7
Universities	0	2	3	8
Total	10	53	39	23

In addition, FPA has had a stable base of approximately 400 Individual Affiliates

FPA began as an industry-based association. When TPX was cancelled and the U.S. withdrew from ITER, opportunities for industry all but vanished and FPA lost most of its industrial members. This has been partially offset by growth in laboratory and university membership.



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