U.S. DEPARTMENT OF ENERGY

Office of the
UNDER SECRETARY
FOR SCIENCE & INNOVATION

U.S. Bold Decadal Vision for Commercial Fusion Energy

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Fusion has the potential to be a safe, on-demand, abundant, non-carbon-emitting, and globally scalable energy source

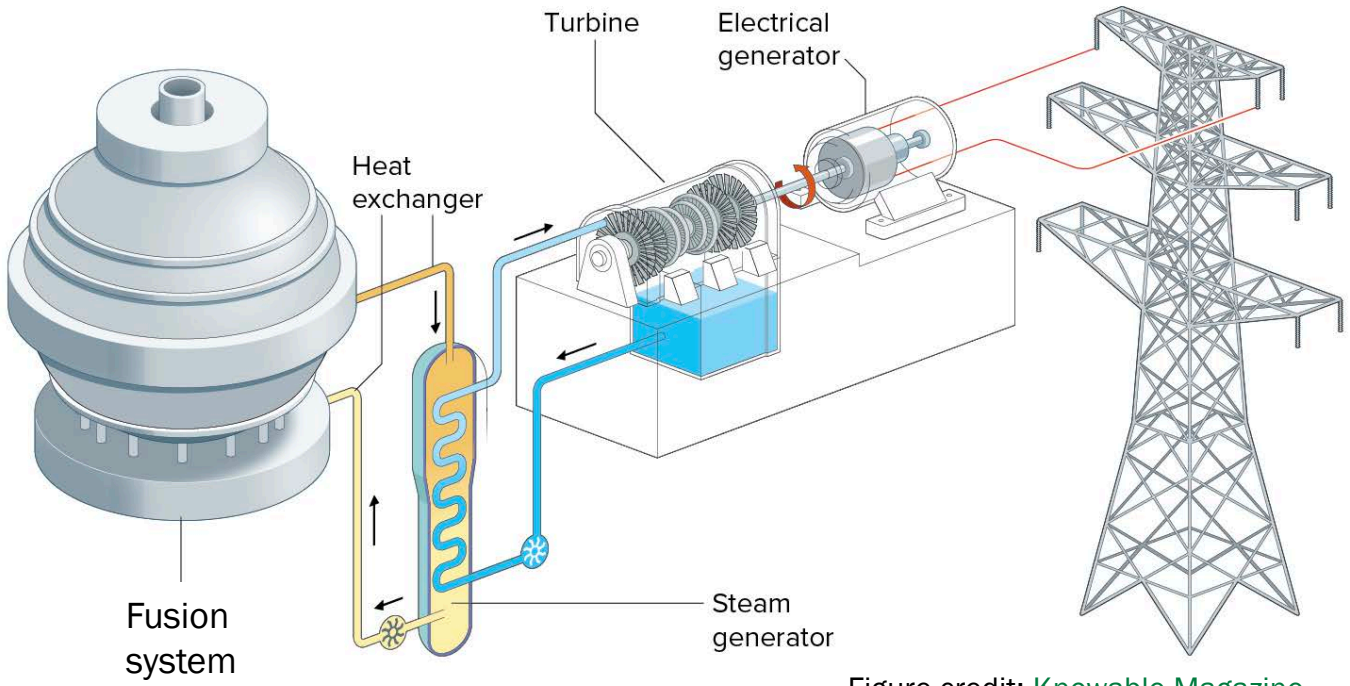


Figure credit: Knowable Magazine

Safety considerations:

- Mildly radioactive tritium
- Short-lived, neutron-activated structural materials
- Conventional risks of any large industrial facility

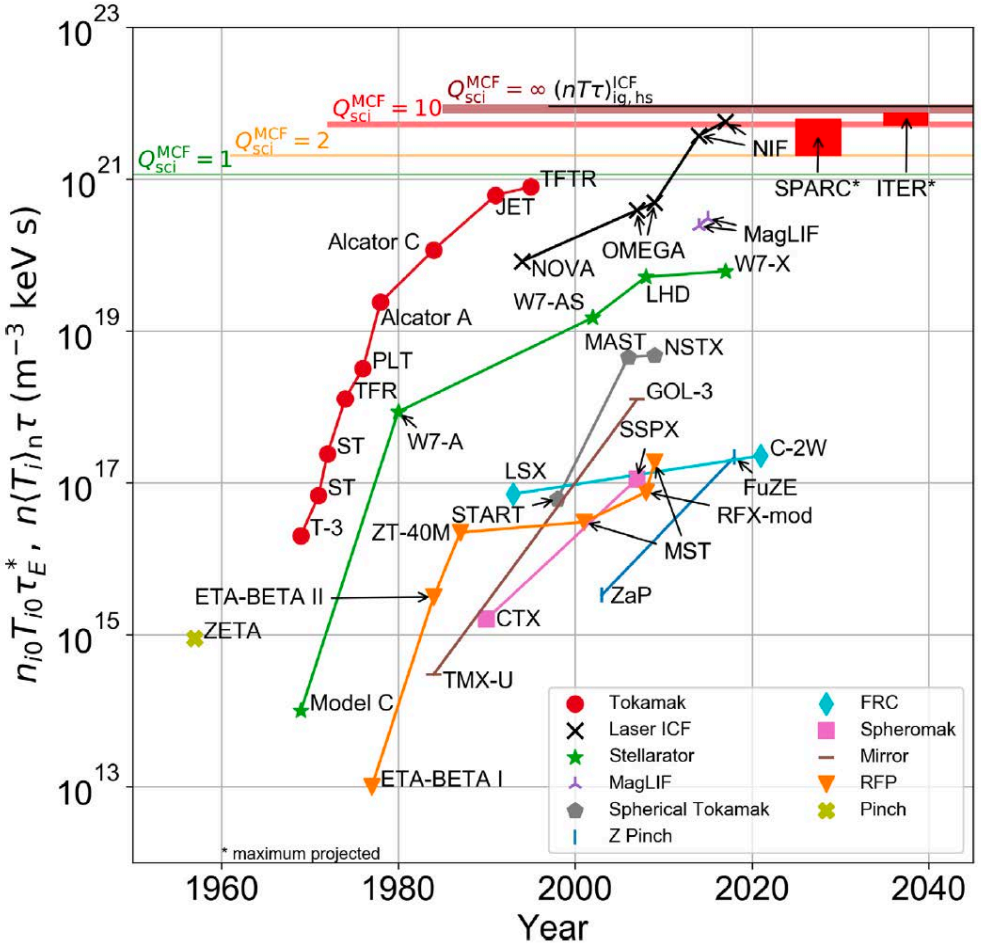
Potential uses:

- Electricity generation
- Industrial processes
- Production of transportation fuels
- Desalination

Potential benefits:

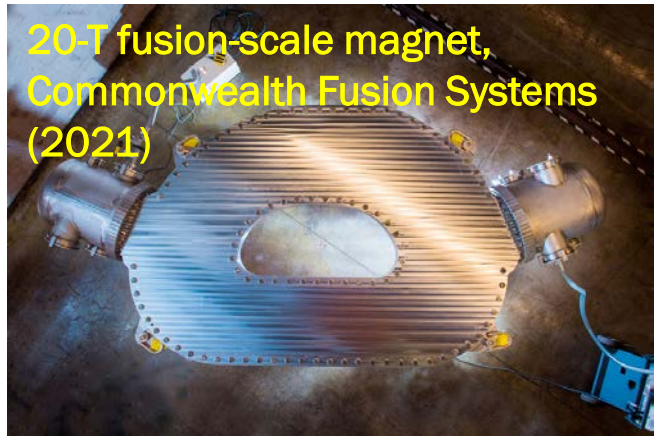
- Firm, on-demand, no carbon emissions
- Globally scalable
- Low land use
- Site near cities
- Manageable risks relating to radioactive waste and nuclear proliferation

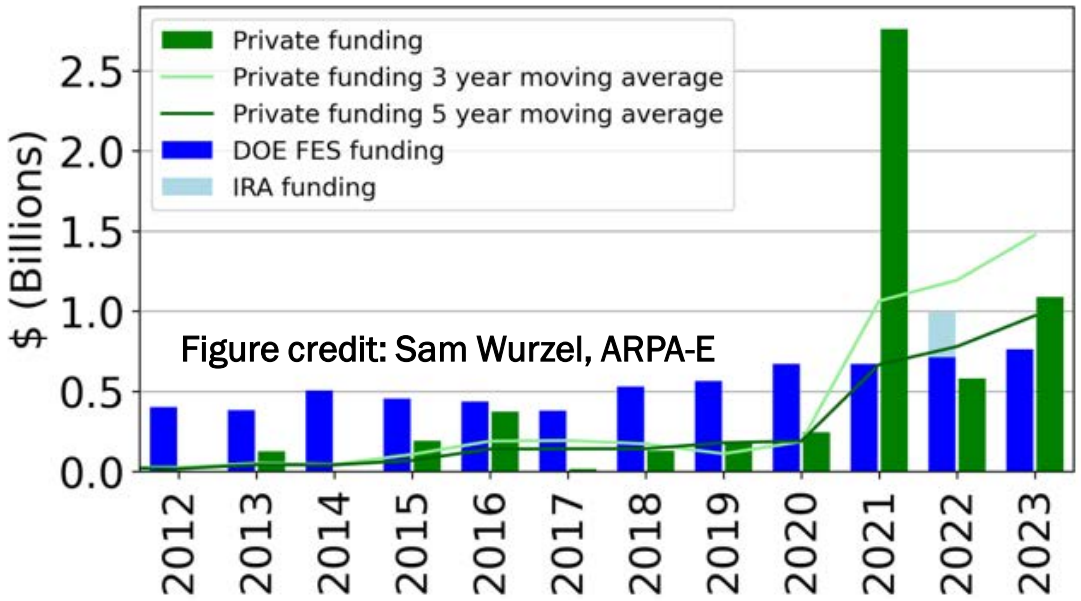
Strong technical progress and private investments warrant a new U.S. strategy for fusion research, development, and demonstration



Wurzel & Hsu, *Phys. Plasmas* (2022); https://doi.org/10.1063/5.0083990.

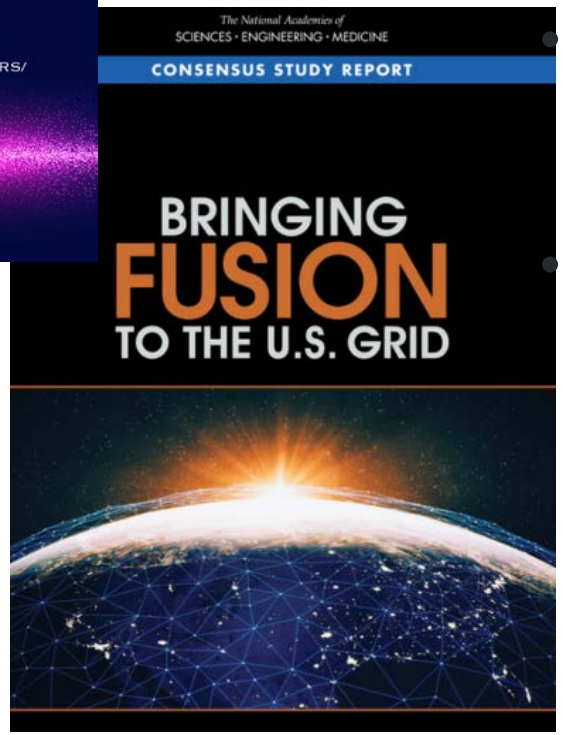
National Ignition Facility achieves scientific breakeven Q>1 (2022)





https://www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition
https://news.mit.edu/2021/MIT-CFS-major-advance-toward-fusion-energy-0908

In March 2022, the White House held a summit on *Developing a Bold Decadal Vision for Commercial Fusion Energy,* guided by the 2021 National Academies report *Bringing Fusion to the U.S. Grid*



Key abbreviated National Academies recommendations:

- DOE and the private sector should demonstrate net electricity in a fusion pilot plant (FPP) in the 2030s
- DOE should move forward now via public-private partnerships to resolve key S&T challenges needed to bring fusion to commercial viability
- Urgent investments by DOE and private industry are needed

https://nap.nationalacademies.org/catalog/25991/bringing-fusion-to-the-us-grid

Additional supporting materials:
https://www.nationalacademies.org/event/02-16-2023/unlocking-new-possibilities-for-commercial-fusion;
S. C. Hsu, *J. Fusion Energy* (2023); https://doi.org/10.1007/s10894-023-00357-9.

The *Bold Decadal Vision* (BDV) is an element of the White House's innovation agenda to help meet 2050 climate goals

2020s | 2030s | 2040s

Energy gain

Pilot plants & first-of-a-kind commercial plants

Materials, fuel cycle, and enabling technologies

Aggressive commercial deployment

Fusion is 1 of 5 White House "net-zero game changers"

Prepare the path to commercialization and support an equitable clean-energy transition

https://www.whitehouse.gov/briefing-room/statements-releases/2022/11/04/fact-sheet-biden-harris-administration-makes-historic-investment-in-americas-national-labs-announces-net-zero-game-changers-initiative

Imperative for U.S. to remain a fusion energy world leader

- Global race to secure leadership in fusion energy
- Major investments** from UK, EU, Japan, Germany, and China

EU: $650M per year (EUROfusion ~ $270M/yr)

UK: $250M per year*

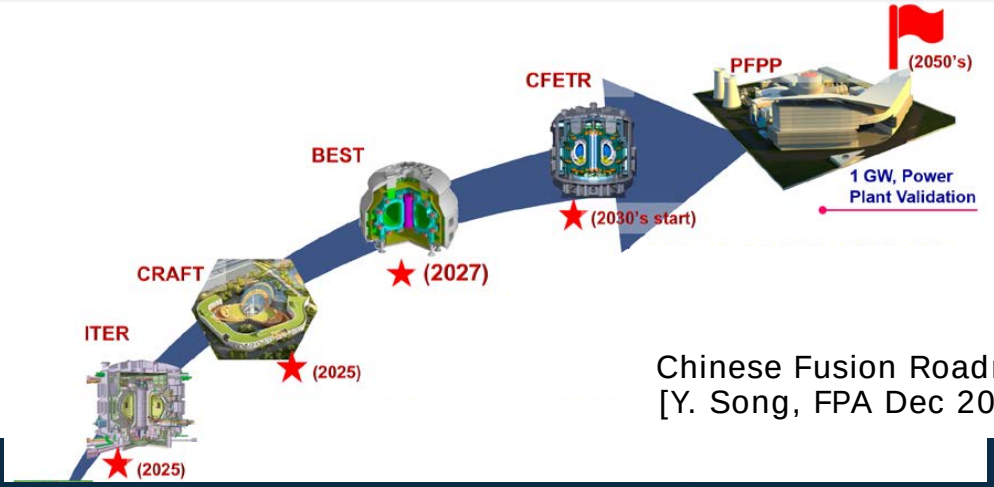
Japan: $237M per year

Germany: $220M/yr

*excludes ITER contrib.
**NOTE: $USD are estimates only with large variance

- In Feb 2023, it was reported that China has surpassed the U.S. in fusion technology patents [Astamuse, 2023]
- Chinese expenditures** in fusion energy **~1.5B/year**

**NOTE: $USD are estimates only with large variance



Chinese Fusion Roadmap
[Y. Song, FPA Dec 2022]

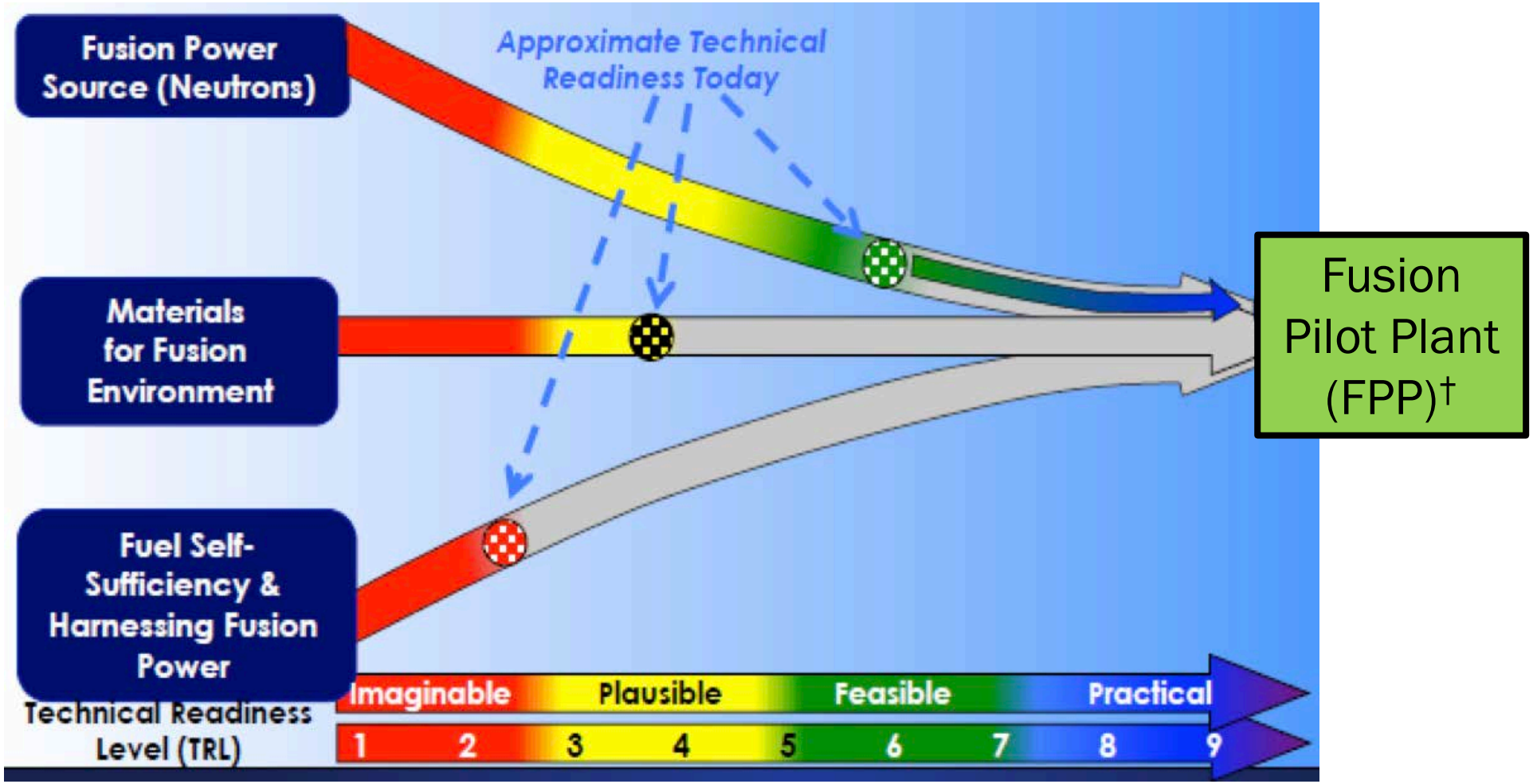
We are at an inflection point between fusion science and fusion-energy development, yet significant R&D challenges still remain

Topics/disciplines

Predict, control, sustain a burning plasma

Survive extreme heat and irradiation flux at the first wall

Tritium breeding, processing, containment



†As defined in the 2021 NASEM report *Bringing Fusion to the U.S. Grid*, i.e., >50 MWe net electricity for >3 continuous hours with timely path to 1 full-power year; on the path to commercial viability.
Figure adapted from presentation by M. Wade at APS-DPP community planning workshop (2019).

Vision for a balanced and bold Fusion Energy Sciences program

"Fulfilling the [fusion] energy mission demands a shift in the balance of research toward FM&T (Fusion Materials and Technology), which connects the three science drivers: Sustain a Burning Plasma, Engineer for Extreme Conditions, and Harness Fusion Energy." pg. 6 FESAC-LRP

- Fusion Science and Technology (S&T) Roadmap
- **Focus:** critical science and technology gaps
- Support public-private partnerships (PPPs)
- Leverage international collaborations

While worldwide public R&D programs are focused on preparing for ITER, 37+ fusion companies have appeared due to a confluence of S&T push and market pull

ITER construction in France (Sep. 2023)

Figure credit: ITER.

FUSION INDUSTRY ASSOCIATION

THE FUTURE IS FUSION

Fusion Industry Association is helping bring clean, safe, sustainable fusion power to the world in the next decade.

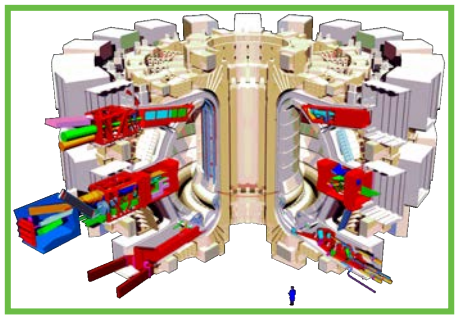
https://www.fusionindustryassociation.org

The Emergence of Private Fusion Enterprises: https://link.springer.com/collections/ijdahfibib

Different fusion approaches; we are in a period of fertile innovation, benefitting from decades of public investments

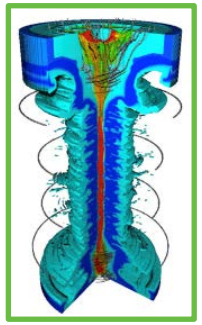
Magnetic confinement fusion (MCF)

iter
china eu india japan korea russia usa



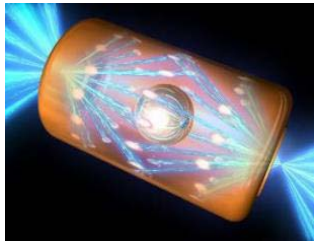
Companies: e.g., Commonwealth Fusion Systems, Tokamak Energy, Type One, Thea, Realta, TAE Technologies

Magneto-inertial fusion (MIF)



Companies: e.g., Zap, General Fusion, Helion

Inertial confinement fusion (ICF)



Companies: e.g., Xcimer, Focused Energy

For a 12-minute, light technical overview of fusion approaches, see video starting at 59 minutes here: https://www.youtube.com/watch?v=aRUnNgfqSIM).

DOE *Milestone-Based Fusion Development Program* is a centerpiece and first step of the BDV for realizing an operating fusion pilot plant in the 2030s

Awardees will:

- Deliver FPP pre-conceptual designs and technology roadmaps within 18 months
- Pursue R&D to resolve S&T up to delivering FPP preliminary designs over 5 years
- Receive Federal fixed payments upon milestone completion, while contributing significant private funding
- Implement Community Benefit Plans

Commonwealth Fusion Systems

XCIMER ENERGY CORPORATION

TYPE ONE ENERGY

ZAP ENERGY

Tokamak Energy

REALTA FUSION

THEA ENERGY

FOCUSED ENERGY

Diversified portfolio of companies, fusion concepts, and commercialization approaches.

https://www.energy.gov/articles/doe-announces-46-million-commercial-fusion-energy-development.

In conjunction with resolving remaining S&T challenges, DOE and the U.S. Government seek to partner broadly with fusion stakeholders to enable timely fusion commercialization

- Workforce development, training, and retraining
- Regulatory, licensing, export control
- Nuclear security and nonproliferation
- Public engagement and acceptance
- Energy and environmental justice
- Supply chains and fuel supplies
- Manufacturing capabilities and scaleup
- Waste disposition/recycling
- Cybersecurity, intellectual-property protection
- Consent-based siting
- Demonstration/deployment assistance, facilitating market entry
- International and interagency coordination/collaboration

NRC voted to license/regulate fusion systems under the Byproduct Materials Framework (10 CFR 30)

DOE/NNSA Fusion Energy and Nonproliferation Workshops (Jan. 2023 and Jan. 2024)

Preliminary DOE assessment of fuel-supply needs has been conducted

OSTP/ODNI workshop on Protecting the US Fusion Energy Industry (June 2023)

US-UK strategic partnership announced in Nov. 2023; US fusion international strategy announced at COP28 in Dec. 2023

International strategy focuses our R&D collaborations and expands into activities that support eventual fusion commercialization

5 Pillars:

- Identify and pursue collaborative fusion R&D opportunities (including test facilities) focused on enabling timely fusion demonstration and commercialization
- Grow the future global marketplace, including resilient supply chains
- Coordinate on regulatory frameworks that create a safe and secure environment for fusion energy
- Foster and strengthen a diverse and global workforce pipeline
- Improve public education and engagement in fusion energy

SPEC John Kerry announces U.S. fusion international strategy at COP28 (Dec. 5, 2023)

DOE Dep. Sec. Turk and UK DESNZ Minister Bowie announce US-UK fusion joint statement (Nov. 8, 2023)

DOE supports the NRC's fusion rulemaking efforts under the Byproduct Materials Framework (10 CFR 30)

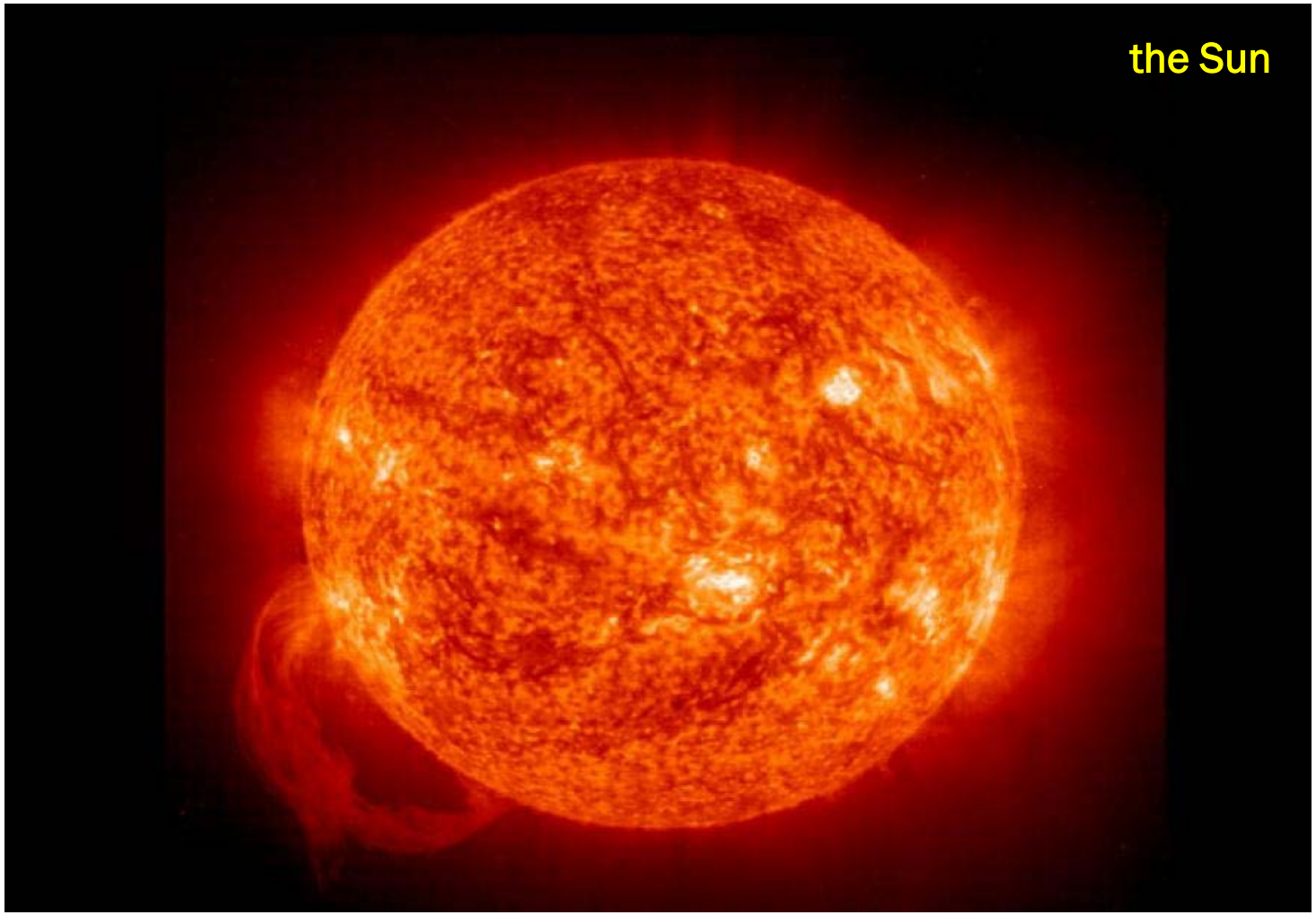
- **DOE coordinates with the NRC on international engagements, e.g., w/IAEA, to support international harmonization of fusion regulatory frameworks**
- **DOE seeks to support the safety and security of eventual commercial fusion deployment through expanded materials and fuel-cycle RD&D**
  - Including development of codes and tools that will underpin fusion plant designs, accident analysis, estimates of tritium inventory and waste generation, and future licensing applications
- **DOE is available to provide objective technical information and expertise on fusion, including from our national laboratories**
- **DOE encourages broad public engagement on fusion rulemaking to facilitate public trust and a social license for commercial fusion deployment**

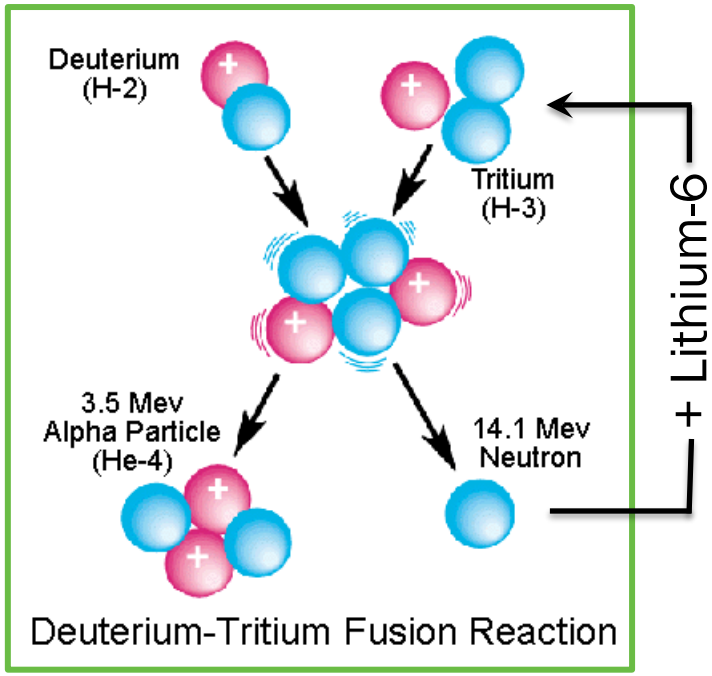
Summary

- Strong recent technical progress and market interest in fusion have initiated a shift in U.S. strategy for fusion energy RD&D
- White House Summit in March 2022 announced the ambition to develop a *Bold Decadal Vision* to accelerate fusion energy RD&D to enable an operating fusion pilot plant on a decadal timescale
- Several new initiatives within DOE, leveraging public-private and international partnerships, have been launched to advance the BDV
- DOE supports NRC's fusion rulemaking under the Byproduct Materials Framework, and stands ready to assist with technical information/expertise and coordination on international engagements

Backup Slides

What is fusion?





1.5 “train cars” of D and Li-6 (200 tons) = 1 year of electricity for the U.S.

Fusion R&D programs in the U.S. Department of Energy

DOE Office of the Secretary

National Nuclear Security Administration

Office of Experimental Sciences

- Supports stockpile-stewardship science
- Inertial confinement fusion
- High-energy-density science

ICF FY23 enacted $630M

National Nuclear Security Administration

Science and Innovation

Office of Science - Fusion Energy Sciences (FES)

- Build the knowledge base for fusion energy
- Magnetic confinement fusion (including ITER)
- Discovery plasma science

FES FY23 enacted $763M

U.S. DEPARTMENT OF ENERGY | Office of Science

Offices reporting to the Secretary

ARPA-E

- Targeted, high-risk, high-reward translational fusion-energy R&D

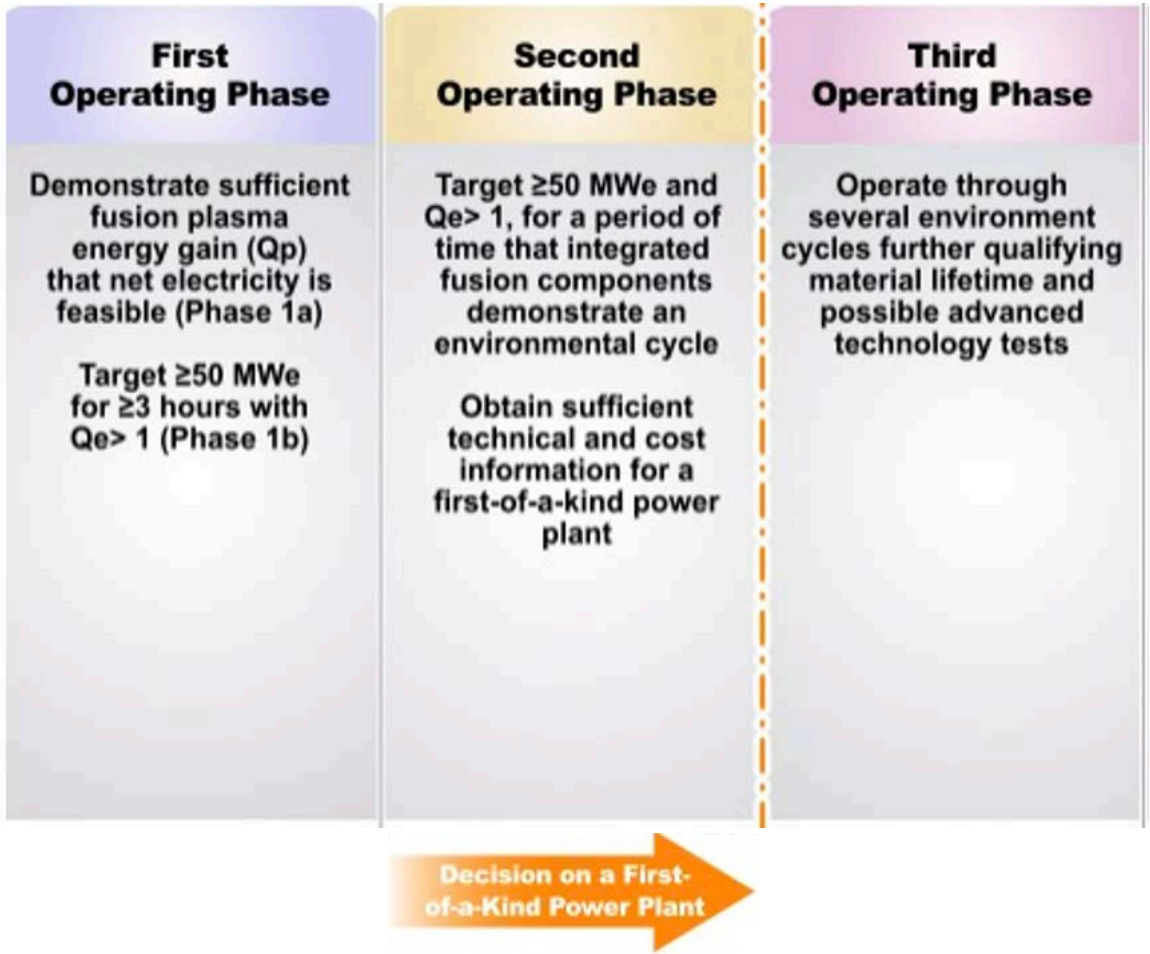
arpa·e CHANGING WHAT'S POSSIBLE

Fusion energy R&D programs ~$150M since 2015

A fusion pilot plant must provide technical and economic information for utilities and other plant owners/operators

NASEM report conclusions on FPP requirements:

- Demonstrate Q_e>1, >50 MWe net electricity for 3 continuous hours, progressing to more than 1 full power year
- Demonstrate feasibility of materials and sustainable fuel cycle
- Capital cost that attracts investors and commercialization partners



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Fusion Energy Sciences (FES) Mission and Strategic Priorities

MISSION

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundations needed to develop a fusion energy source. This is accomplished by the study of the plasma state and its interactions with its surroundings.

The Energy Act of 2020 **expanded the scientific mission of FES** to support "**the development of a competitive fusion power industry in the U.S.**"

FES PROGRAM PRIORITIES

1. Accelerate fusion development as a carbon-free energy source via public-private partnerships ("bold decadal vision")
2. Support R&D Fusion Centers ("FIRE" centers) to establish S&T basis of a Fusion Pilot Plant (FPP)
3. U.S. participation in ITER to leverage engineering and study burning plasma science technology at power plant scale while expanding Inertial Fusion Energy (IFE) program
4. Support discovery plasma science and technology
5. Broaden participation in fusion and DEIA activities to enable the program

Generalized schematic of a D-T fusion power plant

Tritium breeding:

$n + {}^{6}Li \rightarrow \alpha + T + 4.8\ MeV$

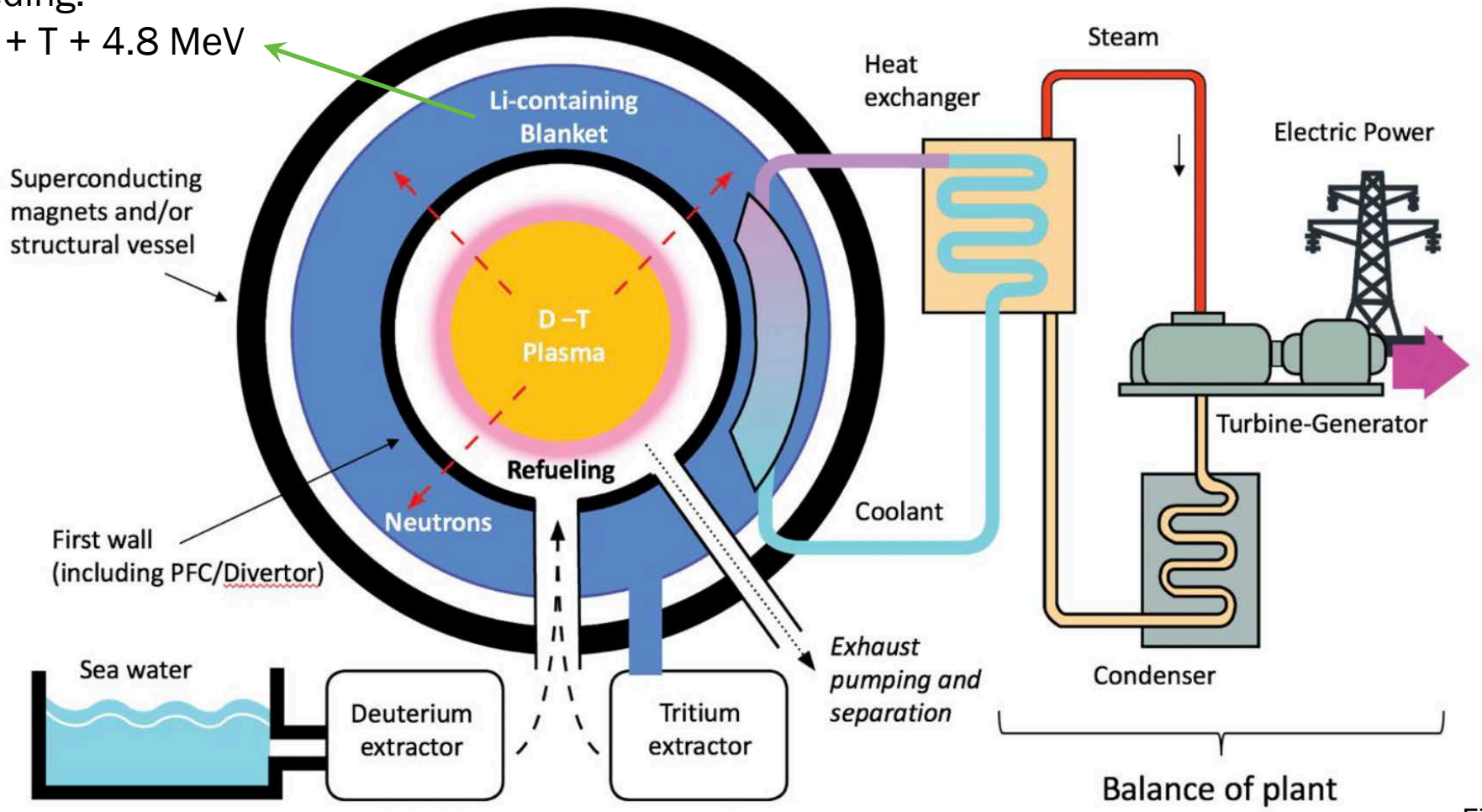

Figure credit: ARPA-E