White Paper

FUSION 2020

Fusion Energy: An Opportunity for American Leadership and Security

Introduction

Electricity is the lifeblood of the American economy. From Silicon Valley to Detroit, Wall Street to Main Street, IT innovators, small and large scale manufacturing companies and investors depend on reliable, affordable access to electricity to power job growth, innovation, and profits.

In the coming years, increasing demand for electricity will need to be met with a commitment to more affordable, sustainable, and secure forms of energy production. By 2050, every power plant in the United States will reach the end of its lifespan and need to be replaced.

The pending recapitalization of American power utilities represents a challenge and an opportunity. But even more fundamentally, it is a choice: between business as usual with its unsustainable, unclean, unsafe, and costly hallmarks, or we can set a new course to firmly establish American leadership in clean, sustainable energy production.

Wind and solar, together with efficiency and conservation measures, will certainly be a part of the new energy paradigm. But none of these will meet the increasing need for baseline power—the power available 24 hours every day, regardless of the weather.

This new course should include fusion, the energy that powers the stars. During the last 30 years, there has been great and generally unrecognized progress toward achieving controlled fusion energy.

Fusion power is safe and clean, and when commercialized, will solve many of the world's energy problems.

The primary obstacle to realizing fusion's potential is the integration of technologies into a power plant scale facility. The leaders of the main U.S. national labs state that they are now ready to start building U.S. pilot plants to find ways to overcome those obstacles.

China, Japan, South Korea, and the European Union are pushing forward with aggressive efforts to resolve these challenges and secure leadership in the energy technology of the future. In contrast, U.S. efforts, although very significant, have been crippled for decades by severe funding constraints.

Clear plans and recommendations for U.S. leadership have <u>not</u> been implemented.

The implications of delay are clear. We are in danger of falling behind.

Establishing a national priority level of effort for fusion, together with support for a balanced energy portfolio, can reestablish American preeminence, achieve absolute energy independence, and develop next generation energy for the world.

ASP
American Security Project

Key Facts

- **We know fusion works. Fusion is taking place** in laboratories all over the world, including in the United States. It is the process that powers the Sun and all the stars.
- The key step, through engineering, is to turn this **science fact into a commercial product.**
- At the heart of fusion energy is the world's most famous equation, $E = mc^2$ which captures the relationship of mass and energy.
- The process is very different from a nuclear reactor, which splits large atoms to create energy but leaves long-lived radioactive byproducts. **Fusion combines small atoms together**. In doing so, energy is released and the byproduct is simply helium gas.
- **Commercial fusion energy plants would use relatively tiny amounts of fuel to generate millions of watts of electrical power.**
- **Fusion is sustainable**: the fuel is extracted from seawater and lithium. Due to the amount of fuel required, the supply of these basic ingredients is essentially limitless.
- **Fusion is safe**: there is no chain reaction and there is no possibility of a meltdown. Unlike a nuclear fission reaction, control of fusion is as simple as flicking a switch. When you turn it off, the reaction stops. There is no spent fuel.
- **Fusion is clean**: there are no pollutants released in the air and no carbon is released.
- Not only will fusion give **America energy independence**, it will also create a large number of jobs.
- The **United States runs the risk of losing the race to commercialize fusion** to China or South Korea, due to lack of political will. America could be forced to buy its energy from foreign countries that may not share its values or have its interests at heart.
- There will need to be mass recapitalization of the energy generation market, as each present power plant in the U.S. will need to be replaced by 2050. The question is: **what will those plants be using for fuel in 2050**?

Potential Strategic Gains for the United States

With the political will and the right investment, the potential strategic gains for the U.S. in the aggressive development and deployment of fusion power plants are extraordinary. These would include:

- Clean, safe, sustainable, and affordable electricity generation in the U.S. and the world;
- Energy independence and associated freedom from foreign countries for our energy supplies;
- Transition to an electricity-generating economy to power our cars and trucks;
- Elimination of the actinides in spent nuclear-fuel by building fusion/fission hybrid plants (using the high neutron fields from fusion to transmute the actinides in spent fuel and thereby render the spent fuel non-toxic within 200 years – not tens of thousands of years);
- The two-fold boost to the U.S. economy of reducing our huge trade imbalance by eliminating the cost of importing oil and making the U.S. a world-leader in the energy market by providing fusion generating plants for the whole world;
- Creation of a large number of jobs in building and maintaining commercialized fusion power plants;
- Demonstration of how U.S. leadership in technology can be leveraged to drive leadership in energy; and
- Increase interest and high-paying jobs for young people going into scientific and engineering fields.

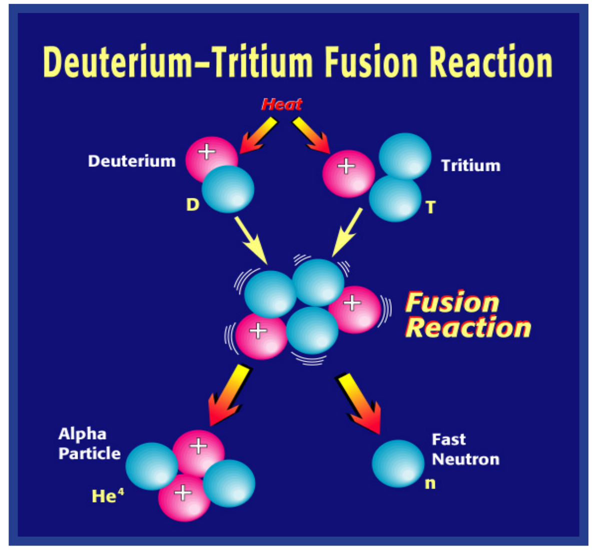
What is Fusion Energy?

At the heart of fusion energy is the world's most famous equation, $E = mc^2$. The basic fuel for fusion is deuterium, a form of hydrogen easily separated from ordinary water.

Fusion energy is obtained by forcing together atomic nuclei from deuterium and tritium (another form of hydrogen). This releases energy due to the slightly smaller mass of the helium nucleus produced.

The amount of energy available through fusion is extraordinary.

A single gram of fuel can yield 90,000-kilowatt hours of energy. Put another way, it would take 10 million pounds of coal to yield as much energy as one pound of fusion fuel.



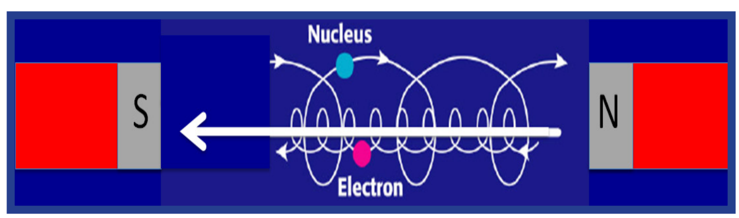
This energy will be available as heat to make steam to run a conventional electric generator.

How is Fusion Energy Practically Obtained?

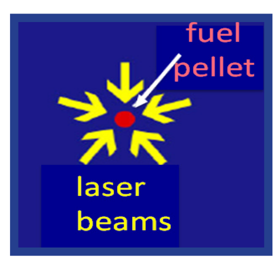
Fusion has been repeatedly achieved in experiments ranging from a table-top apparatus to devices yielding short pulses of up to 15 million watts of power.

However, for practical electric generation purposes, two "mainstream" approaches have evolved. Each of these is designed to get the fuel nuclei close enough together and moving fast enough to fuse into one new nucleus—helium, the same gas that fills a child's balloon.

In a Magnetic Fusion Energy (MFE) machine, strong magnetic fields suspend the reacting particles in a doughnut-shaped (toroidal) chamber. Such machines, called "tokamaks," have been built over many years in several countries and great advances have recently been made in this technology.



The second mainstream approach uses multiple high-energy laser beams to heat and compress a tiny pellet of fuel. This Inertial Fusion Energy (IFE) technique is now coming to fruition as a nearly all-American project in California.



"Ignition" experiments planned for this year and next are expected to yield pulses of fusion energy greater than that used by the huge laser array to trigger them—this would be the first achievement of "breakeven" and energy gain.

The U.S. has led the fusion field for decades, and is now in a position to capitalize on the culmination of over 50 years of effort.

For both these approaches, clear pathways exist for the development of commercial utility-scale power plants.

According to the U.S. fusion program scientific leaders, the first such plants could be operational within 15 years if there was the will to drive forward.

Such next-generation power sources, built in conjunction with other nearer-term energy sources, could change the world.

Are We Ready to Proceed?

In 1980, Congress passed an authorization bill that envisioned a demonstration fusion power plant by the year 2000. This visionary program was never funded and subsequently died.

It may be argued that it was premature. In the thirty years since, and particularly in the last decade, dramatic progress has been made in both the theoretical and practical aspects of fusion energy.

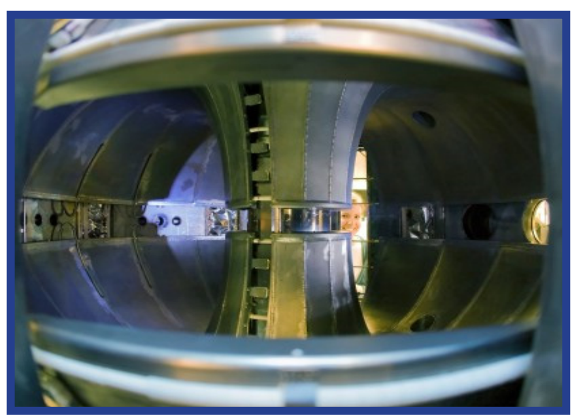
In the United States, the Department of Energy (DOE) has sponsored this effort. More broadly, national laboratories from Argentina to Uzbekistan are involved in fusion research.

Magnetic Fusion Energy (MFE)

Tokamak MFE reactors have been running and creating brief fusion conditions in the United States and elsewhere for more than 30 years. Their properties are becoming better understood every day, thanks in part to American advances in supercomputing.

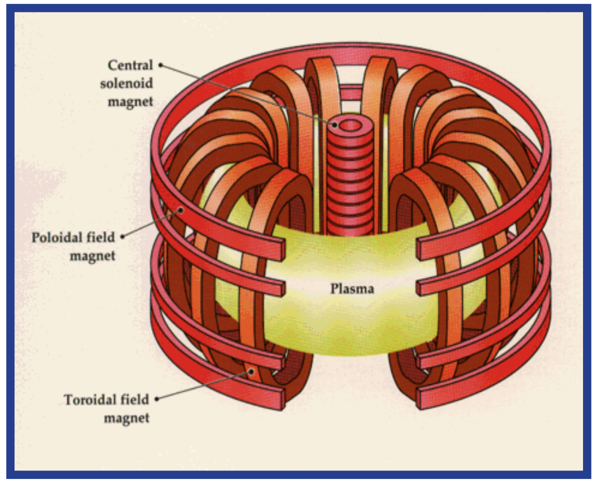
In China and South Korea, new superconducting MFE machines (designed with American help) now surpass any such devices now available in America.

A major international research machine, the "ITER," is now being built in France to test scaling-up tokamak designs to power plant size (though not power plant function).



PPPL LTX--A view through the Princeton Plasma Physics Laboratory's Lithium Tokamak Experiment (LTX) by Elle Starkman/Princeton Plasma Physics Laboratory Office of Communications

When fully operational beginning in 2027, ITER, a purely research device, should produce 500 megawatts of fusion power for periods of minutes—about 5 to 10 times the power input. The total project cost is estimated in excess of $20 billion.



The United States has just 9% and $2.8 billion lifetime participation in this program, the same as South Korea or India.

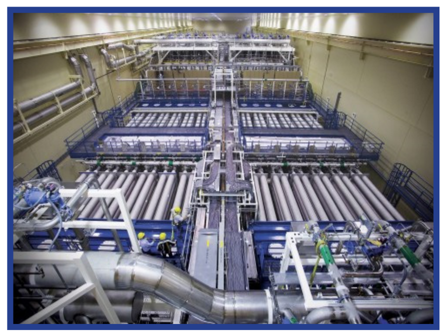
However, the preliminary design of an American magnetic pilot plant ("PILOT") is underway.

This high-duty cycle plant, with net power production, could become operational before ITER begins pulsed operation with fusion fuel.

This development team, based at the Princeton Plasma Physics Laboratory, is ready to move forward rapidly, given funding.

Inertial Confinement Fusion (ICF)

At Lawrence Livermore National Laboratory in California, DOE-sponsored work under the banner of the National Nuclear Security Administration (NNSA) has brought the National Ignition Facility (NIF) into operation.



NIF Laser Bay--Seen from above, each of NIF's two identical laser bays has two clusters of 48 beamlines, one on either side of the utility spine running down the middle of the bay. Credit: Lawrence Livermore National Laboratory

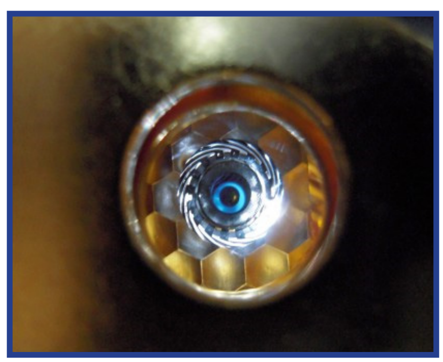
Construction was completed in 2009, following an investment of roughly $3.5 billion.

The demonstrations in the NIF are being used as the basis for design of a laser-driven power plant known as LIFE (Laser Inertial Fusion Energy). A board of executives from utility companies across the U.S. is guiding this project.

The NIF is within months (not years) of achieving ignition and net energy gain. This will beat ITER by at least 15 years.

A first-generation LIFE facility would deliver 400 MW of net electricity to the grid. The technology is scalable to 1500 MW – enough to power a city.

LIFE could start construction tomorrow and be operational within 12 years. This team is ready to proceed, given funding.



Laser's-Eye View of the NIF Target--A view of a cryogenically cooled NIF target as 'seen' by the laser through the hohlraum's laser entrance hole.

<u>Supporting Technologies</u>:

Because a fusion power plant will subject its components to unprecedented thermal, magnetic, electrical, and radiation demands, the widespread deployment of fusion would benefit greatly from rapid access to a Component Test Facility (CTF).

Though not designed to yield net power, such a device would develop and refine materials and technologies for the long-term deployment of fusion energy.

This CTF can be operational in five years. Teams at Oak Ridge, Sandia, and General Atomics have designs ready to proceed, given funding.

Although a small number of specific laboratories are named above, it should be noted that significant fusion research is ongoing across America.

A major fusion effort would be truly a national employment program. The National Ignition Facility, for example, involved 3,000 vendor partners from 47 U.S. states.

What will American Fusion Leadership Cost?

To achieve a fusion power demonstration of the kind described above would require a total investment of approximately $30-40 billion invested over a period of about 15 years.

This breaks out approximately as:

- $15 billion for an American magnetic pilot plant ("PILOT") and Component Test Facility (CTF);
- $10 billion for Laser Inertial Fusion Energy ("LIFE"); and
- $10 billion for associated and necessary research and development activities.

In addition, the United States has a commitment of an additional $2.8 billion to support our small fraction of the ITER program.

In constant dollars, the above investment is less than one-third the cost of the Apollo program that put a man on the moon—a program that, it should be noted, once involved fully six percent of all the scientists and engineers in the country.

The sum is less than invested recently to maintain the viability of General Motors, and only about 10% of the cost of saving the nation's banks.

It would be invested over a period of years, but would require a stable funding platform to enable rational planning and staff recruitment and development.

Are There Reasons for Immediate Action?

Apart from the obvious need for energy independence achieved from clean and inexhaustible sources, there are two additional issues calling for action: American competitiveness and nuclear proliferation.

China has a major program in fusion based on the EAST superconducting tokamak and plans for breakeven machines. They have announced a fast-track goal of net-power demonstration facilities in the 2021-2040 time frame, and the enrollment 1,000 graduate students in fusion studies. In America there are barely 400.

South Korea has the superconducting KSTAR tokamak and has announced plans to supply power to their grid in the 2040s. Japan, with its JT60-SA, likewise intends to "lead the world." The Europeans have ITER and an active public support organization.

By inaction, the United States will accept a position in the second tier; a customer, not a seller of fusion energy technology.

The second and very strong reason for rapid action is based on recent analysis from Lawrence Livermore Laboratory of the consequences of increasing dependence on conventional fission power on worldwide stocks of plutonium.

Increasing energy demand, and the relative cheapness of nuclear power even compared to coal, may drive nations toward uranium and fission.

Experience shows that countries with fission nuclear reactors will tend toward reprocessing fuel and purifying plutonium.

According to one report, a ten-year delay in commercialization of fusion power, or moving first implementation from the 2030s to the 2040s, would result in the additional availability of 800,000-4,000,000 kilograms of plutonium by the year 2100. Just 8 kilograms is enough to make a bomb.

"Leakage" of just one one-hundredth of one percent of this plutonium will create an unacceptable added risk of nuclear terrorism. In this country, loss of such a magnitude has already been documented. The major implications for national security need no emphasis.

What Does Industry Say?

The Electric Power Research Institute (EPRI), which brings together scientists and engineers to conduct research and analysis relating to the generation, delivery, and use of electricity, takes fusion seriously.

EPRI is presently examining the most viable methods for early (10-15 year) demonstration of fusion power.

EPRI's members represent more than 90 percent of the electricity generated and delivered in the United

States. Principals of several of these companies have been instrumental in the design of the LIFE pilot facility.

What are the Potential Strategic Gains?

At the strategic level, creation of a national priority effort for rapid development and deployment of fusion energy will constitute a reaffirmation of American technological preeminence in the world.

It will demonstrate that American exceptionalism is not just a slogan, but is expressed in action.

Success will establish absolute energy independence for this country.

The result will have a direct impact on the lives of people everywhere. As exportable technology, fusion will allow rapid access to low-cost, carbon-free, and nuclear proliferation-free energy to all nations.

What are the Potential Technical & Commercial Gains?

The development of fusion energy will be accompanied by major scientific and engineering achievements.

These include advances in superconductors for application to a wide range of industrial processes, compact super-power lasers and new high-efficiency semiconductor light sources, large- and small-scale robotics, and major advances in supercomputing and modeling as applied to fluid flows and heat transfer in any system.

In system dynamics and project management, the fusion program will demand exceptional skills and require the training of a cadre of leaders.

Young people just entering high school will see a great future in science and engineering as applied to local and national needs and choose careers accordingly.

Indeed, in a dozen years, these young workers could take their places as team members with advanced degrees or as technicians with skills appropriate to this new era.

What is the Department of Energy Doing Now?

The United States Department of Energy (DOE) is the major funder of fusion energy research through both the Office of Fusion Energy Sciences (OFES), largely directed to Magnetic Fusion Energy (MFE), and the National Nuclear Security Administration (NNSA), largely directed to Inertial Confinement Fusion (ICF).

The lack of DOE political will, strategic push, and planning has had a major impact on slowing of U.S. commercialization.

Under OFES, America's major MFE resources, ALCATOR C-Mod at MIT, NSTX at Princeton, and

DIII-D at General Atomics in San Diego, are presently only funded for 50% utilization.

At DIII-D there is a reported four-year experimental backlog due to funding constraints. Other facilities have been closed for lack of funding.

Overall the OFES fusion budget is less, in constant dollars, than in the 1980s.

In 2003, OFES commissioned its Fusion Energy Science Advisory Committee (FESAC) to prepare a "Plan for the Development of Fusion Energy." FESAC's thoughtful 82-page report, delivered in March of 2003, was never implemented.

In February 2007, the DOE Office of Science asked FESAC to review "…the issues arising in the path to DEMO…" [i.e. a demonstration fusion power plant]. The then undersecretary also indicated that a second request would be forthcoming for a long term strategic plan.

FESAC responded with a thorough 209-page report entitled, "Priorities, Gaps and Opportunities" in October 2007.

The recommendations in this report have not been implemented.

No strategic plan has yet been requested.

Indeed, the Department of Energy guidance has asked that the American program be slowed so as not to get ahead of the international program.

Progress under the NNSA has been more focused, but there is no budget as yet to move forward with LIFE for energy applications.

The National Ignition facility (NIF) was begun in 1997 and construction of this, the world's most powerful laser system, was completed in 2009. This project was designed to study fusion reactions related to maintenance of the American nuclear deterrent.

A program of experiments directed toward ignition of a fuel pellet by 2012 is now underway. DOE has asked the National Academy of Science to study whether there is a future in this approach to power production. Their report is not expected for two years.

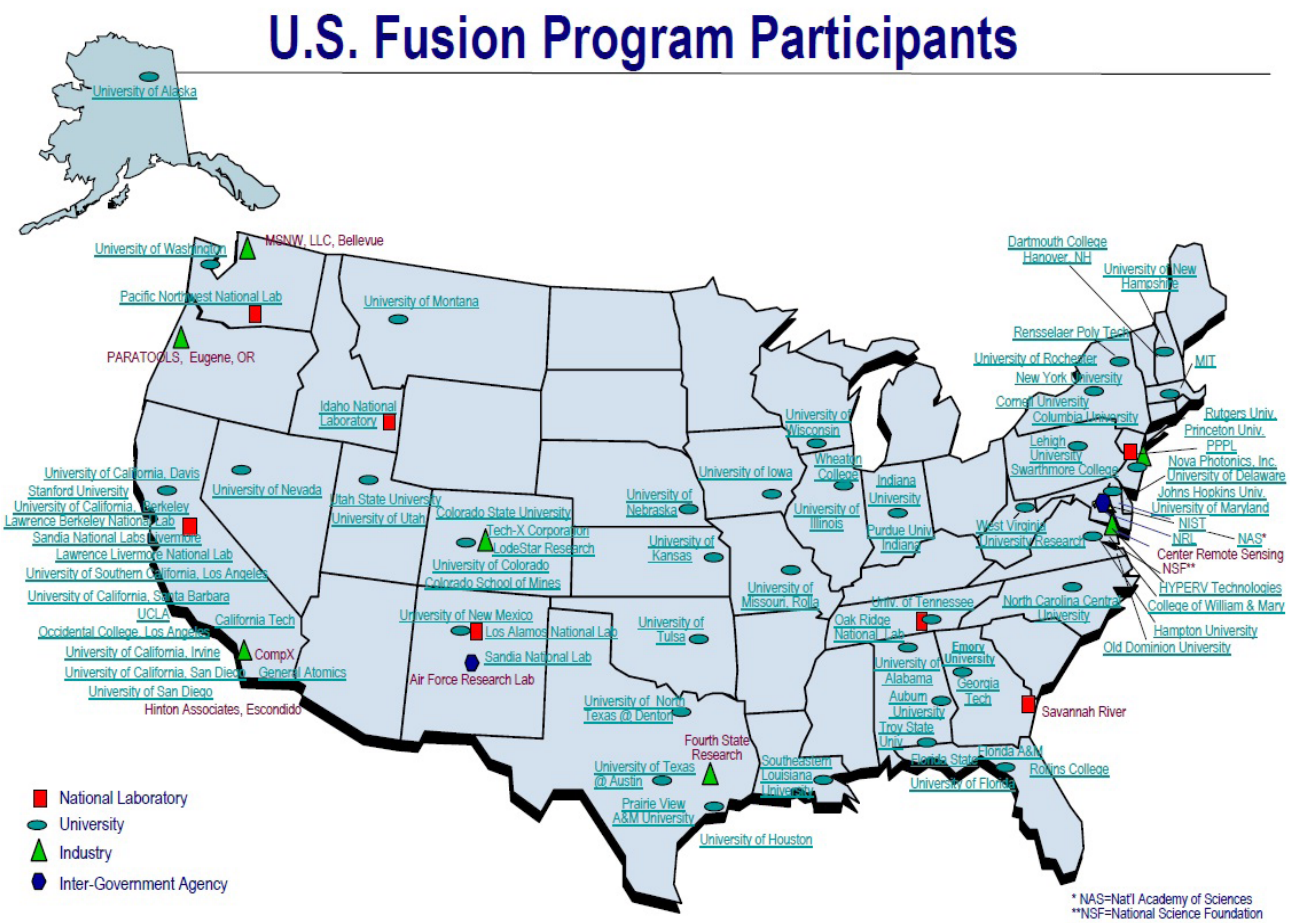
What is the Environmental Impact of Fusion?

Fusion energy seems nearly ideal from an environmental viewpoint. Fusion systems have no chain reaction or meltdown risk. They produce no long-lived radioactive waste stream. They produce no greenhouse gases.

Fusion plants would take no more space than conventional coal- or gas-fueled facilities, and they can be located near population centers where power is needed. Thus they need no long-distance transmission lines.

Because they can produce base-load power, no energy storage system is required.

The fuel supply for a one billion watt (1 Gw) plant would amount to less than two pounds per day.



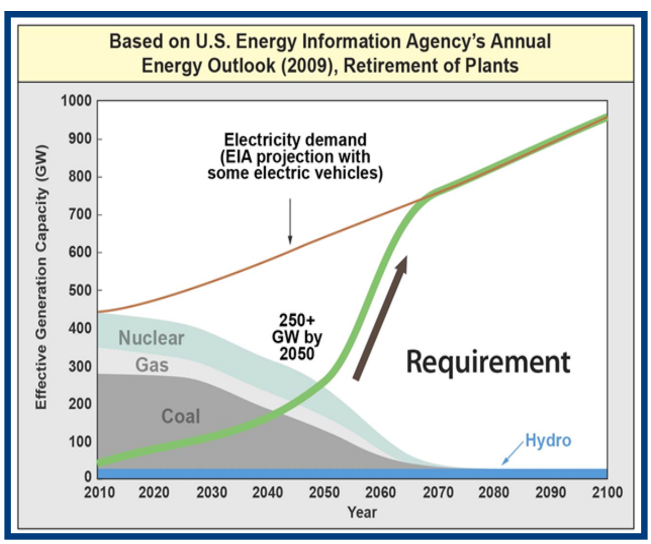


Image Sources: US Department of Energy

What are the Objections to a Fusion Program?

"Fusion is always 50 years in the future."
Fifty years of research and development have led to utility-scale plants now being built or on the drawing board. Commercialization is going to begin in 30 years, even if not in America. Other countries aren't waiting.

"We don't need it. There is lots of coal, gas, oil and uranium, not to mention solar and wind, etc."
Fossil fuels are not limitless and have considerable downsides in both extraction and use. Many countries have little or none of their own, and competition for increasingly scarce supplies destabilizes the world.

Solar and wind are important in the shorter term, but never for base-load power—the power that is "always on."

Dependence on fission power leads to risk of both accident and uncontrolled proliferation.

"Fusion power can never be commercially competitive."
Economic studies both in the U.S. and Europe have concluded that fusion electricity will be cost competitive as soon as available.

(See European Fusion Development report EFDA-RP-RE-5.0.) The scale of Asian efforts in fusion attests to a clear appreciation of commercial practicality.

"Fusion is just too expensive to develop. If it weren't then industry would be doing it."
A world-class effort is not nearly in the expense class of recent government anti-recession programs.

The money will be spent over 15 years, supporting American skills, jobs, energy independence, and world leadership.

Industry does not have the mechanisms, resources, or regulatory structure to do the development job.

Going to the moon cost about $140 billion in today's dollars, yielding untold wealth in industrial technology—beyond international prestige.

"America is too far behind already, why try?"
We have a clear choice now before us as a nation—leadership, or second-rate status. We have leadership in the science underpinning one key route to fusion, and are recognized experts across the board. But we lack the programs to capitalize on this.

We can be creators and exporters in this, the largest market in the world, or we can be followers and customers sending overseas not our products, but our treasure.

We have fallen far behind in both solar and wind.

We have a solid basic position now in fusion, but are at immediate risk of being overtaken.

The American temperament wants a new Apollo, not capitulation.

"The American public is not ready for such a challenge."
The American people are worried that we have lost our position in the world; that we have given up the "can-do' spirit that made this country great.

Many doubt that our political leadership still believes in American exceptionalism. In energy—in fusion—we can regain our position.

The public is ready, but it has not been challenged.

"Fusion is too risky. It may never reach the goal."
This was said of going to the moon. This was said of the Manhattan Project. In fact, the biggest risks are that someone else will succeed before us.

Fusion has now become a worldwide race.

The question is not whether, but when and where. No one knows now just what commercial plants will look like, but then again, today's aircraft don't look much like the Wright Flyer, either.

There can be no better statement about risk than that provided in the October 2007 FESAC report summary:

> "The main risk faced is delay in deployment of fusion energy due to unforeseen technical difficulties in carrying out the plan, to costs which make the first generation of fusion reactors economically uncompetitive or to insurmountable problems along the development path chosen. At some point delay is equivalent to failure, as government and industry conclude that no solution will be forthcoming. That is, **a program carried out so slowly and deliberately as to never make a wrong step may carry more risk than one which tries to move more boldly and accepts that it will make some mistakes and follow some blind paths**. **The principal strategy to mitigate risk is to implement a sufficiently broad program so that alternative approaches or technologies are available at each step"** (p 202) [emphasis added].

Resources:

Website: www.fusion2020.org
Twitter: @fusion2020

Princeton Plasma Physic Laboratory
http://www.pppl.gov

National Ignition Facility
https://lasers.llnl.gov

Academy of Engineering – Challenges for the Future
http://www.engineeringchallenges.org

DOE Map of U.S. fusion sites:
http://www.sc.doe.gov/ofes/Maps/FusionInstitutionsMapH-2.pdf

Online References:

PILOT, LIFE, Materials testing facility
http://fire.pppl.gov/fpa09_Goldston_Pilot_Plant.pdf

https://lasers.llnl.gov/about/missions/energy_for_the_future/life/

http://fire.pppl.gov/fpa10_LIFE_Dunne.ppt

http://fire.pppl.gov/fpa10_FNSP_Abdou.ppt

FESAC Plan 2003
http://www.ofes.fusion.doe.gov/More_HTML/FESAC/DevReport.pdf

FESAC Priorities, Gaps, and Opportunities 2007
http://www.science.doe.gov/ofes/FESAC/Oct-2007/FESAC_Planning_Report

International activities:
http://nds121.iaea.org/physics/index.php

http://fire.pppl.gov/fpa_annual_meet.html

European activities, ITER and economics assessment
http://fusionforenergy.europa.eu

http://fire.pppl.gov/fpa10_ITER_Status_Campbell.ppt

http://www.hiper.org

Building a New American Arsenal

The American Security Project (ASP) is a bipartisan initiative to educate the American public about the changing nature of national security in the 21st century.

Gone are the days when a nation's strength could be measured by bombers and battleships. Security in this new era requires a New American Arsenal harnessing all of America's strengths: the force of our diplomacy; the might of our military; the vigor of our economy; and the power of our ideals.

We believe that America must lead other nations in the pursuit of our common goals and shared security. We must confront international challenges with all the tools at our disposal. We must address emerging problems before they become security crises. And to do this, we must forge a new bipartisan consensus at home.

ASP brings together prominent American leaders, current and former members of Congress, retired military officers, and former government officials. Staff direct research on a broad range of issues and engages and empowers the American public by taking its findings directly to them.

We live in a time when the threats to our security are as complex and diverse as terrorism, the spread of weapons of mass destruction, climate change, failed and failing states, disease, and pandemics. The same-old solutions and partisan bickering won't do. America needs an honest dialogue about security that is as robust as it is realistic.

ASP exists to promote that dialogue, to forge consensus, and to spur constructive action so that America meets the challenges to its security while seizing the opportunities the new century offers.

ASP

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