WHITE PAPER

FUSION ENERGY:

An Opportunity for American Leadership and Security

January 24, 2011

During the last 30 years, researchers around the world have made great and generally unrecognized progress toward achieving controlled fusion energy. This is the energy created by forcing atomic nuclei together and for which the primary fuel is derived from ordinary water. Fusion power is safe, and clean, and when commercialized, will solve the world's energy problems.

Researchers now agree that engineering challenges, as much as science, are the primary obstacles to realizing fusion's potential. The European Union, as well as China, Japan, and South Korea 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 not been implemented. The implications of delay include increased risk of proliferation and continuing energy dependence.

Establishing a national priority level of effort for fusion, together with support for nearer-term energy programs, can re-establish American technological pre-eminence, achieve absolute energy independence and develop next generation energy for the world.

What is fusion energy?

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. (Conventional nuclear power is obtained by breaking apart heavy nuclei, such as uranium, in a chain reaction.) 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 is available as heat to make steam to run a conventional electric generator, to make hydrogen fuel, or

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it can be used directly to desalinate seawater, for example. In some theoretical fusion designs, electricity can even be made directly without the need for a steam turbine.

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.

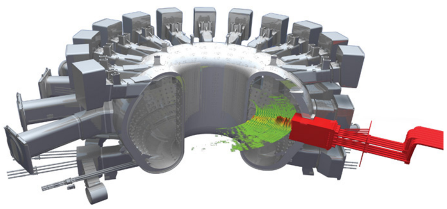
In a Magnetic Fusion Energy (MFE) machine, strong magnetic fields suspend the reacting particles in a doughnut-shaped (toroidal) chamber. Such "tokamaks" have been built over many years in several countries and great advances have recently been made in this technology. A major international research machine, the "ITER", is now being built in France to test scaling-up tokamak designs to power plant size (though not power plant function). When fully operational beginning in 2027, this device should produce 500 megawatts of fusion power for periods of minutes—about 5 to 10 times the power input. Total project cost is estimated in excess of $20Bn. The United States has just 9% and $2.8bn lifetime participation in this program, about the same as South Korea or India.

The second mainstream approach uses multiple high energy laser beams to heat and compress a tiny pellet of fuel. This Inertial Confinement Fusion (ICF) technique is now coming to fruition as a nearly all-American project in California. "Ignition" experiments planned for this year are expected to yield pulses of fusion energy equal to that used by the huge laser array to trigger them—this would be the first achievement of "breakeven."

None of the systems now in operation or under construction has been designed to yield more energy to the power grid than is put in to drive the process. However both MFE and ICF, and other theoretical designs, define clear pathways to the development of commercial utility-scale power plants for installation around the world before the middle of this century. Such next-generation power sources, built in conjunction with other nearer-term energy sources, could change the world.

Are we ready to proceed?

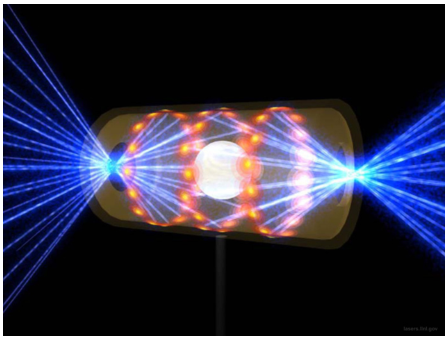
In 1980, Congress passed an authorization bill that envisioned a demonstration fusion power plant by the year 2000. This visionary program was never funded and subsequently died. It may be argued that it was premature. However, in the thirty years since, and particularly in the last decade, dramatic progress has been made in both the theoretical and practical aspects of fusion energy. In the United States this work has been sponsored by the Department of Energy (DOE). More broadly, national laboratories from Argentina to Uzbekistan are involved in fusion research. 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 computer science. In China and South Korea new MFE machines with superconducting magnets designed with American help now surpass any devices now available in America. The ITER MFE project in France is expected to activate in 2019, and operate for short periods with full fusion conditions by 2027.



Cross section of the ITER tokamak. Image credit: Sean Ahern/U.S. ITER Project Office.

Based on current research, and participation in the design work for all these fusion reactors, 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 team, based at the Princeton Plasma Physics laboratory, is ready to move forward rapidly, given funding.

At Lawrence Livermore Laboratory in California, DOE sponsored work under the banner of the National Nuclear Security Administration has brought the National Ignition Facility (NIF) into operation. This ICF demonstration has supplied the basis for design of a laser driven power plant based on utility company requirements. This first-generation facility, designated "LIFE," would initially deliver upwards of 400 megawatts of power, and be directly upgradeable to 1500 megawatts net electrical output from the same facility, while also serving as a test bed for materials and target handling. It could be operational within 10 to 13 years. This team is ready to proceed, given funding.



Artist's rendition of lasers firing on the NIF target pellet. Image Credit: U.S. DOE.

Because a fusion power plant will subject its components to unprecedented thermal, magnetic, electrical and radiation demands, both of these programs need rapid access to a Component Test Facility (CTF). Though not designed to yield net power, such a device would generate continuous fusion conditions in an environment of interchangeable parts. This CTF can be operational in five years, to support the ongoing detail design and construction of both PILOT and LIFE. 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 work in manufacturing and supporting technologies is ongoing across America. Construction of the NIF involved 3,000 vendors from 47 U.S. states. A major fusion effort would be a national employment program.

What will American fusion leadership cost?

To achieve a fusion power demonstration of the kind described above would require a total investment of approximately $35 billion over a period of about 15 years. This breaks out as $15Bn for PILOT and CTF, about $5-8Bn for LIFE, and about $10Bn for associated and necessary research and development activities. In addition, the United States must meet its commitment of an additional $2Bn to support our small fraction of the ITER program.

In constant dollars, this investment is less than the 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.

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 pre-eminence in the world. Success will establish absolute energy independence for this country. It will demonstrate that American exceptionalism is not just a slogan, but is expressed in action. It will be more difficult than going to the moon, but the result will have a more 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. The sense of shared purpose and shared achievement will not only draw Americans together, but will show us as friend to the Earth and all its inhabitants.

What are the potential technical/commercial gains?

The development of fusion energy requires major scientific and engineering achievements. These include advances in superconductors including high temperature and high magnetic field types with appropriate connectors; compact super-power lasers and new high-efficiency semiconductor light sources; large and small scale robotics, new neutron-tolerant structural materials appropriate to conventional nuclear as well as fusion environments; 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 skilled technicians with skills appropriate to this new era.

Are there reasons for immediate action?

There are two critical issues calling for action; competition and nuclear proliferation.

China has a major program in fusion based on the EAST superconducting tokamak and plans for break-even machines. Over the last ten years, China has increased its program ten-fold, and now enrolls more than twice as many graduate students in this area than the United States. They have announced a fast-track goal of net-power demonstration facilities in the 2021-2040 time frame. The U.S. has already lost its position in solar and wind to the Chinese. 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 energy technology.

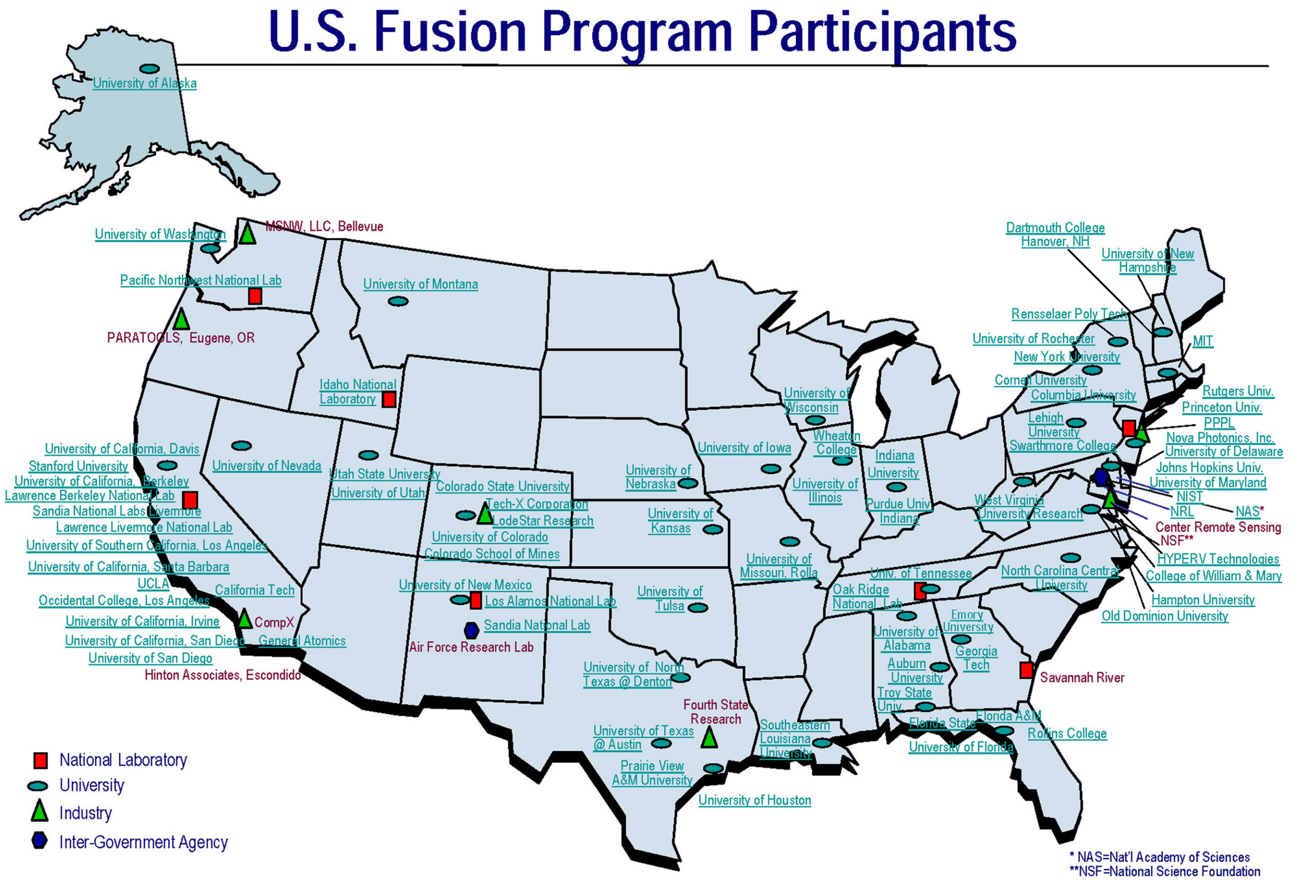
The second, and very strong, reason for rapid action is based on a recent analysis from Lawrence Livermore Laboratory of the consequences of increasing dependence on traditional nuclear power on worldwide stocks of plutonium. Increasing energy demand, and the relative cheapness of nuclear power, even compared to coal, will drive nations toward uranium and fission. Experience shows that countries with such reactors will tend toward reprocessing fuel and purifying plutonium. According to the report, a ten-year delay in commercialization of fusion power, from first implementation in the 2030s to the 2040s, would result in the additional world-wide availability of from 800,000 to 4,000,000 kilograms of plutonium by the year 2100. Just 8 Kg 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. The major implications for national security need no emphasis.

What is DOE doing now?

The United States Department of Energy Office of Science is the major supporter of fusion energy research through both the Office of Fusion Energy Sciences (OFES), largely directed to magnetic fusion (MFE), and the National Nuclear Security Administration (NNSA), largely directed to inertial confinement fusion (laser ICF).

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.



Source: U.S. Department of Energy

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.

Progress under the NNSA has been more focused. The National Ignition facility (NIF) was begun in 1997 and construction of this, the world's most powerful laser system, was completed in 2010. 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 in 2010 is now underway. Based on this progress, 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 radioactive waste stream. They produce no greenhouse gas. Fusion plants would take no more space than conventional coal or gas fueled facilities, and 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. And the fuel supply for a one billion watt (1 Gw) plant would amount to less than one pound per day.

What are the objections to a fusion program?

"Fusion is always 50 years in the future."

Fifty years of research and development has 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 they have problems providing baseload 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 Anklam paper attached and 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 here over 10 to 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 Bn 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 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 were that someone else would succeed before us. Fusion has now become a worldwide effort. The question is not whether, but when, and where. No one knows now just what commercial plants will look like, but then, 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].

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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.

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