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REPORT IN BRIEF

An Assessment of the Prospects for Inertial Fusion Energy

Board on Physics and Astronomy · Board on Energy and Environmental Systems · Division on Engineering & Physical Sciences · **February 2013**

The potential for using fusion energy to produce commercial electric power was first explored in the 1950s. Harnessing fusion energy offers the prospect of a nearly carbon-free energy source with a virtually unlimited supply of fuel. Unlike nuclear fission plants, appropriately designed fusion power plants would not produce the large amounts of high-level nuclear waste that requires long-term disposal. Due to these prospects, many nations have initiated research and development (R&D) programs aimed at developing fusion as an energy source. Two R&D approaches are being explored: magnetic fusion energy (MFE) and inertial fusion energy (IFE). This report describes and assesses the current status of IFE research in the United States; compares the various technical approaches to IFE; and identifies the scientific and engineering challenges associated with developing inertial confinement fusion (ICF) in particular as an energy source. It also provides guidance on an R&D roadmap at the conceptual level for a national program focusing on the design and construction of an inertial fusion energy demonstration plant.

Introduction

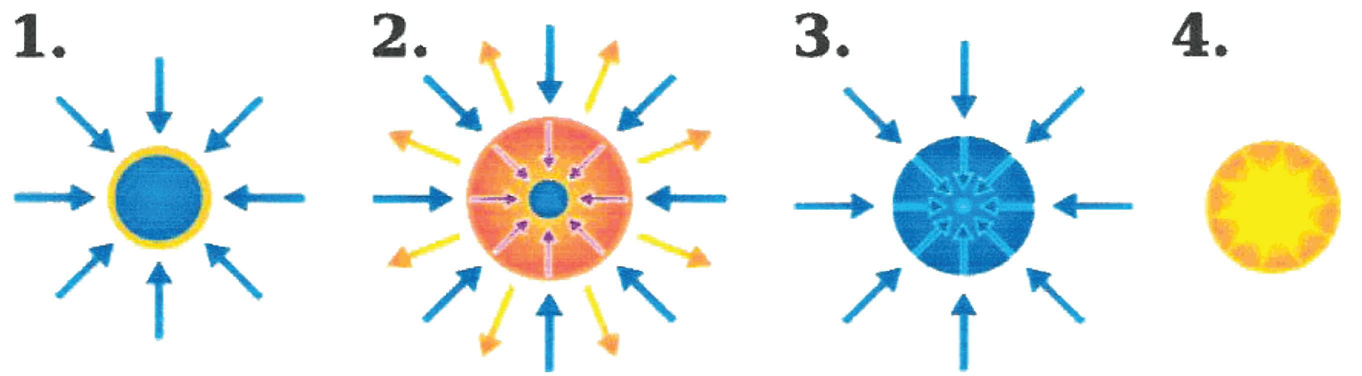
The potential benefits of fusion power are undeniable. There is, after all, sufficient fusion fuel to supply the entire world's energy needs for thousands to millions of years. Furthermore, fusion power plants would have a relatively small environmental impact since they would not produce greenhouse gases during operation or, if appropriately designed, long-lived radioactive waste. However, achieving fusion at the cost and scale needed for commercial energy generation remains a major scientific and engineering challenge, and commercial power production remains decades away.

On a fundamental level, the prospects for using inertial fusion as a commercial energy source depend on the ability to implode a fuel target or capsule to a high enough temperature and pressure to initiate a fusion reaction that could release on the order of 100 times more energy than was delivered to the fuel. Recognizing the difficulty and uncertainty of achieving inertial fusion energy, the report concludes that the potential benefits of IFE justify it as part of the long-term U.S. energy R&D portfolio.

Background on Inertial Fusion Energy

The current U.S. suite of inertial fusion facilities offers a unique opportunity to experiment at the "fusion scale" where fusion conditions are accessible for the first time. There are two alternative approaches to developing fusion as an energy source that are currently being explored: IFE and magnetic fusion energy. This report assesses the prospects for IFE, although there are some elements common to the two approaches. The study did not compare IFE to MFE or any other potential or available energy technologies (such as wind or nuclear fission).

To initiate fusion in either approach, deuterium and tritium fuel must be heated by an external energy source to over 50 million degrees and held together long enough for the reactions to take place. Ignition occurs when the energy produced by the fusion reactions is sufficient to heat the remaining fuel to fusion reaction conditions. At that point, no additional external heating source is needed, and the reaction in essence is self-sustaining until the fuel is depleted. Tritium (heavy heavy hydrogen) and deuterium (heavy hydrogen) are the fuels with the lowest energy threshold for fusion to occur. One liter of sea water contains enough lithium—from which tritium fuel is "bred"—and deuterium to make roughly 1 kWh of fusion energy. The two main approaches to fusion achieve these conditions differently: in magnetic confinement fusion, the low-density fuel is held indefinitely in a magnetic field while it reacts; in inertial confinement fusion (the basis of IFE), a small capsule/target of fuel is compressed and heated so that it reacts rapidly before it disassembles.



Simple schematic of the four stages of inertial confinement fusion via "hot spot" ignition.

Stage 1: Energy is delivered to the surface of a tiny hollow sphere (a few millimeters in diameter) of fusion fuel (the target). The blue arrows represent the driver energy delivered to the target—this is the laser light, x-ray radiation or particle beams that heat the outer yellow shell.

Stage 2: Orange arrows indicate the ablation of the outer shell, the pressure from which pushes the inner shell towards the center. The compression of the fusion fuel to very high density increases the potential fusion reaction rate.

Stage 3: The central low-density region, comprising a small percentage of the fuel, is heated to fusion temperatures. The light blue arrows represent the energy transported to the center to heat the hot spot. This initiates the fusion burn.

Stage 4: An outwardly propagating fusion burn wave triggers the fusion of a significant fraction of the remaining fuel during the brief period before the pellet explodes/disassembles. Steady power production is achieved through rapid, repetitive fusion micro-explosions of this kind.

Current Status of Inertial Fusion Energy R&D

U.S. research on ICF—the basis for inertial fusion energy—has been supported by the National Nuclear Security Administration (NNSA) primarily for nuclear-weapons stockpile stewardship applications. This research has benefitted inertial fusion for energy applications, because the two share many common physics challenges.

The principal research efforts in the United States are aligned along the three major energy sources for driving the implosion of ICF fuel pellets. These are: (1) lasers (including solid state lasers at NIF and the University of Rochester's Laboratory for Laser Energetics, as well as the krypton fluoride gas lasers at the Naval Research Laboratory); (2) heavy ion particle beams, being explored by a consortium of laboratories led by the Lawrence Berkeley National Laboratory; and (3) pulsed magnetic fields, being explored on the Z machine at Sandia National Laboratory.

The scientific and technological progress in ICF has been substantial during the past decade, particularly in areas pertaining to the achievement and understanding of high-energy-density conditions in the compressed fuel, and in exploring several of the critical technologies required for IFE applications. For the first time, a research facility, the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory, conducted a systematic campaign at an energy scale that was projected to be sufficient to achieve ignition. Despite these advances, however, the minimum technical accomplishment that would give confidence that commercial IFE may be feasible—the ignition of a fuel pellet in the laboratory—has not been achieved as of the time of this report. While the committee considers the achievement of ignition as an essential prerequisite for initiating a national, coordinated, broad-based inertial fusion energy program, the committee does not believe that the fact that NIF did not achieve ignition by the end of the National Ignition Campaign on September 30, 2012 lessens the long-term technical prospects for inertial fusion energy.

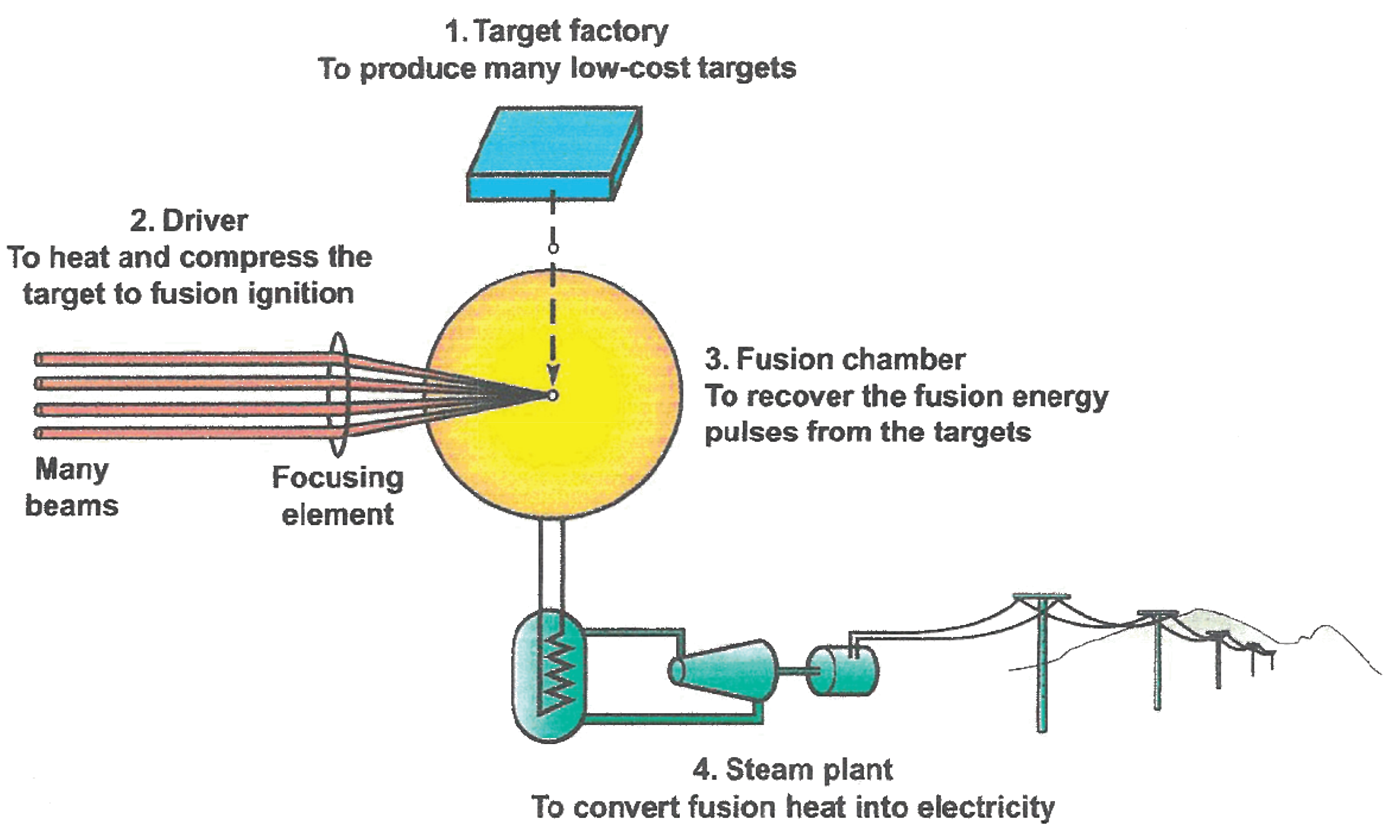
Factors Influencing the Commercialization of Inertial Fusion Energy

An IFE power plant must do much more than ignite a high-gain target. Commercial power production requires many integrated systems, each with technological challenges. It must make the targets, ignite targets repetitively, extract the heat, breed tritium from lithium, and generate electricity. Furthermore, it must do this reliably and economically. The fully integrated system consists of four major components: a target factory to mass-produce low-cost targets, a driver to heat and compress the targets to breed the tritium, and the steam plant to convert fusion heat into electricity. In addition, all of these components would need to operate over many years and with minimal downtime.

The cost of targets also has a major impact on IFE power plants. Very large extrapolations are required from the current state-of-the-art approaches to fabricating targets for ICF research to the capability needed to mass-produce inexpensive targets for IFE systems. As presently understood, an IFE power plant would have a high capital cost. Such plants would have to operate with a high availability—an achievement that is a major challenge for fusion energy systems. This would involve substantial testing of IFE plant components and the development of sophisticated remote maintenance approaches.

Therefore, economic analyses of IFE power systems should be an integral and continuing part of national program planning efforts, particularly as more cost data become available. A comprehensive, systems engineering approach should be used to assess the performance of IFE systems. Such analyses should include the use of the Technology Readiness Levels (TRLs) methodology to help guide the allocation of R&D funds.

Schematic of the four major components of an IFE power plant.



The Establishment of an Integrated National Inertial Fusion Energy Program

While there have been diverse past and ongoing research efforts sponsored by various agencies and funding mechanisms that are relevant to IFE, at the present time there is no nationally coordinated research and development program in the United States aimed at the development of IFE that incorporates the spectrum of driver approaches, the spectrum of target designs, or any of the unique technologies needed to extract energy from any of the variety of driver and target options. In the event that ignition is achieved at NIF or another facility, and assuming that there is a federal commitment to establish a national IFE R&D program, the DOE should develop plans to administer such a national program—including both science and technology research—through a single program office.

The DOE should use a milestone-based (as opposed to time-based) roadmap approach, based on TRLs, to assist in planning the recommended national IFE program. The roadmap would be aimed at creating a conceptual design for a demonstration facility, which would include operational capabilities similar to a commercial power plant and provide the fusion environment needed for testing materials. The report concluded that there has been technical progress on a broad front and that it would be premature to choose a particular driver approach—such as, laser, heavy-ion-beam, or pulsed-power drivers—as the preferred option for an IFE demonstration plant at the present time. A portfolio strategy hedges against uncertainties in future availability of alternatives due, for instance, to unforeseen circumstances.

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