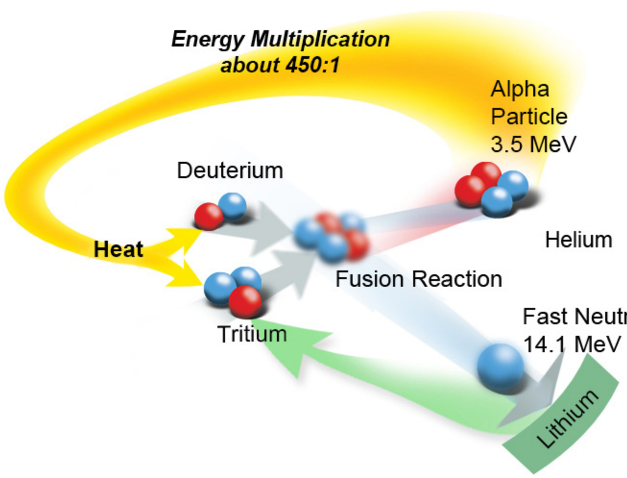
Hydrogen Fusion *An Opportunity for Global Leadership*

Hydrogen fusion, the process that powers our sun and the stars, is the most fundamental energy source in the visible universe. Directly, it provides sunlight, while indirectly it is the driver behind all "renewable" energies (solar-thermal and photovoltaic, wind, biomass and ocean-thermal). Even the fossil fuels (oil, gas and coal), which were derived over long periods of time from ancient biomass, are by-products of hydrogen fusion. The energy released during the fusion process theoretically represents a 450-to-1 gain over the energy required to heat hydrogen nuclei to the fusion point.



The Process of Hydrogen Fusion

In the late 20th century, following decades of scientific research, controlled power from hydrogen fusion was finally achieved, first in the United States at Princeton's Tokamak Fusion Test Reactor and later in Europe at the Joint European Torus. Nations representing over half the world population now have the science largely in hand. The remaining challenges involve a reduction-to-practice. This requires scaling up the fusion reaction to sustain "burning plasma", wherein the power released is re-absorbed and dominates heating of the plasma. Further scientific research will be needed to optimize processes, as well as to train a skilled workforce that can design, operate and maintain fusion energy systems.

Safe, Clean and Virtually Unlimited Energy

Electric power generation by hydrogen fusion can become a low risk, environmentally benign and essentially inexhaustible energy source of the future. Not only does the threat of nuclear proliferation diminish in comparison to fission and fission-fusion hybrid systems[1] but also pure fusion is safer, because there is no threat of a non-recoverable "meltdown" under runaway reactor conditions; the plasma simply self-extinguishes. Fusion also cleanly consumes the fuel isotopes, hydrogen-2 (deuterium) and hydrogen-3 (tritium), without producing long-lived, high-level radioactive wastes. Tritium products, such as gas, dust and particles trapped on tokamak surfaces, have a radioactive half-life of ~12 years, in comparison to fission wastes having a lifetime of up to 10,000 years. Fusion materials can be tailored so that only low-level wastes result[2], whereas this freedom is not available in fission processes. As a result, fusion long-lived wastes can be low-level, in the form of radioactive plant structure and components, and these have already proven manageable.

Deuterium is easily extracted from seawater, and tritium is produced in the hydrogen fusion fuel cycle by transmutation of lithium in a surrounding blanket. The lithium required to form the blanket is also readily available from compounds occurring naturally in minerals and seawater. Currently, it is produced primarily from granitic rock types.

At the Turning Point

One might ask, "What has changed to now bring the practical application of hydrogen fusion within reach?" The answer lies in recognition that scientific research has advanced significantly, particularly with the emergence of disruptive technologies that have allowed rapid advances to occur over relatively short time frames. The unprecedented measurement capability of 21st century diagnostic instruments has made it possible to obtain previously unimaginable data from real-life experiments and validate complex scientific models developed in laboratories around the world. Using experimentally validated models, high-performance "supercomputing" can calculate the extremely complex large-scale flows, turbulent small-scale flows and energetic particle dynamics involved in fusion processes. As a result of these disruptive technologies, fusion is no longer constrained by the science. *Funding for technology development and demonstration has become the limiting factor.*

Advisory committees to the US government recognized this opportunity early in the last decade, and called for production and study of burning plasma as the next major step toward achievement of fusion energy.[3,4] This phase of development focuses on achieving power on an industrial scale, sustaining and controlling burning plasma, and demonstrating a net gain in the basic energy conversion process.

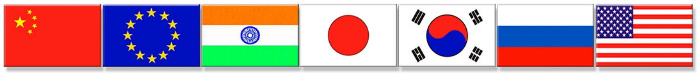
[1]Goldston, R.J., et al., *Proliferation Risks of Fusion Energy: Clandestine Production, Covert Production, and Breakout*, 9th IAEA Technical Meeting on Fusion Power Plant Safety, July 2009, Vienna, Austria.

[2]Petti, D.A., et al., Recent accomplishments and future directions in the US Fusion Safety and Environmental Program, Nucl. Fusion 47 (2007) S427-S435.

[3]U.S. National Academy of Sciences, Burning Plasma Assessment Committee, *Burning Plasma: Bringing a Star to Earth*, The National Academies Press, ISBN 0-309-52766-X, Washington, D.C., 2004.

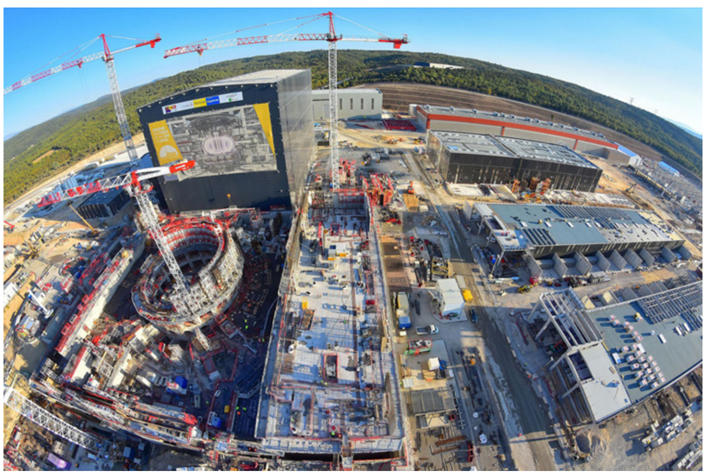
[4]U.S. Department of Energy, Fusion Energy Sciences Advisory Committee, *A Plan for the Development of Fusion Energy*, DOE/SC-0074, Washington, D.C., 2003.

International Partnerships



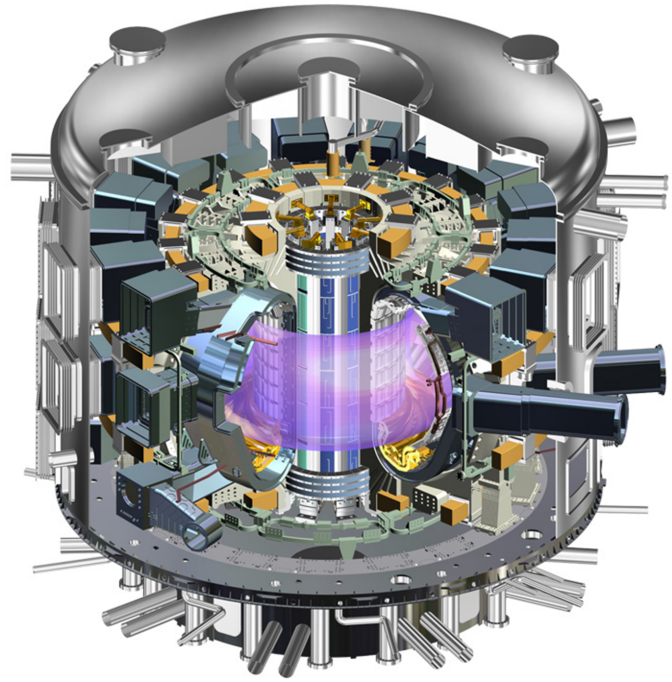
In 2007, nations representing over half the world population (China, Europe, India, Japan, Russia, South Korea, and the US) agreed to partner on design, construction, operations, and decommissioning of an ~500 Megawatt, industrial-scale fusion system termed "ITER" (Latin for "the way").

This landmark experimental plant is now rising up from the ground aside its headquarters in southern France, and is scheduled for plasma operations in the coming decade. The US ITER Project Office at Oak Ridge National Laboratory leads the effort to provide US contributions to ITER, which also contributes to developing a US national industrial capacity to produce fusion energy in the future for domestic purposes.



ITER Construction Site (October 2017)

The US contribution to the worldwide ITER Project is ~9% of the total cost, while the US has access to 100% of the scientific and technological benefits. Presently, there are no new large-scale national fusion research facilities planned in parallel for the US. This is in contrast to the situation overseas in China, India, Japan, and South Korea where new fusion research and development (R&D) facilities are either already operating or under construction.



The ITER Tokamak

Bottom Line

Michael Faraday invented the first electric generator in 1831, and by 1902 there were 3,620 central generating stations operating in the US.[5] Following decades of R&D, widespread and low-cost electrification successfully powered US industry into the forefront of a 20th century global economy. Today, the US is not alone in pursuit of a new generation of safe and clean energy that continues to represent a fundamental factor of production. However, US investment in fusion energy science and technology is falling behind, as overseas projects are expanding. An opportunity for US global leadership remains, once again based on decades of research and development, and the lessons of history should guide our choice as a nation.

"With the potential to provide clean baseload electrical energy without a fuel-resources constraint, fusion can be an important component of a long-term shift away from fossil fuels . . . in addition to providing an attractive solution to our energy needs, fusion offers the potential to drive the development of a new industry".[6]

[5]Wikipedia, Electrification, accessed Apr 16, 2013.
[6]Statement of Thomas E. Mason, Director, Oak Ridge National Laboratory, Hearing on the Next Generation of Fusion Research, U.S. House of Representatives, Washington, D.C., October 29, 2009.