For more information, please visit
science.energy.gov/fes

Fusion Energy Sciences at DOE

The mission of the Fusion Energy Sciences program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to achieve fusion energy. This is accomplished by studying plasma and its interactions with its surroundings across wide ranges of temperature and density, developing advanced diagnostics to make detailed measurements of its properties and dynamics, and creating theoretical and computational models to answer essential physics questions. The economic benefits of non-fusion applications of Fusion Energy Sciences are vast and widespread.

U.S. DEPARTMENT OF ENERGY | Office of Science

Fusion Energy Sciences at the
U.S. Department of Energy

The Unexpected Benefits of Harnessing the Stars

Driven by curiosity and
pursued in wonder

The Science at the Heart of the Star

At the center of all stars, including our sun, fusion occurs. Hydrogen and other simple elements are heated enough that their electrons have been knocked free of their atomic nuclei, forming an ensemble of positively charged ions and negatively charged electrons, known as a plasma, that can conduct electrical currents and respond to electric and magnetic fields.

The science of plasmas—the fourth state of matter—is elegant, far-reaching, and impactful. Comprising over 99% of the visible universe, plasmas are also pervasive.

Plasma is the state of matter of the sun's center, corona, and solar flares. Plasma dynamics are at the heart of extraordinary galactic jets and accretion of stellar material around black holes. Plasma physics describes the processes giving rise to the aurora that vividly illuminates the far northern and southern nighttime skies. Some practical applications of plasmas include various forms of lighting, more efficient electronics and transportation, and improved medical procedures.

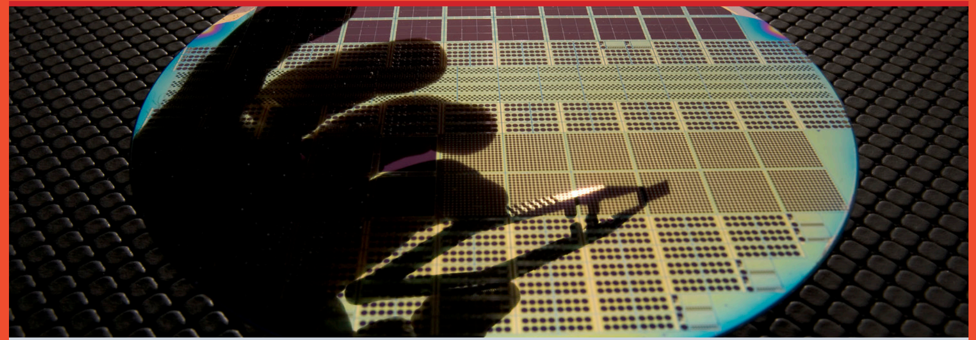
Spinoff Technologies from Fusion Energy Research

The reaction that fuels the stars—fusion—would be a source of energy that is unlimited, safe, environmentally benign, available to all nations, and not dependent on climate or the whims of the weather. In fusion, two hydrogen isotopes, deuterium and tritium, fuse to form a helium nucleus releasing a large amount of energy carried by a neutron. Significant resources—most notably from the U.S. Department of Energy's Office of Fusion Energy Sciences—have been devoted to pursuing that dream, and significant progress is being made. However, that is only part of the story.

Many basic science discoveries, while important by themselves and foundational in their fields, also yield spinoff applications or enabling technologies not envisioned by the scientists doing the original work. This is what makes investment in science like fusion energy research so powerful—the impact extends well beyond the laboratory.

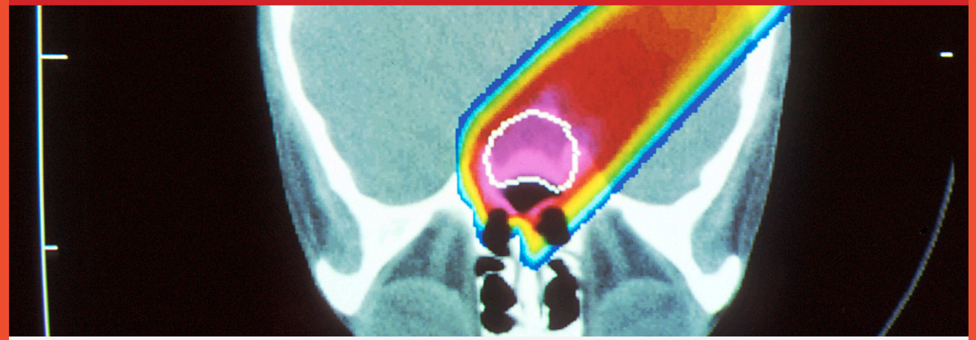
In the quest for fusion energy, numerous new scientific frontiers and technologies have been, and are being, created. Many of these innovations and insights are proving to be invaluable in applications far afield from fusion energy research.

Spinoff technologies from fusion investments have had a transformative effect on society, with the public benefiting greatly from areas such as modern electronics, lighting, communication, manufacturing, and transportation. Owing to its interdisciplinary nature, many different fields of study have benefited from fusion research.



Silicon Wafers
Plasmas are used to etch and deposit materials on thin silicon wafers in a series of steps that result in tiny transistors and capacitors, and the tiny wires that connect them into circuitry. Advances in plasma technology have improved the performance of electronics, doubling the number of transistors on a chip every two years or so. This translates into smaller, lighter, and more energy efficient electronics.

Photo credit: Fermi National Accelerator Laboratory



Annihilating Tumors
Plasma beams have promise to improve cancer therapy. A designer plasma beam, known as an antiproton beam, is four times more effective than conventional proton beam therapy at destroying tumors. The antiproton beams annihilate on impact, releasing much more energy into the tumor.

Photo credit: National Cancer Institute

Spacecraft Propulsion
In chemical rockets, the energy is stored in the fuel's chemical bonds and is thus energy-limited; in plasma rockets, the energy and fuel are separate, allowing one to add more energy and achieve greater velocities—10 to 100 times that of chemical rockets. These plasma engines are being used to keep a spacecraft in an assigned orbit, maintaining the proper position of orbiting platforms such as the Boeing Direct TV communication satellites.

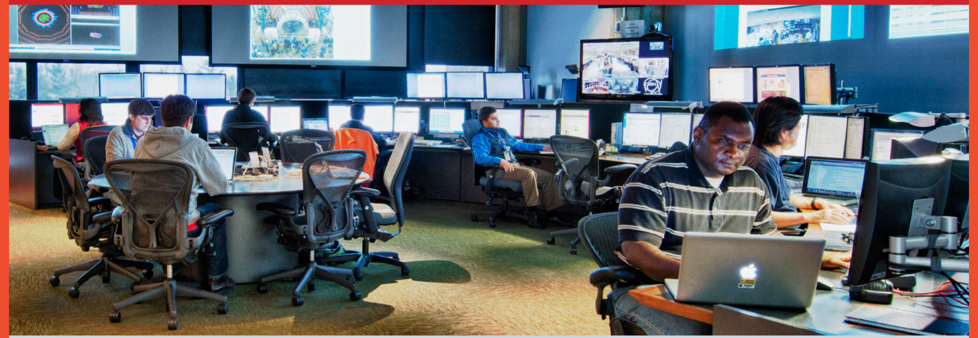
Photo credit: Ad Astra Rocket Company

Making GPS More Reliable
The faint signal transmitted by GPS satellites to your car or cell phone can easily be scattered by disturbances in the ionosphere, which is the dense plasma layer between GPS satellites and the Earth's surface. Research into the stability of plasmas has advanced our understanding of the formation of instabilities in the ionosphere and the potential disruption of satellite signals and communication.

Photo credit: HawaiianMama

Making Lights Brighter
Plasma research has led to low profile, micro-plasma lights that combine strong illumination with energy efficiency. In domestic settings, these mercury-free lights have been fashioned into almost any shape, blending function with aesthetics, and making them ideal for seamless integration into wall or ceiling surfaces.

Photo credit: Andreas Beutel



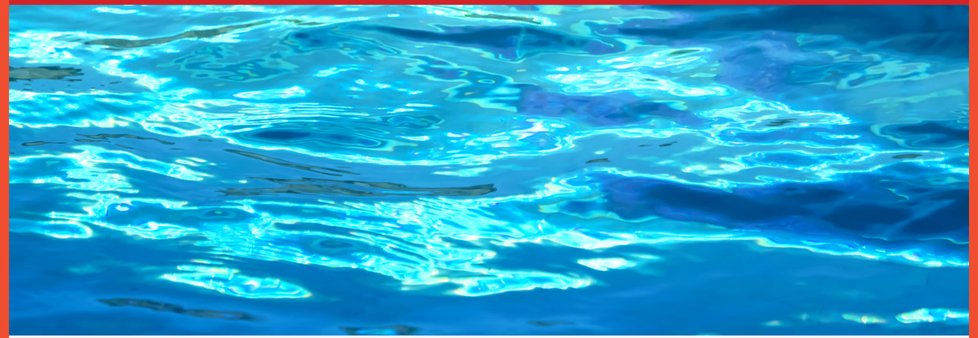
Understanding Our Universe
The scientific instruments, computational tools, and knowledge to generate and control intense fusion plasmas have led to new discoveries about the phenomena occurring in the universe around us. For example, scientists developed the Warp simulation code for fusion research. A revised and expanded version of Warp was used at CERN to improve the Super Proton Synchrotron, which provides beams for the Large Hadron Collider, an engine for discovery about the fundamental structure of matter and elementary particles.

Photo credit: Fermi National Accelerator Laboratory

Safer, More-Efficient Jet Engines
To handle the extreme heat inside a jet engine, turbine blades are typically spray coated with ceramic particles. The coating is done by injecting ceramic powder into a flowing plasma jet. The plasma jet melts the particles and carries them to be deposited as splats on the blades. Fueled by fusion studies, research into creating and melting these injected particles has been vital in understanding and optimizing the process.

Photo credit: Howard Slutsken, Wingborn Ltd.

Electromagnetic Launch System
The USS Gerald Ford was the first carrier to use the electromagnetic launcher, enabled by fusion science. Developed in a fusion experiment by General Atomics, the Electromagnetic Aircraft Launch System, or EMALS, is now replacing the Navy's steam catapults on aircraft carriers. The use of electromagnetics lowers operating costs and improves catapult performance. The enabling innovation came from fusion research that resulted in a precise control of sequencing magnets. For EMALS, that precision enables enormous propulsion capacity and expands the range of aircraft that carriers can now launch.
Photo credit: U.S. Navy



Cleansing Water
Ozone is increasingly replacing chlorine in treating municipal drinking water, due to its effectiveness at destroying viruses and bacteria with minimal ecological impact. Large-scale ozone generation is based on plasmas, an ionized gas made of positive ions and free electrons, created in pure oxygen. Plasma research has enabled recent advances in efficiency and in cost reductions for ozone treatment.

Surviving Accidents At Nuclear Facilities
Whether it is a natural disaster or a human-caused accident, damage to nuclear fuel rods is a concern. Certain ceramics possess exceptional tolerance against different types of radiation. Fusion scientists found that a silicon-based material resists radiation and developed it for accident-tolerant fuels and core technologies for nuclear reactors to better survive severe accidents.

Design: Sandbox Studio, Chicago