# The Future of Renewable Energy: Nuclear Fusion, ITER, and the PPPL

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Fusion reactions occur in the core of the sun 9.2 x 10^37 times per second. At extreme temperatures climbing to 15,000,000°C, hydrogen atoms collide at incredibly high speeds, overcoming the electrostatic repulsion naturally found between protons (ITER, 2024). Thus, the atoms fuse, forming a new atom with two protons: helium. The process of fusion reaction converts some mass to energy. Einstein's famous equation $e = mc^2$ calculates the extremely large creation of energy engendered by this miniscule loss in mass, multiplying the mass by the speed of light squared (ITER, 2024). Nuclear fusion is not to be confused with nuclear fission, another powerful process that breaks apart a singular atom rather than combining—or fusing—two atoms together.

While nuclear fission and fusion are used in hydrogen bombs, a more positive and everyday use of the techniques can serve as a sustainable source of green energy. Fusion energy involves harnessing the energy released by a nuclear fusion reaction, and can provide a renewable source of energy that does not produce greenhouse gasses (Lanctot, n.d.). A pickup truck carrying fusion fuel has the "equivalent energy of 2 million metric tons of coal, or 10 million barrels of oil" (Lanctot, n.d.). The benefits of fusion energy could be enormous, but mobilizing it presents many challenges.

At the extraordinarily high temperatures found in the sun's core, electrons separate from the atoms, creating an electrified gas known as plasma (Princeton University, 2023). Electricity, fire, the technology of computer chips—plasma makes up more than 99% of the universe (ITER, 2024). Nuclear fusion occurs only in this plasma, the fourth state of matter. A laboratory setting with high temperatures, sufficient plasma particle density, and adequate confinement time is required to achieve artificial fusion (ITER, 2024). These three conditions ensure that enough high-energy collisions occur within a confined volume.

The International Thermonuclear Experimental Reactor project (ITER) is a collaboration between seven partners to advance the “worldwide availability of energy from fusion” (PPPL, 2024). The United States, India, China, the European Union, Japan, South Korea, and the Russian Federation established the ITER agreement on November 21, 2006 with a membership duration of 35 years. The members divide the work of the project and are largely dependent on each other for success.

ITER uses a tokamak device to “contain and control the hot plasma” (ITER, 2024). The device contains a magnetic field, which confines the helium nucleus to the plasma. The neutron of the atom, however, is unaffected by the magnetic field. It thus carries away around 80% of the energy produced by the reaction into the walls of the tokamak. The kinetic energy transfers to the walls as heat, captured by cooling water flowing in the device’s walls. In theory, this heat could be used to produce steam and, subsequently, with turbines and accelerators, electricity. Nuclear fusion releases four million times more energy than chemical reactions such as the burning of coal, oil, or gas (ITER, 2024). This could revolutionize our harnessing of energy and pilot the sustainable pathway to renewable energy.

Furthermore, in Lawrenceville’s backyard lies the Princeton Plasma Physics Lab (PPPL), a U.S. Department of Energy national laboratory located in and managed by Princeton University (PPPL, 2024). The lab spans 90.7 acres, receives around $209 million dollars in funding to operate, and employs 752 full-time workers, including physicists, engineers, and technicians (PPPL, 2024). This immense project is one of the branches of the ITER, and members of the PPPL also work on various tokamak devices to advance nuclear fusion science. Additionally, the PPPL leads the “design and construction of six diagnostics that will analyze the behavior of ITER plasmas” (PPPL, 2024). The PPPL’s work is crucial to the immense, international project of obtaining reliable and usable nuclear energy. Across the globe, scientists work to advance nuclear fusion and plasma science, taking their lead off of the very structure at the center of the solar system keeping us alive.

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