Controls engineer wins NSF CAREER Award to advance the viability of nuclear fusion

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Few emerging technologies make claims that are as grand as the promises of nuclear fusion. Few, however, will require as much time and effort before they come to fruition.

Nuclear fusion – the process of joining isotopes of hydrogen under extremely high temperatures – has the potential to provide unlimited supplies of clean, safe energy, says Eugenio Schuster. Fusion emits no pollutants, greenhouse gases, plutonium or uranium waste. It uses such a small amount of fuel that there is no danger of a leak on a deadly scale. In contrast to present nuclear power plants, a nuclear accident is not possible in a fusion reactor, says Schuster.

And unlike the energy from fossil fuel sources, energy from nuclear fusion lies beyond the reach of politics or geography.

There's just one catch: It will take engineers and scientists decades more of research and experiments to make fusion commercially viable.

Much of that research is aimed at developing engineering systems to monitor and control the volatile dynamics inside a fusion reactor, where, under temperatures greater than those inside the sun, hydrogen is converted from a gas to a plasma, or ionized gas, consisting of free electrons and protons. The plasma, which is confined by magnetic fields, is susceptible to a variety of instabilities.

Schuster, an assistant professor of mechanical engineering and mechanics, is at the forefront of the fusion effort. He recently received a five-year, $400,000 CAREER Award from the National Science Foundation (NSF) titled “Nonlinear Control of Plasmas in Nuclear Fusion.” The CAREER Award recognizes young researchers’ commitment to research and teaching. Schuster also receives support for fusion research from the Pennsylvania Infrastructure Technology Alliance.

Schuster began studying fusion controls seven years ago as a graduate student at the University of California at San Diego. In 2005, he helped edit two special editions of the IEEE Control System Magazine dealing with fusion. In 2006, he received an NSF grant to organize a workshop on the mathematical modeling and control of fusion. Also in 2006, he organized a session on fusion at IEEE’s top annual controls conference.

At Lehigh, Schuster works with two of the world’s leading fusion experts, Prof. Arnold Kritz and research scientist Glenn Bateman, of the department of physics. Kritz has studied fusion for 40 years, collaborates with researchers around the world and has monitored fusion research grants for the Office of Fusion Energy Science in the U.S. Department of Energy (DOE). The three Lehigh researchers have close ties to the three major U.S. fusion research centers – General Atomics in San Diego, the Princeton Plasma Physics Laboratory, and MIT’s Plasma Science and Fusion Center.

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Control, in engineering terms, pertains to changing the dynamics of a system, especially an unstable system. The components of a control system include sensors, a feedback loop and actuators. The cruise control in a car, for example, uses a sensor to check the actual speed of a car against the desired speed. The actuator – gas pedal or regulating valve –

controls the flow of gas to the engine to accelerate or decelerate as needed.

Vastly more complex than a cruise control is the control system needed to optimize a nuclear fusion reactor. Inside the tokamak, as the reactor is called, two isotopes of hydrogen, tritium and deuterium, fuse under high pressure and at temperatures of 100 million degrees Celsius to create helium atoms. Under the right conditions, this process becomes self-sustaining and produces energy continuously and in large quantities.

In the past 50 years, says Schuster, scientists have learned how plasmas behave under extreme conditions. Their goal now is to make a commercially viable fusion reactor that will produce at least five or 10 times as much energy as the amount of energy required to heat the tokamak and generate fusion.

Toward that end, the European Union, the U.S., China, Russia, Japan, India and South Korea are building a giant fusion reactor in France called ITER, formerly an acronym for International Thermonuclear Experimental Reactor and also a Latin word meaning “the way.” ITER will cost $10-billion and take 10 years to build.

“For a fusion researcher, these are really exciting times,” says Schuster. “ITER is the biggest scientific endeavor in the history of humankind, a product of 50 years of work with 30 years more to come. Scientists from around the world are pushing in the same direction to make fusion a reality.

“ITER will be the first tokamak to actually generate more fusion than input power. Until now, tokamaks have been used to heat the hydrogen isotopes and to generate and confine the resulting plasma in order to study the plasma’s instabilities and other physics issues related to the plasma.”

The key to generating a higher ratio of fusion energy to input energy, says Schuster, is to develop active control systems that maintain a self-sustaining fusion reaction for lengthy durations. These systems will need to regulate the density, current and temperature of the plasma and its stable confinement inside the magnetic fusion reactor. The shape of the fusion reactor and the material of which it is made are also important variables for control engineers.

“Tokamaks are high-order, nonlinear systems with a large number of instabilities,” says Schuster. “Many extremely challenging mathematical modeling and control problems must be solved before a fusion power system can become a viable entity.”

In his CAREER research, Schuster will tackle several critical challenges in the control of fusion reactors, including stabilization of neoclassical tearing modes, current profile control, and stabilization of resistive wall modes.

Schuster, whose expertise is in nonlinear controls, became interested in control systems in Argentina, where he earned a degree in electronic engineering from the University of Buenos Aires and a degree in nuclear engineering from the prestigious Balseiro Institute. At Lehigh, his graduate students have completed research internships at General Atomics and are beginning research projects at Princeton and MIT.

Schuster is not at all discouraged by the fact that he will most likely be an old man before the promise of fusion is realized.

“I’m very confident that we will succeed,” he says. “This will be something I can tell my grandchildren about.”

Source: Lehigh University