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Fusion's Future – Part 1 of 3: Is it the World's Next Great Energy Source?

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Meeting the world's future energy needs and sustainability goals will require significant contributions from every safe, clean alternative source that can be found. The good news is that many power-generating sources, including wind, solar, hydroelectric, geothermal and photovoltaics, already have established delivery systems that are getting more efficient every year. The still open question, though, is whether the systems in place will advance quickly enough to offset the drop in fossil fuel usage that will be necessary to blunt the effects of climate change.

The race is on. To put the world on stable energy footing, more fuel sources need to be located, developed, enhanced, and commercialized. Work is underway in each of these areas. Solutions can't come soon enough.

One innovative solution pushed its way up the alternative energy agenda over the past year. It is nuclear fusion—a complicated process that scientists have been working on, generating incremental success, for more than half a century. Now, following an engineering breakthrough at the end of 2022, governments are funding research that, if successful, could make fusion a viable energy source sometime in the next decade.

Hewlett Packard Labs is actively involved in these research efforts. Our teams are developing ways to make the fusion process itself more powerful and more efficient using artificial intelligence and machine learning. But the work doesn't end there. Future fusion research will require scientists to amass and integrate incredibly large mounds of data to advance the process of scientific discovery. Labs is partnering on a long-running effort to make fusion data findable, understandable, usable and verifiable. Both of these initiatives are vital to nuclear fusion's prospects for success.

A Fusion Explainer

While Behind the Scenes at Labs will examine the specific projects we're handling in more detail in two upcoming articles, it's fair to ask some leading questions about nuclear fusion itself. What is it? How does it work? What are the barriers to delivery? And why is it capturing so many people's imaginations?

Here are some answers.

Nuclear fusion involves bringing together two isotopes of hydrogen (deuterium and tritium) to form a heavier atom, releasing huge amounts of energy in the process. This is how light and heat get produced in stars, including our solar system's sun.

Fusion reactions in nature take place in a hot, electrically charged gaseous state called plasma. For nuclei to combine, they need to collide at very high temperatures – at millions of degrees Celsius. Stars are big and powerful, so fusion happens organically, with large amounts of energy helping the nuclei overcome the electrical forces that would normally push them away from each other. When the nuclei get close enough to each other, the extreme pressures produced by stars' immense gravity create the conditions for fusion, allowing the nuclei to fuse together.

Back on Earth, fusion is generating buzz for several reasons.

First, it's powerful. If fusion can be efficiently captured in a lab, it could generate up to four times as much energy per kilogram of fuel than fission (the technology used in nuclear power plants) and nearly four million times more energy than burning oil or coal.

Second, it's clean. The fuel that scientists are using to generate fusion reactions is plentiful and accessible. Deuterium can be extracted from seawater, and tritium can be produced in fusion reactions using naturally abundant lithium. And, unlike carbon-producing technologies like coal, oil, or natural gas, nuclear fusion doesn't emit carbon dioxide or other greenhouse gases into the atmosphere.

Third, it's inherently safe. Once a plant creates a fusion reaction, the end product is a bunch of inert atoms that release large amounts of energy. The atoms are slightly radioactive, but their half-lives are short, so the materials stay radioactive for a very short time. Producers of fusion energy would not face the problem of storing the results of these reactions. There is no risk of a runaway reaction or a meltdown because if the system fails, the plasma inside will naturally terminate, lose its energy very quickly, and extinguish before any sustained damage is done to the reactor.

A long runway

Scientists have been working on fusion experiments for decades. Thirty years after the concept first gained traction, researchers at Lawrence Livermore National Laboratory (LLNL) in the 1960s tested the idea that lasers could be used to generate fusion reactions in a laboratory setting.

In the ensuing decades, researchers have developed increasingly powerful and sophisticated reactors that heat hydrogen gas and release energy in the form of neutrons flying outward. LLNL took a leadership role in this research, and on Dec. 5, 2022, scientists there achieved the engineering breakthrough that moved nuclear fusion ahead on the research priority list. For the first time, researchers achieved "scientific energy breakeven" in a fusion experiment—meaning the amount of energy they produced from fusion exceeded the amount they used to drive the ignition of fusion outputs.

Which brings us up to the present. Although the technology still faces high hurdles, governments are hopeful that they'll be able to derive green, carbon-free energy from fusion energy sometime in the not-too-distant future.

The U.S., among other countries, has put fusion on its energy roadmap. In a 2022 planning document, the Department of Energy (DoE) outlined a vision to start producing net electricity in a commercial fusion pilot plant between 2035 and 2040. The DoE based its projections on recommendations in a 2021 study by the National Academy of Sciences that called for a series of public-private partnerships to solve the key problems that stand in the way of fusion becoming a viable fuel source.

Widespread uses of alternate energy sources are clearly a top global priority. Climate scientists and policymakers roundly agree that the world needs to reach net-zero emissions by 2050 to have a fighting chance of controlling global warming. Introducing commercially available fusion energy in the 2040s would represent one small step toward advancing that goal.

What's ahead

But a lot needs to happen between now and then for fusion to progress beyond its current state as a promising concept.

Funding, of course, will be a big issue. Governments will continue to be charged with keeping budgets in line, and private interests will have to prove to investors that fusion will turn into a money maker.

Technology also will be a challenge. At this point, state-of-the-art lasers are powerful but slow and inefficient. The National Ignition facility in Livermore, Calif., was designed to experiment with fusion technology, not to serve as a prototype for electric power generation. It currently averages about ten shots per week. In the future, a commercial fusion facility would need much faster lasers to shoot perhaps ten times a second. Experts also say a viable laser fusion power plant would likely need to generate much higher energy gains than the 1.5 observed in the December 2022 breakthrough fusion shot.

Then there's data. There's already been plenty of fusion data collected over many decades—from fusion experiments and from the increasing volume of simulation data with the increased performance of HPC supercomputers. Those data volumes will explode even further with the use of data being used and generated by AI applications. To put nuclear fusion research on a path to success, scientists need a sophisticated mechanism to manage that data and turn it into insights.

There are dozens of other issues researchers will need to solve before nuclear fusion moves from the drawing boards to the energy grid. Hewlett Packard Labs is working on two of them. We've secured a pair of DoE contracts to deliver solutions to the energy efficiency and data challenges.

Our team will dive into detail about the work we're doing on these projects in the second and third installments of this three-part series.

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