fusion illusion

RSM

> "There is potential in fusion to revolutionize our world and to change all of the options that are in front of us and provide the world with abundant and clean energy without the harmful emissions of traditional energy sources."
>
> — John Kerry, Special Presidential Envoy for Climate, 2023

Hopes that fusion power will save us from the looming crises of global warming appear to be even stronger now than they were in 1954 when Lewis Strauss—then chairman of the Atomic Energy Commission, and in apparent reference to fusion power—infamously declared that nuclear power would one day be too cheap to meter. Indeed, nuclear fusion is widely regarded as the best, and some believe the only, hope for achieving widespread, carbon-free electrical power. But that optimism appears to derive more from desperation than from realistic assessment. Ignoring the enormous and well-known technological problems of trying to maintain a tiny sun in a vacuum vessel, and the all but certain outcome that fusion power will never be economically competitive with other low- or non-carbon energy technologies, the fatal flaw in hopes for fusion power is, unbelievable as it may seem, a shortage of fuel. [1]

As fusion advocates often claim, half of the material required for fusion fuel (deuterium) is readily available from seawater. But what they apparently don't know–or, far worse, they ignore–is that the other half (tritium, the radioactive isotope of hydrogen) can only be created in nuclear reactors. [2] Far from being abundant, tritium is extremely rare—almost all of it has been made by nuclear militaries for hydrogen bombs. Serendipitously for fusion research, however, very small amounts of tritium are also produced in the few nuclear reactors worldwide that use heavy water as a moderator and coolant. Incredibly, the source for half of the fuel required for the world's major fusion energy programs is a minor and extremely rare waste-product from a handful of aging nuclear power plants in Canada. [3]

[1] This essay focuses on the tritium-fueled tokamak reactors used or planned by almost all of the world's major fusion programs. The fatal flaw of insufficient fuel and many lesser but highly problematic issues with tritium fuel do not apply to fusion programs that don't use it. Although the technical difficulty of aneutronic fusion is far more challenging, many smaller fusion programs are going in that direction.

[2] Very tiny amounts of tritium are also produced in the upper atmosphere by cosmic rays colliding with a ^{14}N nucleus.

[3] Almost all of the world's commercially available tritium comes from a Canadian facility that processes used heavy-water from Canada's CANDU reactors to remove the tritium that builds up during reactor operations.

Nuclear power can be said to have been born on December 2, 1942 when a team of scientists and engineers led by Enrico Fermi initiated the world's first controlled chain reaction in a small reactor at the University of Chicago. Thirteen years later nuclear reactors were powering U.S. submarines, and two years after that the first U.S. nuclear generating station started delivering electricity to the grid. By 1992, just fifty years after nuclear power was born, fission reactors were providing 20% of U.S. electricity. There was never any doubt about whether turning atomic fission into electricity could be accomplished. No fundamental engineering challenges needed to be overcome, and no new materials needed to be developed. [4] Fission reactors were basically just a new way to boil water. The physics had been worked out in top-secret pursuit of weapons with unimaginably destructive power; after that, harnessing nuclear fission for electricity was mostly a matter of straightforward engineering. [5]

There were, of course, some problems. Most commercial reactors in the U.S. are scaled-up versions of power systems originally designed for naval warships, particularly submarines: compact reactors with high power density. [6] But light-water reactors are not inherently safe; the reactor can melt if not constantly and carefully managed. Although nuclear engineers in the 50's knew how to design inherently safe reactors (reactors that could not melt even if left unattended), the higher-risk naval reactors had a strong head start and were therefore faster to commercially exploit, so that's what utility companies chose to build. [7]

[4] Other than the isotopic enrichment of uranium and the chemical separation of plutonium, both of which were sufficiently understood such that their production processes worked as predicted.

[5] This is not to diminish the many technical problems encountered and the innovative solutions developed in designing and building fission reactors, but rather to point out that there was never any doubt that a working power reactor could be built.

[6] Pressurized water reactors (PWRs) are the most common type of commercial power reactor in the U.S and the only type of reactor used for U.S. Naval vessels.

[7] Passively safe reactors that do not need human intervention to prevent meltdown have a much lower energy density—larger size per unit of power—and are therefore not suitable for naval power systems.