ITER and the prospects for commercial fusion FREE

Akira Hasegawa

Physics Today **73** (7), 10–11 (2020);
https://doi.org/10.1063/PT.3.4511

ITER and the prospects for commercial fusion

© ITER ORGANIZATION

The article "The challenge and promise of studying burning plasmas" by Richard Hawryluk and Hartmut Zohm (PHYSICS TODAY, December 2019, page 34) contains a nice description of the physics involved in a burning plasma, which ITER, the international prototype fusion energy reactor, hopefully will produce. But ITER has had a troubled history. It was approved in 2005 for an estimated construction cost of approximately $5 billion, and deuterium–tritium experiments were expected to start in 2027. At present, the estimated cost has mushroomed to at least $25 billion in today's dollars, and the start date for D–T experiments has slipped to 2035, with their completion expected around 2040.

Realistically, though, ITER's development path is unlikely to produce commercially competitive electricity in this century. According to the ITER website (www.iter.org), the reactor is designed to produce a 10-fold or better return on energy; that is, it should produce 500 MW of fusion power from its 50 MW of input heating power.

Let's assume that ITER achieves that return in about 2040. What would that mean for power production? Electricity is generally produced with an efficiency of around one-third, so as a power plant, ITER would generate approximately 170 MW of electricity (MWe). Yet it requires 50 MW of beams or microwaves to power it. But beams and microwaves are themselves produced at around one-third efficiency, meaning that they would require 150 MW of input power. That would leave virtually nothing for the power grid. A typical commercial power plant, by comparison, will generate about 3 GW of heat or 1 GW of electricity.

For an ITER-like tokamak to be economically integrated into the grid, it would need its gain increased by at least a factor of three or four, its power increased by about a factor of six (to be on par with a typical commercial power plant), and both its size and cost reduced. Such a tokamak would deliver at least an order of magnitude more power to the wall and diverter plates. These requirements are not minor details! In all likelihood, reaching them would take decades and tens of billions of dollars, assuming they could be accomplished at all.

In addition to these obvious difficulties, tokamaks are limited in pressure and density, as Hawryluk and Zohm point out. They are also limited in current. The limits are not controversial; they have been well established theoretically and confirmed experimentally. Yet the constraints they place on fusion power, which I have called "conservative design rules,"[1,2] have been ignored by the tokamak community. Furthermore, conservative design rules have been in the literature for a decade. I have given many presentations on them at fusion labs and other places, and they have never been challenged, in print or in my seminars.

As long as tokamaks remain so constrained, they are unlikely to generate economic power. However, there is an alternative. As a breeder of nuclear fuel, an ITER-like tokamak would work well. Most likely it could economically breed uranium-233 from thorium. It would be a much more prolific fuel producer than a fission breeder of equal power and could become the basis of a worldwide, sustainable, carbon-free, nuclear infrastructure. Furthermore, it might well be able to do so soon after midcentury, assuming ITER is successful.[1,2]

References

1. W. Manheimer, *J. Fusion Energy* **33**, 199 (2014).
2. W. Manheimer, *IEEE Access* **6**, 64954 (2018).

Wallace Manheimer
(wallymanheimer@yahoo.com)
Allendale, New Jersey

* * *

The article by Richard Hawryluk and Hartmut Zohm addresses several interesting issues in ITER's march toward successful plasma burning. In particular, ITER's design, as presented in the article, relies on the high-confinement mode—the H-mode—that may be achieved with a thermal barrier believed to arise from turbulence-generated zonal flow.[1] As the discoverer of that type of flow, I highlight here a fundamental issue in the H-mode tokamak reactor. If operation depends on the formation of zonal flow possibly created by the self-organization of a type of Hasegawa–Mima turbulence, it is crucial that such turbulence is continuously generated. The scheme may be considered to be dynamic confinement, as compared with the classic static confinement scheme based on a magnetic bottle.

Dynamic confinement requires continuous injection of free energy via RF or neutral beams to sustain the turbulence and hence the thermal barrier—and, in effect, the pressure profile. For that process to take place on a steady-state basis, one must assume that the injected energy is lost continuously. Therefore, if the ITER design is based on dynamic confinement, ITER should be viewed as a power amplifier—that is, the fusion energy output should be regarded as amplified injected free energy. Since the injected power should be considered lost through an inverse cascade of turbulent energy, ignition criteria, such as the well-known Lawson criterion, that are based on energy confinement time become irrelevant: The energy is not confined. Here the crucial time scale is not of energy confinement but of maintaining the plasma pressure profile sustained by the zonal flow.

Reference

1. A. Hasegawa, M. Wakatani, *Phys. Rev. Lett.* **59**, 1581 (1987).

Akira Hasegawa
(a.hasegawa@solitoncomm.com)
Osaka University
Suita, Japan

After the ITER project was initiated, decarbonization of global energy production has emerged as an urgent objective for industrial society. Thermonuclear fusion is an inherently safe, ubiquitous, zero-carbon source of energy on a scale large enough to power a growing global industrial economy. It is therefore appropriate to examine fusion research by asking whether economically viable fusion power plants will come on line soon enough to affect climate change. The field has seen advances in high-temperature superconductors, inexpensive high-field permanent magnets, and other materials and in modeling and manufacturing. Those new technologies enable a range of heating and confinement approaches far beyond what was conceivable at ITER's inception.

The 2019 *Final Report of the Committee on a Strategic Plan for U.S. Burning Plasma Research* from the National Academies of Sciences, Engineering, and Medicine makes the following recommendations:

- First, the United States should remain an ITER partner as the most cost-effective way to gain experience with a burning plasma at the scale of a power plant.
- Second, the United States should start a national program of accompanying research and technology leading to the construction of a compact pilot plant that produces electricity from fusion at the lowest possible capital cost.[1]

Since the publication of that report, much has changed in the US fusion community. In the public sector, the American Physical Society's division of plasma physics led a community planning process that identified scientific and technological opportunities in plasma physics and fu-