Where to Look for Practical Fusion Power

By Robert L. Hirsch, 14th US-Japan IECF Workshop, October 16, 2012;
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We learn; we learn more; we learn throughout life. Some learning is easy; some is very difficult. After my experience in fusion research and many other energy technologies, I feel that I've learned where we might look for practical fusion power. Part of that learning comes from where practical fusion power is not likely to be found.

Fusion is not like fire, although some fusion researchers seem to think so. Fire became a major source of energy for early humankind, partly because it provided special capabilities, and it had essentially no competition. Also, there were no cost or environmental issues to be concerned with when humans discovered fire and learned to use it. Fire worked; it was convenient, and it did wonderful things when measured by then-existing lifestyles.

Fusion research started after World War II at a time when it was felt that science had wonderful things to provide for humankind. The potential cost of fusion power was not an issue. The wonders of the atom, or more properly the nucleus, were felt to be unbounded. Fusion was the fundamental energy source in the universe, powering the sun and the stars. Wonders awaited.

Many outstanding people turned to the pursuit of fusion power. A number of fusion concepts emerged and were investigated. Soon it became painfully clear that practical fusion power would not happen quickly. First, we had to develop the science of plasma physics.

After decades of effort, a great deal has been learned and accomplished, but a practical fusion power concept has not been forthcoming. Note that I said "practical fusion power." Unlike fire, fusion power has to compete against a number of other options. The word "practical" means that a fusion power system must be desirable, based on the realities of the society into which it will be introduced.

An unfortunate problem today is that many people in fusion research believe that producing a fusion-something that simply works is the goal, but that is definitely wrong! Fusion power and fire are distinctly different.

Let's consider some specific criteria for practical fusion power. In 1994, the U.S. Electric Power Research Institute – EPRI – convened a panel of utility technologists to develop "Criteria for Practical Fusion Power Systems." The result was a four-page folder that outlined "Three principal types of criteria:"

- Economics,
- Public Acceptance, and
- Regulatory Simplicity.

The criteria are almost self-explanatory, but let me quote from the Economics Criteria: "To compensate for the higher economic risks associated with new technologies, fusion plants must have lower lifecycle costs than competing technologies available at the time of commercialization." Details for the criteria are given in the report, which I commend to anyone motivated to help develop fusion power.

Against these criteria, let's consider tokamak fusion, the centerpiece of which is ITER – the International Thermonuclear Experimental Reactor – under construction in France. As we know, it's an enormously large machine, which is generally considered to be a prototype of a practical fusion power plant.

Comparing the ITER and the core of a comparable commercial fission reactor shows an enormous difference in size – a factor of 5-10 — ITER being huge by comparison to a fission reactor core.

It is known in engineering and technology development that the cost of a finished machine or product is roughly proportional to the mass of the device. Eyeballing ITER compared to a fission reactor core, it's obvious that an ITER-like machine is many times more massive. Yes, you can argue details, like the hollow bore of a tokamak, but the size of the huge superconducting magnets and their heavy support structures provides no relief.

Bottom line – On the face of it, an ITER-like power system will be much more expensive than a comparable fission reactor, so I believe that tokamak fusion loses big-time on cost, independent of details.

Next, consider the fact that deuterium-tritium fusion inherently emits copious neutrons, which will induce significant radioactivity in adjacent tokamak structural and moderating materials. Accordingly, a tokamak power system will become highly radioactive as soon as it begins to operate and, over time, radiation damage will render those same materials structurally weak, requiring replacement.

In the U.S., as elsewhere in the world, we have a Nuclear Regulatory Commission, which will almost certainly be given the task of ensuring that the public is safe from mishaps associated with tokamak power system failures. Expected regulation will require all kinds of safety features, which will add further costs to tokamak power.

While the character of the plasma in a tokamak power reactor will not likely represent a large energy-release safety issue, the superconducting magnets would contain a huge amount of stored energy. If those magnets were to go normal – lose their superconducting properties – the energy release would be very large. It can be argued that the probability of that happening will be small, but it will nevertheless not be zero, so the regulators will require safety features that will protect the public in a situation where the magnets go normal, releasing very large amounts of energy.

Accordingly, it is virtually certain that the regulators will demand a containment building for a commercial tokamak reactor that will likely resemble what is currently required for fission reactors, so as to protect the public from normal-going superconducting magnet energy release. Because an ITER-like tokamak reactor is inherently so large, such a building will be extremely expensive, further increasing the costs of something that is already too expensive.

Next, there's the induced radioactivity in the structure and moderator of a tokamak power reactor. Some tokamak proponents contend that structure might be made out of an exotic material that will have low induced radioactivity. Maybe, but last I looked, such materials were very expensive and not in common use in the electric power industry. So if one were to decide to use such materials, there would be another boost to cost, along with an added difficulty for industry to deal with.

No matter what materials are chosen, there will still be neutron-induced materials damage and large amounts of induced radioactivity. There will thus be remote operations required and large amounts of radioactive waste that will have to be handled and sent off site for cooling and maybe burial. That will be expensive and the public is not likely to be happy with large volumes of fusion-based radioactivity materials being transported around the country. Remember the criteria of public acceptance.

I could go on with other downsides and showstoppers associated with tokamak fusion power, but I won't. It is enough to say that tokamak fusion power has what I believe are insurmountable barriers to practicability and acceptability.

By the way, my arguments assume that tokamak physics and technology works well and is reasonably simple, meaning that not many more components will have to be added to the system to allow it to operate on a steady basis for very long periods of time between the long shutdowns needed to change out radiation-damaged, radioactive materials.

What I've just described is not a happy story. At some point, probably in a matter of years, a group of pragmatic power industry engineers will be convened to seriously scrutinize tokamak fusion, and they are virtually certain to declare that it cannot become a practical power system. That will certainly be a calamity for the people involved and for the cause of fusion power.

Let's review what I've said. First, we have to recognize that practical fusion power must measure up to or be superior to the competition in the electric power industry. Second, it is virtually certain that tokamak fusion as represented by ITER will not be practical.

So where are we likely to find practical fusion power? First, we must look for a concept or concepts that are inherently small in size, which means high plasma density. Second, we must look for something that can be based on a low or zero neutron fusion reaction. One example is the proton-boron reaction.

We know some things about proton-boron fusion. First it requires much higher temperatures that deuterium-tritium. Second, it cannot be based on a Maxwellian plasma particle distribution, because theory tells us that the plasma radiation losses (Bremsstrahlung) from a very high temperature, Maxwellian, proton-boron plasma will kill the concept.

That means that a proton-boron plasma must be non-Maxwellian, and it must be fashioned in such a way that normal inter-particle scattering reactions can be managed on an on-going basis.

For this audience, the requirements for practical fusion power sound like they could be met by Inertial Electrostatic Confinement (IEC) fusion. As you well know, IEC is a family of possibilities from gridded systems to magnetically constrained systems and on and on. They can in principle be very high density and therefore small, and they could have plasma distribution control as an element. I can't help but wonder if IEC just might be the key to practical fusion power.

In conclusion, in the early days of the U.S. fusion research, the program was classified secret and called Project Sherwood. One explanation for that name was, if it works, it *sure would* be wonderful.

I hope that you and others will be able to help make it happen.

Thank you.

PS. These thoughts were painful to formulate. As a past leader of the U.S. federal fusion program, I played a significant role in establishing tokamak research to the U.S., and I had high hopes for its success. Realities have emerged to dash those hopes. When we learn unpleasant things, it is incumbent on us to speak up, even when it hurts.