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With Tight Research Budgets, Is There Room for the Eternal Promise of Fusion?

By ANDREW C. REVKIN

Moving beyond the country's, and the world's, existing energy menu, which is still by far dominated by abundant and relatively cheap fossil fuels, is hard, whatever your preferred path.

To use a sports analogy (and setting aside, for the moment "stasists" locked into the status quo), the debate tends to break down to those pushing the ground game, investing in deployment of today's non-polluting sources like wind and solar, and those pursuing tough, but potentially game-changing advances in technologies like nuclear power. For decades, nuclear fusion has been the equivalent of the Hail Mary pass.

The recent failure to meet a congressional deadline at the National Ignition Facility -- a giant laser-centered fusion project at the Lawrence Livermore National Laboratory -- generated commentary, including from the editorial page of The New York Times, arguing that it was time to shift limited federal resources away from this particular long-pass approach. The editorial board seemed more broadly to challenge the merits of continued big investments in the ultimate *someday* technology:

> If the main goal is to achieve a power source that could replace fossil fuels, we suspect the money would be better spent on renewable sources of energy that are likely to be cheaper and quicker to put into wide use.

Setting aside specific issues related to the laser ignition facility, I have a different view. Human nature and the political systems that are shaped by it both create a bias toward the near and now. I'd like to think that we might be able to factor in our predispositions and bias when society chooses how to apportion scarce research dollars. It's been clear to me for many years that the proportion of total federal research spending devoted to energy, which has been a dribble for decades under both political parties, is too low. (Read my 2010 post, "A 2-Cent Solution to Help Fuel an Energy Quest," to see how cheap it would be to triple this.)

Yes, I know it's a non-starter to talk about a new revenue source, but the view below of non-defense research spending since the Sputnik moment (energy is the yellow squiggle) shows what a disconnect there is between the political debate over energy -- as crystallized in the protracted energy discussion in the most recent presidential debate -- and what we're willing to spend to expand affordable choices:

But finding the right balance among various energy investments is no easy task.

To get some fresh insights about fusion's role, I reached out to some people, including Burton Richter, a Nobelist in physics, who have far more knowledge and experience in nuclear energy than I do to help clarify why it may be premature to pull the plug on such programs. I'm not saying they're right, and I encourage you to read physicist (and climate blogger) Joe Romm's recent take, which kicked off with this compelling line:

> I am a big proponent of harnessing the power of fusion - from 93 million miles away. [*Read the rest.*]

Here's the reaction from Burton Richter, who is an emeritus professor of physics at Stanford University and author of a valuable book on energy, to my query about how society can best balance its research investments and hedge its bets in trying to move beyond fossil fuels:

> There are two approaches to fusion energy, inertial confinement (the National Ignition Facility or NIF at Lawrence Livermore National Lab, for example) and magnetic confinement (the International Thermonuclear Experimental Reactor or ITER, for example). Both approaches have gone from failure to ever larger failure, but each time a great deal has been learned and enough people have been convinced that we now know how to do it so that the next step has been funded. Some call this a triumph of hope over experience. The hope is for a cost-effective, emissions-free, large-scale source of electricity. The world needs an affordable one and those who argue for fusion believe that it can deliver. The hoped-for schedule is for a power plant by 2050. Cynics say that practical fusion energy is 50 years in the future and will always be so. I have been involved with major reviews of both approaches and will give my take on both.
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> Inertial: The NIF project is the largest of three approaches to inertial fusion and I will focus on it. The program was started by the nuclear weapons part of the DOE so that the performance of hydrogen bombs could be understood without further testing. Funding for NIF and its predecessors at LLNL has come from the DOE's weapons program rather than its energy or science programs. The goal is called "ignition", which is really making what I call a nano-bomb go off. A small capsule of deuterium and tritium a few millimeters in diameter resides inside a larger chamber of a few centimeters in size. A huge laser delivers a large amount of energy in a short time to heat the walls of the larger chamber, and the radiation emitted from those walls in turn drives the small capsule to a very small size, increasing the density of the gases inside to much higher density than lead and heating it at the same time to very high temperatures required for fusion to occur. This is called indirect drive and is what goes on in a hydrogen bomb, so one can learn more about bombs if you can make the nano-bomb go off, justifying funding the program for decades from the weapons part of DOE. If it does work, you can in principle produce electricity though that takes considerably more engineering.

While the physical device did take more time and a lot more money than originally planned, it did reach its goals. The laser itself, the most powerful ever built, exceeded its design specifications and the rest of the facility also meets its specs. However, the nano-bomb did not go off. The problem is that though the laser delivers, for reasons not yet understood the pellet does not get compressed and heated enough. It was thought that previous smaller facilities had led to an understanding of what goes on inside the chamber in which the pellet resides, but experiments are clearly not the complete story. Diagnosing the problem will not be easy, but meanwhile there are other things in science and in weapons technology that the facility can be used for. Is this another in the series of ever larger failures? No one knows yet.

Magnetic: A magnetic confinement system has a donut-shaped chamber containing a ring of ionized gas (the plasma) that carries a huge circulating electric current confined to the donut by very large magnetic fields. Unlike inertial systems, magnetic systems have reached the temperature necessary for fusion, but only through external heating devices that themselves use so much energy that you get no net energy out while they are on.

The goal is to produce a "burning plasma" where the required heat is supplied by the fusion reaction itself. Here the cycle is ionize the gas to make the plasma, build up the current, heat the plasma with an external heater until the temperature for fusion is reached, turn off the heater, and then have the energy require to keep the temperature high generated by the fusion reaction itself. About 25% of the energy released by fusion is required to maintain the temperature.

An international consortium of countries is now building the ITER project in France to demonstrate burning plasma. The device is huge, expensive and is already five years behind schedule and three times over budget, something that seems to be true of all big fusion projects including the NIF. Tuneup will begin in the year 2020, with the first try for burning plasma in 2026. The program will have the burning plasma last for much longer than the time the heater is on. ITER is very expensive and very flexible. Issues include conquering any new instabilities in the plasma that are discovered and finding the optimum configuration for the plasma so that a next phase device can be made smaller and more cost effective. ITER's present budget is about $15 billion and if it could produce electricity (there are components missing necessary for a power plant) the capital cost would be about $100,000 per kilowatt, 100 times the cost of a gas fired plant and 20 times the cost of a nuclear plant.

A personal view: I have told the people at Livermore lab more than once to keep quiet about electricity from inertial fusion until they make a nano-bomb go off

> since they have made promises in the past and failed to deliver. They have not listened and they have reduced their credibility once again. I hope that their analysis leads to an understanding of the problem and that NIF or one of the other approaches can reach its goal.
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> We will have to wait a long time for ITER to try to get the fusion reaction to occur on a sustained basis. The participants in the project believe that they understand plasma stability issues, but then the inertial people believed they understood their issues too. We will have to wait and see.
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> Both approaches are high risk but have a reasonable payoff if they can manage to make affordable electricity and that is a very big if. Fusion folks claim that their system has such advantages that it is worth doing even if the cost of electricity generation is higher than alternatives. I have never believed that, and determining the cost of electricity from fusion is going to have to wait until the conditions for fusion are reached whatever they may be. Incidentally, there are two companies, one American and one Canadian that are taking different approaches to fusion and are entirely privately funded. Stay tuned.

Here's Michel Claessens, the head of communication for ITER (as mentioned by Richter above, this is the International Tokomak Experimental Reactor, which is an international project based in France):

> What should society do to develop and promote efficiently new sources of energy? This is a crucial question indeed. Some people, including some scientists, question the fact that fusion progress is quite slow. But you should take into account the fact that basic science and fundamental research are hardly predictable. You don't know in advance what you will find out.
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> In terms of complexity (in both science and technology), there is more than one order of magnitude of difference between fusion and fission.
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> On the physics side, the core science of fusion is plasma physics, which is highly complex due to its non-linear and stochastic processes. The mastery of the physics is not yet sufficient to enable the construction of a fusion power plant, which requires cutting-edge technologies like superconductivity, high vacuum, and cryogenics. An important mission of ITER is to prove once and for all that it is possible to integrate all these technologies into a single device. The technologies for fission, on the other hand, have evolved over generations of fission machines.
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> The next decades are crucially important to putting the world on a path towards much reduced greenhouse gas emissions. Current and near-term technologies should be deployed as soon as possible for this purpose. However world population will continue to grow and the proportion of populations living in cities

> is expected to continue to increase. Together with the need for a more equitable distribution of energy among the world's inhabitants, this means that even more large-scale, low-CO_2 sustainable energy will be needed later in the century. Fusion is a strong candidate.
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> Fusion is one of the few alternatives available for large-scale energy production and ITER is a major step, necessary to the demonstration of the physics and technology on the way to fusion power plants. Achieving success in ITER will not lead immediately to the building of fusion power plants; another step, usually called DEMO (DEMOnstration fusion power plant) will be necessary. Building on the knowledge and know-how acquired within ITER and parallel research, DEMO will mark the transition to the deployment of fusion energy systems.
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> The timescale to commercial fusion therefore extends until at least the middle of this century, depending strongly on the political will to invest in this area of research. Lev Artsimovitch, the famous Russian academician and one of the major figures in fusion history, used to say: "Fusion will be ready when society needs it."
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> I believe it is important that society continues and supports basic research, which opens doors and provides potential solutions to our (yet unknown) questions and problems.

As a closing image, here's the breakdown of energy research investments by the world's most powerful countries (members of the International Energy Agency):