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Outlook for ICF*

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by

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During the next ten years the National Ignition Facility (NIF) will be completed and substantial fusion gains are likely to be achieved with the NIF megajoule class solid state laser. A facility very similar to NIF is being constructed by the French nuclear weapons program.

Technological advances promise to make ICF increasingly attractive as a practical energy source. These advances include very high gain targets (e.g., the fast ignitor), petawatt lasers, diode pumped solid state lasers, and advanced heavy ion accelerators.

Beyond the next ten years an experimental inertial fusion (IF) reactor will be needed to take the major step from NIF to a practical fusion power plant. A key question: how is this IF experimental reactor to be funded?

A 100 MWe scale IF reactor could produce several kilograms/year of low cost tritium for DOE Defense Programs. Tritium produced by competing fission reactor and accelerator/spallation options is estimated to cost more than one hundred million dollars per kilogram, much more than the cost of tritium

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produced by a fusion reactor. Tritium production provides a defense funded option for IF's next step beyond NIF.

The civilian funded option is not attractive at this time. Currently, the U.S. government does not recognize an urgent need to develop fusion and other advanced energy sources. We have abundant supplies of coal and natural gas, and a seemingly reliable supply of imported oil. Renewable energy sources are steadily being improved—wind is economically competitive. Ultra-high efficiency, low capital cost, natural gas fueled power plants are a major success. These combined cycle plants using aeroderivative turbines can work at ≤100 MWe scales—so that cogeneration is attractive. Because these power plants achieve such high efficiencies (60%) and obtain approximately half of their energy from combustion of hydrogen, CO_2 production is reduced approximately threefold. Natural gas fueled hybrid electric vehicles may limit the demand for imported oil.

Although the U.S. government has greatly reduced funding for development of fusion energy, geopolitical shock waves and powerful long-term global trends may stimulate greatly increased funding and an enduring commitment to energy independence.

Within ten years, unambiguous scientific evidence of CO_2 global greenhouse warming is likely. The Middle East supply of oil to the Western world is not assured. Increased consumption by the Chinese and other rapidly growing economies will drive up oil costs and accelerate depletion of oil resources. After U.N. forces withdraw from Iraq, Iran, and other nations in the region may accelerate acquisition of nuclear, biological, and chemical weapons of mass destruction (WMD). The West is not likely to engage in a Desert Storm II operation against nations armed with WMD. World population centers are vulnerable to attack by a variety of means ranging from ballistic missiles to terrorists.

In a 21st century Energy Independence campaign, use of CO_2 producing coal must be limited, and growing use of fission energy will be limited by public resistance and concerns about proliferation of nuclear weapons. Renewables will have a limited role unless an economically attractive way to store energy can be developed.

In Energy Independence 21, funding for development of fusion energy will substantially increase. But if fusion development costs are too high, the development time too long, or fusion power plants are too expensive, then competing energy sources will achieve dominant market share and make the eventual success of fusion even more difficult. Because of its fundamental modularity (separable driver, target, and reactor chamber), IFE development with civilian funding is an attractive option—providing, of course, that sufficient funds are available.

Historically, fission energy progressed to the threshold of commercial power production through defense funded reactors developed for the production of plutonium and tritium, and for submarine propulsion. In the near future there is a requirement to build a facility to produce several kilograms of tritium per year for the U.S. post-Cold War nuclear stockpile.

Many studies of fusion based tritium production facilities have been completed. However, until fusion experimentally demonstrates substantial gains, it cannot be taken seriously. After NIF experiments succeed, then ICF will become a leading candidate for tritium production. Fusion has major advantages over both fission and accelerator/spallation.

Fusion generates an excess neutron for each 20-30 MeV of energy produced (with n, 2n breeding ratios of 1.5-2) whereas fission produces an excess neutron for roughly 100 MeV of energy produced. Most important, fusion neutrons produce excess tritium as a byproduct when absorbed in lithium. New tritium production fission reactors are estimated to cost more than $2 billion. Purchase or use of existing (or not yet completed) commercial fission power plants for production of tritium provides the least expensive options ($1-2 billion). Assuming 100 MeV per triton created, the cost is approximately $100 million per kilogram of tritium produced.

An accelerator generated 1.5 GeV proton may generate roughly 50 neutrons through spallation of a high Z nucleus and subsequent n, 2n reactions. However, each 1.5 GeV in the beam of a heavy ion accelerator incident on a target with gain "g" releases 1.5 "g" GeV of fusion energy, and $\frac{1.5\,\text{"}g\text{"}}{30x10^{-3}}$ excess neutrons (assuming one fusion neutron per 30 MeV. With gain 30, 1500 fusion neutrons result, 30 times more than with the accelerator driven spallation process. The electrical energy required to drive the heavy ion accelerator will be 10 times smaller than for the light ion accelerator—even assuming the spallation accelerator can be made three times more efficient than the fusion heavy ion accelerator. Accelerator produced tritium costs may be twice as high as reactor produced tritium costs. Capital costs are comparable ($2 billion) and $100 million/year is needed to power the accelerator.

Two billion dollars is the estimated cost of a 1/2–1 GWe IFE power plant which could generate several tens of kilograms/year of tritium, and bring in revenues of several hundred million dollars/year for electricity sold to the commercial power grid (at 5 cents/kwh).

To produce several kilograms of tritium per year, a 100 MW$_{th}$ fusion plant could be constructed for substantially less than the $2 billion estimated costs of the accelerator/spallation and fission systems. An IFE plant could readily be expanded to produce much larger amounts of tritium if a derated system were constructed (e.g., a 2.5 megajoule driver, one-shot/second, gain 40 target system could be upgraded by increasing the shot rate).

Depending on the pace of arms control agreements, DOE's tritium production facility may be needed by 2005 to 2010. An IFE facility could be constructed by 2010 if NIF experiments achieve substantial gain prior to 2005, and in parallel with NIF, prototype high average power drivers are demonstrated (diode pumped solid state lasers and/or heavy ion accelerators). Costs of these driver development programs are relatively small. Consideration should be given to speeding up the building of NIF or using results from the French NIF to meet scenarios where tritium production is needed before 2010.

If START III follows soon after START II and warhead reserves are reduced, it is possible the date to begin tritium production will slip for ten years and the required production rate will be reduced. On the other hand, if the U.S./Russian relationship should become hostile, then there may be a requirement for a much larger tritium production capacity to enable the U.S. to match Russia's 20,000 nuclear warheads.

An IFE tritium production facility would contain the three essential elements of an IFE power plant: the driver, target factory, and explosion chamber (including heat transport and dissipation systems). Building and operating such a tritium production facility would position ICF to make a rapid transition to a commercial fusion power plant.