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Economic viability of large-scale fusion systems

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ABSTRACT

A typical modern power generation facility has a capacity of about 1 GWe (Gigawatt electric) per unit. This works well for fossil fuel plants and for most fission facilities for it is large enough to support the sophisticated generation infrastructure but still small enough to be accommodated by most utility grid systems. The size of potential fusion power systems may demand a different viewpoint. The compression and heating of the fusion fuel for ignition requires a large driver, even if it is necessary for only a few microseconds or nanoseconds per energy pulse. The economics of large systems, that can effectively use more of the driver capacity, need to be examined.

The assumptions used in this model are specific for the Fusion Power Corporation (FPC) SPRFD process but could be generalized for any system. We assume that the accelerator is the most expensive element of the facility and estimate its cost to be $20 billion. Ignition chambers and fuel handling facilities are projected to cost $1.5 billion each with up to 10 to be serviced by one accelerator. At first this seems expensive but that impression has to be tempered by the energy output that is equal to 35 conventional nuclear plants. This means the cost per kWh is actually low. Using the above assumptions and industry data for generators and heat exchange systems, we conclude that a fully utilized fusion system will produce marketable energy at roughly one half the cost of our current means of generating an equivalent amount of energy from conventional fossil fuel and/or fission systems. Even fractionally utilized systems, i.e. systems used at 25% of capacity, can be cost effective in many cases. In conclusion, SPRFD systems can be scaled to a size and configuration that can be economically viable and very competitive in today's energy market.

Electricity will be a significant element in the product mix but synthetic fuels and water may also need to be incorporated to make the large system economically viable. Co-location of large energy consumers such as metal or chemical refiners and/or processors also needs to be considered.

1. Introduction

Energy is the lifeblood of modern society. Companies and nations are searching the globe for any sign of an energy supply that is underdeveloped or underutilized. Fusion, as a new energy source, is looked upon as unproven or too risky for industrial involvement with the result that only a few countries spend significant amounts of money for fusion research and most of that goes into magnetic confinement fusion or laser driven fusion. At the same time more than $1 trillion are being spent each year on the search for new or underutilized fossil fuel energy sources [1]. All of these expenditures come from the profits of the energy industry. Even more billions of dollars are being projected for expenditure on new fission facilities. Energy is a very big and expensive business yet, almost no industry investment is being made in advanced energy systems such as accelerator driven fusion systems.

This failure of industry to accept the challenge of fusion may be rooted in history. Fusion, as a subject, promised to deliver a virtually unlimited supply of energy in 20 years time more that 60 years ago and now we find that scientists are still looking for fusion to be 'on-line' in 30–50 years. Industry has also been led to expect a 'government demonstration of feasibility' as was done for fission. The commitment to achieve 'ignition' by the National Ignition Facility (NIF) is a similar promise to demonstrate feasibility but it has not been delivered.

The root cause of the lack of adequate research support for Heavy Ion Fusion (HIF) probably lies in a committee decision made in late 1981 when a design concept developed by the US National Laboratories and recommended by ERDA, the predecessor of the US Department of Energy, was denied funding in favor of other programs. The appropriation language in PUBLIC LAW 97-90 (1982) says "… (*IV*) *$7,500,000 shall be used for supporting research and experiments, except that none of such funds may be used for the research, development, or demonstration of the use of heavy ion devices as drivers for defense inertial confinement fusion experiments and defense inertial confinement fusion systems.*" [2]

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The purpose of this denial of the funding for the DOE ‘weapons labs’ may have been appropriate for HIF cannot be used as a weapon. Thus the prohibition of use of the funds for “defense inertial confinement fusion” may have been justified. Had a home for HIF in the basic sciences part of DOE been created, as was apparently planned, this prohibition might have been appropriate. But no such home was created and thus the specific deletion of funding for HIF has had the effect of shelving, for decades, one of the most likely ways of achieving fusion. Without an agency leadership home there has been no ‘voice’ in the budget battles for more than three decades. Nor has there been a source of support for the necessary validation experiments.

Lack of leadership within DOE in civilian applications of HIF, as opposed to ‘weapons applications’, was clearly one of the root causes of lack of progress in the application of HIF in the US. But the underlying assumption that fusion has to be like other systems and be able to produce power in a small facility (1 GWe capacity) is clearly a supporting element. This necessity was emphasized in an EPRI report [3] (Kaslow, et al.) where criteria for practical fusion power systems were summarized. Kaslow et al. emphasized size flexibility (1 GWe or less), economics, public acceptance, and regulatory simplicity. This over defining of the requirements for fusion using electrical output as the only output measure makes it difficult for large systems to compete.

Ignition requires a large and complex driver, the cost of which cannot be justified for an output capacity of less than several GWe. Moir et al. [4] and Moir [5] summarized the cost of energy vs. output capacity for an induction heavy ion driver and a Laser driver and shows a $/kW h cost reduction of 30% by going to 2 GWe instead of 1 GWe capacity. This suggests that the economics of larger systems can be strongly influenced by designs that more effectively use more of the driver capacity. Internal analysis made by scientists and engineers of the Fusion Power Corporation (FPC) supports this contention and shows busbar cost reduction more than factor of 10 going from 1 GWe systems (uneconomic in all cases) to a 30+GWe system (economically viable in all cases).

2. Basic considerations for a large system

Heat is the primary product of a fusion reaction. Heat is used by industry to generate steam or to facilitate other energy consuming processes such as chemical disassociation, melting of metals, distillation of water, and hothouse agriculture. The FPC system uses a Single Pass Radio Frequency Driver (SPRFD) to provide the energy for ignition [6]. Additional details of this design are discussed by Burke at this conference [7] and are summarized on FPC's website (www.fusionpowercorporation.com) . The FPC design uses one driver to provide the ignition energy for 10 or more large reaction chambers, each pulse in each of the 10 chambers putting out a nominal 10 GJ of heat energy each second. Thus a fully developed system could generate about 100 GJ of heat, of which up to 60 GJ could be converted to various marketable products using today's technology. These products are electricity, synthetic fuels [8], process heat, and potable water by thermal desalination of seawater or restoration of water quality.

Temperatures of 1100 °C, or higher, are practical with FPC's unique chamber concept, in which 80% of the energy in the neutrons released during ignition is deposited in a lithium sabot surrounding the fuel pellet to form an extremely hot plasma. High temperature capture and use of this thermal energy means process efficiencies are much higher. Yet the walls of the chamber are shielded and cooled by streams of relatively cool lithium (210–250 °C) coating the walls, buffering the wall structure from the neutron flux and the ~5 eV plasma. Thus, the walls of the combustion zone and expansion zones of the fusion chamber remain below 300 °C at places, preponderantly ~220 °C.

Lithium vapor, carrying 5 GWth is channeled, by shaped lithium flows, coolest lithium on the wall, into the HX primary side of a modularized heat exchanger at each end of the chamber: ~2.5 t of lithium per second, at up to the condensation temperature, 1342 °C.

It is utilization of this heat that is the basis of any economic model such as that presented by Helsley and Burke [9]. A general heat and cost recovery model like that shown in Fig. 1 is needed to appreciate the economics of these large fusion systems. In Fig. 1, the SPRFD driver-pellet system provides the heat for the heat generating entity to market to the heat consuming entities such as the electricity generating entity and the hydrogen and synfuels facility, which we note are likely to be separate enterprises of companies with the necessary core competencies. Each is shown with an estimated heat consumption and cash flow in this figure. Although the relationships and details of the cash flows will be

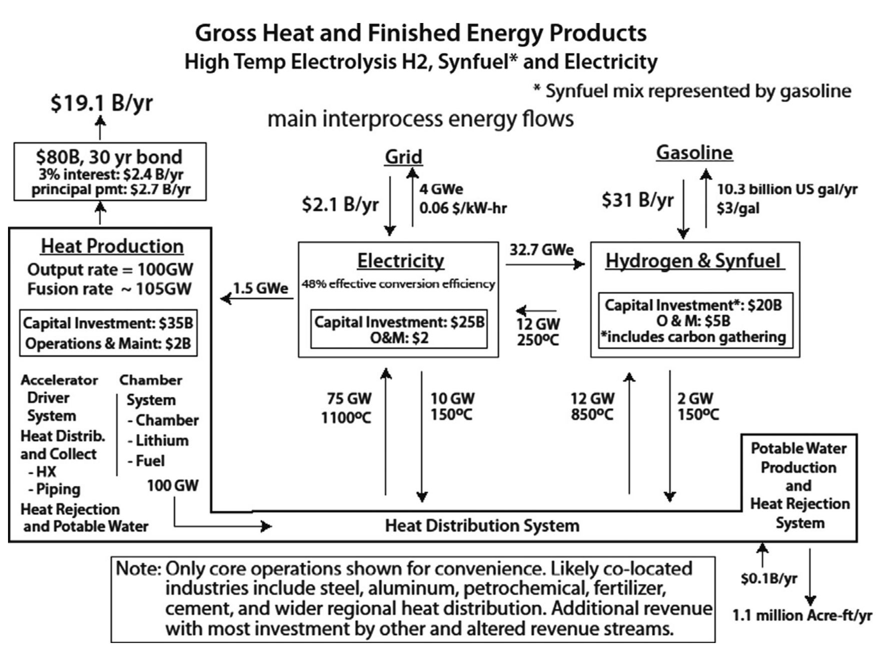

Fig. 1. Conceptual model for energy, finished product, and money flows.