SLAC – PUB – 4658
June 1988
(A)

SCENARIOS FOR FUSION ENERGY*

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ABSTRACT

Are there scenarios for the near future (5–10 years) in which the public interest in, and political support for, fusion energy are likely to increase significantly? If such a scenario should occur, what should the status of Heavy Ion Fusion be at that time so that it is looked upon as a favored approach? If such a status can be identified, what should the research strategy be so that this status can be achieved in a timely way?

This paper will look for answers to the first two of the above questions. If the goal of a desired status can be identified, the research strategy may become obvious. Of the four long-term energy options—coal, solar, fission breeders and fusion—the present position of fusion is in fourth place, never having generated any power. However, coal has environmental and safety problems. Solar has limitations of cost, availability, and space requirements. Fission in general, and breeder reactors in particular, have problems of cost, environment, and public acceptance. To be accepted and elevated to a position of equality with the others, Heavy Ion Fusion must simultaneously avoid their real and perceived major flaws. To succeed, Heavy Ion Fusion must strive to be markedly the best fusion option.

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*Work supported in part by the Department of Energy, contract DE–AC03–76SF00515.

Invited paper contributed to the International Symposium on Heavy Ion Inertial Fusion, GSI, Darnstadt, Germany, June 28–30, 1988

INTRODUCTION

Those of us who gathered together for this conference and/or contributed to the Proceedings, can be said to be the "true believers" in Heavy Ion Fusion (HIF). After the dozen years that the HIF approach has been studied, it continues to look to us to be the best approach to fusion power (magnetic or inertial).

HIF uses classical accelerator theory and experience with working particle accelerators to establish the technology base for drivers for Inertial Confinement Fusion (ICF). The approach has the advantage that it separates all of the critical and expensive components from the reactor chamber, except for the final focussing magnets which can be shielded from most of the radiation and debris. The accelerator drivers can be made with good electrical efficiency and the technology is intrinsically reliable and long-lived because components are not greatly stressed. Such accelerators can also operate with much higher pulse repetition rates than appear to be needed for a single reactor chamber of any of the designs that have been studied.

All of the above advantages, and more, have been recognized by numerous review committees, funding agencies, and individual scientists in the US, Europe, Japan and the USSR. The target physics for ICF has made good progress, as reported during this conference and elsewhere. In many talks and reports, ICF advocates have referred to HIF as the appropriate driver technology for power production from ICF.

In spite of all of these positive factors, HIF funding has stayed at a bare keep-alive level, not enabling it to compete with, for instance, newer generations of lasers for near term applications. Eventually even the "true believers" must ask if there is a future for this promising technology. In particular, are there scenarios for the near future, in which the interest in, and political support for, fusion energy are likely to increase significantly? If such a scenario does occur, what should the status of HIF be at that time so that it is looked upon as a favored approach?

We shall examine the above questions, particularly the first one, looking for scenarios favorable to fusion, from several different viewpoints and points in time.

ENERGY SCENARIOS

We will examine energy supply and energy demand from the viewpoints of various professionals, such as the Electric Power Research Institute (EPRI) and the Energy Research Advisory Board (ERAB). We will also look at constraints as imposed by environmental advocates, public opinion, and political forces. We will examine issues constraining fusion, as a stand-alone technology, and those that compare fission and fusion. We will try to do most of the above for three different points in time:

- **Now:** to establish a frame of reference;
- **In 5–10 years:** because this is the time period during which there should be changes in attitude so that funding for fusion, particularly HIF, can improve and thus enable timely progress to be made; and
- **In 30 years:** because the canonical "30 years till fusion" is a new constant of our time and will certainly color opinion in the 5–10 year future.

In all of this, there is a distinctly U.S. attitude. Those of you from other areas should apply local correction factors to these scenarios.

Energy Supply Now:

Energy is too abundant and too cheap. The low world energy prices prevent related R&D, and have virtually halted oil exploration and development of alternative sources such as solar, coal gassification, shale oil extraction, etc.

Yet, even now, 30% of the U.S. Trade Deficit is due to oil imports. If, or when, oil prices double, this part of the deficit will soar. The U.S. is providing naval protection in the Persian Gulf that costs about $200/barrel transported [1].

Meanwhile, most U.S. oil imports are from neighboring nations—Canada, Venezuela and Mexico—all suffering severely from the depressed oil prices. The economy in the "oil patch" states of the U.S. is also very depressed.

The conclusions are that, while it is nice that oil is cheap (airplane tickets and gasoline are inexpensive), the low prices cause serious problems and are unsustainable for very long.

Energy Supply in the Future:

Fusion is not part of the present energy picture and is only needed for the future if it can be shown to have advantages over coal and fission breeders. Since oil will disappear as an economic fuel, future energy needs must be met by a combination of coal, fission, fusion and the "renewables," including solar and conservation.

At the present rate of use, coal is available for 500 years. Fission fuels are available for 1000 years, even with growth of use, by using fission breeders [2]. The only so-called "renewable" resource that has much prospect for significant development is conservation [3]. The other renewables, led by burning biomass and hydroelectric, presently contribute about 6% of U.S. energy supply, and will be hard pressed to maintain that percentage in the future [2].

Energy Demand Now and in Five to Ten Years:

Table I shows U.S. Primary Energy inputs from 1984, projected to 1995 [4]. Projections of world-wide energy consumption for the next century show a steep rise, presumably while the Developing Nations strive for higher standards of living. By 2050, total consumption is projected to be triple the present rate [5].

From Table I, it is seen that the only sector that will show significant growth in the 5–10 year period is electricity. For 50 years, electricity use in the U.S. has tracked the Gross National Product (GNP). If the real GNP rate of growth is 3%, in 30 Years electricity demand will be 72 Quads, assuming the present (1988) electricity demand is 30 Quads [4].

The present installed generating capacity of the U.S. is about 600 GW, and the peak demand is 450 GW. The apparent 30% margin gets reduced to about 10% by maintenance, forced outages, etc. However, about 25% of all fossil fuel generating capacity will be over 30 years old by 1990 and 50% of all capacity will be over 30 years old by 2000. Thirty years is generally considered to be the lifetime of fossil fuel plants. In the 5–10 year period, there are planned additions of 130 MW, 40% of which is judged to be at risk of not being completed [4].

While it appears that there is a severe deficit in generating capacity coming soon, there are four "new" sources of power [6].

1) CONSERVATION. Government decreed standards for refrigerators and new, more efficient florescent light ballasts are just two items that have the potential of reducing power demand by literally gigawatts [7].
2) COGENERATION. Industrial and institutional heating and cooling facilities are increasingly being built to include electrical power generating capability [8]. The State of California requires the utility companies to purchase this power at a rate that encourages such projects, but disturbs the utilities [9]. A recent example is a 41 MW cogeneration plant just completed at Stanford University to provide heat, cooling and electrical power to the University Campus [10].
3) IMPORTS. The northeast part of the United States is particularly dependent on power imported from Canada.
4) LIFE EXTENSION. Many of the ageing fossil fuel plants will be refurbished to extend their useful life [11,12].

To a large extent, the primary energy input for the above facilities will come from the Natural Gas "bubble" that resulted from the jump in energy prices due to the OPEC embargoes of the 1970's. As this natural gas resource is consumed, conventional wisdom is that gas and oil prices will rise sharply and that coal will replace them. However, most of the new power installations consist of natural gas-fired jet engine turbines that cannot be converted. Thus, if gas prices do rise sharply in 5–10 years, there may be a climate of public opinion that is favorable to fusion. This is one of the scenarios that we were looking for to provide an opportunity for fusion.

There is at least one alternative to the above scenario. There are potentially large resources in "unconventional natural gas" including "tight sands" gas, recoverable Devonian shale gas, and coproduction of natural gas and water. There are other even less conventional sources of natural gas that may have enormous potential including geopressurized zone methane, natural gas hydrates that are frozen in Arctic permafrost, and "deep" gas, including primordial methane, 5–10 kilometers deep [2].

There are large uncertainties in the estimates of the amount of these gas resources and in the cost of production, but the implications are very great. Not only could unconventional natural gas significantly extend the fossil fuel era, but it would have less environmental impact than any energy source except fusion. It would contribute to the CO_2 "greenhouse" effect on the climate. If this problem can be controlled, then the perception of energy needs in ten years may be very different from what could otherwise be expected.

Fission Now and in the Future:

It is hard to imagine how the status of Nuclear Power in the U.S. could be any worse than it is at present. As this is being written, the Long Island Lighting Company has announced an agreement with Governor Cuomo and the State of New York that would abandon the Shoreham Nuclear Power Plant which was completed in 1984, but never started [1].

It is especially important for proponents of a new energy technology like Heavy Ion Fusion to understand what went wrong with Fission Power. We can list most of the major problems facing nuclear power:

- fear of a major accident [13,14],
- the problem of diverting nuclear fuel to make nuclear weapons by terrorist states and groups,
- health hazards from mine tailings,
- how and where to dispose of nuclear waste,
- negative publicity due to real accidents or failures,
- an anti-"big business" attitude in parts of the media and the entertainment community,
- politics, as in the Shoreham case,
- high costs due to the high interest rates on construction funds, which mount continuously until a plant begins to operate and

- the linkage, in the minds of the public, with the destructive force of nuclear weapons.

It is important to note that fusion is not immune to any of the above problems. Pure fusion, as contrasted to fusion-fission hybrids, can refute the proliferation and mine tailing issues and has a qualitative advantage on the nuclear waste issue.

Weinburg describes a future with a "second nuclear era" that will start in 25–30 years. In order for the second nuclear era to begin, he (and many other writers) feel that there must be a decade "without bad news," meaning no new Chernobyl–TMI–Shoreham incidents [15,16]. However, if we look back to the beginnings of nuclear power, starting with Windscale in 1956, there have been major bad-news events about every five years or less.

The new technologies for nuclear power are far safer than the present generation of reactors [17]. Speaking personally, I have become much more of a fan of nuclear power since I started to research this paper. But it is also important to objectively report and understand the public attitude about safety, and how it differs from professional attitudes. In an elaborate comparison of numerous risks facing our population, on a scale of "dread," nuclear power was only a close second to nuclear war [18]. This was true of members of the League of Women Voters and of college students. "Experts" ranked nuclear power far lower as a hazard.

It is not very useful to attempt to rationalize the risks of nuclear power compared to smoking, flying or driving [19]. However, as noted above, conventional wisdom is that coal will be used as the primary source of energy as oil and gas become too expensive. In fact, as is well known and well documented, coal is a terribly dangerous source of energy, being responsible for many accidental deaths and injuries and for an enormous amount of illness. While these problems are somehow usually overlooked, (exceptions do occur such as today when this is being written, the news tells about a coal mine disaster in Germany), it can be expected that when the large scale increase of coal use becomes apparent, then pubic opinion will react to the safety and environmental hazards of coal. This is essentially the second of our scenarios favorable to fusion; when more coal is needed and the real dangers of coal become evident.

FUSION

Safety Issues for Fusion:

The ESECOM [9] report studied safety issues for magnetic fusion. The major concerns are:

— neutron activation of reactor and blanket materials,

— the inventory of tritium and the risk of tritium release.

The report studied a variety of reactor designs and gives safety credits to the construction cost, if parts of a fusion plant do not need nuclear grade materials and procedures.

In Figure 1, we reproduce the principal conclusion from the ESECOM report. The open bars reflect cost credits for safety and the shaded bars represent technical uncertainty. The three systems with the best cost credits are:

1. (SiC–He/TOK), a low-activation tokamak, with a SiC structure and helium cooling, with Li_2O for breeding tritium;
2. (V–Flibe/TOK), a pool-type tokamak, with a vanadium structure and molten salt coolant/breeder;
3. (V–D^3He/TOK), an advanced fuel (D–^3He) tokamak, with direct conversion of microwave synchrotron radiation;

It is worth quoting part of the concluding summary of the ESECOM [9] report:

> *"The most important potential advantages of fusion with respect to safety and the environment are as follows:*
>
> 1. *high demonstrability of adequate public protection from reactor accidents (no early fatalities off site), based entirely or largely on low radioactivity inventories and passive barriers to release rather than on active safety systems and the performance of containment buildings,*

2. *substantial amelioration of the radioactive waste problem by eliminating or greatly reducing the high-level waste category that requires deep geologic disposal, and*

3. *diminution of some important links with nuclear weaponry (easier safeguards against clandestine use of energy facilities to produce fissile materials, no inherent production or circulation of fissile materials subject to diversion or theft)."*

Inertial Fusion:

Inertial Confinement Fusion (ICF) suffers in comparison to magnetic fusion by not being clearly associated with the potential of being an energy producing technology. Several recent stories [21,22,23] enabled ICF to make National Headlines and to gain space on editorial columns. Now at least some people have seen that there are two kinds of fusion approaches. Unfortunately, the news stories were presented in a way that confused many readers into feeling that the results showed that the ICF approach was impractical. Those in responsible positions who participated in releasing statements to the press felt they were attempting to give a picture of solid progress.

In thinking about this event, I feel that the press may have been playing up a single scientist's disagreement with his laboratory management, but that would be hard to prove from the articles. Equally likely are that the authors and readers alike did not use sufficient care in interpreting the information at hand. Although I personally feel the cause of ICF would be substantially aided by more declassification, I doubt that this particular incident would have been much different had there been no classification issues.

It is notable how little appears about ICF when fusion is discussed. The chapter on fusion [24] only mentions that ICF exists and is fundamentally different from magnetic confinement.

Heavy Ion Fusion:

It is beyond the scope of this report to discuss the application of the ESECOM findings to Heavy Ion Fusion. We note that there has been at least one study of Advanced Fuel Inertial Fusion systems, which concluded that the only driver approach which could even conceivably succeed was a Heavy Ion Accelerator [25]. We have also heard of some recent work on applying the "Flibe" molten salt concept to an Inertial Fusion reactor [26].

CONCLUSIONS

The "second nuclear era" is about as far away as is fusion today.

For the very long range, fission breeders and fusion are the only choices.

For the near future, when we hope for improved public concern with energy research issues, the safety and environmental problems of coal and the safety problems of fission should result in fusion being favored.

Conservation and the potential of "unconventional" natural gas may significantly delay the requirement for new generating technology.

Heavy Ion Fusion needs recognition. HIF is not mentioned in most of the references sited in this report.

Newspaper reports of ICF success were misunderstood, even by many scientists.

Safety and environment protection are important fusion criteria that must be very carefully preserved and nurtured, to maintain the advantages that fusion has over fission. This can reduce costs, as shown by the ESECOM study, because nuclear grade systems are not required.

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Table I. U.S. Primary Energy Inputs.

	1984		1995	
	Quads	%	Quads	%
Residential and Commercial	10.1	13.5	10	11
Industrial	19.0	24.4	23	26
Electricity	26.3	35.2	37	41
Transportation	19.3	25.8	20	22
	74.7	100.0	90	100

Figure Caption

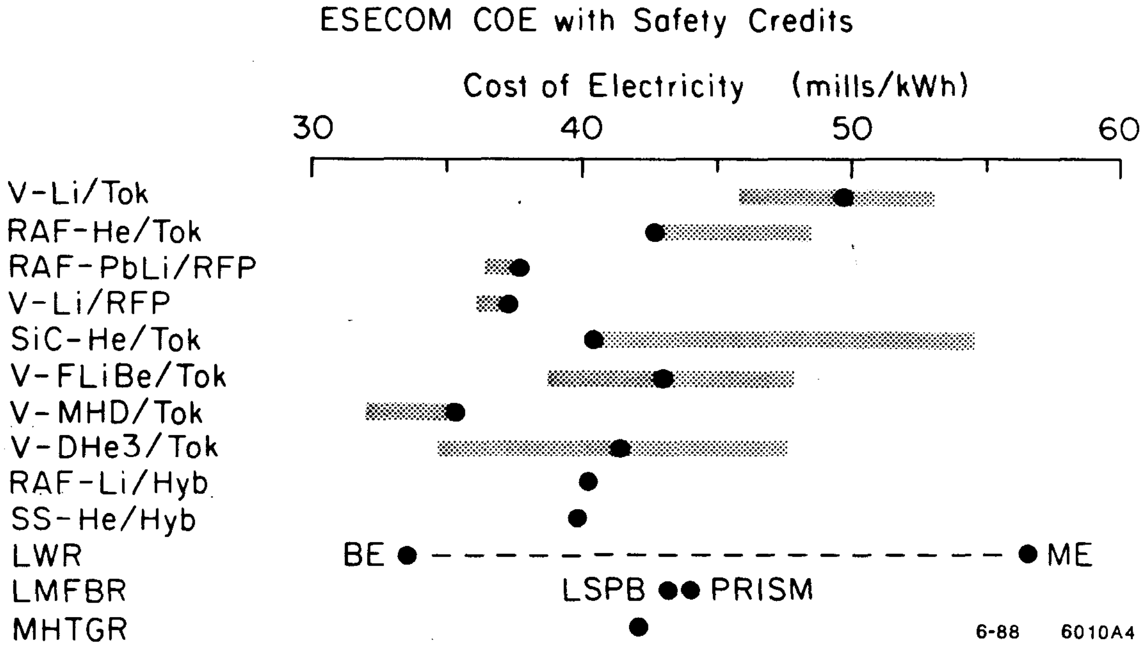
Figure 1. The results of the ESECOM [20] study on cost of electricity (COE) from magnetic fusion reactors. The bars show the range of reduction in COE due to taking safety credits for designs with more inherent safety. The nominal values, marked by dots, reflect the panel's judgement about technical uncertainty. The dotted bar for Light Water Reactors (LWR) shows the range from "Best Present Experience" (BPE) to "Median Experience" (ME).

The other dots for fission systems are; LSPB; large scale prototype breeder, PRISM; power reactor inherently safe module, breeder design, and MHTGR; modular high-temperature gas-cooled reactor.

The abbreviations for the fusion systems are defined as follows:

1. VI–Li/TOK, a D–T tokamak, vanadium alloy structure with liquid lithium cooling,
2. RAF–He/TOK, D–T tokamak, reduced activation ferritic steel structure, Li_2O solid breeder,
3. RAF–PbLi/RFP, reverse field pinch with RAF structure and lithium lead breeding/cooling,
4. V–Li/RFP, RFP with V–Li blanket,
5. SiC–He/TOK, silicon carbide structure, helium cooled Li_2O breeder,
6. V–Flibe/TOK, V structure, molten salt (Flibe) coolant/breeder,

   (Flibe: 78.4% F, 13% Be, 8.6% Li)
7. V–MHD/TOK, V structure with magnetohydrodynamic (MHD) energy conversion.
8. V–D^3He/TOK, advanced fuel tokamak using D-^{3}He cycle.
9. RAF–Li/HYB, RAF structure, fusion-fission hybrid tokamak,
10. SS–He/HYB, stainless steel structure hybrid tokamak with a Flibe molten salt breeder blanket.



ESECOM COE with Safety Credits

Fig. 1