Institutional Constraints to Fusion Commercialization

Donovan, Hamester & Rattien, Inc.

October 1979

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Preface

The major thrust of this report is that the long time frame associated with the development of commercial fusion systems in the context of the commercialization and institutional history of an allied technology, fission-power, suggests that fusion commercialization will not occur without active and broad-based support on the part of the Nation's political leaders. Its key recommendation is that DOE fusion planners devote considerable resources to analytical efforts aimed at determining the need for fusion and the timing of that need, in order to convince policymakers that they need do more than preserve fusion as an option for application at some indefinite point in the future. It is the thesis of the report that, in fact, an "act of political vision" on the part of the Nation's leaders will be required to accomplish fusion commercialization.

An alternative to this "top-down" approach is of course the more conventional identification and addressing of the technical, institutional, and economic barriers to commercialization, such as is outlined in the Appendix, a reproduction of the Commercialization Section of the January 27, 1978 draft FY79 Magnetic Fusion Energy Program Summary Document developed by DOE's Assistant Secretary for Energy Technology. (Input to this Section was prepared by DHR under subcontract to TRW.) This "bottom-up" approach has the advantage that if a demonstrably reasonable and viable commercialization plan could be developed, it would aid greatly in selling the necessary funding to Congress and the President. However, such a plan depends upon the demonstration of the feasibility of a near-economic reactor design in the mid-term. Clearly the type of study recommended by this report would be as useful to the justification of the funding for a more conventional commercialization plan as for that suggested

in the body of the report.

In any case then, the key recommendation of the report, that now is the appropriate time to carefully examine the questions of the need and timing for fusion power, is exceedingly robust. These questions must be answered as a prerequisite to successful pursuit of either the "top-down" or "bottom-up" approaches to fusion commercialization.

Future developments in reactor design and associated experiments will determine the practicality of a system that is near-economic in the mid-term, upon which to base a "bottom-up" commercialization plan. In this context, one option that may warrant further investigation is a focus on small reactors that could:

- (1) require a smaller capital investment and thus become more palatable to utilities; and
- (2) require a good deal less funding for development, since it may not require a progression of successively larger demonstration machines.

Such reactors could be composed of modules like those proposed in the Oak Ridge design of 1977, but smaller in size, resulting in a system considerably less than the 1000 MWE presently envisioned. While experience with the Alcator machine at MIT continues to suggest that confinement at higher densities is feasible, the rub here is the twin problems of radiation damage to the blanket and first wall materials and of heat removal from the blanket which may limit the extent of size reduction possible for a given power output. Only time will tell whether mid-term commercializable fusion systems will emerge that will allow the conventional approach to be pursued vigorously.

Another important commercialization consideration is the development of regulatory approaches that can provide for an acceptable lead time for the siting and licensing of utility fusion

power systems. The "top-down" approach has a distinct advantage here, in that the political commitment associated with the "act of vision" would provide the impetus for the government to assume the financial risk of regulatory delay and/or for the nurturing of regulatory schemes that would minimize the chances of such delay.

One final point. In our view, the "top-down" and "bottom-up" approaches to acceptance of a commercialization plan would not necessarily lead to very different technological programs. Both would require support of industry and government. Obviously, if one could get the "act of political vision," one would likely have smoother sailing in subsequent fusion development. In this sense, perhaps the key point is to be ready to "promote" the act of political vision in the event that some dramatic happening (e.g., another oil embargo) makes it appear to fusion planners that it will, in fact, be undertaken by the Nation's political leaders. We should remember that the acts of political vision associated with the Manhattan Project and Apollo Programs would not have occurred without U.S. involvement in World War II and the initial dramatic manned space flights by the Soviet Union.

INSTITUTIONAL CONSTRAINTS TO FUSION COMMERCIALIZATION

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I. INTRODUCTION

At first glance, an assessment of "Institutional Constraints to Fusion Commercialization" would appear to suffer from an excess of study material; clearly there are numerous barriers to be resolved before any fraction of our energy supplies are provided through the energy of thermonuclear fusion. Of necessity, therefore, this paper provides only an initial and limited overview of those issues surrounding fusion's prospects as an R&D option as well as those critical policy decisions that need to be made in the near term if we are to achieve the fusion deployment schedules currently contemplated by the Department of Energy (DOE). It concludes with recommendations that fusion energy planners can consider regarding actions they may take to improve the likelihood and advance the timing of fusion commercialization.

This study is part of Battelle Pacific Northwest Laboratories' own assessment of "Commercialization of Magnetic Fusion Energy." Its initial focus was on considerations relating to the involvement of industry in fusion commercialization. The study quickly keyed on fundamental issues of national policy since it became clear that such issues are central to the fact that industry holds little interest, at present, in actively participating in fusion commercialization activities. Understanding this lack of interest is not difficult; understanding how to effectively proceed in light of the situation will be a considerable challenge.

This report is a product of the author's involvement with the subject of industry involvement in fusion commercialization, both while a representative of utility industry interests and as a participant and contributor to a variety of industry and government R&D planning exercises relating to the use of the inexhaustible energy resources. During the course of this study, the author held numerous conversations with individuals both inside and out of government. Discussions with Dr. James M. Williams of the Los Alamos Scientific Laboratory and Mr. S. Locke Bogart of Science Applications, Inc. were particularly provocative and helpful; their time and interest are gratefully acknowledged. All opinions, conclusions and recommendations are, of course, the sole responsibility of the author, however.

The report that follows is divided into five chapters as follows:

- This Introduction.
- A discussion of Fusion Commercialization which focuses on understanding the reasons behind the current minimal interest of industry and the realities of our abilities to effectively conceive and direct any fusion commercialization plan.
- An examination of Fusion's Criteria for Credibility, those conditions that must be met in order for fusion to be perceived as a major energy option of immediate importance by all sectors of the energy development marketplace.
- A review of the Importance of Policy Choice in determining fusion's future.
- A presentation of the report's key Conclusions and Recommendations.

To the possible disappointment of some, this report contains no sophisticated models (computer or otherwise) relating to fusion commercialization. It similarly does not provide easy answers or step by step procedures to the resolution of the "Institutional Constraints to Fusion Commercialization." If it does shed light on the identity and extent of a number of these constraints and how their resolution may be addressed, the author's (and, hopefully, his sponsor's) objectives will have been achieved.

II. FUSION COMMERCIALIZATION

One cannot ignore the fact that the topic of fusion commercialization is approached with some measure of skepticism and disbelief, if not ridicule, by almost all but the fusion community. Even on the surface, the reasons for this are numerous; they include the fact that basic science questions and uncertainties relating to fusion continue to exist, that the development timescales are perceived as unusually long, and that overoptimistic technology assessments (on fusion and other technologies) have been made and revised and re-revised before. Such "superficial" reactions may often reflect an additional underlying lack of confidence in technology and technologists or the government's ability to recognize and exploit technology effectively. Perhaps most significantly, there is the additional belief that we will need energy alternatives long before fusion will become available, hence these alternatives to fusion must have higher priorities.

Commercialization: A "Conventional" View

Commercialization has become firmly entrenched in the energy RD&D community as the word which represents the overall objective of all major efforts. It brings to mind an orderly "PERT-like" progression of technology evolving from ideas on a blackboard to laboratory scale experiments to pilot projects to demonstrations to early commercial plants

(with appropriate government subsidies) to the eventual (and conceptually inevitable) free marketplace of purchaser and vendor industries. In this context, one can discuss the rationale of early government involvement in the technology (reasons of high risk, long payback, and significant unquantifiable social benefit) and the process of transfer of expertise and program direction from government to industry. The ultimate goal is a situation where private buyers and sellers constitute the marketplace in which the subject technology is but one option, to survive or fail on its own merits, and where government involvement is largely limited to a regulatory or advanced R&D role.

This logic has been applied to many (if not most) of the energy technologies supported by DOE. Indeed, such a commercialization process has been described in "The Department of Energy Policy for Fusion Energy" (DOE/ER-0018, September 1978). In this document, one or more fusion Engineering Test Facilities (ETF) begin operation in 1992-95, followed by operation of an Engineering Power Reactor (EPR, in 2004), the Demo in 2015 and eventual Initial Operating Capability in the 2020-2030 time frame. This program will be expensive; current expenditures for magnetic and inertial fusion programs total some \$0.5 billion annually and the policy document estimates that by the time of EPR operation, expenditures will have totaled some \$18 billion.

However, fusion is only one option, albeit a unique option, on the "menu" of alternative energy technologies that DOE may select from. The menu includes the array of near term and long term options, fossil and fissile technologies, solar and the renewables, "soft" and "hard" technologies, etc. Here again, the presumption is that DOE supports each technology's development until the private sector can select and commercialize the most promising options. In reality, numerous constituencies compete for shares of the government R&D support dollar and commercialization priority decisions are made by individuals within DOE, OMB, other Administration agencies, and the Congress as well as by industrial decisionmakers. The likelihood that fusion will be selected among its competitors and proceed down the commercialization process as planned is unclear.

Fusion's considerable advantages as an environmentally benign and abundant energy option are unfortunately accompanied by its significant development timespan and cost. It is noteworthy that fusion achieves its current level of support in the absence of any strong congressional, public or industrial constituency. Eventual commercialization will depend on fusion's ability to sustain and expand its annual budgets and commitments for major facilities in an environment of increasing competition from other energy options (often with more vocal constituents) and renewed attempts to balance the federal budget. In this context, it will become increasingly difficult for decisionmakers, who must earn the political "return" from their "advocacy investments" over periods measured in terms of office (2-6 years) rather than the

decades relevant to fusion development, to sustain interest and support for fusion. This fact is generally recognized, often bemoaned, but rarely incorporated into fusion commercialization planning. It is further addressed in Chapter IV of this report.

Industry Involvement

Those that have addressed industry involvement in fusion technology development envision a process of increasing industrial responsibility and investment as the plan proceeds from ETF to EPR to the Demo. Unfortunately, given the time frames involved, and the business history of Light Water Reactor (LWR), High Temperature Gas-cooled Reactor (HTGR) and the Liquid Metal Fast Breeder Reactor (LMFBR), significant investment by industry appears increasingly unlikely. For the foreseeable future, industry is unwilling to provide a substantial share (even, say, 10%) of national fusion funding because of:

- the numerous technical uncertainties associated with fusion development
- fusion's unusually long investment recovery period
- the government's history of policy changes relating to support of key energy options.

Of course, industry is not entirely uninvolved in fusion development. Most large energy companies have modest fusion programs and even more serve as DOE contractors on a cost plus fixed fee basis. However, it is not likely that industrial America is putting its "best and brightest" to work on the fusion problem. Significantly, this level of industrial involvement may not be inappropriate at this time.

The danger may well be the fact that fusion planners continue to project the need for and process of industrial involvement while such involvement (on a level such as that associated with fuel cell or oil shale development) fails to appear. Such failures can be interpreted as industrial rejection of fusion's viability rather than inappropriate planning or support for industry involvement; such an interpretation can yield disastrous (for fusion) consequences.

One of the elements that makes fusion unique from the industrial involvement perspective is the fact that fusion is both long term and perceived as long term. It is important to note that this was not the case with LWRs, HTGRs or LMFBRs. Although history has proved them to have development and investment recovery periods also measured in decades (and there is some question whether LWR returns will ever be positive), it is significant that the options were not perceived as being this long range when industrial involvement decisions were being made. It seems likely that the level of industrial interest and investment (both in terms of financial and human resources) would not have been forthcoming if the political and technical realities associated with fission development had been more clearly foreseen. Given this history and our current understanding of the fusion development process, it is not rational to expect industry to diligently plan for eventual major fusion commercialization responsibilities. The commercial market is simply too distant and uncertain for major industrial investment at this time. Note that a

significant change in this situation will require reduction of fusion's development time scale and uncertainty, a challenge of considerable technical and political magnitude.

Near and Mid-Term Fusion Commercialization Analysis

The above suggests that the detailed "script" accompanying fusion commercialization will not be credible, that it will hold little meaning for industry decisionmakers or, even in the final analysis, for government policy analysts. However, one can and should speculate on how to involve industry and what would motivate involvement in those selected areas of outstanding importance. However, this should not substitute for recognizing the critical issues that fusion faces in the near and mid-term if it is to go on to play the role routinely ascribed to it in our energy future.

Fusion can never become a viable energy contributor unless it first becomes a high priority major R&D option (in the way that synfuels presently are, and the LMFBR once was). It is therefore appropriate to examine the circumstances within the technology, the vendor and user industries, and the government that need occur in order that fusion achieve this status. Such "criteria for credibility" constitute the subject of the following chapter.

Most significantly, it is necessary to inquire into the process under which government evaluates, selects and commercializes a long term, "ultimate," solution such as fusion.

Can fusion be deployed as just one element of an extensive energy option "menu" or must it be singled out and handled as a special case? What steps are needed if one concludes that fusion will or will not be needed by a certain date? How can planners responsibly treat the inevitable uncertainty surrounding both the timing of the need for fusion and the evolution of the technology itself? These concerns are the subject of Chapter IV.

Thus, the overall conclusion of this analysis is not that fusion commercialization is too distant or too difficult to examine, but that one cannot be satisfied with planning platitudes of "eventual transfer" and "increasing responsibility" relating to the industrial role. Rather one must face the existing situation realistically and ask what immediate actions must be taken so that industry interest will be present when it is required. Importantly, this will relate to the timing and level of commitment by government in fusion technology which must be sufficient to assure industry that their investments, when made, offer returns commensurate with the risks taken.

III. CRITERIA FOR CREDIBILITY

In the past, fusion planning has tended to be either microscopic (focusing on detailed decisions relating to near term budgets) or universal (spanning a commercialization period of 30-50 years). It may be instructive to focus on a middle range of the next 10-15 years, a time period for which we can make reasonable projections and during which fusion must become an increasingly visible and significant option for U.S. energy RD&D planning. The operative question should be "under what conditions with respect to fusion technology, industry, government, etc., will fusion become a 'highest priority' energy option," i.e., what are the institutional criteria for credibility for fusion as an energy source.

It is not easy to define what is meant by a "highest priority" option. That the LMFBR once had this distinction only serves to illustrate the inadequacy of any definition and highlight the underlying transitory nature of government commitment. In today's environment, solar energy, synthetic fuels and conservation technologies all appear to enjoy "highest priority" status. It is clear while the importance of fusion to the long term is generally unquestioned and that the program is relatively safe from serious budget reductions, there is not now a level of interest within government, or advocacy outside government to greatly increase fusion activities. Perhaps fusion's achievement of "highest priority" status would be most clearly signaled by a widespread clamor to

to increase fusion budgets and accelerate development schedules through the use of innovative financing concepts in the same way that synthetic fuels are enjoying their current advocacy.

In this chapter, speculation is provided relating to needed prerequisites to such enhanced priority. Specifically, it addresses the criteria for fusion credibility as a top priority option by examining the needed developments in the following areas which must occur before fusion can enter its aggressive development stage.

- Fusion technology
- The potential fusion user industries
- The potential fusion vendor industries
- National policy and government

The analysis begins with the assumption that the success in the science and technology development program that is appropriately at the heart of current fusion efforts is a necessary but not sufficient condition for fusion's continuing viability; that events outside the fusion world will hold major importance in influencing the timing and likelihood of fusion applications.

The sections that follow contain but a first cut at criteria formulation. Clearly additions, deletions and modifications will be forthcoming with review of this report and continued investigation into the commercialization process. In addition, some of these criteria will be far more significant to fusion's viability than others. In spite of these caveats, it is important to begin considering fusion development in this context; one which focuses on

successful entry into the next institutional stage of the commercialization process

Fusion Related Criteria

This report is not intended to provide an in-depth technical discussion of scientific and engineering milestones for fusion development. The following fusion-related areas do seem important, however, if the technology is to be considered a leading option in the next decade.

1. Scientific Feasibility. At a meeting some years ago, Harold Furth of the Princeton Plasma Physics Laboratory observed that scientific feasibility would occur when critics stop saying "fusion won't work" and start saying "it will be too expensive." Over the years, the specter of lack of scientific feasibility has consistently undercut support for the program. Within the fusion community, there is little doubt that scientific feasibility will be soon demonstrated (some would argue that it has already been achieved). In any event, for fusion to expand as a main line energy option, scientific feasibility must be unquestioned by government and private decision-makers. This probably also includes demonstration of significant D-T burn in both magnetic and inertial concepts.

2. Engineering and Cost. Progress must continue in what is currently a serious problem in establishing credibility relating to fusion engineering and capital and operating cost estimates. To be credible, fusion cost estimates must have some basis in experience in dealing with similar (albeit smaller scale) systems such as tritium handling, superconducting magnets, specific laser or ion beam systems, etc. For example, inertial confinement designs that

deal with "Brand X" laser systems or newly invented options will suffer from minimal credibility. An additional key factor will be focusing on prospects for and problems associated with achieving reasonable duty cycle factors on experimental machines such as the ETF and EPR.

3. TFTR Operation. Fusion credibility will clearly be enhanced by successful TFTR operation on D-T fuels. Significant scientific, engineering or even programmatic (e.g. administrative) delays and/or problems could seriously affect the way in which magnetic confinement is viewed. Similar observations may be made regarding results forthcoming from the Shiva and Shiva Nova laser fusion experiments, although these are complicated somewhat by classification issues.

4. Broad-based Success. Interest, enthusiasm and confidence in fusion as the ultimate energy answer will be greatly supported by continued broad-based success across the fusion field. Thus, promising results that continue to be reported in both inertial and magnetic fields, tokamak and mirrors, and domestic and foreign, etc., can only be viewed as significantly improving the comfort level with which policymakers can continue to rely on fusion.

Utility Related Criteria

At present, electrical utilities are thought to be the most probable customers of fusion energy, although fusion's use as a thermal source for process heat or synfuels production is being viewed with increasing interest. As potential users, utilities have individually and collectively funded a wide variety of fusion programs. The

Electric Power Research Institute (EPRI) is the primary vehicle for utility sponsorship of fusion; nevertheless, its fusion support amounts to less than 1% of that of the federal government. Utilities have therefore been willing to support fusion research only at the low level represented by their contributions to the EPRI program. There has been little interest in significant expansion of such support. The following items appear to be critical factors relating to the future prospects for any such increase.

1. Financial Health. Utilities find it difficult to look to the longer term needs of their industry while their immediate financial stability is in jeopardy. A commitment to fusion by a utility requires substantial long term vision at the top of the company (Chairman of the Board or President). Currently, such individuals are far too preoccupied with near term survival issues relating to rate relief and economic system operations. It seems clear that local and national regulatory reform must be a significant factor in relieving this situation. This will be particularly important in those areas that relate closely to the capital needs of the industry such as inclusion of construction work in progress (CWIP) in the rate base or provision of guaranteed returns on equity. Such capital related reforms are crucial if a utility is to maintain the bond ratings and stock value that determine the company's cost of capital, a major factor in computing power costs from a capital intensive technology such as fusion.

2. Load Growth. The rate at which the utility system projects its need for new energy sources will be important as an element of its perceived need for fusion. If the utility's growth curve is flat (base load electricity needs or natural gas needs for electric or gas utilities), the urgency associated with developing alternatives will be low. Of course, other factors may be significant; if fusion's role is to replace imported oil or even coal use in light of feared CO₂ impacts, then the impact of overall load growth diminishes.

3. Commitment to Fission. It seems unlikely that utilities that have elected to not pursue fission technology would be strong advocates of fusion power. This is especially true for utilities that have been discouraged from fission because of insuperable licensing or regulatory problems. Utilities with a strong history of commitment to fission may well embrace this advanced nuclear technology especially if it is supportive of their future needs (as could be the case with fusion-fission hybrid technology).

4. Commitment to Coal. The key element for companies with a significant commitment to coal will be whether they view coal as the transitional fuel or, because of resource-optimism or short sightedness, see it as a long term answer. The case of a utility committed to coal because of anti-nuclear sentiment would be particularly troubling for fusion's prospects.

5. State Regulatory Constraints. In addition to their important role in ensuring utilities' financial viability, state regulatory bodies are showing increasing interest in and scrutiny of utility research expenditures. It is unlikely that utilities can take a major advocacy role in favor of fusion and back this support

financially, if their regulators are not similarly enthusiastic. Another important, if subtle, impact that regulators will have on fusion development will be in the way they treat extended outages such as that resulting from the Three Mile Island incident. If regulators decide to "protect" their customers from the significant repair and cleanup cost and potentially even more significant power replacement costs, the increased risk with which utility investors view utility stocks and bonds will increase the cost of capital intensive systems significantly. Furthermore, prudent utility managements would be understandably reluctant to pursue a new and unproven, high capital cost, complex nuclear technology such as fusion.

6. EPRI Involvement. EPRI enthusiasm in the fusion field will, of course, mirror utility interest. Significantly, the EPRI budget has been dropping in recent years, potentially reducing the influence of the Institute on the national program and limiting its role to one of information gathering and assessment of fusion developments. For fusion to gain widespread national attention, active EPRI involvement in fusion research will have to be present. Clearly much of the impetus for an increased EPRI role must come from the utilities themselves and the importance of educating and seeking input from key utility and EPRI executives cannot be minimized. As synfuel and related applications gain more widespread interest, the involvement of the Gas Research Institute (GRI) and gas industry should also be sought.

Vendor Related Criteria

Support for fusion development must be forthcoming from more than the potential fusion using industry; strong advocacy must also be heard from from companies with serious interest in becoming eventual suppliers or vendors as the fusion industry emerges. A potentially significant development in this regard is the recent incorporation of Fusion Power Associates, a trade association of companies with business interests in fusion technology. Some significant criteria relating to these firms will include:

1. Viability of Fusion Users. The current fission industry is in serious financial difficulties in large part because the utilities went into a period of decline. Vendors will certainly examine their potential fusion market carefully including the technical and financial viability of their prospective customers.

2. Viability of the Fission Business. Potential vendors of fusion technology will view failure of the fission business (if it occurs) as a serious obstacle to fusion commercialization irrespective of whether they themselves are fission system vendors. If currently fission vendors, they will be neither willing nor financially able to devote significant resources to fusion developments (note that if fission is successful, the principal motivation for involvement of LWR vendors in fusion development may be to encourage introduction of fusion-fission hybrids, a technology which could ensure the fuel supply for, and continuing relevance of LWR technology). If currently not fission vendors, such firms (e.g. aerospace companies) will have a difficult time convincing their corporate boards to invest in an even more complex nuclear technology than the one that failed. Here, of course, the reason for fission's

failure will be crucial. If it relates to a weakness in government policy or excessive regulation, the lessons learned by industry will not hold well for fusion. Rationale relating more closely to economics or uncontroversial technical problems may not be fatal to fusion's prospects.

3. Risk Sharing. During LWR commercialization, the vendor industry bore a major share of risk and cost by providing "turnkey" plants at fixed price to utilities; the resulting cash losses and other investments have not yet been fully recovered. With respect to the HTGR, the vendor first took the risk and, with overruns and delays at Fort St. Vrain, has suffered substantial losses. As their customers refused to assume additional risk and cost, this vendor's recent activities have been limited to relatively risk-free, low level of effort R&D programs. In the case of the LMFBR, industry took a modest risk while government assumed the open-ended risk for all major demonstrations. The recent presidential policy change has apparently (unless other policy changes occur) ensured both private and public sector losses in this program. The rapidity with which this number one priority option fell to a lowest priority status will make all future investments in long term energy options appear to have substantial risk.

In the case of fusion development, industry will clearly need to share risk and costs with some party (presumably government). Yet in a recent report ("Development and Commercialization of the Light Water Reactor, 1946-1976" by R. Perry, et al., R-2180-NSF, June 1977), Rand noted that the early nuclear demonstrations in

which industry took responsibility for the open-ended risk, (such as cost overruns) were those that were most successful. Thus government can provide cost sharing and incentives while not entirely removing risk and the talent and resources that risk stimulates (it is not likely that firms will use their most competent managers on government cost plus fixed fee jobs where losses and profits are both limited). The major risk in pursuit of such government dominated programs may well be the likelihood that government policy changes will make key staff and plant facility investments quickly obsolete.

4. The State of the Economy. Although it is apparent, it is nevertheless noteworthy that industry will not look to the long term with significant investments under today's economic conditions of impending recession and double digit inflation.

National Policy Related Criteria.

As may be inferred from the proceeding discussion, the importance of an enlightened national energy policy which recognizes the significance of long term energy issues cannot be over emphasized. The future of fusion development over the next few years may well depend on how national policy evolves on the following issues.

1. LMFBR Development. Although recent Presidential policies have been extremely damaging, the fast breeder is still viewed as the central advanced nuclear option by industry. If this option is eventually restored, fusion must seek its own niche in energy planning, probably a much longer range role relating to improved environmental or economic characteristics. Importantly, a society committed to LMFBR development will probably not approach fusion commercialization with a sense of urgency. As noted earlier, a

politically inspired termination of the LMFBF program will leave fusion's prospects in some doubt unless it is accompanied by a strong commitment to develop fusion and other inexhaustible technologies.

2. Plutonium Recycle and Proliferation. Here again, the most important issue may well be how often and with what logic does national policy shift course. While it is unlikely that fusion will be developed on a time scale that is relevant to current proliferation concerns, some analysts view the hybrid operating on the thorium-uranium (233) cycle as holding potential advantages. It is hard to believe that such advantages would outweigh the potential proliferation problems of the hybrid, however. In addition, proliferation issues relating to the spread of thermonuclear weapons have been raised by the potential dissemination of inertial confinement fusion (ICF) information. This continues to be the subject of security review and could result in limitations placed on ICF development.

3. LWR Improvement. With plutonium recycle in doubt and natural fissile resources limited, interest in improving the efficiency of LWR's has been high. The question relevant to fusion planners is how fusion is seen to fit into an improved LWR economy. It may very well be that the combination of the fusion-fission hybrid with efficient LWR's makes excellent planning sense. In this regard, a return of national commitment to nuclear technology in the form of improving LWR's would also be helpful to fusion.

4. Energy Import Policy. The role of national policy as it relates to dependence on foreign energy supplies will obviously be a cornerstone of overall U.S. energy policy and will hold major importance for fusion development. The key question is how long a view does this policy encompass and how well does it recognize that the long term energy security of other nations will be important to the U.S. (i.e. does it assume that the U.S. has a responsibility to reduce imports beyond the level at which it feels secure and a responsibility to provide technologies that other nations can deploy to promote their own independence?) The degree to which emerging energy import policy addresses such long term issues will be an important and early signal for fusion planners.

5. Other Foreign Policy Issues. International interest in fusion development has always been high and the U.S. may elect to take advantage of opportunities of expanded information and personnel exchanges in the fusion field as an important element of foreign policy. It is conceivable that a major U.S. commitment to fusion, such as that discussed in the following chapter, can and should be highly international in tone and management approach.

6. The Role of Solar Energy. Those who suggest that a choice between the "hard" and "soft" energy technology paths must be made in the long term tend to encourage polarization of long range energy policy by insisting that the paths are mutually exclusive, with negative implications for nuclear technology. To the degree that policy makers continue to be buffeted by the politics of this debate (which changes over very short time frames), the long term

energy policy development that is so vital to fusion deployment will not be forthcoming. It will be a substantial challenge for the political system to be able to resist taking the popular choice in favor of what it truly believes to be in the long term interests of the country when such conflicts exist.

7. Attitude Towards Business. Here again, the political propensity to assume a populist approach to energy policy must be resisted if fusion development is likely to occur. Decisions made over the next few years on such issues as corporate divestiture and government ownership of the energy industries will hold major significance for fusion planners.

* * * *

This chapter has reviewed those institutional elements that can promote or retard the prospects for fusion's continuing evolution from one energy alternative among many to one of the highest priority. The next chapter focuses on the significance of policy choice in the development and commercialization of this longest term option.

IV. IMPORTANCE OF POLICY CHOICE

The last chapter focused on the external influences to the fusion program that will be critical to fusion's ability to assume the role of a "highest priority" option. It did not address the question of how the nation decides on the choice of its highest priority options or how and why fusion may be selected as such a choice. This portion of the report examines the importance of policy choice to the fusion commercialization process. In four sections, it discusses:

- why fusion development is fundamentally different from development of other energy options
- the need for a deliberate, long term policy commitment to fusion commercialization, an "act of political vision," and the problems associated with such an act
- two fundamental questions that must be addressed with respect to a major commitment to fusion, and the observation that only one has been studied in depth in the past
- the likely consequences of avoiding such a commitment, of conducting "business as usual"

Fusion as a Fundamentally Different Option

As noted earlier, fusion has the distinction among energy options of being both unusually long term and perceived as long term. The time frames associated with LWR and LMFBR development were in fact long term but were not perceived to be long term when commitments were made. The current estimated time and resource requirement associated with fusion development makes it both quantitatively and qualitatively different than other business investments, even those relating to energy development. This fact is widely recognized and

generally viewed as the rationale for significant government involvement in the fusion effort. However, government involvement is significant and justified in other energy technologies of much shorter time horizon. Government has a special gap to fill with respect to fusion development.

Other energy concepts typically have both elements of broad based public support and more focused industrial advocates (from both vendors and users). Those that do not (e.g., the Molten Salt Breeder Reactor) have found it difficult to sustain aggressive RD&D programs. That the fusion program has continued to grow and advance without such support is testimony to the advantages of the technology as perceived by government decisionmakers.

Fusion's potential advantages are numerous and have consequences that transcend those of most other alternatives. If successful, fusion can truly free mankind from energy resource constraints in a wide variety of applications. But the challenges are equally numerous and broad. How can the nation, with its history of vacillation and failure in connection with the LMFB program, only uncertain success in the LWR program, and continuing heated controversy in connection with options as diverse as biomass, Ocean Thermal Energy Conversion, passive solar and synfuels, mass the resources and commitment required to proceed with fusion? Under what conditions can we rationally expect industry to become a partner in fusion development; a partner who is more than a paid "employee" but one willing to make substantive and significant human and dollar investments in the technology?

An Act of Political Vision

It is the thesis of this report that fusion development will require an "act of political vision" on the part of the President and Congress in order that fusion commercialization be achieved early in the 21st century. As noted earlier, fusion is a unique case in terms of the time and resources that must be invested in its commercialization. It was also recognized that, for fusion, the usual commercialization factors do not operate as they do for other energy options. It seems clear that, given the history of the last two decades, industry will be unlikely to assume an increased responsibility for fusion activities without a qualitative change in the government's approach to long range energy development. As long as fusion is but one item on the "menu" of energy technologies, it will always be considered too long range and risky to justify significant investment of private capital towards its commercialization.

An act of political vision as it related to fusion would be a qualitatively and quantitatively different commitment to develop the technology. Implicit would be the recognition that there is an undeniable need for fusion, a need that transcends the assumptions of conventional energy investment analysis. It would contain the postulate and understanding that fusion will be necessary to the nation and the world and that it is essential that it be available within the next few decades. The act must be "visionary" since it is unlikely that one can prove to the satisfaction of all (or even most) observers that fusion is the answer. It is

safe to assume that such consensus, which has managed to elude the nation in the past on virtually any subject of national importance, will continue to do so in the future. Importantly, the act would have to set clear targets and goals for the fusion program. In order to sustain interest, it must offer concrete interim successes that are visible and measurable against original plans by Congress, the Administration and the public.

Precedents for such an act, while not numerous, are compelling. The Manhattan Project was never viewed as an optional development program; its urgency and priority were unquestioned in spite of what appeared to be almost insuperable technical challenges. In the same way, the objectives of the Apollo Program, once enumerated by President Kennedy, were never seriously reconsidered. Similarly, defense commitments are not generally viewed as areas where any but the most firm commitment is mandatory. It would be misleading, however, not to observe that each of these precedents dealt with objectives that were much shorter term and more clearly defined than fusion commercialization.

It may, in fact, be argued that political vision (and the lack thereof) played a significant role with respect to LMFBR development. LMFBR supporters will argue that market need was the driving force behind the nation's early commitment, yet it is hard to ignore the influence of key administrators, congressional leaders and successive Presidents on

developments. When the "vision" that reprocessing and the breeder were needed to close and extend the fuel cycle collapsed, so did the program. It is abundantly clear that any restoration of the program will rely on sustained and increased Congressional vision and renewed Presidential leadership.

Assuming that such an act of political vision is necessary for fusion, what would prompt a President to take such a step? Above all, he must be convinced that fusion is essential for the long term future and that its technological promise is sufficient to merit the national investments required. The commitment would probably be placed in the context of a renewed recognition that the nation and the world must continue to rely on technology and technical advances if our society is to remain substantially intact. Fusion would need to be presented in a manner so as to capture the public imagination. Since it is unlikely that the final payoff of the effort would be achievable within a President's political (or possibly even his biological) lifetime, he must see the commitment in a historical perspective and be capable of achieving non-partisan support in this context. His ability to get such support may have hold implications for society's ability to address the class of longer term threats to its survival such as nuclear weapons, environmental concerns, world peace, etc.

The Fundamental Questions

In approaching the decision whether to make an overriding commitment to fusion now, a President and Congress must face two fundamental questions:

- Is the need for fusion certain, and what is the timing associated with this need?
- Is the scientific and technological basis for fusion adequate to meet the need?

The answers to these questions will determine whether it will be sufficient to simply preserve the fusion option for some later decisionmaker to select or alternatively, to decide now to develop the option.

It is interesting that most of the recent reviews of the prospects for fusion have not only been open to a charge of bias, in that the principal contributors have been those individuals long associated with the fusion community, but that they have only addressed the second question, that of scientific and technological status and prospects for advancement. In this light, it is not surprising to observe that although the studies consistently report positive (for fusion) results, no marked acceleration in the program has taken place.

This is not to imply that resolving the first issue will be easy. Addressing this question will involve analysis of:

- estimates of national and international energy need
- judgments relating to domestic and world energy resources, by type
- international political stability
- long term oil (and other resource) politics

- the impact of a number of potentially serious problems (e.g., CO₂ "greenhouse" effect; water limitations, waste disposal, etc.).

ERDA's Inexhaustible Energy Resources Technology Study was a preliminary attempt to address these issues but considerable additional work will be required.

It is important to bear in mind that even the best of such studies cannot resolve these kinds of issues with certainty. Probably the most one can hope for is that the efforts will define where factual knowledge ends and the need for prudence in planning begins to highlight the importance of such long term energy insurance.

Addressing such fundamental issues as these should probably be the subject of a broad based policy review not unlike the recently completed Solar Domestic Policy Review (DPR). There clearly remains lots of homework for DOE planners to do before suggesting such a study, however. The key issue for the fusion program management is, of course, having asked for such a basic assessment, is one willing to live with the results.

Consequences of "Business as Usual"

If the fusion community fails to address these issues and bring them before energy policy decisionmakers, fusion appears destined to a long series of delays in the high cost, long lead time experiments that constitute the main line effort of the program. These delays will result from demands to evaluate fusion anew with each successive device and expenditure in light of the fresh information from preceeding

experiments. Under "business as usual" conditions, the bureaucratic need to avoid responsibility for mistakes could stretch the fusion commercialization point well beyond its projected 2020 date. Without such a commitment, it may in fact be that we will never have the institutional ability to provide the funding levels required to involve industry and commercialize fusion. The concern is that as the energy crisis becomes more apparent, national focus will center more and more on near term issues.

Thus, by entering the period which will surely see energy problems of increasing severity without a carefully considered long term energy strategy and set of commitments that must accompany such a strategy, we may be foreclosing our ability to ever enact such a strategy.

V. CONCLUSIONS AND RECOMMENDATIONS

This report has focused on the particular challenges that fusion commercialization will place on the decisionmaking institutions of our society. It discussed the commercialization process and fusion's unique position relative to it; the criteria for credibility that fusion, government and industry must address if fusion is to advance as a high priority energy option; and the possible need for an "act of political vision" in the context of fusion commercialization. The study's key con-
clusions are:

- Currently, the topic of fusion commercialization is approached with some measure of skepticism and disbelief, if not ridicule, by all but the fusion community.
- Commercialization is not a well understood and automatic process in which DOE planners can engineer and orchestrate the involvement of each key player without substantial investigation of the needs and motivations of each.
- Industrial involvement (by either vendor or user industries) is not likely to occur without a significant additional government commitment and mechanism for cost and risk sharing.
- Fusion is unique among energy options because it is both long term and is perceived as long term. Because of this, the usual commercialization factors which motivate industrial investment and involvement are not operative.
- It is possible to define "criteria for credibility" which relate to prerequisite developments in fusion technology, fusion user industries, fusion vendor industries, and national policy and government. These criteria specify the conditions that must exist if fusion is to have the opportunity to advance from its present status to the "highest priority" status that will be essential for further substantial progress and industrial involvement.

- Fusion commercialization will not proceed as long as fusion remains in its current role as only one among a diverse "menu" of energy options.
- Timely commercialization will require an "act of political vision" on the part of the nation's leadership -- a long term, solid commitment by the nation to ensure development of fusion on a specific time scale.
- Two fundamental questions must be addressed in deciding on such a long term commitment. They are:
 - Is the need for fusion certain and what is the timing associated with this need?
 - Is the scientific and technological basis for fusion adequate to meet the need?

Most fusion studies conducted to date have addressed only the second question in detail. In the context of current policy making, such questions (if deemed of sufficient importance and urgency) would be addressed in a Domestic Policy Review similar to that recently conducted in the solar energy field.

- Failure to address such issues will probably consign fusion to a continuing development program of indeterminate length

These conclusions, if sustained by successive investigations, hold considerable significance for the U.S. fusion program.

Specific recommendations to the program's management include the following:

- The criteria for credibility developed herein need additional analysis and reduction to specific program recommendations and actions where possible and appropriate. The criteria and suggestions thus developed should be reviewed with the relevant industrial and government decisionmakers and stakeholders.
- Continued analysis of the unique aspects of fusion commercialization, unconstrained by historical precedents, is needed as is the communication of this perspective to DOE planners and policy makers.

- The dimensions of a Presidential/Congressional act of political vision needs to be further explored. What constitutes an act of political vision, what kind of analysis leads to one and how a President would select among alternative options are all questions of importance to fusion commercialization.
- Fusion planners must decide whether enough is known about the future and about fusion to responsibly address the fundamental questions identified earlier. Increased emphasis should be placed on the question of need, and timing of the need for fusion.
- A major issue for fusion planners will be whether one can prove that fusion is needed on any specific time frame. Rationale must be developed to convince policy-makers that they need do more than preserve the option for application at some indefinite point in the future. The importance of making a commitment in the near term must be supported by analysis. These issues should be the subject of a high priority assessment conducted within the DOE fusion program but which is nevertheless capable of addressing the subject from the disinterested perspective of an outside evaluator (e.g., DOE policy staff, OMB staff, White House and Congressional Staff, etc.). One possible approach would be to ask "What must I believe (about energy resource extent and cost, energy growth rate, etc.) if I believe that we will need fusion by (say) 2010? Alternatively, what must I believe if I am satisfied to keep fusion in its current 'standby option' status?"
- It will be important to do these studies before soliciting public and senior policy review of the national commitment to fusion. Clearly, fusion planners must have insight into how such a review will probably turn out, and must similarly be prepared to deal with the wrong (for fusion advocates) answer, should it emerge.

Perhaps the key recommendation of this study is the last one. Significant analytical efforts to determine timing of the need for fusion should begin now within the fusion program. Only after such efforts are completed and judged to be sound and convincing to the non-fusion energy community, should outside review be sought. Premature calls for a "Fusion DPR" and an act of political vision will almost certainly result in failure.

These recommendations and conclusions are offered in the conviction that to do nothing with respect to beginning the process that can result in a strong national commitment to fusion commercialization is to ensure that fusion will not be developed in our lifetimes or in the lifetimes of our children. To the extent that one believes that this would be a serious mistake, one must be concerned with the timeliness and quality with which these investigations are conducted.

APPENDIX

Reproduction of Chapter V, "Commercialization Plans"
of the January 27, 1978 Draft Final Report

Magnetic Fusion Energy Program
Summary Document

developed by
the Department of Energy's
Assistant Secretary for Energy Technology

January 27, 1978

V. COMMERCIALIZATION

A. COMMERCIALIZING ADVANCED TECHNOLOGIES IN THE UNITED STATES: PAST AND PRESENT LESSONS

Reviews of past major technology commercialization activities have been ongoing for several years in the context of several Federal efforts to accomplish large-order technological changes in our society's approaches to transportation, pollution control, energy production, and energy use. The most common findings of such studies are that the commercialization process is unpredictable, uncertain, expensive, and inseparable from other stages of development; thus, there are only a few generalized guidelines. These guidelines are:

- The technology development must be "economic" in three ways. The development must be at a stage at which the economics are known to be within the relevant degree of uncertainty for the particular use. The economics must be competitive in specific applications. Finally, the number of potential uses must be sufficiently large to constitute a viable market that justifies investment in supplying and servicing the product.
- The technology must be tailored to an existing industrial or user infrastructure. Alternatively sufficient time must pass after technology introduction to allow necessary changes in the infrastructure to occur.
- The technology as introduced must be compatible with existing and potential regulatory constraints. In our increasingly congested regulatory atmosphere, one is finding this guideline to be of increasing importance.
- The technology introduction must be accompanied by accurate perceptions and information--not only by direct investors and users, but also by the public at large. This requirement derives from the need for increasing capability and willingness of groups, not directly involved, to become so and thereby impact on the manner and extent of technology use.

B. FEDERAL FUSION RD&D ACTIVITIES:
A PERSPECTIVE FOR FEDERAL COMMERCIALIZATION ACTIVITIES

Fusion is an unusual technology in that it has been solely derived from federally funded research and development activities; the Federal Government has undertaken responsibility to not only prove the basic concept but also develop the first commercial-scale units; and the research effort necessary to produce a commercially usable fusion technology is a long-term, expensive venture.

The major responsibility and lengthy Federal effort really encompasses two distinct types of commercialization activities:

- Activities directed toward applying proof-of-concept and prototype reactor results to the development of a commercialization design for a fusion energy technology.
- Activities which accelerate or ease the use and acceptance of fusion energy technology (e.g., loan guarantees, joint venture development).

The strategic implications of thinking about fusion commercialization as two distinct sets of activities are that the Federal Government needs to:

- Identify features of the technology which are user specific, and involve the specific users and incorporate their requirements into the design(s). This process is of a continuous and iterative nature.
- Not concentrate on mechanisms for accelerating or easing technology acceptance until commercializable designs are near-at-hand.
- Emphasize the development of infrastructure in order to assure adequate availability of skilled manpower, fabricated supplies, and raw materials when the market starts to expand.

C. THE CHALLENGE OF DEVELOPING A COMMERCIALIZABLE DESIGN

Current fusion RD&D activities are at a stage in which they have begun to focus on achieving a set of commercializable designs. Accomplishing this task requires confronting the following issues both in terms of design decisions and in terms of undertaking design-specific research. The primary issues in developing a commercializable design are as follows:

- **Application.** Based on current reactor technology, over 80 percent of the energy produced is in the form of high energy neutrons. This leads to many possible alternative fusion energy applications that profoundly affect the commercial system design. Some alternatives are electricity production, fissile fuel production, fission waste transmutation, synthetic fuel production, and process heat.
- **Reactor Size.** The issue is to find a balance between a large enough size reactor to achieve efficiency of scale and reduce capital risk on a \$ per kW basis, and a small enough reactor to minimize capacity risk and maximize the total market share. (See Figures V-I and V-II.)
- **Reliability.** An important performance consideration since the expected cost and performance of fusion technology is meant to provide a high reliability baseload power source.
- **Cold Start Power Requirements.** An important issue is to reduce cold start power requirements because current proof-of-concept results indicate that startup power requirements for fusion energy technology could be prohibitively large.
- **Cooling Requirements.** The major design need is to increase system thermal efficiency or confront the need for large waste-heat handling facilities which could result in limited siting possibilities or excessive expense.
- **Energy Storage Requirements.** Over-and-above the startup problem which may require storage is the need to provide continuous power from those systems which inherently (in some designs) produce pulsed power. This design requirement, if not handled by initial reactor choice or reactor redesign, requires major energy storage capability.
- **Remote Maintenance.** Because of the large expected costs of fusion reactors, there are significant trade-offs between initial capital costs and anticipated reactor maintenance downtimes that must be understood.
- **Complexity.** Fusion technology is highly complex and will require new design manufacturing, construction and operation techniques and more highly skilled personnel to work in a

Figure V-1. Economies of Scale for a Tokamak Fusion Reactor

Figure V-2. Responsiveness of Reactor Design to Utility Market Size (Year 2000)

"fusion" industry. Therefore, attention must be given to anticipating and meeting the infrastructure requirements as implied by any reactor design.

- Reactor Control. It is important that fusion reactor operation and control be compatible and consistent with existing user practices in order to assure that users obtain maximum economic benefit.
- Environmental Impact. This is an area of design concern which is clearly of very major importance. For that reason, the design issues are discussed in Section VI.
- Safety. Although the environmental consequences of normal fusion reactor operation provide substantial design challenge, the task of designing the system to have acceptable modes of abnormal operation (e.g., shutdown, component failure, operator mistake) is also very important.

The Federal Government has, increasingly, addressed these important issues through a variety of mechanisms designed to anticipate and incorporate the needs of potential suppliers and users in the fusion development process. Some of these include:

- Organizing the OFE structure so that the key issues outlined above are addressed by one or more OFE programs (see also Figure II-3).
- Conducting on a regular basis, systems studies to better identify and understand potential fusion applications, development problems and opportunities (see Table II-4).
- Increasing the involvement of industry (both potential suppliers and users) in the Management OFE Program through a large number of Advisory Committees as was discussed in Section II.C. For example:

Advisory Committee

Representative Industrial
Participants

Program Planning
Alternative Concepts Evaluation
TNS Steering Committee
Fusion Materials Coordinating
Committee

EPRI
EXXON Nuclear
San Diego Gas & Electric
Westinghouse

- Increasingly use industrial subcontractors for the major development efforts undertaken by the national laboratories. For example, industrial subcontractors are involved in meeting fusion development needs:

<u>Development Requirement</u>	<u>Representative Industrial Subcontractors</u>
Superconducting Magnets	General Electric, General Dynamics
Plasma Heating Systems	TRW, RCA, VARIAN, Westinghouse
Cryogenic and Vacuum Systems	CTI, CVI, Leybold
Fusion Reactor Design	General Electric, Bechtel, EBASCO, United Technologies, Westinghouse

(A more comprehensive list of major industrial subcontractors to national laboratory efforts is included in Section IV.D.)

- Increasingly examine the trade-offs between fusion reactor size and economics, thereby increasing the understanding of potential market acceptance of fusion electric power. Current designs are becoming small enough to be of widespread use by the utility industry. Figure V-II illustrates the responsiveness of the program to the desires of a user industry for smaller sized fusion technology.

These activities represent major elements in OFE's continuous cooperative and iterative planning efforts. As these efforts are continued and expanded in step with technical progress, the commercialization prospects of magnetic fusion will be significantly enhanced.

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