Chapter 8

Future Paths for the Magnetic Fusion Program

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Chapter 8

Future Paths for the Magnetic Fusion Program

The likelihood that fusion will be developed as a future energy supply option is affected—although not completely determined—by policy choices made today. A decision to accelerate fusion research does not ensure that fusion's potential will be successfully realized, any more than a decision to terminate the current research program implies that fusion will never be developed. Nevertheless, near-term decisions clearly influence the pace of fusion's development. The sooner we wish to evaluate fusion as an energy supply technology, the more important our near-term decisions become. Over the next several decades, the fusion research program can evolve along any of four largely distinct paths:

1. With substantial funding increases, the U.S. fusion program can complete its currently mapped-out research plan independently. This plan is intended to permit decisions concerning fusion's commercialization to be made early in the next century. This approach is called the "Independent" path.
2. **At only moderate increases in U.S. funding levels, the same results might be attainable–although possibly somewhat delayed—if the United States** can work with some or all of the world's other major fusion programs (Western Europe, Japan, and the Soviet Union) at an unprecedented level of collaboration. This path is termed ''Collaboratii'e.
3. In the absence of major collaboration, a flat or declining funding profile would force significant changes to be made in the program's overall goals, including a recognition that fusion's commercialization would be delayed from current projections. This path is called *"Limited,"* indicating that progress in some critical areas would be impossible without additional resources.
4. Shutting down the fusion program would foreclose the possibility of developing fusion as an energy supply option unless and until research were resumed. On this *"Mothballed"* path, progress towards fusion in the United States would halt. Work would probably continue abroad, although possibly at a reduced pace; resumption of research in the United States would be possible but difficult.

Current Department of Energy long-range plans for the fusion program are aimed at the "Collaborative" path. If recent funding declines continue, however, or if the United States does not successfully arrange its participation in major collaborative activities, the U.S. fusion program will evolve along the "Limited" path.

KEY ISSUES AFFECTING THE EVOLUTION OF FUSION RESEARCH

The four paths are differentiated by the degree of commitment and the level of funding provided by the U.S. Government for fusion research. Path characteristics and the choices between them are determined by several factors, including: 1) the likelihood of technical and commercial success in developing fusion technology; 2) the perceived urgency with which a new supply of electricity is needed; 3) the advantages and risks of large-scale international collaboration; 4) the implications of requirements for expensive research facilities; and 5) the value of the "auxiliary benefits" associated with fusion research such as scientific understanding, education, and technological development. Another factor, the potential for surprise inherent in any new technology, may also be an important aspect of one's choice of research approach; however, such a factor is not amenable to analysis.

Discussions earlier in this report have addressed many of these factors, which are summarized below:

- **Likelihood of Success: In evaluating the likelihood of program success, technical success must be differentiated from commercial success. According to chapter** 4, the risk of *technical failure* appears small, particularly if operation of the Compact Ignition Tokamak (CIT) does not uncover serious problems.[1] If CIT operates as anticipated, it seems likely that a fusion device capable of producing electricity can be developed.

  However, the risk of *commercial failure*—the development of a technology that does not interest potential users—is much harder to evaluate. The commercial attractiveness of fusion energy will depend not only on its cost, but also on conditions unrelated to fusion technology that cannot be estimated at present. Different opinions as to the likelihood of successful commercialization and the attractiveness of fusion over other electricity alternatives affect the priority given to fusion research.
- **Perceived Urgency:** Chapter 5 concluded that estimates of future electricity demand neither require nor eliminate fusion as a possible energy source. It appears that electricity technologies other than fusion—principally coal and nuclear fission—should be capable of supplying ample power at reasonable prices through at least the middle of the next century. However, uncertainties as to the continued acceptability of fossil fuels and nuclear fission provide incentives to explore the potential of improved energy efficiency and to develop alternative energy sources. Different estimates of the future attractiveness of coal and nuclear fission, and different judgments of the ability of various alternatives to replace coal and/or fission, affect one's perception of the urgency of fusion research and development.

  None of the research paths presented in this chapter call for a crash program to develop fusion. It is very difficult to formulate a credible scenario of major, irreversible electricity shortages in the early 21st century that would require fusion's development on a schedule faster than that discussed in chapter 4.
- **Advantages and Risks of Large-Scale International Collaboration:** It appears possible that large-scale international collaboration could enable the United States to make progress towards assessing fusion's potential at a substantially lower cost than would be required for the United States to proceed independently. Chapter 7 discussed the advantages and risks of large-scale international collaboration in future fusion projects. Different evaluations of the costs and benefits of large-scale collaboration, which were presented in chapter 7, affect one's willingness to consider undertaking the next stages of fusion research collaboratively. In addition, different assessments of the obstacles to international collaboration may affect one's willingness to negotiate a collaborative agreement.
- **Implications of the Need for Expensive Research Facilities:** Chapter 4 identified several major research facilities that may be required to evaluate fusion's potential. The total worldwide cost of these facilities has been estimated at $6 billion, with a next-generation engineering test reactor alone expected to cost well over $1 billion. **As long as multi-billion-dollar facilities are necessary to assess fusion's potential, development of fusion power cannot proceed without strong financial support at the highest levels of government.** The private sector will not be willing to finance fusion research until fusion's potential is clearer.

  The need for major facilities, along with the need to conduct a diverse array of supporting research, means that the fusion research program will not make progress towards evaluating fusion's energy potential if its funding is too low. With insufficient fund-

[1] CIT is described in the section of ch. 4 titled "Key Technical Issues and Facilities."

ing, the program must either delay complete evaluation of fusion's potential or await technological developments (which may never be realized) that lower the cost of the research remaining to be done.

- **Near-Term Benefits: Chapter 6 discussed near-term benefits of fusion research such as increasing scientific understanding,** educating and training skilled technical personnel, and developing technologies with economic and defense applications. Different values assigned to these benefits, and different estimates of the benefits that would have been derived had the resources spent on fusion been allocated elsewhere, lead to different levels of emphasis on fusion research.
- **Potential for Surprise: In** many respects, fusion technology will be unlike any existing technology, and it may open up capabilities and applications that cannot be foreseen today. Like other qualitatively new technologies, fusion's most significant impacts may be totally different than those that were expected prior to its introduction. Some observers might oppose fusion's development because of this inherent potential for unanticipated consequences; others would eagerly support exploration of the technology primarily because of the new possibilities it may offer. Since unforeseen capabilities or consequences are by definition impossible to predict, this report cannot and does not address them.

The possible advantages and disadvantages of each of the four paths outlined at the beginning of this chapter are described below, along with the assumptions that would lead to each's selection. The discussions of the paths are interdependent; in many cases, the advantages of selecting one approach also describe the disadvantages of selecting another. The paths are discussed in general terms, and the detailed structure of the fusion research program is not specified under any of them. Extensive additional study would be required to determine the best way to implement each path.

THE INDEPENDENT PATH

Description

The goal of the Independent path would be to aggressively establish the scientific and technological base necessary to evaluate fusion's potential and to decide by the early 21st century whether to proceed with a demonstration reactor. All the facilities required to establish this base would be funded and operated domestically under this approach. The exact funding necessary for this path cannot be determined without detailed additional examination, but considerably more support would be required than is currently available to the fusion program. On average, between $500 million and $1 billion per year probably would be required over the next 20 years, with peak annual funding possibly exceeding $1 billion. Widespread international cooperation might continue, but it would fall well short of the shared decision-making and funding that would characterize the Collaborative approach. The Independent path is similar to the one specified (but not funded) in the 1980 Magnetic Fusion Energy Engineering Act.[2]

Motivations and Assumptions

Choice of this path would be motivated by the assumption that evaluating fusion's potential early in the next century is an important national goal. The probability of success and the need for developing fusion would both be assumed high enough to justify considerably increasing the current U.S. investment in fusion research.

The benefits of conducting fusion research without depending on the participation of other countries would be assumed to outweigh the cost savings and other possible advantages of large-scale international collaboration. Although the

[2]This act is described in the section of ch. 3 titled "The 1980s: Leveling Off."

near-term domestic benefits of fusion research probably also would be highly valued, the prospects of developing a viable energy technology would be the primary motivation for selecting this path.

Advantages

Control Over Research and Development.– Under this approach, the United States would be fully self-sufficient in acquiring the information needed to assess fusion's potential. Decisions made in other countries or difficulties in large-scale international collaboration would not affect the U.S. ability to evaluate fusion's potential on a time scale of its own choosing. Under this approach, the United States could attempt to regain a position of world leadership in fusion research, rather than accept the technological parity required for true collaboration and interdependence.

If the United States were to go on to make a positive assessment of fusion's potential, and if the U.S. technological capability in the field were unmatched by other international fusion programs, the United States would have the advantage of leading the development and commercialization of fusion technology.

Energy Supply.—If the United States were to make a positive evaluation of fusion's potential as a result of pursuing this approach and were then able to develop and commercialize fusion technology, a new, potentially attractive source of energy would become available. Even if fusion were not viewed as preferable to other energy technologies, investment in the technology might still be justified since fusion would be available as a hedge against unforeseen or underestimated difficulties with other energy sources.

Manpower, Infrastructure, and Technology Development.–Conducting fusion research independently could have significant domestic benefits, in terms of training personnel, acquiring a domestic fusion infrastructure, and developing associated technologies. Since more funds devoted to the fusion effort would be spent domestically than under any of the other research approaches, these domestic benefits would be realized to a greater extent under this approach. Moreover, the United States would not be dependent on externally acquired information or technical expertise.

International Stature.–Through this research approach, the United States would be able to demonstrate its technological capability and bolster its international stature. In addition to the potential economic returns, being in a position of world leadership could give the United States significant leverage in future cooperative projects and could make the United States a more desirable cooperative partner.

Disadvantages

Cost.–The principal disadvantage of this research approach is its cost, which is considerably higher than that of any other approach. Fusion is not guaranteed to succeed, and the investment in fusion research may not "pay off" with an attractive energy technology. In this case, the investment in fusion research might be considered wasted. Benefits of the fusion program such as scientific return, training of personnel, technological development, and international stature–hard as they are to measure–are unlikely to justify the full cost of independently developing fusion technology.

Potential Overemphasis.–A sense of urgency and direction is necessary in order for the fusion program to command the resources it would require under the Independent path. However, the risks of program failure are increased if an exaggerated sense of urgency pushes the research effort faster than it can responsibly proceed and prematurely forces key decisions. A balance must be struck between proceeding with determination and direction, which is necessary, and rushing into a "crash program, " which can be counterproductive.

A more subtle risk could arise if fusion were emphasized at the expense of improving the existing sources of energy supply, increasing the efficiency of energy use, or developing other energy supply alternatives. if U.S. long-term energy research concentrates heavily on fusion, the implications of technical or commercial failure could be serious. Therefore, if concern over energy supply motivates more intense fusion research, it should also motivate energy research in nonfusion areas.

THE COLLABORATIVE PATH

Description

Ideally, the Collaborative path would accomplish the same technical tasks as the independent path on a similar time scale. However, the Collaborative path would use the combined resources of the world's major fusion programs, making it possible for the individual contribution of any one program to be smaller than would be needed to perform the same tasks alone.

With large-scale international collaboration, the U.S. fusion program would require only modest increases in funding above current levels to evaluate fusion's feasibility early i n the 21st century. Annual funding on the order of $400 million to $500 million probably would be necessary over the next 20 years, with the total being highly dependent on the degree of cost-sharing attainable through collaboration.

Motivations and Assumptions

Choice of this approach, like the Independent approach, is based on the assumption that evaluating fusion's potential in the early 21st century is an important national goal. The assumed probability of success and the perceived need for fusion power would be high, as they would be under the Independent path. The major difference between this path and the Independent path is that under this approach the benefits of large-scale international collaboration would be assumed to outweigh the disadvantages. The United States would consider self-determination in fusion either impossible or not worth the price.

Activities under the Collaborative path could take the form of joint construction and operation of major facilities, in which several nations' fusion programs would be simultaneously involved. Activities could also take the form of allocating various research tasks to particular programs. If such an allocation were done, all programs would eventually need to obtain data (which is rather easily shared) and expertise or "know-how" (which is harder to transfer) from the program that had done a particular piece of research.

The near-term benefits of fusion research would not be judged important enough u rider this approach to justify conducting all the necessary research domestically. Choice of the Collaborative approach assumes that the parties involved will be able to develop a program whose cost and schedule is acceptable to all, that major experimental facilities can be collaboratively built and operated, and that equitable allocation of research tasks and results can be arranged.

Advantages

Cost-Sharing.–The principal benefit of the Collaborative path is the cost-effective utilization of the resources available to the major fusion programs worldwide. Total funding now spent annually on fusion research throughout the world is comparable, or greater than, the amount needed per year to evaluate fusion's potential by the early 21st century. If the major fusion programs can minimize duplication of effort, reaching that evaluation should not require substantial budgetary increases in any of the major programs. Whereas pursuit of the Independent path requires doubling or tripling annual U.S. fusion budgets, the Collaborative path may only require funding increases of 20 to 50 percent above current levels.

Energy Supply.– If successfully implemented, the Collaborative approach would permit the United States and the other major fusion programs to evaluate fusion's potential by the early 21st century. The timing of this evaluation is similar—although possibly somewhat delayed—from that in the Independent path. However, the results of a Collaborative research effort would be more effectively shared among the major fusion programs.

Improving the Technical Base.—Fusion research may proceed more effectively if the research efforts of the major programs are integrated to a greater degree. All of the major programs have technical capabilities and skilled personnel that can contribute to the research and development effort. In addition, effective planning among the major fusion research programs can ensure that more research approaches are investigated. If, through such efforts, research efforts can be mutually supportive rather than duplicative, this widened technological base will benefit fusion research worldwide.

Foreign Policy Benefits.–The United States may wish to participate in a large-scale collaborative project for diplomatic reasons as well as technical ones. Since there appear to be significant technical and financial benefits to the United States from successful collaboration in fusion, diplomatic motivations would not appear to be in opposition to programmatic ones.

Disadvantages

Shared Control and Loss of Flexibility.–Under the Collaborative approach, the United States would sacrifice some control over the research program. International collaboration on the scale necessary for this approach will require compromise by all partners. In particular, some major experimental facilities, such as the international Experimental Thermonuclear Reactor, would probably not be sited in the United States. This approach could be less flexible than the others, since decisions—which would be made multilaterally—would be difficult to modify. Moreover, depending on how time-consuming the negotiation process is, the Collaborative path could take longer than the Independent path to develop fusion.

Obstacles to Large-Scale Collaboration.–If the potential obstacles to large-scale collaboration described in chapter 7 prove insurmountable, the Collaborative approach would fail. In this case, the United States would either have to make more resources available for fusion research, changing to the Independent path, or extend the schedule for fusion development as discussed in the Limited path (below).

Cost.–Although the cost of this approach is substantially less than that of proceeding independently, increases in U.S. annual fusion funding are nevertheless required to carry out this approach. If fusion research does not lead to an attractive energy source, this investment might be considered wasted.

Adverse Impact on Domestic Development.– The Collaborative approach is motivated in part by pressures to share costs and lessen research expenditures. However, if international collaboration is supported at the expense of maintaining a healthy domestic program, both the collaborative projects and the domestic program could be damaged. A viable domestic program is required to contribute to and be attractive for future collaboration.

The Collaborative approach may create tension between undertaking domestic activities, on the one hand, and participating in joint research with foreign programs, on the other. Incentives to minimize costs and avoid duplication will have to be balanced against developing and maintaining sufficient domestic expertise to contribute to and assimilate the results of collaborative projects.

THE LIMITED PATH

Description

Under the Limited path, fusion research would continue but would not be supported at the level necessary to evaluate fusion's potential domestically in the early 21st century. The schedule for developing fusion under this approach therefore would be delayed compared with the independent or the Collaborative approaches. With the Limited path, funding levels would not be sufficient to support a healthy base program simultaneously with the construction of major facilities required' to make progress in critical research areas.

Because there are so many different motivations for pursuing this approach, no single plan, strategy, or estimated funding level can adequately describe it. Clearly, the funding level would be less than that needed for the independent path and more than that for the Moth balled path (below). It probably would be less than that needed for the Collaborative path, although even a funding profile sufficient for the Collaborative path would result in the Limited path if collaboration were found to be undesirable or unworkable.

The Limited approach would attempt to retain a base program in fusion research at universities and national laboratories. The program would be limited to scientific research, however, with funding levels and/or program intent not enabling it to advance to engineering development and demonstration. With the Limited path, fusion's scientific feasibility probably could be determined. It is unlikely, however, that engineering feasibility could be determined domestically, and commercial feasibility would be impossible to evaluate without increased financial support.

Motivations and Assumptions

With the Limited path, pursuit of fusion would not be a high national priority. Many different assumptions could result in a lower priority for fusion research and lead to selection of the Limited path. The Limited path also might be pursued as a "second choice" if either the Independent or the Collaborative approaches could not be sustained.

Assumptions that might lead to selection of the Limited approach include the judgment that fusion's promise or urgency was not high enough to justify the Independent approach but too high to warrant shutting the research program down entirely. Moreover, either the prospects or the rewards of international collaboration could be judged too low to pursue the Collaborative approach.

Perhaps the construction of large experimental facilities would not be seen as warranted unless or until further technological development—in or outside of the fusion program—brought **down** costs. Alternatively, it might be decided that while the near-term benefits of fusion research justified maintaining a limited program, the energy benefits did not justify a more extensive research effort. Delaying development of fusion's energy potential need not necessarily reduce the scientific, educational, and technological benefits of fusion research.

Advantages

Cost.–The major benefit of the Limited path is that the United States could maintain a limited research capability while still retaining the ability to accelerate fusion research at a later time. It would be cheaper–and therefore politically easier—to fund a Limited path program than the higher cost Independent or Collaborative approaches.

Flexibility.–In some ways, research with the Limited path may be more flexible than with either the Independent or Collaborative paths. Early design selections for large and expensive research facilities that would tend to lock in a given line of research emphasis would be avoided. Delaying these investments could make it possible to build them either at substantially lower cost or with a higher probability of commercial success.

Risk Avoidance.–Under this approach, the United States could let the rest of the world shoulder the expense and take the risk of determining fusion's feasibility. The United States would retain a base program in fusion research to preserve the expertise needed to evaluate and eventually reproduce work done abroad. The United States, of course, would start out with a competitive disadvantage in this case and might or might not be able to catch up. However, it would also be able to evaluate whether or not the technology was attractive without the substantial investments required to pursue the Independent or Collaborative paths. The United States would be free to attempt to develop an improved technology at some later time.

Disadvantages

Delaying Energy Supply .–The fundamental disadvantage of the Limited path is that it delays the evaluation of fusion. At our current level of understanding, experimental devices that are inherently large and expensive are required to resolve key uncertainties in the development of fusion power. Unless these facilities are funded, progress cannot be made and fusion's potential cannot be determined or developed,

Technical developments may ultimately decrease the cost or eliminate the need for expensive experiments. However, it is not likely that such developments will occur quickly enough for the Limited approach to make fusion power available on the same schedule as the Independent or Collaborative approaches. Moreover, significant developments may be less likely to occur or be recognized in the absence of a more ambitious research program.

Loss of Direction and Scope.—If the fusion research program is not targeted towards an evaluation of fusion's prospects as an energy source, it might become more of a basic science/plasma physics research program than an energy program. Without the direction provided by a relatively near-term goal—evaluating fusion's engineering feasibility—the program's subsequent evolution might lead it away from **those issues that must be** resolved to develop fusion reactors. This drift would not only delay the development of fusion power but might also make its eventual development less likely.

Damage to Fusion Infrastructure.–Limited Federal funding of fusion research could adversely affect many participants in the fusion research program. Industrial participation would be the most severely constrained; steady and predictable funding is required for industry to develop and maintain the capability to participate in fusion research. Depending on the funding level, national laboratories and universities might also have to cut back on fusion **work.**

Moreover, the field of fusion research in general and university programs in particular might not be able to attract the most talented students if the program were perceived as having an uncertain future, In this event, a valuable **source of new ideas and innovation would be lost.**

Loss of Momentum and International Stature.–With the Limited path, the fusion program could lose its momentum. Unless other countries also limited their programs, the United States would fall behind. If other countries successfully commercialized fusion technology, the United States could be at a competitive disadvantage, at least initially.

However, U.S. decisions and foreign decisions are not independent. Given that fusion research budgets are set in all the major fusion programs through a political process that balances fusion against other priorities, U.S. action to lower the priority of fusion research might weaken the positions of fusion researchers in other programs. Foreign fusion programs might reduce their research efforts. However, the other world fusion programs are clearly developing fusion for broader reasons than simply keeping up with the United States, and none of them are likely to eliminate their programs.

Difficulty in Collaboration.– If foreign fusion programs pursue research more aggressively than the United States, the United States may no longer be seen as a desirable collaborative partner.

THE MOTHBALLED PATH

Description

With the Moth balled path, the magnetic fusion research program would shut down. To capitalize on the research investment to date, this path would ideally be implemented in a manner that preserved the existing state of knowledge in the field and eased the transition of people and facilities from fusion to other areas. To keep open the option of restarting the fusion program in the **future, some resources would be desirable (either provided directly or through other programs) to permit periodic reevaluation of fusion. Technical developments in other fields would have to be monitored, along with progress in alternate** energy supply technologies, to see whether the decision to stop funding fusion research should be reviewed.

In practice, however, monitoring might be difficult. Competing funding priorities, too, might make it hard to acquire the resources needed to reevaluate a canceled program.

Motivations and Assumptions

Choosing the mothballed approach implies that development of fusion–even as a hedge–does not merit appreciable investment now or in the near future. Proponents of this approach might consider the current state of fusion technology analogous to that of computer technology in the 19th century: although many of the fundamental concepts were known, a century of technological progress in widely disparate fields was required before computers of any practical significance could be built.

Technological pessimism is not likely to be the deciding factor in stopping the fusion program, since the operation of CIT—if successful—should confirm the scientific feasibility of fusion. instead, the decision to cancel the program probably would be motivated by the belief that fusion research will not result in a commercially, socially, or environmentally attractive source of energy, or that finding out how useful fusion could be is too expensive. The near-term benefits of conducting fusion research would not be assumed to justify the program, and the expected payoff of fusion would be considered too low to make cost-sharing with other countries attractive.

Advantages

Saving Money .–The major advantage of this approach would be avoiding the costs of future fusion research.

Disadvantages

Unavailability of Possible Energy Supply.–The major risk of this approach is that fusion's potential as an energy source would not be realized. Should future circumstances make reevaluating fusion desirable, restarting the program would be expensive, difficult, and time-consuming.

Destruction of Fusion Infrastructure.–With the Moth balled path, the people and facilities that currently carry out fusion research would switch to other programs; the associated benefits **of fu**sion research such as personnel training, scientific research, and technological development **would not continue** in their current form, Although scientific data and technological accomplishments **would not be lost, the "know-how" of individual researchers** would be. Decades would be required from whenever a decision were made to resume the program until the earliest time that it could lead to a usable product. Dismantling the existing technological base and personnel pool does not irrevocably eliminate fusion as an option, but significant costs (in both time and resources) would be required to rebuild **fu**sion research capability.

Mitigating this disadvantage somewhat is the breadth of plasma physics as a research discipline. Since plasma physics is intrinsic to many applications outside of fusion, plasma physics research and application would certainly persist through non-fusion-program sources, even if fusion research were discontinued. Although the areas of plasma physics most relevant to fusion would suffer, general plasma physics research could provide a core of expertise if a program restart were required.

Inhibiting Technical Development.–Without an extensive base of technical personnel trained in and sensitive to problems relevant to fusion, discoveries that might make fusion easier to achieve could go unrecognized.

Elimination of International Stature in Fusion.– if it is not conducting domestic fusion research, the United States will be unable to collaborate with other countries or benefit from the results of research done abroad. If fusion technology were developed successfully abroad, it could take many years for the United States to reproduce the technology.