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SUPERCONDUCTING SUPER COLLIDER

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SUMMARY

The Reagan Administration has proposed the construction, over the next 8 to 9 years, of the world's largest and highest energy particle accelerator, the Superconducting Super Collider (SSC). In 1988 dollars, the project is estimated to cost about $4.4 billion and have annual operating budgets after 1996 of about $270 million. In current dollars, these costs have been estimated by some observers to be over $6 billion and $500 million respectively. The SSC is envisioned as the "next generation" high energy particle accelerator, needed to expand the frontier of particle physics research beyond the capabilities of existing machines. Although many scientists, policy analysts, and policymakers support such a project, not all do. A major concern is that other areas of science, particularly small science, would suffer if such funding is allocated to a single, large project. In addition to its scientific benefits, the SSC's supporters suggest a number of related technical, economic, and social benefits. Not all agree, however, that such benefits would occur or that they would be significant compared to costs. Because high energy physics is increasingly an international effort, international cooperation and competition also must be considered. This complex of factors makes the congressional evaluation of the relative merits of the SSC a difficult task. Because the DOE proposes to start construction of the SSC in FY89, basic funding decisions probably will have to be made during the 100th Congress.

ISSUE DEFINITION

Given the projected cost and complexity of the SSC, questions arise as to its scientific merit, its impact on other areas of science, and its economic and social costs and benefits. The basic issue is whether the Congress wishes to authorize construction of the SSC at this time, as proposed by the Administration.

BACKGROUND AND ANALYSIS

Scientific Background

High Energy Particle Physics

In the world of subatomic or "elementary particle" physics, most experimental knowledge derives from experiments conducted on large, complex, and expensive machines called particle accelerators. Since the first discoveries of nuclear physics in the 1890s, physicists have uncovered a growing array of elementary particles which constitute the building blocks of matter and the fundamental forces of nature.

The earliest model of the atom consisted of a nucleus formed by protons (particles with a positive electrical charge) and neutrons (particles with no electrical charge) surrounded by a cloud of electrons (particles with a negative electrical charge) in well-described orbits. In the last 30 years, this simple, but effective, model has been greatly complicated by the discoveries of over 100 other subatomic particles. These new elementary particles were discovered by examining the collisions of protons and electrons with each other and with other targets in particle accelerators. The "debris" of these collisions, which was formed by the conversion of energy into matter, contained these new particles, which have lives on the order of only millionths or billionths of seconds. As energies of the accelerators were increased over the years, more and more particles were discovered. The result of these experiments and parallel theoretical developments was a picture of matter that was much more complex than previously thought.

Over the last few decades, a new theory of the structure of matter -- called the Standard Model -- has evolved. This theory currently describes matter as consisting of two sets of elementary particles and a set of fundamental forces of nature. Protons and neutrons once thought to be elementary particles themselves, now are thought to be constructed of one of the new sets of particles called quarks. The electron is a member of the other set called leptons. The four fundamental forces of nature -- strong, weak, electromagnetic, and gravitational -- describe the ways matter interacts and is held together. One of the major triumphs of the Standard Model is its ability to show how two of these forces -- electromagnetic and weak -- are connected. Scientists are currently trying to extend this theory to include the strong force, thus forming a Grand Unified Theory of fundamental forces. Physicists believe that, ultimately, it may be possible to fit the gravitational force into this theory.

Elementary particle physics deals with the very smallest constituents of matter. Cosmology, the study of the creation and evolution of the universe, deals with the very largest accumulations of matter -- stars, galaxies, and intergalactic matter. These two subjects overlap when the origin of the universe is considered. In the accepted theory of the origin of the universe -- the "Big Bang" theory -- the four forces of nature were all unified at the instant of creation and all matter consisted of quarks and leptons. As the universe cooled, the forces separated and the quarks began forming a number of particles including, finally, protons and neutrons. Of the six types of leptons, only the electron remains as a stable particle in ordinary matter.

Although considerable experimental verification of these theories has occurred up through the current generation of particle accelerators, there remains much more to be verified. Certain particles have been predicted in order to satisfy various parts of the Standard Model. These particles require considerably higher energy to produce than exists in current accelerators. In addition, in order to simulate conditions closer to the actual starting point of the universe to test the hypotheses of the Big Bang theory, much higher energy accelerators are needed than now exist. While it will not be possible to produce the energies required to reach the starting point or to verify all the predictions of the Standard Model, much additional exploration can take place by building a larger accelerator. This is the reason that the high energy physics community has proposed the Superconducting Super Collider.

Particle Accelerators

Particle accelerators have evolved from the breadbox size cyclotron invented by Dr. Ernest O. Lawrence in 1930 to the proposed $4 to $6 billion SSC. This growth has been required to achieve the higher energies needed to search for new particles. A number of particle accelerators are in operation throughout the world. Some of these machines are linear accelerators and some are synchrotron (circular) accelerators. Currently, synchrotrons are used to achieve the highest energies because particles can be accelerated repeatedly, as they continuously circle through the machines. Large magnets are required to force the charged particles to move in a circular path. Linear accelerators do not require magnets since the particles travel in a straight line. The length currently required to achieve very high energies, however, is too great to make them practical for the energies needed by the SSC (about 20 trillion electron volts) unless new ways to accelerate particles are formed (see below). Some of these machines are "fixed target" machines where a beam of particles is accelerated into a fixed heavier target. Others are colliders in which two beams of particles hit head on. The world's major high energy particle accelerators, including those under construction and proposed, are listed in the following table.

TABLE 1. Major High Energy Particle Accelerators Operating or Under Construction

Brookhaven - Upton, NY	proton synchrotron (28GeV on fixed target)
Fermilab - Batavia, IL	proton synchrotron (900GeV on fixed target)
CERN - Geneva, Switzerland	proton synchrotron (450GeV on fixed target)
SLAC - Stanford, CA	electron-positron linear accelerator (20-50GeV on fixed target)
Cornell - Ithaca, NY	electron-positron collider (5GeV x 5GeV)
DESY - Hamburg, W. Germany	electron-positron collider (5GeV x 5GeV) (23GeV x 23 GeV)
SLAC SLC - Stanford, CA	electron-positron linear (collider) (50GeV x 50 GeV)
CERN - Geneva, Switzerland	proton-antiproton collider (330GeV x 330GeV)
Fermilab Tevatron - Batavia, IL	proton-antiproton collider (900GeV x 900GeV)
CERN LEP - Geneva, Switzerland	electron-positron collider (50GeV x 50GeV)
Tristan* - Tsukuba, Japan	electron-positron collider (35GeV x 35GeV)
DESY HERA* - Hamburg, W. Germany	electron/positron-proton collider (30GeV x 800GeV)
Inst. of Nuclear Physics - Novosibirsk, U.S.S.R.	electron-positron collider (5GeV x 5GeV)
Institute of High Energy Physics - Serpukhov, U.S.S.R.	proton synchrotron (70GeV on fixed target)
UNK Phase I*	proton synchrotron (3TeV on fixed target)
UNK Phase II *	proton-antiproton collider (3TeV x 3TeV)
	Proposed
SSC - U.S.A	proton-proton collider (20TeV x 20TeV)
CERN LEP-LHC - Geneva, Switz.	large hadron collider (5-10 TeV x 5-10TeV)

* Under construction.

Notes: 1GeV = 1 billion electron volts of energy; 1TeV = 1 trillion electron volts of energy.

The Superconducting Super Collider

The SSC would be the largest and most energetic particle accelerator in the world. The SSC as envisioned currently would require an oval tunnel 52 miles in circumference approximately 30 or more feet underground. This dimension, if superimposed on a map of greater Washington, D.C., would approximate the Capital Beltway.

The tunnel would have a diameter of about 10 feet. Within it would be two pipes, each surrounded by cryogenic superconducting magnets (that is, magnets cooled to liquid helium temperature, 4.3 degrees Kelvin above absolute zero). Superconducting magnets would be used to limit the electric power requirements of the accelerator's magnetic field. Using conventional magnets would make such power costs prohibitively high. Inside each pipe would be a narrow beam of protons. These proton beams would travel in opposite directions. At several locations (interaction halls) in the tunnel, the beams would cross for collisions. Detectors would monitor the interactions which would occur at a rate of about 100 million per second. The detectors would feed data to very large computers for continuous analysis.

The SSC could be constructed with existing technology. The principal of colliding beams of protons was pioneered at the European Center for Nuclear Research (CERN) and has evolved successfully at Fermilab's Tevatron. Fermilab also successfully used cryogenic superconducting magnets in its Tevatron. Detector and computer technologies are advanced enough to make the research productive. In short, there is high confidence in the scientific community that the SSC would live up to scientific expectations.

The DOE Program

1983-1986

The SSC is proposed as a major program of the Office of Energy Research (OER) of the Department of Energy (DOE). Its inception, however, can be traced to the worldwide attention given to the concept of a superconducting super collider since the late 1960s. The views of the U.S. high energy physics community began to crystallize during a meeting of a division of the American Physical Society in Snowmass, Colorado, in 1982. At that time a consensus developed that the next needed step in the development of high energy particle accelerators would be a multi-TeV (multi-trillion electron volt) particle collider.

In 1983, the Subpanel on New Facilities of DOE's High Energy Physics Advisory Panel (HEPAP) recommended, and the full HEPAP unanimously endorsed, the immediate initiation of an SSC having beam energies between 10 and 20 TeV each. In addition, the advisory panel recommended several other actions affecting other accelerators around the country. At about that time, the Tevatron at Fermilab was commissioned and operated successfully. This pioneer facility, which uses superconducting magnets, validated the basic systems concepts needed for the SSC.

In 1983, DOE began preliminary R&D for the SSC. On Nov. 19, 1983, the House Committee on Science and Technology held hearings on the future direction of DOE's high energy physics program and specifically the SSC.

In December 1983, DOE began a "Reference Designs Study" to examine magnet and systems design options, to make technical feasibility studies, and to make first cost estimates of the SSC. The study, completed in April 1984, concluded that the SSC would be technically feasible using existing technology and engineering.

In early 1984, DOE designated the Universities Research Association (URA), a consortium of 55 U.S. and one Canadian research universities, to conduct the SSC research, development, and design activities prior to construction. The SSC Central Design Group (CDG), hosted by Lawrence Berkeley Laboratory, was established by the URA as the operating group to coordinate and supervise those tasks. Research and development related to the SSC have been carried out for the CDG by Lawrence Berkeley Laboratory, Brookhaven National Laboratory, Fermilab, Texas Accelerator Center, universities, and industry.

The objectives of the CDG are to accomplish the R&D necessary to delimit all the machine's and associated system's parameters in order to optimize the performance and cost; to specify in detail the requirements of a site; to prepare a complete and detailed plan of the envisioned SSC facility, including a firm cost estimate and construction schedule; to develop prototype magnets and other components; and to conduct extensive systems tests of the prototype magnets and associated cryogenic and control systems.

The major objectives for 1985 were the preparation of the "Superconducting Super Collider Parameters Document" (June 15, 1985), and the R&D effort to select magnets. Five basic types of magnets were studied by teams at Brookhaven National Laboratory, Fermilab, Lawrence Berkeley Laboratory, Texas Accelerator Center, and cooperating industries. In August 1985, the SSC Magnet Selection Advisory Panel made a unanimous recommendation for the SSC magnets which was accepted by the CDG. The construction and testing of prototype magnets began at that time.

In March 1986, the CDG published "Conceptual Design of the Superconducting Super Collider," a report requested by DOE. It discussed scientific needs of the SSC program, a technically feasible design for the SSC, a detailed cost estimate, and a construction schedule. The cost estimate then was about $4 billion (1986 dollars), including all R&D, preparation costs, and an estimate of the initial complement of detectors and computers, but excluding land acquisition costs which DOE assumes will be provided free by the State or locality. Costs are discussed in detail below.

Work continued throughout 1985 and 1986 on some technical aspects of SSC development but, from the scientific and technical standpoint, the SSC program was largely ready to proceed with site selection and construction.

1987 and Beyond

At a congressional briefing on Feb. 10, 1987, following President Reagan's approval of the SSC program on Jan. 30, 1987, DOE announced its site selection timetable:

April 1987	DOE to issue invitation for site proposals;
August 1987	DOE to receive and screen proposals;
September 1987	DOE to refer qualified proposals to the National Academy of Sciences and National Academy of Engineering for evaluation;
December 1987	The Academies to recommend to DOE the best qualified sites (an unranked list of several sites, with no minimum or maximum number of sites required);
July 1988	DOE to designate preferred site;
Mid-87-88	Safety and environmental review process, including Environmental Impact Statement in accordance with the National Environmental Protection Act; and
January 1989	Final site selection and site preparation by DOE.

The construction phase would begin in 1989 with operations currently expected to begin in about 1996 or 1997.

Current Cost Estimates

When President Reagan approved the SSC program on Jan. 30, 1987, $60 million had already been spent by DOE on R&D and design studies from 1984 through 1986. On Feb. 10, 1987, DOE announced that FY87 funding for the SSC would be $20 million and that for FY88 it would be $35 million ($10 million for construction and $25 million for R&D), all to be taken out of the already requested FY88 DOE high energy physics program budget of $556.6 million. DOE funding estimates for the 8- or 9-year preconstruction and construction program are the following:

TABLE 2. Estimated Budget Authority
(in millions of FY88 dollars)

FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	Total
$35	348	615	675	670	691	709	447	185	$4,375

PROJECT COST BREAKDOWN		
Construction		$3,210
R&D		274
Detectors and computers		719
Pre-operating		172
Total		$4,375
CONSTRUCTION COST BREAKDOWN		
Technical Components		$1,519
Magnets	(1,068)	
Cryogenics	(129)	
Other	(322)	
Conventional Facility		614
Collider Facilities (Tunnel)	(370)	
Other	(244)	
System Engineering and Design		307
Management and Support		205
Contingency		565
Total		$3,210

On Feb. 10, 1987, Dr. Alvin W. Trivelpiece, Director of DOE's Office of Energy Research, stated that these budget figures are accurate to within about 10%, assuming that the required land would be provided free. The SSC's annual operating budget after operations begin is estimated to be about $270 million in 1988 dollars.

Funding Considerations

The Accuracy of the SSC Cost Estimates

The cost of the SSC has been recognized as a major factor in the feasibility of its construction from the very beginning of its consideration in 1983. The DOE "Reference Designs Study" (1984) made the first cost estimates and the "Conceptual Design of the Superconducting Super Collider" (1986) refined those estimates. The latter estimate (p. 170) was $3.0 billion (FY86 dollars) for construction costs, separated into technical components, conventional facilities, systems engineering and design, management and support, and contingency. In the budget estimate discussed at DOE's congressional briefing on Feb. 10, 1987, and set forth above, each of these subcosts, in FY88 dollars, showed an increase, total construction costs being $3.2 billion. To this were added costs for R&D, detectors and computers, and pre-operating costs to bring the current DOE estimate up to $4.375 billion (FY88 dollars).

Three recent reports of the General Accounting Office (GAO) deal with the increasing costs of DOE's particle accelerators and problems associated with accurately estimating the costs of those accelerators (Increasing Costs, Competition May Hinder U.S. Position of Leadership in High Energy Physics, Sept. 16, 1980; DOE Physics Accelerators: Their Costs and Benefits, April 1985; Nuclear Science: Information on DOE Accelerators Should be Better Disclosed in the Budget, April 1986). The last report (p. 38) estimates the cost of the SSC, including detectors, to be about $4.9 billion (FY85 dollars). Taken together, these three GAO report's indicate the continuing concerns of GAO and the Congress with DOE's accelerator costs and the extent and accuracy of the information provided to Congress for its budgetary and oversight functions.

Relationship of the SSC to Other Federal R&D Funding

The Federal R&D Budget. Under President Reagan, the Federal R&D budget has shown steady real growth. In the attempts of Congress and the Administration to deal effectively with large deficits, R&D funding may decline in the years ahead, although no firm indications of such a decline have yet emerged.

The Federal R&D budget is vulnerable to low or no growth in the years ahead because it represents a fairly significant percentage of discretionary or controllable budget items, that is, those budget items which the Congress can fund or not fund without changing existing law. The R&D budget (approximately $66.8 billion in obligations including defense R&D) is about 13% of the discretionary budget and about 22% of the controllable outlays. As such, the overall R&D budget may represent a prime target for deficit reduction in the years ahead. Any large, newly proposed science and technology projects, of which the SSC is only one, may exacerbate the vulnerability of Federal R&D budgets.

The SSC and Civilian R&D. The Federal R&D budget for 1988, including funding for R&D facilities, is estimated to be about $66.8 billion (in obligations) of which $48 billion (72%) is for defense R&D and $18.8 billion (28%) is for civilian R&D. Assuming that the average annual SSC funding from FY87 through FY96 is about $542 million the SSC by itself, on the average, would represent about 2.5% of the Federal civilian R&D budget. If the rest of DOE's high energy physics program also were of this order of magnitude, as the pre-FY88 trend suggests, total DOE high energy physics program funding might approach 5% of the total Federal civilian R&D budget. It is likely, however, that with the initiation of the SSC there would be a substantial reduction in the non-SSC portion of the high energy physics program of DOE.

Other New and Large Federal R&D Programs. Several other major Federal R&D programs in addition to the SSC recently have been initiated or proposed. As a point of comparison in terms of costs only, five of these are presented here.

The NASA space station program was initiated in FY85. It will take until 1996 to complete. The U.S. costs are now estimated to be over $16 billion (1984 dollars) with the operating costs from about 1996 through 2016 of about $1 billion per year. DOE, along with the National Institutes of Health and some private organizations, recently have proposed to "sequence" or "map" the human genome. If started in FY88, sequencing would take perhaps ten years to complete and could cost as much as $3 billion (1986 dollars). The National Science Foundation (NSF) has a FY88 proposed budget of about $1.7 billion. The Administration has proposed a doubling of the NSF budget by FY92. If this were to occur, about $10 billion (1987 dollars) would be added to NSF's existing funding level over the next 10 years. A U.S. program to study changes in the global environment over a 10-year period has been proposed. It might begin in FY90 and extend through 2000. Current cost estimates for the entire program are $1.5 to $2 billion (FY86 dollars). The Strategic Defense Initiative (SDI), first identifiable in the FY85 budget, is largely a packaging of existing defense-related science and technology programs. The Reagan Administration plan is now to fund the first stage at $20 billion (current dollars) over 6 years.

Such large R&D programs have been and will be subject to the same types of programmatic and budgetary scrutiny that the SSC will face. The point here, however, is that a number of recently initiated or proposed large Federal R&D programs, having time scales and funding magnitudes similar to those of the SSC, will be competing for congressional attention and budget dollars in this and the next several Congresses.

Advanced Accelerator Technologies

There is considerable research underway into new ways to accelerate particles to the very high energies needed to continue investigation of elementary particle physics. These methods involve, for example, the use of very intense electric fields that can be created by plasmas and lasers. Such methods would not require the particles to circle in order to gain large amounts of energy, so accelerators built using such concepts would be linear, and could be smaller and possibly cheaper, than equivalent synchrotron machines. In addition, radiation losses resulting when charged particles move in circular orbits limit the ultimate size of a synchrotron. The SSC would be about as large a machine as could be built using synchrotron principles. Future, larger machines probably would have to be linear for these reasons. Continued research into new accelerator methods is essential for the long-term future of elementary particle physics.

Because these new concepts are at the earliest stages of development, they are unlikely to be able to substitute for the SSC if it is desired that such a machine be built much before the end of the century. Some have argued, however, that the pace of elementary particle physics be slowed because, among other reasons, of the possibility of new accelerator techniques. In 1985, the Kendrew report on high energy particle physics in the United Kingdom concluded that,

> in view of the high cost of the research, and the possibility of new techniques being developed for accelerating particles, it would not be counter to the long-term interests of the field if the pace could be reduced worldwide and not merely at CERN. (British Particle Physicists Reject Proposed Cuts for CERN, Physics Today, v. 38, Sept. 1985, p. 69.)

Superconductivity

Recent discoveries of high temperature superconductors have raised questions about the wisdom of proceeding with the SSC if there is the possibility that the new materials could reduce operating costs and complexity. (Record High-Temperature Superconductors Claimed, Science, v. 235, Jan. 20, 1987, p. 531-533). The major attraction of the high temperature materials is their ability to become superconducting with liquid nitrogen rather than liquid helium as current technology requires. Liquid nitrogen is considerably cheaper and easier to handle than liquid helium. The new materials, however, are far from ready to make high strength electromagnets. So far, the high temperature superconductors are unable to carry current densities required of the SSC magnets except as very thin films which would not be adequate for large magnets. In addition, the materials, as ceramics, are very brittle and difficult to shape. Considerable research and development is needed to reach the required current densities, to achieve the flexibility needed for forming electromagnet coils, and to develop inexpensive fabrication techniques. While progress has been unexpectedly rapid, many researchers, while optimistic, expect that it will take years before these goals are reached.

Costs and Benefits

There are few absolute measures of the scientific, technological, economic, and social benefits and costs of large research programs because the consequences of basic research results are often difficult to track. Consequently, the following can describe, only briefly and qualitatively, the costs and benefits associated with the SSC. Such costs and benefits ultimately will be weighed in the political forum vis-a-vis other governmental policies and programs affecting the Nation's welfare.

Scientific

There is a consensus among U.S. high energy physicists that the SSC is the needed next step in high energy physics research. Among all U.S. scientists, however, a consensus about the potential value of the SSC's contribution to science in general does not appear to exist. What is good for one branch of science often is good for science as a whole, because of scientific cross-fertilization and the support of each other's budgets for mutual self-interest. At present, however, there is increasing concern about the allocation of limited governmental funds for science. As discussed above, the Federal R&D budget may be vulnerable to reduction. This and the initiation of one or more new, large Federal R&D programs could adversely affect U.S. science in general, and small science programs in particular, and result in lost opportunities in a number of areas of U.S. science.

Technical and Economic

High energy physics is a premier example of pure or fundamental science and basic research. Although economic benefits may accrue, the target of such research is almost always advancement of knowledge. Recently, Dr. Trivelpiece, at the DOE congressional briefing on the SSC, stated that one-third of the U.S. gross national product is based on the knowledge gained from scientific study of subatomic particles, including nuclear and high energy physics research. In particular, the electronics and computer industries are based on fundamental research in the areas of electronic phenomena and condensed matter physics and owe much of their understanding to research on subatomic particles. As valid as such a statement may be, its converse -- that most fundamental scientific research results in economic benefits -- is another issue entirely. Not every fundamental science program has resulted in significant technological and economic benefits. A recent analysis of research funding by OTA concludes that:

> Economists have shown a strong positive correlation between research and development (R&D) spending and economic growth. They have estimated private returns in excess of 20% per year and social returns in excess of 40% on private sector R&D expenditures. They have <u>not</u> been able to show comparable returns, and at times been unable to show <u>any</u> returns, on Federal R&D expenditures, except for some applied research programs in agriculture, aeronautics, and energy designed to improve industrial productivity. (Emphases in original.)

About direct economic benefits from research, the report states that the "principal benefit of research, especially basic research, is new and often unexpected knowledge, which cannot be assigned a direct economic value." (U.S. Congress, Office of Technology Assessment, Research Funding as an Investment: Can We Measure the Returns? -- A Technical Memorandum. Washington, U.S. Govt. Print. Off., Apr. 1986, p. 3 and 4.)

Many of those competing for the SSC site hope that it will attract other high technology firms like the Route 128 phenomena around Boston-Cambridge, Massachusetts, and Silicon Valley in California. Many analysts of the relationships between basic research, applied research, and development, however, question the value and extent of immediate technological spinoffs as contrasted to longer term economic benefits derived from fundamental scientific research. The SSC also is being promoted by some as a method to help improve the Nation's international technological and economic competitiveness, and science education. It is similarly debatable whether the SSC will be able to contribute much to these goals. For example, many representatives of academia believe that the best way to improve the Nation's science education is to directly fund new scientific facilities and equipment in the Nation's research colleges and universities rather than a large facility like the SSC.

In addition to any direct economic and technological benefits from scientific research, technological developments related to the development and construction of experimental research facilities also can occur. Although the SSC will use mature technologies that were pioneered elsewhere, it will use them on an unprecedented scale. Expected technological developments from such experimentation include large-scale production of superconducting materials and cryogenic refrigeration, improved tunneling technologies, large-volume storage of helium, and computer control and large-scale mechanical alignment systems. (Quigg, Chris, and Roy F. Schwitters, Elementary Particle Physics and the Superconducting Super Collider, Science, v. 231, Mar. 28, 1986, p. 1525.) One cannot expect, of course, that the SSC would be the only source of such technological developments or, indeed, that such developments would have significant economic consequences.

The question of the economic benefits from high energy particle accelerators has not been analyzed to any extent in the United States. In Europe, however, two studies have shown that every franc spent by CERN on associated high technology development has produced about three francs of new business for the firms involved. These technologies include electronics, optics, and computers; electrical equipment; vacuum cryogenics and superconductivity; steel and welding; and precision machining.

In summary, history has shown that many widespread economic benefits have resulted from some fundamental scientific research. European analyses have shown that specific commercial benefits flowed to the firms involved in the construction and operation of CERN's high energy particle accelerator development. On the other hand, many observers hold that possible secondary spinoffs are uncertain at best and should not be used to justify the primary purpose of a basic science program. Thus, while the SSC may provide future economic benefits, equivalent funds spent directly to obtain such possible economic benefits might be more effective.

Only one economic aspect of SSC development seems reasonably assured. The locality that is chosen to be the site of the SSC will benefit. Such communities do run the risk, however, of substantial economic loss should the project be cancelled once construction is underway. Local industry will be called upon to a large extent to construct the "bricks and mortar" part of the 52-mile tunnel and the required research facilities. DOE estimates that the on-site work force would reach about 4,500 people over the 8- or 9-year construction period and that the full-time staff of the SSC facility would be about 2,500, with about 500 visiting scientists expected on-site at any given time.

Social

The SSC also may generate broad social, including cultural, benefits, although such benefits may be offset by associated social and cultural costs. Some proponents of the SSC have been very enthusiastic about the cultural aspects of the SSC. One, for example, has stated that "the supercollider is critically important to the 2,500-year search for the nature of fundamental matter" (Lederman, Leon M. To Understand the Universe, Issues in Science and Technology, v. 1, Summer 1985, p. 56) and that

> ...most people acknowledge that the most important aspect of science is the cultural one. The need is universal -- to give a coherent account of the world and our place in it. (Lederman, Leon M. The Value of Fundamental Science, Scientific American, v. 251, Nov. 1984, p. 40.)

Mankind almost certainly will continue to pursue this search and the SSC may help in reaching that goal. The next insights now being sought, however, are so complex that they are quite remote from most people. It may be asked, therefore, whether we need to continue the current pace of these investigations or whether we can slow down and delay construction of the SSC or its future equivalent for several years. In addition to the possibility of answering some of the great questions about nature and broadening the Nation's intellectual horizons, the SSC may contribute to the Nation's overall scientific prestige and probably would be a source of a number of future Nobel Prizes.

While these and other perspectives of the social and cultural value of big science in general and the SSC in particular are legitimate, many members of U.S. society may place greater immediate value on promoting, for example, health, education, welfare, housing, urban development, and other policies and programs that are more directly related to the social development of the Nation's people than on science per se or even on the economic developments derived from that science. It should be remembered, though, that these programs are not necessarily mutually exclusive.

International Cooperation and Competition

The Administration has proposed that the SSC be located in the United States and constructed mainly with U.S. funds, although international cooperation has been welcomed informally. Such international cooperation might involve the procurement of some system components, like some superconducting magnets, from foreign sources, and certainly the conduct of joint research projects, involving joint project funding, once the SSC is operational. Formal international cooperative agreements would be made through normal diplomatic channels.

The high energy physics community traditionally has been international and cooperative. The increasing costs of high energy particle accelerators and the numbers of smaller machines that have been or will be decommissioned will reinforce this tradition. CERN, at which many U.S. high energy physicists have worked, is operated by an European consortium and the HERA collider at DESY in West Germany has components supplied by a number of European countries. The SSC is a prime candidate for such international cost sharing. However, although DOE is promoting international cost sharing in the SSC project, few, if any, foreign decisionmakers have made a commitment to do so.

There are both benefits and difficulties, however, associated with international cooperation in big science, including high energy facilities and operations. Some of these benefits and opportunities are: making greater resources available in terms of information, knowledge, and know-how necessary for any scientific activity; making possible a wider range of topics and a broader range of approaches; reducing the financial burden on all participants; speeding up the entire innovation process, from basic research to application; reducing wasteful redundancy; and enhancing good will and communication among the participants. Some of the costs and difficulties are: inherent difficulties in meshing disparate national bureaucracies; delays in reaching decisions among differing political and legal systems; complications in varying decision processes, priorities, and competencies; costs of international bureaucracy; the danger that political inertia, which makes projects hard to start, but even harder to stop, will dominate; the possibility of drains on national research budgets because of international commitments; the tendency to undertake, internationally, only low-priority projects; and the apparent conflict between cooperation and improving a Nation's competitive position. (Rycroft, Robert W. International Cooperation in Science Policy: The U.S. Role in Macroprojects, Technology in Society, v. 5, 1985, p. 51-68. Also published as International Cooperation in Science: the U.S. Role in Megaprojects, In Emerging Issues in Science and Technology, 1982, Washington, National Science Foundation, 1983, p. 1-13.)

Although not all of these factors would apply to the SSC, it is clear that international cooperation in big science may not be considered to be a unmitigated good from a national standpoint in every case. A decision by DOE, for example, to enter into agreements with Japan or another country to supply superconducting magnets may be met with disfavor by U.S. industry which has cooperated with DOE in the development of such magnets.

Although high energy physics is characterized by international cooperation, it also is characterized by international competition. The titles of two recent articles in the scientific literature express this forcefully: "European Physicists Push Alternative to SSC: (Science, v. 228, May 24, 1985, p.968-970) and "The Shifting Balance of Power in Experimental Particle Physics" (Physics Today, v.39, Nov. 1986, p.27-34).

228, May 24, 1985, p.968-970) and "The Shifting Balance of Power in Experimental Particle Physics" (Physics Today, v.39, Nov. 1986, p.27-34).

A European large hadron collider (LHC) was once considered to be an alternative to the SSC. The LHC is an idea of Carlo Rubbia, the physicist who won a Nobel Prize for his team's discovery, at CERN, of three particles predicted by the Standard Model. The LHC would use CERN's existing LEP facility and consequently could be constructed much faster and more cheaply than the SSC. It would, however, have an energy of only about one-third that of the SSC and only about one-tenth of the number of particle interactions. Rubbia himself, consequently, has stated recently that, because of such characteristics, an LHC would not, in fact, be a scientific alternative to the SSC. (U.S. Congress, House, Committee on Science and Technology, Status and Plans of the United States and CERN High Energy Physics Programs and the Superconducting Super Collider (SSC), Hearings, Nov. 29, 1985, p. 43.) But, should the SSC not be funded, current European accelerator plans suggest that a "favorable European option" would be a proton collider at LEP having energies of 8.5 TeV each, "targeted at essentially the same physics as the SSC." (Physics News in 1986, Physics Today, v. 40, Jan. 1987, p. S-29.) This option, however, would involve extensive development of magnets.

In addition to the Europeans, the Soviets and the Japanese have large particle accelerators under construction. The Soviet UNK Phase II collider would have a collision energy in the range of the LHC.

In evaluating the Nation's need for the SSC, opportunities for cooperation as well as challenges from abroad will be considered. National scientific prestige will be placed on the side of the scales called competition just as the need for cost sharing will be placed on the side of cooperation.

LEGISLATION

H.R. 2700 (Bevill)
Makes appropriations for energy and water development for FY88, including $25 million for Superconducting Super Collider R&D. Introduced June 17, 1987; referred to Committee on Appropriations. Reported to House (H.Rept. 100-162) June 17. Passed House, amended, June 24. Referred to Senate Committee on Appropriations.

H.R. 3228 (Roe)
Authorizes appropriations for the Superconducting Super Collider program, including $25 million for R&D and $10 million for initial construction. Introduced Aug. 7, 1987; referred to Committee on Science, Space, and Technology.

CONGRESSIONAL HEARINGS, REPORTS, AND DOCUMENTS

U.S. Congress. House. Committee on Science and Technology. Subcommittee on Energy Development and Applications. High energy physics facilities. Hearing, 98th Congress, 1st session, Nov. 19, 1983. Washington, U.S. Govt. Print. Off., 1984. 654 p.

----- Superconducting Super Collider. Hearings, 100th Congress, 1st session, Apr. 7, 8, and 9, 1987. [Not yet printed]

U.S. Congress. House. Committee on Science and Technology. Subcommittee on International Scientific Cooperation. International cooperation on the Superconducting Super Collider (SSC). Hearing, 100th Congress, 1st session, May 7, 1987. [Not yet printed]

U.S. Congress. Senate. Committee on Energy and Natural Resources. Subcommittee on Energy Research and Development. Dept. of Energy's funding request for the Superconducting Super Collider. Hearing, 100th Congress, 1st session. Apr. 7, 1987. [Not yet printed]