BUILD THE SSC USING HIGH-TEMPERATURE SUPERCONDUCTORS

There have been many recent advances in superconductivity at relatively high temperatures. The new discoveries are based on new materials, mainly ceramics, that exhibit superconducting properties (that is, lose all electrical resistance) at temperatures above that of liquid nitrogen. Low-temperature superconducting materials, such as those currently in the SSC, have to be cooled by using liquid helium. Liquid nitrogen is much cheaper and easier to work with than liquid helium. The massive use of superconductors by the SSC has raised the question of whether it would be better to defer construction of the SSC until new high-temperature superconducting cable is developed, which would lower the costs of cooling the superconducting magnets.

While the recent development of high-temperature superconductors has opened many new possible applications for superconductors, these applications promise to become a reality only after many years, perhaps decades in the case of high-energy applications, of further R&D. None of the high-temperature superconductors is ready for industrial applications and especially not at the high power levels necessary for the magnets that hold the SSC's proton beams on course in the accelerator rings. The high-temperature superconductors present exciting potential, but it is also possible that they will remain laboratory curiosities and never find useful applications. Even if they find useful applications, they may not be useful at energy levels sufficient to power the SSC magnets. By contrast, low-temperature superconductor technology is currently available to power the SSC.

Budgetary Risks and Benefits

The SSC Central Design Group has conducted a study to ascertain the impact of the new technology on the design and the cost of the SSC.[15] The study limits itself to the assumption that high-temperature superconducting magnets replace the planned low-temperature superconducting magnets while the size of the machine remains the same. It

15. M. S. McAshan and Peter VanderArend, "A Liquid Nitrogen Temperature SSC" (report prepared for the SSC Central Design Group, April 1987).

examines the impact of the replacement on the design and the cost of the magnets, cryogenics, quench protection system, liquid nitrogen production, and operations.

The Central Design Group concluded that there would be a 3 percent reduction in total estimated costs if high-temperature superconductors were used in the SSC. The savings are clearly not enough to spur interest in delaying the project for at least 10 to 20 years for the development of high-temperature superconductors.

There might be savings in certain components of the SSC, but net savings are not likely to be large because other components may become more expensive. The cryogenic components are projected to cost $129 million.[16] Cost reductions in cryogenics by using liquid nitrogen instead of liquid helium would be in part offset by increased costs in the vacuum system. The low temperature of the liquid helium makes air liquefy and allows the easy maintenance of a vacuum. At a higher temperature the vacuum is more difficult to maintain and special pumps and a larger beam pipe assembly for the particle beams may be necessary. Even if material costs decline, other components of the magnets' cost--engineering, labor, and other components--are likely to rise because the new superconducting materials are difficult to handle.[17] It is therefore unlikely that the new high-temperature superconductors will be in a position to reduce substantially the costs of the SSC in the near future.

16. The complete ring system costs $1.3 billion, but many of these components, such as instrumentation, controls, and safety systems, would be required with any magnets. See SSC Central Design Group, *Conceptual Design of the Superconducting Super Collider* (Berkeley, Calif.: SSC CDG, 1986), p. 697. Costs were deflated using the DOE inflation index for energy research and nuclear construction.

17. Robert Pool, "Superconductors' Material Problems," *Science* (April 1988), pp. 25-27.

APPENDIXES

APPENDIX A

TECHNOLOGY SPINOFFS FROM GOVERNMENT PROGRAMS

There is substantial literature concerning federal government technology programs and commercial innovation, much of it far beyond the purview of this report.[1] One can draw several themes relevant to the Superconducting Super Collider (SSC) from this literature. First, federal agencies have had the greatest success with spinoffs when they directly used the technology in question. (An important exception is in the area of health and agriculture.) The Department of Defense (DOD) and the National Aeronautics and Space Admininistration (NASA) felt they needed integrated circuits to fulfill their respective missions. While they may have envisaged eventual civilian applications (the contractors certainly did), they needed integrated circuits for the Minuteman II missile program and for the Apollo lunar mission. Similarly, military needs such as those for nuclear weapons, air defense, and intelligence programs created a government demand for computers. By contrast, much of the research performed by the Department of Energy (DOE) and the Synthetic Fuels Corporation, where the program's objectives were to champion technologies for private sector users, had little success.

Second, federal agencies played a substantial role in commercial development when they represented a large fraction of total demand. DOD and NASA, for instance, bought the first few million integrated circuits, representing all or nearly all demand at the outset of this technology. With computer technology, federal agencies were the first purchasers of virtually all new advances in technology during the 1940s, 1950s, and early 1960s.

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1. For a compendium of industry studies, see Richard R. Nelson, ed., *Government and Technical Progress, A Cross-Industry Analysis* (New York: Pergamon Press, 1982). For a more recent study, see Kenneth Flamm, *Creating the Computer: Government, Industry and High Technology* (Washington, D.C.: The Brookings Institution, 1988). In the case of integrated circuits, see Philip Webre, "Technological Progress and Productivity Growth in the U.S. Semiconductor Industry" (Ph.D. Dissertation, American University, 1983), pp. 93-111.

Third, even where federal agencies played a crucial role in the development of a particular technology, no single program or instrument was responsible for the entire development of complex devices like computers or integrated circuits. The history of computer technology since the 1940s shows each federal research project adding one new element to the modern computer.[2] Occasionally, the stated mission of the computer would change according to the technology that was developed.

Lastly, many promising technology spinoffs proved to be dead ends. Again, the history of integrated circuits is instructive. For at least 10 years, the federal government supported the development of products designed to perform the function of integrated circuits, but the vast majority of the funds probably went into projects which ended in failure. On the other hand, even programs that initially prove unproductive may make important contributions to other projects. For instance, during the late 1950s, the U.S. Navy funded thin film technology as an alternative to integrated circuits. While the project as a whole came to nothing, advances in photolithography were made that later proved important in the development of integrated circuits.[3]

The importance of these lessons is that the SSC should not be expected to result in more than one or two major technological developments, if any. Moreover, the technological fields in which the SSC is likely to play a role are limited. The SSC will represent the bulk of the market for superconducting magnets during its construction. Consequently, according to the above analysis, the SSC may prove important. (A fuller discussion of the SSC and superconducting magnets can be found in Chapter II of this report.) But outside this field, the SSC may not contribute as greatly to technological progress. Rather, the SSC looks like any other sophisticated consumer of computers and other such instruments, and hence it is no more or less likely to produce an important advance than any other major laboratory.

2. Flamm, *Creating the Computer*, Chapters 3 and 4.

3. Webre, "U.S. Semiconductor Industry," pp. 103-107.

SPINOFFS FROM THE PARTICLE PHYSICS PROGRAM

Research programs in high-energy physics differ from other scientific research studies in one important property: usually these research projects require large investments in the development of new technological tools for research. It is intrinsic to the type of research conducted by high-energy physicists that better and bigger tools are needed to further knowledge. Thus, the chance of a technology spinoff from a particle physics program is enhanced simply because it invests in the development of advanced technology for its own use.

Another unique contribution of particle physics is its scientific role in providing the intellectual basis for the conception of new technologies. Many advances in electronics, and in medical technologies, have their roots in particle physics research. From the magnetron in microwave ovens to fusion reactors, there is a vast range of technologies whose conception can be attributed to particle physics.

Most technological spinoffs from research in high-energy physics have repeat applications for new research in the same field. The technology developed for one accelerator becomes the basis of the next generation of the accelerator. This is most evident in the technology being used for the SSC, much of which was developed at the Fermi National Accelerator Laboratory (Fermilab) for the Tevatron I.

As discussed above, one important trait of all spinoffs from investments in research is that a technology can rarely be attributed wholly to a single research project. Success is usually a cumulative effect of many research programs, procurements, and advances in the basic science. None of the examples of spinoffs described below can be attributed to a single project. In fact, most successful spinoffs that move out of the laboratory evolve only after a concerted effort to develop the technology further for its own sake.

Electronics

The semiconductor industry has gained heavily from research in particle physics. A substantial portion of the knowledge used in the invention of the transistor came from early research on atomic nuclei.

The manufacturing process for integrated circuits today relies heavily on processes rooted in particle physics experimentation.

One such process is ion implantation, a technique in which ions or charged particles are implanted on the surface of a material thereby altering its physical, chemical, electrical, or optical properties. Ion implantation can provide the desired characteristics to metals, alloys, ceramics, and even insulating materials and polymers.[4]

The technique of ion implantation has origins in particle physics research. Scientists developed the technology to bombard an atomic nucleus with ions, and the equipment used in ion implantation is very similar. This process, which was developed in the early 1960s to study a natural phenomenon, has now spurred research of its own to find more applications in industry.

Ion implantation has become the preferred procedure in the manufacture of integrated circuits. It is also aiding in the development of new semiconductors for faster, cheaper, and smaller circuits by implanting a very thin layer of silicon on an insulating material.

Ion implantation is also used to change the chemical and mechanical properties of metals. It can make them harder, increase their resistance to corrosion, lower their friction, and change their magnetic properties. For example, implanting nitrogen in metal surfaces has reduced wear 1,000 times. Such advances are being exploited in the manufacture of engine components, ball bearings, and precise tools and dyes. Another important application that could become highly beneficial is the use of nitrogen-implanted titanium alloy for hip prostheses. Nitrogen implantation will increase the longevity of these devices by reducing wear from friction and chemical degradation.

Medicine

In the medical field, there have been vast improvements in diagnosis and treatment techniques as a result of particle physics spinoffs. Radio-isotopes or radioactive atomic particles, first produced in

4. For a more detailed description of the use of ion implantation in industry, see S. Thomas Picraux and Paul S. Peercy, "Ion Implantation of Surfaces," *Scientific American*, vol. 252 (March 1985).

particle physics research, have since found applications in medical diagnosis. Nuclear medicine and radiology have grown in their capabilities in recent years as a result of the availability of better technology. More and more procedures using radio-isotopes for inpatient and outpatient care are used every year: one out of eight people will at some point receive radiation therapy for cancer.[5] In nuclear medicine, an industry has been created to provide accelerators, detectors, imaging systems, and related services.

Radio-isotopes were first artificially produced by particle physicists before the age of accelerators; now accelerators have made the process easier. Most radio-isotopes used in medicine today are created commercially using accelerators, and almost all pharmaceutical companies operate accelerators for manufacturing and research: short-lived radio-isotopes are now produced in vast quantities by these pharmaceutical companies. In 1982, $130 million worth of pharmaceuticals based on isotopes were sold.[6] Diagnoses using isotopes are a major advance over other diagnostic techniques like exploratory surgery and heart catheterization.

Advances in radiography and software used to recognize patterns have been applied to computer-aided tomography, or CAT scanning. Another important diagnostic technique derived from particle physics is magnetic resonance imaging. Recent advances in studying living organisms have come from tagging monoclonal antibodies with radio-isotopes. Another contribution of particle physics to medicine is the direct use of accelerators in treatment and therapy: particle accelerators are now used to treat cancer patients, and X rays from radio frequency accelerators are used in radiotherapy.

Superconducting Magnets

One of the largest direct effects of particle physics has been on the development of the superconductor industry, which emerged pri-

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5. Waldemar Scharf, *Particle Accelerators and Their Uses, Part 2* (New York, N.Y.: Harwood Academic Publishers, 1986), p. 786.

6. Paul A. David, David Mowery, and W. Edward Steinmueller, "The Economic Analysis of Payoffs from Basic Research--An Examination of the Case of Particle Physics Research" (paper prepared for the Center for Economic Policy Research, January 1988), p. 55.

marily from the research at Fermilab to develop the magnets for the Tevatron I collider.

When Fermilab designed the Energy Saver, the key element was low-temperature superconducting magnets; using these magnets increased the power of the accelerator and reduced its consumption of electric power. Such magnets had been used in other accelerators, but there was no commercial source that could provide the 990 magnets needed for the Tevatron. Fermilab set up its own facilities and, together with commercial contractors, developed the complete procedure from making the superconducting cable to the particle beam correction system and quench protection systems for these magnets.[7]

Once it was shown how niobium-titanium cables could be wound to make low-temperature superconducting magnets, the manufacturers developed other uses for the product. It is possible that superconductors would have eventually found commercial applications in any case, but the impetus provided by Fermilab accelerated the process and bore the initial cost of research and development. The biggest use of superconducting magnets today is in magnetic resonance imaging machines. While the Tevatron I cannot be awarded all the credit for the establishment of this industry, in this particular case it had the largest impact of any previous high-energy research project on the development of a technology spinoff.

Other Spinoffs

Other spinoffs in the history of accelerators have come from research on the subsystems of the accelerators. Applications have been found for components developed for detectors, vacuum systems, magnets, particle storage and acceleration, and communication and computer systems in industry. For example, photomultiplier tubes developed for particle physics detectors are now widely used in medical instruments, and advances in vacuum technology came from initial research in accelerators. While most advances in accelerator subsystems are limited to building better accelerators, there are some that have influenced the development of other technology. For example, the need to

7. Barbara Gross Levi and Bertram Schwarzschild, "Super Collider Magnet Program Pushes Toward Prototype," *Physics Today*, vol. 41, no. 4 (April 1988), pp. 17-21.

collect and process vast quantities of accelerator data quickly had some impact on advances in computer networks and processors.

APPENDIX B

TECHNOLOGY SPINOFFS FROM CERN ACCELERATOR RESEARCH

In 1984, the European Organization for Nuclear Research (CERN) published a report on the economic and commercial spinoffs of its high-energy physics program in Geneva, Switzerland.[1] This study (referred to as the *CERN Contracts Study*) concentrated on the secondary economic effects of the procurement contracts let by CERN. The study's intention was to determine whether firms that sold high-technology goods to CERN experienced subsequent increases in non-CERN sales. The conclusion was that CERN contracts generated 3 Swiss francs in non-CERN sales for each Swiss franc in CERN sales (all francs cited here are Swiss francs). This appendix examines the study for substance, method, and applicability to U.S. circumstances. It shows that the study substantially overstates the added value of CERN contracts to the economy, although not to the firms involved. Moreover, largely because of differences in technology, many of the report's conclusions may not be applicable to the United States.

Summary of the CERN Contracts Study

The *CERN Contracts Study* divided the economic effects of CERN into three categories: primary economic effects, secondary economic effects, and macroeconomic multiplier effects. The first category is the economic usefulness of the research results themselves. In the case of CERN, or the Superconducting Super Collider (SSC) in the United States, the research results are not expected to pay for themselves economically for decades, if ever. While early economic use of these results would be welcome, these projects are being undertaken for the

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1. M. Bianchi-Streit and others, "Economic Utility Resulting from CERN Contracts (Second Study)" (prepared for the European Organization for Nuclear Research, Geneva, Switzerland, December 11, 1984). Reprinted in *Superconducting Super Collider*, Hearings before the House Committee on Science, Space, and Technology, 100:1 (1987), p. 151. This study is referred to hereafter as the *CERN Contracts Study*. Note also that this study is independent of a previous study, which covered similar topics for an earlier period. The Congressional Budget Office did not analyze the first study.

sake of knowledge and any other use of the results is considered fortuitous. The third category, multiplier effects, is simply the stimulus to the economy that results from all government purchases of goods and services. The stimulus would be roughly the same whether the government were building a highway or a particle accelerator. The *CERN Contracts Study* focuses on neither of these, but rather concentrates on the benefits to the firms that provide high-technology equipment under contract to CERN.[2]

The study's method is straightforward: 160 sample high-technology firms that received CERN contracts during the 1973-1982 period were asked how much in additional sales the CERN contracts had generated or would generate during the 1973-1987 period. (Since interviews for the study were conducted between May of 1982 and June of 1984, a substantial portion of the stated gain in sales was, in fact, a forecast.) While the questions asked covered a range of topics--such as how CERN contracts affected management practices, quality control, research and development, and production techniques--the heart of the questioning related to additional sales. For instance, managers were asked to estimate how much CERN contracts had improved production techniques and then estimate how much the improved production techniques had increased, or would increase, sales by 1987. Furthermore, the answers were to be focused only on markets relevant to CERN. For example, unless specifically affected, consumer goods divisions of CERN contractors were excluded from the survey. While the survey intent was straightforward, the range of questions was complex enough to minimize deliberate exaggeration by the contractors.

Once tabulated, the results were screened for irregular data before being extrapolated to the universe of 519 high-technology CERN contractors.[3] The raw data results suggested that each franc in CERN sales produced 4.2 francs in added sales. Especially in the electronics,

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2. The *CERN Contracts Study* did not examine what may be the largest spinoff of pure research projects: the training of the next generation of scientists. The authors of the *CERN Contracts Study* acknowledged that quantifying the secondary effects completely was impossible. See Chapter II of this report.

3. Of CERN's 6,000 suppliers, the *CERN Contracts Study* classified 519 as "high technology," although the study did not define this term. The subsequent tabulations included steel and welding, which are not often classified as high technology.

TABLE B-1. SALES TO CERN AND NON-CERN MARKETS, BY INDUSTRIAL CATEGORY (In millions of 1977 Swiss francs)

	Electronics, Optics, Computers	Electrical Equipment	Vacuum, Cryogenics, Super-conductivity	Steel and Welding	Precision Mechanics	Total
Net Non-CERN Sales	2,245	1,025	400	255	155	4,080
CERN Sales	537	472	152	104	111	1,378
Ratio of Net Non-CERN Sales to CERN Sales	4.7	2.2	2.6	2.4	1.4	3.0[a]

SOURCE: M. Bianchi-Streit and others, "Economic Utility Resulting from CERN Contracts (Second Study)" (prepared for the European Organization for Nuclear Research, Geneva, Switzerland, December 11, 1984). Reprinted in *Superconducting Super Collider*, Hearings before the House Committee on Science, Space, and Technology, 100:1 (1987), p. 151.

NOTE: Details may not add to totals because of rounding.

CERN = European Organization for Nuclear Research.

a. Average of ratios.

optics, and computer industries, however, there were outliers: here the CERN franc produced 7.2 francs. The extrapolated results were tabulated by sector (see Table B-1). The net corrected benefit of each CERN franc to recipient firms was 3 francs.[4] This benefit applies to the high-technology suppliers exclusively, since they were the focus of the CERN study.

The authors of the *CERN Contracts Study* performed an additional test to determine the overall accuracy of the managers' sales forecasts. The study included 40 firms that had participated in an earlier study that used the same method. Comparing the forecasts made by these firms' managers with the subsequent actual events indicated that, while individual forecasts were often wrong, the aggregate forecast was close to actual overall sales. Tests suggested the

4. Among the other factors adjusted for was the effect of the CERN contracts before 1973. The study assumed that non-CERN contracts won by CERN contractors during 1973-1975 resulted from previous CERN work and should not be counted in the 1973-1982 total. Such contracts turned out to be 15 percent of the total.

differences between actual and forecasted sales were not statistically significant. The *CERN Contracts Study* therefore assumed that, on average, managers' forecasts would prove to be accurate.

Assumptions

The central, and perhaps flawed, assumption of the *CERN Contracts Study* is that 100 percent of the sales of CERN contractors are new sales to the economy; that is, these sales do not come at the cost of fewer sales going to firms that do not have CERN contracts. The *CERN Contracts Study* provides some supporting arguments for this 100 percent "additionality" assumption. It is nevertheless an assumption and, to the extent it is incorrect, CERN is merely rearranging sales rather than creating new ones. While such a rearrangement of sales is of great benefit to the firms involved, from a public policy perspective the question naturally arises of why a public agency, whether CERN or the U.S. Department of Energy, should spend money in order to shift sales to one favored group of firms. The following paragraphs discuss the *CERN Contracts Study* assumption and how it is contradicted throughout the study itself.

While the assumption of 100 percent additionality has some merit, it is given no statistical or anecdotal support in the study. It is a polar assumption in the sense that it is at the extreme end of the range of possibilities. At the other end of the range is the assumption that CERN contracts generate no additional sales in the aggregate and that the CERN contractors are merely diverting sales that would have gone to other firms.[5] This second polar assumption is the more conventional one, and thus the burden of proof lies with the *CERN Contracts Study.*

The authors of the study give two arguments in support of their additionality assumption:[6]

5. An even more extreme position would argue that if the government crowded out private investment in the credit markets, research and development spending by CERN would reduce the funds available for private investment and so reduce contracts overall.

6. *CERN Contracts Study*, p. 5.

- o The relevant markets are growth markets, so no firm is actually taking sales from other firms.

- o CERN buys only leading-edge products in these markets, and, by improving the quality of its suppliers, forces the competitors to improve also.

The first argument ignores the concept of baseline rates of growth. If a market is growing independently of CERN sales, then firms in those markets should expect to see sales growth. Investors in these firms would normally regard the failure to grow as indicative that something was wrong with the firm's management, product mix, or marketing. While no European firm may lose already existing sales to CERN contractors, CERN contracts may very well depress the sales growth of non-CERN contractor firms.

The second argument is simply overstated. Not every piece of equipment in CERN's laboratories leads the state of the art in its particular field. There will be certain components that are completely novel and other components that have substantial modifications and improvements. But to argue that CERN is simultaneously providing leadership in all aspects of the high technology it touches is to ignore the incremental and cumulative nature of scientific advance.[7] Like the first argument, this argument ignores improvements in technology that are occurring independently of CERN.

The assumption of 100 percent additionality is also regularly contradicted in the study. One of the major benefits the study claims for CERN contractors is that the contractors can use CERN as a reference. The study cites one case where a firm used its CERN contracts as the basis for admission to a trade association, "and, as a result, was able to obtain an increased number of [non-CERN] contracts."[8] The use of CERN as a reference for admission to a trade association, however, suggests a rearrangement rather than an

7. In the United States, many government programs involving high technology are not at the leading edge of their particular field. For instance, the SSC design includes "off the shelf" components, such as microcomputers for the control of the rings of superconducting magnets and commercially developed networks to link these computers. See SSC Central Design Group, *Conceptual Design of the Superconducting Super Collider* (Berkeley, Calif.: SSC CDG, 1986), pp. 473-476.

8. *CERN Contracts Study*, p. 11.

expansion of sales. An expansion would come from the introduction of new products or from cost reduction.

In another example cited by CERN, a small firm that supplied CERN with "standard, but specialized, hydraulic equipment" became the industry standard, increasing sales and exports. While there may be some increase in sales as a result of the benefits of standardization--consumers benefit by not having to compare and choose among competing equipment standards--these are offset by sales lost by the purveyors of alternative standards.[9] In this case, therefore, there will be some net gain in aggregate sales, but there will also be some losses for other providers of standard, but specialized, hydraulic equipment, showing that sales are once again being redistributed.

In sum, CERN probably has, by pushing technology forward, increased aggregate sales in high-technology products. However, there is no supporting evidence offered for, and a substantial amount of evidence against, the assumption that all or any substantial portion of the new sales obtained by CERN contractors were not diverted from firms without CERN contracts.

Applicability to U.S. Circumstances

In its justification of the additionality assumption, the *CERN Contracts Study* argued that it is "an efficient mechanism for keeping European industry abreast of international competition."[10] Simply put, the argument is that CERN contracts allow European suppliers to keep up with U.S. and Japanese suppliers of electronic goods and other high-technology products. In fact, the earlier CERN study found that roughly 33 percent of added sales came from substitution for imports coming from outside Europe, and that a further 30 percent represented exports to non-European countries.[11]

9. These losses could be magnified if the "wrong" standard--that is, one that limits future technology development--is chosen. See Paul David, "Some New Standards for the Economics of Standardization in the Information Age" (paper prepared for the Center for Economic Policy Research, Stanford University, October 1986).

10. *CERN Contracts Study*, p. 5.

11. From a strictly European perspective, excluded imports or new exports are 100 percent new sales.