dustrial production in space. A Mars mission would not play an important role. We know today that special industry can be established up there. In zero gravity things could be produced which would be impossible to produce here on Earth. Perhaps we could do preliminary experiments toward such a project in order to create the new technology for such a project. And I mean not only technology in the traditional sense, but also medicine, synthetic products. That's the first thing.

Secondly, projects related to the ecology. But not a Moon or Mars program. Any programs in space must be connected to Earth-bound interests. Things must be done for people here.

Q: But what about further in the future? If we succeed in doing this in 10 years, what would we aim at 20 or 30 years down the road?

Rauschenbach: You know, I believe that predictions from professionals are not very good. It's much better for the novelists. If you look at a magazine from the beginning of this century, and look at what the scientists have said and what the novelists have written, you will find that the novelists have been correct and the science professionals have been wrong. And this is understandable, because the professionals are tightly bound by the present, and they could hardly imagine that which a novelist could create with ease. Since I'm no novelist, I have some anxiety in predicting the future.

Science Policy

U.S. magnetic fusion budget in doubt

by Mark Wilsey

On May 27, scientists at the Princeton Plasma Physics Laboratory (PPPL) in New Jersey fired up the Tokamak Fusion Test Reactor (TFTR) and produced 9 megawatts, setting a new world record for fusion power. The result surpassed their previous record of 6.2 MW, set last December. Some who follow the fusion program are expecting fireworks of another kind on Capitol Hill this summer, as the debate over the future funding of fusion research heats up.

Tokamaks are large donut-shaped machines used to study the fusion process. They use magnetic fields to heat and compress hydrogen until the atoms fuse, forming helium and releasing large amounts of energy. Testifying before the House Appropriations Subcommittee on Energy and Water Development on April 11, Ronald Davidson, director of PPPL, noted that more than 60 million people throughout the nation saw reports of Princeton's tests in December. They "were reminded of the promise that fusion offers our energy-threatened world," he said. The tests at PPPL have provided a backdrop for the discussion of the U.S. fusion energy program in various forums over the recent weeks.

William Reddan, vice president of the engineering consulting firm Parsons Brinckerhoff, also testified at the April 11 hearing: "There is no question that fusion works. We see the Sun and the stars, which we know are powered by the fusion process. . . . What we do not know yet is how to harness this source." Indeed, harnessing thermonuclear fusion has been the decades-long dream of researchers, because it would provide a virtually inexhaustible power source, from an abundance of fusion fuel found in the hydrogen isotopes of seawater.

At April 21 hearings on fusion policy, the Subcommittee on Energy of the House Committee on Science, Space and Technology heard John Holdren, professor of energy and resources at the University of California at Berkeley, on future world energy needs. Holdren outlined two senarios; he termed one "business-as-usual," the other "best-plausible." In the first case, world energy demand nearly triples by the year 2050; in the second case, the demand doubles. Holdren's numbers are based on specific sets of assumptions: The starting point is 1990, with a world population of 5.32

billion, and energy use is 13.2 terawatts, two-thirds of that in the "industrial countries." Under the business-as-usual scenario, current trends are assumed to persist into the future, such that, by 2050, the world population has reached 10.6 billion and world energy use has risen to 42.2 terawatts, and three-fourths of demand comes from the "less developed countries." Holdren argued that while this demand could be met with current energy resources, it would be economically unaffordable and environmentally intolerable.

The best-plausible alternative that Holdren offered assumes an energy strategy in which increases in energy efficiency, reduction in emissions, and development of renewable energy sources have been maximized, coupled with expanded programs to spread the effort internationally. This scenario also assumes that the world's population growth is halted at 10 billion or less: The numbers Holdren arrived at for the year 2050 are 9.1 billion population and 26.4 terawatts. Holdren's energy projections are unrealistically low. For one thing, the best-plausible case assumes that, in the industrialized nations, per capita energy use in 2050 would be half that of the 1990 level due to gains in efficiency and conservation. However, were there to be a global economic recovery directed toward developing the Third World, energy demands would easily surpass, perhaps doubling, Holdren's business-as-usual scenario, representing an order of magnitude increase in per capita energy use for most of the world by the middle of the next century.

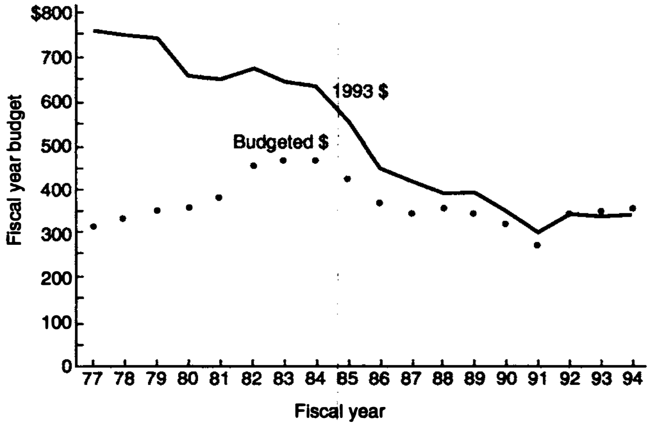
The point of these number games was to raise the question: Where will the energy come from to meet future demand? If the world cannot depend on fossil fuels indefinitely, then other energy sources must be developed. Fusion energy offers the potential of powering the world well into the foreseeable future.

The history of fusion research funding

Let us return to Princeton's TFTR. After the completion of its current series of ground-breaking tests, which are set to end in September, the TFTR will be decommissioned, concluding a program that began over 20 years ago. The design for the TFTR was completed in 1973 and construction began in 1976. It first operated with hydrogen in 1982, then with deuterium, an isotope of hydrogen, in 1983. The burning of tritium, another hydrogen isotope, was scheduled for 1986, and postponed to 1988; it was not actually accomplished until 1993, when the record-setting experiments of last December were conducted. Although the TFTR program presented many technical challenges, the delays were due largely to cutbacks in the magnetic fusion budget.

The oil shocks of the middle and late 1970s called the nation's attention to the need to develop new energy sources. The magnetic fusion budget nearly quadrupled from $57 million in 1974 to $219 million in 1976, and in 1980, the Magnetic Fusion Energy Act, also know as the McCormack

FIGURE 1
Federal funding for magnetic fusion budget, FY 1977-94
(million $)



Sources: DOE, Fusion Power Associates.

Act, called for the demonstration of fusion energy by the turn of the century. The act also laid out certain funding milestones, setting the 1981 magnetic fusion budget at $394 million (see **Figure 1**). In 1983 funding should have risen to $616 million, but only $444 million was budgeted, and the target date for fusion development slid to 2010. By 1988, fusion funding had fallen to $352 million, less than half of the $788 million envisioned for that year by McCormack's sponsors. In recent years, annual federal funding for magnetic fusion had leveled out at $340 million.

The result of this fiscal ratcheting down over the past decade has been to stretch out, scale back, or cancel many fusion programs. One such program was the work on magnetic mirrors at Lawrence Livermore National Laboratory, which works on a concept of producing fusion in a magnetic field "bottle" whose ends are sealed by other magnetic fields. In the mid-1980s, after spending millions of dollars and years in designing and building the magnetic mirror machine, its operating budget was cut just as experiments were about to commence.

Throughout the 1980s, funding for continuing programs shrunk over 50% in real terms from the levels of the late 1970s. As a consequence, for example, PPPL has seen its staff drop from 1,300 to 800 since the mid-1980s.

Future fusion energy programs

The TFTR program has met its goal of producing megawatts of fusion power from deuterium-tritium fuel, an accomplishment which is part of a four-step plan to develop magnetic fusion energy, which includes building an engineering test reactor, then a continuously operating tokamak, and finally, a fusion demonstration reactor. The next steps are just now getting under way with the Tokamak Physics Experiment (TPX) and the International Thermonuclear Experimental Reactor (ITER) programs. The demonstration fusion plant is still some 30 years off.

Princeton is slated to build the TPX to follow the TFTR, in which some of the existing TFTR components and infrastructure will be converted for TPX use. The TPX will be designed to demonstrate continuous fusion power production and to test advanced reactor concepts. It will use state-of-the-art superconducting coils to generate its magnetic fields. It is hoped that results from the TPX will aid in the design of future reactors that are more compact and economical. If approved and funded, the TPX could begin operations in 2000. In the meantime, Princeton has asked for funding to extend research on the TFTR for another six months or more. The Department of Energy (DOE) has not made a decision yet on the request.

The other major project on the horizon is the International Thermonuclear Experimental Reactor, now being planned among the European Union, United States, Russia, and Japan. ITER will be a multibillion-dollar machine that will produce power in the gigawatt range, the scale at which future fusion power plants may operate. It is being designed to meet scientific and technical objectives to address the feasibility of fusion energy. It will be used to demostrate ignition, plasma burn, and eventually continuous operation. ITER will also act as an engineering test bed to demonstrate the technologies needed for fusion energy. ITER is the most ambitious fusion project ever, requiring unprecedented international cooperation to be successful.

Budget battles in Congress

For fiscal year 1994, $343 million was earmarked for magnetic fusion. However, there were a few budget squabbles last year aimed to shrink that amount, notably an amendment from Reps. Tim Penny (D-Minn.) and John Kasich (R-Ohio) to reduce the magnetic fusion program by half. Although their measure failed, some 200 congressmen voted for it. More significant was the all-or-nothing stance taken last year by Sen. Bennett Johnston (D-La.), chairman of the Senate energy appropriations subcommittee. In an effort to secure a firm commitment from the administration for the construction of the ITER, he planned to withhold funding for TPX, citing the supposed need to avoid another embarrassment like the failed Superconducting Super Collider.

On June 9, Rep. George Brown (D-Calif.), chairman of the House Committee on Science, Space, and Technology, introduced legislation to provide a framework to support U.S. fusion energy goals. Entitled the Fusion Energy Research Authorization Act of 1994, H.R. 4553 has as its principal provision that the ITER be financed through a levy on electricity generation, in order to ensure America's commitment to the program. Brown's bill calls for a .1-mils/kilowatt-hour fee on electricity generation, which would generate an estimated $300 million per year. The fees would go into a trust fund and would expire when a sufficient balance were raised to pay for TPS and the U.S. share of ITER. The bill authorizes $380 million for FY 95, $425 million for FY 96, and $475 million for FY 97 for fusion research. Unfortunately, it also would prohibit spending funds on any other major fusion programs. Brown realizes that such a tax may not be popular or fair, but he hopes it will start a process of looking for mechanisms to provide for the steady funding of these multi-year programs and avoid the annual wrangling over budgets. It is also his view that such an approach may help restore the United States' reputation as a reliable partner in international cooperation.

President Clinton proposed a budget of $373 million for magnetic fusion in FY 1995, to which the House has added $4 million, providing $67 million for TPX. An amendment offered by Rep. Richard Swett (D-N.H.) to cut the $67 million from TPX, arguing that while "fusion makes sense, building another tokamak does not. DOE should invest in cleaner, cheaper fusion concepts." His amendment was defeated in a voice vote.

The Senate Appropriations Committee cut the President's fusion budget request by $10 million. Funding for TPX was cut to $28 million, limiting it to the continuation of the preliminary design. The report from Johnston's subcommittee expressed concern that DOE has failed to report on how it intends to move forward with ITER. Pointing out that the primary mission of TPX is linked to ITER, the Johnston report stated, "We strongly believe we should not pursue TPX unless both the President and the Congress have made a full commitment to ITER."

The fate of TPX will now be decided by a House-Senate conference committee.

It is unfortunate that an international fusion program such as ITER is seen as a substitute for a vigorous national program. It is bad enough that funding for a national fusion program such as TPX is held hostage to participation in an international program. It is worse to undermine what success the tokamak fusion program has so far achieved—it is the most advanced fusion technology, although its ultimate success in producing fusion energy may be debatable—by proposing a disproportionate emphasis on alternative fusion concepts at tokamak's expense, purely for the sake of "fiscal responsibility." Primarily as a result of such "fiscal constraints," the United States has been forced to give up a broad-based approach to fusion energy research in which alternative approaches would play a role: Consider the fact that federal spending in 1994 for all energy research and development is less than one-third, in real terms, what it was in 1980.