The Long March to Topnotch Science

China is making impressive strides in upgrading basic research, but reforming its scientific bureaucracy may be the biggest challenge

SHANGHAI—Rivulets of water are flowing down the dark hallway in the Samuel Waxman Laboratory of Molecular Biology in Shanghai's Rui-jin Hospital on a sweltering summer day in China's most populous city. It's not condensation from air conditioners, although a few offices do have window units. Rather, the culprits are several blocks of melting ice, propped against large freezers in an attempt to cope with the 40°C heat.

Looks can be deceptive when it comes to Chinese science, however. Despite its primitive cooling system, the lab, part of the Shanghai Second Medical University, is home to world-class molecular biology, say Western scientists who have collaborated with its director, 42-year-old Chen Zhu, his wife, Chen Saijian, and his mentor, hematologist Wang Zhenyi (see p. 1144). And despite its location in an aging, worn-down building—parts of the university date from its founding in 1911 by French missionaries—the lab boasts a talented team of two dozen scientists, technicians, and students skilled in the latest techniques and working with state-of-the-art equipment. "It's one of the most productive collaborations we have," says Samuel Waxman, professor of medicine at Mount Sinai Medical Center in New York and head of a foundation that supports the lab. "And no matter what obstacles [Chen] faces, nothing keeps this guy down."

Such determination has become an important trait for Chinese scientists. Two decades after the country opened up to the outside, and more than a decade since its leaders embraced a modified market economy, academic and scientific institutions are going through rapid and dramatic changes. China's new 5-Year Plan for 1996 through 2000 speaks repeatedly of "revitalizing China through science and education," and numerous incentive programs to lure overseas Chinese scientists back home are beginning to reverse a 15-year brain drain (see p. 1142). The government is also trying to concentrate limited funds on the best researchers and the top labs by expanding peer review and shrinking the scientific work force. And it is encouraging researchers to broaden their sources of support—including income from commercial products (*Science*, 15 October 1993, p. 362).

J. D. MERVIS

Dynamic duo. Shanghai geneticists Zhu and Saijian Chen: world-class science in aging labs.

But these trends are not yet locked into place. Ambitious plans for world-class facilities and increased international collaboration, for example, must win approval from a bureaucracy with multiple, shifting centers of power and rules that remain a mystery to outsiders. Returning scientists must still cope with an inadequate infrastructure. And personal connections, built up over time and forged by institutional or geographic loyalties, can be more important than peer review in deciding which projects get funded. "I think we're headed in the right direction," says Chu Yaoquan, director of the Center for Astrophysics at the University of Science and Technology of China (USTC) in Hefei and a co-leader of a project to build a novel optical telescope (see p. 1139). "But we still have a long way to go before we get there."

Sometimes the problem lies outside science itself. "For young scientists coming back to Beijing, the hardest thing is to find them good housing," says astronomer Chen Jiansheng, a professor at the Beijing Astronomical Observatory and a member of the Chinese Academy of Sciences (CAS). Housing is a standard part of a scientist's compensation package, but a chronic shortage in the country's two scientific centers, Beijing and Shanghai, means that a junior faculty member typically can wait a decade or longer for a two-bedroom apartment. Indeed, economist Justin Yifu Lin, director of the new China Center for Economic Research at Beijing University, says a major ingredient in building a program staffed entirely with Asian-born, Western-trained economists was persuading university officials to assign him five, two-bedroom housing units. "It was the biggest allocation in the university's history," he says with pride.

Most of the barriers to reform lie within the sprawling research system, however. "The current system of managing research in China is not satisfactory," says Shi Yuanchun, who is stepping down this fall after 12 years as president of the Beijing Agricultural University and who is a member of both CAS and the Chinese Academy of Engineering. "Sometimes it's very chaotic."

Shi, a soil scientist, knows the system firsthand. He not only directs a $375,000, 5-year research project on water conservation in agriculture supported by several agencies; he's also vice chair of separate science and technology advisory committees for the State Education Commission and the Ministry of Agriculture, and he sits on the governing board for the China Association for Science and Technology, an umbrella organization for

FOUR SCIENTISTS IN A POSITION TO MAKE A DIFFERENCE

J. KINOSHITA

Zhang Cunhao

President, National Natural Science Foundation of China

Age: 67

Education: B.S., 1947, Central University, Nanjing; M.S., 1950, U. of Michigan.

Field: Laser chemistry

Challenge: Promote role of basic research, foster more rigorous peer review.

J. D. MERVIS

Wei Yu

Title: Vice Minister, State Education Commission

Age: 55

Education: M.S., 1965, Nanjing Engineering Institute; Ph.D., 1981, Achen (Germany) Industrial U.

Field: Biomedical engineering

Challenge: Strengthen elite universities while improving general literacy.

Song Jian

Title: Chair, State Science and Technology Commission

Age: 64

Education: Moscow University, 1950s

Field: Cybernetics and automation

Challenge: Harness research for economic development, combat scientific illiteracy.

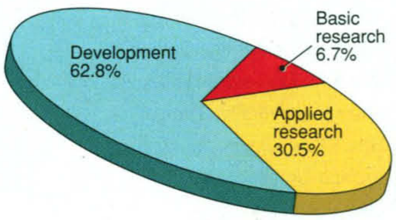
hundreds of scientific organizations. But even a veteran insider like the 67-year-old Shi can get confused. "As a scientist, sometimes I don't know who my boss is," he confesses.

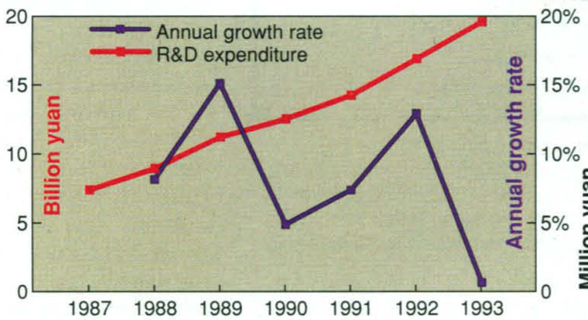
A numbers game

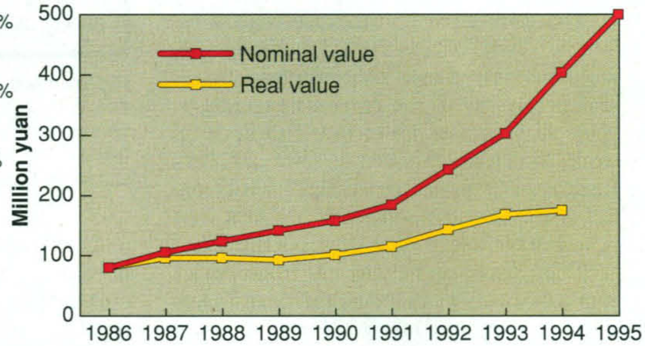
Shi's complaint is a common one in a system where even basic information is a precious commodity. For example, senior officials say they hope to strengthen the country's scientific productivity through a network of state key laboratories—teams of 30 or so researchers who have received large amounts of money in the past decade (see p. 1137). But comprehensive information on the program is scarce because it has so many masters—the labs are affiliated with several funding agencies, and one bureaucratic entity funds the program, another administers it, and a third evaluates the work being done. In fact, a World Bank official admitted that he had never even seen a list of all 155 labs, even though the bank helps to fund 75 of them through a $133 million loan program.

That complexity is combined with a system of considerable size. Data from the State Science and Technology Commission (SSTC) show that the country had 640,000 full-time R&D personnel in 1993, including 418,000 scientists and engineers. Almost half work at state-run R&D institutions, with a third at universities and the rest at companies. (In the United States, by comparison, about 80% of the country's roughly 960,000 scientists and engineers in R&D work in private industry, with about 12% at universities.)

China spent about $7.5 billion in 1993 on science and technology, one third of which is classified as research and development. (The rest covers a variety of activities, including primary and secondary school teachers.) About 7% of those R&D funds are used for basic research, with 30% going to applied research and the rest classified as development. In addition to organizations like the CAS that are focused on research, a broad range of mission-oriented R&D is carried out by most ministries. Among the activities of the Defense Ministry, for example, is the operation of four military medical colleges. These well-equipped institutions contribute to the country's biomedical research system as part of their role in training physicians and serving the 3-million-member People's Liberation Army.







Keeping up. China's overall R&D budget is rising rapidly, but not always faster than inflation. The same is true for the National Natural Science Foundation *(right)*.

One of the fastest growing components of the country's research establishment, the National Natural Science Foundation of China (NSFC), is also one of the newest. Founded in 1985 to support all sectors of the Chinese research establishment, the NSFC is consciously modeled on the U.S. National Science Foundation and divided into six departments—math and physical sciences, chemical science, life science, earth science, materials and engineering science, and information science. The largest, life science, includes agriculture and receives about 33% of the total, with each of the others getting from 10% to 18%. About 70% of its funding goes to applied projects, with the rest classified as basic research.

What sets the NSFC apart from other state agencies is its way of doing business. Rather than supporting its own set of labs and scientists, the NSFC solicits proposals for individual and group projects from throughout China and uses teams of working scientists to judge their quality. Last year, it awarded 3500 individual grants, chosen from 20,000 proposals, at an average size of $10,000 over 3 years. Its largest grants, of which there are now 100, are worth $625,000 over 5 years.

Although its current budget of $63 million is tiny compared to other government ministries, it has grown rapidly from less than $10 million in 1986. Officials say it could double again by 1997 if the economy stays healthy, in keeping with a promise by the central government to raise basic research's share of overall research spending from 7% to 10% by the end of the decade. And there's no end in sight. Ping Chang, chief of staff for the SSTC, says the government would like that figure for basic research to eventually reach 15%, and that the NSFC is a good vehicle for such growth.

Most scientists applaud the NSFC's work in bucking an entrenched system. "It is very difficult to change the system because each ministry wants to retain [financial] control over its own labs," says Shi. "NSFC relies on experts, which is the best way; CAS and the ministries often rely on officials who don't know the research fields very well."

But even the NSFC has room to improve, says its president, Zhang Cunhao. "We want to use international reviewers," he says. "But the proposals are in Chinese, so it's not so easy." Zhang also says that he wishes the reviewers would be tougher, but that cultural norms make it hard for scientists to mark down the work of a colleague.

J. KINOSHITA

Touting success. Beijing University earns millions of yuan from Founder Co., a spin-off that sells publishing software.

A push from CAS

The biggest single player on the science scene, and the one that may be undergoing the most sweeping changes, is the CAS. With annual income of nearly $300 million in 1993, it operates 123 institutes and employs 80,000 people across all fields of science. About half of CAS's institutes perform varying amounts of basic research, and some,

SAM KITTNER

Zhou Guangzhao

Title: President, Chinese Academy of Sciences

Age: 66

Education: B.S., Qinghua U., 1951; M.S., Beijing University, 1954

Field: Theoretical physics

Challenge: Shrink CAS institutes without sacrificing quality.

including the Institute for High-Energy Physics in Beijing, are familiar to scientists around the world. CAS also supports the USTC, whose main campus was moved from Beijing to Hefei in 1970 during the Cultural Revolution as part of a broader campaign to reduce the influence of politically suspect students and intellectuals.

Created in the image of the all-encompassing Soviet system of state-run institutes, CAS once funded all facets of life within its empire. Today, however, only 40% of the budget for a typical CAS research institute comes from CAS, says Gong Wangsheng, head of the bureau of basic research, with the rest coming from grants, special programs, and nongovernment sources.

That reduced support is expected to translate into staffs of one-third the present size, with the savings used to strengthen the research capacity of the remaining scientists. "Not all scientists are qualified to do good work," says Chen Shouyi, director of CAS's Institute of Genetics in Beijing. "It's still very difficult to get rid of someone," she says, "but now we have ways to push them out the door."

Chen, for example, says her 467-member staff will shrink by half over the next 5 years simply through the mandatory retirement of those reaching age 60 and the departure of those who cannot find independent sources of funding. In addition, she says, a CAS policy adopted 2 years ago allows her to fire people if they are not productive: "It applies to scientists at two points in their career—those under 45 who hope to become professors, and those under 35 who hope to become associate professors. If they don't prove that they are good, they will be gone."

At the same time, Chen is eager to make room for promising young talent like plant molecular biologist Li Jiayang. The 39-year-old Li was a Cornell University postdoc working on tryptophan pathways in regulating plant development when he decided to return to China. Li arrived in July as a full professor, a status that, Chen notes without rancor, took her 26 years to achieve. The recipient of a large NSFC grant for young scientists, Li also got money from a special CAS fund, adequate work space with a room for doing plant cultures, and a three-bedroom apartment.

Chen is able to support such new talent, despite a stagnant $600,000 annual budget from CAS for salaries and operating expenses, because of substantial outside funding. In 1990 one of its teams was named a national key lab on plant cell and chromosome engineering, allowing it to purchase more than $1.6 million in state-of-the-art equipment. It has received nearly the same amount from the central government's high-technology program for biotechnology, and lesser but still significant funding through another 5-year national program and individual NSFC grants, which normally run for 3 years. Another $200,000 a year comes from outside funding for specific projects, including the Rockefeller Foundation's support for rice biotechnology research and work on disease resistance in rice and wheat backed by Germany's Bayer AG and Japan's Kirin Beer.

THE CREAM OF THE ACADEMIC CROP
Beijing University
Nanjing University
University of Science and Technology of China, Hefei
Fudan University, Shanghai
Qinghua University, Beijing
Lanzhou University
Nankai University, Tianjin
Shandong University, Jinan
Wuhan University
Jilin University
Shanghai Medical University
Zhejiang University
Beijing Medical University

SOURCE: CHINA SCIENCE AND TECHNOLOGY INFORMATION INSTITUTE

Highly cited. This ranking of Chinese academic institutions is based on the number of citations, covering 1987–1992, from journals listed in the Science Citation Index from the Institute for Scientific Information in Philadelphia.

PHOTOS BY J. D. MERVIS

Making room. Plant geneticist Li Jiayang *(above)* arrives as part of Chen Shouyi's *(top)* plan to improve her institute.

Island adventures

Another way for CAS institutes to survive a reduction in academy support is through commercial activity—a process known in China as "jumping into the sea." Appropriately, that process is in full swing on Hefei's Science Island. Some 2500 scientists, technicians, and support personnel work at four CAS institutes on a tiny island in an artificial lake that is a 45-minute drive from USTC. Two are devoted to basic research in plasma and solid-state physics, while the other two carry out applied work in lasers and robotics and sensors.

"We get 15 million yuan [about $1.8 million] from CAS for salaries, utilities, and operations, and about the same amount from special government research programs," says Qiu Lijian, a plasma physicist and head of the Hefei branch of CAS who serves as the island's unofficial mayor. But the bulk of the island's scientific income comes from business. The institutes earn almost $9 million a year from contracts with industry, Qiu explains, with 20 factories on the island making everything from liquid helium for nuclear magnetic resonance machines in hospitals to smoke detectors for private homes. "In the U.S. the national labs don't need to go into industrial production," says Qiu, "but we need the money to pay for salaries and research."

Each institute has its own tale of commercial adventure. At the Institute for Intelligent Machines, for example, the Hi-Tech Corp., in a burgeoning high-tech park, already provides 80% of the institute's income through the sale of precision measurement instruments for industry. The downside for researchers, however, is that the new jobs being created, says deputy director Ru Jinshao, are for people "with good management and marketing experience."

For Pui Cing, deputy director of the Institute of Solid-State Physics, a 1-year stint as manager of an institute-owned computer company in the same industrial park convinced her that she'd rather pursue her research on nanocrystals. "I liked business, too, but there's too much to worry about all the time," she says. "Now I can go back to science and let someone else manage the company."

However, some scientists worry that basic research may be neglected in the rush to squeeze every yuan from science. "Chinese people are not interested or educated in natural science," says prominent paleontologist Chen Junyuan of the CAS Institute of Geology and Paleontology in Nanjing. "I try to convince government officials about the need to support basic research, but they aren't qualified to discriminate between fundamental and less fundamental research."

Upsurge in academia

The recent policy shifts have had a rejuvenating effect on China's universities, which periodically have been buffeted by political storms. The generous funding for equipment provided through the key lab program, NSFC grants, and contract research has helped to turn some of China's universities into scientific powerhouses. The chance to combine teaching and research is a powerful magnet for scientists like Beijing University's Lin, whose goal is to provide China with the necessary intellectual firepower to lead it to the top of the world economic ladder.

The university system's current rise to

power began in 1978 with the government's approval of the country's first graduate-degree granting programs. Of China's hundreds of universities, some three dozen now have graduate schools, which each year award about 3000 Ph.D.s and 30,000 master's degrees; about 70% of those degrees are in science and technology.

Academic science has also gotten a big boost from the World Bank. Since 1982 the bank has poured money into programs to strengthen the scientific capacities of both comprehensive universities and those affiliated with the various ministries, as well as a third project now winding down to support key labs at 100 academic institutions. Last year, in an attempt to boost morale, the commission announced a program to foster quality at 100 key universities through additional funding for research and greater flexibility to reshuffle departments and form collaborations with other institutions and with the West.

In fact, academic science has improved to the point where education officials feel their institutions can compete evenly with CAS for the best talent. "If you want to do basic research, you should come to a university," says Vice Minister Wei Yu of the State Education Commission. "At a university you are always getting fresh blood as graduate students complete their work and a new generation arrives. At the institutes, people stay and they grow old."

Not surprisingly, CAS officials have a different view. "It's true that we need more young people, but only a third of the staff is fixed," says Wang. "The rest must compete for money to continue their work. In addition, I think the institutes generally have better facilities and a better working environment."

This interagency rivalry is also being played out in the debate over new large scientific facilities. While CAS officials lobby for their top projects (see p. 1139), Wei says that the government's first priority should be improved literacy for all. "I don't think we can afford to expand such large-scale fundamental research," she says. "There's only one bowl of money."

Regardless of the outcome of that debate, most Chinese scientists say the government is doing the right thing in setting priorities, concentrating resources on the highest quality science, and using peer review to help make those decisions. For the Chens of Shanghai's Rui-jin Hospital, it affirms their difficult decision to return home in 1989 after completing their graduate training in Paris. "It was right after Tiananmen," Chen Saijian recalls, "and our friends told us we were crazy what with everything that was going on. But we wanted to help in the modernization of China, and we need to be working here, in this place, to really help our people. And that's what we are trying to do."

–**Jeffrey Mervis**

STATE KEY LABS

Government Focuses Funds, And Hopes, on Elite Teams

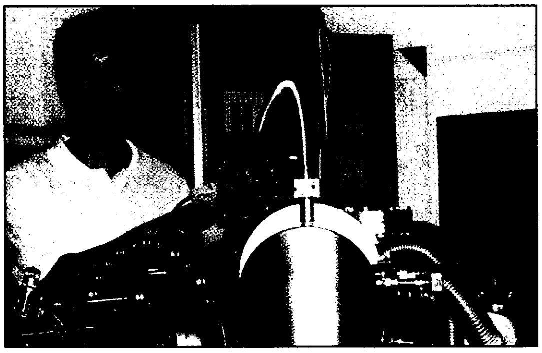
NANJING—Institutions in China customarily shut down for several weeks in the middle of the summer. But not the National Laboratory of Solid State Microstructures (LSSMS). On a muggy morning in late July, associate physics professor Hai Sang is preparing a sliver of cobalt-silver film to test for a phenomenon called giant magnetoresistance. Physicist Wang Guanghou is describing unusual new behavior he has observed in nanoscale clusters of germanium—properties that may have potential uses in optoelectronic devices. In an adjoining lab, two doctoral students from Taiwan are busy setting up an experiment. The hallways of the aging building, darkened to keep both the temperature and the electricity bills down, are plastered with reprints of dozens of articles lab researchers have published in *Physical Review Letters* and other top physics journals.

This buzz of activity is exactly what the Chinese government had in mind when, in 1984, it created a program of state key, or national, laboratories. The Nanjing lab was one of the first to be so designated. The program is intended to help a small number of labs break into the forefront of global science by funding them lavishly—at least by Chinese standards—and turning them into "open" facilities that can be shared by outside researchers.

Key labs receive a large initial grant, typically $1 million or more, to modernize their facilities. (In comparison, an average research grant is about $10,000 over 3 years and does not cover large equipment.) Over time, they are eligible for additional injections of funding to keep up with the latest technology. The labs are distributed unevenly throughout the country, with half in either Beijing or Shanghai, and the research is basic as well as applied, with topics ranging from oncogenes to coal combustion.

A decade into the program, Chinese authorities can cite several successes in the current network of 155 labs. At least a dozen, including LSSMS, are performing at a world level, and many are forging strong links with researchers and institutions overseas. But some Chinese researchers are concerned that the program's funds are being spread too thin, and that what was supposed to be a rigorous scientific review is not being used to weed out weak labs. Others say that many labs have failed to meet the promise of greater openness.

A key lab at the Chinese Academy of Sciences' (CAS's) Institute of Metal Research is widely seen as a success story. Situated in Shenyang, a gritty, northeastern city that is China's second-largest industrial center, the institute has carved out a niche with its key labs for material fatigue and for "quick-solidifying nonequilibrium alloys" used in the aerospace industry. "This lab has few parallels in the U.S. or Japan," says Canadian materials scientist Stewart McIntyre, who reviewed the lab for the World Bank, which has made long-term, low-interest loans to about half of the current roster of key labs. Similarly, the high-performance ceramics and ultramicrostructure state key lab at the Shanghai Institute of Ceramics has won high marks for its work on nanoceramics.



J. KINOSHITA

Fine work. Wang Guanghou probes frontiers of atomic clusters with homemade machine.

Some first-rate key labs are also fulfilling their mandate to become truly national facilities—open to scientists from less endowed labs. The Institute of Physics in Beijing, for example, with its three internationally recognized key labs in magnetism, high-temperature superconductors, and surface physics, carries out joint projects with some 20 other institutions. The institute's scanning tunneling microscopes, superconducting quantum interference devices, and x-ray diffraction system are in constant use by visiting researchers.

Another key lab that appears to function well as a national lab is one on resources and environment information systems in Beijing. Part of the CAS's Institute of Geography, the lab was chosen in 1985 to serve as a national center to monitor floods, soil erosion, deforestation, and urbanization. The lab integrates data from every province and locality, as well as from LANDSAT, and provides advice on protecting ecosystems and developing flood evacuation plans. "We gave the