Colorado State University

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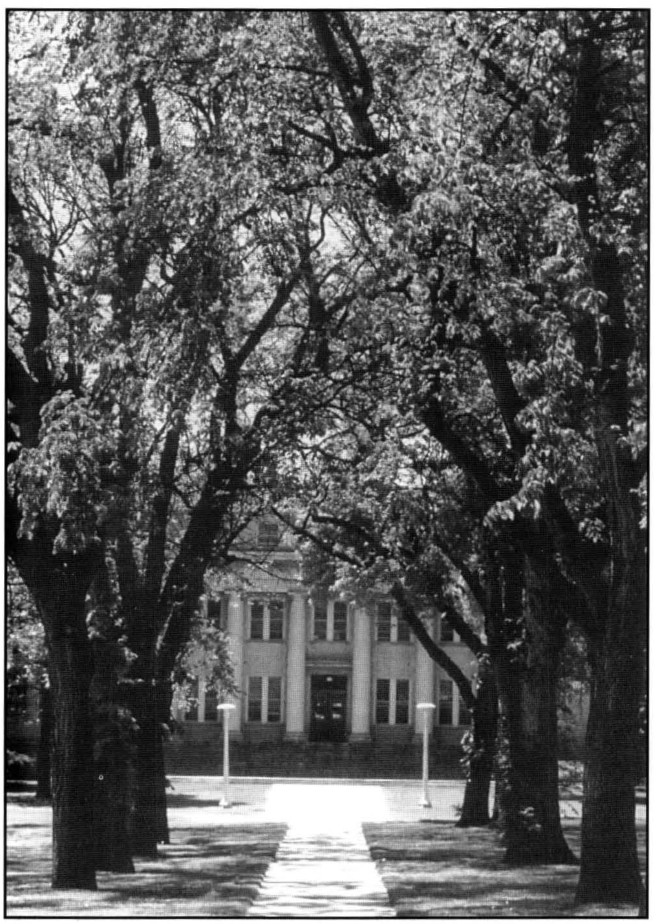

The historic Colorado State University Oval with its twin rows of American elms leading to the Administration Building lies just to the east of the College of Engineering complex.

> ***Paradigm: . . . a set of rules and regulations (written and unwritten) that does two things: (1) it establishes or defines boundaries; and (2) it tells you how to behave inside the boundaries in order to be successful.***
>
> ***Joel A. Barker***

Paradigms may shift, rattle, and roll, but Judson Harper possesses no doubts that new boundaries were established with the advent of chemical engineering at Colorado State University. Now the University's Vice President for Research and Information Technology, Harper speaks of "fresh cloth" and a "new model" when outlining what he calls the genesis of the chemical engineering program in 1976.

Part of the Department of Chemical and BioResource Engineering, chemical engineering at Colorado State started with the coupling of food and chemical engineering undergirded by Harper's own work in food extrusion. In fact, the program was the first one nationally to emphasize the interface between chemical engineering and the biological sciences. Two decades later, Colorado State is still one of the few American universities developing its chemical engineering program in such a unique manner.

If the program is unique, it is because of its origins and evolution; as Harper implies, its genesis is its hallmark—namely, an integration of interdisciplinary collaboration, emerging technology, and applied research.

INTERDISCIPLINARY COLLABORATION

Prior to Harper's arrival at Colorado State, a movement was underway to expand the then Department of Agricultural Engineering. Rather than go down a traditional road such as machinery, however, the powers-that-be decided to expand into food engineering. Harper was hired out of industry to become the department head, and the evolution of chemical engineering at Colorado State began.

The 1970s, with its fuel shortage crises, pushed the evolutionary process along—emphases merged, changed, and moved on. Research on the conversion of biomass to alternative fuels led to broader involvement in biochemical engineering, with strong programs developing in design and control of bioreactors and, more recently, in environmental biotechnology. By the early 1980s, a new front was opened with the addition of the emerging area of advanced materials and its focus on understanding fundamental chemical principles of high-tech thin film and polymer processing.

These areas—biochemical engineering, environmental engineering, and advanced materials—together with the traditional or fundamental chemical engineering areas of thermodynamics, heat and mass transfer, and process control form the core research of the eight-member faculty today. Throughout all of their undertakings, however, the cross- or inter-disciplinary hallmark can be found. According to former department head, Vincent Murphy, "We only hired people who had an interdisciplinary bent. Since we were a small group, if we wanted to accomplish much, we had to form partnerships."

An excellent example can be found in the work of Kenneth Reardon and the area of bioremediation—that is, the use of biological agents such as microorganisms and plants to solve hazardous waste pollution problems. Reardon wants to incorporate bioremediation concepts into both undergraduate and graduate engineering courses. He and five other Colorado State colleagues, through a $350,000 grant from the National Science Foundation's Engineering Education and Centers Division, are developing seven teaching modules that contain laboratory, video, minilecture, and case study components. Two modules are presently being tested at Colorado State and five other universities; one module is in a multimedia (CD-ROM) format and the other is in a video/paper format.

EMERGING TECHNOLOGY

David Dandy builds diamonds one atom at a time. Although Dandy is involved in fundamental research, its future applications are mind-boggling—supercomputers the size of a deck of cards and surgi-

Setting the Scene

Founded in 1870, six years before Colorado gained statehood, Colorado State University has an enrollment of 22,000 on-campus students. The College of Engineering has 1600 undergraduates and 500 graduate students.

Fort Collins, a former territorial army fort, has a population of 100,000 and is nestled in the foothills of the Rockies, 65 miles north of Denver, at an elevation of 5,000 feet. With 300 days of sunshine, residents freely enjoy all the natural beauty for which Colorado is known. Camping, skiing, climbing, boating, fishing—name your pleasure and you'll probably find it within easy distance of Fort Collins.

The University itself consists of an 833-acre main campus that houses most of the administration offices and classrooms. The chemical engineering program is located in the 41,200 square-foot Engineering South Building, which was completely renovated in 1984.

The main campus also houses the Lory Student Center, the hub of student life, which was ranked one of the top ten student unions by the *New York Times* columnist Richard Mall in 1986. Pauline Yoshihashi, writing in the *Wall Street Journal* in March of 1992, cites the Center for its student-oriented services: "Scholars can drop by . . . to buy a computer, and also [to] rent skis or hiking boots for a weekend of work and play." An extensive renovation of the facility was completed recently.

In addition to the main campus, a 1,700-acre Foothills Campus is devoted primarily to research. The Engineering Research Center (ERC) is located on this campus—chemical engineering research programs in semiconductor processing and groundwater/contaminant transport use these facilities.

The eight-member chemical engineering faculty focuses on three applied areas of research: biochemical engineering, environmental engineering, and advanced materials. This work is complemented by more basic research in the traditional chemical engineering fields of thermodynamics, heat and mass transfer, and process control.

Virtually all the chemical engineering research groups interact actively with other departments at Colorado State. These contacts range from information exchange to joint projects with investigators in departments such as microbiology, electrical engineering, biochemistry, civil engineering, and chemistry. The interdepartmental environmental engineering program is an exciting new area of interaction for both teaching and research, bringing together faculty and students from five engineering fields.

For more information about the program, contact

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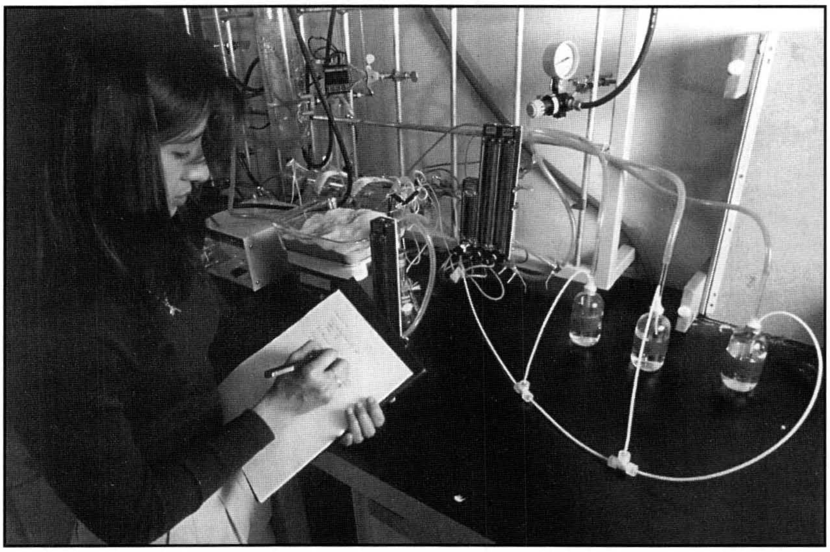
cal blades that never dull, to name a few. Considered a world expert in diamond fabrication, Dandy conducted research at Sandia National Laboratories in Livermore, California, to develop hair-like diamond slivers for a major commercial application—AT&T's transatlantic fiber optic telephone cable. According to Dandy, growing diamonds (using a process called chemical vapor deposition) is easy; the real challenge is understanding how they grow, how they interact with other materials, and how to make them behave in an orderly manner. The complexity of issues that are involved in the process makes any major scientific breakthrough a future event, but Dandy anticipates being part of that ultimate breakthrough.

. . . [Colorado State's] youth is the very factor that has allowed it to do what more established programs often cannot—change the boundaries, alter the rules, shift the paradigm.



Adeyma Arroyo (grad student) records data from an apparatus used to study biofiltration of off-gases from coating operations.

Because his investigations on polymers also fall outside the realm of basic research, Larry Belfiore considers them high risk. His overall objective is to understand how a material's components interact in a mixture and then to use that information to make chemically compatible systems. Since his work is not directly market-driven, Belfiore concentrates on developing methods that will enhance the thermal and mechanical properties of materials. On another project, Belfiore and Allen Rakow are combining stress-strain testing, infrared spectroscopy, and electron microscopy to explore the use of agar, an edible marine polysaccharide, for packaging and potential biomimicry applications.

During the fourteen years she has been on the chemical engineering faculty, Carol McConica has been a key figure in the department's advanced materials thrust. The bulk of her more than $2 million in contracts and grants for integrated circuit process research has been spent on graduate education and a special master's program, which she developed. The program, through twelve months of course work and some eighteen months of experimental, hands-on experience, offers students a broad understanding of microelectronics while identifying the fundamental principles behind manufacturing problems that are supplied from industry. Given a grounding in those principles, the students then develop new processes.

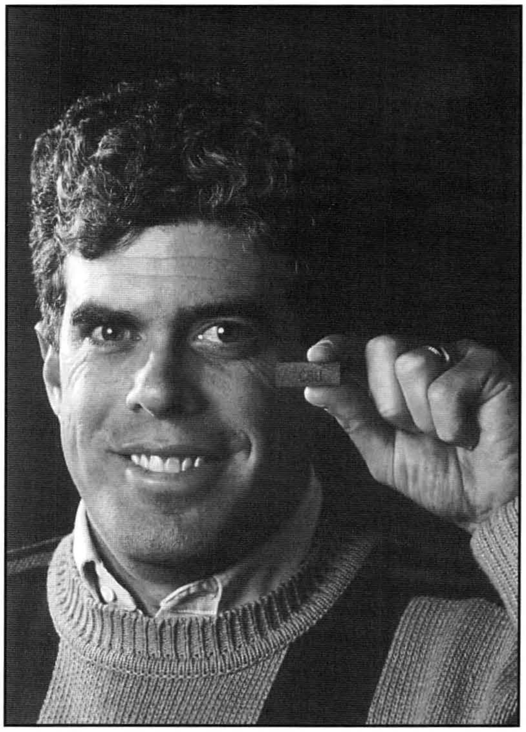
Before joining the faculty, McConica helped Hewlett-Packard design the chemical processes necessary to build more powerful computer chips. The major emphasis of a current grant from the National Science Foundation is to develop more environmentally benign processes for that manufacturing. To McConica, this university-industry cooperation not only fits the land-grant mission of Colorado State ("We are an educational institution."), but it also prepares chemical engineering graduates to fit into an ever-changing technological landscape.

APPLIED RESEARCH

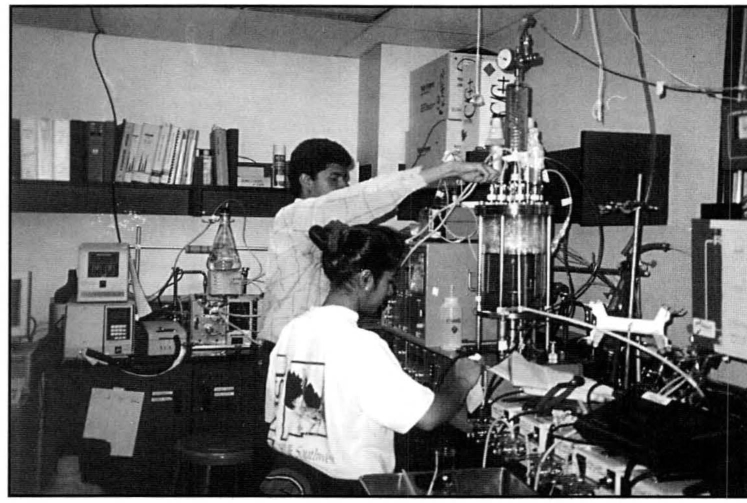
Much of chemical engineering research at Colorado State is applied. In fact, that was part of the program's original mission. This focus spotlights the final characteristic of the program; that is, its emphasis on real-life systems and cooperation with the private sector. Whether developing computer chips, using biotechnology to extract gold in hard-to-mine ores, or developing innovative medical cures, the push is out into the real world.

This push is clearly exemplified by the work of James Linden, who holds a joint appointment with the Department of Microbiology. Linden conducts research into the use of plant cell cultures for production of valuable medicinal compounds such as artimisinin, a possible natural treatment for malaria. On another project, he is studying another plant cell culture process that produces taxol, an anti-cancer drug. Linden works with private chemical research companies on both of these projects, indicative of the growing private/public cooperation.

This cooperative approach is further seen in the work being conducted under the leadership of Brian Batt at the Colorado Bioprocessing Center, a state-supported entity that



"Diamond" Dave Dandy admires the fruits of his latest (thin film) research.



Victor Saucedo (grad student) and Sohana Karim (undergrad) prepare a computer-controlled bioreactor for a fermentation experiment.

is administered through the Department of Chemical and BioResource engineering. The Center houses a full spectrum of pilot-scale equipment for cell culture and product recovery. Its mission is to assist new biotechnology companies in proof-of-concept and process development studies. Researchers at the Center conduct basic and applied research to develop high-value products from genetically engineered microorganisms.

The Center is an integral part of the Research Experiences for Undergraduates Program in Bioprocess Engineering, a project sponsored by the National Science Foundation in which outstanding undergraduates from across the country are given an opportunity to participate in a ten-week research program during the summer months. It also works closely with the Colorado Institute for Research in Biotechnology (CIRB), a university-industry-federal laboratory network that offers seed grants to university researchers to initiate university/industry projects. In addition, CIRB provides support for graduate students and for students who intern in Colorado biotechnology companies.

Professor Karim, who has been at Colorado State University since the Spring of 1981, is regarded as one of the world leaders in the research area of process control application to biotechnology. He is one of the first researchers who has applied neural network technology to model and optimize bioprocesses. He is also involved in multivariate statistical analysis (Principal Component Analysis) for on-line process fault detection and diagnosis of chemical and biological systems. Dr. Karim has researched various microbial species: bacteria, yeast, fungi, mammalian, and plant cell cultures. He has been either an advisor or co-advisor to approximately one-third of the department's PhD graduates. In recognition of his contributions to research and graduate support, the College of Engineering awarded him the Abell Research Award in May of 1997.

EDUCATIONAL MODEL

"Interdisciplinary," "emerging," and "applied" are simply adjectival buzzwords if they do not represent a testable reality within the academic setting. The quality of research must impact the quality of education at both the undergraduate and graduate levels. At Colorado State, that impact exists—with a unique twist that only a smaller program can offer. The faculty like to think that chemical engineering at Colorado State delivers the best of what expensive private schools offer, small classes and high-quality students, plus the best of a research university—all within the context of a nurturing environment.

Numbers can be impressive: 8 faculty members advise 135 undergraduates and 35 graduate students. Because the faculty are aggressive in their research efforts, individually averaging $200,000 a year in contracts and grants, students have numerous opportunities, starting at the undergraduate level, to work on research projects. During the last eight years, 60 BS graduates (25% of the total number) have been involved in research.

FACULTY PROFILES

Judson M. Harper, Professor
Vice President for Research and Information Technology
Ph.D., Iowa State University

Interests: Extrusion processing of foods; manufacturing of low-cost nutritious foods; structural and chemical changes of polymers during processing.

M. Nazmul Karim, Professor
Associate Department Chair
Ph.D., University of Manchester

Interests: On-line adaptive control of solid-state fermentations, use of neural networks, principal component analysis and genetic algorithms in bioprocess control and optimization; lignin biodegradation and recombinant E. coli *fermentation for ethanol production from xylose.*

Terry G. Lenz, Professor
Ph.D., Iowa State University

Interests: Computational and experimental studies in chemical and biochemical thermodynamics as well as in more applied areas such as solar cooling systems.

Carol M. McConica, Professor
Ph.D., Stanford

Interests: The use of ultrahigh vacuum as well as in situ Raman spectroscopy techniques to elucidate reaction mechanisms relevant to integrated chip processing; selective metal deposition processes for three-dimensional integration of integrated circuits.

Vincent G. Murphy, Professor
Ph.D., University of Massachusetts

Interests: Fundamental and applied studies in biochemical and food process engineering; bioremediation of contaminated soils.

Laurance A. Belfiore, Associate Professor
Ph.D., University of Wisconsin

Interests: Phase behavior of polymer blends; polymeric transition-metal complexes that exhibit synergistic macroscopic physical properties; applications of solid-state NMR spectroscopy.

David S. Dandy, Associate Professor
Ph.D., California Institute of Technology

Interests: Vapor deposition of diamond, silicon nitride, and cubic boron nitride; three-dimensional laminar flows; parallel numerical algorithm development; application of physical models to process control design.

James C. Linden, Associate Professor, Joint Appointment
Ph.D., Iowa State University

Interests: Biomass refining to provide starting material for ethanol fermentation; cultivation of fungi and bacteria for enzyme production; plant cell cultures for the production of useful secondary metabolites.

Allen L. Rakow, Associate Professor, Research Appointment
Sc.D., Washington University, St. Louis

Interests: Bioseparations, biorheology, and food engineering

Kenneth F. Reardon, Associate Professor
Ph.D., California Institute of Technology

Interests: Microbial degradation of hazardous organic compounds; the effects of cultivation conditions on genetically modified bacteria.

Ranil Wickramasinghe, Assistant Professor
Ph.D., University of Minnesota

Interests: Application of the principles of mass transfer and rheology to the development of new separation processes for biochemical/biomedical systems.

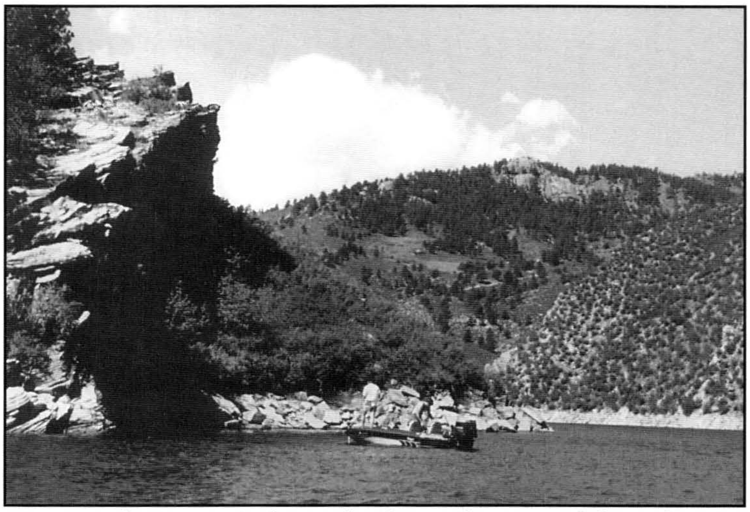
Brian C. Batt, Research Scientist
Director of the Colorado Bioprocessing Center
Ph.D., University of Colorado

Interests: Development of bioprocessing systems involving the use of recombinant microorganisms and mammalian cell cultures.

UNDERGRADUATE PROGRAM

Such hands-on experience is possible because of the quality of the students. At the undergraduate level, for example, students have received two AIChE Outstanding Senior awards and six National Science Foundation fellowships. Over 30% of the undergraduates are high school valedictorians, and the average GPA for the 1996 incoming class was 3.8. Alumni have gone on to graduate programs at MIT, UC Berkeley, Stanford, Purdue, Wisconsin, and Cornell. The program's AIChE Student Chapter has received an Outstanding Chapter Award from the national organization in 12 of the past 14 years.

The faculty have worked hard to develop a cohesive curriculum that begins in the freshman year and includes at least one core chemical engineering course each semester. The design experience is fully integrated, beginning with a project-oriented course in the freshman year. Such attention to the curriculum simply underlines an overall commitment to students as persons and professionals. It permeates the whole program at both the undergraduate and graduate levels.



Horsetooth Reservoir, located a few miles west of the Colorado State campus, provides a wealth of recreational opportunities.

GRADUATE PROGRAM

The graduate students, who represent a number of nations but are primarily American, appear to agree with the undergraduate consensus of an overall departmental commitment. At a recent round-table discussion attended by PhD-track students, the shared stories emphasized the same program characteristics noted by the undergraduates—small numbers, personal contact, teaching ability of faculty, research opportunities, interdisciplinary approach, and real-life challenges.

One student specializing in bioremediation and molecular biology commented, "The faculty seems determined to make you step from graduate school into real life—and do it successfully." Other students concurred, pointing out the numerous ways in which they are not only encouraged, but are also forced, to stand on their own (research) feet. This includes proposal writing, attending conferences, and presenting papers, as well as weekly seminars in which they give research updates to the faculty and regular interdisciplinary reviews of projects. As one student spontaneously shared, "It keeps you alert about what you are doing!"

Asked to support their contention of an interdisciplinary approach, seven students listed the following areas that they themselves were incorporating into their chemical engineering programs: microbiology, biochemistry, physics, chemistry, plant science, and toxicology.

Colorado State alumni are now filling faculty and postdoctoral research positions in chemical engineering throughout the U.S. and abroad, including such institutions as Stevens Institute of Technology, the University of Wyoming, Michigan State University, and Cal Tech. Graduates also are easily found in companies such as Intel, Hewlett-Packard, Sandoz, International Paper, Genentech, Hoffman-LaRoche, J.D. Searle, and Exxon.

PARADIGM OF REALITY

No one denies how young the chemical engineering program at Colorado State is. In fact, its youth is the very factor that has allowed it to do what more established programs often cannot—change the boundaries, alter the rules, shift the paradigm.

As Harper notes, "We created a program out of dust into something substantial that is recognized today both nationally and internationally. We crossed disciplines to create a new model, one more reflective of reality . . . maybe you could call it a paradigm of reality."

McConica expands, "Not only were we created out of dust, but also outside the boundaries. With the advent of emerging technologies and the collaboration of industry and academia, we were already out there, waiting. You could say that the paradigm engulfed us."

Joel A. Barker, quoted at the opening of this article, contends in his book *Paradigms: The Business of Discovering the Future* (Harper, 1992) that with any paradigm shift, a new game begins with a new set of rules. The way to measure your ability to be successful, he maintains, is by your ability to solve problems.

By any measure, chemical engineering at Colorado State is not only in the game, but it also continues to make new rules. ❐