

“Civil Engineering in the Next Millennium”

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(SLIDE #1: TITLE)

It is an honor to participate in the New Millennium Colloquium on the Future of Civil and Environmental Engineering. The organizers of the colloquium and MIT should be congratulated for undertaking this effort to understand the future opportunities and challenges of our profession. It could not be more timely in view of our entry into a new century, the rapid pace of development of new technology, and the growing challenges to our society that will require the expertise of civil engineers.

Today, most of the buzz is about biotechnology and information technology, but the future of our society also rests on technologies that are more basic to its functioning. The combination of a growing world population with the human tendency to delay dealing with infrastructure and environmental needs until they have reached crisis proportions, means that our profession will become more essential than ever before.

The future of civil engineering is a topic not only of importance to our nation, but of consequence to me personally. As a civil engineer, I am concerned about my profession. As an engineering educator of some 30 years, I have a vested interest in making the opportunities I experienced available to future generations. As the president of a university that graduates the largest number of engineers in the nation, I feel a heavy responsibility for the more than 2,000 engineering graduates that leave Georgia Tech each year and the growing number of engineers who return to us for skills renewal.

(SLIDE #2: 3 QUOTES)

It is always dangerous to talk about the future of anything. Despite the fact that the future is arriving around us every second, we still cannot see it clearly. Even those who participated in creating each successive generation of computers could not see beyond the innovation of the moment with any degree of accuracy. These men were leaders and experts in their field, and they still got it wrong, which leads one to undertake predictions about the future with a degree of humility and an appreciation for the difficulty of the challenge.

(SLIDE #3: BATTER)

It's like standing in the batter's box, trying to hit a well-thrown knuckle ball whose speed and trajectory are unknowable. It is easy to whiff on a knuckler, and look foolish

while you are at it. In our case the rate of technological change is the speed element – it can quicken rapidly and suddenly under the right conditions. We also stand to misinterpret the trajectory because we seldom anticipate the impact of developments from other fields on our profession.

(SLIDE #4: BLDG/TRAFFIC)

Yet there are some matters related to the future to which we can speak with clarity. First, the basic challenges to our society that require civil engineering talent are increasing in number and importance. They include housing an expanding population, addressing decaying urban infrastructure, maintaining our environment, dealing with the effects of natural disasters and climate change, and transporting ever more people and goods in a safe and efficient manner. Addressing these challenges successfully will take a new kind of technology and a new kind of civil engineer.

(SLIDE #5: VOSBECK)

Second, the emerging hot fields of biotechnology, materials and nanotechnology, electronic commerce, advanced communications and information technology will have a major impact on civil engineering. Consider, for example, some of the building innovations veteran architect Randall Vosbeck foresees for the 21st century. The driving forces behind developments like these come from outside civil engineering. We need to actively seek to understand and use technology developments from other fields to our advantage, and that will call for a new curriculum for our students and a more entrepreneurial mindset for our engineers and businesses.

(SLIDE #6: STUDENTS)

The third matter about which there can be no doubt is that for civil engineering to be a vital profession in the next century, it must attract its share of the best and the brightest. All else falls below this in priority, since talent and the ideas it generates are the taproot of innovation and success. To achieve this goal, our profession must be full of promise and creative potential as well as offering the satisfaction of contributing to the welfare of our own species and the fellow creatures that share this planet with us. We must also become a profession that aggressively seeks participation from the increasingly diverse population of this nation and the world. I believe we have the opportunity to challenge and excite a future generation of would-be civil engineers if we set our sails on the right course.

(SLIDE #7: TITLE: THE GATHERING STORM)

Our society is enamored of new technology in computing, consumer electronics, communications and biotechnology, but we have a blind spot when it comes to the basics society needs for its very life and breath. As a result, we are facing growing

problems with our infrastructure, environment, and exposure to natural hazards – problems that will come home to roost early in this new century.

(SLIDE #8: POPULATION GRAPH)

By the calculations of the United Nations, the population of the world reached 6 billion last October 12th. It took all of world history up until the early part of the 1800s to reach the 1 billion mark. The second billion took nearly a century. The most recent billion was accomplished in about 12 years. Fortunately, contrary to what Thomas Malthus, the father of population prediction, foresaw, the birth rate around the world has already begun to slow. The next billion is projected to take 14 years instead of 12, and sometime during the latter part of the next century, the UN hopes the world population will peak at 10 billion.

However, the question remains of how to accommodate an additional four billion people in the next 50 years. Civil engineers have traditionally planned, designed and built what society required in the way of housing, transportation, water and energy supply, other infrastructure, air quality, response to natural disasters, and land use. Yet it is unlikely that yesterday's technologies will suffice for tomorrow's challenges.

(SLIDE #9: RIVERS RUN DRY)

Consider the case of fresh water, with supplies being depleted faster than they are renewed. Water tables are falling in China, India and the United States, which together produce half of the world's food. An increasing number of rivers are sucked dry before they ever reach the sea. By the year 2025, 3 billion of the world's people will live in places where fresh water resources have fallen below sustainability levels.

India, for example, now contains 1 billion people – a sixth of the world's population. To feed its growing millions, India has virtually tripled its grain harvest during the past 50 years. It was an agricultural feat, but it barely kept pace with population demand. To do it, farmers drilled more wells – some 8 million of them. As a result, India is now depleting its underground water reserves twice as fast as they are being replenished. The International Water Management Institute estimates that aquifer depletion could reduce India's grain harvest by a fourth.

(SLIDE #10: RIVER QUOTE)

Lower population density has protected the United States from the severity of India's problems, but we are not far behind. Texas, Oklahoma, Kansas, and Colorado have all lost irrigated land during the past two decades because of aquifer depletion. The Colorado River rarely has any water left by the time it reaches the Gulf of California, and the fishery that once existed at its mouth has disappeared. In the southeast, several

states are fighting over the use of the Chattahoochee River. There are no easy answers to the challenge of providing an adequate water supply, and we cannot extrapolate what we have done in the past into the future. Water supply is just one of many issues that are being driven to a critical state by population growth.

(SLIDE #11: INFRASTRUCTURE)

Here in the United States, we have infrastructure problems as well as supply problems. The dowager of American cities, New York, has almost 6,200 miles of underground water pipes, and by 2030, more than half of them will be over 100 years old. They rupture 600 times every year, causing flooding and water cut-offs, and sometimes triggering street cave-ins and breaks in adjacent gas lines.

(SLIDE #12: DRINKING WATER)

The Environmental Protection Agency estimates that America will need to spend \$300 billion over the next 20 years to upgrade its water systems, and because little is being done, it will get worse before it gets better.

The same is true of the 160,000 miles of oil pipelines that criss-cross this nation. Some of them are more than 90 years old, and for the past decade they have been leaking more oil each year than spilled from the Exxon Valdez off the coast of Alaska. In January one of the nation's leading pipeline operators, Koch Industries, was fined \$30 million – the largest civil environmental penalty ever – for more than 300 separate leaks totaling more than 3 million gallons of oil during the 90s.

(SLIDE #13: GARBAGE GRAPH)

Population growth by itself generates more waste, but our society is also famous for outdoing itself in waste production. Toronto, which used to claim it was “New York run by the Swiss,” is succumbing to a growing garbage problem. After years of closing landfills, Massachusetts announced last fall that it will allow six landfills to expand. Manhattan accumulates 28,000 tons of garbage every day – more than 10 million tons a year – with no place to put it. Elizabeth, New Jersey, recently went to court to ban New York City's garbage from its transfer stations. Virginia, which has become a stealth dumping ground for New York City garbage, has passed legislation to restrict the practice – despite Mayor Rudy Giuliani's pronouncement that Virginians should value New York's garbage as their gold mine.

(SLIDE #14: CAR)

Americans are also notorious for vehicle travel, which produces gridlock and air pollution. For most of the 20th century, land-use planning has been driven by the automobile. Affordable housing was out in the suburbs, and that's where many

Americans headed. While the U.S. population increased 30 percent over the past 30 years, the number of licensed vehicles increased 87 percent and the number of vehicle miles traveled increased 130 percent. The Southern California Council of Governments warns that by 2020, rush hour there will last all day, with a top average speed on the area's expressways of 15 miles per hour.

(SLIDE #15: ATLANTA)

In addition to causing gridlock, motor vehicles also generate at least half of America's urban air pollution. Metro Atlanta tops the nation with an average one way commute time of 37 minutes per citizen. In response, government planning agencies have announced a \$37 billion transportation program over 25 years to improve both mobility and air quality. Georgia Tech is presently conducting an innovative study that correlates land-use patterns with travel behavior, and it was commissioned not by city planners or transportation engineers, but by the National Centers for Disease Control. The environmental organization Second Nature claims that today more Americans die prematurely from air pollution than from traffic wrecks.

(SLIDE #16: AIRPORT)

Commercial air travel is also growing rapidly. Last year saw 1.5 billion passengers worldwide, 650 million of them here in the United States. By 2015, airlines will carry 3 billion passengers, with one billion of them here in the United States. And none these calculations include the rapidly increasing air traffic caused by air freight operations, which are being pushed to new levels by e-commerce.

(SLIDE #17: PLANE CRASH QUOTE)

Growth in passengers, flights and planes has already overloaded airport infrastructure, and the Airports Council International says the United States needs \$10 billion a year in new infrastructure to keep up. Atlanta, which already is the world's busiest airport, has announced a \$2.5 billion investment program over the next five years. However, protests from environmental groups and surrounding neighborhoods may cause airport expansions to resemble the Battle of Guadalcanal – achieved an inch at a time.

New air traffic control technologies are being developed, but it is hard to install them in a system that can never shut down. Other promising technology would provide digitized communication between pilots and ground controllers, and inform pilots directly about weather and other planes in their vicinity without the need for a control tower relay.

(SLIDE #18: HURRICANE: NATURE'S REVENGE)

Land-use patterns have not only snarled traffic and generated air pollution, they have also put more people and property at risk for natural disasters. The past several decades have seen a global population migration to marginal land that is at risk for natural hazards. When both the threat of damage to lifeline infrastructure and the speed of commerce are increasing simultaneously, the potential for economic losses from natural disasters expands significantly. In 1998, worldwide damage from storms, floods, drought and fires reached \$89 billion, three times what it was in 1997. Natural disasters killed 32,000 people and drove 300,000 from their homes, and much of the suffering and property loss was the result of humans building on high-risk terrain.

Here in the United States, more than a fourth of the population now lives within 50 miles of the coast, and the value of insured property within that same 50 mile stretch now totals more than \$2 trillion. Coastal development escalated during the 70s and 80s, when we were in a rather quiet hurricane period. But the last five years, 1995 through 1999, have been the most active hurricane period of any five years in recorded history.

(SLIDE #19: STORM QUOTES)

Although the experts are reluctant to blame the increasing frequency of hurricanes on global warming, there is little doubt that it has increased the severity of the storms. Last December, the chief meteorologists of Great Britain and the United States issued a rare joint statement indicating that the 90s were the hottest decade in the past 1,000 years, that global warming is now changing the world's climate rapidly, and that scientists can no longer explain the rapid pace of the warming without taking human activity into account.

Taken together, the effects of population growth, increasing transportation congestion, decaying infrastructure, shrinking waste management options, environmental deterioration, destruction from disasters, and effects of global warming represent a wave threatening to crest over our civilization.

(SLIDE #20: WOODY ALLEN)

It is beginning to sound like Woody Allen's "glass half-full" assessment in *Side Effects*. In Woody's view, both possible options look pretty bleak. Or, if you want to be more academic, it sounds like Paul Ehrlich, biology professor and modern-day Malthus who has been making doom-and-gloom predictions since 1968. But none of them have yet come true, and that, I would like to believe, is because he fails to take the inventiveness of engineers into account.

(SLIDE #21: SAFE HARBOR)

Like Woody Allen, I believe the new millennium offers a crossroads. Fortunately if we take action to prepare, we have the opportunity to meet our challenges with creativity... the opportunity develop cleaner, more sustainable technology and, hopefully to encourage more enlightened public policy. Civil engineering has a rich tradition of building the infrastructure that enabled humans to survive and prosper. If we can link the traditional aspects of our discipline with emerging interdisciplinary research and new management paradigms, we can lead the way in building a safe harbor against the gathering storm.

(SLIDE #22: TITLE: TECH ANSWERS / CE SOLUTIONS)

The problems of the next century require new solutions. We will not solve traffic congestion by adding lanes to a freeway that already has ten. We will not be able to bury more waste when we are already closing landfills. We will not be able to build infrastructure fast enough with the same old materials and paradigms for project management. We cannot reclaim contaminated urban land by incinerating millions of cubic yards of soil.

We must look to technology for most of our solutions, both within our own profession and research as well as from other disciplines. Civil engineering is making progress with new technology and techniques, but we can further enhance our growing capabilities by looking to advances in other fields. Civil engineering may give form to new solutions, but the technology that drives them is unlikely to start with us. While there are successful research and development efforts underway in civil engineering, nevertheless simple arithmetic tells us that much of the R&D money is pouring into areas like biotechnology, nanotechnology, information technology, and advanced communications. Our response must be to draw from fields that are advancing faster than ours wherever possible, and use that technology as a springboard for our own progress. Given the circumstances, technology transfer will be the mother lode for our future.

(SLIDE #23: BIO TECH)

The 21st century has already been declared the age of biology. The medical improvements of the past century doubled the world's average life expectancy, but biomedical engineers assure us that was chickenfeed compared to what they will accomplish over the next hundred years. And incidentally, much of it will be achieved using new computing technologies that enable better modeling of biological systems we want to improve.

The mapping of the human genome is giving us new insights, and genetic engineers are exploring ways to fix congenital defects and diseases. New hybrid mechanisms use silicon chips to activate biological processes such as neural networks. Artificial implants that the body will embrace and weave into its own structure are undergoing testing, and the engineering of living tissues will enable transplants to be grown in the lab from the recipient's own cells. Researchers have also achieved significant improvements in cell longevity, which they hope to extrapolate to entire organisms.

(SLIDE #24: OLDSTERS GRAPH)

While it is still not clear just how much tinkering our delicate, interdependent biological systems will tolerate, life expectancy will definitely increase. The confluence of an increasing life expectancy with a declining birth rate will cause our population to age rapidly.

Peter Peterson, chairman of the Institute for International Economics and author of *Gray Dawn: How the Coming Age Wave Will Transform America – and the World*, writes that “we are confronting demographic changes so substantive that they could redefine economic and political systems in the developed countries over the next generation.” An aging population will call for civil engineers to change their perspectives on how to design housing, transportation and public structures in the coming years. And biotechnology will also help to shape the materials we use to build them.

(SLIDE #25: MICROBES)

The impact of the age of biology is also being felt on environmental engineering. Bio-remediation to clean up waste was unheard of 40 years ago. Today, microbes represent the cheapest and most effective approach to cleaning up oil spills. Biotechnology also has the potential to change the treatment of wastewater dramatically, and even raises the possibility of treating wastewater at the point of generation, significantly reducing the need for large-scale sewage infrastructure.

(SLIDE #26: CIRCUIT BOARD)

The computer's first major impact on civil engineering came in the 1960s, when its ability to solve large sets of simultaneous equations enabled engineers to explore a wide variety of “what if” scenarios using finite element analysis. For the first time, civil engineers could project the interactions of the shear walls that are the backbone of concrete-framed and some steel-framed buildings. Finite element analysis also brought new designs to fruition. The Hoover Dam, for example, had been built on the Colorado River 40 years earlier as a test model of arch dam design, but engineers hesitated to use the design more widely until the 1960s when finite element analysis proved it effective.

(SLIDE #27: 3-D MODEL)

Today, even the most complex systems are susceptible to computer analysis. Computer-aided design is standard, and engineering students whose fine motor skills are not quite up to the rigors of mechanical drafting are no longer flunking out of college. Computers not only calculate “what if” scenarios, but three-dimensional modeling programs allow civil engineers to see their cyber-structures respond to a host of forces from earthquakes to hurricane force winds.

Yet much more is still to come as computing power and optical and wireless networks continue relentlessly to double in power every two years. Researchers in the field will soon enter computer data by voice and it will be relayed instantly to the lab. Robots have already made testing safer at sites with hazardous materials, and they will help to improve construction productivity and safety.

(SLIDE #28: GLASS BLDG)

We now construct “smart” buildings that are wired to serve technology needs while saving energy and water, and maintaining constant internal environments. Energy sources are starting to shift to increasingly efficient solar systems. New York’s newest skyscraper, “4 Times Square,” has two 60-foot swaths of solar panels built into the curtain walls on its south and east sides – a first for a commercial spec building.

The power, lighting, heating, air conditioning, security, and fire protection systems of new buildings are already beginning to talk to each other, and they are about to get even smarter. We are on the cusp of an age when building security systems will routinely read voices, palm-prints or footprints rather than keys or keycards, and computers will automatically adjust the inside environment based on how many people are there, where they are in the building and what they are doing. Building vibrations will be controlled by responsive systems that can interpret precursors to the actual driving events.

(SLIDE #29: DOT CAMERA)

Computers and communication technology are also at the heart of one of the biggest advances in transportation engineering in the past five years – the creation of “intelligent transportation systems.” A variety of advanced sensing, computing and communications technologies handle tasks that range from collecting tolls to controlling traffic signals, and they are integrated into coordinated systems that manage traffic flow.

Last October, the Federal Communications Commission set aside 75 megahertz of spectrum for smart highway technologies. This “air space” is reserved for short-range,

wireless links that allow transportation officials to communicate with vehicle drivers much like air traffic controllers now communicate with pilots. The next step is the incorporation of the technology into vehicles, and that will open a new era in intelligent transportation systems.

(SLIDE #30: VIRT REALITY)

In addition to incredibly diverse uses for computers, we are seeing astonishing computing advances that go beyond sheer power – advances that are destined not only to match human intelligence, but to change it. Computer guru Ray Kurzweil recently published his predictions for the 21st century in a book called *The Age of Spiritual Machines: When Computers Exceed Human Intelligence*.

(SLIDE #31: BRAIN SCAN)

He projects a virtual reality environment that uses neural implants to intercept and intervene in the signals that pass between the brain and sense organs like eyes, ears, nose and skin. These devices will not only correct some sensory disabilities, they will also enable all humans to enter virtual environments without any other equipment than what is in our heads. Imagine what that will do to the way all of us work with each other and carry out our professions! Imagine the possible applications in transportation, construction, and design!

(SLIDE #32: GEODOME)

New materials will also change civil engineering dramatically. Back in the 1960s, civil engineers were struggling to create concrete shells for the irregular, double-curved roof of the TWA terminal at Kennedy International Airport in New York. For those who still want a poured, formed roof today, there are stronger, faster-setting materials that use resins and polymers instead of portland concrete. But a wide variety of other new materials now adorn irregular rooflines. The Denver Airport terminal, opened in 1995, has a tensile fabric roof. London's Millennium Dome, opened last year, features 90,000 square meters of glass-fiber fabric coated with polytetrafluoroethylene and stretched across a web of 2,600 stressed cables.

(SLIDE #33: BRIDGE DECK)

New materials are making today's bridges longer, stronger, and lighter than ever before. They are decked out in slim box girders, lightweight concrete, high-performance steel, epoxy-coated cable strands, and composite prefabricated anchorages.

(SLIDE #34: OPTICAL FIBERS)

Within the past five years researchers have learned how to lace materials with optical fibers that contain strings of sensors. Data from the sensors passes along the fibers to an

opto-electronic data processing unit. These optical fibers are now being tested in carbon fiber composites that can be used as building materials. The goal is for the sensors to detect stress or strain and relay it along the fibers to create a picture not only of the present stress being placed on the structure, but also of the cumulative lifetime stress the structure has experienced. Think of the future ramifications of this development for skyscrapers, bridges, pipelines and tunnels!

(SLIDE #35: NEW MANAGEMENT STRATEGIES)

For all of the incredible possibilities ahead in new technologies, progress will be slow if we do not also take advantage of new management strategies to implement them. This is one of civil engineering's Achilles' heels, since we are too often behind the curve in understanding the human dimensions of change. Today's most agile industries and corporations have adopted techniques that utilize teaming, partnering, entrepreneurial skills and Internet communications. This approach unleashes the creative abilities of technology talent, and it has steered graduate students coming from industry toward studies of technology rather than the classical management track. Civil engineering, as a profession and particularly in our education programs, has been slow to adopt these new strategies.

(SLIDE #36: NET WIRES)

While IPOs and net-based companies have attracted much attention, the real revolution in the way business works is expected to be the blossoming of business-to-business electronic commerce. Boston Consulting Group, Inc. expects business-to-business Internet transactions to total \$2.8 trillion by 2003, and this is a rich area of potential for increased productivity in civil engineering and construction. In a recent survey of industrial buyers conducted by *Purchasing Magazine*, more than a third said they had already begun purchasing over the Internet. Most of the remaining two-thirds are using the Internet to compare suppliers and find new sources, to learn about delivery options and track orders, and to get technical advice. Of the industrial buyers who have not yet begun to make Internet purchases, more than half expect to start within the next three years.

Another e-commerce trend that will change civil engineering is electronic construction management companies that use the Internet to coordinate communications, share design updates, and even hold project meetings in chat rooms. You may have heard of the recent merger of two such companies – eBricks.com and Blueline Online.

(SLIDE #37: BOEING 777)

But the impact of the Internet on business and industry will go beyond merely buying and selling, and even conducting e-meetings. It is beginning to change the entire

process of designing and building in fundamental ways. A good example is the Boeing 777 aircraft, which is one of the world's largest and most complex machines. Yet was designed and built in record time using compatible software on computers that were networked across hundreds of companies in a dozen different nations. Like most e-business, this phenomenon is still in its infancy and is very fluid, but it's not a passing fad that will go away.

(SLIDE #38: CONSTR SITE)

Communications technology represents one facet of a broader change in construction management strategies. Traditional approaches have emphasized a separation between owner, designer, project manager, and contractor. Paul Teicholz of Stanford University's Center for Integrated Facility Engineering has cited this piecemeal approach as one of the reasons why productivity in the construction industry declined by 0.5% a year from 1964 to 1998, while other industrial productivity increased by 1.7% annually.

This old model of construction is a good illustration of the phrase, "complacency is sure death, but complexity is slow death." It is too disjointed and cumbersome in the face of the pressing problems that lie ahead, and it also represents a strategy that does not appeal to today's bright young people who have an entrepreneurial mindset and many other options for their career choices.

(SLIDE #39: BLDG w/ PLANNERS)

The present trend toward design-build is a start in the direction of simplifying management of large civil engineering construction projects. It brings together the owner, design team, contractor and project manager around a consensus vision for the project so they work together to build it. Used correctly, design-build can speed project completion and save money, and we have done that at Georgia Tech with two new buildings. Important as cost savings are to us as a public institution, saving time is even more imperative because of the new facilities we need to meet the demands of modern science and engineering. Our goal is to build one major building every year for ten years, but if each building takes one more year to complete than it should, we will fall a decade behind schedule in ten years alone. As problematic as this would be to Georgia Tech, think of the incredible aggregate inefficiencies if that experience were repeated at hundreds of institutions in 50 states!

When the needs of this nation's infrastructure are considered, it is imperative that we abandon cumbersome old management paradigms. Beyond time to construction, there is a clear and present danger to civil engineering in loss of talent to other professions if our young engineers fear being mired practices of the past.

(SLIDE #40: WATER TREATMENT)

We used to view development as something that of necessity happened at the expense of environmental preservation. I well remember my own experience as a consultant to a major storm water runoff treatment project in San Francisco in the 1980's. We were working on a plan to eliminate sewage spills into San Francisco Bay, and as a civil engineer, I was as proud of this project as any I had been involved with. To my surprise, at a public meeting a group of individuals who called themselves environmentalists accused the engineers working on the project of planning to despoil the environment. Because of the naiveté of the engineering team, no appropriate defense was offered, and the newspapers led a misinformed charge that killed the project. As a result, regular sewage overflows continued to contaminate San Francisco Bay for fifteen more years until a new version of the project was finally adopted. To paraphrase the warden in the movie *Cool Hand Luke*, what we had there was a failure to communicate.

(SLIDE #41: DUNNE QUOTE)

As the population grows and our resources dwindle by comparison, we are coming to realize that any approach that is adverse to environmental preservation and resource conservation will be a dead end. We can no longer measure benefits against financial costs alone, but must also measure them against environmental costs.

Civil engineering grew up at the place where the building of human societies intersects the natural environment. As a result, sustainability calls for civil engineers to be leaders, and we need to exercise that role while there is still time. Most reasonable people today understand that it is as much in the true interest of business, as it is in the interest of the most ardent environmentalist to preserve this small planet for the future of all of its species. Sustainable technology, processes and development reconcile these interests, so that we can work together to protect our environment while simultaneously supporting an economy that offers people meaningful work and enables them to provide for their families.

Prominent anthropologist Jared Diamond, who is also an outspoken environmentalist, recently praised Chevron in the *New York Times* for using the principles of sustainability in developing an oil field in New Guinea. He noted that the project provided needed economic opportunities for the local people, while at the same time protecting the jungle vegetation and animals. And he predicted that during the next century certification of products as environmentally responsible will become common.

(SLIDE #42: KERMIT)

But green materials are not always easy to find, and there are many shades of green. The “green” in concrete, for example, is diminished by the fact that manufacturing cement is very energy-intensive and produces greenhouse gases. Sustainability is also more than simply slipping in a green material here or there. It mandates a different approach to design and problem solving. Georgia Tech Engineering Dean Jean-Lou Chameau likes to say that sustainability is not a problem-set; it is a mindset. It is a large umbrella that covers not only the work of civil and environmental engineers, but also of our colleagues in manufacturing and production, business management, science, public policy, and architecture.

Sustainable technology is also the key to forward-looking solutions for some of the pressing infrastructure problems of developing countries. For example, it makes more sense for them to develop smaller-scale energy systems around renewable resources, than to aspire to the huge utility grids and fossil fuels common in industrialized nations. Petroleum giant Royal Dutch/Shell is developing a small solar power unit for home use in developing countries. The goal is a unit that costs the same or less than the batteries, candles and kerosene such places now rely on.

(SLIDE #43: EDUCATING A NEW CIVIL ENGINEER)

The challenges society faces and the remarkable changes occurring in technology lead to the conclusion that the civil engineer of the next millennium must be educated differently than in the past. The question is not if we must adapt, but how far and how fast can we move. We must look not only at what should be offered in a formal engineering degree curriculum, but also at what enhancements should supplement this staple both during the collegiate experience and in the context of life-long learning.

(SLIDE #44: CE STUDENTS IN LAB)

Curriculum changes have already been underway for the past decade as engineering schools seek to respond to a new generation of industry needs. We are working to develop our students’ ability to communicate, function in teams, solve open-ended design problems, and conduct hands-on laboratory work. The revision process is not yet complete, nor has it arrived at a finished or perfect form. I suspect it never will.

(SLIDE #45: CLASSROOM 2000)

But even as we are still implementing the last decade’s reforms, we can now see the need for civil engineers to learn about biology, information technology, advanced materials, and entrepreneurial management techniques. Sustainable technology is another important consideration. At Georgia Tech, our goal is not merely to educate environmental engineers, although we do, but to teach all of our students to view their

respective professions through the prism of sustainability, so that they are aware of the environmental impact of every decision they make.

Another aspect of engineering education that needs continued attention is the teaching of the practice of engineering. Research universities in particular have to make an effort to recruit enough faculty with relevant industry experience and to be deliberate about injecting practical issues and capstone projects into the curriculum.

(SLIDE # 46: WOMAN COMPUTER)

Incorporating all of that into the conventional four-year curriculum is nigh unto impossible. We need to start by broadening our sights and thinking of formal university studies as the beginning of a longer education process that is continued through distance learning technology.

(SLIDE #47: CHAMBERS QUOTE)

If John Chambers is right, future educational opportunities for engineers will abound, and traditional universities will have to hustle to keep their market share in the face of competition from non-university sources. The range of Internet courses in both degree and certificate programs is growing rapidly. This year Georgia Tech began offering an M.S. degree in mechanical engineering designed specifically for the Internet. It followed by a year Stanford University's initiation of its Internet M.S. in electrical engineering. Within two years, Georgia Tech will also offer Internet M.S. degrees in civil engineering and electrical engineering. Many others are joining this trend.

Internet delivery will also facilitate access to the postgraduate courses engineers will have to take at periodic time intervals to maintain currency. No one will be denied the opportunity to obtain the education they need to keep up. Delivering these courses is likely to involve innovative mergers of educational content from universities with production and delivery by media that today are primarily focused on news, sports and entertainment.

(SLIDE #48: UPDATING FORMAL CURRICULUM)

The development of these ongoing learning opportunities does not solve the problem of how to make the formal four-year university curriculum more relevant. Achieving a curriculum that prepares students for practice in the 21st century will require creative approaches and a willingness to set aside some of what was required in the past. Although the modification of the curriculum will require great effort, the end result can be a more exciting learning experience for both students and faculty, and one that will help attract the talent required to maintain the vitality and adaptability of our profession.

The task will become easier if civil engineering designates the master's degree as the first professional degree, which is under serious consideration. If we take this step, it will be important to allow for a generalist's track as well as offering narrow specialties.

Beyond the curriculum itself, the advantages of the cooperative education option should be recognized and encouraged. As one who was a co-op student, I know firsthand that the value of this option in helping to educate engineers cannot be understated.

(SLIDE #49: CHANGING FACE)

As we look to recruit our share of the brightest and best of coming generations to civil engineering, we need to be aware of dramatically changing population demographics. According to Jeff Passel of the Urban Institute, "The United States is once again on the eve of large ethnic transformations. The current phase has already involved social and political disturbances, and raises new questions about who are 'Americans'?"

In California, which is often the nation's demographic forerunner, whites are expected to slip below 50 percent of the population sometime next year, and in 20 years, Hispanics and Asians are both expected to outnumber whites. Fifty years from now, half of the U.S. labor force will be a mixed palate of people of color. Over the same time, jobs requiring college degrees will have grown twice as rapidly as other jobs.

In light of these projections, we face an incredible challenge of diversifying our students and our profession. According to the National Action Council for Minorities in Engineering, today's engineering workforce is 84 percent white. Minorities comprise only 10 percent of those with bachelor's degrees in engineering, and only 3 percent of those with Ph.D.s in engineering.

(SLIDE #50: BLACK WOMAN)

Half of all minority engineering degrees come from ten percent of the nation's engineering institutions. I am proud to say that Georgia Tech ranks either first or second in the nation in awarding minority engineering degrees, depending on which measurement you choose. The sad reality is that we achieve that distinction with slightly less than 20 percent of our engineering degrees going to minorities. If engineering does not find a way to draw significantly more minorities into our colleges and our workforce, we are going to have a serious problem.

But think about the opportunities and advantages if we succeed in diversifying! Information technology is already making it possible for Americans to straddle cultures as never before. The Internet already offers instant, affordable worldwide communication, and the opportunity to be in two places at the same time will intensify as virtual reality becomes more pervasive. Today we talk about the international nature of the economy and the need to educate students to function in a global context. Imagine the incredible resource offered in the future by a diversified student body and workforce that come to us understanding many cultures and speaking many languages!

The coming century and millennium will bring times of great challenge but also of great opportunity for civil engineers. As we closed out the last century, civil engineering was losing its luster to fields like biotechnology and information technology. Yet this trend will be forced to correct itself in the coming years as a rapidly growing world population appropriates more of the natural environment for its use; demands more water, energy, waste disposal and transportation resources; produces more pollution; and expands its exposure to natural hazards. In addition, American society is about to come abruptly face to face with infrastructure needs and environmental problems that have already been neglected for too long and will grow to crisis levels if left unattended any longer. Yet civil engineering will not be the profession to reap the rewards that will come in meeting these challenges if it clings to old practices and educational paradigms.

(SLIDE #51: KENNEDY QUOTE)

We are at a crossroads... not the one Woody Allen facetiously described, but the one John F. Kennedy referred to in his inaugural address. With many of the world's resources already stretched precariously thin by the juggernaut of population growth, we have entered a make-or-break era in which the die will be cast for the next millennium.

Civil and environmental engineers clearly should have a major role to play in helping a growing population move toward sustainable prosperity rather than destruction. The world needs our expertise to meet the requirements of a growing population, while at the same time reducing the production of pollution and healing the environmental wounds of the 20th century. Innovative technologies spinning off from fields outside of civil engineering will offer new and creative tools to address the issues facing us. Indeed, the success of our profession over the formative decades of the 21st century could well depend on how well we incorporate these new technologies into our ongoing efforts to provide the infrastructure that makes a quality life possible for our citizens. This is a challenge for industry, government and especially for educational institutions.

(SLIDE #52: WORLD)

The first step toward achievement is acknowledging the challenge, and this conference provides an important opportunity for us to do that. I thank you for inviting me to open the discussion on the future of civil and environmental engineering, and I look forward to its continuation in the coming sessions. Given the incredible talent gathered at this meeting, I am confident that we will make great strides in better positioning our profession for the challenges ahead.