The
BRIDGE

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THE NATIONAL ACADEMIES

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Editorial

Brad Allenby is environment, health and safety vice president at AT&T, an adjunct professor at Columbia University's School of International and Public Affairs, and the inaugural Batten Fellow at the Darden Graduate School of Business at the University of Virginia. The views expressed in this editorial are the author's alone.

Earth Systems Engineering

The National Academy of Engineering's annual meeting technical session last October was, as always, informative and entertaining. But it was also noteworthy, for it introduced a new adventure for engineers and the engineering professions: Earth systems engineering (ESE). ESE, as I define it, is the study and practice of engineering human technology systems in such a way as to provide the required functionality while facilitating the active management of the dynamics of strongly coupled fundamental natural systems.

The articles in this issue, based on presentations made at the technical session, begin to flesh out that definition. In the process, several themes that undoubtedly will characterize any ESE discourse can already be discerned: the need for the designer of technology systems, and society as a whole, to assume ethical responsibility for both artifact and systems effects; the role of technology as an absolutely critical element of social response to environmental perturbations; and the significance of complexity, not only of the technical systems, but also of the environmental, social, and cultural systems to which they are inevitably coupled.

Bugliarello provides an ESE vision of cities as places where technology, population, culture, economics, and natural systems intersect and interact. He calls for rethinking the city in terms of efficiency, manageability, and (especially emotional) quality of life. The approach requires not just the traditional engineering of projects within the city but learning how to engineer the city as an organic whole, along its three dimensions: biological, social, and machine.

The challenges that this poses to engineering—in scale, complexity, and multidisciplinarity—are apparent. Moreover, they will grow as the complexity and power of our technologies grow. What will be the impact on the city of biotechnology, information technology, and nanotechnology? At what scales will functionality, such as energy or water services, best be provided?

White discusses an issue on many people's minds these days, climate change, but does so from an ESE perspective. He thus introduces what may be the first branch of ESE: climate systems engineering (CSE). The couplings between human systems and complex natural systems, including not just atmospheric dynamics, but also the carbon, hydrological, and oceanic systems as well, are both apparent and quite complex in this instance.

Moreover, the climate change issue is pervaded by engineering and technology, from the systems that generate greenhouse gases to the systems that enable us to perceive relevant changes in natural systems in the first place to the technologies that can mitigate such impacts. In this regard, the lack of a robust technology dimension to existing global climate change negotiations is both noteworthy and dysfunctional. It is to be hoped that this gap will be addressed in any continuing process intended to address global climate change.

What roles, for example, can biotechnology, information technology, and new energy technologies such as active carbon sequestration play in enabling development, especially in emerging countries, while at the same time reducing anthropogenic climate change forcing?

That this and related questions have not even been asked yet is a serious indictment of the existing process and probably reflects a profound lack of understanding of technological evolution on the part of many parties currently engaged in such negotiations. CSE clearly poses a profound challenge for engineering going forward, and an active role for the Academy in this area would be entirely appropriate.

Pradhan and Pradhan urge the redefinition of cities in an attempt to capture the benefits of both large and small scale, of the urban center and the village. Some may feel that reconceptualizing big cities as conglomerations of small towns can hinder, rather than support, efforts to address regional phenomenon. The existence of hundreds of political and jurisdictional units appears to significantly complicate efforts to deal with regional resource bases such as the Everglades, the Great Lakes, and the Baltic Sea, for example.

Few, however, will regard their call for rethinking boundaries between agricultural and urban activities, and rethinking scales of technologies (what, for example, is the optimum scale for recycling light plastics?), as unimportant. As they point out, beginning an ESE dialog by questioning accepted “opposing concepts” is a productive and necessary first step.

Humans will exist within complex systems, both social and natural, for as long as our species remains dominant on this planet. For this reason, earth systems engineering will challenge the ingenuity and test the responsibility of the engineering community for the foreseeable future. It is exciting, and humbling, to begin that voyage.

Brad Allenby

Rethinking Urbanization

George Bugliarello

Balancing the biological, social, and machine elements of modern cities will be key to creating environmentally sustainable, emotionally satisfying urban centers of the future.

George Bugliarello is chancellor of Polytechnic University in Brooklyn, N.Y. This article is based on remarks he made on 24 October 2000 during the NAE Annual Meeting Technical Session.

Since the emergence of the first concentrated human habitats some 10,000 years ago, urbanization has increased vertiginously. In some of its larger manifestations such as the very large cities we call mega-cities—currently defined by the United Nations as having more than 10 million inhabitants—urbanization has become particularly important in the developing world (Bugliarello, 1999). Even if there are ambiguities as to what exactly constitutes a city or an urban area, rapidly growing urbanization is a new and seemingly uncontrollable phenomenon.

At the beginning of the 20th century, only about 5 percent of the world population lived in urban areas. Today, that figure is 40 percent and is projected to grow to 60 percent in the next 20 years. In the United States, urban living is even more prevalent. Projecting into the year 2030, all of the world's population growth will be in urban areas. Over the next 30 years, urban population will increase from 2.9 billion to 4.9 billion people, mostly concentrated in developing nations. The largest population growth will occur in Asia, but Africa will have the higher rate of growth. The number of cities with 5 million inhabitants will increase from 41 to 59, and the number of cities with 10 million people will climb from 19 to 23 (Brennan-Galvin, 2000).

Urbanization is the most powerful and most visible anthropogenic force on Earth. It affects the surface of the Earth, its atmosphere, and its seas. The expanding surface that cities occupy and the resources required to supply their needs absorb or transform, directly or indirectly, ever-larger extensions of forests and arable land. In the developed world, those extensions may be hundreds of times larger than the surface of a city and consume material and energy resources at rates per inhabitant an order of magnitude greater than those of cities in the developing world. The problems of atmospheric pollution are exacerbated in cities that are virtually devoid of oxygen-generating vegetation. The surface "footprint" of a typical city consists predominately of buildings and concrete or asphalt, which repel water and can lead to deprivation and even subsidence of aquifers. Aquifers under Mexico City, for example, have dropped some nine meters since the beginning of the last century (Rowland, 2000).

Urbanization is the most powerful anthropogenic force on Earth.

Substantial cities began to emerge perhaps 5,000 years ago and, on a greater scale, with cities like Memphis, Babylon, Athens, Beijing, and Rome, in the last three millennia. In the vast period between the growth of agriculture and the Industrial Revolution, most innovations occurred primarily in the social domain—codified laws, organized armies, bureaucracies—but there emerged also some crucial new technologies for the city like aqueducts, bridges, and fortifications.

After the Industrial Revolution, the waves of technological inventions and innovation that succeeded each other with increasing rapidity made the city what it is today. Industrial manufacturing attracted armies of workers to the cities; railroads, and later airports, weakened the commercial advantage of maritime cities; the internal combustion engine helped create the suburbs; electricity made possible all sorts of laborsaving devices; the elevator permitted the vertical city; sanitation made cities healthy; radio, later complemented by computers and the Internet, allowed people to interact without being physically in contact and to work cooperatively at a distance (Moss, 1998). Biotechnology and bio-machines, now emerging, will affect the city in ways we cannot still fully fathom.

The interval between these major innovations has shrunk. If more than 100 years separated the Industrial Revolution from the internal combustion engine, only 50 years separated the computer from the radio, and about 30 years biotechnology from the computer. These innovations have added to the fascination and the promise, whether realistic or not, that the city offers to people from the rural areas, and they have fueled the still unabated growth of most urban concentrations. No matter how undesirable and ultimately unsustainable this may be, there seem to be today, thanks to technology, virtually no limits to the growth of cities based on availability of land or adequacy of critical resources (Groat, 2000).

Many Cities Dysfunctional

Today's cities are essential instruments of social advancement, wealth creation, globalization, creativity, psychic energy, and birth-rate reduction. But many of today's cities also are dysfunctional. They are large consumers of resources, harbors of poverty, and concentrated sources of pollution. They are congested and, in the rapidly growing megacities of the developing world, bursting at the seams. They are difficult to manage, particularly where lack of resources compounds the problem. And they pose risks to their inhabitants.

Cities affect their environment by drawing resources—materials, air, water, energy—from increasingly long distances (the resource "footprint"). Their products tend to be distributed worldwide and become sources of pollution elsewhere. The city-genic pollution on the ground may be limited to a few hundred miles, but air pollution may circle the globe. Cities affect their environment regionally because of the growing surface over which they extend, the intense use of their hinterland, and, with maritime and riparian cities, their encroachment on coastlines.

Pollution in large urban aggregates is aggravated by the traffic caused by the separation of residence and place of work, and by the increasing use of heating and air conditioning. The concentrated nature of the city reduces the space available to its occupants in their dwellings, denying them the less-polluting remedies such as higher ceilings or shading by trees available in less-dense habitats.

The growth of poverty, particularly in cities of the developing world, is a most disturbing trend associated with urbanization. Poverty adds to the dysfunctionality of a city and often contributes to urban sprawl by encouraging the flight of the more affluent from the city core.

The risks associated with urbanization are due to natural hazards, anthropogenic causes, or a mixture of the two. Natural hazards, from earthquakes and floods to volcanoes and diseases such as malaria, are made more dangerous by heedless expansion in areas exposed to such risks. Anthropogenic risks include accidents, war, terrorism, crime, changes in the economy, and lifestyle diseases such as depression, bronchitis and emphysema, tuberculosis, and AIDS.

Congestion, such as overcrowded roadways and air traffic delays at major airports (estimated several years ago to cost some $5 billion annually [Craig, 1988]), is one of the most immediately evident and ubiquitous signs of urban dysfunctionality—whether in developed or in developing countries—and so are slums. Another sign of dysfunctionality is the difficulty most large cities have disposing of their solid waste. This is an issue that offers the possibility of many creative solutions but which generally remains, particularly in the developing world, one of the most intractable problems. More subtle signs of dysfunctionality are urban sprawl, the monotony of the grid pattern of streets, and the monocultural zones devoted exclusively to one set of activities, such as malls or financial districts, which become deserted when those activities end.

A problem common to all but the most affluent of today's cities is that many elements of their infrastructure have not been extended or improved since originally built. Railroads, bridges, sewers, water mains, major roads, and buildings have not been able to keep up with the expansion of many cities because of the speed of that expansion and because of cost.

If we are to make urbanization environmentally and socially sustainable, the great challenge is to rethink the city. The design of the city of the future has been for a long time a passionate battle point of utopias, ideologies, theories, and experimentations. Leonardo da Vinci's separation on two levels of pedestrian and vehicular traffic (Figure 1) and, a century ago, the garden city (Perry, 1929; Relph, 1987) exemplify concepts that continue to make sense today. Many other concepts have not stood the test of time.

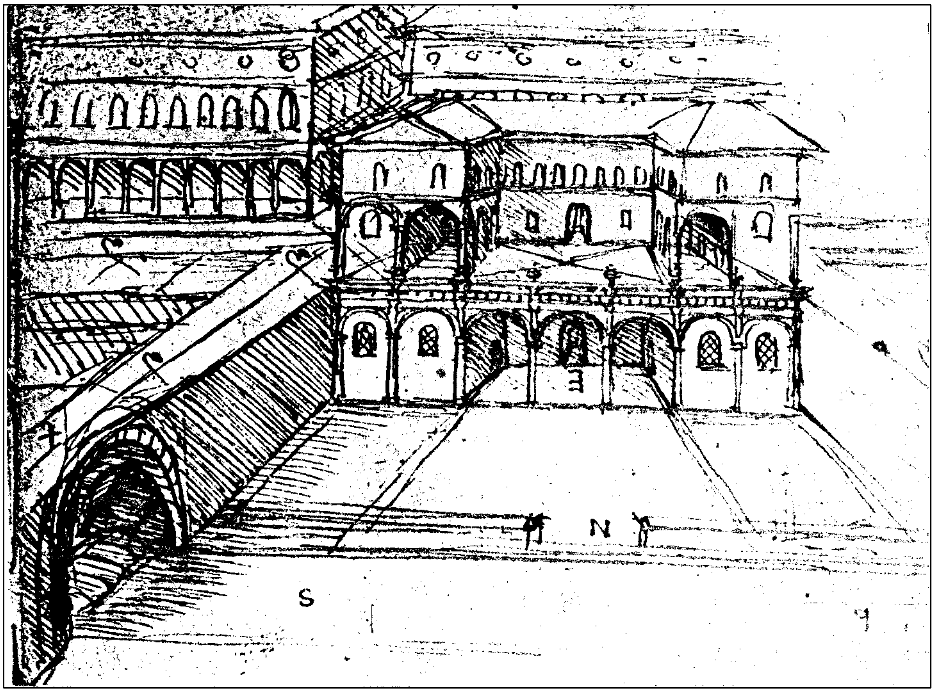

FIGURE 1 A XVIth-century proposal: Leonardo's design for separating pedestrian and vehicular traffic on two levels. SOURCE: Adapted from Istituto e Museo di Storia della Scienza (2001).

Regardless of ideology, few would disagree that there are certain pragmatic imperatives to which the city of the future, whether in America or elsewhere, must respond. It must reduce hazards to its inhabitants, improve livability, and be sustainable, that is, capable of existing indefinitely in time without doing irreparable damage to the environment. A city is an extremely complex organism; its future forms cannot be projected or prescribed. There are, however, some essential characteristics the city needs if it is to respond to the imperatives.

The city of tomorrow must be caring, emotionally satisfying, ecological, intelligent, and manageable.

The city of tomorrow must be caring and emotionally satisfying; it needs to be ecological, intelligent, manageable. These characteristics must interact synergistically in response to the imperatives. Thus, to improve livability, the city must be caring and emotionally satisfying. This, in turn, implies a city that is intelligent, manageable, and ecological. To be sustainable, the city must be ecological. To reduce hazards to its inhabitants, it needs, again, to be intelligent and manageable. Elimination of slums requires the synergy of the "city efficient," the "city manageable," and the "city caring and emotionally satisfying." Similarly, reduction of consumption requires the synergy of the city efficient and the city manageable. These synergies are not easy to achieve but are mandatory if the dysfunctionalities of today's cities are to be remedied.

The city caring and emotionally satisfying is one that provides jobs, housing, health, and education, gives its citizens a sense of protection, and sees the urgency of solving the problem of poverty. Poverty threatens the city's physical and emotional health, and its elimination is viewed by some as a key to any hope of improving sustainability (Perlman, 2000). But this is not enough. A sense of belonging, a sense of pride, and a sense of adventure are also essential ingredients of the city caring and emotionally satisfying. Contributing to them are stability (not the constant tearing down and reconstruction that makes today's city a palimpsest), aesthetics, and good management—the city not only functional but beautiful. A sense of adventure militates against grid layouts that we inherited from the ancient Greeks and Romans, and against the extreme segregation of functions in separate quarters of the city—for example, the impersonal gleaming towers of the business district that leave no room for diverse, smaller-scale activities.

If the city of the future is not to do irreparable ecological damage and is to be sustainable, it must contain or reduce its geographical and resource footprints. The area occupied by the city and the tributary territory necessary to feed and otherwise support it cannot continue to grow proportionally to the city's population or affluence. Reduction of the resource footprint also means reduction of the plume of pollution and waste emanating from the city, both in dimensions and intensity. Since the city is an accumulator of substances, recycling and "mining" those very substances become an important source of materials for the city of the future and a way to reduce its resource footprint (Graedel, 1999). The city ecological relies for its survival as much as possible on natural means, both biological and energetic (Lewis, 1998). For instance, it uses wetlands to reduce wastewater treatment and conservative energy sources, such as wind and solar radiation, to mitigate energy demands. (Today's conservative energy sources are insufficient to satisfy the needs of a city, and their exaggerated development can create in turn ecological stresses, as has occurred with the construction of extensive batteries of large windmills.)

Education Essential

A city intelligent is one that has the ability to adapt to change. Sensors, geographic information systems, telecommunications, the ability to simulate and to rapidly assess trends, and a nimble management structure are all new capabilities that enhance a city's ability to adapt. A city intelligent must also be efficient in its use of resources, including human ones. It must have, for example, advanced traffic control systems and flexible scheduling of city activities to reduce congestion. Education is essential to the city intelligent and efficient, not only traditional education, but also an education for living appropriately in the city—learning how to behave in crowded situations and in traffic, how to reduce pollution through changing one's behavior, and how to participate effectively in community decisions and understand the underlying issues.

A manageable city is one that finds an appropriate balance between what is local and what is centralized. It is a city that, no matter how large its population, relies on community participation as an indispensable component of making decisions, taking full advantage of information and telecommunications technologies. The city manageable endeavors to control its technologies and encourages the creation of technologies that better respond to its needs, rather than being powerless when confronted by new technologies. A good example is the automobile, which today has too large a footprint, demands that a large portion of the city be devoted to parking, and, universally, creates congestion. The city manageable stimulates new technologies to address the automobile's size and parkability, not to mention its other environmental impacts.

Regardless of how it may be physically configured, the manageable city of the future must be governed by the clear recognition that it is an organic phenomenon that defies rigid planning but can be guided in desirable directions through a variety of possible organizational concepts. One concept that transcends any rigid geometric arrangement and can guide the organization of services, transportation, utilities, and other parts of the urban environment is to see the city as a complex "system of systems" (Gallopin et al., 2001) and to clearly identify the relationship among individual neighborhoods, larger neighborhood clusters, and the city as a whole.

Neighborhood As Organizing Unit

Viewing the neighborhood as an organizing unit of the city is not a new idea, but it is one that continues to make considerable sense for the city of the future. Walkable neighborhoods, for instance, help reduce congestion by facilitating the creation of a hierarchy of transportation hubs connecting the city's components. In the developing world, where many cities are expected to double in population in the next 15 to 20 years, it should be easier in principle to devise entirely new organizations and systems than it is in the mature cities of the developed world. However, because of lack of resources and, at times, will, the reverse is often true.

Other important challenges for the manageable city are the role of self-help and sweat equity in housing the poorer segment of the population, the development of financial instruments such as public-private partnerships to encourage entrepreneurship and economic development, and the pooling of resources and markets with other cities to produce needed innovations. The relation of city policies to national policies—including policies to encourage viable alternatives to concentrating growth in the larger cities—is an important challenge for the city manageable, whether the city exerts influence because it contains a large portion of a nation's population, or tends to be neglected because it is small.

> **Fundamentally, a city is a complex bio-socio-machine entity.**

Part of the challenge of making the city manageable is dealing with unrealistic expectations of its population—poor and well-off alike—in an era of burgeoning technological possibilities. These expectations can affect the stability of the city and may have global impact. In this context, the city manageable must also address the problem, particularly acute in the developing world, of how to reach rapidly growing areas with essential services by devising good-enough solutions as opposed to costly traditional infrastructural systems developed in affluent cities. As expressed by a felicitous analogy:

> It remains to be demonstrated who is more skilled, the surgeon who operates in a good environment and with the necessary assistance, or he who operates under emergency conditions with rudimentary instruments and facilities, sometimes below what is indispensable. (Lotti, 1989)

Fundamentally, a city is a complex bio-socio-machine entity that I shall call, for short, *biosoma* (Bugliarello, 1998, 2000). It is an entity created by the interaction of a *biological* component, that is, its inhabitants and other forms of life such as vegetation or microorganisms; a *social* component, the ensemble of collective activities, ideas, and organizations of its inhabitants; and a *machine* component, the artifacts, tangible and intangible, that support the life of the city.

Each of the three components of the biosoma has distinctive influences on the function and design of the city. The biological component can self-replicate and also be recycled by nature (e.g., through microbiological processes), capabilities essential to the sustainability of the city. Humans, in addition, bring emotions and feelings that play a crucial role in the city caring and emotionally satisfying. The machine component embodies reliability, precision, and power, but also inflexibility. The social component embodies characteristics that fall between those of the other two. Like the machine, it increases the reach of the individual and can have reliability, precision, and power (e.g., in social organizations such as bureaucracies), but it also harbors collective feelings and emotions that on occasion can erupt with unforeseeable consequences.

Balance among the three biosomic components is important to maintaining the city's positive characteristics while reducing its dysfunctionalities. For example, there ought to be balance between bioremediation and traditional methods of water and wastewater treatment or between tasks performed by humans and those performed by machines (e.g., a policeman directing traffic versus the use of traffic control devices). Balance considerations have far-reaching implications in making the city caring or manageable. Thus, a totally automated city, technically possible, becomes also an inhuman city. Similarly, within the biological component, the balance between humans and other species determines the extent to which the city favors biological diversity—the plants and animals that enrich the life and the environment of humans.

Trade-Offs Central to Biosoma Paradigm

Within the biosoma paradigm, trade-offs among information, materials, and energy are central to the concept of "intelligent" infrastructure, such as the intelligent highway that can accommodate more traffic without requiring the construction of new roadway. Trade-offs between materials and energy range from the simple but ecologically significant one of using insulation instead of active heating and cooling, to that embodied in the utopian concept of a domed city, unworkable for a variety of reasons but the epitome of the desire to use material structures to control climate and therefore the energy expenditures of the city. The trade-off between biological and machine energy affects the extent to which walking or bicycling can replace motorized means of transportation, an important consideration in the design of cities as clusters of neighborhoods. The biosomic city shaped by these balances and trade-offs is continually evolving. As each component of the biosoma changes so, too, does the balance among them.

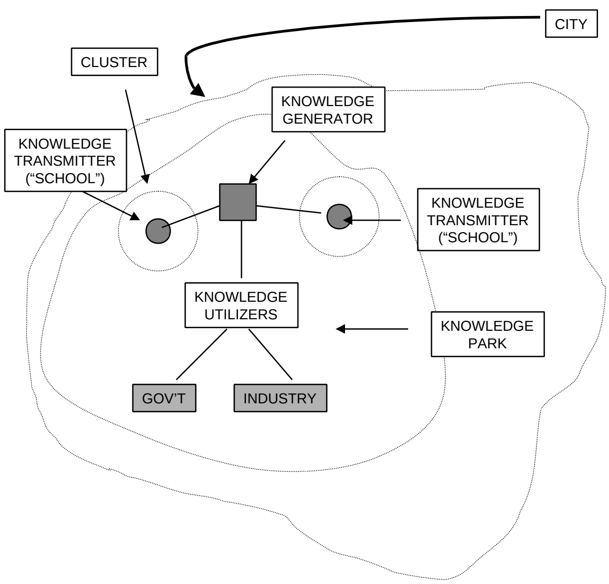

FIGURE 2 The knowledge city.

The emerging knowledge city and eco-industrial city are embryonic manifestations of the biosomic city of the future. In the knowledge city (Figure 2), the emphasis in each of the three biosoma components is on knowledge and information: in the biological component, on learning and biotechnology; in the social component, on education and e-business; and in the machine component, on computers, telecommunications, and nanotechnology.

One instrument of the knowledge city, congruent with the concept of neighborhoods and clusters, is the knowledge park. It coalesces socioeconomic activities around institutions that generate knowledge (e.g., universities or research centers), transmit knowledge (e.g., schools), and use knowledge (e.g., business or industry and government). These institutions are increasingly crucial to the socioeconomic development of a knowledge society and attract to them other elements of the city's organization and infrastructure.

The knowledge park provides a new organizing principle for the knowledge city. Such parks can transform the urban environment and provide an enormous economic boost, as was the case with Metrotech, catalyzed in Brooklyn, New York, by Polytechnic University. Metrotech has attracted some 20,000 jobs around the university, mostly in information technology and telecommunications, and has revived a significant part of downtown Brooklyn (Bugliarello, 1996). An increasing dimension of the evolving knowledge city is also virtuality—the ability to conduct at a distance business transactions and other social interactions.

In the eco-industrial city, the waste of one industry becomes the input to another. In addition, the biological and machine components are integrated and support each other, as in the case of bioremediation of polluted areas. A pioneering example of this integration is the Danish city of Kalundborg (Graedel, 1999). Whatever shape the city of the future might assume, the challenge to its planners, its managers, and its citizens is to determine consciously what the desirable bio-social-machine balance should be.

Creating the City of the Future

Creating the city of the future presents major and unprecedented engineering challenges. One is how to maintain internal conditions within acceptable limits as the city is exposed to changes in temperature, winds, floods, and earthquakes, as well as to anthropogenic disasters such as war and terrorism. The challenge is to reduce the influence of these parameters on the city through appropriate design and operational decisions. For instance, although a city totally covered by a dome is unrealistic, it is not unrealistic to engineer the city skyline—the location and configuration of structures—to affect temperature and wind patterns. A second challenge is to minimize the influence of the city—its wastes and noxious emissions—on its surroundings, such as watersheds. A third challenge is to develop technology for addressing problems at the microscale of the neighborhood or the individual home, such as in-house energy transformers, waste disposal and recycling systems, and the virtual office. Where appropriate, such technology would provide alternatives to the macroscale of trunk utilities and other central services.

To transform today's cities into tomorrow's less dysfunctional ones, resources are necessary, but the will to transform will be even more important and generally more difficult to mobilize. The fundamental instrument for generating that will is education. Citizens need to learn what they could reasonably expect the city to be and what it takes to make their expectations reality. They need to recognize the importance of participating in decision-making and of having the discipline to make sacrifices in the short term for the sake of a greater good in the long term. Similarly, the city must be willing, when necessary, to accept some temporary economic losses in order to secure a more sustainable future.

Current trends strongly suggest that the cities of the future will be home to an increasing share of world population. We do not know, however, at what point in time saturation will be reached or whether urban population might eventually decline. Neither do we know whether the city of the future will be more dense and compact or more spread out (Figure 3). Regardless of these uncertainties, however, we already possess much of the knowledge and technology to make the city of the future a more effective, less dysfunctional instrument of human advancement. We can expect new technologies to strengthen this capability (Ausubel and Herman, 1988). But they must be developed and applied in the context of a vision of the city of the future that is caring and emotionally satisfying, ecological, intelligent, and manageable. Given the rapid pace of urbanization and the exacerbated dysfunctionality of many of today's cities, we cannot tarry.

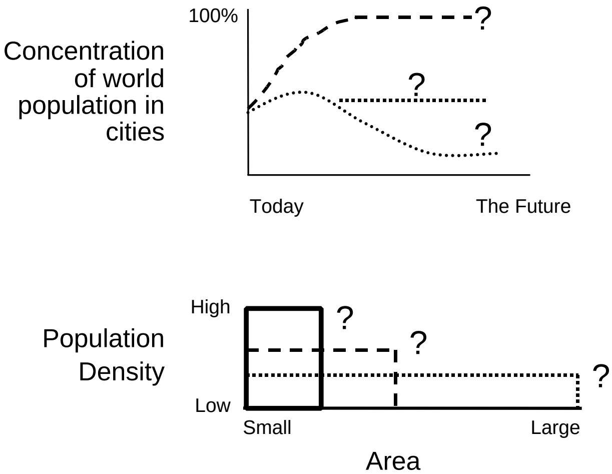

FIGURE 3 Unknowns of the city of the future.

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Climate Systems Engineering

Robert M. White

Forestalling the projected adverse effects of climate change presents an immense and complex challenge to the engineering profession.

Robert M. White, a member of the National Academy of Engineering, is a principal of The Washington Advisory Group, LLC. This article is based on remarks he made on 24 October 2000 during the NAE Annual Meeting Technical Session.

Humans have been engineering Earth systems for thousands of years. Primitive engineering was aimed at local or regional issues and tended to focus on such basics as shelter, water resources, and transportation. Little thought was given to the ancillary and frequently deleterious consequences of the products of human innovation. The need to address these consequences has penetrated our consciousness relatively recently and with it the concept of Earth systems engineering.

Climate systems engineering (CSE), a subset of Earth systems engineering, is a multipurpose, multidisciplinary approach for monitoring, adapting to, and even mitigating the consequences of climate change. Climate change is, of course, a topic of intense national and international interest because of its environmental, economic, and social consequences. For much of history, climate change has been regarded as an act of God over which humans had no control. Recently, however, climate change, and global warming in particular, has come to be seen as at least in part the result of human activities.

Engineering and technology now represent the underpinnings of modern weather and climate science. Scientific weather forecasting became possible 150 years ago with the introduction of the telegraph of Samuel B. Morse, which permitted weather conditions to be transmitted from remote to central locations where they could be analyzed. Since World War II, a host of other technologies has opened our eyes to some of the mysteries of climate. Radiosondes provide a view of the upper atmosphere; radar has transformed our understanding of the dynamics of precipitation and cloud systems; computers have enabled the mathematical modeling of weather and climate, transforming prediction from art to science; and space technology has permitted the imaging, sounding, and location capabilities to provide global monitoring of weather and climate.

It is not my purpose to discuss climate science in any depth. But without some background, the concept of CSE is meaningless. Briefly, the increasing global use of fossil fuels, deforestation, and emissions from other sources have increased dramatically the atmospheric concentration of greenhouse gases since the beginning of the Industrial Age. For example, from barely detectable amounts 140 years ago, annual emissions of carbon dioxide (CO_2) have risen to over 6 billion metric tons per year today (Figure 1). This increase has been essentially monotonic except for seasonal fluctuations, as indicated by the observations at Mauna Loa in Hawaii and other observatories. This level of CO_2 emissions has increased the atmospheric concentration of CO_2 by 25 percent, from approximately 290 parts per million by volume (ppmv) in 1860 to its present level of about 360 ppmv. The result has been a

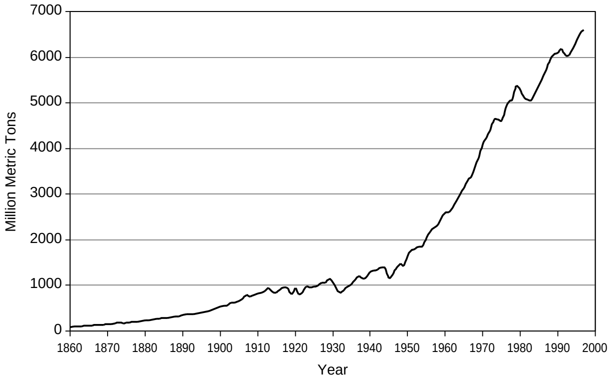

FIGURE 1 Global anthropogenic CO_2 emissions, 1860–1997.
SOURCE: Adapted from Marland et al. (2000).

rise in global mean surface temperature (Figure 2). This temperature change is a matter of observational fact about which there is little dispute.

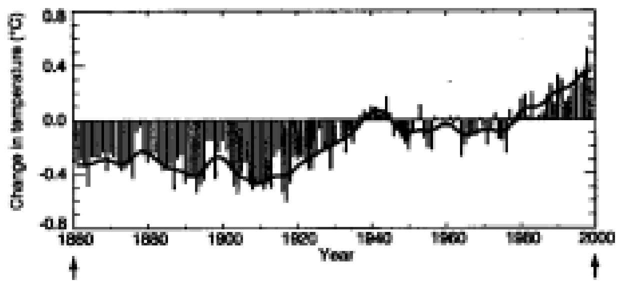

FIGURE 2 Global mean surface temperatures.
SOURCE: Intergovernmental Panel on Climate Change (2001).

Mathematical climate models indicate that global surface temperatures will increase significantly by 2100, according to the Intergovernmental Panel on Climate Change (IPCC; 2001). Most models project an increase in the range of 1.5 to 4.5°C. The latest IPCC assessment estimates a temperature rise of between 1.5 and 5.8°C, with the most likely rise estimated to be 2.5°C. There is also general agreement that global precipitation will increase. Sea level is rising largely due to thermal expansion of seawater, with the most likely rise predicted to be 0.5 meters. Considerable uncertainty exists about the regional distribution of climate change and its impact on agriculture, ecosystems, and water resource availability, as well as its contribution to severe weather events, such as hurricanes.

A recently published report by the National Assessment Synthesis Team (2000) estimates the impact of climate change on the United States. The analysis considers the consequences through 2100 for 5 sectors of the economy and 16 geographical regions. It uses as a basis for its analysis two different climate models, one developed by scientists in Canada and the other by scientists in the United Kingdom. These models yield consistent climate warming projections for the United States as a whole but differ significantly in their regional projections.

Our ability to anticipate future climate change, with all its uncertainties, presents a dilemma. How do we balance the costs of the economic and social impacts of climate change with the costs of the engineering and technology needed to prevent those consequences? When and at what costs do we decide to build dams and seawalls and strengthen bridges? When do we invoke biotechnology to develop drought- and heat-resistant strains of grain?

Almost 10 years ago, in the Framework Convention on Climate Change (FCCC), the international community agreed to try to "achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent *dangerous* anthropogenic interference with the climate system" (United Nations, 1992). In addition to CO_2, the greenhouse gases addressed by the convention are methane, ozone, and nitrous oxide. (Because CO_2 so dominates the greenhouse gas mixtures, what follows focuses on CO_2.)

BOX 1 Possible "Dangerous" Consequences of Climate Change

- Endangered food supply and water resources
- Rising sea level leading to island and coastal inundations
- Increase in severe weather events such as hurricanes, floods, and droughts
- Changes in natural ecosystems
- Health effects such as pulmonary and cardiovascular disease

The convention leaves the term "dangerous" undefined, but it must include the familiar, if sometimes devastating, phenomena indicated in Box 1. Ameliorating global warming is arguably one the most difficult and complex challenges facing engineering and technology. The prime causes of elevated global CO_2 concentrations are shown in Table 1. Humanity's addiction to fossil fuels (coal, gas, and oil) as a source

TABLE 1 Principal Causes of Anthropogenic CO_2 Emissions

	Gt C/yr
Fossil fuel combustion	5.5 ± 0.5
Deforestation	1.6 ± 1.0
Total Anthropogenic Emissions	7.1 ± 1.1

Gt = gigatons. C = carbon.

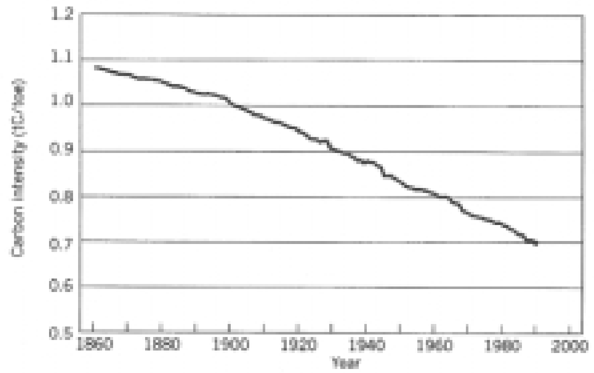

FIGURE 3 Decarbonization: carbon intensity of global energy consumption, expressed in tons of carbon per ton of oil equivalent energy (tC/toe). SOURCE: Nakicenovic (1996).

of energy underlies much of this rise in greenhouse gases. The root solution is to decarbonize the global energy supply. Decarbonization has been proceeding for over a century (Figure 3).

Since the initialing of the climate convention in 1992, governments around the world have been grappling with ways to control atmospheric greenhouse emissions without setting targets for the desired atmospheric concentrations. The Conference of the Parties (COP), the group established to negotiate the details of the FCCC, has met six times to try to seek agreement on international action. The most recent meeting of the group, at The Hague in late 2000, ended in disagreement.

A protocol initialed by the COP in Kyoto, Japan, in 1997 limits the emissions of carbon dioxide and other greenhouse gases and assigns emission targets to industrialized countries. Developing countries unwilling to commit to the protocol were given a pass (United Nations, 1997). The Kyoto agreement requires the United States to reduce greenhouse gas emissions to a level 7 percent below 1990 levels by 2010. Achieving such a reduction would require a lowering of U.S. fossil fuel consumption by some 35 percent below what would be expected in 2010. It could not be accomplished without dramatic changes in the manner of energy production and use in this country.

The Kyoto signatories agreed that sequestration of carbon in the biosphere, principally by trees, could be an ancillary approach for reducing greenhouse gas concentrations in the atmosphere. The United States has proposed that it be permitted to use carbon sequestration by forest and agricultural lands, and emissions trading with other countries, to account for about 50 percent of the required emissions reduction. This proposal was rejected by the European members of COP and was in large part responsible for the collapse of the Hague conference. Alternative scenarios for meeting the Kyoto targets that focus more on non-CO_2 gases have been proposed by Hansen et al. (2000).

There is general recognition that even if successful, the Kyoto protocol is only the first step in the process and by itself will have only a minimal effect on projected global warming. Emissions targets spelled out by the protocol will reduce global average temperatures by an insignificant amount, according to the IPCC. Emissions reductions of 60 to 80 percent would be needed to stabilize atmospheric CO_2 concentrations at their present levels. The fact that China, India, and other developing countries remain unwilling to restrict their emissions has created considerable political controversy.

The U.S. Senate, anticipating the wrenching changes that will be required and aware that not all nations are required to reduce emissions, has voted unanimously against actions by our government to implement the Kyoto protocol. Recently, the Bush Administration announced it will not regulate CO_2 emissions from power plants (Associated Press, 2001), and it has indicated it will withdraw from the Kyoto protocol (Drozdiak and Pianin, 2001).

Target Concentrations Undefined

Forestalling the projected adverse effects of climate change is an example of Earth systems engineering at its most complex. As engineers, we would want to know the target levels of global greenhouse gas concentrations proposed by the FCCC, because it is the concentrations that determine climate change, not emissions. At the present time, however, such targets are undefined.

Setting such target levels is fraught with uncertainty and controversy. It requires knowledge of the consequences of specific limits, a knowledge that we presently do not possess. A commonly accepted target, aiming for greenhouse gas concentrations roughly double those predating the Industrial Revolution, would yield a concentration of about 550 ppmv. This is a number that many believe would avoid dangerous interference with the climate system. Doubling present levels of emissions would yield gas concentration of about 750 ppmv. If the target concentration of 550 ppmv is to be achieved through emission reductions, the trajectory of the emission reductions can vary. Economists refer to this as "when flexibility." A trajectory that permits delays in controlling emissions can have the same effect on CO_2 concentration as one that does not permit delays.

With this kind of framework, engineers and technologists can begin to consider a mind-boggling array of options for achieving specific target concentrations of greenhouse gas. These include those that reduce emissions of CO_2 from fixed and mobile sources, sequester carbon dioxide, reduce the emissions of other greenhouse gases, and employ geoengineering on a global scale (Box 2). Geoengineering is the use of technology to affect the radiation balance of the atmosphere, for example by injecting dust or other particulate matter into the stratosphere to reduce the amount of solar radiation reaching Earth.

CSE Success Depends on Collaboration

However effective the development of a new, low-carbon energy system, the sequestration of carbon, and attempts at reducing other greenhouse gases, if we are to reduce atmospheric concentrations of greenhouse gases, CSE will need to do much more. It must anticipate the consequences of climate change for ecosystems, water resources, agriculture, health, and other concerns of importance to humanity. This must not be a mere afterthought; it must be an integral part of the requirements. Will new technologies have adverse health effects? Will they result in unwanted effects on ecosystems? Will they be culturally acceptable? There are many questions, and collaboration between scientists and engineers from many fields will be required to address them meaningfully.

Because of its global nature, climate change has both political and international engineering dimensions. Not only are international consultations and negotiations about approaches for achieving agreed-upon atmospheric CO_2 concentrations important, but there is also a need to reach out to engineering communities in other countries to enlist their help. The task before us is formidable. The wisest course may be to take actions that contribute to emissions reduction and carbon sequestration at low economic cost now and make the investment in research and engineering to generate the new and advanced tech-

BOX 2 Options for Reducing Concentrations of Atmospheric Greenhouse Gases

CO_2 Emissions Reduction

- Increase efficiency of both mobile and fixed sources of CO_2, for example as in the program for the Partnership for a New Generation of Vehicles (PNGV).
- Increase efficiency of electric power generation by changing power-station fuel sources from coal and oil to gas, and by introducing turbines and distributed energy sources.
- Increase use of renewable energy sources such as wind power, photovoltaics, biomass, and hydropower. (These can produce significant amounts of energy but are not candidates for satisfying base power loads.)
- Increase use of already-proven nuclear energy, a CO_2-emission-free energy source that occupies a central role in power production in France and other countries.
- Continue development of new types of energy systems such as fuel cells for use in automobiles and in fixed locations operating on hydrogen stripped from fossil hydrocarbons.

Carbon Sequestration

- Increase sequestration by growing trees and other plants, which consume carbon dioxide in photosynthesis. This approach can be enhanced through biotechnology by producing fast-growing trees. Sequestration of carbon in soil also merits consideration.
- Sequester carbon stripped from hydrocarbons by pumping it into deep geological structures and use the hydrogen to power fuel cells.
- Inject CO_2 into oceans at depths that allow the formation of CO_2 hydrates.
- Fertilize the oceans by adding iron or phosphorous to increase the production of algae, which then would sequester more carbon in the oceans.

Non-CO_2 Emissions Reductions

- Reduce emissions of non-CO_2 greenhouse gases such as methane, ozone, and nitrous oxide.

Geoengineering

- Disperse dust or inject SO_2 into the stratosphere to reduce sunlight and thereby lower global temperatures. (This proposal is totally speculative.)

nologies that can meet CO_2 concentration targets in the future.

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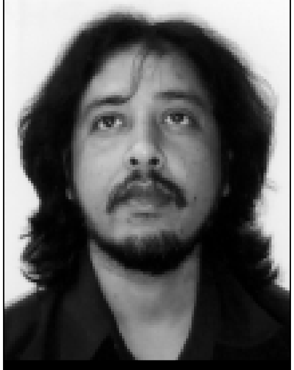
Hybrid Cities: A Basis for Hope

Geeta Pradhan and Rajesh K. Pradhan

Geeta Pradhan



Rajesh K. Pradhan

Combining the best features of city and country life in one place can create the diversity and sense of community needed to nurture creativity and innovation.

Some years ago, the people of Mexico City realized with horror that the city had started sinking. Water drawn over the years to sustain life had far exceeded what trickled down to replenish underground sources, triggering sometimes dramatic subsidence. Excessive paving made matters worse, leading to water run-off, flooding, aquifer depletion, and reliance on an expensive water supply system. Mexico City illustrates starkly how unsustainable our current practices are.

This article draws upon an inspiring thought by the Italian writer-philosopher Italo Calvino to offer an alternative approach to the develop-

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ment of cities. In his 1986 book, *Invisible Cities,* Calvino describes the empire of the Tartan Emperor Kublai Khan. It is crumbling and Kahn is devastated. To divert him, the Venetian traveler Marco Polo recounts for him stories about the several cities he has seen during his travels. He tells of cities of memories, cities of dreams, of thin cities and wide cities, of trading cities and cities of desires, signs, and eyes, cities of names, and hidden cities. Soon it becomes clear to Khan that each of these fantastic places is really the same place—Kublai Khan's empire.

But a down-in-the-dumps Khan cannot see any hope of getting out of this ever closing-in inferno, and Polo tells him:

> . . . There are two ways to escape suffering it. The first is easy for many: accept the inferno and become such a part of it that you can no longer see it. The second is risky and demands constant vigilance and apprehension: seek and learn to recognize who and what, in the midst of the inferno, are not inferno, then make them endure, give them space.

The idea explored in the following pages has precedents in wisdom drawn from the past and echoes the vast literature on administrative decentralization. It takes into account some of today's scientific and technological advances, and it tempers the grandeur and visions of utopia with the realization that human activity and population growth can no longer keep pace with the world's finite resources. Like Calvino's spaces within the inferno, it tries to give legitimacy and room to small trends and innovative concepts emerging in several cities in response to problems created by urbanization. It seeks to offer a new model of development—a hybrid approach—that combines the best of rural and urban attributes to create "a village in a city, a city in a village." Metaphorically, it urges us to look outside cities as we rethink today's urban centers and design those of tomorrow.

The world's population, which reached 6.1 billion in mid-2000, is projected to grow to 8.1 billion by 2030 (United Nations, 2001). Projections show that almost all of this growth will be concentrated in urban areas of the less developed world, and rural to urban migration and the transformation of rural settlements into cities are expected to be key contributors to this trend. Although an increasing share of the world's population is living in urban areas, the percentage of people living in very large urban agglomerations—the megacities—is still small. In 2000, 4.3 percent of the world's population lived in cities of 10 million or more; by 2015, 5.2 percent are expected to. Cities of 5-10 million inhabitants, which currently account for 2.6 percent of world population, will hold about 3.5 percent of the planet's people by 2015. By comparison, the number of people living in smaller cities, though increasing at a slower pace, is considerably larger. In 2000, 28.5 percent of the world's population was living in cities of 1 million or less; by 2015, cities of this size will account for 30.6 percent of total population.

Congestion, health risks, social chaos among problems common to largest cities.

Though cities account for just 2 percent of the world's surface, they use up a disproportionately large portion of the world's resources. For instance, roughly 78 percent of carbon emissions from fossil fuel burning and cement manufacturing, and 76 percent of industrial wood use worldwide, occur in urban areas. Some 60 percent of the planet's water tapped for human use goes to cities in one form or another (O'Meara, 1999).

Cities account for a majority of the world's wealth and provide over 50 percent of the world's employment. If population growth remains on its current trajectory, the global workforce will swell from about 3 billion today to nearly 4.5 billion by 2050 (World Resources Institute, 2000). In a desperate search for jobs, higher incomes, and a greater diversity of options, people will continue to be drawn to cities.

Many urban areas provide an inhospitable environment, creating incentives for people to move away and escape city life. Congestion, health risks related to pollution, ungovernability, and social chaos are common problems in some of the world's largest cities. According to the World Resources Institute (1996), at least 220 million people in cities of the developing world lack clean drinking water, 420 million do not have access to the simplest sanitation, and between one-third and one-half of city trash goes uncollected, contributing to flooding and the spread of disease. Domestic and industrial effluents released with little or no treatment into waterways are affecting the quality of water far beyond cities, rendering many urban rivers like the Pasig in Manila and the Yamuna in New Delhi biologically dead. Breakdowns and undercapacity in the aging infrastructure of cities, especially water-supply and sewer systems, increases the incidence of water-borne and water-related diseases. At any given time, close to half the world's urban population suffers from one or more of these diseases (World Bank, 2000).

Despite problems associated with growth, development policies continue to favor the urban sector.

Rising rates of automobile ownership and the absence of public transportation and environmentally sound rapid transit systems are creating unprecedented pollution levels and traffic congestion in cities. Urban air pollution is estimated to be responsible for over 3 million deaths annually worldwide, almost all of those among children (World Health Organization, 1997). The air in some cities in Latin America, China, and India has concentrations of pollutants, such as nitrogen oxide, sulphur dioxide, and particulates, that are two to four times those set by World Health Organization guidelines (Davis, 1999). The amount of air pollution children in these cities are exposed to is equivalent to smoking two packs of cigarettes per day (World Bank, 2000).

Vehicle exhaust, the dominant ingredient in urban air pollution, also is spewing lead into the air. This toxic metal impairs the kidneys, liver, and reproductive system, and at high levels causes irreversible brain damage. Recent studies suggest that about two-thirds of children in New Delhi and an even greater proportion of children in Shanghai have blood lead levels higher than those expected to cause adverse health effects. In Cairo in early 1999, worsening traffic in the city's industrial areas contributed to atmospheric lead concentrations that exceeded health guidelines by a factor of 11 (O'Meara, 1999).

Despite all the problems associated with the growth of cities, development policies have continued to favor the urban sector. This "urban bias," to borrow a phrase popularized by the economist Michael Lipton (1977) in his work on urban and rural development, grew from a much earlier debate about how less industrialized nations should modernize. In the view that gained acceptance, generally credited to Arthur Lewis (1954), the strategy was to focus on cities (as opposed to agricultural areas) as places that could provide jobs, produce goods using low competitive wages due to surplus labor, generate wealth through exchange, and create a dense environment necessary for economic interdependence and innovation. The result of this development strategy was excessive migration to cities, urban sprawl, and the relative stagnation of villages. Many cities, those in the less industrialized world in particular, have become unmanageable, ungovernable, and unsustainable.

The Consequences of Urban Sprawl

In the United States as in the rest of the industrialized world, the debate about cities now is framed differently, not on economic growth per se but on ways to achieve better quality of life. These are new expressions of old ideas in American history, where city planners saw the ideal city as one that took care of three sides of human experience: work, family, and leisure. Over time, however, quality work life, family life, and leisure time have come to be associated not with inner cities but with suburbs. With employment moving out to the suburbs, with family concerns about schools and safety in cities, and with greater opportunity for leisure in natural suburban settings, cities are witnessing out-migration or suburban sprawl. The result is a substantial loss of agricultural land and forests, urban disinvestments, and an increase in transportation and residential and commercial land use.

As an illustration of this trend, America's metropolitan population, which includes people living in suburbs, grew from 60 percent of the total population in 1950 to about 80 percent in 2000 (Ecological Cities Project, 2001). An implication of this growth in the Boston metropolitan region, for instance, is the loss of over 37 percent of open space to sprawl in just 50 years

(Pradhan and Kahn, 2000). The impact of automobile usage extends even to such issues as loss of productivity. Drivers in 70 U.S. metropolitan areas spend an average of 40 hours each year sitting in stalled traffic, resulting in wasted fuel and lost productivity that costs about $74 billion annually (O'Meara, 1999).

Concerns about health, productivity, and overall quality of life provide an incentive for people to move away from cities. Those with the means can choose to maintain two homes, one in the country to enjoy serenity, the other in the bustling city to experience and enjoy diversity and culture, for employment, and for wealth creation. This phenomenon of dual habitation, growing in both the West and among affluent city dwellers in the developing world, gives one glimpse of what people would do if they could.

Resource Pressures Create Social Stress

As cities continue to expand, whether from urbanization or sprawl, the pressures to manage water and energy resources, organize food production and distribution, and manage basic urban amenities such as housing, transportation, and public health will increase. Access to and control over these resources and services increasingly are becoming arenas of social conflict, particularly in megacities. Ironically, even if population does not grow at the predicted rate, cities will still have to contend with normal wear and tear of vital infrastructure.

Relative to the enormity of problems facing cities, our responses have been timid. They have ranged from popularizing environmentally sound technical solutions (e.g., energy conservation equipment and pollution-prevention and clean-up technologies) aimed at fixing problems to appealing to people to establish a deep (spiritual) bond with environment and nature. Neither approach provides much hope for significantly improving the quality of life in today's sprawling cities and emerging urban centers.

Rather, what we need today is an inspiring vision that provides new direction for cities of the future. We need a utopia of sorts, a basis for hope, and a redefinition of what a city is. The answer to the problems of cities of today may rest with development approaches that concentrate on smaller urban centers, those with populations of one million or less, and on creating coutryside or small-town-like environments within large urban centers.

The vision we propose is of a sustainable community that emphasizes civic engagement, social justice, environmental soundness, and economic diversity. It is based on an understanding of factors that over the ages have lured people to cities and of qualities of life people seek when they move to the countryside and to small towns. Termed the "hybrid city," the proposed approach attempts to combine the best of cities—diversity, density, innovation, opportunities for economic mobility, and access to means for human development—with the best of village or small-town life—cultural wisdom, frugality, conservation, resource efficiency, a sense of scale and place, self-reliance, and a sense of community and connectedness.

The approach uses lessons learned from innovations in such areas as food production, open-space creation, waste management, and transportation. Used to take the heat off the "infernos" that many large cities have become, these innovations also offer hope for the sustainability of smaller urban centers. A few examples should suffice.

- *The creation in cities of village-like, self-reliant activities.* Many small but successful efforts to enhance urban sustainability or livability provide residents with goods and services produced locally. They are, in other words, guided by the principle of self-reliance, a characteristic associated typically with the village or country town of the past, when transportation options were limited.

Public markets testimony to the demand for urban agriculture.

Chinese cities, for instance, have long reserved surrounding areas for agriculture and used city-generated wastes to fertilize the fields. In Africa, urban agriculture is often a survival strategy for the poor (O'Meara, 1999). In Boston, 150 community gardens augment the food budgets of families in the inner city; the gardeners are often low-income and the elderly. New York City is organizing to protect its ad-hoc urban gardens. In one sense, the popularity of public markets that stock locally grown produce and food products is testimony to the latent demand for urban agriculture.

The hybrid cities approach would make urban agriculture an explicit element of city planning. To the extent it creates a variety of jobs in production, processing, and support industries (favoring less-skilled workers), the strategy would further the goals of equity and social justice. And, from an architectural or urban design point of view, it would enhance diversity within cities that may be becoming too city-like.

Creating an island of city life surrounded by a sea of countryside.

- *The creation in cities of village-like open spaces and clean air.* Perhaps inadvertently, urban agriculture is adding badly needed open space in congested cities. Some U.S. metropolitan centers are more consciously working to contain their boundaries, limit growth, and increase countryside-like open spaces. By moving a major above-ground highway underground, for instance, Boston has created huge open spaces in the heart of its downtown. The desire for more pristine air has led Chattanooga to replace automobile traffic in the downtown area with free public transportation that runs on nonpolluting fuels (World Resources Institute, 2001). The change has led to massive economic investments in the city center.
- *The creation in cities of village-like frugality and resource conservation.* Curitiba, Brazil, has managed to link its waste recycling program to efforts to boost nutrition. For every bag of recyclables they turn in, citizens receive a bag of locally grown vegetables. Similar recycling strategies are occurring on an industrial scale. For instance, in Kalundborg, Denmark, waste from one industry feeds directly into another as raw material in a kind of "industrial symbiosis." Metropolitan Tokyo, with over 80 percent of its land covered by asphalt, is harvesting rain water for nondrinking uses (O'Meara, 1999). Boston is conserving its drinking-water resources by replacing leaky pipes, installing water-saving features, and educating the public about the importance of water conservation. It has reduced water loss in the past two decades from 33 percent to about 11 percent (Pradhan and Kahn, 2000).
- *The creation of a city in a village.* Technological advancements and traditional wisdom make it possible to create an island of city life surrounded by a sea of countryside. Anna Hazare's Raley Gaon Sidhhi project in Maharashtra, India, is one such example (Hazare, 1997). The project is hailed as one of the most successful sustainable community projects in India and has been replicated in over 600 villages. It, too, applies the idea of "city in a village," creating not an urban center but a sustainable village with town-like diversity that provides an array of jobs and employs low-cost, environmentally sound technologies and watershed management approaches to sustain what is essentially village life.

Behind many innovative solutions in urban sustainability lies the unspoken idea of adding to cities qualities associated with the countryside. Technology today makes such integration more possible, unleashing forces that respond simultaneously to the longing for the intensity of a city and the ideal of a small-town life in a global economy.

Hybrid Cities and Diversity

Another way of looking at hybrid cities is to focus on the issue of diversity, one of the defining characteristics of the city itself. Introducing the kinds of innovations we have just described will lead to a broadening and deepening of diversity. That diversity, more generally, could allow different ideas, opportunities, and experiences to coexist, thereby creating conditions for constant innovation and creativity. The hybrid city is both an actor in the global economy and a self-reliant entity that meets local need for basic goods and services. Its diverse economy is both industrial and craft based, high tech and low tech, formal and informal.

Ideally, a hybrid city is relatively small, governable, and manageable. It offers a sense of community and allows people to feel connected. The "hybridization" of an existing megacity could occur in a number of ways, some of them complementary: by administratively breaking up the giant settlement into several small towns; through community- or neighborhood-based planning consistent with the decentralized units; or by incorporating countryside-like spaces and activities along the periphery as well as within the city itself. Similarly, one could imagine high-technology based urban clusters within the countryside. The idea, in other words, is to diversify both the city and the countryside.

To put it differently, the small town (or the countryside) needs to become the planning tool for the development of existing large cities. To the extent that the hybrid city incorporates the ideas inherent in small towns and rural settings, it draws our attention inevitably to civic engagement and social justice, issues that get lost in the rush to make the city more modern or manageable but that are critical to making cities more sustainable.

By advocating in cities village- or craft-like activities in production, processing, manufacturing, and services, the hybrid city attempts to create multiple work opportunities and an outlet for many skills that have become irrelevant in cities today.

A Conglomeration of Small Towns

By conceptualizing the big city as a conglomeration of small towns interspersed by pockets of the countryside, the hybrid city inevitably turns resource allocation and city planning into neighborhood- or community-based activities. It facilitates civic engagement by relying on small administrative units as opposed to the centralized administration of traditional megacities. By so doing, hybrids foster diverse power centers and give legitimacy to many different voices. Finally, by drawing attention to small urban centers and developing urban clusters within villages—possibly the hybrid cities of the future—the strategy directs investments to relatively forgotten communities.

The idea of enjoying the best of both worlds is not new. After the Industrial Revolution, when conditions in cities became unbearable, urban thinkers developed visions of utopia that combined the best of technology with ideas of social justice to create equitable societies in harmony with nature. Whether or not we agree with them, ideas from Ebeneezer Howard's Garden Cities movement, Le Corbusier's skyscrapers set in open parkland, and Frank Lloyd Wright's sprawl over suburbia made possible by the automobile found their way into 20th century urban planning throughout the world. Such is the power and influence of visions!

Unlike some of the utopian visions of the past, the hybrid city approach does not pretend to be a fully developed idea. It aims simply to unify disparate and badly needed attempts at sustainability by mixing, like an alchemist, seemingly opposed elements—the city and the countryside, the megacity and the rural village.

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NAE News and Notes

Class of 2001 Elected

In February the National Academy of Engineering (NAE) elected 74 members and 8 foreign associates to membership in the Academy. This brings total U.S. membership to 2,061 and the number of foreign associates to 154.

Election to the NAE is among the highest professional distinctions accorded an engineer. Academy membership honors those who have made "important contributions to engineering theory and practice, including significant contributions to the literature of engineering theory and practice," and those who have demonstrated "unusual accomplishment in the pioneering of new and developing fields of technology."

A list of the newly elected members and foreign associates follows, with their primary affiliations at the time of election and a brief statement of their principal engineering accomplishments.

Members

Rodica A. Baranescu, chief engineer, Performance Analysis Department, Navistar International Transportation Corp., Melrose Park, Ill. For research leading to effective and environmentally sensitive diesel and alternative-fuel engines and leadership in automotive engineering.

Frank S. Barnes, director of interdisciplinary telecommunications program, electrical and computer engineering, University of Colorado, Boulder. For fundamental research on biological effects of electromagnetic fields, surgical procedures, and contributions to telecommunications education.

Steven Bellovin, technical leader, AT&T Labs–Research, Florham Park, N.J. For contributions to network applications and security.

Meyer J. Benzakein, general manager, advanced engineering programs, GE Aircraft Engines, Cincinnati. For achievements in international technical cooperation and propulsion engine technology.

Dimitri P. Bertsekas, professor of electrical engineering and computer science, Massachusetts Institute of Technology, Cambridge. For pioneering contributions to fundamental research, practice, and education of optimization/control theory, and especially its application to data communication networks.

Rafael L. Bras, Bacardi and Stockholm Water Foundations Professor of Civil and Environmental Engineering and head, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge. For innovation in hydrological forecasting and hydrometeorology through application of new technology, probability, and statistics, and for the advancement of civil engineering education.

George H. Brimhall, professor of geology and director, Earth Resources Center, Department of Geology and Geophysics, University of California, Berkeley. For contributions to the advancement of geological modeling and ore deposit exploration.

Joost A. Businger, independent consultant, Anacortes, Wash. For contributions to the field of atmospheric turbulence transport and its applications.

E. Dean Carlson, secretary of transportation, Kansas Department of Transportation, Topeka. For outstanding leadership and dedication in developing national highway policy, systems management initiatives, and research programs.

William C. Cavanaugh III, chairman, president, and chief executive officer, Progress Energy, Raleigh, N.C. For contributions to excellence in the generation of electricity from nuclear power by establishing and achieving exemplary levels of performance.

John Cioffi, professor of electrical engineering, Stanford University, Stanford, Calif. For contributions to the theory and practice of high-speed digital communications.

Richard W. Couch Jr., president, chairman, founder, owner, and principal engineer, Hypertherm Inc., Hanover, N.H. For technological innovation and engineering entrepreneurship in making plasma-arc the dominant thermal metal-cutting process in use today and his company the world's leading manufacturer.

Natalie W. Crawford, vice president and director, RAND Project Air Force Division, Santa Monica, Calif.

For outstanding engineering, development, and analytical contributions to planning for the U.S. Air Force.

Robert F. Davis, Kobe Steel Ltd. Distinguished University Professor of Materials Science and Engineering, North Carolina State University, Raleigh. For contributions in the development of silicon carbide and group III-nitrides as practical electronic materials for devices.

Mark E. Dean, vice president and fellow, systems research, IBM Thomas J. Watson Research Center, Yorktown Heights, N.Y. For innovative and pioneering contributions to personal computer development.

Jack J. Dongarra, distinguished professor, computer science department, University of Tennessee, Knoxville. For contributions to numerical software, parallel and distributed computation, and problem-solving environments.

David A. Edwards, president and chief scientific officer, Advanced Inhalation Research Inc., Cambridge, Mass. For transfer of scientific principles of engineering to industry, including invention and commercial development of a novel, generic aerosol drug-delivery system.

Antonio L. Elias, senior vice president and general manager for advanced programs, Orbital Sciences Corp., Dulles, Va. For conception and execution of a new generation of Earth-orbit transportation systems.

Bruce R. Ellingwood, chair, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta. For leadership in the use of probability and statistics in the design of structures and in the development of new design criteria.

Lawrence B. Evans, chairman and chief executive officer, Aspen Technologies Inc., Cambridge, Mass. For leadership in the development and application of integrated systems for modeling, simulation, and optimization of industrial chemical processes.

Liang-Shih Fan, Distinguished University Professor and chair of chemical engineering, The Ohio State University, Columbus. For leadership and contributions to research and education in the field of fluidization and particle technology.

Eugene C. Figg Jr., president and chief executive officer, Figg Engineering Group, Tallahassee, Fla. For leadership in architectural excellence, structural innovation, and efficient construction of major bridges.

James G. Fujimoto, professor of electrical engineering, Massachusetts Institute of Technology, Cambridge. For pioneering contributions to and commercialization of optical coherence tomography (OCT).

Alice P. Gast, professor of chemical engineering, Stanford University, Stanford, Calif. For contributions to the understanding of the structure of complex fluids, especially polymeric and electro-rheological fluids, and to engineering education.

Eddy W. Hartenstein, president, DIRECTV Inc., and corporate senior executive vice president, Hughes Consumer Sector, Hughes Electronics Corp., El Segundo, Calif. For leadership in developing and implementing satellite digital video and data transmission systems for direct delivery into homes.

Karl Hess, Swanlund Endowed Chair and professor, department of electrical and computer engineering, University of Illinois, Urbana-Champaign. For contributions to hot electron transport and the numerical simulation of semiconductor devices.

W. Daniel Hillis, founder, Applied Minds, Glendale, Calif. For advances in parallel computers, parallel software, and parallel storage.

Gerald D. Hines, founder and chairman, Hines, Inc., Houston. For global leadership in engineering advancements that set the standard for innovative and efficient design in the commercial building industry.

Thom J. Hodgson, James T. Ryan Professor of Industrial Engineering, North Carolina State University, Raleigh. For contributions to the advancement of industrial, manufacturing, and operational systems in industry, academia, and government.

Thomas S. Huang, professor, department of electrical and computer engineering, University of Illinois, Urbana-Champaign. For contributions to the theory and practice of image compression, retrieval, and analysis.

Fazle Hussain, Cullen Distinguished Professor, Mechanical Engineering Department, University of Houston. For fundamental experiments and concepts concerning important structures in turbulence, vortex dynamics, and acoustics, and for new turbulence measurement techniques.

Shirley A. Jackson, president, Rensselaer Polytechnic Institute, Troy, N.Y. For contributions to industry research, education, and the formation of the International Nuclear Regulators Association.

David Jenkins, professor emeritus, Department of Civil and Environmental Engineering, University of California, Berkeley. For theoretical and practical contributions to improving water quality worldwide through applied research on biological wastewater treatment processes.

Barry C. Johnson, senior vice president and chief technology officer, Honeywell International, Morristown, N.J. In recognition of technical and strategic industry leadership in semiconductor devices, processes, and packaging technologies.

Marshall G. Jones, senior mechanical engineer, GE Corporate Research and Development, Niskayuna, N.Y. For pioneering contributions to the application of high-power lasers in industry.

Kristina B. Katsaros, director, Atlantic Oceanographic and Meteorological Laboratory, National Oceanographic and Atmospheric Administration, Miami. For basic advances of ocean-atmosphere energy exchange through innovative measurement techniques.

Sangtae Kim, vice president and information officer, Eli Lilly and Co., Indianapolis. For contributions to microhydrodynamics, protein dynamics, and drug discovery through the application of high-performance computing.

Raymond J. Krizek, Stanley F. Pepper Professor of Civil Engineering and director, Master of Project Management Professional Degree Program, Northwestern University, Evanston, Ill. For advancements in soil-structure interaction, disposal of waste slurries, mechanical properties of grouted sands, and engineering behavior of soils.

Raymond C. Kurzweil, founder, chairman, and chief executive officer, Kurzweil Technologies Inc., Wellesley Hills, Mass. For application of technology to improve human-machine communication.

Stephanie L. Kwolek, research associate (retired) and consultant, E. I. Du Pont de Nemours & Co., Wilmington, Del. For contributions to the discovery, development, and liquid-crystal processing of high-performance aramid fibers.

Max G. Lagally, Erwin W. Mueller Professor of Materials Science and Engineering, University of Wisconsin, Madison. For contributions to surface science, in particular in semiconductor film growth and in the development of novel analytical techniques.

Douglas A. Lauffenburger, co-director, Division of Bioengineering and Environmental Health, and director, Biotechnology Process Engineering Center, Massachusetts Institute of Technology, Cambridge. For contributions in molecular and cellular engineering and for interfacing modern biology with engineering principles.

Brian R. Lawn, NIST Fellow, Materials Science and Engineering Laboratory, National Institute of Standards and Technology (NIST), Gaithersburg, Md. For elucidating the basic principles of brittle fracture that are essential to our understanding of the fracture of complex engineering materials.

Edward D. Lazowska, professor and chair, Department of Computer Science and Engineering, University of Washington, Seattle. For leadership and contributions to computer performance evaluation and distributed systems.

Nancy A. Lynch, NEC Professor of Software Science and Engineering, Massachusetts Institute of Technology, Cambridge. For the development of theoretical foundations for distributed computing.

Christopher W. Macosko, professor, Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis. For the invention, development, and dissemination of new methods of reactive polymer processing and rheological property measurement.

Alfred E. Mann, founder and chairman, MiniMed Inc., Northridge, Calif. For innovations and entrepreneurship in cardiac pacing technology, insulin delivery, and neural prostheses.

Larry V. McIntire, E. D. Butcher Professor and chair, Department of Bioengineering, and chair, Institute of Biosciences and Bioengineering, Rice University, Houston. For pioneering research in cellular and tissue engineering and for leadership in engineering education.

Benjamin F. Montoya, chairman and chief executive officer (retired), and member, Board of Directors, Public Service Co. of New Mexico, Albuquerque. For environmental and organizational leadership in both the U.S. Navy and public power sector while maintaining total dedication to societal values.

Frederick J. Moody, consulting engineer, GE Nuclear Energy (retired), Murphys, Calif. For pioneering and vital contributions to the safety design of boiling water reactors, and for his role as educator.

Norman R. Morrow, professor of chemical and petroleum engineering, University of Wyoming, Laramie. For contributions to the understanding of interfacial phenomena governing wettability, connate water saturation, and spontaneous imbibition.

Sia Nemat Nasser, John Dove Isaacs Professor of Natural Philosophy, professor of mechanical and aerospace engineering, and director, Center of Excellence for Advanced Materials, University of California, San Diego. For pioneering micromechanical modeling and novel experimental evaluations of the responses and failure of modes of heterogeneous solids and structures.

Amos M. Nur, Wayne Loel Professor of Earth Sciences, professor of geophysics, and director of the Stanford Rock Physics and Borehole Geophysics project, Stanford University, Stanford, Calif. For founding and establishing rock physics technology for quantifying rock properties from remote seismic measurements.

Robert S. O'Neil, chief executive officer emeritus, Parsons Transportation Group Inc., Washington, D.C. For leadership in the establishment and growth of environmentally responsible transportation throughout the world.

John K. Ousterhout, chief scientist, Interwoven Inc., Sunnyvale, Calif. For improving our ability to program computers by raising the level of abstraction.

James J. Padilla, group vice president, global manufacturing, Ford Motor Co., Dearborn, Mich. For original contributions to the improvement of the efficiency of engineering and manufacturing in the transportation industry.

Paul S. Peercy, dean, College of Engineering, University of Wisconsin, Madison. For significant fundamental discoveries, important new measurement techniques, and visionary leadership in creating and managing outstanding laboratories in materials research.

Kurt E. Petersen, president, Cepheid, Sunnyvale, Calif. For contributions to the research and commercialization of microelectromechanical systems (MEMS).

Albert P. Pisano, FANUC Chair of Mechanical Systems and director, Electronics Research Laboratory, University of California, Berkeley. For contributions to the design, fabrication, commercialization, and educational aspects of microelectromechanical systems (MEMS).

H. Vincent Poor, professor of electrical engineering, Princeton University, Princeton, N.J. For contributions to signal detection and estimation and their applications in digital communications and signal processing.

Robert O. Ritchie, head, Structural Materials Department, Materials Science Division, Lawrence Berkeley National Laboratory, and professor of materials science, Department of Materials Science and Engineering, University of California, Berkeley. For contributions to the understanding of fatigue fracture and the failure of engineering structures.

Lloyd M. Robeson, principal research associate, Air Products and Chemicals Inc., Allentown, Pa. For significant scientific and technological contributions in polymer blends and engineering polymers.

Theodore Rockwell, principal officer (retired), MPR Associates, Chevy Chase, Md. For contributions to the development of reactor shielding technology and nuclear-power reactor safety.

Sosale Shankara Sastry, director, Electronics Research Laboratory, and professor, electrical engineering and computer sciences, University of California, Berkeley. For pioneering contributions to the design of hybrid and embedded systems.

Peter C. Schultz, president, Heraeus Amersil Inc., Duluth, Ga. For invention and development of manufacturing methods and glass compositions for low-attenuation glass fibers for optical communication.

Mordecai Shelef, corporate technical specialist, Ford Research Laboratory, Ford Motor Co., Dearborn, Mich. For contributions to the science and engineering of automotive exhaust catalysis.

Guy Lewis Steele Jr., distinguished engineer, Sun Microsystems, Burlington, Mass. For contributions to the design, specification, and engineering of programming languages.

George L. Stegemeier, president, GLS Engineering Inc., Houston. For contributions to thermal oil recovery and in situ remediation.

Dwight C. Streit, technical fellow and director, advanced semiconductors, TRW Space & Electronics Group, Redondo Beach, Calif. For contributions to the development and production of heterojunction transistors and circuits.

Gerald B. Stringfellow, dean, College of Engineering, and distinguished professor of materials science and engineering and electrical engineering, University of Utah, Salt Lake City. For leadership in the development of III/V semiconductor alloys, including the organometallic vapor phase epitaxy (OMVPE) growth technique, for modern electronic and photonic devices.

James M. Tien, professor and chair, Department of

Decision Science and Engineering Systems, Rensselaer Polytechnic Institute, Troy, N.Y. For contributions to the development and application of systems engineering concepts and methodologies to improve public services and engineering education.

Don Walsh, president, International Maritime Inc., Myrtle Point, Ore. For contributions to the development and advancement of deep-sea engineering systems.

Chris G. Whipple, principal, Environ, Emeryville, Calif. For developing innovative risk assessment methodologies and for their application to issues of national importance.

Marvin H. White, Sherman Fairchild Professor of Electrical Engineering, Lehigh University, Bethlehem, Pa. For contributions to solid-state imagers and for advances in silicon devices and technology.

Foreign Associates

Eric Ash, treasurer and vice president, The Royal Society, London, England. For innovations in optics and acoustics and for leadership in education.

P. Ole Fanger, director, International Centre for Indoor Environment and Energy, Department of Energy Engineering, Technical University of Denmark, Lyngby. For significant interdisciplinary research on the influence of indoor environment on human comfort, health, and productivity.

Knut Sven Eric Forssberg, professor of mineral processing, Lulea University of Technology, Lulea, Sweden. For innovative fundamental and applied contributions to processing complex ores and recycling waste materials and for international leadership in mineral processing.

Peter Bernhard Hirsch, professor emeritus, Department of Materials, University of Oxford, Oxford, England. For experimentally establishing the role of dislocations in plastic flow and of electron microscopy as a tool for materials research.

Suzanne Lacasse, managing director, Norwegian Geotechnical Institute, Oslo. For enlightened direction of the Norwegian Geotechnical Institute and for advancements in foundation engineering for offshore structures.

Wolfgang Schmidt, director, Aeronautics, Defense, and Space Research Program, DaimlerChrysler Corp., Stuttgart, Germany. For outstanding contributions to computational aerodynamics and air vehicle design and engineering, and for promoting international leadership and cooperation.

Viggo Tvergaard, professor, Department of Solid Mechanics, Technical University of Denmark, Lyngby. For contributions to the theory of stability and the understanding of failure phenomena in solids and structures.

Felix J. Weinberg, professor emeritus of combustion physics, Imperial College, London, England. For contributions to the understanding, diagnostics, and applications of a wide range of flame and combustion processes.

Draper, Russ Recipients Honored

2001 Draper Prize Recipients. From left: Vinton Cerf, Robert Kahn, Leonard Kleinrock, Lawrence Roberts. Photo: Cable Risdon Photography.

2001 Russ Prize Recipients Earl Bakken and Wilson Greatbatch. Photo: Cable Risdon Photography.

NAE President **Wm. A. Wulf** hosted the NAE Awards Dinner and Presentation Ceremony on 20 February to honor the 2001 recipients of the Charles Stark Draper Prize and the first Fritz J. and Dolores H. Russ Prize. The formal dinner was held at Washington, D.C.'s, historic Union Station.

Vinton G. Cerf, Robert E. Kahn, Leonard Kleinrock, and **Lawrence G. Roberts** received the Draper Prize for "principal contributions to the development of technologies that are the foundation of the Internet, a stunning engineering achievement that profoundly influences people, commerce, communications, productivity, and interpersonal relationships throughout the world."

Earl E. Bakken and **Wilson Greatbatch** were honored with the Russ Prize "for saving, extending, and improving the quality of human lives through the engineering development and commercialization of implantable heart pacemakers."

The recipients of the Draper Prize shared the $500,000 cash award, and each received a gold medallion and a hand-scribed certificate. The recipients of the Russ Prize also shared $500,000, and each received a gold medallion and a hand-scribed certificate.

The engineers who were honored at the ceremony "invented two of the world's most significant" technologies, Dr. Wulf said. "It was certainly an honor to recognize them and to share the evening with their friends, family, and colleagues."

Guest speakers included Vince Vitto, president and CEO of the Charles Stark Draper Laboratory; President Robert Glidden, Ohio University; **Thomas Budinger,** chair of the 2001 Draper Prize selection committee and head of the Center for Functional Imaging at the E. O. Lawrence Berkeley National Laboratory; and **Robert Nerem,** chair of the 2001 Russ Prize selection committee and Parker H. Petit Professor and director, Institute of Bioengineering and Bioscience at the Georgia Institute of Technology. Also present at the event were Fritz J. and Dolores H. Russ, benefactors of the Russ Prize.

Following the presentation of the medals, Dr. Wulf commented on the National Academy of Engineering's new advertising campaign. Designed by TGD Communications, the campaign highlights the Draper and Russ prizes and the achievements they recognize, and will be featured in various publications and on National Public Radio.

Dr. Wulf also announced the establishment of the NAE's newest prize, the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education. The prize will be awarded for the first time at the NAE Awards Dinner and Presentation Ceremony on 19 February 2002. Gordon Prize awardees receive a $500,000 cash award, gold medallion, and hand-scribed certificate. (For more information on the Gordon Prize, see article p. 30.)

NAE Hosts Draper Forum for Students

The 2001 Draper Prize recipients sign autographs and meet students at the Draper Prize Forum. Photo: Cable Risdon Photography.

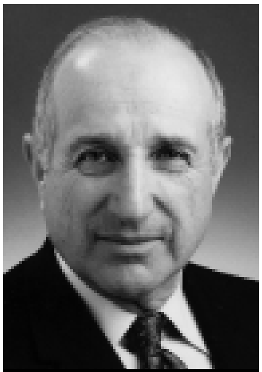
The National Academy of Engineering hosted the first Charles Stark Draper Prize Public Forum at the National Academies' auditorium on 20 February. Moderated by Ann Kellan, science correspondent for CNN, the forum featured **Vinton G. Cerf, Robert E. Kahn, Leonard Kleinrock,** and **Lawrence G. Roberts,** the 2001 recipients of the Draper Prize.

Attending the event were nearly 100 middle-school students who were participants in the National Engineers Week's Future City Competition and 20 high-school students from Cardozo High School, Washington, D.C. During the open discussion, the students questioned the recipients about the Internet, its technology, history, and future, and about censorship and e-commerce.

Prior to the forum, Ann Kellan joined the recipients and NAE President **Wm. A. Wulf** for an hour-long media luncheon for reporters of various publications. The luncheon was designed to create an open dialogue between the recipients and the reporters and to convey the importance of engineering and the National Academy of Engineering's role in recognizing engineering achievement.

The audio portion of the forum is available online at http://video.national-academies.org/ramgen/news/022001.rm.

Gordon Prize Launched



Bernard M. Gordon

Started this year by the National Academy of Engineering, the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education is intended to encourage the improvement of engineering and technology education relevant to the practice of engineering, maintenance of a strong and diverse engineering workforce, encouragement of innovation and inventiveness, and promotion of technology development.

The prize is named in honor of its benefactor, **Bernard M. Gordon,** a leader in analog-to-digital conversion, tomography, and the development of medical and other high-precision instrumentation. Mr. Gordon is chairman and CEO of Analogic Corp., Peabody, Mass., and was elected to membership in 1991. Prior to heading up Analogic, he served as president and co-founder of Epsco, Inc., and as president of Gordon Engineering. He has more than 200 worldwide patents.

"The intent of the prize is to identify experiments in teaching and learning that potentially benefit and impact engineering and technology education," NAE President **Wm. A. Wulf** stated. "The focus is on innovations in curricular design, teaching methods, and technology-enabled learning."

Awarded biennially, the Gordon Prize will carry a cash award of $500,000, half of which will go to the recipient and half to the recipient's institution to support the continued development, refinement, and dissemination of the recognized innovation. The recipient also receives a gold medallion and a hand-scribed certificate.

In addition, each recipient will be asked to present a public lecture during the NAE's Annual Meeting in the year after his or her selection as an awardee.

Nomination information is available online at www.nae.edu/awards. For additional information, please contact the NAE Awards Office at (202) 334-1628.

NAE Treasurer Gray To Step Down

Paul Gray with NAE National Meeting symposium speakers. From left: Wm. A. Wulf, Charles Vest, Paul Gray, Gail Marcus, Corbin McNeill, Jr., Peter Lyons, John Holdren. Photo: Tom Sullivan.

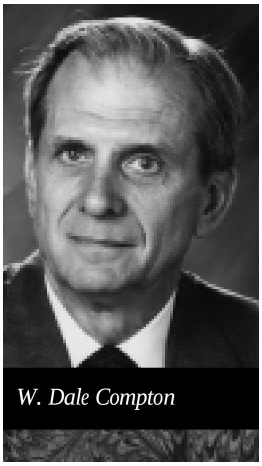
On 8 February, the National Academy of Engineering (NAE) held its National Meeting at the Beckman Center in Irvine, California, in honor of **Paul E. Gray** for his outstanding contributions to the Academy as treasurer and member of the NAE Council. Dr. Gray steps down on 30 June 2001 at the completion of the two-term tenure allowed by the NAE bylaws. His wise counsel on issues of importance to engineering technology have helped to advance the Academy's goals and objectives in support of the nation's technological health. He served the Academy with distinction during a period of change and growth and through several transitions in leadership. His advice on institutional management served the Academy well during good times and difficult times alike. In particular, he played an important role in keeping the Academy on course through a time of crisis in leadership to ensure the continuing vitality of the institution.

Reflecting Dr. Gray's personal interest, the symposium topic was "Nuclear Power: The Option for the 21st Century?" The background synopsis provided to symposium participants stated the following:

> Throughout the 20th century, energy production relied mainly on fossil fuels. With world population expected to double in the next 50 years and developing nations rapidly moving toward industrialized economies, the demand for fossil fuels will continue to grow. The energy and resource needs of the 21st century will require other engineering options and solutions. Nuclear energy sources have the potential to provide energy without carbon dioxide emissions and preserve fossil fuel resources for other uses, such as the production of chemicals. However, the political, social, and safety issues associated with building and operating nuclear plants, waste disposal and proliferation have paralyzed the nuclear power industry. Given the energy, material, and environmental needs of the world in the 21st century, the future nuclear power option must be addressed.

The symposium committee was chaired by **Charles M. Vest,** president, Massachusetts Institute of Technology. Speakers were **John P. Holdren,** Teresa and John Heinz Professor of Environmental Engineering, John F. Kennedy School of Government, Harvard University; Dr. Peter Lyons, Science Advisor to Sen. Pete Domenici (R-N.M.); Dr. Gail Marcus, principal deputy director, Office of Nuclear Energy Science and Technology, U.S. Department of Energy; and Corbin A. McNeill, Jr., chairman and co-chief executive officer, Exelon Corp.

From the Home Secretary



W. Dale Compton

With the approval of the NAE Council on 8 February, I am pleased to announce a new program—*Project 2003*—that we hope will identify the new directions that engineering is taking. The goal is to have these new directions reflected in the membership of the Academy. While we will continue to recognize outstanding individuals for their contributions to the many aspects of engineering already represented by the current NAE membership, we hope also to identify and reward individuals who are at the forefront of the new areas in engineering.

The program has three components. First, we will ask all members to help identify emerging disciplinary and interdisciplinary areas. A Delphi process will be used to obtain a consensus on the two most exciting new disciplinary areas relevant to each section and on the two most exciting new areas that cross the disciplinary boundaries of the sections. After a ranking process by the sections, the Council will choose two emerging disciplinary and two emerging interdisciplinary areas that it believes the Academy should emphasize.

Second, a search will be undertaken to identify and nominate individuals who are leaders in these new areas. An ad hoc peer committee, composed of one individual from each section of the Academy, will be formed by the Council to handle this task.

Third, the Committee on Membership will determine whether any of these nominations will appear on the 2003 election ballot. The current quota of 65 slots for the peer committees and 10 members at-large will be expanded to 65 slots for the peer committees and 15 members at-large. The additional five slots for members-at-large will be allocated to the Committee on Membership to be filled from recommendations from the ad hoc committee. Any slots that are not filled from this source cannot be used for other candidates and will not be filled. Individuals elected through this process will be asked to choose membership with one of the existing sections.

The Delphi study will be undertaken during the coming weeks with the expectation that the Council will be in a position to identify the areas to be emphasized and to appoint the ad hoc peer committee at its August meeting.

The Council considers this to be an experiment in encouraging the identification of newly emerging areas. After a two-year trial, the Council and the Membership Policy Committee will analyze how successful this effort has been and whether it should be continued, modified, or abolished. I encourage your participation.

W. Dale Compton
Home Secretary

NAE Thanks Donors

Sheila E. Widnall

It gives me enormous pleasure to report on another year of outstanding financial support from NAE members and our corporate friends. The breadth of support is indicated by the fact that about 30 percent more members participated in the 2000 annual fund drive than did so in 1999. The depth of support is defined by the growing list of major gift commitments to the Joint Campaign, which was formally launched last November. A campaign is, of course, not an end unto itself; it is a means toward an important end. And the gifts and grants the Academy has received are allowing it to move toward the broadened vision embodied in the NAE Strategic Plan—a vision that expands our historical mission to include a proactive role helping the engineering and technology enterprises anticipate and shape the future.

The Strategic Plan, first presented to the membership in 1999, represents a significant change in both the NAE's mission and business model. For over 36 years, we have undertaken studies at the federal government's request and with its funding support. In the last decade alone, the NAE and NRC conducted 1,000 such studies, on issues ranging as widely as the Department of Energy's effectiveness at managing nuclear waste sites, to the United States' high-technology workforce needs over the next 10 years.

In the 1990s, the NAE's leadership began to look beyond the federal government and reach out more aggressively to U.S. industry. We developed partnerships with industry to nurture a new generation of engineering talent. Those efforts have included programs such as *Frontiers of Engineering*, an annual roundtable of young engineers doing cutting-edge research in fields from biomedical imaging and robotics to advanced materials and manufacturing simulations, and *Celebration of Women in Engineering*, a web site that spotlights accomplished women engineers to encourage girls in middle school to pursue engineering careers.

And now, in this new century, the NAE is expanding its vision again, adapting to a nation and world being reinvented by the knowledge revolution and to new challenges requiring long-term, systematic, multistakeholder solutions. With this broader vision, we're taking the lead to identify and contribute to the resolution of those "over-the-horizon" issues with high science and technology content. The resolution of issues requires the sustained interactions of diverse stakeholders; an orientation toward exploring scenarios rather than finding one "best" answer; and the joint efforts of the NAE, the National Academy of Sciences, and the Institute of Medicine.

Examples of our new initiatives include:

- *Earth Systems Engineering:* An integrated approach to ecologically sustainable engineering. A key goal: making sure that mandated industry reforms are technologically feasible and can be implemented without reducing the competitiveness of U.S. industry.
- *Engineer 2020:* A look at the competencies industry will demand of engineering graduates in 2020, and how these competencies will and should impact engineering education. The program will also identify and promote innovations in engineering education likely to create value for employers.
- *Megacities:* An analysis of engineering challenges inherent in the creation of huge and expanding new cities around the globe, as well as of societal issues such as livability, employment, and governance.
- *Intellectual Property Rights (IPRs):* A frank look at the issues, from growing international friction over the assertion and exercise of IPRs, to heated criticism of "overly" protective mechanisms in the United States. The U.S. Patent and Trademark Office is an active stakeholder in this program.

Such initiatives, because they establish a path to the future that is both science-based and collaborative, can be enormously valuable to America. Yet, because they are necessarily broad in scale and open ended, they will not receive support from the U.S. government.

Certainly we will continue to respond to the federal agencies and their need for answers to clearly defined projects. But to truly fulfill our mission, the NAE increasingly must anticipate major, global issues and be ready with answers before the government even recognizes the questions, much less the options and constraints. This effort demands private support—the commitment of stakeholders like you.

We have asked our membership to help fund this new dimension of our mission, and you have begun to step forward in a marvelous fashion. I want to give special recognition to some recent, extraordinary commitments from our membership.

- Norm Augustine, who is using a combination of current and estate funds to support a new industry fellowship for over-the-horizon issues.
- Steve Bechtel, whose family foundation is supporting the NAE's Public Understanding of Engineering initiative.
- Si Ramo, who is terminating a charitable remainder trust and transferring the principal to help build an endowment for Frontiers of Engineering.
- John A. Armstrong, who made a major commitment to support Frontiers of Engineering.
- Robert Pritzker, who provided generous funding for the continued development of the "Greatest Engineering Achievements" project.
- Morris Tanenbaum, who also is supporting Frontiers of Engineering.

These gifts—and yours—are ensuring that the NAE rises to the new challenges before it; that it takes on an enhanced and expanded mission; and that it works to guarantee the technological health of our nation.

Sheila E. Widnall, NAE Vice President
Institute Professor
Massachusetts Institute of Technology

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The Golden Bridge Society, founded in 1995, recognizes the generosity of individuals who have made cumulative contributions of $20,000 or more, as well as planned gifts of any size.

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Committee on Engineering Education Adds Staff

Patricia F. Mead

Patricia F. Mead, Ph.D., accepted a full-time position as senior program officer for NAE's standing Committee on Engineering Education in January 2001. Dr. Mead previously was an assistant professor of mechanical engineering at the University of Maryland, College Park. During her tenure at the University of Maryland, Dr. Mead was actively involved in the Computer Aided Life Cycle Engineering Electronic Products and Systems Center (CALCE). Her research activities involved the development of physical models for life-cycle performance of photonic components, including fiber-optic components, semiconductor lasers, and light-emitting diodes. Dr. Mead was also actively engaged in several engineering education research initiatives and was a principle investigator in the Building Engineering Student Team Effectiveness and Management System (BESTEAMS) Teaching Center. In 1997, Dr. Mead received the NSF Faculty Early CAREER Award for her work in packaging and reliability of photonic components. She has been a faculty fellow of the Hewlett Packard Company (San Jose, Calif.), a doctoral fellow of the Eastman Kodak Company (Rochester, N.Y.), and has published numerous journal and conference papers in photonics and engineering education research. She looks forward to her new role with the Committee on Engineering Education and is excited about the prospect of participating in the development of policies impacting engineering education.

NAE Fellow On Board

Margaret E. Layne

Margaret E. (Peggy) Layne, P.E., accepted a two-year fellowship position as director of the Program on Diversity in the Engineering Workforce at the National Academy of Engineering in November 2000. Ms. Layne previously spent a year as an AAAS Science and Technology Fellow in the office of Sen. Bob Graham (D-Fla.), where she was responsible for water, wastewater, and solid and hazardous waste policy issues. She has 17 years of consulting experience and was formerly a principal at Harding Lawson Associates in Tallahassee, Fla., where she managed the office and directed hazardous waste site investigation and cleanup projects. Ms. Layne has degrees in environmental engineering from Vanderbilt University and the University of North Carolina School of Public Health. She served as president of the Society of Women Engineers in 1996–97 and is currently a member of the American Society of Civil Engineer's Committee on Diversity and Women in Civil Engineering. She is a registered professional engineer in three states.

NAE Newsmakers

Arthur E. Bergles, Clark and Crossan Professor of Engineering, Emeritus, Rensselaer Polytechnic Institute, received the 2000 **F. Paul Anderson Medal,** the highest technical award of the American Society of Heating, Refrigerating and Air-Conditioning Engineers. He was also elected a **foreign member of the Royal Academy of Engineering** in the United Kingdom. In November 2000 he received the **ASME Medal** from the American Society of Mechanical Engineers "for leading research and experimentation in thermal control of electronic components and dissemination of his findings worldwide."

Charles Elachi has been appointed director of NASA's Jet Propulsion Laboratory. He previously served as director of the lab's space and Earth science programs.

John W. Fisher, Joseph T. Stuart Professor of Civil Engineering and co-director, ATLSS Engineering Research Center, Lehigh University, is the recipient of the **2001 International Award of Merit,** presented on 21 March 2001 by the International Association for Bridge and Structural Engineering. The award recognizes Dr. Fisher's "contributions to the advancement of the knowledge of fatigue and brittle fracture of steel structure failures and to the applications of scientific research and technological developments in the fields of civil engineering structures." On 10 January 2001, Dr. Fisher received the **Roy W. Crum Distinguished Service Award** presented by the Transportation Research Board of the National Research Council. The award recognizes his outstanding contributions to bridge engineering and research. On 9 May 2000, Dr. Fisher received the **John Fritz Medal** at the Structures Congress 2000 for his "extraordinary vision in researching safety and performance of steel structures, and leadership in making discerning judgments for the public good."

John B. Goodenough, Centennial Professor of Engineering, University of Texas at Austin, received the 2001 **Japan Prize** from the Science and Technology Foundation of Japan at an April 2001 ceremony in Tokyo. Dr. Goodenough is being recognized for his "discovery of environmentally benign materials for high-energy density rechargeable lithium batteries."

Keith E. Gubbins, W. H. Clark Distinguished University Professor of Chemical Engineering, North Carolina State University, received the **William H. Walker Award** from the American Institute of Chemical Engineers for excellence in contributions to chemical engineering literature.

Matthys P. Levy, executive vice president and director, structural division, Weidlinger Associates, and Richard Panchyk are the authors of a new book titled *Engineering the City: How Infrastructure Works,* published by Chicago Review Press. Geared toward ages 9 and up, it introduces the principles that explain how structures are built, how they work, and how they affect the environment of the city and land outside it.

Gordon E. Moore, co-founder and chairman emeritus, Intel Corporation, has been selected to receive the fifth annual **Othmer Gold Medal** from the Chemical Heritage Foundation. He received the award on 27 April 2001 in New York in recognition of his seminal roles in the semiconductor world and on a wider stage, thus broadening and furthering the chemical enterprise and its heritage.

Shirley E. Schwartz, materials engineer, General Motors Powertrain, received the **Forest R. McFarland Award** at the 2001 Society of Automotive Engineers (SAE) meeting in Detroit. She was recognized for outstanding service in the organization of technical sessions or professional development seminars for SAE international meetings and conferences.

Arnold H. Silver, independent consultant and former manager, superconductor electronics and technical fellow, TRW Space and Electronics Group; **Z. J. John Stekly** (1981), consultant and former vice president, advanced programs, Intermagnetics General Corporation; and **Theodore Van Duzer**, professor in the graduate school, Department of Electrical Engineering and Computer Science, University of California, Berkeley, received the 2000 **IEEE Award** for significant and continuing contributions in the field of applied superconductivity.

Ponisseril Somasundaran, La Von Duddleson Krumb Professor and director of the NSF/IUCR Center for Advanced Studies in Surfactants and the Langmuir Center for Colloids & Interfaces, Columbia University, was elected a **foreign member of the Russian Academy of Natural Sciences** on 11 November 2000.

Savio L-Y. Woo, A. B. Ferguson Professor and director, Musculoskeletal Research Center, Department of Orthopaedic Surgery, University of Pittsburgh School of Medicine, was recently appointed to the position of **general secretary for the International Olympic Committee (IOC) Olympic Academy on Sport Sciences.**

NAE Calendar of Meetings

2001

8 March	NAE Regional Meeting Harvard University, Cambridge, Mass.
13 March	NRC Governing Board Executive Committee
17–18 March	Committee on Technological Literacy
19 March	NAE Regional Meeting Texas A&M University, College Station, Tex.
23 March	NAE Congressional Lunch
29–30 March	Forum on Diversity in the Engineering Workforce Smith College, Northhampton, Mass.
10 April	NRC Governing Board Executive Committee
26 April	NAE Regional Meeting Northwestern University, Evanston, Ill.
28 April–1 May	NAS 2001 Annual Meeting
2–3 May	Committee on Diversity in the Engineering Workforce Beckman Center, Irvine, Calif.
4 May	NAE Finance and Budget Committee Meeting
7–8 May	NAE Convocation of Professional Engineering Societies
8 May	NRC Governing Board Executive Committee
8–9 May	NRC Governing Board
10 May	NAE Audit Committee
10–11 May	NAE Council Meeting
21–22 May	Engineering and Healthcare Delivery Systems Workshop
31 May	NAE/AAES International Advisory Committee NAE Regional Meeting Columbia University
8 June	NAE Regional Meeting Lawrence Berkeley National Laboratory, Berkeley, Calif.
11 June	Council of Academies of Engineering and Technological Sciences (CAETS) Governing Board Helsinki, Finland
12–15 June	13th CAETS Convocation Helsinki, Finland
14 June	NRC Governing Board Executive Committee

All meetings are held in the Academies Building, Washington, D.C., unless otherwise noted.

In Memoriam

T. LOUIS AUSTIN, JR., 78, retired chairman and CEO, Brown & Root, Inc., died on 16 September 2000. Mr. Austin was elected to the NAE in 1979 for leadership in developing advanced power generations capabilities.

CHARLES F. AVILA, 94, retired chairman, Boston Edison Company, died on 29 October 2000. Dr. Avila was elected to the NAE in 1968 for inventive solutions to electric utility problems and contributions to optical science.

BERNARD B. BERGER, 88, professor emeritus of civil engineering, University of Massachusetts, died on 8 December 2000. Dr. Berger was elected to the NAE in 1979 for contributions to the solution of complex water resource problems.

LINCOLN ELKINS, 82, petroleum consultant, died on 27 January 2001. Mr. Elkins was elected to the NAE in 1980 for achievements in the field of petroleum reservoir mechanics and the use of these principles in establishing crude oil reserves.

RALPH E. FADUM, 87, dean emeritus, School of Engineering, North Carolina State University, died on 12 July 2000. Dr. Fadum was elected to the NAE in 1975 for contributions as a civil engineer, educator, consultant, researcher, and author; a pioneer in soil mechanics and foundation engineering.

WALLACE D. HAYES, 83, professor emeritus, Princeton University, died on 2 March 2001. Dr. Hayes was elected to the NAE in 1975 for contributions to the basic understanding of transonic and supersonic flow, and the Hayes equivalence principle for hypersonic similitude.

ALLAN F. HENRY, 76, professor emeritus of nuclear engineering, Massachusetts Institute of Technology, died on 28 January 2001. Dr. Henry was elected to the NAE in 1985 for continuous outstanding achievements in the understanding of reactor kinetics and in the development of methods for reactor analysis.

WILLIAM R. HEWLETT, 87, director emeritus, Hewlett-Packard Company, died on 12 January 2001. Mr. Hewlett was elected to the NAE in 1965 for his contributions to electronics.

HIROSHI INOSE, 73, director general, National Institute of Informatics, died on 11 October 2000. Mr. Inose was elected a foreign associate of the NAE in 1985 for outstanding contributions to digital communications and road traffic control, and for unflagging service to his profession.

TOM KILBURN, 79, emeritus professor, University of Manchester, died on 17 January 2001. Professor Kilburn was elected a foreign associate of NAE in 1980 for contributions to computer hardware design, including floating point arithmetic, paging, and read-only store.

LEE A. KILGORE, 95, retired consultant, died on 23 October 2000. Dr. Kilgore was elected to the NAE in 1976 for contributions in electromechanical engineering, particularly in the development and design of large rotating electric machinery.

RAY B. KRONE, 78, professor emeritus of civil and environmental engineering, University of California, Davis, died on 7 December 2000. Dr. Krone was elected to the NAE in 1995 for theoretical development and experimental verification of cohesive sediment dynamics and applications in design of control facilities in estuaries and coastal systems.

THOMAS H. LEE, 77, president emeritus, Center for Quality of Management, died on 3 February 2001. Dr. Lee was elected to the NAE in 1975 for leadership in better understanding and the advancement of high power switching devices through physics and engineering.

EUGENE F. MURPHY, 87, retired director, office of technology transfer, U.S. Department of Veterans Affairs, and retired consultant, died on 18 December 2000. Dr. Murphy was elected to the NAE in 1968 for pioneering developments in artificial limbs, braces, hearing aids, and aids to the blind.

WARREN H. OWEN, 73, retired executive vice president, Duke Power Company, died on 30 September 2000. Mr. Owen was elected to the NAE in 1985 for pioneering the first digital control of a coal power plant, designing the nation's highest efficiency generating plants, and for leadership in industry and the engineering profession.

C. DWIGHT PRATER, 83, retired senior scientist and consultant, Mobil Research & Development Corporation, died on 1 January 2001. Dr. Prater was elected to the NAE in 1977 for contributions to chemical kinetic theory, which helped delineate the effects of diffusion on chemical reactions.

WILL H. ROWAND, 92, retired vice president, Babcock & Wilcox Company, died on 21 February 2001. Mr. Rowand was elected to the NAE in 1968 for development of apparatus and systems for fossil and nuclear fuel conversion.

A. RICHARD SEEBASS, 64, professor, Aerospace Engineering Sciences, University of Colorado, died on 14 November 2000. Dr. Seebass was elected to the NAE in 1985 for fundamental contributions in aerodynamic theory related to development of computational fluid mechanics and for service in engineering education.

CLAUDE E. SHANNON, 84, Donner Professor of Science, emeritus, Massachusetts Institute of Technology, died on 24 February 2001. Dr. Shannon was elected to the NAE in 1985 for devising a mathematical theory of communication, now called information theory.

National Research Council Update

High-Tech Labor Squeeze

A recent congressionally mandated report by the National Research Council's Committee on Workforce Needs in Information Technology says that while skilled foreign workers can help relieve a tight high-tech labor market in the United States, cultivating adequately trained U.S. workers is a critical element as well. The report focuses primarily on professional occupations in information technology, such as systems analysts, computer scientists, and programmers.

Congress recently responded to concerns about the availability of skilled workers in the high-tech industry by increasing the number of H-1B visas, which allow highly skilled foreigners to work in the United States on a temporary basis. The report calls for changes to the government's policies on foreigners who work in the United States temporarily and permanently.

The committee also examined claims of age discrimination in the high-tech industry. While it found some difference in the experiences of workers over the age of 40 and younger workers, the committee could not determine whether such differences were the result of illegal age discrimination, legal conduct by employers that may be perceived as discriminatory, personal choices, or the ramifications of a rapidly changing industry.

The committee's recommendations include establishing more diversified corporate recruiting practices, improving secondary mathematics education, upgrading the skills of existing college and university faculty, and more flexible government hiring policies.

NAE member **Joel Moses,** Massachusetts Institute of Technology, was a member of the committee that produced the report *Building a Workforce for the Information Economy*. The report can be purchased or read online at www.nap.edu/catalog/9830.html.

An Agenda for Environmental Sciences

To help the U.S. government identify new environmental science projects that should receive high priority, a recent NRC report identifies eight important areas of environmental research for the next generation. Produced by the Committee on Grand Challenges in Environmental Sciences, the report further narrows this list to four areas of research that merit immediate investment. The committee did not prioritize the challenges, briefly described below, saying that they were of equal importance. However, the first four listed are those that should receive immediate attention, according to the committee.

- **Biodiversity and ecosystem functioning.** An improved understanding is needed of the factors—including human activities—that affect biodiversity and of how biodiversity relates to the overall functioning of an ecosystem.
- **Hydrologic forecasting.** More research is needed to help predict changes in freshwater resources and in the environment caused by floods, droughts, sedimentation, and contamination.
- **Infectious disease and the environment.** To prevent outbreaks of infectious diseases in plants, animals, and humans, better understanding is needed of how pathogens, parasites, and disease-carrying species, as well as the humans and other species they infect, are affected by changes in environments.
- **Land-use dynamics.** Recent advances in data collection and analysis should be used to document and understand the causes and consequences of changes in land cover and use.
- **Biogeochemical cycles.** A major challenge is to understand how changes in the balance of carbon, oxygen, hydrogen, nitrogen, sulfur, and phosphorus in soil, water, and air affect the functioning of ecosystems, atmospheric chemistry, and human health.
- **Climate variability.** More needs to be learned about how the Earth's climate varies over a wide range of time scales, from extreme storms that develop quickly to changes in weather patterns that occur over several decades.
- **Institutions and resource use.** More information is needed about how the condition of natural resources is shaped by markets, governments, international treaties, laws, and informal rules that govern environmentally significant human activities.
- **Reinventing the use of materials.** Additional data are needed on the forces driving human use of reusable metals such as copper and zinc, hazardous metals such as mercury and lead, reusable plastics and alloys, and ecologically dangerous compounds such as CFCs and pesticides.

NAE member **Robert A. Frosch,** Harvard University, was a member of the committee, which solicited nominations for "grand" challenges from the United States and abroad. The report, *Grand Challenges in Environmental Sciences*, can be purchased or read online at www.nap.edu/catalog/9975.html.

Publications of Interest

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Biobased Industrial Products: Research and Commercialization Priorities. Discusses the concept of the biorefinery and outlines proven and potential thermal, mechanical, and chemical technologies for conversion of natural resources to industrial applications; illustrates the developmental dynamics of biobased products through existing examples, as well as products still on the drawing board; and identifies priorities for research and development. Paperbound, $35.00.

Building a Workforce for the Information Economy. Offers an in-depth look at information technology workers—where they work, what they do, and the policy issues they inspire. The report suggests a number of steps—in government, education, and industry—for reducing the current shortage of IT workers. Paperbound. $39.95.

Design in the New Millennium: Advanced Engineering Environments: Phase 2. Advanced simulation, computing, and telecommunications technologies will someday enable teams of widely scattered researchers, designers, manufacturers, and customers to develop new products and carry out new missions with unprecedented effectiveness. This report describes organizational and procedural changes that government, industry, and academic organizations can make to take advantage of existing and soon-to-be-available technologies. Print on demand, $23.00.

Female Engineering Faculty at U.S. Institutions: A Databook. Contains statistical information about the status and careers of women on U.S. engineering faculties. Includes information on race/ethnicity, degrees held, employment history, work activities, and tenure status. Forthcoming. Paperbound, $36.00.

Grand Challenges in Environmental Sciences. Identifies a handful of important areas for environmental research in the coming decades, including four that merit immediate investment: biodiversity and ecosystem functioning; hydrologic forecasting; infectious disease and the environment; and land-use dynamics. Forthcoming. Paperbound, $35.00.

LC21: A Digital Strategy for the Library of Congress. Examines the impact of digital information on the Library of Congress and makes recommendations for developing a new system for digital objects that is integrated with the existing systems for acquiring and archiving physical formats. Paperbound, $37.00.

Making IT Better: Expanding Information Technology Research to Meet Society's Needs. Highlights the fundamental importance of research to ensure that information technology, a critical underpinning to our nation's success, keeps pace with society's expanding needs. Paperback, $34.95.

Nature and Human Society: The Quest for a Sustainable Future. Over the next 100 years, two-thirds of all life forms on Earth face extinction, largely because of uncontrolled development by humans. This summary of the second National Forum on Biodiversity describes the crisis ahead and the need to build a sustainable world in which animals, plants, fungi, microorganisms, and people coexist harmoniously. Hardcover, $79.95.

Renewable Power Pathways: A Review of The U.S. Department of Energy's Renewable Energy Programs. Reviews the DOE Office of Power Technologies (OPT) and makes recommendations for OPT as a whole as well as for individual OPT programs, including research into biopower, hydropower, geothermal, solar, and hydrogen energy generation methods. Paperbound, $30.75.