Spring 2011

URBAN SUSTAINABILITY

The BRIDGE

LINKING ENGINEERING AND SOCIETY

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

Promoting the technological welfare of the nation by marshalling the knowledge and insights of eminent members of the engineering profession.

The BRIDGE

NATIONAL ACADEMY OF ENGINEERING

The Bridge (ISSN 0737-6278) is published quarterly by the National Academy of Engineering, 2101 Constitution Avenue, N.W., Washington, DC 20418. Periodicals postage paid at Washington, DC.

Vol. 41, No. 1, Spring 2011

Postmaster: Send address changes to *The Bridge*, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Papers are presented in *The Bridge* on the basis of general interest and timeliness. They reflect the views of the authors and not necessarily the position of the National Academy of Engineering.

The Bridge is printed on recycled paper.

A complete copy of *The Bridge* is available in PDF format at *http://www.nae.edu/TheBridge*. Some of the articles in this issue are also available as HTML documents and may contain links to related sources of information, multimedia files, or other content.

The BRIDGE

Volume 41, Number 1 • Spring 2011

LINKING ENGINEERING AND SOCIETY

Editor's Note

Features

NAE News and Notes

(continued on next page)

Editor's Note

GEORGE BUGLIARELLO
1927–2011

As this issue went to press, we learned of the death of our dear friend and mentor George Bugliarello, NAE Foreign Secretary and long-time "Interim Editor in Chief" of *The Bridge*. His wise counsel, kind disposition, and can-do spirit will be greatly missed.

A tribute will appear in the June issue.

Perspectives on Urban Sustainability

Cities are home to half the world population—about 80 percent in the United States. These vibrant centers of activity impact global sustainability with their large footprints; concentrations of pollution and consumption; financial, technological, and knowledge networks; global business reach; and cultural influence. As the world urban population increases, however, risks to urban dwellers also increase.

Recent disasters have reminded us that most large cities are located in areas susceptible to natural disasters, such as floods, earthquakes, hurricanes, volcanic eruptions, and tsunamis. In addition, they are potential targets for mass destruction (e.g., Tokyo, London, Warsaw, etc.) and terrorism (e.g., New York, London, Mumbai, Madrid, and Baghdad). Cities are also subject to epidemics and dramatic social upheavals (e.g., the American, French, and Russian revolutions). The fact is that cities are risky, and the risks extend to the rest of the world.

Thus cities are critical national, as well as global infrastructures. Today, the urban and global contexts for sustainability often clash. For example, the introduction of electric cars in a city is likely to increase pollution from power plants in the countryside, and when a city expands, it destroys precious natural resources. Ultimately, however, the two contexts are bound to coincide. The challenge is how to make this happen without catastrophic consequences on either level.

Rapid advances in the knowledge of living systems, a myriad of inventions and innovations, and the rapid tempo of change in social paradigms, such as networking, flatter organizations, decentralization, conservation, and less authoritarianism, make it difficult to predict how these phenomena will shape cities in the future. We will need realistic models that consider cities as complex systems with biological, social, and technological components that interact with each other and with the external environment. Jonathan Fink's article in this issue of *The Bridge* argues for an Urban Genome Project (inspired by the Human Genome Project) to develop road maps and predictions for individual cities based on both common urban characteristics and idiosyncratic features (p. 5).

Security, economic, environmental, health, and quality of life are essential for evaluating the sustainability of all cities. A model that includes the biological, social, and technological dimensions of a city can inform decisions about potential trade-offs and synergies, predictions for the future, and unexpected or unwanted consequences. A simple example is the unemployment caused by the elimination of traditional, labor-intensive occupations that have provided livelihoods for generations. Another example is the decrease in the number of inhabitants per dwelling in the United States in the last 40 years. Even if the U.S. population remains stable, we will need a substantial number of new dwellings.

The optimization of technological systems can have profound biosocial implications. Centralization *versus* decentralization, for example, which implies a shift in control from community to individuals or *vice versa*, is a central factor in modernizing power-delivery and water-delivery systems. The article by Glen Daigger of C2HM Hill focuses on the effective, efficient treatment, delivery, and overall management of water resources (p. 13).

New infrastructure and public works must also be designed to enhance the quality of life and contribute to urban sustainability. Co-location, equity, and sustainability are important criteria for the innovative structures and systems described in the article by Hillary Brown of New Civics Work and City College of New York (p. 19).

Assessing the myriad feedback loops of a city is essential for ensuring good governance and adaptability, whether for reducing energy consumption, addressing traffic congestion, or enhancing quality of life. Aging populations, a feature of cities in the developed world and China, will require infrastructural modifications, particularly in suburbs, which have limited mass-transport capabilities. Older workers will also require new forms of employment in industry and services. Conversely, in the cities of the developing world, particularly in the Middle East, where the majority of the population is under 30. The pressing issue is to structure economies and industries to provide employment for them.

The unstoppable trend toward automation and the replacement of manual laborers is bound to reshape cities and, perhaps, lead to the realization of the age-old dream of machines that free us from the servitude of work. However, as a result, cities must be reorganized to ensure the livelihoods of displaced workers and ensure that cities remain sustainable.

U.S. suburbs, where half of urban populations live and where more jobs are being generated than in cities proper, are affected by unsustainable consumption of resources and changing socio-economic profiles. In many areas, middle class suburbanites are migrating back to cities, and city residents are migrating to suburbs in search of better schools for their children and better job opportunities.

As cities face these new challenges, they will need multidimensional, multiscale models, from the microscale of the individual to the hyper macroscale of urban agglomerates and megalopoles. The article by Catherine Ross and Myungje Woo of Georgia Tech raises issues related to megaregions—areas that encompass agglomerations of cities and suburban areas, and sometimes exurban and rural areas (p. 27).

In general, cities in both the developed and developing world must improve social institutions to manage emerging problems related to demographics, security, resources, innovation, and quality of life. However, because of major differences in the development of biosocial and technological systems, cities in the more affluent developed world do not provide a satisfactory model for cities in the developing world, which are likely to have weaker service sectors, more widespread and desperate poverty, and a lower quality of life. Improving human services is one of the most important ways of improving efficiency and economic conditions in cities in the developing world. Xuemei Bai, of CSIRO Ecosystem Sciences, describes examples of sustainability experiments in Asia (p. 35).

Today, a *de facto* global system connects, with different intensity, cities world-wide through loosely organized networks of geopolitical connections, trade, tourism, and cultural and personal relations, and the transmission of knowledge is a key element of the world infrastructure. However, these networks have not yet systematized the exchange of knowledge or enabled cities to take advantage of potential synergies.

Attempts to balance biological, social, and technological systems are raising new questions and forcing new policy choices, such as hard technological solutions versus potentially cheaper but often more difficult to accomplish biosocial soft solutions, or centralized *versus* decentralized systems.

Examples of cross-cutting policy choices include whether to subsidize an infrastructure system, such as a water supply system, or to subsidize only those who are unable to pay and charge the full cost to other users to ensure that the system remains economically viable. Other examples are decisions related to improving connections between individual health, social goals, and food technologies (e.g., ordinances for reducing salt and fats in restaurants and fast food).

From a different perspective, cities, with their concentrations of materials and resources, can be seen as "mines of the future." A recent focus has been on the potential reuse of materials embedded in outdated urban structures and products, from bridges and buildings to personal electronic devices. The potential of "city mining" is the subject of an article by Tom Graedel of Yale University (p. 43).

Urban concentrations increasingly impact global sustainability. They generate more than half of the world's economic output and its pollution. Will they continue to grow? Will people from rural environments continue to migrate to cities in search of more opportunities and a better life? Will the dysfunctionalities in every large city abate or become more intractable, leading to smaller urban concentrations? What is the future of suburbs? How will cities adapt to major changes in population dynamics?

Answering these questions will require a better understanding of the complex phenomenon of urbanization, sustainability, and potential impacts on the future of our species. The articles in this issue, which address some of these questions, are part of ongoing discussions about the challenges of urban sustainability.

George Bugliarello

The Human Genome Project may provide a model for mapping the "urban genome."

The Case for an Urban Genome Project

A Shortcut to Global Sustainability?

Jonathan Fink

Jonathan Fink is Foundation Professor in the School of Earth and Space Exploration, Arizona State University, and Vice President for Research and Strategic Partnerships, Portland State University.

We live in an urbanizing age, an age when people seeking economic opportunity, better health care and education, and cultural engagement are migrating from the countryside to cities. Despite the popular belief that cities are sites of wasteful consumption and pollution, when properly designed and administered they can have lower per capita environmental impacts than the rural areas from which their populations come. In fact, more and more people living in places where they can potentially consume less is arguably the single most effective way to achieve global sustainability goals (Calthorpe, 2010).

Despite the promise of cities, however, they do not automatically become engines for positive social transformation. Every city requires a complicated road map showing which policies, practices, and technologies can move its residents toward a more prosperous, healthier, and environmentally responsible future.

Because every metropolitan region has idiosyncrasies that influence the character of its road map, the discovery of general principles that might apply to all cities has been slow. What if we could classify the myriad attributes of a city into a finite set of characteristics, and these categories could in turn point urban policy makers toward the best options for alleviating poverty, stabilizing climate, and achieving energy independence? Is this just a utopian fantasy?

Perhaps not. Think, for example, of the Human Genome Project (HGP), one of the most celebrated scientific accomplishments of the late 20th century. The major public- and private-sector investments in HGP were justified on the grounds that all people share a common genetic framework, which when fully deciphered could point the way to cures for human diseases. Might we apply the same logic to cities, using a classification system for all urban traits—an Urban Genome Project (UGP)—to suggest the way(s) to metropolitan health?

Could such a typology inform computer-based models that can map alternative futures for individual cities and for the urbanized world as a whole? What new kinds of data would we have to collect? And how should the contributions of governments, non-governmental organizations (NGOs), companies, and their academic partners be funded, coordinated, and applied?

In this article, we explore these questions through an analogy with genetics and cite examples of technology and policy options that are already moving us toward a more scientific approach to achieving urban sustainability.

A critical first step for an Urban Genome Project would be to measure and classify cities using a set of common indicators.

The Components of an Urban Genome Project

It took 13 years to characterize the human genome (McElheny, 2010), and the translation of that knowledge into treatments for disease is just beginning. Nevertheless, the initial political and financial support for HGP would not have materialized without the expectation that these applications would eventually be possible. In addition, the U.S. government's intent to fund and coordinate the mapping of the genome shifted the emphasis from competition to collaboration and turned a seemingly unattainable idea into reality.

Similarly, a critical first step for a UGP would be to measure and classify cities using a set of common indicators. The greatest benefit of this exercise would be realized only later, when that information is entered into models that can forecast alternative outcomes. Those outcomes would, in turn, support informed choices, based partly on the real-world experiences of other cities. Equally important would be setting up a coordinating body to help finance and oversee the project.

A successful UGP would thus require: (1) a strategy for collecting and classifying urban characteristics; (2) the use of models and decision-making tools to sift through alternative future options; and (3) a well respected organization to administer and assemble resources. As we will see, many steps along this path have already been taken.

Urban Measurement: Identifying the DNA of Cities

Cities come in all shapes and sizes, from compact, sophisticated Scandinavian centers to disorganized East African refugee camps[1] to automobile-dominated Sun Belt urban sprawl. Despite their variety, these conurbations can all be described in terms of common factors, such as physical and political boundaries, demographics, infrastructure, governance systems, commercial institutions, and natural resources. Each of these factors can, in turn, be subdivided into dozens of variables.

Physical attributes of cities, such as air quality, water flow, traffic patterns, building materials, and land use, can be tracked directly. Socio-economic properties, such as jobs, housing, and health outcomes, must be inferred from financial, demographic, occupational or service records maintained mostly by governments.

The Infusion of New Technologies

A key step in the development of a UGP will be the infusion of new technologies. In less affluent areas, urban information is still assembled and transmitted manually. In more advanced countries, data retrieval is becoming automated through embedded sensors, wireless transmitters, GPS devices, and software that can extract critical information from web-based databases. Some of these digital methods may soon become cheap enough to be deployed without capital-intensive intermediate steps, just as cell phones have penetrated markets in countries that never had landlines.

For example, a promising application is cell-phone geo-positioning to track mobility patterns (Ratti et al.,

[1] Some African refugee camps have populations of 300,000 people. Online at *http://www.msnbc.msn.com/id/31569565/ns/world_news-africa/*.

2006). In order to send a signal to a particular phone, wireless companies must repeatedly calculate its geospatial coordinates. This information, when stripped of personal identifiers, aggregated, and interpreted, can reveal trends in group activity. For instance, highway traffic and transit ridership can be monitored based on the locations of cell phones in commuters' pockets. Similarly, text messaging and postings to social media[2] can be mapped as a function of geography and time to illustrate, for example, dispersal patterns of people leaving a cultural or sporting event.

Cell phones can also be a tool for residents to help manage their cities through distributed data measurement. For instance, OpenStreetMap and other groups now commonly rely on volunteers with cell phones to prepare and aggregate real-time information for plotting passable routes through disaster zones.[3]

Bottom-Up and Top-Down Data Collection

Most methods of urban data collection are "bottom-up"; that is, sensors are located on or near the phenomena being monitored. "Top-down" approaches include remote sensing instruments mounted on satellites or aircraft. Although such instrument packages were initially deployed for non-urban purposes, such as observing oceans, the atmosphere, or agriculture, they can provide detailed, consistent, and objective coverage of city characteristics without direct physical access. So far, the use of top-down information by municipal governments has been largely restricted to mapping resources on visible-spectrum images.

Other promising tools include infrared spectrometers that measure both the temperature and composition of urban surfaces (Quattrochi et al., 2000). These data can track dust generation in cities, reveal heat loss through poorly insulated roofs, and map vulnerabilities to urban heat-island effects. LIDAR can show the shapes of individual buildings and can help estimate the vulnerability of low-lying areas to sea-level rise.[4] Interferometric synthetic aperture radar (InSAR) can show how falling water tables beneath cities lead to ground subsidence.[5]

If satellites with sensors and targeting schedules were optimized for urban priorities, they could be even more useful. However, this idea has not yet gained traction with government agencies because no single application has been considered important enough to justify their expense ($50–$200 million). The most likely motivation will be the mitigation of urban heat, which has killed tens of thousands of people in Europe in the past decade and which will certainly worsen as global warming accelerates. One or more "CitySats"[6] could provide standardized inputs for all cities, which is not possible today.

Once an over-arching program has been established, interest groups can develop subsets and analyses for particular applications.

The Need for Standardized Measurements

For the purposes of a UGP, it will be critical that there be broad agreement on a strategy for common indicators. Once an over-arching program has been established, interest groups can develop subsets of measures and analyses related to particular applications, such as transportation planning, energy use, or housing affordability. A UGP could not only catalogue these indicator subsystems, but would also serve as the host database that would ensure the quality control, correlation, and distribution of data to city administrators and the public.

Every municipal body regularly already records many urban variables. But because no two cities measure all of them the same way, it is extremely difficult to compare cities or to identify common patterns of urban practice. To overcome this limitation, several groups, including United Nations Habitat,[7] ICLEI (Local Governments for Sustainability),[8] the Inter-American Development Bank (IDB),[9] academic groups, and private companies

---

2 Online at *http://www.casa.ucl.ac.uk/tom/*.

3 Online at *http://haiti.openstreetmap.nl/*.

4 Online at *http://www.epa.gov/climatechange/effects/coastal/*.

5 Online at *http://www.adwr.state.az.us/azdwr/Hydrology/Geophysics/LandSubsidenceInArizona.htm*.

6 Online at *http://cesa.asu.edu/sites/default/files/Phil%20Christensen%20Intro.pdf*.

7 Online at *http://ww2.unhabitat.org/programmes/guo/guo_indicators.asp*.

8 Online at *http://www.iclei.org/index.php?id=801*.

9 Online at *http://www.iadb.org*.

(e.g., SustainLane)[10] have attempted to create urban indicator systems.

Each of these groups has focused on a subset of urban interests. For instance, Habitat's indicators track progress toward meeting housing goals, IDB's concentrate on natural hazards, and SustainLane's are focused on sustainability measures. These limited approaches cannot capture interconnections among urban factors and, therefore, have less value for managers than more broad-based urban measures.

In 2006, the World Bank initiated the most ambitious and general urban-indicator project to date. First, they commissioned a study in which nine cities were asked to develop a list of essential metrics that they would be willing to measure on a regular basis. This exercise resulted in the launching, in 2009, of the Global City Indicators Facility (GCIF),[11] housed at the University of Toronto.

The Global City Indicators Facility provides a communication platform that enables cities to learn best practices from each other.

As of November 2010, GCIF had enlisted 125 cities and metropolitan areas in the program. Each city agrees to collect and annually update information, which is stored on a city-specific web page maintained by GCIF. Currently, 115 variables are grouped into 20 themes (e.g., water management, governance and finance, climate vulnerability, and aging) under the broad categories of city services and quality of life. Because of the breadth of data collected, GCIF can provide input for an unlimited number of analyses.

The backing of the World Bank for GCIF increases the chances that it may become the *de facto* global standard for city metrics. GCIF also provides a communication platform through which cities can learn best practices from each other.

Urban Modeling and Communication: Diagnosing Healthier Futures

The genetic information compiled by HGP cannot by itself provide cures for illness. It must be combined with models for determining how genetic conditions and non-genetic environmental factors influence human health. Once identified, suspected correlations between diseases and genetic factors must be evaluated by medical researchers who can test them against databases that may not yet exist.

A UGP would face a similar problem. Data collection and compilation programs provide a foundation for characterizing the status of cities. But identifying paths to reducing urban environmental and social impacts requires the ability to make predictions and show the implications of alternative policies.

For instance, a city that wants to reduce its water use would have to take into account the size, consumption patterns, and receptivity to conservation strategies of its population; the amount of water used to produce food, generate energy, support industry, and protect the natural environment; and the cost of infrastructure construction and maintenance. The interdependence of some of these variables might be approximated based on existing functional relationships, but other variables would have to be derived empirically from diverse data sets. These interactions would then have to be tested against historical data, and those data sets might or might not yet exist.

Approaches to Modeling Urban Systems

There are two general approaches to modeling urban systems: comprehensive and partial. The former, like the popular computer game SimCity, attempts to show how all components of a city interact and change as a function of policy choices. To date, such models have remained beyond computational capabilities or data availability.

Urban engineers, computer scientists, natural scientists, and planners have developed models that describe portions of urban systems, many in considerable detail. For example, ModFlow,[12] a model developed by the U.S. Geological Survey, shows how subsurface ground water flows beneath cities. The National Center for Atmospheric Research model, Weather Research and Forecasting (WRF) Model,[13] simulates urban climate.

[10] Online at *http://www.sustainlane.com/us-city-rankings/*.

[11] Online at *http://cityindicators.org*.

[12] Online at *http://water.usgs.gov/nrp/gwsoftware/modflow.html*.

[13] Online at *http://www.wrf-model.org/*.

And the Los Alamos National Laboratory model, Transims,[14] describes how intercity transportation networks function.

Note that no single model connects climate, ground water, and transportation. Even UrbanSim[15] (Waddell, 2000) uses agent-based microsimulation algorithms to forecast interactions among housing, jobs, and transportation, but does not directly link to ecological or geophysical variables.

The goal of developing a comprehensive, dynamic, urban modeling tool is also being pursued in the private sector. As an offshoot of IBM's Smarter Cities campaign, the company recently launched a game, called CityOne,[16] that combines SimCity's interactive appeal with real-world problems in four domains: water, energy, retail, and banking. In contrast to research- and operations-oriented models like UrbanSim, the purpose of CityOne is to educate professionals and the public about the trade-offs associated with managing urban systems.

Given the state of the art in city modeling today, a UGP should encourage researchers to bundle more focused models (e.g., Modflow; WRF) into an overarching framework like CityOne or UrbanSim.

Innovative Programs

Although building urban models is technically difficult, an even bigger challenge is ensuring that their outputs are useful to planners, politicians, and the public. The two innovative programs described below are designed to combine metrics, models, and visualization-based feedback mechanisms to aid decision making.

IBM is not the only company actively involved in addressing urban issues. Cisco Systems, Siemens, Autodesk, Google, and Microsoft all have programs for improving how cities function. In 2006, Cisco, NASA, and the city of San Francisco launched Connected Urban Development (CUD),[17] an initiative to provide Internet-based tools to help urban residents understand and reduce their carbon emissions.

The heart of CUD is the Urban EcoMap,[18] an interactive, web-based interface that aggregates information about city dwellers' energy consumption, transportation choices, and recycling rates. Individuals can input personal data to see how they compare with neighbors in their zip code or with people in the city as a whole.

EcoMap takes the "Prius effect"—the tendency of individuals to make positive changes in behavior if they can see the effects in real time (Fantino, 2008)—to a new scale. The EcoMap website currently shows only San Francisco and Amsterdam, but several other cities in Europe and Asia are in the process of joining the program.

One of the biggest challenges will be ensuring that the outputs of urban models are useful to planners, politicians, and the public.

EcoMap represents a promising element of a UGP. It offers residents several ways of understanding and contributing to the health of their cities. Future versions will include more urban characteristics (e.g., water consumption) and will link more closely with inventory functions for which city managers are responsible.

Other helpful innovations would be a standard format applicable to all cities and closer integration with indicator programs, such as GCIF, and other models, such as CityOne or UrbanSim. These enhancements would make it possible for managers and the public in all participating cities to interact and make decisions that promote sustainability.

Tools for Day-to-Day Decision Making

Day-to-day policy-making requires tools optimized for small, focused groups. One example is Decision Theater (DT), a facility housed at Arizona State University.[19] DT began as an immersive environment in

[14] Online at *http://tmip.fhwa.dot.gov/community/user_groups/transims*.

[15] Online at *http://www.urbansim.org*.

[16] Online at *http://www-01.ibm.com/software/solutions/soa/innov8/cityone*.

[17] Online at *http://www.connectedurbandevelopment.org*. In 2010, Cisco handed over leadership of CUD to NGOs The Climate Group (*http://www.theclimategroup.org*) and Metropolis (*http://www.metropolis.org*).

[18] Online at *http://www.urbanecomap.org*. The Urban EcoMap and companion San Francisco Solar Map (*http://sf.solarmap.org*) were developed in partnership with engineering firm CH2M HILL.

[19] Online at *http://www.decisiontheater.org*.

which decision making could be assisted by advanced visualization and collaborative techniques. Initially, DT projects used system dynamic models that enabled audiences of up to two dozen people to explore alternative futures in real time. Projects have since evolved to include technology-independent practices intended to help individuals from a variety of professional backgrounds communicate with each other.

Most DT projects involve urban issues, such as water management, land-use planning, crime fighting, and disaster response. Because so many groups in Metro Phoenix have used DT in their projects, the community has embraced it as a regional decision-making asset.

Sister sites are being set up in other cities around the world, making inter-urban comparisons easier.[20] Because the technical details of such facilities or programs may vary greatly, an organization or office that can serve as a neutral convener and synthesizer will be essential for a successful UGP.

Managing the Urban Genome Project

Prospects for Government Support

The success of HGP depended on cooperation among several sectors. The federal government provided funding and oversight; academia supplied research facilities and talent; industry provided technical advances, venture capital, and scientists; and NGOs served as advocates for political support. Federal sponsorship was the most critical factor, just as it would be for a UGP.

No federal mission agency "owns" the urban agenda.

HGP was one of the first federally funded "megascience" projects in biology. It was backed by the U.S. Department of Energy (DOE), which focuses on high-performance computing and the development of new technology, and by the National Institutes of Health (NIH), which is responsible for finding cures for disease.

Ultra-large-scale research programs in particle physics, astronomy, climate science, geology, and ecology have also secured political and federal agency support.[21] In contrast, the social sciences have not proposed an analogous project, in part because social science research is less instrument-intensive and, therefore, tends to be less expensive, and in part because many members of Congress tend to be skeptical of the social sciences.

Obtaining federal funding for a UGP would also have to overcome political challenges beyond the social science stigma. First, the federal government does not have a major emphasis on urban research. In fact, no federal mission agency "owns" the urban agenda, even though most of them oversee selected aspects of city life (e.g., the U.S. Department of Housing and Urban Development, [HUD], deals with shelter; U.S. Department of Transportation [DOT] addresses urban mobility; and U.S. Geological Survey [USGS] and Environmental Protection Agency [EPA] monitor urban water supplies).

Second, the unique role of cities in alleviating global sustainability challenges is not well understood by U.S. policy makers. Third, the short-term benefits of better planning and exchanges of ideas for urban policies would accrue disproportionately to developing countries.

There are signs, however, that the orphan status of urban research by government agencies may be coming to an end. The National Research Council (NRC), which often develops and articulates new federal research priorities, held a workshop in 2009 that brought together representatives of federal agencies and academia to discuss how government-funded urban research programs could be coordinated (NRC, 2010). Since then, a series of symposia on urban sustainability have been held in cities around the country to explore synergies between federal, state, and local participants. Coincidental with these meetings, HUD, DOT, and EPA launched the Partnership for Sustainable Communities, the first multi-agency research initiative that focuses on urban sustainability.[22]

Past NRC recommendations have led to the funding of major new academic and government research centers. The urban research community would benefit tremendously from the establishment of a National Science Foundation Engineering Research Center, Science and Technology Center, or Industry/University Cooperative Research Center.

[20] Online at *http://asunews.asu.edu/20100610_hustdecisiontheater*.

[21] The Manhattan Project and linear accelerators (physics); ground- and space-based telescopes (astronomy); U.S. Global Change Research Program (climate); Earthscope (geology); NEON (ecology).

[22] Online at *http://www.epa.gov/smartgrowth/partnership/*.

In the longer term, the federal government could establish a federal laboratory focused on sustainable urban systems. This facility could be affiliated with one of several mission agencies, such as DOE, EPA, or DOT. However, the most appropriate and novel arrangement would be a multi-agency center that would support interdisciplinary and interagency partnerships.

Prospects for Academic Support

A UGP might also have difficulty obtaining support from academia, because research universities are not well organized to participate. HGP relied on highly interdisciplinary research groups, including geneticists, biologists, chemists, computer scientists, mathematicians, ethicists, and policy experts. In addition, HGP promoted and benefited from the emergence of bioinformatics as a subfield of genetics and computer science programs in leading universities across the United States, Europe, and Japan.

An aggressive attempt to unravel an urban genome would require not only participation by large numbers of university faculty and students, but also the creation of urban taxonomy and dynamics, a new subdiscipline at the nexus of geography, sociology, history, political science, architecture, civil and environmental engineering, ecology, economics, computer science, and planning.

The timing for this kind of initiative may be propitious, as universities have recently begun formulating administrative structures in response to growing interest in sustainability. Experiments range from sustainability minors offered in traditional departments to free-standing schools of sustainability[23] to the repurposing of entire colleges[24] to support an emphasis on sustainability. Similarly, interest in urban systems could lead to a variety of new pedagogic approaches, from new degree programs to, perhaps, the redesign of entire universities.

Unlike the growth of genetics, which required large investments in infrastructure that could be supplied only by the wealthiest schools, "urban genomics" could be initiated without major financial outlays, especially at institutions that already have an "applied" urban focus. In the United States, many of these institutions are members of the Coalition of Urban Serving Universities.[25] As often happens, academic research and training changes direction in response to signals based on government funding priorities.

Global Aspects of Urban Studies

Unlike genetics in the 1980s, the applied study of cities is not dominated by U.S. institutions. In fact, many European[26] and Asian[27] universities have strong individual and collective programs already in place.

However, mapping and interpreting "urban DNA" will require complex new consortia that include academic groups as well as companies, NGOs, and government agencies. In addition, the participation of and application to cities in the global South, which have the largest populations and growth rates, will be as important as the participation of cities in the North.

Funding for international research may come from a wide variety of public and private sources, including the United Nations, development banks, international programs of government science foundations, the charitable arms of multinational corporations, and other major philanthropic organizations.

By linking data generation tools like CitySat with the validation capabilities of an indicator system like GCIF, modeling approaches like UrbanSim and CityOne, and decision-support tools like EcoMaps and Decision Theater, a UGP could significantly increase the contributions of cities to achieving global sustainability. Requirements for a UGP will include a well articulated vision for how all of these pieces would fit together, a multi-strategy approach for obtaining funding, and an international organization with enough "clout" to bring all of the players to the table.

HGP promised new solutions to age-old threats to human well-being. Even if the idea of a UGP is not fully implemented, just discussing its possibility could open doors to comparable benefits for society as a whole.

---

23 Arizona State University. Online at *http://schoolofsustainability.asu.edu*.

24 College of the Atlantic. *Online at http://www.coa.edu*.

25 Online at *http://www.usucoalition.org*.

26 European Urban Knowledge Network (*http://www.eukn.org/*), Sustainable Urban Development European Network (*http://www.suden.org/*), World Health Organization European Healthy Cities Network.

27 Asian Network of Major Cities. Online at *http://www.anmc21.org/english/*.

References

Calthorpe, P. 2010. Urbanism in the Age of Climate Change. New York: Island Press.

Fantino, E. 2008. Choice, conditioned reinforcement, and the Prius Effect. Behavioral Analysis 31(2): 95–111.

McElheny, V. 2010. Drawing the Map of Life: Inside the Human Genome Project. New York: Basic Books.

NRC (National Research Council). 2010. Pathways to Urban Sustainability. Washington, D.C.: National Academies Press.

Quattrochi, D.A., J.C. Luvall, D.L. Rickman, M.G. Estes, C.A. Laymon, and B.F. Howell. 2000. A decision support information system for urban landscape management using thermal infrared data. Photogrammetric Engineering and Remote Sensing 66: 1195–1208.

Ratti, C., R.M. Pulselli, S. Williams, and D. Frenchman. 2006. Mobile landscapes: using location data from cell phones for urban analysis. Environment and Planning B: Planning and Design 33(5): 727–748.

Waddell, P. 2000. A behavioral simulation model for metropolitan policy analysis and planning: residential location and housing market components of UrbanSim. Environment and Planning B: Planning and Design 27(2): 247–263.

The challenge of effective water management can also be an opportunity for enhancing the urban environment.

Sustainable Urban Water and Resource Management

Glen T. Daigger is senior vice president and chief technology officer, CH2M Hill, and an NAE member.

Glen T. Daigger

The National Academy of Engineering included urban water supply in the top five engineering achievements of the 20th century (Constable and Somerville, 2003), and in a survey by the *British Medical Journal* (2007), sanitation was the single most important contributor to improving public health in the past 150 years. Clearly, efficient water management is crucial to public health, a viable economy, and a livable urban environment.

Effective, efficient management of water resources is essential to a sustainable urban area. Water must be supplied for domestic, commercial, and industrial use, as well as irrigation and maintaining and enhancing local environments (e.g., urban streams). In addition, storm water must be managed to prevent flooding and environmental damage, and used water, which contains heat, organic matter, nutrients, and other constituents that can be extracted and reused, must be collected and managed.

Historically, with the exception of certain locations, such as the desert Southwest of the United States, water has been available in sufficient quantities, and providing supporting infrastructure has been relatively straightforward (Novotny and Brown, 2007; Solomon, 2010). Governments plan, implement, operate, and manage the physical assets (infrastructure) and institutions (urban water management utilities) to ensure adequate water management services, often the single most costly infrastructure investment by a municipal government. As populations increase, however, water is becoming increasingly scarce, leading to competition among users, one of which is urban areas (Daigger, 2007).

Enlightened professionals are also becoming increasingly aware that water is not only an essential public service, but can also be a vehicle for enhancing the urban environment (Novotny and Brown, 2007). For example, managing storm water by taking advantage of natural systems not only relieves the burden on infrastructure, but also enhances natural areas, reduces heat-island effects, and contributes to a pleasing, livable urban environment. In short, the challenges of providing urban water management services, which some consider a problem, can also be considered an opportunity for enhancing the urban environment. For example, the International Water Association Cities of the Future Program (IWA, 2011) promotes the idea of water-centric urban design (Hao et al., 2010; Novotny and Brown, 2007).

In this article, I describe a new approach to supplying and managing water and resource infrastructure to achieve urban sustainability. Examples of system components are also identified, as are challenges to implementing higher performing systems.

Sustainable Urban Water and Resource Management

Urban water and resource management involves the following steps: collecting water in sufficient quantities to meet needs throughout the urban area; treating collected water to achieve the quality required for specific purposes; distributing water to end users; collecting used water; treating used water for reuse, including for environmental enhancement; managing residuals from treatment processes; and extracting useful materials, such as heat, energy, organic matter, and nutrients, from the used water stream.

This approach differs from the historical approach in several respects (Daigger, 2009). First, water-supply options today include not only imported surface and groundwater, but also locally collected rainwater ("rainwater harvesting") and used water for reclamation and reuse. Second, all used water is reused, either to meet water-supply needs or to enhance and restore the environment.

Finally, the waste stream (used water) is no longer viewed as a necessary "evil" that must be managed to minimize harm. Instead, it is considered a resource from which useful products can be extracted. Heat can be extracted directly. Organic matter can be removed and used for energy production and the production of soil-conditioning products. Nutrients can also be extracted and re-used.

Infrastructure for implementing this newly defined system requires a significantly different approach to urban water and resource management (Table 1). For several reasons, water supply has historically depended on the importation of sufficient quantities of relatively pristine water from remote sources. First, because of the lack of pollution-control systems and technologies, local water supplies inevitably became polluted, making it impossible to produce safe drinking water in sufficient quantities. Thus, remote sources of water had to be imported.

This situation has changed, however, most importantly because of the development of effective treatment technologies that can produce clean water from a wide variety of sources (Daigger, 2003, 2008). In addition, the availability of remote, pristine source waters has diminished greatly in comparison to the human population. These trends have combined to make the use of local water supplies necessary.

Second, the historic system evolved when water was abundant and energy was inexpensive. Thus, the least expensive systems were those that optimized infrastructure costs. Moreover, because water was inexpensive,

TABLE 1 Comparison of Historical and Evolving Approaches to Urban Water and Resource Management

	Approach	
Item	**Historical**	**Evolving**
Water supply	Remote sources	Local sources
Optimized costs	Infrastructure	Water use, energy consumption
Functions	Single purpose systems for drinking water, storm water, and used water	Multipurpose systems to integrate functions
Configuration	Centralized systems	Hybrid systems (centralized and decentralized components)

economies of scale led to the selection of systems focused on meeting demand rather than managing consumption, which often also increased water use. Today, with limited water supplies and expensive energy, evolving systems focus much more on increasing water efficiency and minimizing energy use. Water demand is also managed to ensure a sufficient supply.

Third, water managements systems have evolved from single-purpose to multipurpose systems. Urban water and resource management systems were historically implemented sequentially as specific needs were identified and funding was obtained. As a result, systems for handling drinking water, storm water, and used water were often separate (except for sewers, which collected and conveyed both storm water and used water). These separate systems also provided services independently. Today, we know that many benefits are provided by integrating these functions into a single system (Daigger, 2008, 2009; Hao et al., 2010; Novotny and Brown, 2007).

Finally, systems have evolved from a centralized to a hybrid configuration that includes both centralized and decentralized components (Daigger, 2009). Because water was historically imported from outside the urban area, the most cost-effective infrastructure was a single or small number of systems, referred to as centralized systems, that treated and distributed water throughout the urban area. Similarly, because storm water had to be collected and removed from the urban area (because it was polluted), the most cost-effective approach was a single or small number of collection and conveyance systems. The same held true for the used water system.

The following sections address two key components of the evolving urban water and resource management infrastructure paradigm: (1) hybrid systems; and (2) water-supply and used-water source separation.

Hybrid Systems

Enabled by improved treatment technologies, local water resources are becoming increasingly usable, and treatment systems are being distributed throughout service areas. The resulting hybrid systems include both centralized and decentralized components. Three illustrative examples of hybrid systems are described below.

Green Infrastructure

Traditional, centralized storm water-management systems generally consist of drains and collection points that direct rainwater into pipes that convey it to existing streams and waterways. The objective is to collect and remove storm water rapidly to prevent local flooding.

Although these systems achieve their objective, they also have side effects. First, storm water picks up pollutants from urban surfaces, and those pollutants are thus conveyed into local waterways. Second, by inhibiting the infiltration of rainwater into the local groundwater, the system ultimately depletes local water resources. Third, fast-moving water directed through local waterways causes significant erosion.

Analyses of the hydrology of urban areas have shown that rainfall often has two principal components: (1) long-duration, low-intensity storms that produce significant volumes of storm water, which tends to build up pollution because of their frequency; and (2) short-duration, high-intensity storms, which are less frequent and therefore carry less pollution overall (Daigger, 2009).

Distributed storm water management and rainwater-harvesting systems collect rainwater and direct it either to storage areas for later use or to natural systems (e.g., swales and bioretention structures) that reduce the velocity of the water, infiltrate rainwater into the ground, and thereby remove pollutants. Such systems are often referred to as "green infrastructure," because (1) they typically rely on plants to control pollution and (2) they maintain or increase local water resources by recharging groundwater.

Although peak storm water flow rates are reduced by the processing capacity of distributed systems, rapid conveyance is usually necessary to deal with high-intensity storms. These supplementary systems, coupled with healthy local streams and waterways, prevent erosion.

Green infrastructure systems also have added benefits, such as the restoration of local ecosystems, reductions in urban heat-island effects as a result of replacing impermeable surfaces with natural surfaces that reflect less heat, and a more aesthetic, livable urban environment. Progressive urban areas (e.g., Portland, Oregon; Seattle, Washington; Philadelphia, Pennsylvania) are adopting this hybrid approach.

Used-Water Reclamation and Reuse Systems

Another hybrid system is the distributed used-water reclamation and reuse system (Jimenez and Asano, 2008). Driven by the increasing scarcity of water and enabled by modern treatment technology, used water is increasingly being reclaimed and reused in a variety of ways. Non-potable water produced from used water can be reused for irrigation and to supply industry. Potable water is achieved by treating used water to levels beyond those required for typical drinking water and introducing it into the local ground or surface water, where it mixes with the existing water supply. Water can then be withdrawn for further treatment and distribution.

Used-water reclamation and reuse require extensive collection and distribution systems, especially for centralized, non-potable systems that necessitate separate distribution for potable and non-potable water. The need for dual water-distribution systems presents a significant cost barrier, especially in existing urban areas, as well as a substantial increase in energy to convey both water supplies.

Only about 40 liters of water per person per day are needed for truly potable purposes.

In distributed used-water reclamation and reuse systems, treatment facilities are located adjacent to used-water pipelines. When sufficient capacity has been reached, enough used water can be removed and reclaimed to meet non-potable water demands in a modest service area. This approach not only reduces the size of the non-potable water-distribution system, but also reduces the required size of the used-water conveyance system downstream of the diversion point. Thus, significant system savings in cost and energy can be realized.

In-Home Treatment Devices

In-home devices can also be used to provide potable water. Generally purchased and installed on an elective basis by individual homeowners, these devices provide good quality water for most purposes, thereby reducing the amount of water that must be treated to a higher standard for truly potable purposes. In fact, the widespread consumption of bottled water represents another approach to achieving the same end.

Separation of Potable and Non-potable Water Supplies

We now turn to systems that provide separate non-potable and potable water supplies (Jimenez and Asano, 2008). A relatively small volume of water, on the order of less than 40 liters per person per day (L/capita-day), is needed for truly potable purposes (e.g., direct consumption and food preparation). A much larger volume of water, ranging from 100 to 400 L/capita-day, is used for other purposes (e.g., laundry, toilet flushing, bathing, and outdoor water use).

When water supplies were pristine and required little or no treatment to meet potable water standards, the provision of separate potable and non-potable supplies made little sense. Today, however, pristine water supplies are limited, and alternate water supplies must be used. However, because of the small amount of water used for drinking and cooking, treating all water to potable standards makes little sense. Moreover, water quality deteriorates in the distribution system. Thus water exiting a drinking-water treatment plant may exceed potable water-quality standards, but water that reaches the consumer may not.

One approach to addressing this problem, referred to as distributed water treatment (Weber, 2004), has been contemplated but not implemented at full scale. This approach consists of treating water on a centralized basis to non-potable standards, distributing it through a centralized system, and using some of it to supply distributed treatment systems that can treat small, necessary quantities of water to potable standards. A second approach is dual distribution of non-potable and potable water.

Numerous examples can be found of both approaches, but in general, treatment for potable water continues to be centralized, while treatment of non-potable water is either centralized or decentralized. Decentralized systems are less expensive, however, and have the advantage of treating locally harvested rainwater and reclaimed used water to non-potable standards, as required, and distributing it to meet local needs.

Another idea being evaluated and selectively implemented is the separation of used water into various components (Daigger, 2009; Henze and Ledin, 2001). Collecting used-water components made little sense when an abundant water supply was available to convey it, minimal treatment was required to dispose of it, and technologies for recovering resources from it were limited. Today, however, treatment requirements are

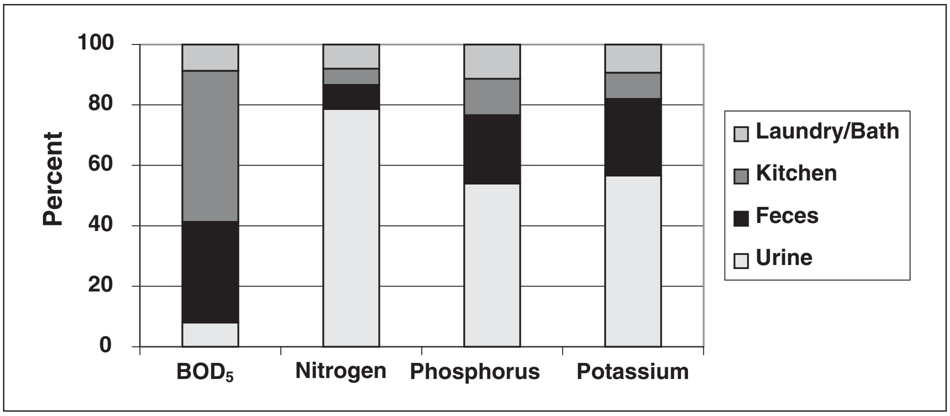


FIGURE 1 Distribution of constituents in domestic wastewater streams. BOD_5 = five-day biochemical oxygen demand. Source: Adapted from Henze and Ledin, 2001.

significant, and many options are available for extracting energy and nutrients from used water.

The logic for separating components is based on an analysis of the domestic wastewater stream (Figure 1). The principal constituents in this used water stream are biodegradable organic matter, expressed by five-day biochemical oxygen demand (BOD_5), and nutrients (nitrogen, phosphorus, and potassium). Organic matter can either be treated by conventional technology, which requires significant amounts of energy, or it can be used as a source of energy in and of itself. The nutrients have obvious value for agriculture if they can be recovered in a useful form.

Figure 1 also shows that the three principal contributors to the used water stream are grey water, black water, and yellow water. Grey water, which is used for laundry, bathing, and similar purposes, is the largest volume of domestic water. It also contains the most heat, as is apparent from the way it is used. When separated out, grey water, which is only modestly polluted, can be readily treated to non-potable standards.

Black water (feces) and kitchen waste, a relatively small volume of water, contain most of the organic matter in used domestic water. A variety of technologies are available for converting this organic matter into useful energy.

Most of the nutrients in used water are contained in yellow water (urine), less than 1 percent of the total volume of used water (generally 1 to 2 L/capita-day). Because the body excretes most unused pharmaceuticals and hormones through the kidneys, yellow water also contains a disproportionate amount of these materials. Thus separating out yellow water reduces the treatment required for grey and black water.

Challenges and Opportunities

Even though much remains to be learned about the potential of highly integrated urban water and resource management systems, we already know they have significant advantages. The direction of change is clear—from centralized, single-purpose components to hybrid, integrated systems.

The transition from past, centralized systems to hybrid, integrated systems presents many challenges (Table 2). In the past, the various components of urban water and resource management systems were managed separately, often by different utilities or different departments in a utility. Integrated systems will

TABLE 2 Implementing Integrated Urban Water and Resource Management Systems

	Approach	
Item	Historical	Evolving
Institutions	Single purpose	Integrated
Management		
Conveyance	Distributed	Distributed
Treatment	Centralized	Distributed
Financing	Volume-based	Service-based
Planning	Independent, followed city planning	Integrated with city planning

require a new management structure, hence institutional reform.

Professional education and practice have also historically been organized according to system components (e.g., drinking water, storm water, and used water). To accelerate the transition to integrated, higher performing systems, education, professional practice, and utilities' institutional structures must also become more integrated.

Management of a hybrid, integrated system is necessarily more complex than management of a traditional system. Distributed water treatment and integrated potable and non-potable water supplies, storm water, and used water significantly increase the complexity of management and will require the development of new managerial systems.

In the future, the responsibility for system management may also be in private rather than public hands, which has raised concerns that public health and environmental protection might be compromised. Fortunately, we already have technology to manage increasingly distributed systems, and this technology will no doubt improve with "learning by doing."

Urban water and resource management utilities have traditionally been financed on the basis of "volume"—the volume of water sold and the volume of used water collected and treated. As happened with electrical utilities, when the volume sold decreases, financial resources for the utility also decrease, which may compromise the availability of financing for new systems. Thus we will need a funding approach based on service rather than volume.

The most difficult challenge, however, may be associated with planning and implementing urban infrastructure as a whole. Historically, the planning and expansion of urban areas occurred with minimal consideration of water and resource management, often with the assumption that traditional, centralized systems would be used.

However, evidence is accumulating that water can be a central feature of sustainable urban areas, and the concept of water-centric urban areas is becoming more common (Hao et al., 2010; Novotny and Brown, 2007). Achieving this vision will require that water professionals become strategic partners with urban planners. The International Water Association Cities of the Future Program promotes such partnerships (IWA, 2011).

Conclusions

In conclusion, urban water and resource management systems are evolving in a clear and unified direction: (1) from the use of remote water supplies to the use of local water supplies, such as rainwater and reclaimed used water; (2) from optimizing the cost of infrastructure to optimizing water use, energy production, and nutrient extraction; (3) from independent, single-purpose components to integrated, multi-purpose systems; and (4) from centralized systems to hybrid systems that incorporate centralized and decentralized components. These changes are necessitating changes in institutions, system management, financing, and urban planning.

References

British Medical Journal. 2007. Medical milestones. British Medical Journal 334: S1–S20.

Constable, G., and B. Somerville. 2003. A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives. Washington, D.C.: Joseph Henry Press.

Daigger, G.T. 2003. Tools for future success. Water Environment Technology 15(12): 38–45.

Daigger, G.T. 2007. Wastewater management in the 21st century. ASCE Journal of Environmental Engineering 133(7): 671–680.

Daigger, G.T. 2008. New approaches and technologies for wastewater management. The Bridge 28(3): 38–45.

Daigger, G.T. 2009. Evolving urban water and residuals management paradigms: water reclamation and reuse, decentralization, and resource recovery. Water Environment Research 81(8): 809–823.

Hao, X., V. Novotny, and V. Nelson. 2010. Water Infrastructure for Sustainable Communities. London, U.K.: IWA Publishing.

Henze, M., and A. Ledin. 2001. Types, Characteristics and Quantities of Classic, Combined Domestic Wastewater. In Decentralised Sanitation and Reuse: Concepts, Systems and Implementation, edited by P.G. Lens, G. Zeeman, and G. Lettinga. London, U.K.: IWA Publishing.

IWA (International Water Association). 2011. Cities of the Future. Available online at www.iwahq.org/Home/Themes/Cities_of_the_Future.

Jimenez, B., and T. Asano. 2008. Water Reuse: An International Survey of Current Practice, Issues and Needs. London, U.K.: IWA Publishing.

Novotny, V., and P.R. Brown. 2007. Cities of the Future. London, U.K.: IWA Publishing.

Solomon, S. 2010. Water: The Epic Struggle for Wealth, Power, and Civilization. New York: Harper Collins Publishers.

Weber, W.J. Jr. 2004. Optimal uses of advanced technologies for water and wastewater treatment in urban environments. Water Science and Technology: Water Supply 4(1): 7–12.

Multipurpose constructions aligned with natural systems, integrated into social context, and designed for a changing climate offer a new paradigm for public works.

Eco-logical Principles for Next-Generation Infrastructure

Hillary Brown

Hillary Brown, Fellow, American Institute of Architects, is founding principal, New Civics Work, and professor in the Spitzer School of Architecture, City College of New York.

Today's global complex of networked infrastructure is indispensable to economic and social development. It is not clear, however, whether current infrastructure can support the metabolism of an urbanizing, carbon-conscious world facing a destabilizing climate. If it cannot, we must reset our compass and develop new strategies for civil infrastructures that support mobility; supply energy, water, and materials; and assimilate wastes.

To achieve these goals, changes will have to be made in U.S. investments in public works based on new paradigms for reconstructing and managing waterworks, bridges, power grids, sewers, landfills, rail systems, ports, and dams. One of these new paradigms would be multipurpose constructions aligned with natural systems, integrated into social context, and designed for a changing climate.

The Crisis Ahead

In 2009, America's electric utilities, roads, bridges, public transit, rail systems, drinking water and wastewater treatment systems, dams, and airports earned an average grade of "D" for adequacy and safety from the American Society of Civil Engineers (ASCE).[1] ASCE contends that it will take

[1] In a 2007 report, the consulting firm Booz Allen Hamilton estimated that from 2005 to 2030 the United States and Canada combined would have to invest $6.5 trillion to address these infrastructure problems (Doshi et al., 2007).

$2.2 trillion over a period of five years just to restore our existing infrastructure to good condition. With 26 percent of our bridges (162,000 structures) deemed "structurally deficient" or "functionally obsolete," and the collapse of the I-35 bridge in Minneapolis still fresh in our minds, the dangers ahead should be apparent (ASCE, 2009).

America's investments in infrastructure, which have been funded at roughly the same level for 45 years, lag behind those of many developed and developing nations. U.S. investments account for about 3.5 percent of total non-defense spending (GAO, 2001). Although the United States is three times the size of Europe, we spend on average $150 billion to Europe's $300 billion, less than 1 percent of our GDP to Europe's approximately 3 percent (Tal, 2009). The disparity can be partly explained by the EU's ability to leverage private-sector capacity in addition to solid, tax-based, public spending. In the developing world, outlays by India and China account for 8 and 9 percent of GDP, respectively (Urban Land Institute, 2009).

America's investments in infrastructure have been funded at roughly the same level for 45 years.

Reasons for U.S. Underinvestment

America's lower level of investment may be symptomatic of its general disinvestment in the public realm. For decades, infrastructure has been pushed to the back burner behind spending for defense, social security, and education. Although a $1 gasoline and diesel fuel tax would yield close to $140 billion annually and could effectively double current expenditures for highway and bridge maintenance and free up funds for public transit (Verleger, 2005), the focus on *tax relief* has worked against increasing the gas tax, which has not changed since 1993.

Our ability to recapitalize public utilities and transportation has been further undercut by shortcomings in governance and infrastructure delivery mechanisms. Even very large projects are vulnerable to the vagaries of political cycles. For example, an incoming governor single-handedly killed America's largest public works project, negating a 20-year quest to build an interstate commuter train tunnel beneath the Hudson River.

Projects are also at the mercy of special interest groups and lobbyists. The railroad industry, for example, which has almost monopolized the transport of coal, refuses to allow track easements for the construction of coal-slurry pipelines, a more efficient way to fuel power plants.[2]

"Silo-ed" thinking by government agencies, regulators, and funding entities also undermines creative efficiencies. Compartmentalized policies for housing, transportation, water, and energy continue to stymy efforts to undertake transit-oriented, energy-efficient, and water-adequate developments. Up until the establishment of the Interagency Partnership for Sustainable Communities in 2008, we had no capacity to coordinate critical initiatives among the U.S. Departments of Transportation and Housing and Urban Development and the Environmental Protection Agency.

Even now, we lack flexible instruments for implementing complex projects that combine infrastructural modes and cross state lines. Such mechanisms might weigh complex trade-offs among transportation infrastructures to determine, for example, whether expensive airport expansions to relieve air traffic congestion could be avoided by improvements in more cost-effective, less carbon-intensive intercity rail.[3]

The imperative for infrastructural investment choices today is for meaningful reductions in greenhouse gas (GHG) emissions. According to climate scientists, reductions in the next 20 to 30 years will be critical to avoiding profound disruptions in Earth's climate. Thus we must increase public awareness of how investments in conventional infrastructure lock us into long-term carbon-intensive consumption patterns.

Highways all but guarantee emissions of carbon dioxide (CO_2) and GHGs for their 20 to 50 year lifespan. Coal-fired power plants take 30 to 75 years to recover their investment costs, whereas light rail, freight rail, and mass transit can diminish carbon emissions for their entire 50 to 150 year lifespan.

[2] National Research Council (U.S.). Maritime Transportation Research Board.

[3] Conversation with Anthony Shorris, former executive director, The Port Authority of New York and New Jersey, July 2009.

FIGURE 1 Khadju Bridge, Isfahan, Iran.

The 2009 American Resource and Recovery Act

Funds expended by the 2009 American Recovery and Reinvestment Act (ARRA)—approximately $575 billion of the $787 billion package as of November 2010—hardly represent a meaningful "new deal" for America's public works. Aimed primarily at job creation and representing just a fraction of current needs, ARRA has largely underwritten backlogged, construction-ready projects that reinforce the carbon-intensity on which our economy depends.

Of the $132 billion apportioned for infrastructure, the 20 percent, or $27.5 billion, dedicated to highways, bridges, and roadways, overshadows the $17.7 billion earmarked for mass transit and rail projects (Urban Land Institute and Ernst & Young, 2009). The $4.5 billion allocated for basic upgrades of the electrical grid is one-tenth of the projected $40 to 50 billion we need (Doggett, 2009; Wall Street Journal, 2009). Only $2.5 billion will underwrite renewable energy infrastructure compared with $8 billion purposed for the remediation of nuclear sites.

By favoring private over public transportation and short-changing cleaner energy, ARRA undercut its own pitch for a "green economy" and has positioned us unfavorably in comparison with other industrialized nations.[4] Even worse, it has perpetuated our disproportionately high per capita CO_2 emissions—approximately 20 metric tons to Europe's 9 and India's 1.07.[5]

Finally, public perceptions of ARRA as an infrastructural "windfall" may undercut support for future investments critical to meeting increasing demands and redressing chronic underinvestment in repair and maintenance, as well as the replacement of obsolescent assets. Unfortunately, ARRA 2009 missed a unique opportunity to send a tough message about crucial infrastructural needs.

"Infrastructural Ecologies" and Multipurpose, Synergistic Systems

Today's transportation, waste disposal, water, sewage, and energy distribution systems are necessarily interdependent. Power plants require water cooling, water treatment and public transit require electricity, energy generation requires the transport of coal, and so on. And all of these systems rely on information technology (IT).

Nevertheless, we continue to disaggregate them physically and jurisdictionally into distinct sectors. and we mentally separate utilities and the natural systems from which nearly all infrastructural services are derived. Infrastructural systems are man-made extensions of natural flows of carbon, water, and energy, so appropriate modeling might be based on the symbiotic relationships of natural ecosystems. Based on this whole-system perspective, we might reinvent an ecologically informed, post-industrial generation of infrastructure.

Eliminate Mono-functional Facilities

Just as organisms self-organize by exchanging energy and assimilating waste for their mutual benefit, infrastructural systems might combine functions within single assets. Precedents can be found in pre-industrial, monumental works that show the human capacity to build tectonically remarkable, multipurpose structures.

Multifunctional bridges were built in medieval Europe. The 12th century London Bridge was inhabited and supported structures as high as seven stories, and within its arches, water wheels powered pumps and grain mills. The 17th century "multi-modal" Khaju Bridge in Isfahan (still in use) has a main aisle for wheeled vehicles

---

4 China, for example, has poured $200 billion over four years into a modern rail system and $34.6 billion last year into renewable energy.

5 Earth Trends, 2004 data. Available online at *http://earthtrends.wri.org/*.

and aisles for pedestrians; when the sluice gates between spans are closed, the water is redirected upstream to irrigate gardens. Steps on the downstream side still provide public access to the river, and occupied vaults offer cool comfort in summer (Figure 1).

Step-wells in India's arid Gujerat and Rajastan regions (11th through 16th centuries) are feats of engineering based on traditional knowledge of weather patterns and hydro-geology. Uphill dams direct monsoon rains into underground aquifers, and elaborate below-grade stairways provide access to water at levels that vary seasonally. These stone-lined chambers are also social spaces that provide respite from summer heat (Figure 2).

FIGURE 2 Chand Baori (step-well), Abhaneri, Rajasthan, India.

Today, we might similarly "co-locate" assets to gain economies and operational advantages from the shared use of facilities and real estate. Joint utility trenches or common utility tunnels, for example, could accommodate otherwise chaotic runs of cables for sewers, water supplies, gas mains, telephones, and IT and provide shared access points. Greater use of these unified systems would reduce costs and eliminate disruptions and noise from continuous street trenching.[6]

Other examples include photovoltaic noise barriers (PVBs) along highways—either PV arrays hung from south-facing concrete walls or stand-alone arrays capable of deflecting highway noise. There are even bi-faced (east and west) PVBs that produce more energy while simultaneously diffusing sound (Nordmann and Clavadetscher, 2004).

In dense urban environments, public works might combine infrastructure with amenities. By 2013, New York City's drinking water will be filtered and treated in a facility built beneath the Mosholu Golf Course in the Bronx. The intensively planted green roof of the facility will not only provide protective covering, but will also be a community driving range. This roof and an encircling moat of biofiltration trenches will both secure the facility and cleanse storm water, which can then be used to irrigate the golf course.[7] A similar mixed-use facility, the Forum in Barcelona, has a municipal wastewater treatment plant completely concealed under a popular harbor venue of public plazas, parks, hotels, and civic facilities.

Noxious utilities, such as electric substations that house unsightly transformers, switchgear, and other equipment and raise concerns about noise and electromagnetic frequency, all but disappear with co-locations like the ones described above (Cohen, 2008.). In Japan, for example, substations are commonly topped by other structures, and in London they are concealed in public parks or beneath sidewalks (Pincus, 2009).

Rare examples of piggybacking in the United States include the lower Manhattan substation, which was grandfathered in when its earlier version was destroyed on 9/11. Today it is artfully concealed by stainless steel panels within the 11-story concrete base of the rebuilt 7 World Trade Center office tower. Another recent example is a substation in Anaheim, California, that received neighborhood approval once it was buried beneath a two-acre public park. In the same spirit, the Enneüs Heerma Bridge (Figure 3), which connects Ijburg island to mainland Amsterdam, carries multiple lanes of vehicular traffic, two tramlines, two bicycle lanes, and pedestrian footpaths, as well as water, sewage, and other utilities (Wurth and Koop, 2003).

The best examples of the logistical and operational benefits of multi-asset planning are inter-modal transportation hubs, which have attracted significant ARRA sponsorship. U.S. cities from Norfolk, Virginia, to Minneapolis, Minnesota, Normal, Illinois, and Holyoke, Massachusetts, plan to eliminate redundancies by constructing downtown hubs that provide seamless modal transfers while reducing travel time and GHG emissions.

San Francisco is building a five-story Transbay Transit Center that will integrate 11 services (regional bus and rail lines, including intercity high-speed service).

[6] In New York City, street cuts in a typical right of way occur an average of 12 times annually.

[7] Interviews with David Burke (Nicholas Grimshaw and Partners) and Ken Smith, landscape architect, May 2010.

FIGURE 3 Enneüs Heerma Brug (Enneüs Heerma Bridge) in Amsterdam, Holland, with 'IJtram.'

With a 4.5 acre rooftop public park, this public/private complex will also incorporate commercial facilities and residential towers that are expected to catalyze neighborhood redevelopment even as they help underwrite this $4.5 billion undertaking.

Another advantage of co-location is using waste from one operation as feedstock or energy for another. The University of New Hampshire, as part of its Climate Change Action Plan, constructed a gas-purification facility at a nearby landfill; as a result, otherwise-wasted methane, now piped to campus, supplies up to 85 percent of the university's electricity and heating requirements (Ward, 2009). In a similar cross-sector, waste-to-energy project in Lille, France, a new biogas facility, located beside a bus terminal, processes municipal organic waste, which is then combined with sewage gas and used to fuel all of the city buses (Le Saux, 2010).

A computer data farm, installed in bedrock under the Uspenski Cathedral in Helsinki, redistributes its waste heat to warm 500 homes, at the same time lowering its cooling costs by about 50 percent (Virki, 2009). Geothermal energy extracted from subterranean waters that flood abandoned coal mines in Heerland, Holland, is used for heating and cooling in the town and has reduced energy-related CO_2 emissions by 50 percent (Demolin-Schneiders and Opt't Veld, 2007).

Leverage Natural Processes

Sustainable designs combine the functions of man-made and natural systems for the benefit of both. "Living roofs," for example, insulate, impound, and treat storm water, provide local cooling and recreational space, and simultaneously extend the life of the roof.

Comparable benefits might be realized by rethinking public rights-of-way—cross-sections of sidewalks and street trees, parking and travel lanes, and subsurface utility and storm water infrastructures. In the Hunts Point section of the Bronx, productive green space was created by eliminating travel and parking lanes. Continuous trenches for new street trees allow room for root growth and storm water storage for irrigation. The resulting tree canopy will shade and cool the air by evapo-transpiration,[8] thus reducing stress on asphalt pavement and increasing its longevity.

Other infrastructural changes can increase the benefits of daylight in a dense city. Rooftop heliostats (solar tracking and reflecting devices) atop towers in Battery Park City Authority in Manhattan redirect hours of sunlight to a children's park otherwise shaded by buildings. The simple, low-tech substitution of light-colored paving for dark paving in streets and sidewalks not only reduces daytime "heat islands," but also increases reflectivity at night, improving the efficacy of street lighting.

FIGURE 4 Wadi Hanifah: Bioremediation of dry weather flow. Source: Buro Happold/Moriyama & Teshima Planners. Image © of ADA (Ariyadh Development Authority).

The rehabilitation of Wadi Hanifah (Figure 4), a formerly polluted, degraded wadi[9] channel bi-secting Riyadh, Saudi Arabia, provides water quality enhancement along with restored natural habitat. In lieu of

[8] Leaf surfaces evaporate water, expending heat energy.

[9] A gully or streambed (in northern Africa and the Middle East) that remains dry except during the rainy season.

FIGURE 5 Newtown Creek Wastewater Treatment Plant and Nature Park, Brooklyn, New York. Photo courtesy of Heather Letzkus.

an expensive water treatment plant, a wide area of the wadi has been laid out with stone weirs, pools, falls, and riffles that reintroduce oxygen. This supports bio-remediation of the urban wastewater by micro-organisms for downstream reuse in agricultural irrigation. With its channel banks re-profiled to accommodate flooding and re-naturalized as urban parkland, Wadi Hanifah is now a major recreational and tourist destination (Arriyadh Development Authority, 2010).

Serve Local Constituencies

Next-generation infrastructure will increasingly be called upon not only to mitigate the noxious effects of operations, but also to deliver benefits to host communities. Unlike many public utilities that prohibit public access or screen operations from view, the Willamette River Water Treatment Plant in Wilsonville, Oregon, provides community meeting facilities and educational exhibits on biofiltration processes used to treat drinking water.

Otherwise-wasted combustion heat from a municipal waste-to-energy plant in Hiroshima, Japan, warms water for a nearby community pool, and a "waste museum" features the processes of garbage handling and air pollutant removal.[10] Visitors can also enjoy new waterfront access thanks to careful siting of the facility.

Community-benefit agreements spell out specific amenities and/or mitigations. In Los Angeles, in 2004, a private agreement between a coalition of community-based organizations and labor unions and the operators at Los Angeles International Airport provided for benefits to the affected community worth an estimated $500,000. These included mitigation of noise and air pollution, local hiring and training for aviation-related jobs, traffic mitigation, and long-term studies to determine health impacts. New paradigms like these agreements create opportunities for reframing debates about the siting and maintenance of infrastructure facilities.

Waterfront Nature Park, which runs along the expanded Newtown Creek sewage treatment plant in Greenpoint, Brooklyn, exemplifies how local enhancements can become trade-offs for community acceptance (Figure 5). At a recently added visitors' center, employees of the Department of Environmental Protection describe the unique features of New York City's water and wastewater systems.

Adapt to a Changing Climate

As climate instability increases, infrastructural facilities must be designed or fortified to withstand heat stress, drought, severe storms, sea-level rise, forest fires, and other meteorological stressors. For example, changes in precipitation can affect hydropower, higher temperatures can reduce power plant efficiency, and transportation and transmission systems are subject to weather-related damage. On a more basic level, water resources per se will vary.

Risk analyses based on long-term climate forecasting may indicate the need for upgrading new or existing critical infrastructure. For example, in anticipation of fluctuations in hot weather peak demand, California is implementing policies that encourage locally based renewable energy microgrids and building integrated power systems (Vine, 2008).

The Netherlands has developed synergistic solutions that include active (barriers) *and* passive means of

[10] See *http://www.arch-hiroshima.net/arch-hiroshima/arch/delta_others/naka_e.html.* Accessed 1-07-11.

FIGURE 6 Singapore Marina Basin Barrage and Visitors' Center. Photo courtesy of CDM.

coping with storm surge from sea-level rise, salt-water intrusion, and river flooding. This "living with water" solution eliminates the need for expensive artificial barriers by dedicating farmland and even designing underground garages and playgrounds that can temporarily impound floodwaters and store them as a hedge against summer drought.

Singapore is diversifying its sources of water with new water-reclamation plants capable of producing potable water and constructing a raised barrage around its Marina Basin (Figure 6) to prevent flooding and create a reservoir for impounding fresh water (World Bank, 2009). In Zimbabwe, the country relies on natural rather than constructed solutions to desertification. The proper rotation of livestock for grazing and fertilizing grasslands has restored millions of acres of formerly eroded, desiccated soil and almost miraculously replenished aquifers and surface waters (Savory and Butterfield, 2010).[11] These projects represent innovative solutions to growing water shortages.

Supporting and Renewing Innovation

The needs of America's large, complex 21st century infrastructure are daunting to contemplate. Ultimately, to regain economic stability and prosperity and to remain a creative and competitive nation, we will first have to demonstrate a capacity for holistic thinking and integrative action.

Finding and using sustainable technologies may be the least challenging step in making public works smarter. We must first move away from silo-ed thinking, compartmentalized policies, and outdated infrastructural delivery mechanisms. We need a program that engenders interstate, regional, county, and local cooperative development models and promotes "eco-logical," "yield-more-for less" synergies. We will also need a sustained public commitment, logically emanating from a federal model. Other industrialized nations have already reorganized federal ministries and agencies, or formed specialized sub-units to encourage cross-sector development.

Perhaps a strategic, "acupunctural" approach might get us started quickly. To seed and finance progressive investment agendas nationally, for instance, we might consider a pilot program aligned with the proposed National Infrastructure Bank or other government-owned and -capitalized infrastructure financing entity capable of recruiting both foreign and domestic investment.[12] By circumventing politics, this approach could promote regional, "triple bottom line" investments that privilege multipurpose, socially contextual, resilient projects based on innovative plans for transportation and utility systems. The financing entity could offer loans or tax credits based on social, economic, and environmental returns on investment, accountability, and transparency (DB Advisors, 2008; Rediker and Crebo-Rediker, 2008).

In addition, there would be a mandate to achieve regulatory coordination and interagency and cross-sector collaboration to ensure the timeliness, quality, and other performance outcomes of each project. Finally, the financing entity could encourage novel infrastructural delivery models through design and construction procurements and contracts that reward innovative, cooperative accomplishments.

References

Arriyadh Development Authority. 2010. Wadi Hanifah Restoration Project. Available online at *http://bit.ly/fBLnSd*. Accessed 01-07-11.

ASCE (American Society of Civil Engineers). 2009. 2009 Report Card for America's Infrastructure. Washington, D.C.: ASCE. Available online at *http://www.infrastructurereportcard.org/report-cards*.

Cohen, H. 2008. The Neighborly Substation: Electricity, Zoning, and Urban Design. White paper. New York:

[11] This program, called Operation Hope at the Africa Center for Holistic Management, was winner of the 2010 Buckminster Fuller Challenge.

[12] The National Infrastructure Bank, proposed by Senators Christopher Dodd and Chuck Hagel in 2007, later backed by President Obama, would complement existing federal infrastructure programs and build on the experiences of established state infrastructure banks that have provided more than $6 billion for merit-based projects.

Manhattan Institute for Policy Relevance. Available online at *http://www.manhattan-institute.org/html/crd_neighborly_substation.htm*.

DB Advisors. 2008. Economic Stimulus: The Case for "Green" Infrastructure, Energy Security and "Green" Jobs. November. Available online at *http://www.dbadvisors.com/content/_media/1113_GreenEconomicStimulus.pdf*.

Demolin-Schneiders, E., and P. Opt't Veld. 2007. The Mine Water Project Heerlen, the Netherlands–low exergy in practice. In Proceedings of Clima 2007 WellBeing Indoors. Available online at *http://www.irbnet.de/daten/iconda/CIB8366.pdf*. Accessed 01-07-11.

Dogget, T. "U.S. Electric Grid Needs Major Overhaul: Utility." Reuters, July 23, 2009. Available online at *http://www.reuters.com/article/idUSTRE56N0HQ20090724*.

Doshi, V., G. Schulman, and D. Gabaldon. 2007. Lights! Water! Motion! Available online at *http://www.boozallen.com/media/file/Lights_Water_Motion.pdf*.

GAO (U.S. General Accounting Office). 2001. U.S. Infrastructure: Funding Trends and Federal Agencies' Investment Estimates. GAO-01-986T. Available online at *http://www.gao.gov/new.items/d01986t.pdf*.

Le Saux, G. 2010. Get on board with biowaste. Waste Management World 11(2). Available online at *http://bit.ly/bIxYxX*.

Nordmann, T., and L. Clavadetscher, L. 2004. PV on noise barriers: research and applications. Progress in Photovoltaics 12(6): 494–495.

Pincus, W. 2009. GIS Substations That Embellish, Not Blemish the Urban Streetscape. Living Energy, Issue 1/November. Available online at http://bit.ly/gdsiRF.

Rediker, K., and H. Crebo-Rediker. 2008. Financing America's Infrastructure: Putting Global Capital to Work. New America Foundation. Available online at *http://www.newamerica.net/publications/policy/financing_americas_infrastructure*. Accessed 1-12-11.

Savory, A., and J. Butterfield. 2010. The Holistic Management Framework: Social, Economic, and Environmental Sound Development. Pp. 149–175 in Sustainable Development: Principles, Frameworks and Cases, edited by O. Ukaga, C. Maser, and M. Reichenbach. Boca Raton, Florida: CRC Press.

Tal, B. 2009. Capitalizing on the Upcoming Infrastructure Stimulus. CIBC World Markets Occasional Report #66, January 26, 2009. Available online at *http://research.cibcwm.com/economic_public/download/occrept66.pdf*.

Urban Land Institute. 2009. Infrastructure 2009: A Global Perspective. Washington, D.C.: Urban Land Institute.

Urban Land Institute and Ernst & Young. 2009. Infrastructure 2009: Pivot Point. Washington, D.C.: The Urban Land Institute, 2009. Available online at *http://bit.ly/63ide*. Accessed 01-12-11.

Verleger, P.K. Jr. 2005. Energy: The Gathering Storm? Pp. 209–246 in The United States and the World Economy: Foreign Economic Policy for the Next Decade, edited by C. Fred Bergsten. Washington, D.C.: Peterson Institute for International Economics.

Vine, E. 2008. Adaptation of California's Electricity Sector to Climate Change. San Francisco, Calif.: Public Policy Institute of California. Available online at *http://www.ppic.org/content/pubs/report/R_1108EVR.pdf*.

Virki, T. 2009. Cloud Computing Goes Green Underground in Finland. Reuters, November 30, 2009. Available online at *http://www.reuters.com/article/idUSGEE5AS01D20091130*.

Wall Street Journal. 2009. What's in the Stimulus Bill: Getting to $787 Billion. February 17, 2009. Available online at *http://online.wsj.com/public/resources/documents/STIMULUS_FINAL_0217.html*. Accessed 10-11-10.

Ward, A. 2009. UNH Launches Landfill Gas-to-Energy Project. Environmental Building News, July 2009.

World Bank. 2009. Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Climate Change Impacts and Strengthening Disaster Risk Management in East Asian Cities. Available online at http://www.worldbank.org/eap/climatecities. Accessed 01-08-11.

Wurth, G.J.J., and M.J.M. Koop. 2003. Enneus Heerma Bridge, IJburg, The Netherlands: Recent structures in Belgium and The Netherlands. Structural Engineering International 13(1): 7–10.

Planning on the "megaregion" level can ensure the connectivity of major metropolitan areas.

Megaregions and Mobility

Catherine L. Ross and
Myungje Woo

Catherine L. Ross

Myungje Woo

Globalization, the accumulation of production, commodity trading, and finance capital on a global scale, is being accelerated by advances in communication and mobility (Douglass, 2000). In a globalized world, economic, trade, and mobility systems are closely linked and interdependent. However, globalization also produces winners and losers, not only among nations, but also among regions.

Although trade relationships are based on global networks, the origins and destinations of global interactions are concentrated in specific agglomerated regions called "megaregions." These new economic and geographic units, which have arisen in the past few decades, are "networks of metropolitan centers and their areas of influence" that have developed social, environmental, economic, and infrastructure relationships (Ross and Woo, 2009). Thus megaregions extend beyond metropolitan areas, sometimes beyond state lines, as more and more people and economic activities are concentrated there.

Most megaregions are connected cities and surrounding areas with populations of 10 million or more. In the United States, the 10 largest megaregions (seven of which have populations of more than 10 million) represent 80 percent of U.S. economic activity. By 2050, the U.S. population is

---

Catherine L. Ross is Harry West Professor and director of the Center for Quality Growth and Regional Development at Georgia Institute of Technology. Myungje Woo is a research scientist at the Center for Quality Growth and Regional Development at Georgia Institute of Technology.

projected to increase by another 130 million people, which will undoubtedly increase the populations of existing megaregions and could very well lead to the emergence of new ones.

Megaregions, which provide focal points for global connections to existing and emerging markets of opportunity, require planning across jurisdictional borders for everything from parks to ports. They are logical geographical and economic units for planning the construction and expansion of 21st century transportation systems. Investments in transportation connectivity and other improvements in and among megaregions are crucial to economic growth (Meyer, 2007). However, as megaregions expand, they must contend with intense traffic congestion, increasing pressures on the natural environment, resource constraints, and existing institutional and governmental boundaries.

Investments in transportation connectivity and other improvements in and among megaregions are crucial to economic growth.

Spatial Planning and Investment in Transportation Infrastructure in Other Countries

A cursory examination of spatial planning and transportation infrastructure investment in other countries shows the benefits of planning on the megaregion scale: prioritizing infrastructure investment; sharing transport infrastructure; and diversifying and expanding economic activities (Glaeser, 2007; Sassen, 2007). Megaregion-scale transportation and infrastructure that includes all geographic areas within its borders can have significant economic, social, and mobility benefits.

Planning at the megaregional scale can improve the efficiency of freight and passenger transportation and high-speed/intercity rail; highways and concurrency; land use and green infrastructure planning on a multi-jurisdictional scale; accessibility to U.S. economic centers and global markets; management of natural resources and the environment; preparations for responding to natural disasters and other events that are not confined to political boundaries; mitigations and adaptations to climate change; and the creation of new revenue streams to improve mobility in corridors critical to economic success.

Megaregions in Transportation Planning

An expanding spatial footprint is typical of the sprawling development patterns in and around U.S. metropolitan areas, and urban functions and service delivery systems are increasingly becoming the province of non-urban areas, such as suburbs and exurbs (Lang and Dhavale, 2005). Transportation networks, particularly highways, are frequently considered contributors to urban sprawl, because they enable people and businesses to move to and serve rural areas, which then become part of the "larger" metropolitan area. Clusters of these metropolitan areas along inter-metropolitan corridors (typically interstate highways) create new megaregions. Thus transportation planning on the megaregional scale seems logical and appropriate.

Sustainable, livable megaregions require intra- and inter-urban access and mobility coordinated with public transportation, land use planning, and other critical public and private development and investment activities (Banerjee, 2009). Planning at the scale of the megaregion should ensure the inter-connectivity of major metropolitan areas and increase the economic competitiveness of the region.

Europeans are dealing with many of the same issues—expanding and changing urban structures that are outgrowing traditional jurisdictional boundaries and a rapidly globalizing marketplace in which an entire region becomes a single economic entity (Salet et al., 2003). These issues have intensified with the creation and expansion of the European Union (EU). "City-regions," areas that are not limited to the boundaries of local authorities, are "the new and emerging sub-national scalar focal point and territorial fix for the global capitalist economy" (Harrison, 2007). In the United Kingdom (UK) city-regions were the planning units for the Sustainable Communities Plan for the South East, a project to improve the region's economic competitiveness.

Another primary concept in European spatial planning is polycentric development (Meijers, 2008), which, according to the European Spatial Development Perspective (ESDP), stimulates economic progress and better territorial planning. In the EU, polycentricism is credited for creating "multi-growth centers" across Europe, and polycentric regions are believed to eliminate the social and environmental disparities of monocentric cities and to be better equipped to contribute to global competitiveness. Asia and Europe have also created Global Integration Zones by linking major economic nodes with separate high-speed rail systems for moving people and goods.

In the new international division of labor, production processes are being moved from developed countries to developing countries in Asia and Latin America where low-cost labor pools are available. In this scenario, it is important for a country not only to secure air and overseas networks, but also to develop and maintain infrastructure that ensures the efficient movement of trade goods within the country and efficient connectivity to global markets and emerging opportunities.

At the same time, interactions of higher order functions, such as financial transactions and information flows, are increasingly concentrated in networks linking world cities. Salet et al. (2003) suggest that "regional economies have become more dependent on their position in global networks than on the traditional powers and investments of local industries and local entrepreneurs." The "regional economies" of megaregions are at the heart of these changes, because globalization requires a physical geography of regions with transportation networks and communication linkages (Douglass, 2000), and most world cities are located in megaregions.

The success of an economy depends on attracting global investment. As competition among regions has increased, infrastructure, efficient mobility systems, labor supply for higher order functions, reliable energy supply, and facilities that can support world events have become crucial factors in luring investors (Douglass, 2000). Although U.S. megaregions are relatively well equipped with infrastructure when compared to non-megaregions in the country, international competition for global investment is creating strong incentives for improving their performance.

World megaregions are home to significant portions of national populations and account for a large proportion of a country's productivity (Florida et al., 2007). In the United States, megaregions accommodate more than 76 percent of the total population and employment (Table 1), even though they occupy only 30 percent of the total area of the country. In 2008, megaregions accounted for more than 80 percent of the nation's gross regional products.

In terms of globalization and innovation, the headquarters of 92 percent of Fortune 500 companies (based on revenues) were located in megaregions. In 1999, more than 86 percent of U.S. patents were issued in 10 megaregions (Ross et al., 2009a). Because megaregions are expected to continue to grow faster than the rest of the country in terms of population and productivity, it is critical that we develop an effective infrastructure plan to mitigate negative externalities resulting from that growth and to ensure the competitiveness of these regions.

Functional Megaregions

Researchers are focusing much more attention on identifying, defining, and integrating megaregions (Florida et al., 2007). By overlapping population and geographic criteria with other characteristics, including cultural, environmental, and transportation networks, and projecting increases in population, Lang and Nelson (2009) identified eight megaregions, and the Regional Plan Association (2006) identified 11 emerging megaregions in the United States. However, these and other studies have focused on agglomerations of population and employment rather than on functional and operational characteristics. In addition, their methodologies have tended to rely

TABLE 1 Comparison of Major Variables in Megaregions and Non-megaregions

	Geographic Area	Population (2008)	Employment (2008)	Gross Regional Product (2008)	Fortune 500 Companies' Revenue (2008)	Patents (1999)
Megaregion	29.60%	76.54%	76.98%	81.47%	92.07%	86.77%
Non-megaregion	70.40%	23.46%	23.02%	18.53%	7.93%	13.23%

Source: Ross et al. (2009a).

on descriptive analyses and global information system (GIS) mapping rather than on economic relationships within and among regions.

Recently, Ross et al. (2009a) delineated 10 megaregions using a mathematical model to measure functional relationships in terms of commodity flows (Figure 1). The delineation included three stages: (1) identification of metro regions with core areas and their areas of influence; (2) identification of functional regions and measurements of interactions among regions; and (3) delineation of megaregional boundaries with proximity and contiguity conditions.

- Stage 1: Delineation of a metro region. Megaregions are based on combinations of cores and areas of influence, called "metro regions." A metro region includes: (1) an agglomerated, globalized, highly productive, and innovative core area and (2) economic areas, called areas of influence, that support the functions of the core area. The core area and its areas of influence are also defined by shared characteristics, such as history, culture, and environment. Metro regions are evaluated according to five criteria—agglomeration, productivity, globalization, innovation, and infrastructure—and 29 variables.
- Stage 2: Delineation of functional regions. In previous studies, megaregions were defined as clusters of metropolitan statistical areas based on proximity. In this study, functional regions are constructed, using a Markov chain model and cluster analysis, not only according to physical proximity, but also based on functional relationships measured by commodity flows among regions. A functional region is composed of clusters of metro regions based on these interactions.
- Stage 3: Delineation of megaregions. Megaregions are delineated based on contiguity, proximity, and local and regional characteristics. Thus, a megaregion is a functional region in which the components are (1) physically and functionally interconnected and (2) interact with each other via certain types of networks.

Two theoretical considerations embedded in this analysis have significant implications for transportation

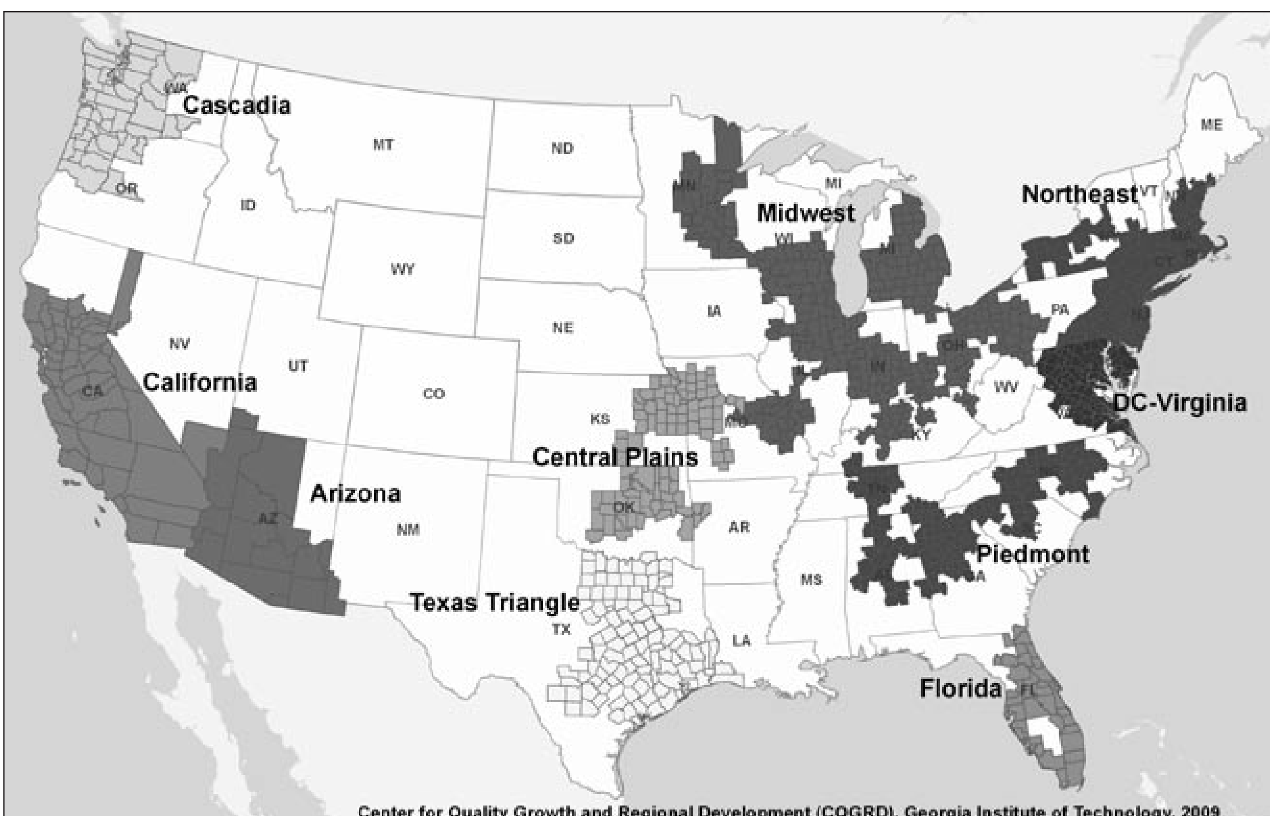


FIGURE 1 U.S. megaregions based on commodity flows. Source: Ross et al., 2009a.

systems. First, every megaregion is related to internal mobility in metro regions. Sassen (2007) suggests that megaregions are large enough to contain multiple levels of agglomeration economies—from higher order functions, such as "specialized advanced corporate settings," to modest and lower order functions, such as "suburban office parks and regional labor-intensive, low-wage manufacturing."

Second, functional relationships between metro regions, which are the core of analysis in the identification of functional regions, were measured by the origins and destinations of commodity flows, that is, data that characterize a high volume of freight movements in the megaregion. Although megaregions vary in size, natural environments, major industries, and existing infrastructure and mobility, they clearly warrant higher priority for investment in transportation infrastructure.

Megaregions and Mobility

Travel by Car, Rail, and Air

Recent trends in travel clearly reveal the need for new investment in transportation infrastructure. For example, a significant increase in vehicle miles traveled by private cars in the United States in the last few decades has resulted in longer average personal trips, lower vehicle occupancy rates, and longer commutes. In addition, travel alternatives, such as transit services and non-motorized travel facilities, are either insufficient or not available at all.

Trucking accounts for approximately 66 percent (in millions of dollars) of total domestic commodity movements, generating enormous amounts of greenhouse gases and consuming enormous amounts of energy. Megaregions are more dependent on trucks than other areas. For example, in 2002, more than 77 percent of commodities were moved from megaregions to domestic destinations by truck, and the percentage is projected to increase to approximately 80 percent by 2035 (Table 2).

Only 4 to 5 percent of freight in megaregions is transported by rail, compared to 13 percent in non-megaregions. In addition, export commodities in megaregions are estimated to increase by 134 percent and imported goods by 124 percent, by 2035, most of which will require transport by truck (Ross et al., 2009b). These numbers may go even higher in the next few years as construction to enlarge the Panama Canal continues.

Air travel at major airports, most of which are located in megaregions (Figure 2), are subject to increasing delays and higher costs to passengers, which may indirectly affect the relative costs of moving passengers and freight along the highway system. These trends are expected to continue, or even worsen, in the near future.

New Mobility Systems

To relieve traffic congestion in major corridors in megaregions, mobility systems should be based on alternative modes of transportation and combinations of different modes and technologies. Several potential high-speed rail (HSR) corridors were designated under Section 1010 of the Intermodal Surface Transportation Efficiency Act and Transportation Equity Act-21. In 2007, the Passenger Rail Working Group, created by Congress, developed a plan for an intercity passenger

TABLE 2 Transportation Modes for Exporting Goods to Domestic Destinations from Megaregions and Non-megaregions

	Megaregion		Non-megaregion	
Transportation Modes	**2002 (%)**	**2035 (%)**	**2002 (%)**	**2035 (%)**
Air and Truck	0.02	0.04	0.01	0.02
Pipeline and Unknown	14.01	11.97	25.74	26.03
Rail	4.45	4.56	13.34	13.09
Truck	77.16	80.23	56.36	57.02
Others	4.34	3.19	4.55	3.83

Source: Derived from the Freight Analysis Framework Commodity Origin-Destination Database (FHWA, 2006).

rail network by 2050. More than 63 percent of the proposed routes for HSR services include corridors that cross state lines (Schwieterman and Scheidt, 2007). In addition, many corridors are divided into segments to accommodate differences in ownership and operations.

With the announcement of new rail initiatives in 2010 and the allocation of $8 billion in federal funds as a "down payment," the federal government has made a substantial commitment to the development of HSR, thus signaling a new direction in U.S. rail history. Although most of the proposed HSR routes are located in megaregions, the funding allocations are still based on state lines (Figure 3).

Given the trends in population and economic growth and the current condition of the nation's transportation infrastructure, the federal government should (1) continue to encourage the implementation of HSR to improve mobility, environmental conditions, and regional economic growth and connectivity and ensure the integration of transit in long-range and regional policies; (2) invest in improving and expanding the freight rail system to support functional relationships between regions and reduce congestion on critical highway corridors; (3) continue collaborative efforts and initiatives by local, state, and regional bodies to mitigate congestion and establish regional policies that encourage coordination in planning and investment in multi-jurisdictional passenger mobility systems.

Lessons learned by experience in European and Asian countries could help guide U.S. infrastructure investment toward more sustainable infrastructure and transportation systems. Working from a megaregional framework will make coordination and progress toward these goals easier to achieve.

Mitigating and/or Adapting to Climate Change

The megaregion is an ideal scale for assessing climate change and air quality on a "super" regional level. The intensity of the environmental impacts of climate change is expected to vary by region throughout the United States, with sub-continental divisions corresponding closely to the geography of several megaregions. To be most effective, mitigation and adaptation responses in transportation systems should be planned

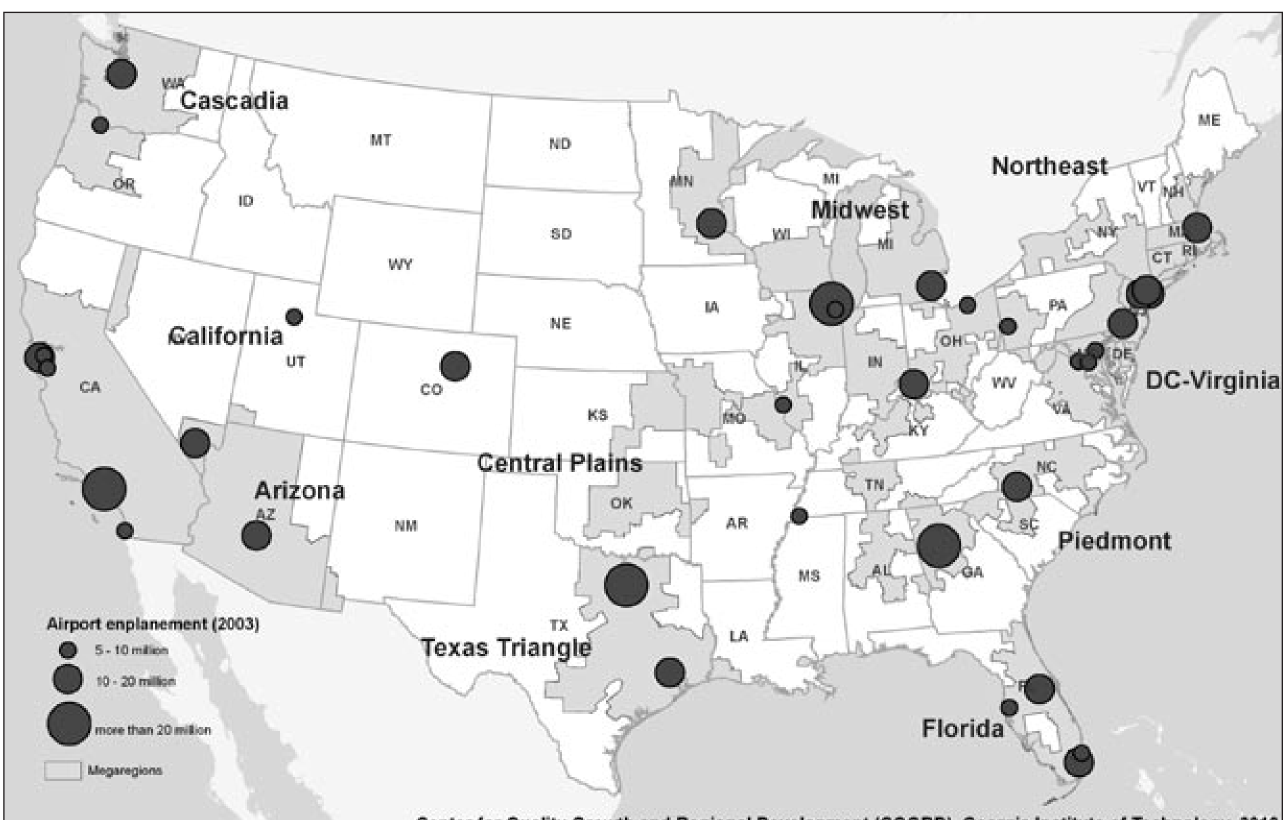


FIGURE 2 Megaregions and major airports in the United States. Source: Ross et al., 2009a.

for these climatologically distinct zones and should be tailored to the expected impacts and particular classes of infrastructure in each megaregion.

Conclusions

At the highest level of competition, the United States needs public policies and infrastructure planning that can reshape existing and emerging megaregions into world-level competitive regions, both economically and in terms of mobility systems. Currently, the country is not organized in a way that can lead to effective planning and implementation of new systems within and between megaregions.

Given limited resources, it is crucial that we understand the interactions of economic and transportation needs as a basis for prioritizing investment. We will need more coordination by planners on all levels for new passenger and freight mobility systems that relieve congestion and enhance economic competitiveness and sustainability.

To attain these goals, public policies and investments in national infrastructure systems must be considered through a new, innovative lens—a megaregional framework—that links local, state, and multistate jurisdictions. Megaregions are also an appropriate scale for managing a national transportation system, the skeletal foundation of the nation's economy and the global economy.

Acknowledgments

This article is based partly on a 2009 project, *Megaregions and Transportation Planning*, Catherine L. Ross, Principal Investigator, sponsored by the U.S. Department of Transportation Federal Highway Administration.

References

Banerjee, T. 2009. Megaregions or Megasprawls? Issues of Density, Urban Design, and Quality Growth. Pp. 84–106 in Megaregions: Planning for Global Competitiveness, edited by C.L. Ross. Washington, D.C.: Island Press.

Douglass, M. 2000. Mega-urban regions and world city formation: globalization, the economic crisis and urban policy issues in Pacific Asia. Urban Studies 37(12): 2315–2335.

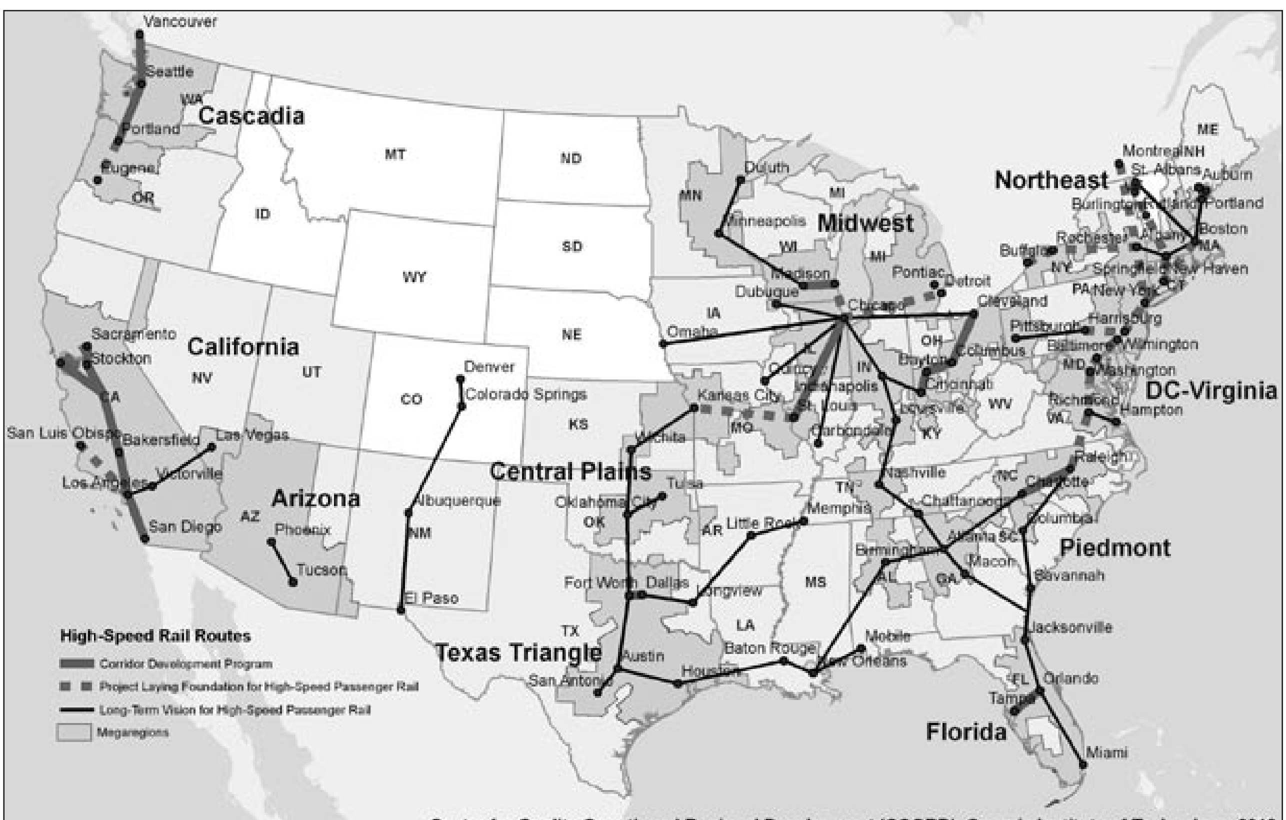


FIGURE 3 Megaregions and the high-speed rail plan. Sources: U.S. DOT FRA, http://www.fra.dot.gov/rpd/passenger/2243.shtml and Ross et al., 2009a.

FHWA (Federal Highway Administration). 2006. Freight Analysis Framework (FAF) Version 2.2, User Guide: Commodity Origin-Destination Database: 2002-2035. U.S. Department of Transportation. Released 20 November 2006.

Florida, R., T. Gulden, and C. Mellander. 2007. The Rise of The Mega Region. The Martin Prosperity Institute, University of Toronto, Canada.

Glaeser, E. 2007. Do Regional Economies Need Regional Coordination? In The Economic Geography of Megaregions, edited by K.S. Goldfeld. Princeton, N.J.: The Policy Research Institute for the Region, Princeton University.

Harrison, J. 2007. From competitive regions to competitive city-regions: a new orthodoxy, but some old mistakes. Journal of Economic Geography 7(3): 311–332.

Lang, R.E., and D. Dhavale. 2005. Beyond Megalopolis: Exploring America's New "Megapolitan" Geography. Metropolitan Institute Census Report Series 5(1): 1–35.

Lang, R.E., and A.C. Nelson. 2009. Megapolitan America: Defining and Applying a New Geography. Pp. 107–126 in Megaregions: Planning for Global Competitiveness, edited by C.L. Ross. Washington, D.C.: Island Press.

Meijers, E. 2008. Measuring polycentricity and its promises. European Planning Studies 16(9): 1313–1323.

Meyer, M.D. 2007. Toward a Vision for the Nation's Surface Transportation System: Policies to Transcend Boundaries and Transition to a New Era. In The National Roundtable on Surface Transportation. Tarrytown, N.Y.: Regional Plan Association and Lincoln Institute of Land Policy.

RPA (Regional Plan Association). 2006. America 2050: A Prospectus. New York: RPA.

Ross, C.L., and M. Woo. 2009. Identifying Megaregions in the US: Implications for Infrastructure Investment. Pp. 53–80 in Megaregions: Planning for Global Competitiveness, edited by C.L. Ross. Washington, D.C.: Island Press.

Ross C.L., J. Barringer, J. Yang, M. Woo, A. Danner, H. West, A. Amekudzi, and M. Meyer. 2009a. Megaregions: Delineating Existing and Emerging Megaregions. Center for Quality Growth and Regional Development. Prepared for the U.S. Department of Transportation, Federal Highway Administration.

Ross, C.L., M. Woo, J. Barringer, J. Yang, A. Danner, M. Marcus, H. West, M. Meyer, and A. Amekduzi. 2009b. Megaregions: Policy Implications for Passenger and Freight Movement. Center for Quality Growth and Regional Development. Prepared for the U.S. Department of Transportation, Federal Highway Administration.

Salet, W., A. Thornley, and A. Kreukels. 2003. Institutional and Spatial Coordination in European Metropolitan Regions. Pp. 3–19 in Metropolitan Governance and Spatial Planning Comparative Case Studies of European City-Regions, edited by W. Salet, A. Thornley, and A. Kreukels. London, U.K.: Spon Press.

Sassen, S. 2007. Megaregions: Benefits beyond Sharing Trains and Parking Lots? In The Economic Geography of Megaregions, edited by K.S. Goldfeld. Princeton, N.J.: The Policy Research Institute for the Region, Princeton University.

Schwieterman, J.P., and J. Scheidt. 2007. Survey of current high-speed rail planning efforts in the United States. Transportation Research Record. Journal of the Transportation Research Board, No. 1995, Railways 2007: 27–34.

We urgently need a comprehensive, systematic analysis based on a large number of in-depth case studies.

Emerging Patterns of Urban Sustainability in Asia

Xuemei Bai is Senior Principal Research Scientist, CSIRO Ecosystem Sciences, Canberra, Australia.

Xuemei Bai

More than half of the world population lives in cities—centers of economic growth, resource use, environmental impacts, and innovation. Thus, cities are the centers of technological invention and progress, as well as the way we address sustainability issues and navigate our way forward (Grimm et al., 2008).

Most of the world's megacities, and the largest urban population in the world, are in Asia, where the number and size of cities are increasing rapidly, often coupled with rapid economic development. Recent studies have explored the importance of innovative practices in transitions toward sustainability and alternative development pathways for Asia and Asian cities (Bai, 2003; Berkhout et al., 2009, 2010).

The environmental and sustainability challenges (and opportunities) facing Asian cities are more complex than for cities in developed countries (Bai and Imura, 2000). As they struggle to meet these challenges, some cities have discovered and adopted innovative strategies and became front runners in improving sustainability.

City planners and administrators seem to learn from each other much more than from the scientific literature (Campbell, 2009). To facilitate such learning, it is important that we understand why some cities adopt innovative practices, how they do it, and how we can extract transferable knowledge from their successes and lessons learned.

Cross-Case Analysis

Many good practices have been documented for addressing various aspects of urban sustainability. The documentations can mostly be found in two types of sources: (1) case studies published as scholarly articles (Dimitriou, 2006; Ng and Hills, 2003; Roberts and Kanaley, 2006; Schwela et al., 2006) and (2) best-practices databases (e.g., UN-Habitat Best Practices and Local Leadership Program).

However, neither type is sufficient for building transferable knowledge and facilitating cross-city learning. Because case studies are often context specific, the extent to which the findings can be generalized or applied in other contexts can be inferred, at best. In addition, learning based on single cases is often treated as anecdotal evidence in academic debate and thus does not receive much attention.

International, agency-driven, best-practices databases often include only brief information and do not provide clear conceptual designs specifying the information to be collected. Thus readers often cannot find relevant information. In addition, few, if any, attempts have been made to identify commonalities and patterns among the large number of individual cases.

We urgently need a systematic, comprehensive analysis based on a large number of in-depth case studies that identifies key characteristics and emerging common patterns and extracts transferable knowledge. The development of such an analysis must overcome two challenges. First, a sound conceptual and analytical framework must be developed to conduct cross-case analyses and extract commonalities. Second, an effective methodology must be developed to facilitate the analysis.

A Five-Tier Analytical Framework

For an effective, systematic, comprehensive, cross-case analysis of sustainability experiments, analyses of individual cases must be based on a set of common questions that reveal underlying circumstances, factors, and mechanisms, both within and among cases. The questions must include: (1) what triggered the practice; (2) who the main actors are; (3) what the relationship is between actors and upper or lower levels of government and other stakeholders, including international organizations; (4) what the major barriers are to planning and implementing the experiment; (5) which pathway the experiment followed, whether it has served as an example for and been duplicated by others; (6) what the common pattern of experimentation in the region is in answer to each of these questions; and (7) whether a "formula" for success or pattern can be found in the combination of triggers, actors, linkages, and barriers that leads to certain pathways and outcomes.

Based on these questions, Bai and colleagues (2010) proposed a five-tier analytical framework: (1) triggers; (2) actors; (3) linkages (a network among institutions and actors); (4) barriers; and (5) pathways (Figure 1). Under each tier, a range of possible elements are identified (Table 1).

Triggers

Triggers are defined as events and factors (e.g., natural disasters, accidents, public health concerns, policy changes, media exposure, etc.) that create a need for action to address a problem or issue. For example, a change in national policy on energy efficiency and climate change can trigger an experiment by a city to adopt an innovative practice that encourages energy efficiency in buildings or improves public transportation. In some cases, there may be multiple triggers or cumulative causal events (Coombs, 2000; Toner, 1999).

Actors

Actors are the key stakeholders in projects. Actors' roles and commitment to projects can range from

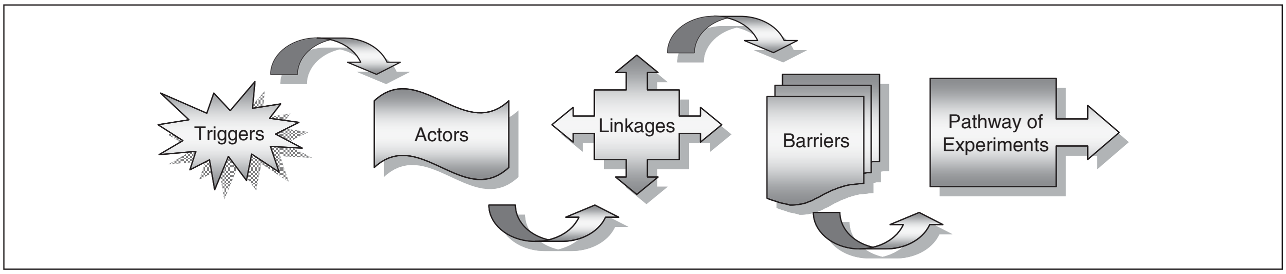


FIGURE 1 A five-tier conceptual framework for analyzing urban sustainability practices: Triggers, Actors, Linkages, Barriers, Pathways. Source: Bai et al., 2010. Reprinted with permission from Elsevier.

TABLE 1 Main Items in Each of the Five Tiers

Event Triggers	Actors	Linkages	Barriers	Pathways
• natural disaster • public health issue • poverty • employment • pollution or congestion • media exposure • policy change • community concerns and action • global concern	• local community • local government • state/national governments • local activists • international organizations • international development assistance agencies • private sector • media	• local-state governments (vertically integrated) • cross/inter-agency involvement (horizontally integrated) • community-based partnerships • public/private sector partnerships • networks of program activities/experiments • international/global linkages	• political • institutional • economical/ financial • technological • natural/physical • historical • cultural • social • capacity	• upscaled to regional regimes (mainstreamed) • multiplied (project duplicated elsewhere) • experiment to experiment (project expanded locally) • experiment (down-scaled) • experiment failure (terminated with no net benefits) • experiment failure (terminated with net loss of benefits)

Source: Bai et al., 2010.

political, technical, consultative, design, financial, and implementation support.

Linkages

Actors function in a network of linkages—vertical linkages between local and state governments (i.e., upper or lower levels of government institutions) and horizontal linkages, such as cross/inter-agency involvement, community-based partnerships, public-private sector partnerships, networks of program activities/experiments, and international and global linkages.

Barriers

Barriers to sustainability experiments can limit or impair their effectiveness. Barriers can include political, institutional, economic and/or financial, and technological factors; natural/physical limits; historical limits; cultural factors; and lack of social acceptance.

Pathways

In this study, a pathway is defined as the eventual trajectory and outcome of an experiment. An experiment can follow one or a combination of the following pathways: remain an individual experiment; be repeated in similar projects or methodologies in other cities; be upscaled to change regional or national practices; or eventually be downscaled or terminated.

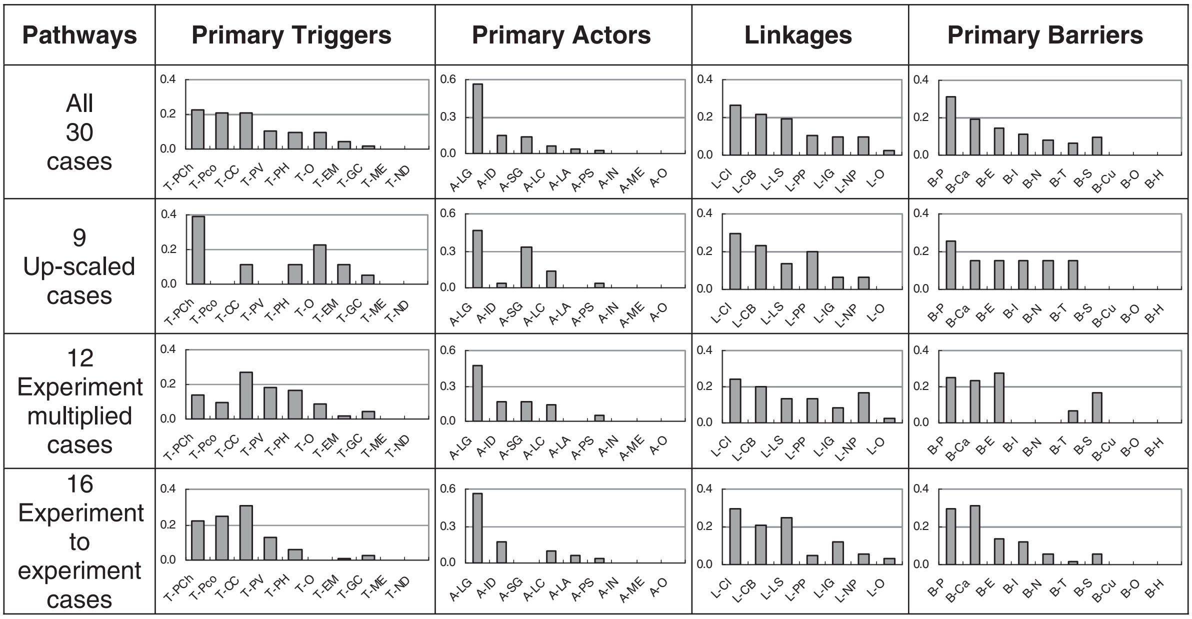
Findings Based on 30 Innovative Practices in Asia

The analytical framework described above has been applied to 30 case studies of best urban sustainability practices in Asia. Drawn from a recent book, *Urbanization and Sustainability in Asia: Good Practice Approaches to Urban Region Development in Asian Countries* (Roberts and Kanaley, 2006), these case studies come from 12 countries—Bangladesh, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Pakistan, Philippines, Sri Lanka, Singapore, Thailand, and Vietnam.

The case studies include examples of infrastructure, environmental, housing, social, and governance projects and programs of different sizes and complexity. The cases are up to date and documented for the purpose of identifying and highlighting good urban practices in the region. More than half of them have won national or international awards for best practices.

In the present study, the initial authors of the 30 cases, all experts on urban issues in the region, were asked to provide input to the analysis by identifying and ranking, on a scale of 1 (most important) to 6 (least important), the elements in each tier. The data were then aggregated and analyzed to identify key features and common patterns of urban sustainability practices (for details of the methodology, see Bai et al., 2010).

Figure 2 shows the distribution pattern of primary triggers, actors, linkages, and barriers for all cases and



Note: Prefix T, A, L, and B refers to Triggers, Actors, Linkages, and Barriers, respectively. For triggers, PCh, PCo, CC, PV, PH, O, EM, GC, ME and ND, represents policy change, pollution or congestion, community concern and action, poverty, public health issue, others, employment, global concern, media exposure, and natural disaster, respectively. For actors, LG, ID, SG, LC, LA, PS, IN, ME and O, represents local government, international development assistance agencies, state/national government, local community, local activists, private sector, international NGOs, media, and others, respectively. For linkages, CI, CB, LS, PP, IG, NP and O, represents cross/inter-agency involvement (horizontal integrated), community based partnerships, local-state governments (vertically integrated), public private sector partnership PPP, international/global linkages, networks of program activities/experiments, and others, respectively. For Barriers, P, Ca, E, I, N, T, S, Cu, O, and H, represents political, capacity, economical/financial, institutional, natural/physical limits, technology, social acceptance, cultural factors, others, and historical limits, respectively.

FIGURE 2 Distribution of primary triggers, actors, linkages, and barriers according to different pathways. Source: Bai et al., 2010. Reprinted with permission from Elsevier.

according to pathway. Figure 3 shows the distribution pattern of cumulative factors (a normalized sum of all factors identified by experts). The figures also include patterns specific to certain pathways. The results below are organized according to the five tiers in the analytical framework and according to pathways.

Triggers

All Cases

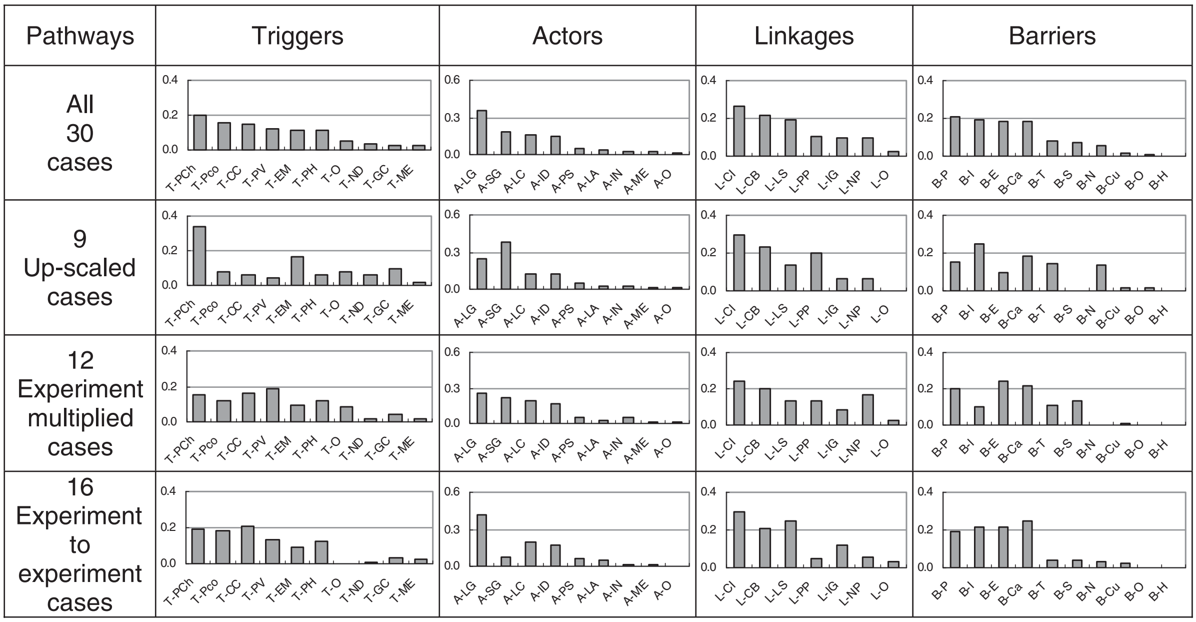
In both the primary and cumulative distributions, the most important triggers were changes in public policy focused on improving the sustainability of urban development. This finding reflects the importance of policy and politics in initiating sustainability practices. The next most important triggers were related to pollution, public health, poverty, and job creation.

In most case studies, more than one trigger was important. Fourteen indicated that more than three triggers had led to the decision to take action. Both primary and cumulative triggers showed similar distribution patterns.

Pathway-Specific Triggers

Experiments with different pathways have different triggers. Among the nine up-scaled cases, the importance of policy changes was even more prominent than in the cases cited above, indicating that political will is essential for innovative experiments to be mainstreamed. The second important trigger was job creation. Among experiments that were “multiplied,” alleviating poverty was the most prominent trigger, followed by public-health issues.

Among the 16 cases that were not duplicated or expanded (experiment-to-experiment cases), pollution and congestion were the most prominent triggers,



Note: Prefix T, A, L, and B refers to Triggers, Actors, Linkages, and Barriers, respectively. For triggers, PCh, PCo, CC, PV, EM, PH, O, ND, GC, and ME, represents policy change, pollution or congestion, community concern and action, poverty, employment, public health issue, others, natural disaster, global concern, and media exposure, respectively. For actors, LG, SG, LC, ID, PS, LA, IN, ME and O, represents local government, state/national government, local community, international development assistance agencies, private sector, local activists, international NGOs, media, and others, respectively. For linkages, CI, CB, LS, PP, IG, NP and O, represents cross/inter-agency involvement (horizontal integrated), community based partnerships, local-state governments (vertically integrated), public private sector partnership PPP, international/global linkages, networks of program activities/experiments, and others, respectively. For Barriers, P, I, E, Ca, T, S, N, Cu, O, and H, represents political, institutional, economical/financial, capacity, technology, social acceptance, natural/physical limits, cultural factors, others, and historical limits, respectively.

FIGURE 3 Distribution of cumulative triggers, actors, linkages and barriers according to different pathways. Source: Bai et al., 2010. Reprinted with permission from Elsevier.

followed by community- and poverty-related concerns. The distribution patterns for primary and cumulative triggers were similar.

Actors

All Cases

Local government stands out as the most important primary actor for the 30 cases. Communities, international development assistance, and state/national governments had a much lower level of importance. Local government was the leading actor in more than 12 of the case studies. This result is not unexpected because many projects related to sustainability involve public initiatives to improve local services, infrastructure, and environmental conditions. In all but three projects, government had primary responsibility for the design and implementation framework for the project.

Pathway-Specific Actors

Although local government is the most important actor in these 30 cases, there is an interesting variation in terms of the importance of other actors. For up-scaled experiments, state government seems to have much higher relative significance than in other pathways, indicating the importance of involving state governments in local experiments.

Interestingly, our results indicate that experiments initiated by the international development sector were less likely to be up-scaled, although international organizations can play a supporting role for up-scaling (as indicated in Figure 3).

Among the multiplied experiments, local community seems to have the same level of importance as local government. Again, the distributions of primary and cumulative actors show similar patterns.

Linkages

All Cases

More than one-third of the projects involved some form of collaboration among actors. Most involved three levels of linkages, interagency and intergovernmental linkages and community partnerships. However, the types of linkages and levels of collaboration varied significantly.

Pathway-Specific Linkages

Among up-scaled cases, vertical linkages between local and state governments and public-private partnerships seem to play more significant roles than in other pathways. This result affirms the importance of vertical and horizontal linkages for local good practices to be up-scaled (Bai et al., 2009).

This result also reinforces the findings in the actors tier, where the importance of upper level government was prominent in up-scaled cases. For cases that are multiplied, or repeated, in other cities, community-based partnerships seem to be slightly more important than they are in the cases overall. The distributions of linkages in experiment-to-experiment (experiments that were not repeated elsewhere) cases are similar to distributions in the overall cases.

Evidence suggests that identifying a particular good practice is still more of an "art" than a "science."

Barriers

All Cases

Four kinds of barriers—policy, economic and financial, institutional, and capacity—had significant impacts on project implementation. These findings are supported in the literature on barriers that affect sustainable urban development projects (Banister, 1998; Steinemann, 2003). Only six cases in the present study identified a single barrier to project implementation and ongoing operations. Most identified multiple barriers through the various stages of project development and implementation.

Interestingly, technology, identified as a primary barrier in only two cases, seems not to be as significant as other factors. One reason for this may be that the technologies used in the examined cases might have already been proven, in which case the project risk assessment procedure would effectively have removed technological barriers.

Similarly, cultural and historical factors seem to be negligible as barriers. A possible explanation may be that effective community engagement and consultation might have lowered cultural and historical barriers. However, we do not have enough evidence to resolve these questions definitively.

Pathway-Specific Barriers

Among up-scaled cases, institutional and capacity barriers were identified as slightly more important than policy and economic barriers, which were identified in the general pattern. For both experiment-multiplied cases and experiment-to-experiment cases, economic and capacity barriers seem to be the most prominent factors.

Pathways of Experiments

Some of the experiments examined are ongoing, which means their pathways may be evolving, so this discussion is based on current results. At this point, 22 projects have developed single pathways, and eight have developed multiple pathways. Taking the latter into account, the aggregated results shows that, among the 30 cases, 9 are up-scaled cases, 13 are experiment-multiplied cases, and 6 are experiment-to-experiment cases.

The majority of projects, some of which are going through an evaluation and expansion phase, involve the experiment-to-experiment pathway. Several projects involve community-based initiatives, in which responsibility for ongoing operations and maintenance has or will be handed over to a non-governmental organization or community-based organization.

Conclusion

Although the number of studies analyzing individual sustainability experiments is increasing, the context-specific nature of many practices means experiences are often not directly transferable. Evidence based on numerous individual cases seems to suggest that identifying a particular good practice is very much an "art" rather than a "science." Thus it requires significant trial and error, which in turn requires a commitment to ongoing learning. Nevertheless, exploring ways to facilitate multiplication of experiments and eventually up-scaling a good practice into a system change is essential to sustainability transition.

It is also important to benchmark sustainable development practices. This has not been attempted very often but is important to supporting ongoing learning and knowledge dissemination related to good-practice sustainable urban development (World Bank, 2001). We will need substantial, in-depth research to draw more general insights from individual cases and enhance those insights into scientific knowledge.

The analysis of 30 cases described above has revealed good urban practices in the region: (1) the importance of policy change and the cumulative effect on triggers; (2) the importance of local government, community, and international agencies as main actors; (3) the wide range of size and complexity in linkages and networks in different projects; and (4) the prominence of political and institutional barriers, followed by financial and local capacity issues.

In terms of pathways, at the time of this evaluation about half of the experiments had either been mainstreamed or duplicated elsewhere, indicating a strong potential for overall sustainability transition in Asia. However, about half of the experiments remain as individual, unduplicated experiments. Two reasons might contribute to this outcome: (1) some experiments may not have fully evolved beyond the single-case pathway, which suggests a need for continuous monitoring and evaluation; and (2) evolving a successful pathway is a process that involves not only the supply side of lessons and insights (e.g., the city that carried out the experiment), but also the capacity and willingness to learn on the demand side (e.g., other cities or upper level government agencies).

Can we extract a "formula for success" or a "winning pattern" from these cases? The initial results of the analysis show some distinctive patterns that have important theoretical and practical implications.

First, cases that are up-scaled often have strong vertical linkages with state or national government, whereas initiatives by international development agencies tend to remain as experiment-to-experiment or multiplied projects and are seldom up-scaled. Although the specific reason for this emerging pattern is not clear, it might imply that for international development agencies to leverage sustainability outcomes beyond specific urban projects, they might have to pay more attention to vertical linkages and engage more closely with upper level governments. The pattern provides empirical support for a proposition by Campbell (2009) suggesting that a radical departure from customary policy by donor institutions might be necessary.

Second, among all cases, and particularly among cases with more successful pathways, the importance of political factors was manifested repeatedly (e.g., policy changes as triggers, local governments as main actors, the importance of state government support, and the prominence of institutional factors as major barriers). In practice, this suggests that political will and support are essential to the success of urban sustainability experiments in terms of sustainability transition.

Third, technological factors do not play a prominent role in urban sustainability practices in the cases we analyzed. This may be another indication that technical assistance projects by international development agencies should be designed based on social-technical systems, rather than technology per se.

Although innovative cities have identified cross-city learning as the most important vector for knowledge transfer, cross-city learning is not simple, and innovative practices have yet to reach the majority of cities. Lessons from individual cases provide invaluable insights, but they are often context specific. Thus, without systematic, comprehensive analysis, it is often difficult to transfer these lessons to other contexts.

The emerging patterns discussed above are based on cross-case analysis and therefore provide transferable knowledge that reflects, but is not dependent on, the local context. Thus, this knowledge can be used for designing and navigating urban sustainability experiments and managing overall sustainability transition. To be successful, however, international agencies that construct and maintain large databases on innovative or best practices for sustainable cities must pay more attention to and facilitate systematic comparative analysis.

References

Bai, X. 2003. The process and mechanism of urban environmental change: an evolutionary view. International Journal of Environment and Pollution 19(5): 528–541.

Bai, X., and H. Imura. 2000. A comparative study of urban environment in East Asia: stage model of urban environmental evolution. International Review for Global Environmental Strategies 1(1): 135–158.

Bai, X., A. Wieczorek, S. Kaneko, S. Lisson, and A. Contreras. 2009. Enabling sustainability transition in Asia: the importance of vertical and horizontal linkages. Technological Forecasting and Societal Change 76: 255–266.

Bai, X., B. Roberts, and J. Chen. 2010. Urban sustainability experiments in Asia: patterns and pathways. Environmental Science & Policy 13(4): 312–325. doi:10.1016/j.envsci.2010.03.011.

Banister, D. 1998. Barriers to the implementation of urban sustainability. International Journal of Environment and Pollution 10(1): 65–83.

Berkhout, F., D. Angel, and A.J. Wieczorek. 2009. Sustainability transitions in developing Asia: are alternative development pathways likely? Technological Forecasting and Social Change 76(2): 215–217.

Berkhout, F., G. Verbong, A.J. Wieczorek, R. Raven, L. Lebel, and X. Bai. 2010. Sustainability experiments in Asia: innovations shaping alternative development pathways? Environmental Science & Policy 13(4): 261–271.

Campbell, T. 2009. Learning cities: knowledge, capacity and competitiveness. Habitat International 33(2): 195–201.

Coombs, G. 2000. Influences on Regional Economic Development—Basic Factors. Pp. 43–59 in Essays on Regional Economic Development, edited by G. Coombs. South Australia: Wakefield Press.

Dimitriou, H.T. 2006. Towards a generic sustainable urban transport strategy for middle-sized cities in Asia: lessons from Ningbo, Kanpur and Solo. Habitat International 30(4): 1082–1099.

Grimm, N.B., S.H. Faeth, N.E. Golubiewski, C.L. Redman, J. Wu, X. Bai, and J.M. Briggs. 2008. Global change and the ecology of cities. Science 319(5864): 756–760.

Ng, M.K., and P. Hills. 2003. World cities or great cities? A comparative study of five Asian metropolises. Cities 20(3): 151–165.

Roberts, B., and T. Kanaley, eds. 2006. Urbanization and Sustainability in Asia: Case Studies of Good Practice. Manila, Philippines: Asian Development Bank and Cities Alliance (World Bank).

Schwela, D., G. Haq, C. Huizenga, W.-J. Han, H. Fabian, and M. Ajero, eds. 2006. Urban air pollution in Asian cities: status, challenges and management. London, U.K.: Earthscan Ltd.

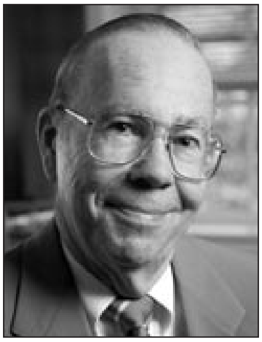
Steinemann, A. 2003. Implementing sustainable development through problem-based learning: pedagogy and practice. Journal of Professional Issues in Engineering Education and Practice 129(4): 216–224.

Toner, P. 1999. Main Currents in Cumulative Causation: The Dynamics of Growth and Development. New York: Macmillan.

World Bank. 2001. Brazil—Learning from Best Practice in Five Urban Projects: Medium-Sized Cities, the Recife Metropolitan Region, Preparations of Metropolitan Development Programs for Fortaleza and Salvador, the Parana Market Towns Improvement and Northeast Urban Flood Reconstruction Projects. Independent Evaluation Group, August 09. Available online at *http://bit.ly/h2wh9X*.

Mining "urban ore" may provide an alternative to the continued extraction of virgin metals.

The Prospects for Urban Mining



T.E. Graedel is Clifton R. Musser Professor of Industrial Ecology, Center for Industrial Ecology, Yale University, and an NAE member.

T.E. Graedel

A half-century ago, the visionary urbanist Jane Jacobs (1961) proclaimed that "cities are the mines of the future." This prediction was based on some hard facts that are more evident today than they were when Jacobs penned her words: (1) hard-rock mining is energy intensive and environmentally problematic; (2) as the metal content of rock being extracted continues to decline, the extraction rates continue to increase; (3) a large fraction of the metal being mined flows to cities, where it is used in structures, transportation, and the wide variety of products that are the hallmarks of modern life; and (4) this "urban ore" may provide an alternative to mining virgin metals.

The prospect of urban mining raises many questions. To what degree is its promise being fulfilled? What are the successes of urban mining? What are its challenges? Perhaps most important, does urban mining matter, or could it matter?

In this article, I review the current state of urban mining of metals in the periodic table and discuss how important Jacobs' grand idea is turning out to be. A central message is that, as with more traditional mining, each step of the process—recovery, separation, sorting, and processing—must be evaluated as components of systems. Only by optimizing these systems can urban mining reach its potential.

Urban Mining Resources

Three significant questions relate to assessing the potential of urban mining resources: how much metal there is; when it will be available; and what form it is in. It is worth examining each of these questions in turn.

How Much Metal Is There?

From the standpoint of a specialist, the question becomes: What are the sizes of the in-use metal stocks in urban regions? There are two ways—"bottom up" and "top down"—to estimate these stocks.

For a bottom-up estimate, the analyst first identifies the major uses of a particular metal. Copper, for example, is used primarily for power distribution, transportation, plumbing, and consumer electronics. Next, the analyst must determine, based on field research and other information, approximately how often a metal is used for each type of use in the particular urban region (e.g., how many vehicles have been registered, how much copper plumbing is in a typical building, etc.) and second, the typical amount of metal in each unit of use. A straightforward calculation then provides an estimate of in-use stock.

The alternative, top-down method is more workable on the national and global levels. This method requires determining flows of the subject metal into each major use over a number of years and then applying product-lifetime determinations to estimate the amount of material that is no longer in use. The difference is the in-use stock.

It has been shown (Figure 1) that careful bottom-up and top-down studies yield similar results. Although the magnitudes of urban stocks are modest compared with the amount in existing ore deposits, they can be significant compared to annual demand: 538 teragrams (Tg) in-use stock and 29 gigagrams (Gg) annual demand for aluminum (IAI, 2006); 354 Tg in-use stock vs. 13 Tg annual demand for copper (Kapur and Graedel, 2006); and 18 petagrams in-use stock vs. 860 Tg annual demand for iron (Müller et al., 2011). (The data are for 2000 for copper and iron and 2004 for aluminum. Annual demand is based on studies by the U.S. Geological Survey for the appropriate year.) In each case, the in-use stock is about 20 times the annual demand, although much of that stock is still being used and is thus not available for immediate mining.

National and global results (i.e., top-down results) are not the same as urban results, of course. Binder et al. (2006) and Graedel and Cao (2010) have shown that both flow-into-use and stocks remaining in use follow per capita wealth. Because urban dwellers are, on average, significantly wealthier than rural dwellers, cities are magnets for materials, and the bulk of in-use stocks can be found in urban areas. Therefore, when bottom-up studies are not available (Kennedy et al. [2007] review the available information), national figures can be scaled to urban regions on the basis of per capita gross domestic product.

When Will Urban Stocks Become Available?

This question relates to how products are used and for how long. The baseline is set by the physical lives of products—a few years for electronics, a decade or so for vehicles, a few decades for industrial machinery. Other factors must also be considered, however, such as the improved utility of new products and social pressures (Allwood et al., 2010; van Nos and Cramer, 2006). In

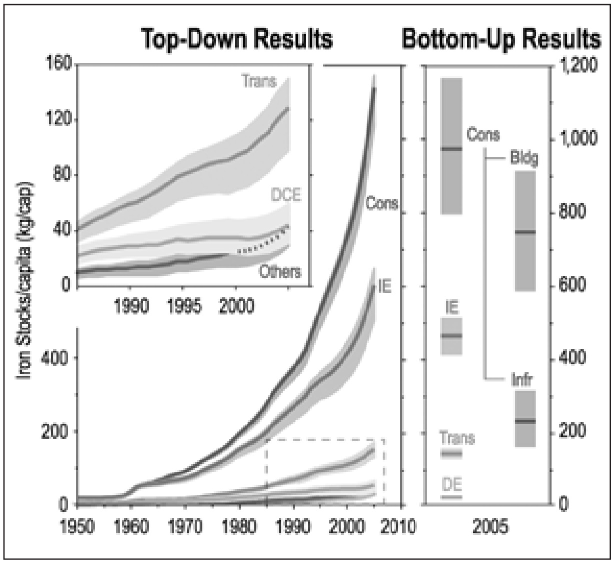


FIGURE 1 Per capita in-use iron stocks in China: top-down estimates results ca. 1950–2005 and bottom-up results ca. 2005. An expanded insert shows top-down results for transportation, domestic, and commercial equipment. A normal lifetime distribution function is applied to each category of product in the top-down analysis with various average product lifetimes and standard deviations. The uncertainty of the top-down results is indicated as a band, with the lower bound, midline, and upper bound corresponding to minimum, medium, and maximum lifetime assumptions. For the bottom-up estimates, the range reflects uncertainties in available data. Abbreviations: Cons (construction), Bldg (buildings), Infr (infrastructure), DCE (domestic and commercial equipment), DE (domestic equipment), IE (industrial equipment), Trans (transportation). Reproduced with permission from T. Wang, "Forging the Anthropogenic Iron Cycle," doctoral dissertation, Yale University, 2009.

any case, it is clear that urban stocks of materials, especially large-magnitude stocks related to buildings and infrastructure, are released for possible reuse very gradually over a period of many years.

In What Forms Do Urban Stocks Exist?

This question is, perhaps, the most arresting. Unlike polyethylene in plastic bags or wooden flooring in buildings, which are used largely in pure form, metals may be present in a variety of forms, some simple, some complex. The form, which differs greatly for different metals, significantly influences recycling potential.

Table 1 lists the three predominant uses for each metal in the periodic table, accompanied by judgments as to whether, for each use, the metal is readily recoverable in (1) pure form, (2) multicomponent alloys (as in stainless steel), (3) complex assemblages (as in computer chips), or (4) dissipative forms (such as paint).

TABLE 1 Principal Uses (by percentage of total use) and Recycling Potential of Metals in the Periodic Table

Metal	Principal Uses#	Reference
Li	Batteries (25,b), glasses (18,c), greases (12,d)	SQM, 2007
Be	Electronics (60,c), aerospace (20,c), appliances (10,c)	USGS, 2010
B	Ceramics (76,c), soaps (5,d), agriculture (4,d)	USGS, 2010
Mg	Refractories (40,d), chemicals (37,d), Al alloys (16,b)	USGS, 2010*
Al	Transport (28,b), buildings (25,b), electrical (18,a)	IAI, 2006
Sc	Al alloys (85?,b), lamps (?,c), electronics (?,c)	USGS, 2010
Ti	Pigments (94,d), aerospace (4,b)	USGS, 2010
V	Steels (85,b), Ti-Al alloys (10,b), chemicals (5,d)	Perron, 2001
Cr	Metal goods (30,b), buildings (25,b), indust. machinery (25,b)	Johnson et al., 2006
Mn	Steel (96,b), Al alloys (1,b)	Nakajima et al., 2008
Fe	Construction (45,b), transport (24,b), indust. machinery (20,b)	Wang et al., 2007
Co	Superalloys (49,b), chemicals (27,c), metallurgy (15,b)	USGS, 2010
Ni	Stainless steel (68,b), superalloys (11,b), plating (6,b)	Reck et al., 2008
Cu	Buildings (50,a), electronics (21,a), transport (11,a)	USGS, 2010
Zn	Galvanizing (55,b), Zn alloys (21,b), brass/bronze (16,b)	USGS, 2010
Ga	Electronics (67,c), optoelectronics (31,c)	USGS, 2010
Ge	Fiber optics (35,c), infrared optics (30,c), catalysts (15,c)	USGS, 2010
As	Wood preservatives (50,d), batteries (?,d), electronics (?,c)	USGS, 2007
Se	Glass (25,d), metallurgy (22,b), agriculture (19.d)	Kirk-Othmer, 2009
Sr	Pyrotechnics (30,d), magnets (30,b), alloys (10,b)	USGS, 2010
Y	Lighting (45,c), flat panel displays (33,c), glass additives (12,c)	Du and Graedel, 2011
Zr	Ceramics (54,d), refractories (13,d), metallurgy (13,b)	TZ Minerals Int'l, 2007
Nb	Steels (76,b), superalloys (24,b)	USGS, 2010
Mo	Steels (50,b), stainless steel (25,b), chemicals (14,d)	IMOA, 2010
Ru	Electrical (59,c), chemical (20,d), electrochemical (14,c)	Butler, 2010
Rh	Autocatalyst (86,a), chemical (8,c), glass (4,c)	Butler, 2010

TABLE 1 Principal Uses (by percentage of total use) and Recycling Potential of Metals in the Periodic Table (continued)

Pd	Autocatalyst (54,a), electrical (17,c), jewelry (12,a)	Butler, 2010
Ag	Industrial (57,c), jewelry (20,b), photography (16,a)	Silver Institute, 2011
Cd	Batteries (83,b), pigments (8,d), platings (7,b)	USGS, 2009
In	Monitors (33,c), TV (24,c), computers (15,c)	Matos et al., 2005
Sn	Electrical (50,b), cans (18,b), chemicals (14,c)	Tin Technology Ltd., 2006
Sb	Flame retardant (40,d), transport (22,b), chemicals (14,c)	USGS, 2010
Te	Metallurgy (60,b), chemicals (25,d), electrical (8,c)	Kirk-Othmer, 2009
La	Catalysts (30,b), metallurgy (22,b), batteries (14,b)	Du and Graedel, 2011
Ce	Autocatalyst (35,b), metallurgy (31,b), glass additives (16,c)	Du and Graedel, 2011
Pr	Computers (27,b), audio systems (21,b), wind turbines (12,b)	Du and Graedel, 2011
Nd	Computers (29,b), audio systems (22,b), wind turbines (13,b)	Du and Graedel, 2011
Sm	Defense applications (70,b), batteries (30,b)	Du and Graedel, 2011
Eu	Lighting (50,c), flat panel displays (33,c), plasma (12,c)	Du and Graedel, 2011
Gd	Computers (32,b), audio systems (25,b), wind turbines (15,b)	Du and Graedel, 2011
Tb	Lighting (27,c), flat panel displays (20,c), computers (15,c)	Du and Graedel, 2011
Dy	Computers (33,b), audio systems (26,b), wind turbines (15,b)	Du and Graedel, 2011
Ho	Magnetics (100,b)	Du and Graedel, 2011
Er	Fiber optics (75?,c), lasers (20?,c), optical glass (5?,c)	Du and Graedel, 2011
Tm	X-ray (75?,c), lasers (20?,c), electronics (5?,c)	Du and Graedel, 2011
Yb	X-ray (75?,c), lasers (20?,c), electronics (5?,c)	Du and Graedel, 2011
Lu	Electronics (80?,c), medical (20?,c)	Du and Graedel, 2011
Hf	Superalloys (40?,b), nuclear power (30?,a), electronics (5?,c)	USGS, 2009*
Ta	Capacitors (68,c), other electronics (11,c), superalloys (8,b)	Nassar, 2010
W	Cutting tools (60), metallurgy (15?,b), superalloys (10?,b)	USGS, 2010
Re	Superalloys (77,b), catalysts (15,a), crucibles (8,a)	USGS, 2008
Ir	Electrochemicals (25,c), chemical (21,c), electrical (15,c)	Butler, 2010
Pt	Autocatalyst (46,a), jewelry (26,a), chemical (5,d)	Butler, 2010
Au	Jewelry (72,a), electronics (7,c), dental (2,b)	USGS, 2010
Hg	Mining (75?,d), medicine (10?,a), lighting (10?,c)	USGS, 2010*
Tl	Medicine (40?,d), radiation detection (30?,c)	USGS, 2010*
Pb	Batteries (75,a), pipe and sheet (5,a), cable sheathing (2,a)	Mao et al., 2008
Bi	Metallurgical (45,b), alloys (29,b), chemicals (25,d)	USGS, 2010

[#] (a) Largely existing or readily recoverable in pure form; (b) largely in multicomponent alloy form; (c) largely in complex assemblages; (d) largely dissipative uses.

* Use percentages are estimated in the present work, based on the cited text information.

When this information is used to construct a "periodic table of recyclability" (Figure 2), it becomes immediately apparent that there are large differences. The only metals judged to be relatively easy to recycle in pure form in their principal uses are copper (used in pure form as a conductor of electricity and heat), lead (used in nearly pure form in batteries), and five precious metals (gold, silver, platinum, palladium, and rhodium).

Metals found predominantly in multicomponent alloys (e.g., 0.1 percent niobium in high-strength steel) are difficult, sometimes impossible, to recover. Recovering metals in complex assemblages (e.g., tantalum capacitors in electronics) is similarly challenging. Because metals in alloys and assemblages are commonly used in very small amounts, the separation process is extremely complicated. Metals in dissipative uses, of course, cannot be recovered.

The distribution of metals among the four groups is: only 12 percent in the easy to recycle group; 46 percent in the recyclable only as alloy group; 33 percent in the complex and unlikely to be recycled group; and 9 percent in the predominantly dissipative group. Thus materials scientists are facing a major challenge, which, so far, they have not addressed. The challenge is to invent and/or prescribe forms of materials that support a high level of product performance while simultaneously maintaining significant recycling potential. Until this challenge is met, the "urban mining" of almost all metals will remain problematic.

The Urban Mining Stock

Abandoned, Comatose, and Hibernating Stock

Not all metal in urban mines is destined to become available for reuse, or at least not for a very long time. For example, abandoned stock (e.g., port revetments, skyscraper pilings, etc.), is material used in a way that makes recovery difficult, expensive, and sometimes essentially impossible. Tanikawa and Hashimoto (2009)

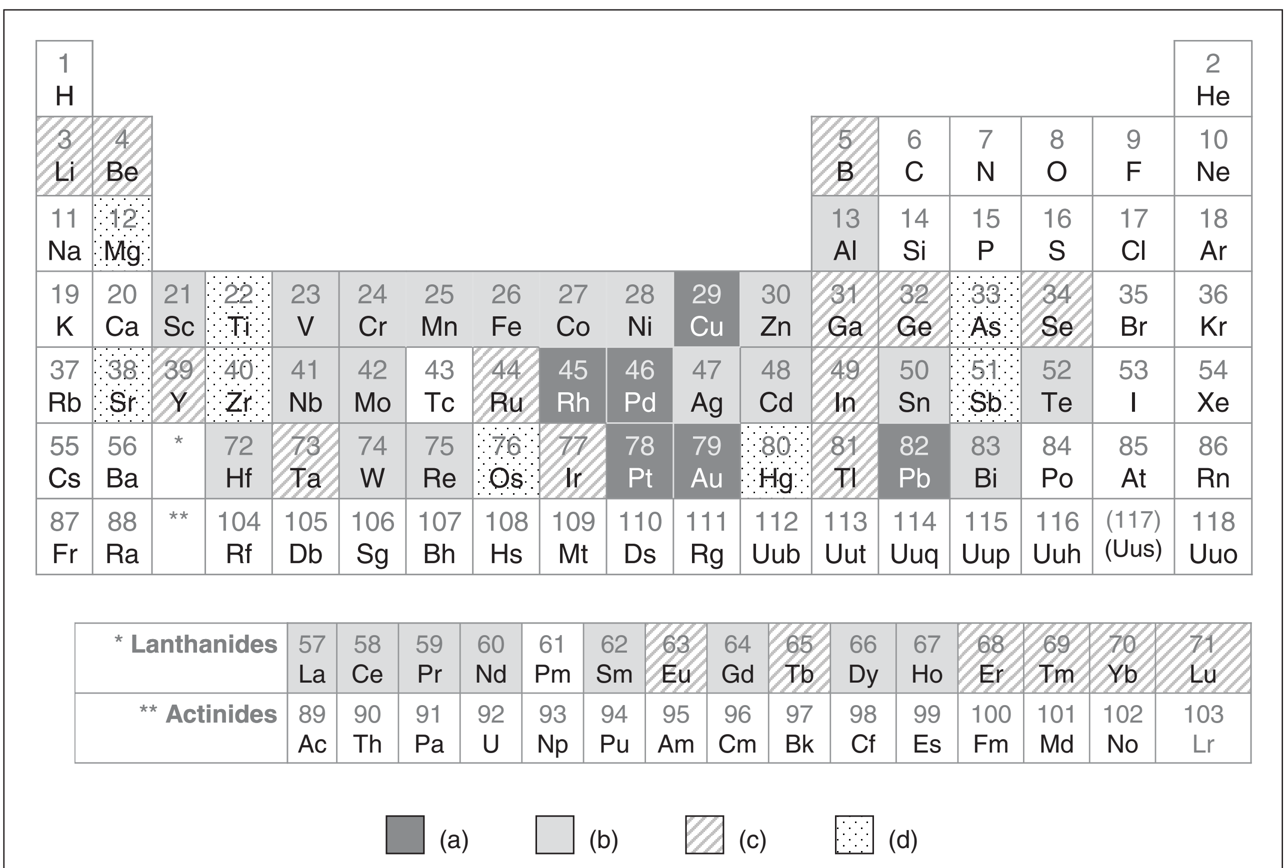


FIGURE 2 The recycling potential of metals in urban stocks. Pattern (a) indicates that the metal in its most common applications is relatively easy to recycle because it is in, or can be relatively easily returned to, its pure form. Pattern (b) indicates that the metal's most common applications are in multicomponent alloys, so recycling is likely only in alloy form, if at all. Pattern (c) indicates that the most common applications are in highly mixed assemblages for which recycling is difficult and can be done at only a few facilities worldwide. Pattern (d) indicates that the predominant uses of the metal are dissipative, so little or no recovery is possible.

have shown that the amount of iron in abandoned stock in Japan is nearly equal to the amount providing above ground services.

A second example can be called comatose stock (e.g., obsolete copper conductors in buried cables). Like humans to whom the term comatose is applied, recovery of these materials is possible in theory, but for various reasons (e.g., difficulty of locating and retrieving it from buried cables, plus unfavorable economics) recovery is unlikely.

A third category is hibernating stock, material now asleep (not performing a useful service) that might someday wake up (e.g., an old cell phone in a drawer).

The Recycling Sequence

For the present discussion, I will not address problems raised by the three categories of material listed above. Instead, I will focus on the recycling sequence, using the example of a metal-containing product that has been discarded.

The common perception of recycling—if you drop an item into the right bin, good things will happen—does not take into account many of the social, political, and technological aspects of the recycling sequence. Collection is indeed vital to success, but collection is only the first step in recycling. Unless the discard is that rare item that consists entirely of a single material (e.g., a piece of copper pipe), the materials in the item must be separated from each other.

This happens with varying degrees of efficiency. For example, when an automobile goes through a shredder at a recycling yard, rivets, adhesives, and other "heroic joining" materials can make separation a challenge (van Schaik et al., 2004). Once separated, the materials must be sorted, a task performed (again with varying degrees of efficiency) using magnets, flotation, eddy-current separation, and a host of other technologies.

Only after the collection and separation steps have been completed can materials be moved to the final stage of metallurgical separation in which individual metals or alloys are reprocessed for reuse. This step may require a very high level of technology and capital investment. For example, state-of-the-art reprocessing of electronic circuit boards can be done in only a handful of facilities worldwide.

Figure 3 shows the recycling sequence and efficiencies typical of modern technology for electronics (some other product groups have higher efficiencies, some lower). The overall system efficiency is the product of the efficiencies of each step. In this typical scenario, only about one-quarter of the metal discarded in products actually ends up as recycled metal.

The sequence is further complicated because different players, many of whose roles are not well understood by outsiders, are responsible for each step in the process. It is easy to understand that collection is crucial, and if it is not carried out successfully, all else is of minimal benefit. Municipalities, the main actors at this stage, oversee regular pickups of discarded appliances, electronics, and other consumer products.

Next are demolition contractors, scrap yards, agglomerators, and metal marketers, who recover or trade many different kinds of discarded metal-containing products. Contractors perform with varying degrees of efficiency and are generally subject to little external oversight.

In some parts of the world, recycling is informal. For base metals (e.g., steel and copper) this approach probably works at least as well as the more structured approaches of highly developed countries. However, for metals in complex, highly integrated products, the informal approach is extremely inefficient.

Thoughts on the Potential of Urban Mining

In the introduction to this article, I posed three questions: What are the successes of urban mining? What are its challenges? Does urban mining matter, or could it? It should be clear at this point that the successes to date are not very significant or exciting, and that enormous challenges remain. Nevertheless, urban mining

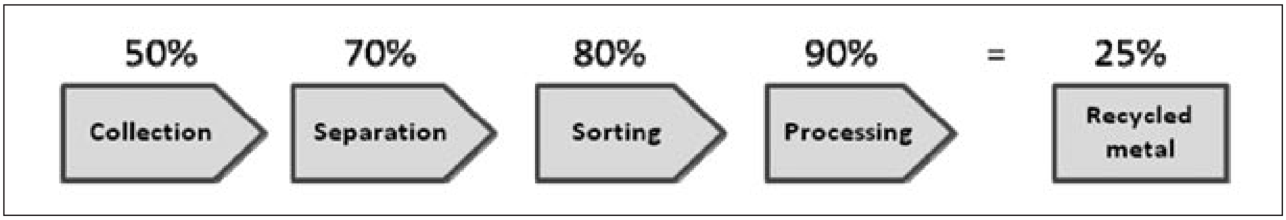


FIGURE 3 The urban mining sequence, with typical efficiencies of each step indicated. Source: Adapted from Hagelüken, 2009.

does matter. Every kilogram recovered and reused displaces a kilogram that must be mined and processed, with all the environmental, social, and economic implications those actions entail.

A conundrum is that contemporary product design is increasingly at odds with effective urban mining. The mixing of materials in products is increasing, and the improved performance that results is achieved at the expense of efficient urban mining (Dahmus and Gutowski, 2007). Clearly, product designers are crucial, if invisible and unrecognized, actors in the recycling chain. Good designs (and some certainly exist) can markedly improve recycling potential, and thoughtless designs from the end-of-life standpoint can effectively nullify it.

Urban mining today is rather successful when the economic incentives are high (e.g., gold in jewelry, rhenium in gas turbine blades, lead in batteries). However, absent economic incentives or other imperatives, our society seems likely to persist in mining and processing virgin metals, using them once or twice, and letting them dissipate back into the environment. This is not Jane Jacobs' vision, nor is it ultimately sustainable.

We can do better as a society, but only if every participant in the chain—product designer, customer, collector, sorter, and processor—realizes that urban mining is about sustaining the resources on which all of technology depends, whether or not it is economical at the present time. Metals are gifts from the stars that were generated over billions of years; we should treat them with the awe and respect they deserve and devise ways to recycle them over and over. Only then will sustainability become a reality.

References

Allwood, J.M., M.F. Ashby, T.G. Gutowski, and E. Worrell. 2010. Material efficiency: a white paper. Resources, Conservation, and Recycling 55(2011): 362–381. DOI: 10.1016/j.resconrec.2010.11.002.

Binder, C.R., T.E. Graedel, and B.K. Reck. 2006. Explanatory variables for per capita stocks and flows of copper and zinc: a comparative statistical analysis. Journal of Industrial Ecology 10(1–2): 111–132.

Butler, J. 2010. Platinum 2010 Interim Review. London, U.K.: Johnson Matthey Public Limited Company.

Dahmus, J.B., and T.G. Gutowski. 2007. What gets recycled: an information theory based model for product recycling. Environmental Science & Technology 41: 7543–7550.

Du, X., and T.E. Graedel. 2011. Global in-use stocks of the rare earth elements: a first estimate. Environmental Science & Technology 45, in press.

Graedel, T.E., and J. Cao. 2010. Metal spectra as indicators of development. Proceedings of the National Academy of Sciences of the United States 107: 20905–20910.

Hagelüken, C. 2009. Recycling of Technology Metals—Opportunities and Limits. Presentation at R'09 Twin World Congress on Resource Sustainability, Davos, Switzerland, September 20, 2009.

IAI (International Aluminium Association). 2006, Global Aluminium Recycling: A Cornerstone of Sustainable Development. London: IAI.

IMOA (International Molybdenum Association). 2010. Molydenum Uses. Available online at *http://www.imoa.info/moly_uses/molybdenum_uses.html*. Accessed Jan. 17, 2011.

Jacobs, J. 1961. The Death and Life of Great American Cities. New York: Random House.

Johnson, J., L. Schewel, and T.E. Graedel. 2006. The contemporary anthropogenic chromium cycle. Environmental Science & Technology 40: 7060–7069.

Kennedy, C., J. Cuddihy, and J. Engel-Yan. 2007. The changing metabolism of cities. Journal of Industrial Ecology 11(2): 43–59.

Kapur, A., and T.E. Graedel. 2006. Copper mines above and below the ground. Environmental Science & Technology 40: 3135–3141.

Kirk-Othmer. 2009. Selenium and Selenium Compounds, and Tellurium and Tellurium Compounds. Kirk-Othmer Encyclopedia of Chemical Technology. New York: Wiley-Interscience.

Mao, J.S., J. Dong, and T.E. Graedel. 2008. The multilevel cycle of anthropogenic lead. I. Methodology. Resources, Conservation, and Recycling 52: 1058–1064.

Matos, G.R., J.D. Jorgenson, and M.W. George. 2005. Historical statistics for mineral and material commodities in the United States. USGS Data Series 140, Reston, Va.

Müller, D.B., T. Wang, and B. Duval. 2011. Patterns of iron use in societal evolution. Environmental Science & Technology 45: 182–188.

Nakajima, K., K. Yokoyama, and T. Nagasaka. 2008. Substance flow analysis of manganese associated with iron and steel flow in Japan. ISIJ International 48: 549–553.

Nassar, N. 2010. Private communication, Yale University.

Perron, L. 2001. Vanadium. In Canadian Minerals Yearbook 2001, Natural Resources Mineral and Metal Commodity Reviews. Available online at *http://www.nrcan.gc.ca/mms/cmy/content/2001/65.pdf*.

Reck, B.K., D.B. Müller, K. Rostkowski, and T.E. Graedel. 2008. Anthropogenic nickel cycle: insights into use, trade, and recycling. Environmental Science & Technology 42: 3394–3400.

Silver Institute. 2011. Silver uses. Available online at *www.silverinstitute.org/silver_uses.php*. Accessed Jan. 17, 2011.

SQM (Sociedad Quimica y Minera de Chile, S.A.). 2007. SQM 2007 Annual Report. Available online at *http://www.sqm.com/PDF/Investors/AnnualReport/SQM_Annual_Report_227_EN.pdf*. Accessed 4-12-2010.

Tanikawa, H., and S. Hashimoto. 2009. Urban stock over time: spatial material stock analysis using 4d-GIS. Building Research and Information 37: 483–502.

Tin Technology Limited. 2006. New ITRI study illustrates the reasons behind continued boom in tin use. St. Albans, U.K.: ITRI Innovation.

TZ Mineral International. 2007. Mineral Sands Annual Review. Perth, Australia: TZ Mineral International Pty Ltd.

USGS (U.S. Geological Survey). 2004. Minerals Yearbook, 2007. Reston, Va.: USGS.

USGS. 2005. Minerals Yearbook, 2007. Reston, Va.: USGS.

USGS. 2007. Minerals Yearbook, 2007. Reston, Va.: USGS.

USGS. 2009. Mineral Commodity Summaries, 2009. Reston, Va.: USGS.

USGS. 2010. Mineral Commodity Summaries, 2010. Reston, Va.: USGS.

Van Nos, N., and J. Cramer. 2006. Product lifetime optimization: a challenging strategy towards more sustainable consumption patterns. Journal of Cleaner Production 14: 1307–1318.

Van Schaik, A., M.A. Reuter, and K. Heiskanen. 2004. The influence of particle size reduction and liberation on the recycling rate of end-of-life vehicles. Minerals Engineering 17: 331–347.

Wang, T., D.B. Müller, and T.E. Graedel. 2007. Forging the anthropogenic iron cycle. Environmental Science & Technology 41: 5120–5129.

NAE News and Notes

Class of 2011 Elected

In February, NAE elected 68 new members and 9 new foreign associates, bringing the number of U.S. members to 2,290 and the number of foreign associates to 202. Engineers are elected to NAE for their outstanding contributions to "engineering research, practice, or education, including . . . significant contributions to the engineering literature" and to "new and developing fields of technology, . . . major advancements in traditional fields of engineering, or . . . innovative approaches to engineering education." A list of the newly elected members and foreign associates follows, with primary affiliations at the time of election and brief descriptions of principal accomplishments.

James F. Albaugh, executive vice president, Boeing Company, and president and chief executive officer, Commercial Airplanes, Renton, Washington. For technical leadership in the defense and commercial aerospace industries.

John E. Allison, senior technical leader, Ford Research and Advanced Engineering, Ford Motor Company, Dearborn, Michigan. For contributions to automotive casting technology and computational materials engineering.

Nadine N. Aubry, Raymond J. Lane Distinguished Professor and head of the Mechanical Engineering Department, Carnegie Mellon University, Pittsburgh, Pennsylvania. For contributions to low-dimensional models of turbulence and microfluidic devices, and for leadership in engineering education.

David D. Awschalom, Peter J. Clarke Professor, director of the California NanoSystems Institute, and director of the Center for Spintronics and Quantum Computation, University of California, Santa Barbara. For contributions to the understanding of spin coherence and spintronics.

William F. Baker Jr., structural and civil engineering partner, Skidmore, Owings, & Merrill LLP, Chicago, Illinois. For leadership in the development of innovative structures for high-rise buildings worldwide.

James Edwin Barger, chief scientist, BBN Technologies, Cambridge, Massachusetts. For applications of acoustic technology and engineering solutions for the benefit of national security and society.

Jeffrey S. Beck, manager, Corporate Strategic Research Laboratory, ExxonMobil Research and Engineering Company, Annandale, New Jersey. For discovery and commercialization of selective, environmentally beneficial catalytic routes to major petrochemicals and for leadership in industrial engineering.

John R. Birge, Jerry W. and Carol Lee Levin Professor of Operations Management, Booth School of Business, University of Chicago, Chicago, Illinois. For contributions to the theory of optimization under uncertainty.

Lawrence D. Burns, retired vice president of research and development and strategic planning, General Motors Corporation; and professor of engineering practice, University of Michigan, Ann Arbor. For leadership and technical contributions to automotive technologies.

Albert Carnesale, Chancellor Emeritus and professor of public policy and mechanical and aerospace engineering, University of California, Los Angeles. For bringing engineering excellence and objectivity to international security and arms control, and for leadership in higher education.

Michael J. Cima, Sumitomo Electric Industries Professor of Engineering, Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge. For innovations in rapid prototyping, high-temperature superconductors, and biomedical device technology.

James Joseph Collins, professor of biomedical engineering and co-director, Center for BioDynamics, Boston University, Boston, Massachusetts. For contributions to synthetic biology and engineered gene networks.

William John Cook, Chandler Family Chair Professor in Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta. For theoretical and computational contributions to discrete optimization.

Stuart L. Cooper, University Scholar Professor and chair, Department of Chemical and Biomolecular Engineering, Ohio State University, Columbus. For contributions to polymer chemistry, biomedical polyurethanes, blood compatibility, and academic administration.

Armen Der Kiureghian, Taisei Professor of Civil Engineering, University of California, Berkeley.

For contributions to risk and reliability and earthquake engineering to advance the practice of civil and structural engineering.

Susan T. Dumais, principal researcher, Adaptive Systems and Interaction Group, Microsoft Research, Redmond, Washington. For innovation and leadership in organizing, accessing, and interacting with information.

Daniel C. Edelstein, IBM Fellow and manager, BEOL Technology Strategy, IBM T.J. Watson Research Center, Yorktown Heights, New York. For contributions to the implementation of copper/low-dielectric chip interconnects.

Abbas Firoozabadi, senior scientist and director, Reservoir Engineering Research Institute, Palo Alto, California. For contributions to oil and gas recovery processes through application of surface science and thermodynamics.

Christodoulos A. Floudas, Stephen C. Macaleer '63 Professor in Engineering and Applied Science and professor of chemical and biological engineering, Princeton University, Princeton, New Jersey. For contributions to theory, methods, and applications of global optimization in process systems engineering, computational chemistry, and molecular biology.

Jacqueline Gail (Berg) Gish, director of special projects, Northrop Grumman Aerospace Systems, Redondo Beach, California. For technical and programmatic contributions to high-power diode-pumped solid state lasers for defense applications.

John C. Gore, Hertha Ramsey Cress University Professor of Radiology and Radiological Sciences, Biomedical Engineering, Molecular Physiology and Biophysics, and Physics; and director of the Center for Imaging Sciences, Vanderbilt University, Nashville, Tennessee. For contributions to the development and applications of magnetic resonance and other imaging techniques in medicine.

Linda G. Griffith, professor of biological and mechanical engineering and director, Biotechnology Process Engineering Center, Massachusetts Institute of Technology, Cambridge. For contributions to 3D functional biomaterials, engineered hepatic tissues, and cell transplant devices.

Daniel M. Hancock, vice president, Global Strategic Product Alliances, General Motors Corporation, Pontiac, Michigan. For contributions to automotive engines and transmissions and leadership in advanced powertrain technology and engineering education.

James S. Harris Jr., James and Ellenor Chesebrough Professor of Electrical Engineering, Materials Science, and Applied Physics, Stanford University, Stanford, California. For contributions to epitaxial growth of compound semiconductor materials and their applications.

Chris T. Hendrickson, Duquesne Light Company Professor of Engineering and co-director, Green Design Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania. For leadership and contributions in transportation and green design engineering.

Michael R. Hoffmann, James Irvine Professor of Environmental Science, California Institute of Technology, Pasadena. For oxidative treatment technologies for the removal of organic and inorganic contaminants from water.

Mark S. Humayun, professor of ophthalmology, biomedical engineering, and cell and neurobiology, University of Southern California, Los Angeles. For contributions to development and clinical implementation of the visual prosthesis for restoration of sight.

Linos J. Jacovides, retired director, Delphi Research Labs, Delphi Corporation, Gross Pointe Farms, Michigan. For research on interactions between power electronics and electrical machines in electric vehicles, hybrid electric vehicles, and locomotives.

Keith P. Johnston, M.C. (Bud) and Mary Beth Baird Endowed Chair and Professor of Chemical Engineering, University of Texas, Austin. For advances in science and technology of particles and colloids used in drug delivery, biomedical imaging/therapy, microelectronics, and energy applications.

Min H. Kao, chairman and chief executive officer, Garmin Ltd., Olathe, Kansas. For leadership in developing and commercializing compact GPS navigation systems.

Henry Z. Kister, senior fellow and director of fractionation technology, Fluor Corporation, Aliso Viejo, California. For leadership in distillation technology and for transforming distillation troubleshooting into an engineering science.

Daphne Koller, professor, Department of Computer Science, Stanford University, Stanford, California. For contributions to representation, inference, and learning in probabilistic models with applications to robotics, vision, and biology.

Jindrich Kopecek, Distinguished Professor of Pharmaceutics and Pharmaceutical Chemistry and Distinguished Professor of Bioengineering, University of Utah, Salt Lake City. For contributions to the design of hydrogel biomaterials and polymeric drug delivery systems.

Mark J. Kushner, George I. Haddad Collegiate Professor and director, Michigan Institute for Plasma Science and Engineering, University of Michigan, Ann Arbor. For contributions to low-temperature plasmas for semiconductors, optics, and thin-film manufacturing.

Cato T. Laurencin, Van Dusen Endowed Chair in Academic Medicine; Distinguished Professor of Orthopaedic Surgery and Chemical, Materials, and Biomolecular Engineering; dean, School of Medicine; and vice president for health affairs, University of Connecticut, Farmington. For biomaterial science, drug delivery, and tissue engineering involving musculoskeletal systems, and for academic leadership.

Fred C. Lee, University Distinguished Professor, Bradley Department of Electrical and Computer Engineering, and director, Center for Power Electronics Systems, Virginia Polytechnic Institute and State University, Blacksburg. For contributions to high-frequency power conversion and systems integration technologies, education, industry alliances, and technology transfer.

Henry M. Levy, Wissner-Slivka Endowed Chair in Computer Science and Engineering and department chair, University of Washington, Seattle. For contributions to design, implementation, and evaluation of operating systems, distributed systems, and processor architectures.

Donald Liu, retired executive vice president and chief technology officer, American Bureau of Shipping, Houston, Texas. For finite-element techniques for ship structural designs and contributions to the principles for safer ships.

Lester L. Lyles, independent aerospace consultant, The Lyles Group, Vienna, Virginia. For leadership in advancing air and space technology and for national service in space exploration.

Asad M. Madni, retired president and chief technical officer, BEI Technologies, Inc.; and independent consultant, Los Angeles, California. For contributions to development and commercialization of sensors and systems for aerospace and automotive safety.

Joanne M. Maguire, executive vice president, Lockheed Martin Space Systems Company, Littleton, Colorado. For individual and team leadership of successful space programs.

Jitendra Malik, Arthur J. Chick Professor of Electrical Engineering and Computer Science, University of California, Berkeley. For contributions to computer vision and image analysis.

Ralph D. Masiello, senior vice president and innovation director, KEMA Inc., Chalfont, Pennsylvania. For online analysis, operator training simulation, and modern market development for secure operation of electric power grids.

Nicholas William McKeown, professor of electrical engineering and computer science, Stanford University, Stanford, California. For contributions to the design, analysis, and engineering of high-performance routers.

Richard B. Miles, professor, Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey. For development of laser-based flow field diagnostics and contributions to hypersonic testing technologies.

Donald A. Norman, Allen K. and Johnnie Cordell Breed Senior Professor in Design, professor of electrical engineering and computer science, and co-director of the Segal Design Institute, Northwestern University, Evanston, Illinois. For development of design principles based on human cognition that enhance the interaction between people and technology.

Amedeo R. Odoni, T. Wilson Professor of Aeronautics and Astronautics and professor of civil and environmental engineering, Massachusetts Institute of Technology, Cambridge. For contributions and global leadership in air traffic control and airport systems.

John Arthur Orcutt, professor of geophysics and Distinguished Researcher, San Diego Supercomputer Center, Scripps Institution of Oceanography, University of California, San Diego, La Jolla. For international leadership in development of new ocean-observing infrastructure and environmental and geophysics research.

Parker H. "Pete" Petit, president, The Petit Group, Roswell, Georgia. For developing and manufacturing the first home Sudden Infant Death Syndrome monitor and for pioneering pediatric home health care.

Karsten Pruess, senior scientist, Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California. For advances in modeling and engineering performance assessment of subsurface heat and mass transport processes.

Ramamoorthy Ramesh, Plato Malozemoff Chair Professor in Materials Science and Physics, University of California, Berkeley. For contributions to the science and technology of functional complex oxide materials.

Aristides A.G. Requicha, Gordon Marshall Chair in Engineering, University of Southern California, Los Angeles. For contributions to solid modeling and programmable automation at the macro- and nano-scales.

Thomas J. Richardson, vice president, engineering, Qualcomm-Flarion Technologies, Bridgewater, New Jersey. For contributions to error control coding theory and their application to multiple access wireless systems.

Franklin D. Robinson, retired president and chairman, Robinson Helicopter Company, Torrance, California. For the conception, design, and manufacture of low-noise, low life-cycle cost, and high-reliability helicopters.

John A. Rogers, Lee J. Flory-Founder Chair in Engineering, Department of Materials Science and Engineering, University of Illinois, Urbana-Champaign. For novel electronic and optoelectronic devices and systems.

Ares J. Rosakis, Theodore von Kármán Professor of Aeronautics, professor of mechanical engineering, and chair, Division of Engineering and Applied Science, California Institute of Technology, Pasadena. For discovery of intersonic rupture, contributions to understanding dynamic failure, and methods to determine stresses in thin-film structures.

Joan B. Rose, Homer Nowlin Endowed Chair of Water Research, co-director of the Center for Water Sciences, and co-director of the Center for Advancing Microbial Risk Assessment, Michigan State University, East Lansing. For contributions to improving water quality safety and public health.

Joseph C. Salamone, chief scientific officer, Rochal Industries LLP, San Antonio, Texas. For advances in ophthalmological devices and wound healing therapies and for distinguished academic and professional service.

Fred B. Schneider, Samuel B. Eckert Professor of Computer Science, Cornell University, Ithaca, New York. For contributions to the design of trustworthy and secure computer systems.

Terrence J. Sejnowski, Francis Crick Professor and director of the Computational Neurobiology Laboratory, Salk Institute for Biological Studies, La Jolla, California. For contributions to artificial and real neural network algorithms and applying signal processing models to neuroscience.

Alexander J. Smits, Eugene Higgins Professor of Mechanical and Aerospace Engineering and chair, Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey. For contributions to the measurement and understanding of turbulent flows, fluids engineering, and education.

James C. Stevens, research fellow in core research and development, Dow Chemical Company, Freeport, Texas. For contributions to the discovery and commercialization of polyolefins and polyolefin products.

John M. Undrill, independent consultant, John Undrill LLC, Scotia, New York. For the development and application of testing methods and power system analysis tools in the electric utility industry.

Wallace R. Wade, consultant and retired chief engineer and technical fellow, Powertrain Systems Technology and Processes, Ford Motor Company, Novi, Michigan. For implementation of low-emission technologies in the automotive industry.

Yulun Wang, founder, chairman, and chief executive officer, InTouch Health, Santa Barbara, California. For creation of remotely operated surgical robots and telemedicine devices.

Mihalis Yannakakis, Percy K. and Vida L.W. Hudson Professor of Computer Science, Columbia University, New York, New York. For contributions to algorithms and computational complexity.

Gregory J. Yurek, founder, chairman of the board, president, and chief executive officer, American Superconductor Corporation, Devens, Massachusetts. For engineering and leadership in development of high-temperature superconductor commercial products.

Mark D. Zoback, Benjamin M. Page Professor of Geophysics, Stanford University, Stanford, California. For advances in the application of geomechanics to oil and gas production, geothermal stimulation, and carbon dioxide sequestration.

New Foreign Associates

Ronald Bullough, consultant, Goring, Reading, United Kingdom. For contributions to understanding irradiation effects in solids and leadership in nuclear technology.

M. Elizabeth Cannon, president, University of Calgary, Calgary, Alberta. For innovative use of GPS data for a wide range of applications and for pioneering the field of geomatics.

Guilherme de Oliveira Estrella, director of exploration and production, Petróleo Brasileiro S.A. Petrobras, Rio de Janiero, Brazil. For leadership in development of deepwater technology and discovery of giant oil fields offshore Brazil in pre-salt formations.

Prabha S. Kundur, president, Kundur Power Systems Solutions Inc., Toronto, Ontario. For contributions to modeling and control techniques to enhance the stability and reliability of large electric power systems.

Ingemar Lundström, Professor Emeritus, IFM-Linköping University, Linköping, Sweden. For contributions to the development and commercialization of sensing platforms for biological interactions.

Jacob H. Masliyah, University Professor Emeritus, Department of Chemical and Materials Engineering, University of Alberta, Edmonton. For advancing the science and technology for recovery of bitumen from oil sands.

D. Roger J. Owen, professor in civil engineering, Swansea University, Swansea, United Kingdom. For contributions to computational solid mechanics and industrial application of finite and discrete element methods.

Jonathan Scott Rose, professor, Department of Electrical and Computer Engineering, University of Toronto, Toronto, Ontario. For contributions to research and engineering of field-programmable gate array architectures and computer-aided design tools.

Michael J. Rouse, independent international consultant, Oxford, United Kingdom. For international leadership in water governance, regulation, and research to ensure safe drinking water.

NAE Newsmakers

Diran Apelian, Howmet Professor of Mechanical Engineering, and director, Metal Processing Institute, Worcester Polytechnic Institute, received the **2010 National Materials Advancement Award** from the Federation of Materials Societies at the National Press Club in Washington, D.C., on December 8, 2010. Dr. Apelian was recognized for founding and developing the Metal Processing Institute, "a prime example of building bridges between the industrial, government, and academic communities that bring the capabilities of materials science and engineering to bear on societal challenges, while always valuing the role of the human element."

James M. Duncan, University Distinguished Professor of Civil Engineering, Emeritus, Virginia Polytechnic Institute and State University, is the recipient of the **G. Brooks Earnest Award and Lecture** from the Cleveland Section of the American Society of Civil Engineers. The award is presented annually to an outstanding individual of national and international prominence, preferably an individual who works in the field of civil engineering. Dr. Duncan is well known for his contributions to geotechnical engineering.

B. Jayant Baliga, director, Power Semiconductor Research Center, North Carolina State University, has been **inducted into the 2010 class of the Electronic Design Engineering Hall of Fame**. Dr. Baliga was honored for inventing the insulated-gate bipolar transistor (IGBT), an energy-saving semiconductor switch that controls the flow of power from an energy source to the application that needs energy. The device, which he developed while working at General Electric in the 1970s, is used in everything from light bulbs to washing machines and automobiles. An estimated 100 gigawatts of electricity have been saved by using IGBTs in electric motors and energy-efficient compact fluorescent light bulbs alone. In addition, IGBTs in compact heart defibrillators save an estimated 100,000 lives annually.

Howard J. Bruschi, retired senior vice president and chief technology officer, Westinghouse Electric Company, has been **elected an International Fellow of The Royal Academy of Engineering** of the United Kingdom. Mr. Duncan was recognized for his exceptional leadership and ingenuity in the design, development, and licensing of the Westinghouse advanced passively safe AP600 and AP1000 nuclear power reactors.

Arogyaswami J. Paulraj, Professor Emeritus, Information Systems Laboratory, Stanford University, received the prestigious Institute of Electrical and Electronics Engineers (IEEE) **Alexander Graham Bell Medal**. Dr. Paulraj was selected "for pioneering contributions to the application of multiantenna technology to wireless communications systems."

NAE Members Receive One National Medal of Technology and Innovation and Three National Medals of Science

Harry Coover, 2009 National Medal of Technology and Innovation Laureate.

Esther Conwell, 2009 National Medal of Science Laureate.

Warren Washington, 2009 National Medal of Science Laureate.

Amnon Yariv, 2009 National Medal of Science Laureate.

On November 17, 2010, at a ceremony in the East Room of the White House, President Barack Obama presented the 2009 National Medals of Science and National Medals of Technology and Innovation. Four NAE members were among the recipients of these prestigious awards.

A 2009 National Medal of Technology and Innovation was presented to **Harry Coover**, independent consultant, Kingsport, Tennessee, for the invention of cyanoacrylates (novel adhesives widely known as "super glues"), which are used in medicine and industry.

National Medals of Science were awarded to three NAE members. **Esther Conwell**, professor, Departments of Chemistry and Physics, University of Rochester, was honored for advancing our understanding of electron and hole transport in semiconducting materials. Her many contributions have led to commercial applications of semiconductor and organic electronic devices. She was also honored for the analysis of the electronic properties of DNA.

Warren Washington, senior scientist, National Center for Atmospheric Research, received the medal for the development and use of global climate models that have advanced our understanding of climate and the role of human activities and natural processes in Earth's climate system and for his efforts in support of a diverse science and engineering workforce.

Amnon Yariv, Martin and Eileen Summerfield Professor of Applied Physics and professor of electrical engineering, California Institute of Technology, was cited for foundational scientific and engineering contributions to photonics and quantum electronics that have profoundly impacted light-wave communications and the field of optics as a whole, including the demonstration of the semiconductor distributed-feedback laser, an essential component of high-speed, optical-fiber communication.

All photos by Ryan K Morris Photography and the National Science & Technology Medal Foundation.

Mirzayan Fellows Join Program Office

Kellie Green

Erica Lively

Kellie Green is a native of White Castle, Louisiana, a rural community south of Baton Rouge. She attended Southern University and A&M College in Baton Rouge, where she majored in chemistry and mathematics. She then earned a master's degree in chemical education at Purdue University. Kellie's master's project was an investigation of differences between online and face-to-face dialogue in chemistry. In addition to writing a master's thesis, she earned a teaching certificate in chemistry.

Kellie recently completed doctoral work in science education at Purdue University in the Department of Curriculum and Instruction. Her dissertation focused on the assessment of a research-based laboratory designed by the Center for Authentic Science Practice in Education (CASPiE). For her research project, she documented whether this type of laboratory intervention had influenced students' understanding of the nature of science and experimental design. Kellie hopes to secure a position in academia and later transition to an administrative position.

Kellie's activities at CASEE will focus on developing briefs of research-to-practice studies highlighting the applicability of research in social sciences and education to classroom and administrative practices in engineering education. She plans to use the lessons learned during her fellowship to further her research and teaching goals.

Erica Lively is currently completing a Ph.D. in electrical and computer engineering at the University of California, Santa Barbara (UCSB). She holds an M.S. and B.S. in electrical engineering from UCSB and the University of Idaho, respectively. Her thesis research is on nano-scale patterned metals for integrated lasers and optical telecommunications applications.

As a science fellow with the Center for Nanotechnology in Society at UCSB, Erica conducted research on several topics related to nanotechnology, such as government and NGO (non-governmental organization) discourse, media coverage and framing, and how comparisons can affect the judgment and acceptance of emerging technology. Erica's long-term career goals are to maintain her connections with the science and technology community while working to solve problems that overlap with policy, business, and society.

During her fellowship, Erica will be working with the Program on Engineering and Health and the Program on Engineering, Economy, and Society on opportunities at the intersection of engineering, biology, and medicine. In her free time, she enjoys golf, skiing, and good food.

EngineerGirl! News

NAE developed the *EngineerGirl!* website to encourage students to consider engineering as a potential career path. Designed to appeal to middle school girls, the website features profiles of women engineers, an annual essay contest open to boys and girls grades 3 through 12, and an "Ask an Engineer" column that enables students to ask questions of profiled engineers. The questions and answers appear on the website.

NAE recently produced bookmarks and posters (18" x 24") for engineers and educators to include in outreach materials for pre-college students. Electronic versions of both are available at *www.engineergirl.org*.

For free bookmarks and/or posters, NAE members should contact Catherine Didion (*cdidion@nae.edu*). Please include the number of bookmarks/posters you want and your mailing address.

New Engineering Messaging Website

In early January, NAE launched a new website intended to help the engineering community improve its outreach activities. The site, <*engineeringmessages.org*>, which draws on the results of the 2008 NAE publication, *Changing the Conversation: Messages for Improving Public Understanding of Engineering*, explains why the image of engineering needs improving, reviews messages and related research presented in the 2008 report, showcases more than 100 examples of engineering messaging by other organizations, and encourages community-building through the use of Web 2.0 features. The website is part of an ongoing project funded by the National Science Foundation. NAE President **Charles M. Vest** and DuPont Chair of the Board and CEO Ellen Kullman are co-chairs of the NAE committee that oversees the messaging project. For more information, contact Greg Pearson (*gpearson@nae.edu*).

Calendar of Upcoming Events

April 1	Nominations deadline for 2011 NAE Awards
April 5	NRC Governing Board Executive Committee Meeting
April 7	NAE Regional Meeting University of Texas, Austin
April 14	NAE Regional Meeting Harvard University, Cambridge, Massachusetts
April 26	NAE Regional Meeting University of Pennsylvania, Philadelphia
May 10	NRC Governing Board Executive Committee Meeting
May 10–11	NRC Governing Board Meeting
May 12–13	NAE Council Meeting
May 16	NAE Convocation of Professional Engineering Societies
May 18–19	Workshop on the Role of Engineering in STEM Education
May 24–25	NAE-Chinese Academy of Engineering Workshop on Global Navigation Satellite Systems Shanghai, China
June 5–8	Japan-American Frontiers of Engineering Symposium (JAFOE) Tsukuba, Japan
June 6–8	Workshop on Climate, Society, and Technology Irvine, California
June 7	NRC Governing Board Executive Committee Meeting
June 27–30	International Council of Academies of Engineering and Technological Sciences Mexico City, Mexico

All meetings are held in Washington, D.C., unless otherwise noted. For information about regional meetings, please contact Sonja Atkinson at <*satkinso@nae.edu*> or (202) 334-3677.

NAE Annual Meeting, October 16–17, 2011

The 2011 NAE Annual Meeting will be held October 16–17 at the JW Marriott Hotel and the Keck Center of the National Academies in Washington, D.C.

Orientation for members of the Class of 2011 will be on Saturday, October 15. A black-tie dinner in honor of new members and foreign associates, hosted by the NAE Council, will be held that evening.

The induction ceremony for the Class of 2011 will take place at noon on Sunday, October 16. An awards program will follow.

The Business Session for members and foreign associates will be held on Monday morning, October 17, followed by the Forum. Section meetings that afternoon will be held at the Keck Center and the JW Marriott. The meeting will conclude with an optional dinner dance at the JW Marriott that evening.

The flyer for the NAE 2011 Annual Meeting and online registration form will be available on the NAE website in mid-June.

In Memoriam

GEORGE BUGLIARELLO, 83, President Emeritus and University Professor, Polytechnic Institute of NYU, died on February 18, 2011. Dr. Bugliarello was elected to NAE in 1987 "for outstanding contributions in biomedical engineering, fluid mechanics, and sociotechnology, and for leadership in technological education."

CHARLES A. DESOER, 84, Professor Emeritus, University of California, Berkeley, died on November 1, 2010. Dr. Desoer was elected to NAE in 1977 "for contributions to control and system theory, and for innovation in engineering education."

CHARLES H. ELMENDORF III, 97, retired assistant vice president, engineering, AT&T Corporation, died on October 31, 2010. Mr. Elmendorf was elected to NAE in 1971 "for technical contributions and leadership in creating high capacity communication systems."

JOHN A. FOCHT JR., 87, senior consultant, McClelland Engineers Inc., died on October 22, 2010. Mr. Focht was elected to NAE in 1986 "for developing innovative, practical methods of designing piles subject to extreme loads and heavy mat foundations on deep soil formations."

JOSEPH G. GAVIN JR., 90, retired president, Grumman Corporation, died on October 30, 2010. Mr. Gavin was elected to NAE in 1974 "for leadership in the design and production of the Apollo Lunar Module."

CYRIL M. HARRIS, 93, Charles Batchelor Professor Emeritus of Electrical Engineering and Professor Emeritus of Architecture, Columbia University, died on January 11, 2011. Dr. Harris was elected to NAE in 1975 "for contributions to the field of acoustical engineering through engineering practice, research and the engineering literature."

W. JACK HOWARD, 88, consultant, Sandia National Laboratories, died on September 13, 2010. Mr. Howard was elected to NAE in 1979 "for contributions to nuclear ordnance engineering, particularly in systems concepts, command, control, intelligence, and safety."

ROBERT G. KOUYOUMJIAN, 87, Professor Emeritus of Electrical Engineering, Ohio State University, died on January 3, 2011. Dr. Kouyoumjian was elected to NAE in 1995 "for contributions to the development of the uniform geometric theory of diffraction and the analysis and design of antennas and scatterers."

CHARLES R. O'MELIA, 76, Abel Wolman Professor of Environmental Engineering Emeritus, Johns Hopkins University, died on December 16, 2010. Dr. O'Melia was elected to NAE in 1989 "for important contributions to the theories of coagulation, flocculation, and filtration leading to improved water-treatment practices throughout the world."

DAVID W. SINCOSKIE, 55, professor of electrical and computer engineering, University of Delaware, died on October 20, 2010. Dr. Sincoskie was elected to NAE in 2000 "for contributions in packet switching for integrated networks."

CHARLES P. SPOELHOF, 80, retired vice president, Eastman Kodak Company, died on December 18, 2010. Mr. Spoelhof was elected to NAE in 1981 "for exceptional technical insight and skill in conceiving and developing analytical techniques and optical and photographic instruments for industry and government."

MAURICE V. WILKES, 97, Emeritus Professor, Cambridge University, died on November 29, 2010. Sir Maurice was elected a foreign associate of NAE in 1977 "for pioneering development of practical electronic computers and leadership in computer science."

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at *http://www.nap.edu* or by phone at (888) 624-8373. *(Note: Prices quoted are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Interim Report on Causes of the Deepwater Horizon Oil Rig Blowout and Ways to Prevent Such Events. This interim report by a National Academy of Engineering/National Research Council committee includes preliminary findings and observations on well design, cementing operations, monitoring, and well control, as well as management, oversight, and the regulatory regime for offshore operations. At the request of the U.S. Department of the Interior, the committee continues to look into probable causes of the Deepwater Horizon explosion, fire, and oil spill to identify measures to prevent similar events in the future. In the final report, the study committee will assess the performance of technologies and practices involved in probable causes of the Macondo well blowout and explosion on the Deepwater Horizon. Based on its findings, the committee will also identify and recommend available technologies, industry best practices, best available standards, and other measures in use around the world for deepwater exploratory drilling and well completion that could help avoid future explosions and spills. The study will not address issues associated with the fire (rescue and fire response) or the release of oil and gas into the Gulf of Mexico (plans for responding to spills, spill response and cleanup, or environmental and health consequences of the oil spill). The full report will be available in June 2011.

NAE members on the study committee were **Donald C. Winter** (chair), former Secretary of the Navy, U.S. Department of the Navy; **David E. Daniel**, president, University of Texas, Dallas; **Roger L. McCarthy**, consultant, McCarthy Engineering; **Keith K. Millheim**, president, Strategic Worldwide LLC; **M. Elisabeth Pate-Cornell**, Burt and Deedee McMurtry Professor and chair, Management Science and Engineering, Stanford University; **Robert F. Sawyer**, Class of 1935 Professor of Energy, Emeritus, Department of Mechanical Engineering, University of California, Berkeley; and **Arnold F. Stancell**, retired vice president, Mobil Oil and Turner Professor of Chemical Engineering, Emeritus, Georgia Institute of Technology. Free PDF (for interim report).

The Power of Renewables: Opportunities and Challenges for China and the United States. As of 2010, the United States and China were the top two energy consumers and the two largest economies in the world. Consequently, they play a decisive role in a clean energy future. Both countries are working toward related goals, including diversified energy portfolios, job creation, energy security, and pollution reduction, and renewable energy development is an important strategy for reaching those goals. Given the size of their energy markets, substantial advances in renewable energy by these two countries will lead to global benefits in terms of enhanced technological understanding, lower costs, and reduced greenhouse gas emissions relative to emissions from fossil fuels. In this context, the National Academies, in collaboration with the Chinese Academy of Sciences and Chinese Academy of Engineering, reviewed renewable energy development and deployment in both countries to highlight prospects for collaborative efforts in research, development, and deployment and to suggest strategies for accelerating the achievement of goals for renewable energy. The report includes assessments of renewable resources, technology development, environmental impacts, market infrastructure, and other relevant factors. Specific recommendations are limited to pragmatic, achievable steps to accelerate the pace of deployment, improve cost competitiveness, and shape the future market for renewable energy.

NAE member **Lawrence T. Papay**, CEO and principal, PQR LLC, and retired sector vice president for integrated solutions, Science Applications International

Corporation, was chair of the study committee. Paper, $36.00.

Global Technology: Changes and Implications: Summary of a Forum. During a three-hour forum, part of the annual meeting of the National Academy of Engineering on October 4, 2010, a panel of seven experts from a variety of disciplinary and sectoral backgrounds explored the effects, complexities, and risks associated with the global spread of technology and the opportunities and responsibilities this entails for engineering leaders. This summary of the forum, prepared by rapporteur Steve Olson, captures the essence of the presentations and the ensuing discussion. Panelists were former Finnish prime minister Esko Aho, now executive vice president of corporate relations and responsibility at Nokia; **Bernard Amadei**, professor of civil engineering at the University of Colorado and founder of Engineers Without Borders-USA and Engineers Without Borders-International; John Seely Brown, visiting scholar and advisor to the provost at the University of Southern California and, for nearly two decades, director of the Xerox Corporation Palo Alto Research Center; **Ruth A. David**, president and chief executive officer of Analytic Services Inc. and former deputy director for science and technology at the Central Intelligence Agency; Eric Haseltine, a consultant in management and innovation and former longtime head of Disney Imagineering; Nicholas Negroponte, founder and chairman of the One Laptop per Child Association and co-founder, with Jerome Wiesner, of MIT's Media Lab; and **Raymond Stata**, cofounder and chairman of the board of Analog Devices Inc. and a quintessential American technology-based entrepreneur. The panel was moderated by NAE president Charles M. Vest. Paper, $15.00.

Adapting to the Impacts of Climate Change. Some impacts of climate change—such as rising sea levels, disappearing sea ice, and the frequency and intensity of extreme weather events (e.g., heavy precipitation and heat waves)—are already being felt across the country. A National Academies study committee concludes in this new report that reducing vulnerabilities to the impacts of climate changes that are either inevitable or that cannot be avoided with reasonable actions is a highly desirable strategy for managing and minimizing risks. The committee advises policy makers to assume a wide range of possible climate conditions and take action to minimize their adverse effects, despite uncertainties about their exact timing and magnitude. In fact, the committee argues that increasing adaptive capacity now can be a kind of "insurance policy against an uncertain future." Inaction, they say, will increase risks, especially if changes occur sooner than anticipated.

NAE member **W. Peter Cherry**, chief analyst, Science Applications International Corporation, was a member of the study panel. Paper, $49.95.

Limiting the Magnitude of Climate Change. Meeting internationally discussed targets for limiting atmospheric concentrations of greenhouse gases (GHGs) and associated increases in global average temperatures will require major changes in how energy is used and produced around the world. This report, a volume in the America's Climate Choices Series, recommends that a U.S. policy goal be stated in terms of a budget for cumulative GHG emissions from 2010 to 2050. With only so much to "spend" during this period, the nation should act now to: (1) take advantage of near-term opportunities to limit GHG emissions and develop new and better emission-reduction approaches for the longer term; (2) develop a national policy framework within which actors at all levels can work toward a common goal; and (3) develop policy mechanisms durable enough to persist for decades but flexible enough to adapt to new information and changes in our understanding of climate change. The report committee concludes that a carbon-pricing system (either cap-and-trade or taxes or a combination of the two) is the most important step for providing incentives to reduce emissions. However, we will also need complementary policies to ensure improvements in energy efficiency; accelerate the development of renewable energy sources; enable full-scale demonstrations of nuclear power and carbon capture and storage systems; and ensure the retrofitting or replacement of existing emissions-intensive energy infrastructure. Research and development on new technologies that could help reduce emissions in the long term should be strongly supported. Overall, the committee argues that decisive U.S. action to reduce emissions would not only encourage other countries to follow suit, but would also establish the United States as a leader in the development and deployment of technologies for limiting and adapting to climate change.

NAE member **James A. Trainham III**, vice president, Sundrop

Fuels Inc., was a member of the study panel. Paper, $49.95

Advancing the Science of Climate Change. The National Academies committee that conducted this study as part of the America's Climate Choices Series makes a compelling case, based on strong, credible evidence, that climate change is occurring, is caused in large part by human activities, and poses significant risks to a wide range of human and natural systems. The committee concludes that the core phenomena, scientific questions, and hypotheses have been examined thoroughly and have held up in the face of serious debate and careful evaluations of alternative explanations. As decision makers attempt to respond to the risks, the U.S. scientific community can contribute by improving our understanding of the causes and consequences of climate change and by providing options for limiting the magnitude of climate changes and adapting to their impacts. This will require a comprehensive, integrated, flexible climate change research enterprise closely linked to action-oriented programs at all levels. The committee recommends that a single federal entity or program, such as the U.S. Global Change Research Program (GCRP), established in 1990, be given the authority and resources to coordinate an integrated, multidisciplinary national research effort. To be successful, GCRP would first have to address internal weaknesses and then form partnerships with action-oriented programs. The goals of a national research initiative should include: the development of a comprehensive climate observing system; improved climate models and other analytical tools; investment in human capital; and stronger links between research and decision making.

NAE members on the study panel were **George M. Hornberger**, Distinguished Professor and director, Vanderbilt Institute for Energy and Environment, Vanderbilt University; **Warren M. Washington**, senior scientist and section head, Climate Change Research Section, National Center for Atmospheric Research; and **David A. Whelan**, vice president, deputy-general manager Phantom Works, and chief scientist, Boeing Defense, Space, and Security, Boeing Company. Paper, $49.95.

Review of the Research Program of the FreedomCAR and Fuel Partnership: Third Report. The FreedomCAR (cooperative automotive research) and Fuel Partnership is a research collaboration by the U.S. Department of Energy, U.S. Council for Automotive Research (which includes the Detroit automakers), five major energy companies, and two electric utility companies. The goal of the partnership is to advance technologies essential for the components and infrastructure for a full range of affordable, clean, energy-efficient cars and light trucks. Until recently, the program was focused primarily on technologies to enable U.S. automakers to make production and marketing decisions by 2015 about whether or not to produce hydrogen fuel cell-powered vehicles, which have the potential to be much more energy efficient than conventional gasoline-powered vehicles, produce no harmful tailpipe emissions, and would significantly reduce petroleum use. In 2009, the partnership changed direction and stepped up its efforts to advance near-term technologies for reducing petroleum use in combustion engines (including engines that run on biofuels) and batteries for plug-in hybrid-electric or all-electric vehicles. According to the review committee that authored this third volume in the FreedomCAR Series, because these nearer term technologies will face significant challenges, including high cost, to their widespread use, the FreedomCAR and Fuel Partnership should continue to include fuel cells and other hydrogen technologies in its research and development portfolio.

NAE members on the study committee were **Harry E. Cook**, Professor Emeritus, Department of Engineering, University of Illinois; **Christopher L. Magee**, Professor, Engineering Systems Division, Massachusetts Institute of Technology; **Bernard I. Robertson**, senior vice president, Engineering Technologies and Regulatory Affairs, Chrysler LLC (retired); and **Kathleen C. Taylor**, director, Materials and Processes Lab, General Motors Corp. (retired). Paper, $49.75.

Evaluation of a Site-Specific Risk Assessment for the Department of Homeland Security's Planned National Bio- and Agro-Defense Facility in Manhattan, Kansas. Congress requested that the U.S. Department of Homeland Security (DHS) produce a site-specific biosafety and biosecurity risk assessment (SSRA) of the proposed National Bio- and Agro-Defense Facility (NBAF) in Manhattan, Kansas. The laboratory would study dangerous animal diseases—including highly contagious foot-and-mouth disease (FMD), which affects cattle, pigs, deer, and other cloven-hoofed animals—and diseases that are deadly to humans that can be transmitted from animals. Congress also asked that the National

Research Council (NRC) review the validity and adequacy of the DHS document as a prerequisite to funding. In this review, an NRC committee found "several major shortcomings." For example, based on the DHS risk assessment, during the 50-year lifetime of the facility there would be an almost 70 percent chance that a release of FMD could result in an infection outside the laboratory, which could impact the economy by $9 billion to $50 billion. However, the review committee concluded that the risks and costs could be significantly higher. The committee also raised concerns that DHS does not include other risks, such as the cleaning of animal rooms, that would increase the chances of an FMD leak, especially in light of the proximity of the facility to the Kansas State University College of Veterinary Medicine clinics, the football stadium, and other facilities.

NAE member **Kishor C. Mehta**, P.W. Horn Professor of Civil Engineering, Texas Tech University, was a member of the study committee. Paper, $35.50.

Review of the Department of Homeland Security's Approach to Risk Analysis. The events of September 11, 2001, changed perceptions, rearranged national priorities, and led to the creation the U.S. Department of Homeland Security (DHS). The principal missions of DHS are to secure the nation against attacks by terrorists and other forces that wish to do us harm, as well as to prepare for and respond to other hazards and "natural" disasters, such as floods, earthquakes, and so on. Although risk assessment is critical to making informed decisions about processes and methods, DHS risk analyses are heavily weighted toward protecting against terrorism. The focus of this report is on how DHS is building its capabilities in risk analysis to inform decisions ranging from high-level policy choices to fine-scale protocols for minute-by-minute actions by DHS employees. The review committee evaluates the efficacy of the current approach to estimating risk and recommends improvements. For example, the committee recommends that DHS not only continue to improve its integrated risk management framework, but that it also improve the way models are developed and follow time-tested scientific practices.

NAE members on the study committee were **John R. Howell**, Ernest Cockrell, Jr., Memorial Chair, Department of Mechanical Engineering, University of Texas, and **Danny D. Reible**, Bettie Margaret Smith Chair of Environmental Health Engineering, University of Texas. Paper, $28.75.

Air Traffic Controller Staffing in the En Route Domain: A Review of the Federal Aviation Administration's Task Load Model. TRB Special Report 301. This study examines the structure, empirical basis, and validation methods of a Federal Aviation Administration model that estimates the time air traffic controllers spend on tasks for handling en route traffic. The model's task load output is used to inform workforce planning. The committee that developed this report concluded that the model is superior to past models because it takes into account traffic complexity when estimating task load. However, the committee also recommends that more operational and experimental data on task performance be obtained to establish and validate key model assumptions, relationships, and parameters.

NAE member **Antonio L. Elias**, executive vice president and general manager, Orbital Sciences Corporation, was a member of the study committee. Free PDF.

New Worlds, New Horizons in Astronomy and Astrophysics. Astronomers and astrophysicists are working more with physicsts, chemists, biologists, and computer scientists. Realizing the scientific benefits will require maintaining and reinforcing technological development, theory, computation and data handling, laboratory experiments, and human resources. The authoring committee of this report proposes improving and expanding innovative, moderate-cost programs in space and on the ground that will enable rapid, responses to new discoveries that advance the search for habitable planets and shed light on dark energy and dark matter, the history of the universe, and the formation of the earliest stars and galaxies. The committee recommends the construction of survey telescopes in space and on the ground, including next-generation, ground-based, giant optical telescopes and a new class of space-based gravitational observatory.

NAE member **A. Thomas Young**, retired vice president, Lockheed Martin Corporation, was a member of the study committee. Paper, $39.95.

The
BRIDGE

(USPS 551-240)

National Academy of Engineering
2101 Constitution Avenue, N.W.
Washington, DC 20418

Periodicals
Postage
Paid