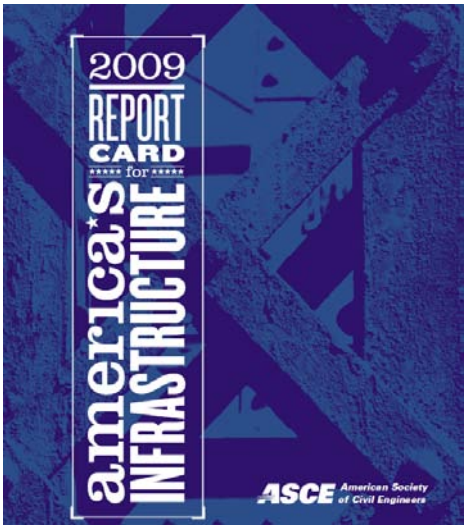
AUSTRALIAN AMERICAN LEADERSHIP DIALOGUE

The Transition to Intelligent, Secure, Low Carbon, and Climate Adaptive Infrastructure: Some Web Resources

Compiled by Larry Smarr and Gregory McRae
July 16, 2010

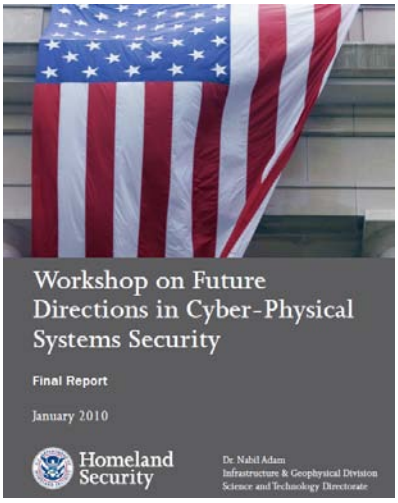
Our society is critically dependent on infrastructure (highways, bridges, water supply system, cities, etc.) which has been built over hundreds of years. As the world simultaneously replaces its aging infrastructure and builds out vast new systems, there is a historic opportunity to make this infrastructure intelligent, secure, low carbon, and adaptive. This document points out these emerging trends and provides web resources that provide examples from around the world, with a focus on the U.S. and Australia.



The deteriorating state of America's civil infrastructure has been well documented. In their 2009 report[1], the American Society of Civil Engineers state: "The 2009 Report Card for America's Infrastructure finds not much has changed since the last edition four years ago. Years of delayed maintenance and lack of modernization have left Americans with an outdated and failing infrastructure that cannot meet our needs." The Society gives America's infrastructure a grade of "D" and suggests over $2 Trillion would be needed to modernize it over the next five years.

[1] www.infrastructurereportcard.org/sites/default/files/RC2009_full_report.pdf

Furthermore, a recent report [2] from the U.S. Department of Homeland Security indicates that there are significant risks from cyber-attacks on critical infrastructure systems including: transportation, chemical plants, water supplies, healthcare, and energy. These cyber-attacks can impact the health and safety of human lives and threaten severe damage to the economy. Future infrastructures need to be resilient to such attacks.



As the United States debates this infrastructure upgrade[3], there is a unique opportunity to innovate in ways that have not been possible in earlier centuries.

This is because the traditional field of infrastructure deployment, which in many ways is being carried out today as it has been for decades, will undergo three major disruptive waves over the next few decades.

- *The first wave:* infrastructure will gradually become "intelligent," because of the exponential decrease in cost of embedded computing, sensing, actuating, and telecommunications. This positive development must be tempered by aggressive efforts to defend against the increasing potential risk of cyber-attacks.
- *The second wave:* societal infrastructure must transition from high to low carbon emissions, implying rethinking of how our cities are assembled and use energy.
- *The third wave:* human-induced climate change is now occurring on a time scale commensurate with the lifetime of infrastructure, meaning that societies must begin adapting their infrastructure to major shifts, such as droughts, sea level rise, and increased frequency of severe storms.

[2] www.ee.washington.edu/faculty/radha/dhs_cps.pdf
[3] www.asce.org/uploadedFiles/Publications/CE_Magazine/2010_Issues/04_April/410CE-A.pdf and www.asce.org/uploadedFiles/Publications/CE_Magazine/2010_Issues/04_April/410CE-B.pdf]

Fortunately, these trends can work together. If infrastructure is intelligent, it can "tune" buildings to use less energy, thus requiring less carbon emissions to operate. Similarly, intelligent infrastructure, being aware of changes in its immediate vicinity, can dynamically adapt to climate-induced changes or cyber-threats over the lifetime of the infrastructure. However, such "integrated system engineering" is in its infancy.

In this white paper, we briefly describe a number of pioneering studies and leading edge examples. Our goal is not to be comprehensive in our references, but rather to give the reader a sense of how widespread and revolutionary this innovative thinking has already become.

The Transition to Intelligent Infrastructure

To date the physical infrastructure of roads, bridges, levees, ports, and water transport systems is usually treated as a passive system that is not interactive and does not adapt or change with time. Repairs, emergency fixes, and upgrades are done only on fixed schedules or as needed after the infrastructure breaks or becomes obsolete. With this 20th-century approach we will always be in a reactionary mode, repairing or upgrading our infrastructure only when it no longer functions. However, the widespread use of embedded information and telecommunications technologies can "enable structures and systems to self-monitor, self-diagnose, and self-correct throughout their life cycle." [4]

"Intelligent infrastructure" systems use networked sensors to monitor the detailed health of physical structures and their environment, initiating maintenance and rehabilitation as warning signs develop, well prior to a crisis that may require the closing of the infrastructure for an extended time.

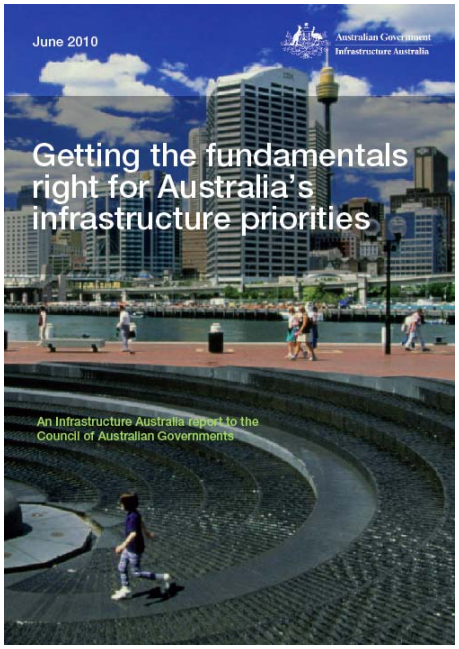
There are numerous early examples of the movement toward "intelligent" infrastructures: smart power grid[5], smart buildings[6], smart bridges[7], smart

[4] Civil Engineering News June 2009
http://ftp2.bentley.com/dist/collateral/docs/press/investing-in-intelligent-infrastructure.pdf
[5] www.oe.energy.gov/SGSRMain_090707_lowres.pdf
[6] canmetenergy-canmetenergie.nrcan-rncan.gc.ca/fichier/79207/intelligent_building-batiments_intelligent_eng.pdf
http://ftp2.bentley.com/dist/collateral/docs/press/investing-in-intelligent-infrastructure.pdf

transportation systems[8] and smart cars. Interconnections created by these technologies form a complex, interdependent "system of systems" across national and international critical infrastructures. While providing an opportunity to improve economic efficiency and reduce environmental impacts these systems must be resilient in the face of cyber attacks. [9]

A brief white paper on the use of Intelligent Infrastructure in Australia was prepared and distributed at the 2008 Australian-American Leadership Dialogue[10] and Australia held a recent conference on this topic[11]. Australia will be an interesting testbed to watch, since its ubiquitous National Broadband Network[12] provides a high-bandwidth platform on which a national-scale intelligent infrastructure system can be built.

The Transition to Low Carbon Infrastructure



Australia is one of the most advanced countries in the world for having a unified approach to planning, funding and implementing the nation's future infrastructure needs. The Infrastructure Australia Act 2008 came into effect on 9 April 2008, paving the way to establish "Infrastructure Australia."

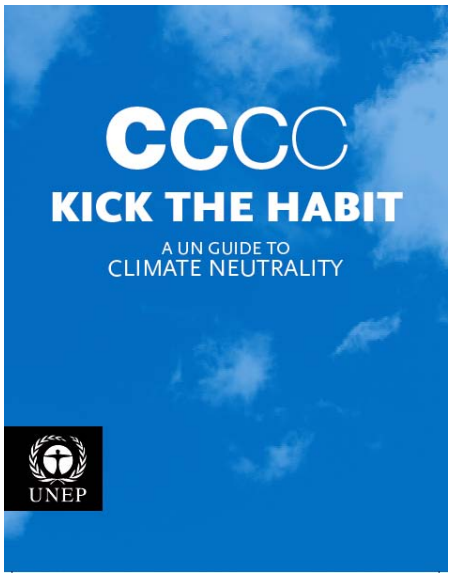
The latest report[13] (June 2010) from Infrastructure Australia to the Council of Australian Governments focuses on recommendations "aimed at getting the fundamentals right for Australian infrastructure, instilling a discipline of long-

---

[7] www.asce.org/uploadedFiles/Vision_2025_-_New/TheVisionforCivilEngineeringin2025_ASCE.pdf
[8] www.fhwa.dot.gov/publications/research/general/08068/08068.pdf
[9] www.ee.washington.edu/faculty/radha/dhs_cps.pdf
[10] http://lsmarr.calit2.net/repository/Intelligent%20Infrastructure%20Initiative%20for%20Australian%20Society%20%20Homeland%20Security.pdf
[11] www.aph.gov.au/house/committee/itrdlg/smartinfrastructure/thinkfuture/Summary_Paper.pdf
[12] www.dbcde.gov.au/broadband/national_broadband_network
[13] www.infrastructureaustralia.gov.au/files/Report_to_COAG_2010.pdf

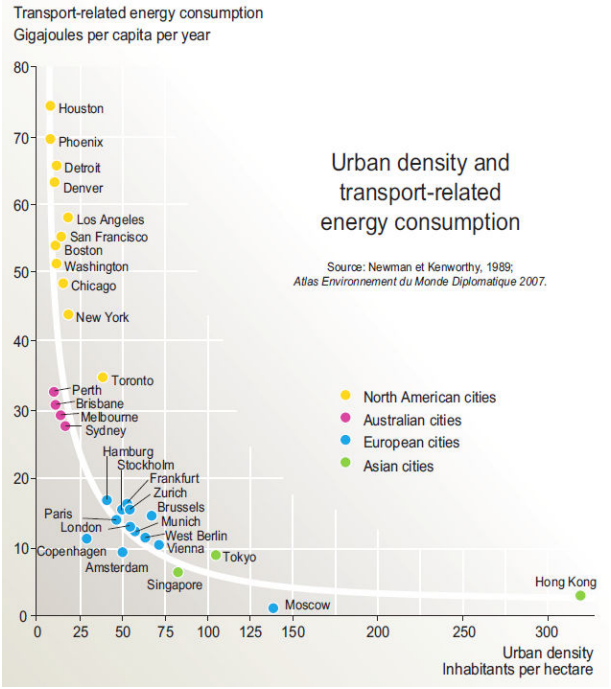
term infrastructure planning that can meet Australia's future productivity challenge, and making better use of our existing infrastructure networks."

The report recognizes four fundamental challenges which must be met as Australia builds out its national infrastructure. The fourth of these challenges is: "Reducing greenhouse gas emissions is one of Infrastructure Australia's priorities." The need to reduce such emissions has informed the development of the seven themes for action, including increasing the use of public transport in cities. Infrastructure Australia requires submissions for major new projects to provide a quantified analysis of environmental costs and benefits (including greenhouse gas emissions).



However, incremental changes to today's infrastructure will not achieve the level of greenhouse gas emissions that will be required to avoid catastrophic levels of global climatic disruption. Rather, we need rethinking about how our society is organized so that we rapidly move toward a carbon neutral environment. A major study on this topic is the United Nations Environment Programme 2008 study.[14]

One of the major opportunities is to re-imagine the structure of our cities, focusing on the relationship between where people live and work and the nature of the transportation system (see graph at right from the study.) For instance, the



[14] www.unep.org/publications/ebooks/kick-the-habit/pdfs/KickTheHabit_en_lr.pdf

UNEP study states “Spatial planning is an important civic function which can help significantly to cut energy use in urban transport. Cities can retain their focus and sense of place if they plan for “densification” as opposed to Los Angeles-style sprawl. By avoiding “bedroom communities” and planning mixed functions in neighborhoods, commuting can be minimized. This can save GHG emissions, because energy consumption in cities is directly linked to the number of inhabitants per square kilometer.

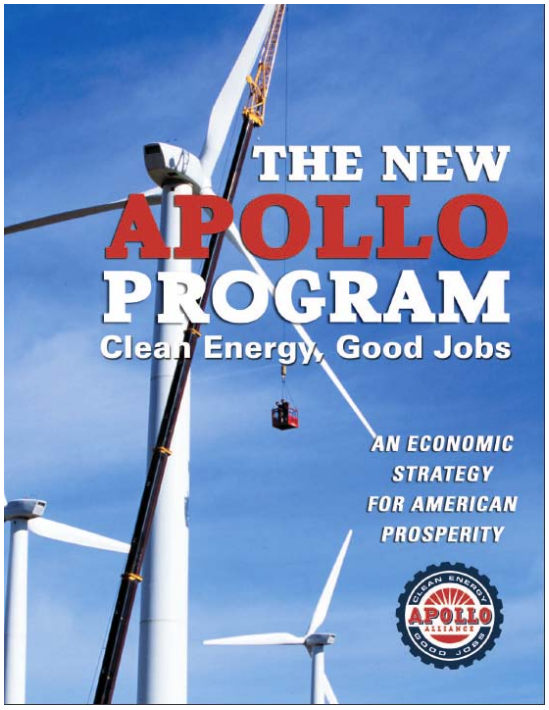
The economic opportunity to completely transform our energy infrastructure is enormous — a once in a century opportunity. A report[15] just released in June 2010 by the American Energy Innovation Council, a distinguished set of business leaders of U.S. corporations, calls for creating an independent U.S. energy strategy board (much like Infrastructure Australia), greatly increased funding of clean energy innovation, and increased Federal funding for both research and large-scale pilot projects.



[15] www.americanenergyinnovation.org

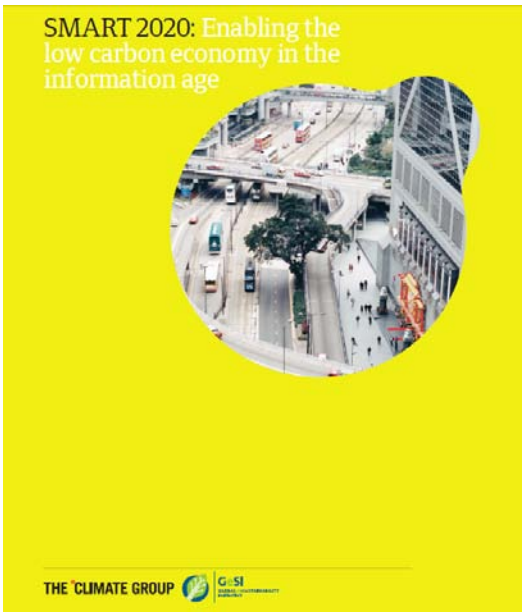
Similarly, a coalition of labor, business, environmental, and community leaders formed the Apollo Alliance to catalyze a clean energy revolution in the United States. Their September 2008 report[16] includes key low-carbon infrastructure goals:

- Establish a national energy efficiency commitment to reduce energy use in new and existing buildings at least 30% by 2025.
- Provide the support necessary to produce 25% of the nation's power from renewable and recycled energy resources by 2025.
- Bring the U.S. power grid into the 21st Century.
- Improve efficiency by 20% in existing power plants and industries by 2025.
- Connect America's 21st century neighborhoods and cities with world-class transit systems.
- Strengthen and improve America's transportation infrastructure.
- Invest in a national low-carbon fuel infrastructure and next generation alternative fuels.



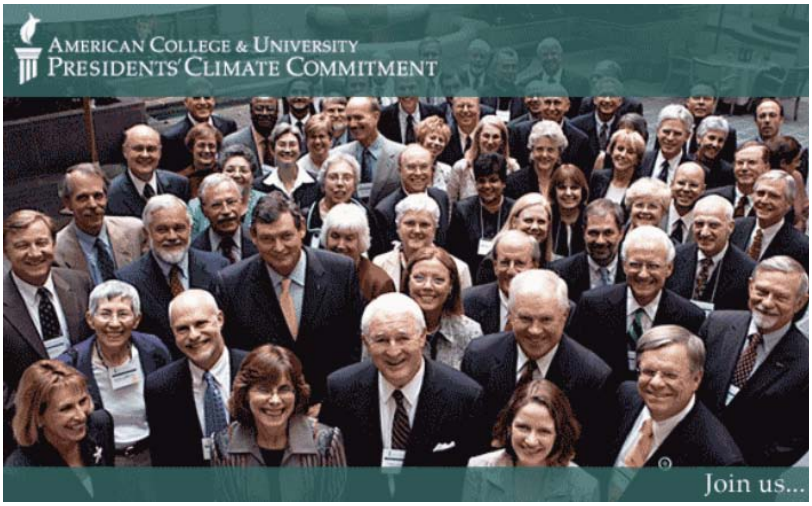
One of the key enablers of the transition to a low-carbon economy will be the adoption of intelligent infrastructure. A large number corporations which are global leaders in information and communication technologies (ICT) came together to develop a report[17], "Smart2020-Enabling the Low Carbon Economy in the Information Age," which shows how striking the reduction in GHG emissions can be by widespread use of ICT.

[16] http://apolloalliance.org/wp-content/uploads/2009/03/fullreportfinal.pdf
[17] www.smart2020.org/publications/



Their report concludes: "The ICT sector has a powerful role to play in tackling climate change by enabling other sectors, such as transport, buildings, power and industry, to become more efficient. Although the ICT sector's own emissions will rise as global demand for products and services increases, these are estimated to be *five times less* than the emissions that can be *reduced* through the 'enabling effect.' To realize this opportunity will require *a radical transformation of current infrastructure*: companies will need to identify and monitor energy use and employ the data obtained to become more efficient and ultimately transform the way they operate throughout value chains, cities, regions and whole countries."

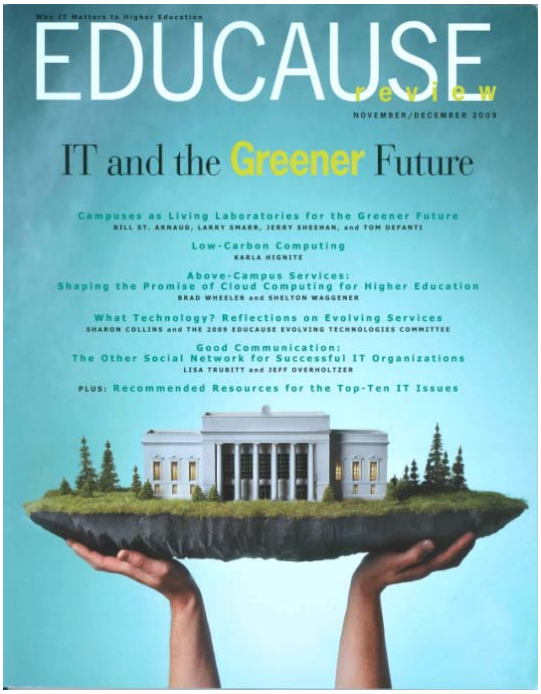
Modifying the current societal use of carbon-based energy is exceedingly complex, and at-scale experiments on carbon reduction techniques need to be carried out immediately. Since college and university campuses are effectively small cities, they are an ideal scale for exploring innovative approaches to the reduction of carbon footprints. Realizing that this challenge may also be an opportunity, a number of higher education institutions are turning themselves into experimental, living laboratories of the "greener" future.[18]



[18] American College & University Presidents' Climate Commitment (www.presidentsclimatecommitment.org); Amanda Leigh Mascarelli, "How Green Is Your Campus?" Nature, vol. 461 (September 10, 2009).

The current generation of students is enthusiastically pursing many of these goals.

By transforming their building, transportation, and electrical-generation energy subsystems into instrumented test beds, academic institutions can use their actions to reduce carbon footprints as learning and optimization environments for society at large.[19]



Throughout the world pioneering cities are addressing the urgent need for political, social and economic infrastructure solutions that make investments that are both economically efficient and at the same time reduce the carbon emissions into the atmosphere.

Here are some examples: **London** – The ZeroCarbonBritain2030 is providing solutions[20] which will transform the UK into an efficient, clean, prosperous zero-carbon society. **Seattle** – The Seattle City Council has included creating a carbon neutral Seattle as one of its 2010 priorities, with specific milestones and implementation steps, along with a plan for adaptation to the effects of climate change.[21] See also Defining a 'Carbon Neutral' City.[22] **Amsterdam** – Its Smart City program[23] is a unique collaboration between



[19]www.educause.edu/EDUCAUSE+Review/EDUCAUSEReviewMagazineVolume44/CampusesasLivingLaboratoriesfo/185217
[20] ZeroCarbonBritain2030 http://www.zcb2030.org/
[21]Seattle City Council http://www.seattle.gov/council/issues/council_priorities.htm
[22]Defining a Carbon Neutral City http://www.worldchanging.com/archives/010988.html
[23]Amsterdam Smart City http://amsterdamsmartcity.com/#/en

citizens, businesses and government that focuses on innovative technology combined with stimulation of behavioral changes that lead to substantial energy savings.



Europe—The RoadMap 2050 is a practical plan with objective analysis pathways to achieve a low-carbon economy in Europe, in line with the energy security, environmental and economic goals of the European Union[24]. The Roadmap 2050 project is an initiative of the European Climate Foundation (ECF) and has been developed by a consortium of experts funded by the ECF. **Masdar City (Abu Dhabi)** has ambitions to be a showcase[25] for renewable energy and low-carbon technologies that also provides a test bed to develop commercially viable, sustainable energy solutions. Its goal is to be the first carbon neutral, zero waste city.



The cities profiled are exemplars of the worldwide infrastructure innovation underway.

The Transition to Climate Adaptive Infrastructure

With the climate forcing from manmade greenhouse gases beginning to exceed[26] those of the natural forcing variations (solar radiation 11-year cycle, la Nina/el Nino oscillations, volcanic dust), we will see a much more rapid change in climate in the coming decades of the 21st century. So much so that significant local environmental changes will be possible on times scales comparable to the lifetime of the infrastructure. These environmental changes will depend on location, but they range from loss of

[24] Roadmap 2050 http://www.roadmap2050.eu/
[25] Masdar City (UAE) http://www.masdar.ae/en/home/index.aspx
[26] www.aip.org/history/climate/summary.htm

summer Arctic sea ice and melting of permafrost, to increased droughts and intense rainfall, to secularly increasing sea level rise, important since roughly half of the world's population lives near a coast line.

Over the last hundred years, sea level has steadily risen about 15-20 cm. However, over the next hundred years, driven by climate-induced rising average global temperature, the sea level will probably rise[27] between 75 and 190 cm. Thus, infrastructure that is designed to last for a century or more needs to take this much more rapid rise into account. Furthermore, this sea level rise will continue for centuries to come (during the last interglacial period the sea level was ~700cm (23 feet) higher[28] than today even though the CO_2 level then was significantly lower than the human-increased value today).

One meter sea level rise, the minimum expected by 2100, may not sound like much, but according[29] to the United Nations it will submerge over 2 million sq. km of land where ~150 million people live, mostly in Asia.



Clearly, this challenge alone will drive a great deal of infrastructure build-out for hundreds of years that would not have been anticipated were it not for human-induced climate change.

A good example of the innovation in infrastructure planning and public education that being stimulated by the challenge of climate change is the "Rising Currents" Exhibit at Museum of Modern Art[30] (MoMA) in New York City. Whereas the traditional approach to sea level rise is to build dikes or other rigid barriers to protect the interior living area, the MoMA and P.S.1

[27] "Global sea level linked to global temperature," Martin Vermeer and Stefan Rahmstorf, PNAS, v. 106, 21527–32 (2009)
[28] "Probabilistic assessment of sea level during the last interglacial stage," Robert E. Kopp, et al., Nature v.462 863-868 (2009)
[29] maps.grida.no/go/graphic/population-area-and-economy-affected-by-a-1-m-sea-level-rise-global-and-regional-estimates-based-on-
[30] www.moma.org/explore/inside_out/category/rising-currents#description

Contemporary Art Center joined forces to foster new research and fresh thinking about the use of New York City's harbor and coastline and how it could be restructured to deal with the rising sea level.

An architects-in-residence program at P.S.1 (November 16, 2009–January 8, 2010) brought together five interdisciplinary teams to re-envision the coastlines of New York and New Jersey around New York Harbor and to imagine new ways to occupy the harbor itself with adaptive "soft" infrastructures that are sympathetic to the needs of a sound ecology.



The teams had to take into account not only sea level that will be 1-2 meters higher, but also storm surges up to six meters higher still. By 2080, a class-2 hurricane could flood over 60% of lower Manhattan, so the teams needed to come up with innovative approaches to rethinking the storm and sewage drainage infrastructure using a blending of natural ecological thinking with traditional city architectural design.

The NY Times review[31] stated: "The MoMA show asks us to rethink what the city could be, and in doing so nudges us away from a parochial mentality that tends to cling to the city's past greatness rather than embracing — and facing up to — its future. If the show has a flaw, it is that it should push even harder."

The Future of Infrastructure

As cities and countries around the world invest in rebuilding their aging infrastructure or building new "green field" systems, they should take into account these three major trends discussed here. This will lead us into a world that is more flexible, affordable, resilient, and sustainable -- able to deal with the unprecedented challenges that the 21st century will present.

[31] www.nytimes.com/2010/03/26/arts/design/26rising.html

Acknowledgements: We thank the Phil Scanlan, the Australia Consul-General in New York and the Australian-American Leadership Dialogue for bringing us together to discuss these issues at the AALD on the July 16, 2010 panel on “Smart Infrastructure,” held in New York City. UCSD’s Professor Benjamin Bratton provided some essential references. LS would like to thank Phil Smith for his inspiration.

Contact Information for further information

Larry Smarr (@soe.ucsd.edu) is the founding Director of the California Institute for Telecommunications and Information Technology (Calit2), a UC San Diego/UC Irvine partnership, and holds the Harry E. Gruber professorship in Computer Science and Engineering (CSE) at UCSD’s Jacobs School. At Calit2, Smarr has continued to drive major developments in information infrastructure-- including the Internet, Web, scientific visualization, virtual reality, and global telepresence--begun during his previous 15 years as founding Director of the National Center for Supercomputing Applications (NCSA). His views have been quoted in Science, Nature, the New York Times, Wall Street Journal, Time, Newsweek, Wired, Fortune, Business Week, the Sydney Morning Herald, the Age, and the Australian Broadcasting Company. Smarr is currently principal investigator of the Moore Foundation’s CAMERA project and co-principal investigator on NSF’s GreenLight project. He is a member of the National Academy of Engineering and a Fellow of the American Physical Society and the American Academy of Arts and Sciences. In 2006 he received the IEEE Computer Society Tsutomu Kanai Award for his lifetime achievements in distributed computing systems. He spent October 2008 in Australia as the Leadership Dialog Scholar. You can follow Larry at http://twitter.com/lsmarr and on his life-streaming portal at http://lsmarr.calit2.net.

Gregory McRae, (.j.mcrae@gmail.com) is the Hoyt C. Hottel Professor of Chemical Engineering at the Massachusetts Institute of Technology and an Executive Director of Morgan Stanley. He obtained his Ph.D. in Engineering from Caltech and his undergraduate degrees in Australia. His teaching and research is related to process systems engineering, new

energy technologies and finance/project risk management. He is the recipient of numerous awards for his work in computational science, and process engineering including the prestigious Presidential Young Investigator Award, the National Computer Graphics Prize and a AAAS fellowship. He is an advisor to many industrial, academic and government organizations including the National Academy of Sciences, the National Research Council and the U.S. Department of Energy. He is the founder of four companies that provide services to the chemical, microelectronics and financial communities. He has written numerous papers and reports and was a co-author of the recent MIT Future of Coal study (web.mit.edu/coal).