The University of Arizona

Chemical and Environmental Engineering Department – Seminar

"Gigatechnology: Developing Sustainable Urban Infrastructure to Solve Gigaton Problems"

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Zoom: https://arizona.zoom.us/j/99357350715

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ABSTRACT

Gigaton problems refer to those most severe problems challenging humanity, which can often be measured at the "gigaton (billion tons)" scale. For example, the annual world energy consumption is around 12 billion tons of oil equivalent (Gton), 80% of that from nonrenewable fossil fuels. The combustion of these fossil fuels emits approximately 29 billion tons (Gton) of CO_2. In addition, the world uses more than 79 Gton of materials each year, only about 29% of which are renewable. These gigaton problems call for solutions which can meet the gigaton scale, or gigaton solutions.

The current practice of designing, building, and operating infrastructure is rooted in the Eisenhower era and is a barrier to the future. Its failure to recognize the interdependencies between infrastructure components results in a sub-optimal system that is viable only because of the availability of cheap fossil fuels and non-renewable resources, and the externalization of costs, risks, and harms. For infrastructure to support societies moving forward, a reimagining and restructuring needs to occur that:

1) uncovers the interconnections and interdependencies among civil infrastructure systems and their interactions with social, financial, and natural systems;
2) works with industry, government, and non-governmental organizations to create an interoperable systems platform that is necessary to design, simulate, test, monitor, build, control, and protect massive, open, and complex infrastructure systems;
3) develops, tests, and implements the new laws, rules, standards, and best practices for designing, building, financing, operating, and decommissioning sustainable and resilient infrastructure across its total life cycle;
4) develops the pedagogy that teaches, trains, and empowers the workforce, organizations, and agencies that will transform infrastructure from isolated, simple, and vulnerable components into a connected, complex, and resilient system; and
5) recruits and retains a new generation of change agents that are as diverse as the communities in which they serve.

This is not a call for incremental improvement. It is a proclamation of the dire need for bold infrastructure reform that can best be characterized as the creation of a new *Science of Gigatechnology*, and for which Georgia Tech and Atlanta has the intellectual resources and progressive vision to be the epicenter. Gigatechnologies are the largest engineered systems that humans create. They include regional electric power grids; networks of interstates and roads; municipal water systems; connected communications, sensors, and computing devices; and clusters of buildings that aggregate to form blocks, neighborhoods, and cities. The science of Gigatechnology is more than just the designing, building, and operating of these and other big systems, however. And they are more than just a digital overlay on top of physical systems conceived in a pre-cyber age. Gigatechnology is about the properties that emerge from big systems interacting with each other, and with

social, economic, technological, and natural systems. Smog, climate change, flooding, inequality, and community identity are just a few examples of emergent properties. They cannot be seen or anticipated from the examination of just one element of the system, and those responsible for the overall function and fitness of the parts are rarely challenged to address infrastructures as a system of systems. Unlocking the mysteries of Gigatechnology is essential to the health and well-being of people, the planet, and the worldwide economy.

Urban centers are the largest complex, adaptive gigatechnology systems that humans create and within which humans manipulate mass and energy. They are the largest infrastructures in which human manipulate matter and energy. Design of more sustainable and resilient urban system can solve the gigaton problems. A new transformative science for gigatechnologies has been established called, ”Infrastructure Ecology,” with new engineering standards, protocols, tools, and workers to apply its laws and rules for building cities that are sustainable, resilient, equitable, and efficient. Analogous to natural ecology, the urban system of systems are combined to produce larger functional wholes, and new properties emerge (e.g., quality of life, air quality, traffic congestion) that were not present or evident at the next level below. By examining the complex interactions among social decision making, economic drivers, (re)development, sustainability metrics, Infrastructure Ecology is being developed to allow stakeholders to design and choose infrastructure solutions that consume fewer resources and generate less waste. And at the same time build infrastructure that creates more wealth and comfort for urban dwellers.

We have been focusing on the development of common metrics, algorithms, principles, standards, frameworks, architectures, units, methods, and vocabulary that are needed to start creating the shared mental models and language of the new science of Infrastructure Ecology (Epistemology). To date, Infrastructure Ecology involves three components to understand, anticipate, and control the emergent properties that result from systems interactions, i.e.: (1) the creation of the novel infrastructure technology genome, (2) infrastructure integration, and (3) management of complexity for improving adoption of more sustainable infrastructure. The first component is the discovery of the novel infrastructure genome through advanced computing and innovative designs that can lead to a more sustainable nexus among water, energy, transportation, buildings, land use, the socioeconomic environment, etc. For example, our contribution to the infrastructure technology genome includes: (1) life cycle assessment of decentralized/ centralized water systems combining grey water reclamation, (2) centralized systems and low impact development (LID), (3) evaluation of the sustainability performance of decentralized combined cooling heat and power (CCHP) and solar PV to improve energy efficiency and reduce water demand and NOx emissions, and (4) examination of working fluids to improve the coefficient of performance of HVAC systems. Obviously, there are hundreds of other technologies that belong to the infrastructure technology genome and we will discuss some of these technologies and others.

The second component is the development of gigatech platform that allows one to examine the cost, sustainability, resilience, and performance of integrated infrastructures. In the past, we have designed infrastructure in a siloed fashion and this has resulted in suboptimum solutions. The gigatech platform integrates the technologies to create more sustainable and resilient infrastructure. Our research includes deciding on interoperability standards that can accommodate the broad array of models now and in the future; building the actual platform that will integrate the models and systems; and creating simulation and data analysis algorithms, visualization and other communication utilities that allow interested parties deep insight into the connection of gigatechnologies and their resultant impacts throughout the system. Our approach involves first specifying a model in a common modeling language (e.g., SysML), and then using software to automate the transformation of the model into federated simulation code.

The third component is the management of inherent complexity for improving the adoption of more sustainable infrastructure. Complexity results from the millions of decisions and interactions of diverse adaptive entities (i.e., citizens, firms, developers, and governments). These decisions and interactions drive the dynamic and evolving interdependence between the urban physical infrastructure and the socioeconomic environment through which it operates. This interdependence leads to the emergence of, among other things, specific land use arrangements, quality of life issues, and carbon footprints. To manage this complexity, we develop a better understanding of people’s preferences and demands for more sustainable infrastructure designs. The tools include big data analytic analysis of social media, crowdsourcing based surveys for preference analysis and choice modeling. If we provide a suitable combination of more sustainable features and develop suitable policies to meet their preferences, we have shown that combining technologies increases citizen’s adoption of more sustainable infrastructures. For example, we developed an agent based model that predicts the adoption of LID, and its impact of tax revenue, adoption rate and water use, as a result of several policies. Complexity management also includes novel sustainability and resilience metrics development and application to support decision markings. For example, we have examined the impacts of fractal connectivity of metropolitan area road networks on the urban built environment and found that a high fractal dimension leads to a small-world connectivity. The small-world connectivity leads to sprawl and this increases energy consumption for personal transport. We also developed an approach to include both resilience and sustainability in the design of urban infrastructure. In a sense, we developed a benefit cost analysis not in terms of dollars but in terms of sustainability metrics to identify optimum Sustainability and Resilience Zone.

BIOSKETCH

Prof. John C. Crittenden is the director of the Brook Byers Institute for Sustainable Systems and a professor in the School of Civil and Environmental Engineering at the Georgia Institute of Technology. He holds the Hightower Chair and is a Georgia Research Alliance Eminent Scholar in Environmental Technologies. Prof. Crittenden received his Bachelor's in Chemical Engineering and his Master's and Ph.D. in Civil Engineering from the University of Michigan. Prof. Crittenden was elected to the National Academy of Engineering in 2002 and the Chinese Academy of Engineering in 2013. He is the co-holder of five patents and the primary author of the text book, Water Treatment: Principles and Design, now in its third edition (Wiley). He is the author more than 333 articles in refereed journal articles, more than 100 book chapters, reports, and symposia and has more than 22,500 citations and an H index of 72.

Prof. Crittenden's current research focus is on sustainable urban infrastructure systems. His colleagues and he are conducting research on alternative energy technologies, sustainable materials, food energy water nexus, advanced modeling of urban systems, sustainable engineering pedagogy, and urban form and policy. He also conducts research in various water and air treatment technologies (e.g., membrane technology, advanced oxidation processes, photocatalytic oxidation, adsorption, selective catalytic reduction) and energy harvesting technologies (photocatalytic water splitting and aqueous phase reforming of biomass).

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