Infrastructure Ecology: An Evolving Paradigm for Sustainable Urban Development

John C. Crittenden, Ph.D., P.E., NAE (US & China)
Arka Pandit, Ph.D.

Brook Byers Institute for Sustainable Systems,
Georgia Institute of Technology, Atlanta, GA

E-Mail: john.crittenden@ce.gatech.edu; Arka.Pandit@gatech.edu
Nature’s Scream
A Call for the Sustainability Movement

"I was walking along a path with two friends - the sun was setting - suddenly the sky turned blood red - I paused, feeling exhausted, and leaned on the fence - there was blood and tongues of fire above the blue-black fjord and the city.

"My friends walked on, and I stood there trembling with anxiety - and I sensed an infinite scream passing through nature."

Nature’s infinite scream: I cannot provide the resources you need in a sustainable way

Who can hear it?

- The scream could only be heard by the golden billion (those who have reached the self actualization point on Maslow’s pyramid).
- One would not care if one does not have access to clean water, sanitation, food, and housing.
- It would be important for the golden billion to hear the scream and do something to reduce childhood mortality and poverty, to provide the means for people to lead useful and productive lives, and to develop technologies for a more sustainability world.

Skrik(The Scream), Edvard Munch. Pastel version auctioned for a record $119.9 million at Sotheby’s on May 2, 2012.
Reductionism versus Systems Analysis

• There will always be room for engineering reductionism but the greatest sustainability gains in the 21st century will be from systems analysis and managing complexity.

• Managing complexity will drive greater adoption of more sustainable infrastructure.

• What do I mean by complexity?
  – Complexity results from the interaction of diverse (not just faces but in this case infrastructures etc.) adaptive entities and properties emerge from this interactions.
  – By managing complexity, our desire is to create infrastructure that has the right combinations of features that will increase adoption of more sustainable infrastructure.
Reductionism versus Systems Analysis

**Unsustainable Strategy**

- **Reductionist thinking:**
  - Invest in infrastructures separately

- **Create unintended consequence:**
  - congestion, heat island, bad air quality

- **Find technical solutions:**
  - more roads, big pipes, wastewater treatment

**More Sustainable World**

- **System Approach:**
  - Invest infrastructures as a system of systems

- **Create a sustainable and resilient system**

- **Adaptive management of systems**
Increasing Material and Energy Uses Depletes Resources and Impacts the Environment:

Engineering alone is not the answer. How many hybrids can the earth sustain? We need to think about reducing demand at the systems level.

(Credit: Jonathan Lash (2005))
Outline

• What is Sustainability and the Gigaton Problem?

• How to transform the Urban Infrastructure Systems:
  – The Role of Infrastructure Ecology

• Managing the Complexity of Urban Systems

• Future Cities

• Summary
Sustainable Systems

- We need to recreate the anthroposphere to exist within the means of nature. That is, use renewable resources that nature provides and generate waste nature can assimilate without overwhelming natural cycles.

- This will require us to examine the interactions between the natural, engineered, social and economic systems.
First Premise of ‘Sustainability’

- Generate waste that nature can assimilate without overwhelming natural cycles.
- Need to look at fate of toxics, Nitrogen, Phosphorus, Water, and Carbon cycles and more.

**Fate of Toxics**

- In 80% of the 139 streams (in the US) sampled by USGS in 2001:
  - One or more of the 95 organic wastewater contaminants were detected
  - Mixtures of the chemicals were common
  - 75% of the streams had more than one
  - 50% had 7 or more
  - 34% had 10 or more
Nitrogen and Phosphorus Cycle

- **Nitrogen Cycle**
  - **The anthropogenic intervention to the Nitrogen-Cycle (One of the largest geoengineering experiment by humankind):**
    - \( \frac{2}{3} \) rd **N in the protein in human body** is from N fixed from the atmosphere through using an anthropogenic process (Haber Bosch Process)
    - Energy required to fix atmospheric N: 32 MJ (9 kWh)/kg NH\(_3\)-N (does not include energy required for steam reforming)
    - Energy required to remove N from wastewater: 18 MJ (5 kWh)/ kg NH\(_3\)-N
    - **Total energy required to chemically fix 1 kg of N from and release it back to the atmosphere:** 50 MJ or 14 kWh/ kg
    - Energy consumed for NH\(_3\) production in 2010 = 1.82 TWh \( \approx 1.2\% \) of global total energy consumption

- **Phosphorus Cycle**
  - With the current trend of increasing mining continuing, **the global reserve would last hundreds of years**, provided the current reserve estimate is accurate.
  - In certain sense, phosphorus is a more critical resource than Nitrogen. Unlike Nitrogen, it can’t be harvested at will (the energy requirement notwithstanding).
Let's Look at CARBON Cycle in Detail
ETP 2012 – Choice of 3 Futures

2DS
a vision of a sustainable energy system of reduced Greenhouse Gas (GHG) and CO₂ emissions

The 2°C Scenario

4DS
reflecting pledges by countries to cut emissions and boost energy efficiency

The 4°C Scenario

6DS
where the world is now heading with potentially devastating results

The 6°C Scenario
Choosing the Future Energy System

CO₂ Target – 70% Reduction

Current Trajectory

Observed Emission

6 Degree Scenario
4 Degree Scenario
2 Degree Scenario

Gt C per year

1990 2000 2010 2020 2030 2040 2050

11.5 Gt C (-72%)
6.6 Gt C (-80%)
5.0 Gt C (-31%)
4.4

Choosing the Future Energy System

CO₂ Target – 70% Reduction

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Global GHG abatement cost curve beyond business-as-usual – 2030

Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO₂e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0
How to Fund the Global Energy Revolution for a 4 °C Rise?

The values in red represent the Mean of the estimates.

Required Investments in Energy Sector to Limit Temperature Rise to 4°C

Total Investment per Year = .580 Trillion 2010 USD

Source: Climate Change 2014: Mitigation of Climate Change, IPCC Working Group III
Unsustainable Animal Farming

Resource and pollution
• Livestock uses 30% of the world’s ice-free landmass (geoengineering)
• Livestock produces 14.5% of all greenhouse emissions

Food and water consumption: 1kg (2.2lb) meat

Growing appetite for MEAT!

Population growth

2015: 7.2 billion
2050: 9 billion

Source: Green Food. Economist Technology Quarterly Q1 2015
Green Food
- Sustainable “Meat” and “Dairy” from Plants
(14,000 species of plants and each plant species has 1000s of proteins)

Tech Startups are trying to create plant-based foods

- Cheaper
- Healthier
- Satisfying as animal-based products
- MUCH LOWER ENVIRONMENTAL IMPACT

Mimic the taste of animal-derived foods with plants

Enormous efficiency in terms of energy, water and other inputs

Source: Green Food. Economist Technology Quarterly Q1 2015
Examples of “Green Foods”

- Plant-based chicken strips
  *Beyond Meat*

- Eggless mayonnaise
  *Hampton Creek*

- Plant “beef” burger patty
  *Impossible Foods (Rancid Polenta)*

- Beverage as complete substitute for food
  *Soylent (Occasional Recreational Eating)*

Source: Green Food. Economist Technology Quarterly Q1 2015
The end of wild fish?

Fish facts:
• Although 70% of the planet is ocean, only about 2% of the world's food supply comes from the seas
• The World Bank estimates that by 2030, some 62% of the seafood we eat will be farm-raised
• Globally, fish provides more than 2.9 billion people with almost 20% of their intake of animal protein
• However, 90% of the world's wild fish stocks are already at capacity or overfished

The Controversy of Fish Farming
- Waste products in the local waters
- Escapes of farmed fish into the wild population
- Sea lice infestation: the sea louse is found in much higher numbers where fish are penned together for farming. Lice can harm the salmon and damage the wild fish population if allowed to get out of control.

Source: the United Nations Food and Agriculture Organization, BBC News

The fish are farmed to maturity in giant pens in Norway.
### Norway: Wild fishing v farmed fishing

- Around 100,000 fewer fishermen now go out to sea than in the 1940s
- There are now just over 6,000 registered fishing vessels in Norway - down from 13,000 at the start of the century
- Fish products are Norway's second largest source of exports - after oil and gas - worth more than $9bn (£6bn) a year
- About 95% of Norwegian aquaculture production is exported
- In 2014, Norwegian vessels delivered 2.3 million tons of fish, crustaceans and mollusks
Second Premise of ‘Sustainability’

• Use renewable resources/ recycle materials in commerce
  – Look at Materials in Commerce not including food and fuels
  – Look at all materials
Overwhelming Dependence on Nonrenewable Materials

- 4% of the 9 billion tons of material flow in commerce (by weight) is renewable (excluding food and fuels)

The increasing dependence on nonrenewable materials over time, rising to 96% by weight today. (Data in part from USGS [2002])

*Michael F. Ashby, Materials and the Environment*
Resource Consumption for Material Production
(Energy Required for top 7 materials 1.5 TW - 10%)

Credit: Mike Ashby

• Ratio based on mix design for 30 MPa compressive strength at 28 days
(http://www.ctre.iastate.edu/pubs/sustainable/strulesustainable.pdf)
Gigaton Problems Need Gigaton Solutions -
We need 1 million kiloton solutions

- With 1 billion people using 70 Gt of materials, 12 Gtoe of energy, 120 Gm³ of water and emitting 9 Gt of Carbon per year globally, a shift of scale and paradigm is needed to address the issues of global sustainability.

- From an egalitarian point of view, we should expect this to increase by a factor of 9 for 9 billion people in 2050, if every one has the same life style and uses today's technologies.

<table>
<thead>
<tr>
<th>Population (Total)</th>
<th>Material Use (Gt/yr)</th>
<th>Energy Use (ton of oil equivalent)</th>
<th>Carbon from Fossil Fuels (Gt/yr)</th>
<th>Water Use (10 Km³/yr)</th>
<th>Passenger Cars (Total number of units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 billion</td>
<td>70 billion</td>
<td>12 billion</td>
<td>9 billion</td>
<td>120 billion m³</td>
<td>1.02 billion</td>
</tr>
</tbody>
</table>

Note: Material use includes food
Two Possible Paths to Choose From

Complete Segregation Between Human and Natural Environment

- Even larger-scale geoengineering projects take over
- Humans live in their own micro-climate bubbles
- Unlimited energy becomes available (possibly fusion)
- Top-down governance to make it viable
- Engineered food replaces conventional agriculture

Re-integration of Human and Natural Environment

- Accelerated drastic efforts to reduce emissions
- Restricted use of fossil fuels
- Policies in effect to mandate use of renewable resources and energy
- Bottom-up rebuild of our economic system
- Responsible agricultural practices to sustain the food system
Reducing Population Growth

Total fertility vs. Child Survival Rate (\%) Time-trend (1950-2010)

Replacement Rate for Developed Countries = 2.1 Children

Credit: Hans Rosling
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China’s Infrastructure Challenge

By 2025:

- 5 billion square meters of road will be paved.
- 170 mass-transit systems could be built.
- 40 billion square meters of floor space will be built in five million buildings.
- Build between 700 and 900 Gigawatts of new power capacity.
No longer can infrastructure be designed, built, and operated as separate isolated systems.

There is a need to create the science and engineering to understand and model infrastructure interdependencies and guide transformations toward sustainability.

Urban Infrastructure
- Socioeconomic Properties
  - Community Values
  - Financial Capital
  - Leadership
- Physical
  - Transportation
  - Energy
  - Water
  - Buildings
  - Parks/Greenways

The Need for the Transdiscipline: Infrastructure Ecology

ASCE: Underfunded infrastructure will result in GDP loss of $3.2T & 3.5M jobs
12 Principles of Infrastructure Ecology

1. Interconnect rather than segregate
2. Integrate material, energy & water flows
3. Manage inherent complexity
4. Account for systems dynamics
5. Decentralize to increase response diversity and modularity
6. Maximize sustainability and resilience of material & energy investment
7. Find synergies between engineered & ecological systems
8. Take stakeholder preferences into account
9. Maximize the creation of comfort & wealth
10. Take advantage of socioeconomics as a driver in achieving change.
11. Require adaptive management as the policy strategy
12. Utilize renewable flows rather than depleting stocks
Sustainable Urban Systems

• **Sustainable Urban Systems: Key questions**
  – How are energy, materials, information, and water utilized by the different configurations and populations of systems?
  – How can we reduce energy, emissions, materials and water inputs and increase the creation of wealth and comfort?
  – How do “communities of infrastructure” emerge from the cultural, physical, and economic conditions of the region?

• **Infrastructure Ecology:**
  – A Hyper Nexus of material use, water, energy, transportation, land use/planning, commercial and residential buildings, community design, and socioeconomics as they occur in urban environments.
‘Water for Energy’ and ‘Energy for Water’ in US

**Water for Energy**
- Thermoelectric power generation accounts for ~ 52% of fresh surface water withdrawals.
- The average (weighted) evaporative consumption of water for power generation over all sectors is around 2.0 Gal/kWh.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Gal/kWh (Evaporative loss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>18.27</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.62</td>
</tr>
<tr>
<td>Coal</td>
<td>0.49</td>
</tr>
<tr>
<td>Oil</td>
<td>0.43</td>
</tr>
<tr>
<td>PV Solar</td>
<td>0.030</td>
</tr>
<tr>
<td>Wind</td>
<td>0.001</td>
</tr>
</tbody>
</table>

**Energy for Water**
- About 4% of the total electricity consumption in the US is for the water and wastewater sector.
- Of the total energy required for water treatment, 80% is required for conveyance and distribution.

### Water Treatment* kWh/MGal
- Surface Water Treatment: 220
- Groundwater Treatment: 620
- Brackish Groundwater Treatment: 3,900-9,700
- Seawater Desalination: 9,700-16,500

*Includes collection but does not include distribution
Water for Transportation: Impact of Biofuels

Life Cycle consumptive water use by different transportation fuel alternatives

(Source: Harto, C; et al., Life cycle water use of low-carbon transport fuels, Energy Policy, 2010)
Water for Mobility Network: Vehicle Electrification
Metro Atlanta, 2010 and 2030 Conditions

Source: Jeffrey Yen (2011) A system model for assessing water consumption across transportation modes in urban mobility networks, Masters thesis
Water as a Heat Source: False Creek Neighborhood Energy Utility Vancouver, BC

Sewage heat recovery supplies 70% of annual energy demand and reduces GHG emission by 50%
Water Flows within the Urban System with LID Implementation: Case Study of Atlanta, GA

- Individual water use (91 Gpcd) in 2-story apartment (RG-1)
- *Implemented LID technologies*: rainwater harvesting, grass pavement, rain gardens, and xeriscaping
- Reduces dependence on the centralized potable water system by \( \sim 50\% \) (entire non-potable demand)
- Uncontrolled Stormwater runoff (kGal/cap-yr) : 16 → 0

![Water Flow Diagram](image)

**Unit:** Gallon per capita per day (Gpcd)
Water Flows within the Urban System with Reclamation: Case Study Atlanta, GA

- Individual water use (91 Gpcd) in 2-story apartment (RG-1)
- 60% satisfaction of residential water demand regardless of population density
- Reduces dependence on the centralized potable water system by ~60% (entire non-potable demand)
- Reduces stress on the centralized wastewater treatment plant by ~60%
- Citywide implementation of Hybrid (Reclamation + Centralized) System would save the city ~$1.0 million per year in energy costs.
Low Impact Development (Reducing Stormwater Runoff, Erosion and Surface Water Contamination) - LID Best Management Practices (BMPs)

- Rain Gardens for local flood control at Cuyahoga Falls, OH¹.
- Green roof of City Hall in Chicago, IL.
- Rainwater Harvesting tanks for residential water supply at Perth, Australia².
- Increased walkability through greening of alleyways at Vancouver.
- Porous parking lot at the Reliant stadium, Houston, TX³.
System-based Benefits of LID Best Management Practices

Water Resources
- Rainwater
- Surface water
- Groundwater
- Reclaimed water

Wastewater/Stormwater
- Storm sewers
- Combined sewers
- Wastewater systems

Green Infrastructure

Water & Wastewater
- Stormwater management
- Stormwater treatment
- Water recharge

Social Benefits
- Well-being
- Public health
- Property values
- Urban gardens

More Concentrated Wastewater

Reduced/Delayed Flow

Transportation Infrastructure
- Pedestrian walkways
- Cycling

Food Infrastructure
- Urban agriculture

Energy Infrastructure
- Reduced heat island

Credits: Keolian, Love UM
Decentralized Energy Production at Perkins + Will, Atlanta Office

- Air Cooled Microturbines are used to for heating and cooling using Absorption Chillers and supply 40% of the total electricity.

Adding Distributed Generation as part of the Grid:

- Water Reduction: >50%
- CO₂ Reduction: 15 - 40%
- NOₓ Reduction: ~90%

Adsorption Chiller

65 kW Microturbine

Perkins+Will Office Building
A Possible Future Infrastructure for Heating, Cooling, and Electricity

Conventional System

Proposed CCHP System

Alternative 1: Thermal Storage

Alternative 2: Battery/Electric Vehicle

Alternative 3: Photovoltaics

Wind
The large variation in PV output demands a higher capacity of spinning reserves.
MICROGRID: PV System (160 kW) and Gas Turbine (270 kW) Supplying Feeder
Transit-oriented Development (TOD)

• Creation of compact, walkable, mixed-use communities centered on high quality public transit services

• Affordable house
• Walkable community
• Mixed land use
• Reasonable density
• Multiple modes of transport
The Synergistic Effects of “Infrastructural Symbiosis”

- Designing UIS using an infrastructure ecology approach alters and reorganizes energy and resource flows, allowing one to consider the potential synergistic effects arising from infrastructural symbiosis.

The accumulated synergistic effects:

- reduced water and energy consumption,
- lower dependence on centralized systems,
- larger share of renewables in the electricity mix,
- reduced vehicle-miles travelled, &
- an increase in tax revenue.
Grids: Closing the Loops on Carbon, Water, Nutrients, Material Flows

• To become more sustainable and resilient, we need coordinate and restructure at least 7 important grids. They include: (1) nutrients, (2) natural gas, (3) water, (4) electricity, (5) thermal, (6) transportation and (7) material grids.

• In past, these grids were mostly constructed in isolation and we did not consider there interactions.
Chicago Is Hoping to Retire the Word “Waste Water”: Now Resource Water

The vision statement of Metropolitan Water Reclamation District of Greater Chicago’s new five-year strategic plan is “Recovering Resources, Transforming Water” Four resources: phosphorus, class A biosolids, energy and water.
Closing the Urban Water, Nutrient and Carbon Loop

- Stormwater Management with Low-Impact Development
- More Concentrated Wastewater
- On-site Energy and Nutrient Recovery
- Harvested Rainwater
- Stormwater treated through LID
- Urban Agriculture (Aquaponics, Urban Farming, Greenhouse Farm)
- Fertilizer for Farms, Food for Aquaponics
- Local Composting
- Heat and Energy
- Natural Gas from Compost
- Combined Cooling Heating and Power (Air-cooled microturbines)

Natural Gas
Heat and Energy
Water
Fertilizer
Robustness of Network Flow

Food webs provide examples to build a robust industrial network

ASC: ascendancy
DC: development capacity

\[ ASC = \sum_{i,j} T_{i,j} \log \left( \frac{T_{i,j}T_{\cdot \cdot}}{T_{i,T_{\cdot \cdot}}} \right) \]

\[ DC = -\sum_{i,j} T_{i,j} \log \left( \frac{T_{i,j}}{T_{\cdot \cdot}} \right) \]

\( T_{i,j} \) is the flow from taxon \( i \) to another taxon \( j \)
\( T_{\cdot \cdot} \) is the sum of all measurable flows

Ascendancy: the efficiency of the network in transporting the flows. The network with larger flows along fewer pathways will have a higher efficiency, or ascendancy.

Development Capacity: the diversity of flow pathways provided by the network, a measure of redundancy.

Robustness is a balance between efficiency and redundancy because there is a trade-off between efficiency and redundancy. The flow in Fig (a) is more efficient than that in Fig (b). But the redundancy in Fig (b) in terms of feeding A is higher than that in Fig (a) because of the existence of B-C-A. That is why the existence of maximum value in Robustness by changing the flows in the network.
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Emergent Properties and Complexity

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• What do I mean by complexity?
  – Complexity results from the interaction of diverse adaptive entities (not just faces but in this case infrastructures and people, firms, etc.) and properties emerge from this interactions.
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Interconnections between Infrastructure and Socio-Economic Environment

Macro

Infrastructure Systems

Socio-Economic Environment

Micro

Quality of Life

Interconnectedness with Infrastructure and Socio-Economic Environment.
Emergent Properties of Complex Urban Systems

<table>
<thead>
<tr>
<th>Social</th>
<th>Economic</th>
<th>Environmental</th>
<th>Built Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of life</td>
<td>Gross domestic product</td>
<td>Water consumption</td>
<td>Land use</td>
</tr>
<tr>
<td>Social equity</td>
<td>Economic structure</td>
<td>Energy intensity</td>
<td>Accessibility</td>
</tr>
<tr>
<td>Social segregation</td>
<td>Economic resilience</td>
<td>Material intensity</td>
<td>Mobility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Toxic emissions</td>
<td>Congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pollutant emissions</td>
<td>Fractal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green gas emissions</td>
<td></td>
</tr>
</tbody>
</table>

Examples of Emergent Properties: Power Laws

Social Measures: Gross Domestic Product - Exponent = 1.13

1.6 times more for 1M people

2 times more for 10M people

Source: Bettencourt 2013
Examples of Emergent Properties: Power Laws

Source: Bettencourt 2013

Infrastructure Measures: Road miles: Exponent=.85

50% of Linear Extrapolation for 1M people

31% of Linear Extrapolation for 10M people
RENOVATION OR RECESSION

Time Square in the 50s

Produced Poor Quality Cars, Fought CAFE Standards and the Use of Catalytic Converters

Detroit in the 50s

Detroit today
Emergent Property: Ozone in ATL

Credit: Ted Russel
Big Data for Social Decision and Urban Complexity Modeling

Collect
- Social Media
- Blogs
- Twitter
- News
- Product Reviews

Analyze
- Enrich and prepare social media content with metadata

Modeling
- Agent-based urban model and visualization

Topic Modeling
Sentiment Results on “Green Roof” From 30 Billion Tweets

- In 6054 tweets about green roof:
  - 4543 tweets are neutral
    - “We do green roof systems for today’s homeowners and building owners”
  - 1422 tweets are positive
    - “4 best reason to grow a living roof! Beautiful, beneficial, efficient, green living rooftops”
  - 89 tweets are negative
    - “Green roof garage has been nixed. Too expensive. :(’”
Housing Market Simulation

Prospective homebuyers
- Socioeconomic attributes
- Preference
  1. Evaluate candidate houses
  2. Decide the bidding house
  3. Determine willingness to pay

Homeowners
- Property value
- Living community
- Green space
- Transportation accessibility

Government
- Collect property tax
- Distribute property tax for infrastructure improvement

Developers
- Asking price
- New house investment decision
- Consider LID options if impact fee exists

Infrastructure improvement

House inventory:
- Apartment, single-family

House demand for next period

Impact fee?
Agent-based Modeling: Simulating the Adoption Rate for More Sustainable Urban Development

Principal Agents: Prospective Homebuyer, Homeowners, Developers, Government

Implemented Policy Tool

Impact fee for Low Impact Development non-compliance penalty:
- $13,000 per unit for single-family house
- $1,500 per unit for apartment home

Policy Implementation Effect
After 30 years:
- 40% reduction in potable water demand from centralized plant in MSD as compared to BAU
- 36% increase in net property tax revenue generation in MSD as compared to BAU
The SMARTRAQ project

- Supports research on land use impact on transportation and air quality
- 1.3 million parcels in the 13 metropolitan Atlanta non-attainment counties
SMARTRAQ DATA AND ATTRIBUTES

- Address
- Road Type
- City
- Zip Code
- Owner Occupied
- Commercial/Residential
- Zoning
- Sale Price
- Sale Date
- Tax Value
- Assessed Value
- Improvement Value
- Land Value
- Year Built
- No. of Stories
- Bedrooms
- Parking
- Acreage
- Land Use Type
- Number of Units
- X,Y Coordinate
- Estimated Sq Feet
- Total Sq Feet
Urban Growth Policy

Business As Usual
Year 2030

More Sustainable Development
Year 2030

Base Year 2005

_Agriculture_  _Commercial Office_  _Commercial WholeS_

_Conservation_  _Forest_  _Multifamily Res_  _Open Water_

_Industrial_  _Single-family Res_  _Other Developable Parks_  _Pub Institutional_

Courtesy of: Steve French and Marty Sung
Possible Atlanta Energy and Water Savings (with low flow fixtures + rooftop rainwater harvesting + decentralized CCHP system + Solar PV)

More Sustainable Development Scenario

- **Residential Energy Demand**
  - (Air Cooled Microturbines & Solar PV in Decentralized CCHP system)
  - 69% reduction

- **Withdrawal**
  - 63% reduction

- **Evaporation**
  - 60% reduction

Graphs showing:
- Electricity from Grid vs. Electricity from Grid with CHP
- Withdrawal (Municipal Water Demand vs. Water for Energy' Demand for Commercial & Residential Energy Production)
- Water Demand (Withdrawal)
- Water Consumption (Evaporation)
Potential GHG and Cost Reductions in 2030

By 2030, implementation of CHP in all the residential and commercial buildings (new and existing) will reduce the CO$_2$ emissions by~ 0.04 Gt CO$_2$ and the energy costs by $1.1$ billion per year for the Metro Atlanta region.

The costs reduction calculation is only based on the cost of natural gas and the cost of electricity from firms in the region.

The 2030 grid+CHP scenarios assumed residential and commercial units in the base year were also retrofitted with CHP systems.
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What Could Future Cities Look Like
How your City could look in Future

The top 10 most likely architectural advancements within the next 100 years were:

- Super-deep basements
- Floating sea cities
- High-rise or rooftop farms
- 3D printed homes
- Buildings with their own micro-climates
- Bridges that span entire cities
- Spaceports with easy access to the moon and Mars
- Super-high buildings - 'cities in the sky'
- Underwater cities
- Collapsible/stackable living pods

Many of the predictions were influenced by environmental conditions, with global warming and rising sea levels encouraging a focus on water-based architecture.

The predictions came from a distinguished panel including Dr. Rhys Morgan, Director of Engineering and Education at the Royal Academy of Engineering and award-winning architects and lecturers at the University of Westminster.

Super-Deep Basement below the Houses of Parliament includes:

- 6 levels of living and functional spaces including gardens, parks, swimming pools, gyms, hotels, a football pitch and a secure bunker
- Glass pyramid atrium which sits under the Palace of Westminster itself - The light well for the pyramid lets in light from the courtyard

If all the Ice Melted: Sea Level Rise by 216 ft.

North America

The entire Atlantic seaboard would vanish, along with Florida and the Gulf Coast. In California, San Francisco’s hills would become a cluster of islands and the Central Valley a giant bay. The Gulf of California would stretch north past the latitude of San Diego—not that there’d be a San Diego.
Floating City:

- Reef-like structure formed on the water
- Interlinking pods allow for living space within the city
- The use of glass and bone structures reflect sea-life and helps to sit the floating city into the environment

Source: http://www.plymouthherald.co.uk/Plymouth-2115-city-look/story-26568015-detail/story.html#ixzz3bBdzNvgY
High Rise Farm:

- Animals graze on pastures on top of high-rise London buildings with familiar landmarks in the background.

Source: http://www.plymouthherald.co.uk/Plymouth-2115-city-look/story-26568015-detail/story.html#ixzz3bBdzNvgY
Outline

• What is Sustainability and the Gigaton Problem?

• How to transform the Urban Infrastructure Systems:
  – The Role of Infrastructure Ecology

• Managing the Complexity of Urban Systems

• Future Cities

• Summary
Emerging Engineering Solutions for Sustainability and Resilience

- Network of Wireless Sensors
- Performance Monitoring
- Network of Things
- Social-Media Data Analytics
- Understand Stakeholder Preference

- Sustainable & Resilient Systems

- Energy Independent Buildings
- Living Buildings
- High Performance Buildings

- Decentralized Energy Infrastructure
- Grid Scale Energy Storage
- Solar Powered Public transit
- Flow Batteries
- Super Capacitor

- Efficient Water Use
- Decentralized Water Infrastructure

- Transit-oriented Development
- Bike Friendly Neighborhood
- Shared Autonomous Vehicles
- Tele-commute to work
Summary

• Urban Systems Are All Connected and More Efficiency Can be Achieved by Looking at Their Interactions

• Decentralized Energy and Combined Heat and Power Can Save Energy and Water

• Decentralized Water / Low Impact Development Can Save Water, Energy and Money

• Land Use/ Planning Is Vital in Reducing the Impact Of Urban Systems and Examining Their Interactions

• Agent Based Models May Be Useful to Examine the Adoption Rate of Policy Instruments
PV System at Georgia Tech Aquatic Center (1996)

THANK YOU!

John C Crittenden, Ph.D., P.E., U.S. and Chinese N.A.E.
E-Mail: john.crittenden@ce.gatech.edu
Web Site: http://www.sustainable.gatech.edu/