Infrastructure Ecology: Developing the Gigatech Road Map for a more Sustainable and Resilient Future

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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.
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.
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):

- ⅔rd 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 NH₃-N (does not include energy required for steam reforming)
- Energy required to remove N from wastewater: 18 MJ (5 kWh)/ kg NH₃-N
- Total energy required to chemically fix 1 kg of N from and release it back to the atmosphere: 50 MJ or 14kWh/ kg
- Energy consumed for NH₃ production in 2010 = 1.82 TWh ≈ 1.2% of global total energy consumption

Phosphorus Cycle

- With the current trend of increasing mining continuing, the global reserve would last 125 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).
Lets 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

- 11.5 Gt C (-72%)
- 6.6 Gt C (-60%)
- 5.0 Gt C (-31%)

1990 2000 2010 2020 2030 2040 2050

Gt C per year

- 6 Degree Scenario
- 4 Degree Scenario
- 2 Degree Scenario

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

Abatement cost
€ per tCO$_2$e

- Residential electronics
- Residential appliances
- Retrofit residential HVAC
- Tillage and residue mgmt
- Insulation retrofit (residential)
- Cars full hybrid
- Waste recycling
- Organic soil restoration
- Geothermal
- Grassland management
- Reduced pastureland conversion
- Small hydro
- 1st generation biofuels
- Rice management
- Efficiency improvements other industry
- Electricity from landfill gas
- Clinker substitution by fly ash
- Cropland nutrient management
- Motor systems efficiency
- Insulation retrofit (commercial)
- Lighting – switch incandescent to LED (residential)
- Low penetration wind
- Cars plug-in hybrid
- Degraded forest reforestation
- Nuclear
- Pastureland afforestation
- Degraded land restoration
- 2nd generation biofuels
- Building efficiency new build
- Reduced slash and burn agriculture conversion
- Gas plant CCS retrofit
- Coal CCS retrofit
- Iron and steel CCS new build
- Coal CCS new build
- Power plant biomass co-firing
- Reduced intensive agriculture conversion
- High penetration wind
- Solar PV
- Solar CSP

Abatement potential
GtCO$_2$e per year

10.3 gT as C

Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO$_2$e 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
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

Population growth

2015: 7.2 billion
2050: 9 billion

Growing appetite for MEAT!

Source: Green Food. Economist Technology Quarterly Q1 2015
Green Food
- Sustainable “Meat” and “Dairy” from Plants (400,000 species of plants and each plant species has tens of thousands 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
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 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%)

• Ratio based on mix design for 30 MPa compressive strength at 28 days
(http://www.ctre.iastate.edu/pubs/sustainable/strubesustainable.pdf)

Credit: Mike Ashby
Analysis of Material Use in Infrastructure

**Problem:** Material use, particularly non-renewable use is increasing at an unsustainable rate.

- Highest demand of raw materials is in construction sector
- Material demand high for urban areas
  - Increasing population
  - Increasing in demand per capita
China Used More Cement in Three Years than the US did in a Century

Gigatech: Chinese Cement Investment $\approx 10^{14}$ moles

US
1900-1999

China
2011-2013

4,405 million tonnes
6,615 million tonnes

Source: USGS, International Cement Review
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 Gm$^3$ 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.

*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
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
The Future of Urban Infrastructure

- Currently, 53% of world population is living in urban areas.
- By 2050, over 70% of global population will be urban residents.
- Urban population is increasing by 5.5 million every month.
- Worldwide, there are 560 cities with more than 1 million population and the number of mega-cities, i.e. cities with a population greater than 10 million, is steadily increasing².
- To keep pace with the current urbanization trend, the global infrastructure is likely to double in the next 30 years and will require an investment of $57 trillion investment⁶.
- Cities already account for 60% of global drinking water consumption, 75% of global energy consumption and 80% of global greenhouse gas emissions⁵.
Importance of Building Sustainable and Resilient Infrastructure

• Challenge will be to insure that we develop long terms social, economic and environmental assets and not liabilities.
• It will last more that 50 years and 80 to 90% of the impact is during the use phase.
• A livable climate and sustainable resource flows depend on this
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.
US Infrastructure Grade from ASCE: D+; Underfunded infrastructure will result in:

- GDP loss of $3.2T per year
- 3.5M jobs
- $3100 loss in disposable income per family
- Investment needed by 2020 is $3.6 trillion
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
‘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.

**Energy for Water**

- About 4% of the total electricity consumption in the US is for the water and wastewater sector.1

- Of the total energy required for water treatment, 80% is required for conveyance and distribution.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Gal/kWh (Evaporative loss)</th>
<th>kWh/MGal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>18.27</td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>PV Solar</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Surface Water Treatment</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>Groundwater Treatment</td>
<td>620</td>
<td></td>
</tr>
<tr>
<td>Brackish Groundwater Treatment</td>
<td>3,900-9,700</td>
<td></td>
</tr>
<tr>
<td>Seawater Desalination</td>
<td>9,700-16,500</td>
<td></td>
</tr>
</tbody>
</table>

*Includes collection but does not include distribution
## Water for Transportation: Impact of Fuel Types and Vehicle Technologies

### Life-cycle Water Consumption Per Vehicle Mile

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Water Consumption (gallons per vehicle mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal + Carbon sequestration</td>
<td>0.77</td>
</tr>
<tr>
<td>Solar PV</td>
<td>0.59</td>
</tr>
<tr>
<td>Concentrated Solar Power</td>
<td>0.79</td>
</tr>
<tr>
<td>Unleaded</td>
<td>0.32</td>
</tr>
<tr>
<td>Corn ethanol—no irrigation</td>
<td>4.35</td>
</tr>
<tr>
<td>Switchgrass—irrigation</td>
<td>12.25</td>
</tr>
<tr>
<td>Soy biodiesel—open</td>
<td>2.45</td>
</tr>
<tr>
<td>Algae biodiesel—open</td>
<td>3.85</td>
</tr>
<tr>
<td>Algae biodiesel—closed</td>
<td>0.97</td>
</tr>
</tbody>
</table>

- **Plug-in hybrid electric vehicle (PHEV)**
- **Conventional (internal combustion engine)**
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%
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, OH\(^1\).

Green roof of City Hall in Chicago, IL.

Rainwater Harvesting tanks for residential water supply at Perth, Australia\(^2\).

Increased walkability through greening of alleyways at Vancouver.

Porous parking lot at the Reliant stadium, Houston, TX\(^3\).
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 ~50% (entire non-potable demand)
- Uncontrolled Stormwater runoff (kGal/cap-yr) : 16 → 0
Typical Greywater Reclamation System at the Household Level

Approved by the N.S.W. Department of Health

Used to treat grey-water, bathwater, hand basin water and washing machine water to acceptable Department of Health standards for re-cycle and re-use to flush toilets, car washing, garden irrigation and even re-filling washing machines.


Note: N.S.W. denotes New South Wales, Australia
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.
Potential of Water Supply by Combining Greywater Reclamation & Rainwater Harvesting

Average annual rainfall in metro Atlanta: 49.71 inches.

If we have less or more rainfall?
Chicago Is Hoping to Retire the Word “Waste”

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

The Stickney Water Reclamation Plant in Stickney, Illinois, the largest wastewater treatment plant in the world.
System-based Benefits of LID Best Management Practices

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

Green Infrastructure
- Water & Wastewater
  - Stormwater management
  - Stormwater treatment
  - Water recharge
- Social Benefits
  - Well-being
  - Public health
  - Property values
  - Urban gardens

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

Reduced/Delayed Flow

Enables:
- Energy Efficiency and Recovery (reduces energy demand)
- Nutrient Recovery (can be utilized for green infrastructure projects)

Can Enhance Other Infrastructures

Transportation Infrastructure
- Pedestrian walkways
- Cycling

Food Infrastructure
- Urban agriculture

Energy Infrastructure
- Reduced heat island
Decentralized Energy Production at Perkins + Will, Atlanta Office

- Microturbines are used 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%
A Possible Future Heating Cooling and Electricity

**Conventional System**

- Energy Inputs
- Furnace or Boiler
- Heat
- Electricity
- Power Grid
- Energy Inputs

**Proposed CCHP System**

- Energy Inputs
- Air-cooled Microturbine
- Electricity 30%
- Heat
- Cooling
- Energy Inputs

- Alternative 1: Thermal Storage
- Absorption Chiller
- Heat
- Cooling

- Alternative 2: Battery/Electric Vehicle
- Alternative 3: Photovoltaics

+ Wind
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 Connection between Autonomous Vehicles, Transport, Green Space and Water

80% penetration of autonomous vehicles

28% of the cars we have today; Extend the distance of TOD (10 min)

At least 72% reduction in parking space

24.7% reduction of impervious area and stormwater runoff

Additional 17% of city land for green space and stormwater management
## Controlled Environment Agriculture (CEA) Hydroponic Indoor Farms vs. Traditional Field Growth

<table>
<thead>
<tr>
<th></th>
<th>CEA Fresh Farms Romaine (Local Grown, Georgia)</th>
<th>Filed-Growth Romaine (California)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land Requirements</strong></td>
<td>20 Acres</td>
<td>620 Acres</td>
</tr>
<tr>
<td><strong>Leafy Green Production Yields Per Year</strong></td>
<td>33 Million Heads</td>
<td>33 Million Heads</td>
</tr>
<tr>
<td><strong>Fossil Fuel used during Growth Cycle (not including crop transport)</strong></td>
<td>200 Gallons equiv. Diesel</td>
<td>3,720 Gallons Diesel</td>
</tr>
<tr>
<td><strong>Food Miles</strong></td>
<td>100 miles/truckload</td>
<td>2,577 miles/truckload</td>
</tr>
<tr>
<td><strong>Fossil Fuel to Transport 100 Miles or CA to Local Markets</strong></td>
<td>22,200 Gallons Diesel</td>
<td>571,000 Gallons Diesel</td>
</tr>
<tr>
<td><strong>Carbon Footprint</strong></td>
<td>3,000 metric ton CO2</td>
<td>12,000 metric ton CO2</td>
</tr>
<tr>
<td><strong>Fresh Water used during Growth Cycle</strong></td>
<td>1.2 Gallons per Head</td>
<td>9-42 Gallons per Head</td>
</tr>
<tr>
<td><strong>Fresh Water Used to Wash Lettuce per heat for market</strong></td>
<td>0.7 One Water per Head</td>
<td>2.5 Three Washings per Head</td>
</tr>
<tr>
<td><strong>Total Fresh Water Annually</strong></td>
<td>64 Million Gallons</td>
<td>0.3-1.5 Billion Gallons</td>
</tr>
<tr>
<td><strong>Time from Harvest to Market</strong></td>
<td>6-12 Hours</td>
<td>4-7 Days</td>
</tr>
</tbody>
</table>

**Source:** CEA Capital Holdings

**Caveat:** CEA have not build the farms at scale. The optimistic yields and operational parameters need verification.
The Synergistic Effects of “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.

- enhanced system resilience
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.
Robustness of Network Flow

Food webs provide examples to build a robust industrial network

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

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

ASC: ascendency
DC: development capacity

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Emergent Properties and Complexity

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  – 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.
  – By managing complexity, our desire is to create infrastructure that has the right combinations of features that will increase adoption of more sustainable infrastructure.
Interconnections between Infrastructure and Socio-Economic Environment
Emergent Properties of Complex Urban Systems

Social
- Quality of life
- Social equity
- Social segregation

Economic
- Gross domestic product
- Economic structure
- Economic resilience

Environmental
- Water consumption
- Energy intensity
- Material intensity
- Toxic emissions
- Pollutant emissions
- Green gas emissions

Built Environment
- Land use
- Accessibility
- Mobility
- Congestion
- Fractal

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

Infrastructure Measures: Road miles: Exponent=.85

50% of Linear Extrapolation for 1M people

31% of Linear Extrapolation for 10M people

Source: Bettencourt 2013
RENOVATION OR RECESSION

Time Square in the 50s

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

Time Square today

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”

• We synthesized the topics of 1.2 millions sustainability-related tweets collected from April, 2016 to June, 2016. The topic modeling algorithm takes less than 40 minutes.

• 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. : (”
Agent-based 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

Housing Market
House inventory:
- Apartment, single-family
- Infrastructure service
- Stormwater management (1st yr)
- Transportation improvement (5th yr)

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

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

Prospective homebuyers
- Bid
- Price
- Success

Housing Market
- Ask for price
- New house
- Bid

Infrastructure improvement

Impact fee?

House demand for next period

Property Tax

Agent-based Housing Market Simulation
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
Growth Scenarios in Atlanta

- Business As Usual Year 2030
- More Sustainable Development Year 2030

Existing Land Use Base Year 2005

Courtesy: French, S; GT
Atlanta Water Demand for New Residential and Commercial Buildings in More Compact Growth Scenario (with low flow fixtures + decentralized CCHP system)

Installation of Air Cooled Microturbines save 2.4 times the amount of water used for domestic consumption
By 2030, implementation of CHP in all new residential and commercial buildings will reduce the CO$_2$ emissions by $\sim 0.007$ Gt CO$_2$, NOx emissions by $\sim 15000$ Tons, and the energy costs by $680$ million per year for the Metro Atlanta region.
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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.

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

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

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
  - Transit-oriented Development
  - Bike Friendly Neighborhood
  - Shared Autonomous Vehicles
  - Tele-commute to work
  - Efficient Water Use
  - Decentralized Water Infrastructure

- High Performance Buildings
  - Energy Independent Buildings
  - Living Buildings

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

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