Infrastructure Ecology: A Path for More Sustainable and Resilient Cities

Presented at

Pathways to Urban Sustainability: Lessons from the Atlanta Metropolitan Region

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Sponsored by the National Academies
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Georgia Tech

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Outline

- **Sustainability, Resiliency**
- **Infrastructure Ecology**
- **Redevelopment Examples**
- **Decision Support**

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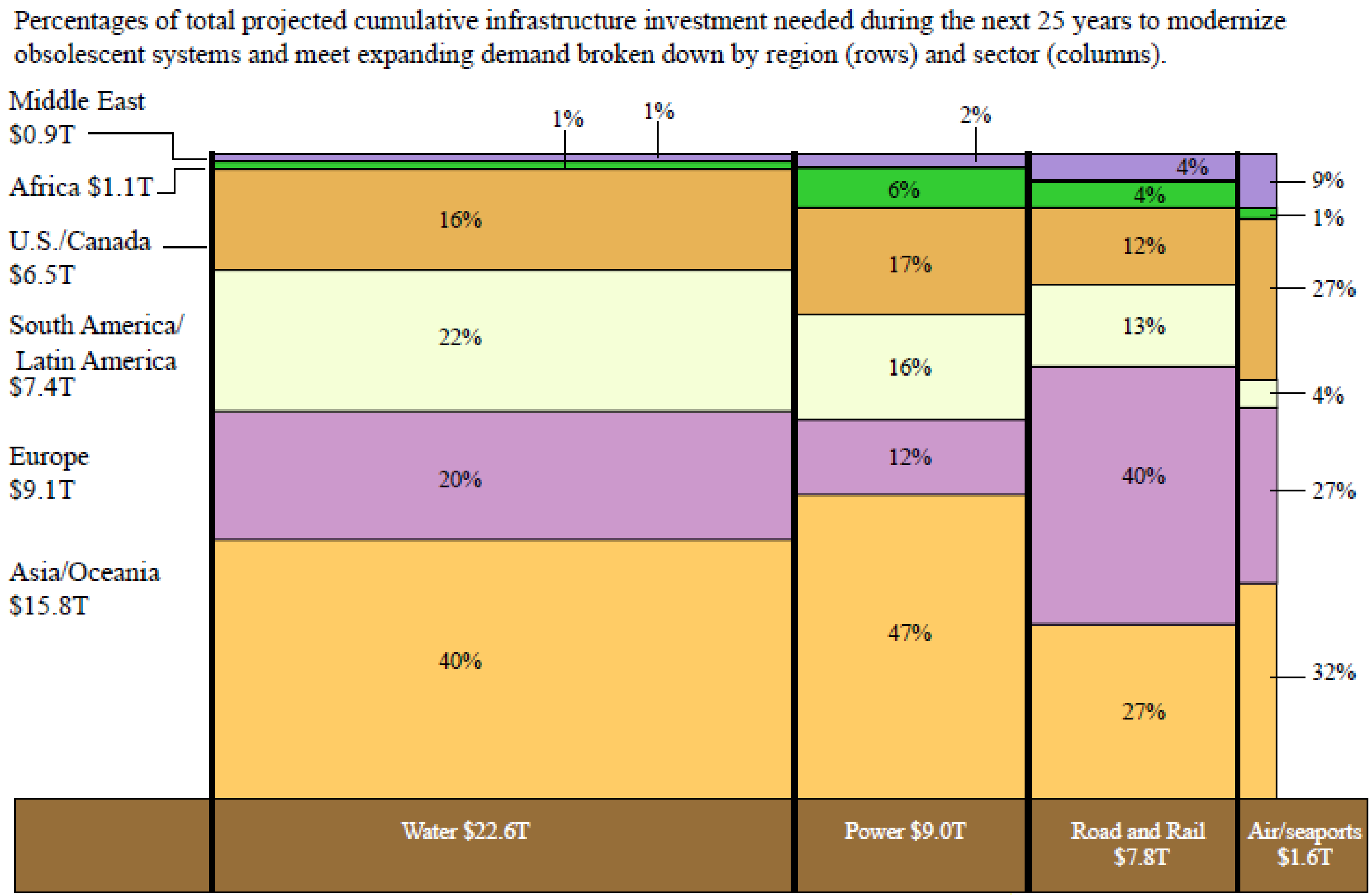
Global Infrastructure Demand:



Total projected cumulative infrastructure spending 2005-2030: **$41 trillion**

Source: Moavenzadeh, F; Frazier, K. The Impact of Globalization on the Built Environment , Lecture Notes, MIT OCW

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Sustainable and Resilient Urban Systems

Sustainability: managing the anthrosphere (the place where humans live) to exist within the means of nature.

Resiliency: maintaining functionality in the face of exogenous and endogenous stressors; quick recovery.

Stressors:

- Climate change
- Increasing and aging population
- Economic and environmental inequities
- Increasing demands for energy, water, and materials
- Aging and deteriorating infrastructure
- Fiscal constraints
- Extreme weather events such as hurricanes, floods, tornados, and drought
- Earthquakes

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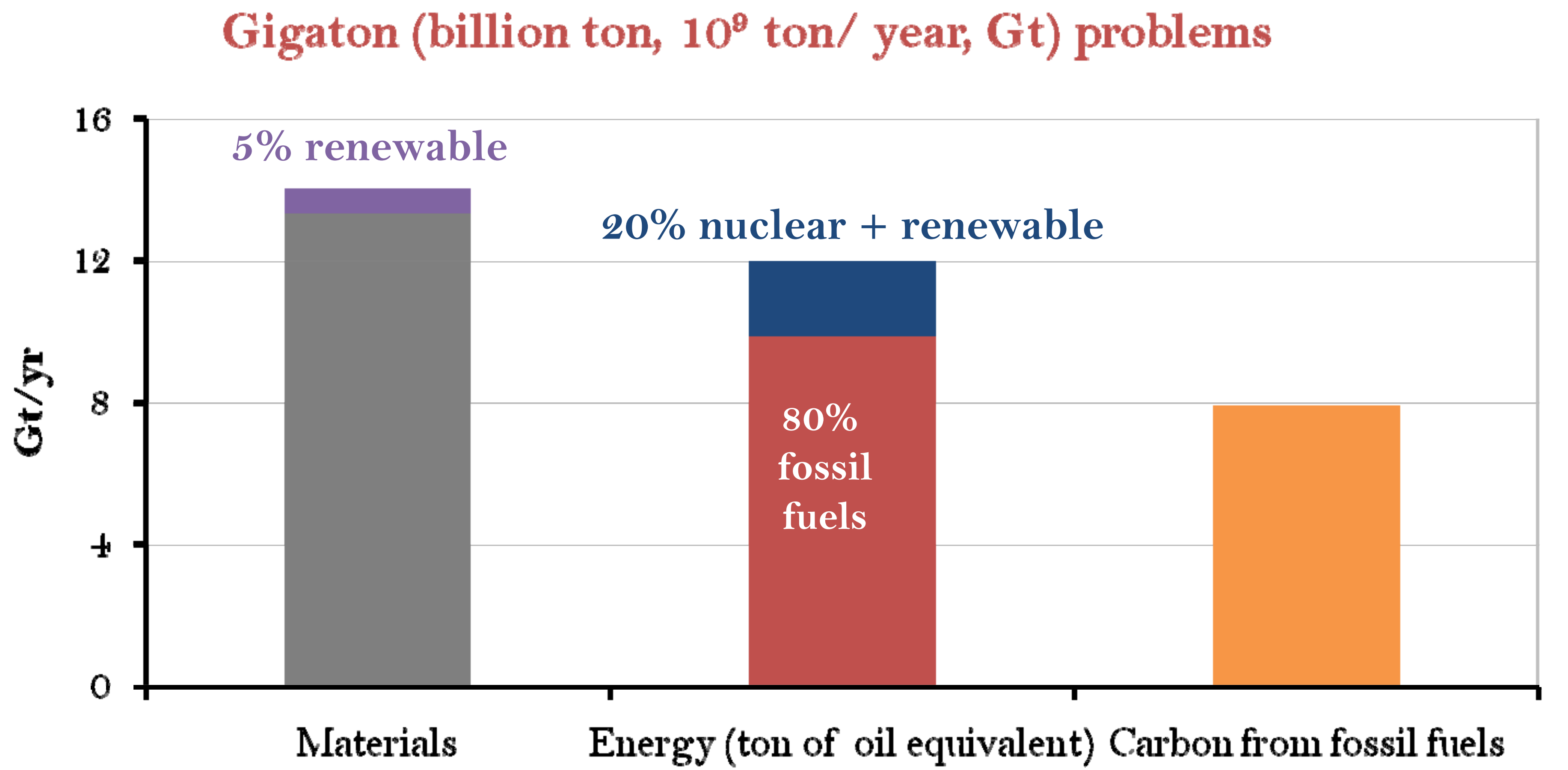
Gigaton problems Require Gigaton Solutions! Infrastructure Ecology



Ming Xu, John Crittenden, Yongsheng Chen, Valerie M. Thomas, Douglas Noonan, Reginald DesRoches, Marilyn Brown, Steve French, Env. Sci and Tech. June 2010

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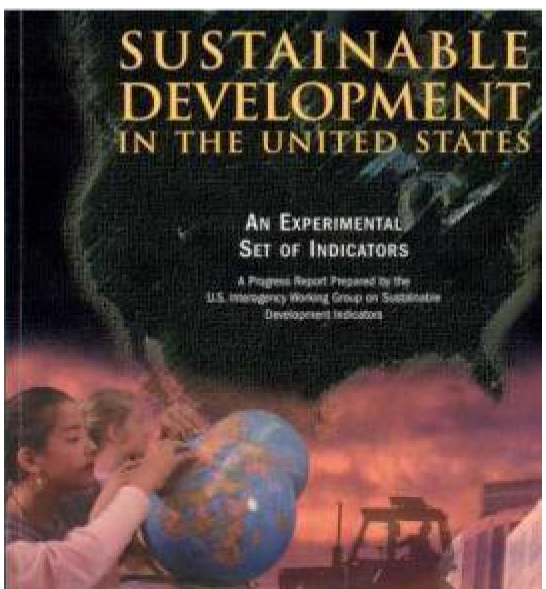
Infrastructure Sustainability

Economic Sustainability
Productivity,
Technological Growth,
Profit and Employment

Environmental Sustainability
Human Health,
Ecosystem Health,
Biodiversity,
Natural Resources:
Protection and Restoration

Sustainability Issues



Societal Sustainability
Citizens Capacity Building,
Stakeholder Participation,
Social Justice and Equity,
Consumer Choices,
Provide Opportunity for
Useful And
Productive Lives

Vibrant, Economically Sound and Livable Communities have realized the benefit of promoting all three attributes.

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Infrastructure Resilience

<u>The 4 R's of Resiliency</u>

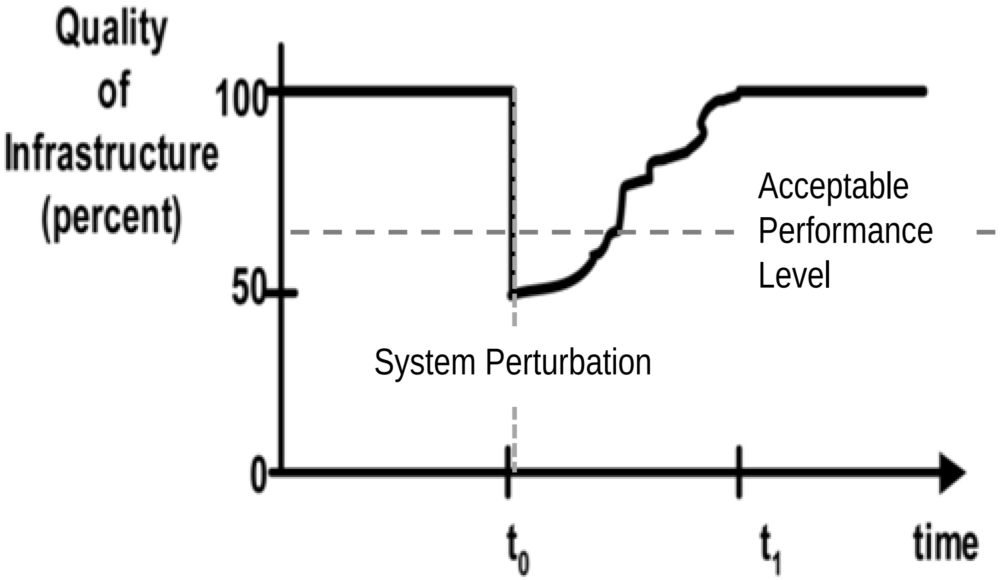
Robustness –

ability of the system to withstand a given level of stress and/or demand

Redundancy –
measure of the inherent substitutability

Resourcefulness
measure of the capacity to mobilize resources in the event of disruption

Rapidity
measure of the capacity to contain losses or prevent further degradation in a timely manner



Source: Exploring the Concept of Seismic Resilience for Acute Care Facilities, Michel Bruneau and Andrei Reinhorn

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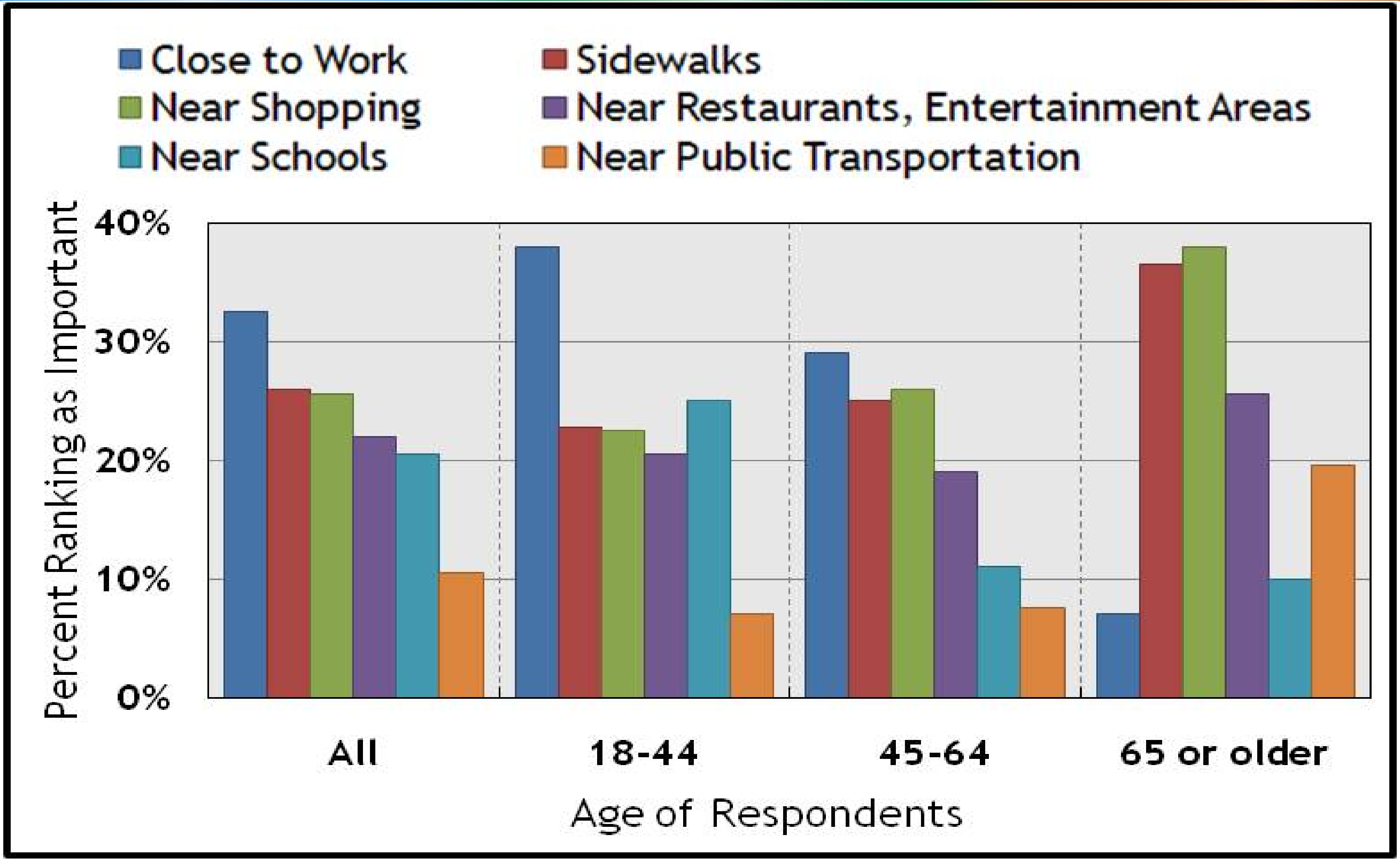
Demand for Urban Infrastructure: Citizen Capacity Building
What are the consequences of these preferences?
Can we alter these preferences through education?



Neighborhood features valued by home researchers (Source: Transportation for a New Era, ULI, 2009)

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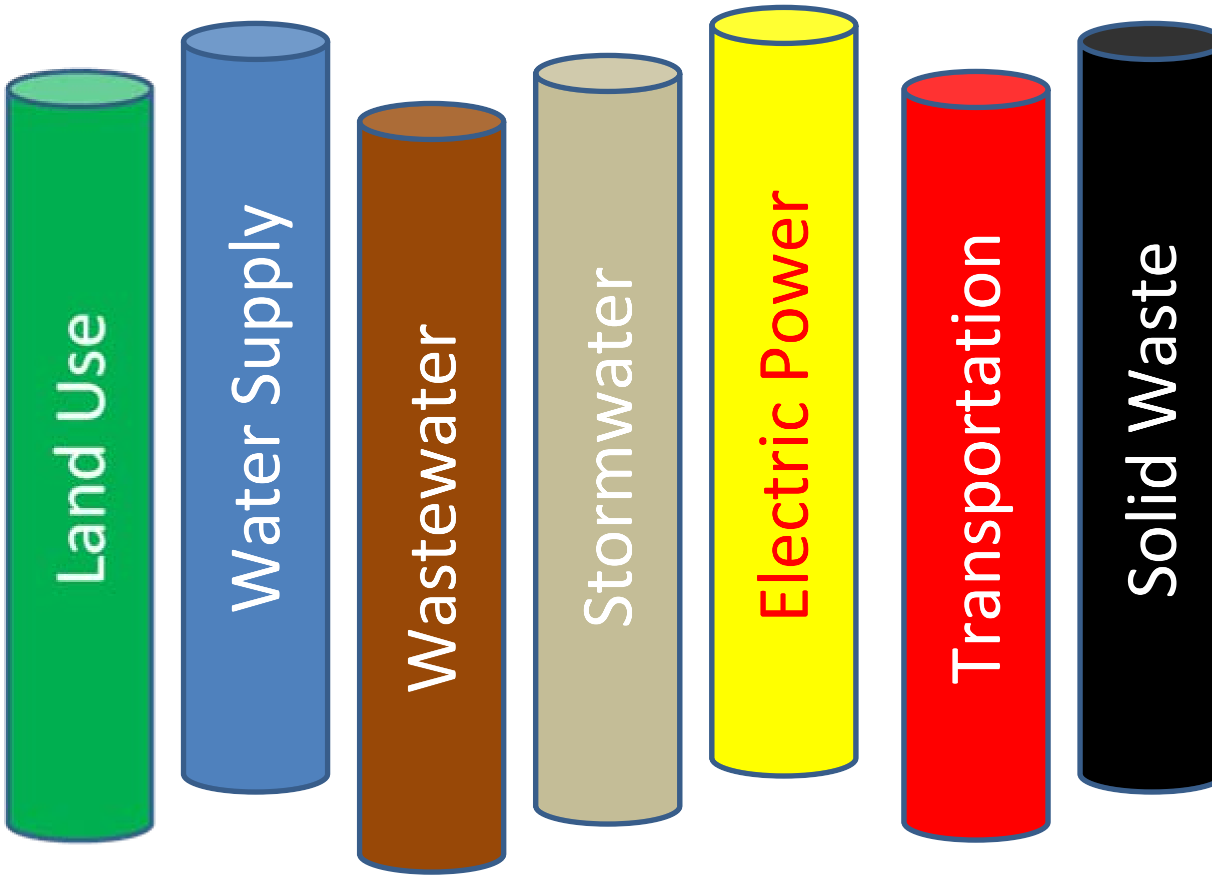
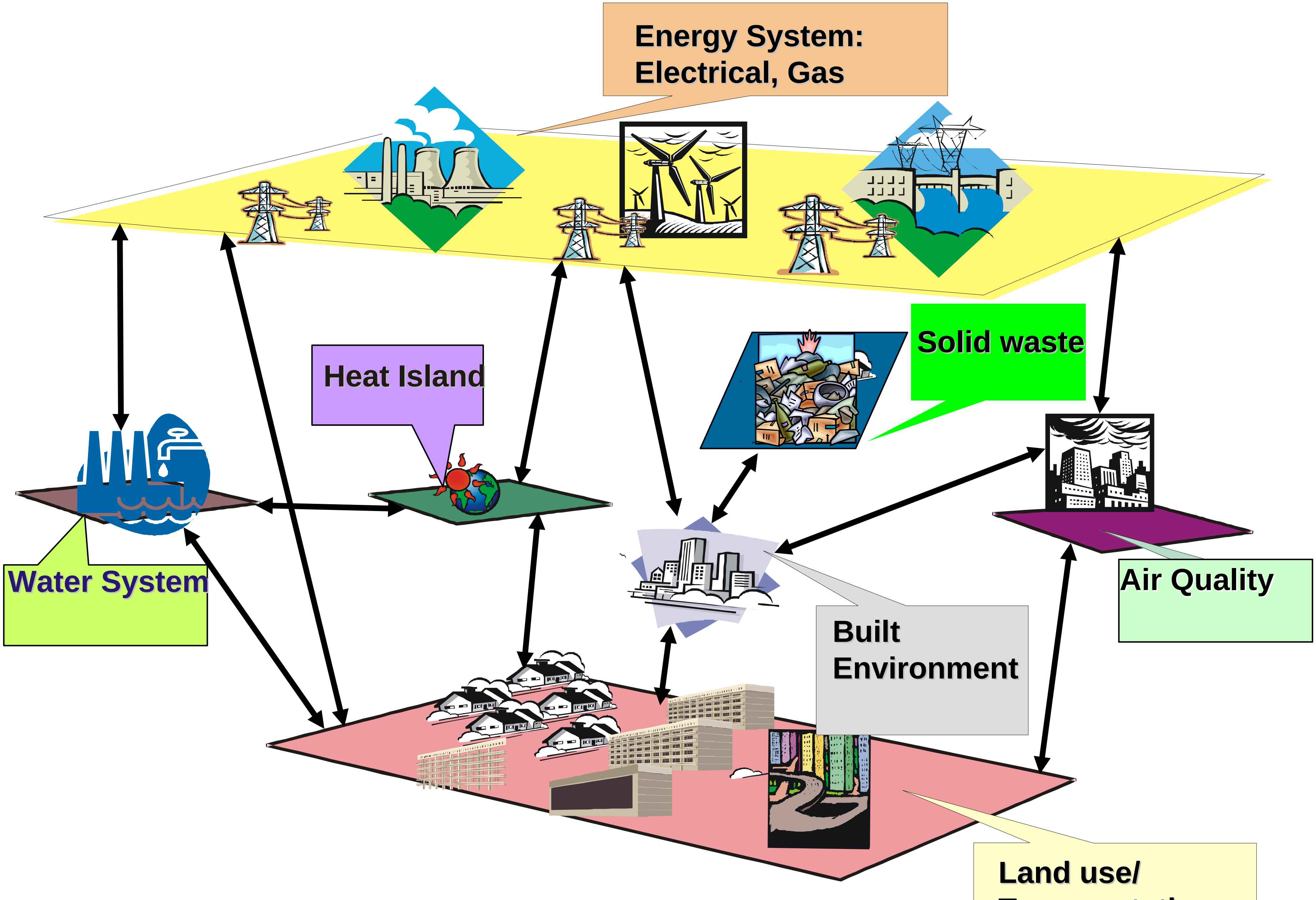
Key Urban Infrastructure Systems

Land Use
Water Supply
Wastewater
Stormwater
Electric Power
Transportation
Solid Waste



These systems are currently designed and operated as separate stovepipes



Urban Landscape a System of Systems:

Infrastructure Ecology

Urban form and material selection → Heat island → Increased water use → Hotter near buildings → Increased energy use → Increased water use for energy production → Health impacts

Urban form → Transportation → Air quality → Less rain → Increased water use → Health impacts

Compact communities → More green space → Increased livability and Distributed energy production → More resilience → Health impacts, Cleaner Air, Recreation

(combined heat and power capture 85% of the energy as compared to 30 % for centralized electrical energy generation)

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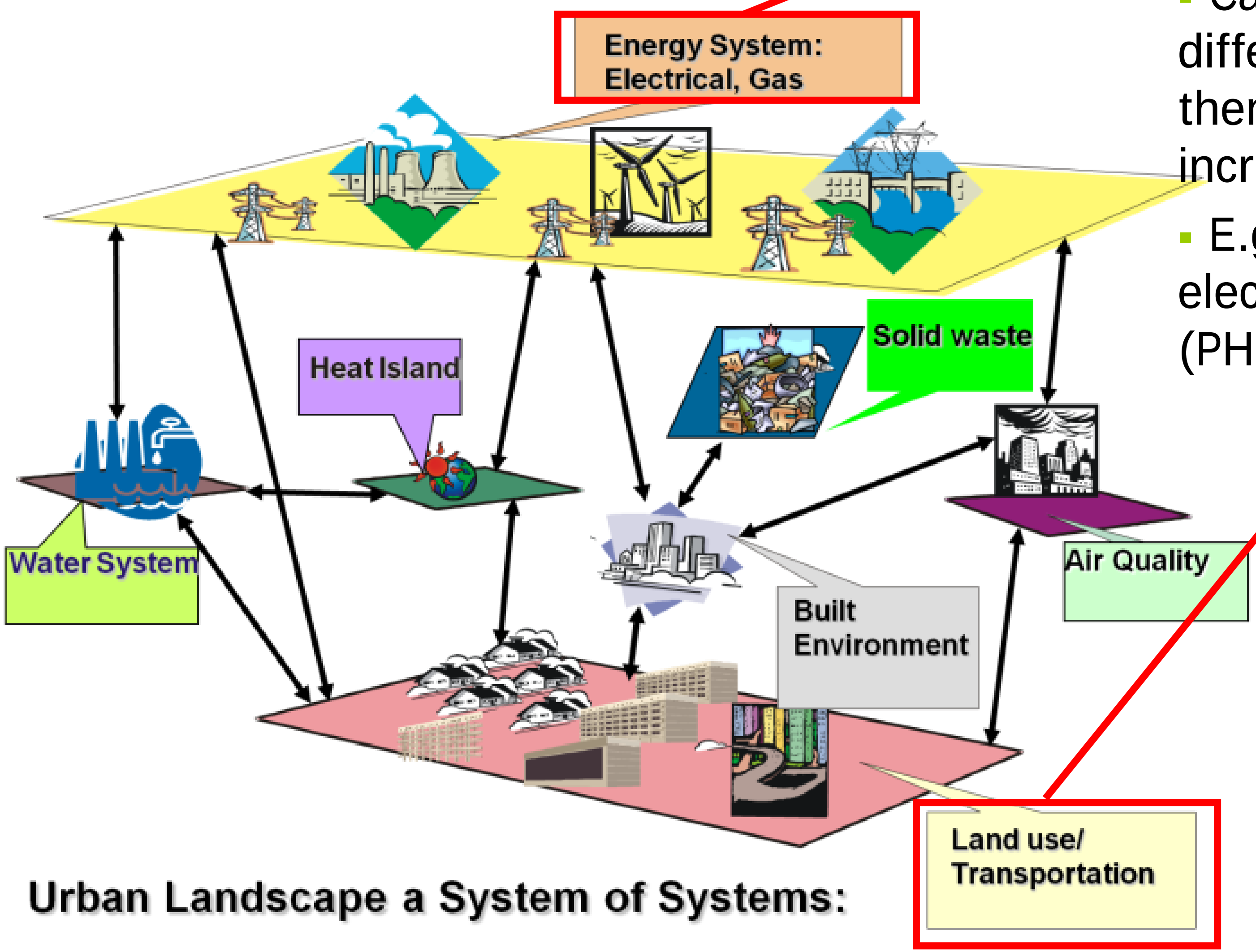


- Two of the largest components of the urban system
- Can make big difference by combining them together to increase efficiencies
- E.g., plug-in hybrid electric vehicles (PHEVs)

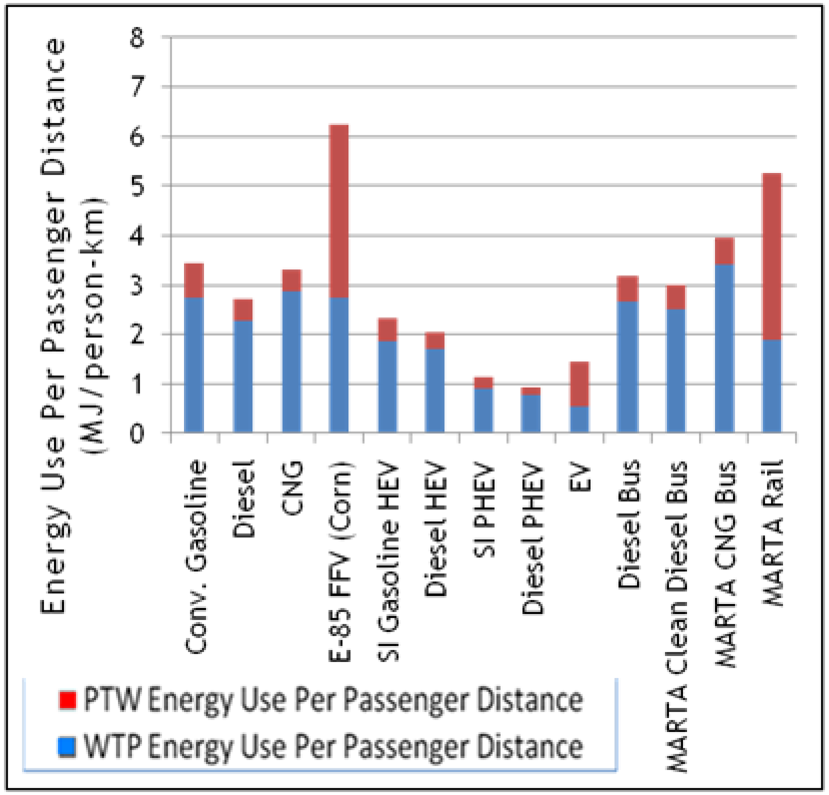
Plug-in Hybrid Electric Vehicles (PHEVs)

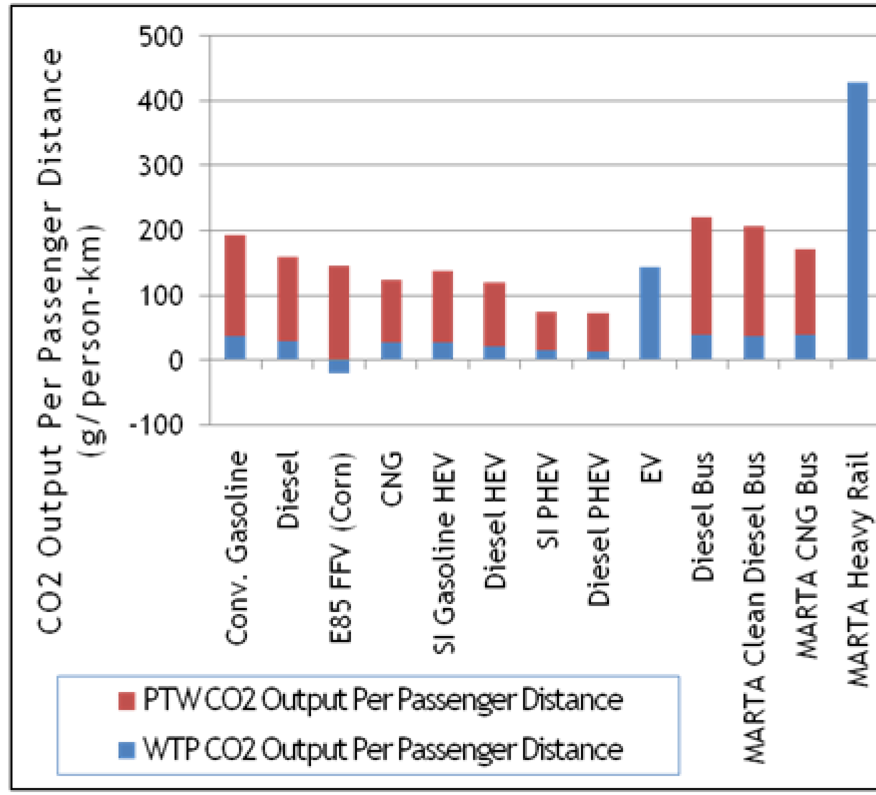
- ❑ 73% of the U.S. light duty vehicle fleet (cars, pickup trucks, SUVs, and vans) can be supported by existing electric power infrastructure
  - ✓ 43% if only charging vehicles between 6pm-6am
- ❑ This is equivalent to 52% of the USA's use of oil

Plug-in Hybrid Electric Vehicles (PHEVs)

- 27% of total greenhouse gas emissions can be reduced even if we use coal fired power plants
  - ✓ Key driver: overall improvement in efficiency of electricity generation compared to the conversion process from crude oil to gasoline to the combustion in the vehicle
- Utility cost (life-cycle) can be reduced between 7% and 26%

Energy for Transportation: Atlanta

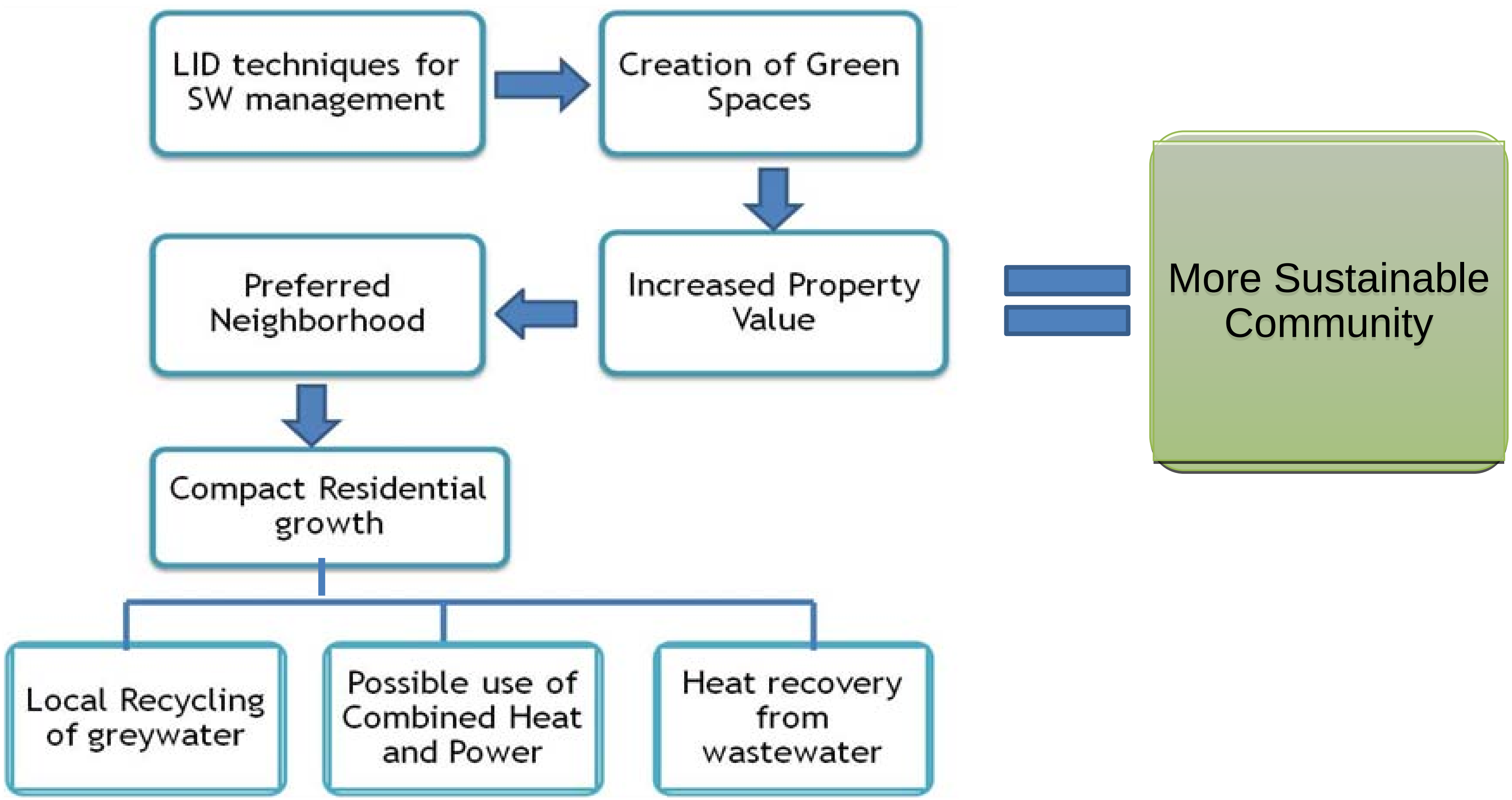




Preliminary Energy & CO_2 Results, Atlanta (Base Case) Courtesy: Bras, B; GT

- Poor environmental performance of electric vehicles, all sizes, due to coal fired power plants
  - Georgia Power's Plant Bowen emits about 0.9kg CO_2/kWh
- MARTA rail & bus performance bad due to low ridership

Interconnection between Infrastructure and Socio-economic Environment



Example Flow Schematic for Stormwater (SW) management using LID techniques

Infrastructure Ecology:

- Reorganizing the linkage among individual infrastructure systems is like changing food chains in ecology. The analogy is infrastructures are species and the urban system is an ecosystem.
- This ***infrastructure ecology*** has a high potential to significantly contribute to solving the gigaton problems.

Combined Heat & Power Generation

In the U.S., combined heat and power

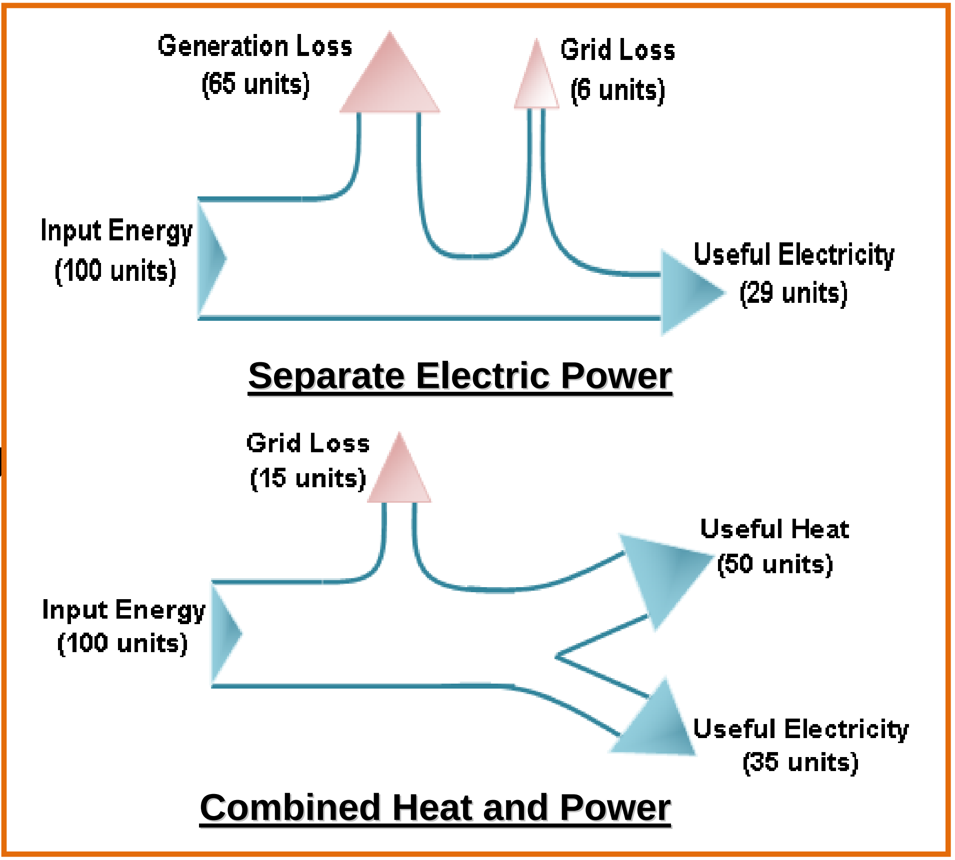
•Accounted for ***7%*** of U.S. electricity ***generation capacity*** as in 1999.

•Had a typical ***system efficiency*** of ***68%***, with some new systems exceeding 90%.

•Emitted on average $^{1}/_{10}$ of the nitrogen oxides (NO_X) per kWh of average utility grid electricity.

•Could potentially provide ***20%*** of U.S. ***electricity by 2030***, ***reducing*** CO_2 emissions by ***0.8 gigatons*** annually

Source: http://www.aceee.org/energy/chp.htm



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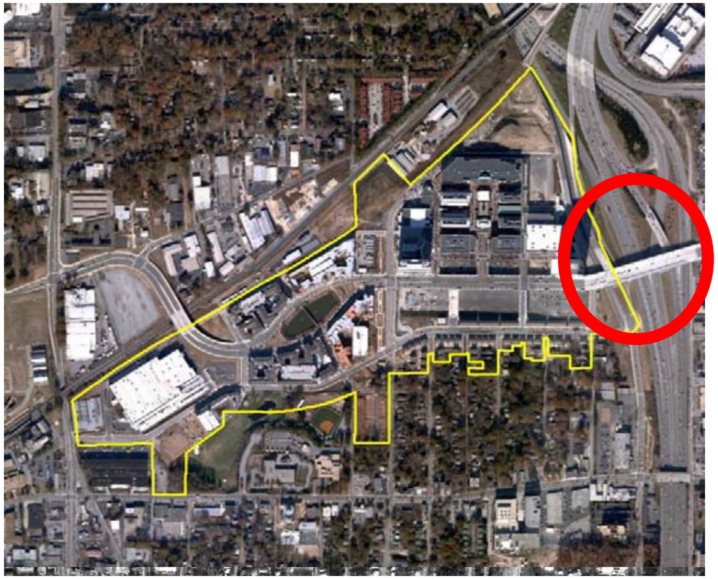
Atlantic Steel becomes Atlantic Station

(Photo Courtesy of USEPA)



<u>1997</u>

- 138 acre brownfield site in Midtown
- Jacoby redevelopment plan
- Atlanta Clean Air Act nonconformity
- Moratorium on Federal highway spending
- Converted plan to GIS database
- Comparative analysis by EPA
- Project XL exception for 17th Street bridge

<u>Today</u>

- Mixed Use Development
- 30,000 employees,10,000 residents
- 12 acres of public space
- Less traffic and air pollution
- Cleaned up brownfield site
- Improved tax base

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Problem Statement

- Given $5B, what could be done in Atlanta and within the metro region to:
  - Purchase toxic assets
  - Reduce the supply of CRE
  - Create greenspace and jobs
- What impact would be realized?

Take home message:

This is a BIG supply and demand problem.

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One Possible Solution: Red **Fields to Green Fields**

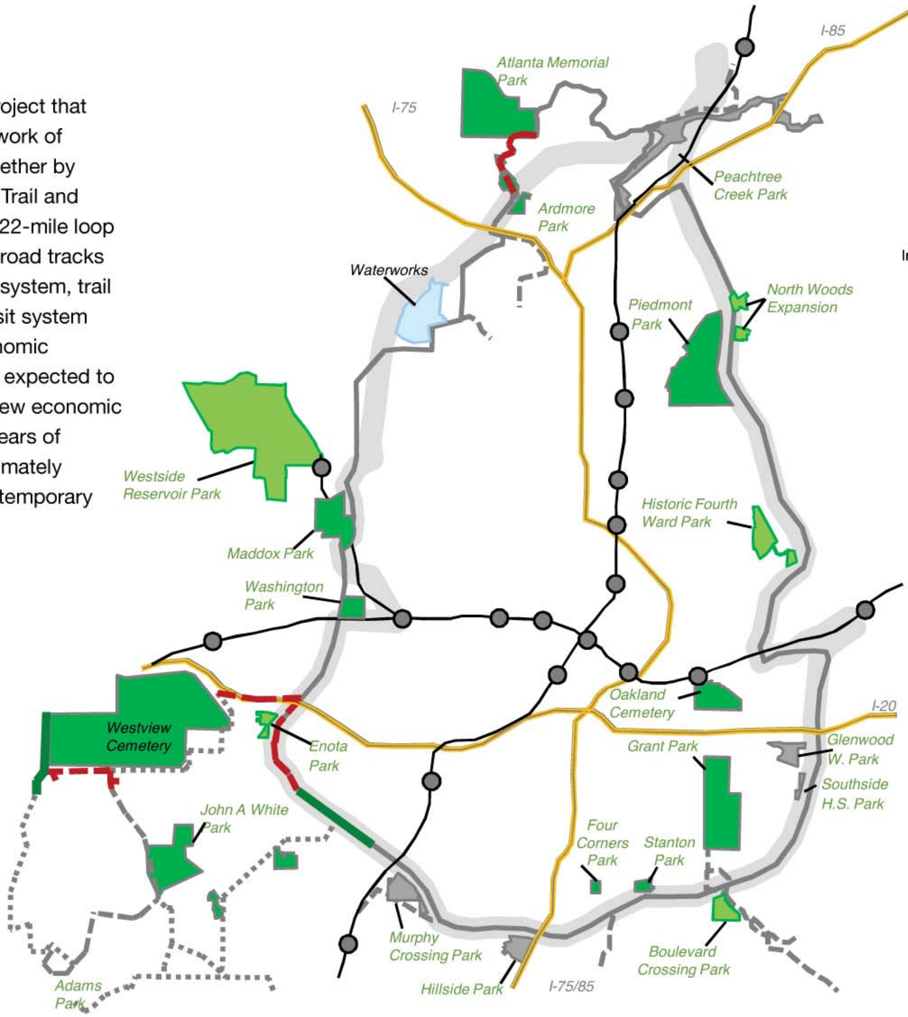
- $200bil landbank to buy up failed commercial properties, get them off banks' books, convert them to "parks" for 10 years, giving remaining commercial properties better chance of survival, then re-develop 70% of the land while 30% becomes dedicated public park space

.

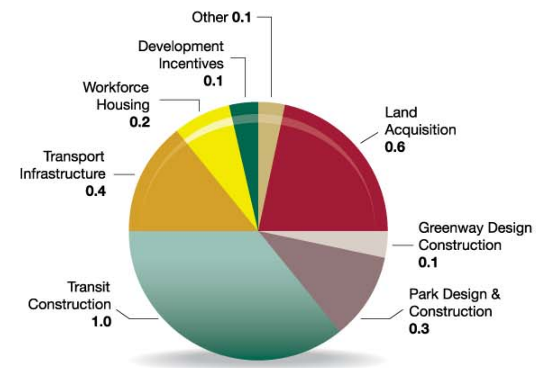
The Process in Action: Atlanta at Work

The BeltLine

The BeltLine is an ongoing project that consists of an integrated network of urban greenspace, linked together by an easily accessible BeltLine Trail and BeltLine Transit System. The 22-mile loop of largely unused, historic railroad tracks can accomplish a new parks system, trail system, and low-impact transit system and act as a catalyst for economic development. The BeltLine is expected to generate over $20 billion of new economic development during the 25-years of the project as well as approximately 30,000 new jobs and 48,000 temporary construction jobs.



Uses of Funds ($2.8B)



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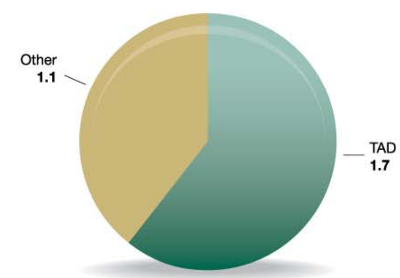

Gap of $1.1 billion needed to be met by "other" funding; over $150 million identified to date:

- **Federal**
- **Local/State**
- **Private**

Note: "other" uses of funds include administration, contingency funds and other bond requirements

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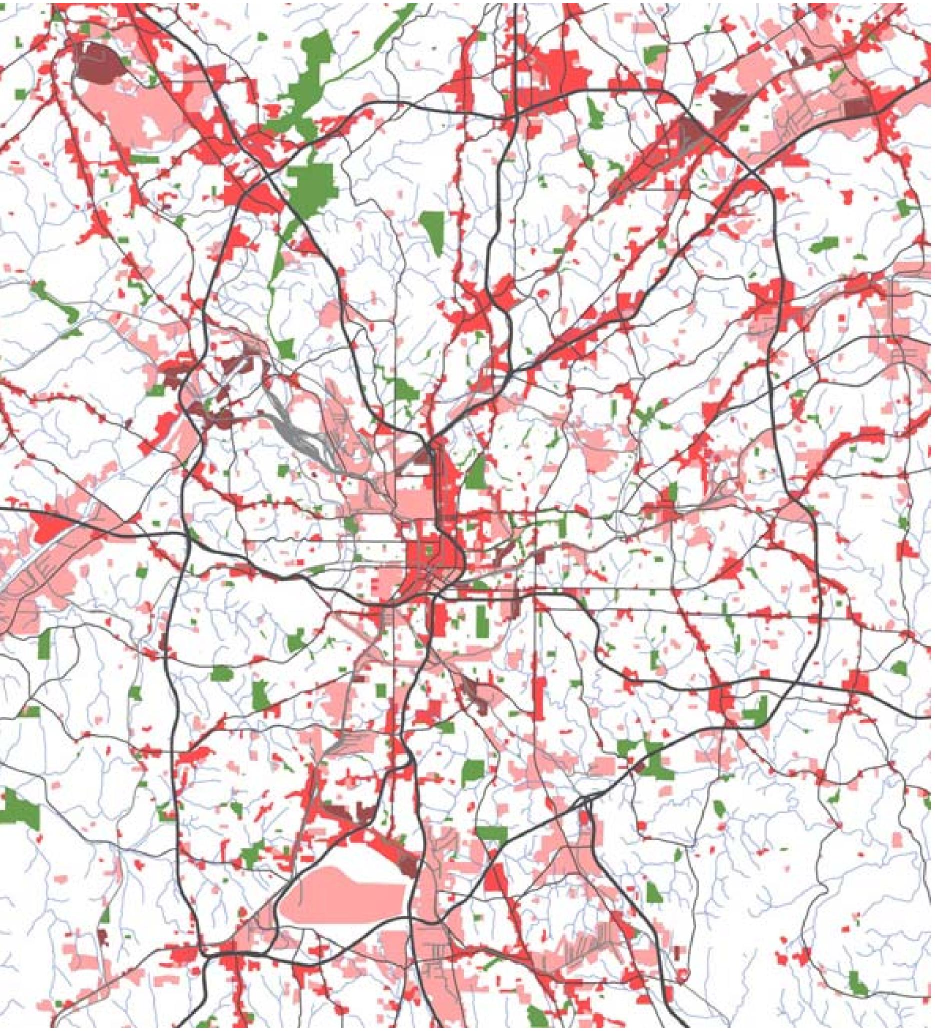
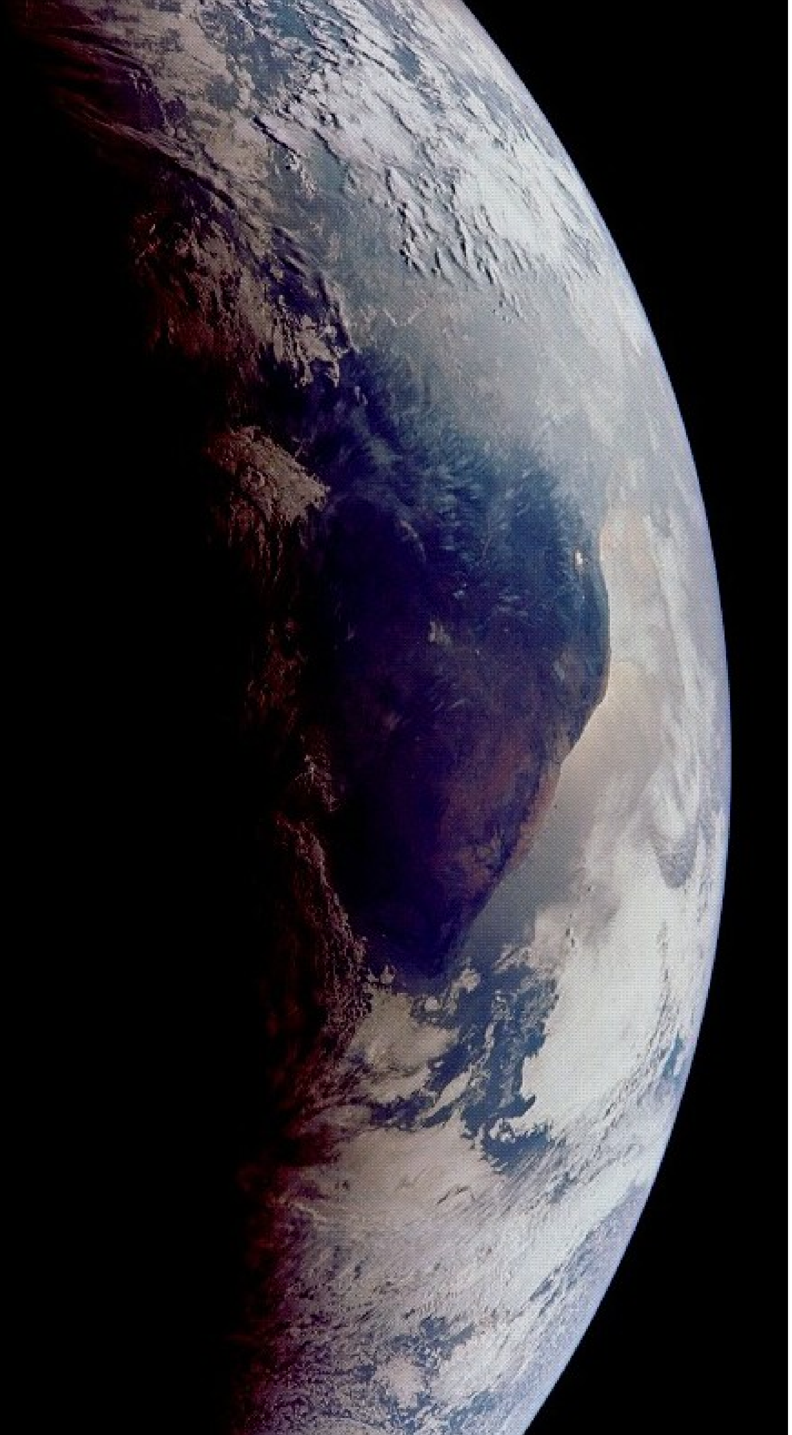
LWARPS - "we can reverse sprawl", City of the Future competition, Georgia Tech entry



Atlanta, 2008

Atlanta, 2108

1. In 100 years: transit on all major rail and road corridors
2. In 100 years: 1000' buffers on all stream corridors
3. In 100 years: subdivisions too close to water or too far from transit won't be viable. "Eco-Acre transfers" will allow them to transfer development rights to transit corridors and their properties to be regreened for food and energy production



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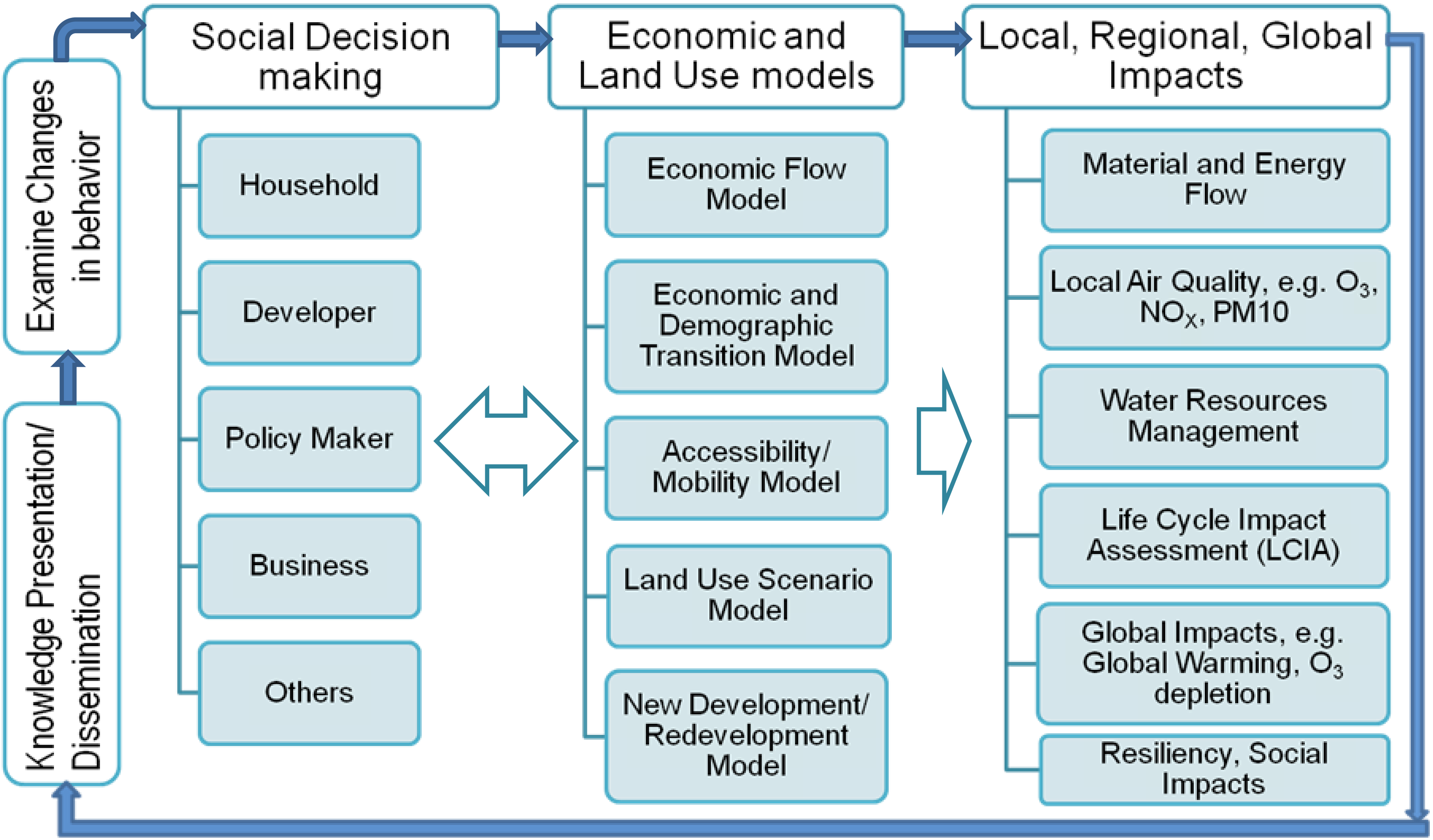
Decision Support Activities



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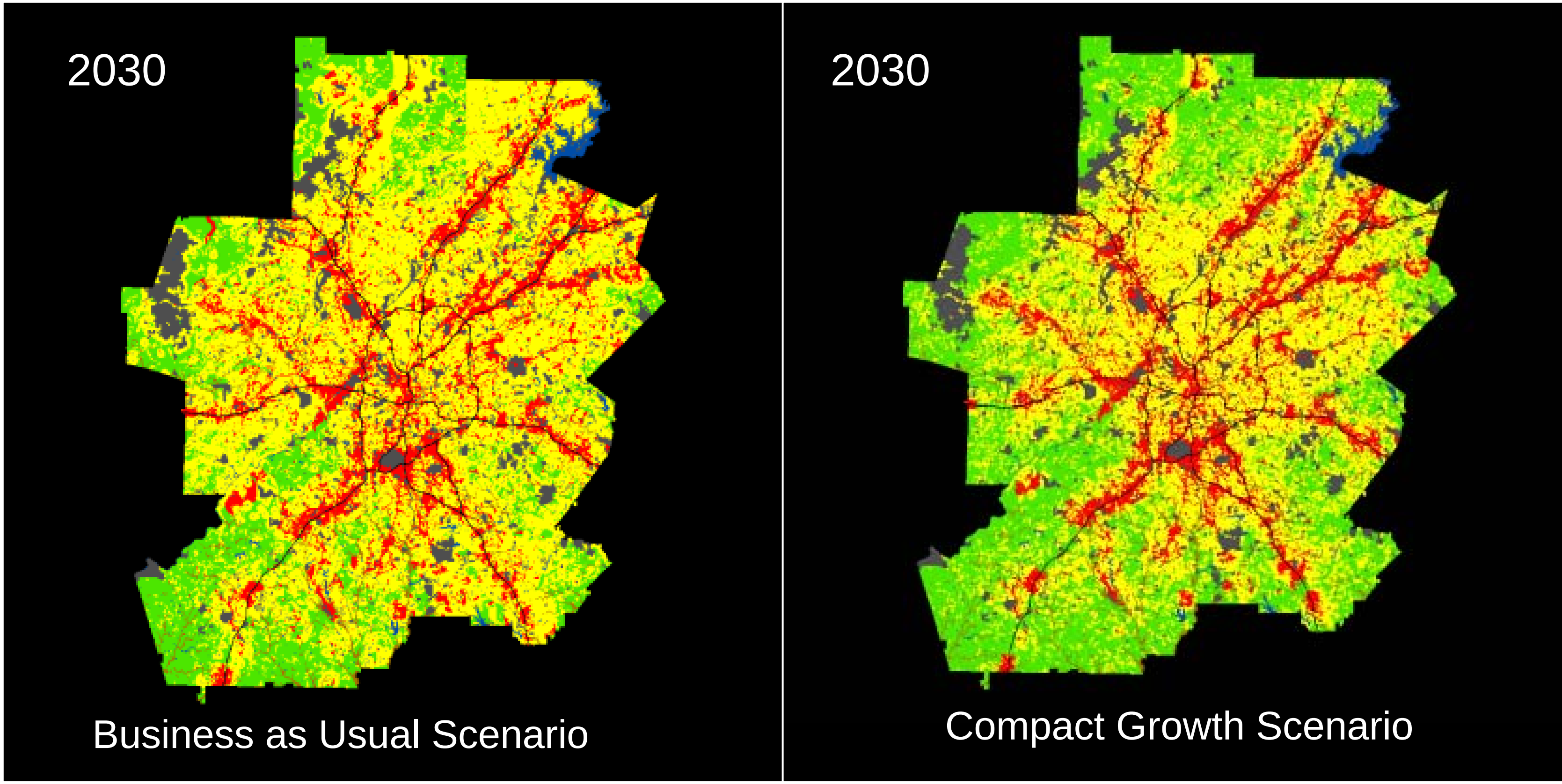
Predicting Social Decision Making: Growth Scenarios in Atlanta

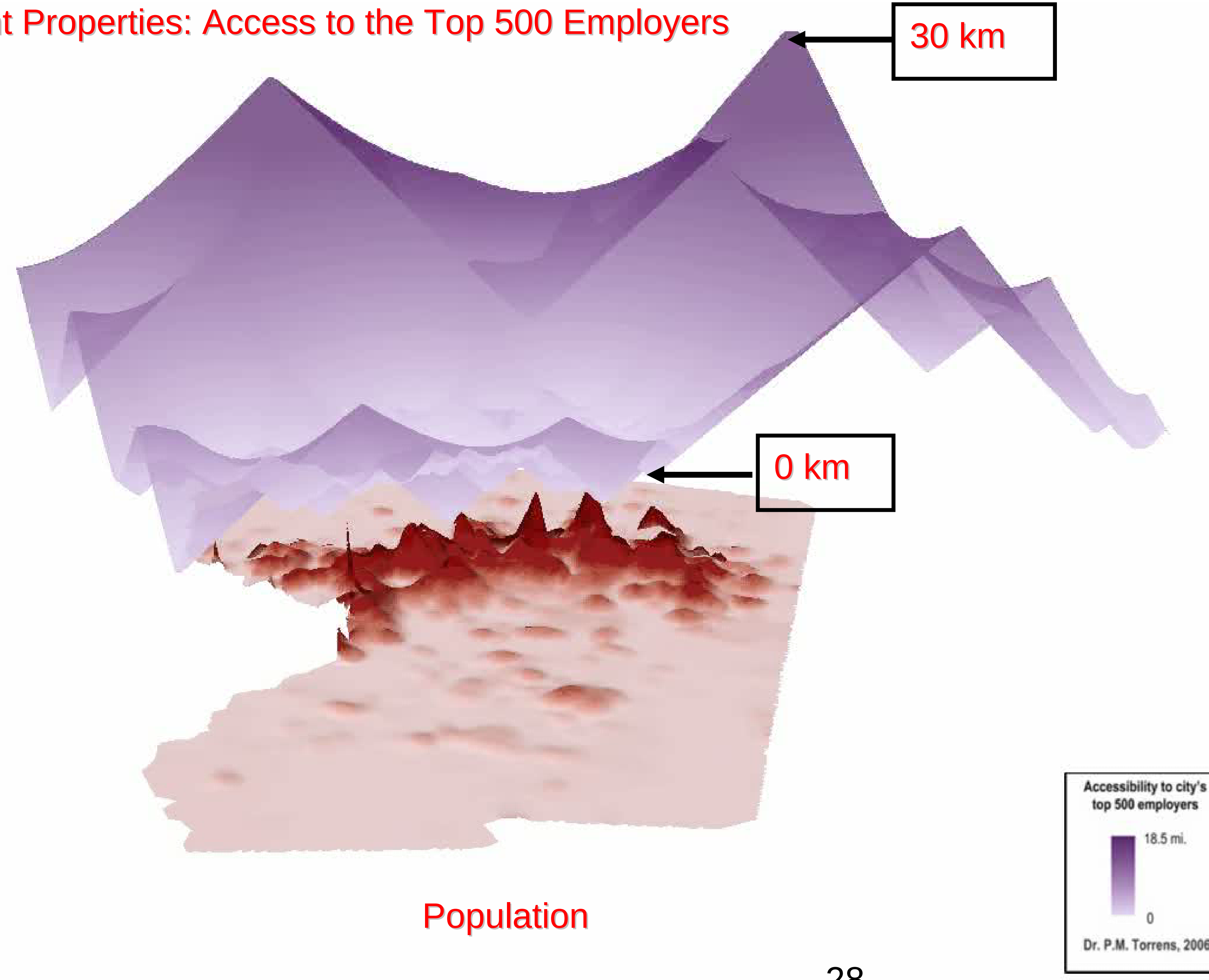


Comparison of two different growth scenarios for Atlanta in 2030 using *What-If* urban modeling tool

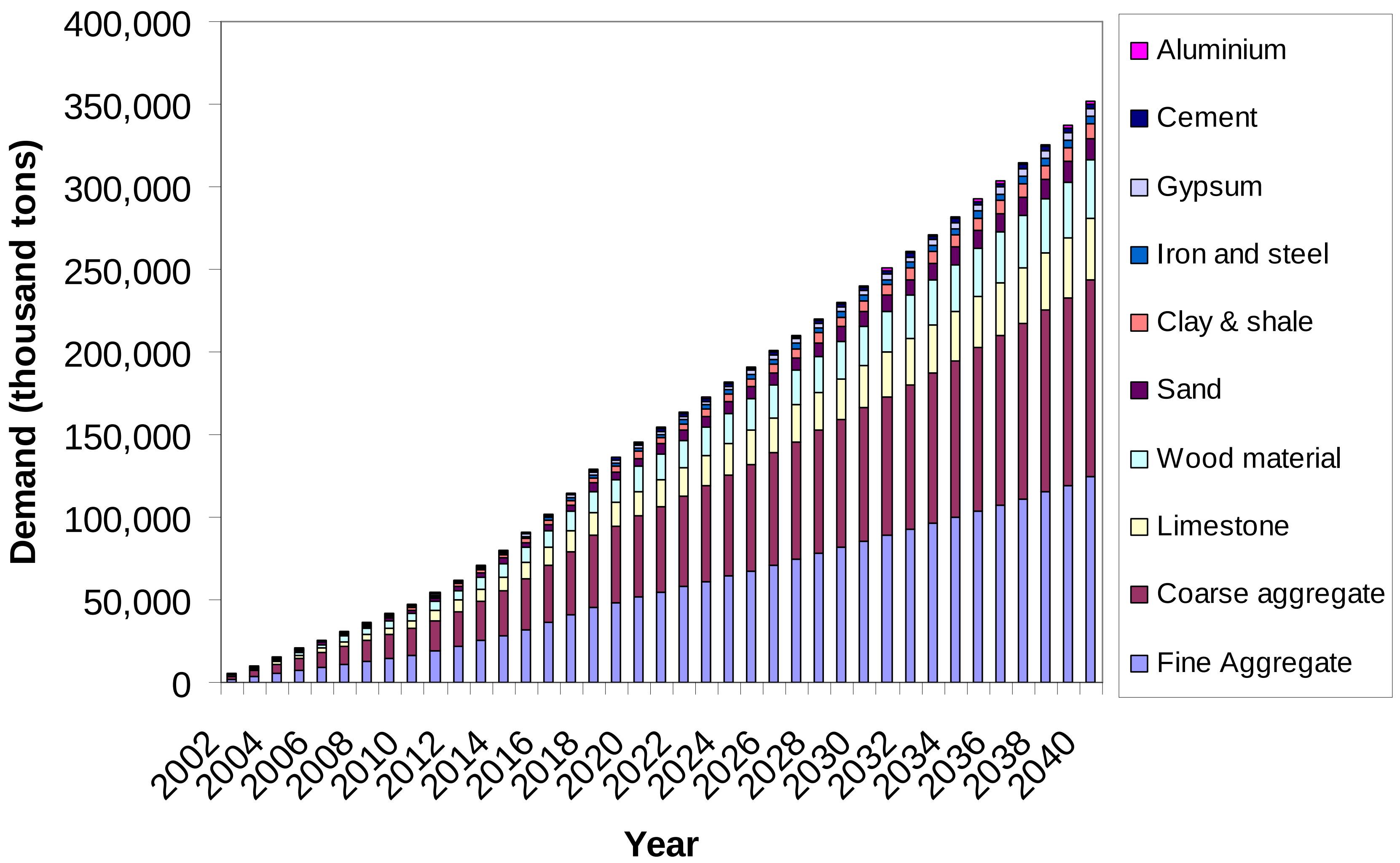
Land Use

- Residential
- Employment
- Open Water
- Undeveloped
- Wetlands
- Undevelopable

Emergent Properties: Access to the Top 500 Employers



Emergent Property: Cumulative Residential Construction Material Demands From 2002 to 2040 – Business as Usual



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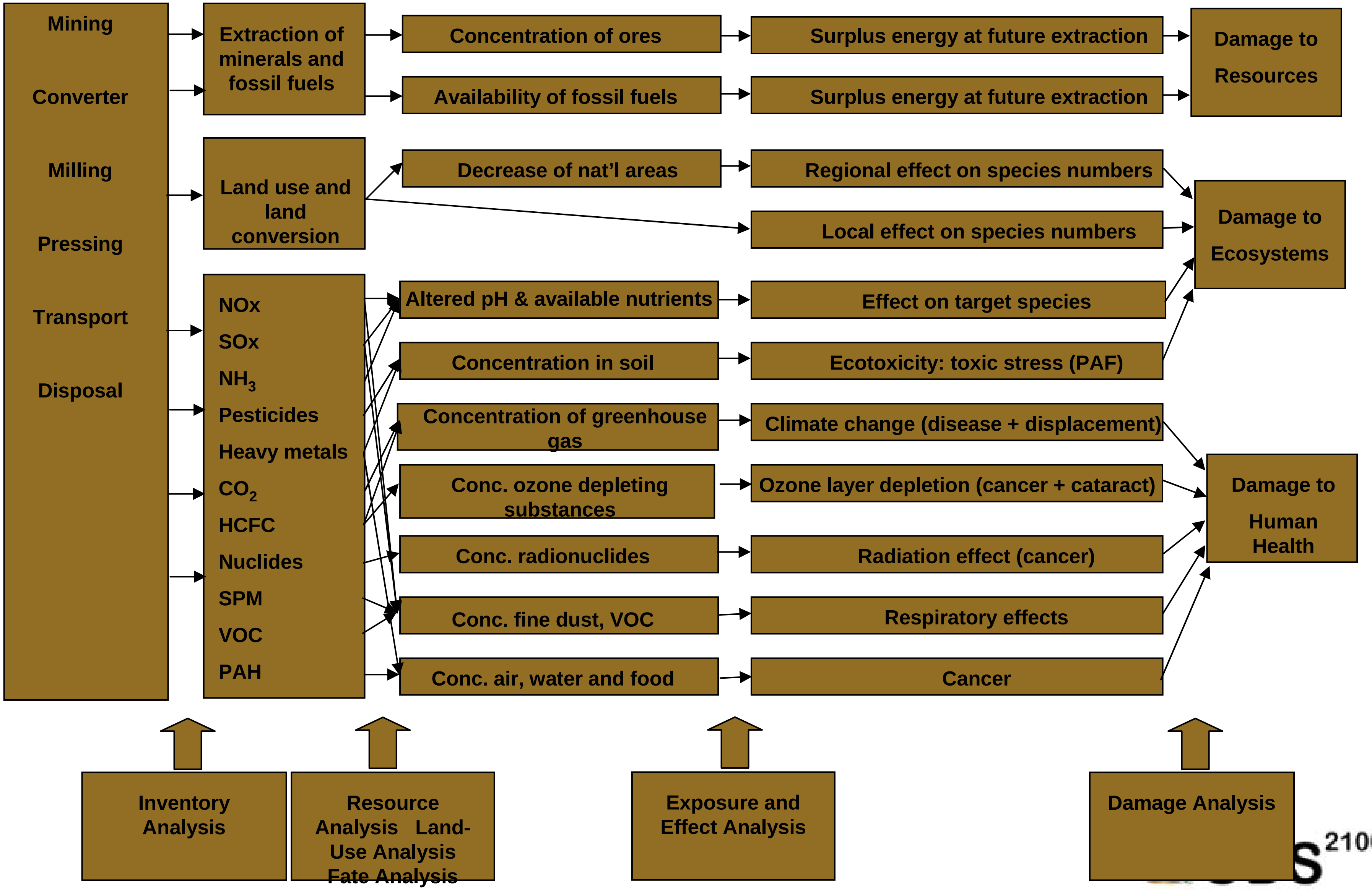
Eco-Indicator 99 Calculations: Example of Estimating the Local, Regional and Global Impacts



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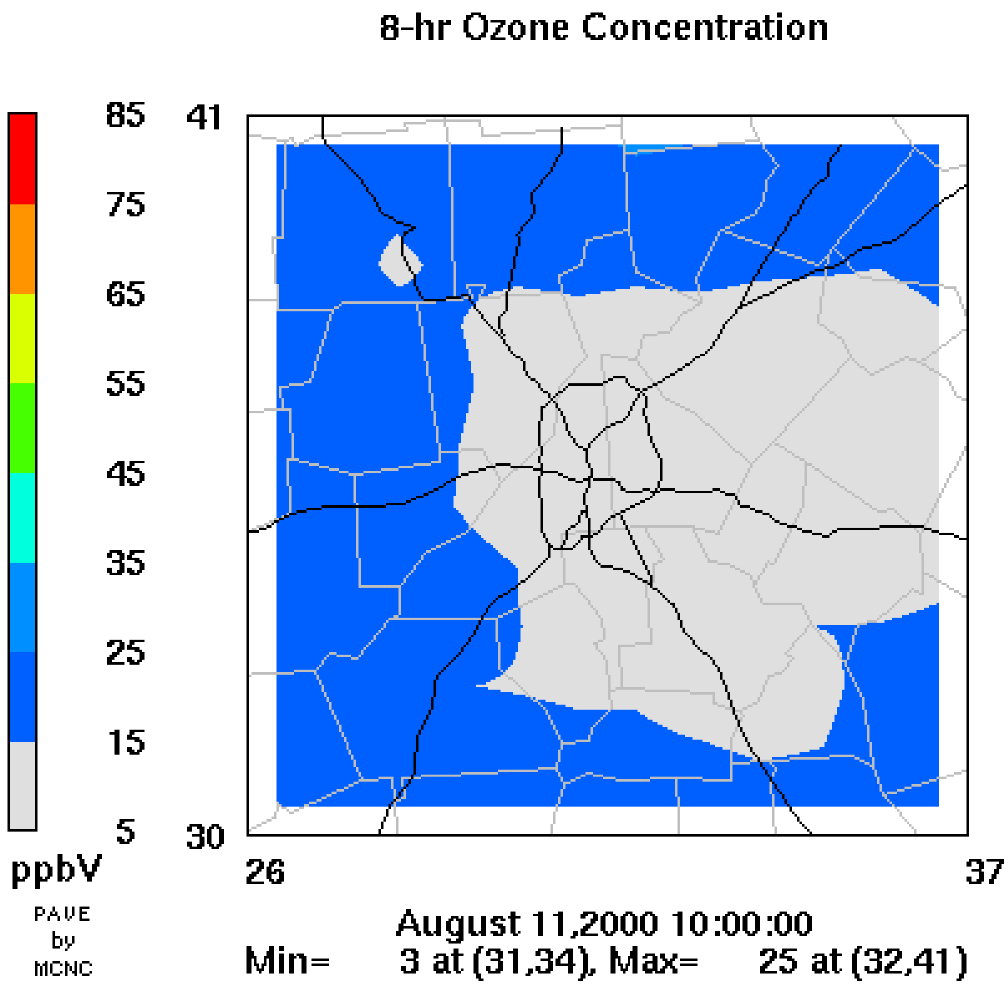
Emergent Property: Ozone



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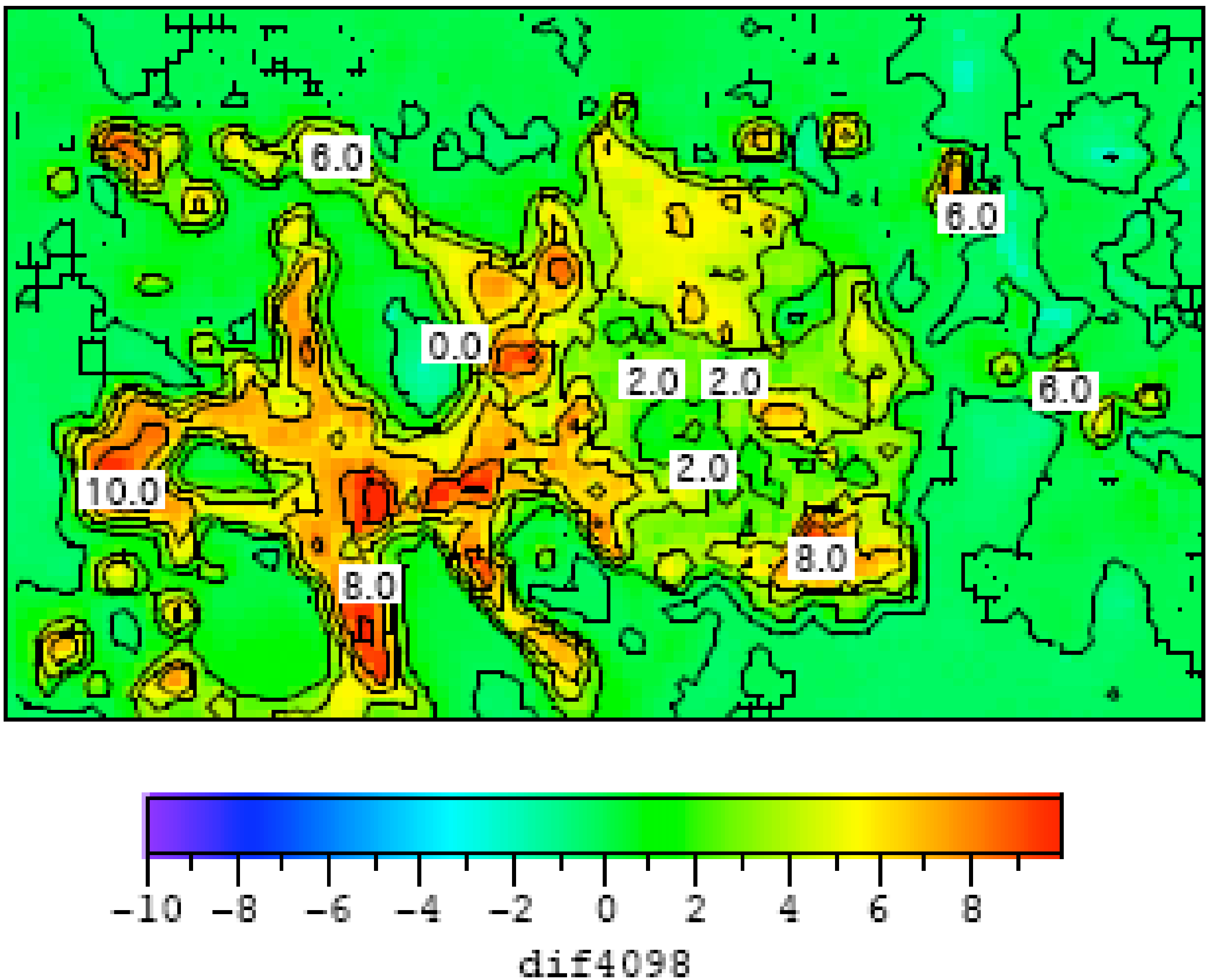
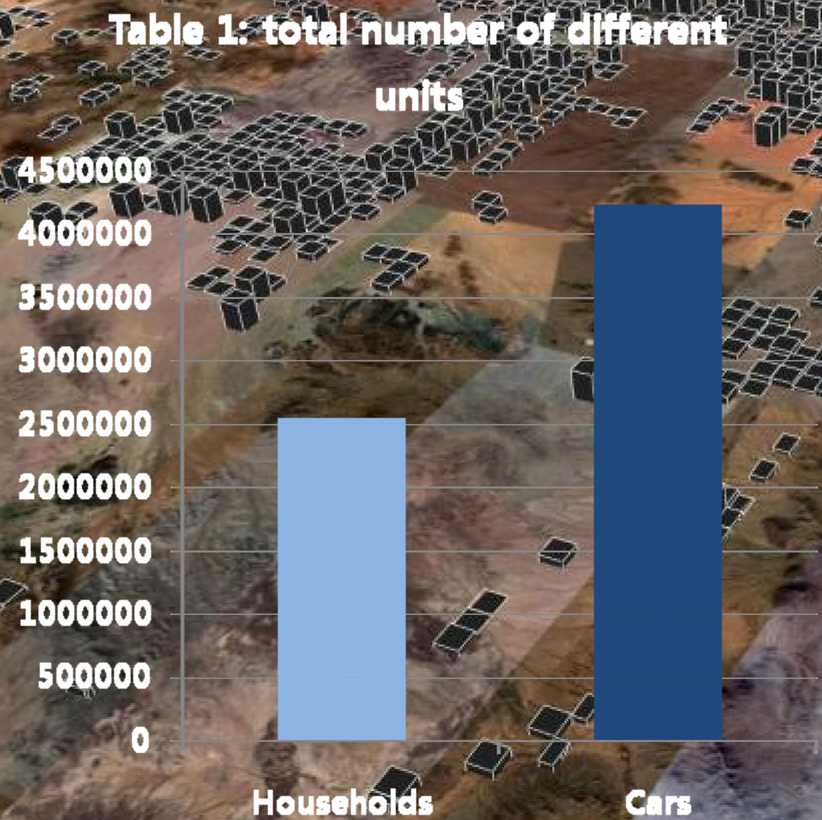
Emergent Property Heat Island: Temperature Contour in 1998 and 2040 (Predicted by UrbanSim)

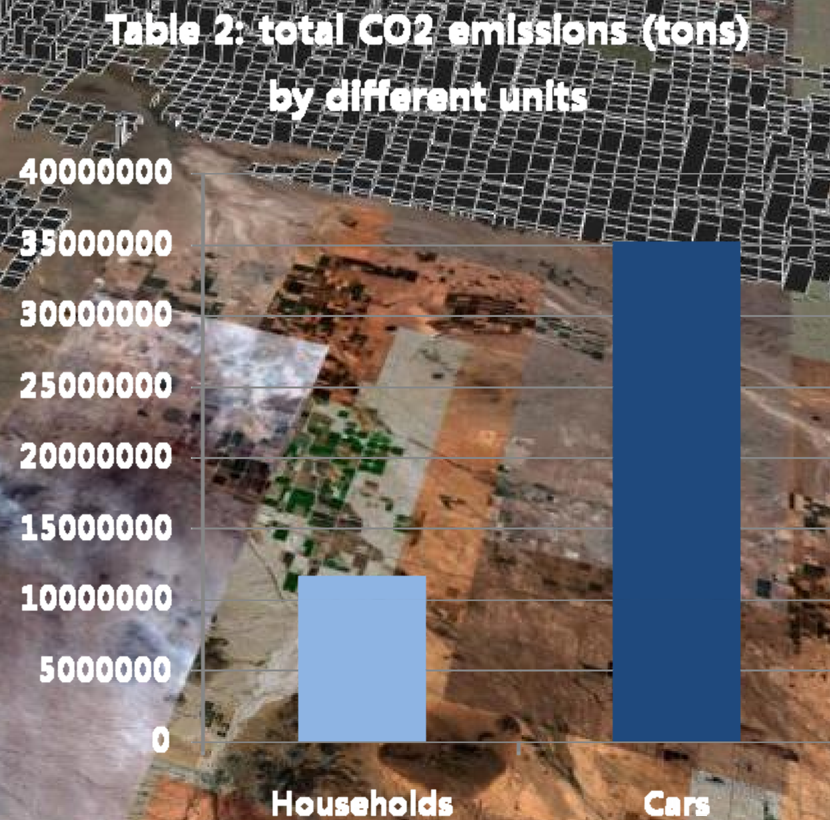


Zehnder, Clarke, Guhathakurta, Li Crittenden

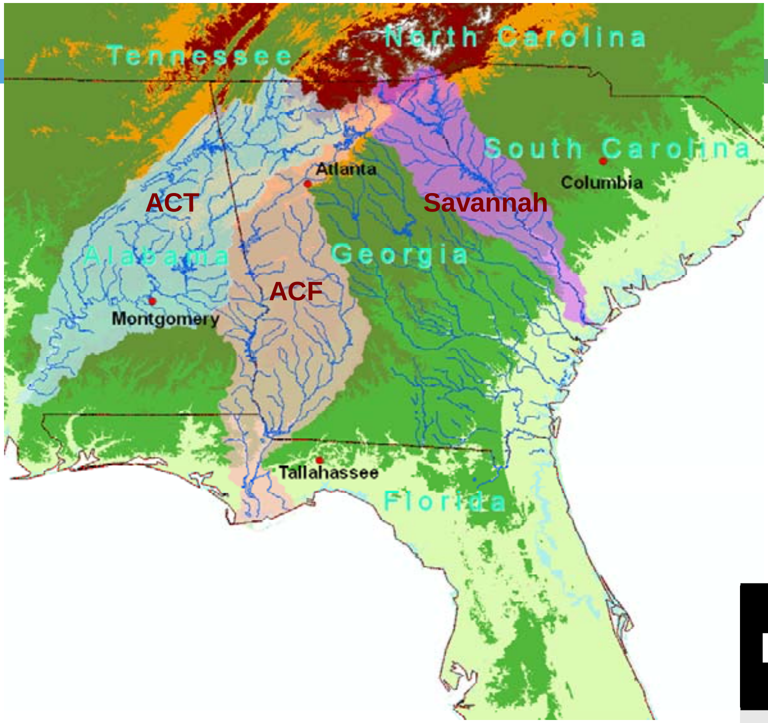
DigitalPhoenix:

Emergent Property: Carbon footprint in 2030





Emergent Properties: Water Resource Development and Use



ACF, ACT & Savannah River Basin

- Since water use is higher in summer for all purposes there is a potential of conflict among different sectors in the event of water scarcity (agriculture, ecosystems)

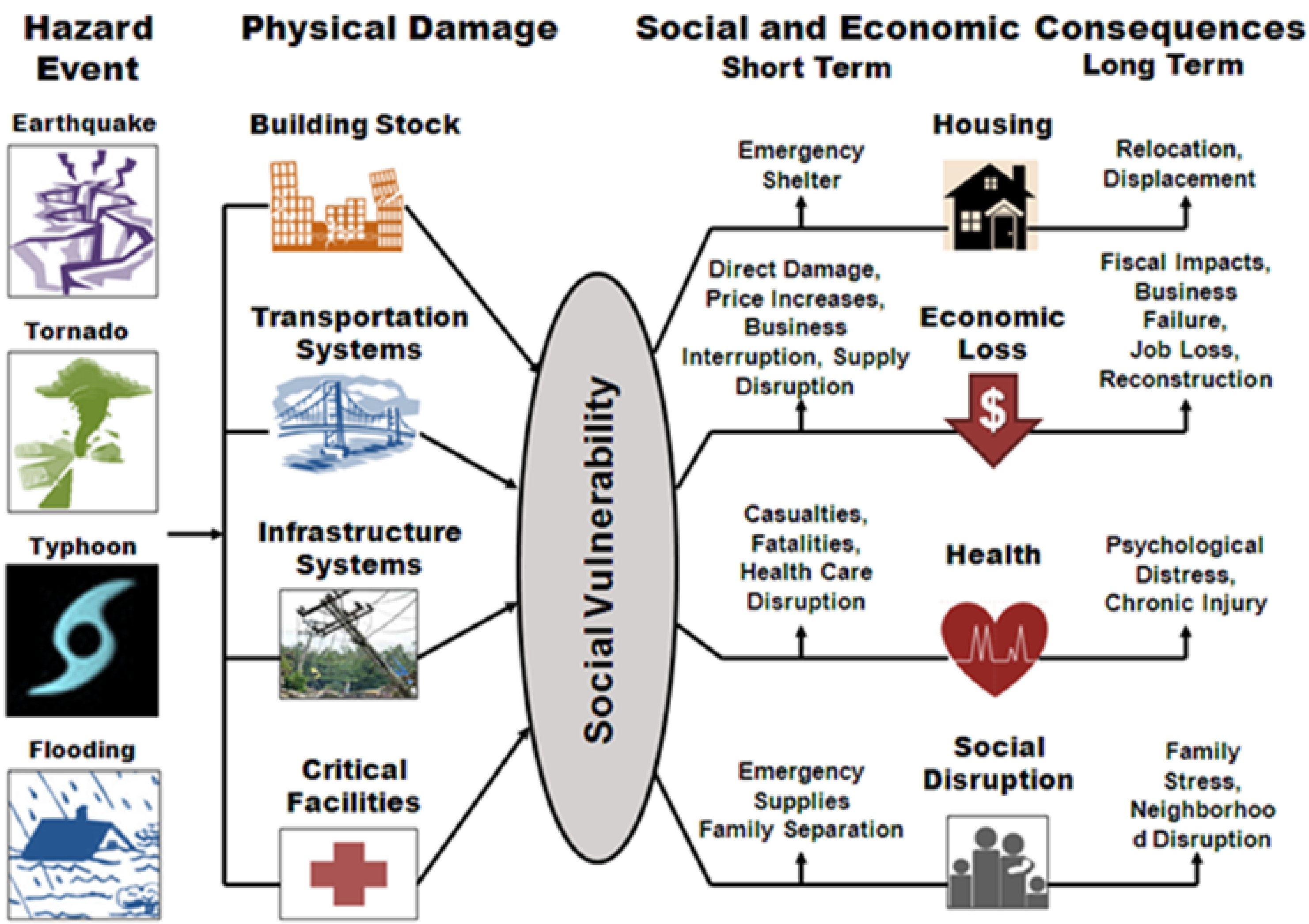
Principle water uses

Purpose of water use	Summer (in bgd)	Winter (in bgd)
Irrigation	2.89	0.18
Municipality* & Industries	1.82	1.42
Thermoelectric	2.53	2.19

*Municipal use include residential water supply

River Basin	Shared by	Power plants supported
Apalachicola-Chattahoochee-Flint (ACF)	AL, FL, GA	6 fossil fuel plants
Alabama-Coosa-Tallapoosa (ACT)	AL, GA	6 fossil fuel and 1 nuclear plants
Savannah	GA, SC	3 fossil fuel and 2 nuclear plants.

Emergent Properties: Reducing Social and Economic Consequences of Natural Hazards



Vulnerability Models for Infrastructure Systems

- Investigate the resilience of various infrastructure systems to a variety of stressors –
  - Natural Hazards
  - Climate Change
  - Technological Hazards
  - Facility Aging
  - Demographic Change
  - Fiscal Constraints
- It will build on the vulnerability work of key team members.
- It will investigate interactions among these stress factors and link these stresses to social and economic consequences.

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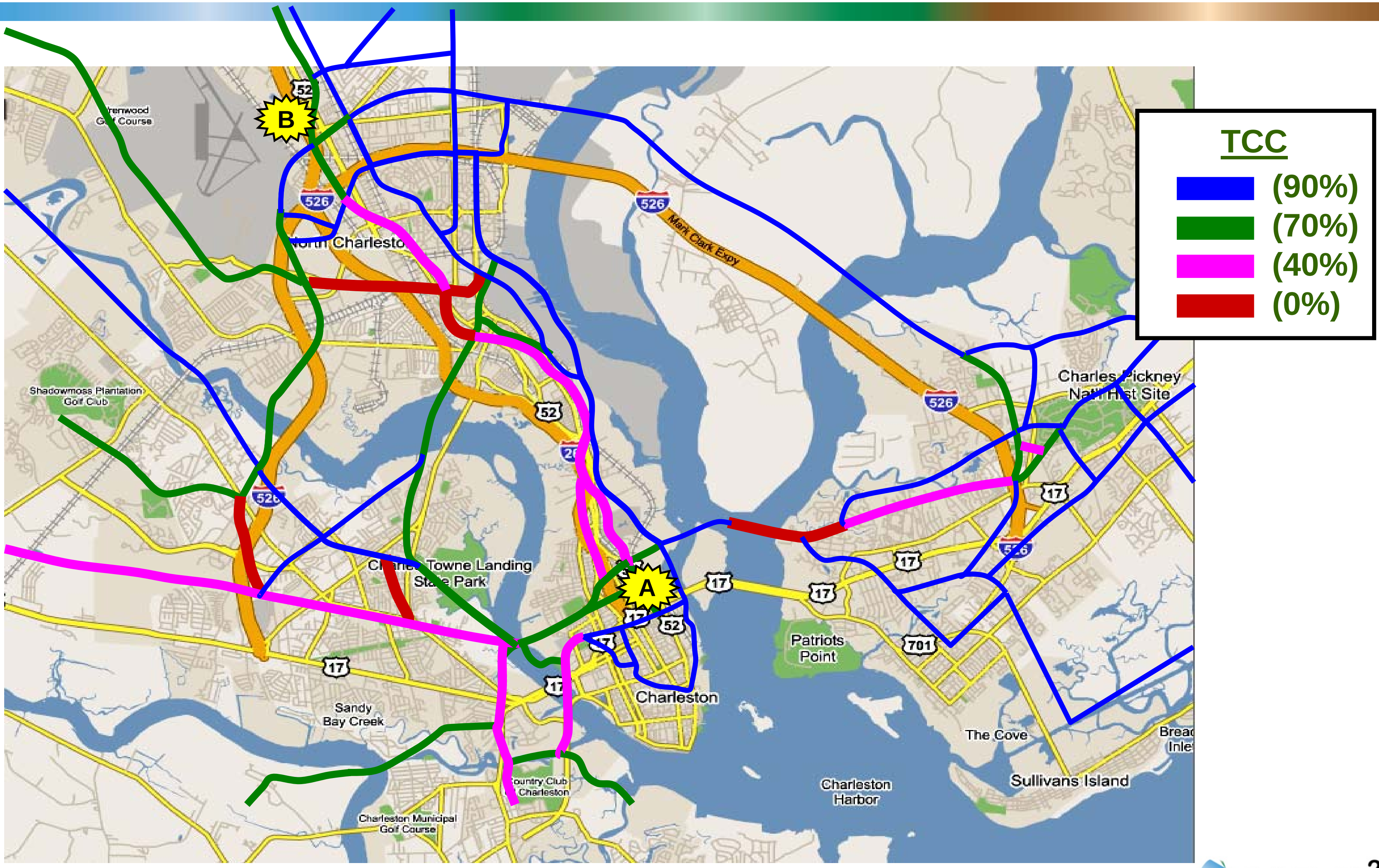
Transportation Systems under Stress



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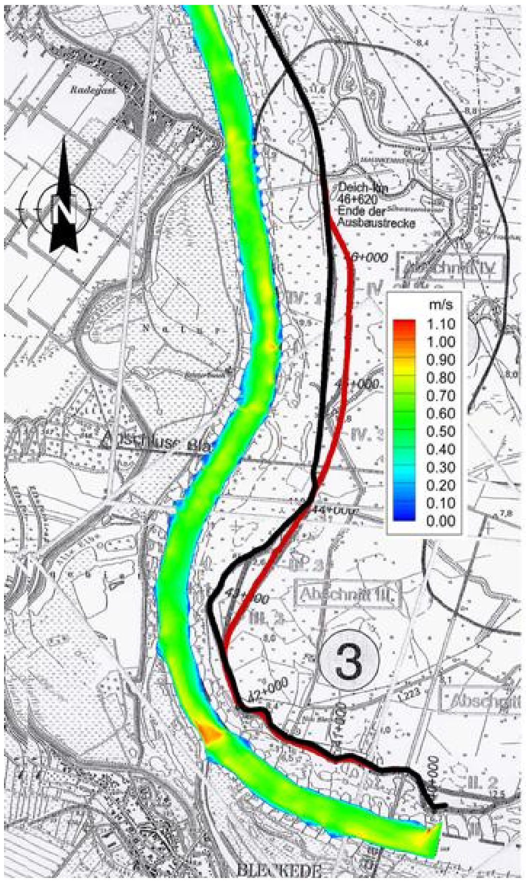
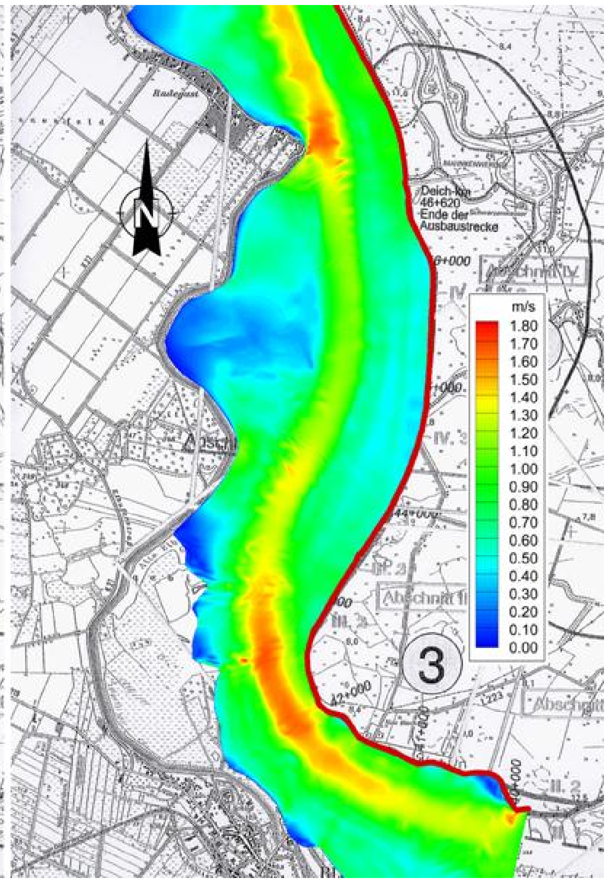
Modeling Flooding and Associated Bridge Scour

Computational Fluid Dynamics Modeling of Flood Protection Measure – Here: New Dike Alignment (Black and Red Line)v

Bankfull Discharge



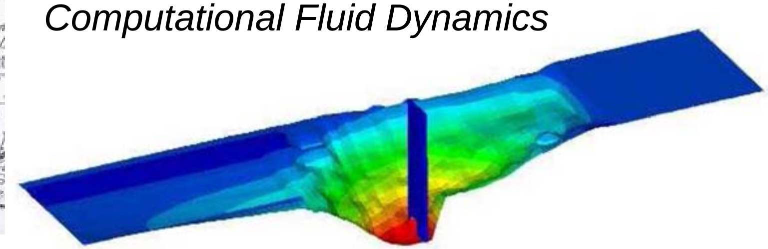
Flood Discharge



Computational Fluid Dynamics Modeling of Bridge Pier and Abutment Scour

Bridge Failure due to pier scour during stormwater event

Predicted bridge abutment scour using Computational Fluid Dynamics



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Recycling Material Flows for Economic Development

- This project will extend the work of a current MUSES project to model the economic development and environmental impacts of recycling a wider variety of products within the metropolitan economy.

- This project will link material flows with engineering processes and economic development.

- An input-output (IO) model will be used to estimate the employment and income impacts of increased material recycling.

- Typical questions:
  - Should we recycle plastics back into plastics or make transportation fuels from them?
  - Can advanced Hybrid and Electric Vehicle batteries be repurposed for stationary applications in an urban region?
  - What socioeconomic groups benefit from this?

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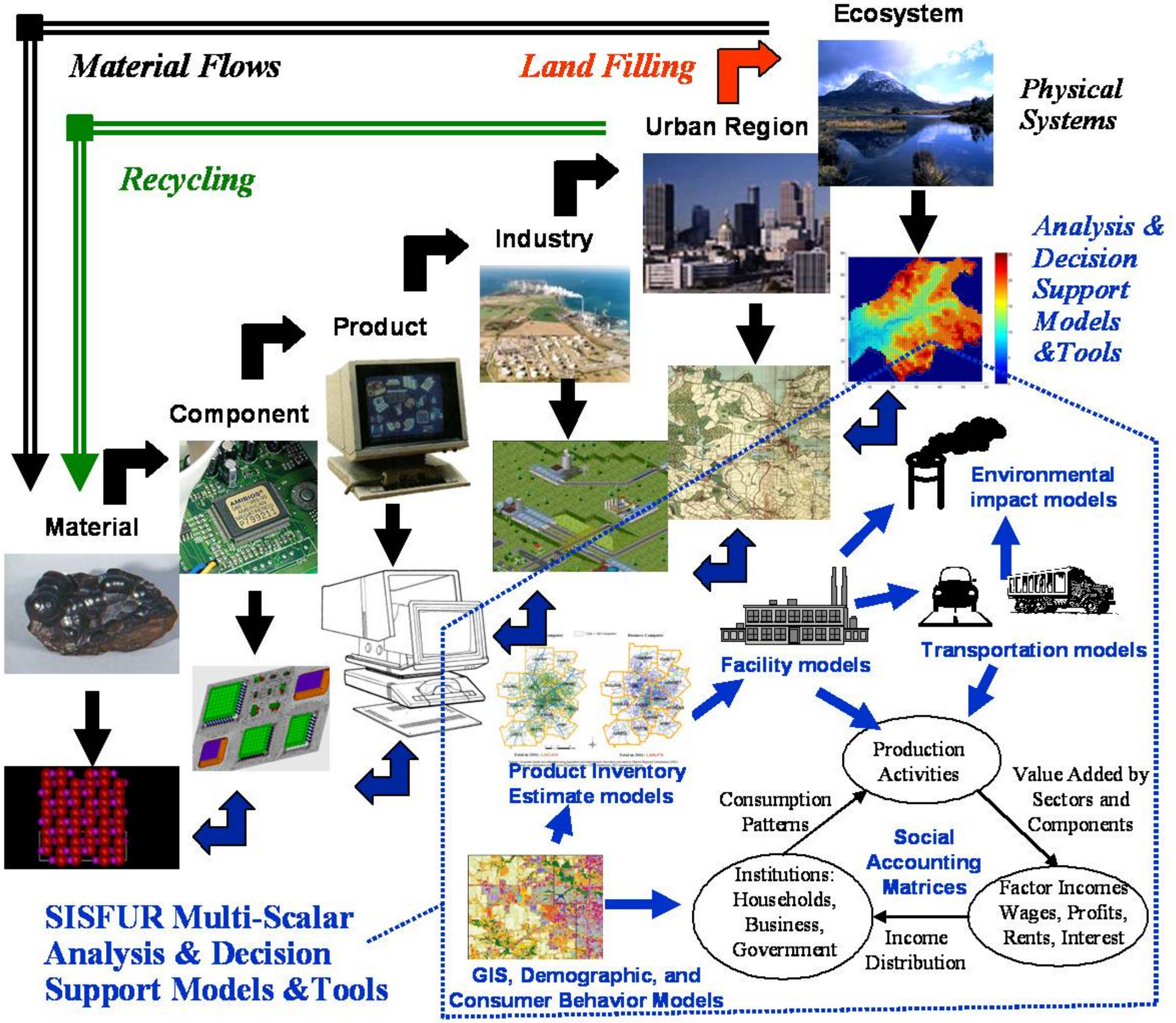
Modeling Material Flows in Urban Regions



Integration of models into seemless decision support structure for multiple stakeholders is major challenge, especially in recycling networks

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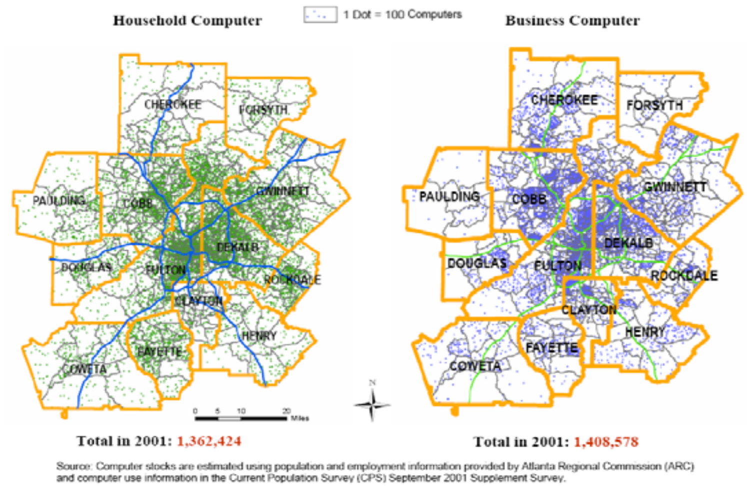
Regional Product & Material Re-X

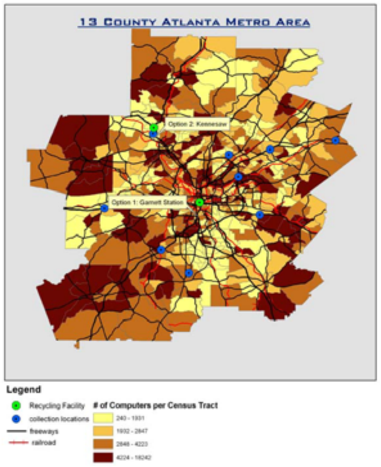
Urban Region

Recycling facility locations

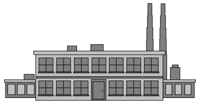
Products



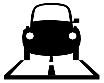
Product Inventory Estimate (PIE) models



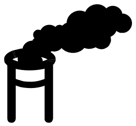
Where will future manufacturers and cities get their materials from?



Re-X Facility/Process



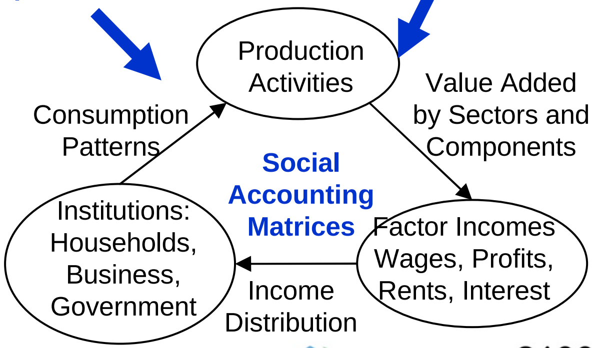
Transportation



Environmental impact

Could material reclamation create new manufacturing activities in distressed areas and be an economic development strategy promoting urban sustainability & resiliency?

Which materials need to be reclaimed from where with which technologies for which new purpose?



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Questions?

Thank you

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Extra Slides

Brook Byers Institute for Sustainable Systems

1. Develop strategies to design, build, and operate modern, sustainable, and resilient urban systems

Brook Byers Institute for Sustainable Systems

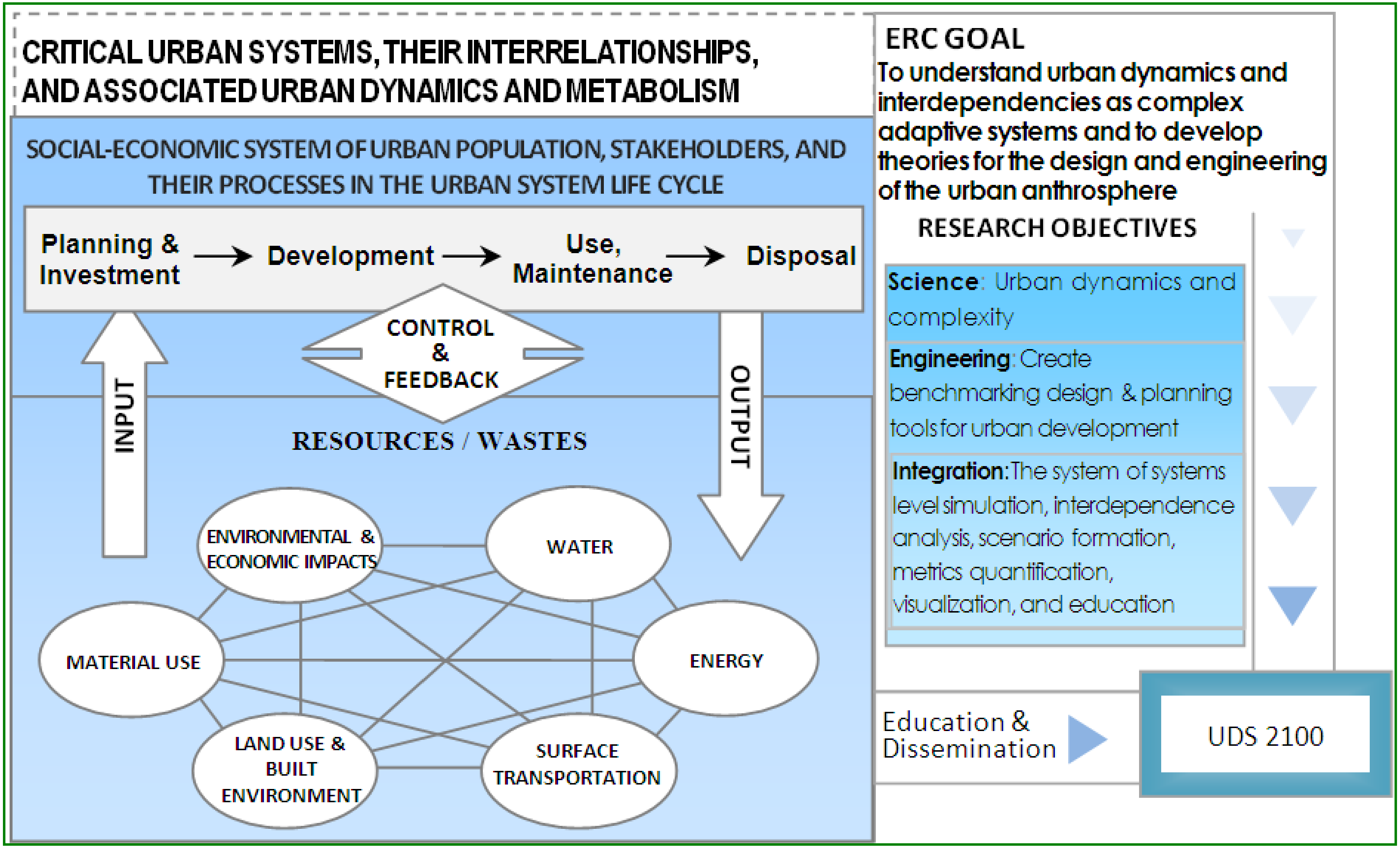
2. Develop the cyberinfrastructure to monitor, model, visualize and predict the emergent properties of urban infrastructure and their resilience to stressors

- ✓ **Emergent properties** such as material and energy use, traffic and transportation patterns, urban health implications, heat islands, land use and density, air quality, and the local, regional and global impacts of resource demands and waste generation
- ✓ **Stressors** such as climate change, natural hazards and fiscal constraints.

Brook Byers Institute for Sustainable Systems

3. Integrate the human perspective (livability, social interactions, sense of community, open space) into urban infrastructure to create socially beneficial and sustainable outcomes and policies.

Our systems approach



Metamodel Steps

- Predict the demand and location for urban infrastructure for development and redevelopment, including the resulting economic flows and socioeconomic drivers based on emergent properties
- Determine the infrastructure system options (e.g., community design, net zero buildings, construction methods, material choices) available to meet this demand and (re)design the virtual city
- Choose a transportation options (e.g., walking, biking, automobiles, public transportation,automobiles) and simulate traffic flows and travel times using micro-simulation models (e.g., TranSims)
- Determine the materials and energy needed to construct and maintain the urban infrastructure
- Assess the infrastructure's vulnerability to natural hazards (e.g., floods, earthquakes, hurricanes) and manmade challenges (e.g., resource constraints or supply chain disruptions)
- Aetermine the local, regional, and global impacts (e.g., carbon footprint) of various scenarios using life cycle impact assessment
- Predict heat island effects using microclimate models and determine increases to water and energy demands
- Visualize various sustainability and resiliency metrics (e.g., carbon footprint; water, material, and energy demands; and social and economic impacts)

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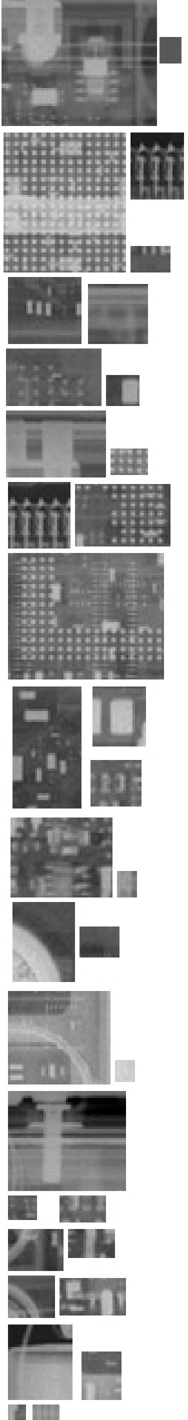
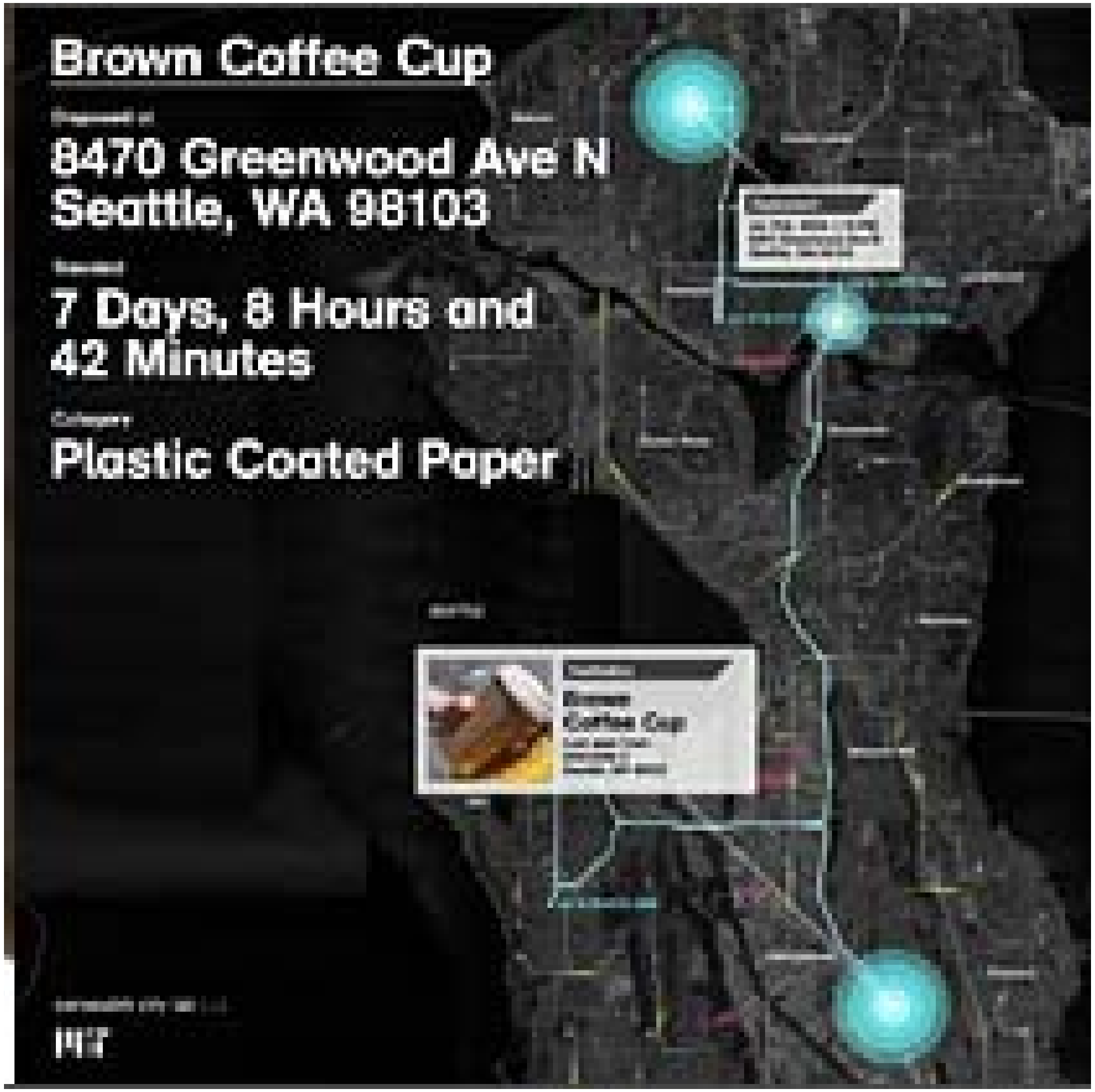
Cyber Infrastructure

- Tremendous Opportunity to Influence it for Urban Sustainability
- IBM has 1800 people working on their smart cities program
- NAE Definition
  - Human
  - Hardware
  - Software
- Wireless Communication
- Sensors (Remote and Embedded)
- Modeling
- Data Mining and Fusion
- Visualization

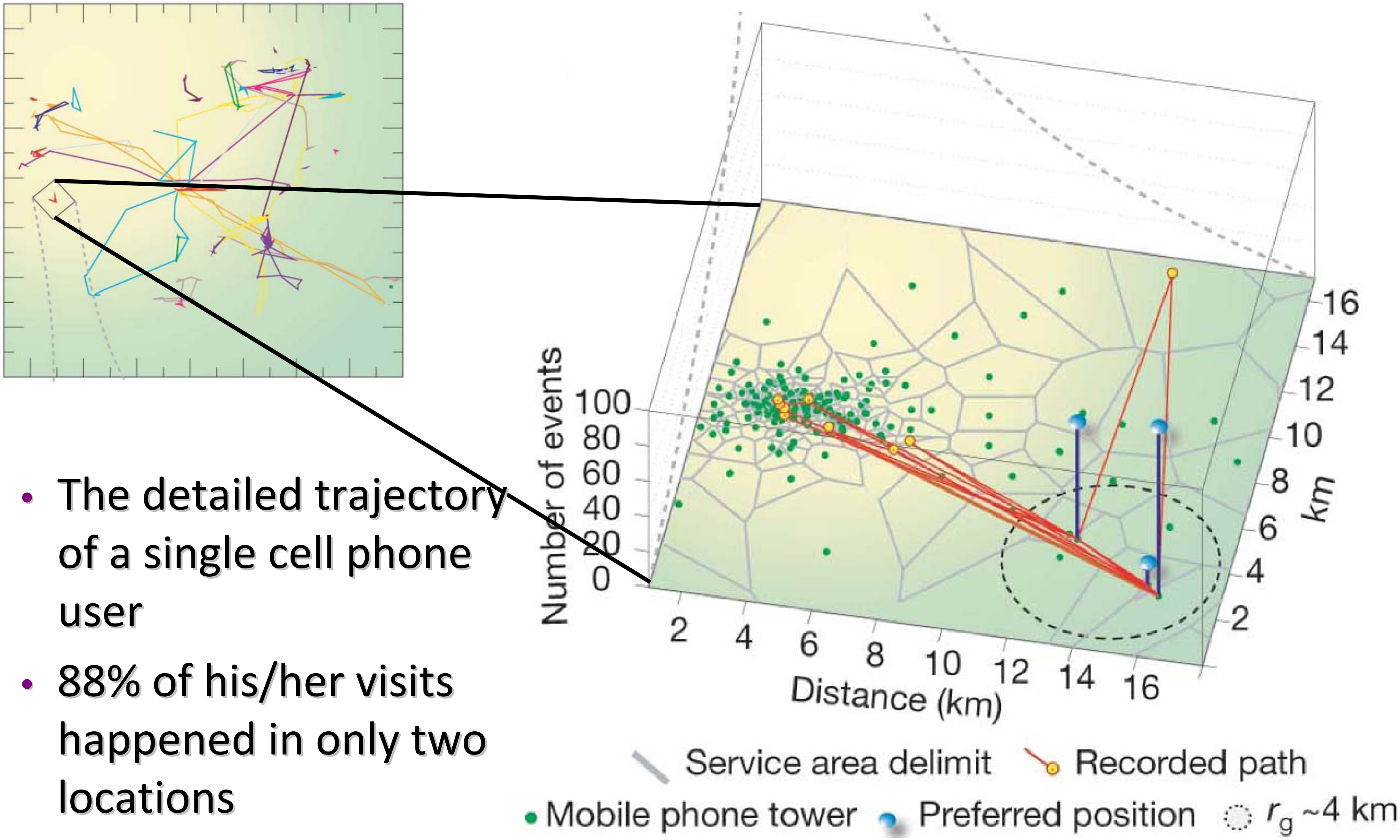


Computable tags for material flow and recycling

Radio Frequency Induced Device Indentification tag could be used for material flow analysis and include environmental, social and economic performance information nBrown Coffee Cup deployed on Jul 11, 2009 in Seattle

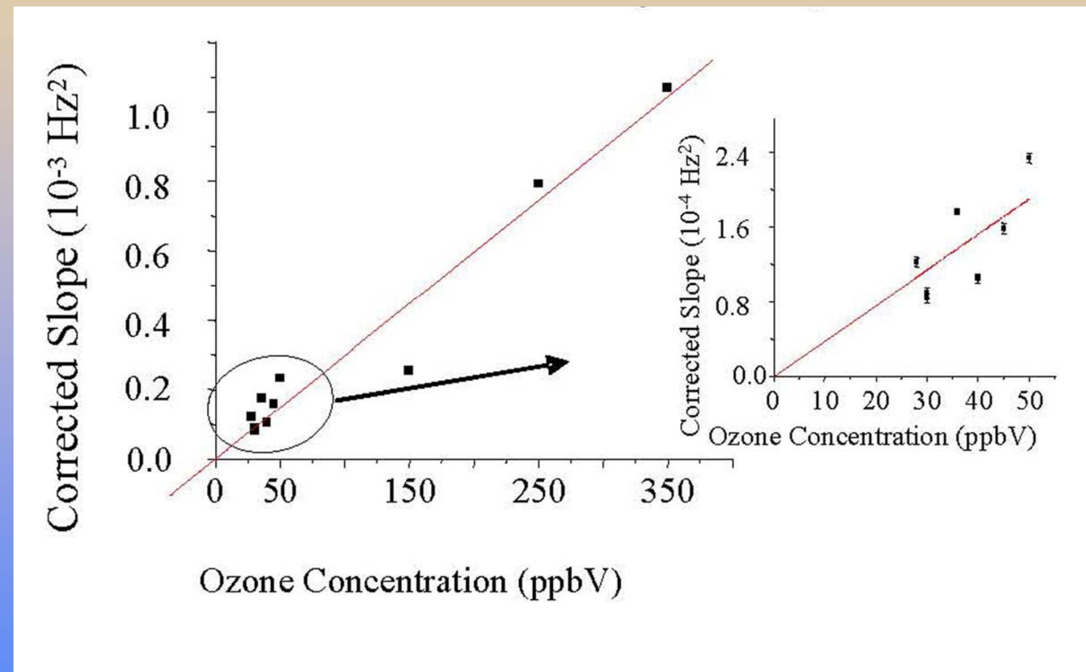


Citizens as Sensors



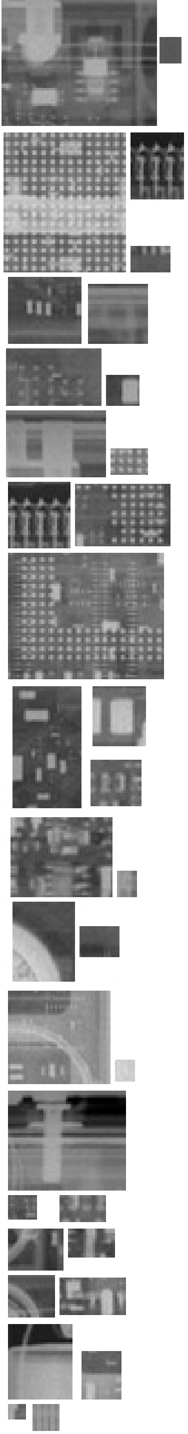
- The detailed trajectory of a single cell phone user
- 88% of his/her visits happened in only two locations
  - Gonzalez et al, 2008

Tuning Fork Ozone Detector for a Cell Phone

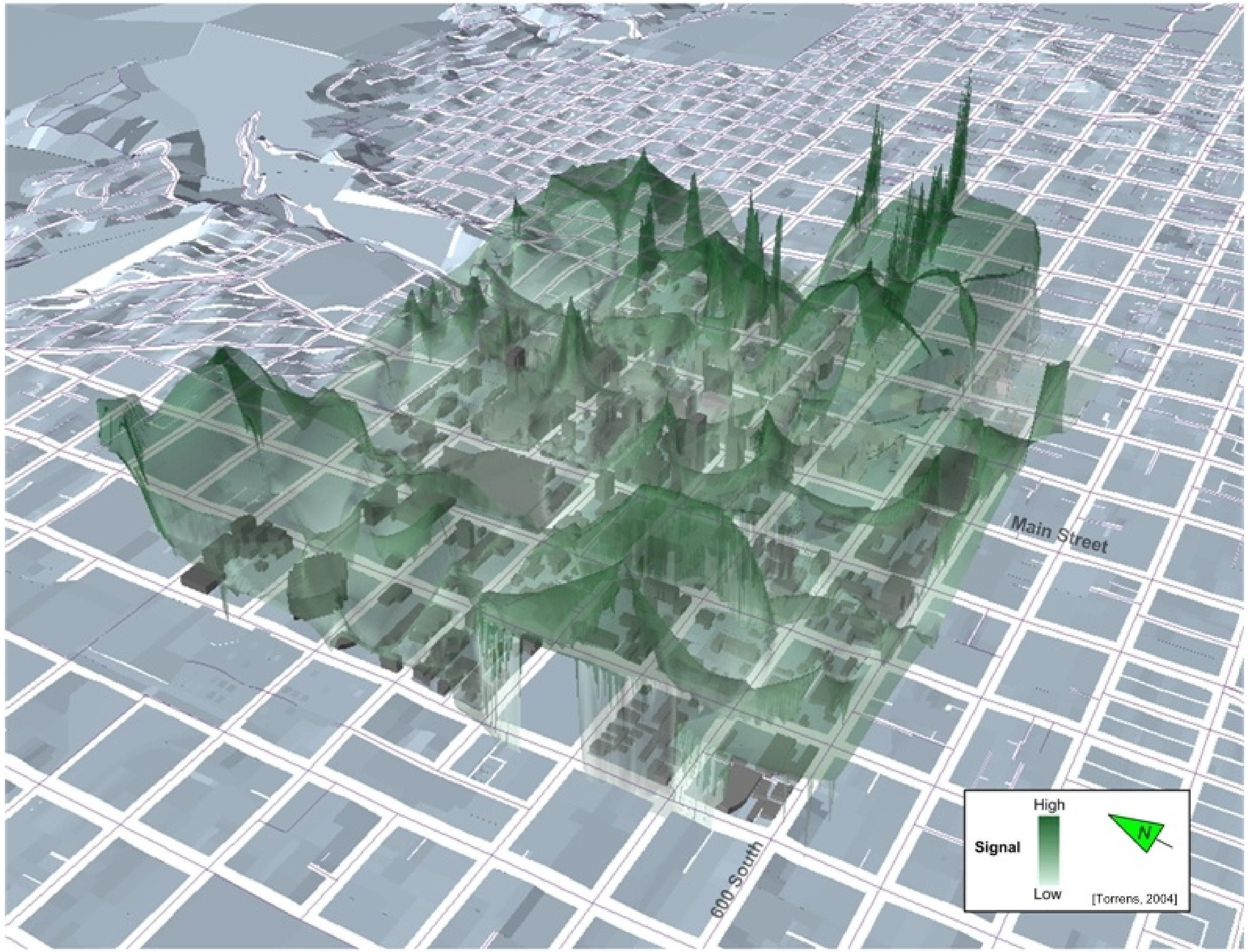


Real-Time Ozone Detection Based on a Microfabricated Quartz Crystal Tuning Fork Sensor

Rui Wang [1,2], Francis Tsow [1,2], Xuezhi Zhang [3], Jhih-Hong Peng [2], Erica S. Forzani [1,2], Yongsheng Chen [3,#,*], John C. Crittenden [3,#], Hugo Destaillats [3,4,*] and Nongjian Tao [1,2,*]



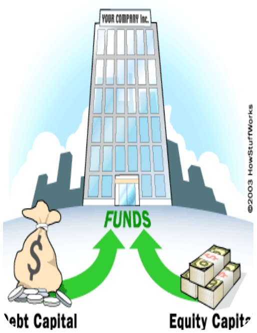
Mapping urban data clouds



Paul Torrens work…

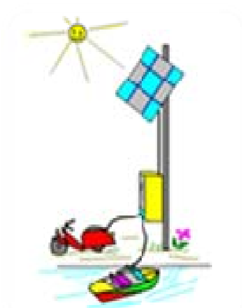
All signals, central Salt Lake City, UT

Improving Global Competitiveness by Improving Infrastructure



- Use capital for infrastructure more efficiently and effectively (projected world wide infrastructure spending 2005-2030: **$41 trillion;** ATL will invest $285+ billion over the next 30 years)

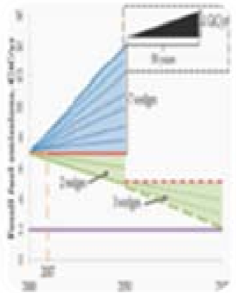
- Develop the platform that enables our partners to fullfill the cyberinfrastructure needs for smarter cities (e.g. sensors, materials and energy management software, etc…)



- Use material and energy more efficiently and effectively

UDS 2100

Improving Global Competitiveness by Improving Infrastructure

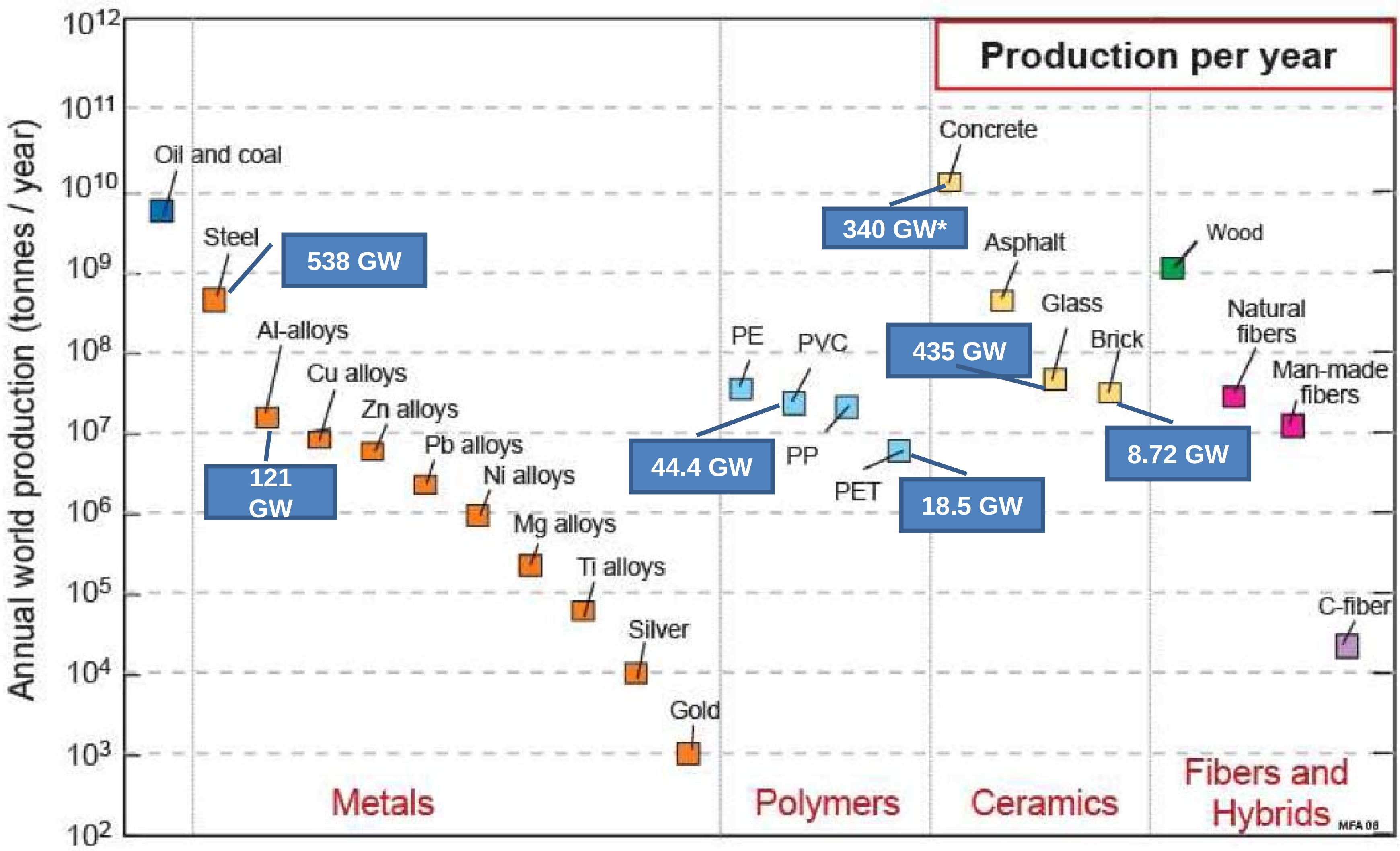


- Help inform policy decisions that lead to markets that engage gigainvestors and gigaentrepreneurs that create the gigabusinesses to solve the gigaton problem

- Ensure that the US is the leader in infrastructure ecology and cyberinfrastructure for more resilient and sustainable cities

UDS[2100]

Resource Consumption for Material Production

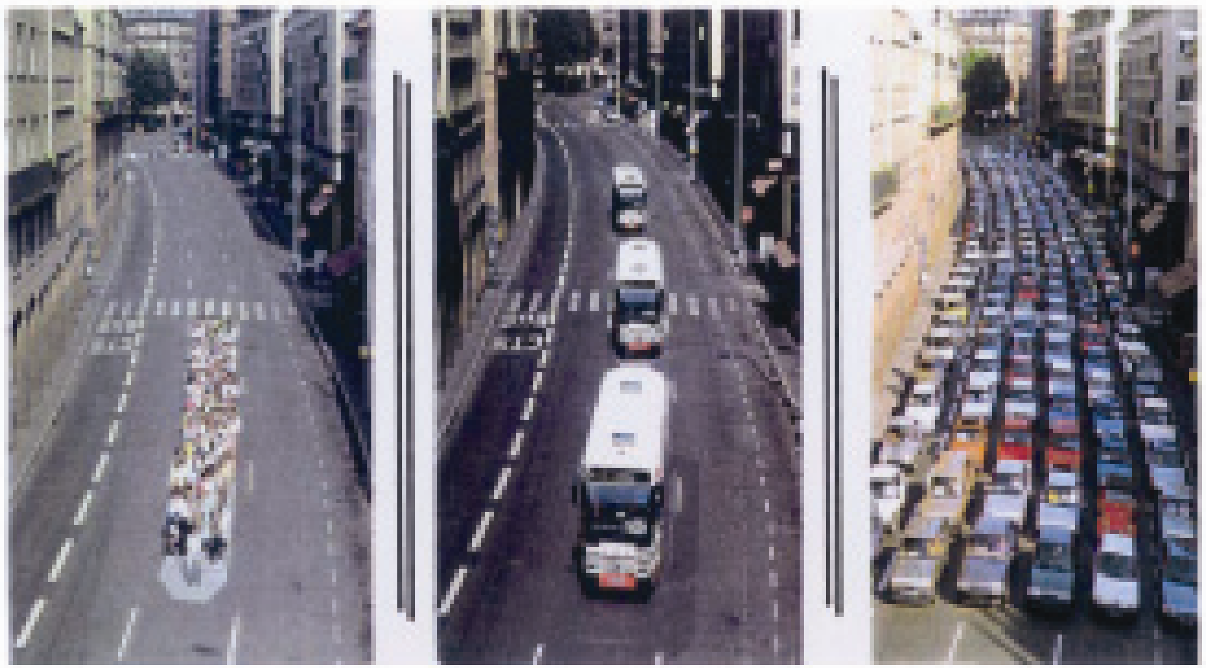


Credit: Mike Ashby

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

Iron Intensity for Transportation Options (180 persons)

Transport Technologies and Iron Intensity



- No iron

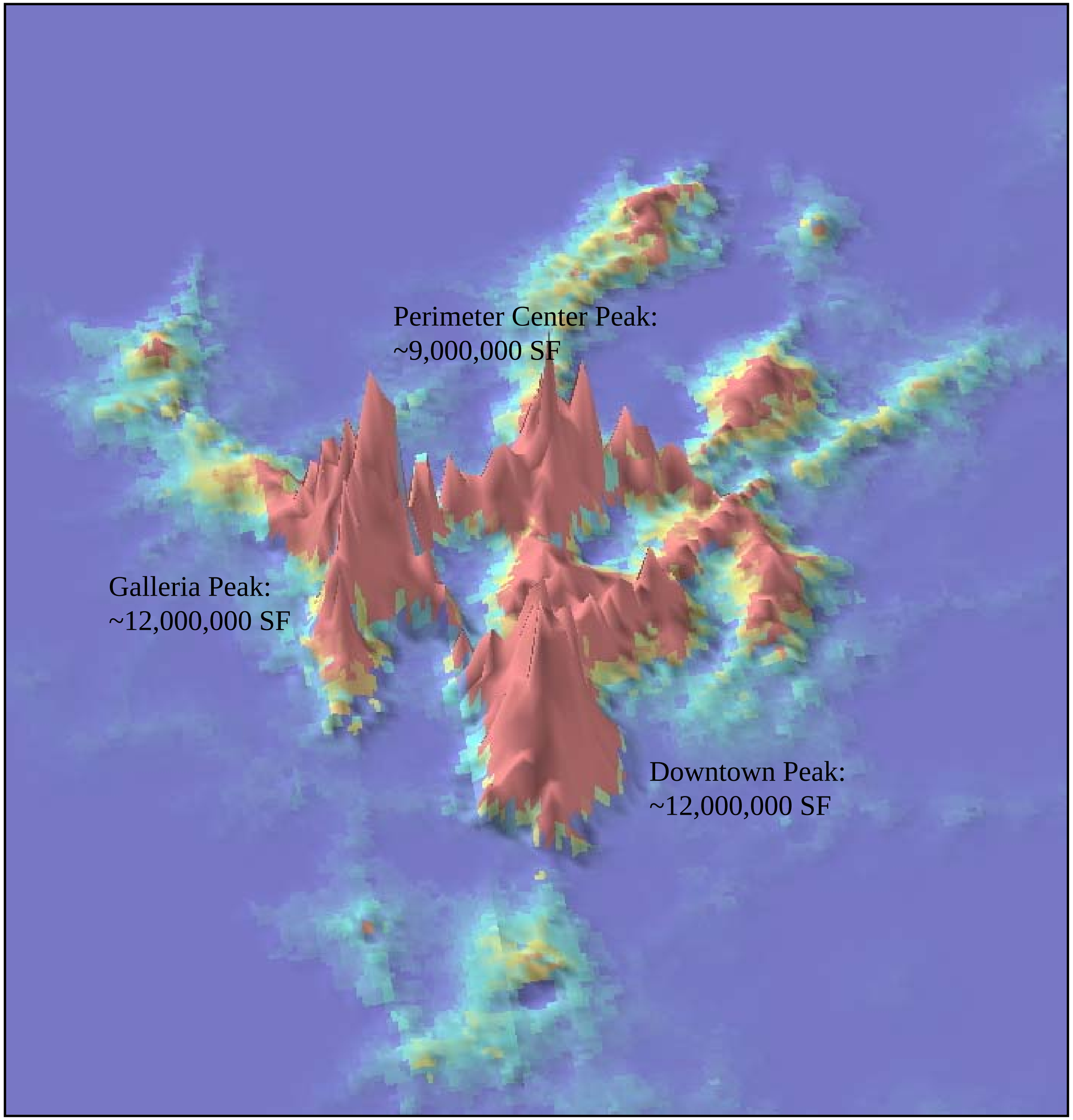
Bicycles 15 kg/cap

- 10 Mg Fe/bus
- 170 kg Fe/cap

- 1 Mg Fe/car
- 670 kg Fe/cap

Credit: Tom Graedel

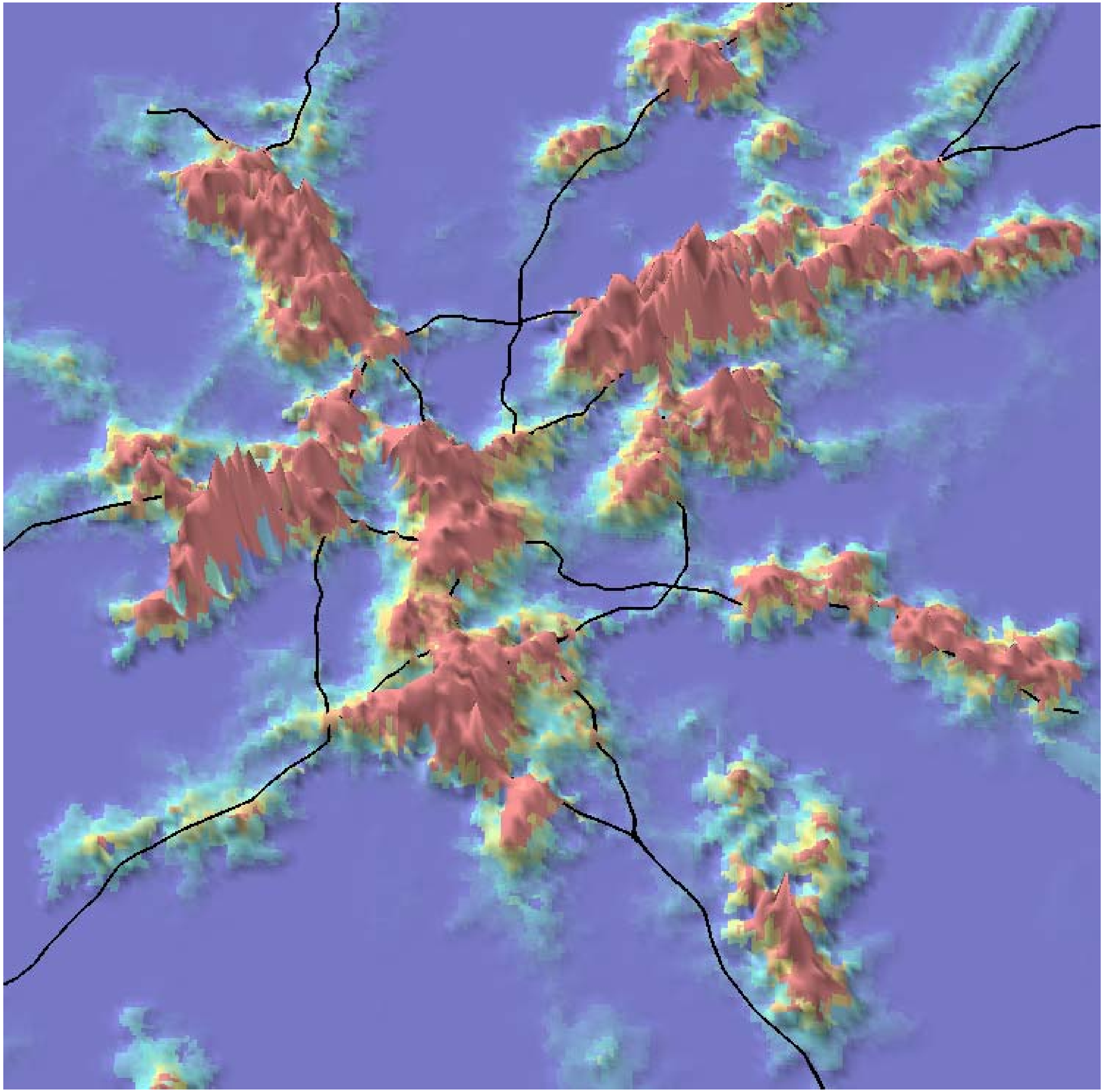
S2100



Office Accessibility

Square Footage of Office Accessible Within 5 Minutes Driving Time

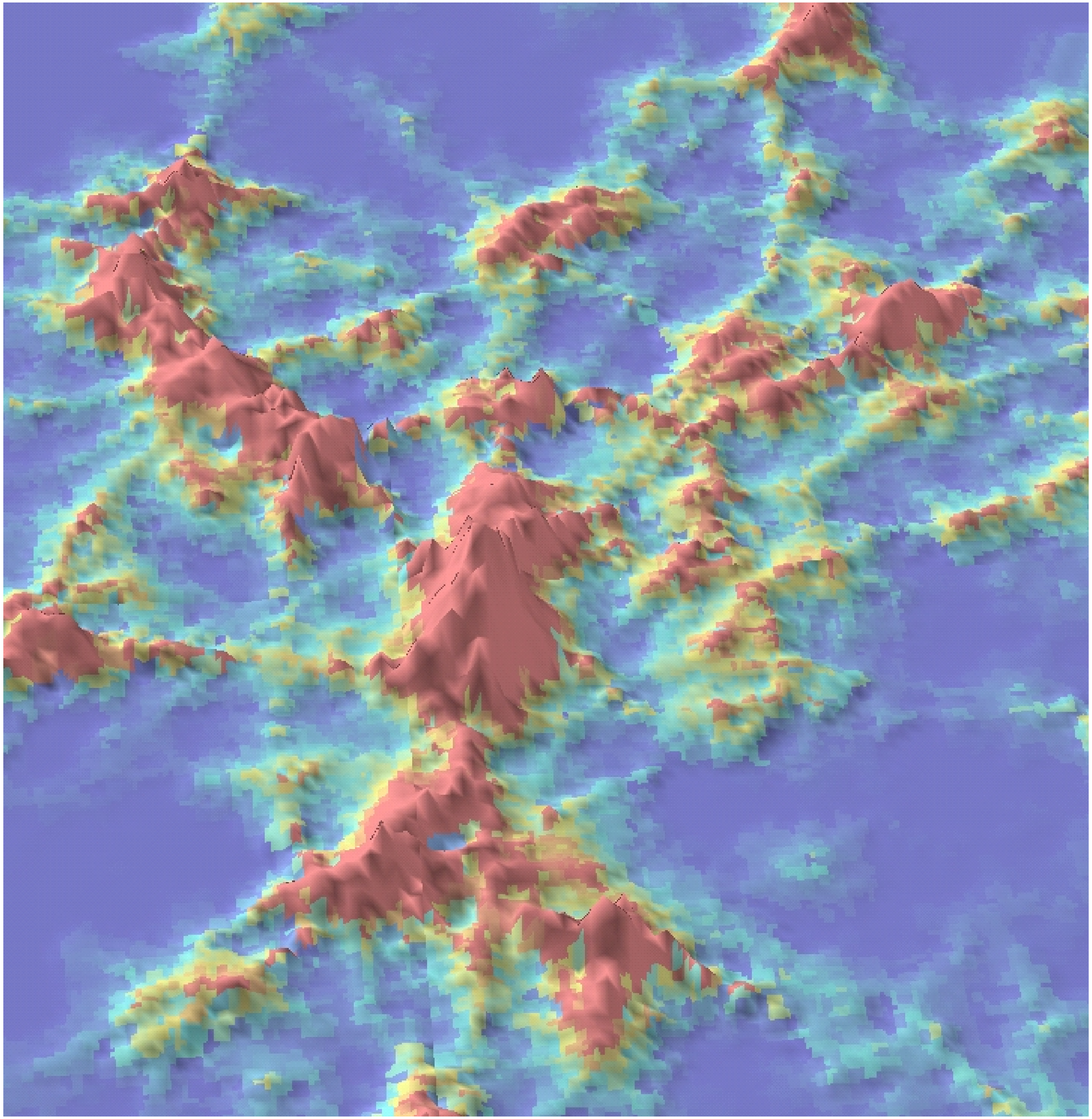
Based on the 1999 ‘lu1.3’ parcel land use database created at the Georgia Tech GIS Center



Industrial Accessibility

Square Footage of Industrial Accessible Within 5 Minutes Driving Time

Based on the 1999 'lu1.3' parcel land use database created at the Georgia Tech GIS Center



Commercial Accessibility

Square Footage of Commercial Accessible Within 5 Minutes Driving Time

Based on the 1999 ‘lu1.3’ parcel land use database created at the Georgia Tech GIS Center