PROJECT: SUSTAINABLE INFRASTRUCTURE FOR ENERGY AND WATER SUPPLY (SINEWS)

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Outline

• Infrastructure Ecology
• Decentralized Water Resource Development: Low Impact Development (LID)
• Decentralized Energy Production:
  • Combined Heat and Power (CHP)
  • Renewable Energy
• Policies for Adoption of Rain Water Harvesting and Compact Living
• Large Scale Urban Development Simulation: Water Savings and GHG Emission Reductions from LID and CHP
• Implications for Decision Making
• Summary
INFRASTRUCTURE
ECOLOGY
Q: With the next generation of infrastructure, what are the implications if we design, build, and operate these systems separately, as we have done in the past?
Interdependence of Different Infrastructure Components

- Land Use
  - Intensity & Type
  - Availability

- Energy
  - Production
  - Treatment & Transport

- Transportation
  - Activity Pattern
  - Accessibility

- Water
  - Potable
  - Wastewater
  - Stormwater

Fuel Choice
Interconnection between Urban Infrastructure System, Natural Environmental Systems and Socio-Economic Systems

Increasing Spatiotemporal Scale
Why Infrastructure Ecology?

**Analogies between UIS and Ecological Systems:**
- are complex, dynamic and adaptive;
- are comprised of interconnected components;
- connect the natural and human environments;
- are scalable and show efficiency of scale;
- share some general architectural dynamics across time and space;
- create novelty; and
- cannot be evaluated by looking at any component element, but instead must be examined as a system.

**Problems with current paradigm of Urban Infrastructure Planning:**

1. Compartmental Optimization resulting in:
   1. Unintended Consequences
   2. Sub-optimal System Level Performance
   3. Non inclusion of macro-level emergent properties
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 of this particular model of infrastructure ecology is significant:
  • 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.
DECENTRALIZED WATER RESOURCE DEVELOPMENT: LOW IMPACT DEVELOPMENT
Implementation of Low Impact Development Techniques: Case Study of Atlanta, GA

- Benefits:
  - For a 3-story apartment community,
    - 40% reduction of potable water demand, about 12,000 Gal/cap/yr
    - 37% reduction in impervious area
    - 50% reduction in irrigated area
    - 20% reduction of Life Cycle Impacts

Citywide implementation of Hybrid (LID + Centralized) System would save the city ~$1.2 million per year in energy costs.
Rain gardens occupying 11% - 16% of community size can control 100% of stormwater runoff generated in extreme rainfall events up to 8 in/24-hr.
DECENTRALIZED ENERGY PRODUCTION: COMBINED HEAT AND POWER (CHP)
The design criteria for:
- R4 buildings is based on the usage of a 30kW microturbine
- RG4 buildings is based on the usage of a 60 kW microturbine
Summary of building energy requirements met by CHP

RG4: 2 6-story apartment buildings
- 60kW MT
  - Electricity: 778 MWh (66%)
  - Thermal: 900 MWh (140%)

Grid Energy
- Electricity: 260MWh (34%)
- Electricity: 218MWh (46%)

Water for energy savings
- 985300 Gal

R4: 12 Single Family homes
- 30kW MT
  - Electricity: 477MWh (54%)
  - Thermal: 452.5 MWh (123%)

Thermal load includes heating and cooling demand
DECENTRALIZED ENERGY PRODUCTION: RENEWABLE ENERGY
Simulation Results in Hourly Resolution

The large variation in PV output demands a higher capacity of spinning reserves.
Plug-in Hybrid Electric Vehicles (PHEVs) and Vehicle-to-Grid (V2G) power

PHEVs can send power back to the grid when parked, and function as distributed storage for intermittent energy from renewable sources.

Credit: Kempton and Tomić, 2005

US demand-supply balances during maximum demand with various V2G ratios in 2045

30% V2G penetration could reduce ~100 GW or about ⅓ of the total peak demand of ~300 GW in US by 2045

Source: Modelling Load Shifting Using Electric Vehicles in a Smart Grid Environment – © OECD/IEA 2010
POLICIES FOR ADOPTION OF RAIN WATER HARVESTING AND COMPACT LIVING
Interactions between Infrastructure and Socio-Economic Environment

**Macro**

Emergent Properties: land use, water, energy and material consumption, transportation quality, quality of life, and other sustainability metrics.

**Water**

**Energy**

**Heating/Cooling**

**Transportation**

**Socio-Economic Environment**

- Jobs
- Business
- Neighborhood
- Housing

**Infrastructure Systems**

**Micro**

Decisions, behaviors of Individual Agents and the relationship of individual agents: location choice, traffic activity, and willingness to pay
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)

Prospective homebuyers
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

Bid
Success

Property Tax

Impact fee?

House demand for next period
Land Use Pattern Between Business As Usual (BAU) and More Sustainable Development (MSD)

The total area for new development: 9 sq mi

The total area for new development: 9 sq mi

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Total households</th>
<th>% of households living in apartment</th>
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</thead>
<tbody>
<tr>
<td>BAU</td>
<td>23,630</td>
<td>35.0%</td>
</tr>
<tr>
<td>MSD</td>
<td>24,475</td>
<td>58.0%</td>
</tr>
</tbody>
</table>

Impact fee for LID non-compliance penalty:
- $13,000 per unit for single-family house
- $1,500 per unit for apartment home
Property Tax Revenues

- BAU versus MSD
- Accumulation of property tax revenues for 30 years
  - $Surplus \text{ at time } t = (\text{property tax revenues at time } t) - (\text{new construction cost for stormwater management at time } t) + (\text{Surplus at time } t-1)$
  - Property tax revenues at time $t = (\text{house value at time } t) \times 0.4 \times 0.01 \times (\text{number of households})$
URBAN DEVELOPMENT SIMULATION AND LARGE SCALE WATER SAVINGS CARBON EMISSION REDUCTIONS FROM LID AND CHP
Projected Growth Scenarios for Atlanta

Business As Usual
Year 2030

More Sustainable Development
Year 2030
ATL Residential Energy Demand from Grid (with Air Cooled Microturbines in a Decentralized CHP system)

- **Base year (2005)**
  - Single Family: 1170283
  - Apartments: 458207
  - Energy from grid: 59,531 GWh
  - Energy from grid w/ CHP: 22,906 GWh
  - 62% reduction

- **BAU (2030)**
  - Single Family: 1783935
  - Apartments: 649907
  - Energy from grid: 90,116 GWh
  - Energy from grid w/ CHP: 34,741 GWh
  - 61% reduction

- **MSD (2030)**
  - Single Family: 1671596
  - Apartments: 763019
  - Energy from grid: 86,444 GWh
  - Energy from grid w/ CHP: 33,110 GWh
  - 62% reduction

Note: The 2030 grid+CHP scenarios assumed all residential units in the base year were retrofitted with CHP systems. BAU = Business As Usual, MSD = More Sustainable Development, CHP = Combined Heat and Power.
ATL Water Demand Projection (Withdrawal)  
(with low flow fixtures + rooftop rainwater harvesting + CHP)

Note: The 2030 grid + CHP scenarios assumed all residential units in the base year were retrofitted with CHP systems
ATL Water Consumption Projection (Evaporation) (with low flow fixtures + rooftop rainwater harvesting + CHP)

Note: The 2030 grid + CHP scenarios assumed all residential units in the base year were retrofitted with CHP systems

(Courtesy: Crittenden et al., Georgia Tech)
Potential GHG reductions in 2030

- The reduction is based on the electricity produced by CHP replacing that from the centralized power plant.
- Base year case assumes that all existing homes are retrofitted to facilitate a CHP system.
- The 2030 grid+CHP scenarios assumed residential units in the base year were also retrofitted with CHP systems.
- For MSD implementation the CO$_2$e Savings is 0.065 Gt

~ 40% Reduction in all cases
Projected Domestic Water Demand
(with low flow fixture + rooftop rainwater harvesting + reclamation)

<table>
<thead>
<tr>
<th>Year</th>
<th>Water Withdrawal</th>
<th>Water Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>507 MGD (10⁶ Gallon per day)</td>
<td>0 MGD</td>
</tr>
<tr>
<td>2030</td>
<td>800 MGD</td>
<td>163 MGD</td>
</tr>
<tr>
<td>2030 (w/ low flow fixture)</td>
<td>729 MGD</td>
<td>34 %</td>
</tr>
<tr>
<td>2030 (w/ low flow fixture + rooftop rainwater harvesting)</td>
<td>707 MGD</td>
<td>11.6 %</td>
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- **Water Withdrawal**: Base year and BAU data for both years.
- **Water Consumption**: MSD data for both years.
- **Reclamation**: Baseline data for both years.
IMPLICATIONS FOR DECISION MAKING
Dimensions of Decision Making

- Sustainable and Resilient Design
- Adaptive Management
- Traditional Engineering Optimization
- Sustainable and Resilient Design
Sustainable and Resilient Design and Adaptive Management

**Sustainable and Resilient Design**
- **Technological Intervention**
  - Increase the capacity of the system to absorb shocks from a perturbation and minimize the damage.
  - Decrease the response time in the aftermath of a perturbation
  - *Smart infrastructure*: wireless sensors to communicate failure events

**Adaptive Management**
- **Policy Intervention**
  - To make the Urban Infrastructure Systems more flexible and adaptable to changing scenarios.
  - To increase and promote adoption of more “sustainable and resilient” alternatives (both technological and behavioral) across the urban System through policy tools.
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!!