Water, Energy, Land Use, Transportation and Socioeconomic Nexus: A Blue Print for More Sustainable Urban Systems
Projects under SINEWS

- **Physical Environment**
  - Land use scenarios and forecasting
  - Hedonic price estimation for reliable infrastructure
  - Land use and policy
  - Life cycle assessment of centralized and decentralized water/wastewater systems
  - Reliability of water distribution system
  - Water resources
  - Resiliency of water infrastructure
  - Life cycle assessment of centralized and decentralized energy production system
  - Decentralized energy production and electrified transportation
  - Resiliency of Energy Infrastructure

- **Socio-Economic Environment**
  - Charles Perrings, Doug Noonan
  - Marilyn Brown

- **Water Infrastructure**
  - John C. Crittenden, Eric Williams
  - Sam Ariaratnam
  - John Crittenden, Ke Li
  - Reginald Desroches
  - George Karady, Miroslav Begovic, Eric Williams

- **Energy Infrastructure**
  - Bert Bras
  - Reginald Desroches
Outline

- **System Interaction**
- Urban Growth Modeling and Network Simulation
- Distributed Energy Supply
- Community Growth and Decentralized Water Alternatives
- Social and Economic Issues
Infrastructure Interdependencies

Arka Pandit, Hyunju Jeong, John C. Crittenden, Steven P. French, Ming Xu, Ke Li, “Sustainable Infrastructure and Alternatives for Urban Growth”, Book Chapter (in review), 2010
Consumptive Water Use for Electricity

<table>
<thead>
<tr>
<th></th>
<th>Thermoelectric</th>
<th>Hydroelectric</th>
<th>Weighted Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arizona</strong></td>
<td>0.32</td>
<td>64.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.85</td>
<td></td>
</tr>
<tr>
<td><strong>Georgia</strong></td>
<td>0.60</td>
<td>47.42</td>
<td>1.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>US Aggregate</strong></td>
<td>0.47</td>
<td>18.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>
### Energy Water Nexus - Phoenix Vs. Atlanta

<table>
<thead>
<tr>
<th></th>
<th>The City of Phoenix</th>
<th>The City of Atlanta</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Residential Water Demand</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoor (gpcd)</td>
<td>48^a</td>
<td>71</td>
</tr>
<tr>
<td>Outdoor (gpcd)</td>
<td>110^a</td>
<td>20</td>
</tr>
<tr>
<td><strong>Power Use</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential Electricity, kWh/person-day</td>
<td>36</td>
<td>41</td>
</tr>
<tr>
<td>Fuel, kWh/person-day</td>
<td>5.5</td>
<td>12.3</td>
</tr>
<tr>
<td><strong>Water Consumption for Electricity Production</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gal/kWh</td>
<td>7.85</td>
<td>1.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Georgia)</td>
</tr>
<tr>
<td><strong>Electricity Consumption for Water Supply and Treatment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water kWh/MG</td>
<td>8,600</td>
<td>1,700^b</td>
</tr>
<tr>
<td>Wastewater kWh/MG</td>
<td>10,700</td>
<td>1,830^b</td>
</tr>
<tr>
<td></td>
<td>Scott et al. (2009) Wastewater Collection and Treatment, 1500 kWh/MG Reclamation, 9200 kWh/MG</td>
<td></td>
</tr>
</tbody>
</table>

^a. The numbers are modified assuming 4 people for one household

^b. The numbers are estimated based on the water and wastewater production of City of Atlanta, the electricity use of Atlanta Watershed Management Department (Thomas, 2007), and the Electricity demand for water supply and wastewater treatment of South Atlantic Region (DOE, 2006)
**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
Water for Transportation - Atlanta

- Conventional Gasoline: 0.04 gal/km-person
- Diesel: 0.03 gal/km-person
- CNG: 0.01 gal/km-person
- E-85 FFV (Corn): 6.57 gal/km-person
- EV: 0.25 gal/km-person
- Diesel Bus: 0.04 gal/km-person
- MARTA Clean Diesel Bus: 3.27 gal/km-person
- MARTA CNG Bus: 0.01 gal/km-person
- MARTA Rail: 0.87 gal/km-person
Water for Mobility Network
- Metro Atlanta, 2010 and 2030 Conditions

- 2010 (w/o extraction)
  - CNG: 0.005
  - EV: 0.007
  - HEV: 0.087

- 2030 (w/o extraction)
  - CNG: 0.001
  - EV: 0.051
  - HEV: 0.051

- 2030 100% EV Penetration
  - 91

- 2010 Domestic Water Consumption
  - 105

- 2010 Domestic Water Demand
  - 600 million gallon/day
Outline

- System Interaction
- **Urban Growth Modeling and Network Simulation**
- Distributed Energy Supply
- Community Growth and Decentralized Water Alternatives
- Social and Economic Issues
Interconnection between Infrastructure and Socio-economic Environment

Compact Living Space (Smart Growth):

- Increase Green Space
- Manage Storm Water (Blue Belts)
- Improve Health
- Distributed Energy Production – Combined Heat and Power
- Distributed Water Production – Rain Water Harvesting

Case Study: Storm water treatment for Vancouver

It was estimated that there was a **$4 billion expense** to separate stormwater systems from wastewater. However, when they opted for **distributed stormwater treatment using green swales and bioretention**, there was an estimated **$400 million income** from increased property value and associated tax revenue.
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
Parcel-Based Spatial Data
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
- Residential Units
- X,Y Coordinate
- Estimated Sq Feet
- Total Sq Feet
Important Features

- Floodplain
- Highway Buffers
- Sewer Service
- Employment Centers
- Lake Buffers
- Public lands
- Parks
- Ramp Buffers
Social Decision Making Model
(Agent: Household, Developer, Business, Policy Maker and Other)

- Infrastructure Demand
  - Demographic model
  - Economic Flows
  - Development/Re development
  - Accessibility/ Mobility Model
  - Policies, Regulation, Management

Example of Infrastructure Choices
- Community Design
- Material Selection
- Centralized vs. Decentralized Energy & Water System
- Transit-based or Vehicle-Dominated Traffic System

Built Environment
- Buildings
- Land Use
- Transportation
- Energy
- Water Facilities
- Solid Waste Handling

Output, Visualization
- Environment
  - Material and Energy Flow
  - Economic Impact
  - Local Air Quality, e.g. O3, NOx, PM10
  - Global Impacts, e.g. Global Warming, O3 depletion
  - Genuine Progress Indicator, Social Impacts

Local, Regional, Global Impacts (Examples)

Knowledge Presentation/ Dissemination

Examine Changes in behavior
Growth Scenarios in Atlanta

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

Courtesy: French, S; GT
Water Demand By Location - Residential

Business As Usual Scenario

Year 2010

Residential Water Use:
- **Blue** = Single Family Residential
- **Brown** = Multi Family Residential

Unit:
1 dot = 250,000 gallon per day
Water Demand By Location - Residential

Year 2020

Business As Usual Scenario

Residential Water Use:
Blue = Single Family Residential
Brown = Multi Family Residential

Unit:
1 dot = 250,000 gallon per day
Water Demand By Location - Residential

Year 2030

Business As Usual Scenario
Residential Water Use:
Blue = Single Family Residential
Brown = Multi Family Residential

Unit:
1 dot = 250,000 gallon per day
Current Land Use and Energy

Higher per capita consumption out of urban core

Brown and Chandler
**Scale-Free Networks**

A scale-free network is a network whose degree distribution follows a power law.

**Random Networks**

The node degrees follow a Poisson distribution indicating most nodes have approximately the same number of links (close to the average degree).
Complex Urban Networks

- Urban systems are a conglomerate of interrelated complex networks.

Water-wastewater and Energy distribution are scale-free networks while transportation network is random network.

While scale-free networks are generally more resilient to random perturbations (natural or anthropogenic) they are more vulnerable to targeted attacks and vice-versa for random networks.

Hypothesis: Decentralized/Distributed Water/Energy infrastructure is more resilient due to its higher redundancy attributable to its structure rather than resources.
Hypothesis:

Decentralized/Distributed Water/Energy infrastructure is more resilient due to its higher redundancy attributable to its structure rather than resources.
## Different Residential Community Development

### Traditional community with low level of open space

<table>
<thead>
<tr>
<th>Community</th>
<th>Traditional</th>
<th>Smart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential acreage for development(acre)</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Potential house units</td>
<td>10000</td>
<td>10000</td>
</tr>
<tr>
<td>Gross density (unit per acre)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Net residential density (unit per acre)</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

### Smart Community with high level of open space

<table>
<thead>
<tr>
<th>Land use per house unit</th>
<th>Lot size</th>
<th>House size</th>
<th>Private yard</th>
<th>Infrastructure</th>
<th>Open space</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5000 ft²</td>
<td>3000 ft²</td>
<td>2000 ft²</td>
<td>3312 ft²</td>
<td>502 ft²</td>
</tr>
<tr>
<td></td>
<td>56.7%</td>
<td>34.0%</td>
<td>22.7%</td>
<td>37.6%</td>
<td>5.7%</td>
</tr>
<tr>
<td></td>
<td>2100 ft²</td>
<td>1890 ft²</td>
<td>210 ft²</td>
<td>1068 ft²</td>
<td>5573 ft²</td>
</tr>
<tr>
<td></td>
<td>24.1%</td>
<td>21.7%</td>
<td>2.4%</td>
<td>12.2%</td>
<td>63.7%</td>
</tr>
</tbody>
</table>
Agent-based Modeling (ABM) Approach to Evaluate the Advantages of Compact Growth

**Primary Agents**

- **Home Buyers**: Valuate and purchase houses - Willingness to pay, Preference
- **Homeowners**: Pay taxes - Household income
- **Government**: Support green infrastructure investment including open space with stormwater management - Tax revenue
- **Real Estate Agents**: Collect house market information, sell house - Asking price
- **Contractors**: Construct new houses - Construction cost

**Behavior**

- **Compact living with public green space** & **Traditional large-lots with private green space**
Impact Fee Paid by Developers
Traditional $6,000,
Compact Growth: $3,500

Business as Usual

Compact Growth
Sustainable & Resilient Water Distribution

- A multi-objective genetic algorithm model connected with a water network solver (EPANET) was developed to design water distribution systems
  - Minimize life cycle costs
  - Minimize life cycle carbon emissions
  - Maintain high reliability for life time
- Cost vs. Reliability tradeoff
  - Need to pay more for reliability
  - As high as 20-25% more (from the preliminary analysis of smaller networks)
  - High costs are due to larger diameter pipes
- From the preliminary investigation on smaller networks it is understood that the CO₂ emissions could be reduced up to 15%
Minimum Cut-Set Method: Reliability Metric

- Minimum cut-sets: critical sets of pipes in a water distribution system
- Failure probability of a minimum cut-set, $P(MC_i)$
  \[
P(MC_i) = \prod_{j=1}^{n} P_j
\]
  where, $n =$ number of pipes in the cut-set $i$; $P_j =$ Failure probability of pipe $j$ which is estimated from historic pipe break data
- Probability of system failure, $P_s$
  \[
P_s = \sum_{i=1}^{M} P(MC_i)
\]
  where, $M =$ number of minimum cut-sets in the system
- System reliability, $R_s$
  \[
  R_s = 1 - P_s
  \]
Pipe Break Data Analysis - Phoenix

Water Main Break Data: Analysis

Breaks (Pipe Type)

Breaks (Diameter)

Breaks (Break Type)
Water Distribution Network:

Distribution Network Alternatives:

Water Main Break Repairs in Downtown Phoenix
Core
• Critical resources consumed in pipe break repairs are Energy and cost
• For a 20 year analysis period (2010-30):
  • Total Cost: **$17.1 million (in present $)**
  • Total Energy: **2,486 MWH**

Reliability of Distribution Network:

Water Main Break Data

Legend:
ACP: Asbestos Cement Pipe,
DIP: Ductile Iron Pipe,
CIP: Cast Iron Pipe,
GALV: Galvanized Steel Pipe,
PVC: Polyvinyl Chloride Pipe,
STL: Steel pipe

Courtesy: S Ariaratnam, ASU
DER (Distributed Energy Resource) Network Capacity Determination Based on Systems Integration

- Future load growth supplied by DERs rather than building new power plants
- Appropriately sized and located DERs are critical to the safety and normal operation of distribution networks

![Diagram showing the process flow of DER network capacity determination based on systems integration.]

Courtesy: X. Zhang
Water and Power System Integration
Coupling Point between Water and Energy Systems

- Natural Gas
- Water
- CHP Unit
- Load
- Boiler
- Expansion Tank
- TS

- Fuel Flow
- Power Flow
- Thermal Flow

Courtesy: X. Zhang
Integrated System Optimization

- Base case study to determine the DER (distributed energy resource) penetration capacity by considering only electrical factors
- Improved study by incorporating water system optimization model and CHP model into the electrical model
- Investigate the influence and limitations of existing water distribution system to the DERs’ network capacity
Outline

- System Interaction
- Urban Growth Modeling and Network Simulation
- **Distributed Energy Supply**
- Community Growth and Decentralized Water Alternatives
- Social and Economic Issues
The Springs community (81 homes), located in Chandler, AZ, was first selected and used as a test bed to research microgrid design methods.
Power Supply Simulation
- 65 kW Microturbines and PV Arrays.
Optimal Microgrid Configuration

- **Optimal Configuration** of microgrid system
  - PV capacity: 157 kW
  - Microturbine capacity: 270 kW
  - For total five units

- COE (cost of electricity): $0.336 per kWh

- **Natural gas demand**
  - 3830 SCFH (cubic feet per hour) for microturbines
  - *about 0.005%* of Natural gas capacity, 69.699 ~ 101.23 x 10^6 CFH
Alternative Microturbine Cooling and Fueling

• Air Cooling
Microturbines designed with foil-air bearings and air-cooling operate without water, oil, coolants or other hazardous materials

• Biogas from landfills and sewage treatment plants
Typically landfill gas (LFG) 40 to 55% methane, with energy value of 400 to 550 BTU/ft³
  - Can be blended with natural gas (energy value of 1000 BTU/ft³)
  - Although only 35% methane content needed for operation
**Use Phase LCA Solid Oxide Fuels Cells**

<table>
<thead>
<tr>
<th></th>
<th>Electrical emissions (CO₂/kWh)</th>
<th>Thermal emissions (CO₂/kWh)</th>
<th>Total emissions (CO₂/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOFC</td>
<td>~0.5 lb</td>
<td>~0.5 lb</td>
<td>1 lb</td>
</tr>
<tr>
<td>NGCC + Natural gas water heater</td>
<td>0.82 lb</td>
<td>0.44 lb</td>
<td>1.26 lb</td>
</tr>
<tr>
<td>Grid + natural gas water heater</td>
<td>0.003 - 2.8 lb</td>
<td>0.44 lb</td>
<td>0.44 - 3.2 lb</td>
</tr>
</tbody>
</table>

As long as the local electrical grid emits more than 0.56 lb CO₂/kWh, SOFC users will lower their CO₂ emissions.

Only CA, ID, ME, OR, and VT would not see CO₂ emissions savings.

SOFCs (and other fuel cells) do not require water to operate.
Cascading Experience Curve

Experience Curve (50,000 initial units, learning rate 20%)

- AK, CA, NY (50,000 units)
- ME (180,000)
- CO, CT, MA, NM, NH, NJ, VT (400,000)
- IA, IL, IN, MN, MT, OH, PA, TX, UT, WI, WY
• Can use them to determine the amount of government subsidy necessary to expand SOFC market.
• Also, the amount of emissions offset per $ of subsidy.
• Using the previous exp. curve and a $1000 per unit subsidy (up to 900,000 units) --> $1.45 /lb CO2 offset.
Combined Heat and 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 $\frac{1}{10}$ of the nitrogen oxides (NOX) per kWh of average utility grid electricity.

• Could potentially provide
  • 20% of U.S. electricity by 2030, &
  • reduce CO$_2$ emissions by 0.2 Gt-C annually

• EU27 produced 366 TWh of CHP electricity, i.e. 11% of the total electricity generation in 2007.

• Combined Cycle Natural Gas is 60% Efficient – Georgia power retiring 500 MW plant and building 2500 MW at McDonough.

Source: US EIA database
http://www.aceee.org/energy/chp.htm
Electric Power Infrastructure of Denmark

Exemplary Case-study on
Combined Heat and Power Generation
Distributed Power Generation
Electric Power Infrastructure of Denmark

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Capacity</td>
<td>13,409 MW</td>
</tr>
<tr>
<td>Wind Turbine Capacity</td>
<td>26%</td>
</tr>
<tr>
<td>- Share of Total</td>
<td></td>
</tr>
<tr>
<td>Electricity Capacity</td>
<td></td>
</tr>
<tr>
<td>CHP Production</td>
<td>55%</td>
</tr>
<tr>
<td>- Share of Total</td>
<td></td>
</tr>
<tr>
<td>Thermal Electricity</td>
<td></td>
</tr>
<tr>
<td>CHP Production</td>
<td>77%</td>
</tr>
<tr>
<td>- Share of Total</td>
<td></td>
</tr>
<tr>
<td>District Heating</td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td></td>
</tr>
</tbody>
</table>

Today all cities and most towns in Denmark are supplied with district heating.
As much as 55% of all electricity produced in Denmark is from CHPs. No other EU country has such a large share.

About 30% of the fuel is saved in CHP compared to a situation, where heat and electricity were supplied by separate productions.

Denmark is in the international forefront with regard to modern CHPs with a net efficiency ratio of 90-98%.

60% of the total demand for heating of buildings and supply of hot water is covered by district heating. A remarkable market share compared to other countries.

The annual statistics document that 9 out of 10 families pay less for their district heat compared to heat from individual supply from oil or gas.

The use of cleaner fuels also matters. The fuels have for decades been diversified ranging from coal and natural gas to waste and biomass. It is estimated that CHP and district heating has reduced total national CO₂-emission by 8-11 million tonnes per year.
Energy Savings with Local PV

- PVs may be installed on 3620 [kW] urban feeder
- 3620 [kW] feeder can supply about 1000 households (assuming maximum 4kW per household and 0.4 load factor)
- Random variable: Location, capacity and field orientation
  - PV system spatial locations uniformly scattered across the feeder
  - PV system capacity size uniformly ranged from 10% to 40% penetration level
  - PV system field orientation consisting of uniformly ranged from -90 ° (facing west) and 90° (facing east)
Energy Savings with Local PV Generation

The effect of PV generation on a typical day of the year (horizontal axis represents time of the 244th day of the year)

PV Output Estimation during One-Year (10%~40% Penetration)
## Ecological Impact of PV System

### Annual savings in emissions and water usage for power supply

<table>
<thead>
<tr>
<th>Penetration Rate [%]</th>
<th>Emissions</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO$_2$</td>
<td>SO$_2$</td>
</tr>
<tr>
<td></td>
<td>ton/(yr·house)</td>
<td>kg/(yr·house)</td>
</tr>
<tr>
<td>0</td>
<td>6.22</td>
<td>36.98</td>
</tr>
<tr>
<td>10</td>
<td>5.84</td>
<td>34.86</td>
</tr>
<tr>
<td>30</td>
<td>5.19</td>
<td>31.14</td>
</tr>
</tbody>
</table>

0 % penetration = Georgia Electricity mix

(Coal 70 %, Natural Gas 15%, Nuclear 14 %, Hydroelectric 1 %)
Daily Water Saving by PV Penetration

- Household peak demand
  4 kW

- PV penetration
  10%(0.4 kW) and 30%(1.2 kW)

- Load factor
  0.4

\[
\frac{\text{Energy Consumption}}{\text{Energy Availability}}
\]

- Average water consumption for energy
  1.65 gal/kWh
  based on Georgia Energy Mix
  Coal 70%
  Natural Gas 15%
  Nuclear 14%
  Hydroelectric 1%

- Domestic water consumption
  Evapo-transpiration is around 80%
  % of outdoor water use

![Bar chart showing water saving by PV penetration.]

- Water Saving with 10% PV Penetration
- Water Saving with 30% PV Penetration
- Water Consumption for Energy Demand
- Domestic Water Demand
- Domestic Water Consumption
PV Impact on Economic Dispatch

- Economic Dispatch Simulation
  - Short-term determination of the optimal output of a number of electricity generation facilities
  - PV installation may have an impact on the economic dispatch of conventional power plants
  - A typical ramp rate for a non-nuclear thermal power plant is 1% of its maximum operating rate per minute
  - Ramp rate for hydroelectricity is much faster
  - Find optimal economic dispatch for minimizing the generation cost and ecological impact, simultaneously

Outline

- System Interaction
- Urban Growth Modeling and Network Simulation
- Distributed Energy Supply
- Community Growth and Decentralized Water Alternatives
- Social and Economic Issues
LID Best Management Practices (BMPs)

- Bioretention
- Cistern
- Constructed Wetland
- Dry Pond
- Grassed Swale
- Green Roof
- Infiltration Basin
- Infiltration Trench
- Porous Pavement
- Rain Barrel
- Sand Filter
- Vegetated Filterstrip
- Wet Pond

Rain Barrel and Green Roof, Atlanta (Southface)
Vegetated Swale, Vancouver (Crown Street)
Vegetated Slopes, NYC
Sand filter near garages, NYC
Alternatives and Case Studies

- Rainwater Harvesting
- Green space & Onsite WW reclamation
- Sewer Mining and Onsite WW reclamation
- Energy Recovery
- Nutrient Recovery
- Smart Irrigator
- Small Water Fixture
**Wastewater as Energy/Nutrient Resource**

- **Nutrient Recovery**
  Phosphorus reserves: 50 ~ 100 years (Florida source)
  Phosphorus available from feces and urine: 22% of total global phosphorus demand (Mihelcic, 2011)

- **Energy Use for NH₃-N Removal and Fixation**

<table>
<thead>
<tr>
<th>NH₃-N Removal from Wastewater</th>
<th>HABER-BOSCH process for Ammonia Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 kWh/kg as NH₃-N</td>
<td>9 kWh/kg as NH₃-N</td>
</tr>
</tbody>
</table>

- **Energy Recovery with Anaerobic Digester Biogas (CH₄ and H₂)**
  
  - Wastewater Organics (potential): 1.9 kWh/m³
  - King County South Treatment Plant (WA): 0.2 kWh/m³

  for electricity supply by carbonate fuel cell
LID Application to Residential Communities

Water Cycle Per house unit land use, kgal/yr

<table>
<thead>
<tr>
<th>BAU + Rooftop Rain Harvesting</th>
<th>Compact Growth + Rooftop &amp; Rain Garden Harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>Precipitation</td>
</tr>
<tr>
<td>135</td>
<td>298</td>
</tr>
<tr>
<td>2,925 ft²</td>
<td>5,000 x 2 gal</td>
</tr>
<tr>
<td>12,000 gal</td>
<td>Rain garden 2,227 ft²</td>
</tr>
<tr>
<td>81</td>
<td>61</td>
</tr>
<tr>
<td>217</td>
<td>53</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>77</td>
<td>69</td>
</tr>
<tr>
<td>100</td>
<td>53</td>
</tr>
<tr>
<td>sewer</td>
<td>runoff</td>
</tr>
<tr>
<td>54</td>
<td>95</td>
</tr>
</tbody>
</table>

Drinking water supply | Stormwater | Sewer + Runoff | Evaporation
LID for Stormwater Infiltration and Rain Harvesting

Annual Stormwater Management Per house unit land use

- BAU: 72% Stormwater runoff, 28% Infiltration
- BAU + Rooftop rain harvesting: 43% Stormwater runoff, 29% Infiltration
- Compact growth: 52% Stormwater runoff, 48% Infiltration
- Compact growth + Rooftop rain harvesting: 30% Stormwater runoff, 22% Infiltration
- Compact growth + Rooftop & Rain garden harvesting: 25% Stormwater runoff, 41% Infiltration

Bar chart showing the percentage of annual stormwater management per house unit land use for different scenarios.
LCA for Water System

City of Atlanta Water Supply Environmental Life Cycle Assessment

<table>
<thead>
<tr>
<th>Category</th>
<th>Decommissioning</th>
<th>Construction</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuels</td>
<td>14%</td>
<td>79%</td>
<td></td>
</tr>
<tr>
<td>Minerals</td>
<td>30%</td>
<td>69%</td>
<td></td>
</tr>
<tr>
<td>Land use</td>
<td>78%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Acidification/Eutrophication</td>
<td>10%</td>
<td>86%</td>
<td></td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>39%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Ozone layer</td>
<td>9%</td>
<td>20%</td>
<td>70%</td>
</tr>
<tr>
<td>Radiation</td>
<td>6%</td>
<td>25%</td>
<td>69%</td>
</tr>
<tr>
<td>Climate change</td>
<td>2%</td>
<td>18%</td>
<td>80%</td>
</tr>
<tr>
<td>Respiratory inorganics</td>
<td>8%</td>
<td>10%</td>
<td>82%</td>
</tr>
<tr>
<td>Respiratory organics</td>
<td>5%</td>
<td>11%</td>
<td>84%</td>
</tr>
<tr>
<td>Carcinogens</td>
<td>69%</td>
<td>5%</td>
<td>26%</td>
</tr>
</tbody>
</table>
Weighting Factors: Human Health (400), Ecosystem Quality (400), Resources (200)

Eco-Indicator 99 method was used, which ignores “Eutrophication/Acidification” caused by waterborne pollutant.
**Water Supply Stress Index (WaSSI)**

- Water Supply Stress Index (WaSSI)

\[
WaSSI = \frac{\text{Water Intake}}{(\text{Precipitation} - \text{Evapotranspiration}) + \text{Return flow}}
\]

<table>
<thead>
<tr>
<th>Sun et al. (2008)</th>
<th>Southeastern, U.S.</th>
<th>Atlanta, GA</th>
<th>Austin, TX</th>
<th>Nashville, TN</th>
</tr>
</thead>
<tbody>
<tr>
<td>WaSSI</td>
<td>0.146</td>
<td>0.248</td>
<td>0.420</td>
<td>0.189</td>
</tr>
</tbody>
</table>

- WaSSI application for City of Atlanta Water Balance

<table>
<thead>
<tr>
<th>Different Cases</th>
<th>WaSSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010 demand</td>
<td>0.249</td>
</tr>
<tr>
<td>2010 demand with drought*</td>
<td>0.366</td>
</tr>
<tr>
<td>2030 demand</td>
<td>0.269</td>
</tr>
<tr>
<td>2030 demand with drought*</td>
<td>0.392</td>
</tr>
</tbody>
</table>

*drought (30 in.) Vs Average (50 in.)*
Outline

- System Interaction
- Urban Growth Modeling and Network Simulation
- Distributed Energy Supply
- Community Growth and Decentralized Water Alternatives
- Social and Economic Issues
Controlling for other home attributes, what is the impact of energy efficient HVAC systems on home sales prices?

- Chicago MSA (1992-2004); 300,000+ sales

2-5% premiums for energy efficient (zoned) HVAC systems
Neighbor Effects on Adoption Behaviors (micro-level)

- Does your neighbor’s adoption of energy-efficient HVAC affect yours?

- Analyzing house sales records with random effect logistic regression model, contagion matters

- Policy-application example:
  - A block-group of 900 housing units and 40 sales in past 5 years
  - Induce additional 30 sales to adopt:
    - Likelihood to adopt zoned heat: 2% → 6.5%; Zoned A/C: 2% → 4%

- Paper submitting to *Southern Economic Journal*
Genuine Progress Indicator (GPI)

Sum of 24 measures grouped into 4 dimensions of sustainability

- Economic (5): income – adjusted for equality, underemployment, non-market labor
- Social (5): social cohesion – including family, leisure, and crime
- Environment (5): cost of pollution (air, water, noise, waste)
- Resources (9): natural and man-made capital
Development in Atlanta

- Development measured as change in welfare
- Welfare measured by GPI

Graph shows average of 28 county results for MSA

From it, we can say:
- GPI increased 1980-2000
- Only Economic dimension positive
- Social, Environment, Resources dimensions reduce overall welfare by about half of Economic welfare
- Gains in Economic dimension somewhat at the expense of Social and Resource welfare decline


Conference Proceedings


Conference Proceedings

- Bert Bras. Effect of water policies on vehicle design, Panel Presentation, ASME IDETC, Washington, DC, August 30.
Conference Proceedings

Book Chapters

- Sustainable Infrastructure and Alternatives for Urban Growth, John Crittenden, Steve French, Arka Pandit, Hyunju Jeong, Ke Li, Ming Xu, in C. Heriberto, U. Diwekar (Eds) Sustainable Infrastructure and Urban Growth
Journal Paper

Journal Paper

In Press


Under Review

• Maliszewski, P. J. and C. Perrings. “Estimating the capitalized value of 'resilience' in urban power distribution infrastructures”, Energy Policy
• Maliszewski, P. J., Larson, E. K. and Perrings, C. “Valuing the reliability of the electrical power infrastructure: A two stage hedonic approach”, Energy Journal
• Bozchalui, M. C., Sharma, R. and Zhang, X. “Optimal operation of rural hybrid microgrids using multi-objective optimization,” IEEE Trans. on Smart Grid, special issue on microgrids,
• P. Zhai and E. Williams, “The coordinative function of renewable energy policies—regulations, financial subsidies and funding sources”, Renewable Energy
THANK YOU!