Water for Everything & the Transformative Technologies to Improve Water Sustainability

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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.

- 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 will drive greater adoption of more sustainable infrastructure.
Gigaton Problems Need Gigaton Solutions

We need 1 million kiloton solutions

- With 1 billion people using 78 Gt of materials, 13.4 Gtoe of energy, 3,906 Gm$^3$ of water and emitting 8.6 Gt of Carbon per year globally to produce 71,000 G$\$$ GDP, 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 everyone has the same life style and uses today's technologies.

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**World Water Use by Sector**

- **Irrigation**: 66.88%
- **Electricity**: 15.94%
- **Manufacturing**: 6.63%
- **Domestic**: 9.78%
- **Livestock**: 0.77%

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**Material Use by Sector**

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- **Electricity**: 15.94%
- **World Water Use**
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**Population and Resource Use**

- **Population (Total)**: 7.3 billion
- **Material Use (Gt/yr)**: 13.4 billion
- **Energy Use (ton of oil equivalent)**: 8.6 billion
- **Carbon from Fossil Fuels (Gt/yr)**: 3,906 billion m$^3$
- **Water Use (100 Km$^3$/yr)**: 0.8 billion

Note: Material use includes food
Anthropogenic warming is estimated to have accounted for 8–27% of the observed California drought anomaly in 2012–2014 and 5–18% in 2014. (Source: Williams, A. P., et al 2015)

Climate Change

Rate of temperature change (°F per century) in the United States, 1901-2014

*Alaska data start in 1925.


For more information, visit U.S. EPA’s “Climate Change Indicators in the United States” at www.epa.gov/climatechange/indicators.
Climate Change

The Palmer Drought Severity Index (PDSI) uses readily available temperature and precipitation data to estimate relative dryness. It is a standardized index that spans -10 (dry) to +10 (wet).
El Niño could bring torrents of rain for California by the end of this year

The concerns:

- Turn from trying to manage water rationing and forest fires to preparing for floods, mudslides and debris flows that follow extended dry periods;
- Lull Californians back to long showers and daily dousing of lawns and the game of conservation will be over.
- What if the prediction was wrong?
Climate Change and Changing Landscape for Municipalities

On 16 April 2014, Farmers Insurance Company filed a lawsuit against nine municipalities in and around the Chicago

• Municipalities failed to prepare for climate change
• Farmers had to pay claims resulting from strong storms a year earlier that had overwhelmed sewer systems and flooded homes and businesses.
• Farmers claimed that the municipalities knew about climate change and its increased potential to cause flooding.
• They failed to take reasonable preventative actions.
• Farmers sent a clear signal to local governments, private developers, and others that a new era had arrived.
System View of Water
Water for Energy in US

Water for Fuel Extraction and Processing

- Cellulosic ethanol: 90
- Corn ethanol: 1010
- Coal + coal to liquid: 50
- Natural gas + gas to liquid: 43
- Oil sands: 30
- Oil (enhanced oil recovery): 76
- Oil (primary - secondary): 73
- Uranium mining + enrichment: 9.5
- Coal + slurry pipeline: 9
- Coal mining + washing: 4
- Natural gas + transportation: 3
‘Water for Energy’ and ‘Energy for Water’ in US

Water for Energy

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

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

Energy for Water

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

<table>
<thead>
<tr>
<th>Water Treatment*</th>
<th>kWh/MGal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water Treatment</td>
<td>220</td>
</tr>
<tr>
<td>Groundwater Treatment</td>
<td>620</td>
</tr>
<tr>
<td>Brackish Groundwater</td>
<td>3,900-9,700</td>
</tr>
<tr>
<td>Seawater Desalination</td>
<td>9,700-16,500</td>
</tr>
</tbody>
</table>

*Includes collection but does not include distribution
Unsustainable Livestock

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

- 2.5kg feed (5.5 lb) for 5.8m³ water (1000 gallons)
- 5kg feed (11 lb) for 5.5m³ water (1500 gallons)
- 10kg feed (22 lb) for 16.7m³ water (4400 gallons)

Growing appetite for MEAT!

2015: 7.2 billion
2050: 9 billion

Source: Green Food. Economist Technology Quarterly Q1 2015
Water Consumption for Food

Agriculture Water Consumption and Use Efficiency in California, 2010: 8.7 million acre-foot in total

- Alalfa
- Rice
- Pasture
- Al Pistachio
- Corn
- Oth Fld
- Oth Dec
- Oth Trk
- Vine
- Subtrop
- Grain
- Cotton
- Pr Tomato
- Cucurb
- On Gar
- Dry Bean
- Sg Beet
- Fr Tomato
- Potato
- Safflower

Water Consumption (Acre-foot) vs. Water Efficiency (% of Efficiency)

- Water Consumption (green)
- Water Efficiency (blue)

- 0.50
- 0.55
- 0.60
- 0.65
- 0.70
- 0.75
- 0.80
- 0.85
- 0
- 200,000
- 400,000
- 600,000
- 800,000
- 1,000,000
- 1,200,000
- 1,400,000
- 1,600,000
- 1,800,000

- 0.50
- 0.55
- 0.60
- 0.65
- 0.70
- 0.75
- 0.80
- 0.85

- 0
- 200,000
- 400,000
- 600,000
- 800,000
- 1,000,000
- 1,200,000
- 1,400,000
- 1,600,000
- 1,800,000
California is the country’s largest agricultural producer and exporter.

California agricultural production was valued at $46.7 billion in 2013, accounting for 17.3% of total U.S. agricultural output.

California’s agricultural production includes more than 400 commodities, primarily comprised of specialty crops including almonds, grapes, and strawberries.

California’s top-ten valued commodities for 2012 were: Milk ($6.9 billion); Grapes ($4.4 billion); Almonds ($4.3 billion); Nursery plants ($3.5 billion); Cattle, Calves ($3.2 billion); Strawberries ($1.9 billion); Lettuce ($1.4 billion); Walnuts ($1.3 billion); Hay ($1.2 billion); and Tomatoes ($1.17).
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
# 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>Land Requirements</td>
<td>20 Acres</td>
<td>620 Acres</td>
</tr>
<tr>
<td>Leafy Green Production Yields Per Year</td>
<td>33 Million Heads</td>
<td>33 Million Heads</td>
</tr>
<tr>
<td>Fossil Fuel used during Growth Cycle (not including crop transport)</td>
<td>200 Gallons equiv. Diesel</td>
<td>3,720 Gallons Diesel</td>
</tr>
<tr>
<td>Food Miles</td>
<td>100 miles/truckload</td>
<td>2,577 miles/truckload</td>
</tr>
<tr>
<td>Fossil Fuel to Transport 100 Miles or CA to Local Markets</td>
<td>22,200 Gallons Diesel</td>
<td>571,000 Gallons Diesel</td>
</tr>
<tr>
<td>Carbon Footprint</td>
<td>3,000 metric ton CO2</td>
<td>12,000 metric ton CO2</td>
</tr>
<tr>
<td>Fresh Water used during Growth Cycle</td>
<td>1.2 Gallons per Head</td>
<td>9-42 Gallons per Head</td>
</tr>
<tr>
<td>Fresh Water Used to Wash Lettuce per heat for market</td>
<td>0.7 One Water per Head</td>
<td>2.5 Three Washings per Head</td>
</tr>
<tr>
<td>Total Fresh Water Annually</td>
<td>64 Million Gallons</td>
<td>0.3-1.5 Billion Gallons</td>
</tr>
<tr>
<td>Time from Harvest to Market</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.
About

Functions:
• Fish hatchery
• Hydroponic garden
• Commercial kitchen
• Brewery

Former meat packaging building situated in the middle of a food desert - Huffington Post

System based farming and agriculture, with **aquaponics** at the core

“Chicago’s first off-grid vertical farm & artisanal food biz incubator” - (Facebook page)

Video:

[https://youtu.be/zMBxJTQqnR](https://youtu.be/zMBxJTQqnR)
In 2013, gold production was 146,500 ounces. Gold dominated California’s metal production and comprised over 99% of the value of the state’s metals production. The water consumption of gold production was 848 acre-feet.
Water Productivity of U.S. Industries ($ in 2015 per gallon water)

Water for Transportation: Impact of Fuel Types and Vehicle Technologies

Life-cycle Water Consumption Per Vehicle Mile

<table>
<thead>
<tr>
<th>Fuel Consumption</th>
<th>Vehicle Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal + Carbon sequestration</td>
<td>0.77</td>
</tr>
<tr>
<td>Solar PV</td>
<td>0.79</td>
</tr>
<tr>
<td>Concentrated Solar Power</td>
<td>0.32</td>
</tr>
<tr>
<td>Unleaded</td>
<td>4.35</td>
</tr>
<tr>
<td>Corn ethanol</td>
<td>12.25</td>
</tr>
<tr>
<td>Switchgrass—no irrigation</td>
<td>2.45</td>
</tr>
<tr>
<td>Switchgrass—irrigation</td>
<td>3.85</td>
</tr>
<tr>
<td>Soy biodiesel</td>
<td>0.97</td>
</tr>
<tr>
<td>Algae biodiesel—open</td>
<td></td>
</tr>
<tr>
<td>Algae biodiesel—closed</td>
<td></td>
</tr>
</tbody>
</table>

Plug-in hybrid electric vehicle (PHEV) vs. Conventional (internal combustion engine)
Water for 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
System Thinking of Infrastructure Ecology
Water Resource Withdrawal Profile in the United States

- Irrigation: 39%
- Thermoelectric: 39%
- Industrial: 5%
- Public Supply: 13%
- Mining: 1%
- Aquaculture: 1%
- Livestock: 1%
- Domestic: 1%
- Decentralized Water Production: 13%
Low Impact Development (Reducing Storm Water Runoff, Erosion and Surface Water Contamination) - LID Best Management Practices (BMPs)

Rain Gardens for local flood control at Cuyahoga Falls, OH¹.

Green roof of City Hall in Chicago, IL.

Rainwater Harvesting tanks for residential water supply at Perth, Australia².

Increased walkability through greening of alleyways at Vancouver.

Porous parking lot at the Reliant stadium, Houston, TX³.
Water Flows with LID and Reclamation

a 2-story apartment unit of Atlanta, GA (Gal/Capita-day)

Smaller Flow, More Concentrated;
Smaller Plant:
Better energy and nutrient recovery.
System-based Benefits of LID Best Management Practices

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

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

Green Infrastructure

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

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

Can Enhance Other Infrastructures

Transportation Infrastructure
- Pedestrian walkways
- Cycling

Food Infrastructure
- Urban agriculture

Energy Infrastructure
- Reduced heat island

Enables:
- Energy Efficiency and Recovery (reduces energy demand)
- Nutrient Recovery (can be utilized for green infrastructure projects)
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%
Decentralized Energy Production at Perkins + Will, Atlanta Office

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

**Adding Distributed Generation as part of the Grid:**

- Water Reduction: >50%
- CO$_2$ Reduction: 15 - 40%
- NO$_x$ Reduction: ~90%
Future Research: Expanding the Current CCHP System 2.0

Conventional System
- Energy Inputs
- Furnace or Boiler
- Heat → Building
- Electricity → Power Grid
- Energy Inputs

Proposed CCHP System
- Energy Inputs
- Air-cooled Microturbine
- Electricity 30% → Electricity 70%
- Heat
- Cooling
- Alternative 1: Thermal Storage
- Absorption Chiller
- Alternative 2: Battery/Electric Vehicle
- Alternative 3: Photovoltaics
- Wind
Closing the Urban Water, Nutrient, Energy and Carbon Loops

**Urban Agriculture**
(Aquaponics, Urban Farming, Greenhouse Farm)

- Stormwater Management with Low-Impact Development
- More Concentrated Wastewater
- On-site Energy and Nutrient Recovery
- Stormwater treated through LID
- Harvested Rainwater
- Fertilizer for Farms, Food for Aquaponics

- Local Composting
  - Heat
  - Heat and Energy
  - Natural Gas from Compost

- Landfill
  - Natural Gas from Landfill
  - Natural Gas from Anaerobic Digestion

- Combined Carbon Capture, Cooling, Heating and Power (Air-cooled microturbines)

- Natural Gas
- Heat and Energy
- Water
- Fertilizer
- CO2 Injection
Transit-oriented Development

• 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
The Synergistic Effects of “Infrastructural Symbiosis”

The possible 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 8 important grids. They include: (1) nutrients, (2) natural gas, (3) water, (4) electricity, (5) thermal, (6) transportation and (7) material grids, and (8) economic flows.

• In past, these grids were mostly constructed in isolation and we did not consider there interactions.
Manage the Complexity in Infrastructure Systems
Interconnections between Infrastructure and Socio-Economic Environment

Macro

Infrastructure Systems

Socio-Economic Environment

Micro
Los Angeles 1950s versus Today

Air and Water Quality has improved dramatically
Big Data for Social Decision and Complexity Modeling

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

Analyze
- Enrich and prepare social media content with metadata

Topic Modeling

Modeling
- Agent-based urban model and visualization
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 ~ 0.007 Gt CO$_2$, NO$_x$ emissions by ~ 15000 Tons, and the energy costs by $680 million per year for the Metro Atlanta region.
Summary

- Infrastructure Systems Are All Connected and Greater Sustainability Gains in Water Management Can be Achieved by Looking at Their Interactions

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


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

- Complexity Models May Be Useful to Examine the Adoption Rate of Policy Instruments

- Caveat: We need to test the ideas that were presented
THANK YOU!

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