Sustainable Water Use in Cities and Industry: *Future Challenges and Promising Strategies*

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Key to addressing

Sustainability

is to

Define it.

The definition of ***Sustainable Development*** according to the World Commission on the Environment & Development (1987) is:

"To meet the needs of the present without compromising the ability of future generations to meet their own needs"

Future = 2 generations = 50 years

Social justice

Update:

"Yet in the end, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs. . .Painful choices have to be made. Thus in the final analysis, sustainable development must rest on political will."

WCED 1987, Our Common Future

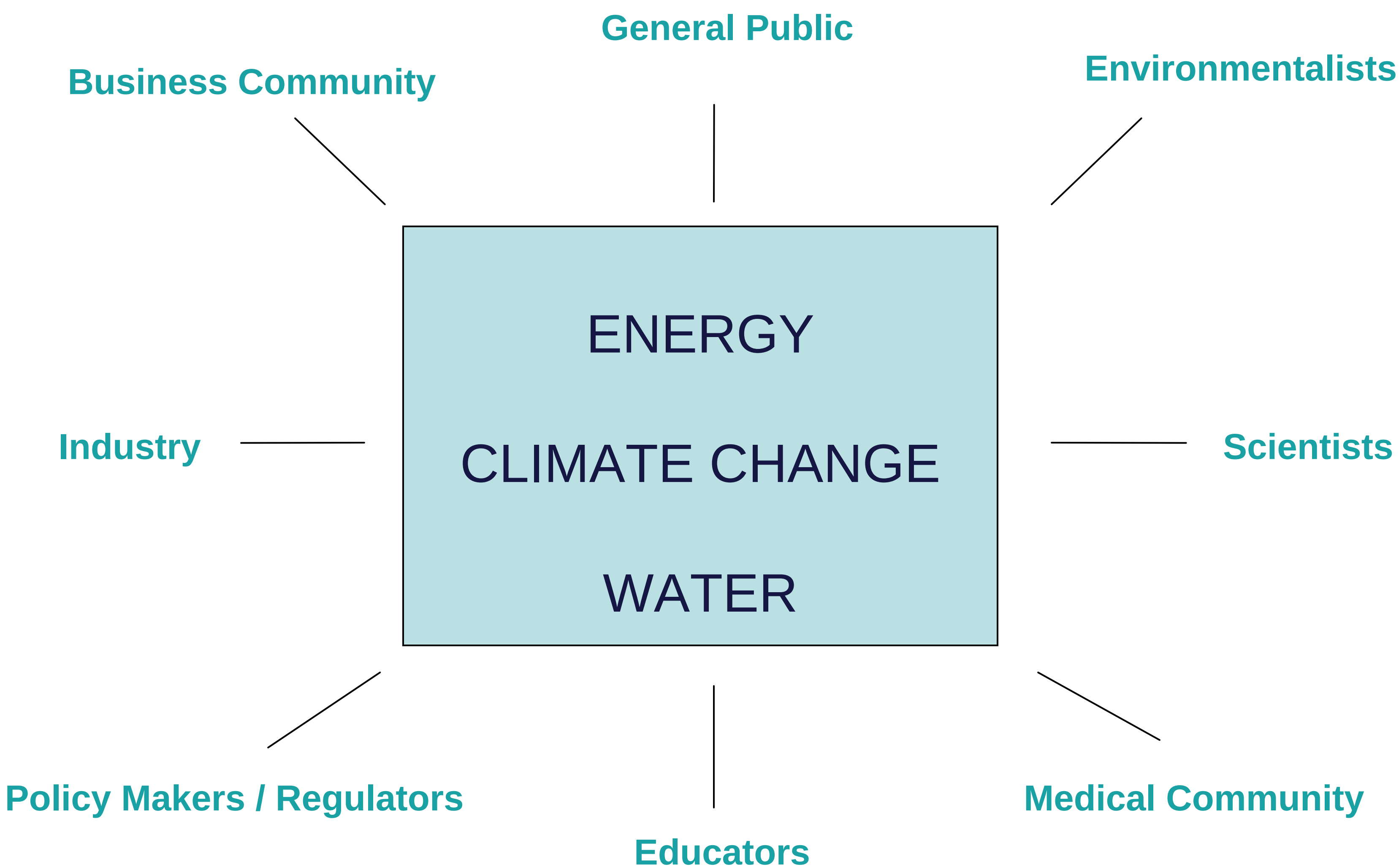
Define Sustainability - simply

- Universal goal - survive and prosper, **indefinitely**
  - Corporations - sustainable enterprises
  - Societies - sustainable social systems
  - Ecosystems - sustainable ecological systems
- Yet, there is some reluctance (although this is waning) to embrace sustainable development because of sense that it is "anti-growth," static?
- What is sustainable growth?

Create value without depleting non-renewable resources or causing irreparable environmental damage

Depending on our perspective, our understanding of issues and appropriate action is highly

VARIABLE



Canadian Tar Sands/Heavy Crude

(2.5 T Barrels Alberta, 315 B Barrels Recoverable)

- **Extraction**: Between 2 to 4.5 volume units of water are used to produce each volume unit of synthetic crude oil (SCO) in an ex-situ mining operation. Despite recycling, almost all of it ends up in tailings ponds; currently 349M m^3/y.

- **Refining:**

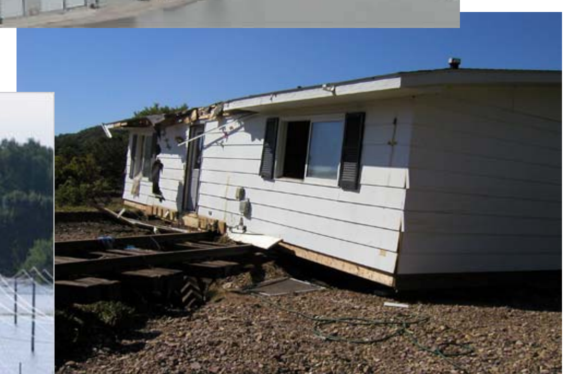
Emissions per Barrel Produced

Emission	Conventional Oil	Oil Sands
SOx (g)	43	106
NOx (g)	95	132
Greenhouse Gas (kg)	29	78
Water (barrels)	0	3-5

Energy, Climate Change & Water Tightly Coupled

- Climate Change-Water: Floods (Midwest region of USA)
  Droughts (Western USA)



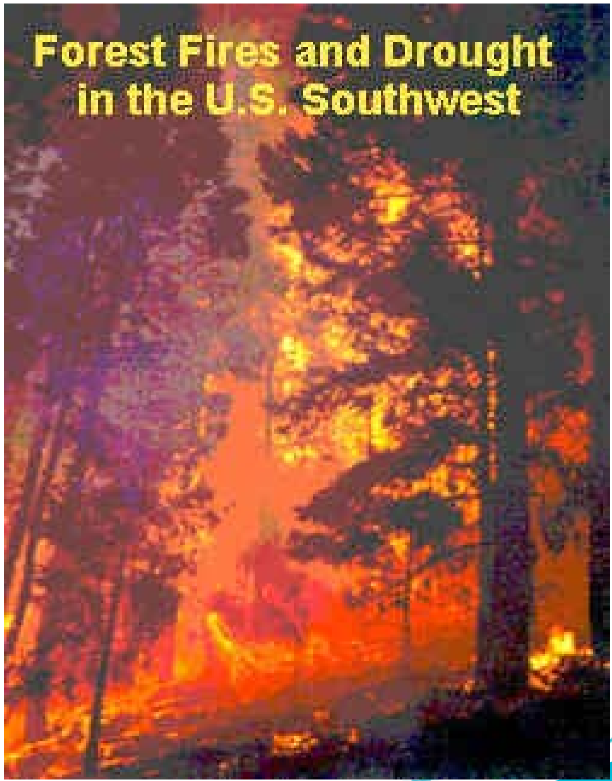



Energy, Climate Change & Water Tightly Coupled

- Climate Change -Water: Floods (Midwest region of USA)
  Droughts (Western USA)

- Steven Chu– Climate change & no more agriculture in CA

Lake Powell, Arizona/Utah



- In a worst case, Chu said, up to 90% of the Sierra snowpack could disappear, all but eliminating a natural storage system for water vital to agriculture. **"I don't think the American public has gripped in its gut what could happen," he said.**
- We face desertification of perhaps a third of the earth that is "largely irreversible for 1000 years" — if homo sapiens are not sapiens enough to sharply and quickly reverse emissions trends.
- "Australia faces collapse as climate change kicks in. "But the Southwest from Kansas and Oklahoma to California are right behind Australia, according to a 2007 Science paper: Here we show that there is a broad consensus among climate models that this region will dry in the 21st century and that the transition to a more arid climate should already be under way. **If these models are correct, the levels of aridity of the recent multiyear drought or the Dust Bowl and the 1950s droughts will become the new climatology of the American Southwest within a time frame of years to decades.**

Water:

- < 3% of water on earth fresh; we use only about 0.003 of that quantity & only about 10% of freshwater falling to earth’s surface

  - From this perspective - naturally scarce

- Human use - 70% agriculture

  19% industry

  9% homes

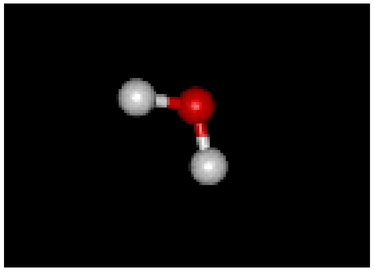
  2% evaporation reservoirs

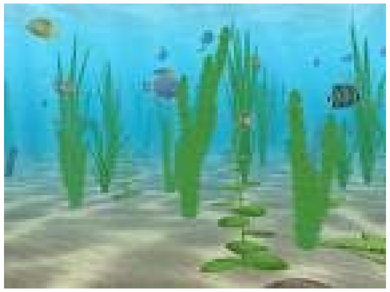
- Irrigation - almost tripled in 50 yrs.

  - 1950 - 100M hectares; 2005 - 276 ha

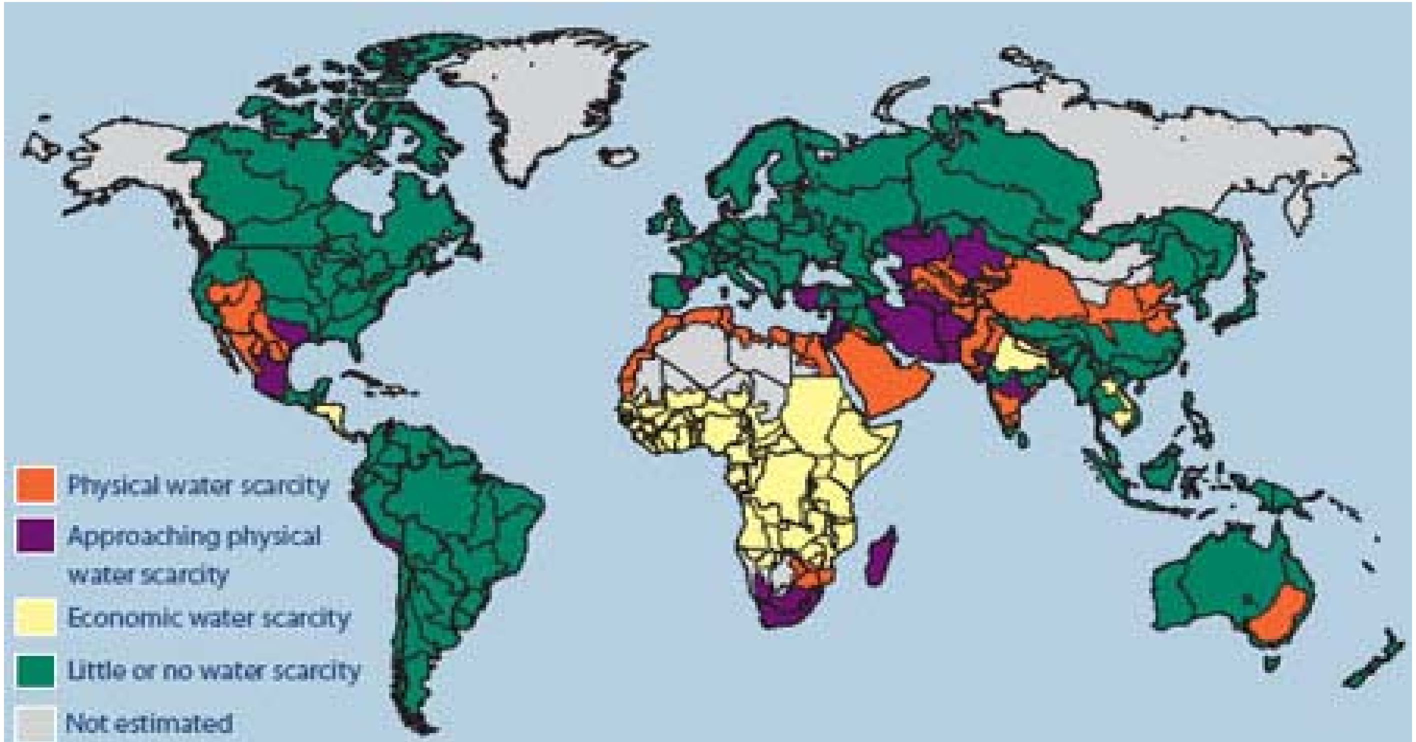
- By 2025 - global water withdrawals and consumption expected to rise by up to 30% in de veloping countries and 10% in developed world

- UN estimates: By 2025, 1.8 billion people affected by absolute water scarcity (can’t meet basic needs)





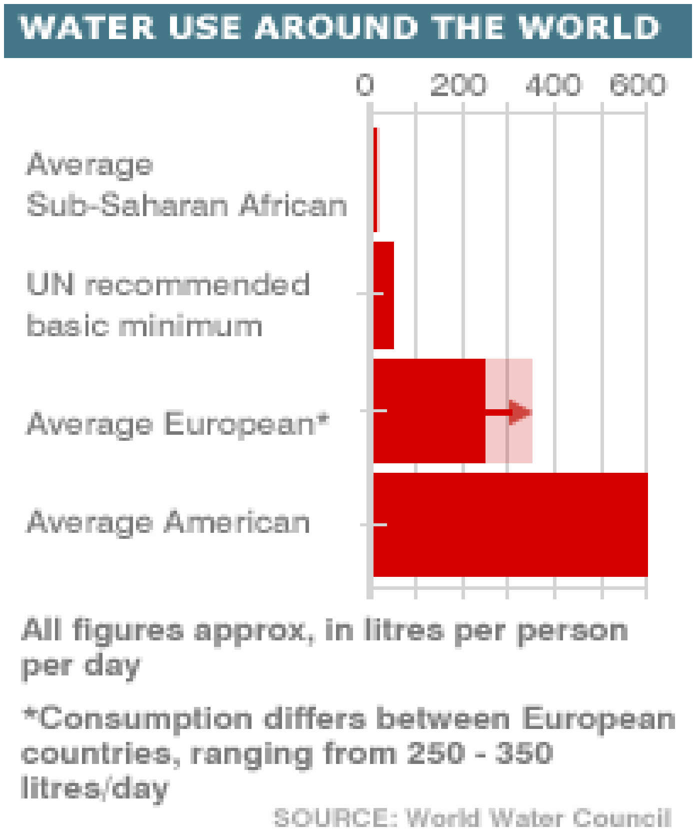
Areas of Physical & Economic Water Scarcity

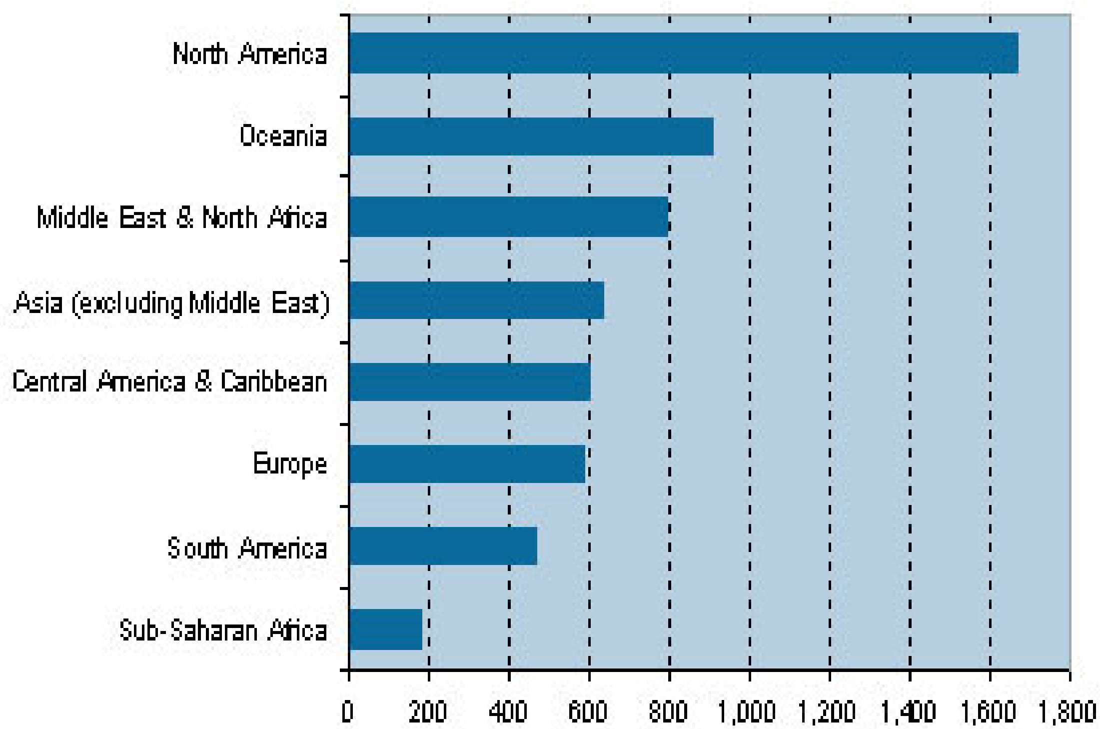


- **Little or no water scarcity.** Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- **Physical water scarcity** (water resources development is approaching or has exceeded sustainable limits). More than 75% of the river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- **Approaching physical water scarcity.** More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- **Economic water scarcity** (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: UN-Water 2007 http://earthtrends.wri.org/updates/node/264

Per Capita Water Use





Cubic meters /yr

Source: EarthTrends, 2007

Much of our current efforts focused on :

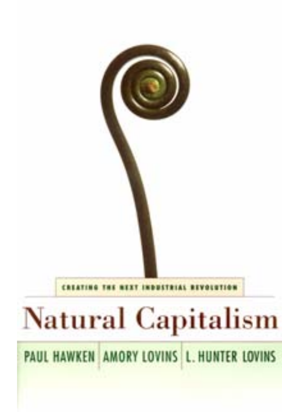
- **Working to be *less bad***

- **Tacking new technologies on old models**

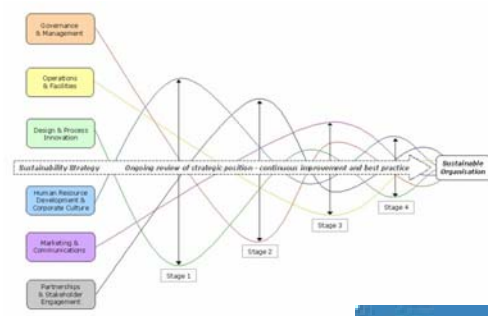
- **Reuse or recycle (down-cycle) of materials as simply a detour along route to landfill**

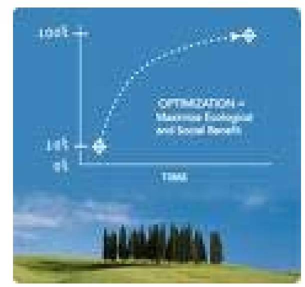
- **Inappropriateness of resource use**
  - **Tree ---> Paper ??**
  - **Products typically contain only 5 - 7% of raw materials consumed in making them**
  - **99% of original materials of most products waste with 6 weeks of sale**
  - **80% of most products discarded after single use.**

Design Paradigm of *Natural Capitalism*



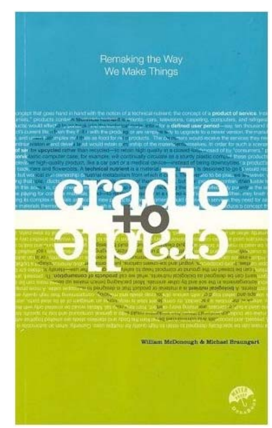
- Radical resource productivity
- Biomimicry
- Service & flow economy
- Investing in Natural Capital





Design Paradigm of *Cradle to Cradle*

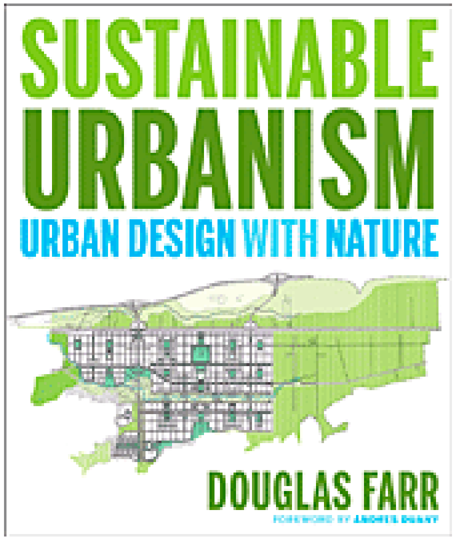
- Waste = Food
- Use current solar income
- Celebrate diversity
- Base design on "operating system of nature"



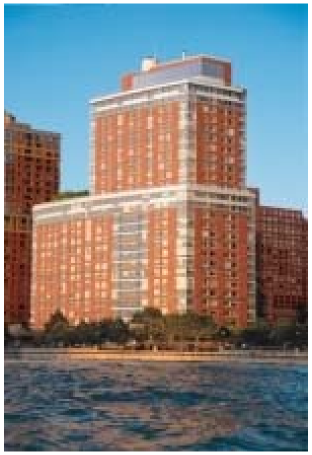
Design Paradigm of *Sustainable Urbanism:*

Urban Design with Nature (Doug Farr)

- **Walkable & transit-served**
- **Integrated with high-performance buildings & high-performance infrastructure**
- **Context – neighborhood**
  - **Definition (defined center & edge)**
  - **Compactness (density)**
  - **Completeness (meeting needs)**
  - **Connectedness**
  - **Biophilia (human access to nature)**



Ecologically Sound City:

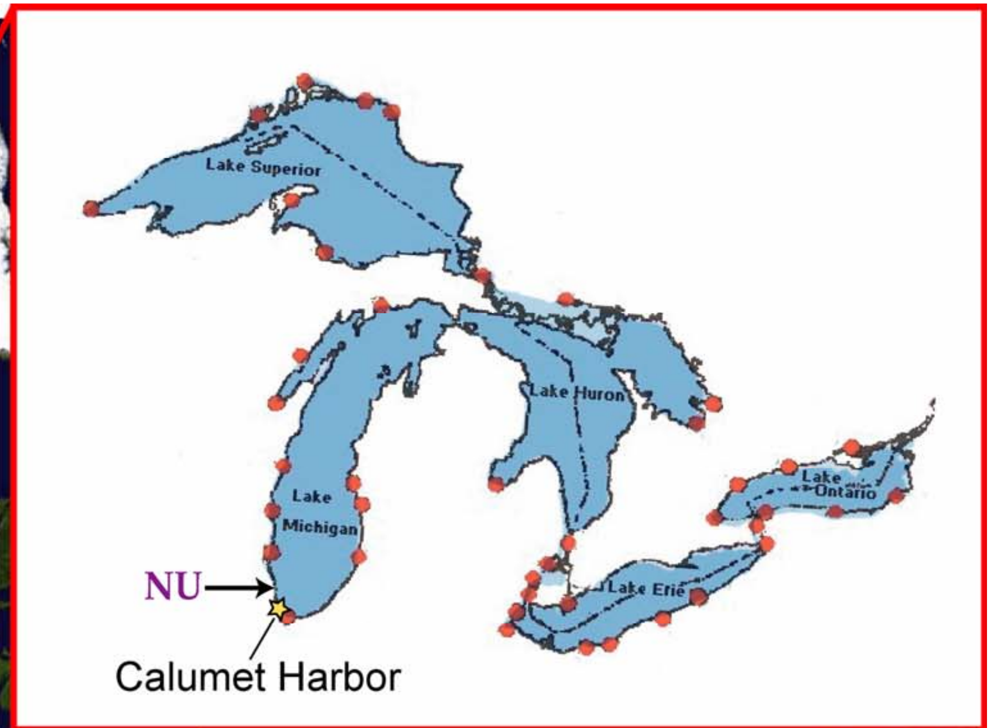


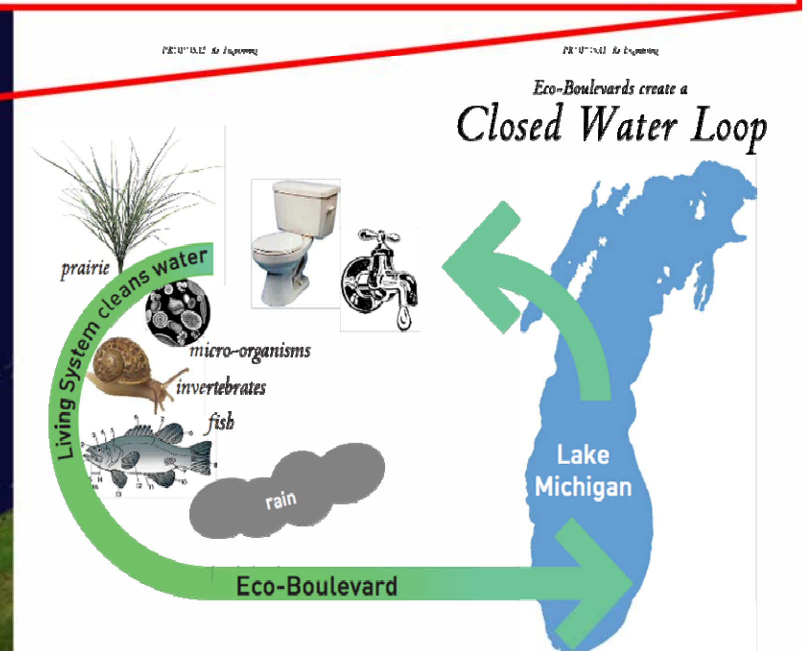
Solaire Building, Battery Park

- **Rediscovery of old, passive strategies**
- **Greater reliance on nature**
- **Technologies in place, but need to be more efficient, miniaturized, *integrated* and adapted to renewable energy sources, bio-inspired**
- **Context – systems thinking**
- **All sustainability is local**

Capitalize on principles of ecological cycling

Chicago, Illinois USA

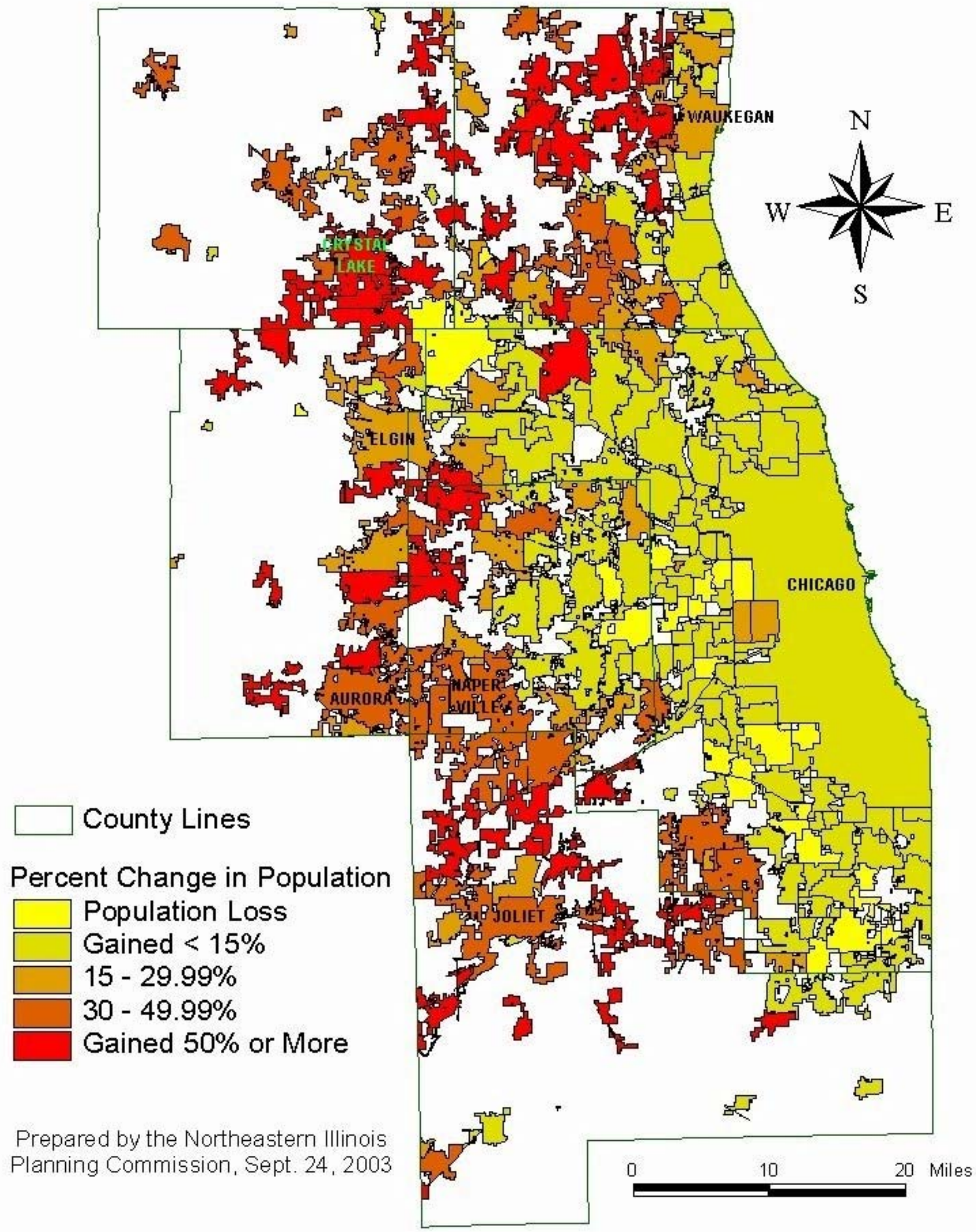




North American Great Lakes:

- Total population – 34 M
- 20% of global freshwater supply.
- Largest continuous freshwater mass.
  - Highly vulnerable:
  - Spatial constraints.
  - Urban/industrial centers.
  - Shipping

Percent Change in Population by Municipality in Northeastern Illinois, 1990-2000

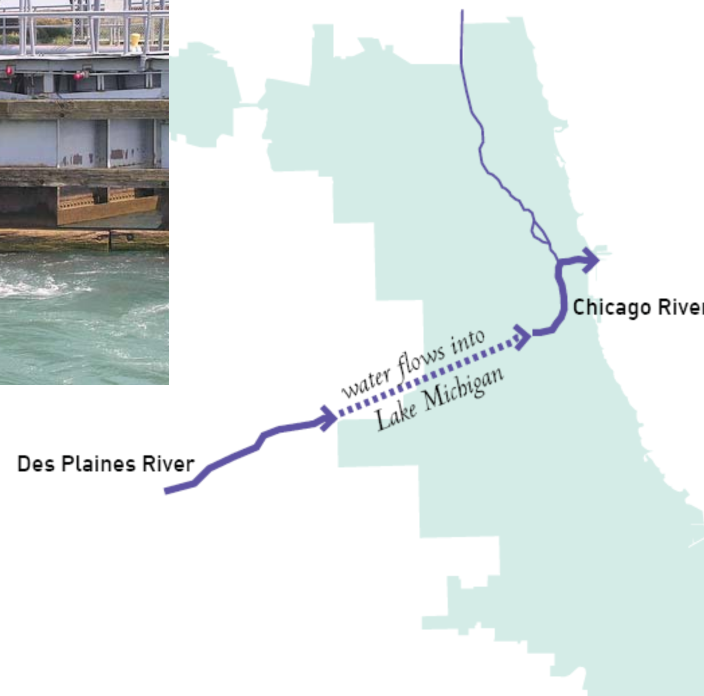


Design Idea

1900 – Reverse the flow

of the Chicago River

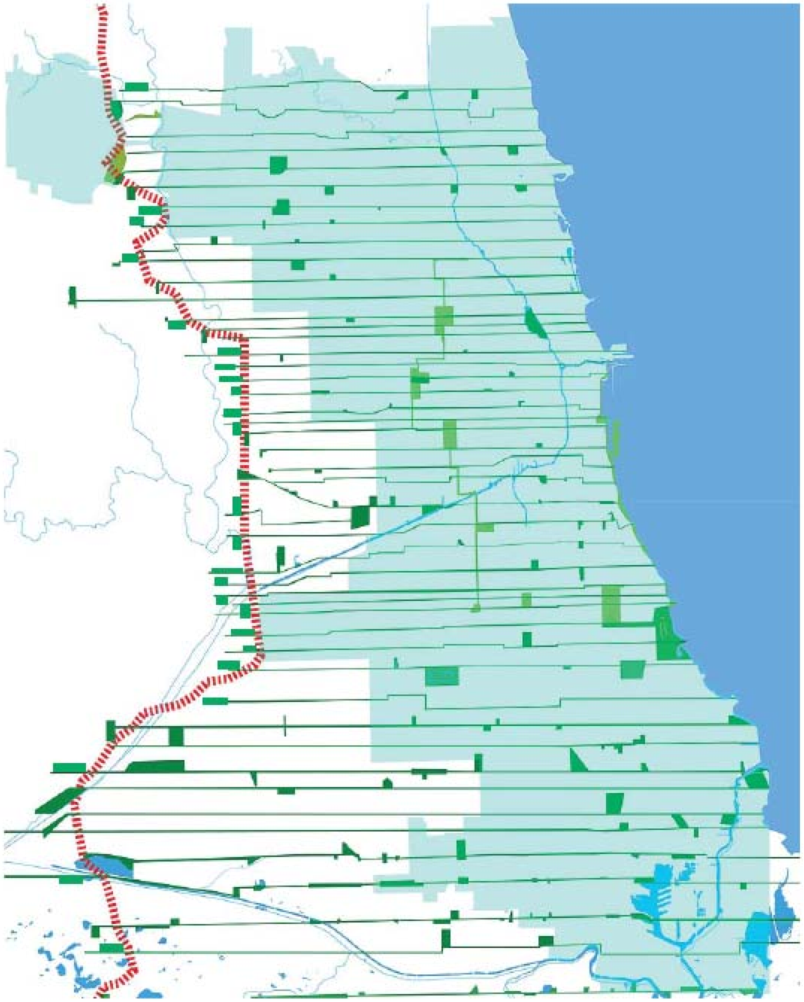
Un-Reverse River



The river will no longer divert water from the Great Lake Basin to the Mississippi Watershed.

Source: UrbanLab

UrbanLab's Vision: Growing Water



Indicates the location of the Eco-boulevards

the city will become a holistic

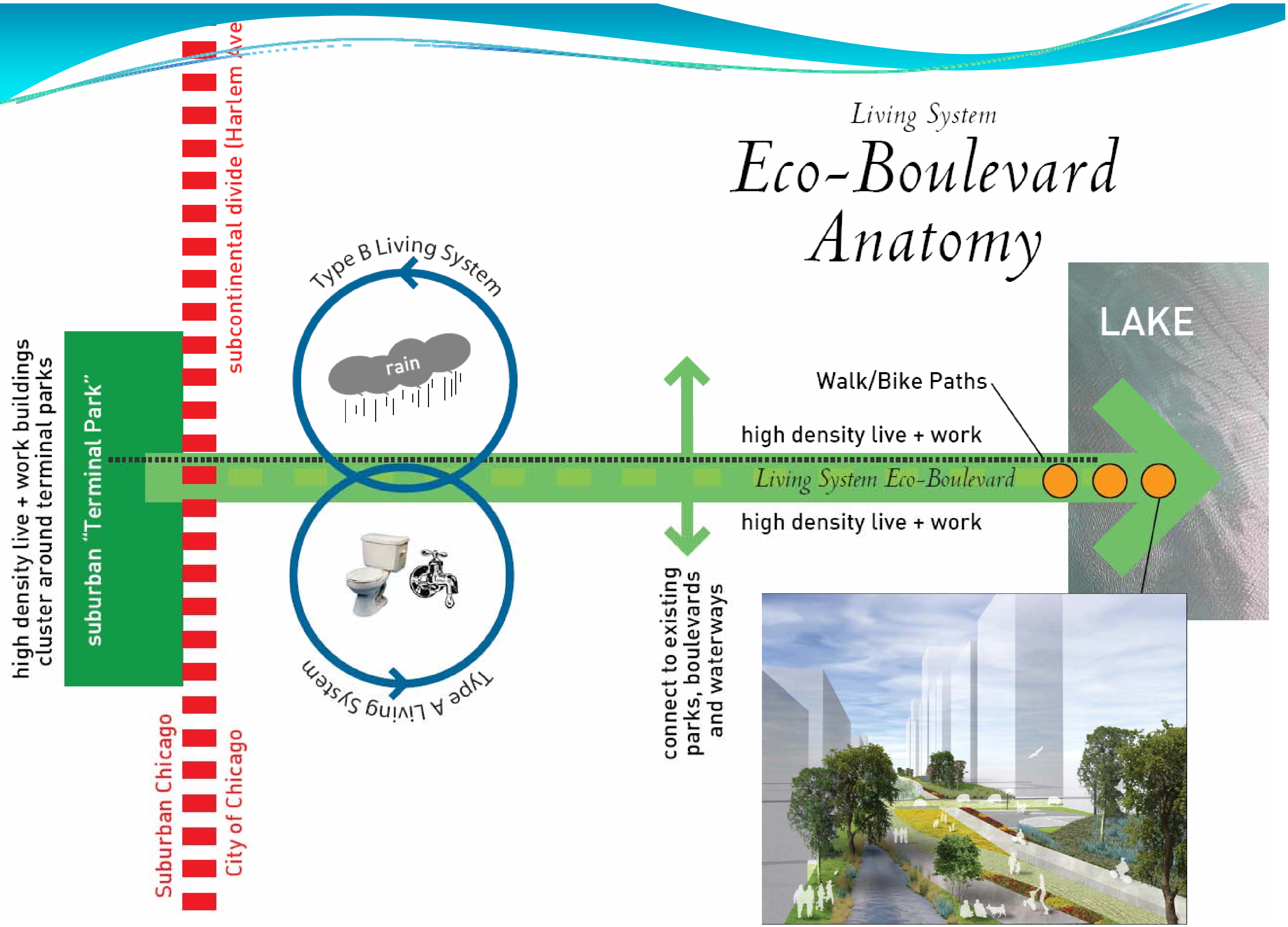
Living System

multiplying + intensifying Chicago's
"Emerald Necklace"
of parks, boulevards and waterways;
and,
saving, recycling and "growing"

100%

of its own water,
which will become the
world's most valuable resource.

Source: UrbanLab



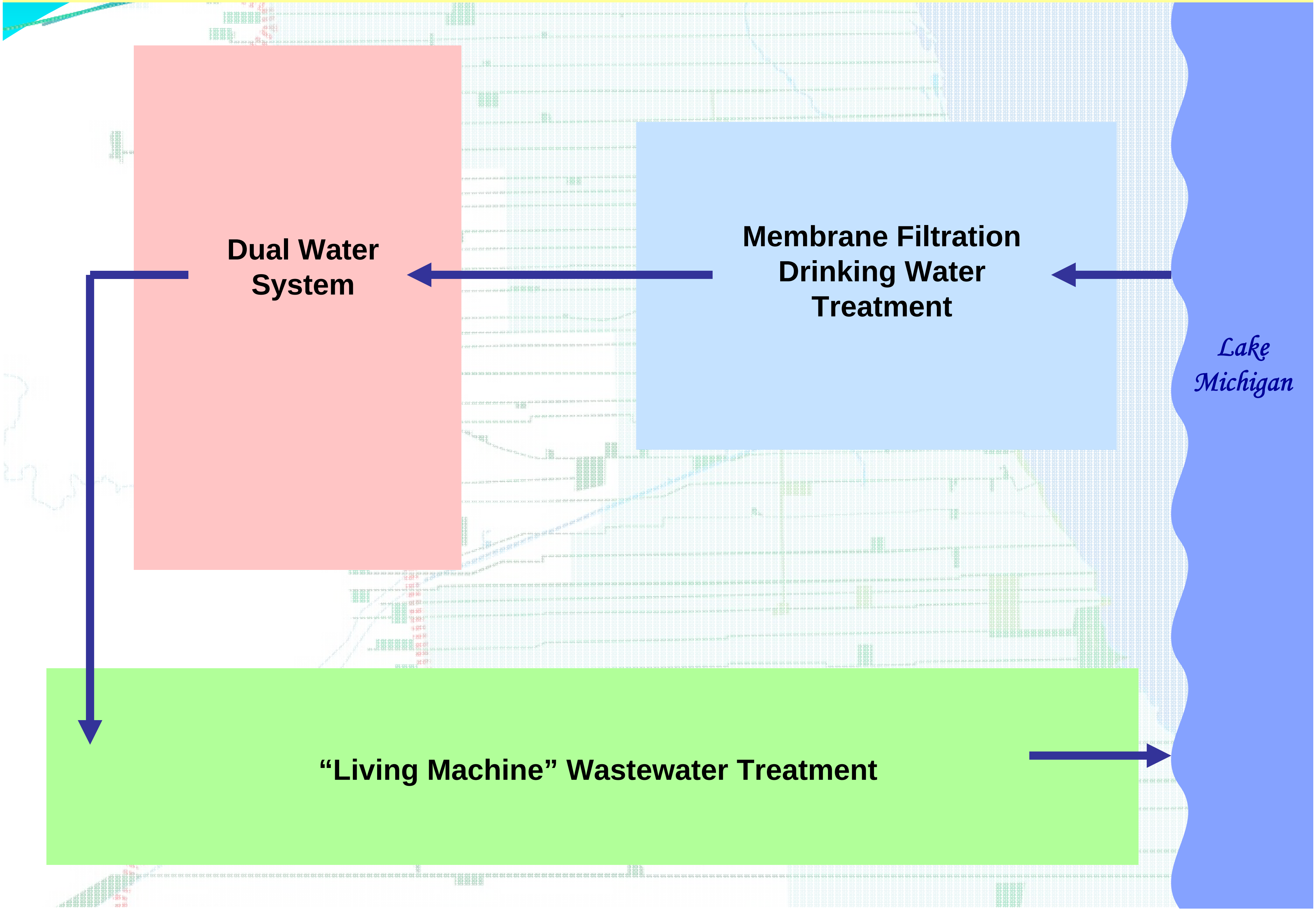
Source: UrbanLab

Guiding Principles:

- Biomimicry
- Decentralization
- Integrated systems
- Reduced water & energy use
- Renewable energy

- Closed-loop
- Reduction of synthetic chemicals
- High density
- Couple energy + water

Water to Water: Reengineering the "Nature" of Chicago's Water Cycle for 2107



Water Demand Projections

Base Water Use: 2000 *versus*

1. No Conservation: 2100
2. Conservation: 2100

Sector	2000	2100 (no conservation)	2100 (conservation)	Unit
Commercial	93.4	113.8	95.1	MGD
Industrial	49.6	60.5	50.5	MGD
Average Daily Demand	462.6	845.2	596.9	MGD
Residential - Multifamily	319.6	670.8	451.3	MGD
Gallons/person/day (residential only)	110.35	136.95	92.14	GPCD

24.1% increase
in per capita demand
without conservation

16.5% decrease
in per capita demand
with conservation

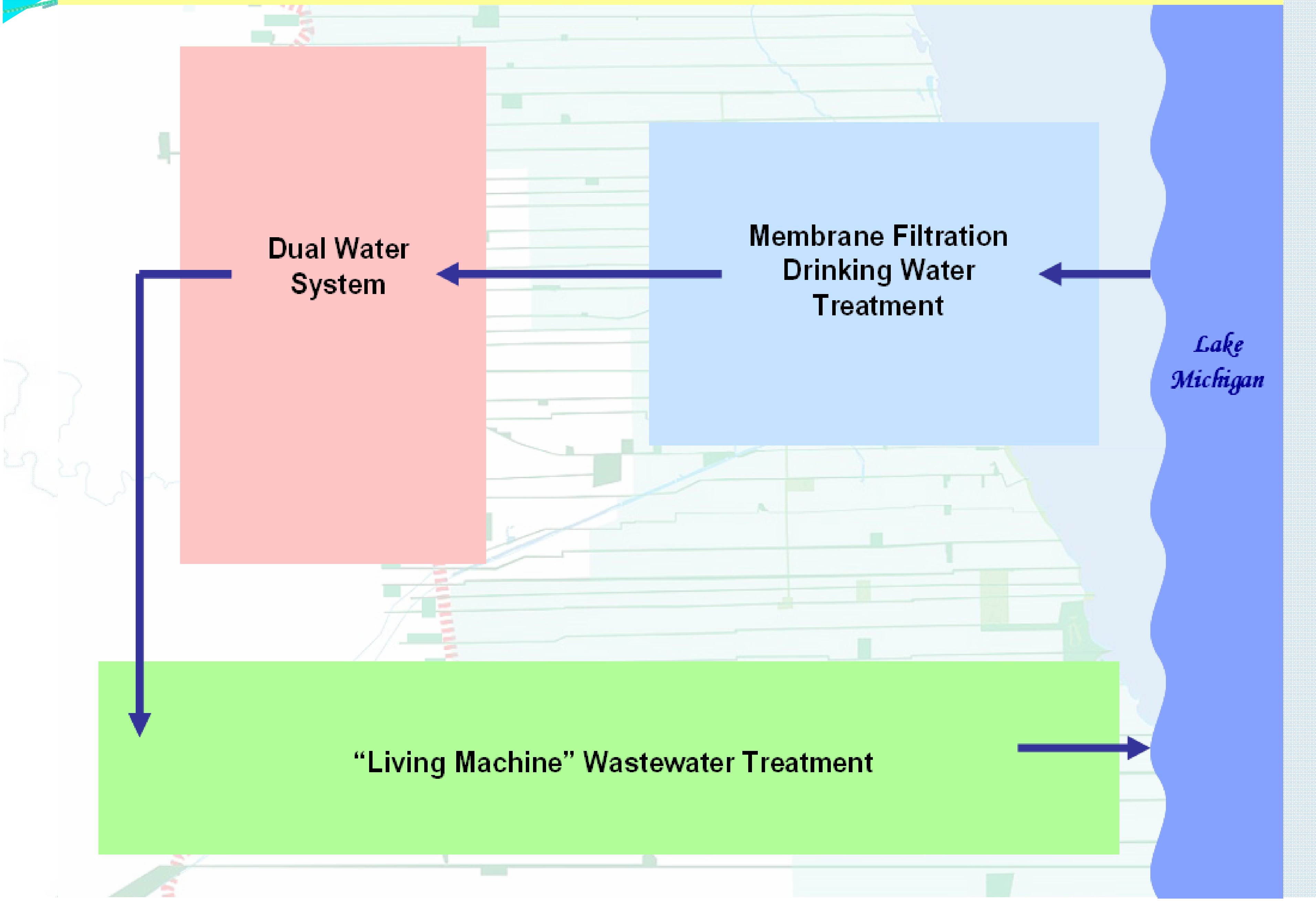
Solutions to Decrease Water Demand

- Only a portion of the total water supplied to each sector must be potable → this quantity will be processed by advanced membrane filtration → increased efficiency, cost and energy savings

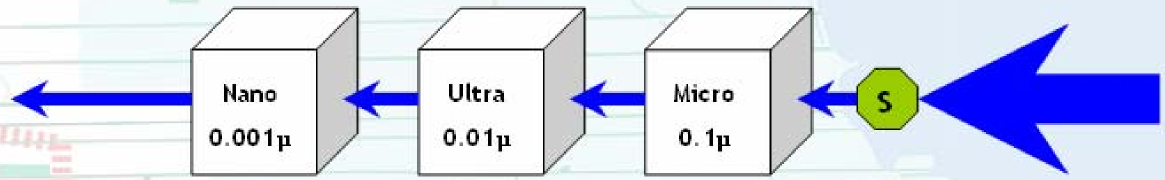
- Highly efficient fixtures/appliance and dual water systems → enable overall reduction, recycling, and reuse of drinking water

Potable Water Supplied to Each Sector	2000 (MGD)	2100 (MGD)	% Change
Residential	319.6	246.2	-23.0%
Commercial	93.4	54.4	-41.8%
Industrial	49.6	52.88	+6.6%
Total Potable Water	**462.6**	**353.5**	**-23.6%**

Water to Water: Reengineering the “Nature” of Chicago’s Water Cycle for 2107

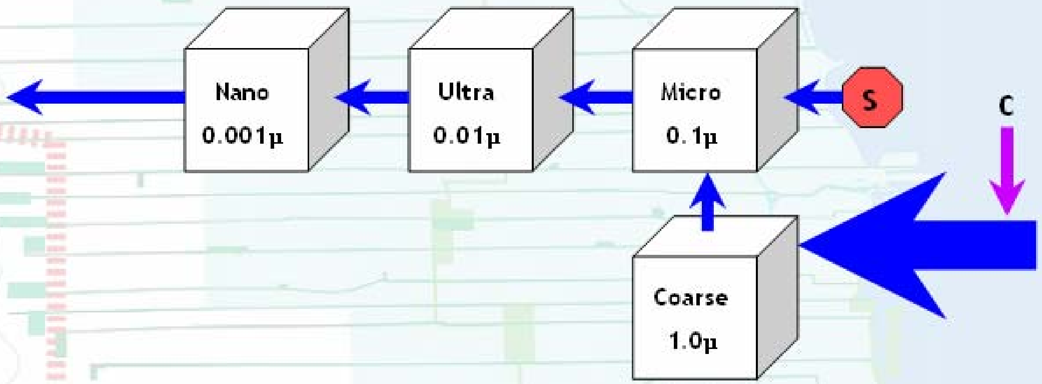


Membrane Potable Water Treatment



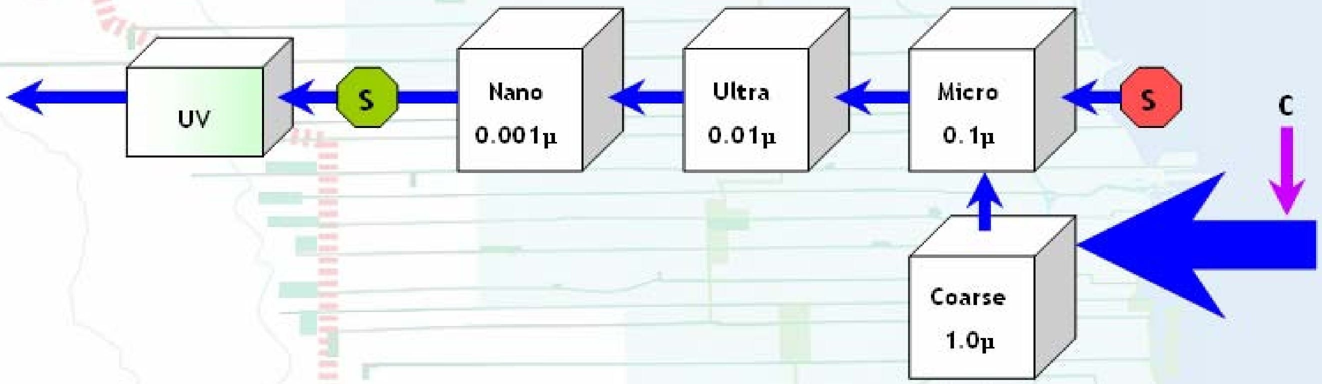
- 20 decentralized treatment stations near Lake Michigan for freshwater withdrawal
- Tiered treatment train combining micro-, ultra-, and nanofiltration
- Achieves superior water quality by removing:
  - Standard pathogens (E.Coli, giardia, cryptosporidium, viruses…)
  - Colloids and nanoparticles
  - Synthetic organic compounds including **endocrine disrupting chemicals**

Membrane Potable Water Treatment



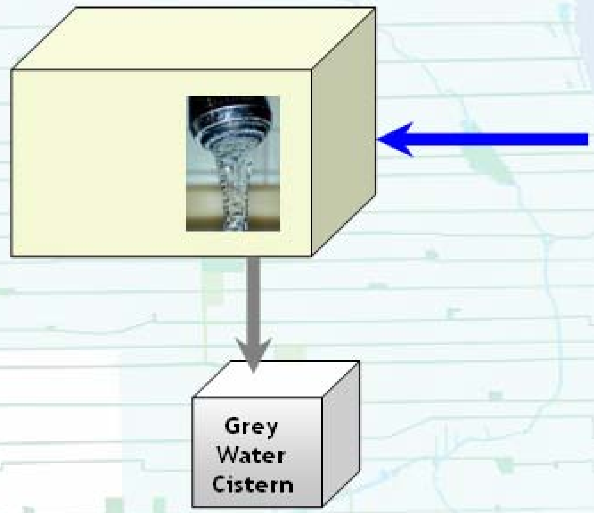
- High turbidity from storms in Lake Michigan can clog membranes
- When sensors detect elevated turbidity:
  - Cationic polymer coagulant added
  - Coarse microfiltration system brought online
- Retentate and backwash flows discharged to wastewater treatment

Decentralized UV Disinfection



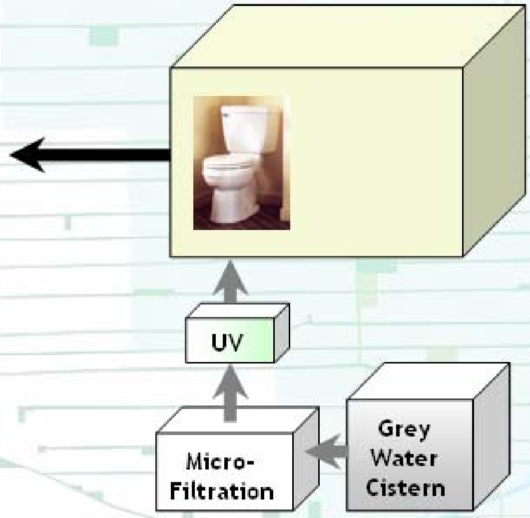
- Pathogen protection ensured through in-line UV stations located throughout distribution system
- Biochip sensors detect pathogen presence and activate UV
- UV LEDs provide high energy efficiency
- No chlorine residual required
- Avoids disinfection by-product formation

Dual Water System



- Create a cycle of reuse to diminish total water demand; minimize advanced drinking water treatment flow
- Grey water produced from showers, washing machines, dishwashers, cooking, etc.
- Underground cisterns store grey water

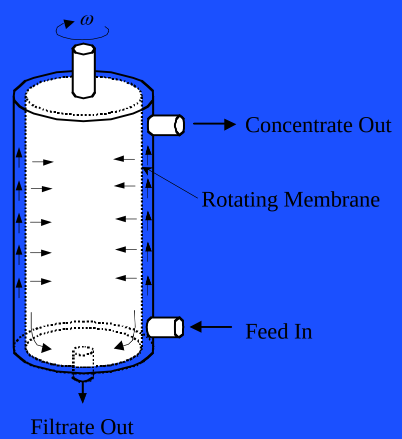
Dual Water System

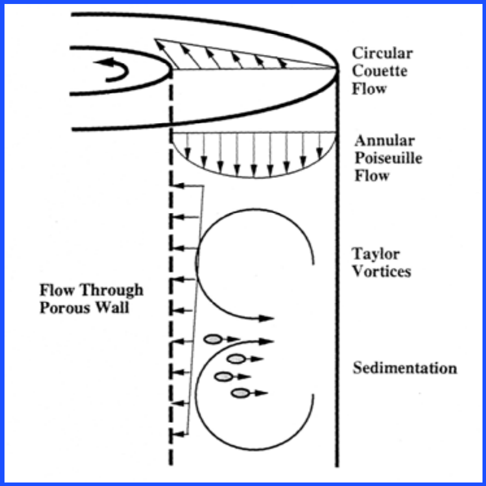


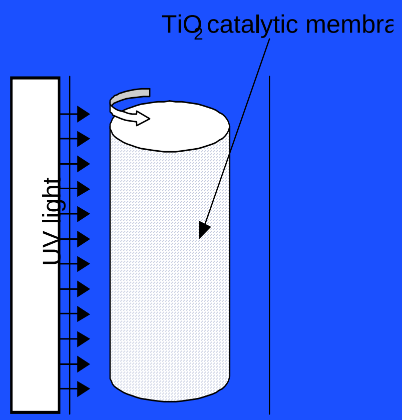
- Grey water treated with microfiltration and UV disinfection
- Reused in toilets, landscaping, other outdoor uses

Commercial Application: Water Reuse

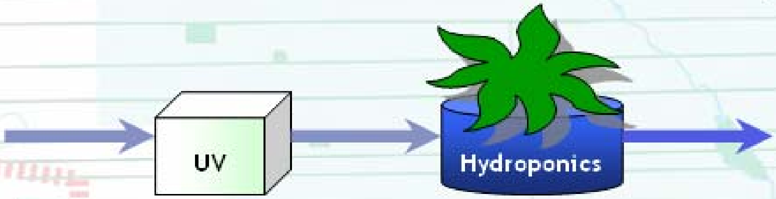
- **Reactive Rotating Ceramic Membrane Reactor**
  - Reduced membrane fouling
  - Oxidation, disinfection
  - Water Reuse





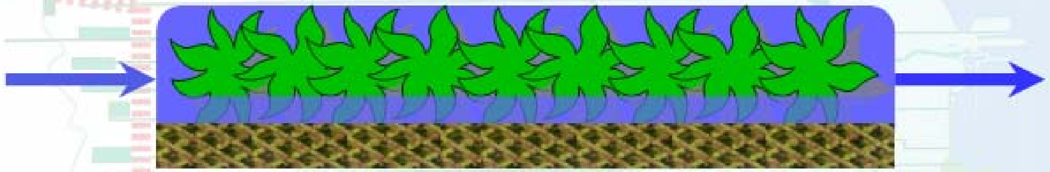


Wastewater Treatment: Hydroponics

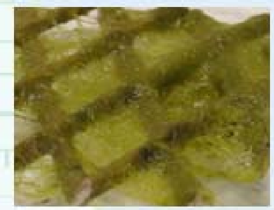


- UV disinfection prior to entering
- Plants grow suspended on nets with roots directly in water
- Plant, invertebrate, and aerobic bacterial communities perform nutrient uptake
- Located inside greenhouses for winter operation near the head of each eco-boulevard
- Provides additional green space for city
- Produces valuable crops (vegetables, cut flowers, etc.)

Wastewater Treatment: Wetlands



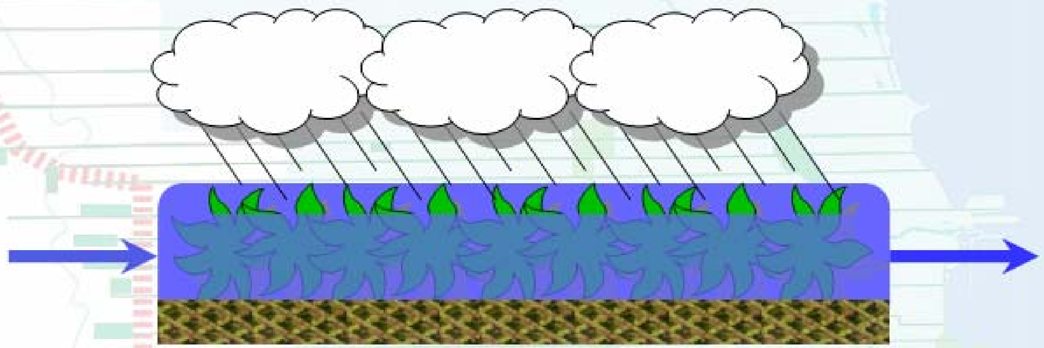
- Located along UrbanLab's Eco-Boulevards
- Constructed wetland, surface flow, benthic net*
- Polish discharge from hydroponics
- Pedestrian access provided on raised nature walkways through 20 Eco-Boulevards



Benthic Net

*Source: Ishida, et. al., "*Microbial Ecology*", 2008, 56:140-152."

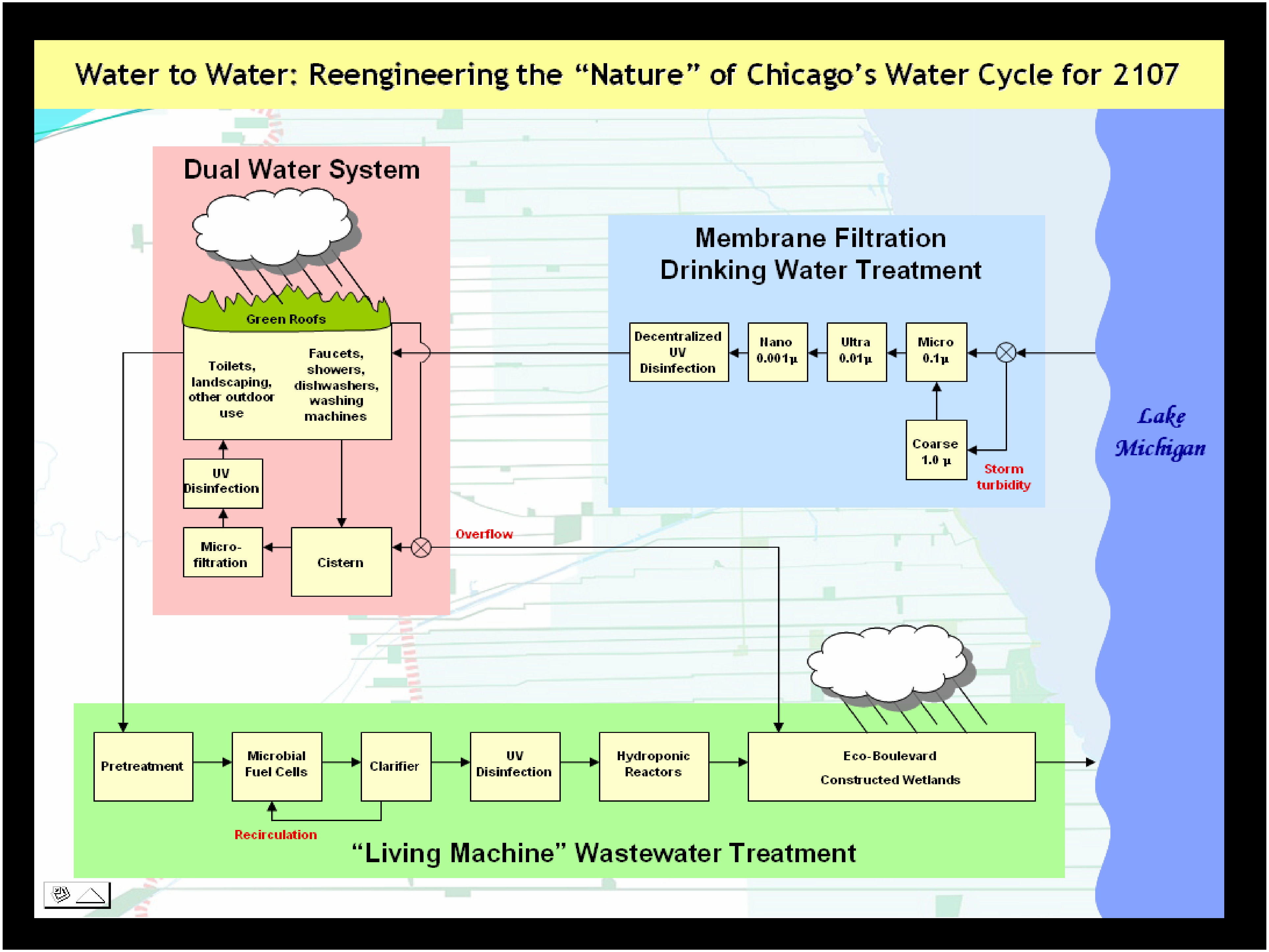
Wastewater Treatment: Wetlands



- Designed for worst-case scenario: 100-yr storm event (1hr)
- Runoff drains directly to wetlands
- Water level in wetlands rise from baseline level (0.3m) to 1 meter
- Decrease concentration of nutrients, metals, and particles
- Wetlands act as an environmental buffer during storms

Benthic Net

"Source: Ishida, et. al., "*Microbial Ecology*", 2008, 56:140-152."


Water to Water: Reengineering the "Nature" of Chicago's Water Cycle for 2107
Dual Water System
Green Roofs
Toilets, landscaping, other outdoor use
Faucets, showers, dishwashers, washing machines
UV Disinfection
Micro-filtration
Cistern
Overflow
Membrane Filtration Drinking Water Treatment
Decentralized UV Disinfection
Nano 0.001µ
Ultra 0.01µ
Micro 0.1µ
Coarse 1.0 µ
Storm turbidity
Lake Michigan
Pretreatment
Microbial Fuel Cells
Clarifier
UV Disinfection
Hydroponic Reactors
Eco-Boulevard
Constructed Wetlands
Recirculation
"Living Machine" Wastewater Treatment

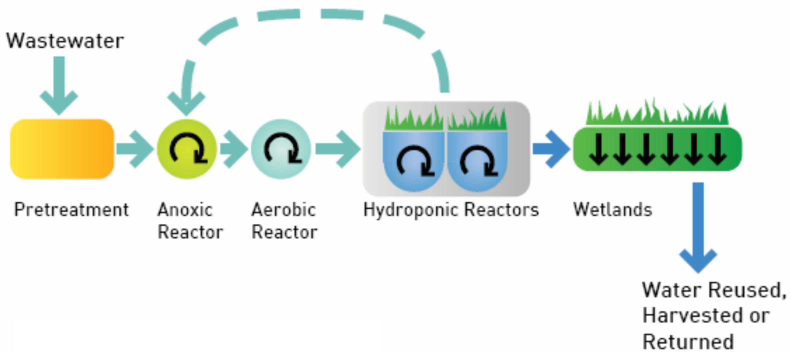
UrbanLab's Plan for WW Treatment

Type A

Indoor/Greenhouse Specs:

Hydroponic Living Systems

are ecological treatment "machines" that use aquatic and wetland ecological processes to treat wastewater naturally.



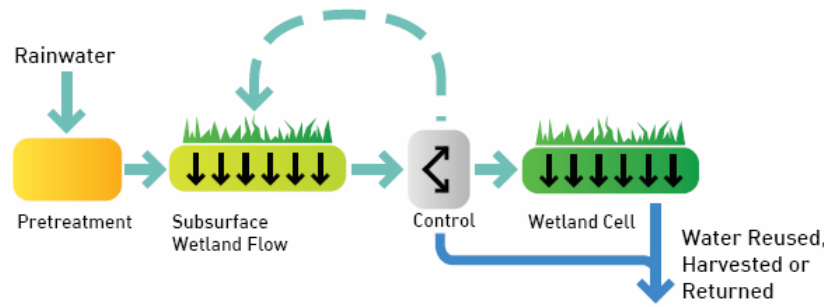
Source: Living Designs Group + OceanArks

Type B

Outdoor Specs:

Wetland Living Systems

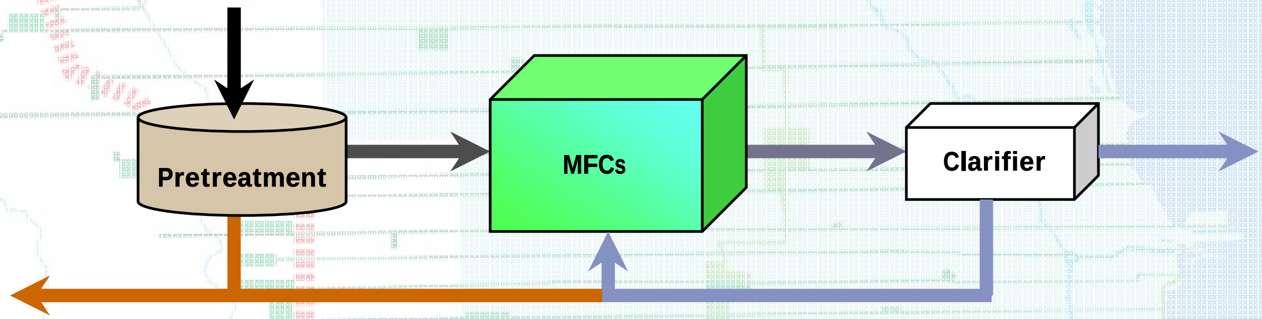
are constructed landscapes such as wetlands, prairies and forests that use low energy processes to biologically filter stormwater naturally.



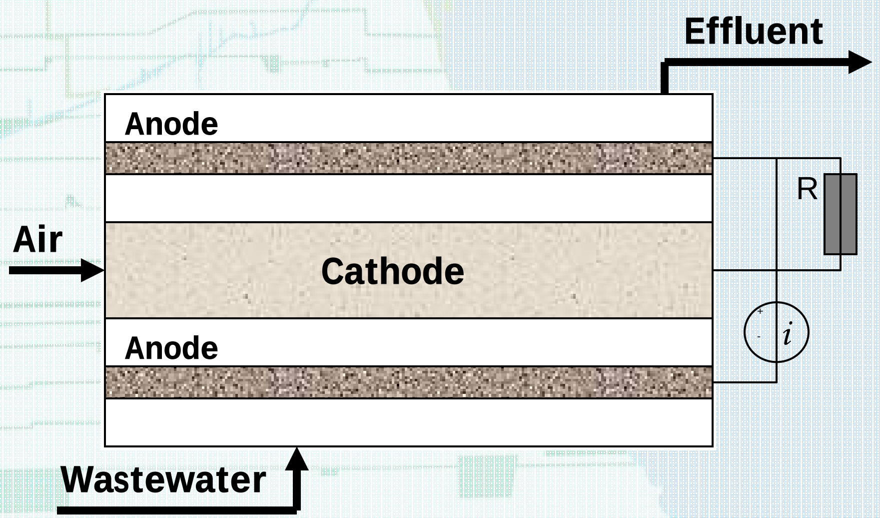
Source: Living Designs Group + OceanArks

Source: UrbanLab

Wastewater Treatment: MFCs

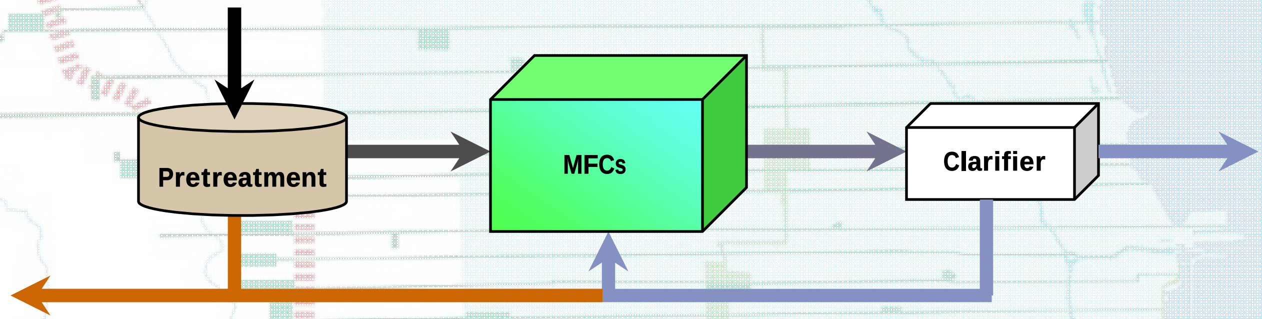


- Pretreatment = physically remove solids
- Microbial fuel cells (**MFCs**) replace anoxic & aerobic reactors
- Anode
  - Anaerobic bacteria in anode
  - Wastewater feeds the bacteria
  - Oxidize organic material → e^- flow to electrode
- Cathode
  - O_2, e^-, & H^+ combine → clean water
  - Power generated as current flows
- Clarifier or membrane separates and returns biomass



Based on design of Dr. Bruce Logan

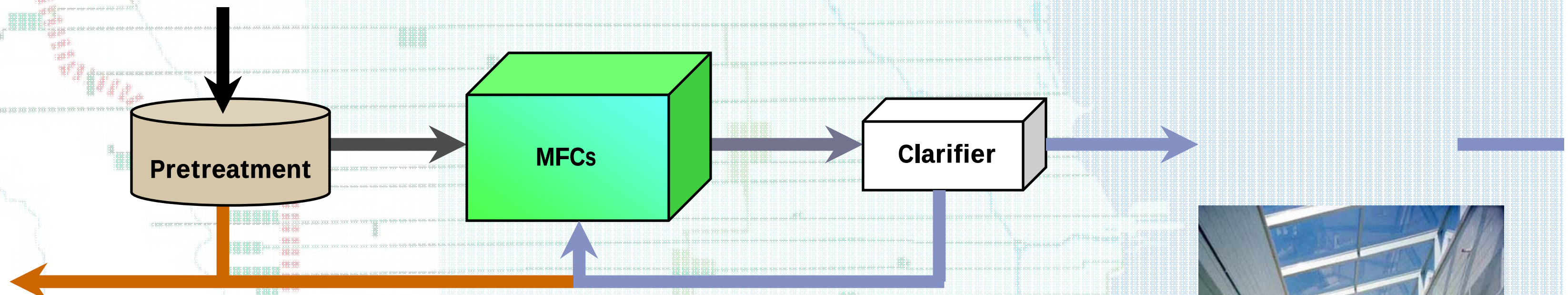
Wastewater Treatment: MFCs



- Remove up to 80% of organic matter
- Self-sufficient wastewater treatment plant
- Likely there will be a surplus of energy

Three Power Projections for the City of Chicago Based on Different Parameters of MFCs	
Dr. Bruce Logan's goal of $1W/m^2$	434 MW
Naval Research Lab estimate of $500W/m^3$	145 MW
Wastewater influent estimate of 0.5 kJ/g COD	251 MW

Wastewater Treatment: Hydroponics



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- Located inside greenhouses for winter operation near the head of each eco-boulevard
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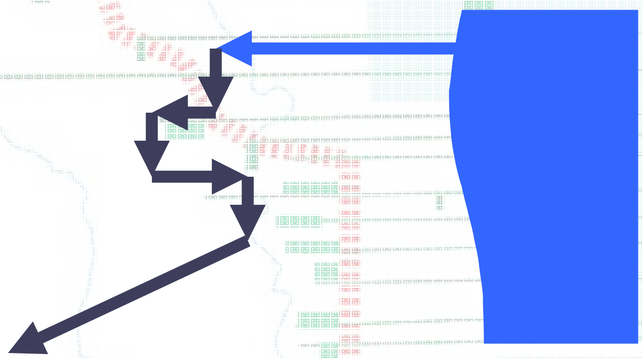
Energy Benefits

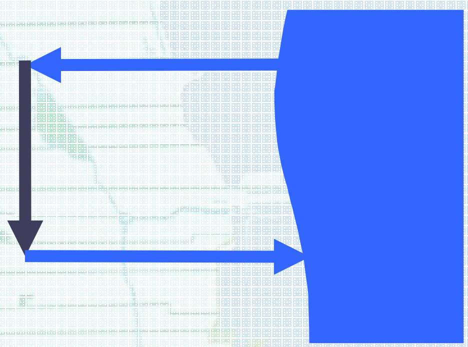
- Water recovery & reuse (dual H_2O System)
- Energy recovery (MFCs)
- Resource recovery (hydroponics)
- Renewable energy (wetlands, green roofs)

Closing the Loop



2007:

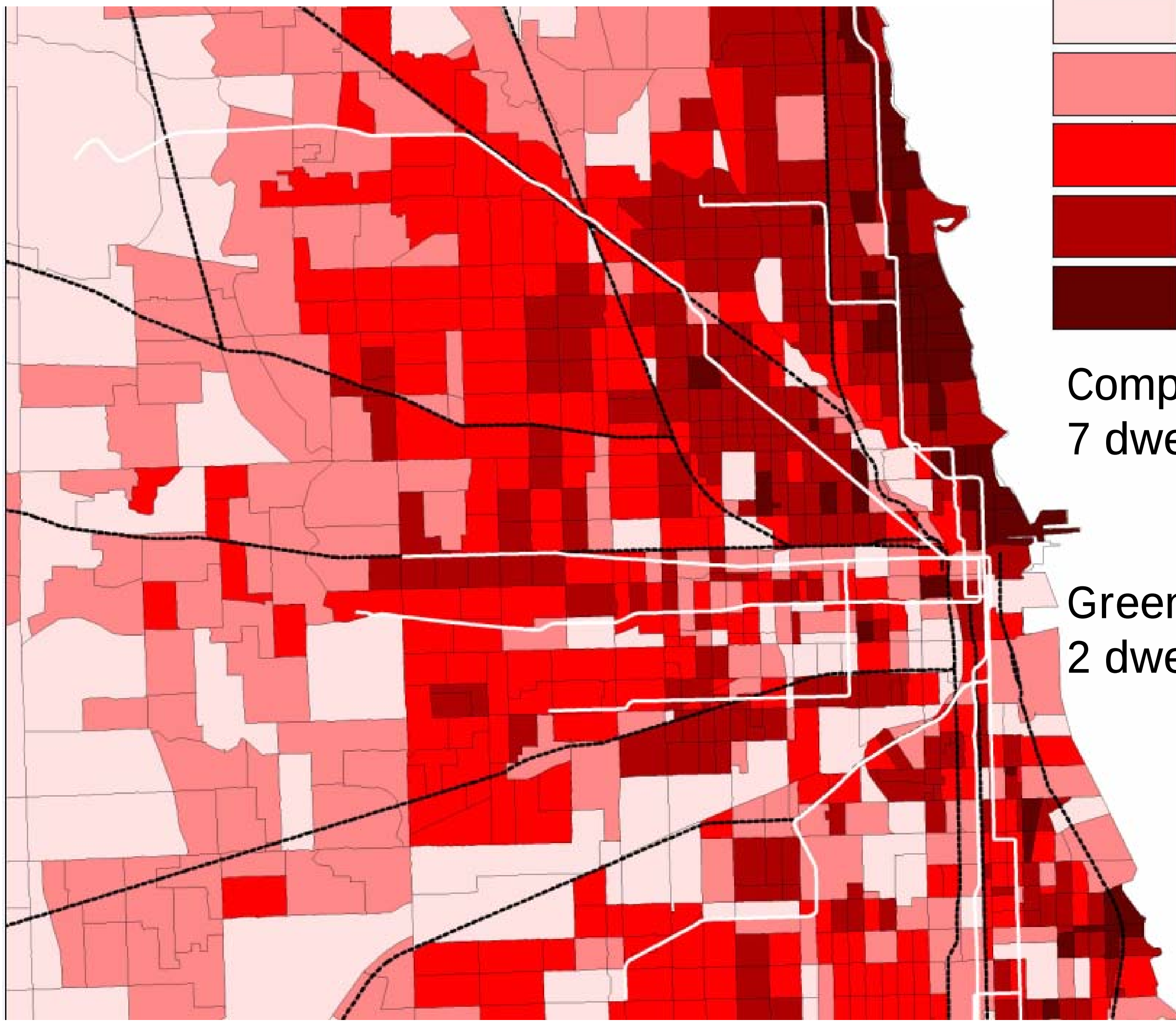
- Chicago withdraws 2.1 BG/day out of Lake Michigan
- TARP (Deep Tunnel) System increases capacity of current system – 15 BG



2107:

- Innovative water system allows **safe** closure of loop
- Storm water management & better design = no need for TARP

City of Chicago and Some Surrounding Suburbs



Dwellings per acre

0 - 2

2 - 5

5 - 10

10 - 20

20 - 1000

Compact Developmt > 7 dwellings/acre

Greenfield Developmt < 2 dwelling/acre

Portion of Greater Chicagoland Area

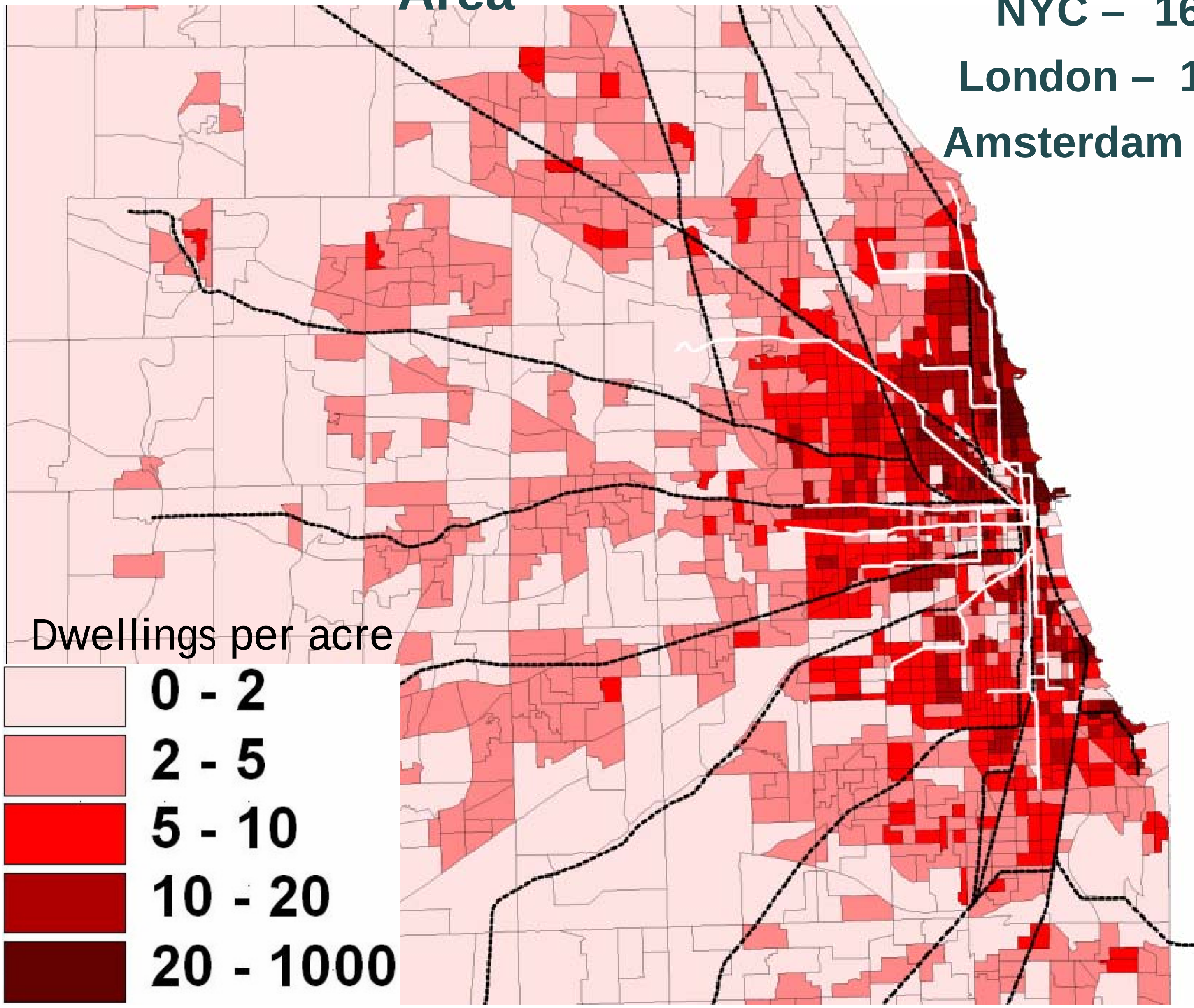
Residential Density:

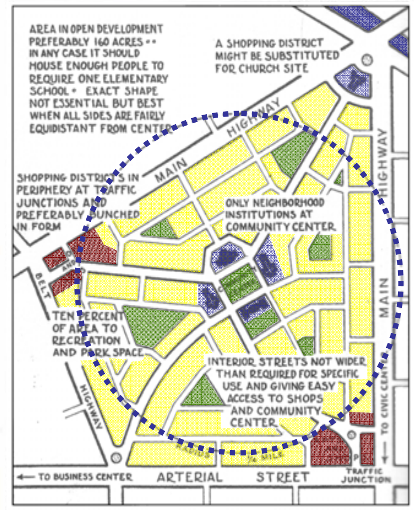
Chicago – 7 dwellings/acre

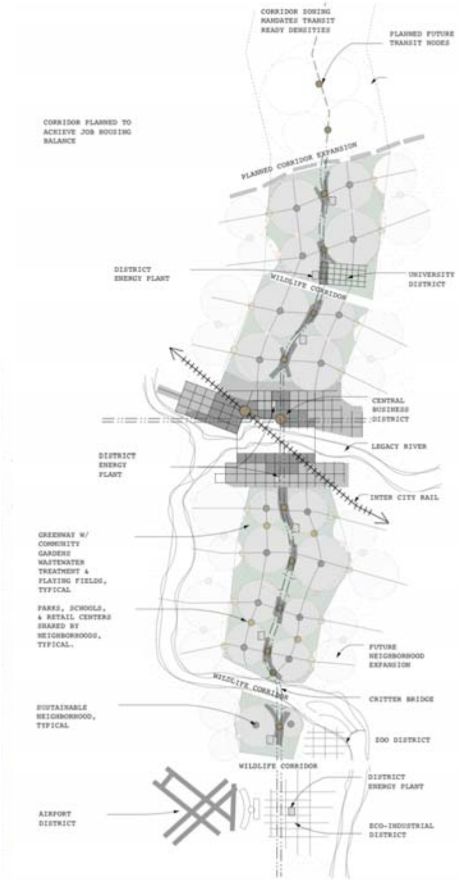
NYC – 16 dwellings/acre

London – 13 dwellings/acre

Amsterdam – 9 dwellings/acre







5

10

25

20-50

20-100

Years required to reform each human tool

Doug Farr & Assoc.

Primary Energy Use (FL)

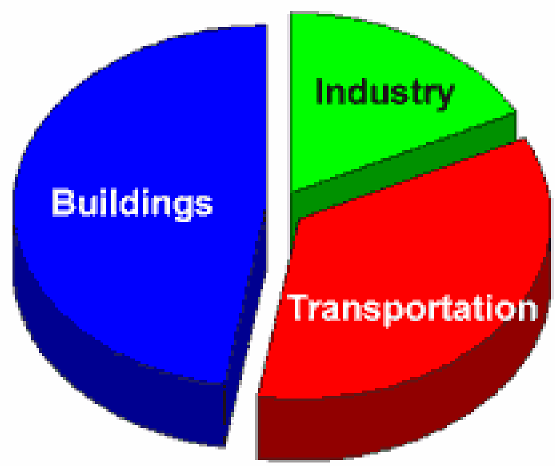
47% - Buildings (90% electric)

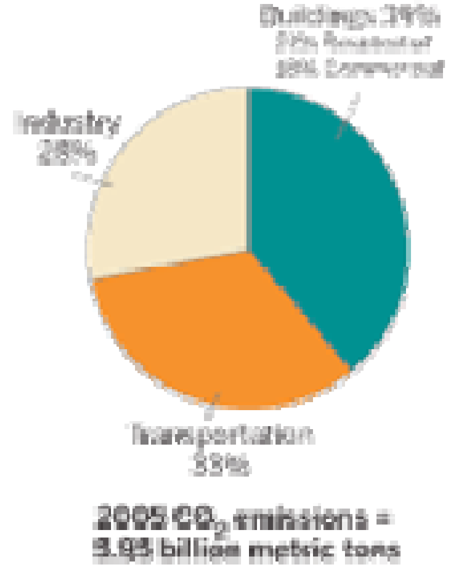
55% - homes

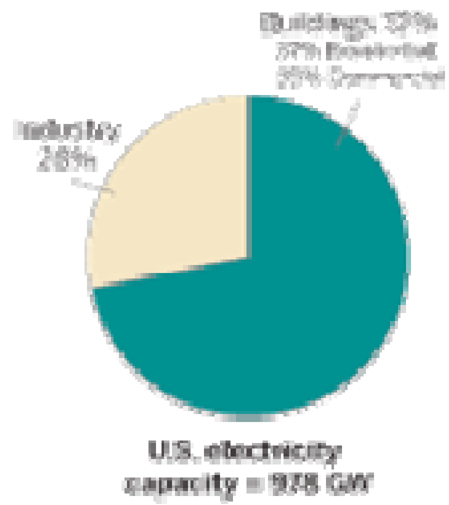
45% - non-residential

35% - Transportation

18% - Industrial uses



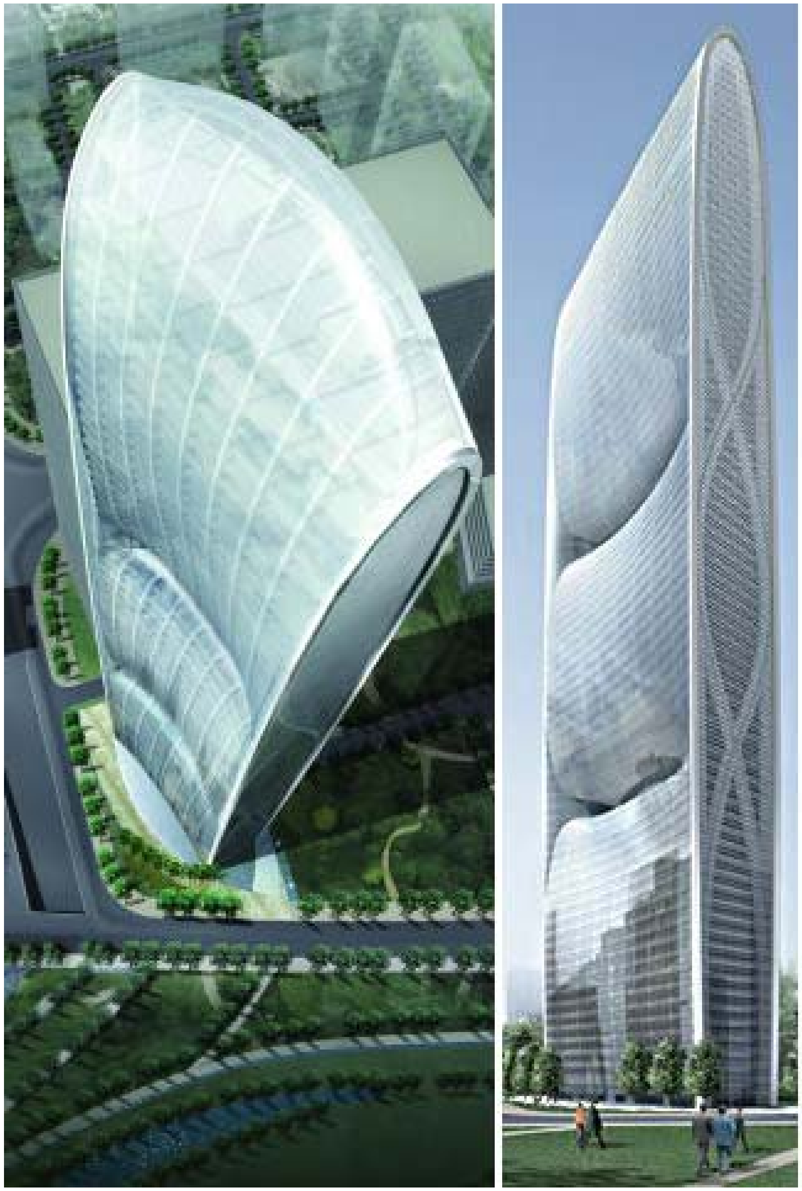


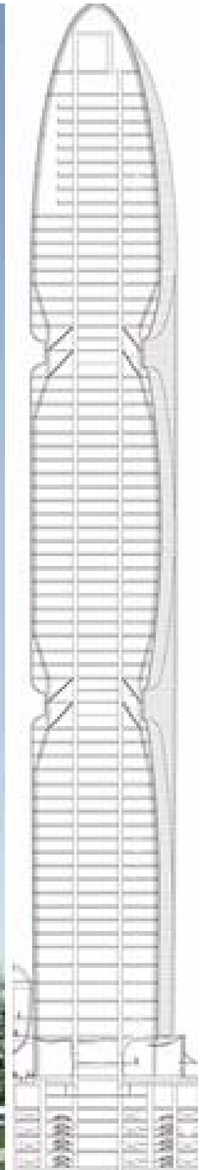


Feasible to reduce energy use by 15-30%

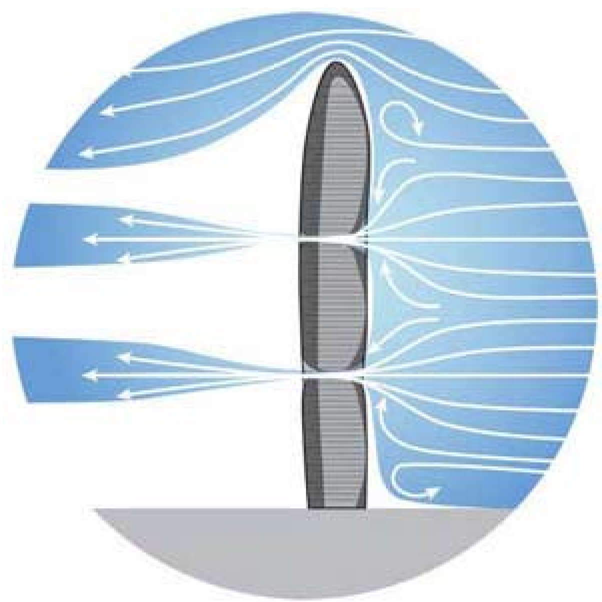
60-75% reduction possible

Pearl River Tower





- Designed by Skidmore, Owings, & Merrill
- Located in Guangzhou, China
- Intended for office use by China National Tobacco Corporation
- Began construction 2006, will be finished 2009/10
- 71 Stories (994 ft)
- Includes wind turbines and solar, humidity and rainwater collectors



Building design enhances wind flow

The Bank of America Tower at One Bryant Park, NYC

- $1 Billion Project in Midtown Manhattan Will Result In the World's Most Environmentally Responsible High-Rise Office Building; 2.1M Sq. Ft.
- LEED Platinum

Environmental Goals

- World's most environmentally responsible high-rise office building, focusing on sustainable sites, water efficiency, indoor environmental quality, and energy and atmosphere
- First high-rise to strive for U.S. Green Building Council's Leadership in Energy & Environmental Design "Platinum" designation
- Reduce energy consumption by a minimum of 50%
- Reduce potable water consumption by 50%
- Reduce storm water contribution by 95%
- Utilize 50% recycled material in building construction
- Obtain 50% of building material within 500 miles of site

Green Features

• Higher ceilings and translucent insulating glass in floor-to-ceiling windows permit maximum daylight in interior spaces, optimal views and energy efficiency

• Advanced double-wall technology provides remarkable views in and out of building, while dissipating the sun's heat

• Pioneering filtered under-floor displacement air ventilation system and floor-by-floor air handling units allow for individual floor control and more even, efficient, and healthy heating and cooling

• CO_2 monitors automatically adjust the amount of fresh air when necessary

• Gray-water system captures and re-uses all rainwater and wastewater, saving millions of gallons of water annually

• Waterless urinals, low-flow fixtures, etc. decrease H_2O use

• Daylight dimming and LED lights reduce electric usage

• Recyclable and renewable building materials (steel, blast furnace, drywall)

- Thermal storage system at cellar level, produces ice in the evening when electricity rates are lowest to reduce peak daytime demand loads on the city
- Green roofs reduce urban heat island effect
- State-of-the-art onsite 5.1-megawatt co-generation plant provides a clean, efficient power source for the building's energy requirements
- Anaerobic digester plan converts food waste into electricity (being studied)
- 95% air filtration

To leap forward, think backwards

Architect

Cook + Fox Architects,

New York

BedZed

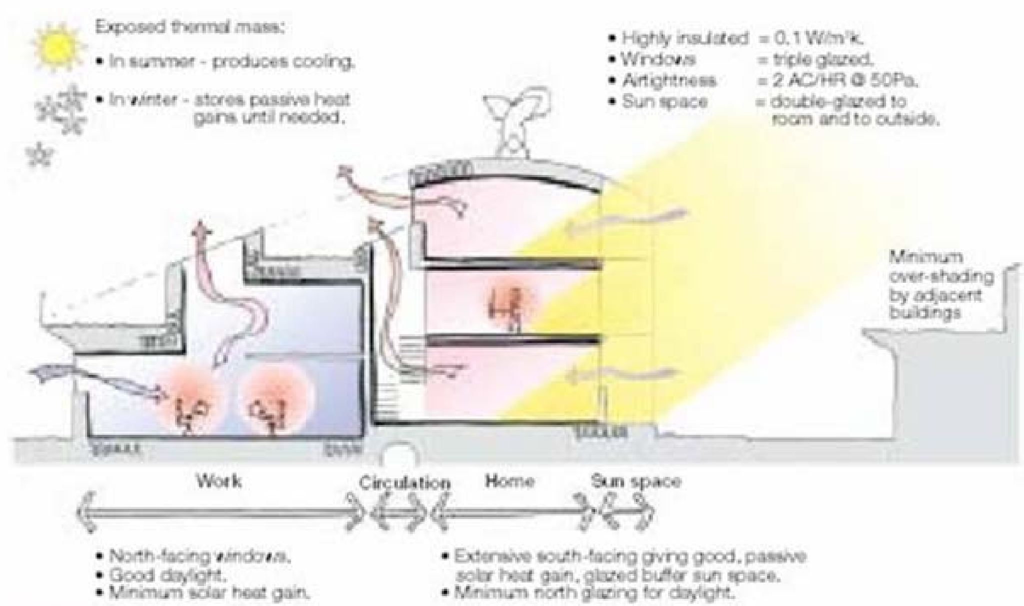
- Beddington Zero Energy Development, Sutton, London
- Bill Dunster, architect
- Net zero fossil fuel
- Britian's largest C-neutral, ecologically friendly community
- 82 homes, mixed use
- Solar gain & light
- South facing homes, offices face North with indirect, diffuse light
- Green planted roof scapes
- Low tech strategies

- Green planted roof scapes

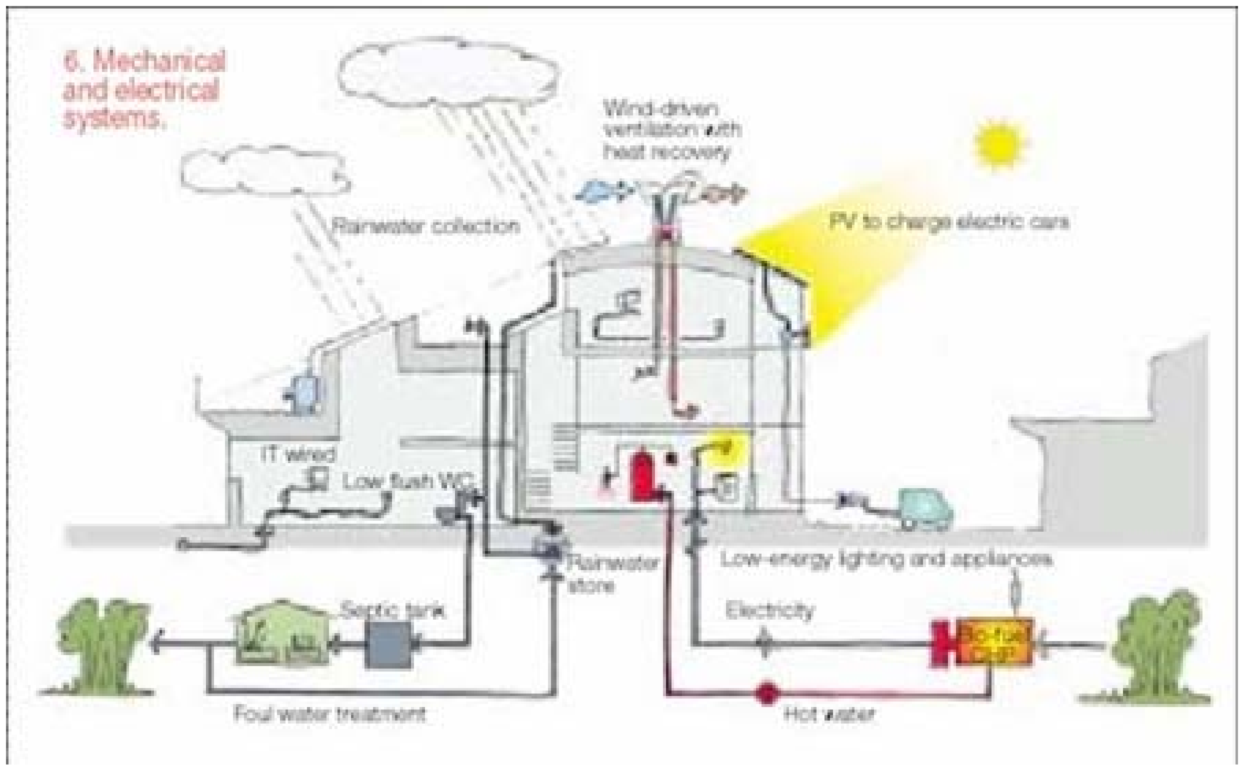
One Planet Living (1.8)

63% Technology

37% Behavior



5. Building physics.



6. Mechanical and electrical systems.

Conclusions

- **Ecology – mimic & integrate into urban design**

- **System approach – highly integrated & coordinated**

- **Distributed, rather than centralized, facilities, & processes**

  - Tailored to local conditions

  - Highly flexible

Acknowledgements:

The City of the Future: A Design and Engineering Challenge

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Thank you

Questions or Comments?