Development of the Sustainable Cities of the Future

Water/Energy Nexus and International Cooperation

Vladimir Novotny
Northeastern University Boston/AquaNova, Ltd, Newton, MA

Lecture supported by JICA

July 6, 2010

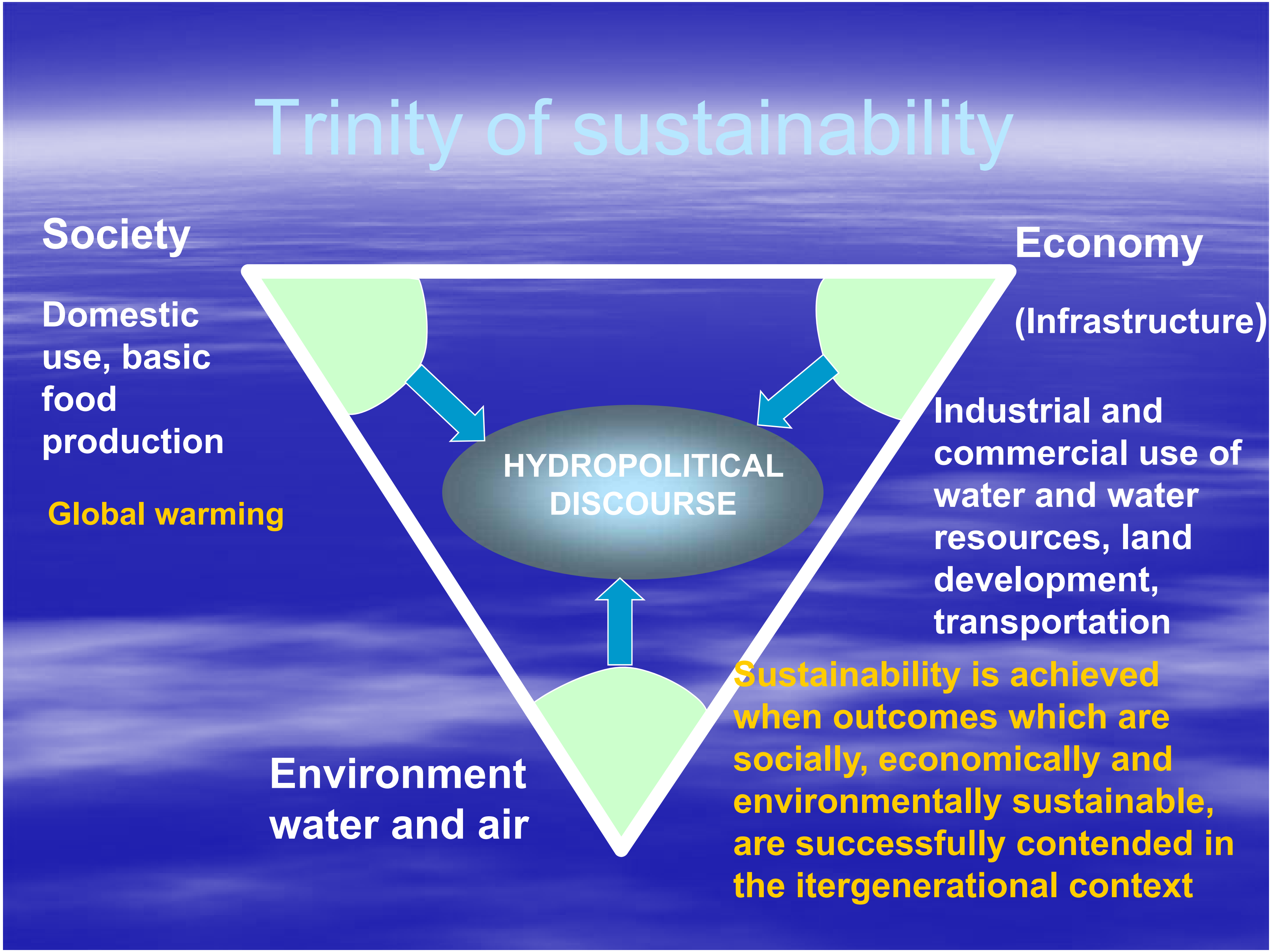
University of Tokyo

© V. Novotny

Sustainable development

- Defined as one that meets the needs of the present without compromising future generations.

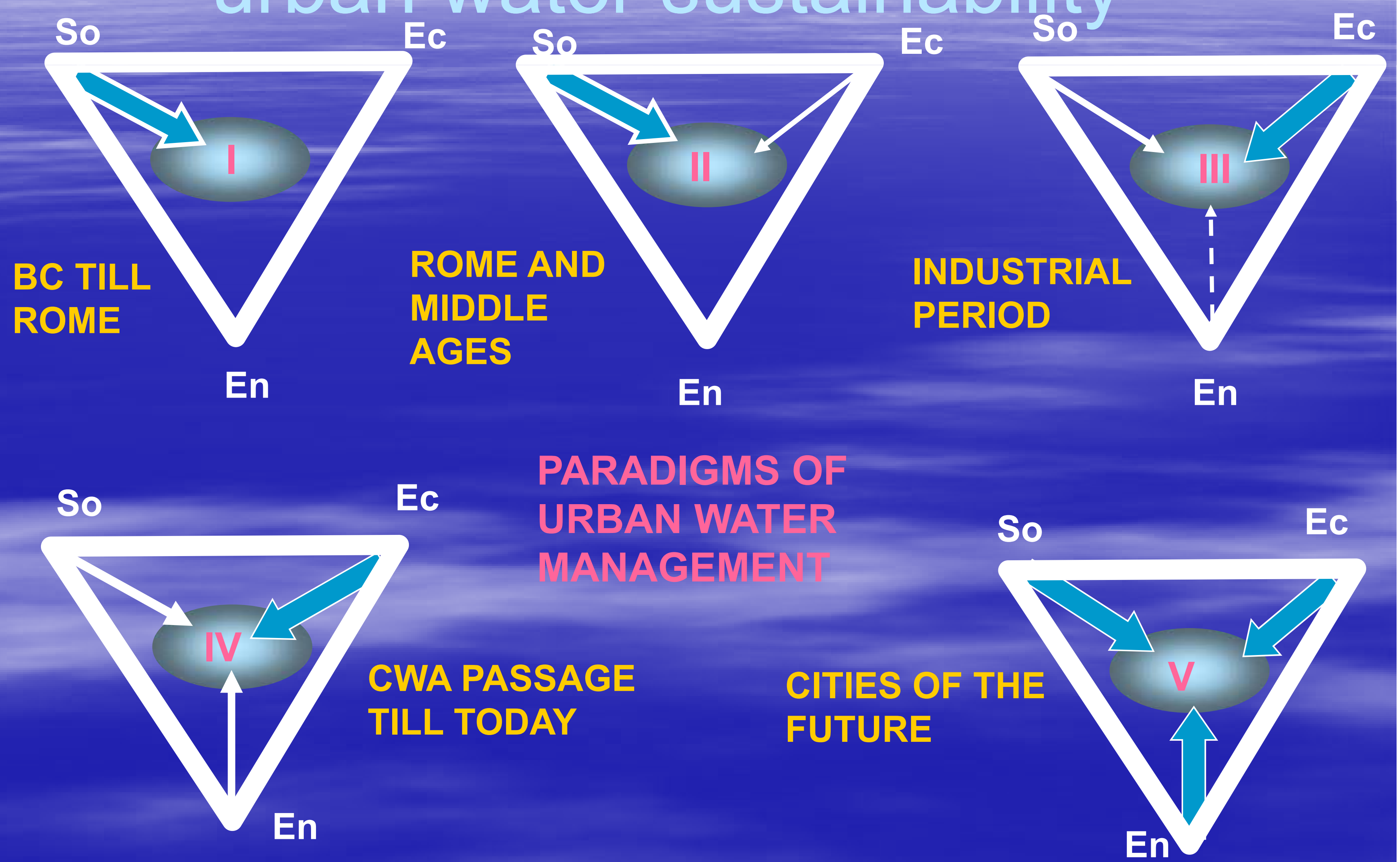
- Urban sustainability is compromised by
  - Population increases and migration
    - In the next 50 years the world population is expected to increase 50% and the US population by 30-40%. The largest increases will occur in urban areas.
  - Unbalanced hydrology
    - Increasing imperviousness of watersheds, more polluted runoff
    - Fast conveyance drainage mostly underground and vulnerable to extreme events
    - Excessive use of water
  - Energy demand and GHG emissions


Trinity of sustainability
Society
Domestic use, basic food production
Global warming
Economy
(Infrastructure)
Industrial and commercial use of water and water resources, land development, transportation
HYDROPOLITICAL DISCOURSE
Environment water and air
Sustainability is achieved when outcomes which are socially, economically and environmentally sustainable, are successfully contended in the itergenerational context

PARADIGM

- A model and a set of rules how ideas are linked together and form a conceptual framework by which people build and operate the cities and manage their water resources
- It is based on logic, common sense, generational experience, and later, scientific knowledge
- It is derived by a discourse in the political domain; science or good engineering alone may not be the primary determinant of a paradigm
- A wrong or outdated paradigm may persist because of tradition, lack of information about the pros and cons of the outdated paradigm or lack of resources to change it

Historic changes of the paradigm to urban water sustainability



First paradigm of urban water/stormwater and used water management

Drainage of Agora in Athens

In Pompeii in Italy the street was the drainage

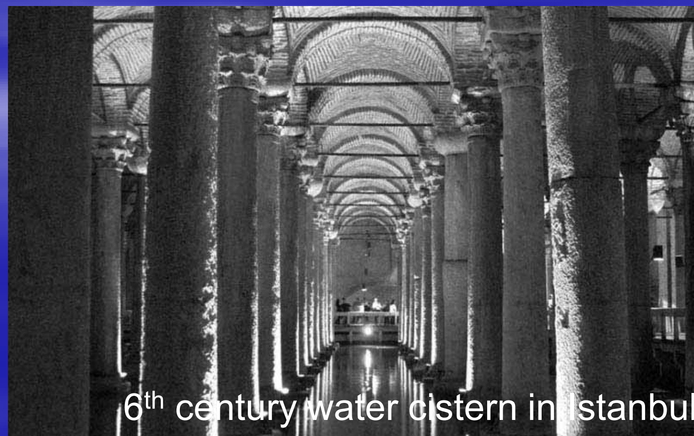
Wells for water supply , streets for drainage, night soil disposal

Paradigm II

II. Long distance water transfers and storm water with some sewage drained by sewers

Rainwater harvesting and storage has been used for thousands years

Pont du Gard



6th century water cistern in Istanbul

Paradigms of urban drainage have changed over millennia - Paradigm II

Long distance water transfers and storm water with some sewage drained by sewers

Pont du Gard

Lead (Rome) and wood pipes

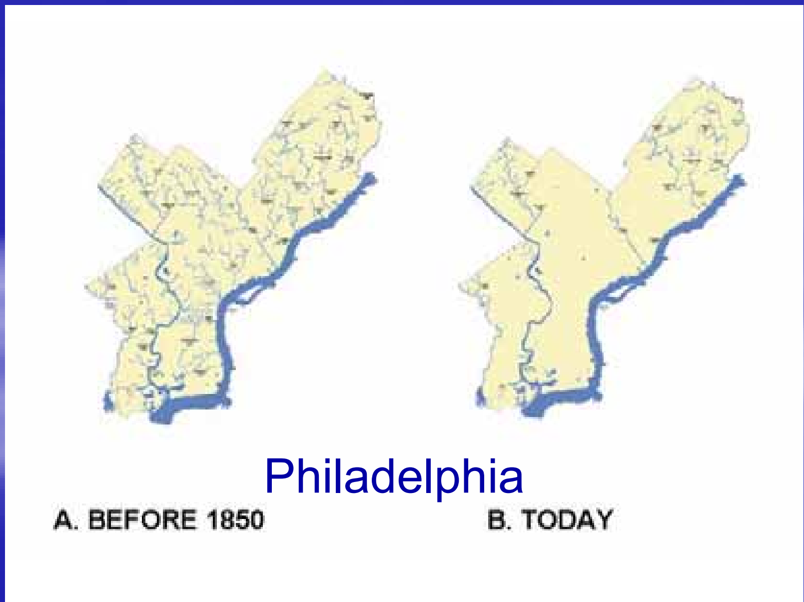
Another aqueduct in France

Roman sewer Cloaka Maxima

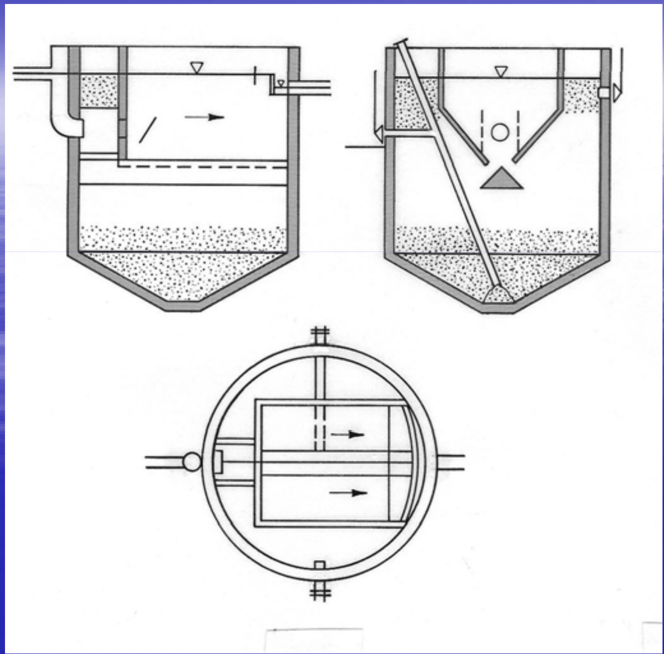
3th Paradigm (Industrial age)

- Surface streams disappeared from the surface and were converted to combined sewers

Mill Creek in Philadelphia



Credit Historic Archives of the Philadelphia Water Department



Cuyahoga River in Cleveland on fire

Simple treatment plants were built in the first half of the 20th century

Gulf of Mexico on fire in May 2010

Courtesy Cleveland Press collection at Cleveland State University and Iowa DNR

Paradigm IV

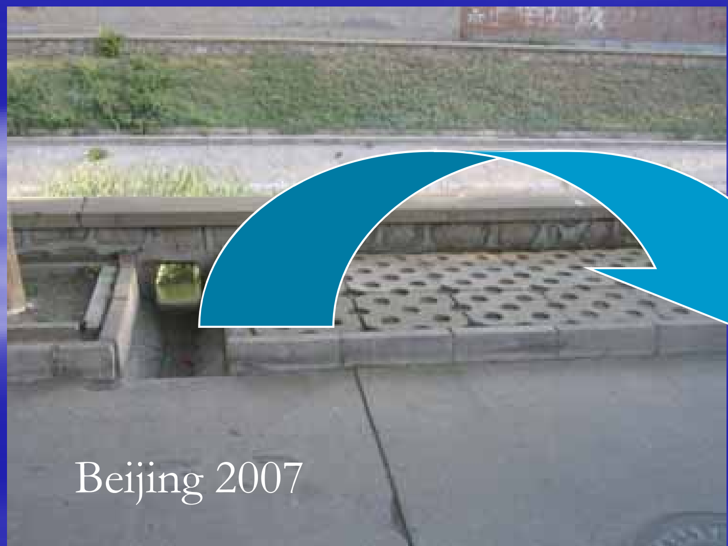
From Clean Water Act Enactment

Fast conveyance – end-of-pipe treatment

Milwaukee has build 4 million m3 underground tunnel to store CSOs and by-passes from sanitary sewers. The tunnel reduced the frequency of overflows from about 40/year to 2/year. The target frequency was ordered by a court.

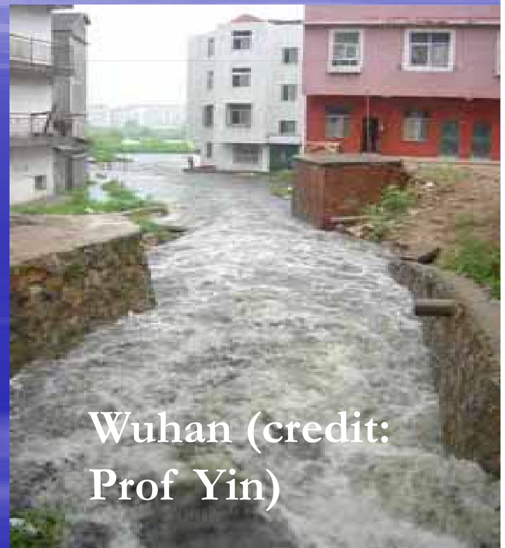
The tunnel was drilled 100 meter below surface in the dolomite formation (soft rock). Wall of the tunnel were grouted by epoxy grout to minimize groundwater infiltration.

3rd an 4th Paradigm resulted in a perfect delivery of pollutants to receiving waters



PROBLEMS WITH THE 4th PARADIGM

- Natural hydrologic status of urban water bodies and watersheds has been modified by imperviousness, building sewers and stream modifications with the impacts on
  - **Streams**
    - Increased high flows (more flooding).
    - Peak flows increase by a factor of 4 to 10
    - Less base flow - not enough base flow to sustain viable fish population
    - Increased variability (flow, temperature, DO)
    - Increased stream bank erosion
  - **Groundwater recharge is diminished**
    - Effect on foundations (Boston, Venice, Mexico City, Philadelphia
    - Diminishing groundwater supply
    - Diminish base flow in river
  - **The goals of the Clean Water Act and OPL goals cannot be attained using the IVth paradigm infrastructure heavy and energy demanding concepts**



Mexico City subsidence

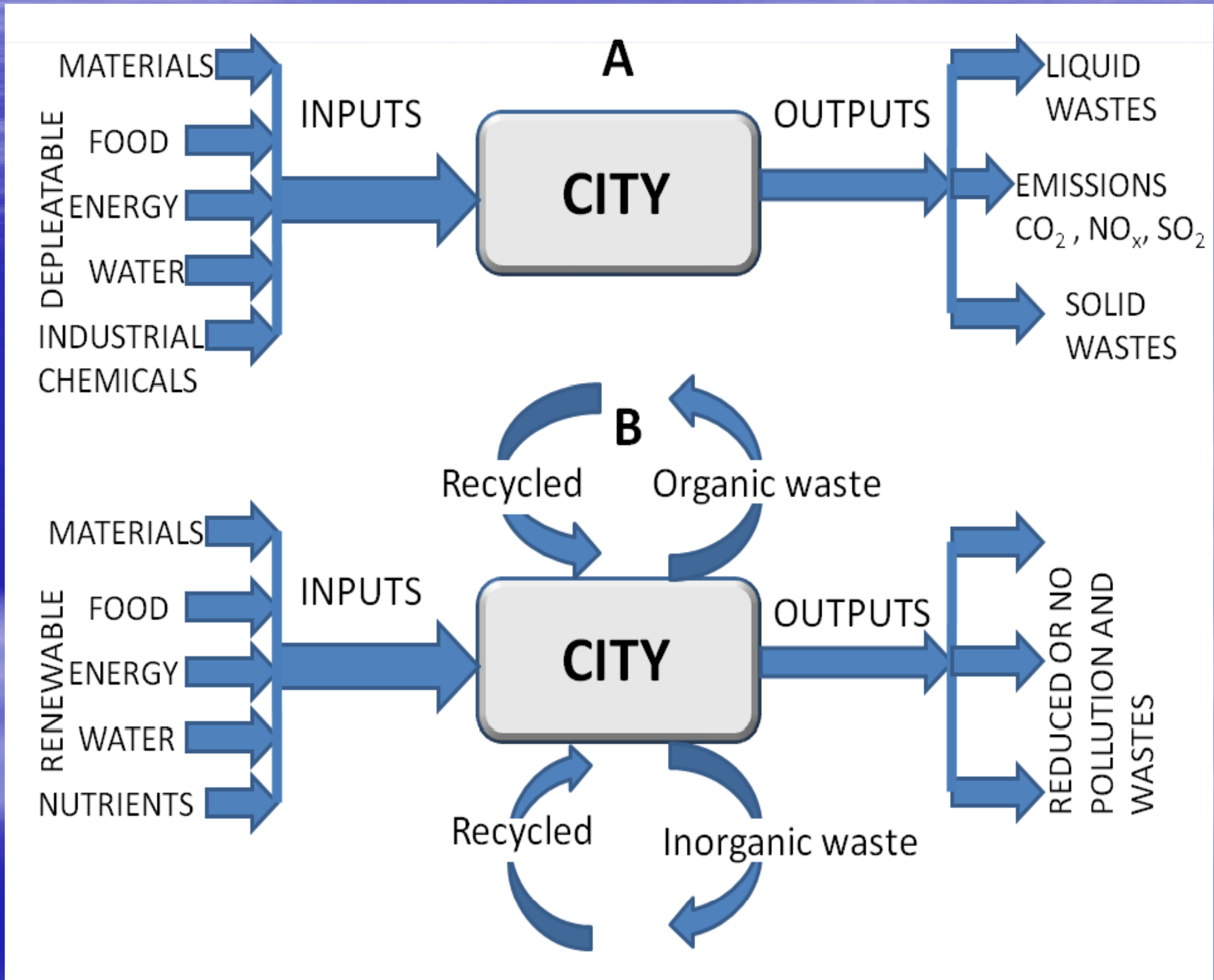
New Threats to Water Supplies and Ecology


Urban pond in China


Reservoir supplying water for Prague

- Hypertrophic water bodies (too much nutrient discharge causing extreme algal infestation – algal bloom)
  - Toxins
  - Loss of oxygen and biota
  - Loss of recreation
- New chemicals accumulate in the environment
  - Endocrine disruptors
  - Pharmaceutical
    - Antibiotics
  - Nanoparticles

Urban Metabolism



A Linear

B Cyclic or Hybrid

- Current urban systems are mostly linear
  - Excessive water volumes are withdrawn from mostly distant surface and groundwater sources
    - Inside the community water is used only once and wastefully, e.g., treated drinking water is used in landscape irrigation for growing grass
    - Great losses of water by leaks and evapotranspiration
  - Water is transferred underground to distant large wastewater treatment plants
    - The WTP use a lot of energy and emit carbon and often methane which are green house gases
    - The receiving water bodies become effluent dominated after discharge

Footprints

- A “footprint” is a quantitative measure showing the appropriation of natural resources by human beings
  - Ecological - a measure of the use of bio-productive space (e.g., hectares (acres) of productive land needed to support life in the cities), including waste assimilation
  - Water - measures the total water use on site and also virtual water (usually expressed per capita)
  - Carbon - is a measure of the impact that human activities have on the environment in terms of the amount of GHG emissions measured in units of carbon dioxide

Ecological footprint

Year	World Population	Available productive land	
		Ha/person	Ac/person
1995	< 6 billion	1.5	3.6
2040	10 billion	<<1	2
Current ecological footprint			
Countries with 1 ha/person or less		Most cities in undeveloped countries	
Countries with 2-3 ha/person		Japan and Republic of Korea (democratic)	
Countries with 3-4 ha/person		Austria, Belgium, United Kingdom, Denmark, France, Germany, Netherlands, Switzerland	
Countries with 4-5 ha/person		Australia, Canada and USA	

Imbalance

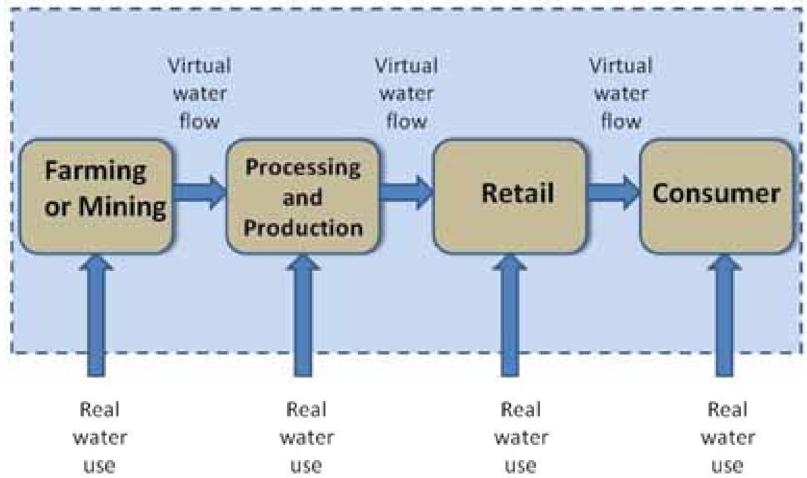
If the cities in the currently rapidly developing countries (China, India, Brazil) try to reach the same resource use as that in developed countries, conflicts may ensue

Ecological Footprint (Local)

- Urban waterways and impoundments
  - Responsible nutrient management
  - New and traditional toxic pollutants
    - Total Maximum Daily Load Assessment
- Ecological corridors and open space
  - Health and extent of riparian corridors
  - % stream channelization (surface and underground)
  - Connectivity/fragmentation
  - Natural area/person
- Urban hydrology (resilience to extreme events)
  - Frequency and extent of impacts of extreme events
  - Deviation from natural (predevelopment) hydrologic cycle
  - Percent and type of impervious area

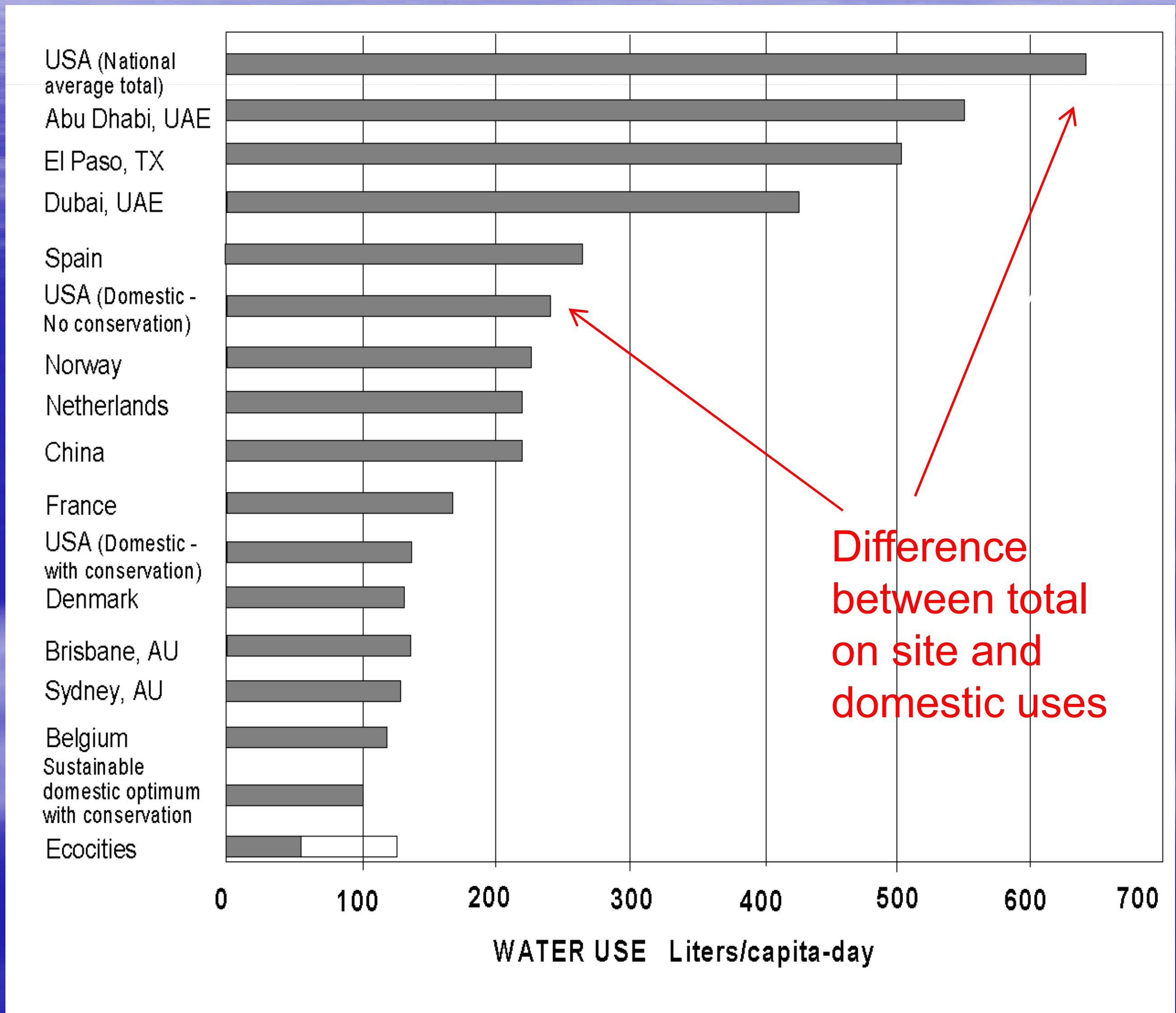
Water footprint

- On-site water use
  - Domestic
    - Indoor
    - Outdoor (irrigation)
  - Commercial
  - Public (fire, parks)
- Virtual
  - All water used in production in imported food and materials needed in the city



Source Hoekstra (2008)

Water use in some cities



VIRTUAL WATER

	l/cap-day
Food	1928
Electricity	53-73

	liter/kg
Beef	15,500
Corn	900
Milk	1,000

1 gallon=3.78 liters
1 kg = 2.2 lbs

GHG (carbon) Emission by Cities

Top ten countries in the CO_2 emissions in tons/person-year in 2006[1]									
Qatar	UAE	Kuwait	Bahrain	Aruba	Luxembourg	USA	Australia	Canada	Saudi Arabia
56.2	32.8	31.8	28.8	23.3	22.4	19.1	18.8	17.4	15.8
Selected world cities total emissions of CO_2 equivalent in tons/person-year[2]									
Washington DC	Glasgow UK	Toronto CA	Shanghai, China	New York City	Beijing China	London UK	Tokyo Japan	Seoul Korea	Barcelona Spain
19.7	8.4	8.2	8.1	7.1	6.9	6.2	4.8	3.8	3.4
Selected US cities domestic emissions of CO_2 equivalent in tons/person-year[3]									
San Diego CA	San Francisco	Boston MA	Portland OR	Chicago IL	Tampa FL	Atlanta GA	Tulsa OK	Austin TX	Memphis TN
7.2	4.5	8.7	8.9	9.3	9.3	10.4	9.9	12.6	11.06

[1]Wikipedia (2009); [2] Dodman (2009) ; [3]Gleaser and Kahn (2008)

[2,3] Values include transportation, heating, and electricity

GHG = Green House Gases (CO_2, methane, nitrogen oxides and other gases)

Vision of the Cities of the Future

Definition/Vision of an Ecocity:

An ecocity is a city or a part thereof that balances social, economic and environmental factors (triple bottom line) to achieve sustainable development. A sustainable city or ecocity is a city designed with consideration of environmental impact, inhabited by people dedicated to minimization of required inputs of energy, water and food, and waste output of heat, air pollution - CO2, methane, and water pollution. Ideally, a sustainable city powers itself with renewable sources of energy, creates the smallest possible ecological footprint, and produces the lowest quantity of pollution possible. It also uses land efficiently; composts used materials, recycle or convert waste-to-energy. If such practices are adapted, overall contribution of the city to climate change will be none or minimal below the resiliency threshold. Urban (green) infrastructure, resilient and hydrologically and ecologically functioning landscape, and water resources will constitute one system

Adapted from R. Register UC-Berkeley

Driving Forces towards Sustainability

- Increasing water scarcity, excessive flooding and conversion into effluent dominated waters will require management of the total urban water hydrological cycle and decentralization of the urban sewerage
- Goals of achieving good ecological status and integrity are mandated by Clean Water Act in US and Water Framework Directive in EU and desired by public
- Limits have been reached and something has to be done
- Cities are rapidly expanding and new large cities have to be build to accommodate population growth and movement from rural to urban areas
- Severe problems with global warming caused by GHG emissions are expected and will ensue unless something is done globally

Towards closed or hybrid metabolism by resource recovery and conservation

- Water conservation and reclamation and reuse of used water
- Energy use savings and reclamation from various sources, such as heat, electricity, methane recovery from wastewater and organic wastes, and renewable wind, solar, and geothermal power sources
- Recycling of organic solid waste (sludge, vegetation, food waste, etc.)
  - power generation by incineration, methane biogas and hydrogen production, considering also carbon sequestering
  - Recycled products (paper, cardboard, construction materials
- Recycling of inorganic waste from metal, asphalt, glass, insulation, and construction materials

What is a Water Centric Ecocity ?

- Water conservation
- Distributed stormwater management (surface)
- Distributed water treatment
- Water reclamation and reuse in buildings, irrigation and for ecologic stream flow
- Infiltration and repair of hydrology
- Stream restoration – multi-functional water bodies are a life line of the ecocity

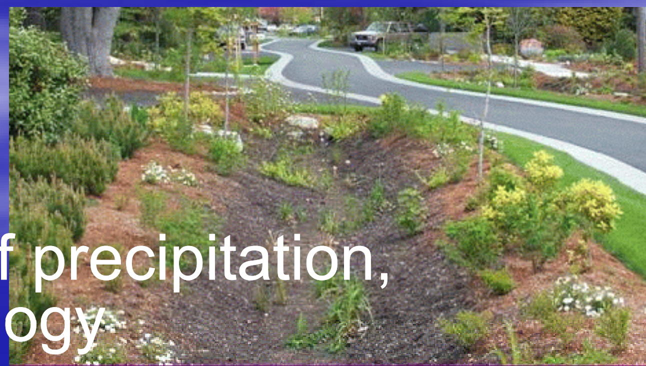
- Heat and energy recovery
- Organic solids management for energy recovery
- Source separation
- Nutrient recovery

Also

- Renewable energy source (solar, wind, hydropower)
- Sustainable low carbon traffic emissions
- Recreation, walking, biking
- Suburban organic agriculture

Microscale Assessment

- Microscale (buildings, neighborhoods, subdivision
  - Leadership in Energy and Environmental Design- LEED
    - Sustainability of the site – smart location
    - Green design
    - Energy efficiency
    - Indoor environmental quality
    - Innovation and design
    - Neighborhood patterns, etc.
  - Low Impact Development (LID)
    - Capture, storage and infiltration of precipitation, mimicking predevelopment hydrology



Missing link in the assessment

- Fuzzy impact of LEED and similar criteria on
  - Sustainability of water resources, their water quality and integrity
  - Improving resilience against the impact of extreme events
  - Protection and enhancement of urban natural resources (nature preserves or parks)
  - Access of people to recreation
- Conversion to or building ecocities, requires a comprehensive and hierarchical macroscale approach to the microscale and often piecemeal transformation
- Sustainability means that future developments and city retrofits address the societal, environmental and economic concerns and goals

CITY OF THE FUTURE

BUILDINGS AND "NEIGHBORHOODS" CONFORMING TO LEED CRITERIA CO... STAINABLE S...

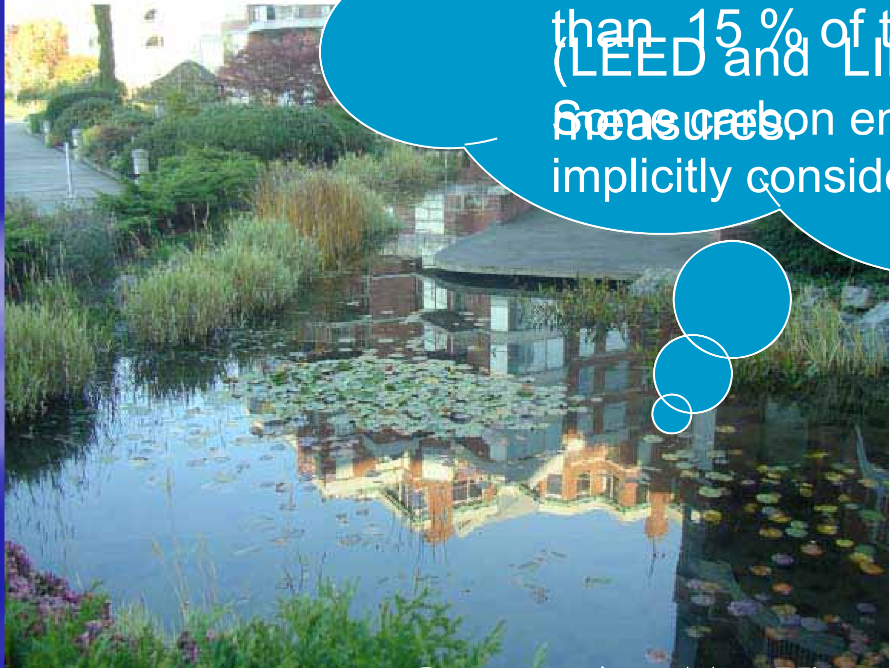
POTENTIAL PROBLEM

LEED do not consider carbon emission reduction they are strictly focused on water and pollution

LEED water (reclamation, conservation and stormwater management) criteria represent less than 15 % of the Total LEED index

(LEED and LID are small (microscale) measures.

Some carbon emission controls are implicitly considerd

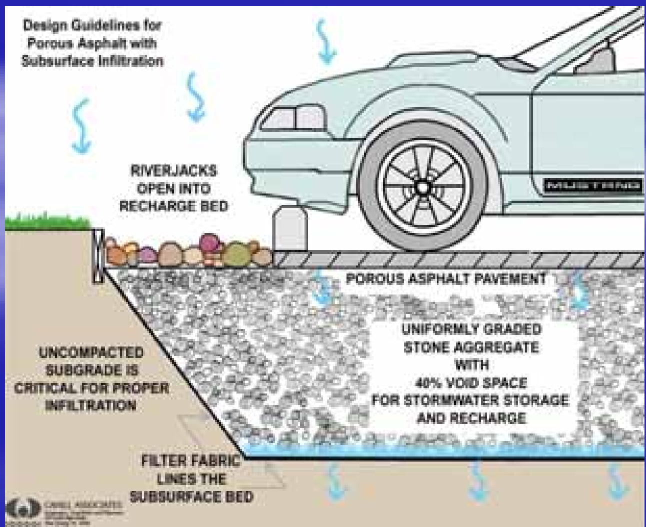


Courtesy AquaTex, Victoria, British Columbia

One Planet Living (WWF)

- zero net carbon emissions- 100% of the energy from renewable resources;
- zero solid waste
- sustainable transportation with zero carbon emission in the city;
- local and sustainable materials used throughout the construction;
- sustainable foods, outlets providing organic and or fair trade products;
- 50% reduction in water use from the national average;
- natural habitat and wildlife protection and preservation;
- preservation of local culture and heritage ;
- equity and fair trade with wages and working conditions; and
- health and happiness for every demographic group.

Best Management Practices are an integral part of the COFs



Green Roofs

Save energy and store water

Raingarderns

Infiltrate and treat runoff

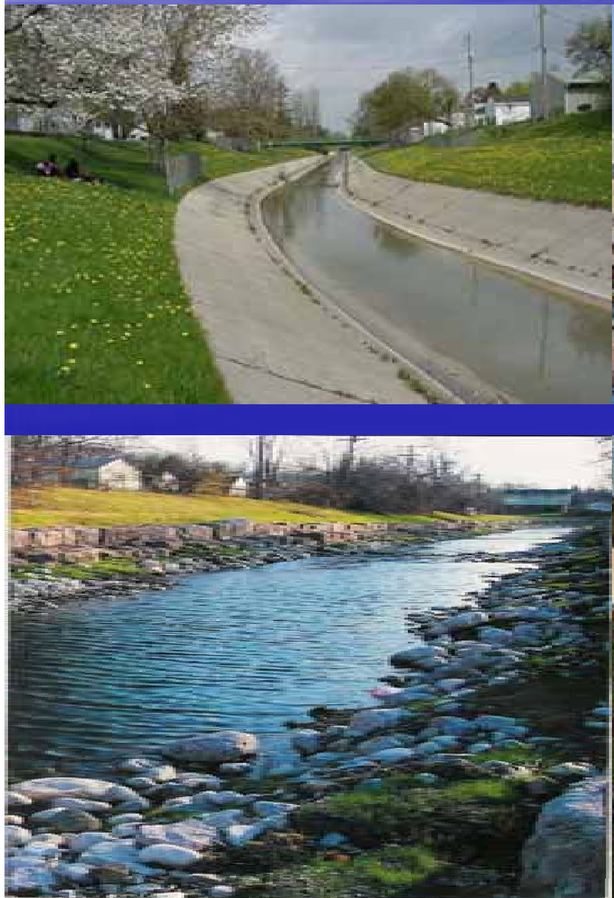
Porous pavement

Infiltrate, store and treat runoff

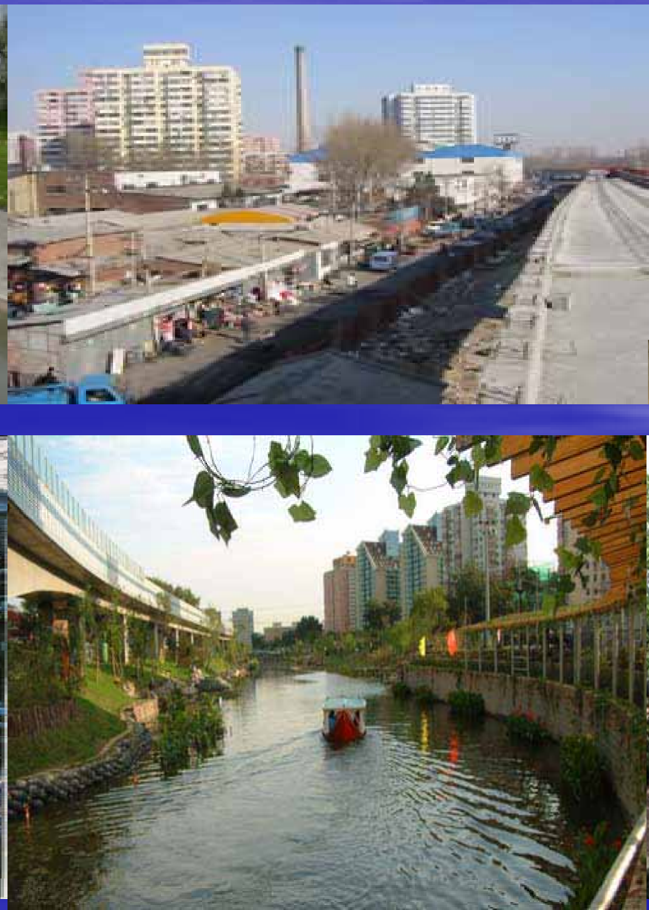
Ponds and wetlands

Store, treat and infiltrate runoff

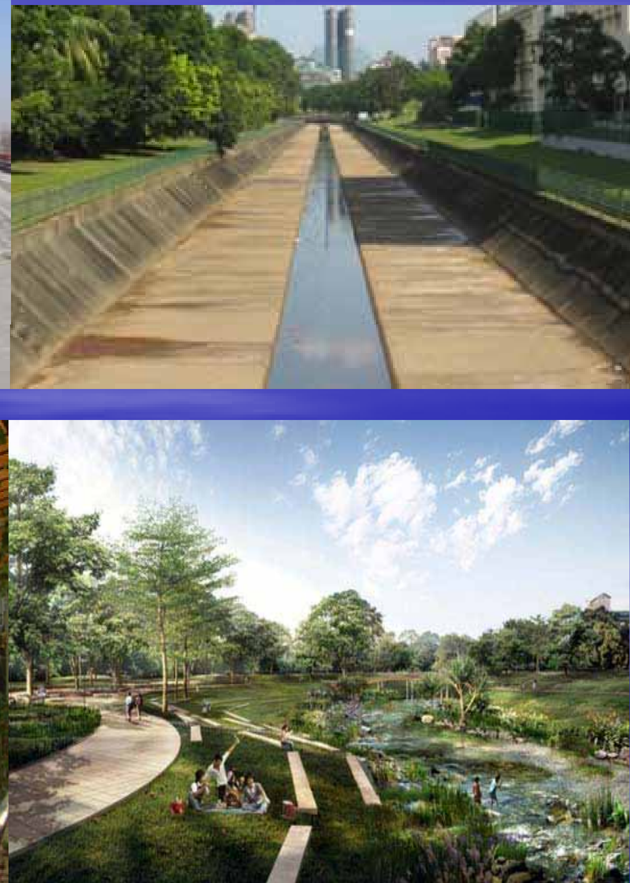
Urban water body restoration and daylighting is important



Lincoln Creek in Milwaukee



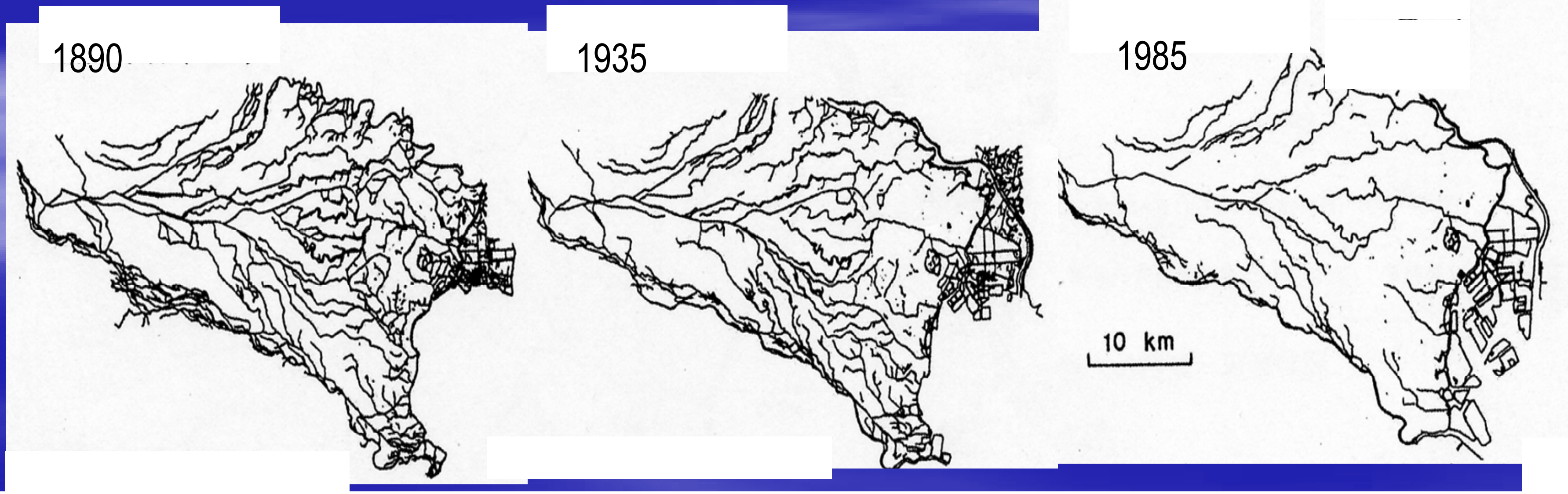
Zhuan River in Beijing



Kallong River in Singapore

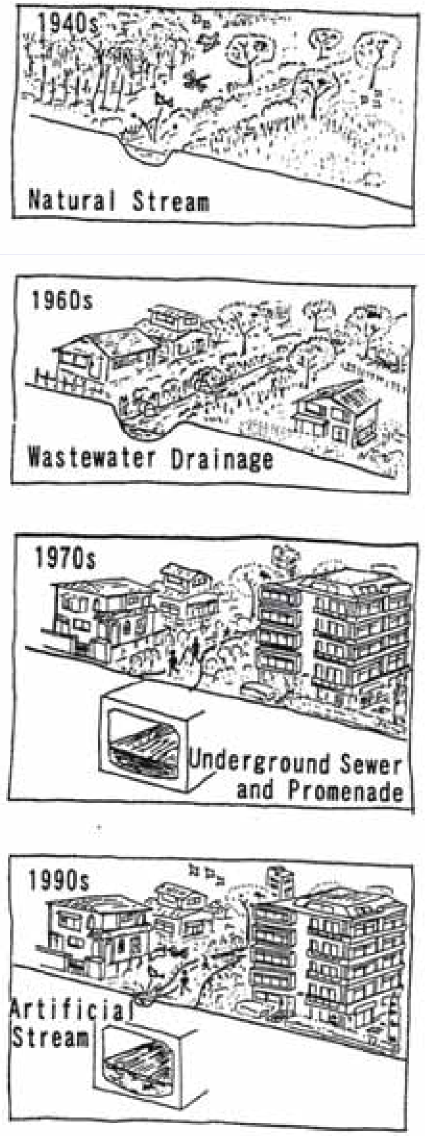
DAYLIGTHING

- With the high degree of treatment required in the new cities it does not make sense to use sewers for conveyance; they were invented and used for conveyance of highly polluted urban wastewater and urban runoff
- Streams covered, converted to culverts or combined sewers can be brought to the surface
- A new stream can be recreated in a place where the old stream is irreversibly lost



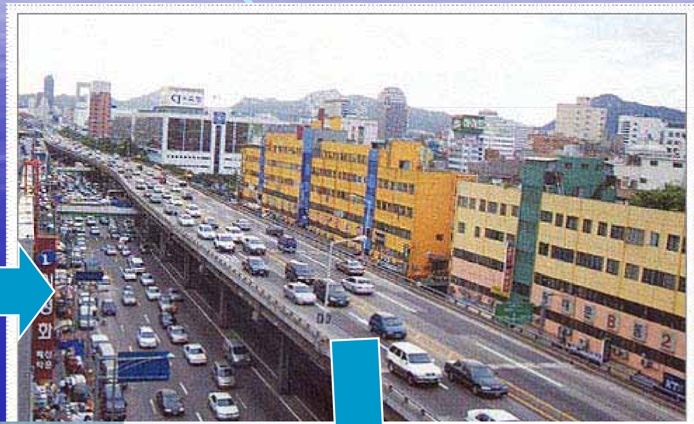
KITAZAWA STREAM IN TOKYO

- Flow in the "upper" stream is provided by a highly treated effluent from a nearby treatment plant
- Fish is living in the stream and looks healthy



The history of Kitazawa Stream

CheongGyeCheon (Seoul, KR)



Benefits ++++

City revitalization, Aesthetic

Flood control, Ecology

Sustainability -

No water reclamation, water is pumped from a larger river downstream, carbon negative

Under the new paradigm there is no waste – new sustainability terminology

- Waste water → Used water
- Treated wastewater that meets standards for discharge into receiving waters and other nonpotable uses → Reclaimed water
- Reclaimed water treated to potable water quality for reuse in buildings→ NEWater (Singapore terminology)
- Waster water treatment plant with recovery of biogas, energy, nutrients, etc. → Integrated resource recovery facility

Rainwater harvesting requires minimum energy

Roof rainwater collecting tank in Orange District in Australia

Decentralized Management Clusters and Ecoblocks

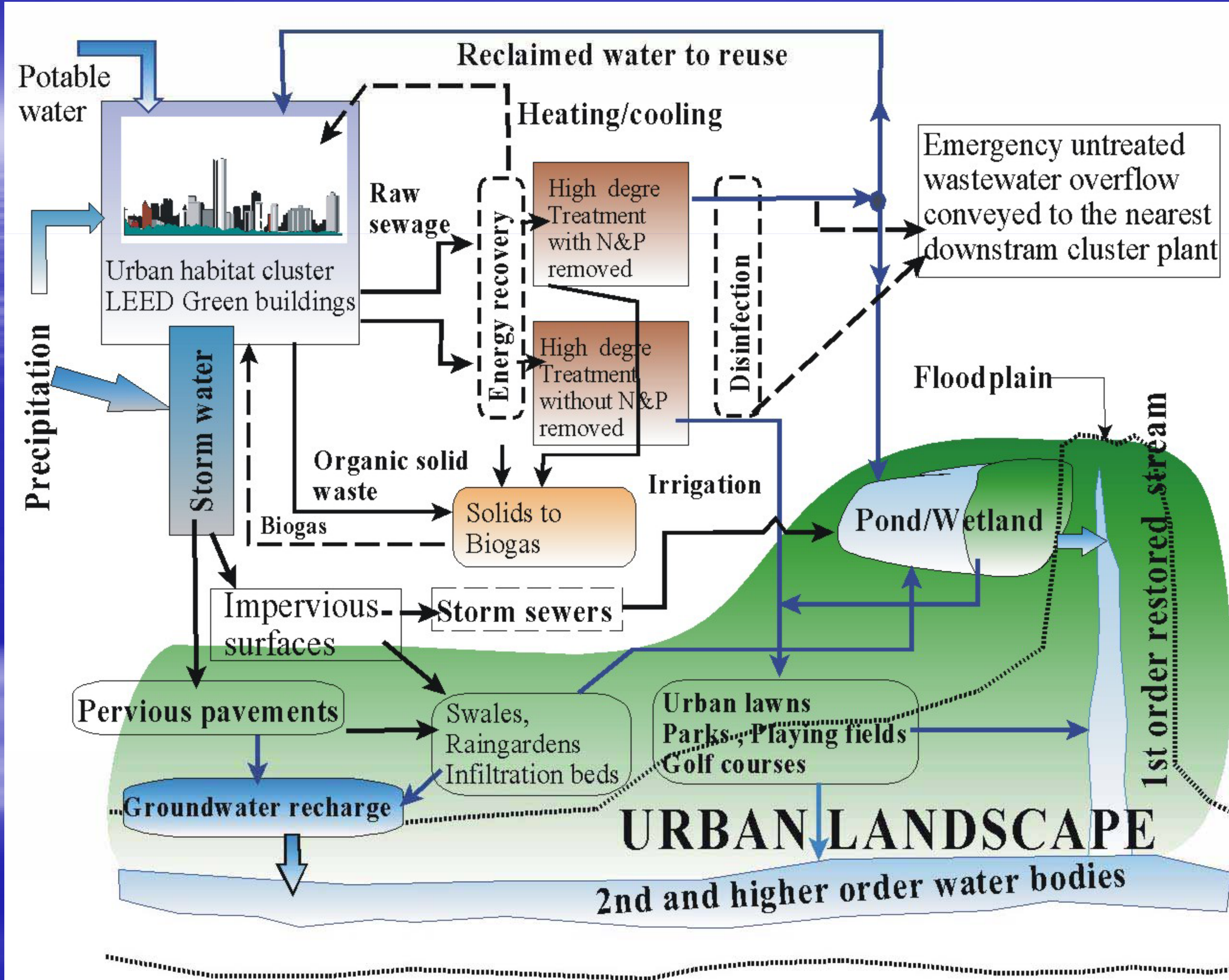
- A cluster (Ecoblock) is a semiautonomous part of the city that, for most part, has its own water/stormwater/wastewater management
  - Cluster may range in size from a high-rise building to a subdivision or a section of the city with thousands of inhabitants
  - Cluster infrastructure
    - Distributes water and practices water conservation and reuse
    - Implements energy saving in buildings (e.g., green roofs, solar energy)
    - Provides stormwater conveyance (mostly surface), storage and infiltration (groundwater recharge) and nature mimicking BMPs
    - Water reclamation units (high efficiency WWT)
    - Energy recovery from wastewater
  - Centralized or distributed biogas/Energy recovery
  - Ecologically and hydrologically functioning landscape
- Clusters are interconnected for increased resiliency

A water reclamation plant does not have to be far from the community

Courtesy AquaTex, Victoria, BC

Distributed (cluster) water reclamation plants are needed to provide water for on-site uses such as

- toilets
- irrigation
- ecological flow to restored and recreated streams


Reclaimed water to reuse
Potable water
Heating/cooling
Raw sewage
Energy recovery
High degre Treatment with N&P removed
High degre Treatment without N&P removed
Disinfection
Emergency untreated wastewater overflow conveyed to the nearest downstram cluster plant
Urban habitat cluster LEED Green buildings
Precipitation
Storm water
Organic solid waste
Solids to Biogas
Biogas
Irrigation
Floodplain
Pond/Wetland
1st order restored stream
Impervious surfaces
Storm sewers
Pervious pavements
Swales, Raingardens Infiltration beds
Urban lawns Parks, Playing fields Golf courses
Groundwater recharge
URBAN LANDSCAPE
2nd and higher order water bodies

Seven Ecocities Review

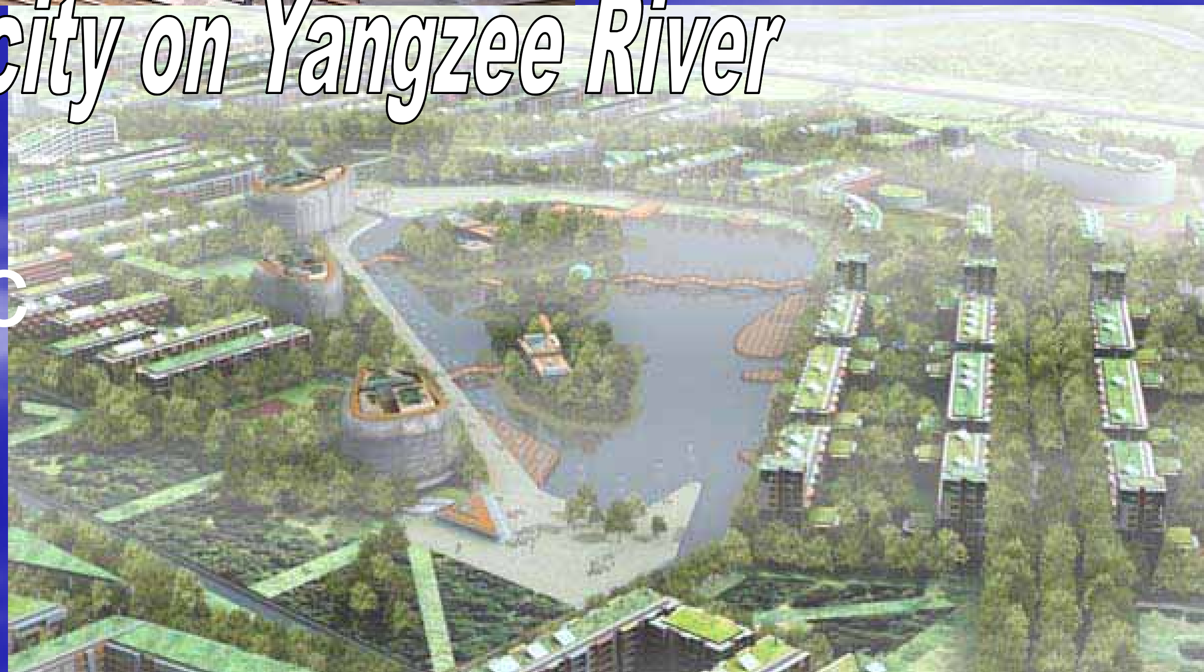
- Hammarby Sjőstad
- Dongtan
- Qingdao
- Tianjin
- Masdar
- Treasure Island
- Sonoma Valley

Water Centric Hammarby Sjöstad


BEIJING
TIANJIN
Tianjin
ecocity
Qingdao
North Ko
Shaanxi
XI'AN
Dongtan
Shanghai
© 2008 ZENRIN
© 2008 Europa Technologies
© 2008 Kingway Ltd.
© 2008 NFGIS
©2006 Google™
Pointer 36°15'53.60" N 116°35'42.81" E
Streaming |||||||||| 100%
Eye alt 891.93 mi

Dongtan

Venice -type ecocity on Yangzee River



Water centric

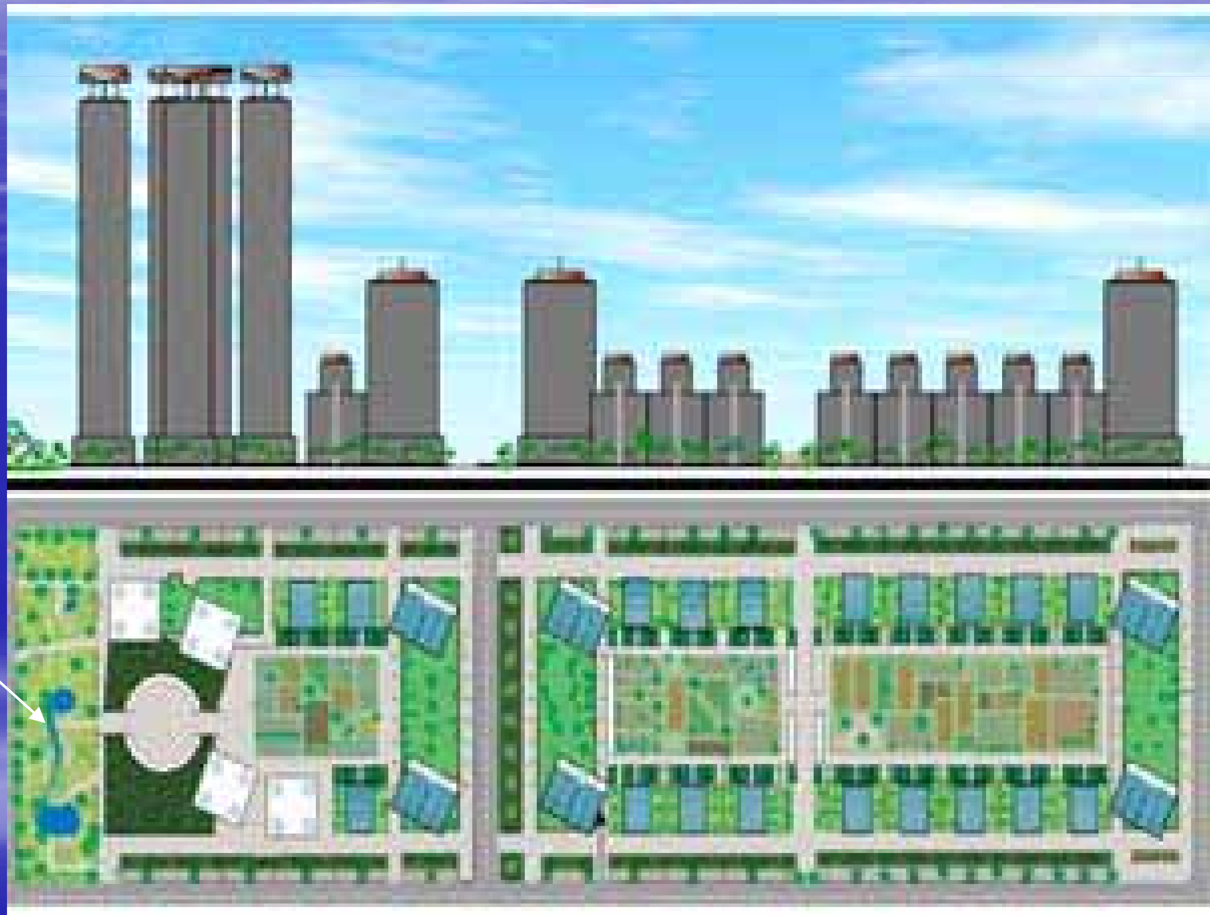
British (Arup and
Chinese Cooperation

QINGDAO (China) Ecoblock

Size 3.5 ha

1530-1800 pop

Treatment wetland



Cooperation
Veolia (France),
University of California
China

Subsurface flow wetland

Constructed wetland in CR for 1000 connected inhabitants. Area 0.5 ha (J. Vymazal)

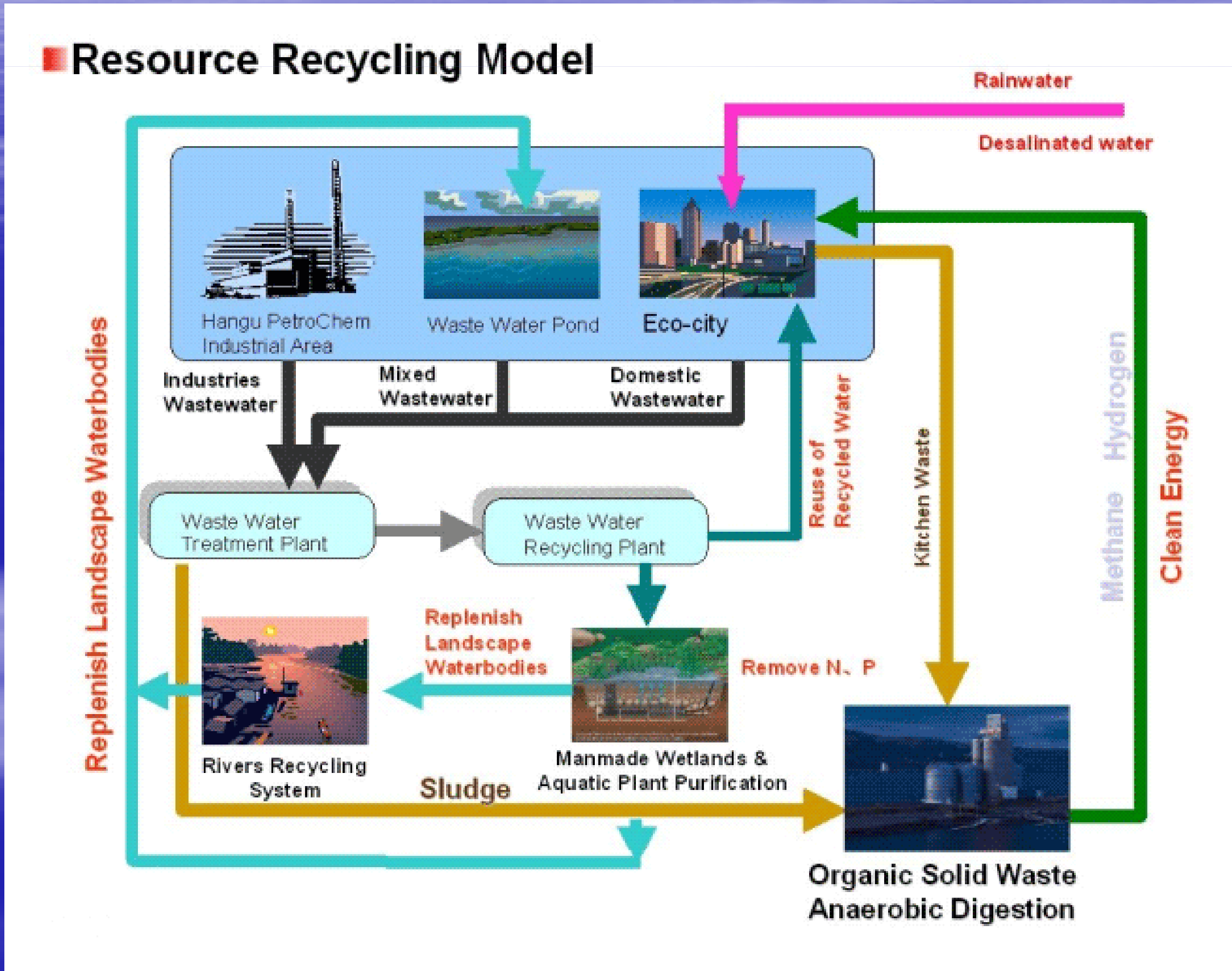
Source Harrison Fraker and ARUP

600 units on 2.7 ha (6.5 acres)

Sino-Singapore Ecocity Tianjin

Cooperation:
Singapore
US (CH2M-Hill)
Germany (Atelier Drteiseitl)
China

Recycling - Reuse



TIANJIN

Masdar (UAE)

Cooperation:

UK – Foster and Associates
USA – CH2M-Hill
United Arab Emirates

Siemens

Courtesy: Masdar Development Corporation/CH2M-HILL

Treasure Island (CA)

Location
San Francisco Bay, California
Developer City of San Francisco

Sonoma Mountain Village (CA)

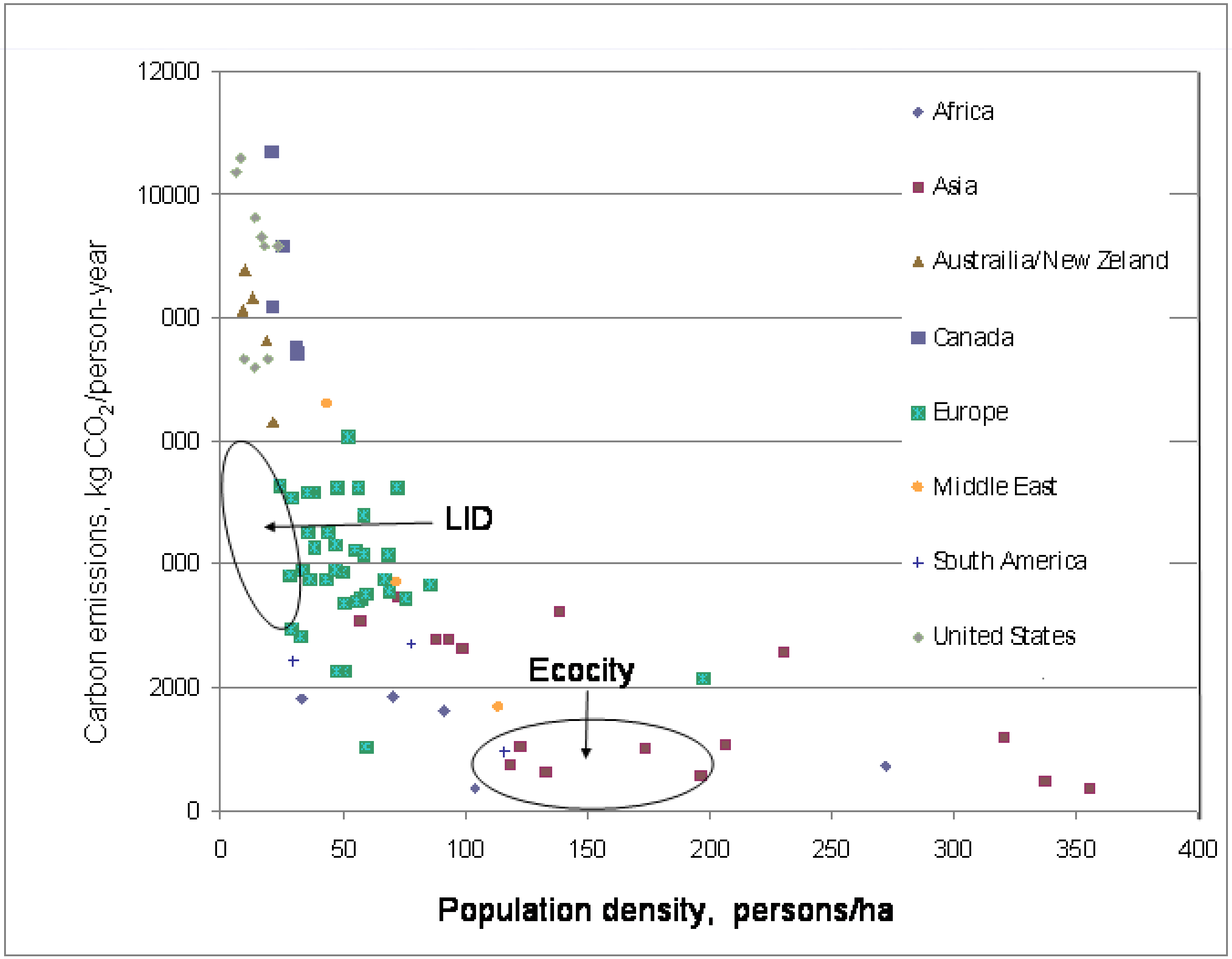
What have we learned?

Courtesy: Sonoma Mountain Village - SOMO

City	Population Total	Population Density #/ha	Water use L/cap-day	% water recycle	Water System	% Energy savings renewable	Green area m^2/cap	Cost US$/unit*
Hammarby Sjőstad	30,000	133	100	0	Linear	50	40	200,000
Dongtan	500,000 (80,000)++	160	200	43	Linear	100	100	~40,000
Qingdao	1500+	430 - 515	160	85	Closed loop	100	~15	?
Tianjin	350,000 (50,000)++	117	160	60	Partially closed	15	15	60,000 – 70,000
Masdar	50,000	135	160	80	Closed loop	100	<10	1 million
Treasure Island	13,500	170	264	25	Mostly Linear	60	75	550,000
Sonoma Valley	5,000	62	185	22	Linear	100	20	525,000

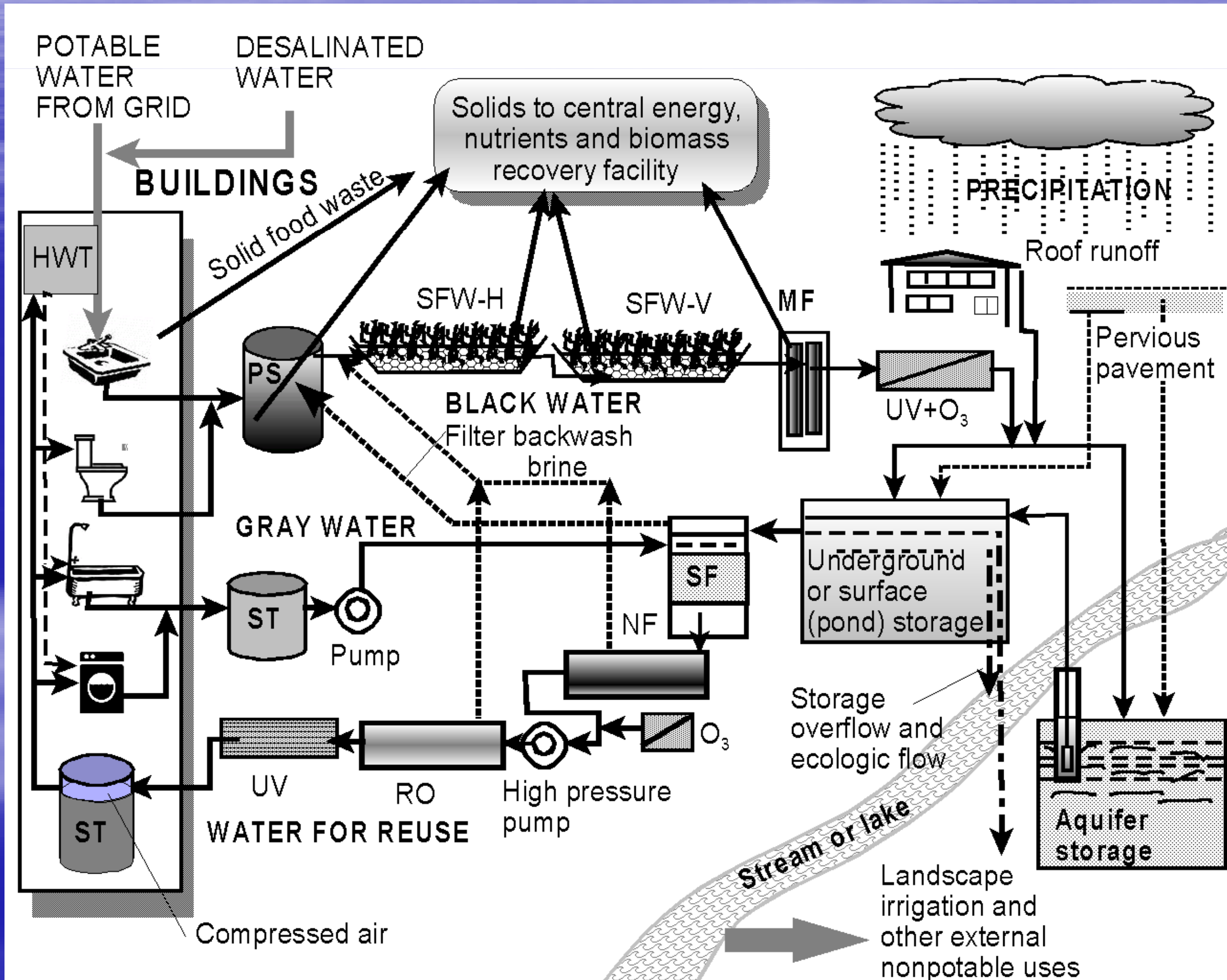
+ ecoblock only, an ecocity may consist of many interconnected ecoblocks

Population density matters



- Difficult to compare US cities with Asian Cities or countries with different economic levels
- Based on Newman and various other sources

Qingdao - The cycles need urban runoff



The number of cycles without make up water is very limited.

Make up water comes mainly from treated (and stored) storm water

PS – primary settler
MF microfiltration
UV ultraviolet
ST storage
RO reverse osm.
NF nanofiltration

Reuse

Energy demanding

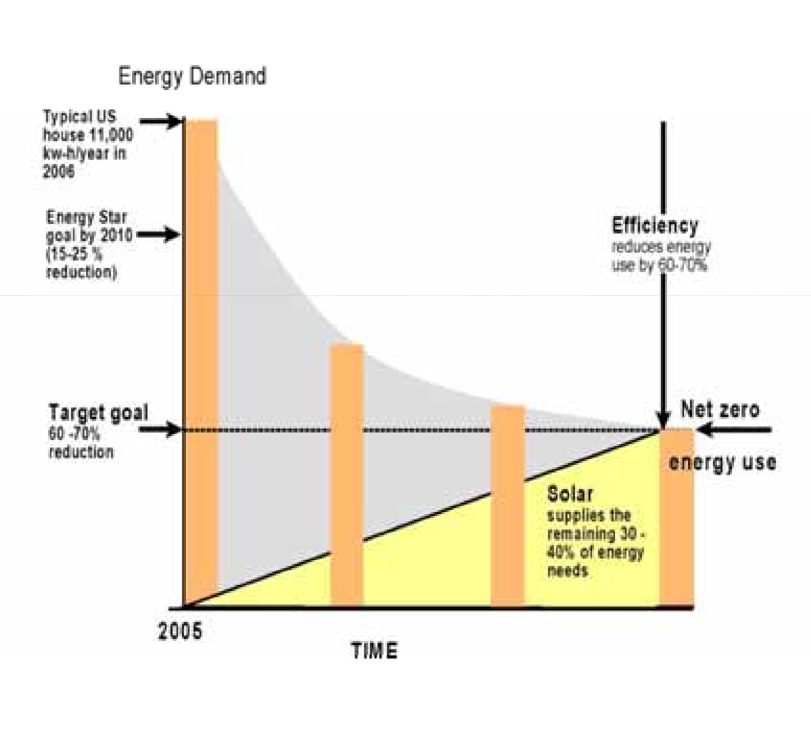
Microfiltration

Reverse osmosis

UV radiation

Water Energy Nexus

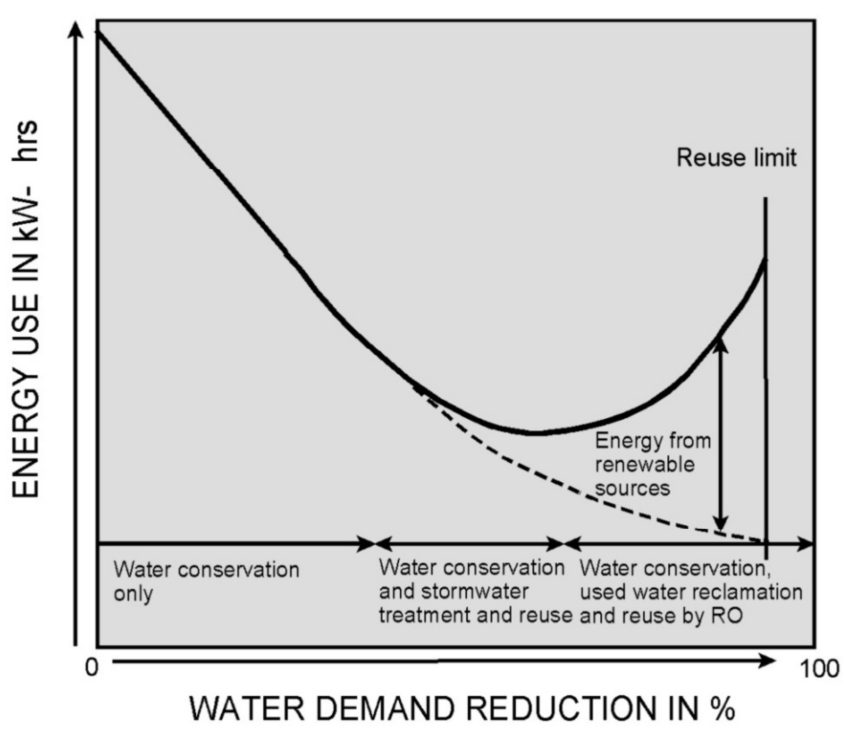
How to get to net zero energy



National Science & Technology Council (2008) of the US President

Energy delivered from the grid

1 kW-hr = 0.6 kg CO_2 emissions



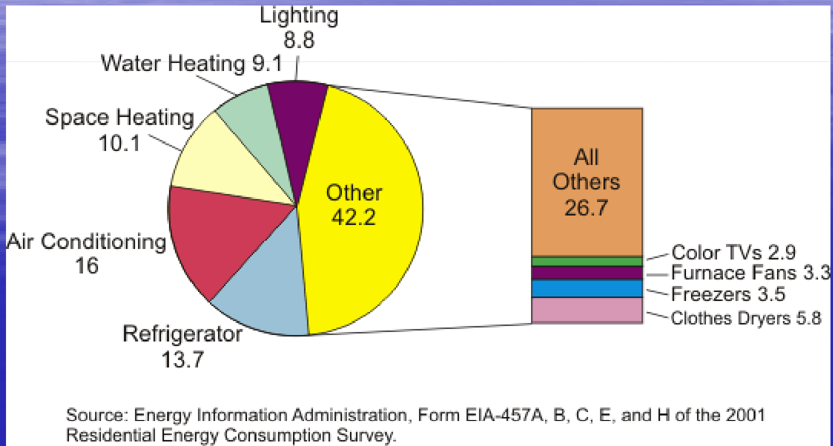
Indoor and outdoor water use in a single family home in 12 monitored cities in North America

Water use	Without water conservation*		With water conservation	
	Liter/cap-day	Percent	Liter/cap-day	Percent
Faucets	35	14.7	35	25.8
Drinking w[illegible]e and cooling	3.6	1.2	2.0	1.5
Sh[illegible]	42	17.8	21	15.4
Bath and Hot Tubs	[illegible]	[illegible]	[illegible]	[illegible]
Laundry	54	22.6	40	29.4
Dish washers	3.0	1.4	3.0	2.2
Toilets	63	26.4	14	10.3
Leaks	30	12.6	15	11.0
Total Indoor	238	100	136	100
Outdoor	313	132	60**	44
Total	551	232	196	144

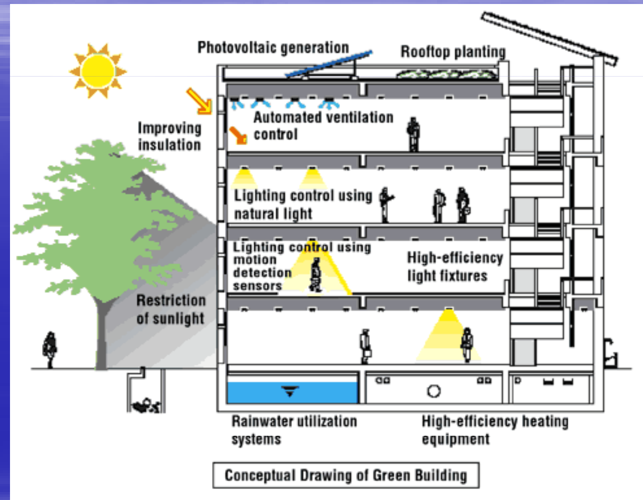
Water conservation reduces proportionally carbon emissions

AWWA RF (1999); Heaney, Wright and Sample (2000) and Asano et al. (2007) ** Converting from lawn to xeriscape.

Domestic energy savings



Passive energy savings



Tankless water heaters

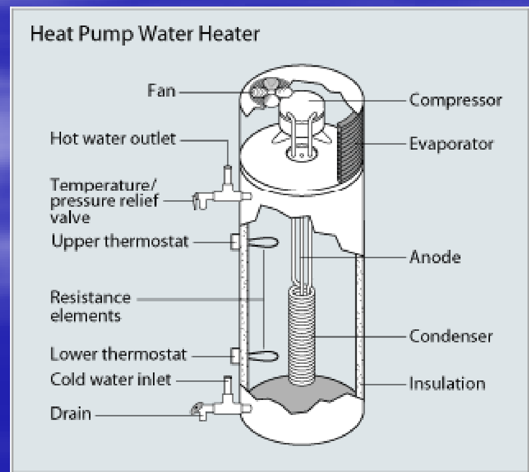
Heat pump

* Air to air

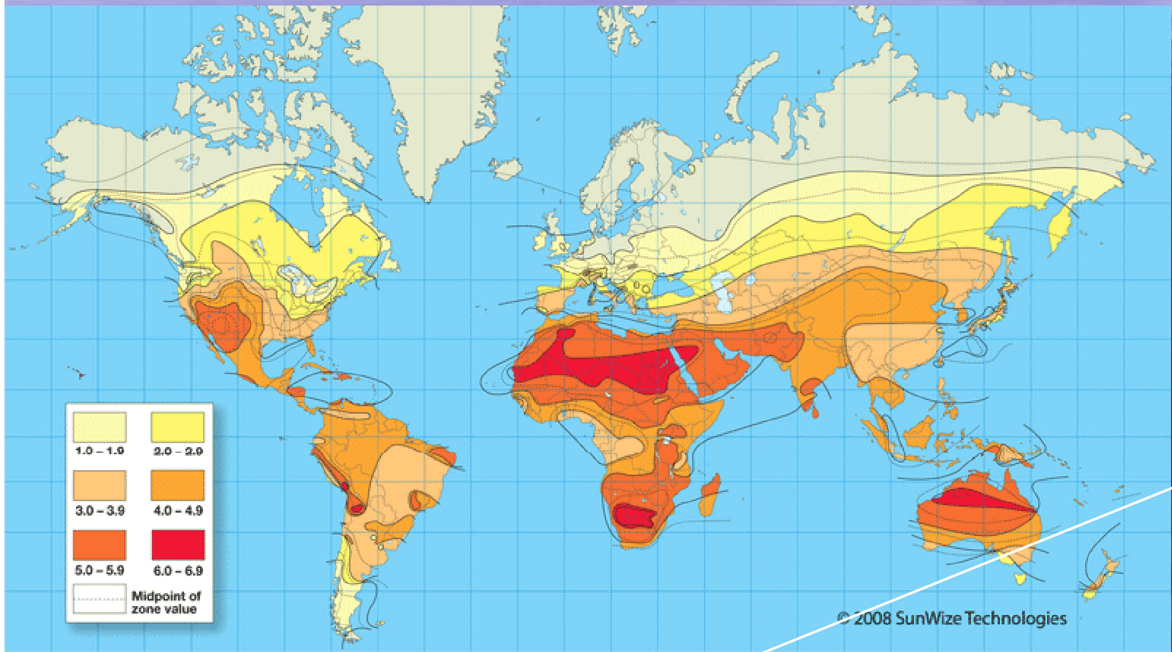
•Water to air

•Water to water

•Ground to water



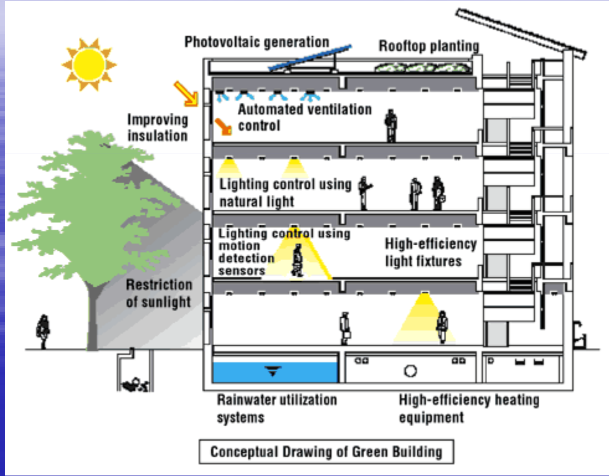
Solar energy



Concentrated heat

Photovoltaics

30 % from Renewable Energy



Passive energy sources

1.4. MW Voltaics array in Sonoma County

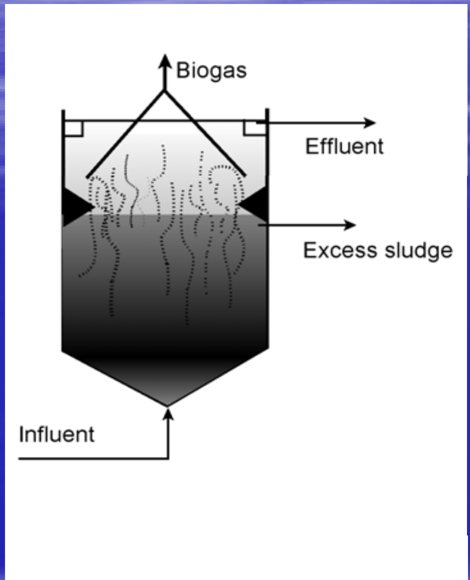
Wind turbines

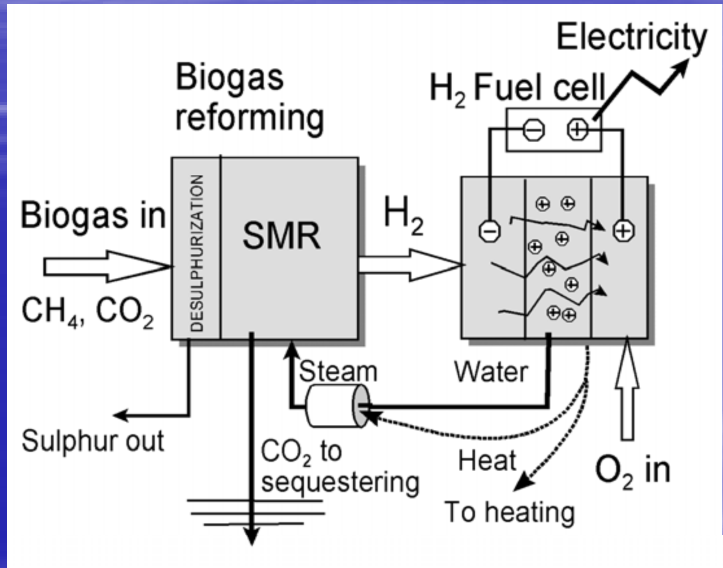
Energy from used water

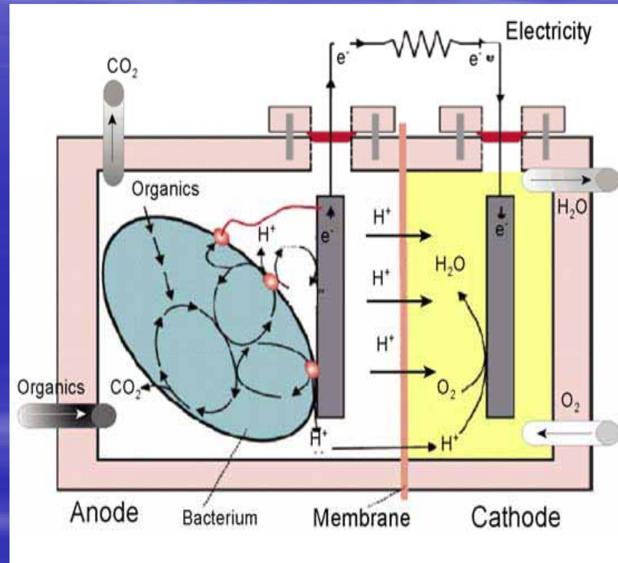
- Heat recovered by heat pumps
- Biogas from anaerobic processes
  - Digester
  - Upflow anaerobic sludge blanket reactor
- Hydrogen fuel cell
- Microbial fuel cell

Types of gas	Biogas 1 Household waste	Biogas 2 Agrifood industry	Natural gas
Composition	60% CH_4 33 % CO_2 1% N_2 0% O_2 6% H_2O	68% CH_4 26 % CO_2 1% N_2 0% O_2 5 % H_2O	97.0% CH4 2.2% CO_2 0.4% N_2 0.4 % other
Energy content kWh/m^3	6.1	7.5	11.3

Examples of new technologies







UASB Reactor

- 0.4 L CH4/g COD removed
- 9.2 kW-hr/m^3 of methane

Hydrogen fuel cell with biogas reforming

•Converts methane into hydrogen and electricity

•Greater efficiency than methane combustion

SMR = Steam methane reforming

Microbial fuel cell (Logan 2008)

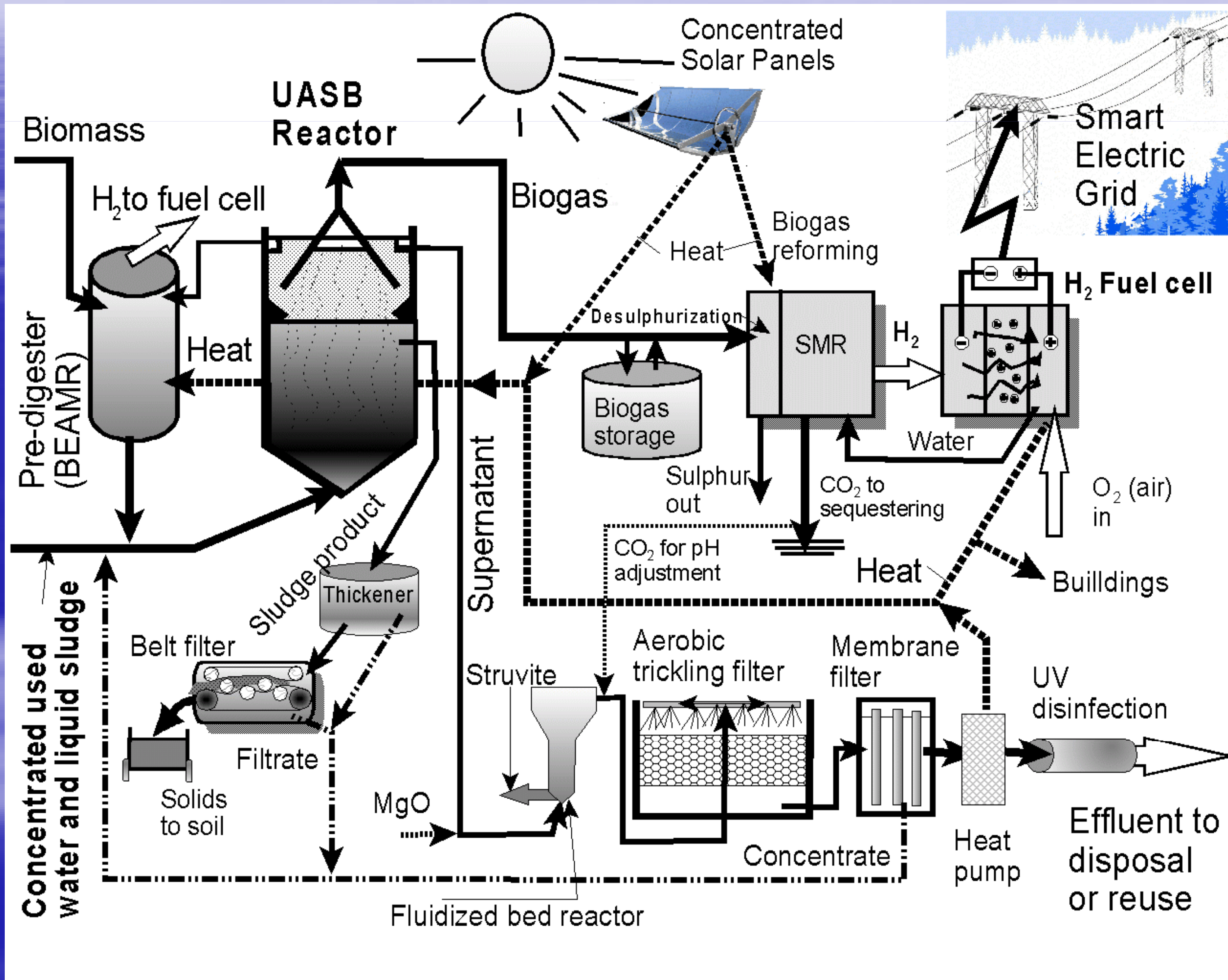
•Convert organic biomass directly into electricity or hydrogen

Hydrogen Fuel Cell

Installed in Glashusett in Hammarby Sjöstad

Converts biogas to electricity

Integrated Resource Recovery Facility



Recovers:

- Water
- Electricity
- Heat
- Struvite (N+P)
- Organic solids
- Biogas
- Hydrogen

SMR = steam methane reforming

CONCLUSIONS ON ECOCITIES

- Ecocities are emerging and will be tested
- A complete change of the paradigm
    - Closed hydrologic cycle (reuse, recycle), surface drainage
- Zero or minimal carbon imprint
    - Energy recovery from wastewater
    - Distributed resource recovery, minimum sewers
    - Alternate energy sources
    - Carbon sequestering
- Terrific public transportation, walking and biking
- Alternate energy sources
- Stream restoration and protection of ecosystems
- Leisure and recreation
- Huge new infrastructure business potential

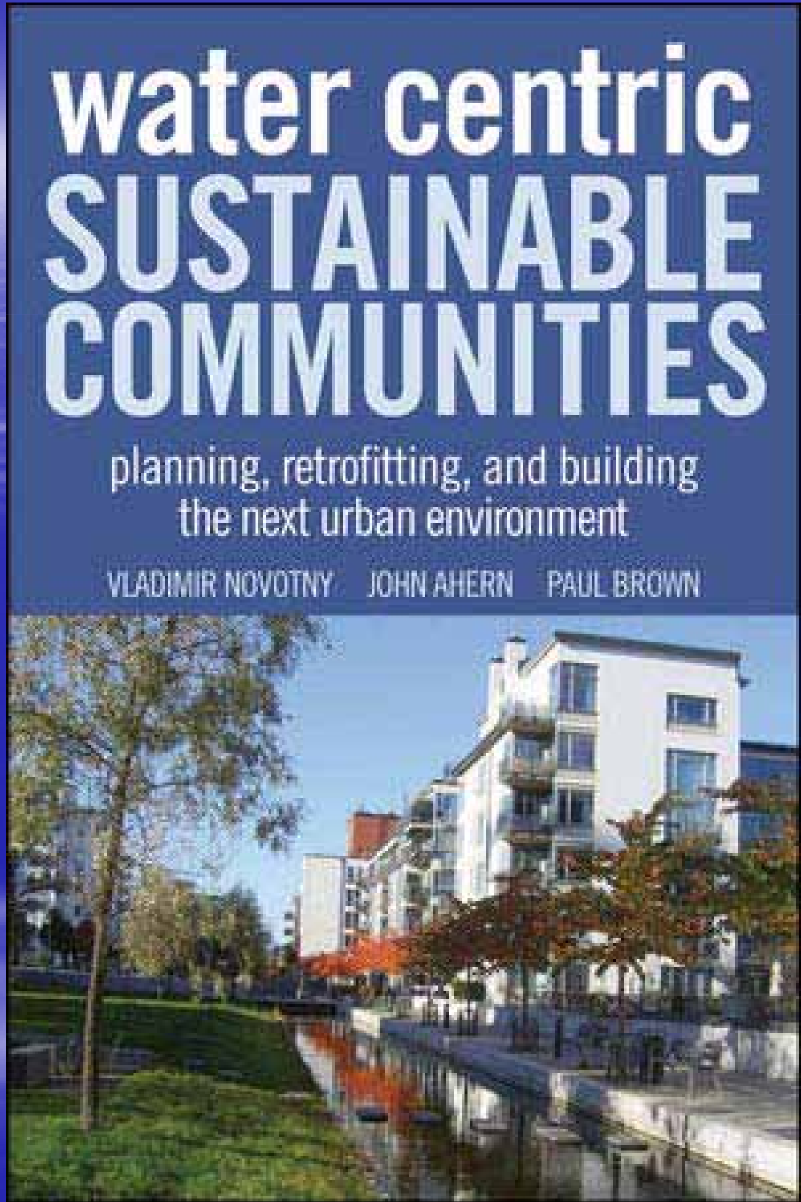
Conclusions

- US has one of the highest per capita footprint
  - Low density urban centers
  - High automobile use
  - Great reliance on fossil fuel (primarily coal) power production
- Adopting and adapting the ecocity guidelines is Increasing significantly production from renewable carbon free sources
  - Water conservation is effective
  - Biogas conversion to electricity or hydrogen with carbon sequestering is effective
  - Wind turbines on each block
  - Large inclusion of solar power
  - Limiting automobile use, hybrids and electric pug-ins are very effective
  - Heat recovery from used water
  - More efficient appliances and heating (e.g., heat pumps)
- The goal of net zero carbon footprint is achievable by 2030 even in the US

Worldwide Initiative –Cities of the Future

- Beginning in US - Wingspread Workshop -2006
- IWA Congresses Beijing 2006, Vienna 2008
- Singapore International Water Week Convention – CoF became the major IWA initiative- Steering Committee formed
- Beijing Conference – November 2009
- WEF/IWA Conference March 2010 – Boston
- Singapore International Water Week – June-July 2010
- IWA World Water Congress 2010 -Montreal
- IWA/WEF Conference 2011 – Stockholm
- IWA Conference 2011 – Xi'an (China)
- WEF/IWA Conference 2012

All invited



http://www.wiley.com/WileyCDA/WileyTitle/productCd-0470476087.html