Closing the Water Cycle, Recovering Energy and Resources in Future Sustainable communities

Freeman Lecture

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Outline:

1. The New (fifth) Paradigm for Sustainable Communities
2. Cities of the Future - Ecocities
3. Urban Metabolism - 4 Rs, 3 Ss and 2 Ts
4. Sustainability Footprints –Present and Future Outlook
5. Distributed Water, Used Water and Energy Management - Ecoblocks
6. Integrated Resource Recovery Facility
    1. Syngas vs. Methane vs. Hydrogen towards Electricity
    2. Nutrients, Biomass, Fuel, Solids
    3. Incorporating Solar and Wind Energy, GHG Sequestering
7. Worldwide Developments and Trends

Cities of the Future – Utopia or Unavoidable Reality

Model of Tianjin Ecocity, China

- "Urbanites now outnumber their rural cousins – and that's surprisingly **good news for the environment"**
- "The average New Yorker produces just 30 per cent of the greenhouse emissions of the average US citizen"

Barley 2010, *New Scientist* 2785, 32-37

COF – an international movement towards urban water, energy and resources sustainability

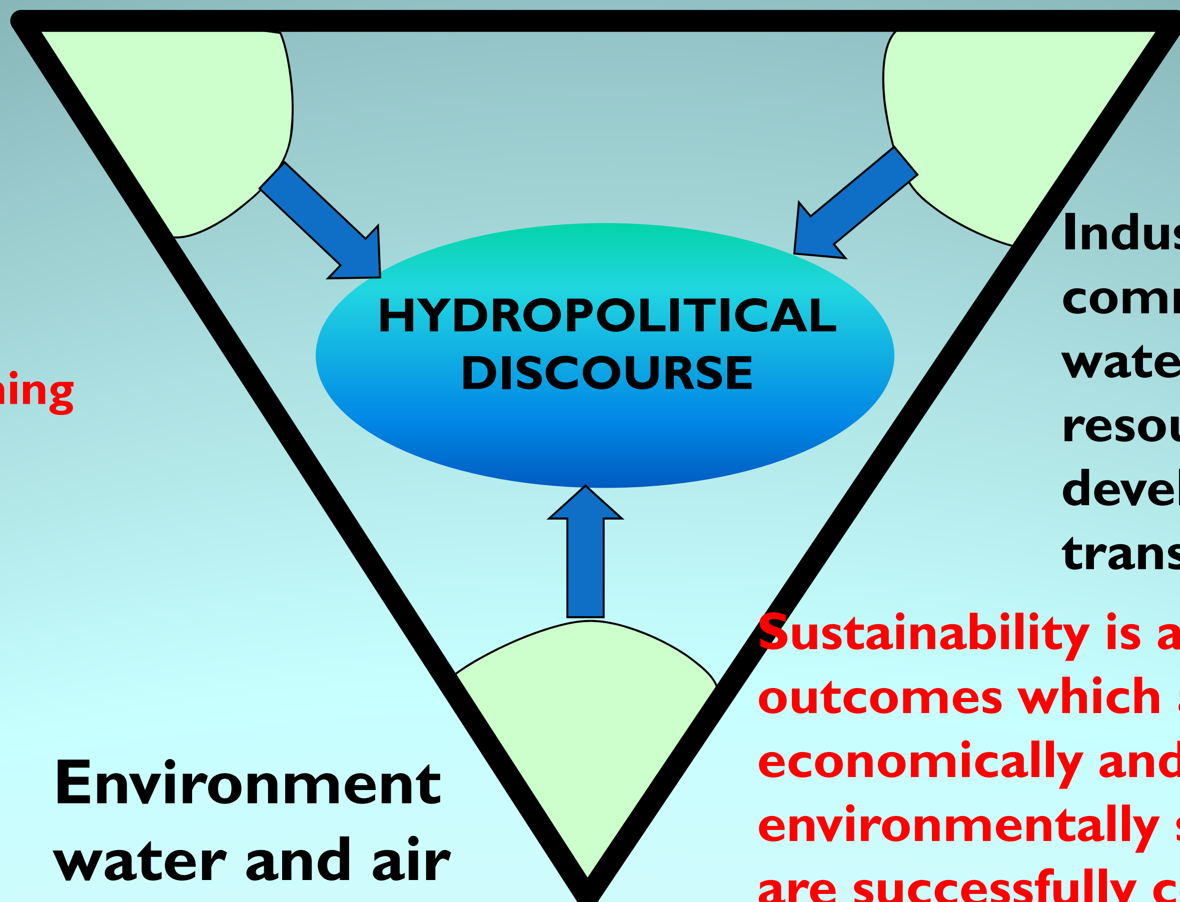
In the next 25-30 years China will build cities for 300 million people

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

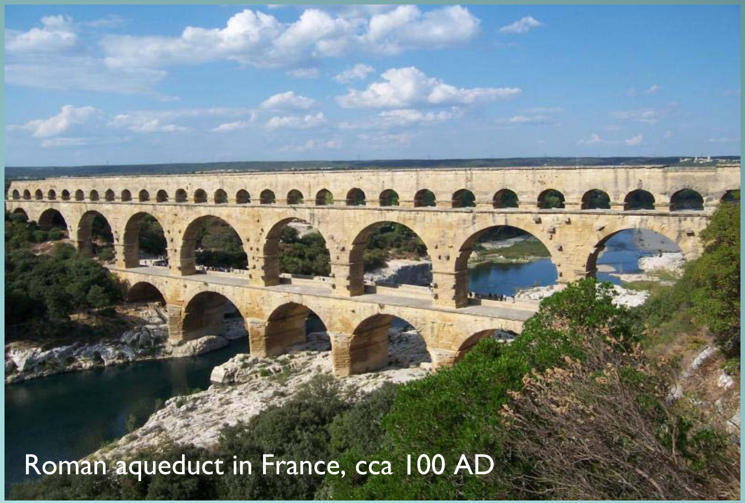
Environment water and air

Sustainability is achieved when outcomes which are socially, economically and environmentally sustainable, are successfully contended in the itergenerational context

Historic Paradigms

I

II



Roman aqueduct in France, cca 100 AD

Drainage in old market in Athens, cca 2500 BC

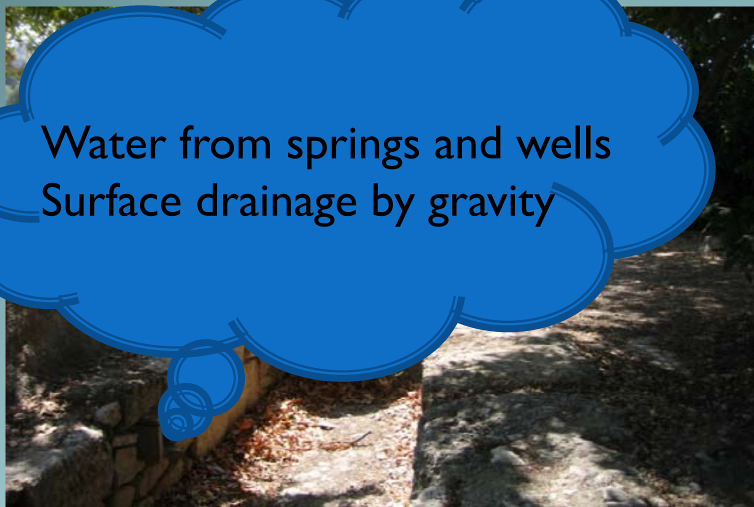
Cuyahoga River fires in 1050s-1960s

III IV

Milwaukee's deep tunnel for CSO storage – late 1990s

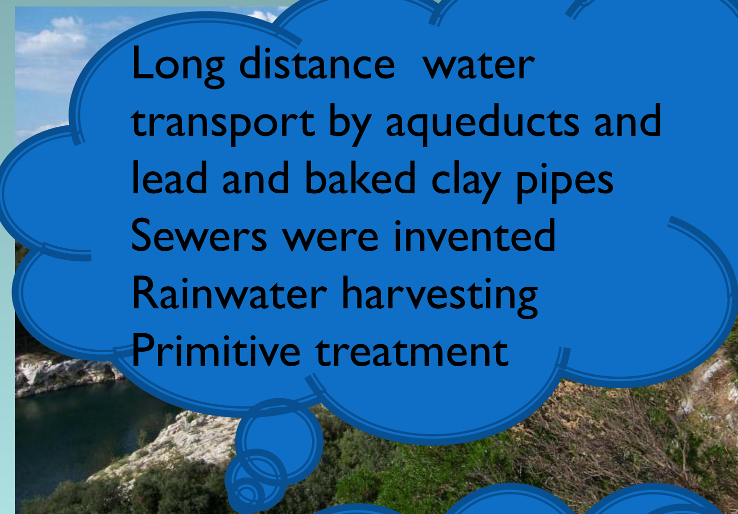
Historic Paradigms

I



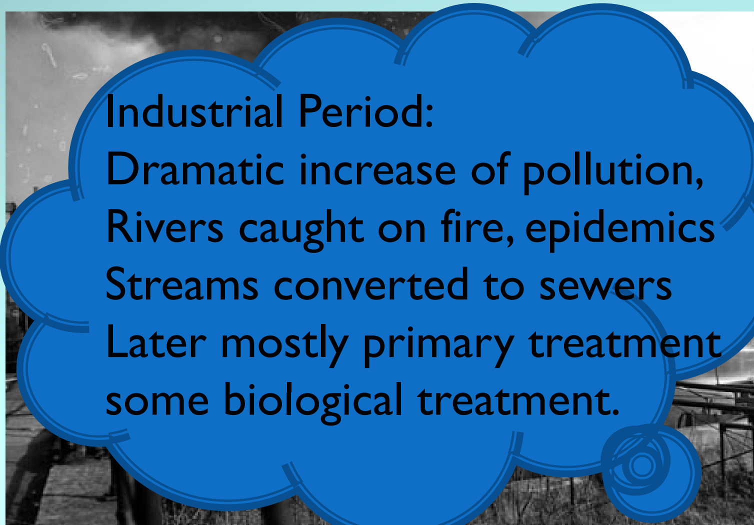
Water from springs and wells
Surface drainage by gravity

II



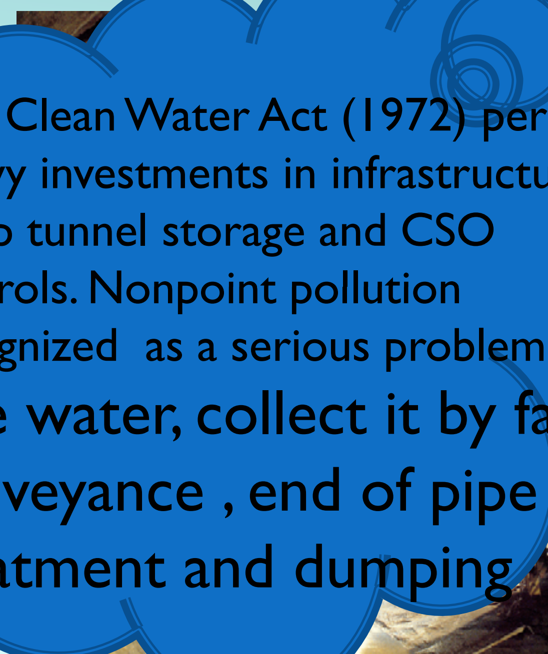
Long distance water transport by aqueducts and lead and baked clay pipes
Sewers were invented
Rainwater harvesting
Primitive treatment

III



Industrial Period:
Dramatic increase of pollution,
Rivers caught on fire, epidemics
Streams converted to sewers
Later mostly primary treatment some biological treatment.

IV

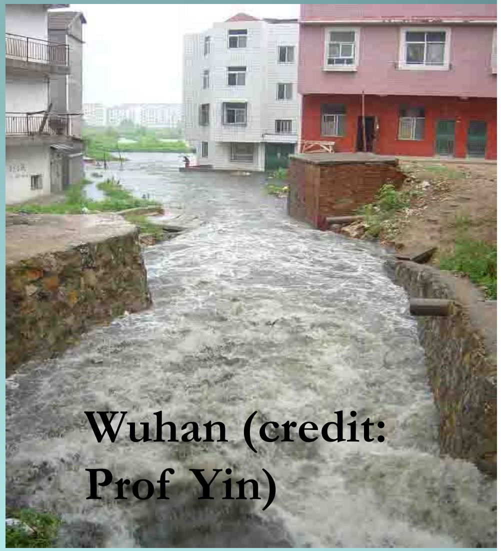


Post Clean Water Act (1972) period:
Heavy investments in infrastructure
Deep tunnel storage and CSO controls. Nonpoint pollution recognized as a serious problem.

Use water, collect it by fast conveyance , end of pipe treatment and dumping

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 sustainability goals cannot be attained using the IVth paradigm infrastructure heavy and energy demanding concepts



Wuhan (credit: Prof Yin)

Mexico City subsidence

Damages to Water Bodies

- **Wastewater disposal**
  - Effluent dominated – flow deprived streams
- **Urbanization effects other than wastewater**
  - Substrate degradation
    - Embeddedness
    - Habitat loss and fragmentation
  - Increases peak flow
    - Channel lining and cutting trees along the water body
  - Decreased base flow
    - Decreases water quality
    - Restricting channel by dikes and levees
    - Increases bank erosion
- **Loss of streams –conversion into sewers**

New Threats to Water Supplies and Ecology

Urban pond in China

Forbay of the reservoir supplying water for Prague

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

Vision of the Cities of the Future The 5th (Sustainable) Paradigm

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, recycles or converts 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

Microscale Assessment

- Micro-scale goals (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

Cities of the Future incorporates both LEED and LID principles and concepts but they are not traditional LID communities

CITY OF THE FUTURE

IS IT BUILDINGS AND "NEIGHBORHOODS" CONFORMING TO LEED CRITERIA CONNECTED TO SUSTAINABLE LID SURFACE DRAINAGE ?

Courtesy AquaTex Consulting, Victoria, BC

CITY OF THE FUTURE

IS IT BUILDI… AN… …MING TO LEED C… …CE DRAI…

PROBLEM

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

Some carbon emission controls are implicitly considered

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

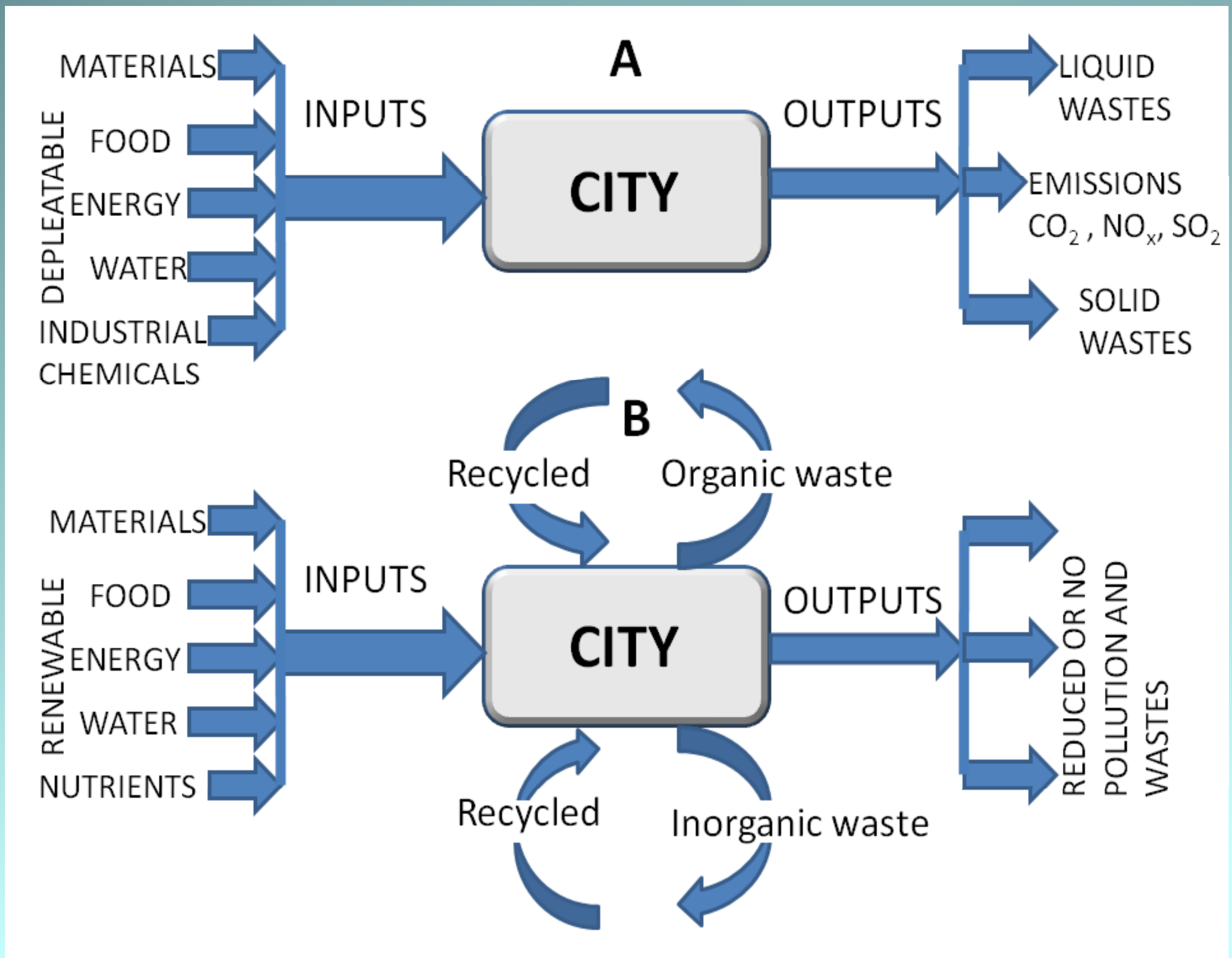
LEED and LID are microscale measures

Courtesy AquaTex Consulting, Victoria, BC

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.**

Urban Metabolism



A Linear

needs to be changed to

B Cyclic or Hybrid

Macroscale (Giant) 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)
  - 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

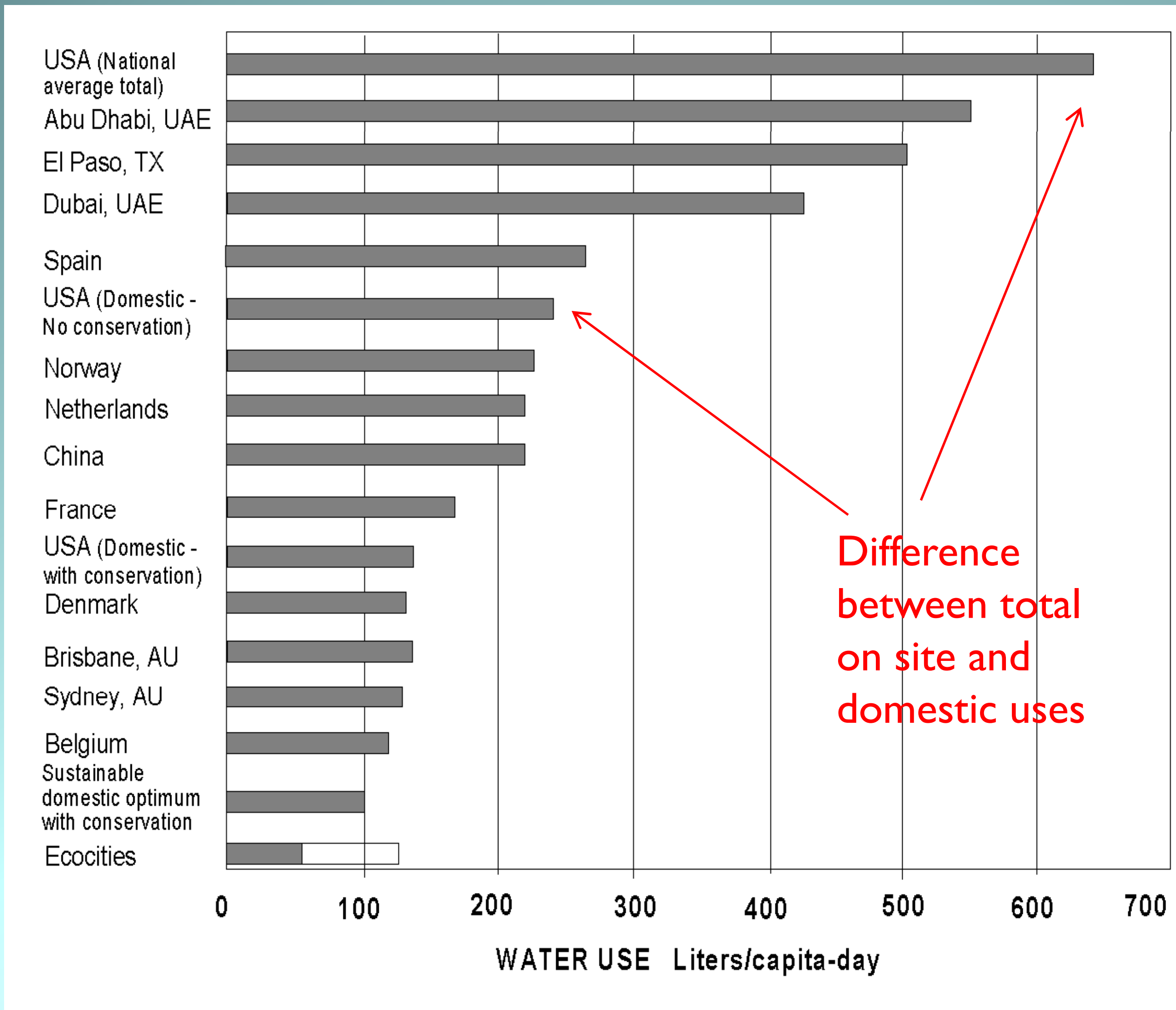
Year	World Population	Available productive land	
		Ha/person	Ac/person
1995	< 6 billion	1.5	3.6
2040	10 billion	<<1	2

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

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

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 water and cooling	3.6	1.2	2.0	1.5
Showers	42	17.8	21	15.4
Bath and Hot Tubs	6.8	2.0	6.0	4.4
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

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

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 (private and public), heating, and electricity

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

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 excessively energy and emit carbon and often methane which are green house gases
  - The receiving water bodies become effluent dominated after discharge

"Conventional system based on activated sludge wastewater treatment (ASWT)– the wrong road towards sustainability!" (Willy Verstraete Professor at the University of Ghent)

- Drinking water is primarily used as a transport vector and irrigation; only a minor part (less than 3%) for nutritional purposes
- Total carbon footprint of Activated Sludge Wastewater Treatment is not sustainable and represents in Belgium/France 125 kg CO_2/cap-year which could be about 340 kg CO_2/cap-year in the US
- Conventional removal of nutrients and potential reuse/recycle would require additional energy and emit more GHGs
- Heat and nutrients are generally not recovered
- Energy recovered from sludge digestion is rarely practiced and represents only a minor portion of the energy potential
- Residual pollution load is still significant

Closing the Cycle

- Reduce, Reclaim, Reuse and Restore - **4 Rs**
  1. Reduce - Water and energy conservation
  2. Reclaim
     1. Treat for safe discharge into environment – TMDL
     2. Reclaim energy (heat), nutrients
  3. Reuse after additional treatment
  4. 4th R – Restore water bodies as a resource
- Separate, Sequester and Store- **3 Ss**
  1. Separate Blue, White, Gray, Yellow, and Black Water
  2. Sequester GHGs and remove/detoxify toxics
  3. Store reclaimed water on the surface and/or underground
- Toilet to Tap – **2 Ts** (is it needed?)
  - Reclamation with or without 3S for potable reuse

4 Rs, 3 Ss and 2 Ts

NEW CONCEPTS

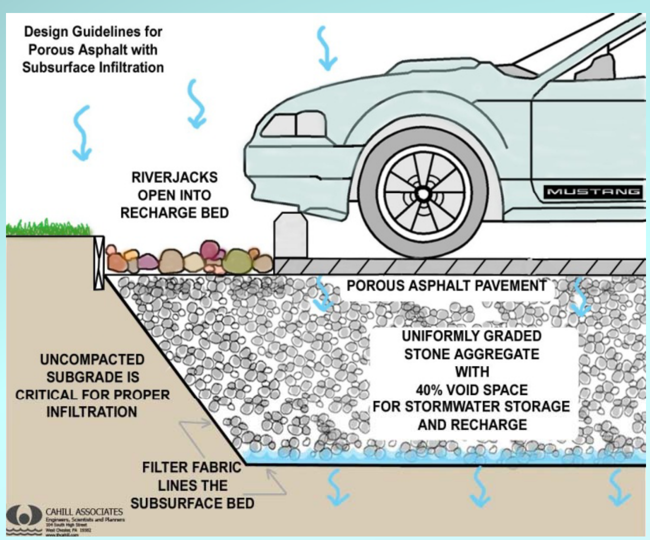
Green and Sustainable

- Eco-mimicry for the landscape
  - Develop urban landscape that would mimic but not necessarily reproduce the predevelopment natural system
    - Xeriscape
  - Minimize imperviousness
  - Drainage service mostly on the surface
- Reduction of energy consumption
  - Public transportation, nonpolluting fuels, electric buses and light rail
  - Green buildings, passive energy savings, water saving appliances
- Green space for recreation along the rivers
  - Interconnected riparian buffers and wetlands
- Urban brown-field remediation and development
- Ecologically sound stream restoration and daylighting including base flow
- Resiliency to Extreme Meteorological Events

There is no waste – new sustainability terms

- 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)**
- Treatment plant with recovery of biogas, energy, nutrients, etc. → **Integrated resource recovery facility**
- **Water colors of use and reuse**
  - **Blue - clean natural water**
  - **White – surface runoff**
  - **Black - water containing urine, feces and kitchen solids**
  - **Gray - domestic used water without black water contribution**
  - **Yellow - urine contains most of nutrients in 1% volume**
  - **Green - water used for irrigation and not available for reuse**

Urban Best Management Practices with LID Concepts are an Integral Part of the COFs



Green Roofs

Save energy and store water

Rain gardens

Infiltrate and treat runoff

Porous pavement

Infiltrate, store and treat runoff

Ponds and wetlands

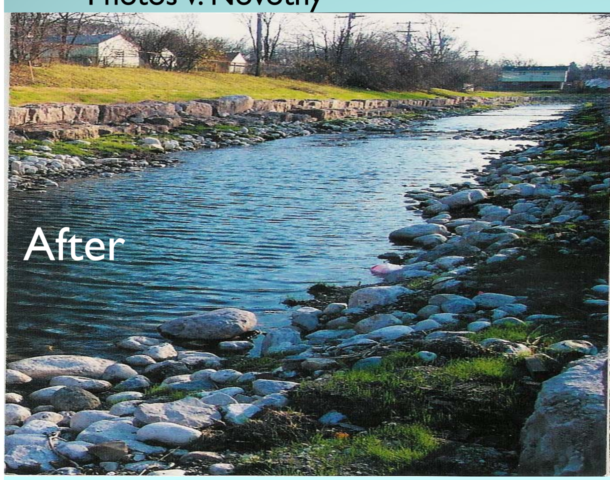
Store, treat and infiltrate runoff

Courtesy City of Seattle

Courtesy of AquaTex Sci. Consulting

Urban Water Body Restoration and Daylighting are Important

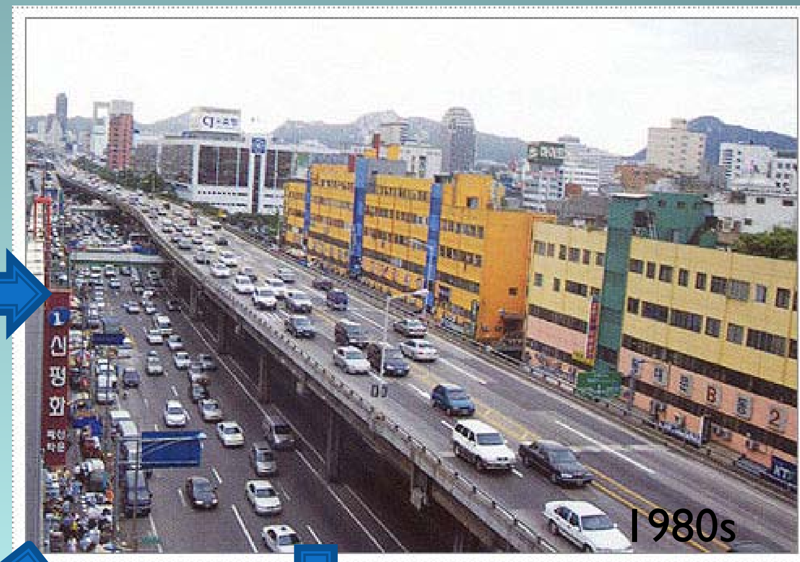
Photos V. Novotny   Courtesy Beijing Hydraulic Research Institute   Courtesy CDM



Courtesy PUB Singapore

Lincoln Creek in Milwaukee   Dayligthted Zhuan River in Beijing   Kallong River in Singapore

Seoul , Korea Cheonggye River



Photos public domain files of the City of Seoul (top) and V. Novotny (bottom)

Creating ephemeral surface drainage

Green roof

insulation, water storage

Green Building

Water &Energy Conservation

Rain gardens with storage , e.g. , dry ponds

Pervious pavement – side roads

Pervious pavement - parking

How big is the flow and pollution load?

Urban perennial streams need base flow

- Water reclamation plants providing clean effluent for ecological flow do not have to be far from the city

- Base flow can also be provided by
  - o Groundwater inflows
  - o Sump pumps in basements
  - o Upstream streams
  - o Cooling water
  - o Condensate from AC
  - o Stored urban runoff in ponds
  - o Irrigation return flow
- None of the above should enter underground sanitary sewers

Courtesy AquaTex Victoria, BC

Dockside Greens Ecocity, Victoria, BC photo provided by AquaTex Sci. Consulting, Victoria, BC

Water centric (LID) drainage in ecocities' 1st order streams

Berlin, Landseberger Tor. Credit Jack Ahern, U.Mass

Dockside Greens, Credit AquaTex Sci. Consult.

Hammarby Sjöstad Credit Malena Karlsson

Zhiangjiawo, PRC. Credit Herbert Dreiseitl ,

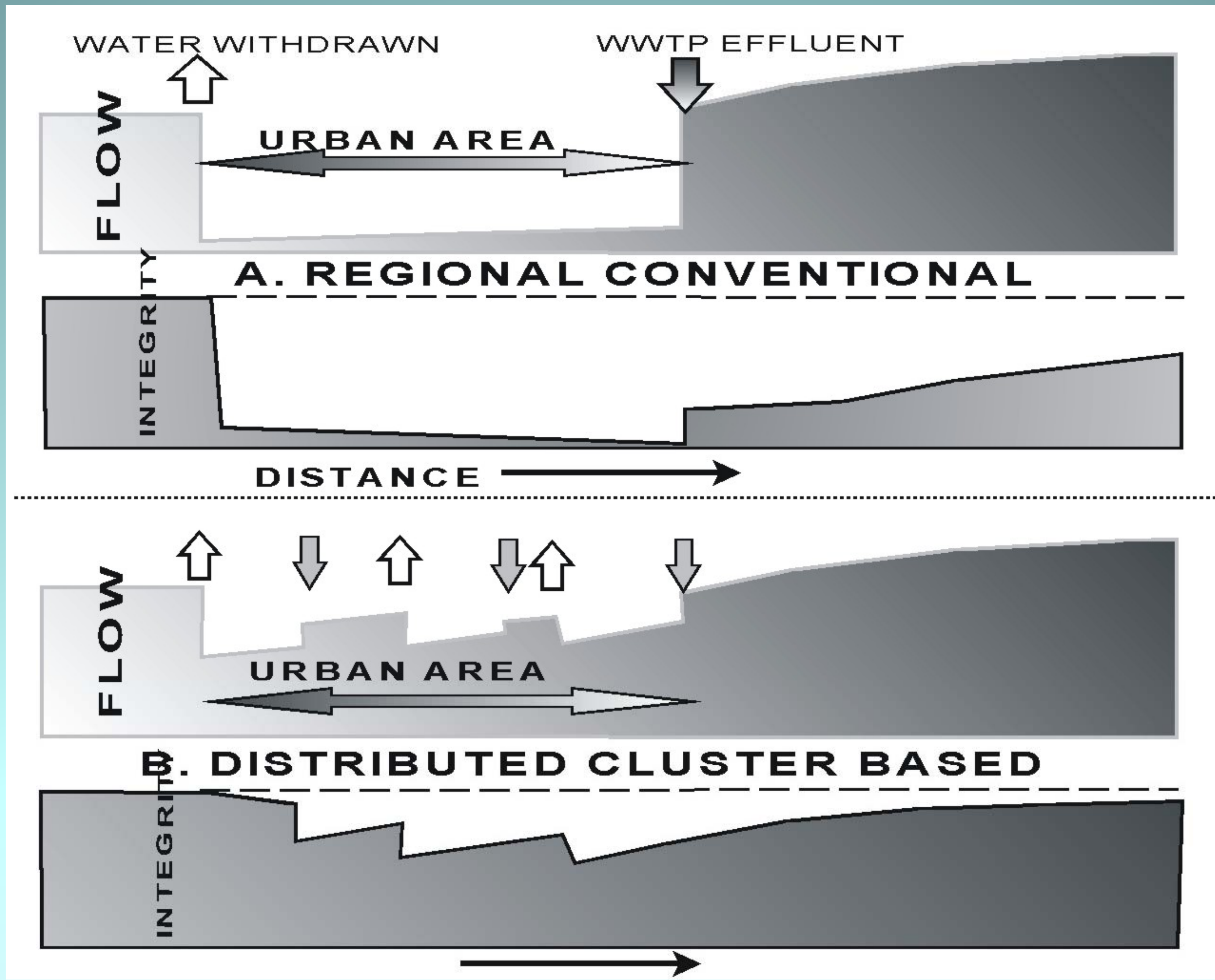
Centralized or decentralized water management systems

- Centralized – once through system is appropriate if only water conservation is considered with no reuse
  - Heat energy recovery may not be feasible
  - Water reuse for toilet flushing and irrigation may not be economical or efficient – system wide dual piping and long transfers are needed
  - Nutrient and biogas recovery and conversion to electricity are less than moderately efficient (Milorganite, heating of digesters)
  - Difficult or impossible to restore urban streams
- Fully decentralized into small clusters
  - Most efficient for heat and water reclamation
  - Energy and labor demanding but savings on transporting used water – reclaimed water is used on site
  - Biogas production, use and conversion to energy may be efficient in developing countries
- Hybrid system – retains advantages of both systems

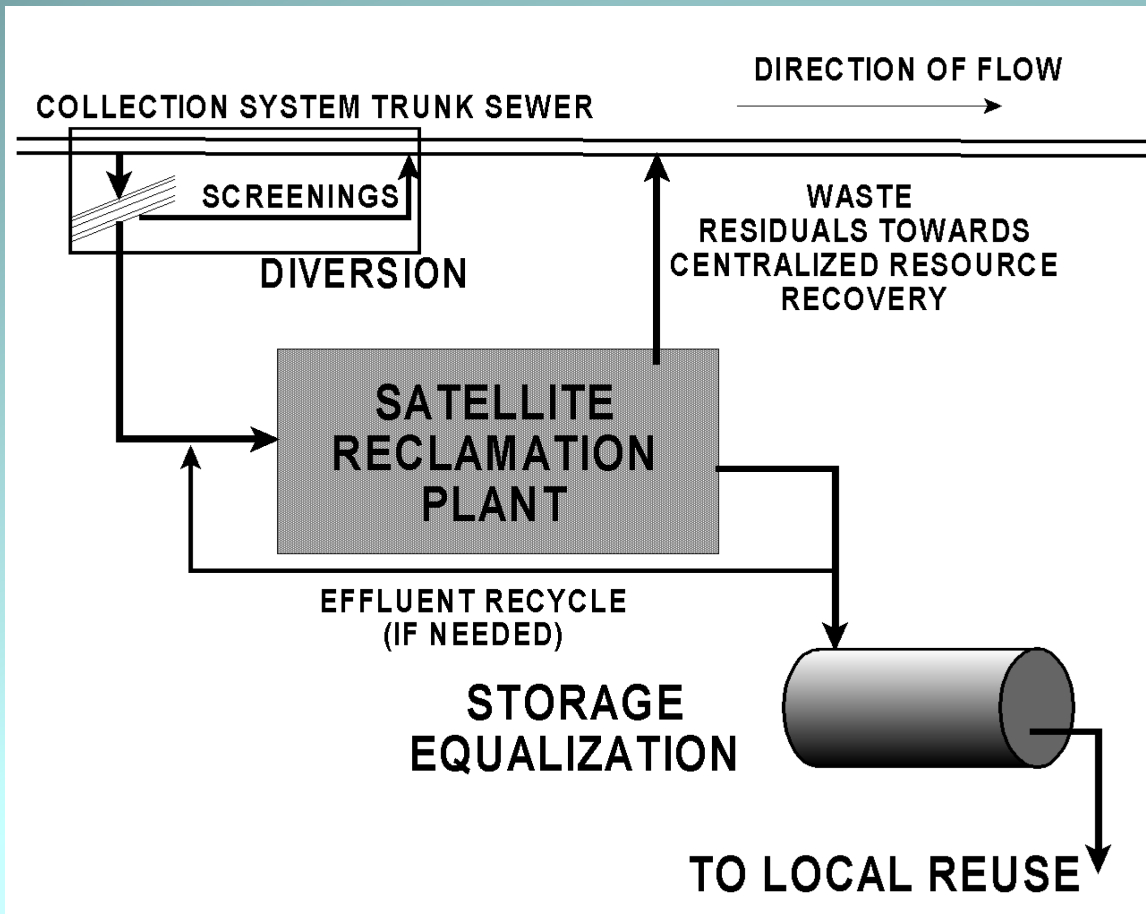
Closing the Cycle Necessitates Decentralized Management - Clusters and Ecoblocks

- A cluster (Ecoblock) is a semiautonomous part of the city that, for the most part, has its own water/stormwater/used water 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 package WWTs)
    - Energy recovery from wastewater
  - Centralized or distributed biogas/energy/nutrients recovery
  - Ecologically and hydrologically functioning landscape
- Clusters are interconnected for increased resiliency

Ecological and Hydrological Effects of Distributed vs. Linear Systems



If water is needed for local reuse, sewers can also be a source



Adapted from Asano et al. (2007)

Package and small high efficiency treatment units can be installed to provide locally water for:

•Ecological flow of restored streams

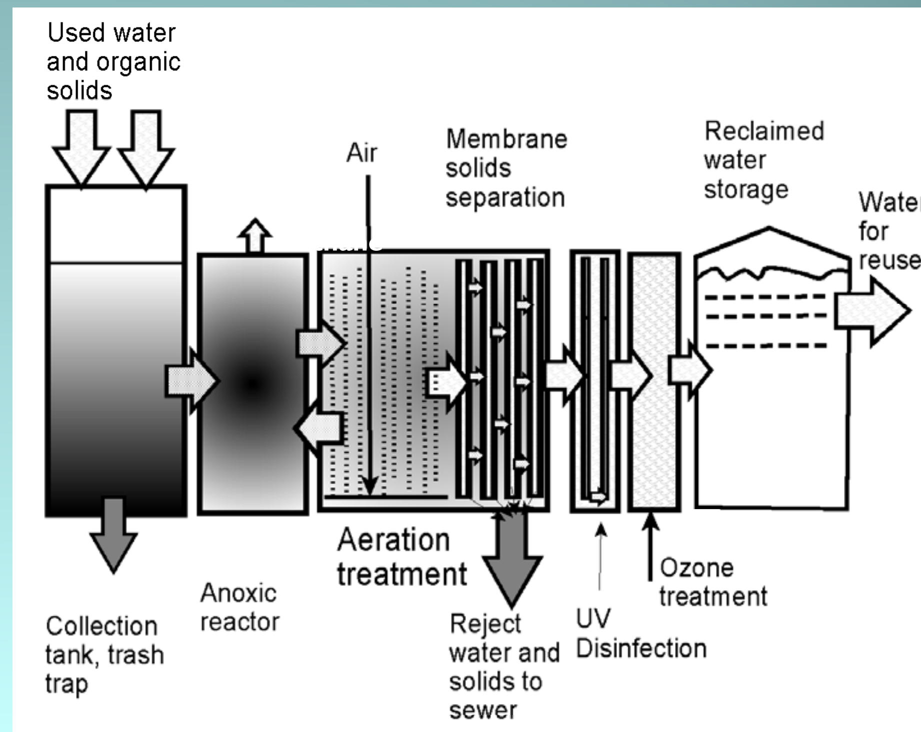
•Toilet flushing

•Landscape irrigation

•Street flushing

Idea:
Concentrate used water for centralized resource recovery

Water reclamation and reuse for toilet flushing and possibly irrigation



Rainwater harvesting and reuse for irrigation is also practiced

Battery Park Solaire development in New York - a semiautonomous water/used water management cluster

Designer Alliance Environmental

Need for reuse

It could be energy demanding

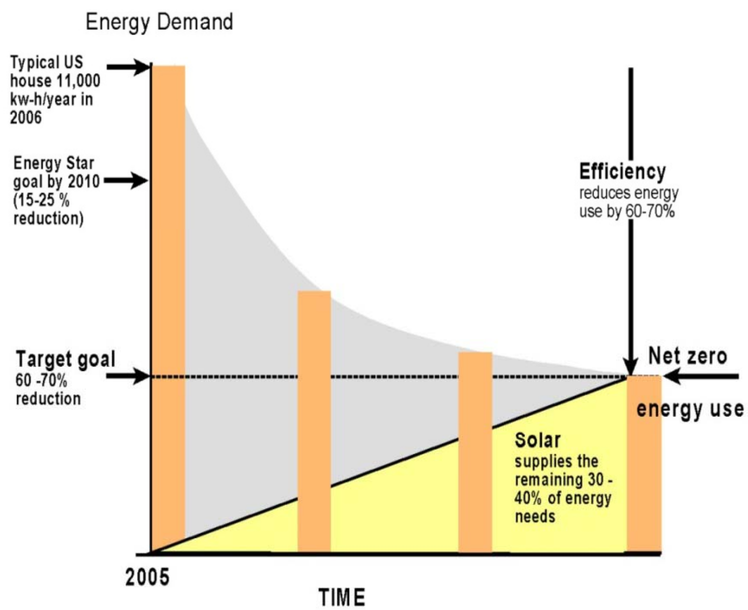
Reverse osmosis

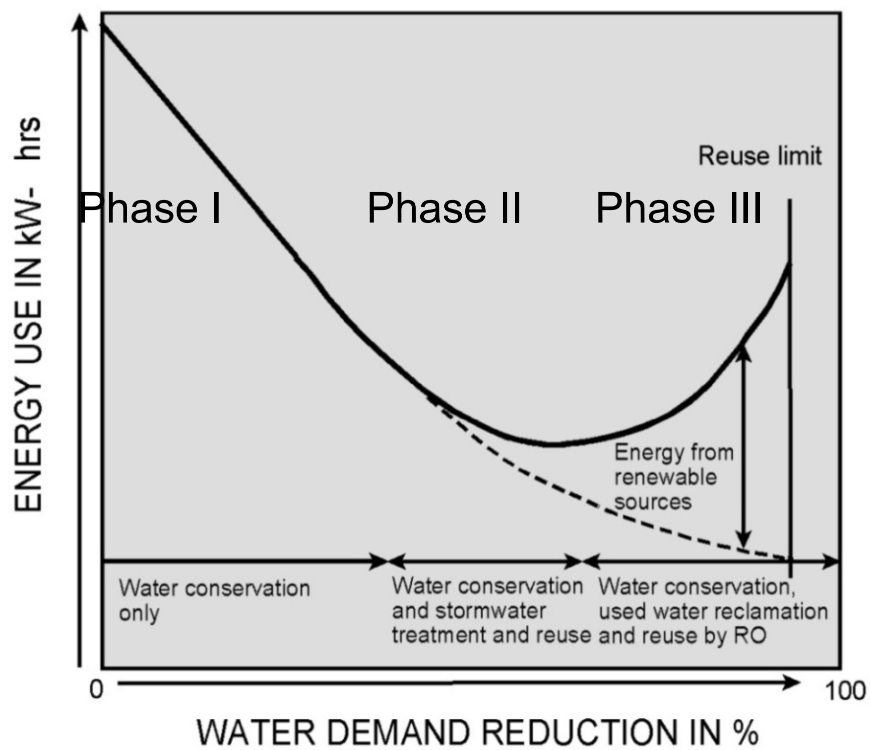
Microfiltration, courtesy Siemens

UV radiation

Water Energy Nexus

Implement water conservation first; it also concentrates used water for better energy recovery

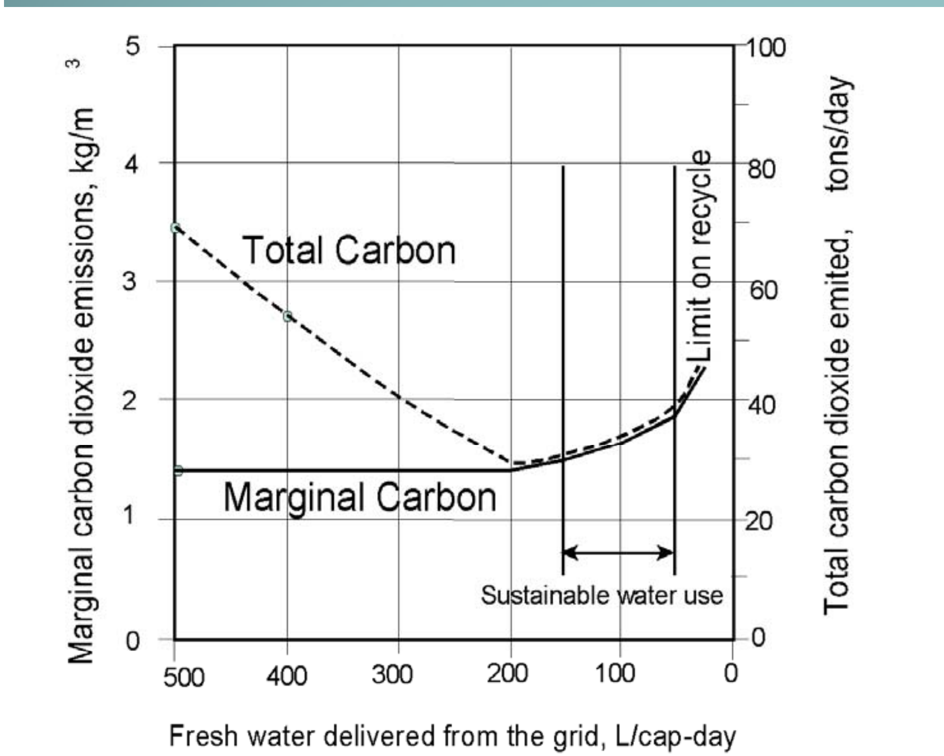




Energy delivered from the grid

In the US 1 kW-hr = 0.6 kg CO_2 emissions

In France 1 kW-hr = 0.22 kg CO_2

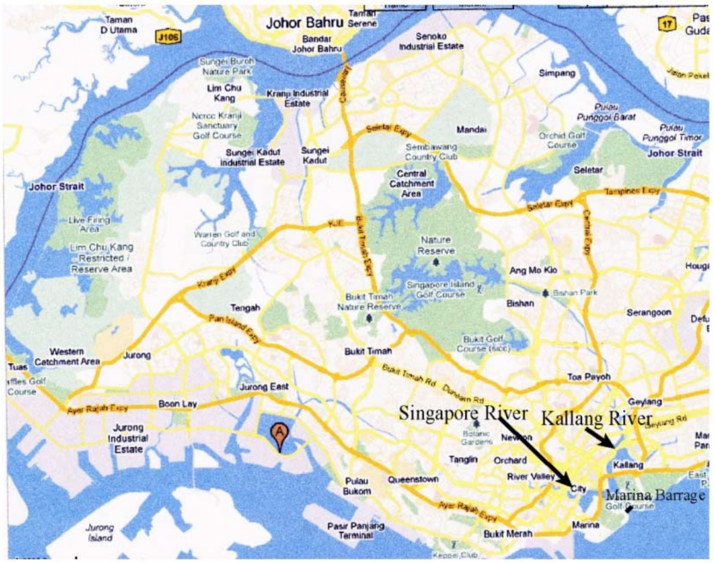


Total population	100,000
Original water demand	500 L/cap-day
Sustainable water available from freshwater source	100 L/ cap-day
Sustainable rainwater and stormwater reclamation	20 L/cap-day
Sustainable brackish groundwater (TDS 1500 mg/l)	30 L/cap-day
Maximum water conservation limit	200 L/cap-day

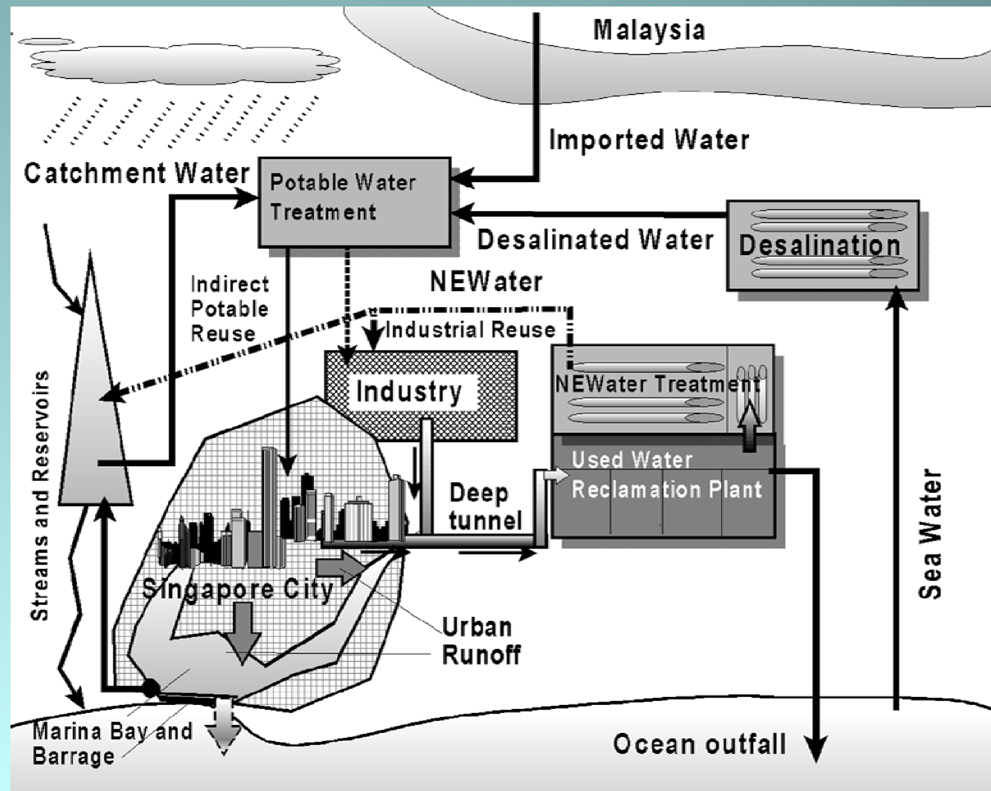
Because sustainable water is available only to satisfy 150 L/cap-day demand, water use must be reduced by water conservation and reuse..

Wastewater treatment includes the activated sludge process with nitrification. Reuse will be done by filtration of the effluent, followed by reverse osmosis and ozonization. Reused water will not be available for potable use.

Water Quality Management in Singapore
Ultimate Infrastructure-heavy Closed Cycle



Singapore and Kallang Rivers, Marina Bay



o Before 1980 – Heavily polluted estuary (sewage, pig wastes, heavily polluted urban runoff, oil spills, unsewered premises)

o 1977-1987 A complete clean-up and sewerage, polluting industries and activities removed, street and household refuse collected daily

A small island republic at the equator
Area ~ 710 km^2
Population ~ 5 million
One of the highest per capita GNP and living standard in the world
Specific water use 157 L/cap-day

Marina Barrage and Bay

- 1995 – 2005 Marina Barrage changed the estuary into a fresh water non tidal reservoir from which some water will be reused
- Marina Bay is a tourist attraction and center of the republic

Photos by V. Novotny

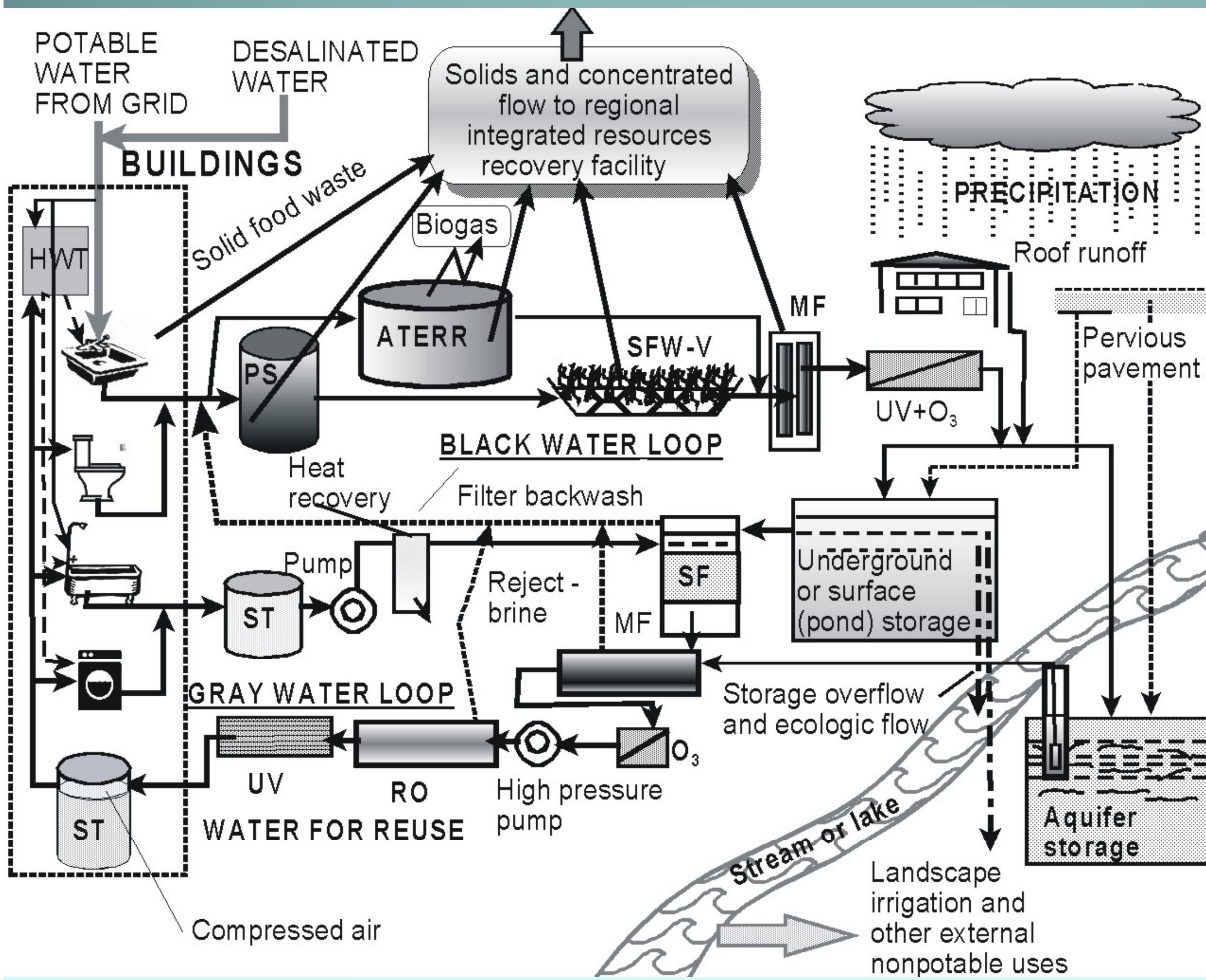
Switch from aerobic treatment in linear systems to water, energy and other resource recovery

- 3 Ss- Separate, Store and Sequester (Gray and Black water, CO_2)
- 3 R-s, Reclaim, Reuse, Recycle (Blue and White water,)
- No 2 Ts
- Distributed water and energy reclamation/recovery (Gray, Blue, White and some Black water, heat, methane)
- Concentrate Black water and with sludge send it to the regional Integrated Resource Recovery Facility

Anaerobic Processes are Key

Distributed recycle needs urban runoff

Losses by evapotranspiration, ecological flow and reject water



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

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

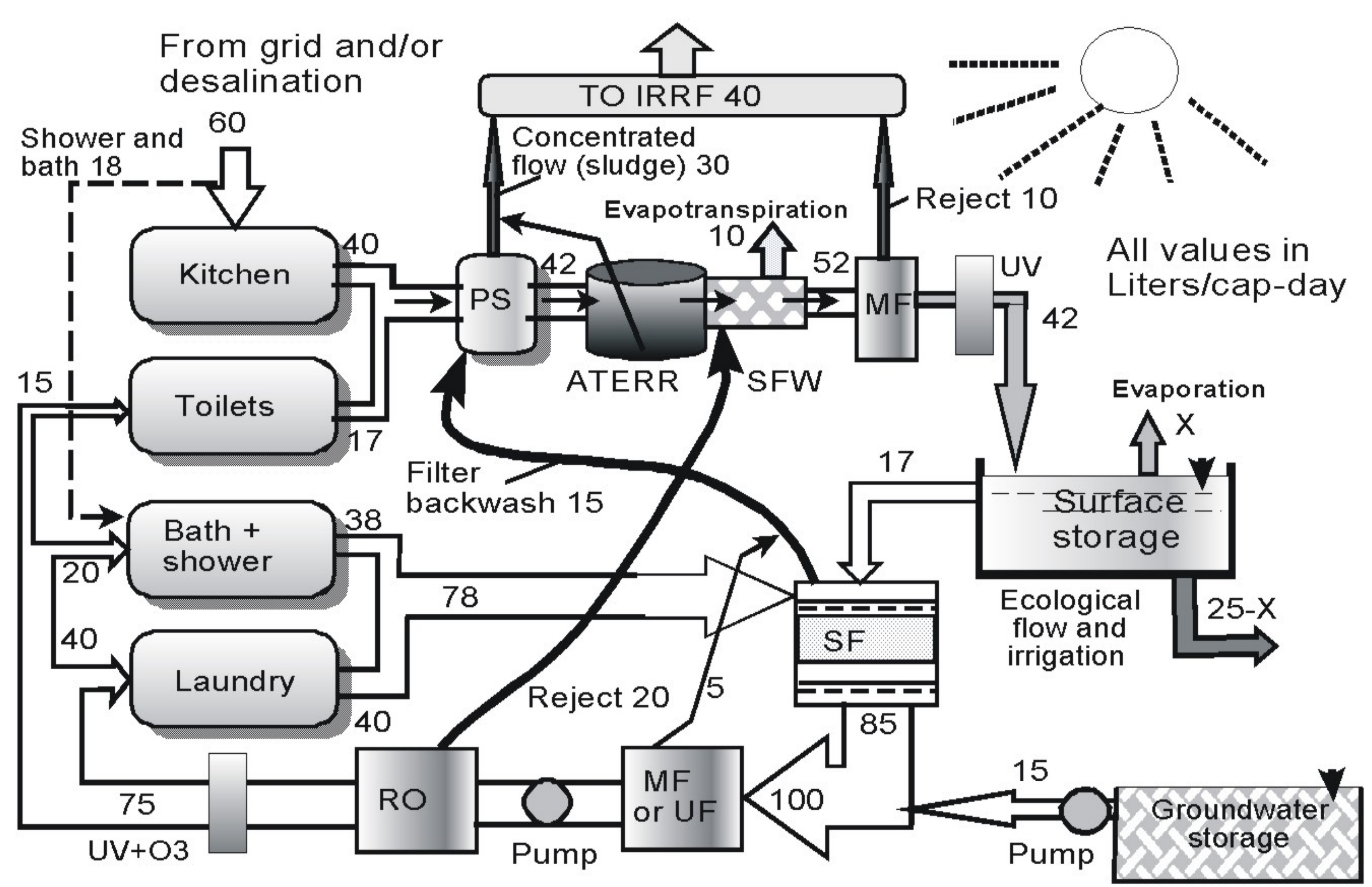
PS – primary settler

MF microfiltration

UV ultraviolet disinfection
ST storage

RO reverse osmosis

SFW – subsurface flow wetland
SF – sand filter
ATERR –anaerobic treatment and energy recovery reactor - concentrator

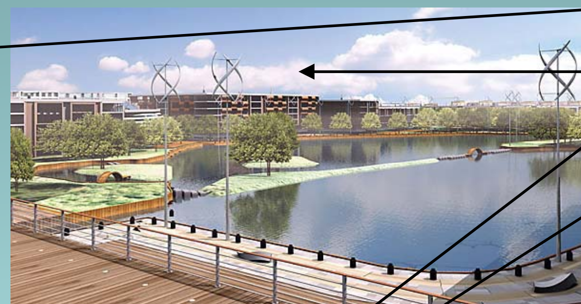


ATERR – Anaerobic treatment and energy recovery reactor

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

Review of Seven Ecocities

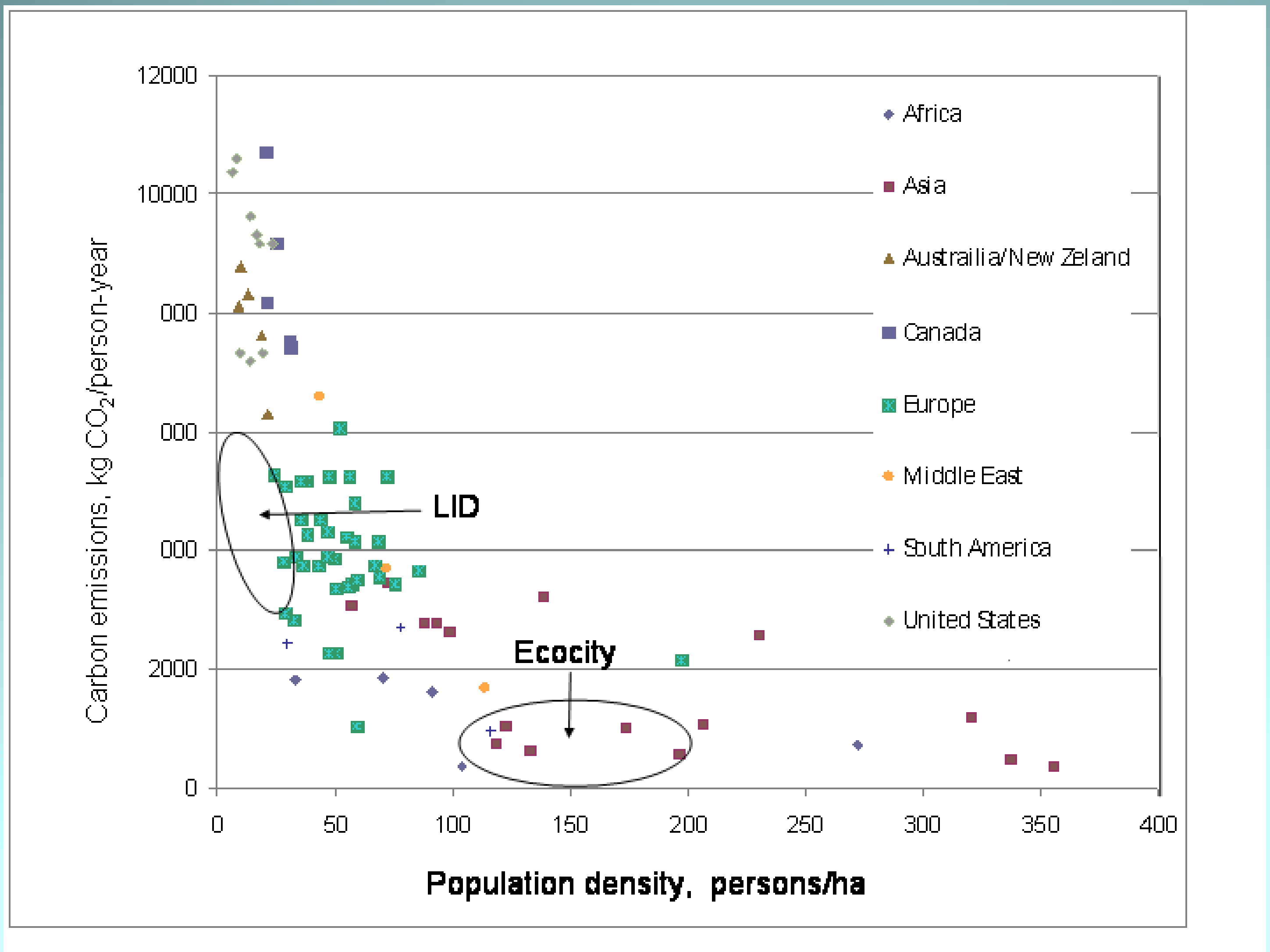
Hammarby Sjőstad
Dongtan
Qingdao
Tianjin
Masdar
Treasure Island



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



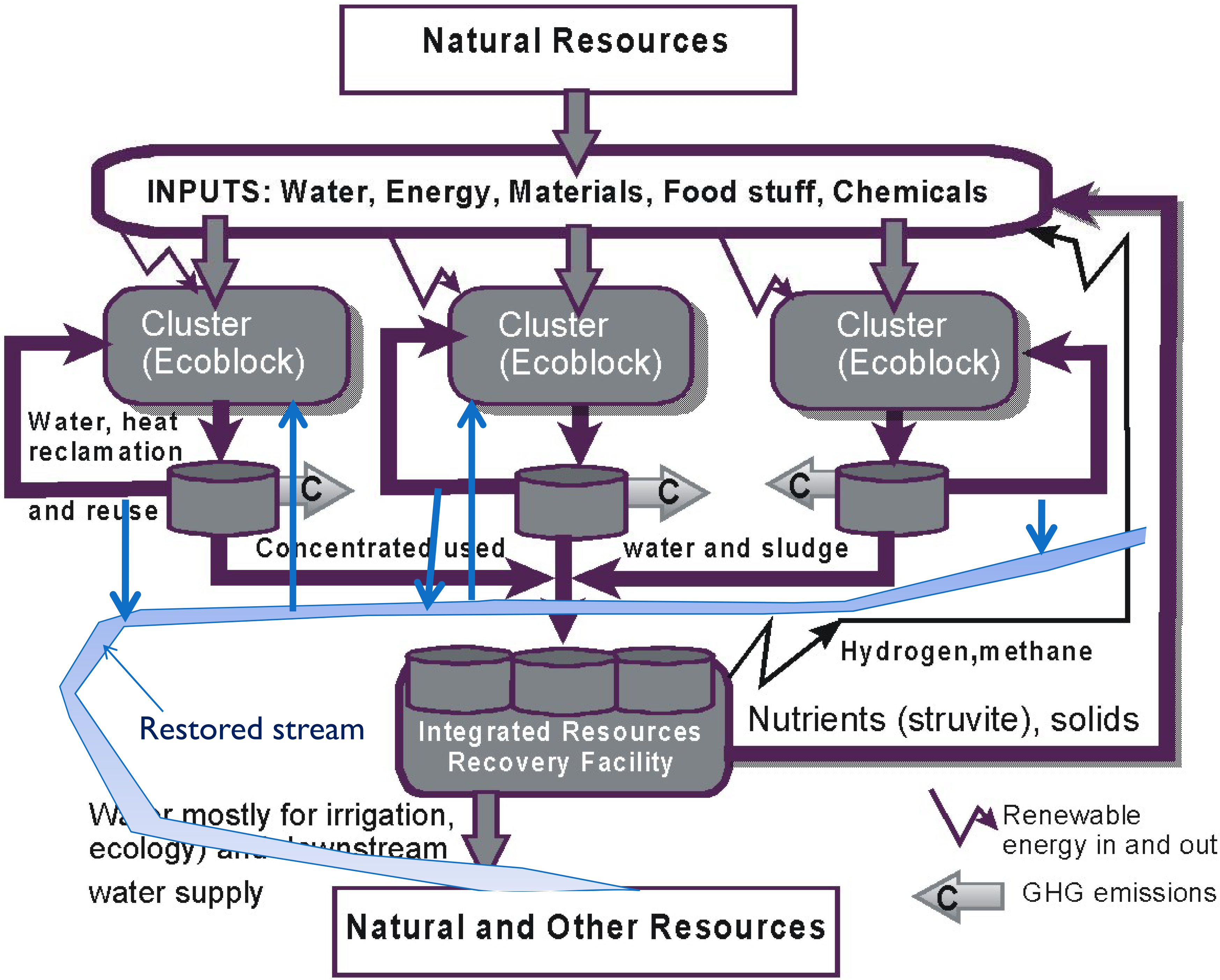
Difficult to compare US cities with Asian countries with different economic levels

Based on Newman and various other sources

Qingdao

More centralized resource recovery

- Characteristics of integrated resource recovery facility
  - More concentrated influent (COD > 3000 mg/L desirable)
  - Urine may be separated (contains 50% of P and >75% N) in 1% of flow
  - Inflow and input contains sludge and other solids (shredded food and other organic solids). Other organic biodegradable solid waste may be trucked in (co-digestion)
- Because of high COD, conventional (energy demanding) activated sludge treatment is not feasible and should be replaced by anaerobic processes
  - Conventional sludge digester requires large detention and high concentrations of solids and COD
  - Use Upflow Anaerobic Sludge Blanket (UASB) reactor

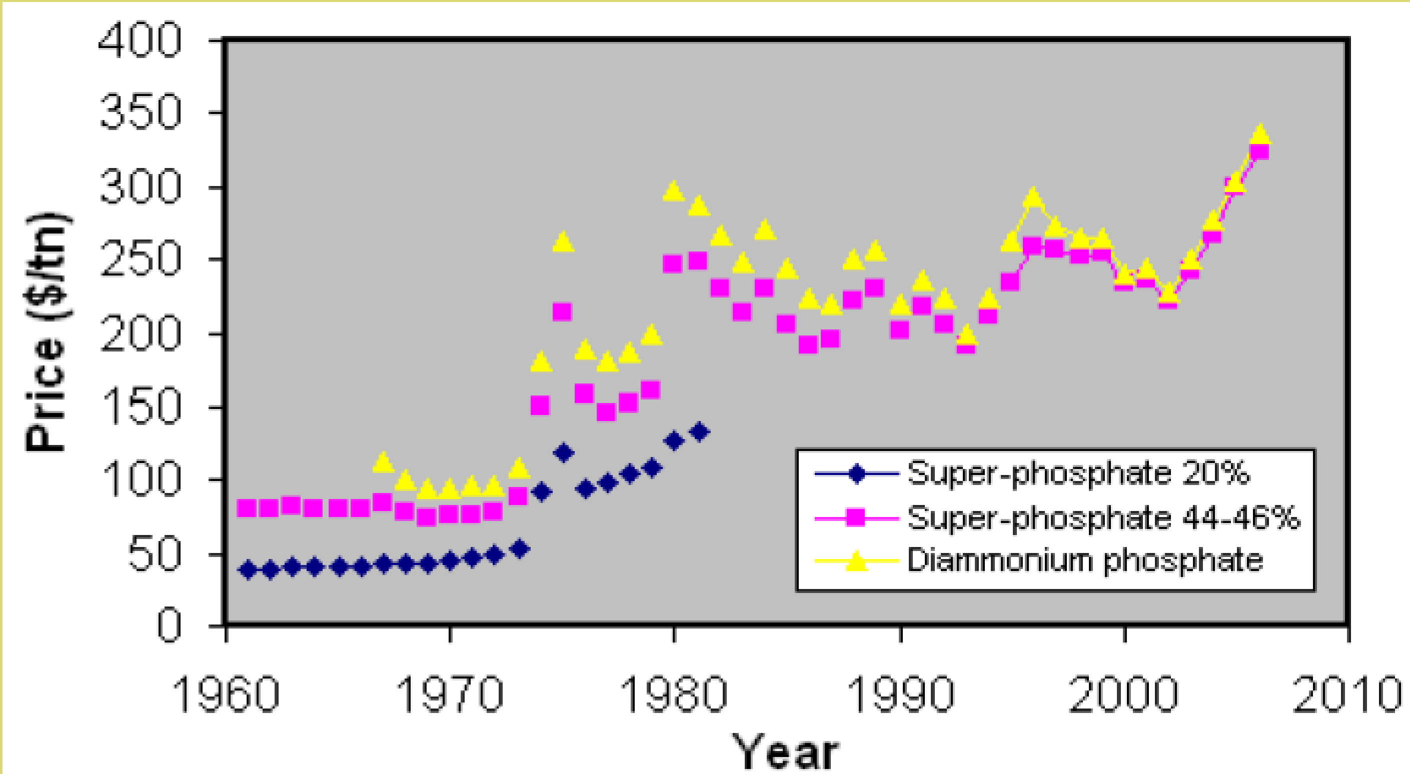


Natural Resources
INPUTS: Water, Energy, Materials, Food stuff, Chemicals
Cluster (Ecoblock)
Cluster (Ecoblock)
Cluster (Ecoblock)
Water, heat reclamation
and reuse
C
C
C
Concentrated used
water and sludge
Hydrogen,methane
Nutrients (struvite), solids
Restored stream
Integrated Resources Recovery Facility
mostly for irrigation,
ecology)
water supply
Renewable energy in and out
C
GHG emissions
Natural and Other Resources

Energy use of treated volume of municipal used (waste) water and corresponding CO_2 emissions. Raw data from Asano et al. (2007) and from Novotny et al. (2010)

Treatment process	Daily flow volume of treated used water m^3/day)		
	10,000	25,000	>50,000
	Energy use kw-hr/m^3 (CO_2 emissions kg/m^3)		
Activated sludge without nitrification and filtration	0.55 (0.33)	0.38(0.23)	0.28 (0.17)
Membrane bioreactor with nitrification	0.83 (0.51)	0.72 (0.44)	0.64 (0.37)
Reverse osmosis desalination			
Brackish water (TDS 1 – 2.5 g/L)		1.5 (0.91) – 2.5 (1.52)	
Sea water		5 (3.05) - 15 (9.15)	
Ozonization (ozone produced from air)			
Filtered nitrified effluent		0.24 (0.15) - 0.4 (0.24)	
Desalination by evaporation (using waste heat)		~ 25 (15.25)	

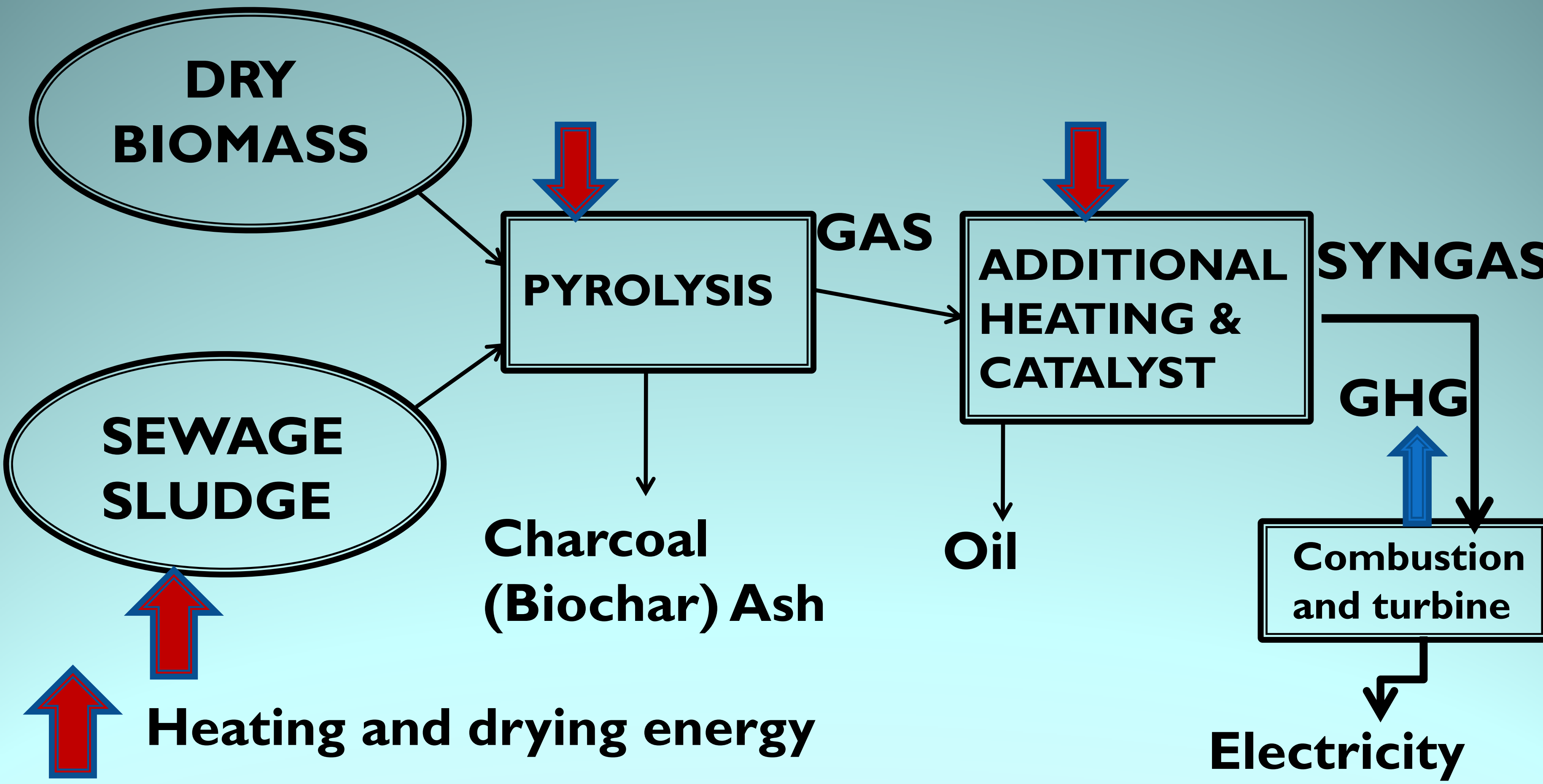
We are running out of phosphorus (by 2040)



Phosphate rock (2010):	119.6 $/mt
Diammonium phosphate (2010):	482.6 $/mt
Currently (2010):	**1.1 – 1.6 $/kg-P**

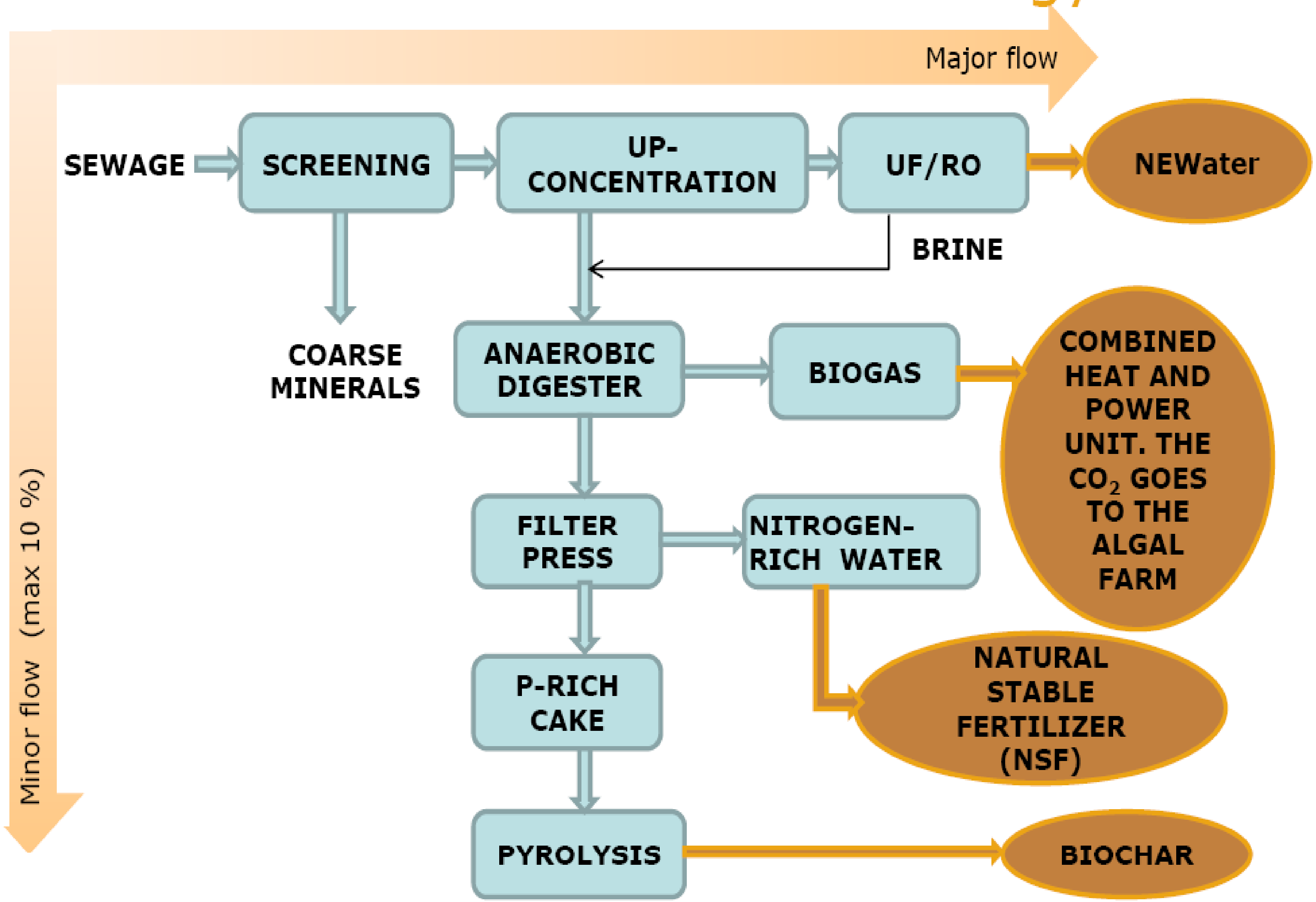
Sources: US Geological Survey Minerals Yearbook 2006 and the World Bank commodity data 2010, graph from Verstraete 2010

Energy from Used Water and Solids via Syngas (H_2 + CO) and Oil Production



This traditional energy recovery will provide less than ½ of energy needs of an aerobic/anoxic WWTP

The "Zero-Waste" Water Technology



(Verstraete et al. 2009; Bioresource Techn. 100, 5537-5545; LabMET)

Verstraete (U. of Ghent) system for GHG reduction

	Energy gain (kWh IE^{-1} $year^{-1}$) Electricity	Heat	Avoided CO2 emission (kg CO_2 IE^{-1} $year^{-1}$)
Kitchen grinder	-1.4		-0.9
Advanced concentrator	-6.0		-3.6
OLAND	12.8		6.6
Heat recovery	-179	496	41.7
Anaerobic digestion	38.9		23.3
Sludge dewatering	1.8		1.1
N recovery	-9.6	40.8	4.5
P recovery	1.2		2.0
Biochar			13.3
sum	**-141**	**537**	**88** (237)*

Zero WasteWater prevents 4.4% of the global CO_2 emissions!!

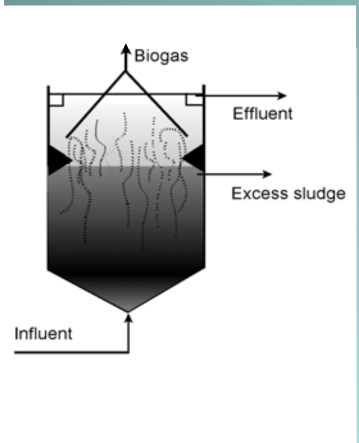
(Verstraete & Vlaeminck, 2010; Keynote Paper 2nd Xiamen Intern. Forum on Urban Environment; LabMET)

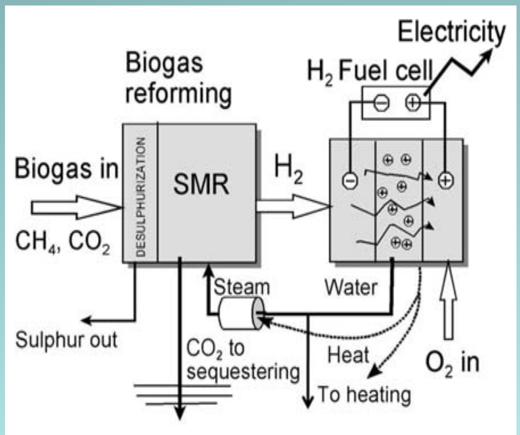
OLAND – Oxygen Limited Autotrophic Nitrification/Denitrification Process

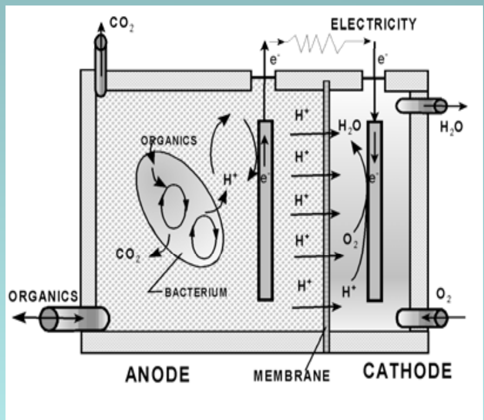
•US conditions (0.61 kg CO_2 /kWh vs. 0.2 kg CO_2 /kWh in France-Belgium)

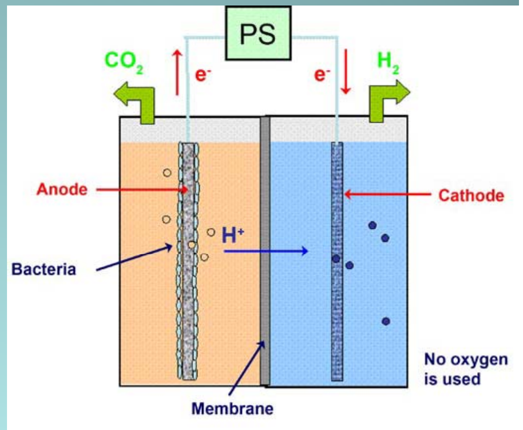
We can do better in the future

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, electricity and water

• Greater efficiency than methane combustion

Microbial fuel cell

Converts organic biomass directly into electricity (from Rabaey and Verstraete, 2005 with a permission)

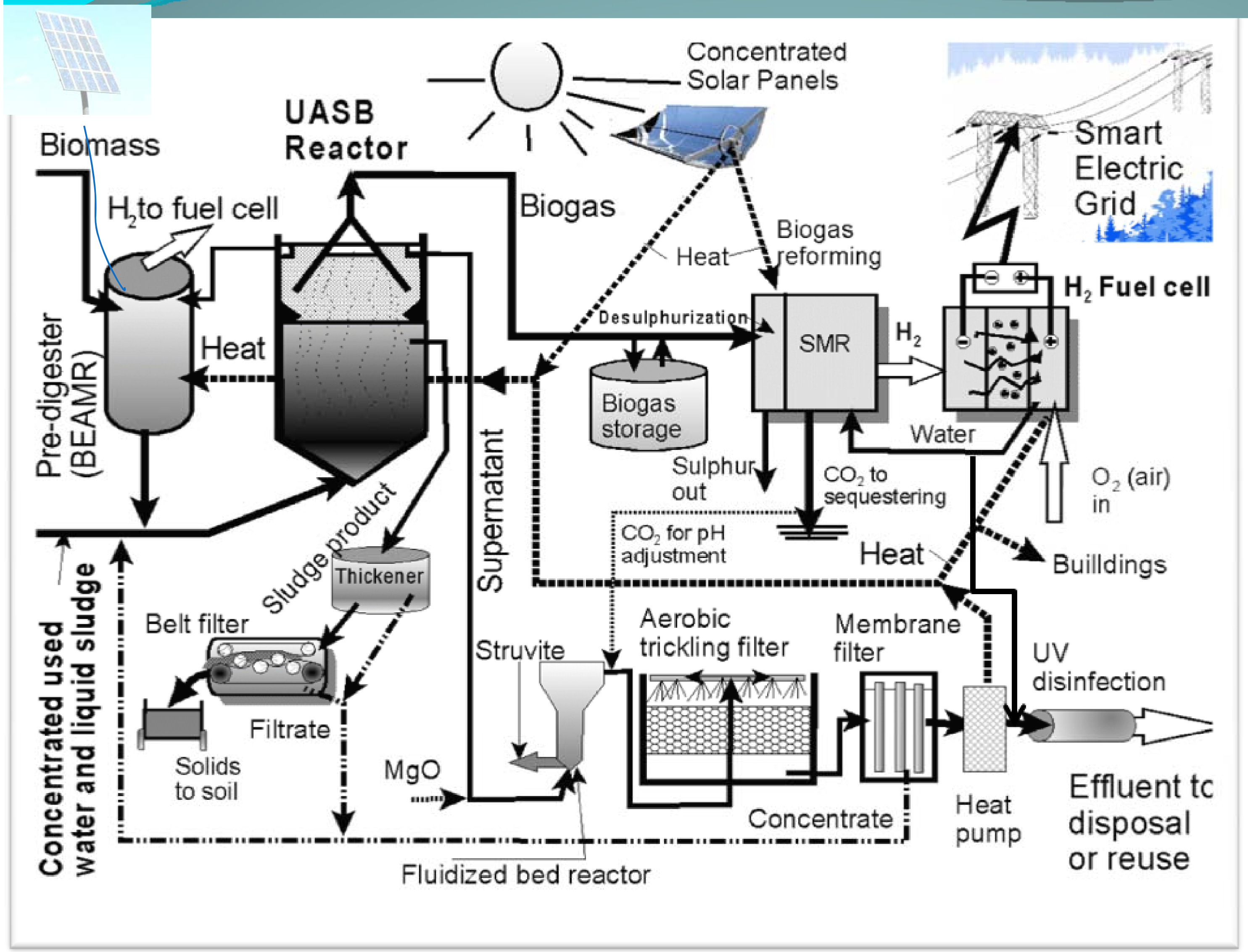
Bioelectrochemically Assisted Microbial Reactor (BEAMR)

Converts organic biomass directly into hydrogen by adding small electricity to the reactor (from Liu, Grot and Logan, 2005)

95 % energy recovery from produced acetate

SMR = Steam methane reforming

Integrated Resource Recovery Facility – IRRF (Future)

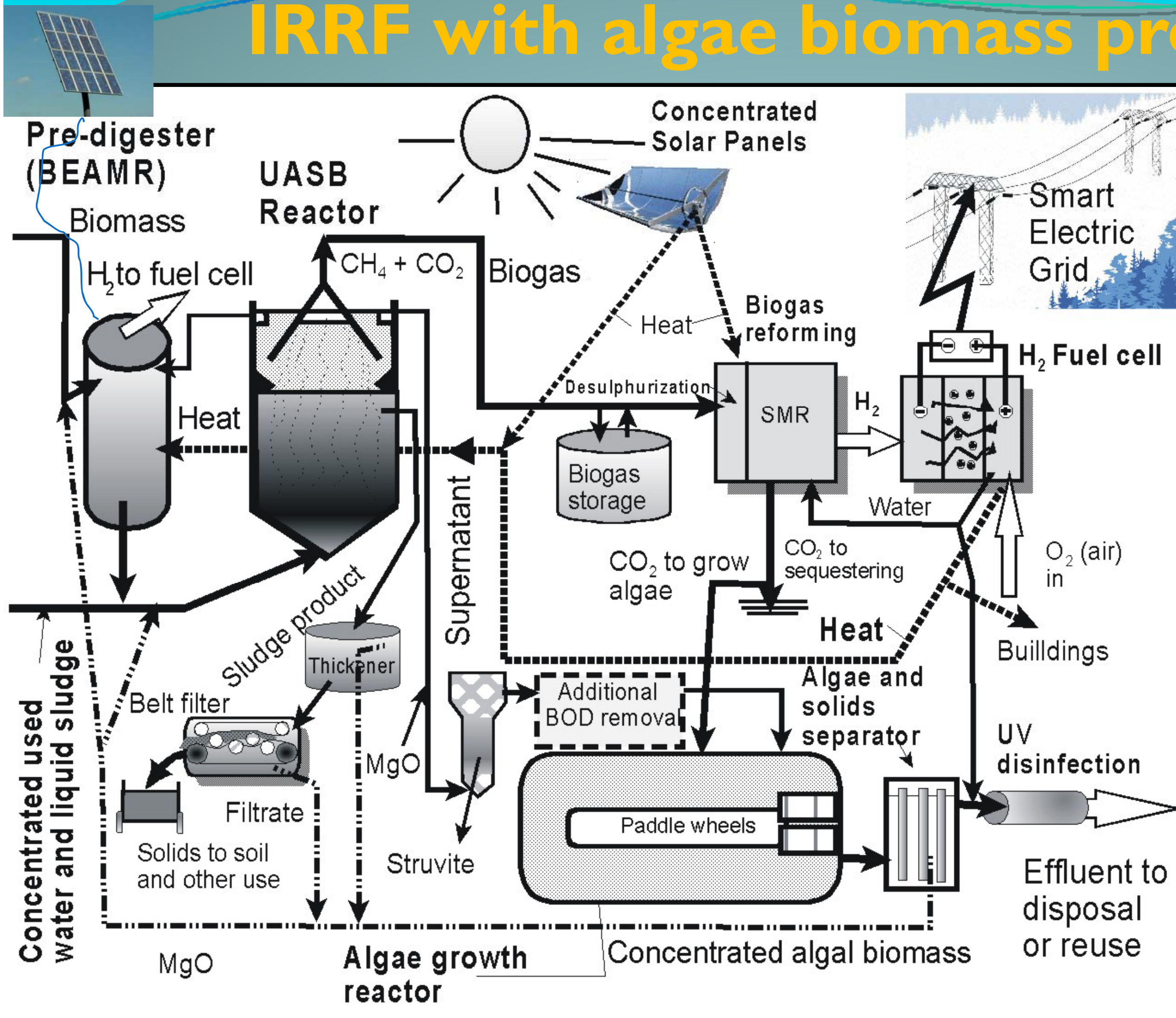


IRRF produces

- Reclaimed water for reuse
- Heat for heating reactors and buildings
- Struvite (ammonium-magnesium phosphate) fertilizer
- Biogas and hydrogen
- Electricity
- Organic solids
- Carbon sequestration

BEAMR = Bioelectrochemically assisted microbial reactor - Logan (2008)

Integrated Resource Recovery Facility – IRRF with algae biomass production



BEAMR = Bioelectrochemically assisted microbial reactor - Logan (2008)

IRRF produces

- Reclaimed water for reuse
- Heat for heating reactors and buildings
- Struvite (ammonium-magnesium phosphate) fertilizer
- Biogas and hydrogen
- Electricity
- Organic solids rich with nutrients
- Carbon sequestration

Other features of ecocity

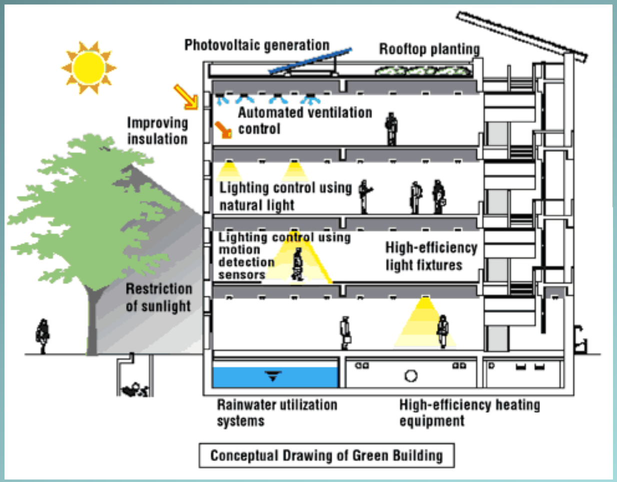

Masdar driverless personal transport


Czech SKODA streetcars in Portland, OR


Solar panels in Hammarby, courtesy Malena Karlsson


Solid waste receptors in Hammarby, courtesy Malena Karlsson

Renewable Energy



Passive energy sources

Household voltaics

1.4. MW Voltaics array in Sonoma County (CA)

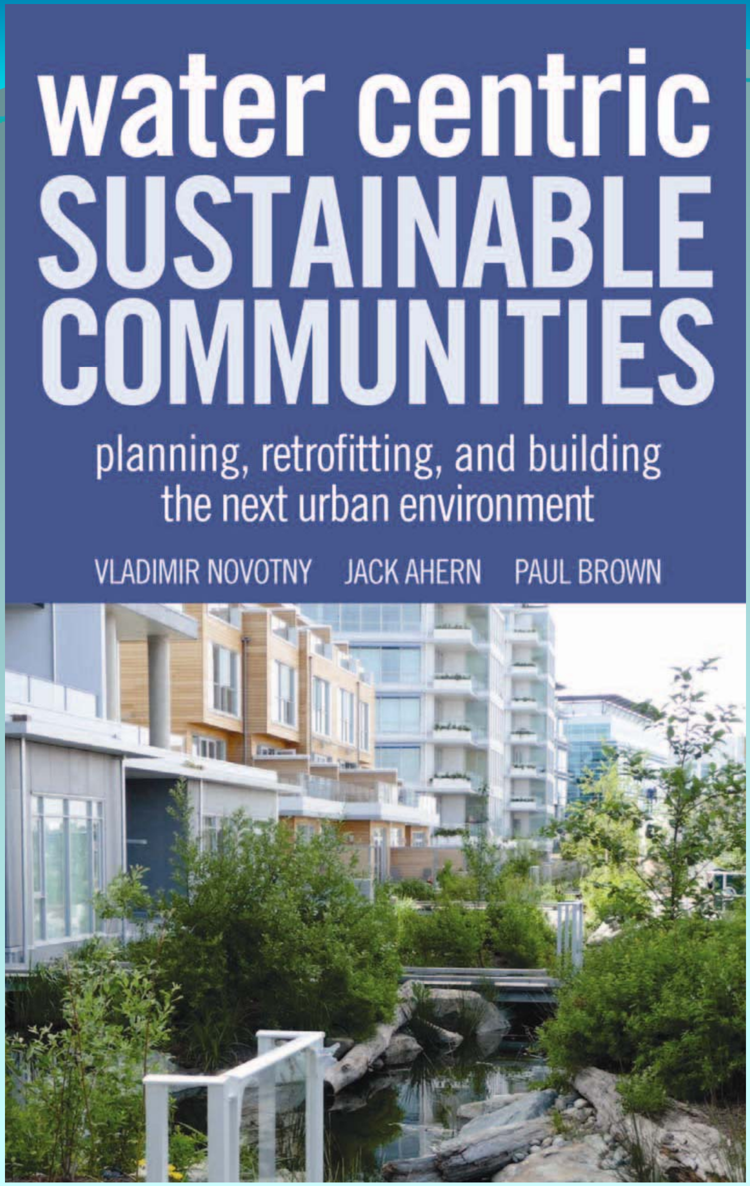
Wind turbines in Dongtan, courtesy ARUP

Summary and Conclusions

- Water conservation is the best alternative solution to a water availability problem. There is a direct relationship between water use and energy reductions.
- Combined sewers will become obsolete and no CSOs or SSOs
- Excess capacity of existing sanitary severs leased to cable
- Reuse with high efficiency solids and pollutant removals (e.g., microfiltration and reverse osmosis) in a closed cycle requires more energy because of the energy requirement in the treatment. This energy should and could be provided by renewable sources
- Reuse/recycle needs make-up water to offset losses by reject water and liquid content in sludge and possibly by evaporation
- A new paradigm of urban drainage and used water reuse with resource recovery needs to be developed and implemented. These new systems would be carbon neutral and greatly reduce water and GHG footprints.

Summary and Conclusions – cont.

- Energy from separated and concentrated used water can be extracted by anaerobic processes in a form of methane and in COF as electricity or hydrogen and by heat pumps as heat (or cooling)
- Higher COD concentration and reducing used water volumes of separated black water is key for efficient anaerobic energy separation
- Co-digestion of concentrated used black water, sludge and other organic solids should be considered
- Nutrients, especially phosphorus, will be recovered
- Hybrid system with an integrated resource recovery facility will dramatically reduce water use, could achieve zero pollution, produce energy, heat, fertilizers, solids, and even produce energy biomass and sequester carbon
- Switch from methane and syngas energy recovery to hydrogen and/or direct electricity is on the horizon
- Energy and resources recovery could bring about significant economic benefits when compared to current costs of wastewater disposal and damages to the environment



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PUB Singapore + many others

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