Water Energy Nexus – Towards Zero Pollution and GHG Emissions

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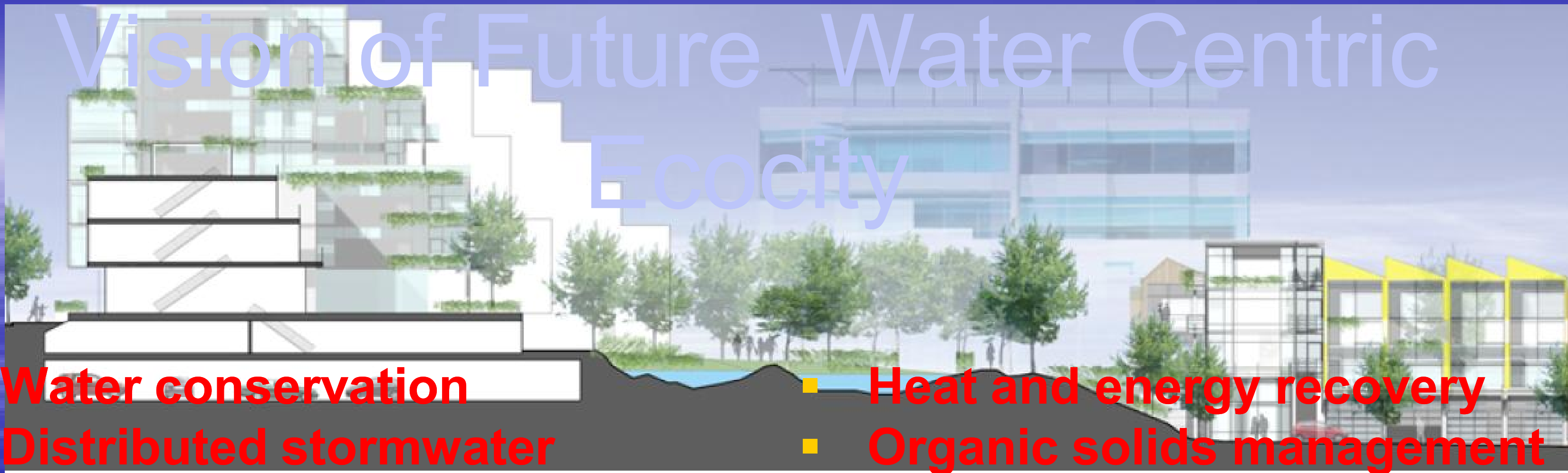
New Urban Water Sustainability Paradigm is Needed

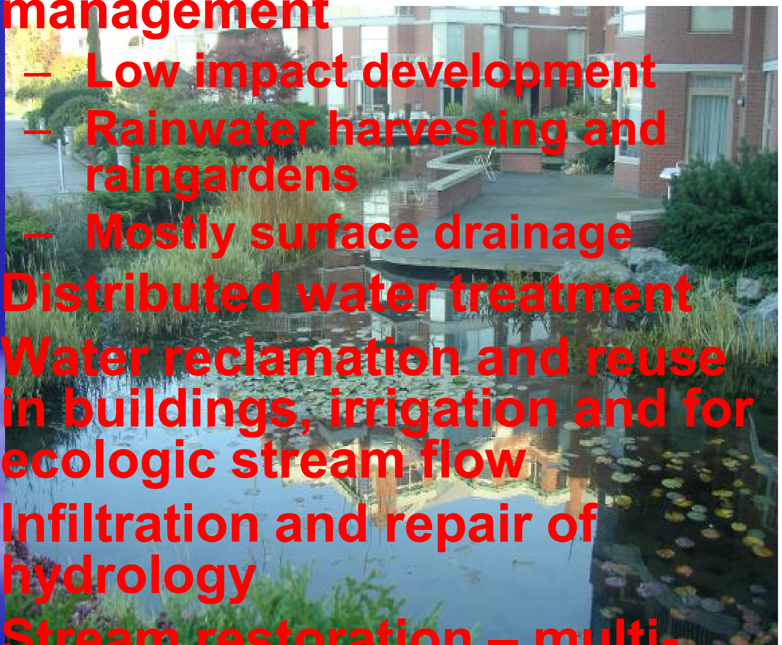
Water Centric Ecocity

VISION: Achieve sustainable integrated urban water, energy reclamation, drainage and transportation infrastructures connected to receiving waters that will be resilient to natural and anthropogenic stresses, including extreme events, implement water conservation, provide good quality of reclaimed water for diverse uses and reduce carbon emissions when compared to the current situation.

Urban (green) infrastructure, resilient and hydrologically and ecologically functioning landscape and water resources will constitute one system

Vision of Future Water Centric Ecocity

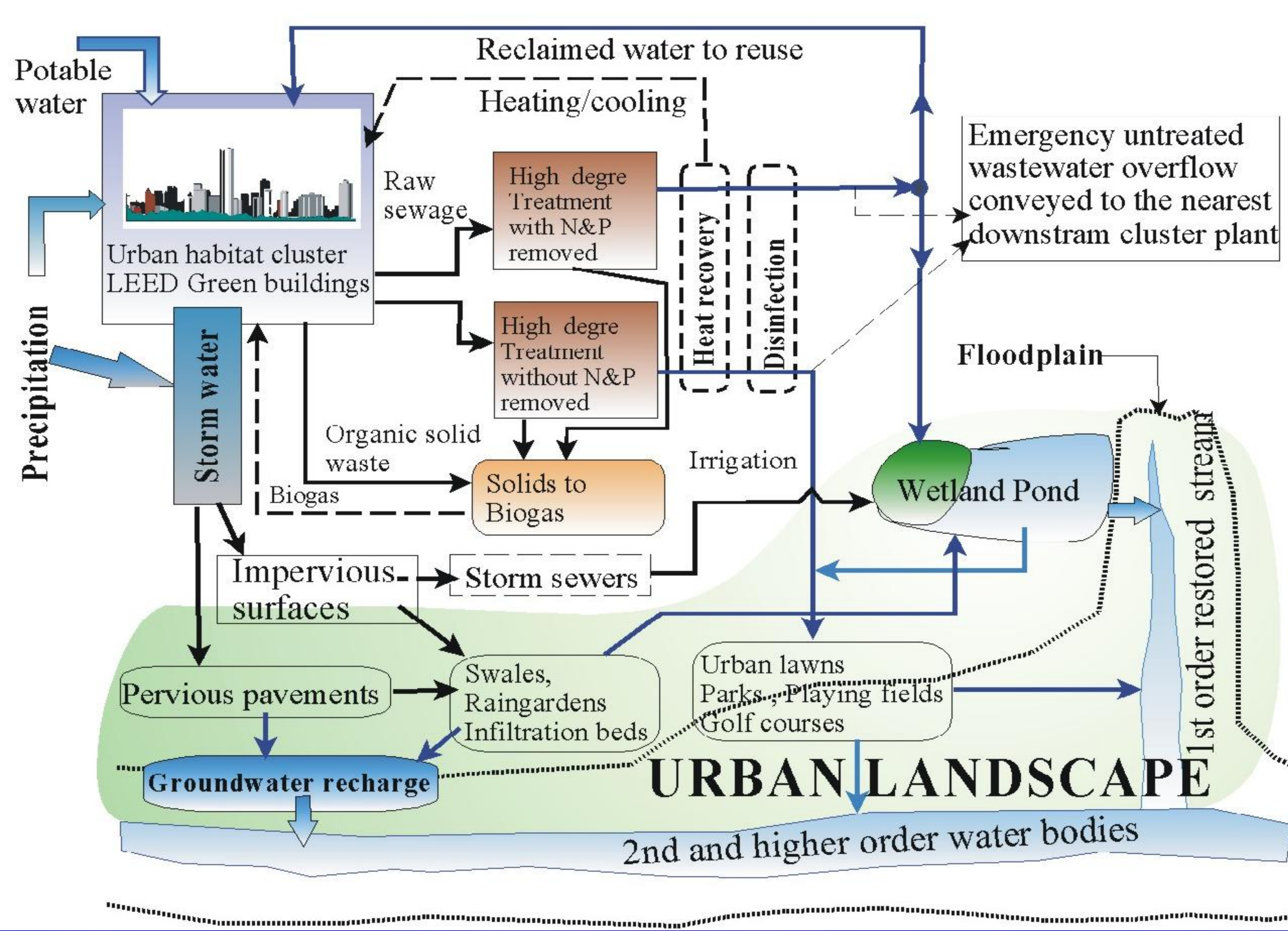




- Water conservation
- Distributed stormwater management
  - Low impact development
  - Rainwater harvesting and raingardens
  - Mostly surface drainage
- Distributed water treatment
- Water reclamation and reuse in buildings, irrigation and for ecologic stream flow
- Infiltration and repair of hydrology
- 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
- Renewable energy source (solar, wind, hydropower)
- Sustainable low carbon traffic emissions
  - Accessible public transportation
  - Hybrids and plug-ins
- Recreation, walking, biking
- Suburban organic agriculture

DECENTRALIZED CLUSTER WATER MANAGEMENT



Cluster (EcoBlock) based decentralized management

- A cluster (Ecoblock) is a semiautonomous part of the city that, for most part, which 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 several thousands 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
    - Biogass recovery
  - Ecologically and hydrologically functioning landscape
  - Clusters are interconnected to provide resiliency against failure

One Planet Living (WWF)

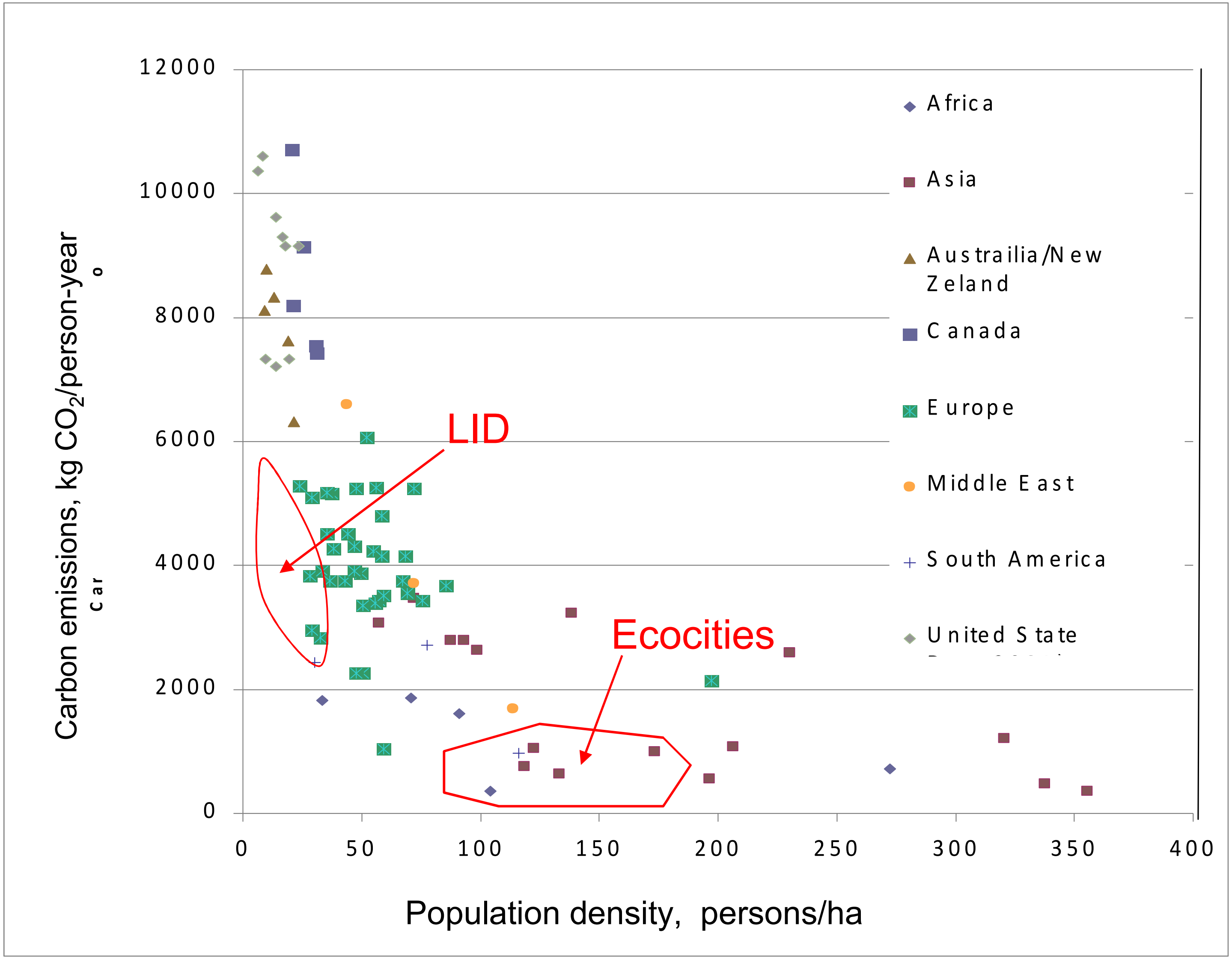
- zero carbon emissions with 100% of the energy coming from renewable resources;
- zero solid waste with the diversion of 99% of the solid waste from landfills;
- sustainable transportation with zero carbon emission from transportation inside of the city;
- local and sustainable materials used throughout the construction;
- sustainable foods with retail outlets providing organic and or fair trade products;
- sustainable water with a 50% reduction in water use from the national average;
- natural habitat and wildlife protection and preservation;
- preservation of local culture and heritage with architecture to integrate local values;
- equity and fair trade with wages and working conditions following the international labor standards; and
- health and happiness with facilities and events for every demographic group.

Seven Cities Ecocities Review

Hammarby Sjőstad
Dongtan
Qingdao
Tianjin
Masdar
Treasure Island
Sonoma Valley

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

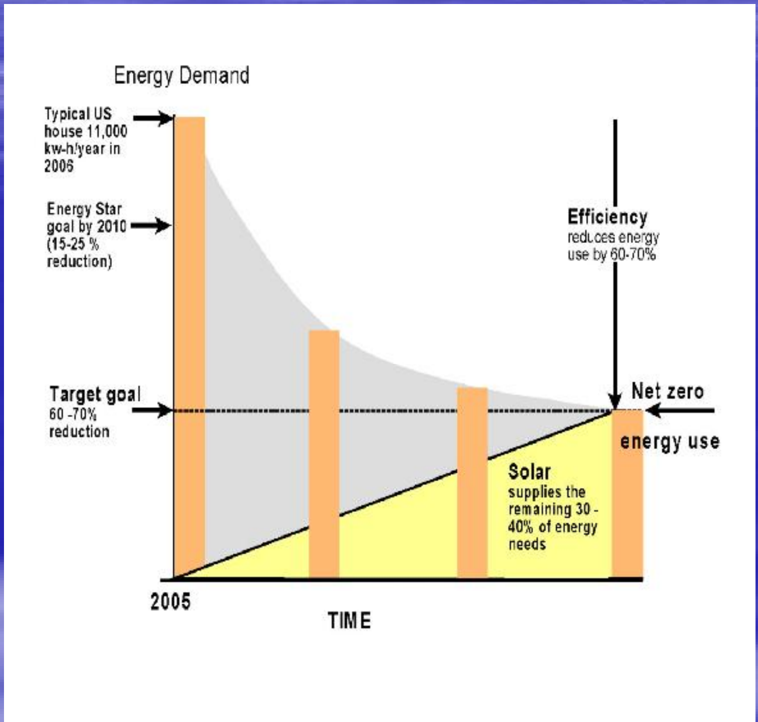
Population density matters



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

Based on various sources

Net zero carbon footprint



- National Science and technology Council (US)
  - 60 – 70 % reduction by efficient appliances, automobiles, water and used water disposal and reuse
  - In US up to 7 % of energy is for water delivery and management
    - In California 20 % of electricity and 37% of natural gas use is for water and used water
- 30% from renewable sources

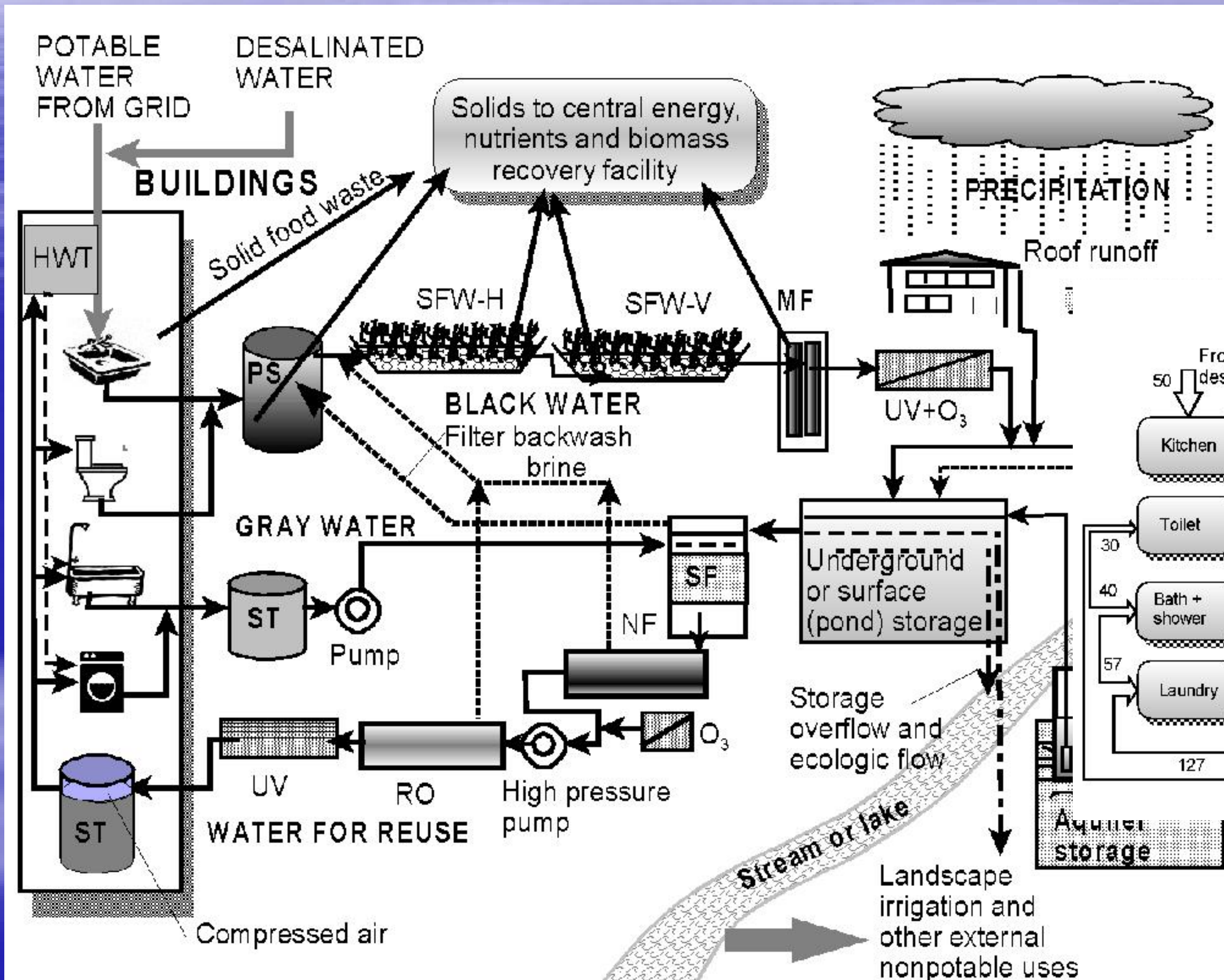
Is it realistic?

Water conservation – linear system

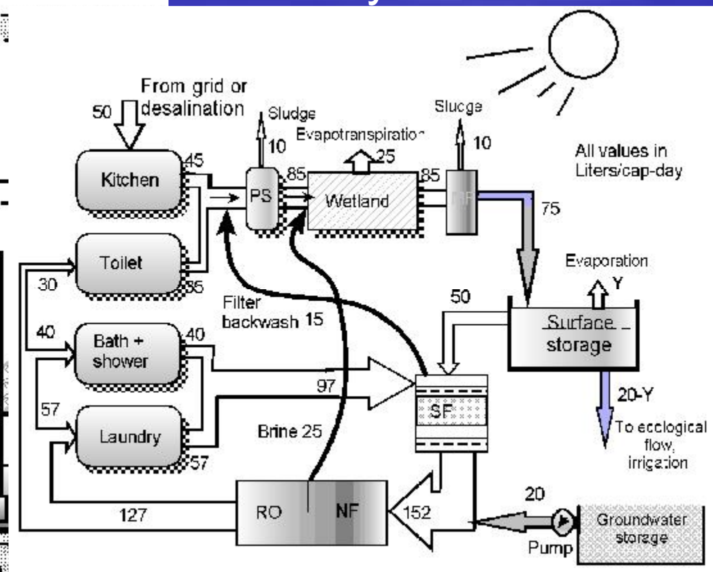
Water use	Without water conservation*		With water conservation	
	Liter/cap-day	Percent	Liter/cap-day	Percent
Faucets	35	14.7	35	25.8
Drinking water and cooling	3.6	1.2	2.0	1.5
Showers	42	17.8	21	15.4
Bath and Hot Tubs	6.8	2.0	6.0	4.4
Laundry	54	22.6	40	29.4
Dish washers	3.0	1.4	3.0	2.2
Toilets	63	26.4	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

** Reflects converting from lawn to xeriscape using native plants and ground covers with no irrigation. Water use is for swimming pools, watering flowers and vegetable gardens

Closed cycle distributed system



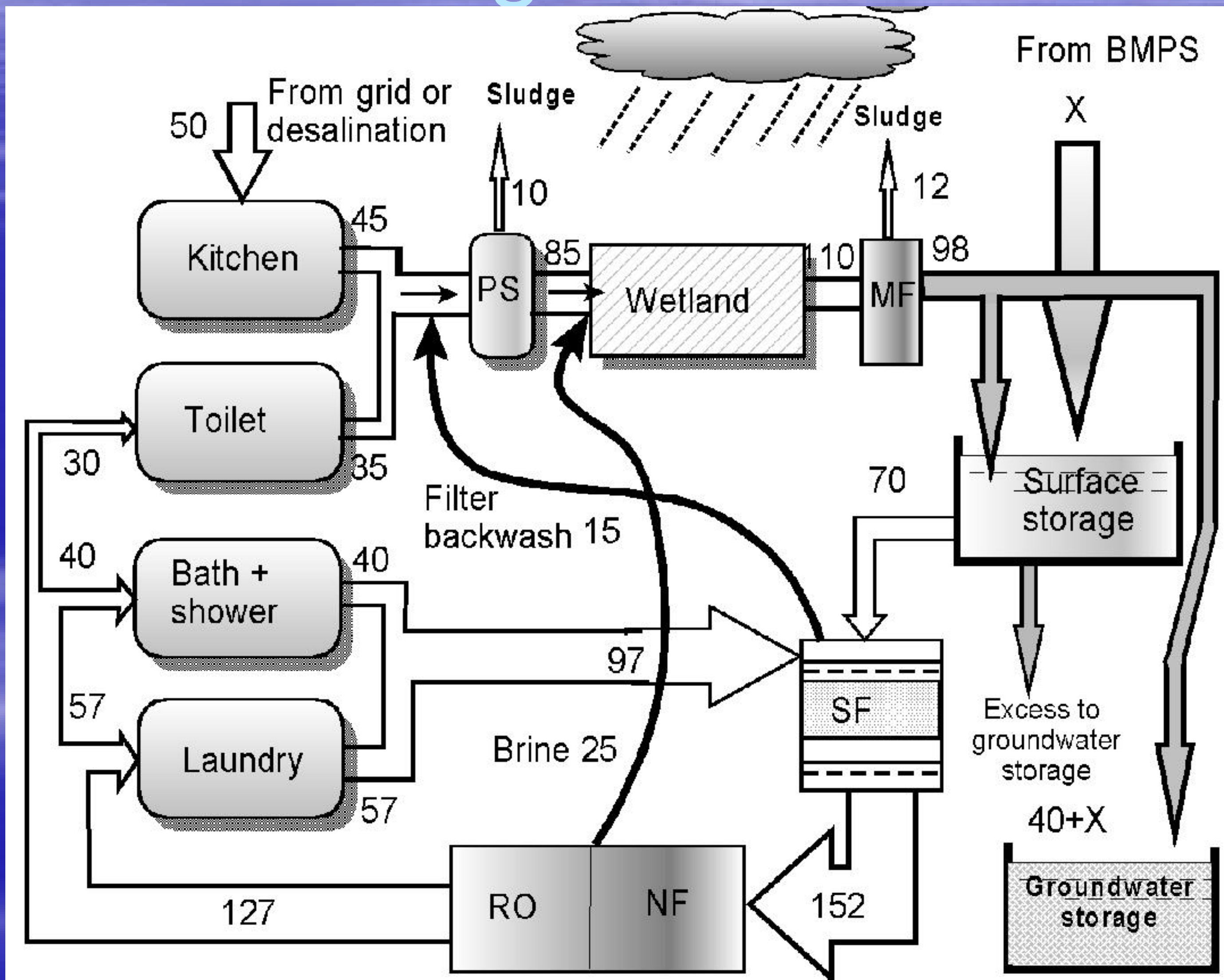
The number of cycles without make up water is very limited.



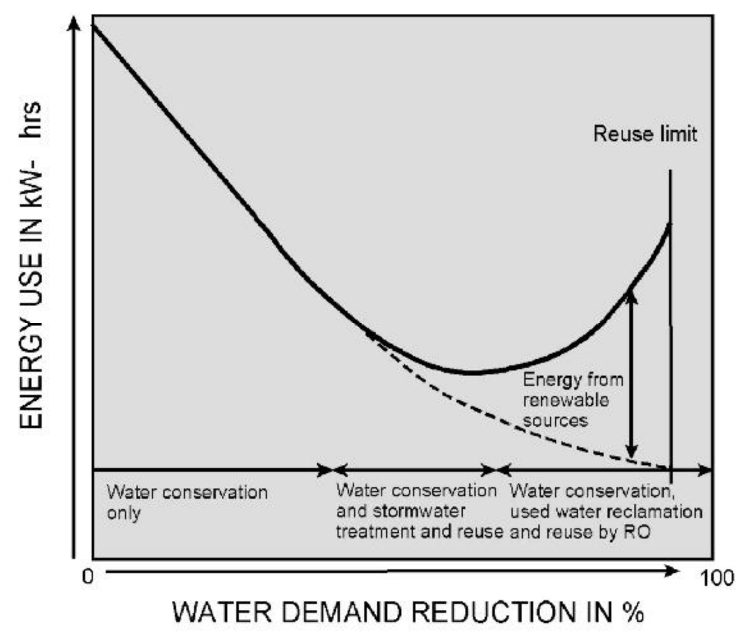
Make up water comes mainly from treated (and stored) storm water

PS –Solids separation, SFW –submerged wetland, MF membrane filter, SF sand filter, NF Nanofilter, RO – reverse osmosis, ST-storage, HWT – hot water tank

Treated surface runoff and rain harvesting is needed



Energy savings by reducing water demand



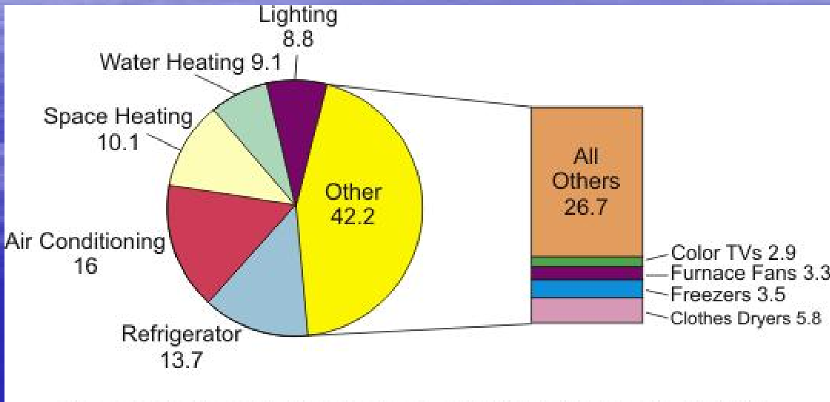
- In US 1 kW-hour represents 0.61 kg of CO_2 emitted
- Examples of energy use
  - Activated sludge process with nitrification 0.72 kW-hr/ m^3 (0.44 kg CO_2 emitted per m^3)
  - Reverse osmosis in reuse and desalination 5 - 15 kW-hr/ m^3 (3-9 kg CO_2 per m^3)
  - National average energy cost of providing water and treatment from the grid 2.26 kW-hr/ m^3

    (1.4 kg CO_2 emitted)

Water conservation is the best altenrative

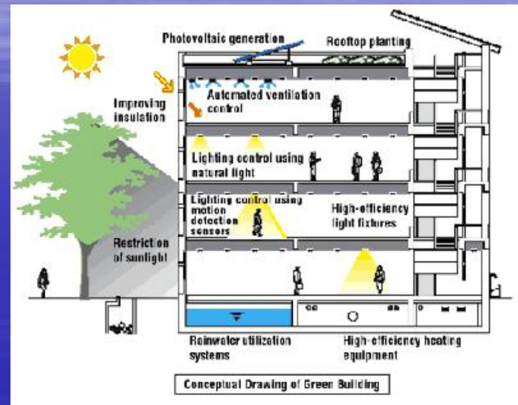
Reuse with high efficiency solids and pollutant removals (e.g. microfiltration and reverse osmosis [illegible] Orange County in US) require a lot of energy

Domestic energy makes and savers



Source: Energy Information Administration, Form EIA-457A, B, C, E, and H of the 2001 Residential Energy Consumption Survey.

Passive energy savings



Tankless water heaters

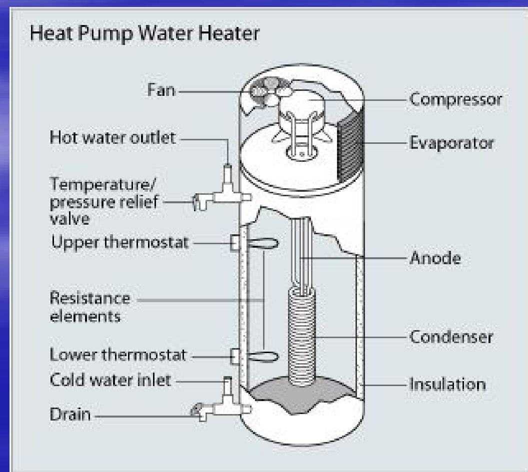
Heat pump

* Air to air

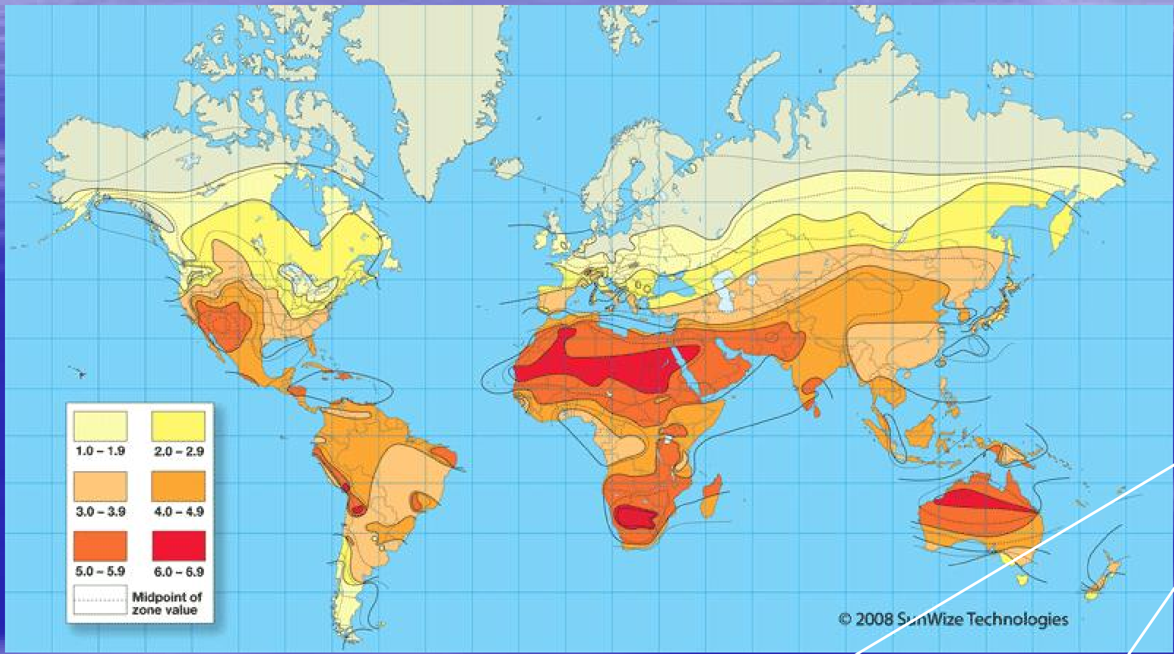
•Water to air

•Water to water

•Ground to water



Solar energy



Concentrated heat

Photovoltaics

Wind energy

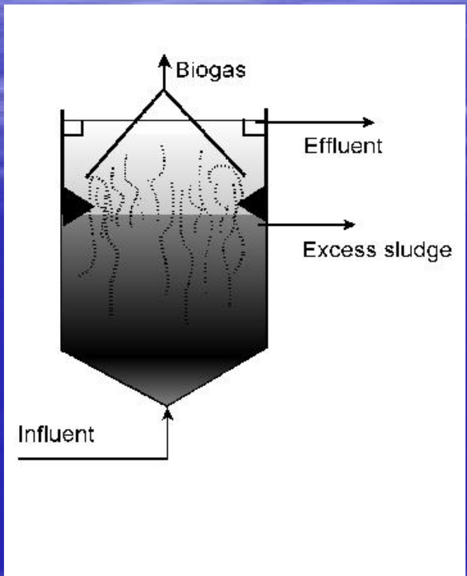
- Individual homes   kWatts
- Distribited
- Winfarm   GWatts

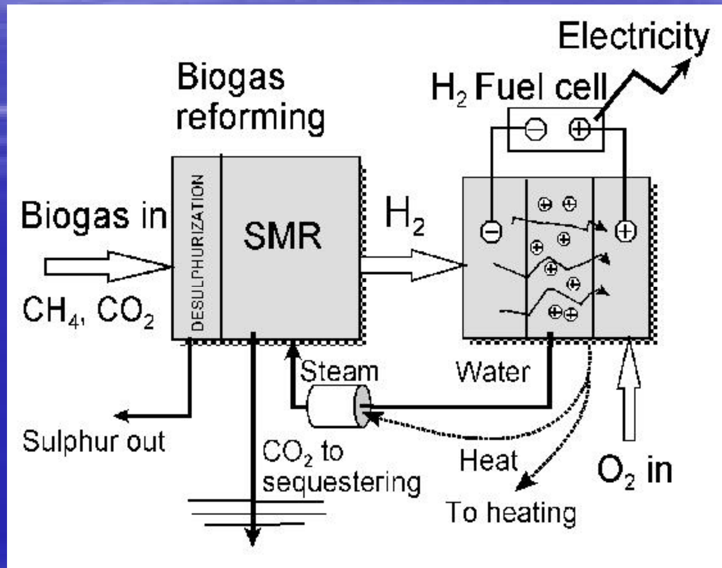
Energy from water used water

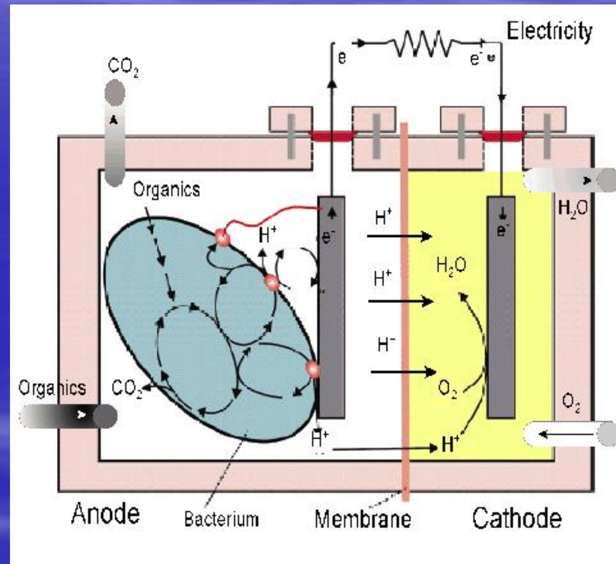
- Heat recovered by heat pumps
- Biogas from anaerobic processes
  - Digester
  - Upflow anaerobic sludge blanket reactor
- Hydrogen fuel cell
- Microbial fuel cell

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/m3 of methane

Hydrogen fuel cell with biogas reforming

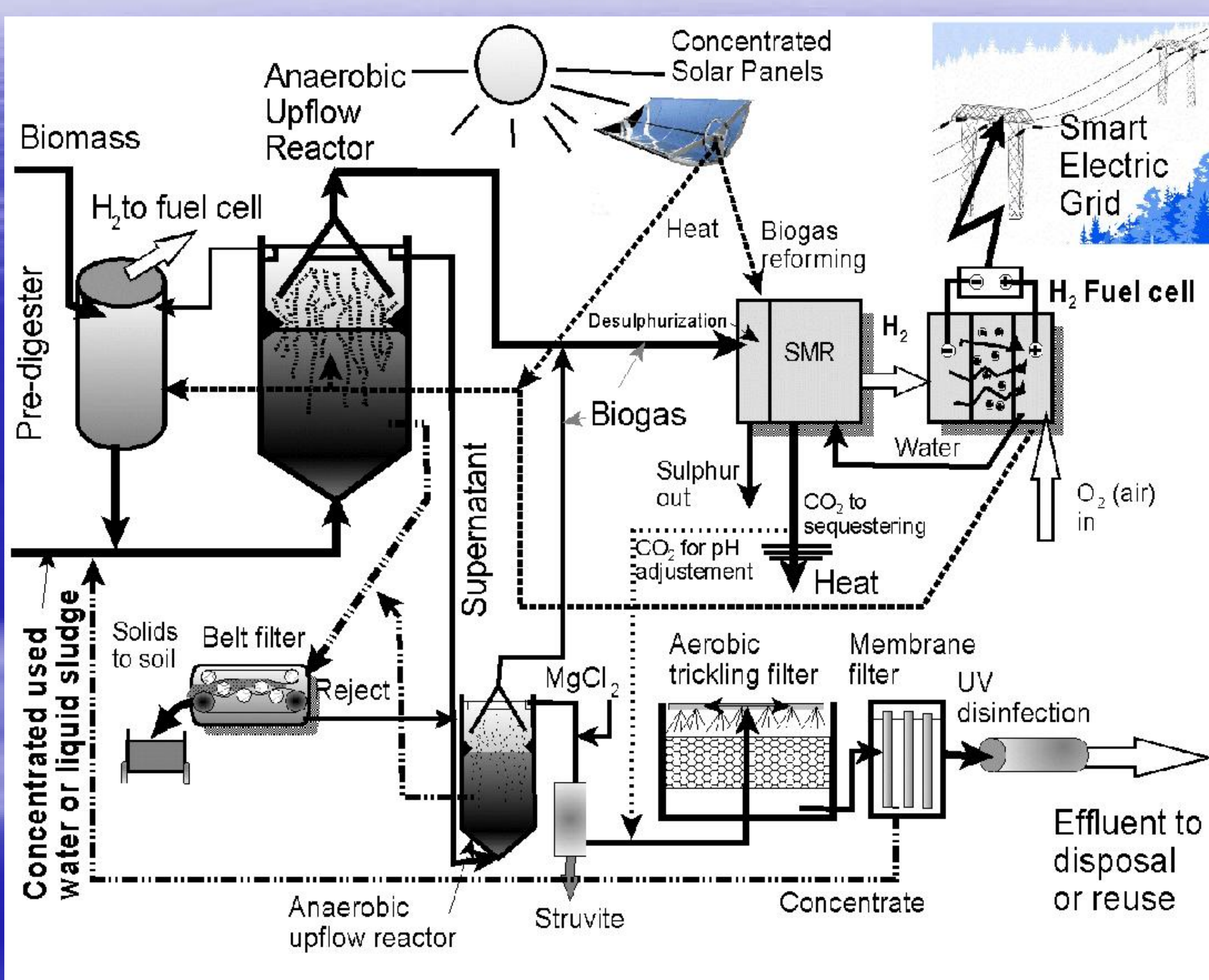
•Converts methane into hydrogen

•Greater efficiency than methane combustion

Microbial fuel cell (Logan 2008)

•Convert organic biomass directly into electricity or hydrogen

Integrated resource recovery facility



Includes Lettinga's Natural Biological Mineralization Concept

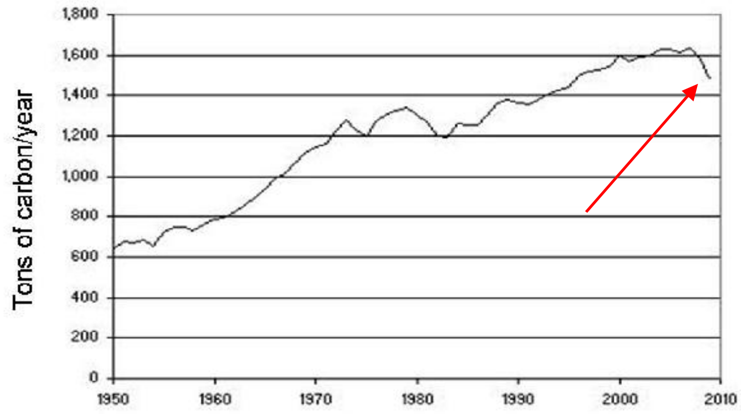
When treating concentrate used water it can produce = 0.8 kW-hrs/cap-day of clean energy

More energy can be produced jointly from digested solids (vegetation, refuse, shredded wood)

20 – 25 years ahead outlook

Per capita CH_2 emissions in 100 US cities

Energy use for	CO_2 emissions in tons/cap-year	% of total
Transportation by cars	4.091	47.0
Public transportation	0.388	4.4
Home heating by gas or oil	1.470	17.0
House electricity including that for cooling	2,751	31.6
Total	8.71	100



Source Gleaser and Kahn (2008)

It appears that the US increasing trend of carbon emissions has been reversed in 2007 (Brown, 2009)

- Higher appliance energy standards
- Stricter automobile emissions standard
- Virtual phasing out of coal power plants
- Very large increase of renewable energy production, etc.

Conservative assumptions for the future

- Carbon foot print of the electric energy production will be reduced from 0.62 kg CO_2/kW-hr today to 0.35 kg CO_2/kW-hr by 2030 – 2035
- Vehicular traffic- majority of cars will be hybrid and plug-ins, expected GHG emissions reduced by 60%. Minimum traffic is anticipated in ecocities
- Public transportation by electric trains, light rail and buses will increase but the carbon footprint will decrease
- Heating by passive energy savings, insulation and using heat pumps will reduce heating carbon footprint
- Electricity us by households is expected to decrease by 60 – 70 % (National Science and Technology Council)

These measures could reduce carbon footprint from 8.7 tons of CO_2/cap-year to 3 tons CO2/cap-year (slightly less than Barcelona today)

Water/used water contribution

- Reducing water use from 0.5 m^3/person-day to 0.2 m^3/person-day will reduce carbon footprint by 0.2 tons/cap/-year
- Extracting heat from used water and producing electricity from UASB biogas by fuel cell 0.47 tons/cap/-year
- Miscellaneous (reduction of pumping cost by bringing stormwater drainage to surface, etc.) 0.3 tons/cap/-year
- Biogas combustion or burning vegetation residues, and combustible refuse in incinerators is carbon neutral

Total new water/stormwater/used water management carbon footprint reduction

1 ton/cap-year

Looking for 2 more t CO_2/cap-year

- More reduction by private automobiles
  – Higher density settlements with short distance to public transportation, walking, biking -1.1 ton CO_2 /cap-year
- Photovoltaics on the roof of each house - 1.1 tons CO2/cap-year
- Small horizontal wind turbines in each block – up to 1.5 CO2/cap-year

It is realistic an doable

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., feat pumps)
- The goal of net zero carbon footprint is achievable by 2030 even in the US