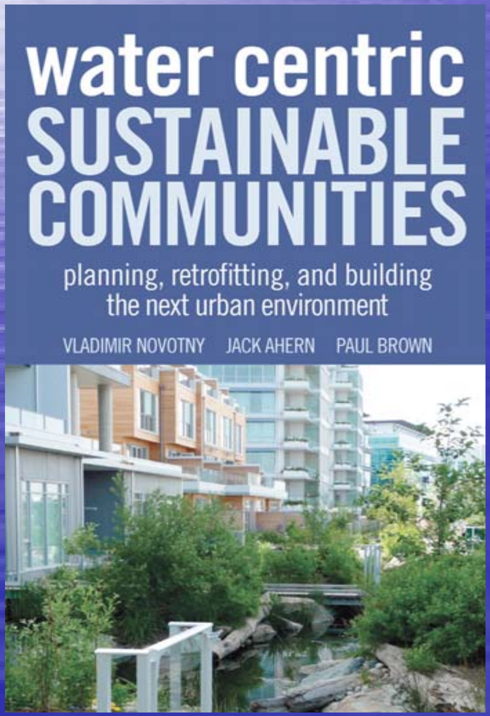
Water – Energy Nexus in the Cities of the Future Chapter VIII



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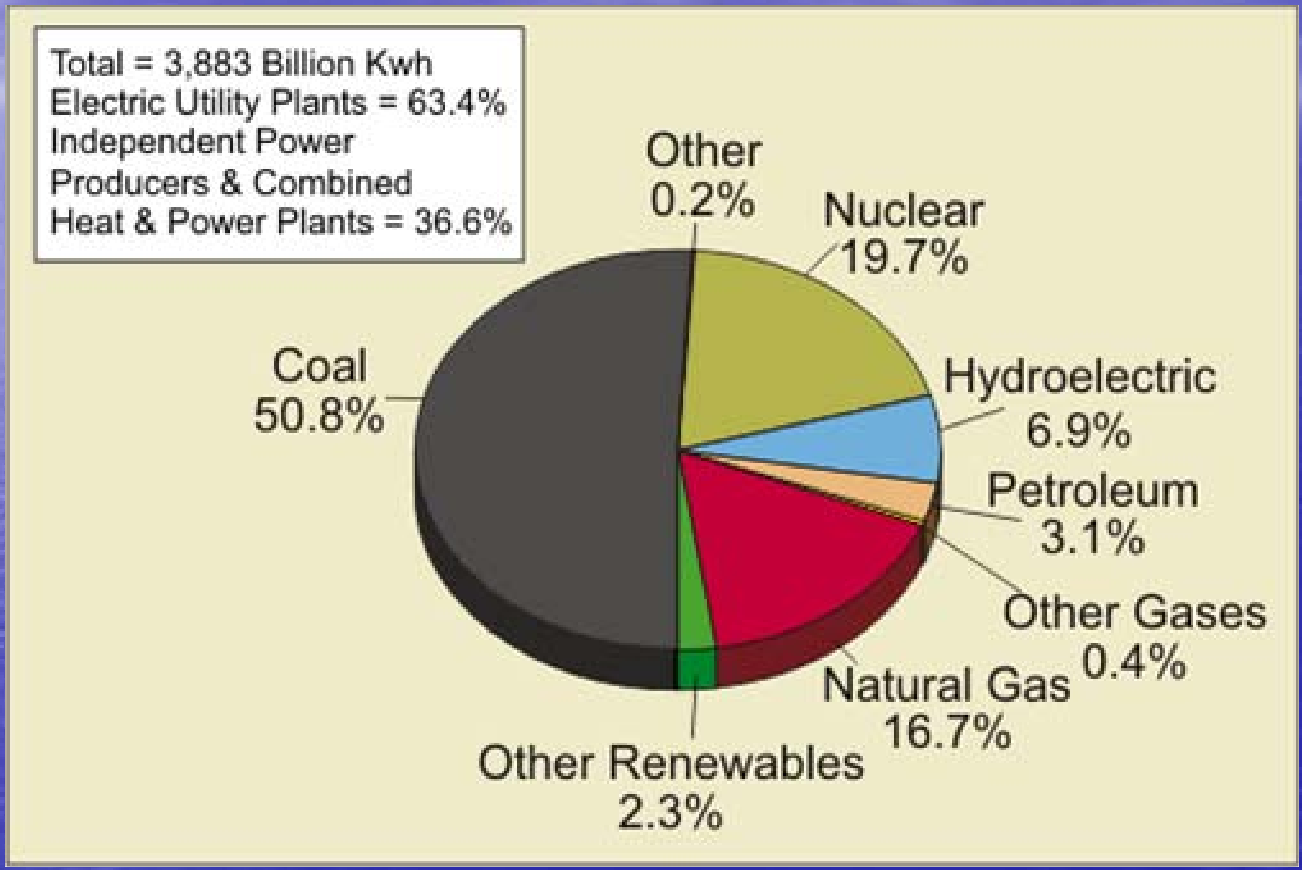
Energy produced in US



1 Kw-hr = 0.61 kg GHG

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

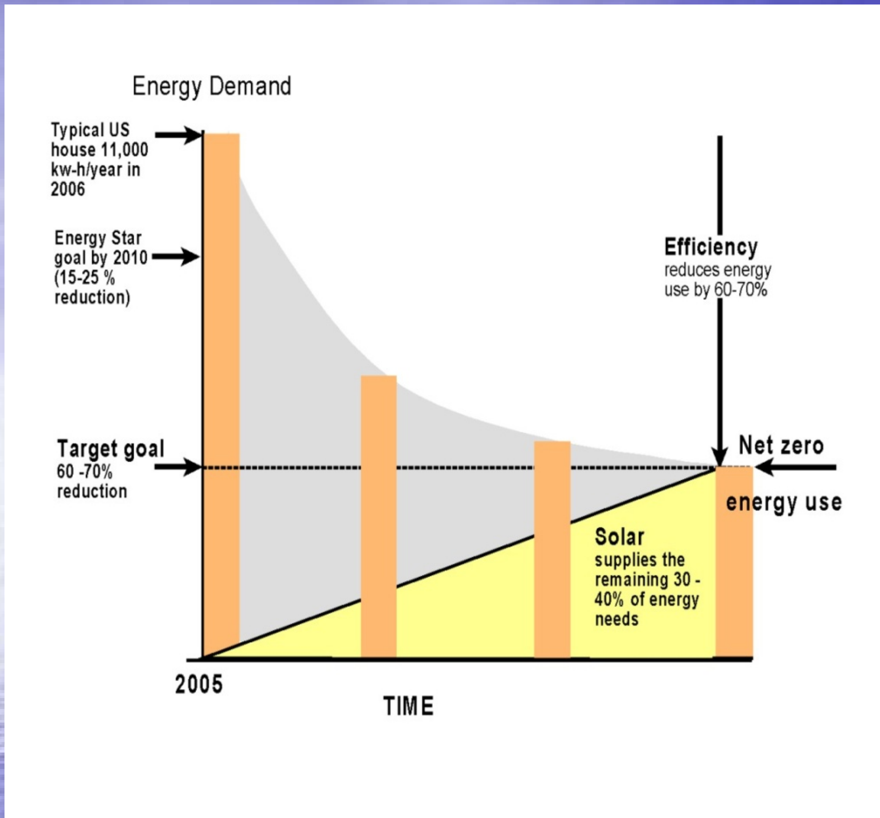
[1]Wikipedia (2009); [2] Dodman (2009) ; [3]Gleaser and Kahn (2008)

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

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

Water Energy Nexus

How to get to net zero energy



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

- Implement water and energy conservation – 60-70% of the goal of net zero
- Wind and solar energy to supply remaining 30 – 40 %
- Switch to more efficient transportation
  - o Walking, biking
  - oElectric cars, plug-ins
  - oPublic transport

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 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.

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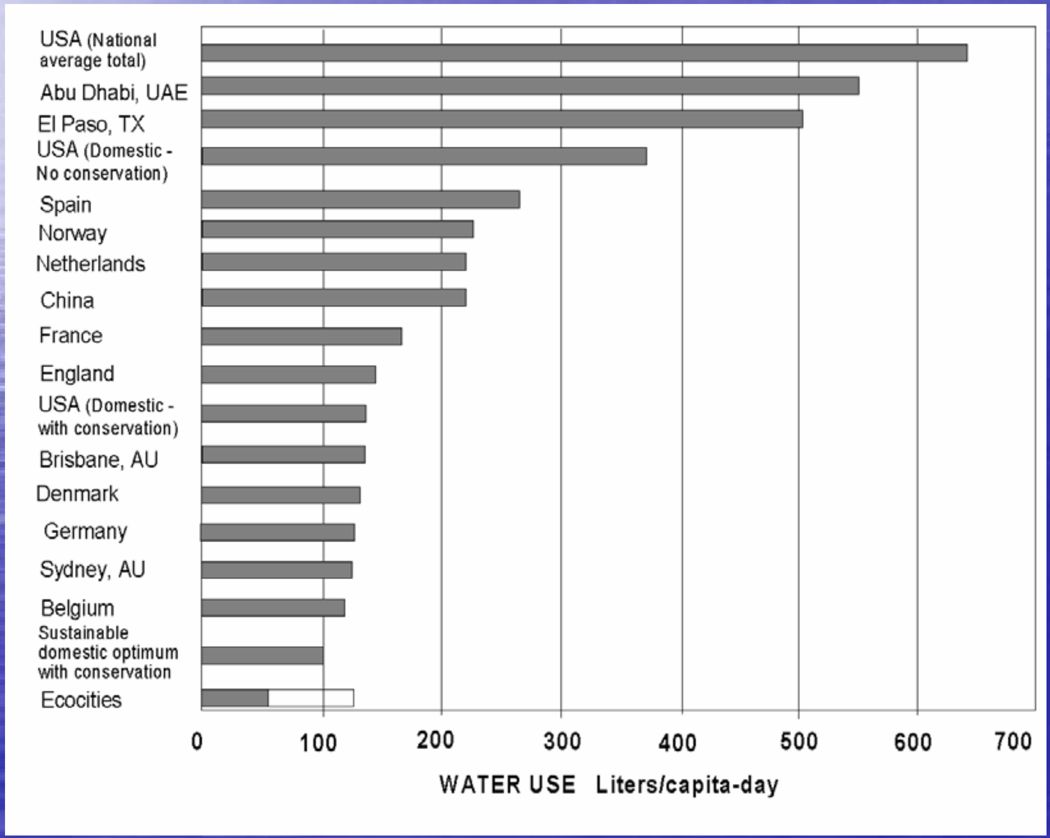
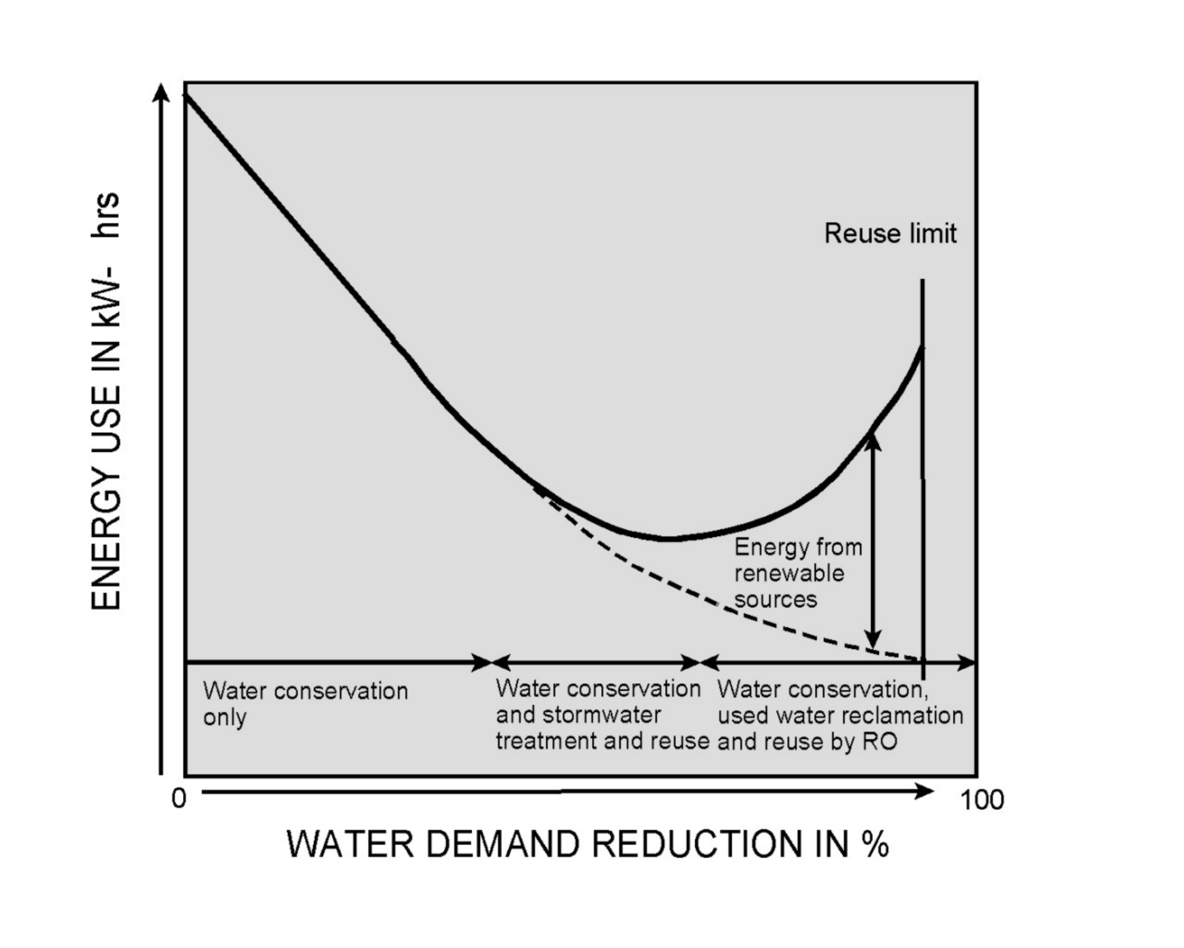
Water conservation reduces proportionally carbon emissions



In the US, producing, transporting, treating, and disposing used water and sludge requires 2.25 kw-hr/m^3 of delivered water

This corresponds to 1.37 kg of CO_3 /m3

Water conservation vs. Recycle

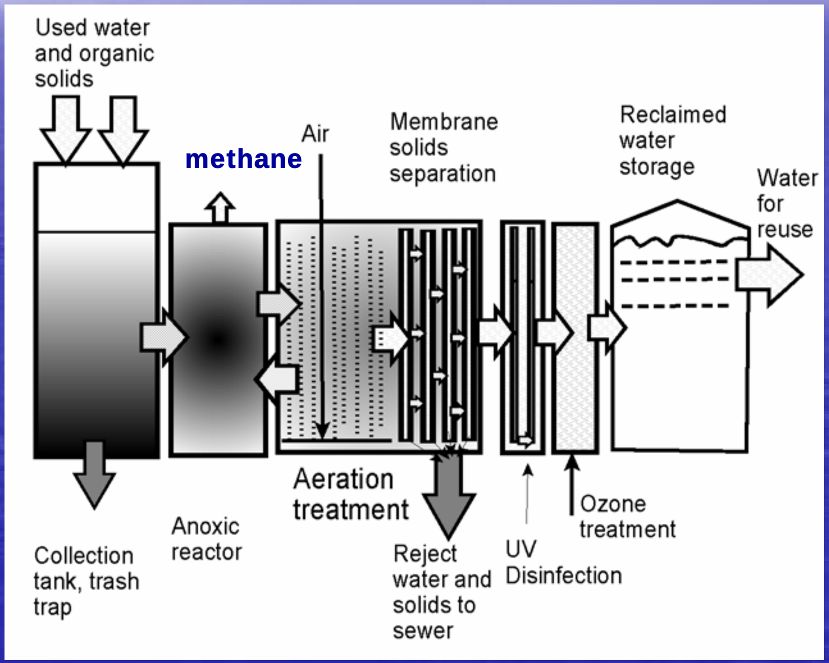


- Water conservation reduces proportionally energy and GHG emissions
- Reclaiming rainwater and stormwater needs some energy
- Adding reuse by microifiltration and reverse osmosis increases energy use and GHG emissions

Rainwater harvesting requires minimum energy

Roof rainwater collecting tank in Orange District in Australia

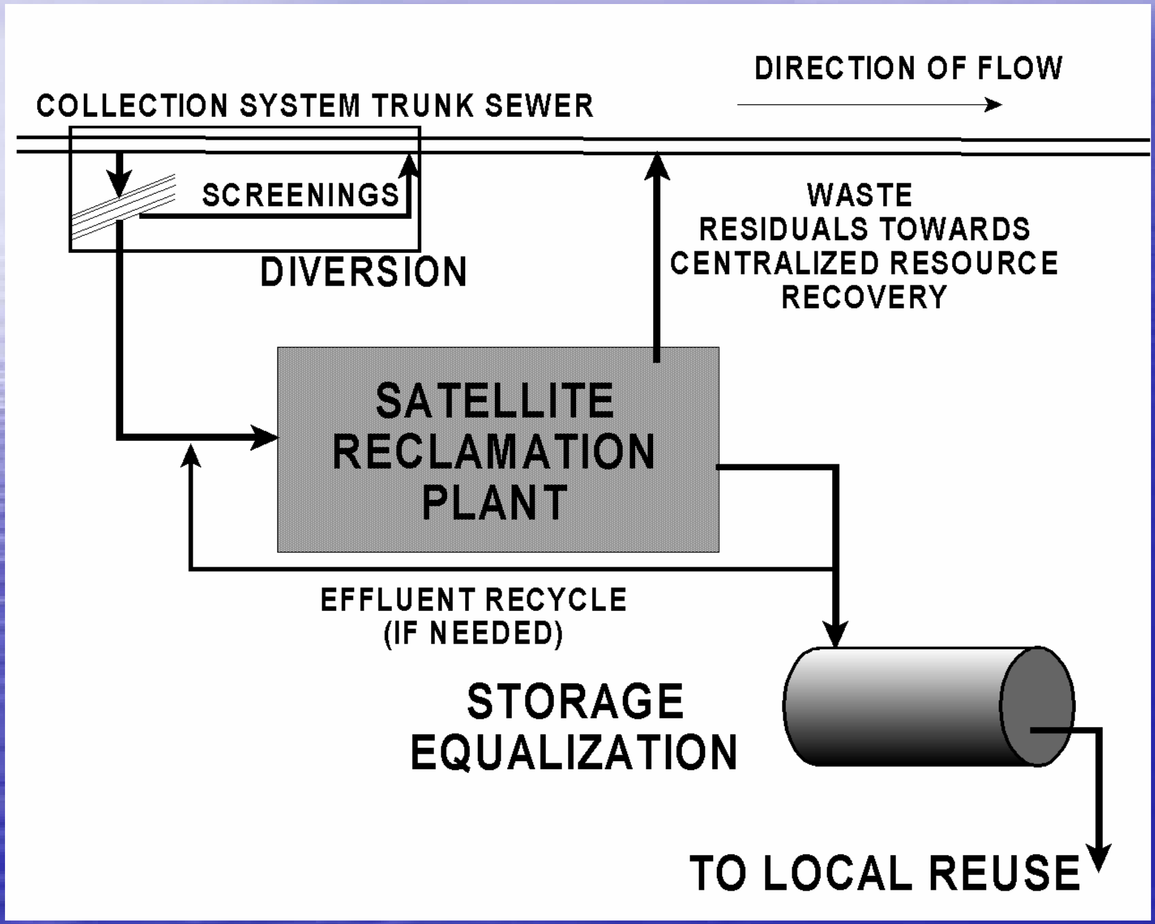
Water reclamation and reuse for toilet flushing and possibly irrigation



Rainwater harvesting and reuse for irrigation is also practiced

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

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

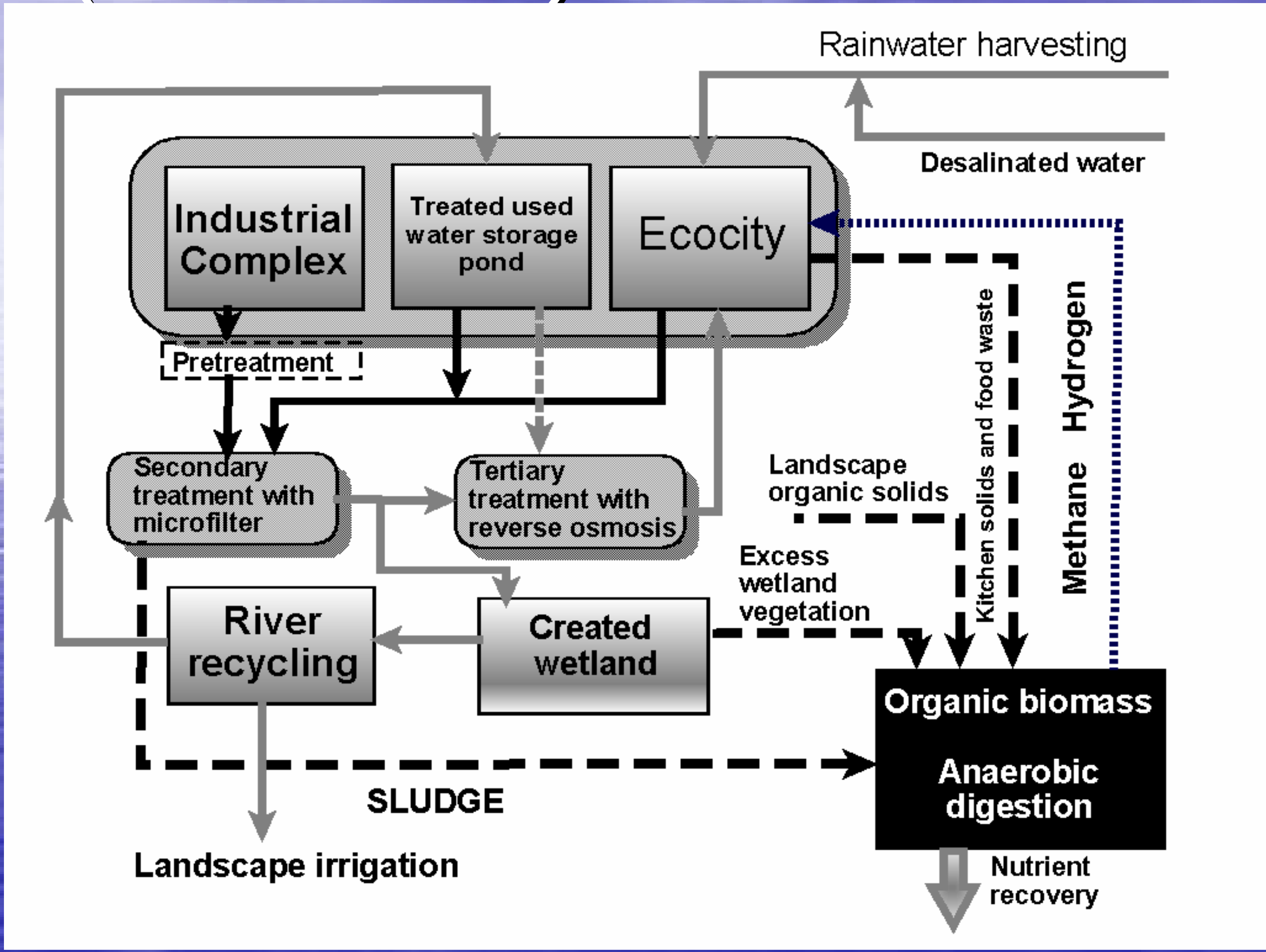


Package and small high efficiency treatment units can be installed to provide locally water for:

- Ecological flow of restored streams
- Toilet flushing
- Landscape irrigation
- Street flushing

Adapted from Asano et al. (2007)

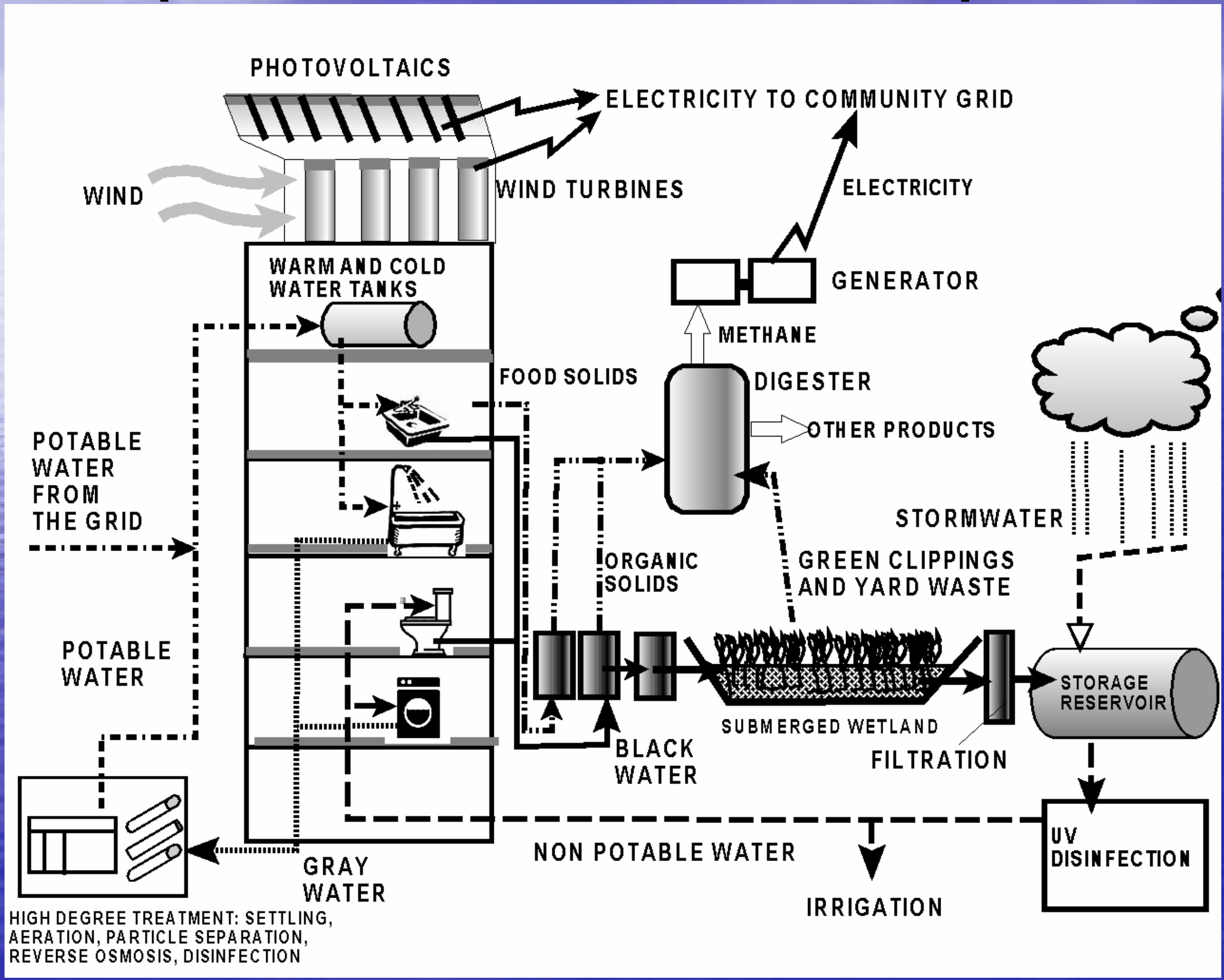
System – wide reclamation (centralized) and reuse - Tianjin



Picture credit

Sino – Singapore development agency - replotted and adapted

Qingdao double partially decentralized loop with used water separation



Problem:

- Small direct potable reuse
- Wetland (surface) treating black used water too close to inhabited buildings

Reuse

Energy demanding

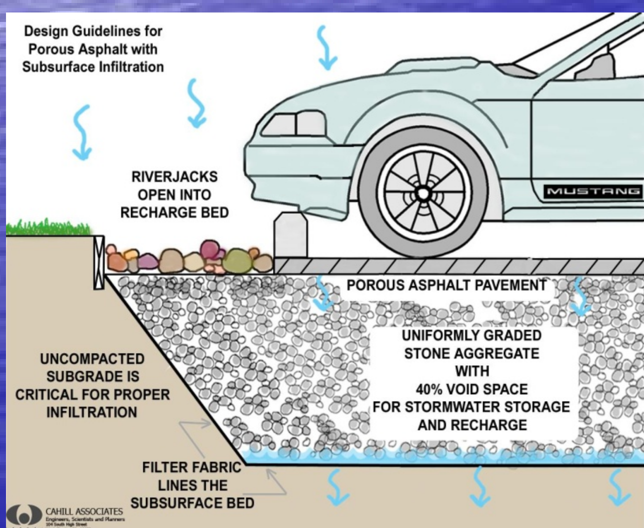
Microfiltration

Reverse osmosis

UV radiation

Picture credits V.Novotny and Siemens

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

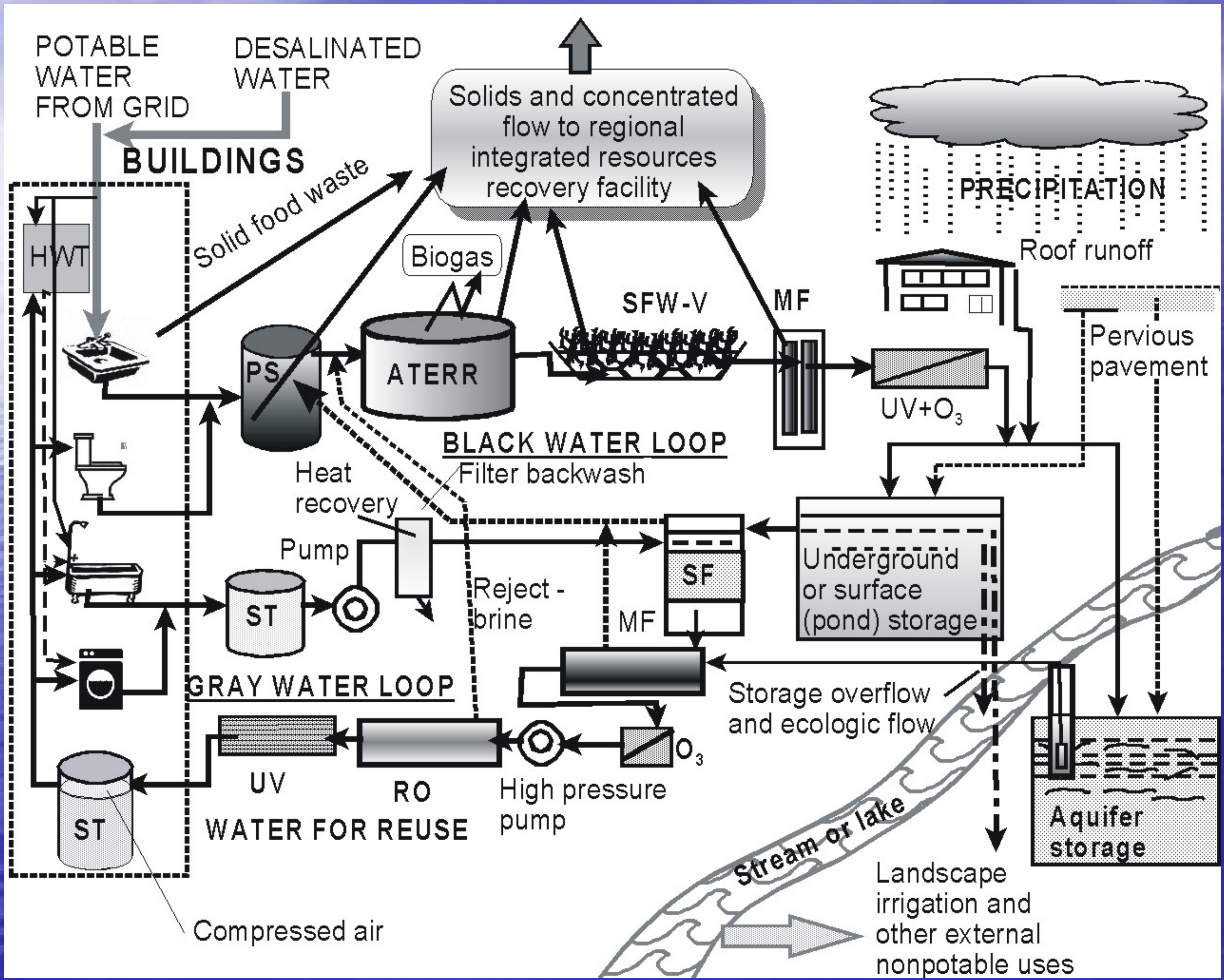
Store, treat and infiltrate runoff

Centralized or decentralized water management system

- Centralized – once through system is appropriate if only water conservation is considered
  - Heat energy recovery may not be feasible
  - Water reuse for toilet flushing and irrigation may be not economical or efficient – system wide dual piping is needed
  - Nutrient recovery and biogas recovery and conversion to electricity is efficient
- 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 electricity may be difficult and inefficient
- Hybrid system – retains advantages of both systems

Double loop reuse with separation

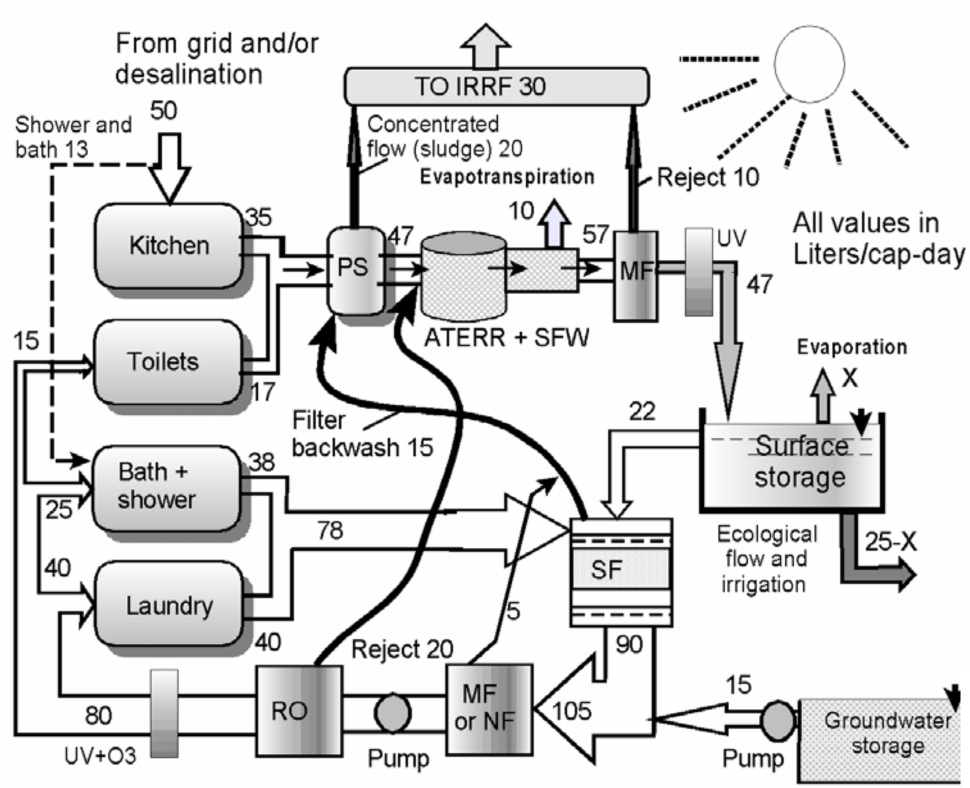
based on Qingdao double loop for a cluster (ecoblock)



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 ATERR anaerobic treatment and energy recovery reactor
MF microfiltration
SFW-V subsurface flow wetland –vertical flow
UV ultraviolet radiation
ST storage
RO reverse osmosis
NF nanofiltration



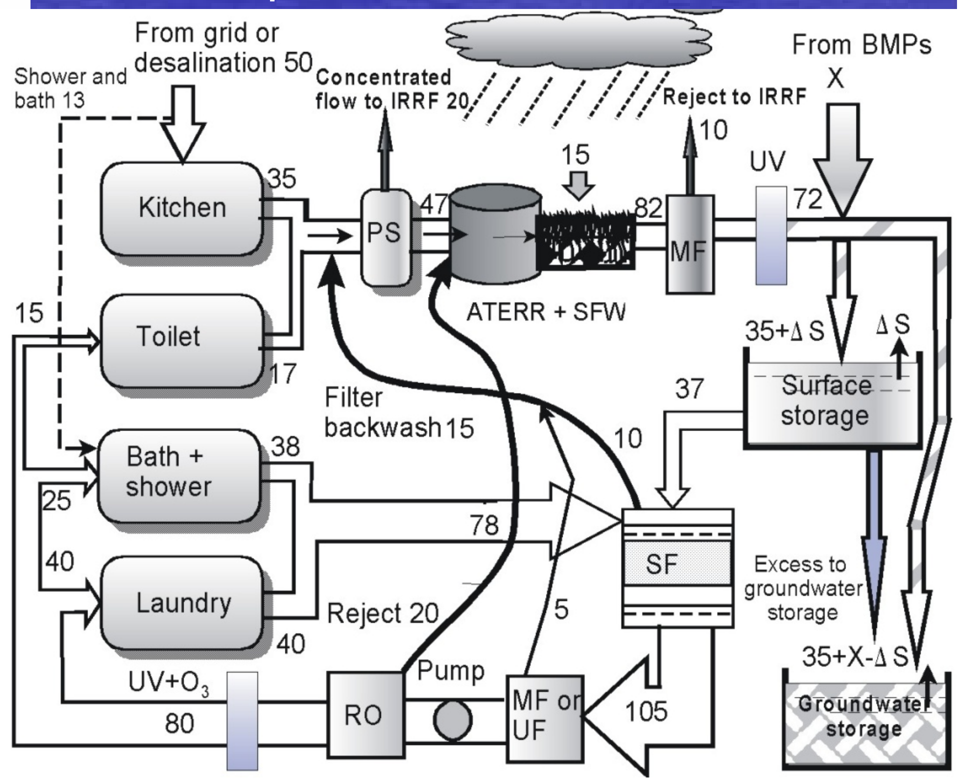
Water demand on grid and water use in liters/person-day

•Grid (desal) water demand	50
•Concentrated used water and sludge flow to IRRF	30
• Water use within the cycle	130
•Potable	50
•Nonpotable	80

DRY DAY

RAINY DAY

Min 30% of the recycled water needs to be replaced



Rules of recycle

- During dry weather conditions the system must provide ecological flow (plus irrigation) otherwise the ecology of the urban waters will collapse
  - All excess flow plus flow from storage goes towards ecological flow and irrigation
- During wet weather conditions the system
  - Provides make up water for the second (gray water recycle)
  - Treats and stores urban runoff
- Drinking water provided from the grid or desalination supplemented by harvested rain and/or groundwater

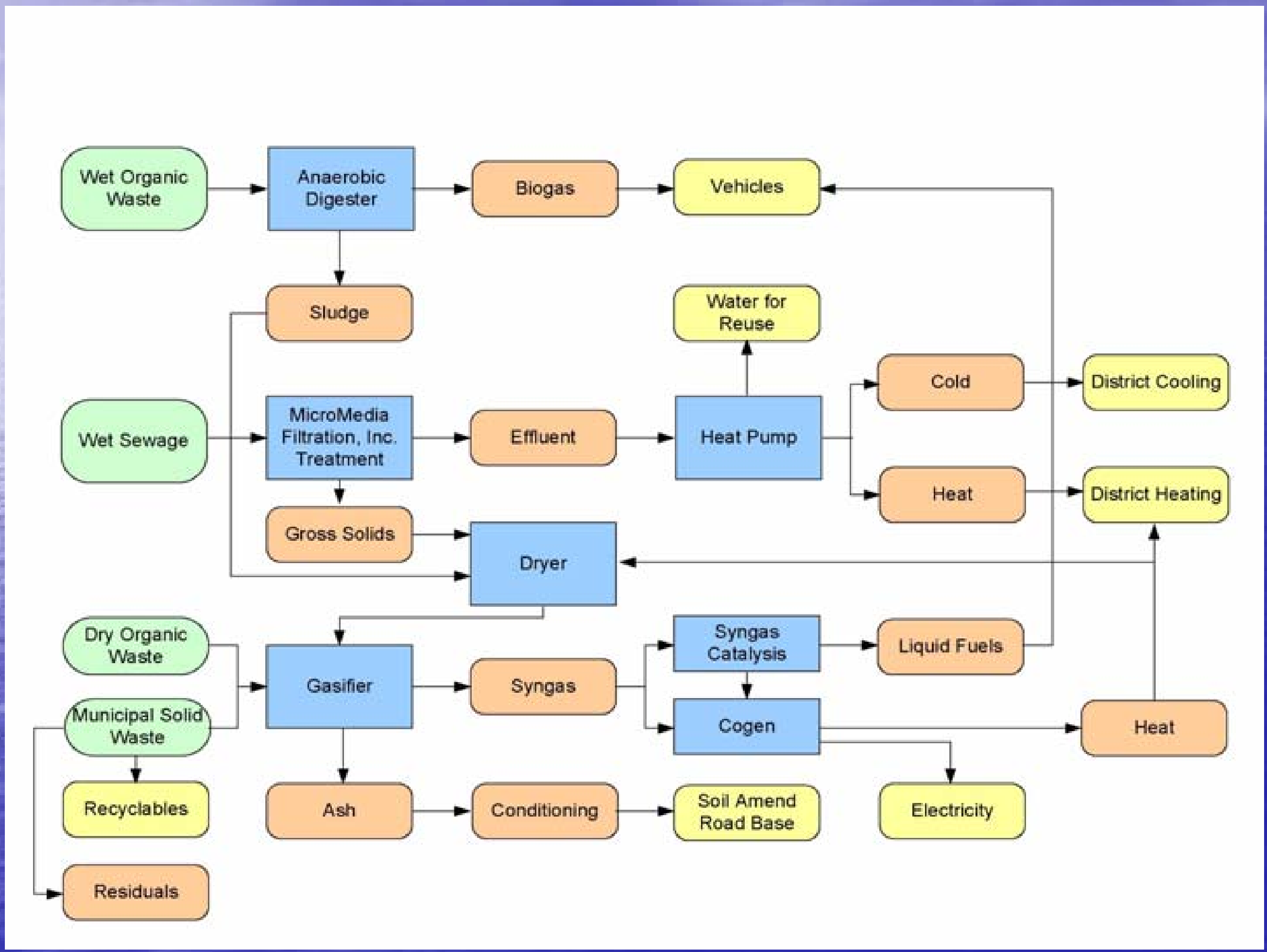
A water management based on quality parameters is needed

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
- Syngas from organic solids

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

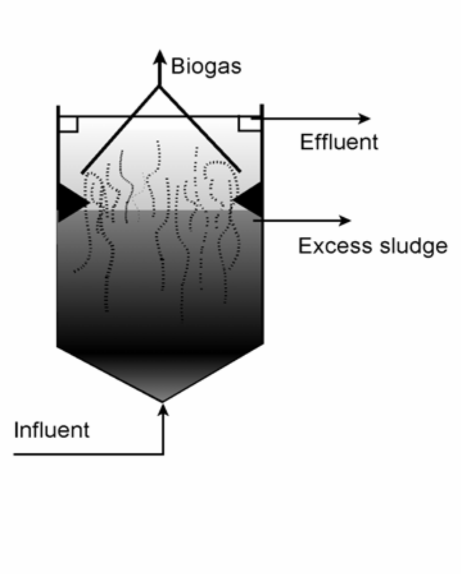
Integrated Resource Management™

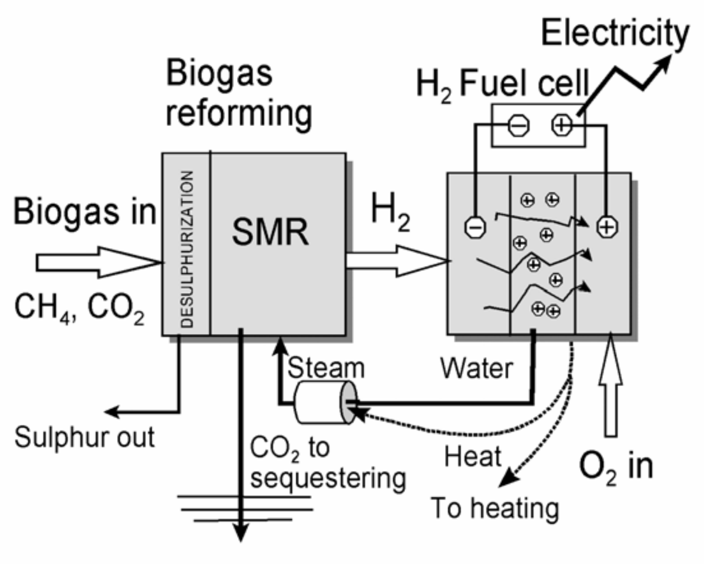


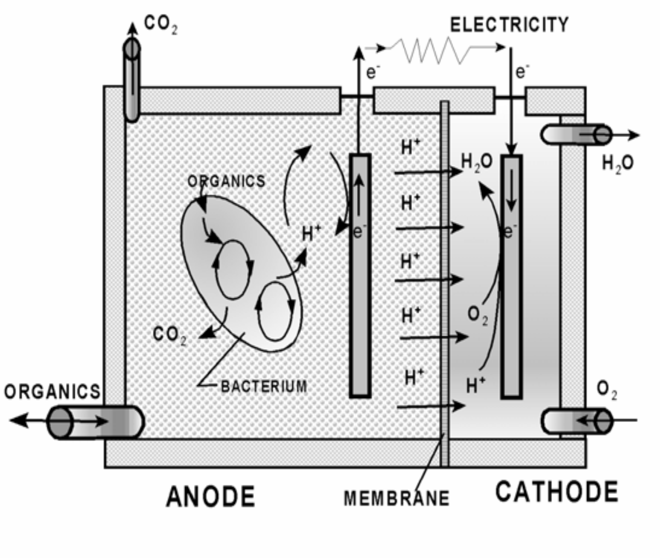
Syngas = wood gas produced by high temperature heating of organic solids without oxygen main content is carbon monoxide

Source and credit AquaTex Scientific Consulting Ltd, Victoria BC

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

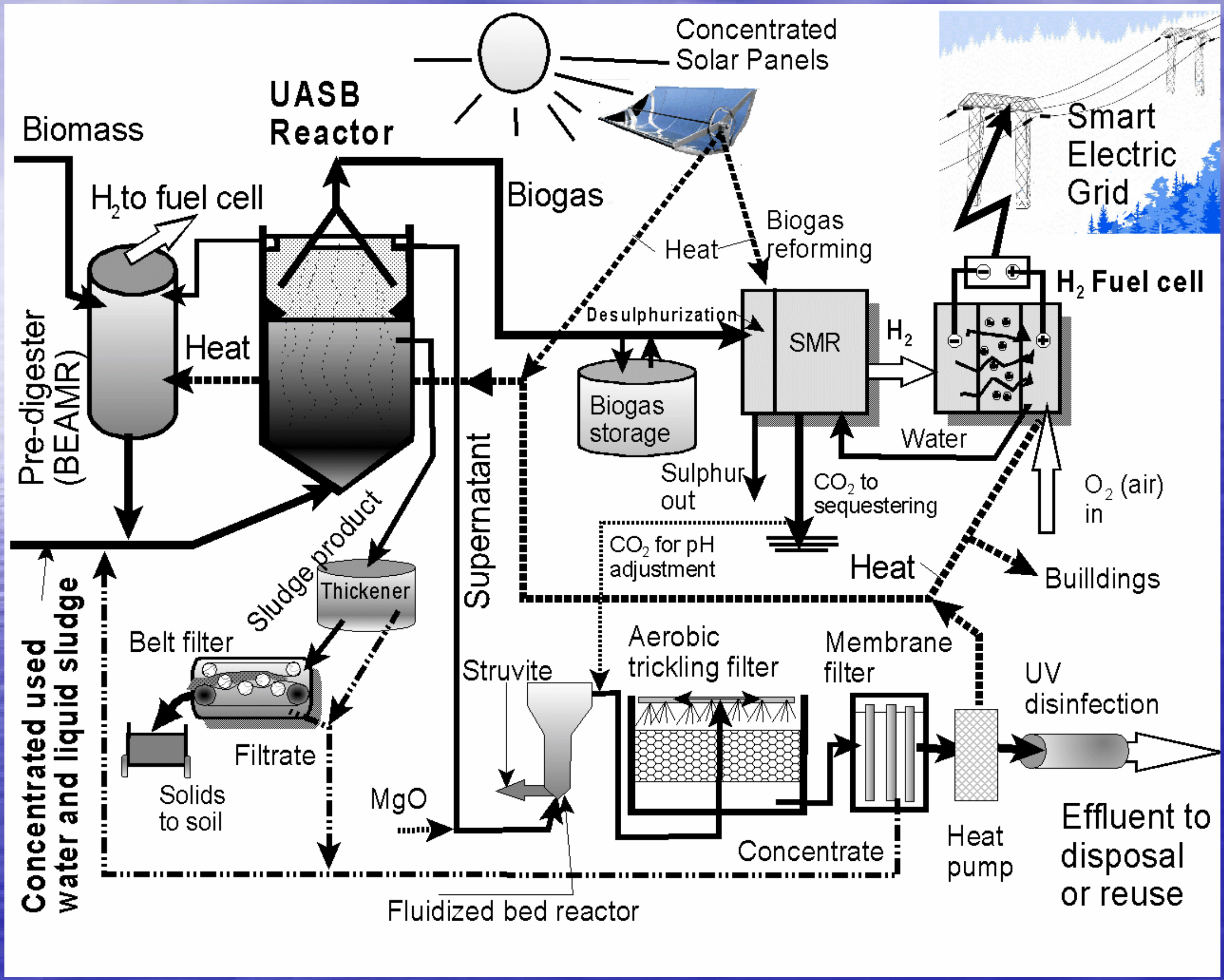
•Greater efficiency than methane combustion

SMR = Steam methane reforming

Microbial fuel cell

Converts organic biomass directly into electricity or hydrogen (from Rabaey and Vestrate, 2005)

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 sequetering

BEARM = Bioelectrochemically assisted microbial reactor - Logan (2008)

Fuel cell converts biogas into electricity

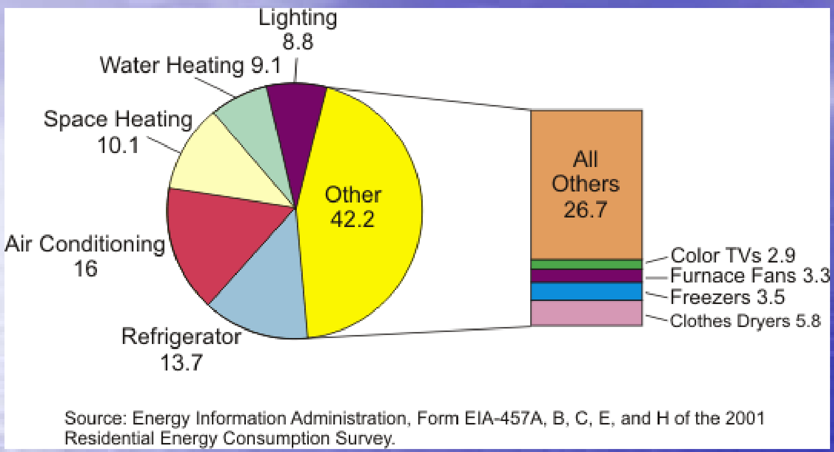
High Temperature Fuel Cell by Acunmetric has been installed in Hammarby Sjöstad.

Low temperature cell operates around 60 – 70°C while the high temperature cell shown herein operates at 600-700°C. This enables to utilize heat more efficiently.

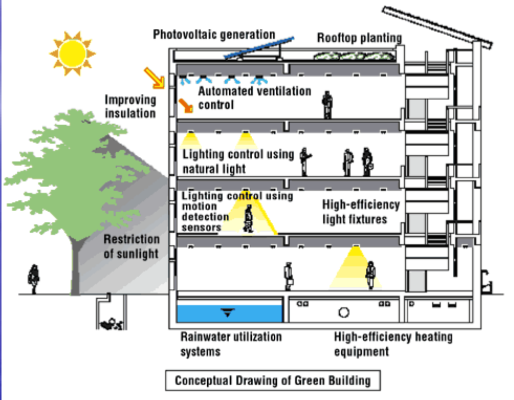
Fuel cell reforms biogas into CO_2 and H_2 . Hydrogen is then combined with oxygen (air) to produce electricity and water. Carbon dioxide can be sequestered.

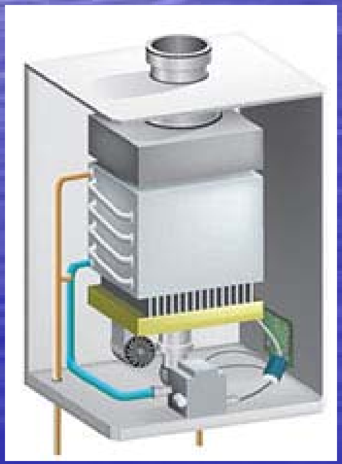
Source: GlashusEtt, Hammarby Sjöstad, Stockholm

Domestic energy savings



Passive energy savings





Tankless water heaters

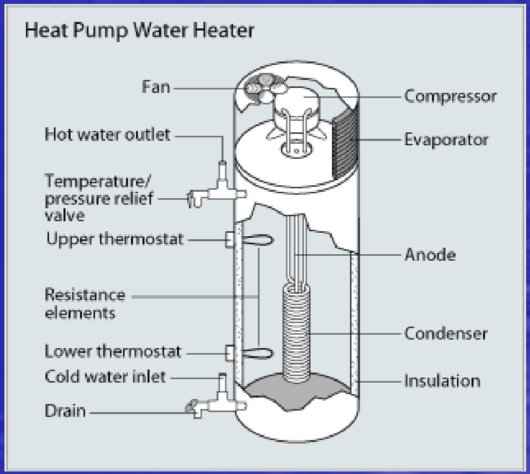
Heat pump

* Air to air

•Water to air

•Water to water

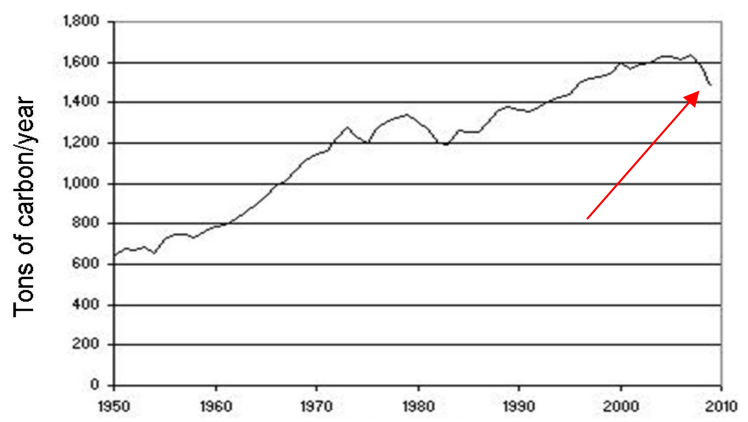
•Ground to water



20 – 25 years ahead outlook

Per capita CO_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 in 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.

Renewable energy sources

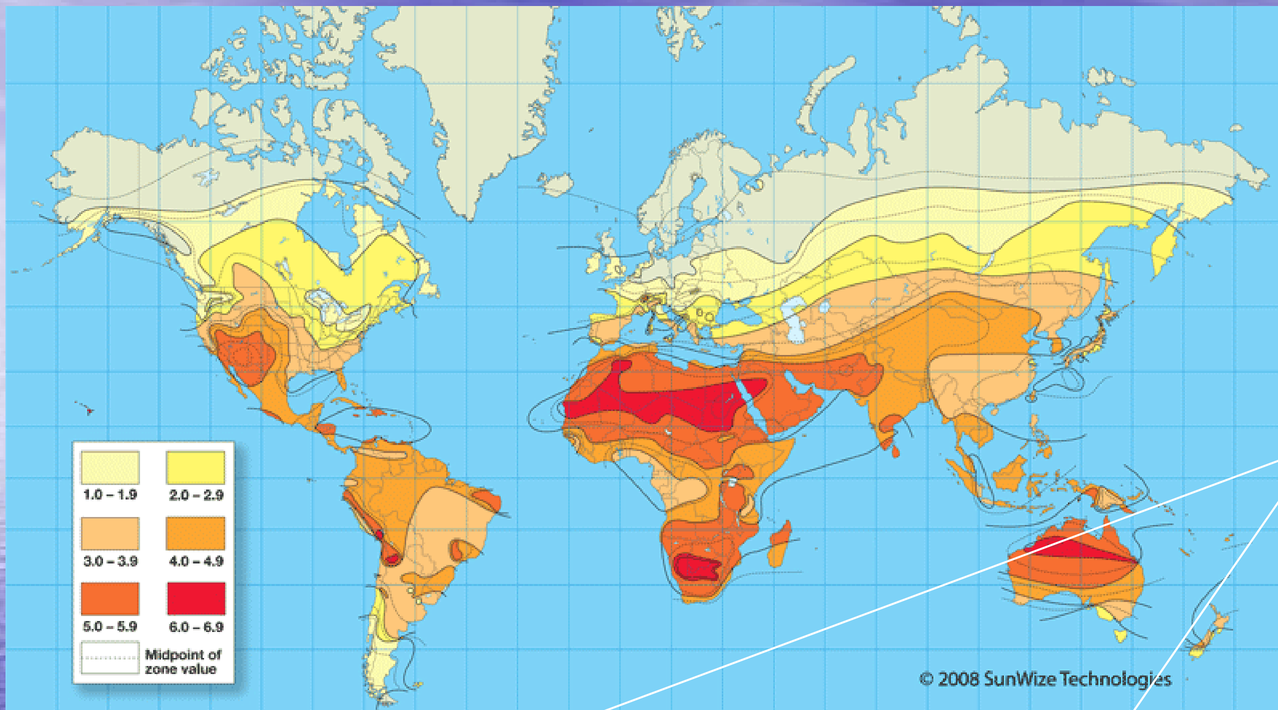
Potential renewable energy sources (from Johnson, 2009)

Source	Electric energy generation potential worldwide TerraWatts-hrs in a year*
Solar photovoltaics	470,278
Concentrating solar	275,556
Wind (land based)	105,556
Ocean (tidal and wave)	91,398
Hydropower	13,889
Geothermal	12,500
Wind (offshore)	6,111

Sources: NASA, World energy statistics and balances; OECD/IEA 2008, National Renewable Energy Laboratory;

1 Terra Watt = 10^{12} Watts

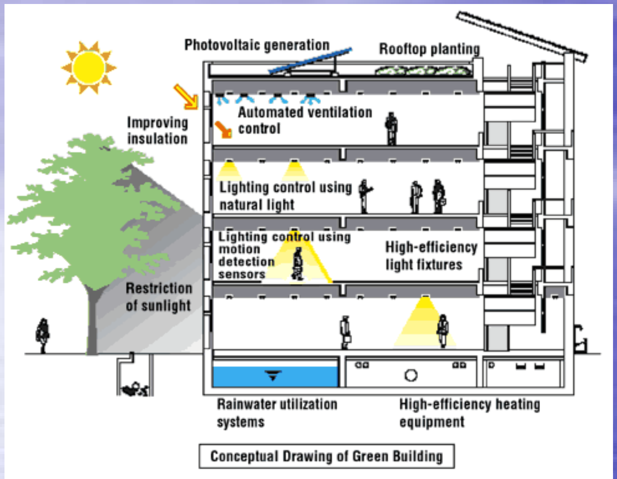
Solar energy



Concentrated heat

Photovoltaics

30 % from Renewable Energy



Passive energy sources

Mariah power

1.4. MW Voltaics array in Sonoma Valley

Wind turbines in Dongtan – courtesy Arup

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 use 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

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 increases 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 plug-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

Dockside Greens in Victoria, BC. Courtesy AquaTex Scientific Consulting