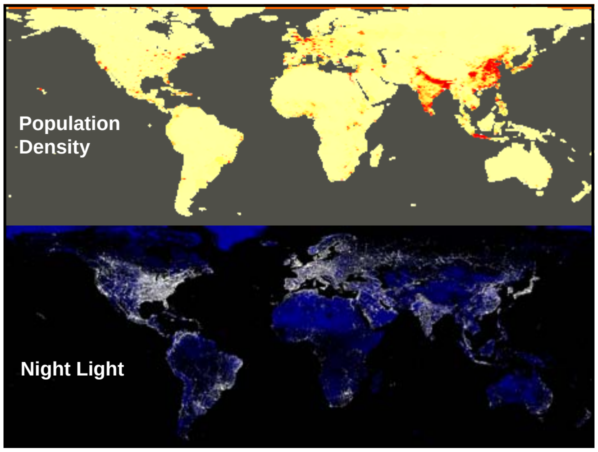
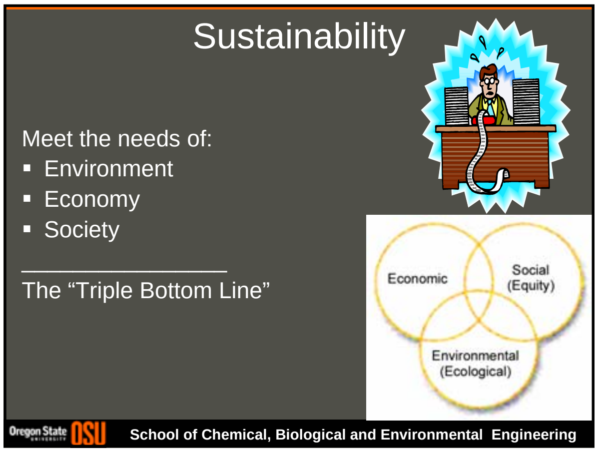
What would a sustainable wastewater treatment plant look like?

Kenneth J. Williamson
Professor and Head

Mark Lasswell
CH2M-Hill, Transportation Business Group

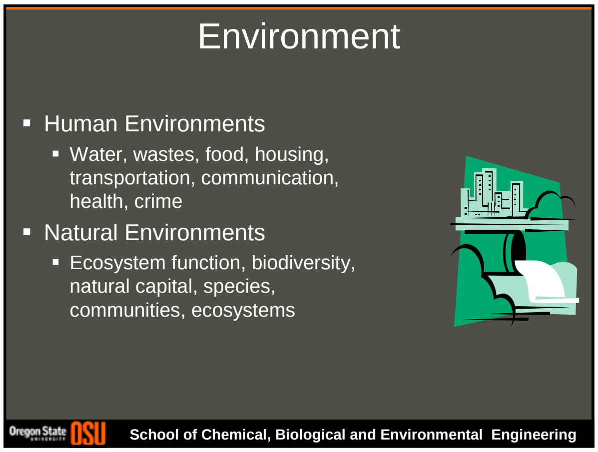




Sustainability

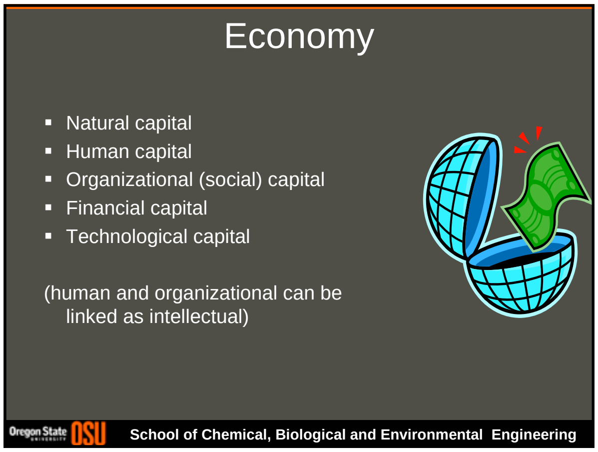
Meet the needs of:
- Environment
- Economy
- Society

The “Triple Bottom Line”



Environment

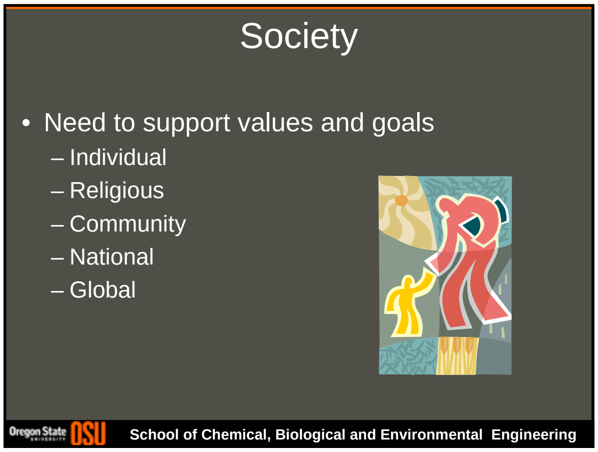
- Human Environments
  - Water, wastes, food, housing, transportation, communication, health, crime
- Natural Environments
  - Ecosystem function, biodiversity, natural capital, species, communities, ecosystems



Economy

- Natural capital
- Human capital
- Organizational (social) capital
- Financial capital
- Technological capital

(human and organizational can be linked as intellectual)



Society

- Need to support values and goals
  - Individual
  - Religious
  - Community
  - National
  - Global

Sustainability Criteria

- Improve effluent quality: oxygen demand, nutrients, micro pollutants
- Minimize energy use
- Maximize energy production
- Increase water reuse, biosolids recycling
- Reduce greenhouse gas emissions

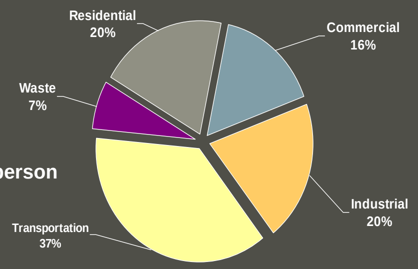
Improve quality of effluent

- Oxygen demand
  - – Activate sludge, long sludge age
  - – Nitrification, even longer sludge age
  - – Increase aeration requirement
- Nitrogen
  - – Nitrification, then denitrification in anoxic zones
- Phosphorus
  - – Concentrate biologically
  - – Can precipitate as calcium phosphate or sturvite

Improve quality of effluent

- TSS
  - – Alum flocculation, filtration
  - – Nanofiltration
- Micropollutants
  - – Non-degradable COD
  - – Colloids
  - – Pharmaceuticals
  - – Endocrine disrupters
  - – Personal care products

Minimize Energy Use



12,756 kWh/person

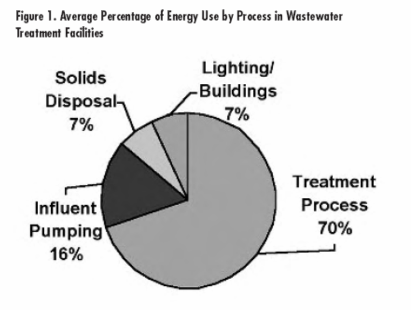
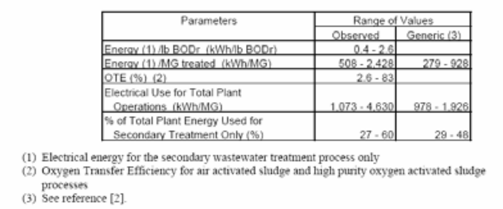


Figure 1. Average Percentage of Energy Use by Process in Wastewater Treatment Facilities

Lampman, O'Connor and Santos, 2008

Minimize Energy Use



Parameters	Range of Values	
	Observed	Generic (3)
Energy (1) /lb BODr (kWh/lb BODr)	0.4 - 2.6	
Energy (1) /MG treated (kWh/MG)	508 - 2,428	279 - 928
OTE (%) (2)	2.6 - 83	
Electrical Use for Total Plant Operations (kWh/MG)	1,073 - 4,630	978 - 1,926
% of Total Plant Energy Used for Secondary Treatment Only (%)	27 - 60	29 - 48

(1) Electrical energy for the secondary wastewater treatment process only
(2) Oxygen Transfer Efficiency for air activated sludge and high purity oxygen activated sludge processes
(3) See reference [2].

SBW Consulting, 2002

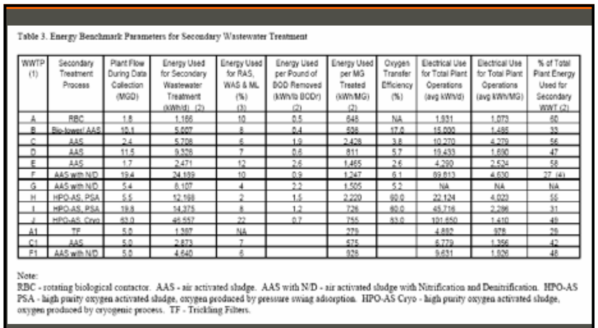


Table 3. Energy Benchmark Parameters for Secondary Wastewater Treatment

WWTP (1)	Secondary Treatment Process	Plant Flow During Data Collection (MGD)	Energy Used for Secondary Wastewater Treatment (kWh/d) (2)	Energy Used for RAS, WAS & ML (%) (3)	Energy Used per Pound of BOD Removed (kWh/lb BODr) (2)	Energy Used per MG Treated (kWh/MG) (2)	Oxygen Transfer Efficiency (%)	Electrical Use for Total Plant Operations (avg kWh/d)	Electrical Use for Total Plant Operations (avg kWh/MG)	% of Total Plant Energy Used for Secondary WWT (2)
A	RBC	1.8	1,166	10	0.5	648	NA	1,931	1,073	60
B	Bio-tower/ AAS	10.1	5,007	8	0.4	508	17.0	15,000	1,486	33
C	AAS	2.4	5,708	6	1.9	2,428	3.8	10,270	4,279	56
D	AAS	11.5	9,328	7	0.6	811	5.7	19,433	1,690	47
E	AAS	1.7	2,471	12	2.6	1,465	2.6	4,290	2,524	58
F	AAS with N/D	19.4	24,189	10	0.9	1,247	6.1	89,813	4,630	27 (4)
G	AAS with N/D	5.4	8,107	4	2.2	1,505	5.2	NA	NA	NA
H	HPO-AS, PSA	5.5	12,198	2	1.5	2,220	60.0	22,124	4,023	55
I	HPO-AS, PSA	19.8	14,375	8	1.2	726	60.0	45,716	2,286	31
J	HPO-AS, Cryo	63.0	46,557	22	0.7	755	83.0	101,650	1,410	49
A1	TF	5.0	1,387	NA		279		4,882	978	29
C1	AAS	5.0	2,873	7		575		6,779	1,356	42
F1	AAS with N/D	5.0	4,640	6		928		9,631	1,926	48

Note:
RBC - rotating biological contactor. AAS - air activated sludge. AAS with N/D - air activated sludge with Nitrification and Denitrification. HPO-AS PSA - high purity oxygen activated sludge, oxygen produced by pressure swing adsorption. HPO-AS Cryo - high purity oxygen activated sludge, oxygen produced by cryogenic process. TF - Trickling Filters.

SBW Consulting, 2002

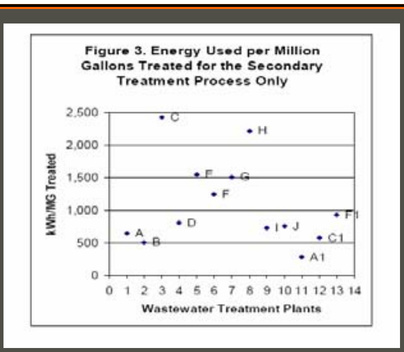


Figure 3. Energy Used per Million Gallons Treated for the Secondary Treatment Process Only

SBW Consulting, 2002

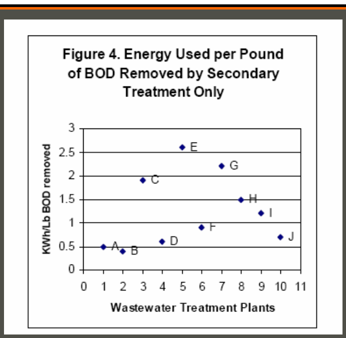


Figure 4. Energy Used per Pound of BOD Removed by Secondary Treatment Only

SBW Consulting, 2002

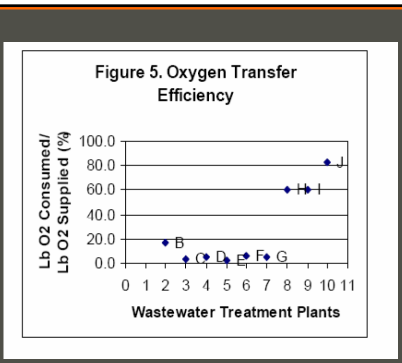


Figure 5. Oxygen Transfer Efficiency

SBW Consulting, 2002

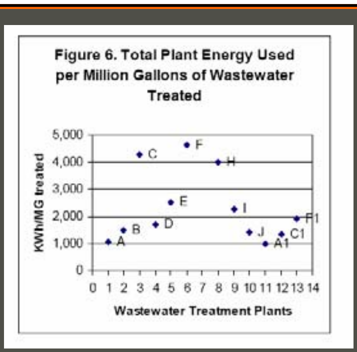


Figure 6. Total Plant Energy Used per Million Gallons of Wastewater Treated

SBW Consulting, 2002

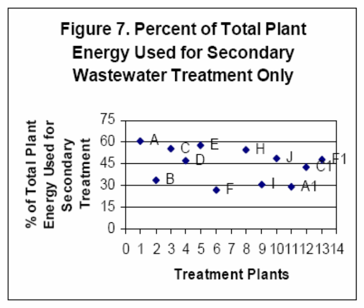


Figure 7. Percent of Total Plant Energy Used for Secondary Wastewater Treatment Only

Table 1. Average Electricity Consumption per Million Gallons Treated for New York State Municipal Wastewater Treatment Facilities

Million Gallons per Day (MGD)	Average kWh/MG	% Statewide Capacity Capacity	% Statewide Energy Use*
<1	4,620	3.8	11.0
1 to <5	1,580	7.5	8.5
5 to <20	1,740	13.1	14
20 to <75	1,700	23.8	26.8
<75	1,100	51.8	39.7
Statewide	1,480	100	n/a

*kWh/MG = kilowatt-hours per million gallons. Values shown include collection system usage.

Increase of Energy Demand for Treatment (%)

Technology	1 mgd	10 mgd	50 mgd	100 mgd
Conventional	N/A	N/A	N/A	N/A
Conventional + UV	10	20	20	10
Conventional + O_3 .5 log	30	100	110	120
Conventional + O_3 2 log	50	160	170	190
Conventional + MF/UF	60	170	190	190
Conventional + NF/RO	210	700	780	830

LINDA MACPHERSON
Presented to: WateReuse Association
Northern California Chapter Meeting
May 16, 2008

Energy Efficiency

- Optimize aeration
- Increase size
- Improve dewatering
- Technologies: Variable frequency drives, high efficiency motors, high efficiency HVAC
- Manage lighting

Energy Production

Table 6—Energy available from pollutants contained in wastewater in W/person.[1]

	Garbage grinders	
Fraction of wastewater constituents included in calculation	Without[2]	With[3]
Biodegradable chemical oxygen demand (COD)[4]	17.4	21.8
Biodegradable COD[4] + total Kjeldahl nitrogen (TKN)[5]	27.4	31.1
Total COD[6]	25.5	31.9
Total COD[6] + TKN[5]	35.5	41.9

[1] Based on 0.145 (W-d)/g oxygen demand converted to energy. Computed from methane equivalent of COD (0.35 m^3/g COD) using methane energy equivalent of 35 800 kJ/m^3 and recognizing that 1 J = 1 (W-sec).
[2] 80 g 5-day biochemical oxygen demand (BOD$_5$)/(person-d).
[3] 100 g BOD$_5$/(person-d).
[4] 1.5 g biodegradable COD/g BOD$_5$.
[5] 15 g TKN/(person-d), 4.6 g O_2/g TKN.
[6] 2.2 g COD/g BOD$_5$.

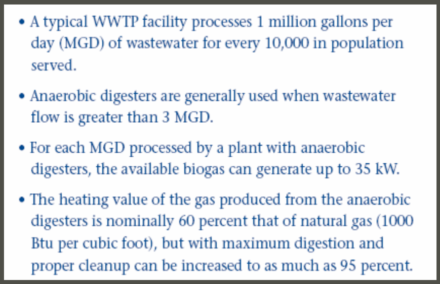
Daigger, WER, 2009

0.4-0.8 kWh/person-d

Table 7—Energy recovery options.

Option	Feedstock	Constraints
Anaerobic treatment		
Direct	Biodegradable organic matter	• Organic matter conversion efficiency • Loss of methane in treated effluent resulting from solubility • Hydrolysis of particulate organic matter • Conversion of biogas to energy
Sludge	Settleable biodegradable organic matter in wastewater plus biodegradable fraction of biomass produced in downstream biological treatment	• Organic matter conversion efficiency • Hydrolysis of particulate organic matter • Conversion of biogas to energy
Sludge (staged, pre-treated)	Settleable biodegradable organic matter in wastewater plus biomass produced in downstream biological treatment	• Organic matter conversion efficiency • Conversion of biogas to energy
Thermal	Particulate organic matter in wastewater plus biomass produced in downstream biological treatment	• Proportion of water that must be evaporated compared with organic matter, which can be combusted • Efficiency of use of thermal energy
Combined thermal/ biological	Particulate organic matter in wastewater plus biomass produced in downstream biological treatment	• Constraints of thermal and biological systems applied
Microbial fuel cells	Biodegradable organic matter (current application and nitrogen (future potential)	• Hydrolysis of particulate organic matter and nitrogen • Efficiency of conversion of liberated electrons to useful energy

Daigger, WER, 2009



- A typical WWTP facility processes 1 million gallons per day (MGD) of wastewater for every 10,000 in population served.
- Anaerobic digesters are generally used when wastewater flow is greater than 3 MGD.
- For each MGD processed by a plant with anaerobic digesters, the available biogas can generate up to 35 kW.
- The heating value of the gas produced from the anaerobic digesters is nominally 60 percent that of natural gas (1000 Btu per cubic foot), but with maximum digestion and proper cleanup can be increased to as much as 95 percent.

www.eere.energy.gov/femp

Microbial Fuel Cells

- High efficiency
- H2 production at anode
- Low power production

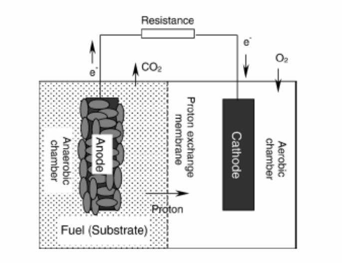


Fig. 1. Schematic diagram of a typical two-chamber microbial fuel cell.

Solar Energy

ODOT Solar Facility

112,000 KWh
16 ft x 540 ft
$50/watt installed
34,000 sq ft/MG

Biofuels from algae

Much more complicated than first considerations

Algal capture of sunlight is not efficient

Algae need to be metabolically limited

Ponds need to be shallow and covered

High cost of biodiesel results from high cost of ponds, processing of algae

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Water Reuse

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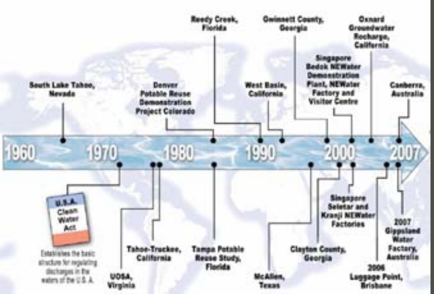
Presented to: WateReuse Association
Northern California Chapter Meeting
May 16, 2008



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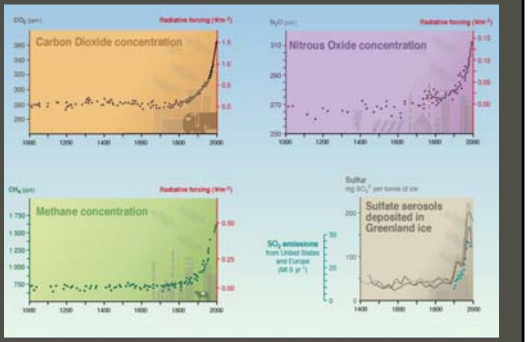
Reduction of GHGs

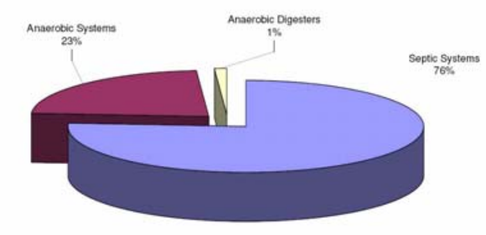


U.S. Wastewater GHG Emissions (2004)

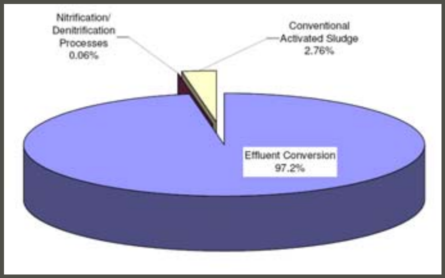
- 52.9 $TgCO_2e$ total
  - 36.9 $TgCO_2e$ CH_4 (6th largest source of CH_4)
  - 16.0 $TgCO_2e$ N_2O (5th largest source of N_2O)
- Emissions from wastewater have increased 40% since 1990
- <1% of total U.S. GHG emissions (7,074.4 $TgCO_2e$)
  - 27% of GHG emissions from Waste sector (Landfills largest waste source)

Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-20

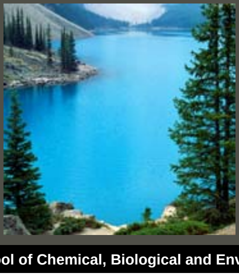
U.S. Wastewater Treatment Plant CH4 Emission Sources



U.S. Wastewater Treatment Plant N2O Emission Sources

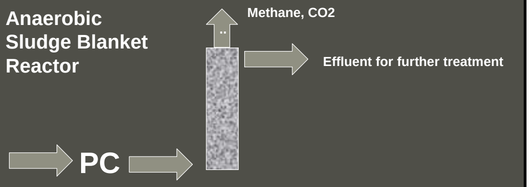


What would a sustainable WWT look like that maximized effluent . quality?




New Technologies and **NEW THINKING**
are Needed for Sustainable Water Supplies
Linda Macpherson April 21, 2009
National League of Cities Green Cities Conference

What would a sustainable WWT look like to minimize energy consumption and maximize production?



Anaerobic Sludge Blanket Reactor

Methane, CO2

Effluent for further treatment

PC

See publications of Lettinga

- Use BOD to make methane
- Large solar panels
- Reduce aeration
- Reduce sludge age
- Do not nitrify if possible
- If nitrification is required, then denitrify

What would a sustainable WWT look like to maximize water reuse?

Water Types

- Wastewater
- Primary Treated Water
- Secondary Treated Water
- Reclaimed Water
- Drinking Water
- Purer than Drinking Water

A huge paradigm change: separate wastewater, treat locally

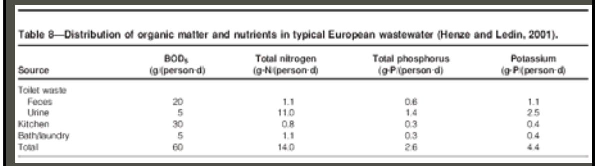


Table 8—Distribution of organic matter and nutrients in typical European wastewater (Henze and Ledin, 2001).

Source	BOD_5 (g/(person·d)	Total nitrogen (g-N/(person·d)	Total phosphorus (g-P/(person·d)	Potassium (g-P/(person·d)
Toilet waste				
Feces	20	1.1	0.6	1.1
Urine	5	11.0	1.4	2.5
Kitchen	30	0.8	0.3	0.4
Bath/laundry	5	1.1	0.3	0.4
Total	60	14.0	2.6	4.4

Daigger, WER, 2009

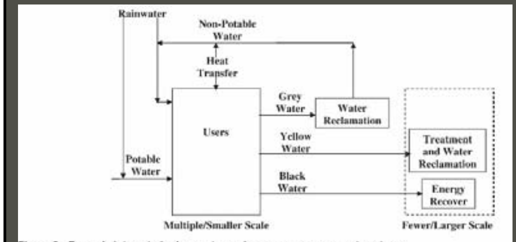


Figure 6—Example integrated urban water and resource management system.

Daigger, WER, 2009

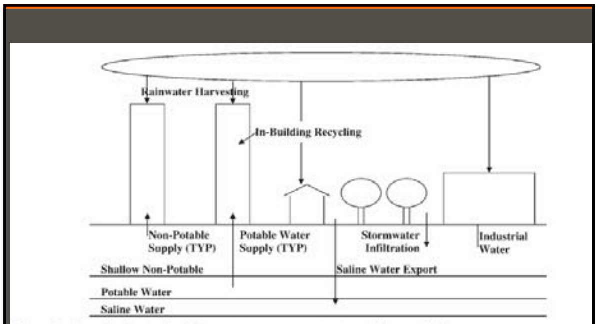


Figure 5—Example decentralized urban water management system (Daigger, 2008).

Daigger, WER, 2009

What would a sustainable WWT look like to minimize GHG emissions?

Listen to Ruffier's talk this afternoon.

WWT appears to not be a major contributor to GHG emissions

Need greater understanding of N_20 production in nitrification

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The Sustainable Plant

1. **Reduce water use, increase organic inputs if possible, use anaerobic methane generation after primary clarifier if organic concentration if high enough.**

2. **AS with nitrification and denitrification plus biological phosphorus removal.**

3. **Anaerobic digestion with land disposal, composting if possible, strict source controls of toxics and metals.**

4. **Further additions of sand filters, MF, NF, and RO to fill water reuse opportunities.**

Meeting the Triple Bottom Line

Economy

Environment

Social