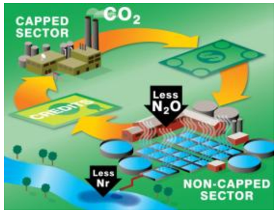
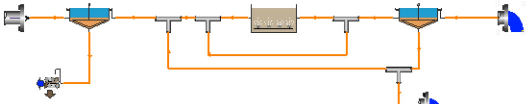
DECENTRALIZED WASTEWATER TREATMENT AND WATER REUSE

Kartik Chandran

Columbia University





Mainstreaming Citywide Sanitation:

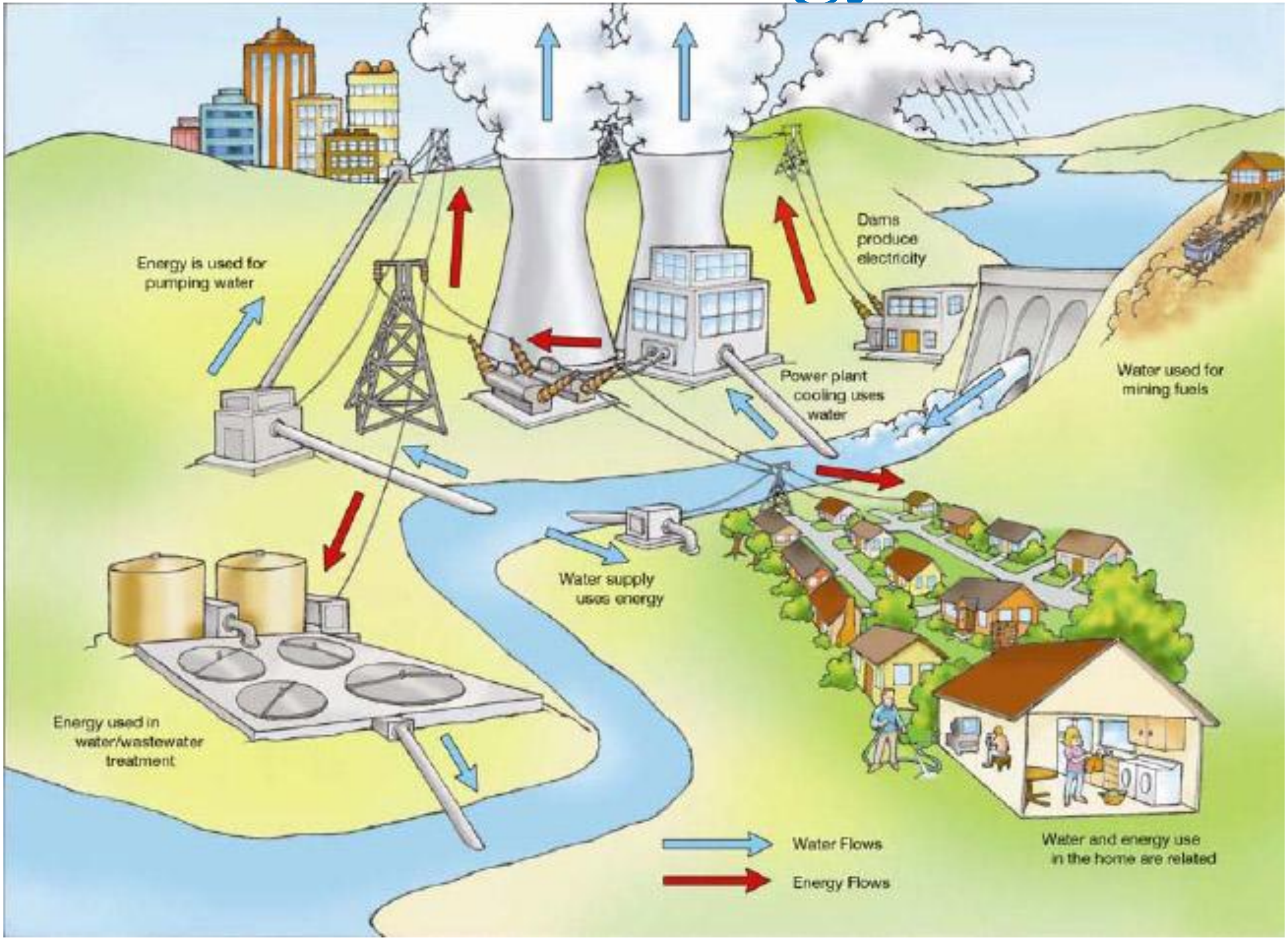
CSE, New Delhi, April 5th, 2016

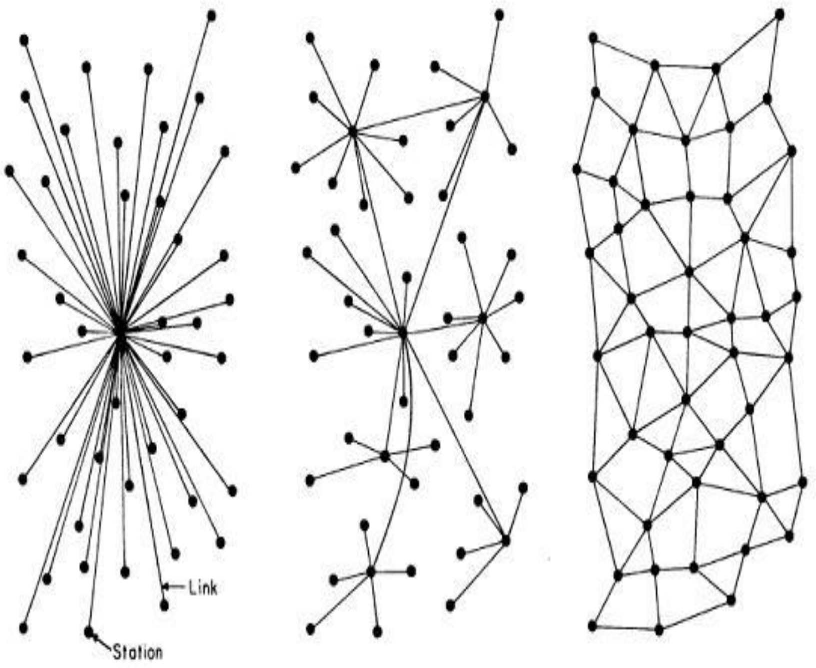
The water cycle today

Photo credit: Blacksmith Institute

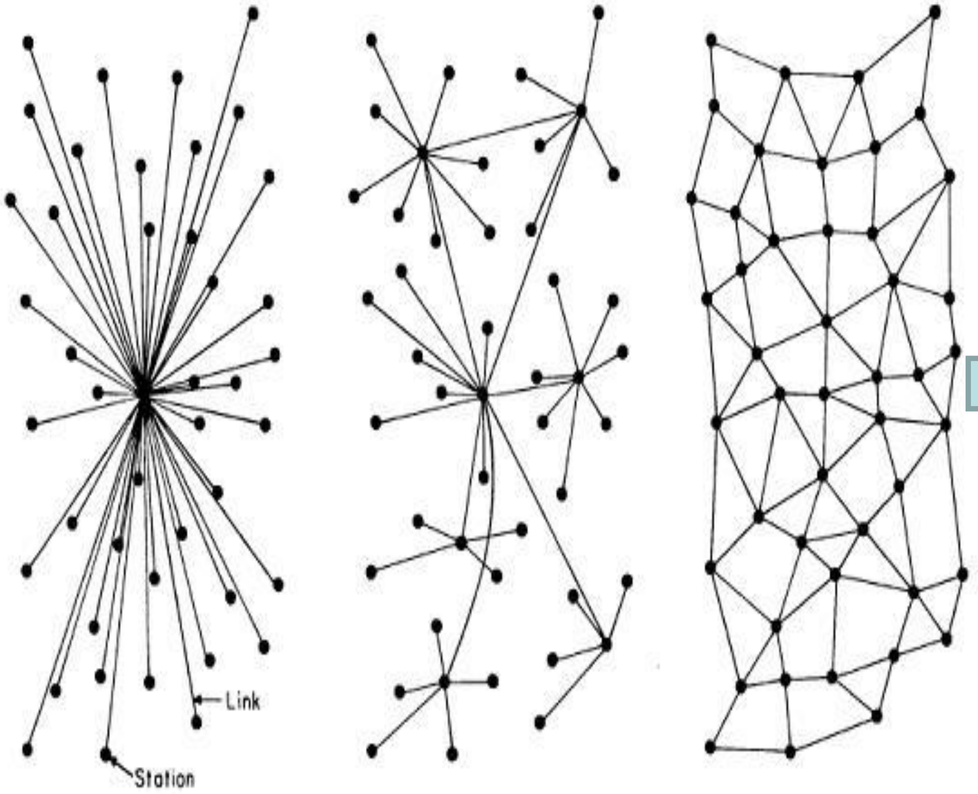
Photo credit: Blacksmith Institute

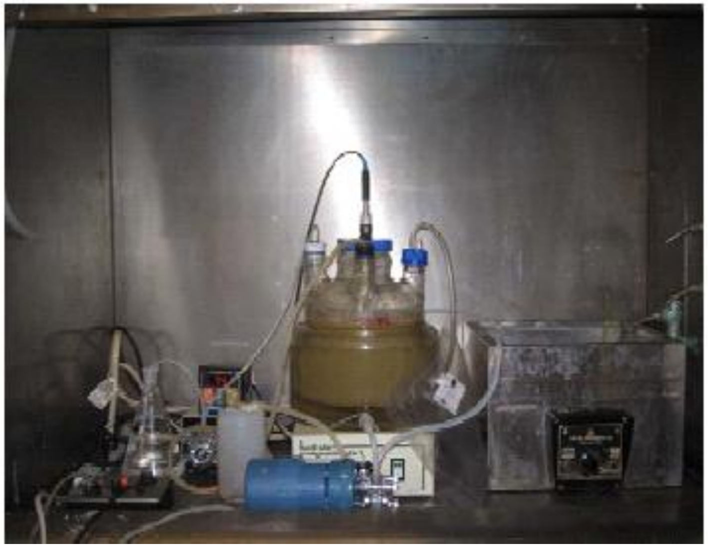
The Water-Energy Nexus





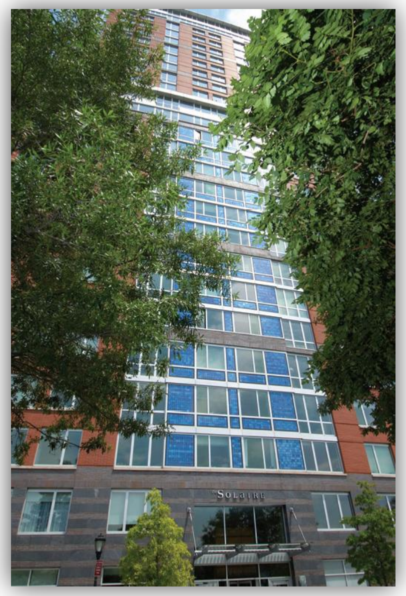
- **Distributed (networked) treatment in NYC**
- **Flow: 1.2 billion gallons per day**
  - 1860 tons of organic carbon per day
  - 280 tons of N(-III) per day
  - 60 tons of P(+V) per day





- Does decentralization truly enhance resilience?
- Is there an optimum (cost, energy?)

Water Reuse Drivers: New Drivers are Emerging



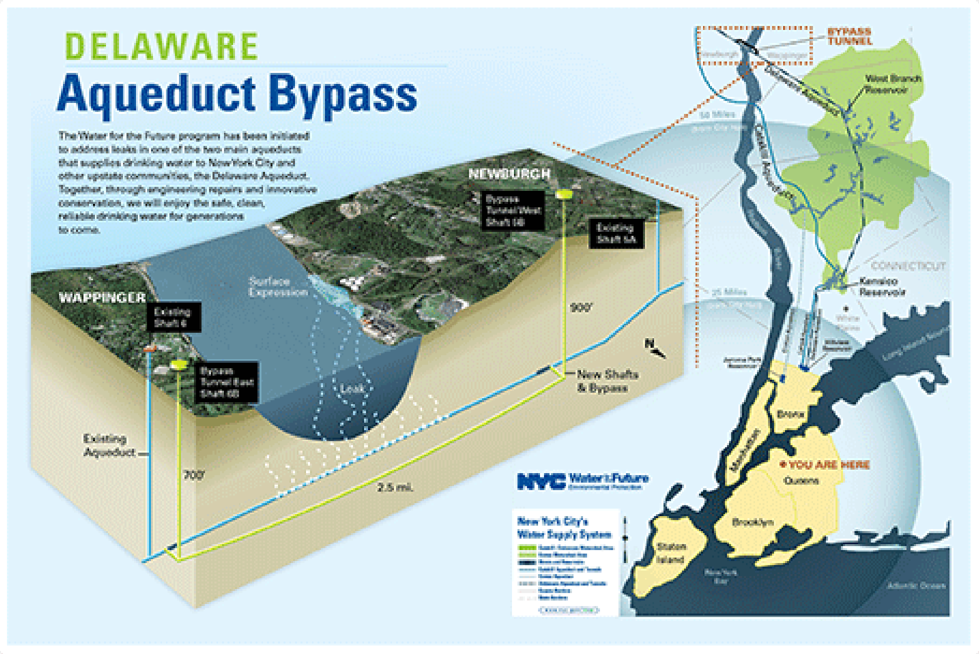
- Demand & Supply: Increasing Population & Inefficient Use
  - >7 billion today, estimated 9 billion by 2050
  - Water use has been increasing at more then twice the rate of population growth over the last century
  - Agriculture accounts for 70% of the total use
- Pollution
  - Possibility to drive overall better environmental water quality??
- Aging Infrastructure & Resiliency
- Increasing Water & Sewer Costs
- Climate variability

Courtesy, Natural Systems Utilities

Aging Infrastructure & Resiliency

- Atlanta, GA – WXIA11 reports on January 9th that multiple water main breaks turn streets into sheets of ice – forcing traffic closures.
- Indianapolis, IN – Fox59 reports on January 9th that eight water main breaks occurred over the course of just a few days.
- Louisville, KY – WLKY32 reports on January 9th that an 8” water main break forces the closure of a major intersection.
- Washington, DC – ABC7 reports on January 14th that a 6” water main burst disrupted water service to 40 homes.

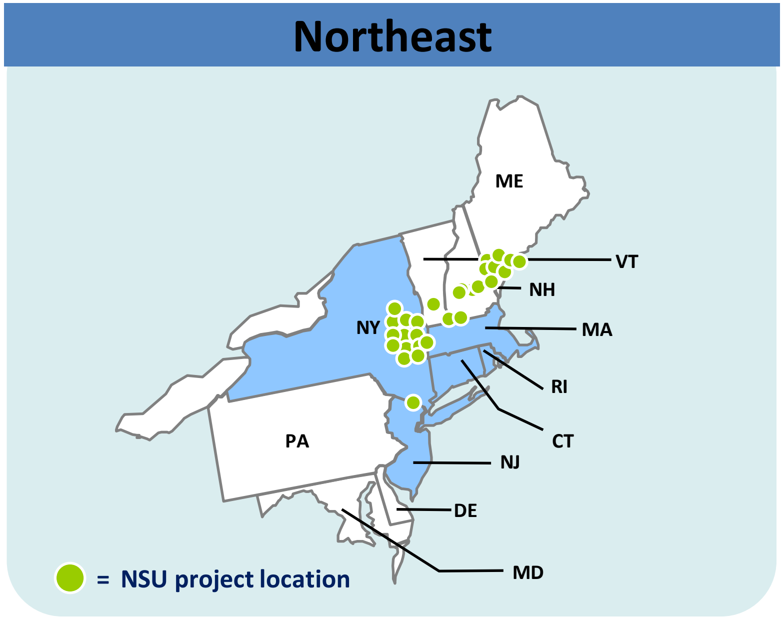
- **Onsite water reclamation and reuse could address multiple challenges with environmental water quality and resilient water supply (of a given quality)**



Courtesy, Natural Systems Utilities

Centralized & Decentralized, Resiliency:

Lessons learned from Super-Storm Sandy



- >160 systems in US across 9 states
  - Manage one of the largest bases of distributed wetland & water reuse treatment systems in the U.S.
- >90 systems currently in the Northeast
- Annually treat over 2.6 billion gallons of water in the Northeast region
- ~10-15% <u>Direct Water Reuse</u>
- ~80% <u>Indirect Reuse</u> (Groundwater Dispersal)

Water Treatment Facility

End User

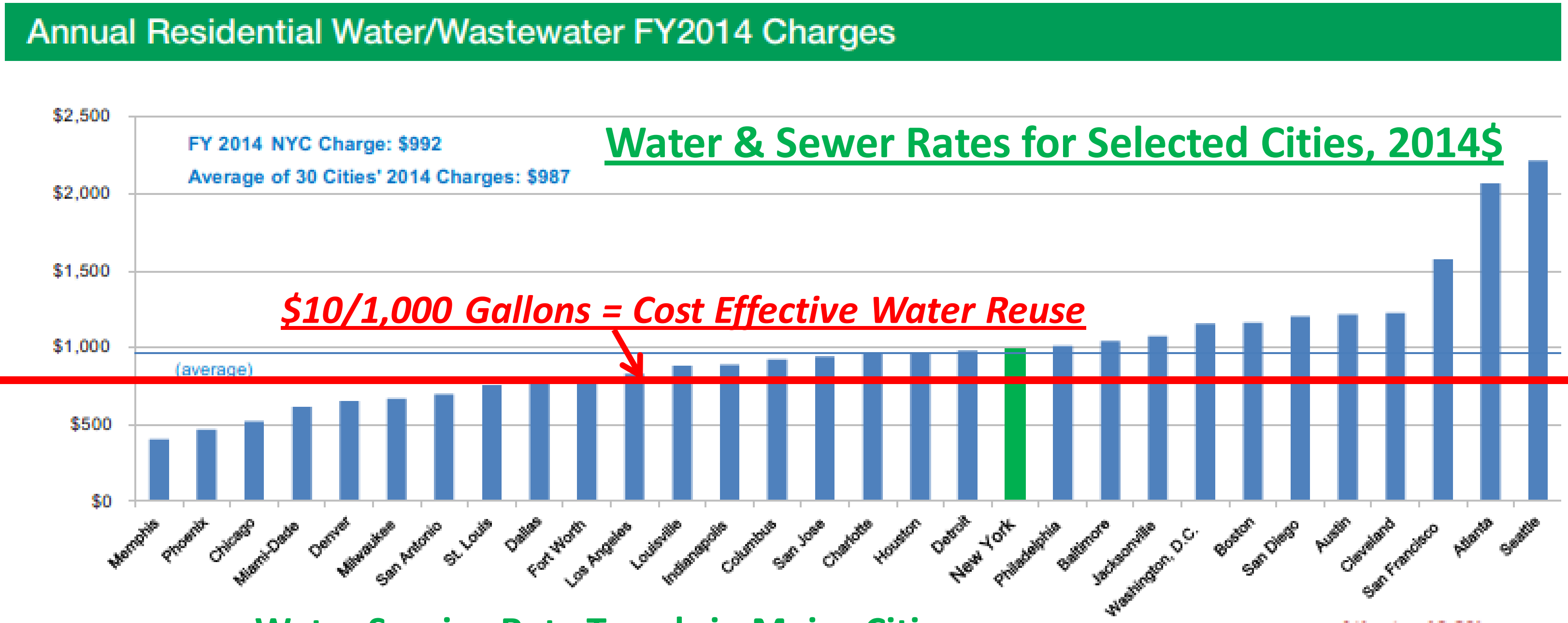
~5-10+ miles

Wastewater

Reclaimed Water

Courtesy, Natural Systems Utilities

The Emerging Water Reuse Business Case

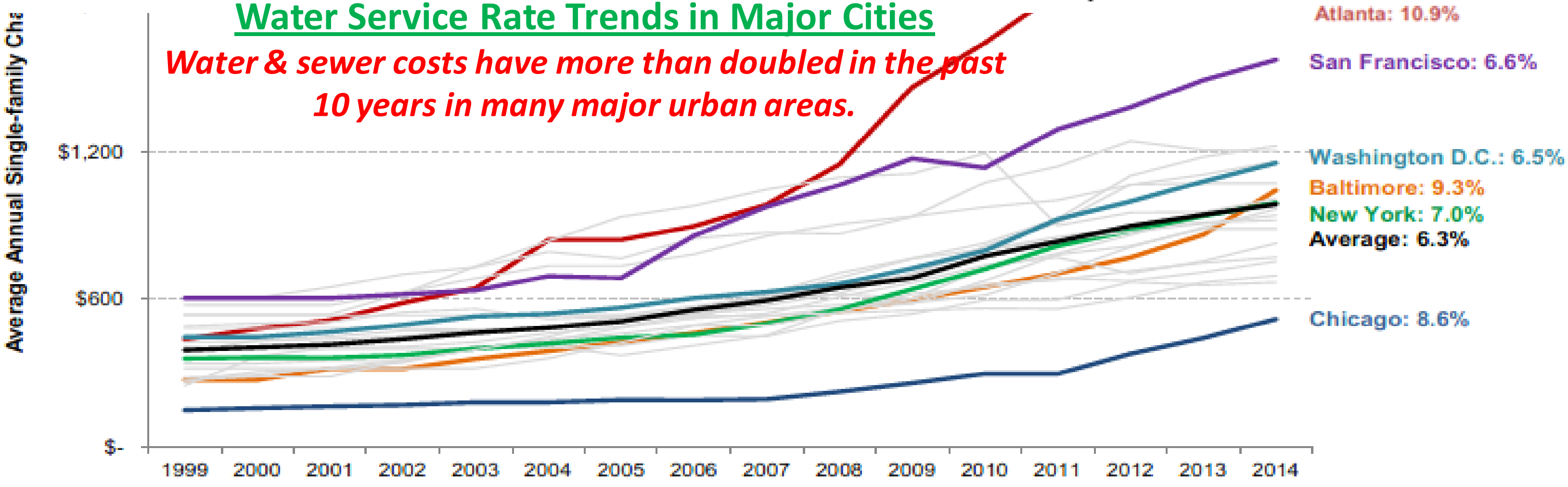


Water & Sewer Rates for Selected Cities, 2014$

$10/1,000 Gallons = Cost Effective Water Reuse

Other Notable Cities Not Listed which are Above The Line

- Portland
- Kansas City
- Virginia Beach
- Oakland
- Colorado Springs
- Raleigh

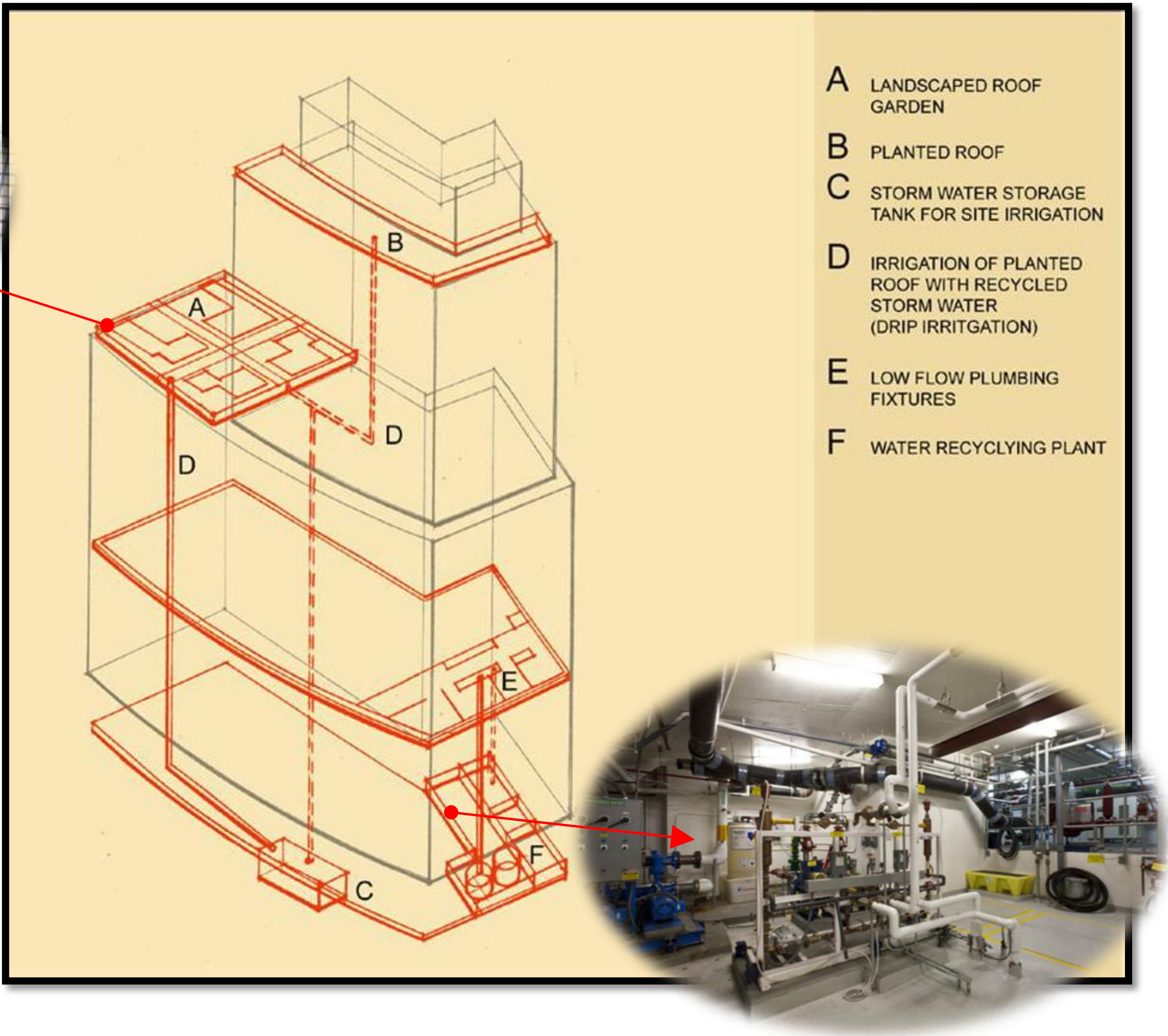


Water Service Rate Trends in Major Cities

Water & sewer costs have more than doubled in the past 10 years in many major urban areas.

Courtesy, Natural Systems Utilities

Integrated Water Resource Management in Urban Communities



Reuse Applications:

- Toilet Flushing
- Cooling Tower Make-Up Water
- Landscape Irrigation
- Laundry

Courtesy, Natural Systems Utilities

Water Reuse Performance Requirements

Parameter	DOB Limit	Membrane Specs
BOD (mg/L)	<10	<2
TSS (mg/L)	<10	<2
Fecal Colliform (CFU/100mL)	<100	<10
Turbidity (NTU)	<2	<0.2
E. Coli Colony Count (#/100mL)	<2.2	N/A
pH	6.5-8.0	N/A

Over 10 years of in-building urban reuse system performance data consistently exceeding permit requirements

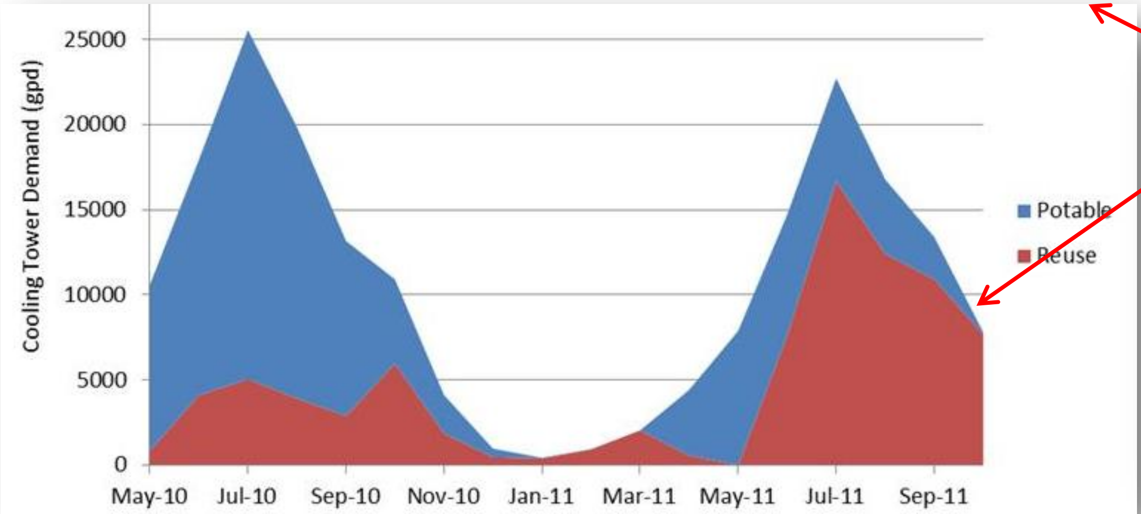
System Location	BOD, mg/l	TSS, mg/l	Turbidity NTU	Fecal Coliform #/100 ml	E. Coli #/ 100 ml
The Solaire (2003)	< 6	< 1	0.05 – 0.25	< 1	—
Millennium Tower Residences	< 6	< 1	0.15 – 0.45	< 1	—
The Visionaire	< 6	< 1	0.15 – 0.45	< 1 (Total coliform)	< 1
The Helena	< 6	< 1	0.05 -0.20	< 1	—

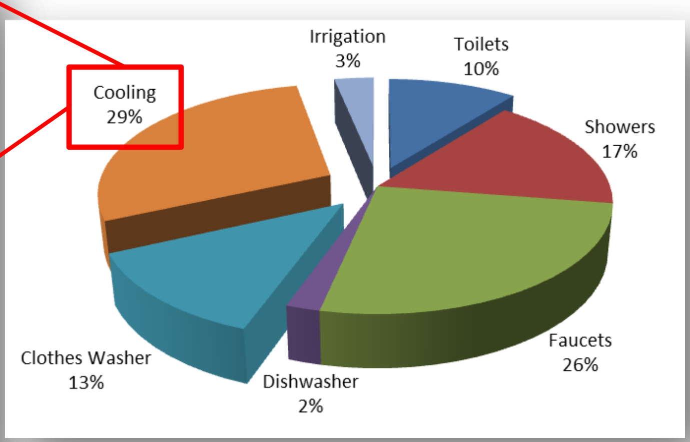
Courtesy, Natural Systems Utilities

Maximize Water Reuse Demand Opportunities

Metric	Cooling Tower Limits	Conc. in Reuse Water	Conc. in City Water	Unit
pH	8.5	7.3	6.9	N/A
Conductivity	5,000	500-650	100	umhos
Ca Hardness	500	40-60	16	ppm
Orthophosphates	10	0.7-1.5	1.7	ppm
Chlorides	200(2)	50-100	12	ppm
Iron	0.2	<0.05	<0.05	ppm
Copper	0.1	0.05-.1	<0.05	ppm
Ammonia	1	<0.10	-	ppm

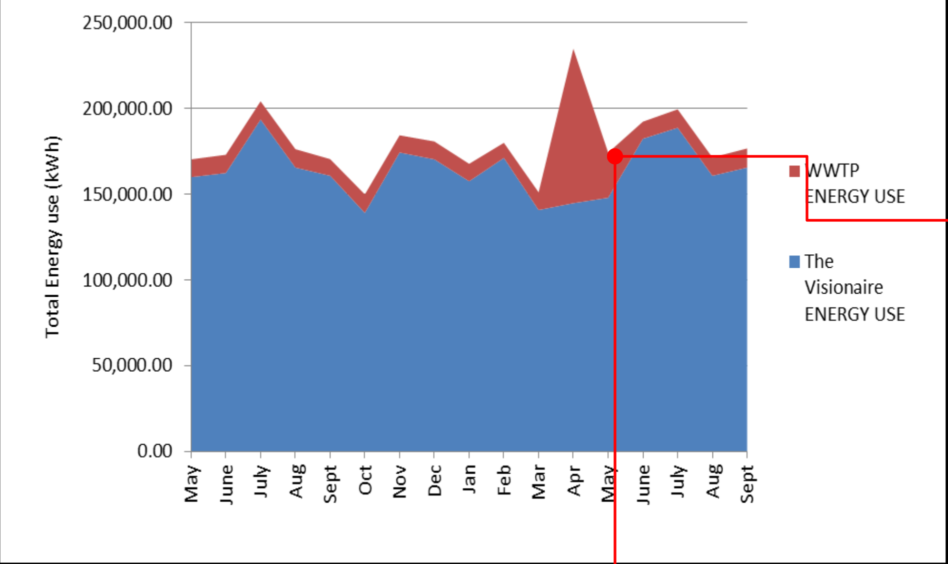
Reclaimed water provided for over 55% of residential demands (commercial and academic >75%).



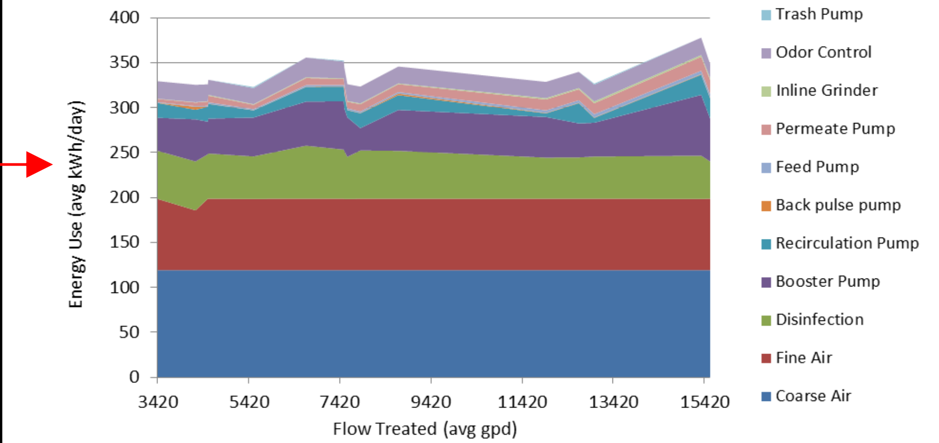


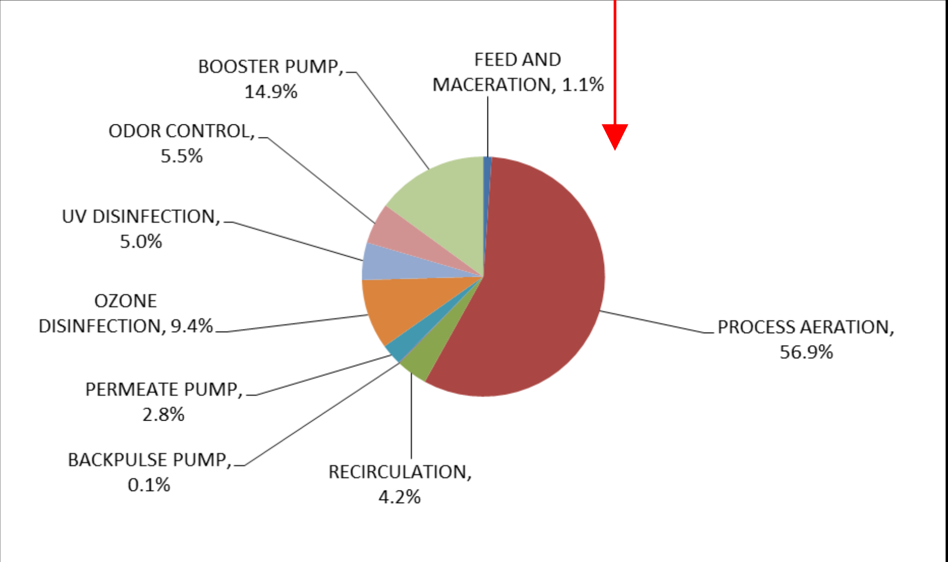
Courtesy, Natural Systems Utilities

Optimize Water Reuse Energy Performance

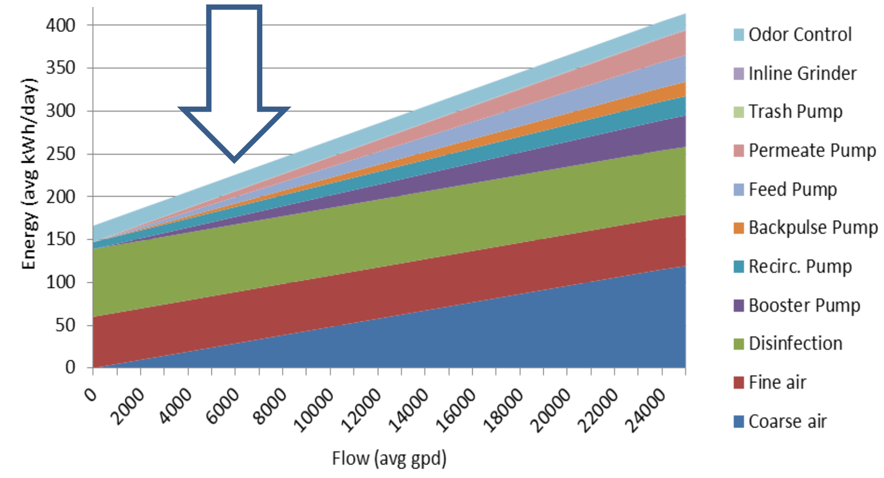


Typical Energy Performance





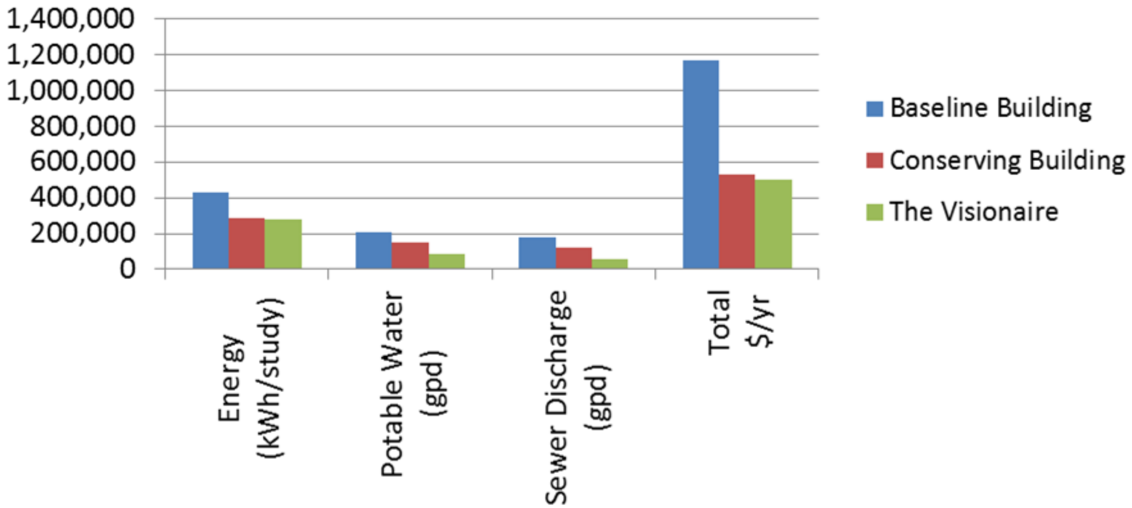
Optimized Energy Performance



Courtesy, Natural Systems Utilities

The Building/Block Scale

- Achieve 55% Water Use Reduction
- Achieve 64% Sewer Discharge Reduction
- 100% Reuse For Cooling Tower Make-up
- Energy Profile Optimization
- 25% Credit on Water & Sewer Bill – CWRP Established 2004
- Simple implementation for single building/owner
- **More cost effective than NYC water & sewer at the block scale**
- **Lower energy use than NYC utility infrastructure at the block scale (prior to energy recovery)**



Courtesy, Natural Systems Utilities

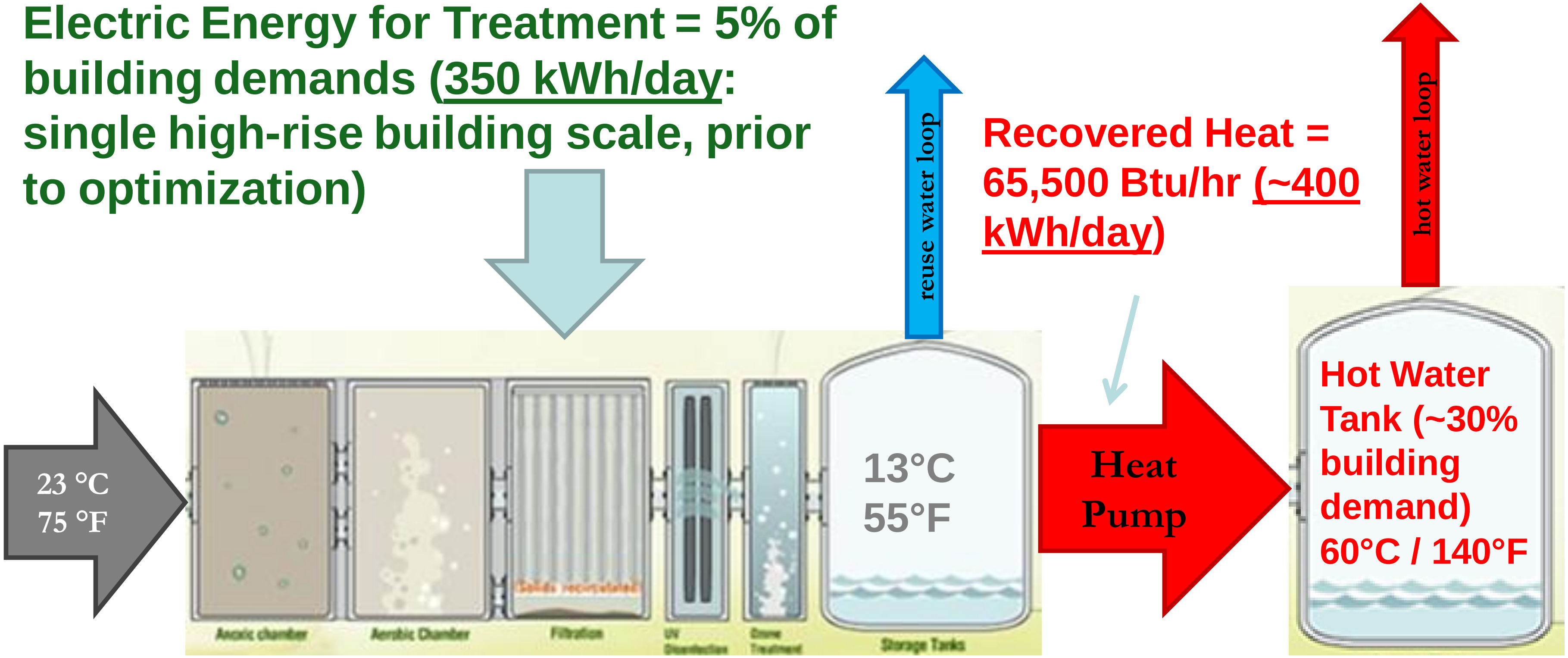
Energy self-sufficiency for sewage treatment?

Energy present	Energy needed
~ 2500 kWh/MG	~2500 kWh/MG

- Assuming 34% conversion of organic matter to methane and electricity
- Assuming ‘conventional’ nitrogen removal
- Can ‘import’ carbon (several water utilities already energy +ve, NYC starting with this)
  - Not at the expense of excessive N discharges

Water / Energy Nexus: Thermal Energy Recovery

Electric Energy for Treatment = 5% of building demands (<u>350 kWh/day</u>: single high-rise building scale, prior to optimization)



23 °C
75 °F

reuse water loop

13°C
55°F

Recovered Heat = 65,500 Btu/hr <u>(~400 kWh/day)</u>

Heat Pump

hot water loop

Hot Water Tank (~30% building demand)
60°C / 140°F

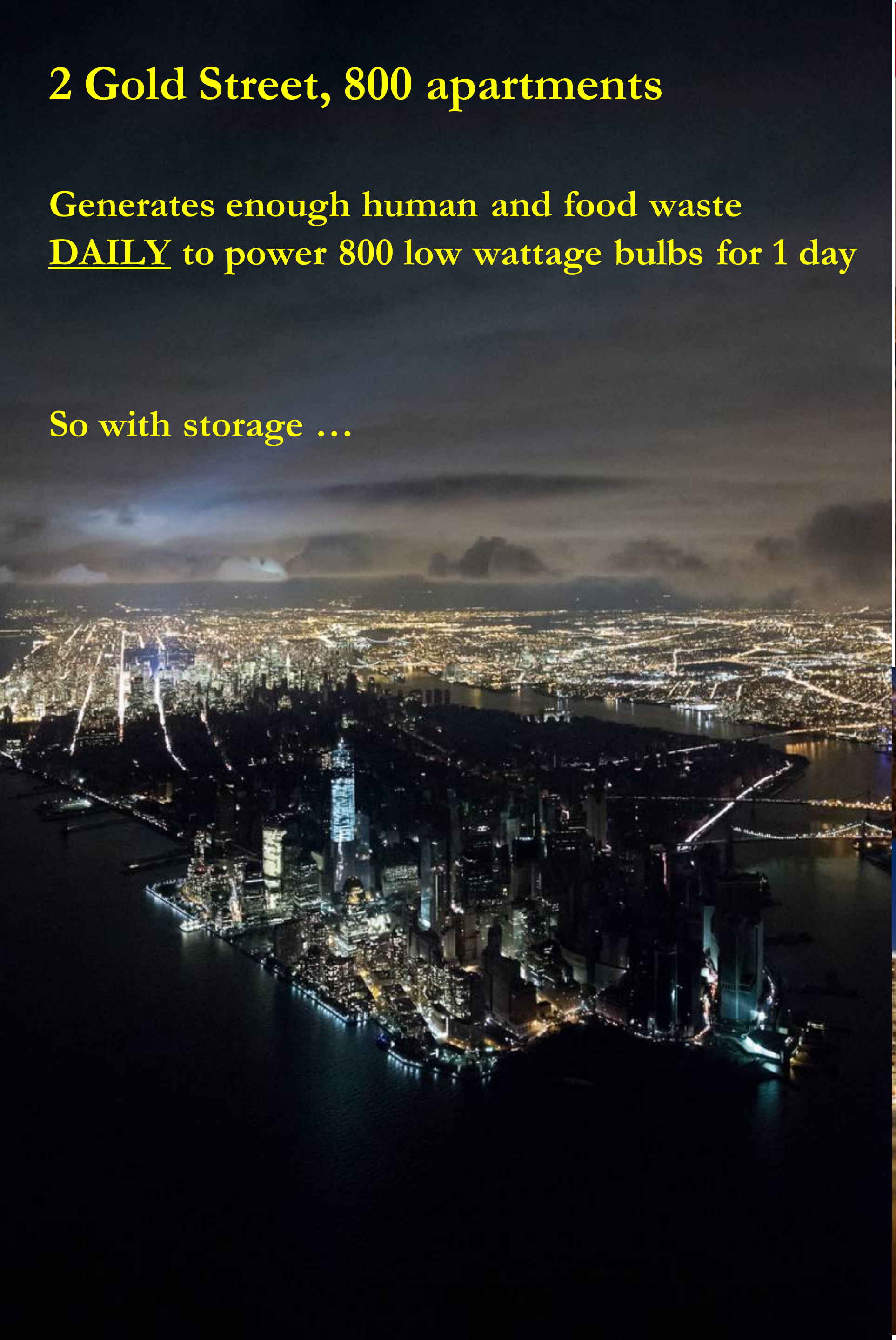
- **Embedded energy in wastewater is greater than 4x the amount of energy used for treatment (43 kwh/kgal).**
- **Water reuse systems can now become <u>net energy neutral</u> and net energy positive at the high-rise building scale or larger with this technology (after accounting for conversion losses)**

Courtesy, Natural Systems Utilities

2 Gold Street, 800 apartments

Generates enough human and food waste **DAILY** to power 800 low wattage bulbs for 1 day

So with storage …



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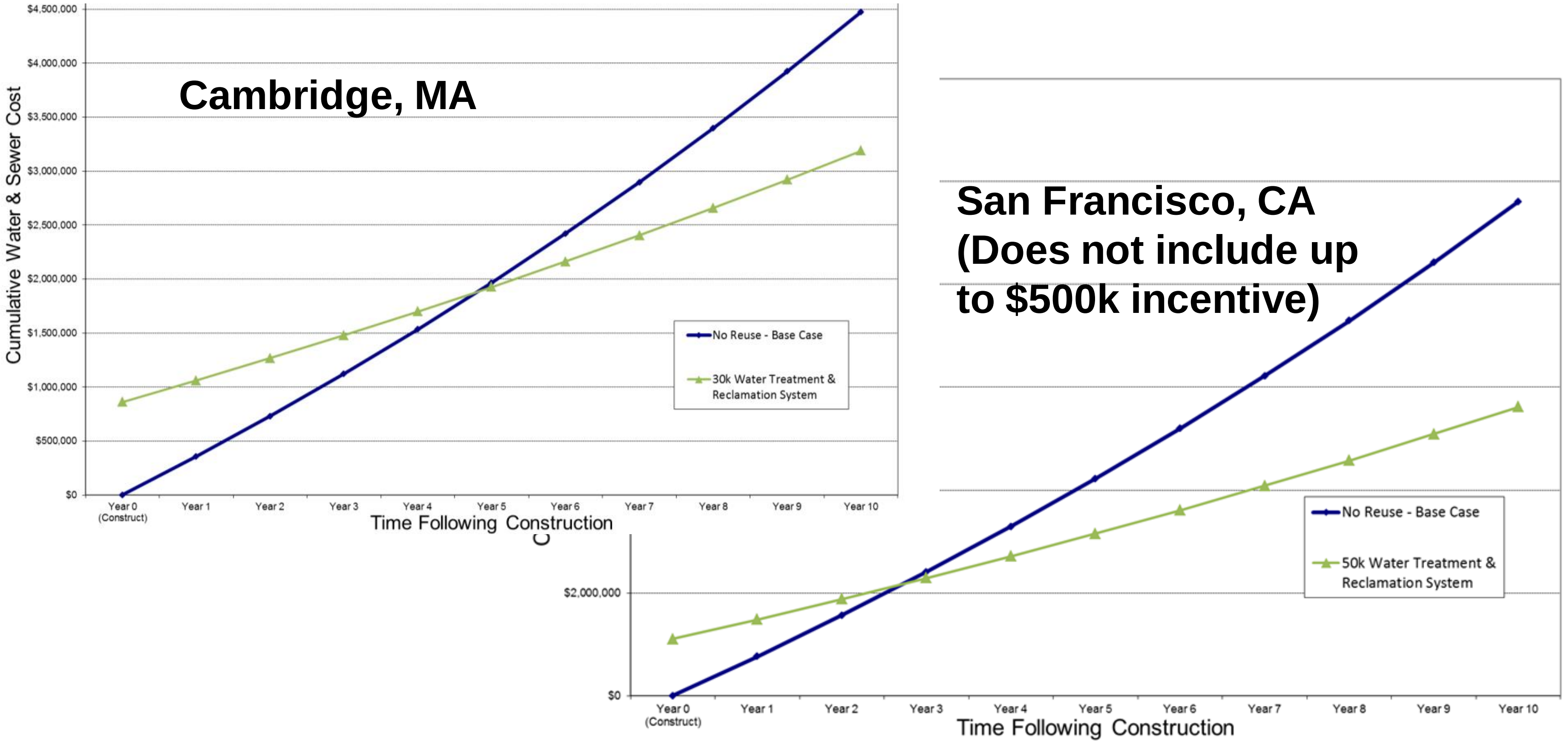
Water Reuse Economics: The Business Case, East to West Coast

New York City

	A	B	C	D = B-C	E = (B/1,000) x A	F = (D/1,000) x A	G = F x -0.25	H = F + G	I = E - H	J	K = I - J
Yr	NYC Water & Sewer Fee (per 1,000 gal)	Total Building Water Use (NYC Supply & Reuse Supply - annual gallons)	Reuse Water Produced (annual gallons)	NYC Water Supply (annual gallons)	Annual Water & Sewer Fee (without reuse)	Annual Water & Sewer Fee (with reuse)	Annual Comprehensive Water Reuse Program (CWRP) Incentive	Annual Water & Sewer Fee (with reuse + CWRP)	Annual Water & Sewer Savings (with reuse)	Annual Reuse System Operating Cost	Annual Net Savings (with reuse)
2015	$12.81	78,475,000	23,725,000	54,750,000	$ 1,005,067.51	$ 701,209.89	$ (175,302.47)	$ 525,907.42	$ 479,160.09	$ 120,000.00	**$ 359,160.09**



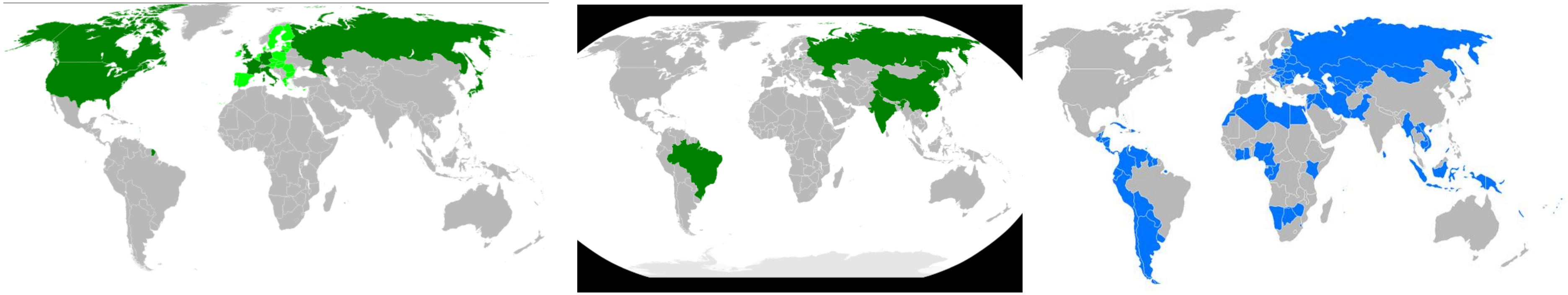
The connection to food

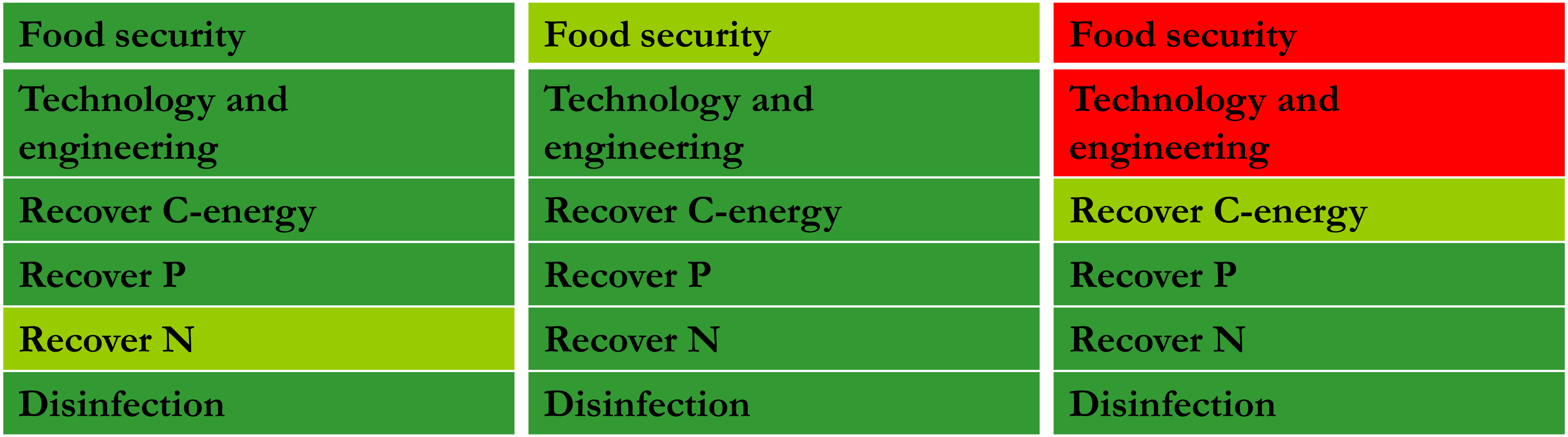
(one example of embedded water-energy-resources)

Need more work prior to DPR an IPR

(Source: WateReuse Association)

Resource recovery application framework





Food security	Food security	Food security
Technology and engineering	Technology and engineering	Technology and engineering
Recover C-energy	Recover C-energy	Recover C-energy
Recover P	Recover P	Recover P
Recover N	Recover N	Recover N
Disinfection	Disinfection	Disinfection

Contact information

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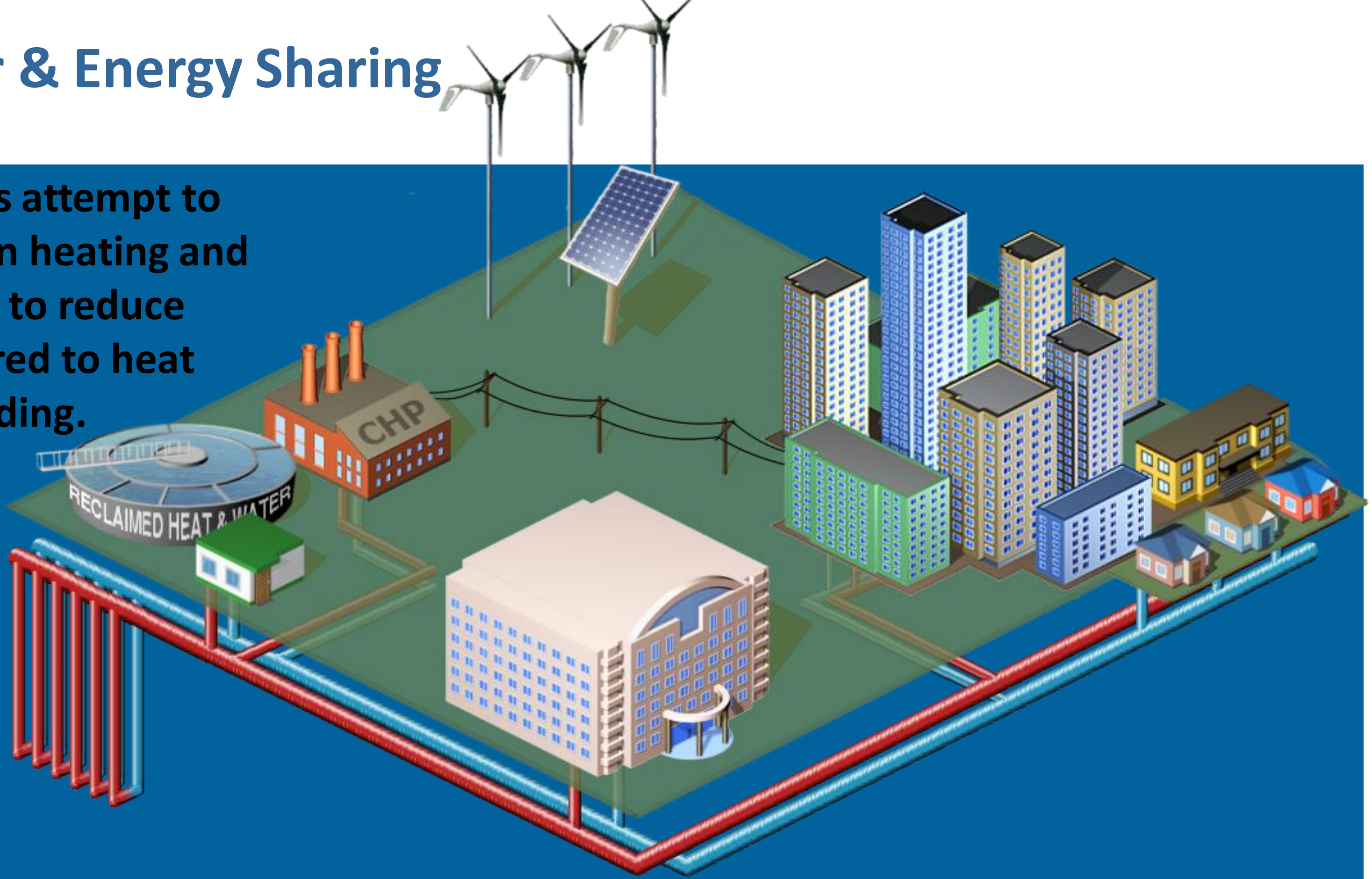
District Water & Energy Sharing

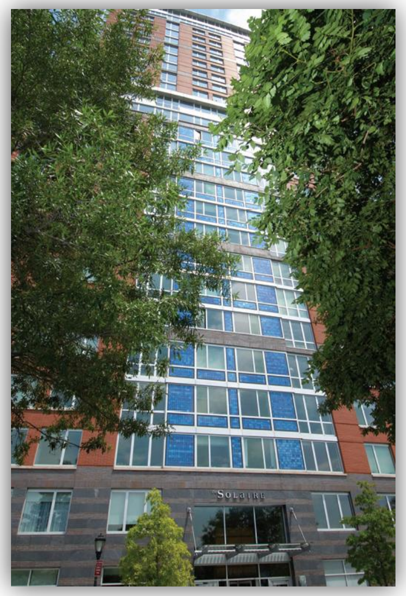
1. Modern buildings attempt to balance their own heating and cooling demands to reduce the energy required to heat and cool the building.



2. District Energy and Water Sharing balances the heating and cooling demands of an entire community to reduce the energy and water required to meet the needs.

3. Mixed Use Energy sharing can supply 25% to 35% of the total thermal energy.
4. 25-30% of a buildings energy use is for water heating.
5. Dual purpose pipe for energy transfer and water reclamation.

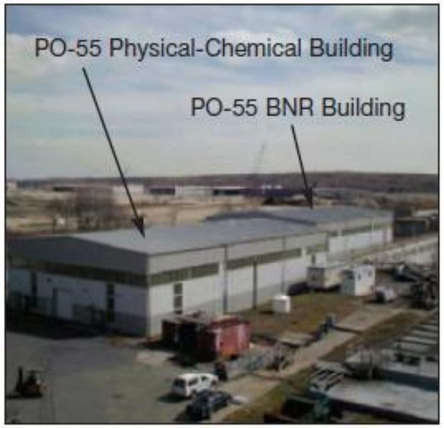
Water Reuse Drivers: New Drivers are Emerging



- **Water/Energy Nexus**
  - Biofuels, electric cars, natural gas and wind power use less oil, however, these alternatives dramatically increase water use
- **Onsite/Distributed Systems**
  - To combat these issues, many communities have opted to provide onsite water resource management systems to help reduce the amount of potable water being used and the amount wastewater entering the receiving environment.

Courtesy, Natural Systems Utilities

Nitrogen Control Applied Research Program

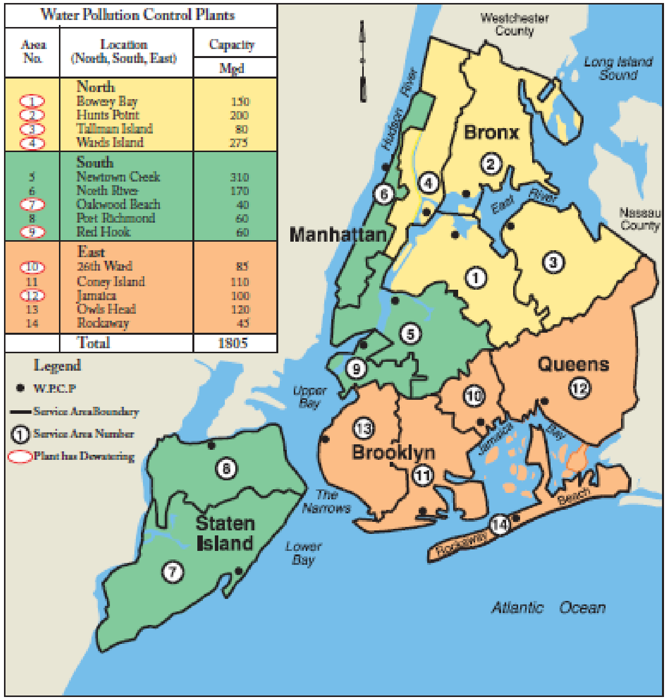


Applied Research Facilities

Interior of Applied Research Facilities

View of Centrate Tank at 26th Ward WPCP

New York City Plant Locations and Capacities



Water Pollution Control Plants

Area No.	Location (North, South, East)	Capacity Mgd
	North	
①	Bowery Bay	150
②	Hunts Point	200
③	Tallman Island	80
④	Wards Island	275
	South	
5	Newtown Creek	310
6	North River	170
⑦	Oakwood Beach	40
8	Port Richmond	60
⑨	Red Hook	60
	East	
⑩	26th Ward	85
11	Coney Island	110
⑫	Jamaica	100
13	Owls Head	120
14	Rockaway	45
	Total	1805

Legend

- ● W.P.C.P
- — Service Area Boundary
- ① Service Area Number
- ○ Plant has Dewatering

A BETTER WAY TO DENITRIFY WASTEWATER

Call it the case of the missing nitrogen. Forty years ago, wastewater treatment engineers noticed that a common process used to convert ammonia into nitrate sometimes failed to produce as much nitrate as expected. The nitrogen "must have gone somewhere," says Mark van Loosdrecht, an environmental engineer at the Delft University of Technology in the Netherlands. Fermentation engineers determined that the process was producing nitrogen gas, but nobody knew how.

Then, in the early 1990s, microbiologist Gijs Kuenen of Delft University and his colleagues discovered a new microbe in wastewater that helped solve the mystery—and turned existing dogma about ammonia's conversion to nitrogen compounds on its ear. Called anammox (for anaerobic ammonium oxidation), the microbe was converting ammonia into nitrogen gas in the absence of oxygen, a reaction previously thought impossible.

It took several years to convince the skeptics. One problem was that the bacterium—which is in the phylum *Planctomycetes*—grows slowly. It divides every 2 weeks, rather than in just half an hour like some bacteria; that means it can take months and sometimes years to get a culture up and running reliably in the laboratory. Another challenge was that the bacteria had never been found in the wild. Once researchers knew what to look for, however, they found it and its relatives living in many places—in oxygen-poor waters of the Black Sea, Lake Tanganyika, and off the coast of Namibia, for example.

Now, researchers consider anammox bacteria to be essential components of the global nitrogen cycle and estimate that they account for 50% of the world's nitrogen turnover. And they believe the microbes could dramatically improve methods of removing ammonia from wastewater streams at large municipal plants like the Blue Plains treatment facility in Washington, D.C. (see main text). "It's possibly going to be a game-changer in the U.S.," says Kartik Chandran, an environmental engineer at Columbia University.

Harnessing anammox's potential, however, requires a mastery of microbial ecology. The microbe must be grown in conjunction with a second bacterium that converts ammonia to nitrite; anammox converts the nitrite into water and nitrogen gas. But to operate efficiently, the system must also exclude bacteria that make nitrate. That's proven relatively easy in industrial processes that operate at high temperatures and produce relatively warm, ammonia-rich wastewater streams; several companies have already commercialized anammox systems for use in such environments.

But excluding nitrate producers has proved harder in lower-temperature municipal wastewater treatment plants, where the concentration of ammonia can also be low, says van Loosdrecht. Under those conditions, it's been tricky to create a stable anammox community, although a number of plants have installed pilot anammox, also called deammonification, systems.

To solve that problem, van Loosdrecht has been experimenting with very slow-growing anammox microbes. Typically, dividing bacteria form suspended particles called floc. But these slow-growers form a much larger, denser particle called a granule. The larger granules somehow tend to exclude the nitrate-producing bacteria. To take advantage of that characteristic, he's engineering a reactor that retains larger granules but excludes smaller floc; he predicts the reactors will enable treatment plants to "do the same process [with] 25% of the space" used by current systems, and cut energy and other costs by about one-third.

Columbia's Chandran, who once isolated a strain of anammox bacteria from a Brooklyn, New York, treatment plant and now has it happily growing in his lab, is also perfecting ways to keep the microbe happy and healthy in wastewater treatment plants. Since 2010, treatment plants developing anammox systems have been sending him samples weekly, or more often if they suspect problems. Drawing on findings from his research, he tests the health of a plant's anammox community by sequencing the DNA that covers the microbes' 16S ribosomal subunits. Each type of microbe has a unique 16S fingerprint, and he can tell what kind and how many anammox organisms are present by the number of copies of the 16S genes. His team also looks at the expression of the microbe's key ammonia-fixing genes by monitoring messenger RNA. If Chandran sees 16S numbers and gene activity dropping, he knows the system needs tweaking—there might be too much oxygen, for example. If gene activity is dropping, but the population is stable, it's likely to be a transient phenomenon that should right itself, he says.

Such efforts are nudging deammonification into more widespread use. "There's no scientific limitation," van Loosdrecht says. "It's purely an engineering question."

—E.P.

Going red. With this cone, engineers gauge the density of the clumps of red anammox bacteria (inset), a new way to denitrify wastewater.