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FOR THE ENVIRONMENT
STANFORD UNIVERSITY

Wastewater as a Resource

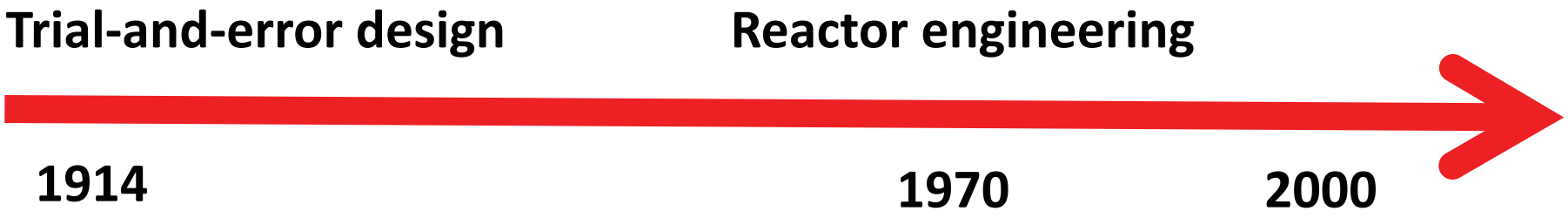
Craig Criddle

Senior Fellow, Woods Institute
Professor, Department of Civil and Environmental Engineering

By the year 2000, there were more than 15,000 bioreactors treating wastewater in the US alone

Their function: removal of organics and nutrients

toxic substances



Life before 2000

- **Linear markets**
- **Cheap energy**
- **Climate change not on the radar**

Why things must change now

- Increased water scarcity
- Energy more expensive
- Climate change increasingly urgent
- Increased need for nitrogen removal
- infrastructure has reached design life
- New contaminants
- New science, new tools, & new opportunities for innovation

Woods Initiated Projects on Water

Microbial ecology of nitrogen removal from wastewater

Chris Francis

Nitrogen Removal with Catalytic Converter

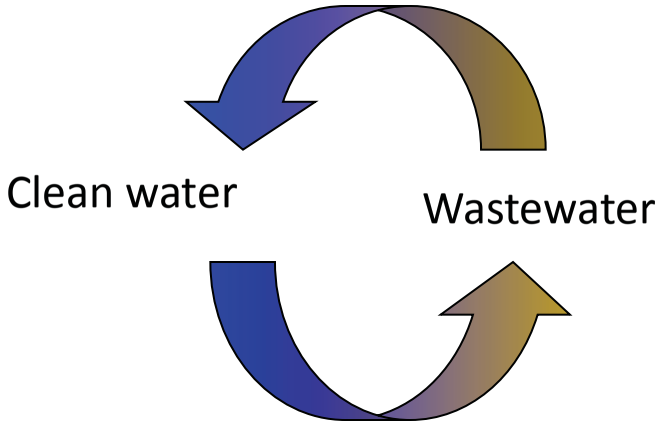
Brian Cantwell

Economics of Resource Recovery from Wastewater

Frank Wolak

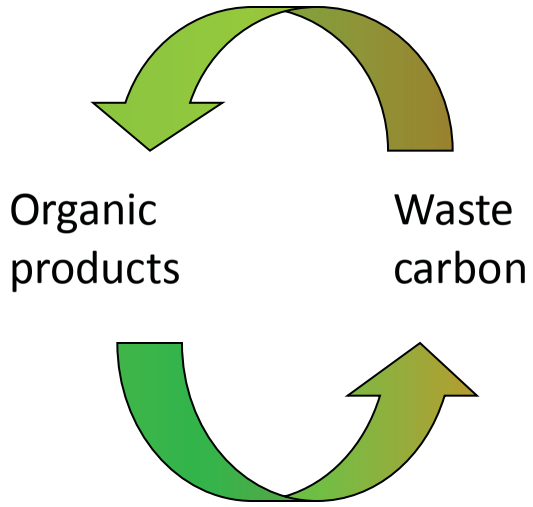
Wastewater Resource Recovery Team

Products in wastewater



Components of wastewater:

- Water (99.9%)
- Biodegradable organics
- Nutrients (N and P)



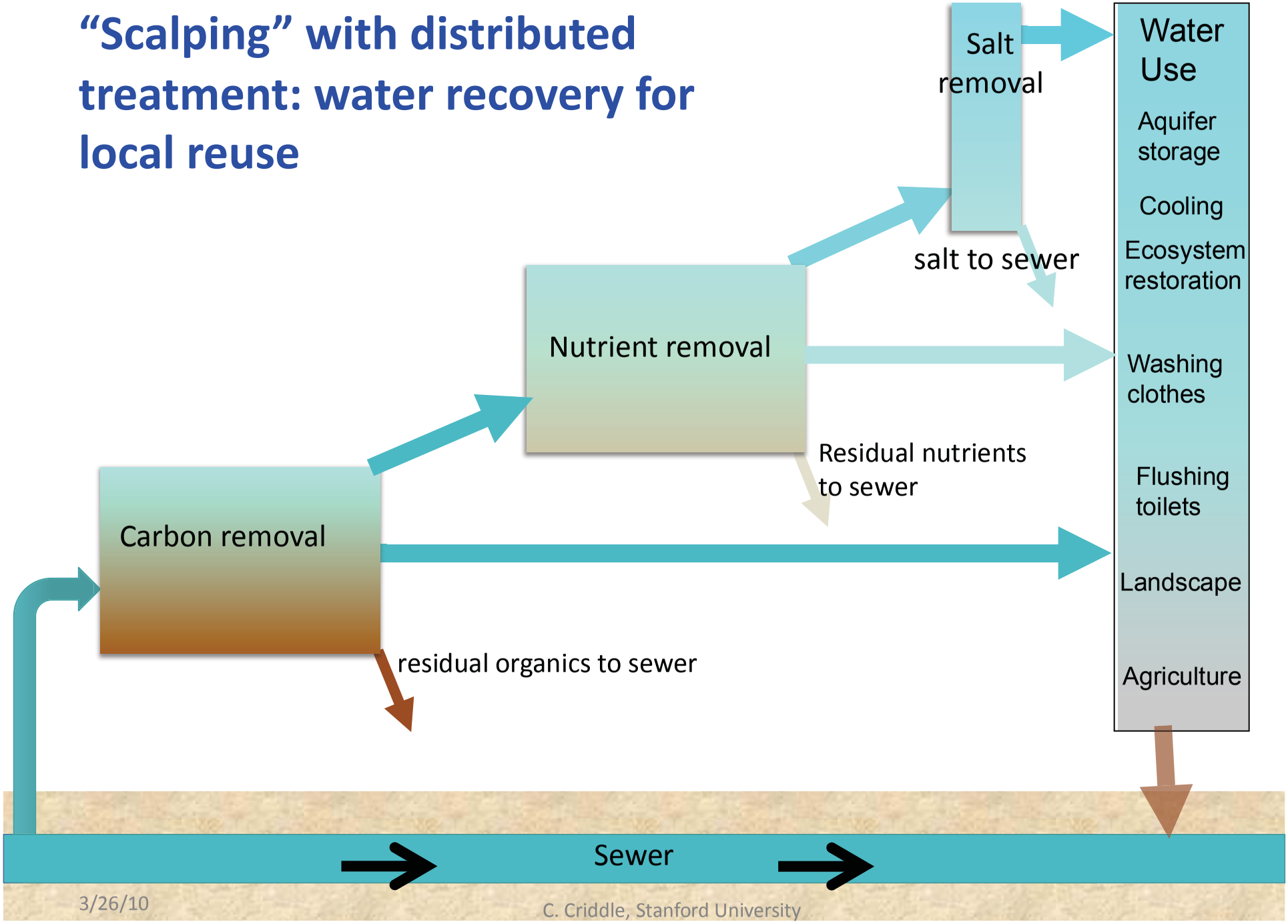
- Pathogens
- Salt
- Refractory organics

The value of the resource

Resource	Per m^3	US $ per m^3	US $ per 1000 gal
Organic soil conditioner	0.10 kg	0.026	0.10
Methane	0.14 m^3	0.065	0.25
Nitrogen	0.05 kg	0.065	0.25
Phosphorus	0.01 kg	0.013	0.05
Water	1 m^3	0.325	1.20

From Willy Verstraete (2008)

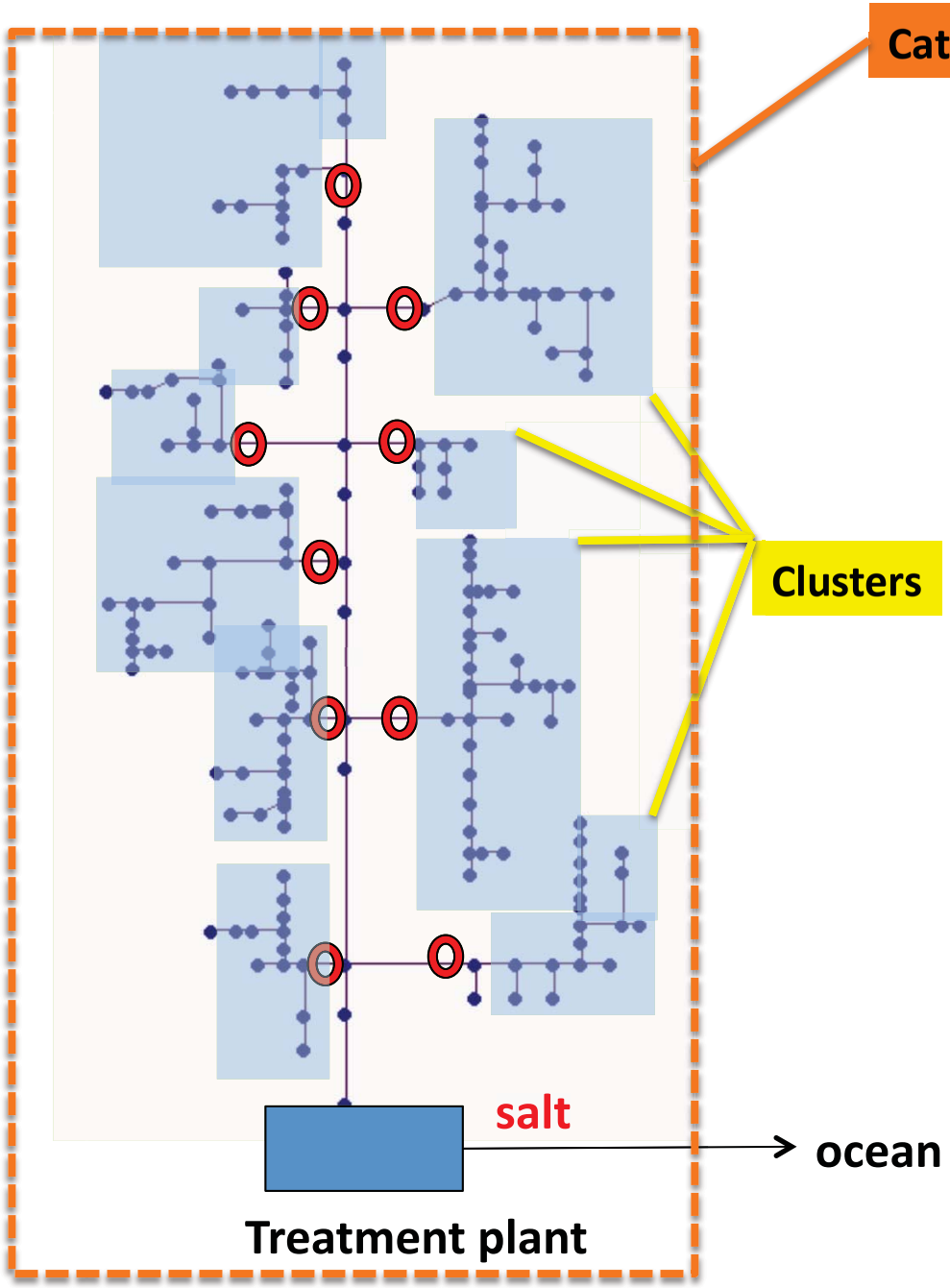
“Scalping” with distributed treatment: water recovery for local reuse



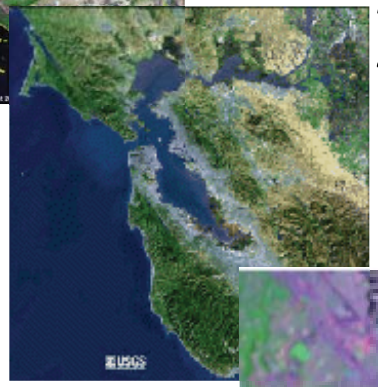
Scalping facilities

Harvest water

Distributed scalping facilities for water recovery and local reuse within a catchment



What would be the impact of widespread water reuse?



San Francisco Bay Watershed

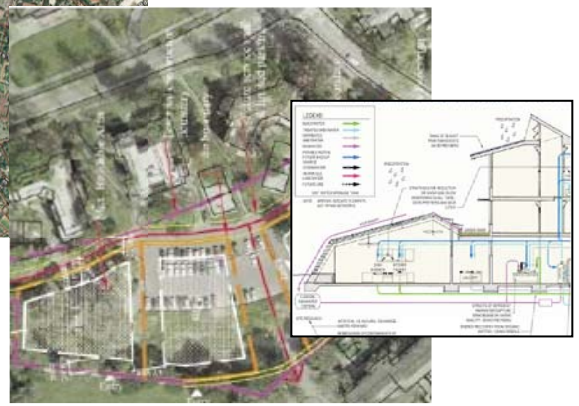
Watershed
Multiple cities
Water Districts
Irrigation Districts
>500,000 individuals

Catchment
Medium to large cities
Regional wastewater collection systems; Large farms
100,000-500,000 individuals

Service Area of the City of Palo Wastewater Collection System

Cluster
Small cities, HOAs, campuses, medium-size farms
1,000-100,000 individuals

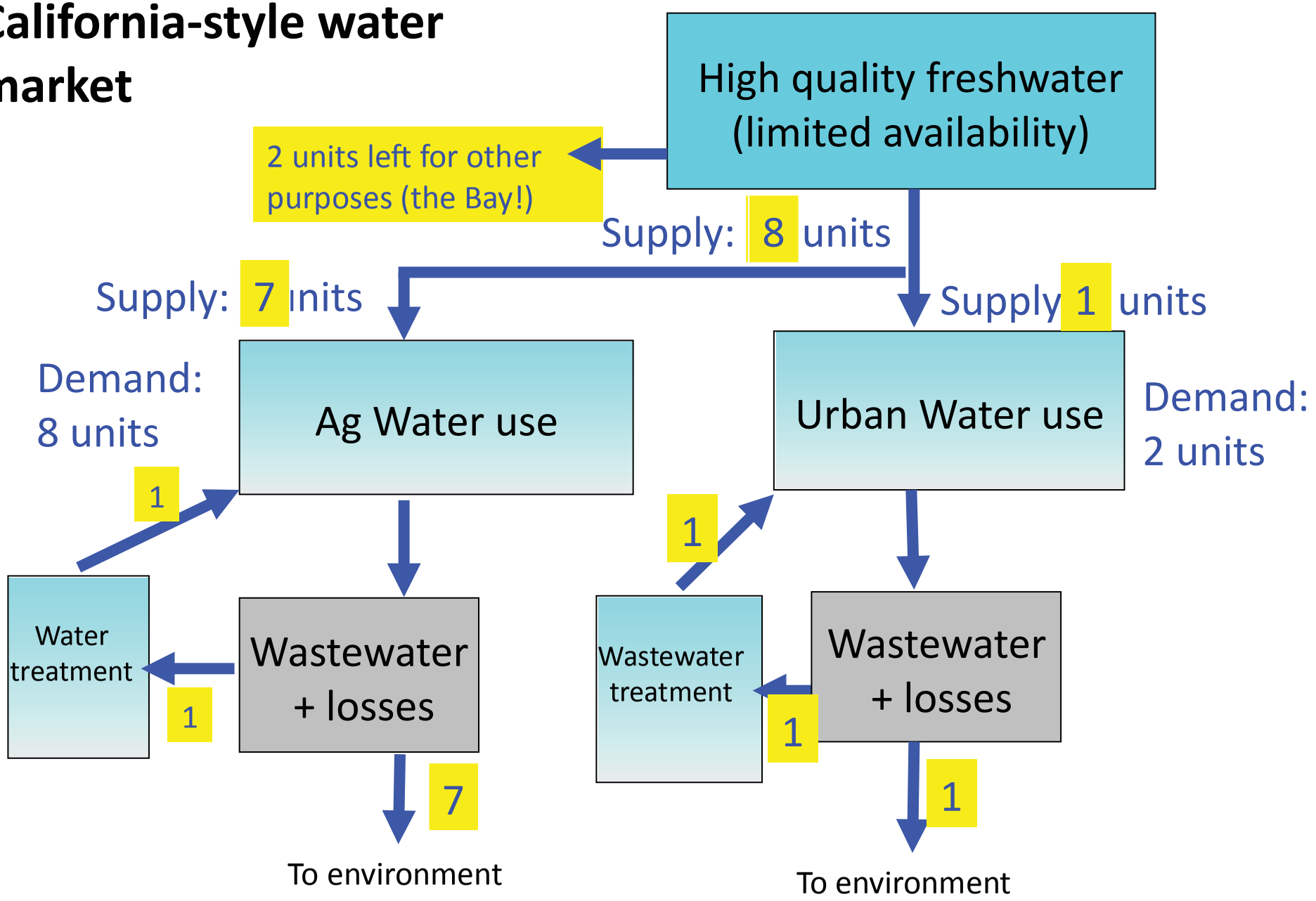
Stanford campus



Stanford green dorm

Building
(Hotels, Dorms, etc.)
10-1,000 individuals

California-style water market



What are the effects of scalping at the catchment level?

Widespread “scalping” in clusters within the City of Palo Alto catchment would change the composition of the water to be treated at the centralized facility.

If 75% of the water is removed by scalping, resource values change at the centralized facility

Resource	Per m^3	US $ per m^3	US $ per 1000 gal
Organic soil conditioner	0.40 kg	0.10	0.40
Methane	0.56 m^3	0.26	1.00
Nitrogen	0.20 kg	0.26	1.00
Phosphorus	0.04 kg	0.05	0.20
Water	1 m^3	0.325	1.20

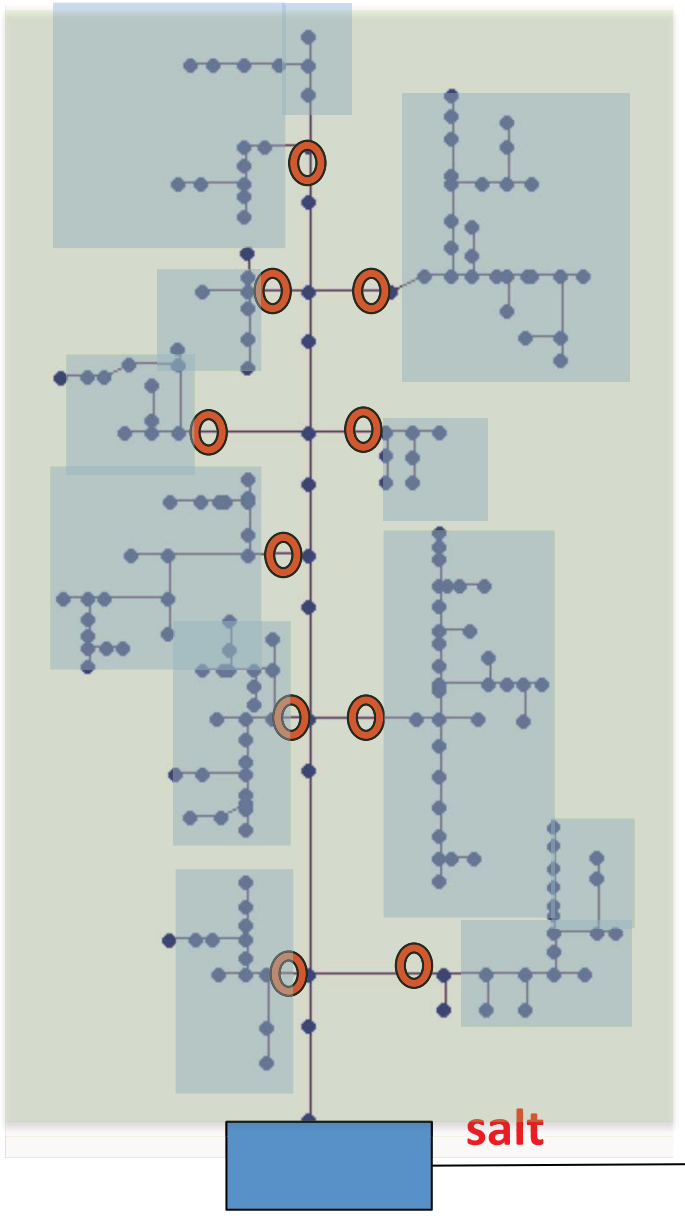
The energy and nutrient value becomes equivalent to the value of the water.

Centralized facilities for water, carbon and nitrogen recovery

Scalping facilities

Harvest water in clusters

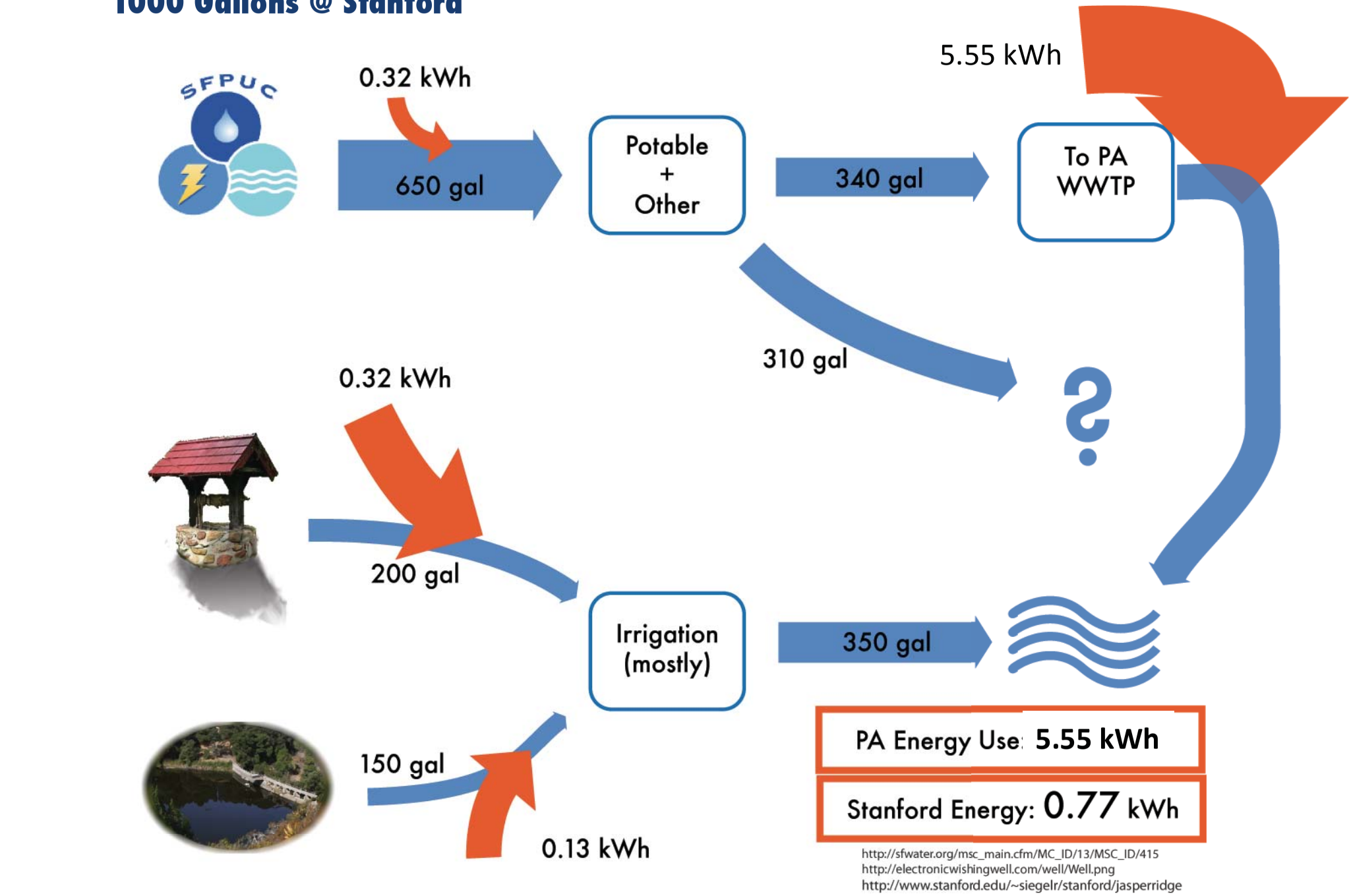
Harvest water, energy, nutrients in catchment



We are currently developing water balances and energy audits for the service area of the City of Palo Alto

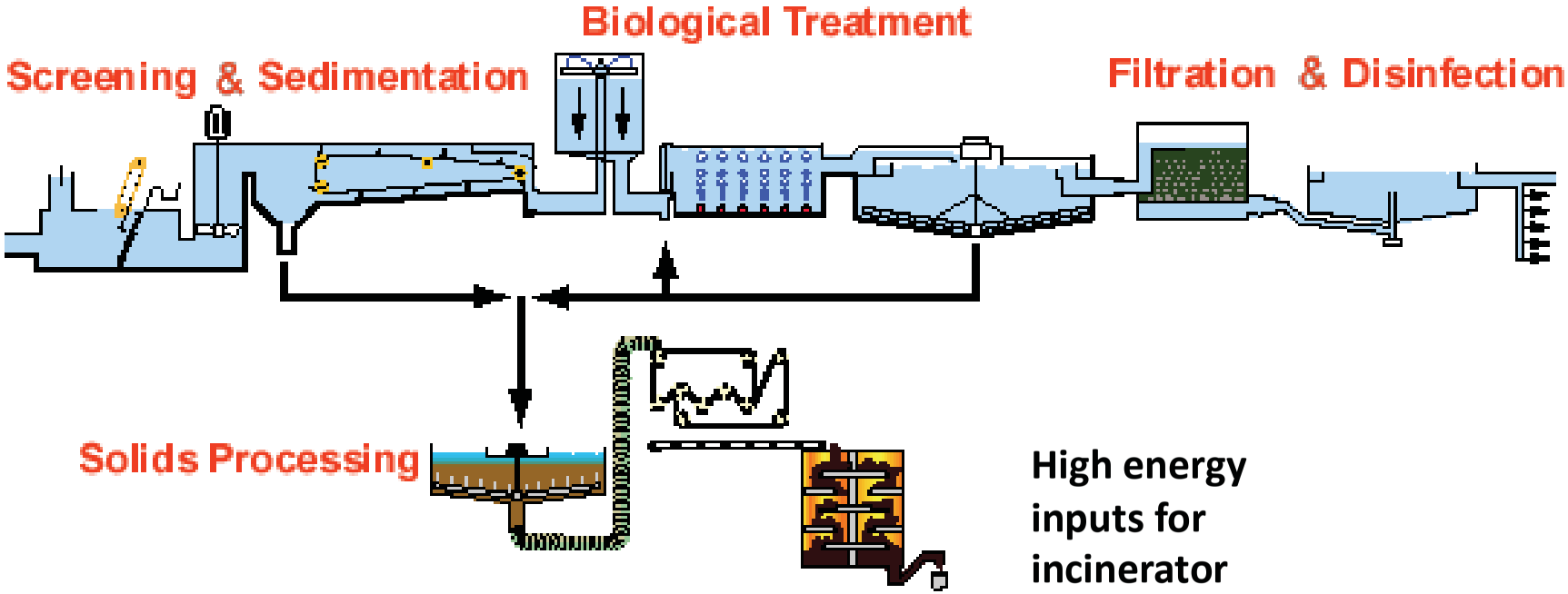
C. Criddle, Stanford University

1000 Gallons @ Stanford



http://sfwater.org/msc_main.cfm/MC_ID/13/MSC_ID/415
http://electronicwishingwell.com/well/Well.png
http://www.stanford.edu/~siegelr/stanford/jasperridge

Palo Alto Treatment Plant



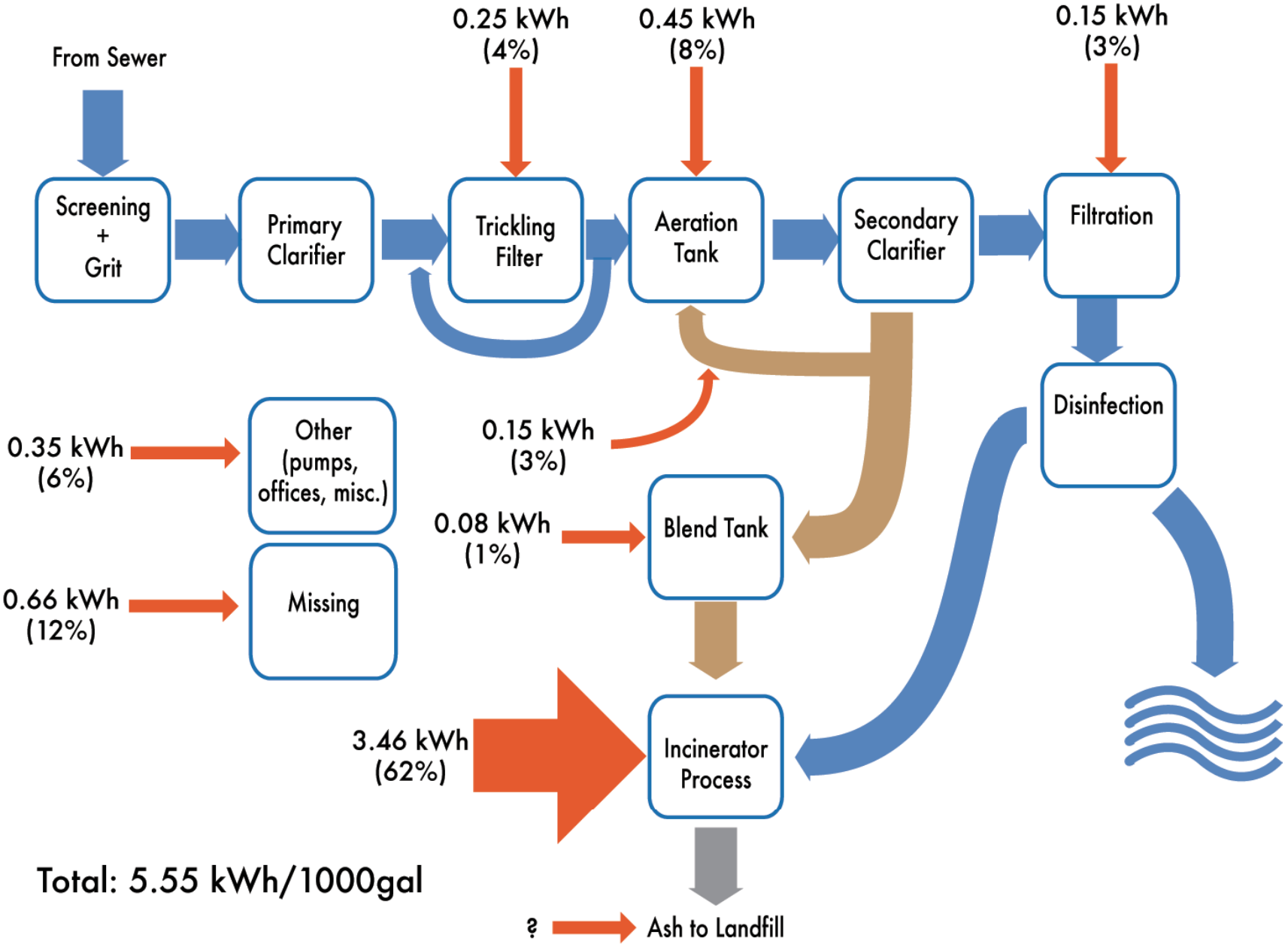
High energy inputs for incinerator

Ammonia & organic nitrogen goes in

Nitrate nitrogen comes out

High energy inputs for aeration

Palo Alto Energy Balance



Over the past decade, insights into the microbial ecology of **nitrogen removal** have vastly improved the energy balance of centralized systems in Europe.

Anaerobic Ammonium Oxidation

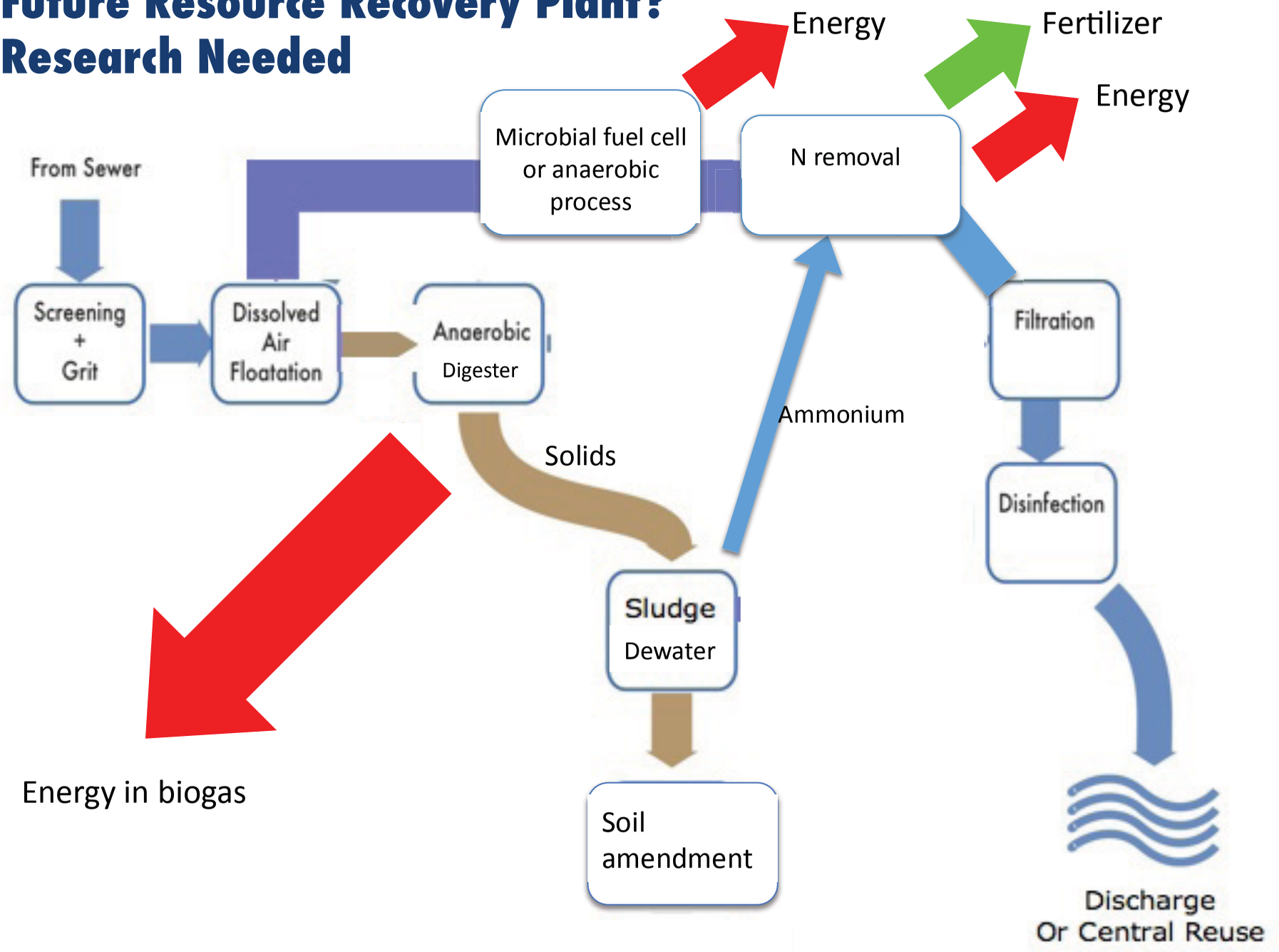
1985: Gist-Brocades yeast factory in Delft, the Netherlands installs anaerobic treatment unit…
And notices that N_2 is produced

Gijs Kuenen & colleagues puzzle over the microbial mystery

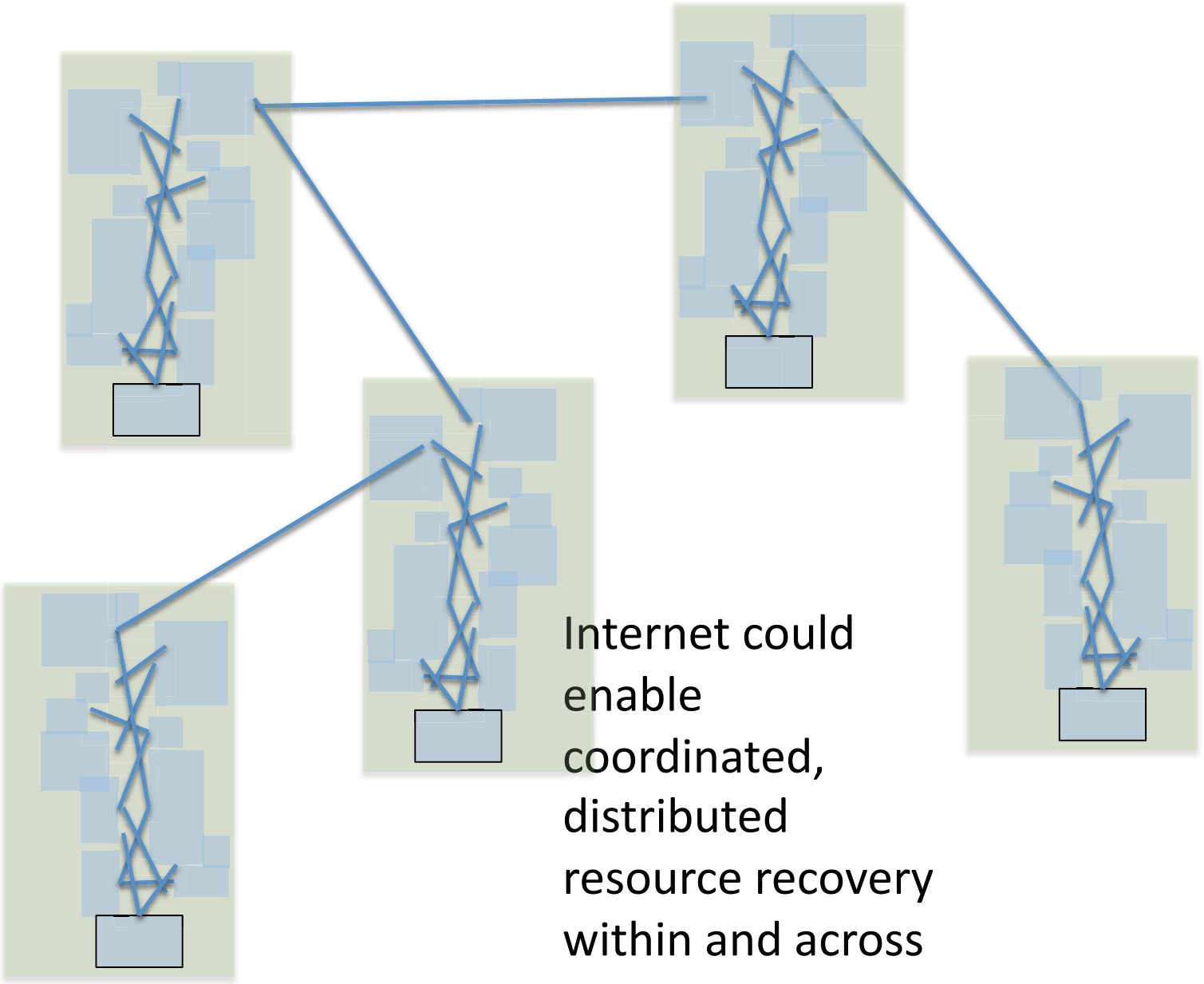
1992: US Patent granted for Anaerobic Ammonium Oxidation

In Europe, several full-scale centralized systems are now reportedly **energy-neutral**.

Future Resource Recovery Plant? Research Needed



and between adjacent service areas



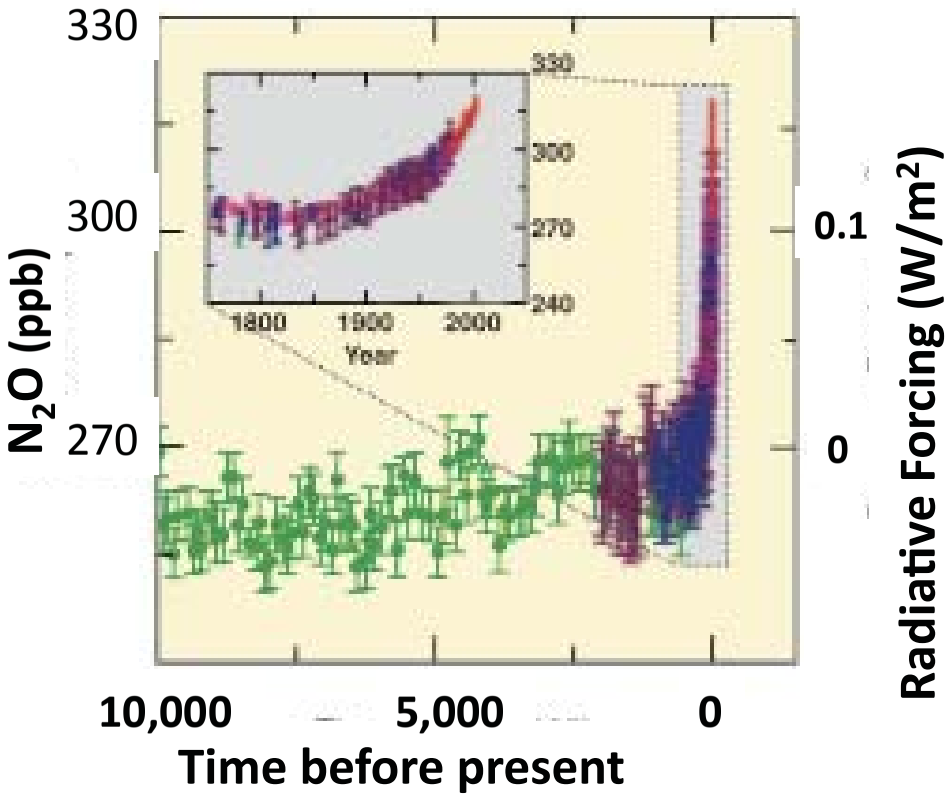
Internet could enable coordinated, distributed resource recovery within and across service areas

In 2005, we began using DNA-based tools used to monitor the microbial ecology of the Palo Alto wastewater treatment plant.

Discoveries:

- Ammonium oxidizing bacteria vary temporally; some produce nitrous oxide
- Bioreactor microbial communities are like islands
- Enormous genetic diversity

N_2O is a serious greenhouse gas



N_2O is 298 X more powerful as a global warming agent than CO_2 over a 100 year period.

Source: Denman et al., 2007. 4th assessment of the IPCC.

CANDO: Completely Autotrophic Nitrous Decomposition Operation

Nitrous oxide
$0.5N_2O$

$0.5N_2$+ $0.25O_2$
+ 41 kJ

N_2O decomposition cell: Yaniv Scherson and Brian Cantwell (2008)

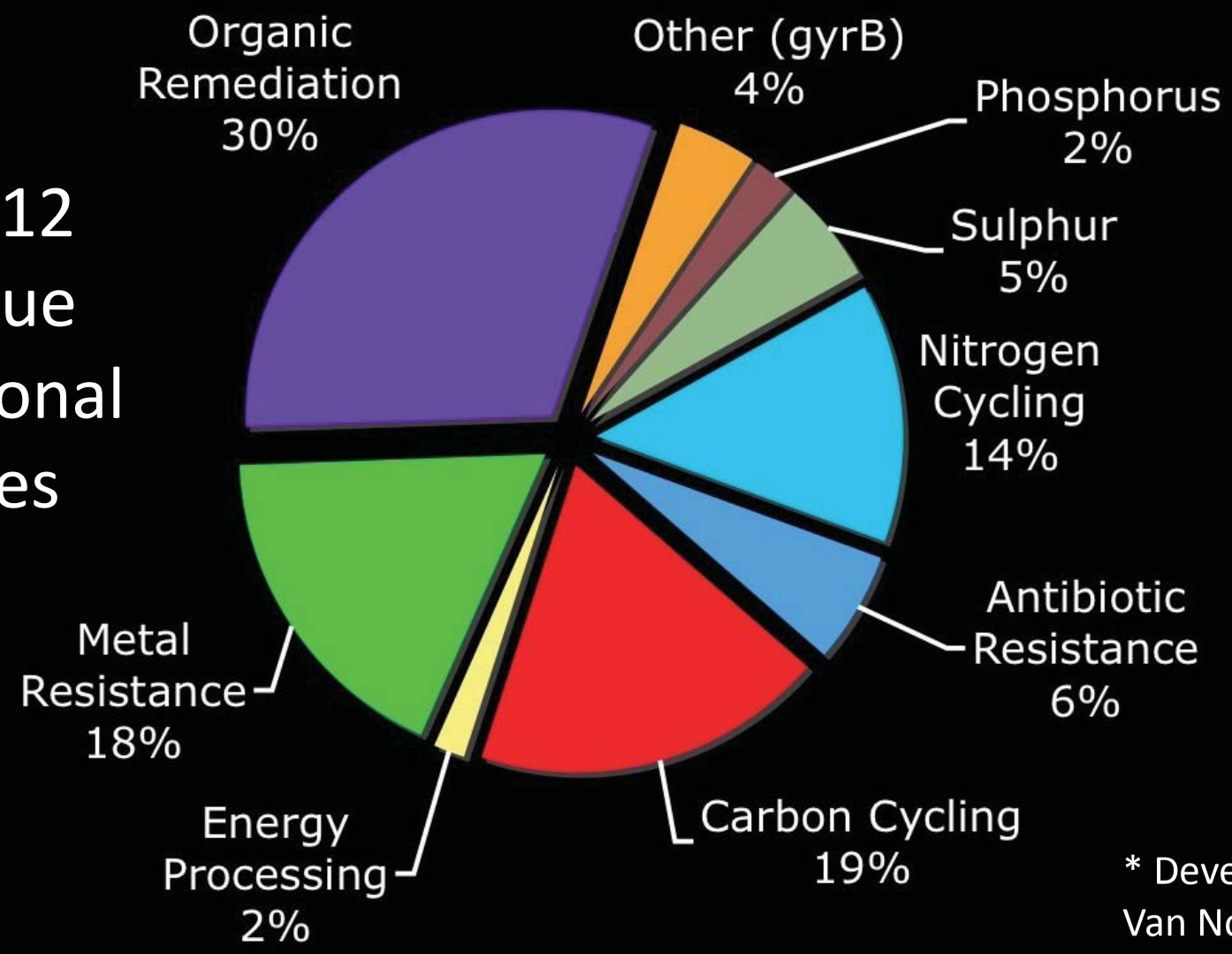
Destroys N_2O, produces energy, and saves oxygen!

1.0 O_2

Ammonia NH_3

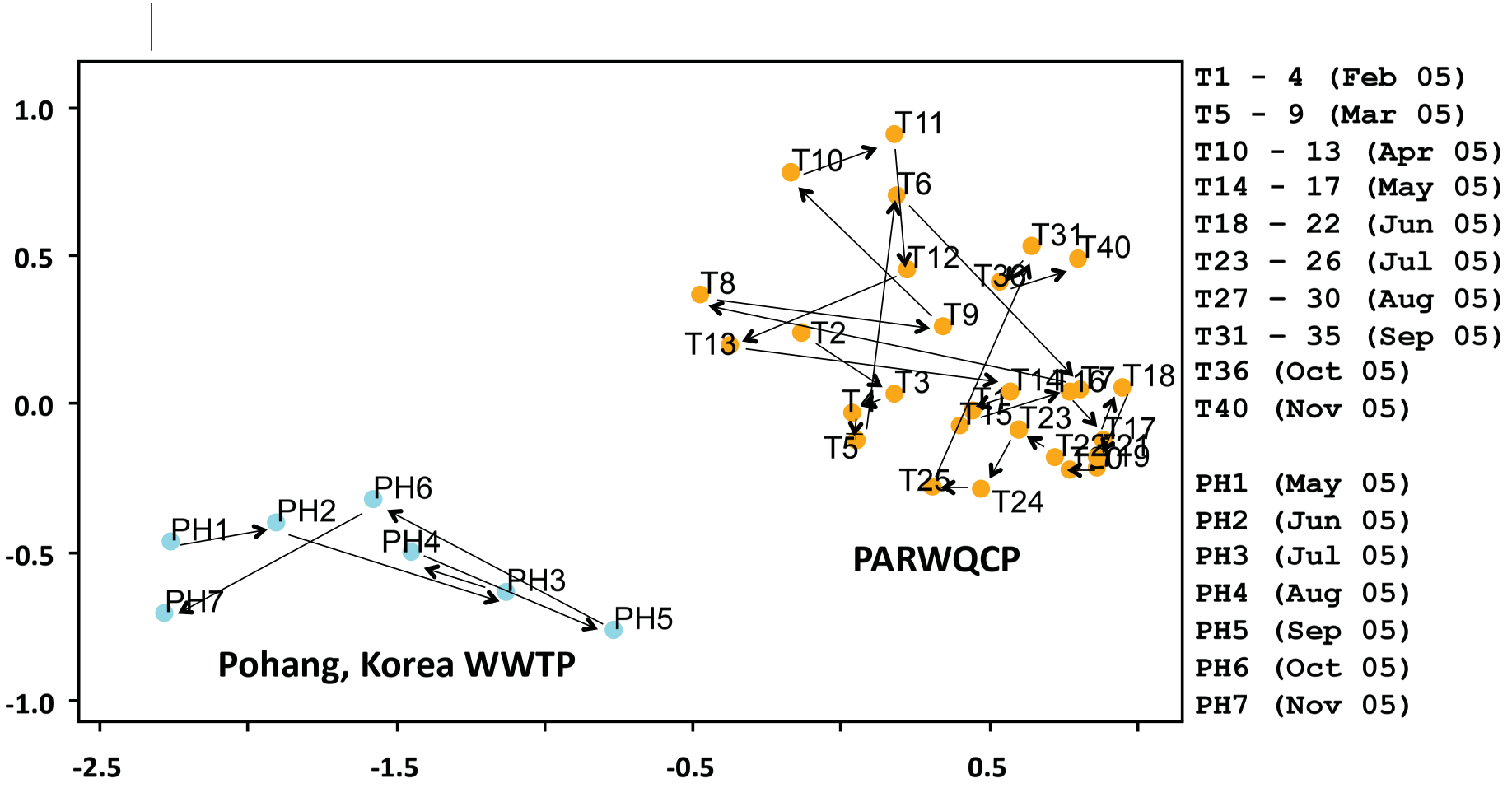
Gene diversity detected by GeoChip*

27,812 unique functional genes



* Developed by Van Nostrand et al. (2008)

Palo Alto vs. Pohang



Evidence for “island biogeography”.

Towards a global bioreactor network

2006 core group

2008 requests to join

Nanyang Technological University, Singapore, Nov 29-Dec 1, 2006

Uncommon Dialogue on
May 21 to be sponsored
by the Woods Institute

Wastewater as a Resource: Focus on the Bay

Workshop will promote investments to revitalize Bay Area water and wastewater infrastructure, improve the stability of Bay area ecosystems, increase the security and reliability of freshwater supplies, decrease dependence upon imported freshwater, and increase renewable energy generation.

Support

Woods Institute for the Environment, Stanford University

Palo Alto Regional Water Quality Control Plant

U.S. National Science Foundation

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