Scale & Scale-Up

Craig Criddle
Professor, Department of Civil and Environmental Engineering
Senior Fellow, Woods Institute for the Environment
Stanford University

By the year 2000, there were more than 15,000 wastewater treatment facilities in the US alone

Their function: removal of organics and nutrients

toxic substances

Trial-and-error design | **Reactor engineering**

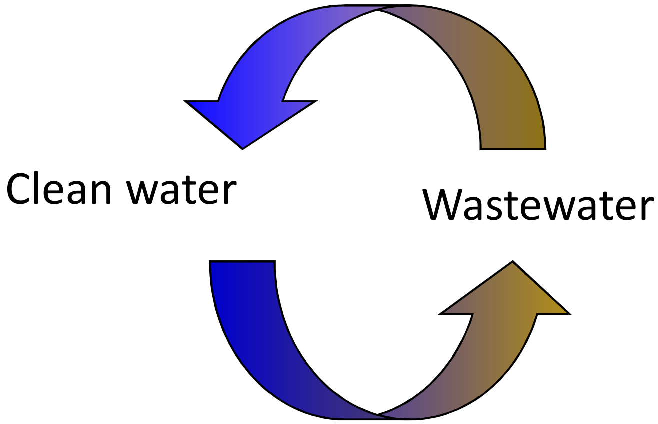
1914 | **1970** | **2000**

Life before 2000

- **Little recycling or reuse**
- **Cheap energy**
- **Climate change not on the radar**

Why things must change

- Water scarcity & need for a reliable supply
- Increasing urban water demand
- 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

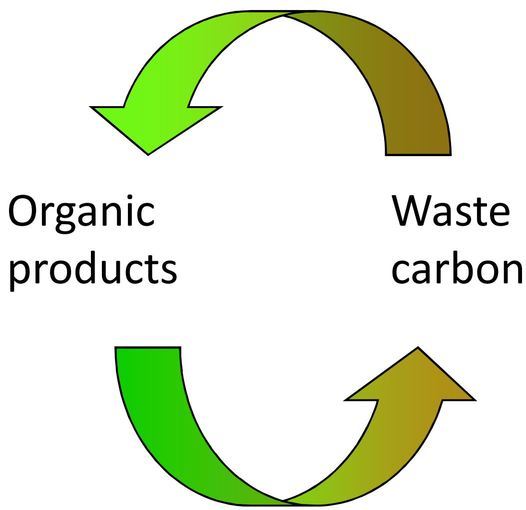


Products in wastewater

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)

Treatment plants as *local* resource recovery centers

- Water

- Organics

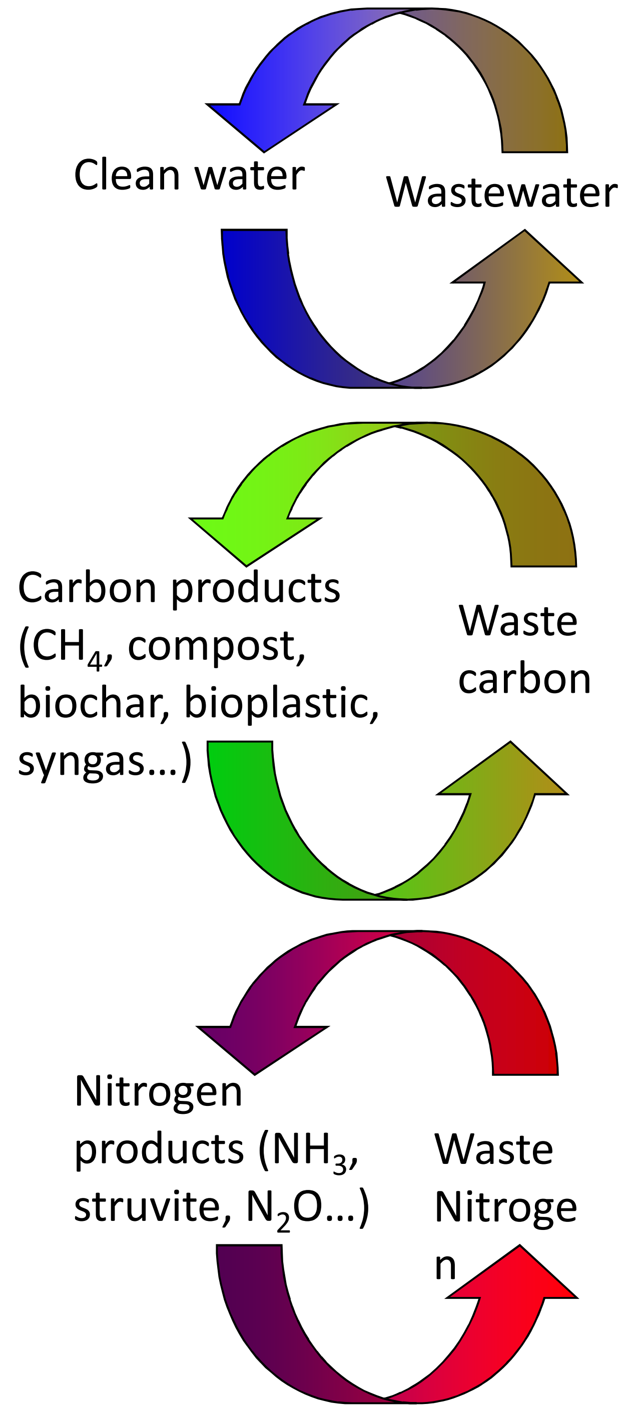
-energy

-materials

- Nutrients

-fertilizer

- energy

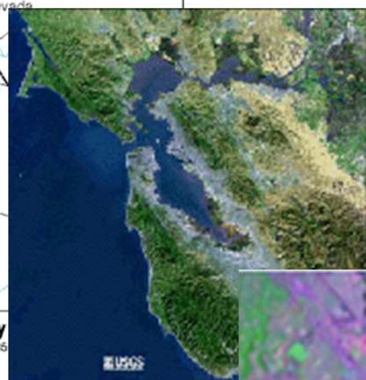


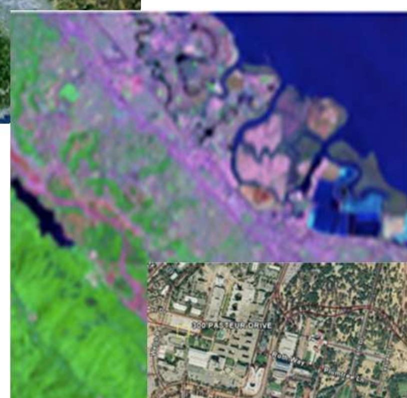
At what scale should these resources be recovered?

Wastewater Resource Recovery Team

Scale

San Francisco Bay Watershed





Catchment of the City of Palo Alto

Stanford campus

Stanford Green Dorm

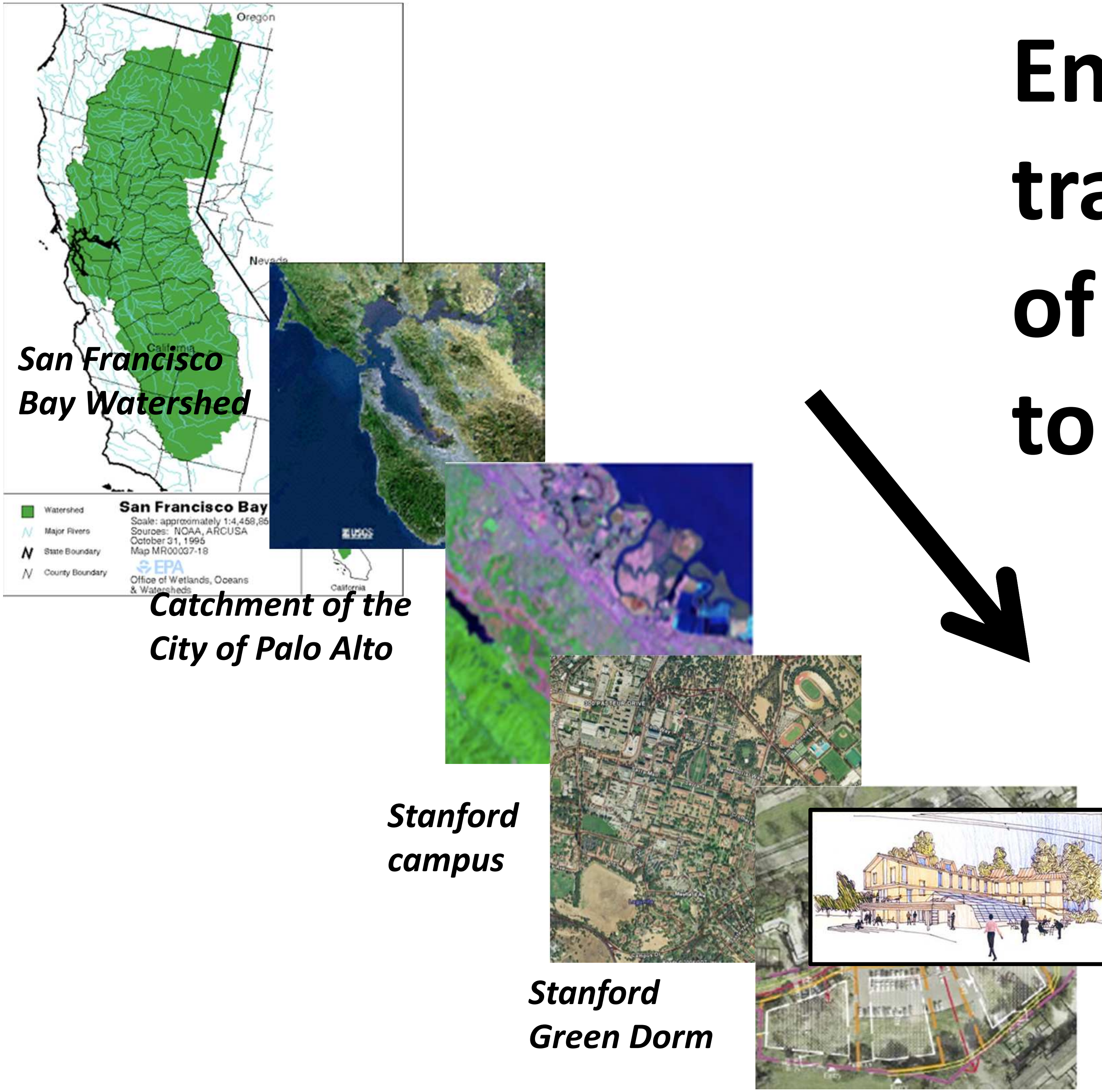
Watershed: a region defined peripherally by a divide & draining to a particular water body; the set of all catchments within a drainage basin.

Catchment: a region defined by the set of all clusters with a shared drainage system. includes cities with a shared treatment facility & shared storm drains; farms with shared drainage.

Cluster: a collection of buildings with a shared drainage line for wastewater collection. Includes: small cities, HOAs, campuses, farms.

Building: a set of rooms with shared drainage Includes: hotels, dorms, houses.

Energy for transport of water to user



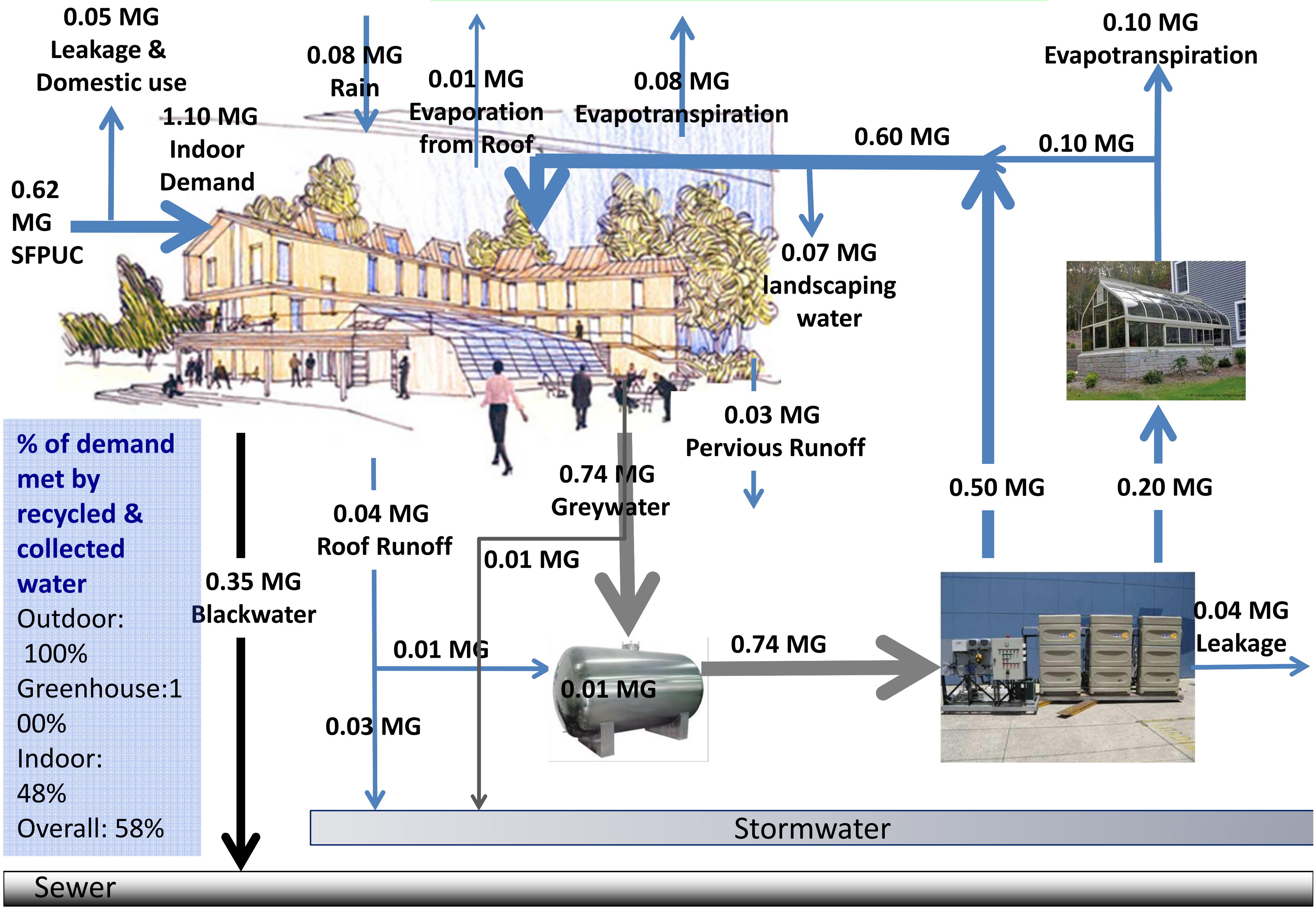
Approach

- Determine baseline water balances at each scale.
- Determine baseline energy audits at each scale.
- Identify appropriate technologies at each scale.
- Conduct a cost benefit analysis to assess technologies and costs across scale.

Proposed Building Scale Test Bed

Stanford Living Innovation Center
(Green Dorm)

Projected Annual Water Balance



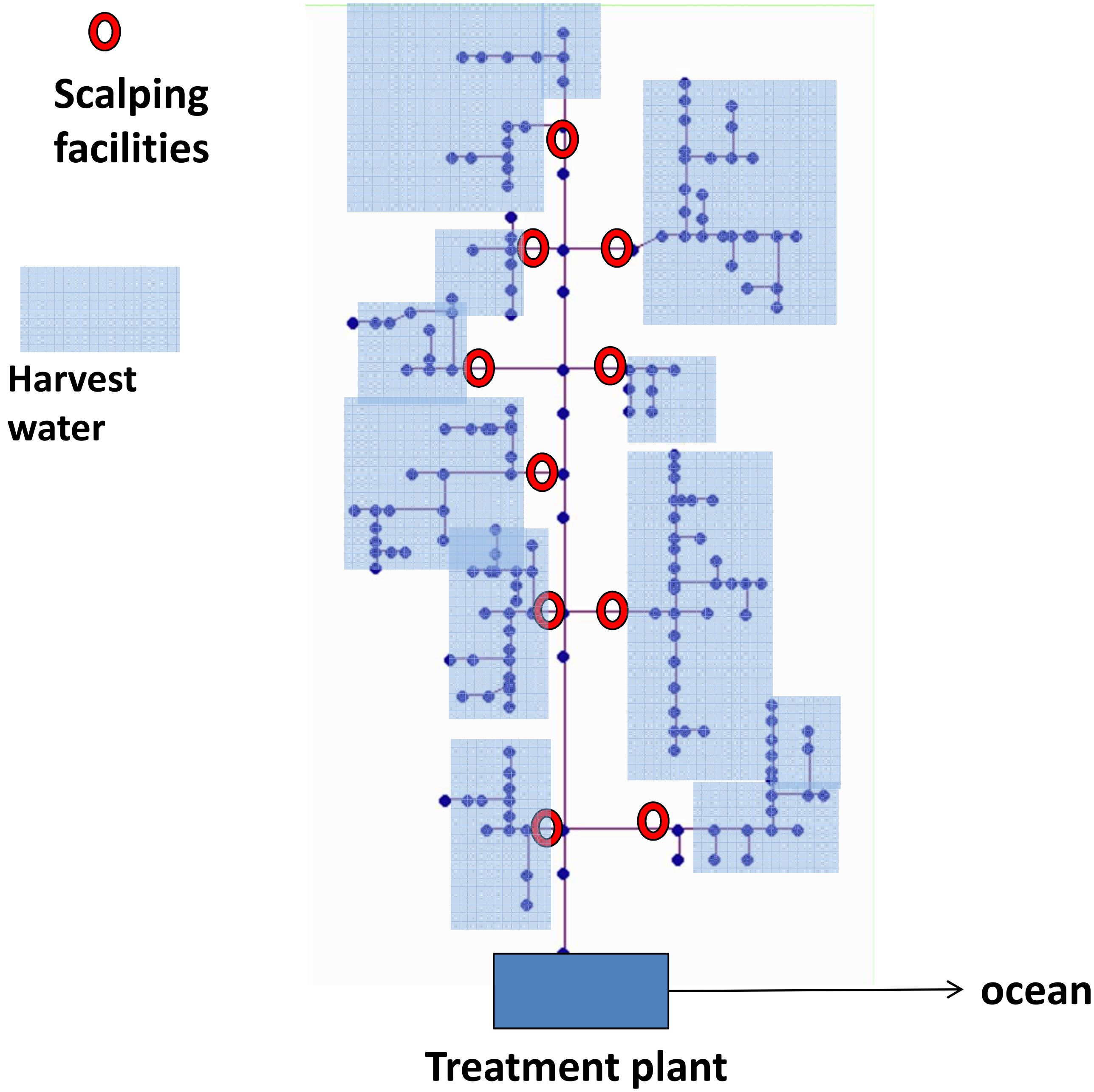
Building scale technology: what makes sense?

- Greywater treatment and reuse
- Rainwater harvesting
- Energy recovery by anaerobic digestion (dining halls, restaurant wastes, etc.)
- Energy recovery from heat in the wastewater
- Source separation and collection (metals and organics at manufacturing facilities, urine, etc.)

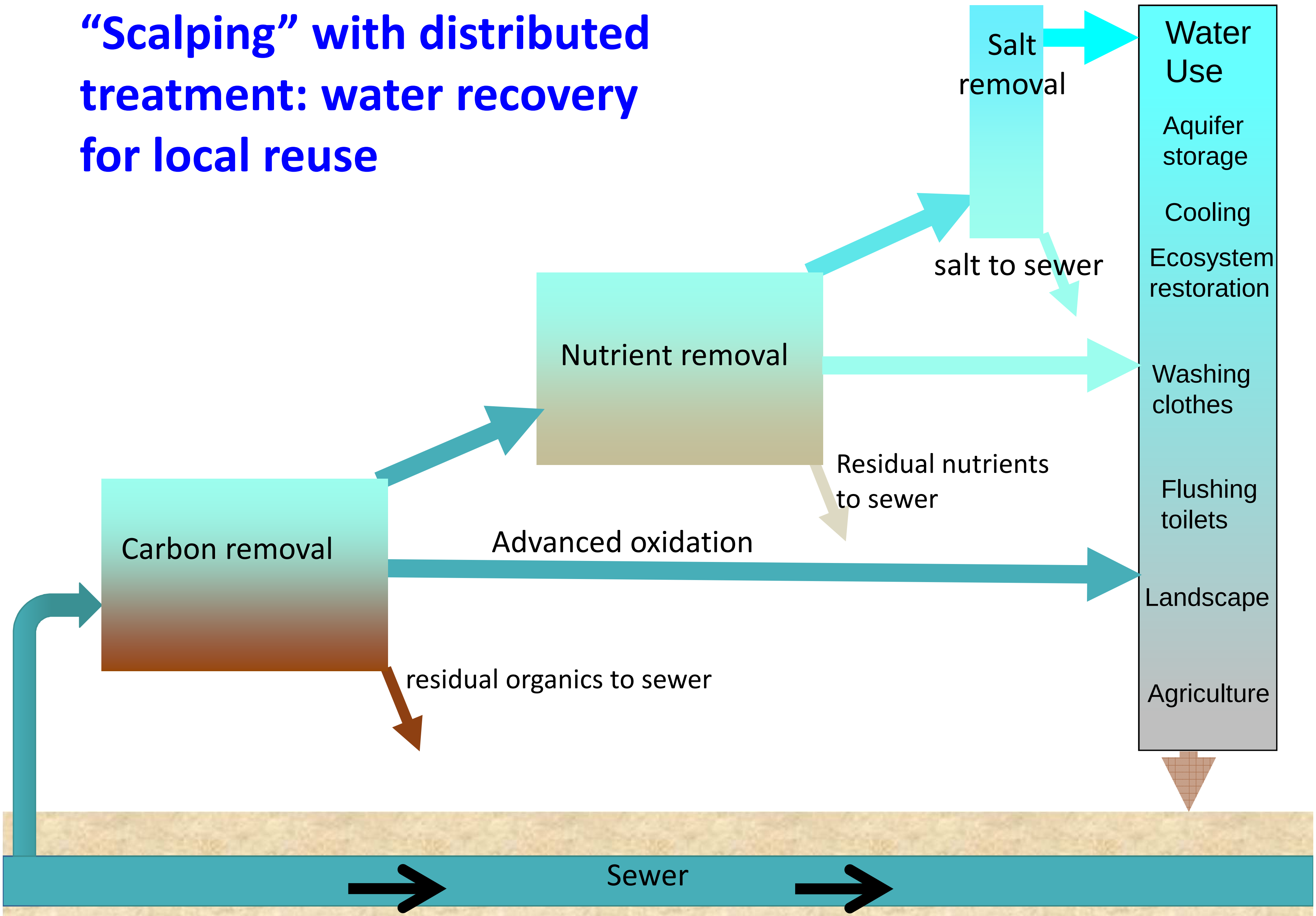
Cluster Scale

What might make sense?

scalping



"Scalping" with distributed treatment: water recovery for local reuse

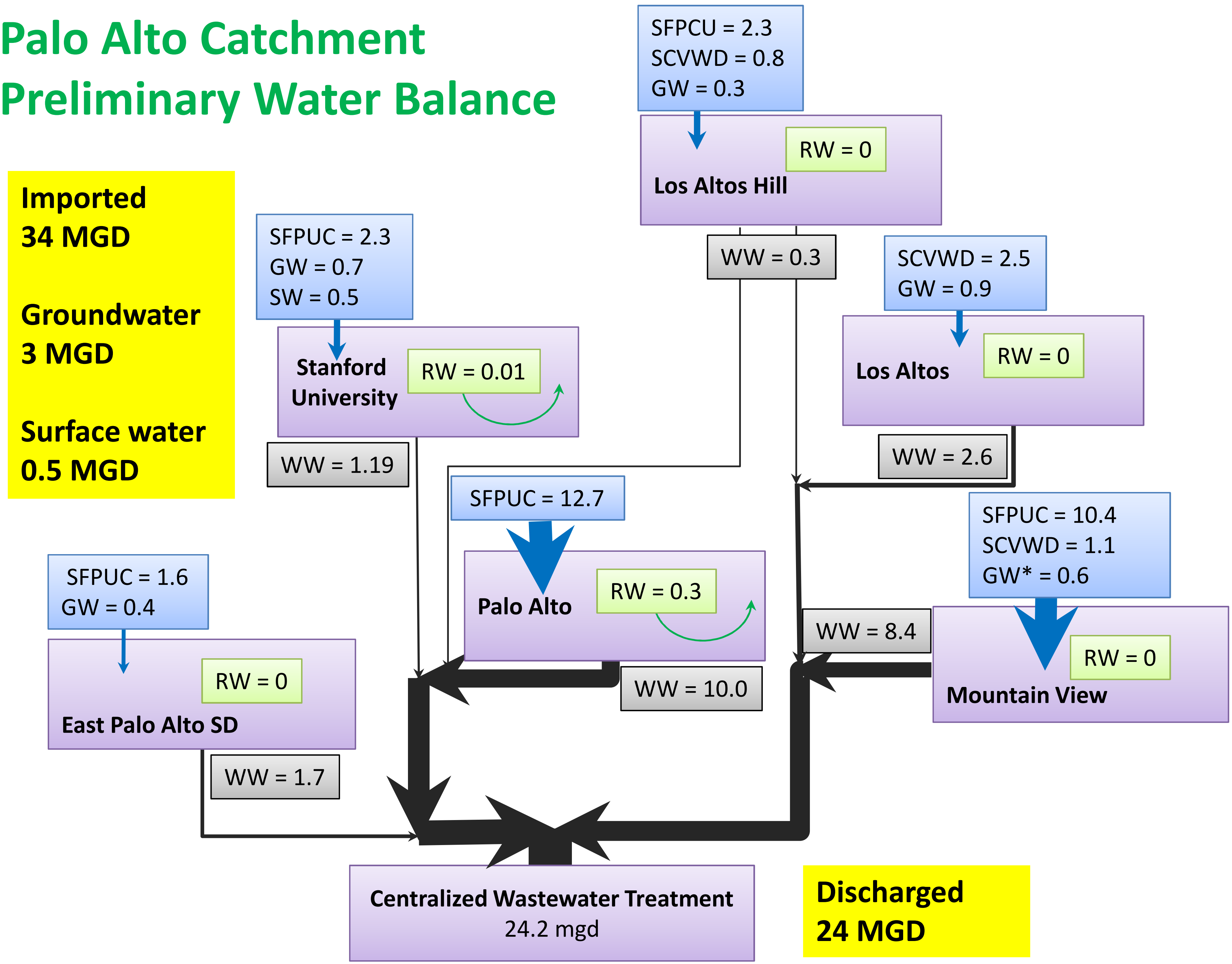


Cluster-scale Technology Needs:

- Advanced primary
- Low-energy BOD & N removal
- Advanced oxidation
- Distributed monitoring and control

How will water reuse at the building and cluster scale affect the catchment scale?

Palo Alto Catchment
Preliminary Water Balance

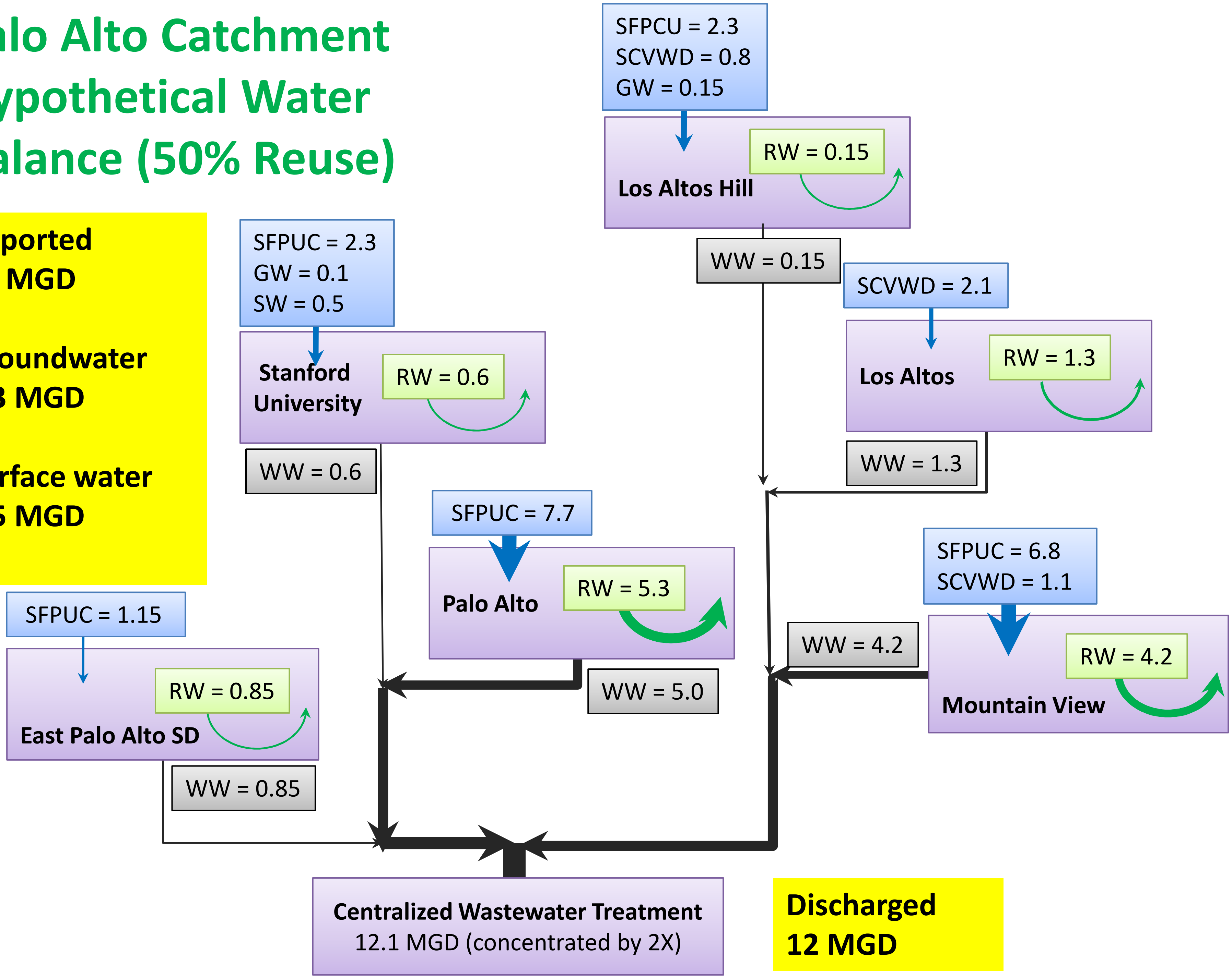


Palo Alto Catchment Hypothetical Water Balance (50% Reuse)

Imported
24 MGD

Groundwater
0.3 MGD

Surface water
0.5 MGD



How does resource value change if clusters scalp and reuse 50% of their water?

Resource	Per m³	US $ per m³
Organic soil conditioner (kg)	0.10	0.03
Methane (m³)	0.14	0.07
Nitrogen (kg)	0.05	0.07
Phosphorus (kg)	0.01	0.01
Water (1 m³)	1.00	0.33

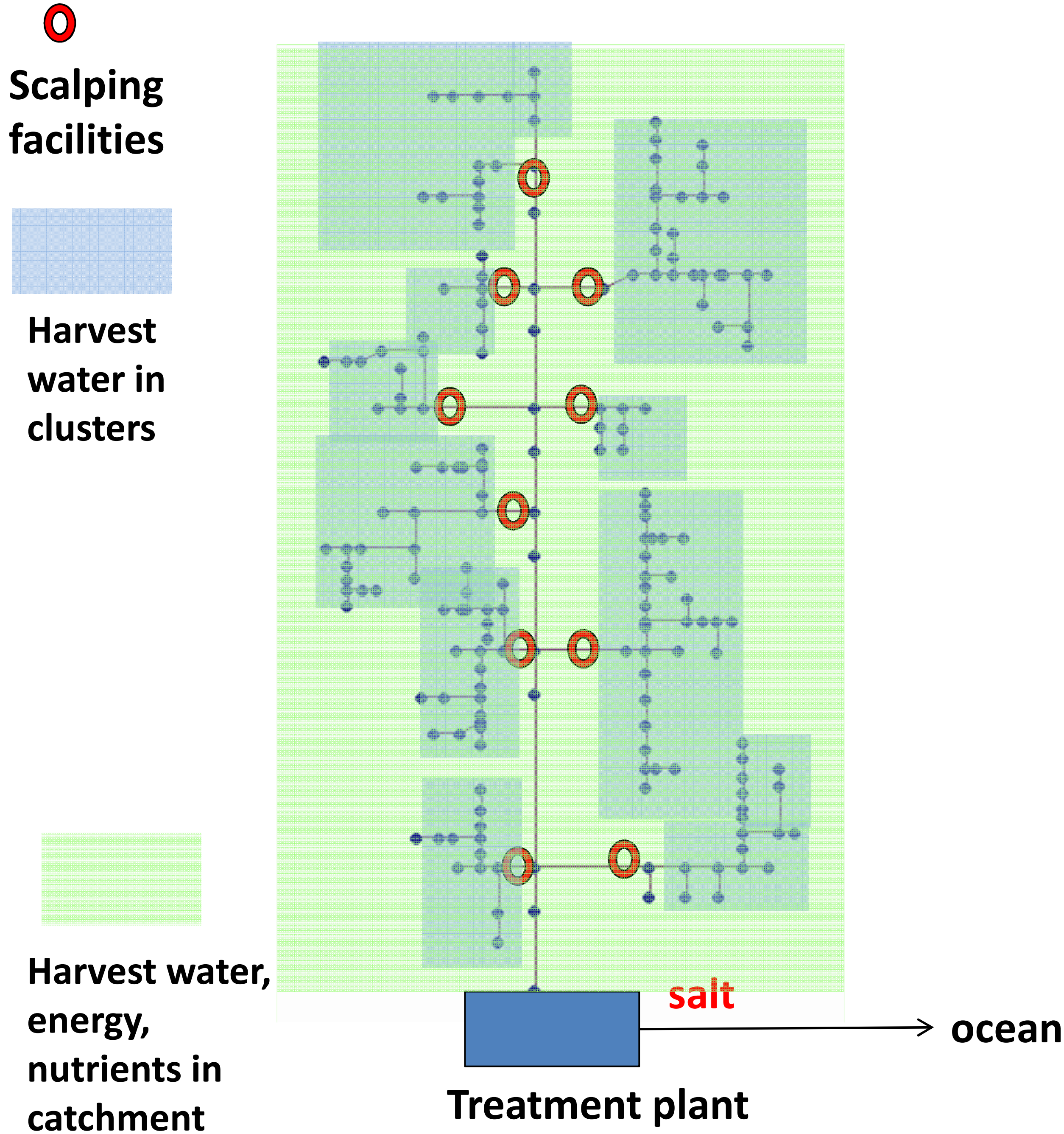
x 2

Resource	Per m³	US $ per m³
Organic soil conditioner (kg)	0.20	0.06
Methane (m³)	0.28	0.14
Nitrogen (kg)	0.10	0.14
Phosphorus (kg)	0.02	0.02
Water (1 m3)	1.00	0.33

$0.36 per m³

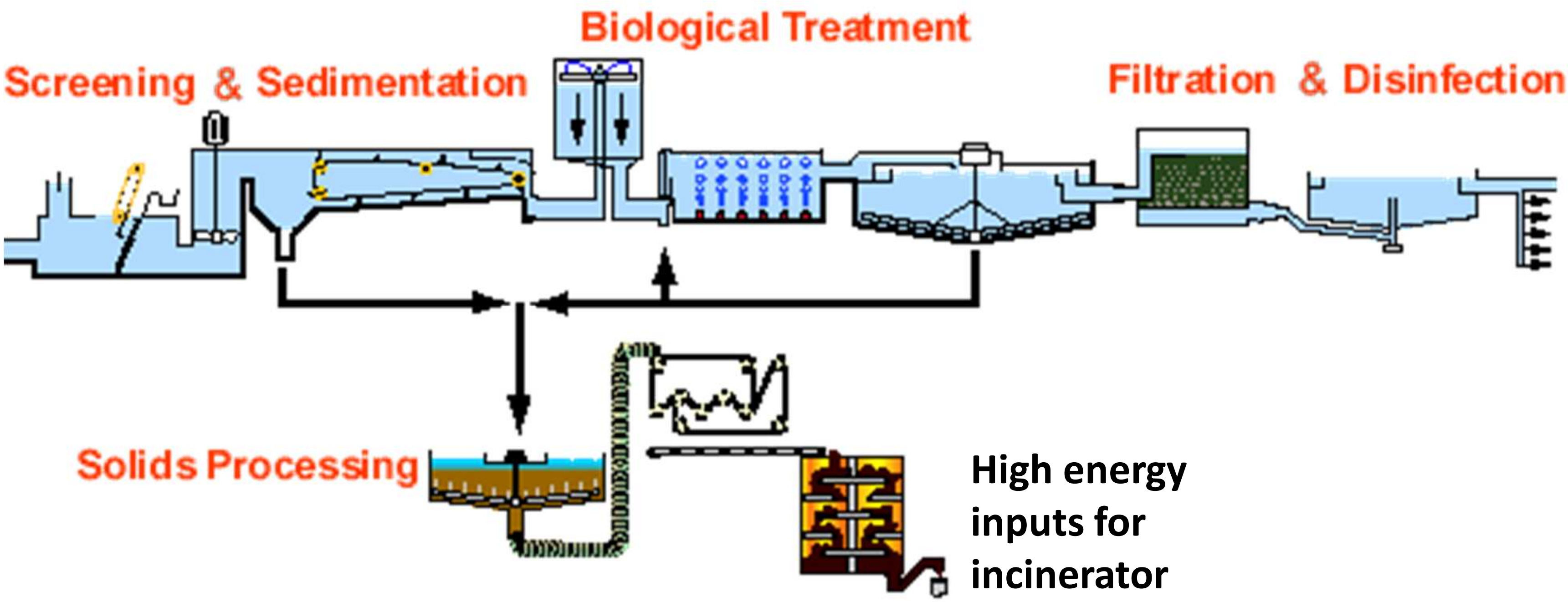
The value of the energy and nutrients arriving at the centralized facility becomes equivalent to that of the water

Centralized facilities for water, carbon and nitrogen recovery



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

Palo Alto Treatment Plant



High energy inputs for incinerator

Organics in

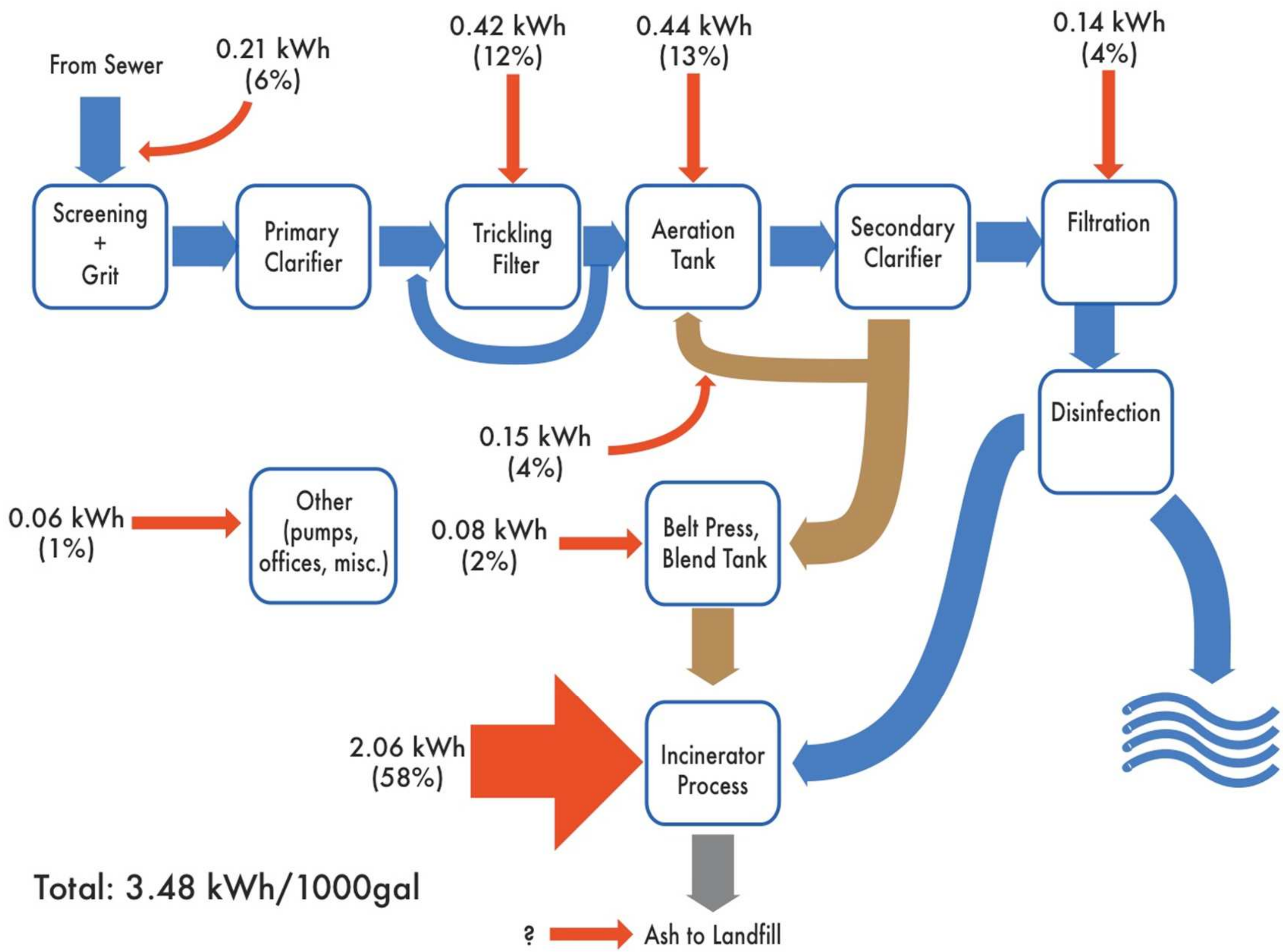
Nitrogen in (ammonia & organic)

CO_2 out

Nitrate 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

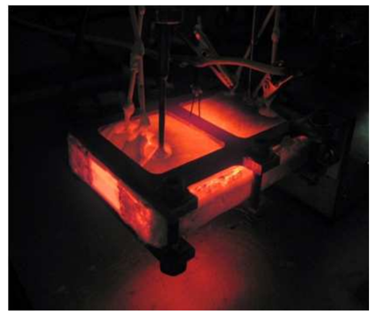
TU Delft
Delft University of Technology

Gijs Kuenen & colleagues puzzle over the microbial mystery

1992: US Patent granted for Anaerobic Ammonium Oxidation

In Europe, full-scale centralized systems using anaerobic ammonium oxidation are approaching **energy-neutral** operation.

CANDO: Completely Autotrophic Nitrous Decomposition Operation

Nitrous oxide $0.5N_2O$ →  → $0.5N_2 + 0.25O_2$ **+ 41 kJ**

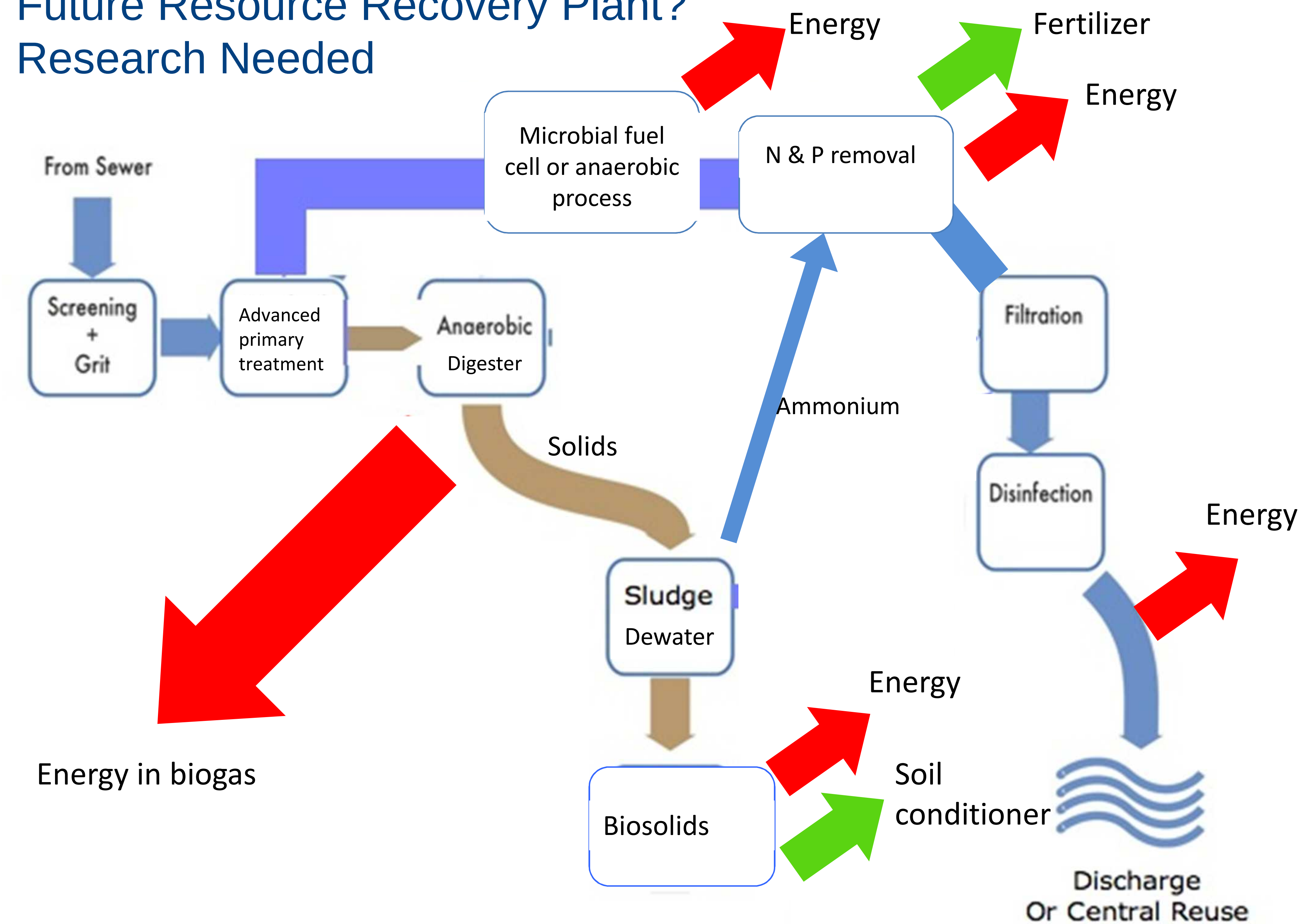
N_2O decomposition cell: Yaniv Scherson and Brian Cantwell (2008)

Destroys N_2O, produces energy, and saves oxygen!

↑ $1.0\ O_2$

Ammonia NH_3

Future Resource Recovery Plant? Research Needed

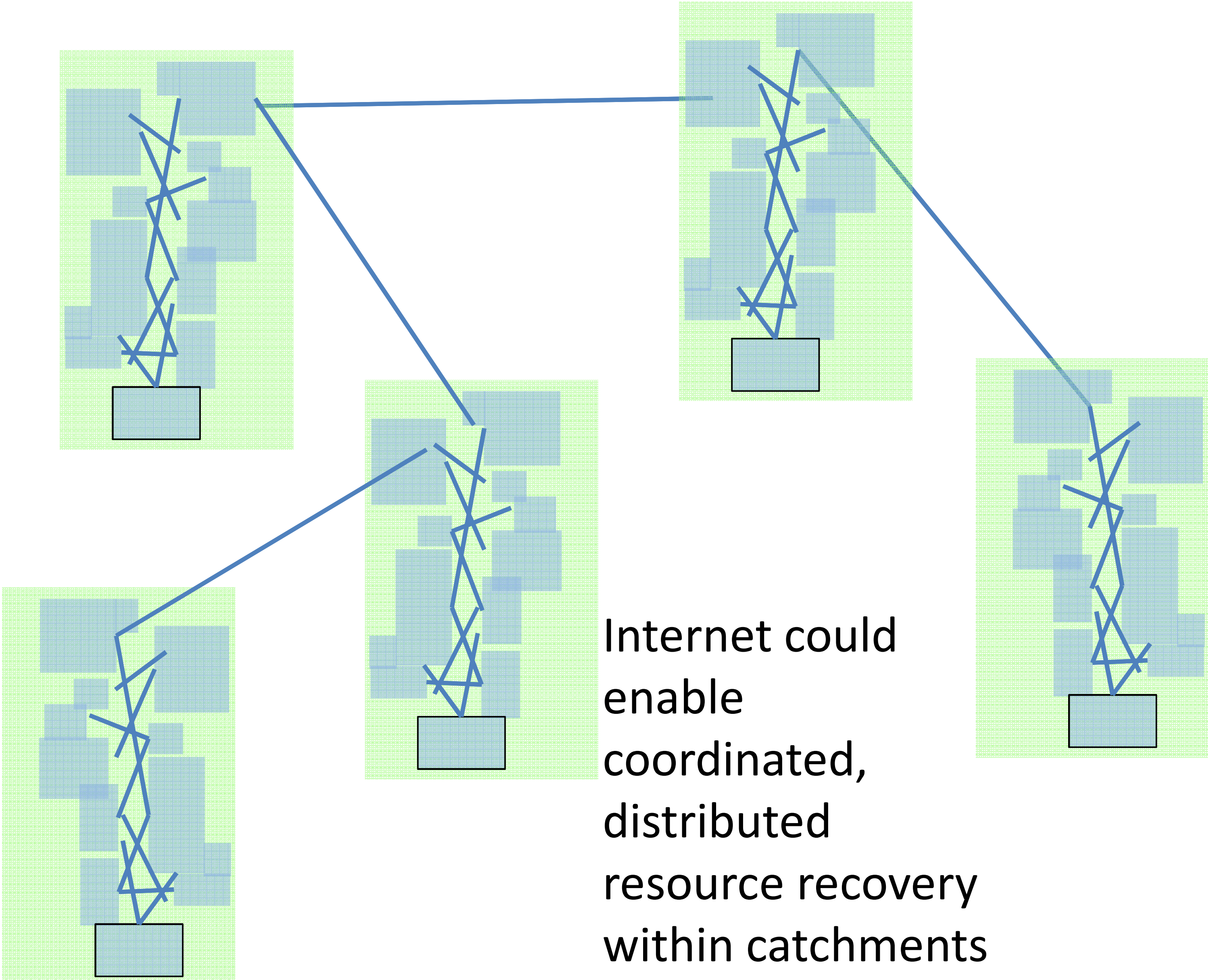


Economics

Frank Wolak

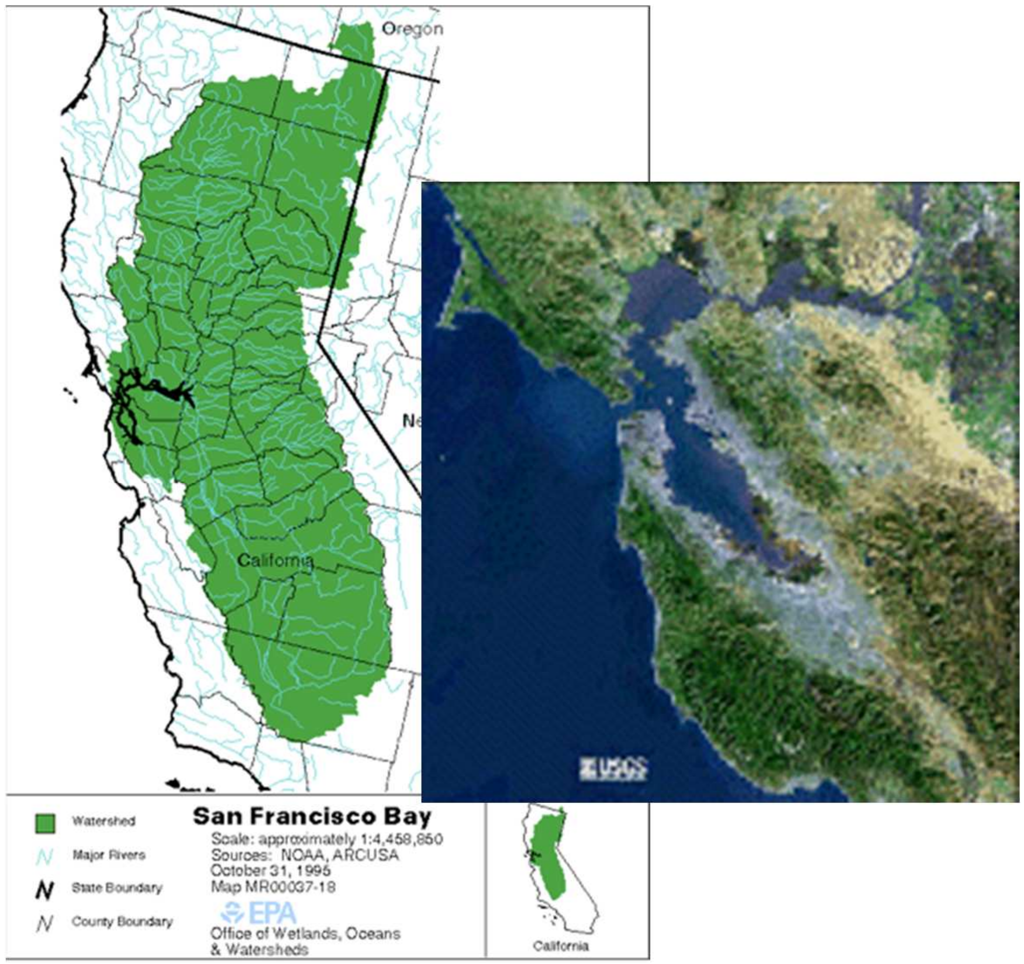
- Larger scale operations could subsidize technology development at lower scales.
- An optimal fee structure could take this into account.
- Need to consider how changes in water demand affect prices.

and between adjacent catchments



Internet could enable coordinated, distributed resource recovery within catchments

How would widespread water reuse affect the regional scale?



California Recycled Water Policy

"The State Water Board hereby establishes a mandate to increase the use of recycled water in California by 200,000 afy by 2020 and by an additional 300,000 afy by 2030."

Support

Woods Institute for the Environment, Stanford University

Palo Alto Regional Water Quality Control Plant

U.S. National Science Foundation