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Transforming Urban Water Systems Towards A More Sustainable Future

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**Eastern Research Group, Inc.

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Professional Experience

1999-2004	**Doctoral Researcher** University of Minnesota
2004-2007	**Postdoc Research Associate** University of Wisconsin – Madison
2007-2010	**Federal Postdoc** US EPA, ORD, Athens, GA
2010-present	**Research Engineer** US EPA, ORD, Cincinnati, OH

History of Research Focus

- Anaerobic Reductive Dechlorination
- Prion Proteins
- Nanomaterials
- Sustainability
- System Analysis – emergy, LCA
- Sustainable Water Systems

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A system is more than the sum of its parts.

– Aristotle

- Tools: emergy and LCA (life cycle assessment)
- System analyses examples
  - Nutrient recovery and removal
  - Energy recovery
  - Water reuse
  - City of Tomorrow
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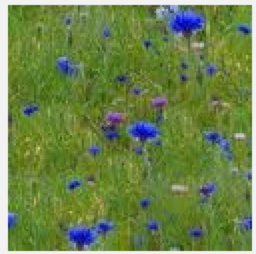
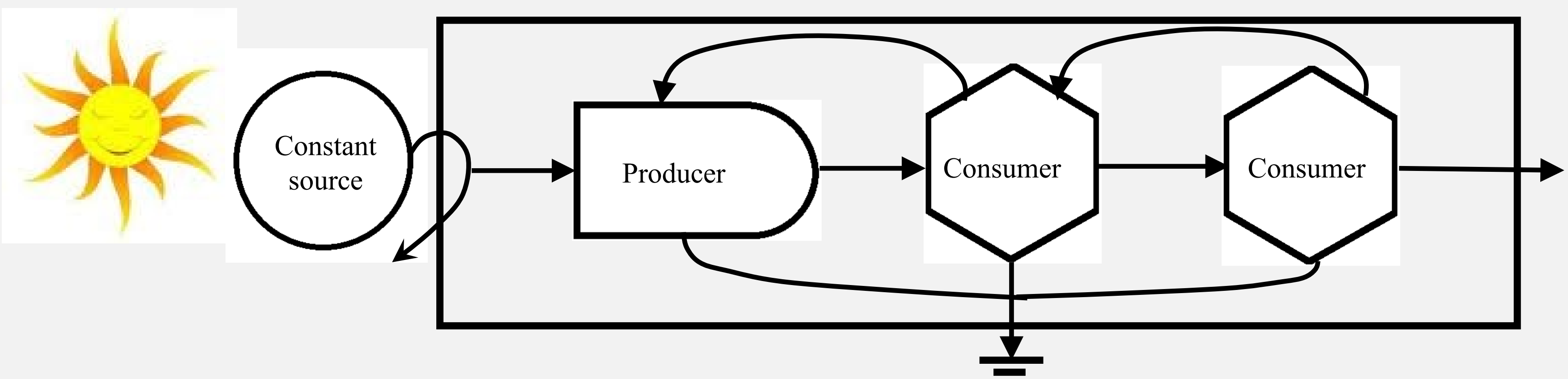
What is EMERGY?

- **Emergy** is the available energy of any kind previously used both directly and indirectly to make another form of energy, product or service. (Odum, 1996)
- Emergy might be thought of as energy memory.
- Emergy analysis is an environmental accounting method.

What is EMERGY?





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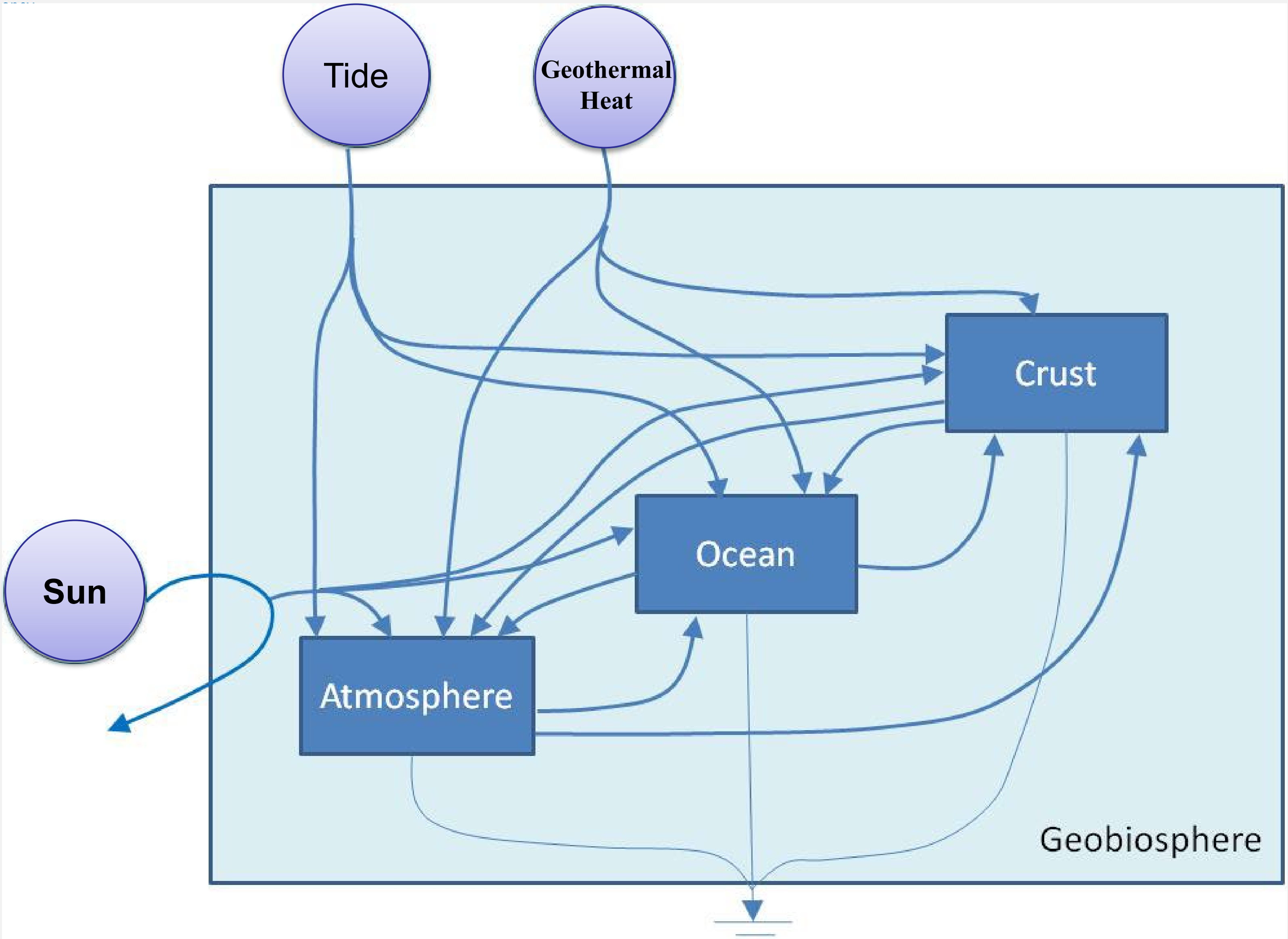
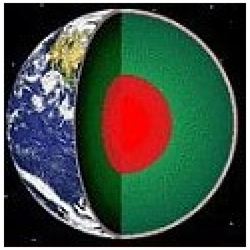


What is EMERGY?

- Its unit is the emjoule.
- In this global system, use the solar emjoule (sej).
- 3 primary energy sources: solar, crustal heat, tidal energy
- Annual energy and emergy input for geobiosphere

			
	solar	crustal heat	tidal
Energy (J/yr)	39300×10^{20}	13.21×10^{20}	0.52×10^{20}
Emergy (sej/yr)	3.93×10^{24}	8.06×10^{24}	3.83×10^{24}

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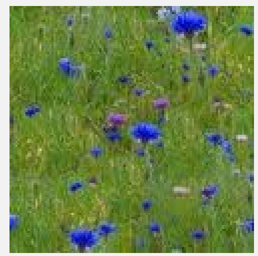
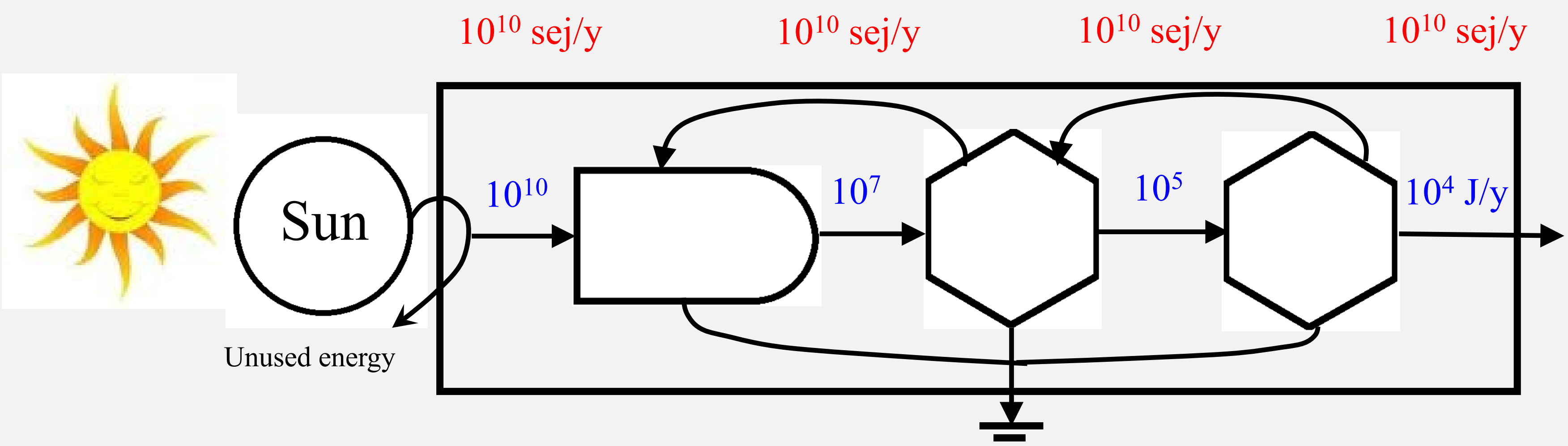
What is EMERGY?





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Unit Emergy Value (UEV)

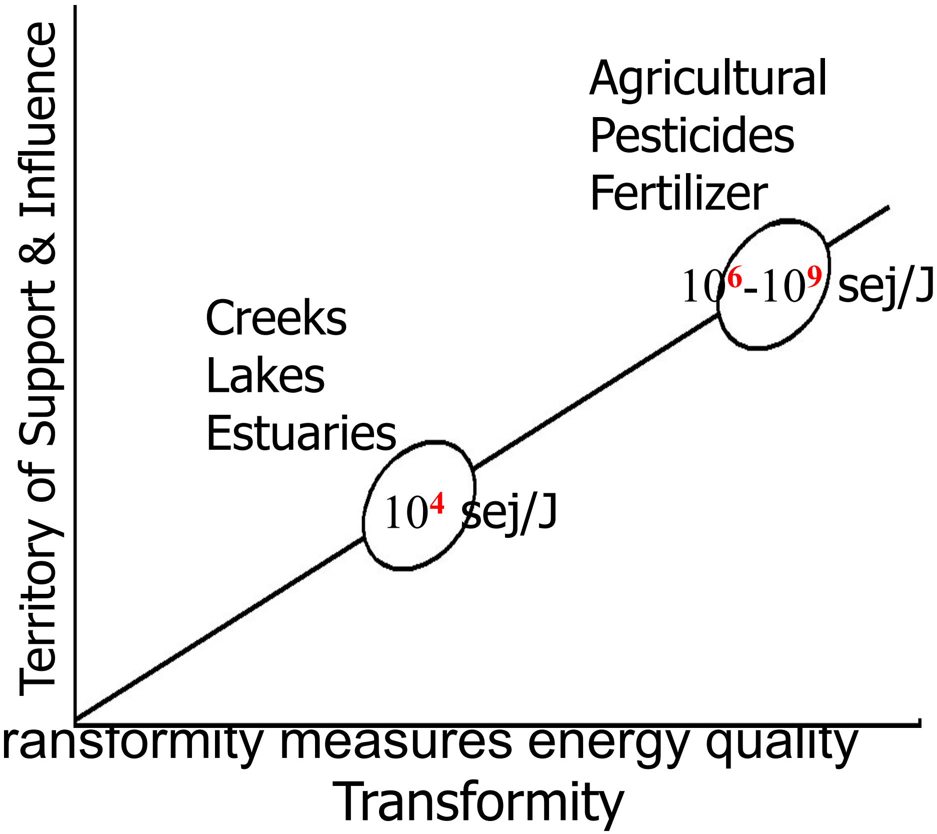
- Material (per mass) – specific emergy

$$\frac{\text{total emergy input}}{\text{mass output}} = \text{sej/g}$$

- Energy (per joule) –Transformity

$$\frac{\text{total emergy input}}{\text{energy output}} = \text{sej/J}$$

Transformity



- Transformity measures energy quality

- High transformity = high hierarchical order
- High transformity = high territory of influence
- High transformity = more emergy required to make product flow
- High transformity = less efficient

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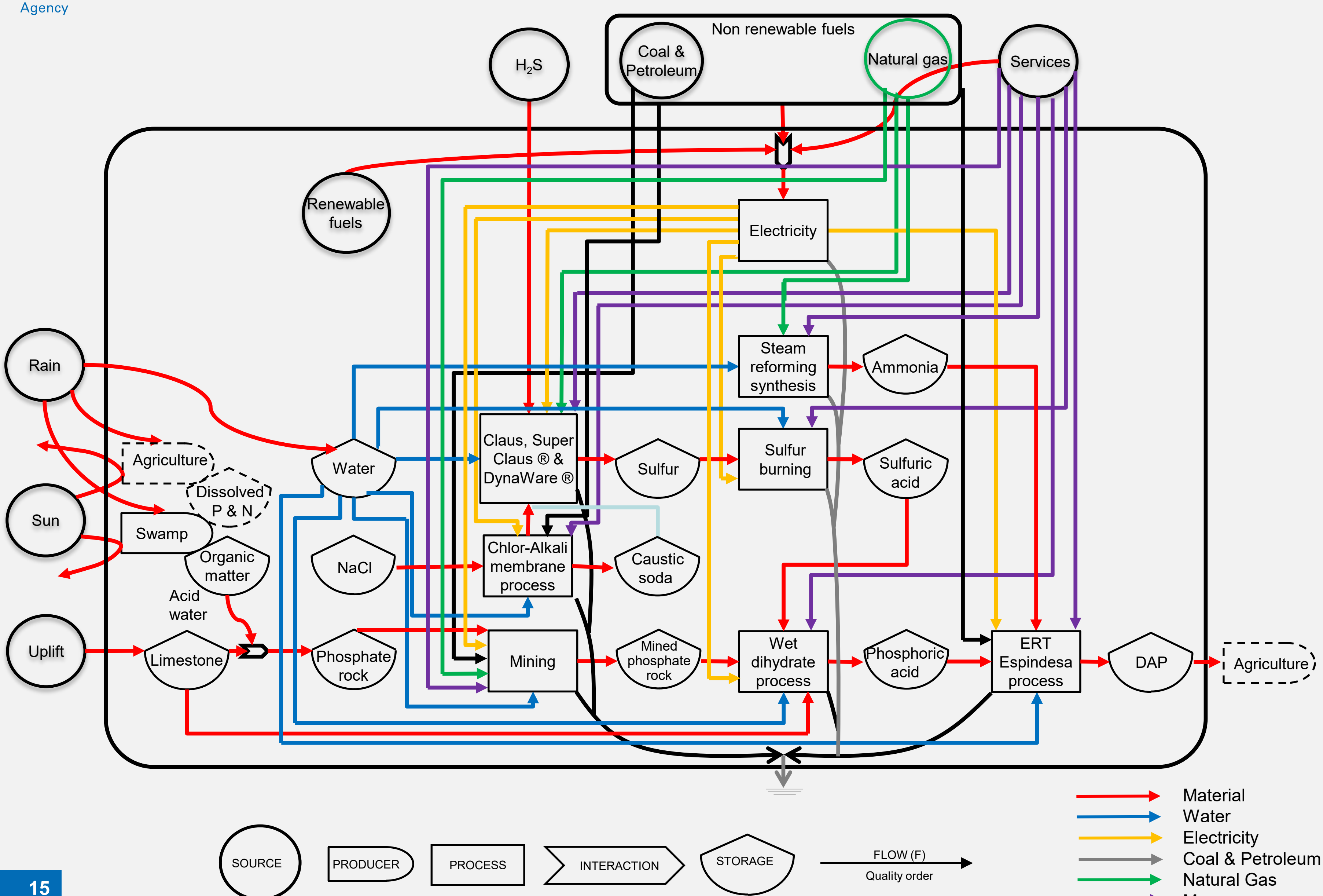
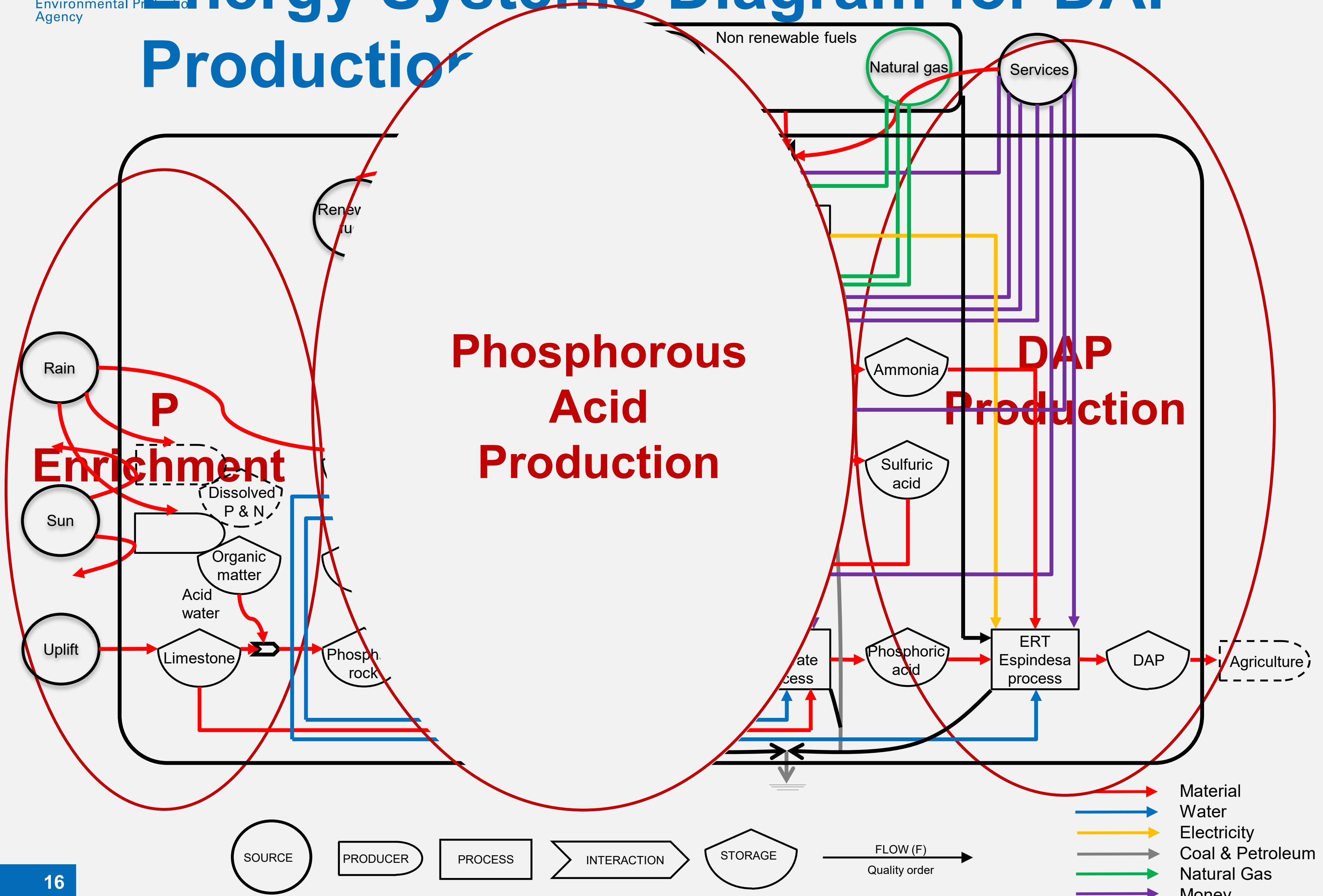
Energy Systems Diagram for DAP Production



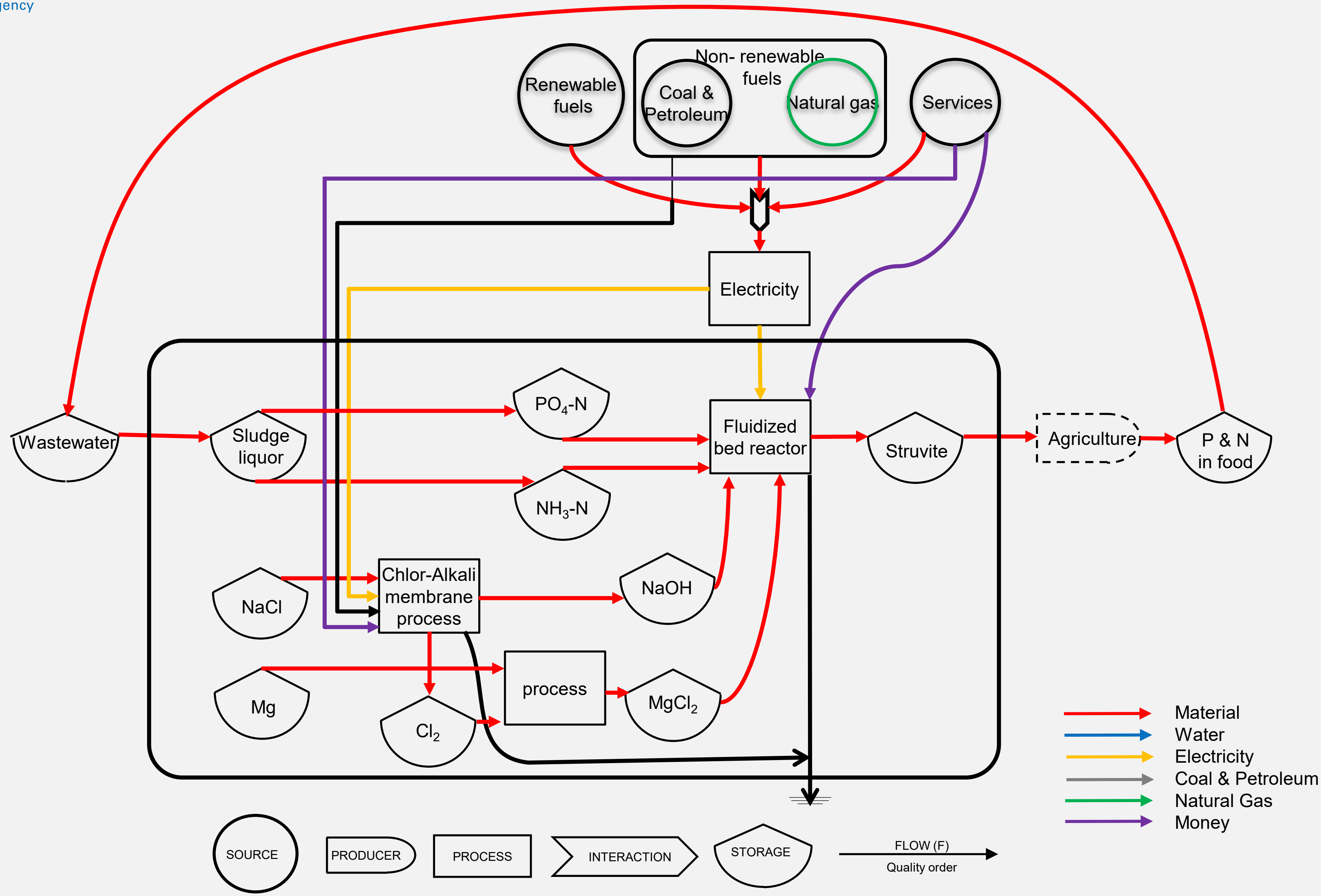
External forcing functions (circles) provide inflow energy materials and information to the producers (bullet-shape symbols). Internal storages (tank symbols) and economic and social subsystems (boxes) are shown

Energy Systems Diagram for DAP Production



External forcing functions (circles) provide inflow energy materials and information to the producers (bullet-shape symbols). Internal storages (tank symbols) and economic and social subsystems (boxes) are shown

Emergy Systems Diagram for Nutrient Recovery



External forcing functions (circles) provide inflow energy materials and information to the producers (bullet-shape symbols). Internal storages (tank symbols) and economic and social subsystems (boxes) are shown

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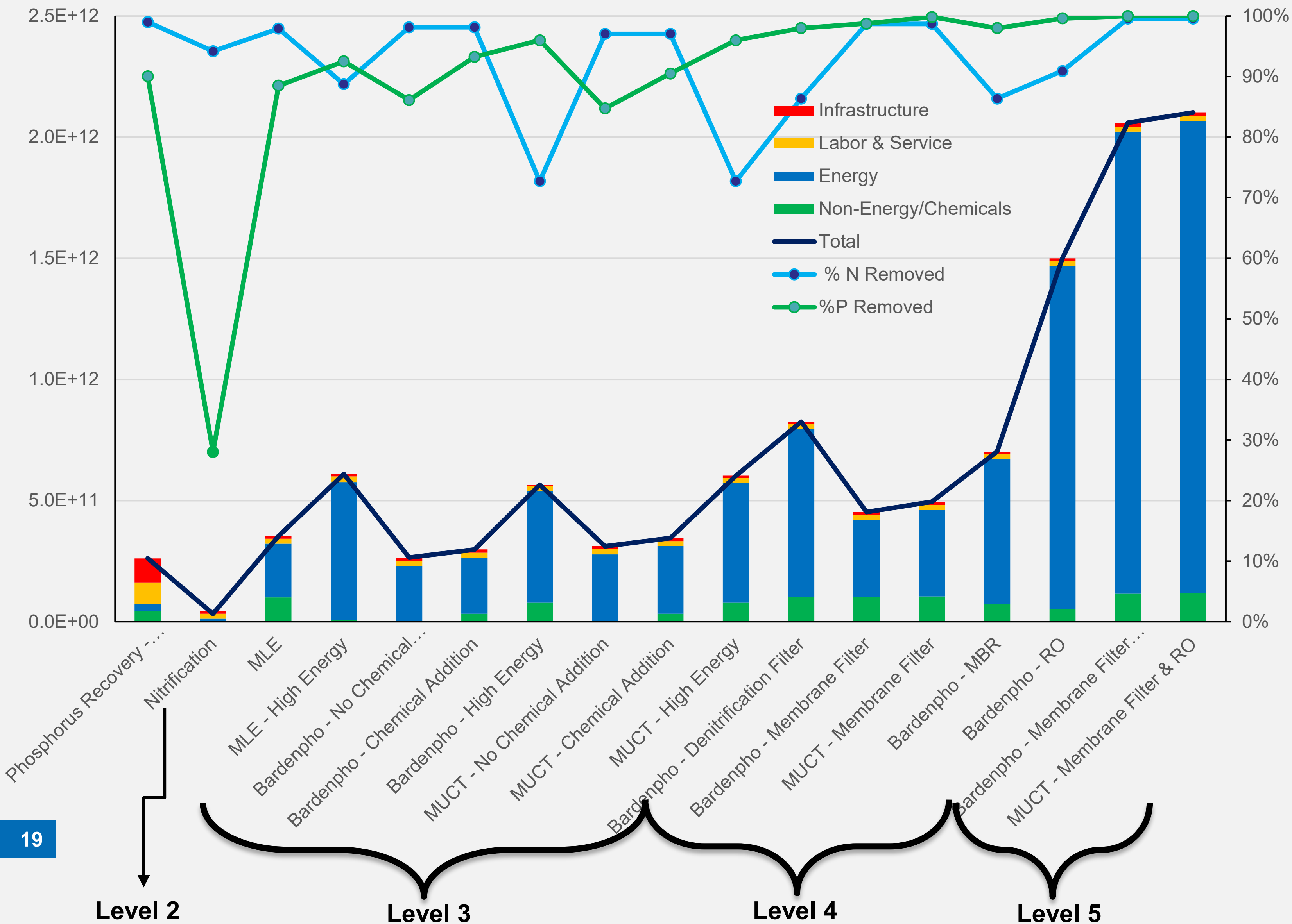
Removal Processes Considered for

Treatment Level (Effluent Limits)	Nutrient Removal/Recovery Process	Energy (kWh/m³)	Influent Ammonia (mg/L as NH_3-N)	Influent P (mg/L as P)
Recovery	Phosphorus Recovery - Anammox	0.14	20	7
Level 2 (TN – 8 mg/L, TP – 1 mg/L)	Nitrification	0.23	24	10
Level 3 (TN – 4-8 mg/L, TP – 0.1-0.3 mg/L)	MLE	0.28	23	8
	MLE - High Energy	0.59	32	8
	Bardenpho - No Chemical Addition	0.29	23	8
	Bardenpho - Chemical Addition	0.29	23	8
	Bardenpho - High Energy	0.58	22	5
	MUCT - No Chemical Addition	0.35	23	8
	MUCT - Chemical Addition	0.35	23	8
	MUCT - High Energy	0.56	22	5
Level 4 (TN – 3 mg/L, TP – 0.1 mg/L)	Bardenpho - Denitrification Filter	0.53	22	5
	Bardenpho - Membrane Filter	0.4	23	8
	MUCT - Membrane Filter	0.45	23	8
	Bardenpho - MBR	0.53	22	5
Level 5 (TN - <2 mg/L, TP<0.02 mg/L)	Bardenpho - RO	0.60	22	5
	Bardenpho - Membrane Filter & RO	2.4	23	8
	MUCT - Membrane Filter & RO	2.45	23	8

Total Emergy Comparison between Different Nutrient Removal and Recovery Technology



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- Tools: emergy and LCA
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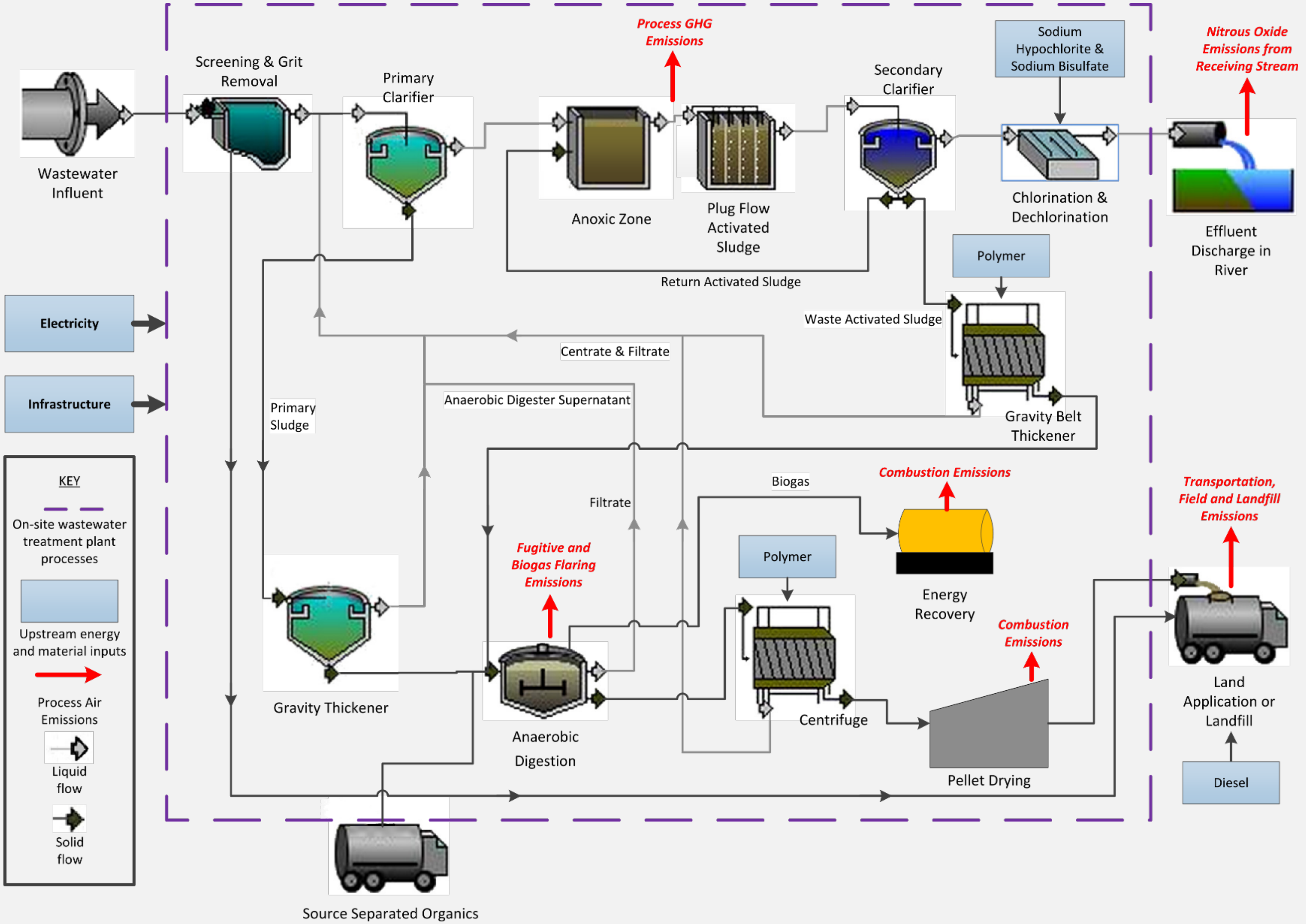
Study Objectives

- Assess environmental and cost impact of:
  - –Expanding anaerobic digester (AD) capacity for food waste co-digestion.
  - –Installing combined heat and power (CHP).
  - –Variable digester performance.
  - –Avoided waste scenarios.

Process Flow Diagram



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Waste Scenarios Analyzed

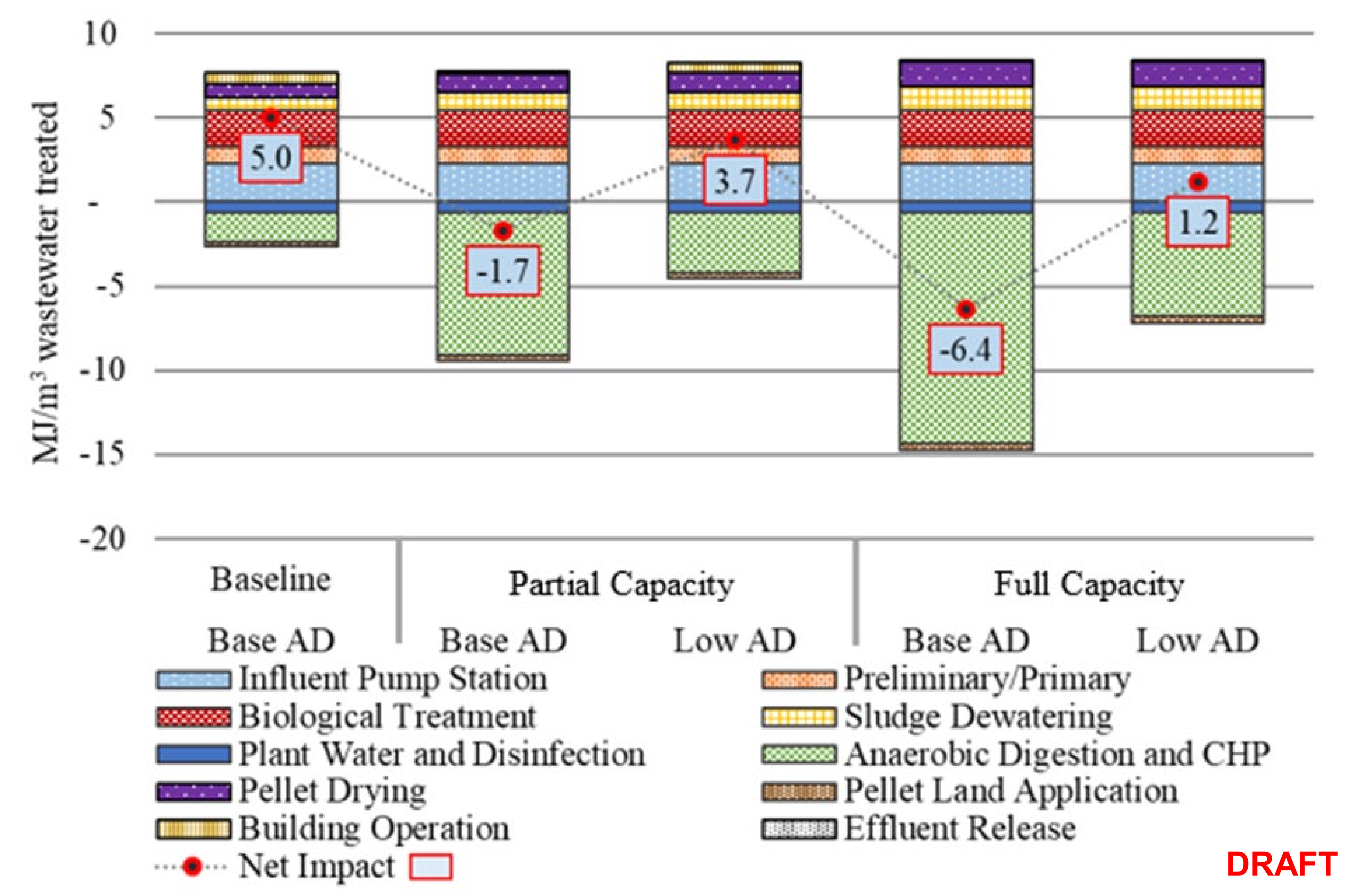
Scenario	Waste Type	Quantity (gpd)
All Scenarios	Septage	80,000
	Municipal Solids*	8,000
Scenario 1: Base (2016)	Primary & WAS	172,000
	SSO	-
Scenario 2: 50% SSO Capacity	Primary & WAS	179,000
	SSO	46,000
Scenario 3: 100% SSO Capacity	Primary & WAS	188,000
	SSO	92,000

Partial Capacity (Scenario 2)

Full Capacity (Scenario 3)

***Municipal Solids:** Trucked in primary and waste activated sludge.

Cumulative Energy Demand
(Base AD Results by Treatment Group)



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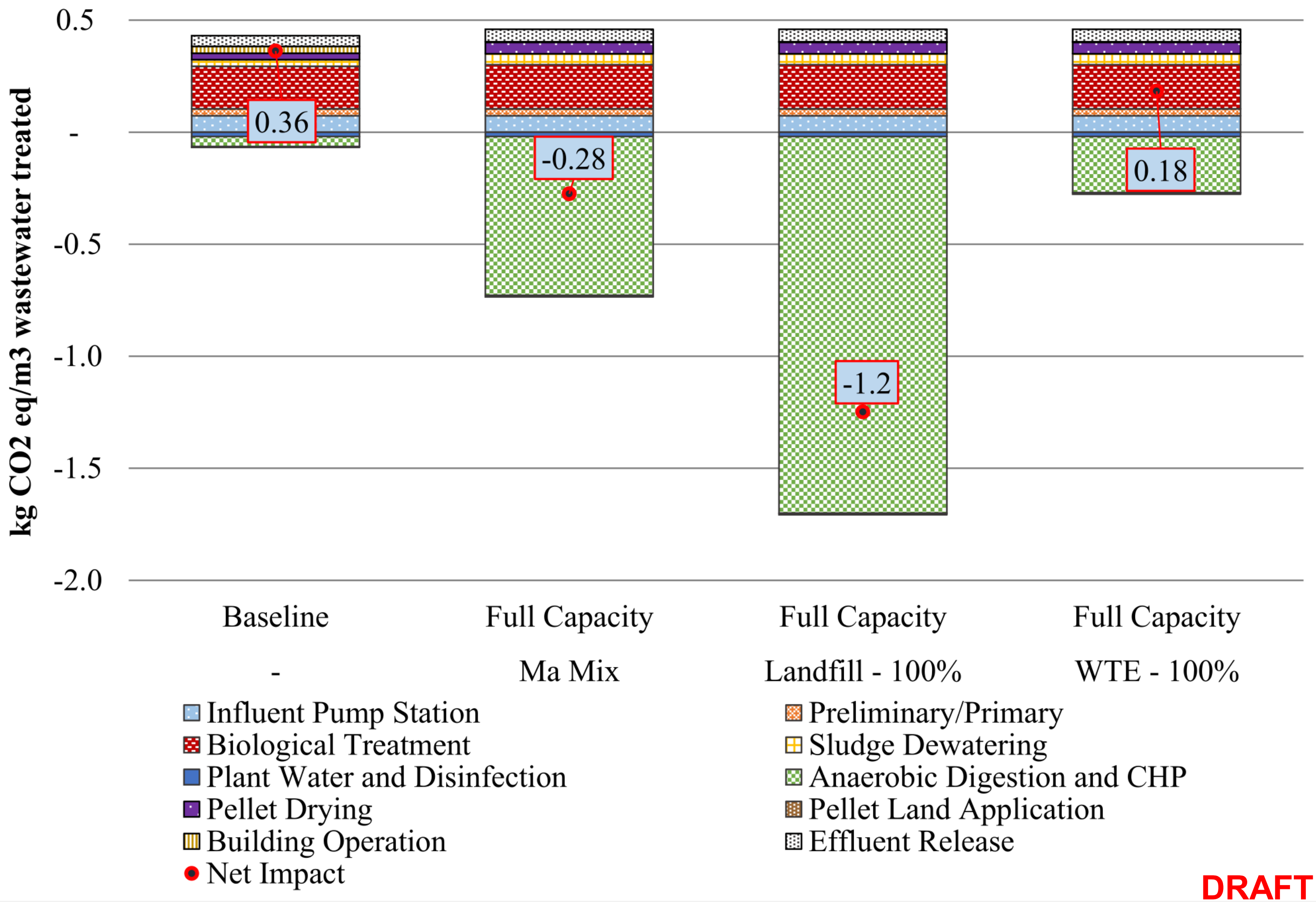
Avoided EOL Process Sensitivity



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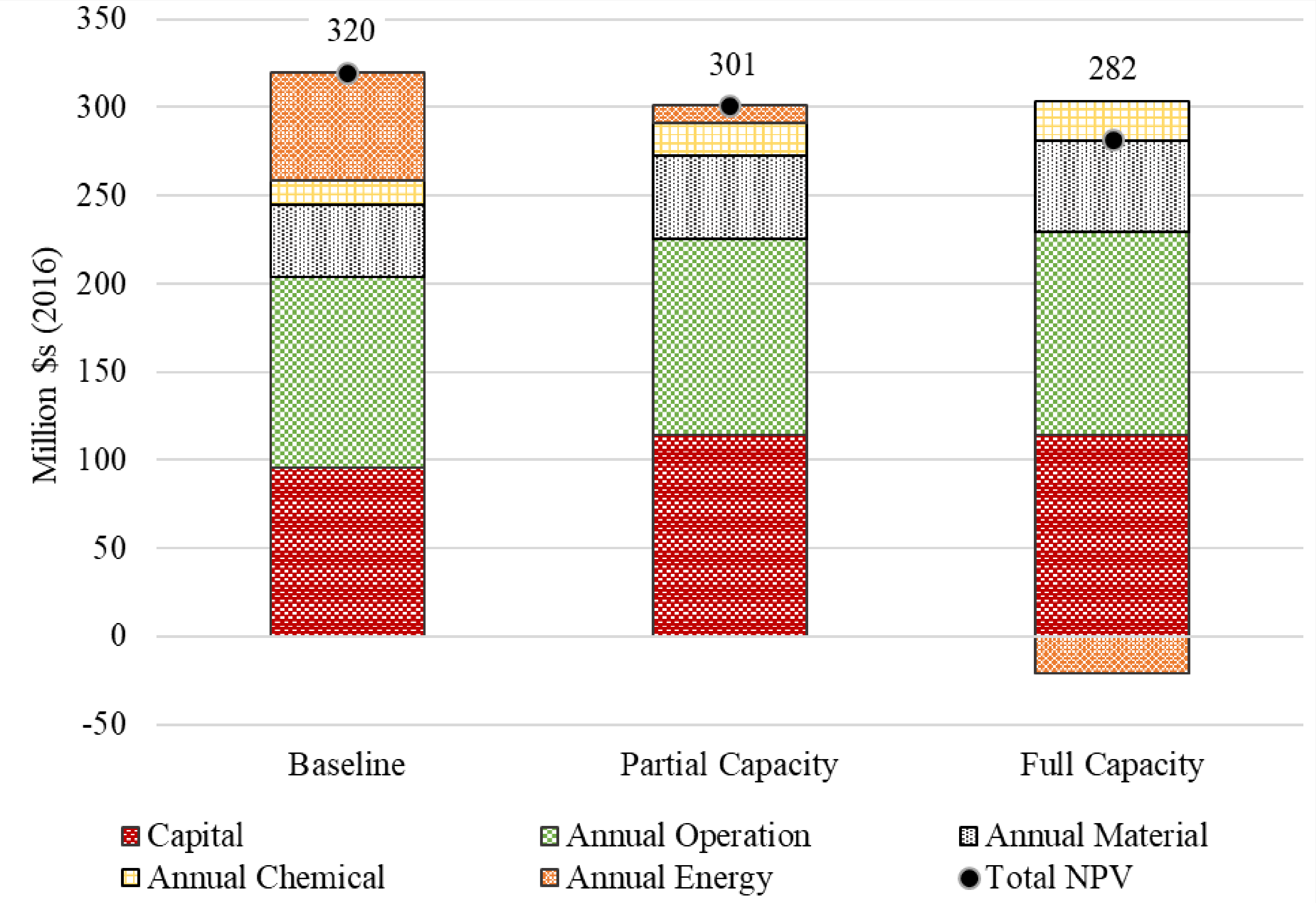
Cost Analysis Results

- Indicate a 7 and 14 year payback period for the investment in AD and CHP systems for the full and partial capacity scenarios.



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Project Background

- Project team has completed several life cycle assessment (LCA) and cost studies on decentralized NPR configurations
- Latest study focused on large urban buildings in San Francisco, treating mixed wastewater or source separated graywater with aerobic membrane bioreactor (MBR)
- Work expanded to an EPA web-based calculator

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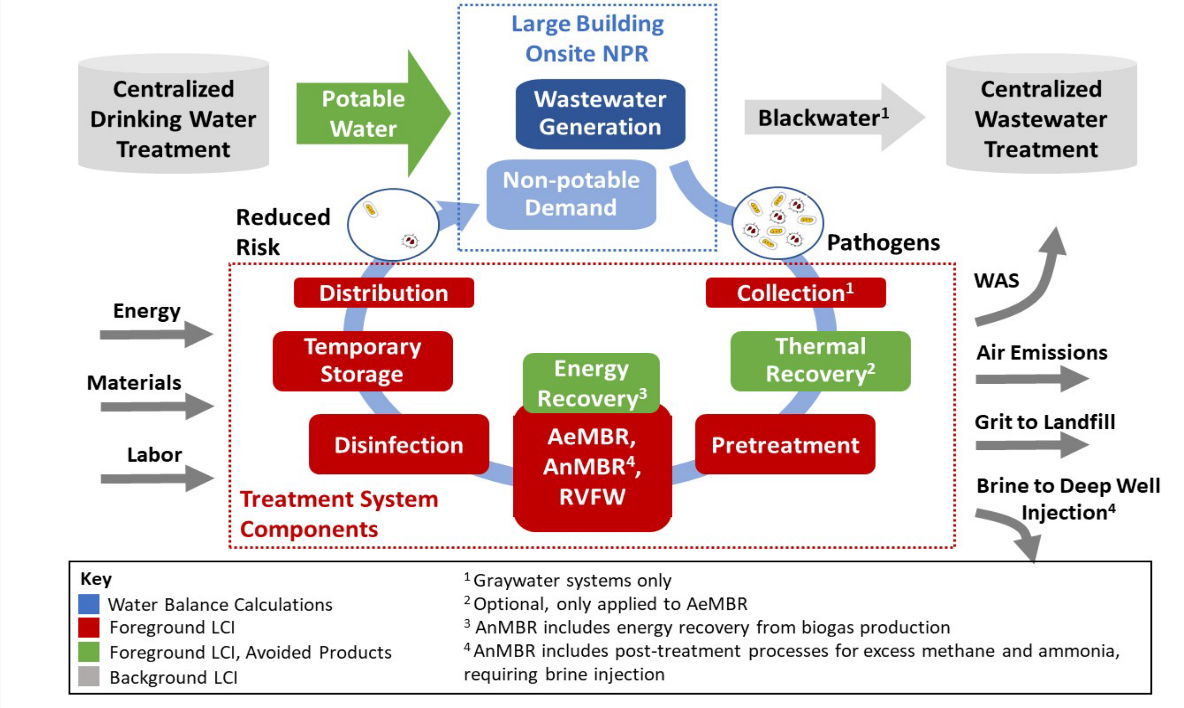
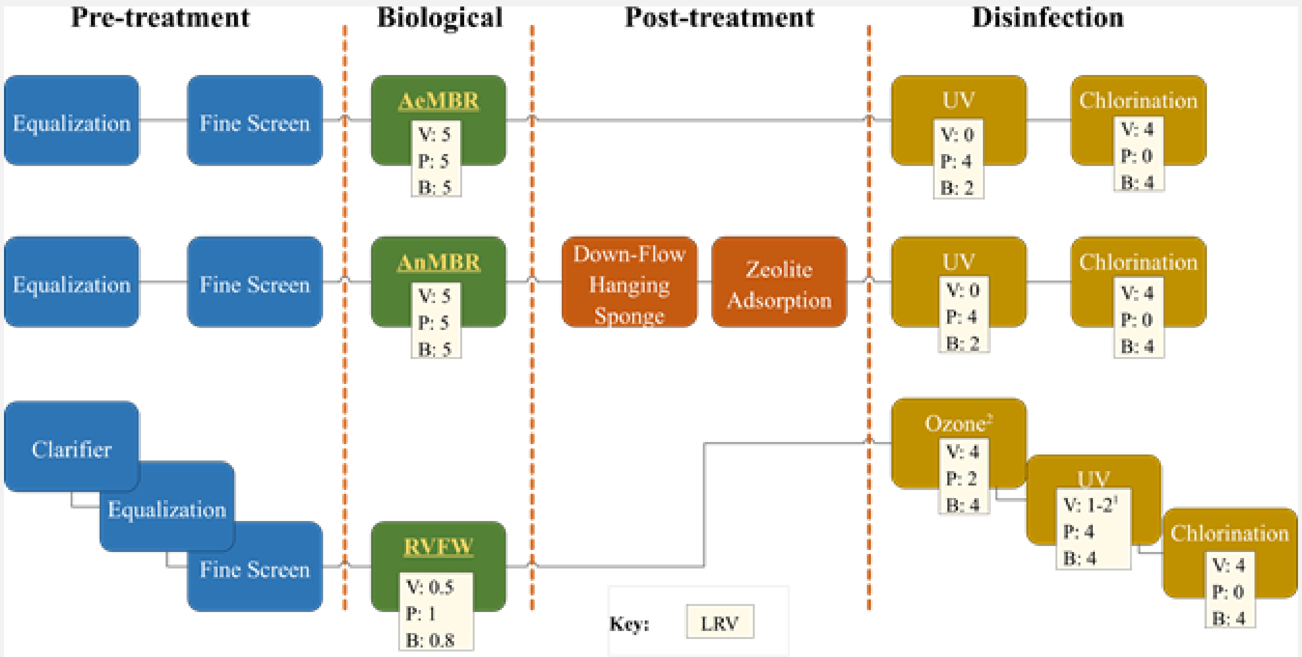
Life Cycle Approach



Analyze cost and environmental impact of systems treating mixed wastewater and source separated graywater for onsite NPR (0.01-0.016 MGD). Integrated results with microbial risk assessment.

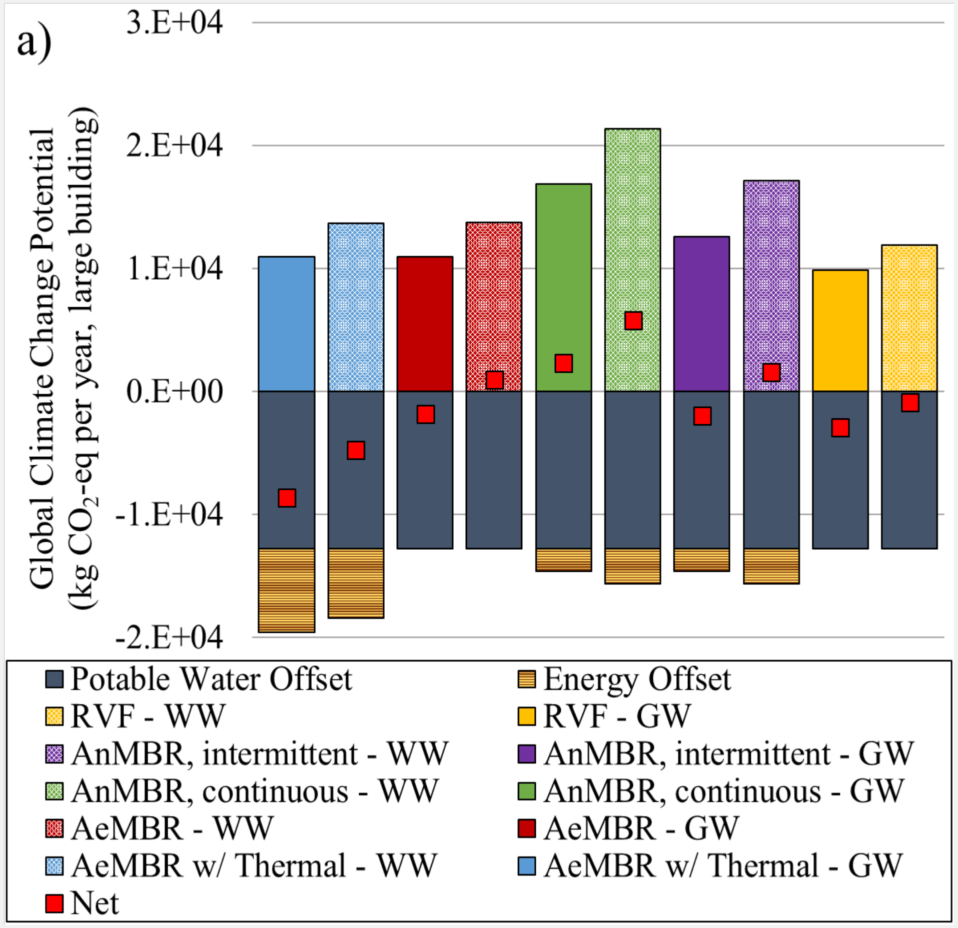
Life Cycle Approach



[1] UV virus LRV varies due to application of different UV doses for mixed WW and GW RVFWs.
[2] The ozone disinfection process only applies to the RVFW system treating mixed wastewater.

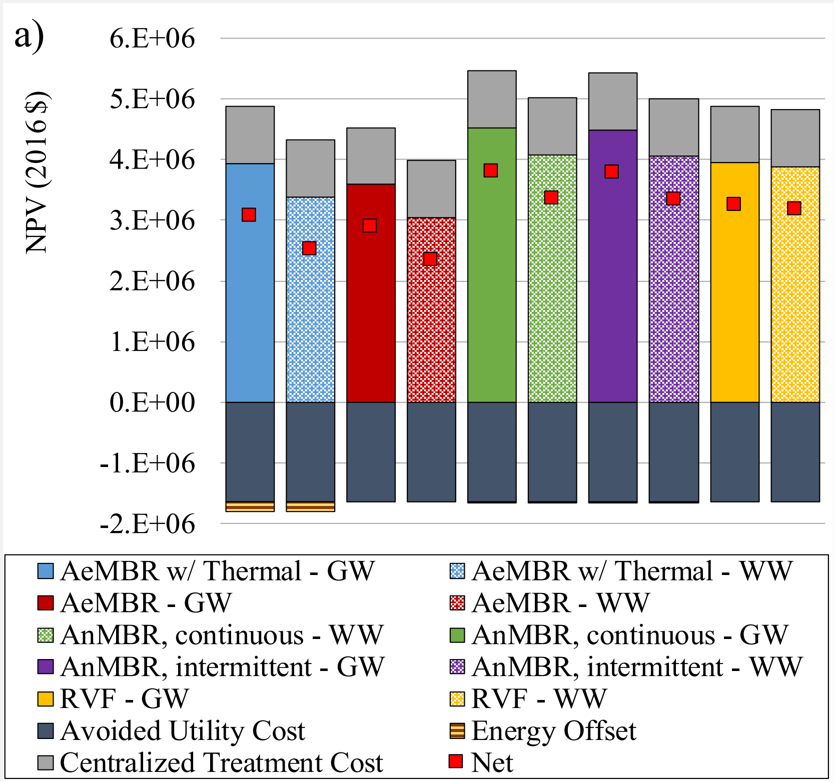
Analyze cost and environmental impact of systems treating mixed wastewater and source separated graywater for onsite NPR (0.01-0.016 MGD). Integrated results with microbial risk assessment.

Global Warming Potential



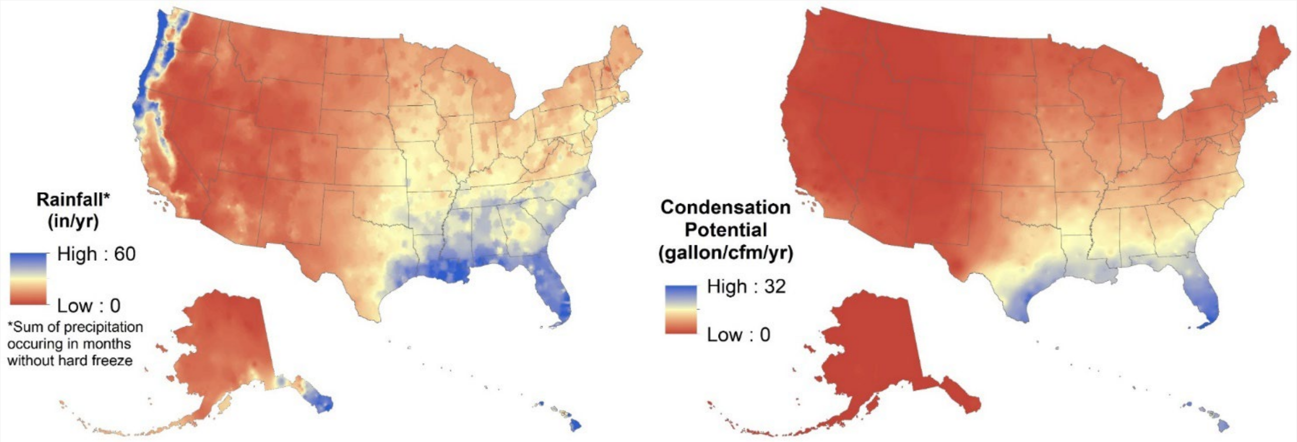
From Arden et al. 2020

System Cost (Net Present Value)



From Arden et al. 2020

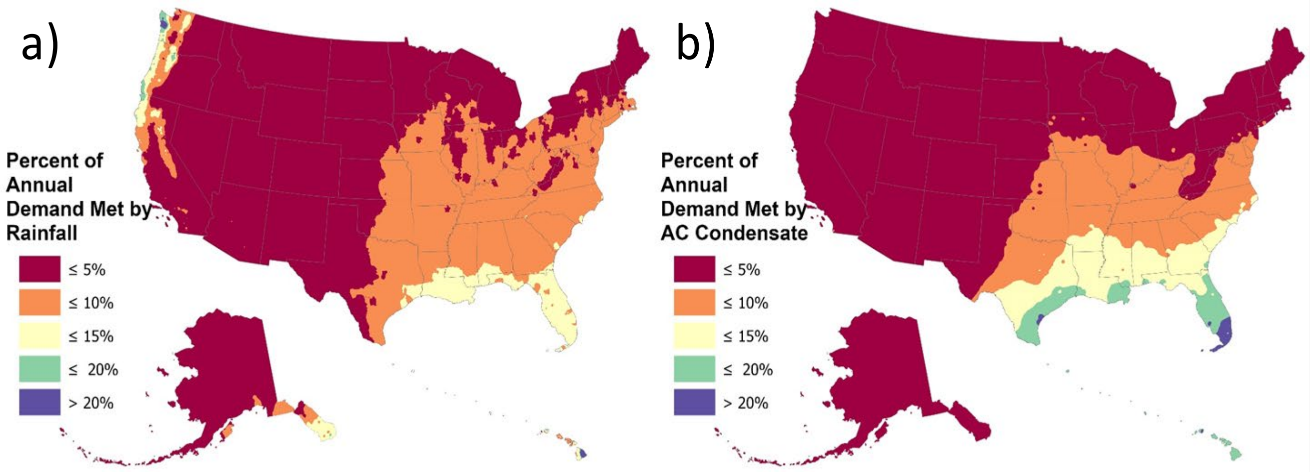
RWH and ACH Availability Models



- Long-term monthly data
- Filtered for hard freeze (TMY3 data, >4 consecutive hours with temperatures <28˚F)

- Relative humidity (RH) model
- Function of outdoor RH, indoor RH, % outdoor air
- TMY3 data used (~2000 stations)

Percent of Annual Non-Potable Demand Met



Mixed WW and GW systems always meet non-potable demand under modeled conditions.

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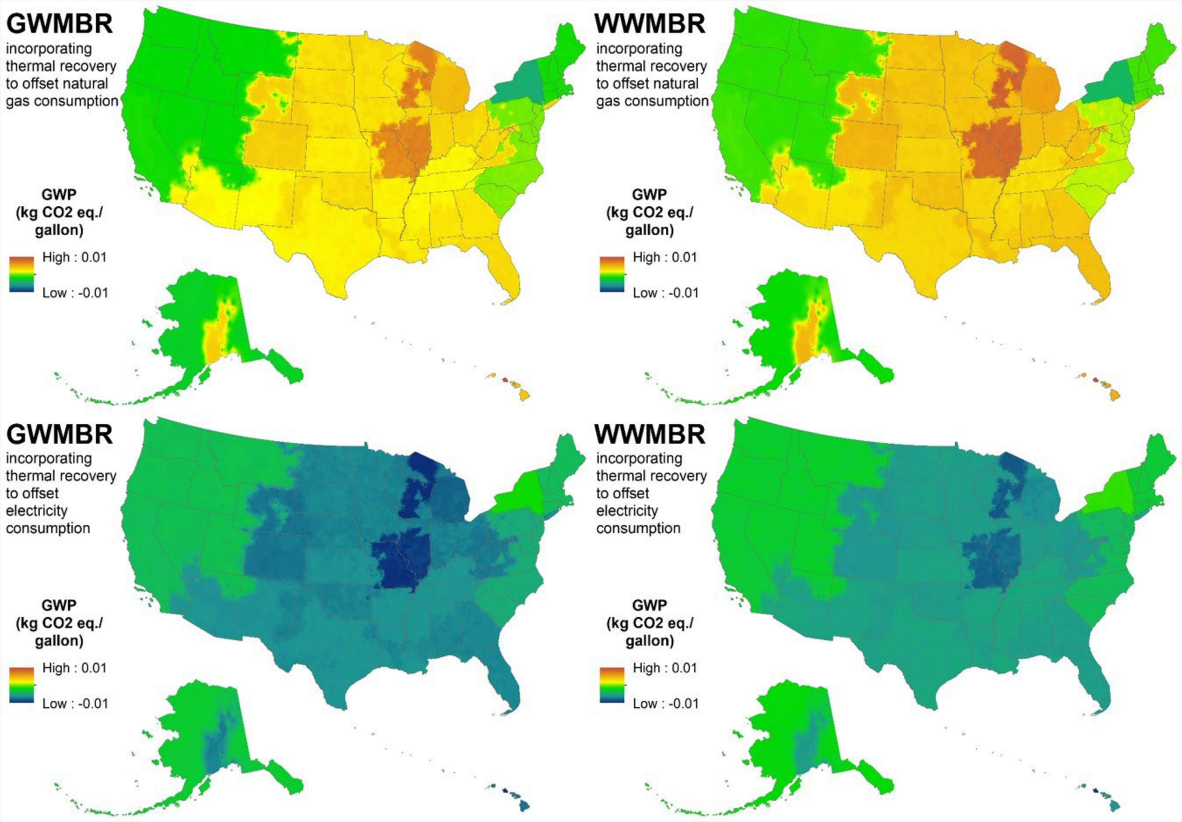
Fixed Building Global Warming Potential Across Source Waters

(With thermal recovery offsetting NG (top) and electricity (bottom))



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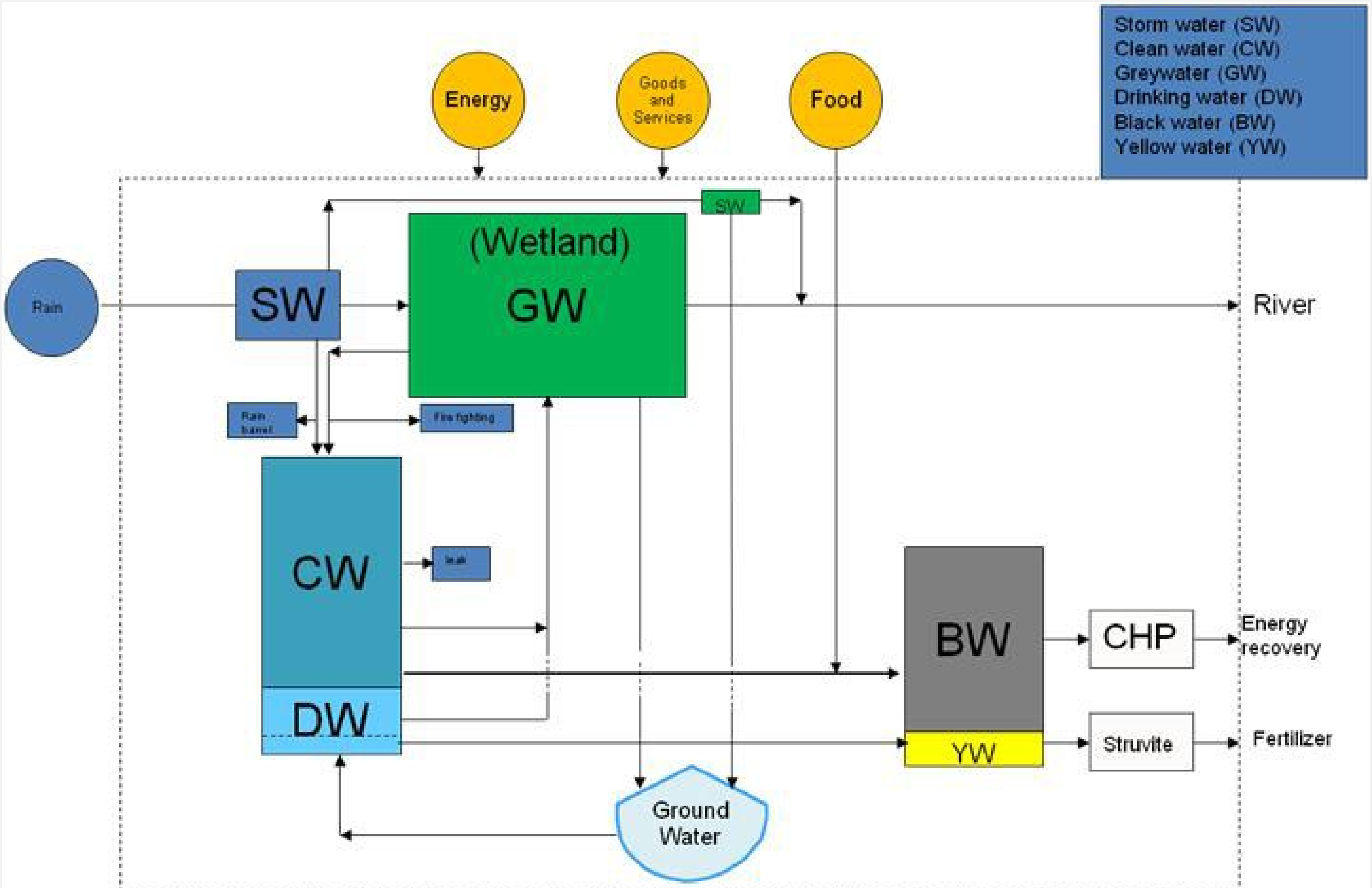
New concepts

- Fit for purpose
- Source separation and resource recovery
  - Nutrient recovery
  - Energy recovery
- Decentralization

Water Systems for the City of Tomorrow



Ma, X., Xue, X., Gonzalez-Mejia, A., Garland, J., and Cashdollar, J. (2015). "Sustainable Water Systems for the City of Tomorrow — A Conceptual Framework." ***Sustainability* 7**(9): 12071

Water Systems for the City of Tomorrow

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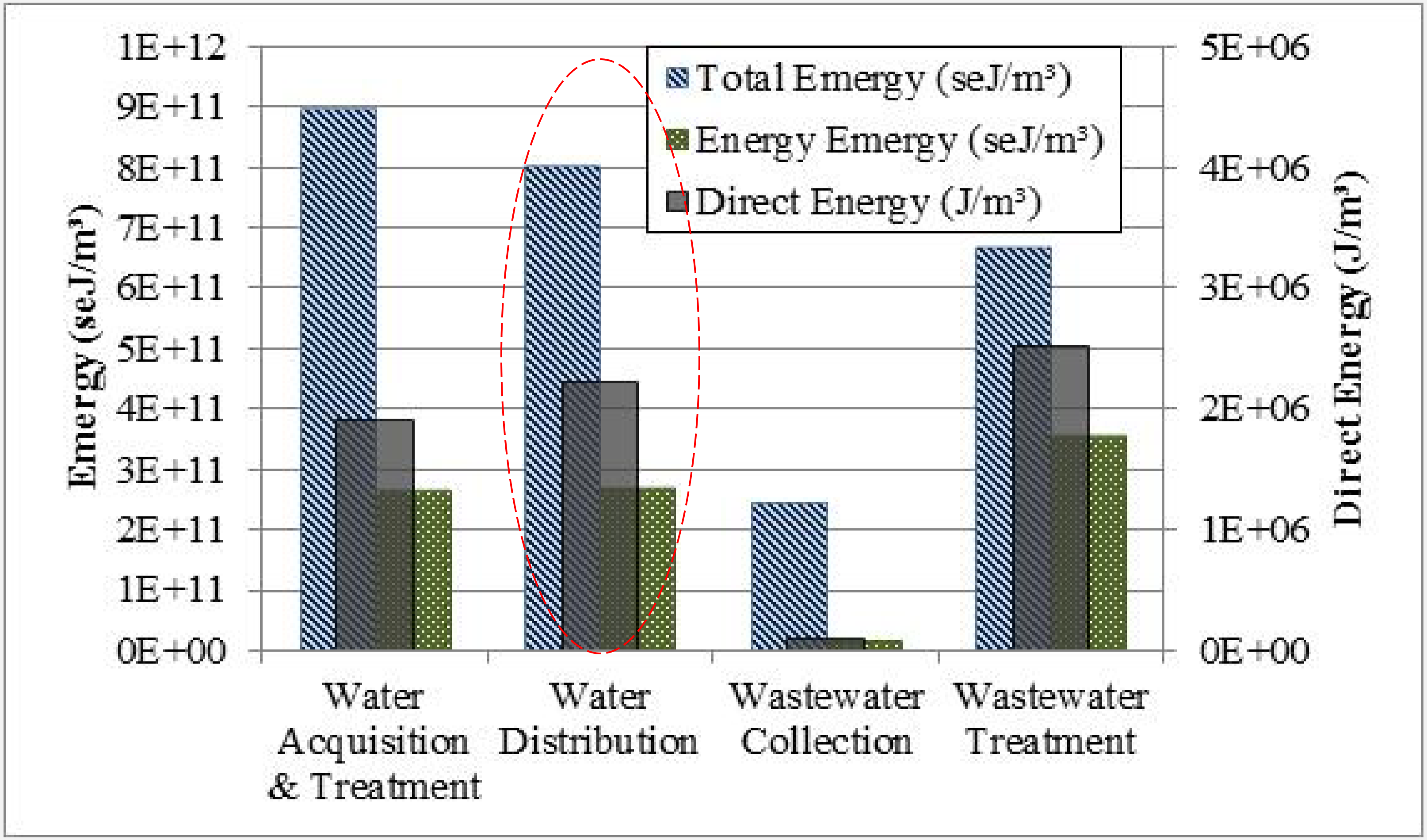
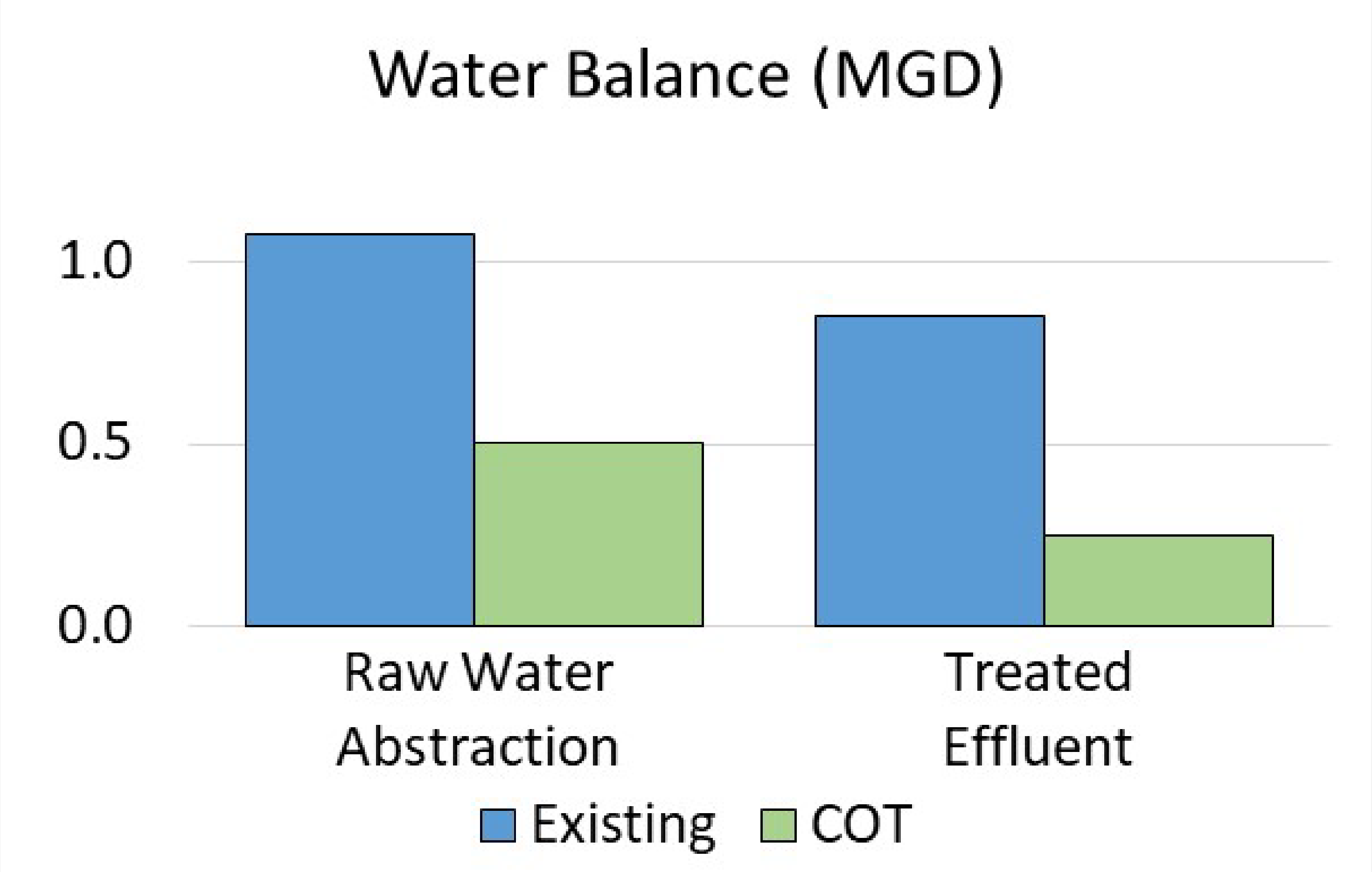
Current Urban Water Systems - Cincinnati

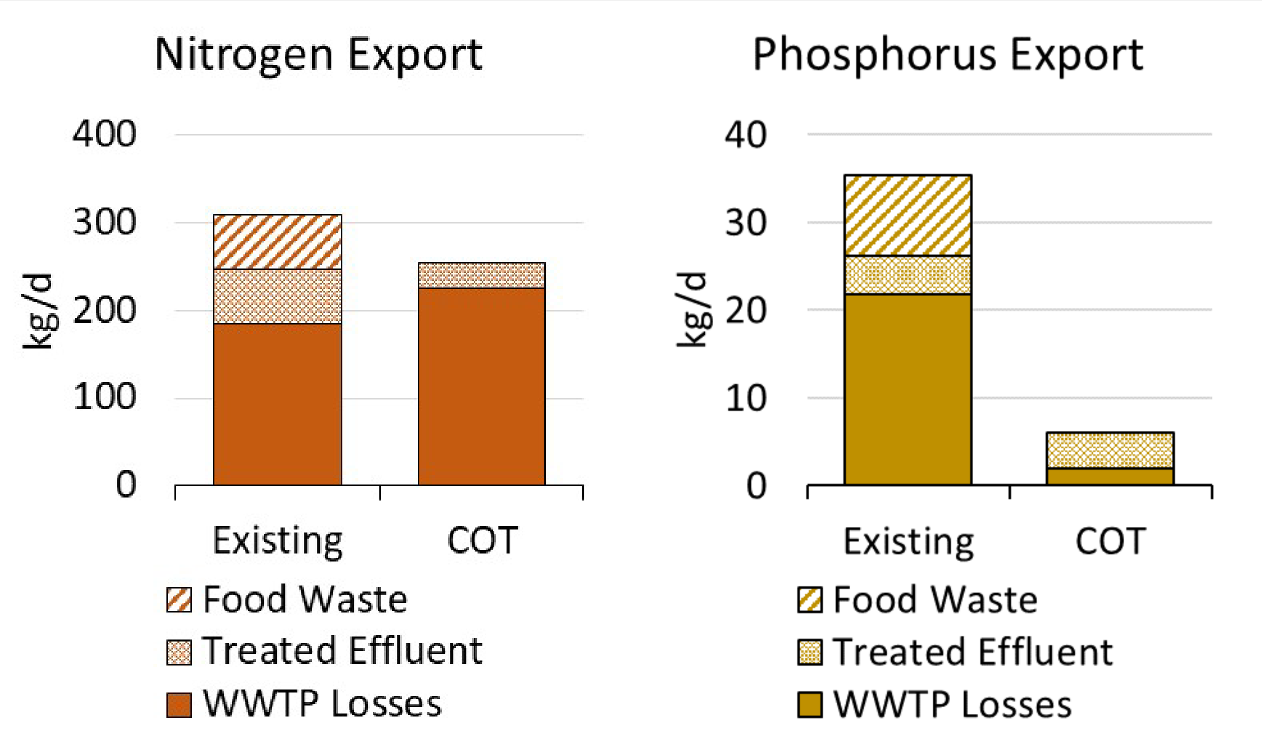


City of Tomorrow Results – Water Balance



- Per-capita demand between each scenario same except toilets – assumed high efficiency toilets for COT (6.6 vs 17 gpcd)

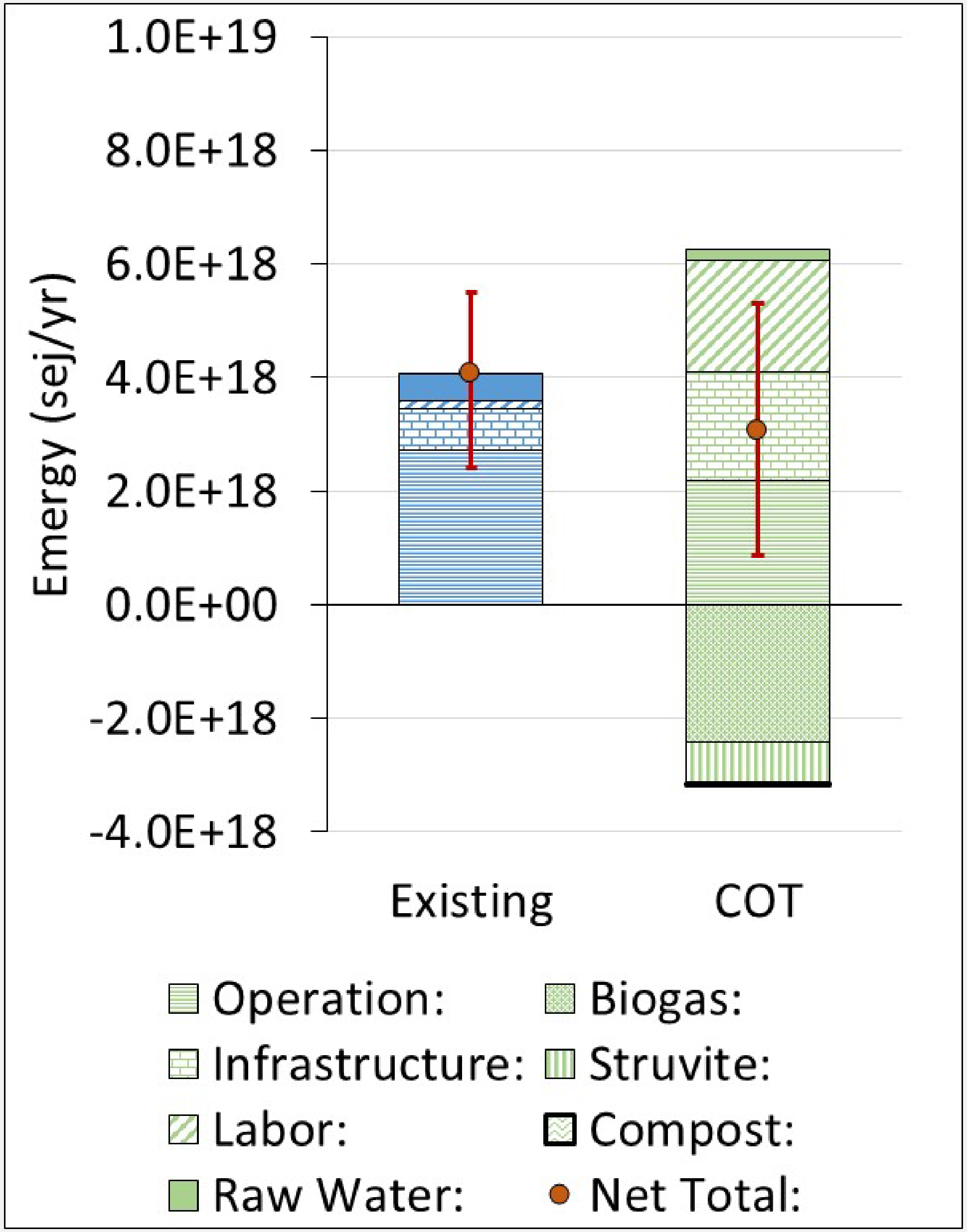
City of Tomorrow Results – Nutrient Balance



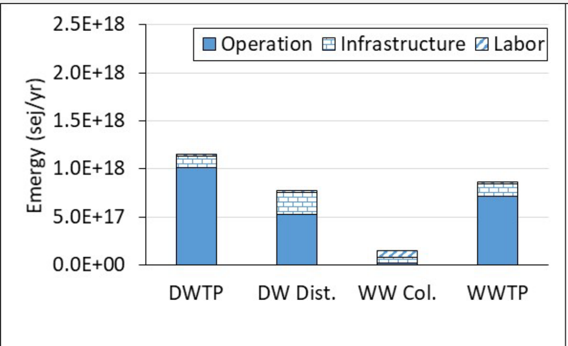
- Struvite production is much more effective at capturing phosphorus (by weight, struvite is 12.6% P, 5.7% N)
- WWTP Losses refer to denitrification and sludge disposal pathways
- ***Nitrogen concentration in COT effluent is still too high (~50 mg/L)

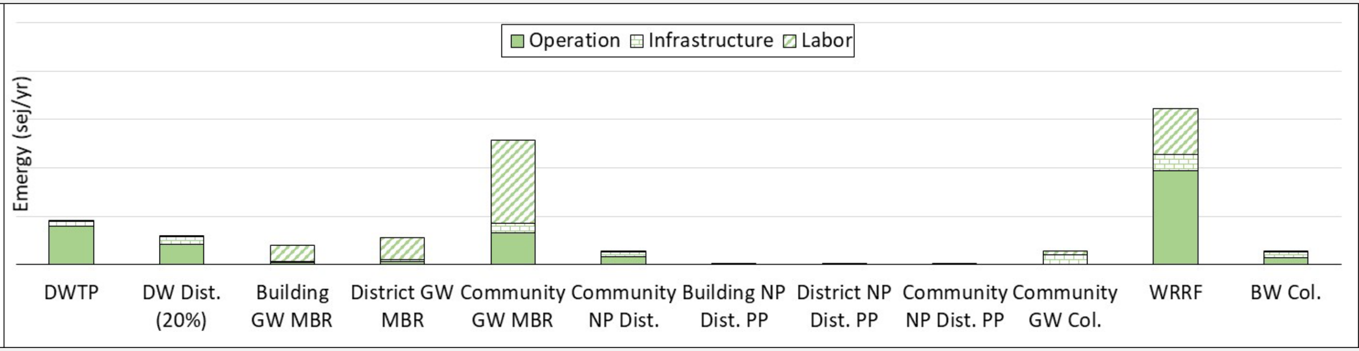
City of Tomorrow Results – Emergy

- 10,000 simulations run with random selections within pre-defined range for each UEV
- Error bars represent min/max of Net Total results
- Net totals are slightly less under COT conditions
- Note large difference in labor inputs – economies of scale
- Biogas is most important resource recovery pathway



City of Tomorrow Results – Emergy





- Total emergy inputs to each major system component
- Existing system dominated by DWTP, WWTP
- COT dominated by labor to MBRs and WRRF (economies of scale)
- WRRF has relatively large resource requirements, but is responsible for production of all beneficial products (biogas, struvite, compost)

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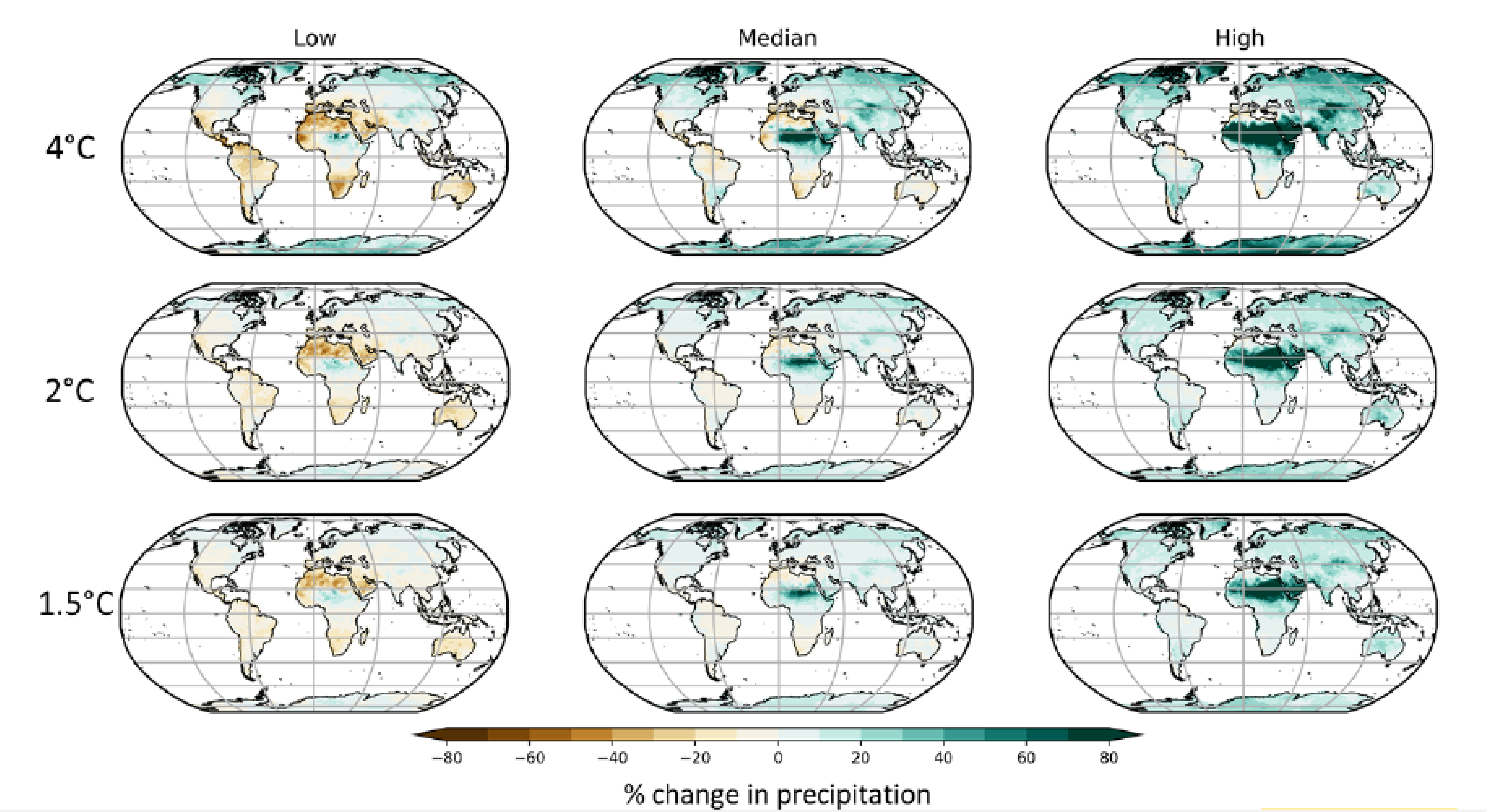
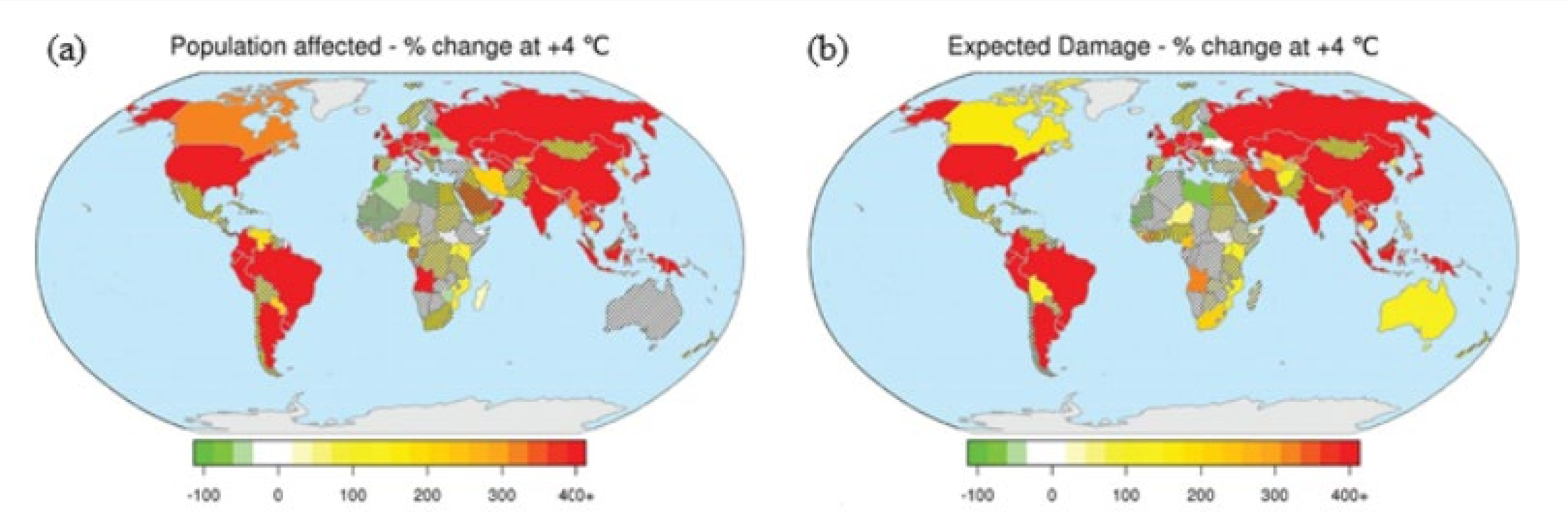
- IPCC (The Intergovernmental Panel on Climate Change)

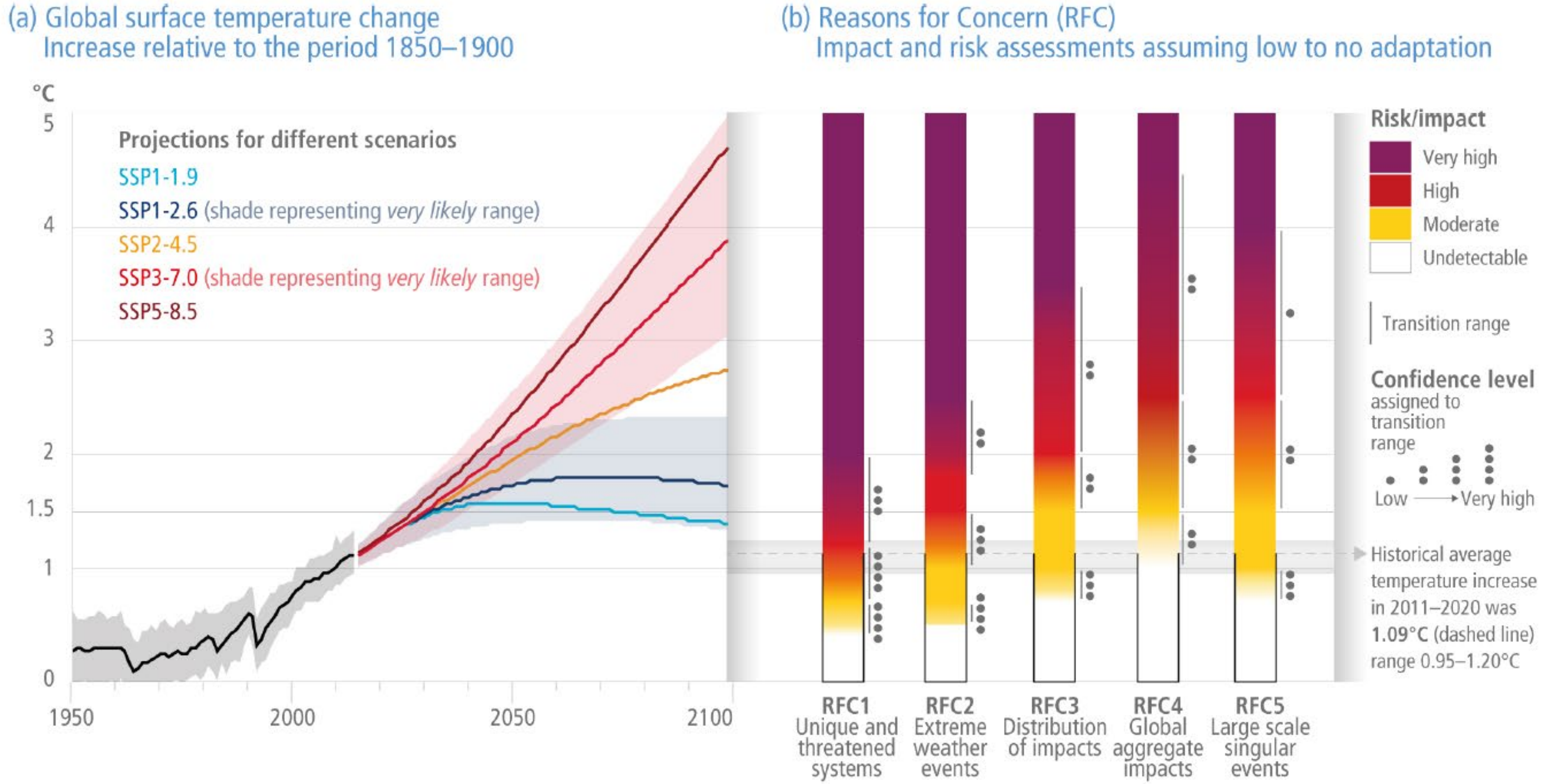
Projected Changes in Annual Mean Precipitation



Projected changes in population affected by flooding and expected damage



Global Risks for increasing levels of global warming



Take Home Messages

- Adopt system thinking in environmental management
- Apply integrated assessment metrics on innovative technologies
- Design for resilience and sustainability

Questions?

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