Life Cycle Assessment and Cost Analysis of Membrane Bioreactor Systems:
Influence of Scale, Population Density, Climate, and Methane Recovery

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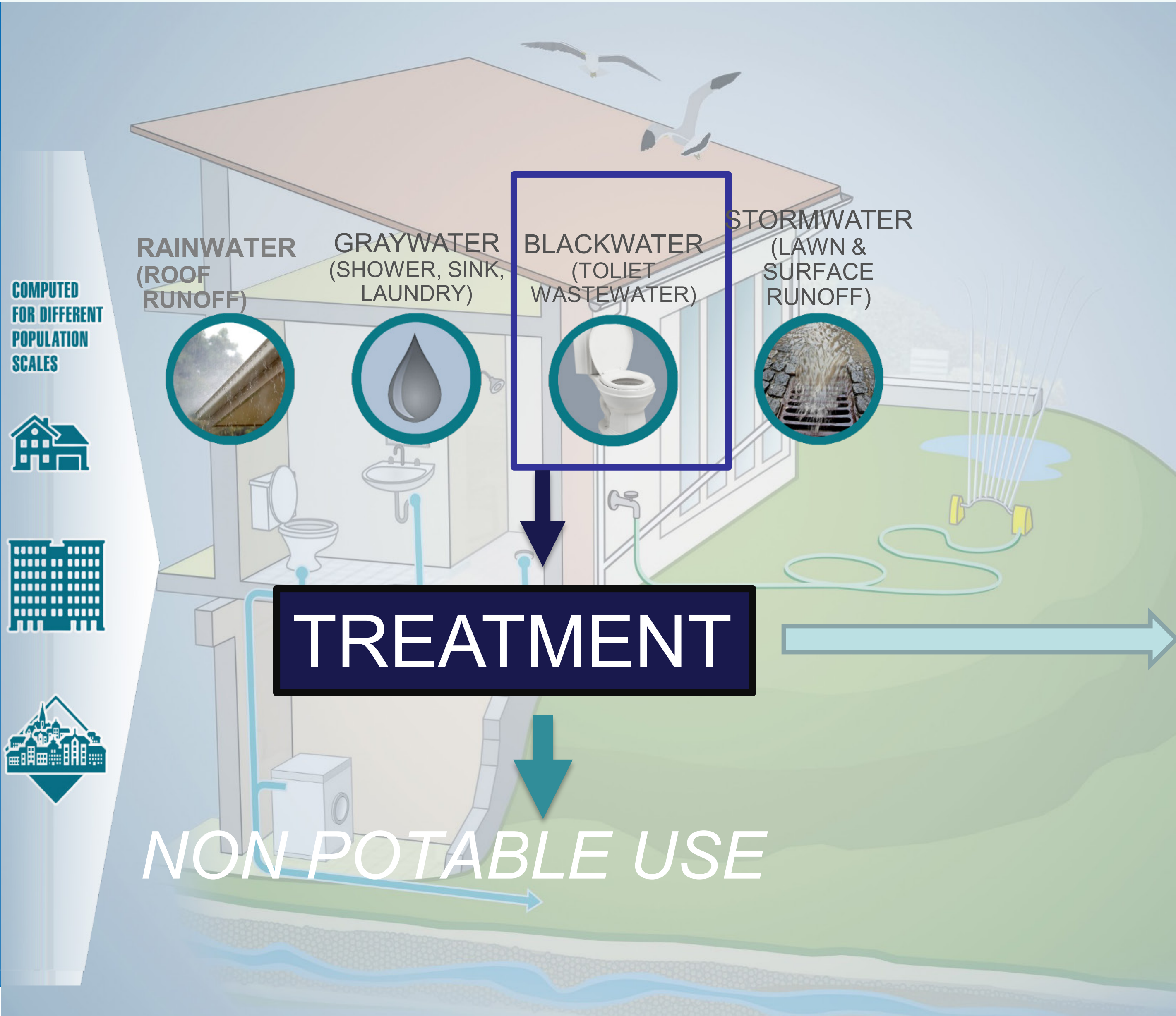
The Challenge

- Aging infrastructure and costs associated with upgrading or expanding of centralized treatment systems and distribution systems
- Water scarcity and challenges in meeting water system demands
- Meeting green building and net-zero development goals

FINDING NEW WATER Alternative Water Reuse



Aerobic Membrane Bioreactor (MBR)

Mesophilic Anaerobic MBR (AnMBR)

Psychrophilic AnMBR

Energy, Greenhouse Gas (GHG) & Cost Analysis of MBRs

- Understand environmental and cost impacts of transitional decentralized MBR systems with sewer mining
- Investigate life cycle assessment (LCA) and life cycle cost (LCC) performance of MBRs under various regional and technological parameters

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Energy and greenhouse gas life cycle assessment and cost analysis of aerobic and anaerobic membrane bioreactor systems: Influence of scale, population density, climate, and methane recovery

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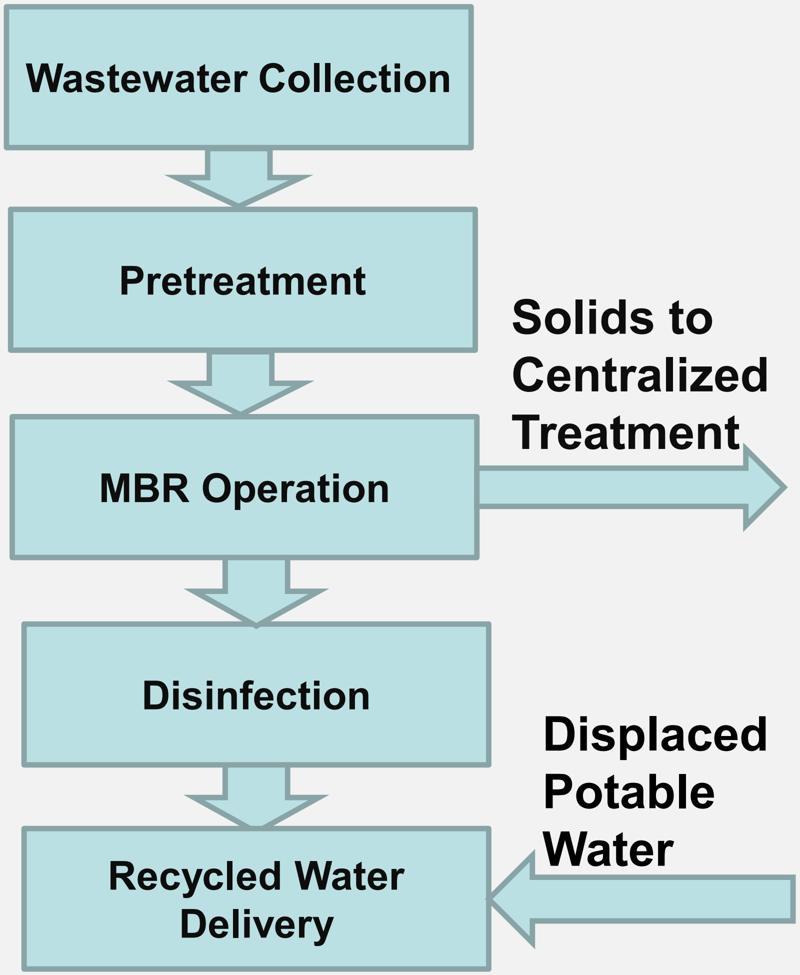
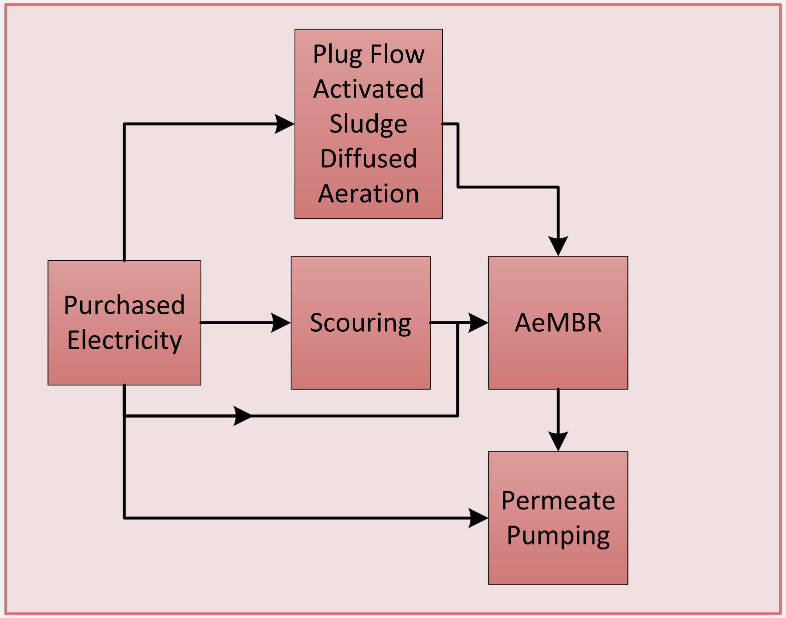
General Decentralized Treatment System Boundaries

- Boundaries start at household wastewater collection
- End at downstream use of recycled water
  - Recycled water displaces production of potable water
- MBR treatment systems transitional, use existing infrastructure for sludge processes
- For AnMBR, CH_4 from headspace and is recovered converted to electricity/heat

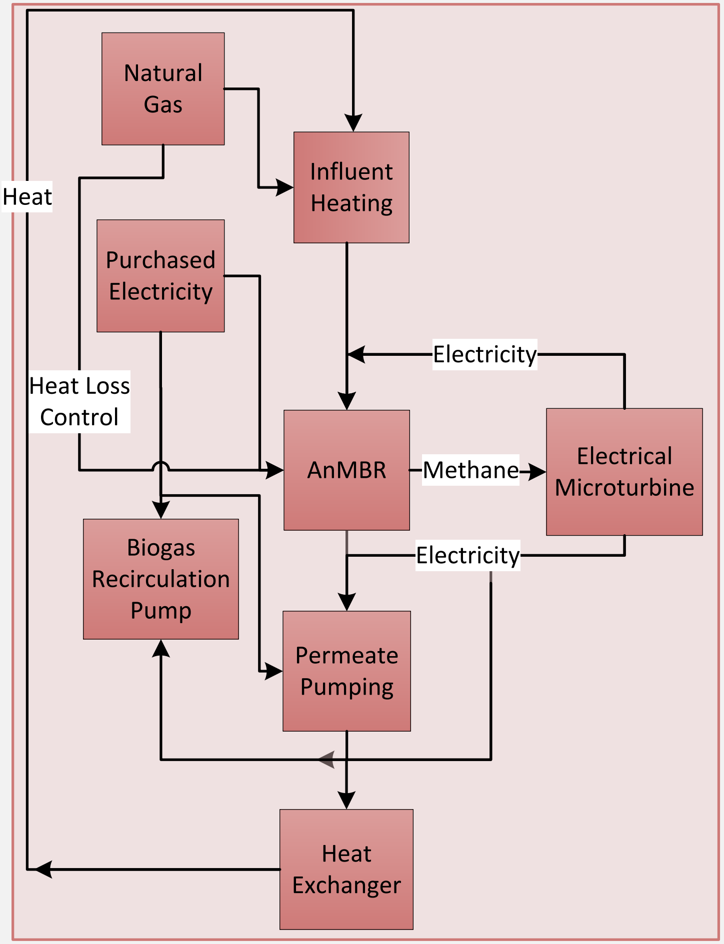


MBR Operation

AeMBR Subprocesses



AnMBR Subprocesses

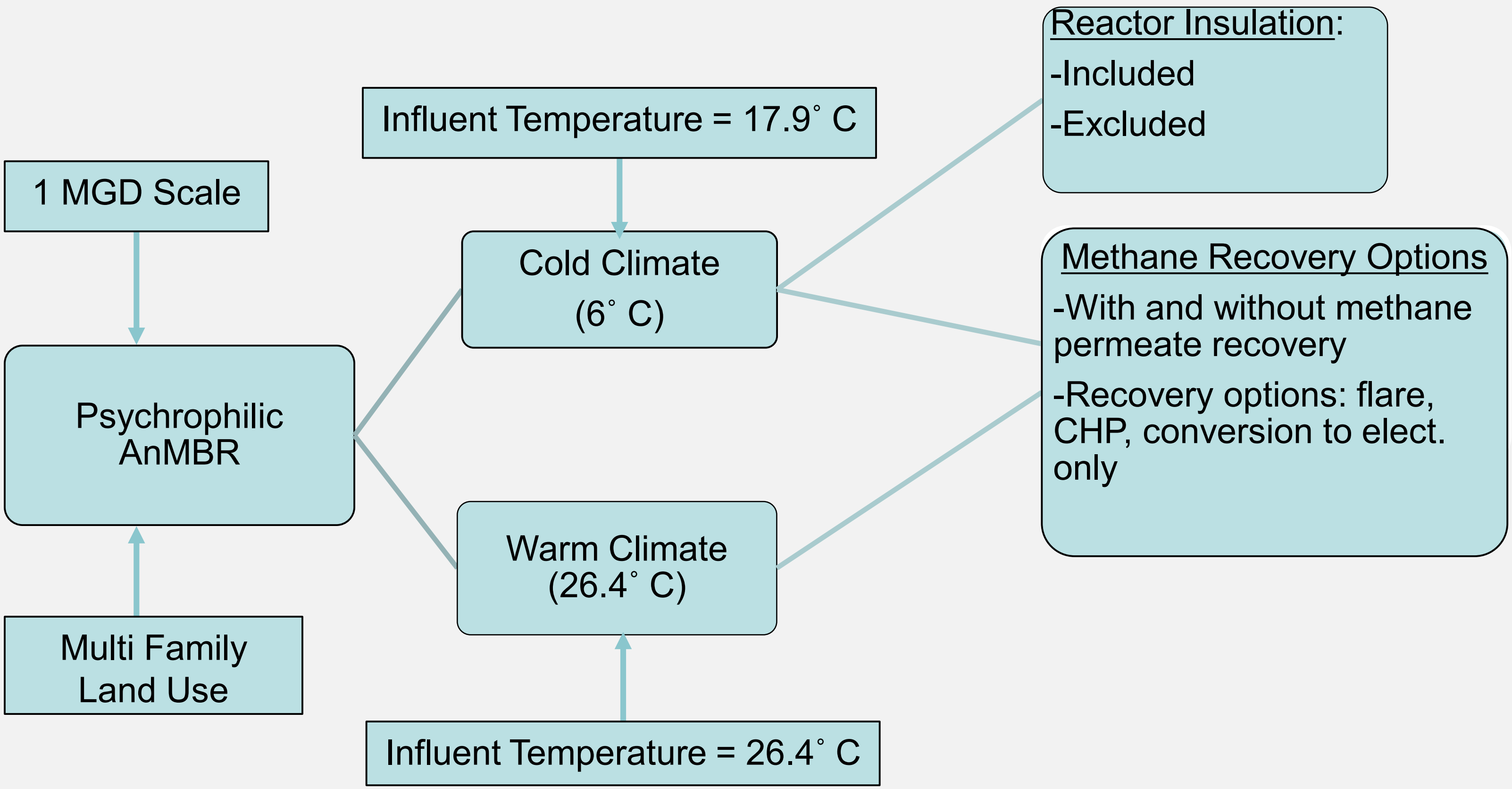


Scale and Land Use Scenarios

	Land Use Type	0.05MGD (500 ppl served)	0.1MGD (1,000 ppl served)	1MGD (10,000 ppl served)	5MGD (50,000 ppl served)	10MGD (100,000 ppl served)
100,000 #ppl/sqm	High density urban	0.005 sqm	0.01 sqm	0.1 sqm	0.5 sqm	1 sqm
50,000 #ppl/sqm	Multi family	0.01 sqm	0.02 sqm	0.2 sqm	1 sqm	2 sqm
10,000 #ppl/sqm	Single family	0.05 sqm	0.1 sqm	1 sqm	5 sqm	10 sqm
2,000 #ppl/sqm	Semi-rural single family	0.25 sqm	0.5 sqm	5 sqm	N/A	N/A

-Scenarios applied to AeMBR, mesophilic AnMBR (35˚ C), psychrophilic AnMBR (Ambient).
-Average U.S. weather conditions (21.5˚ C).
-Note: ppl = people

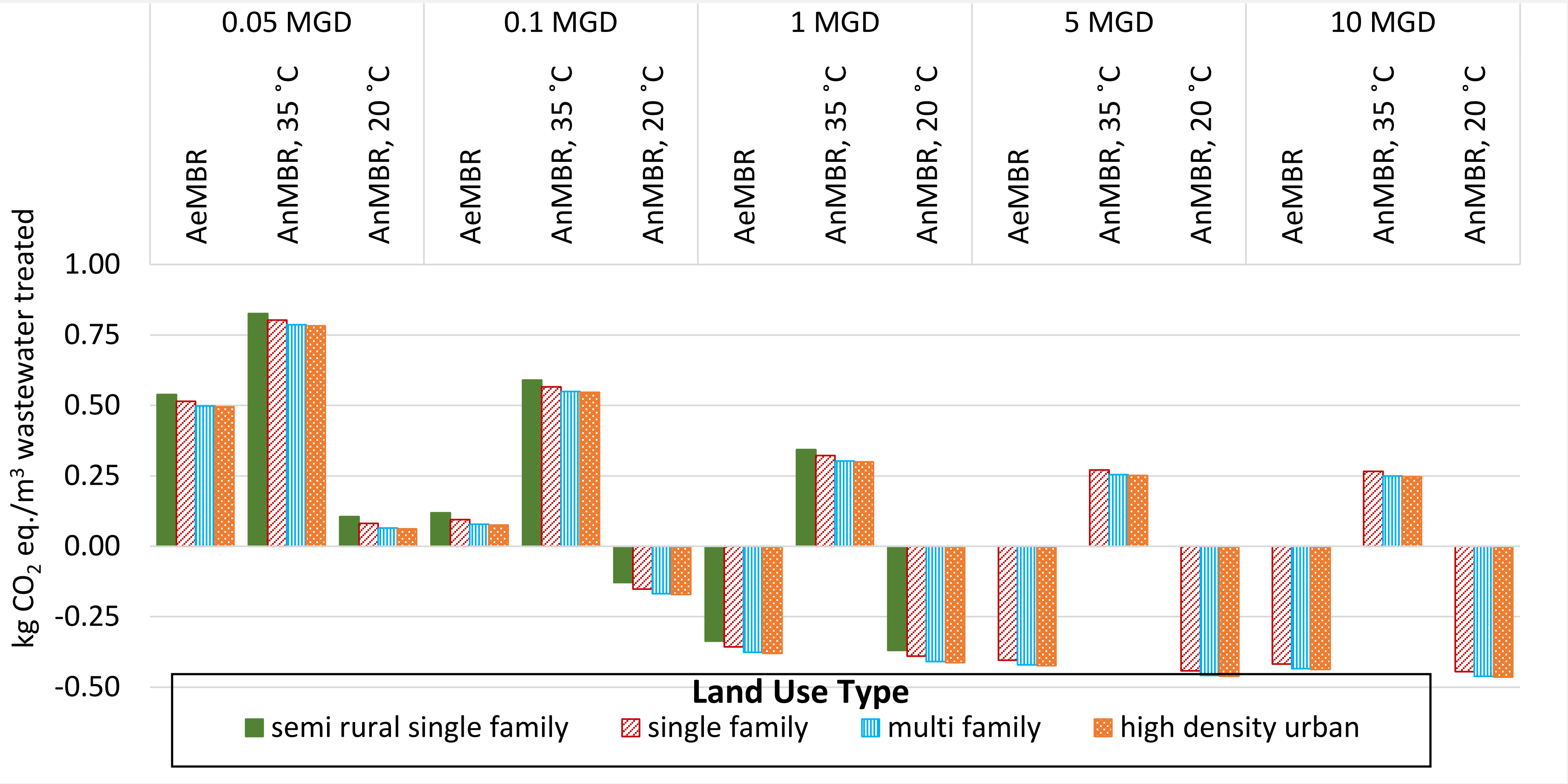
Psychrophilic AnMBR Scenarios



Methods and Data Sources

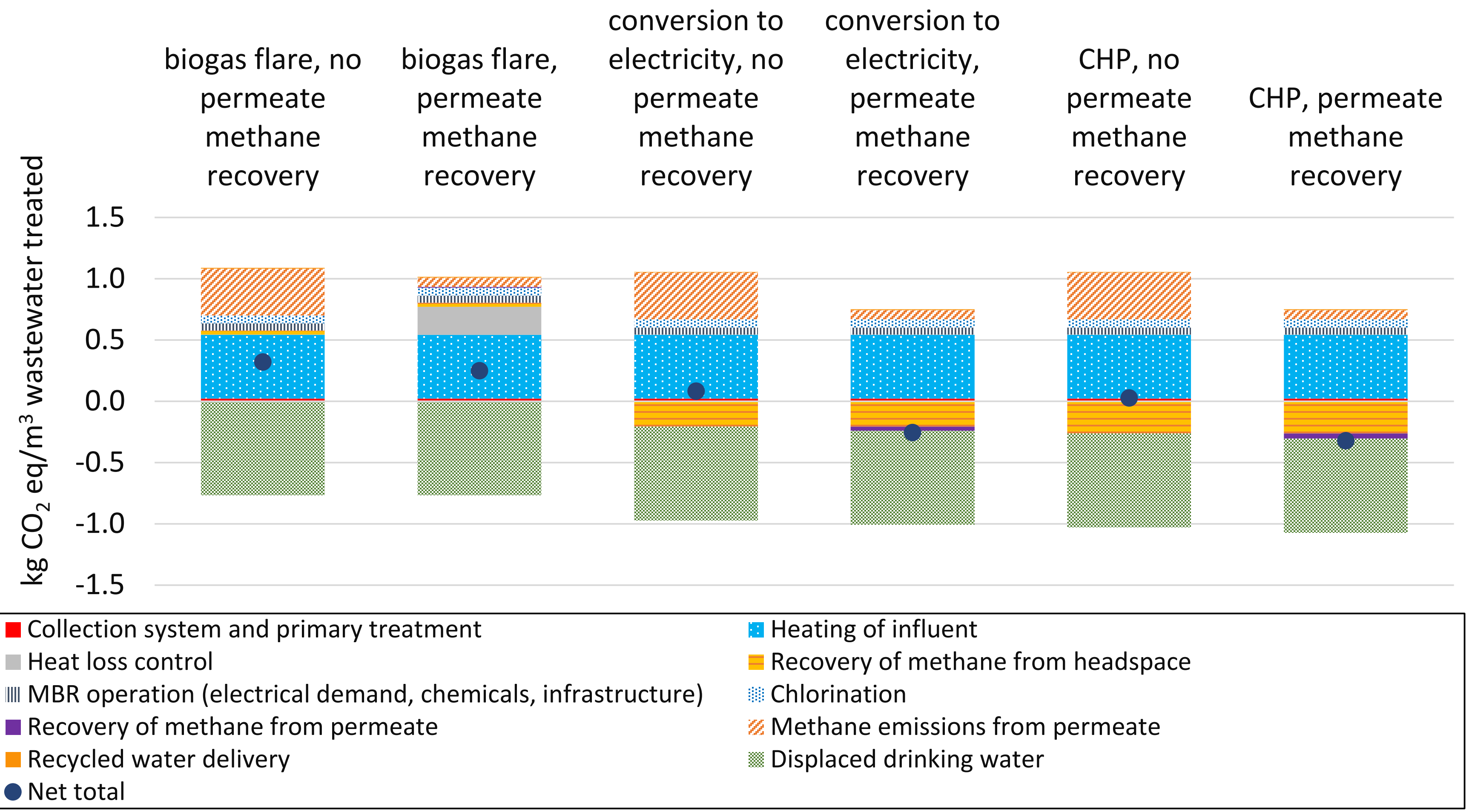
- MBR technology modeled using flux, cleaning, and module specifications for GE ZeeWeed® 500D hollow-fiber membrane with LEAPmbr aeration
- CAPDETWorks™ software used to develop life cycle inventory for preliminary treatment, fine screening, AeMBR operation and infrastructure, AnMBR infrastructure, and disinfection with chlorine
- Energy modeling for AnMBR process derived from Feickert et al., 2012
- Quantity of methane dissolved in permeate and energy use for dissolved methane recovery based on engineering calculations
- Recycled water delivery based on engineering calculations for pumping friction losses and infrastructure
- Completed full LCA using openLCA software

Influence of Population Density and Scale on Global Warming Potential (GWP)



Same General Trends for Cumulative Energy Demand

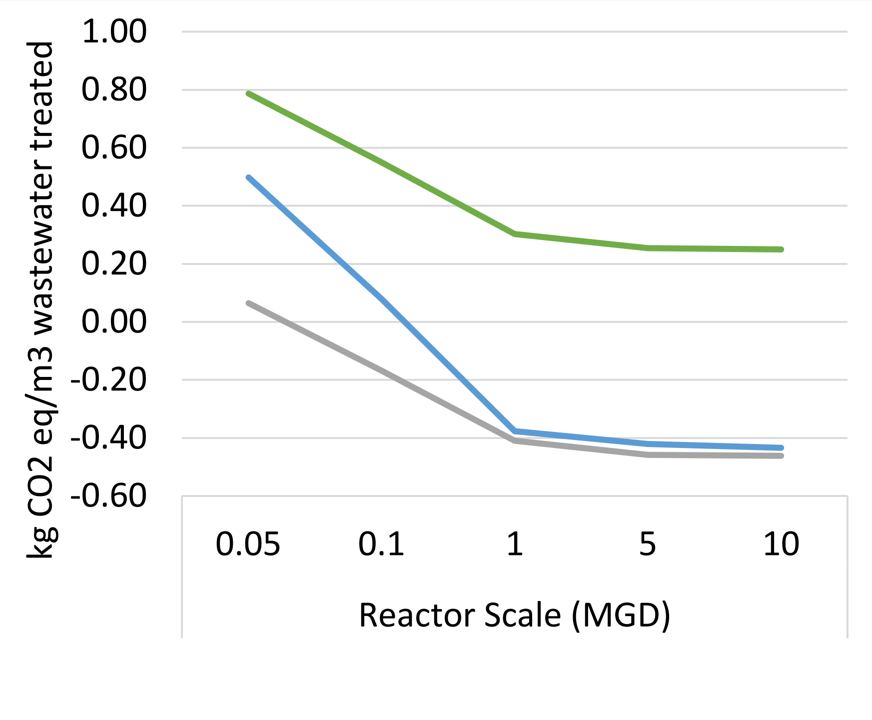
Influence of Methane Recovery Options on GWP



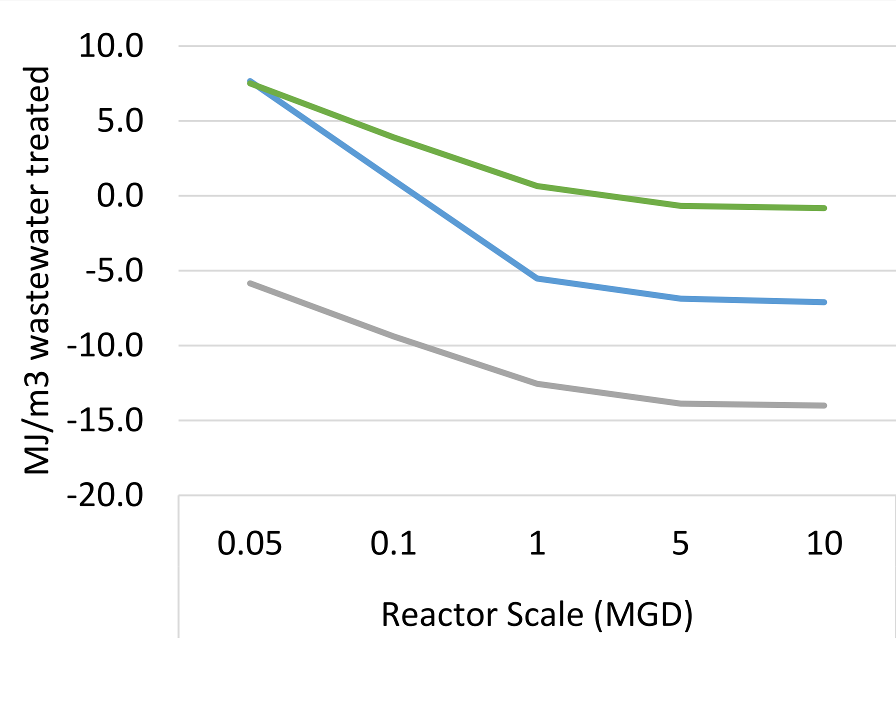
Base scenario assumes cold climate and reactor insulation.

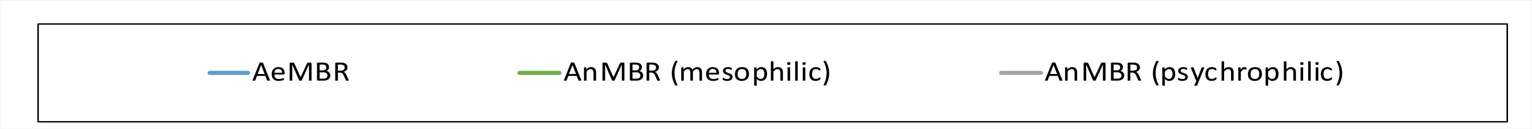
Influence of Reactor Scale

Global Warming Potential

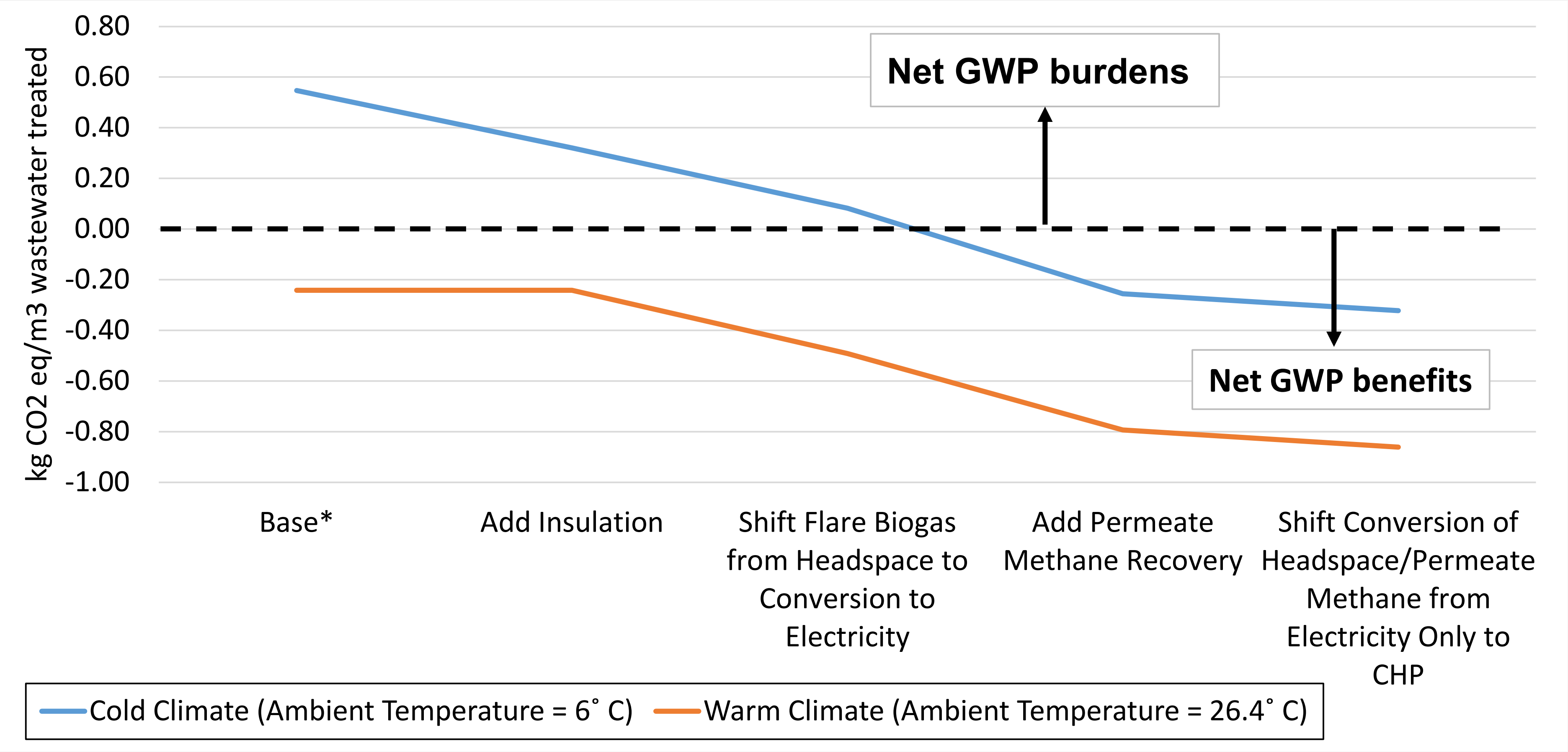


Cumulative Energy Demand





Effect of MBR Improvements Strategies on GWP under Different Climate Conditions



*Base = no reactor insulation, biogas flare only, no permeate methane recovery

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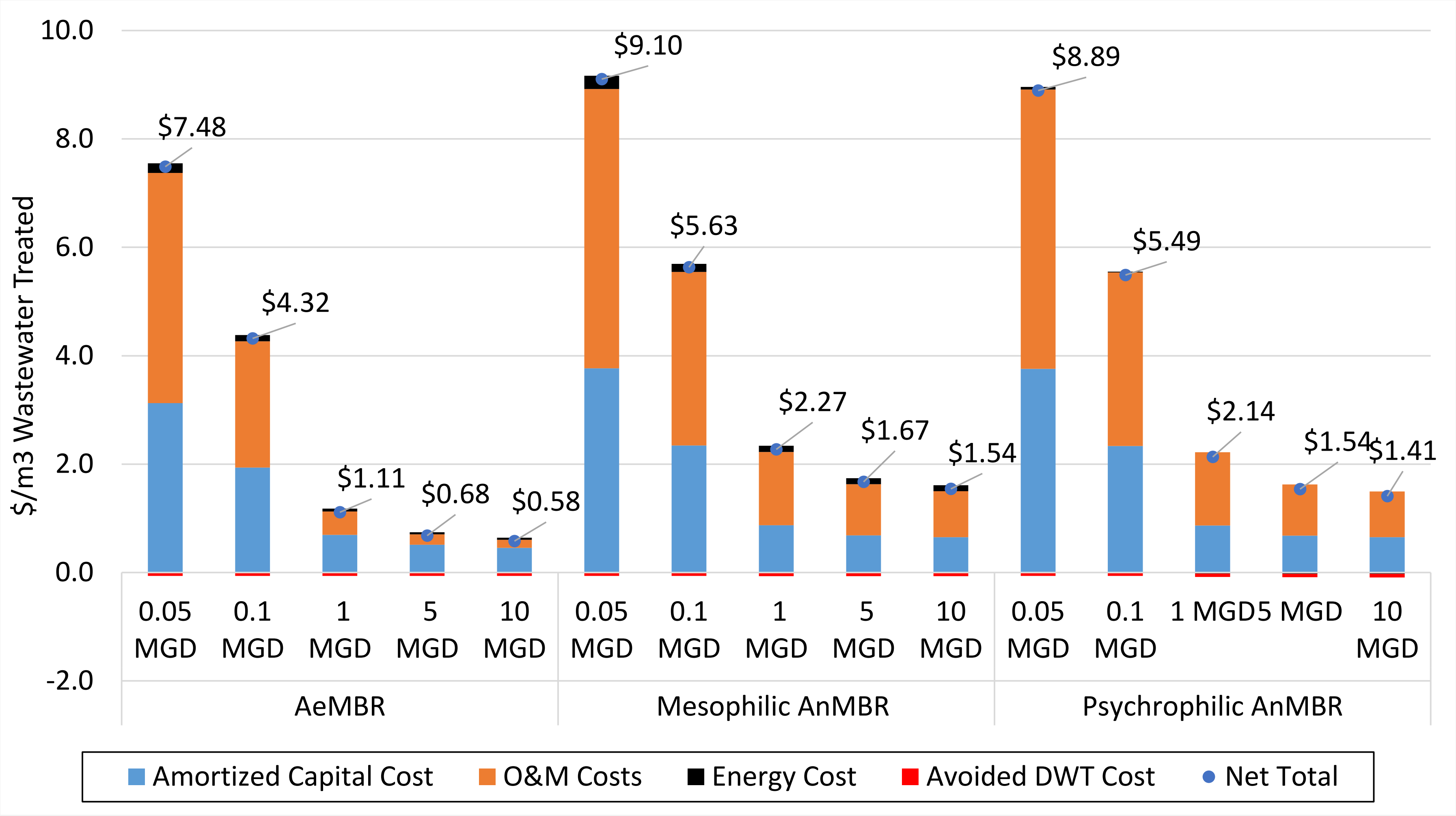
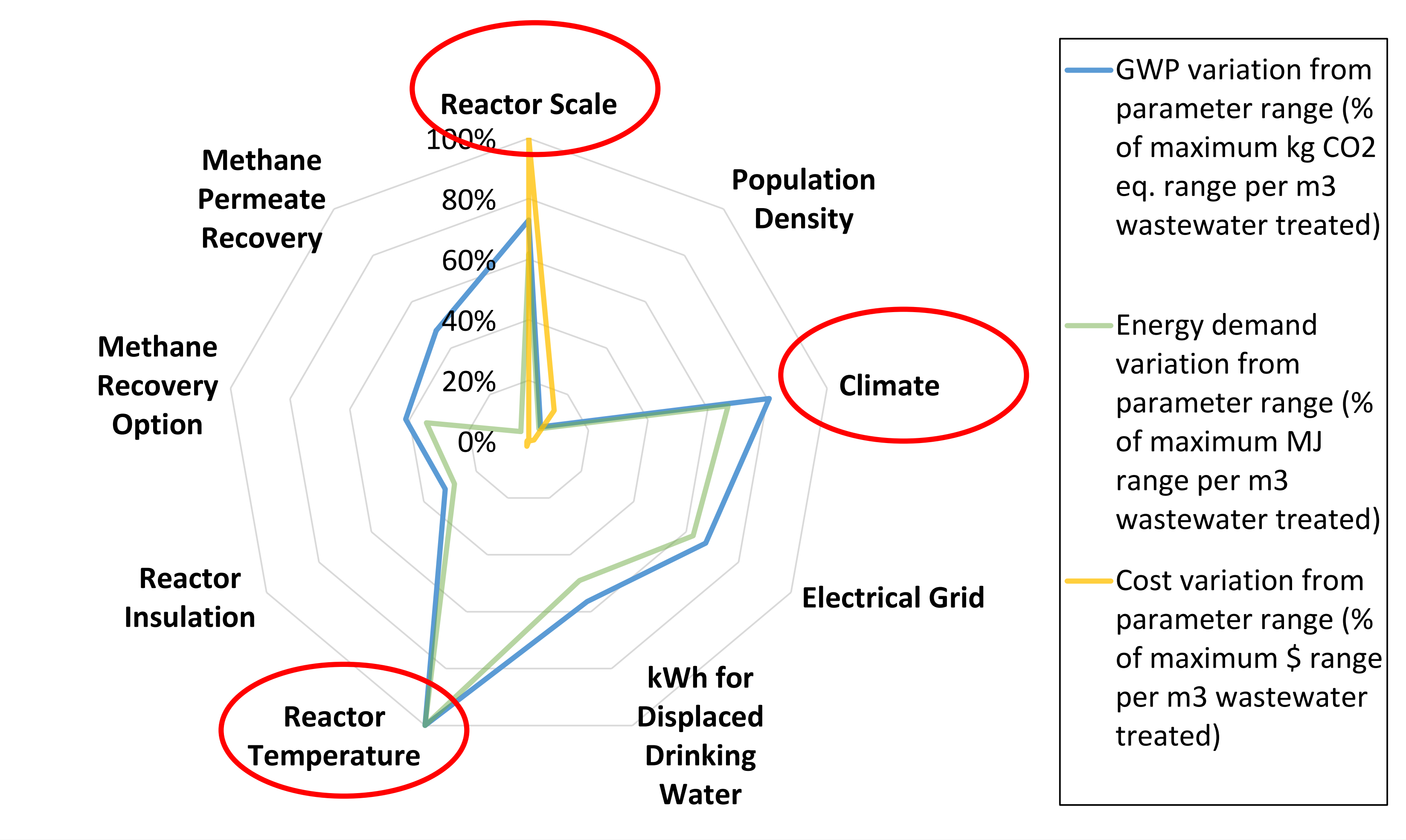
Comparative MBR Costs ($/m³ Wastewater Treated)

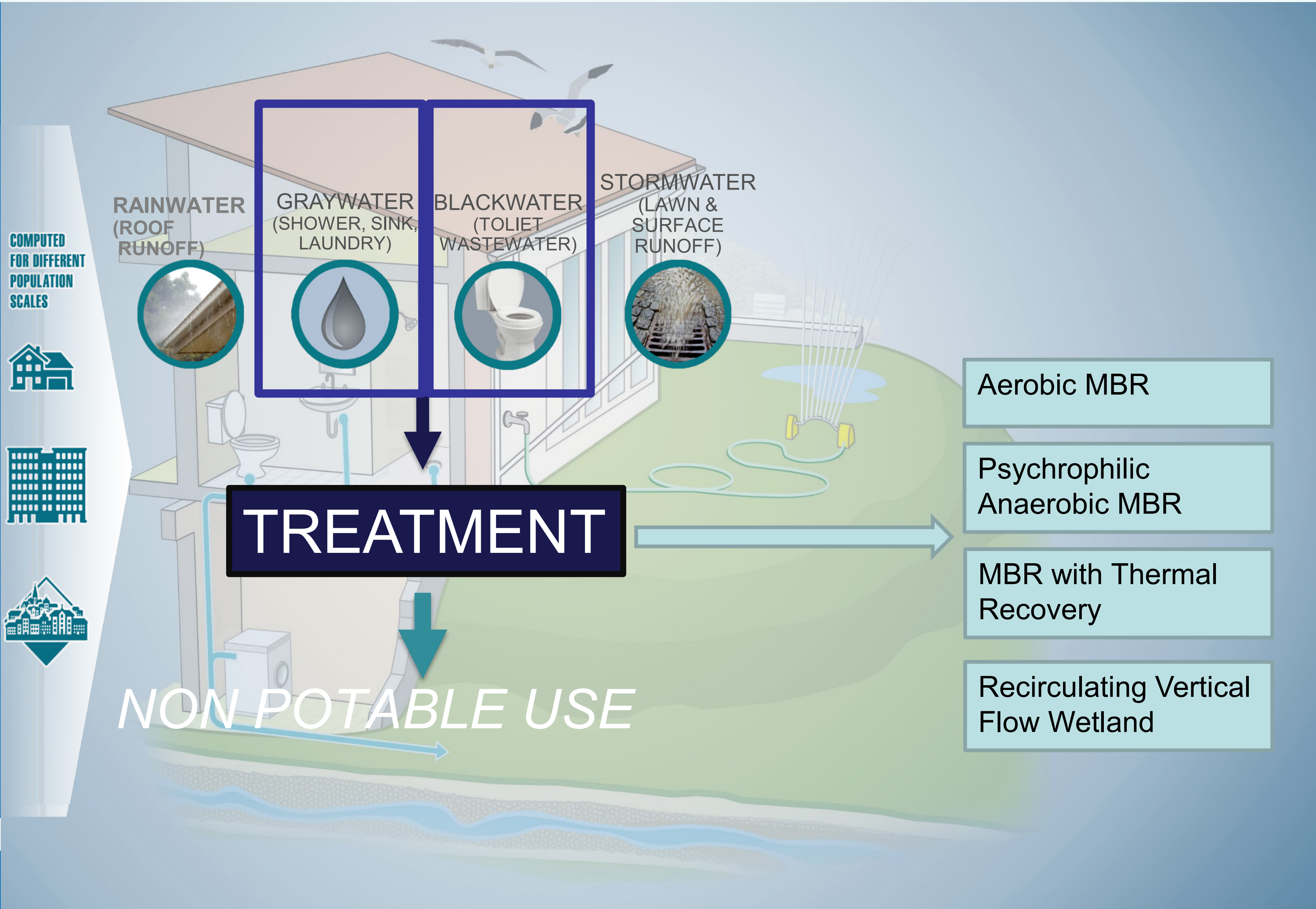


Applicable for multi-family land use scenario

Influence of Parameters on Study Outcome



FINDING NEW WATER – Urban Case Study



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Urban Case Study Scenarios

		Mixed Wastewater			Separated Graywater	
		Large Mixed Use (Office/Residential)	District-Sewered	District-Unsewered	Large Mixed Use (Office/Residential)	District-Sewered
Total Flow Rate	0.025 MGD	✓			✓	
	0.05 MGD		✓	✓		✓
Flow Rate of Water Treated	0.016 MGD				✓	
	0.025 MGD	✓				
	0.031 MGD					✓
	0.05 MGD		✓	✓		
People Served		1,100	2,249	1,100	2,249	1,100
Building Footprint (Roof Area)		20,000	155,969	20,000	155,969	20,000
Area Served (sq. ft)		380,000	754,981	380,000	754,981	380,000

AeMBR System Boundaries

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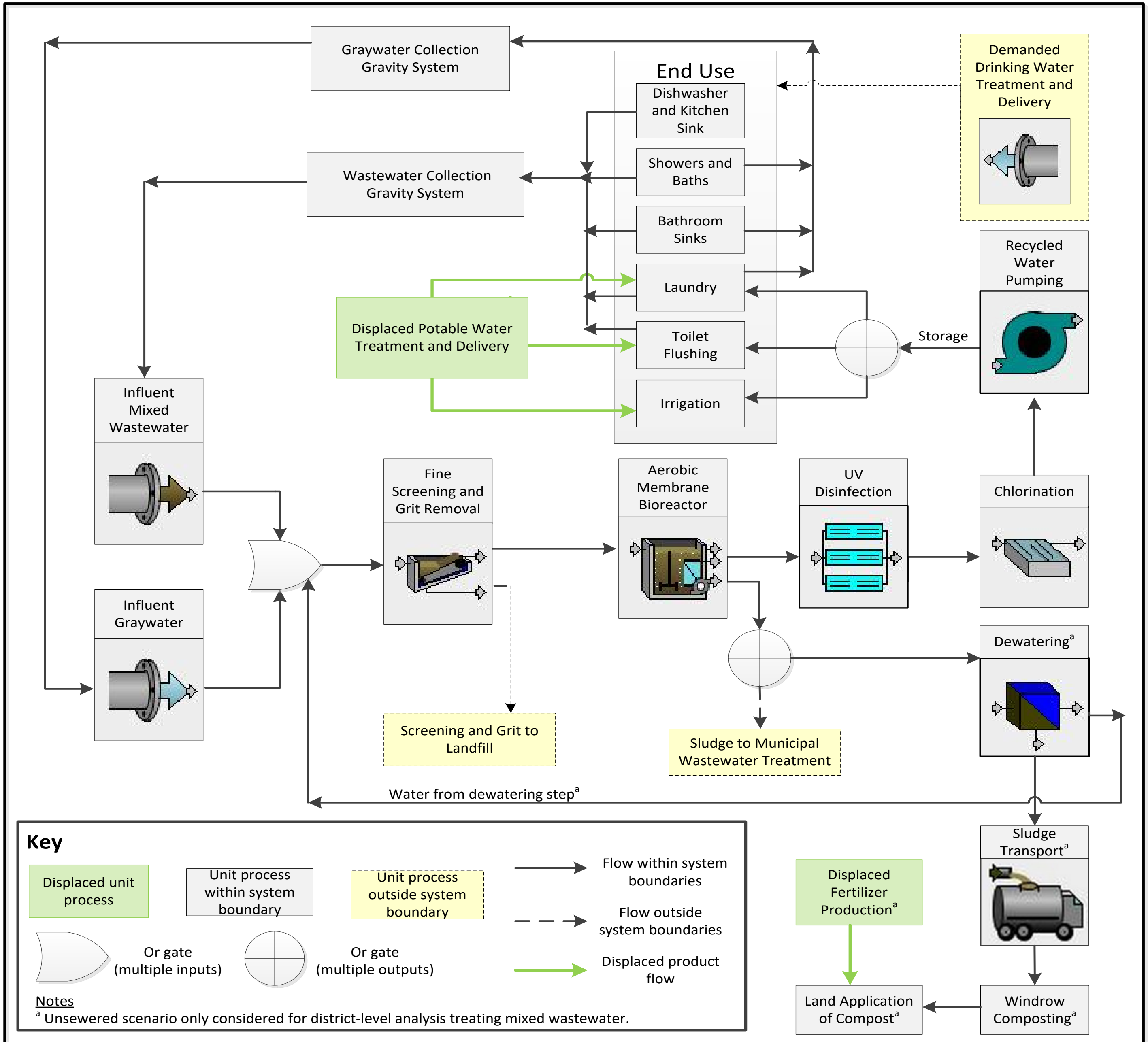

Conclusions and Next Steps

- MBR LCA and cost impacts decrease as the scale increases due to economies of scales, scale strongly influences overall impacts esp. cost
- All assessed impacts decrease in both AeMBR and AnMBR as population density increases, but population density does not drive results
- In warmer climate, AnMBR results in notable energy and GHG benefits compared to the AeMBR
- Significant energy, GHG benefits from displaced drinking water and energy recovery (in case of AnMBR)
- Communities can adapt LCA/LCC model framework for specific technological and regional conditions

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ADDITIONAL SLIDES

LCA database development

U.S. DEPARTMENT OF ENERGY

USDA

TRACI

Tool for the Reduction and Assessment Of Chemical and Other Environmental Impacts

openLCA

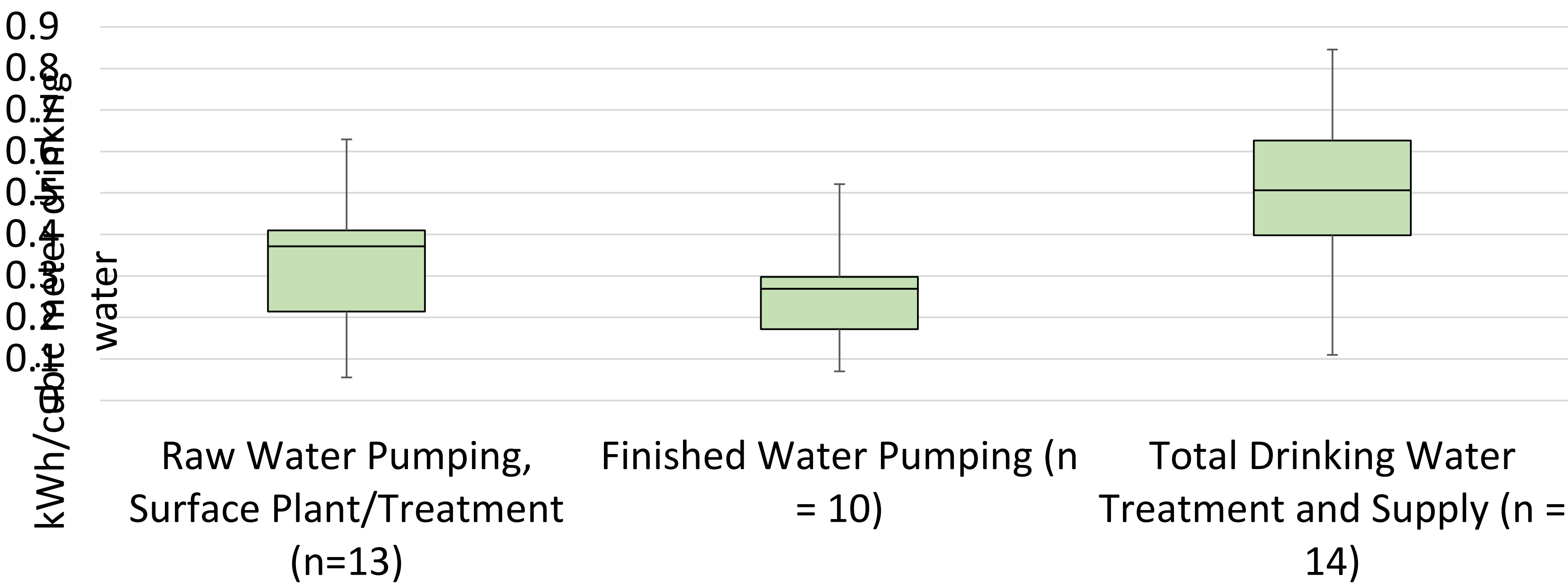
GaBi

Product Sustainability Performance

ecoinvent Centre

Swiss Centre for Life Cycle Inventories

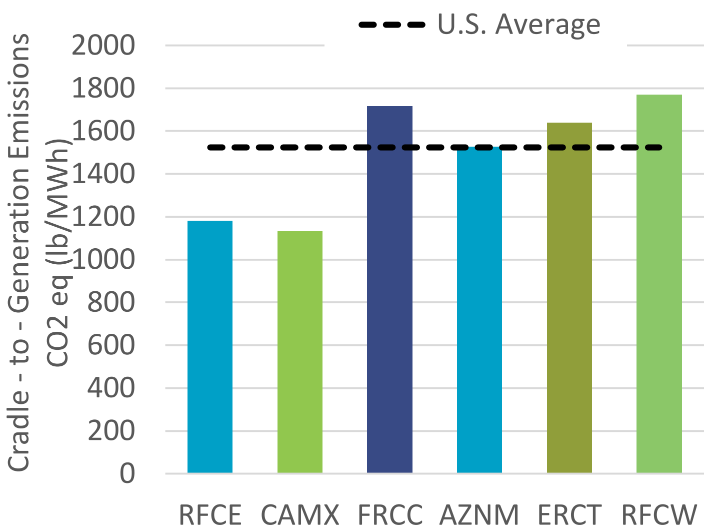
Range of Displaced Potable Water Energy Demand Reported in Literature

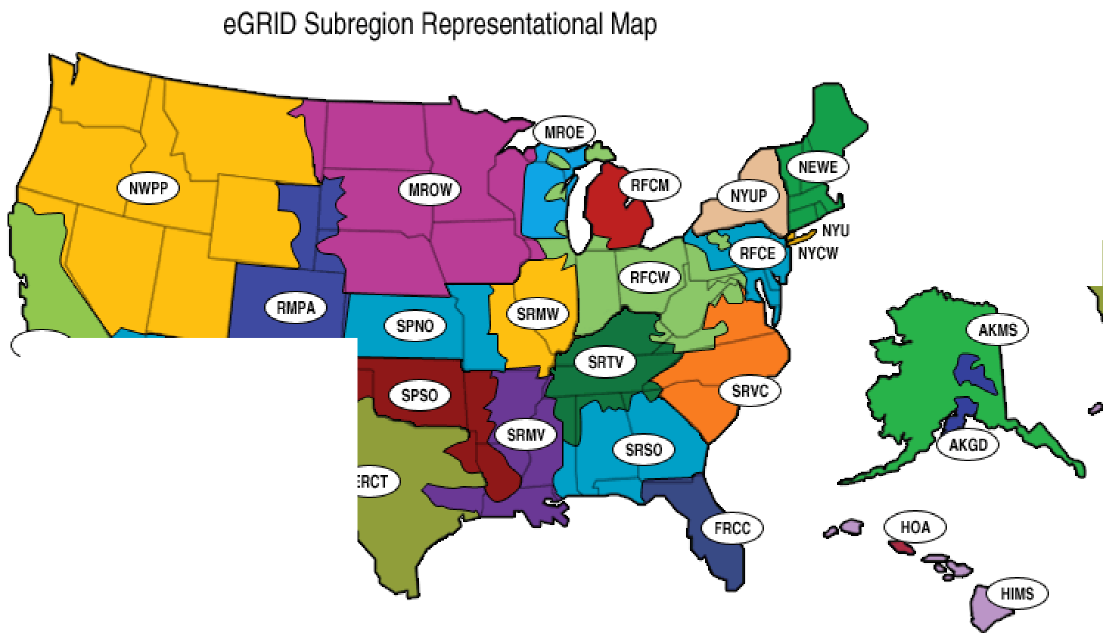


From: Cashman S., Mosley J., Ma C., Garland J., Cashdollar J., and Bless D. Life Cycle Assessment and Cost Analysis of Water and Wastewater Treatment Options for Sustainability: Influence of Scale on Membrane Bioreactor Systems. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/243, 2016.

Regionalized Electrical Grid Profile

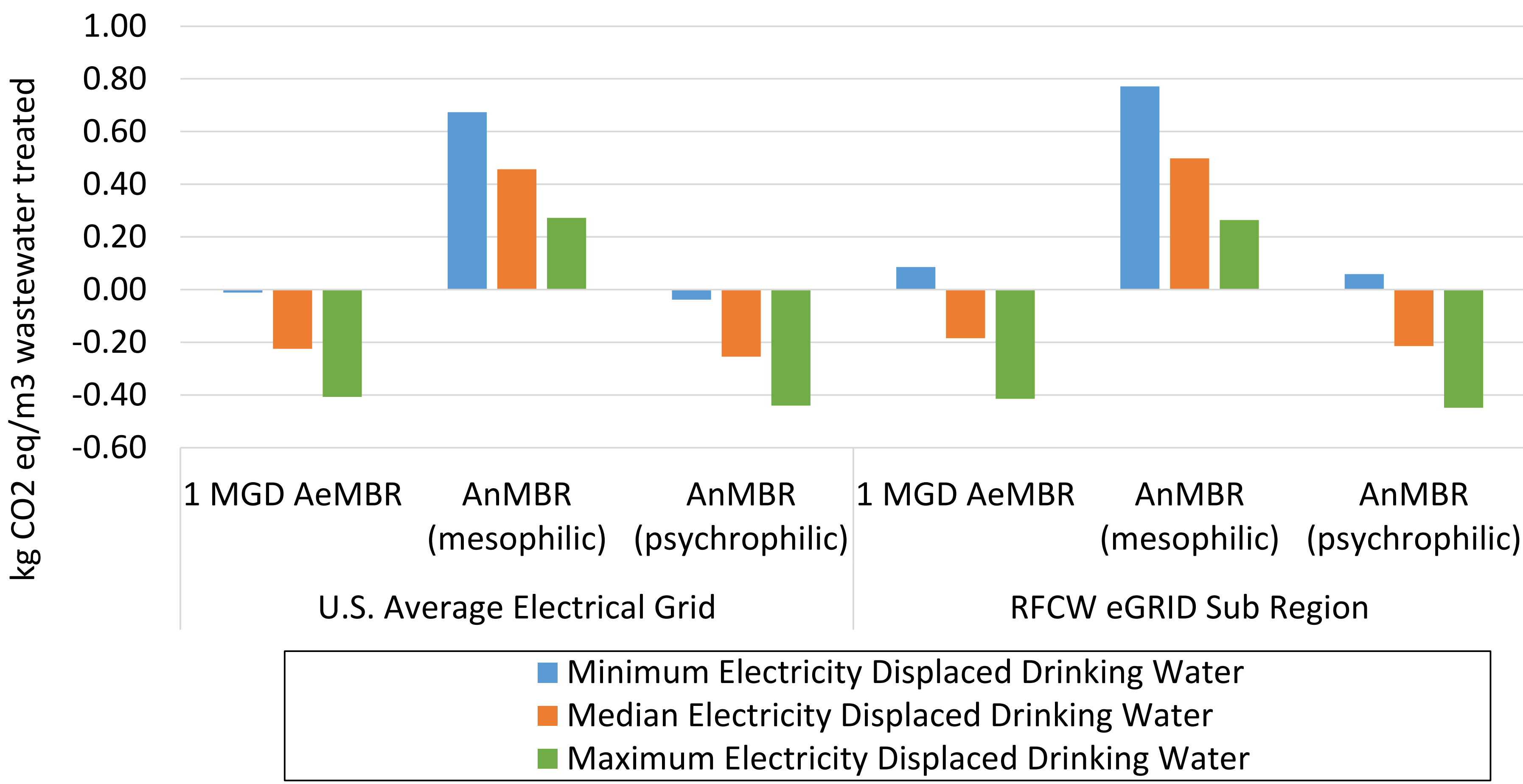
Fuel mix of electrical grid affects magnitude of environmental burdens for both the MBR life cycle and the displaced potable water





Source: U.S. EPA eGRID 2012

Influence of Electrical Grid and Displaced Water Assumptions on GWP



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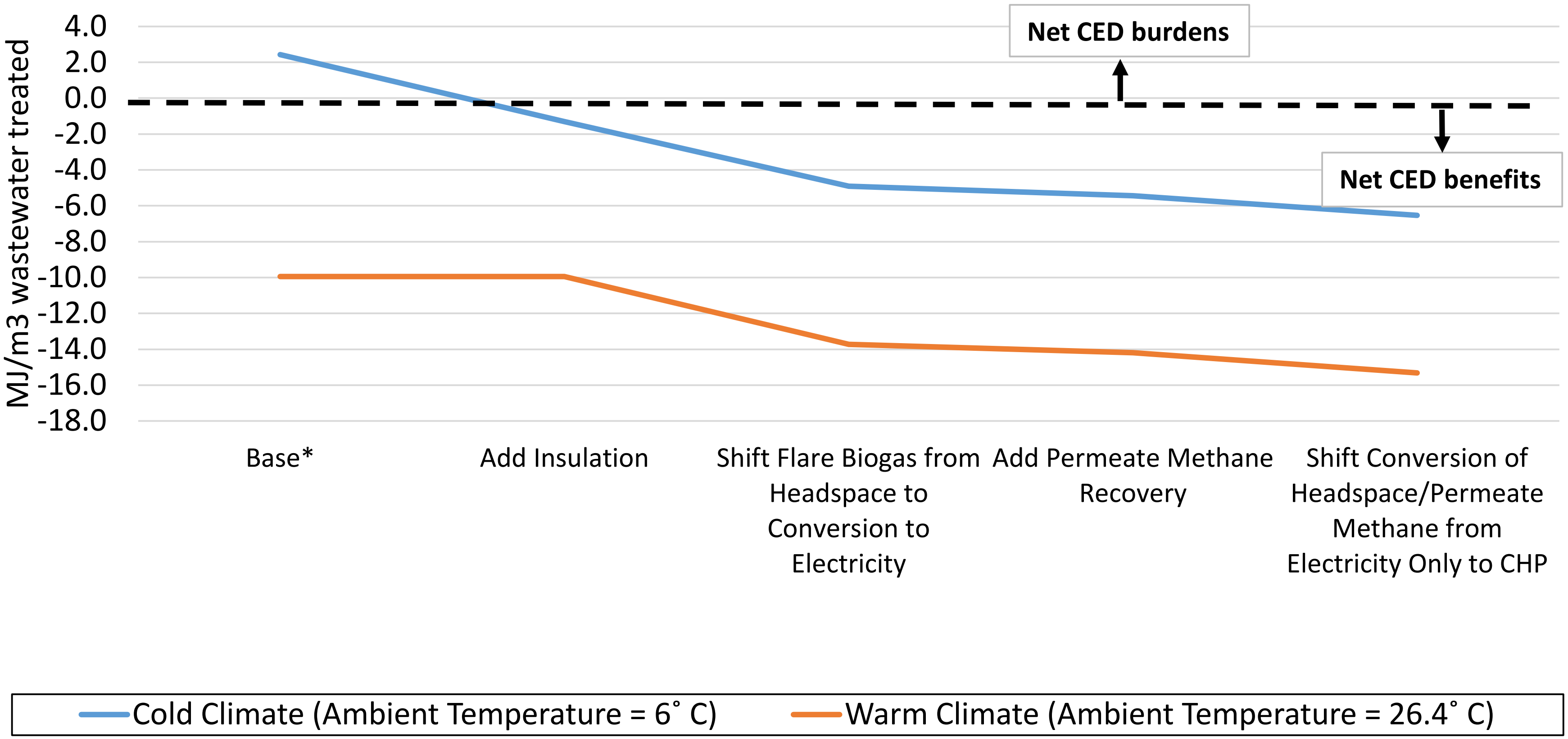

**Base = no reactor insulation, biogas flare only, no permeate methane*