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2018 WATER RESEARCH FOUNDATION CONFERENCE
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ADVANCING REUSE & INTEGRATED WATER

Life Cycle Assessment and Cost Analysis of Membrane Bioreactor Systems:

Influence of Scale, Population Density, Climate, and Methane Recovery

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Office of Research and Development
National Exposure Research Laboratory
National Risk Management Research Laboratory

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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

COMPUTED FOR DIFFERENT POPULATION SCALES

Finding New Water

MIXED WASTEWATER

GRAYWATER (SHOWER, SINK, LAUNDRY)

BLACKWATER (TOLIET WASTEWATER)

STORMWATER (LAWN & SURFACE RUNOFF)

TREATMENT

NON POTABLE USE

- Aerobic Membrane Bioreactor (MBR)
- Mesophilic Anaerobic MBR (AnMBR)
- Psychrophilic AnMBR

Energy, Greenhouse Gas & 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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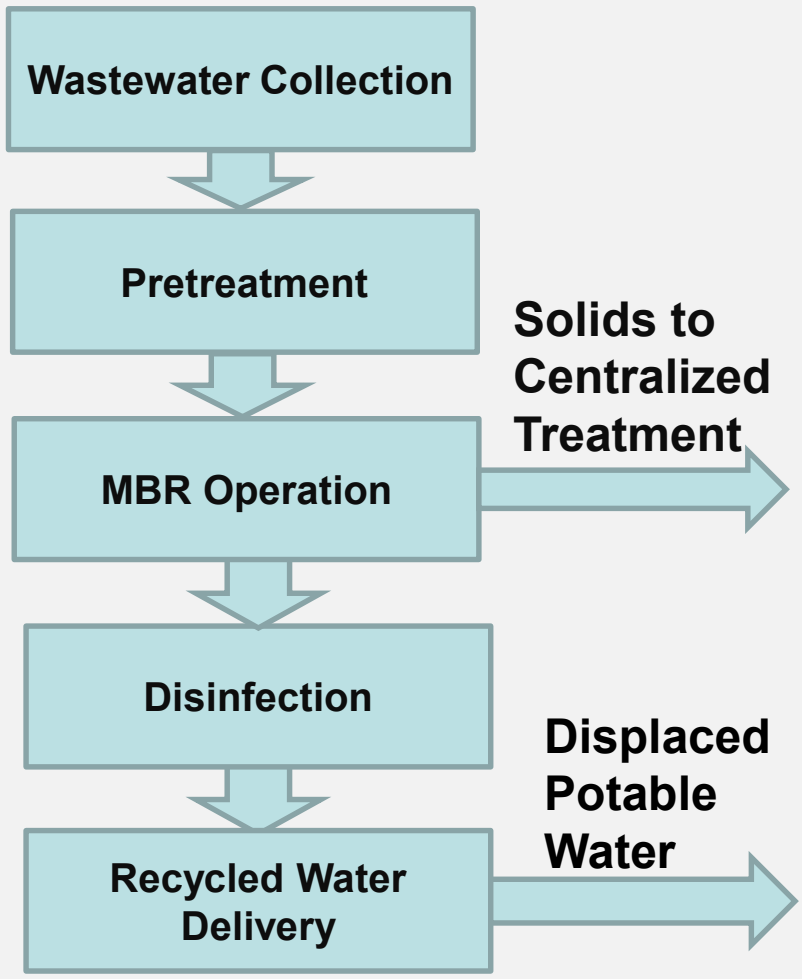
General Decentralized Treatment System Boundaries

- 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



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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; sqm = square mile

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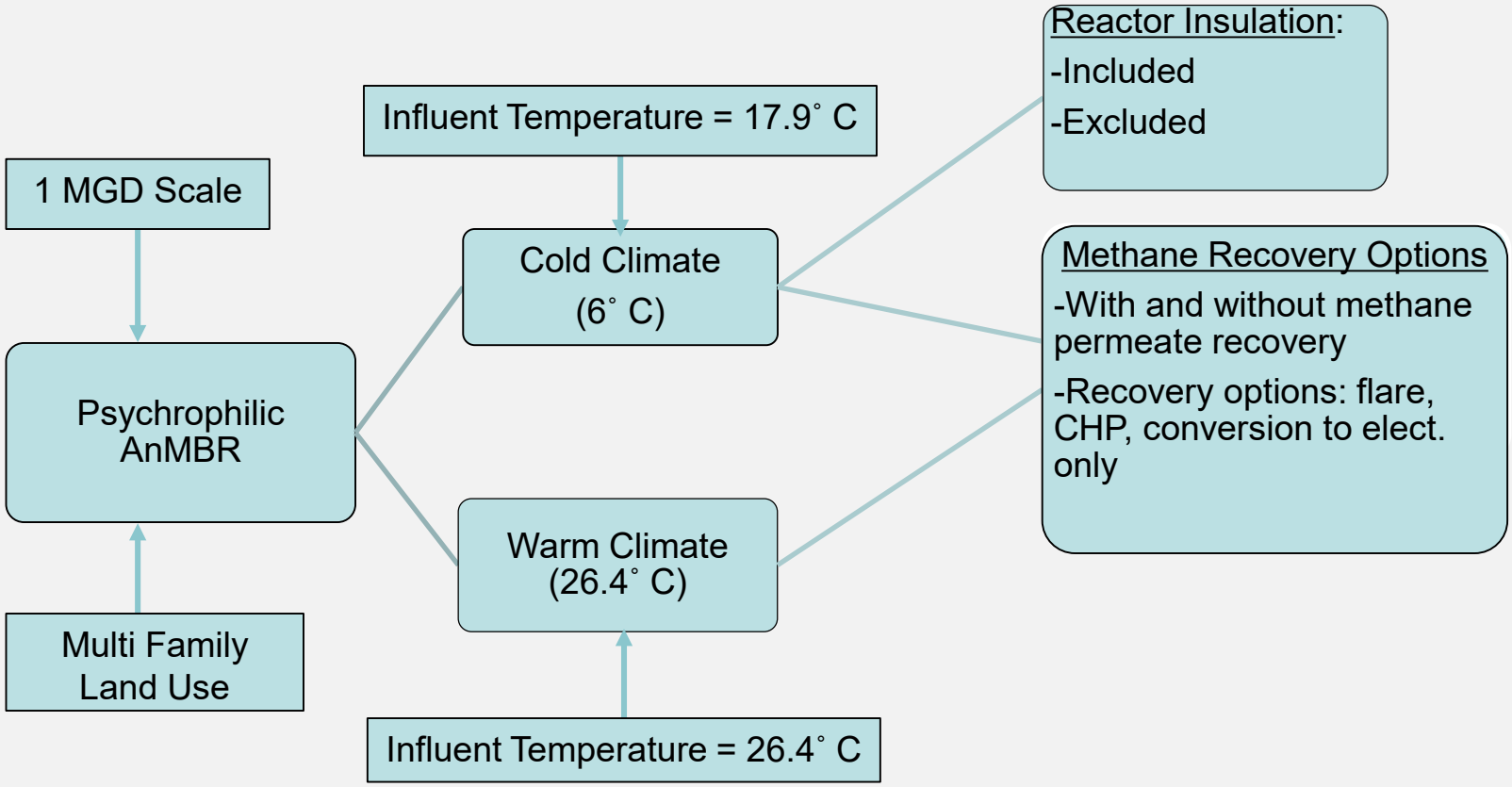
Psychrophilic AnMBR Scenarios



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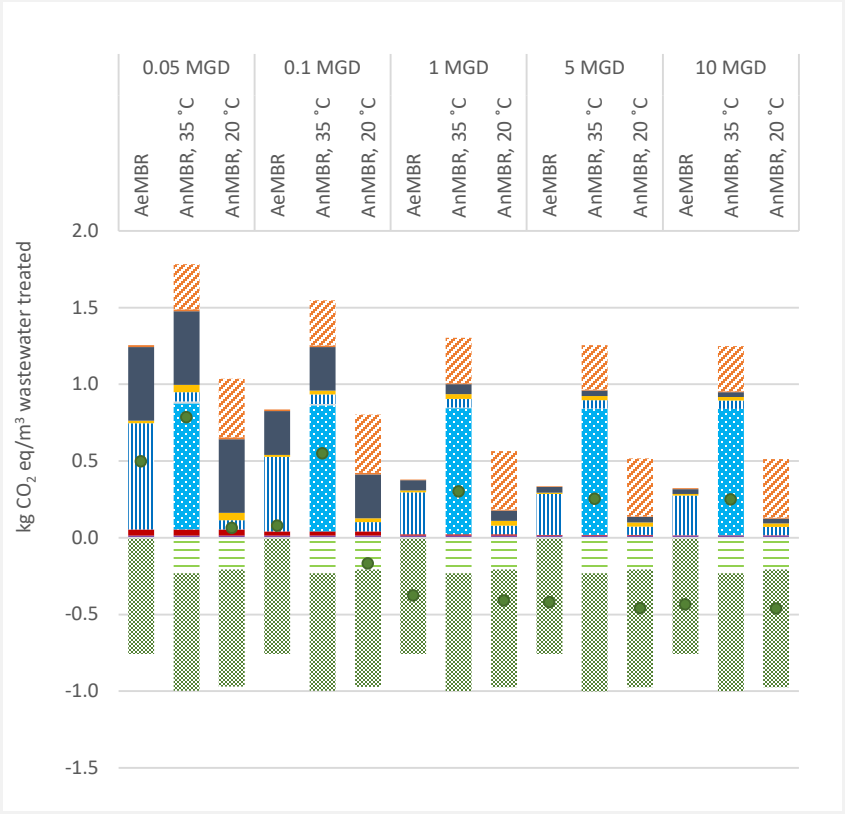
Methods and Data Sources

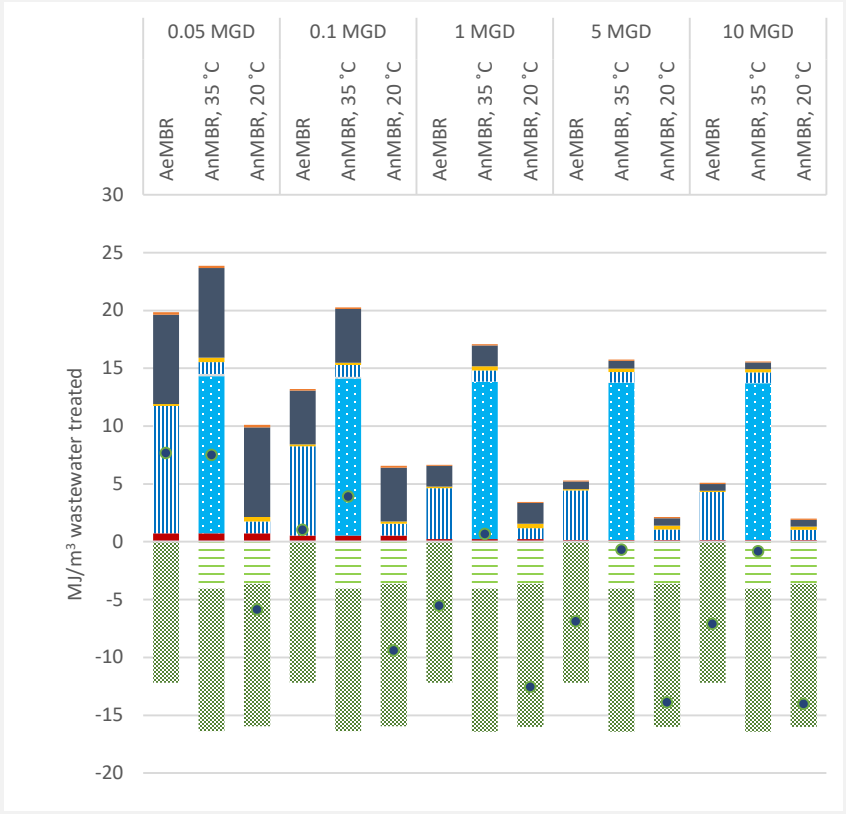
- MBR technology modeled using flux, cleaning, and module specifications for GE ZeeWeed® 500D hollow-fiber membrane with LEAPmbr aeration
- CAPDETWorks™ software used to develop life cycle inventory for preliminary treatment, fine screening, AeMBR operation and infrastructure, AnMBR infrastructure, and 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
- Functional unit based on one cubic meter of wastewater treated

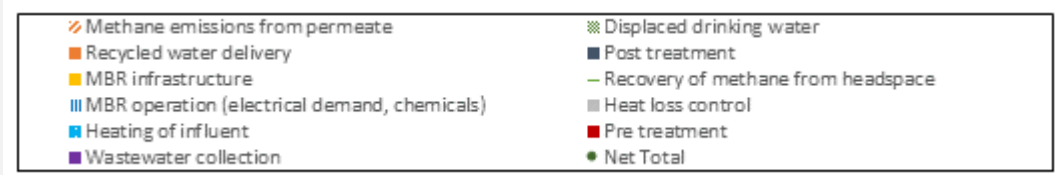
AeMBR and AnMBR multi-family land use comparison by life cycle stage

Global Warming Potential (GWP)

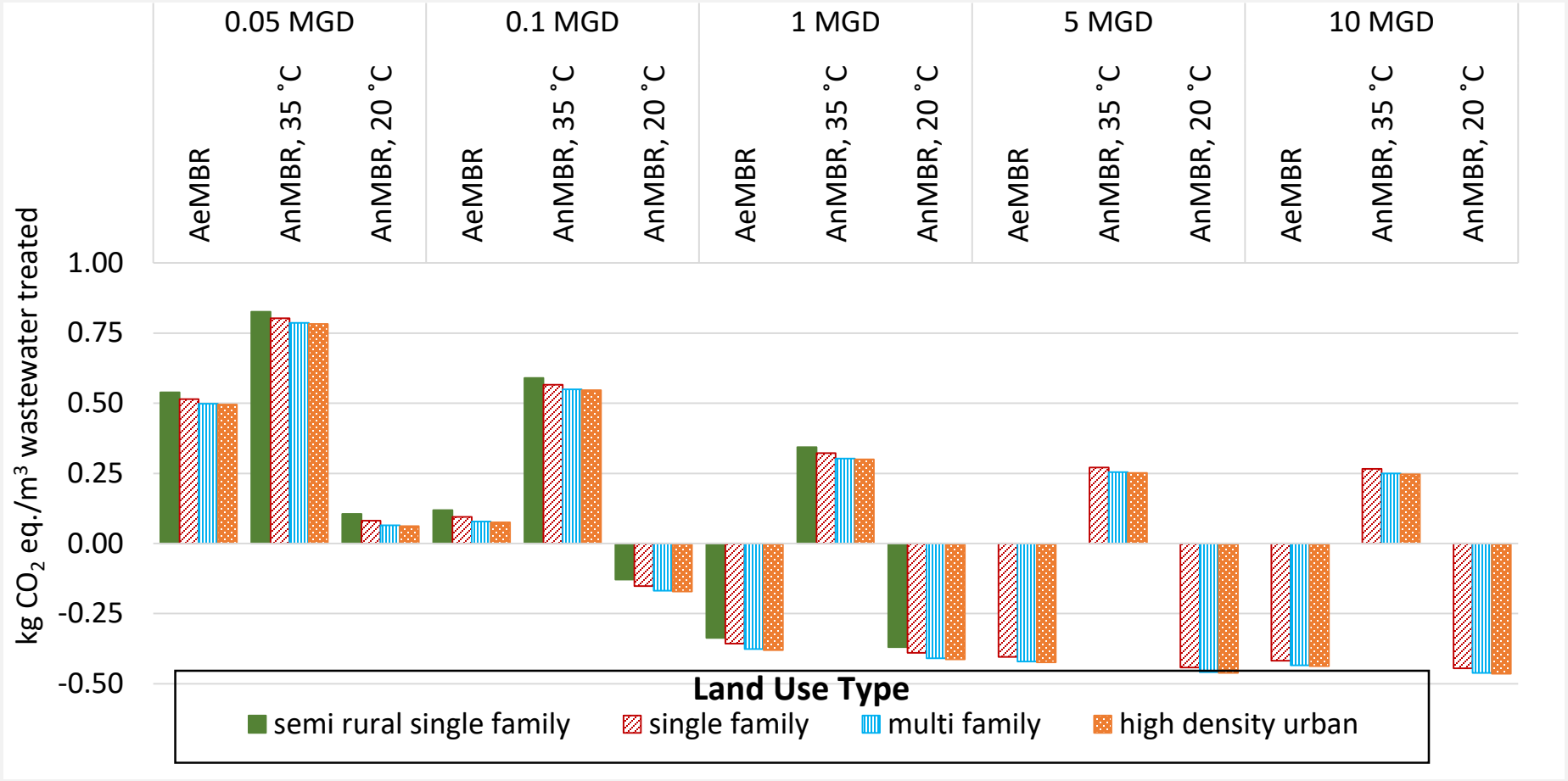


Energy Demand



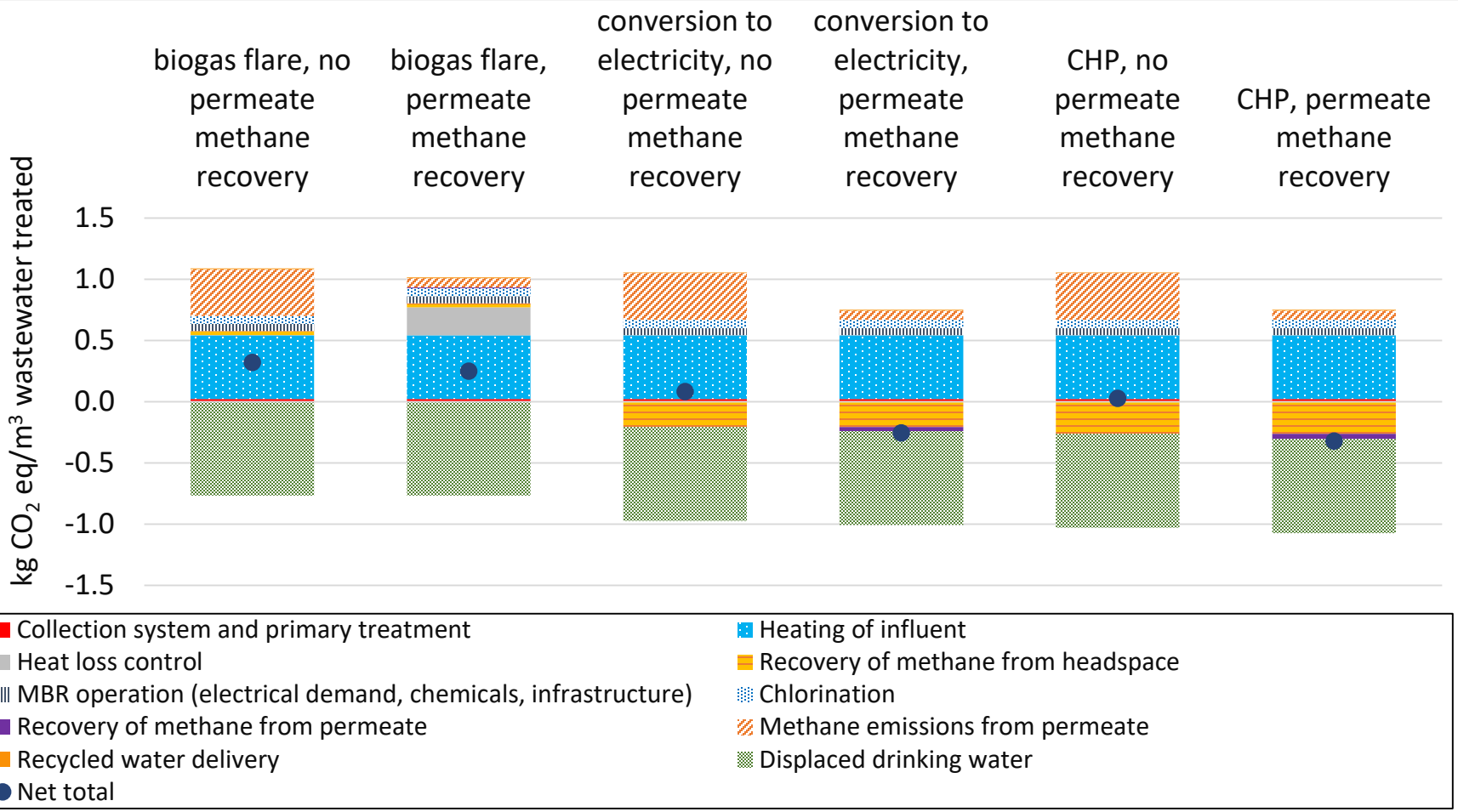


Influence of Population Density and Scale on GWP



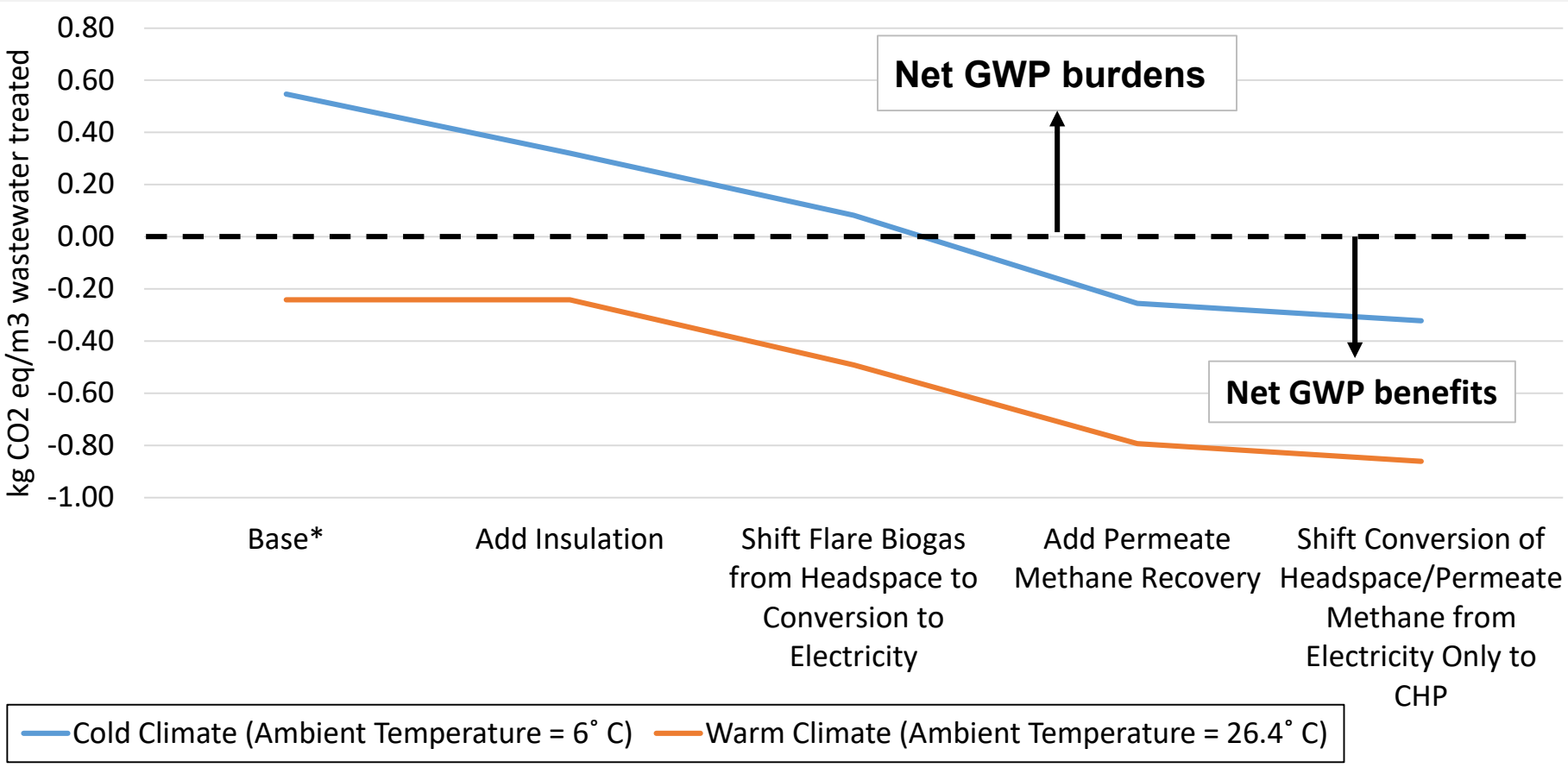
Same General Trends for Cumulative Energy Demand

Influence of Methane Recovery Options on GWP



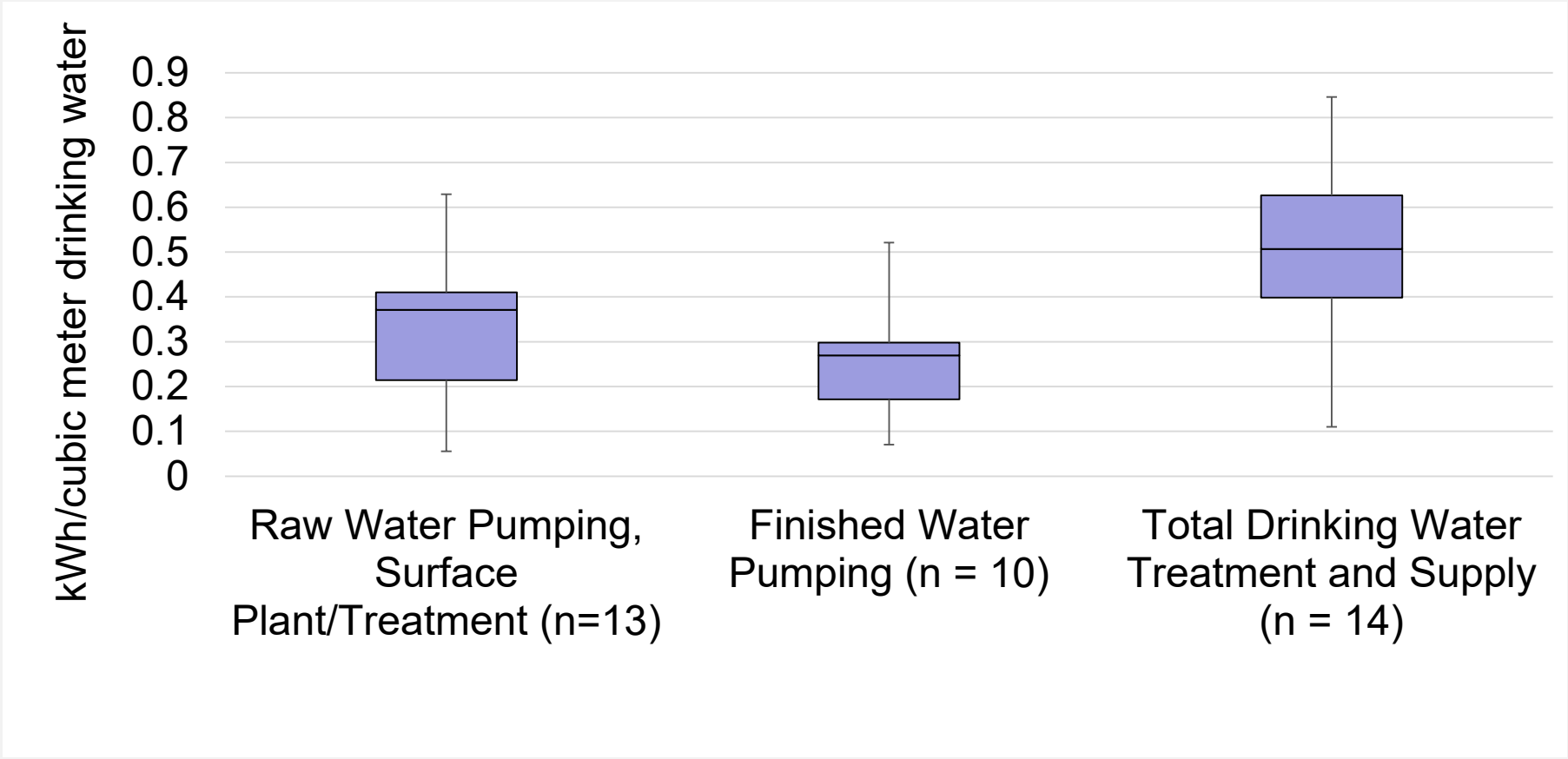
Base scenario assumes cold climate and reactor insulation.

Effect of MBR Improvements Strategies on GWP under Different Climate Conditions



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

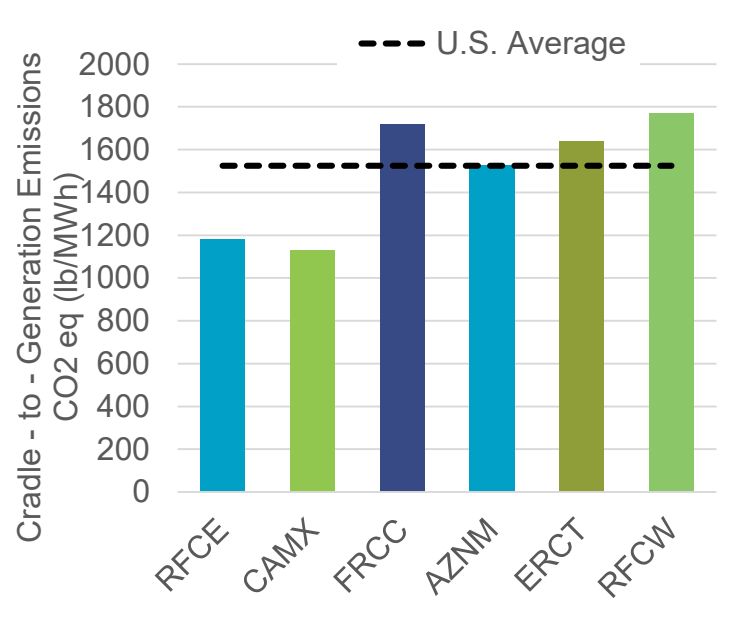
Range of Displaced Potable Water Energy Demand Reported in Literature

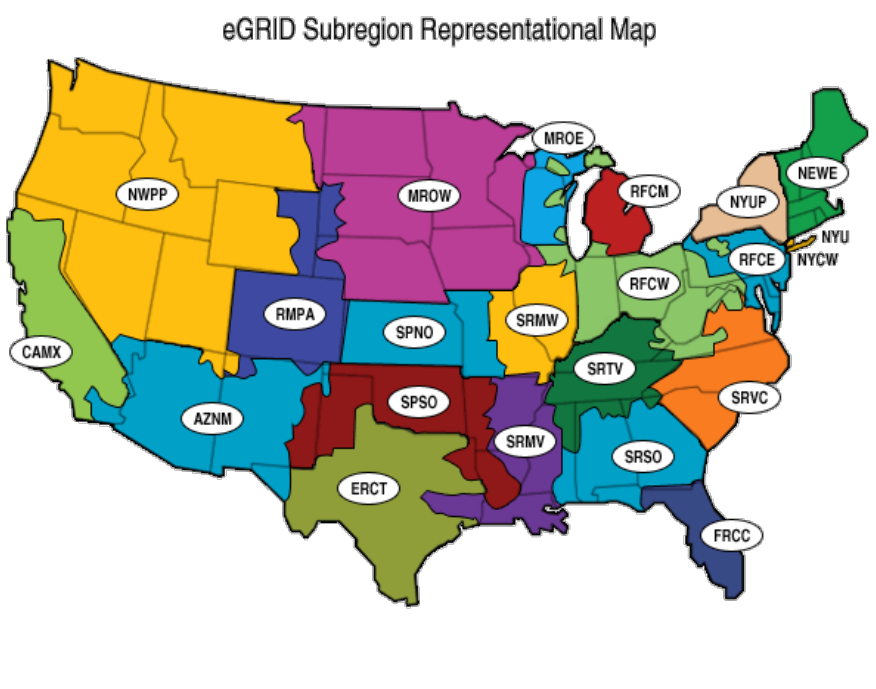


From: Cashman S., Mosley J., Ma C., Garland J., Cashdollar J., and Bless D. Life Cycle Assessment and Cost Analysis of Water and Wastewater Treatment Options for Sustainability: Influence of Scale on Membrane Bioreactor Systems. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/243,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

Regionalized Electrical Grid Profile

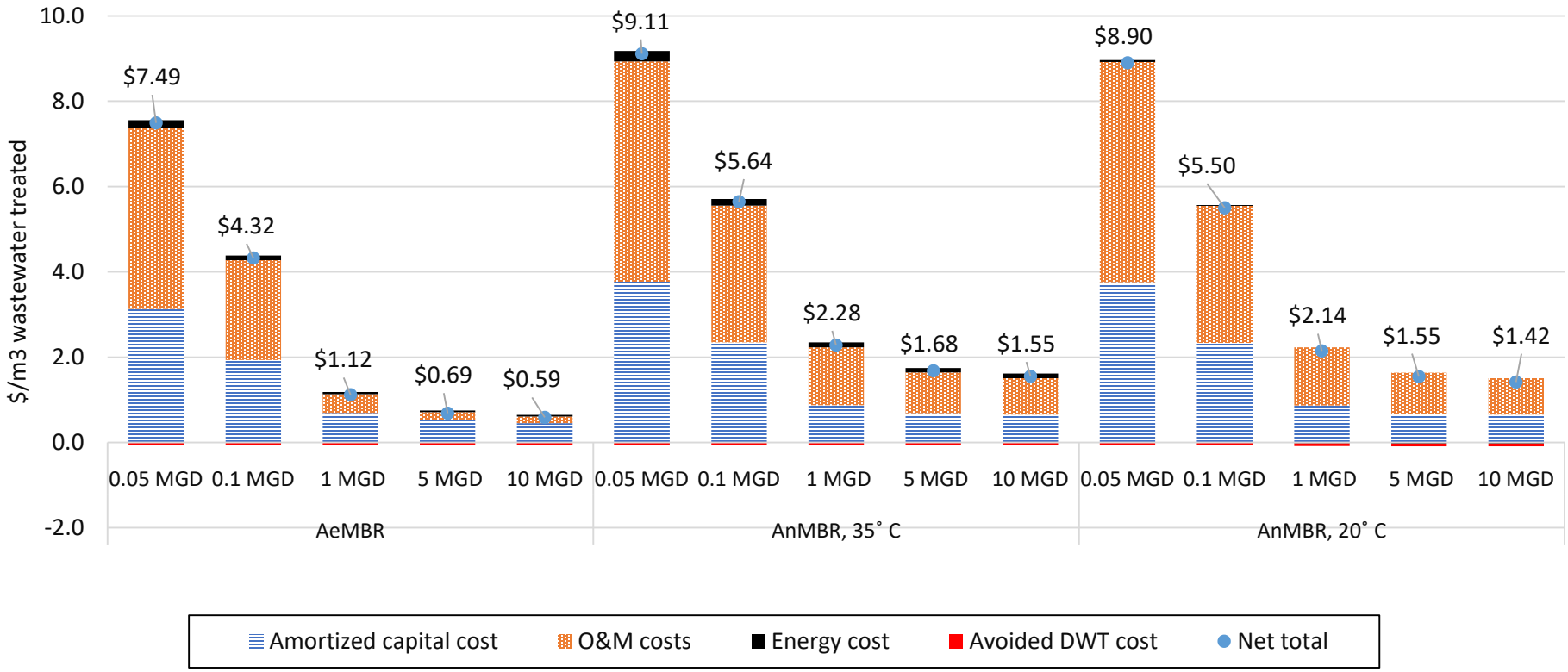
Fuel mix of electrical grid affects magnitude of environmental burdens for both the MBR life cycle and the displaced potable water





Source: U.S. EPA eGRID 2012

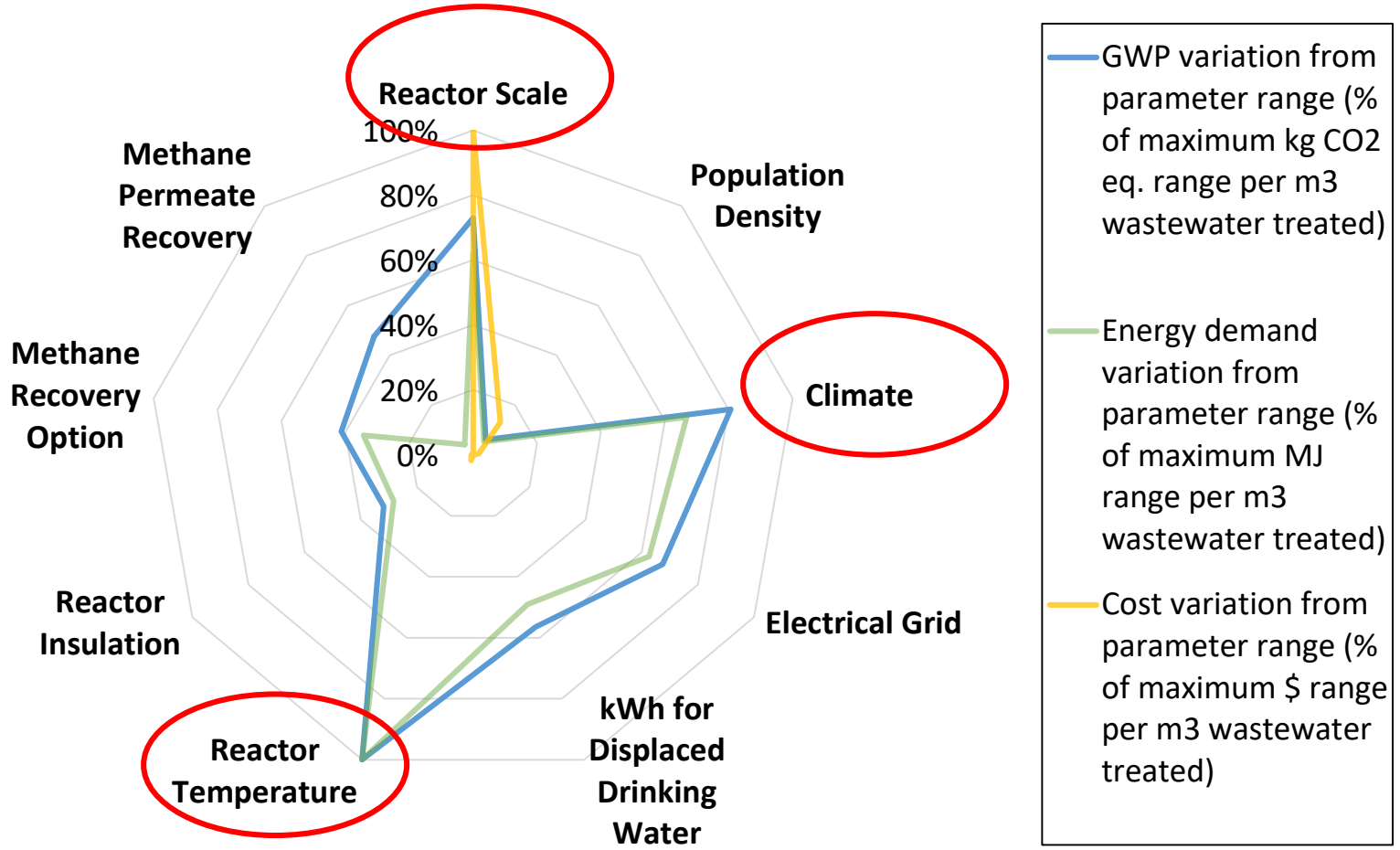
Comparative MBR Costs ($/m^3 Wastewater Treated)



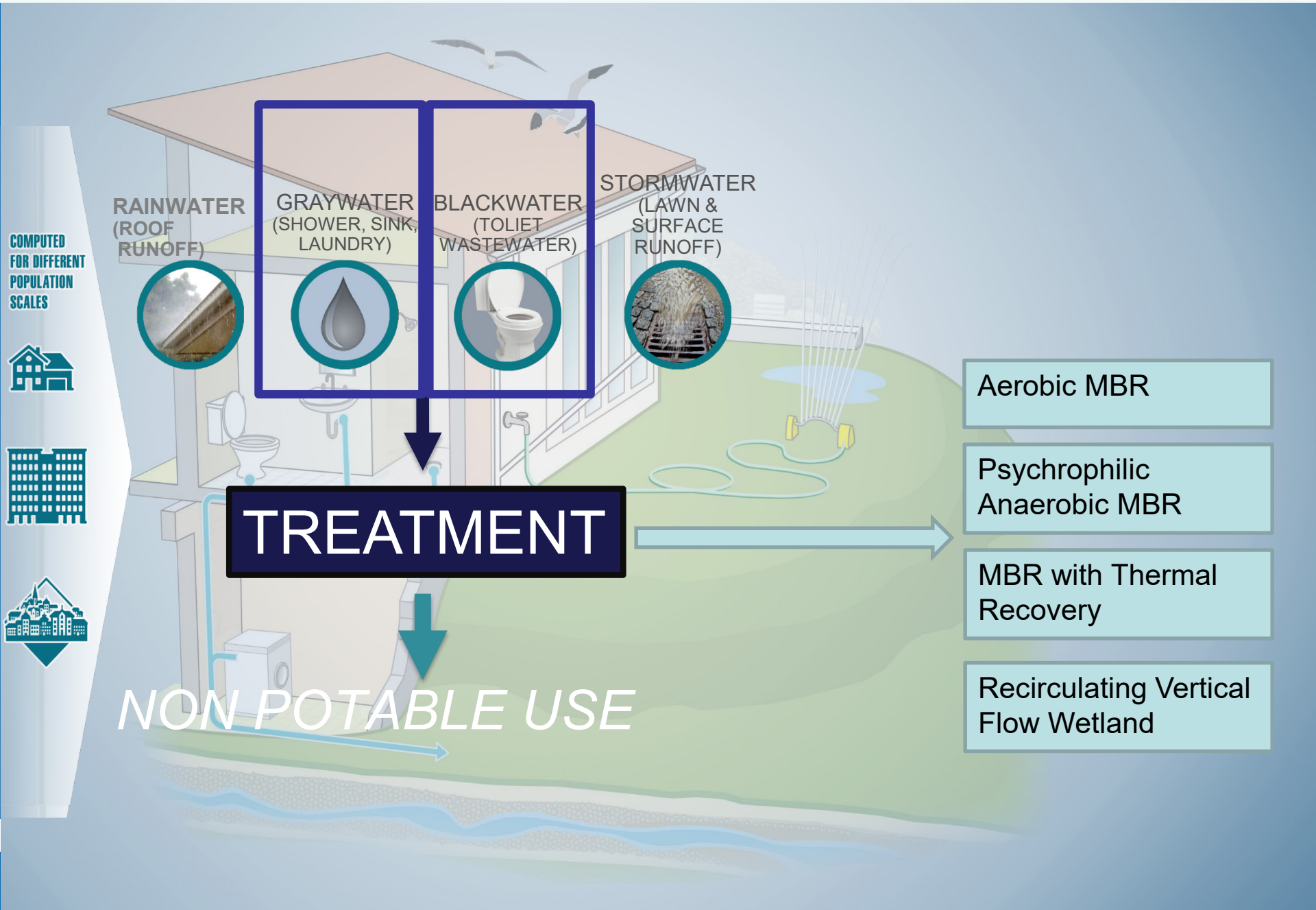
Notes: DWT – drinking water treatment; MGD – million gallons per day; O&M – operation and maintenance

Applicable for multi-family land use scenario

Influence of Parameters on Study Outcome



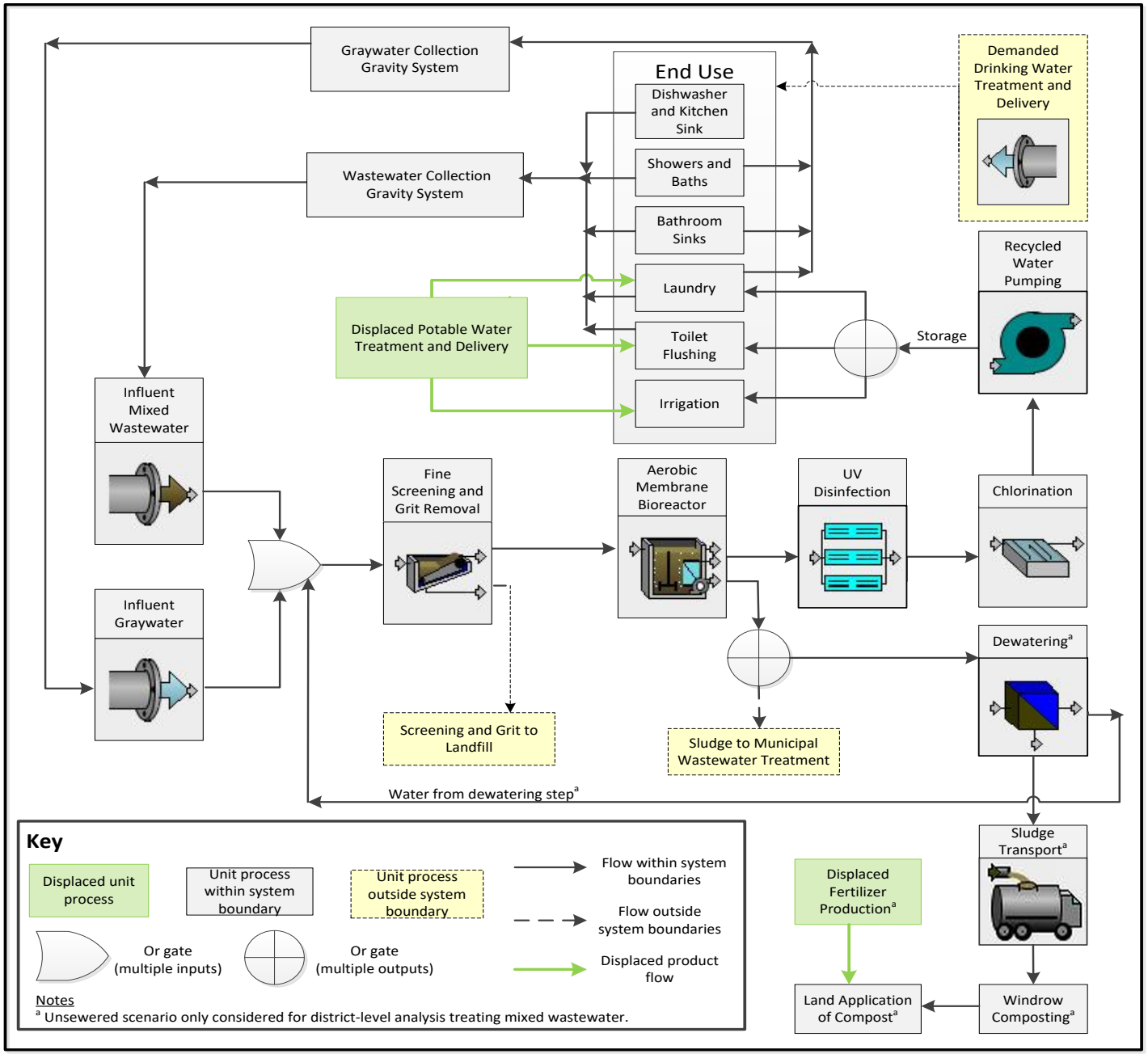
FINDING NEW WATER – Urban Case Study



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	2,249	1,100	2,249
Building Footprint (Roof Area)		20,000	155,969	155,969	20,000	155,969
Area Served (sq. ft)		380,000	754,981	754,981	380,000	754,981

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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Acknowledgements and Disclaimer

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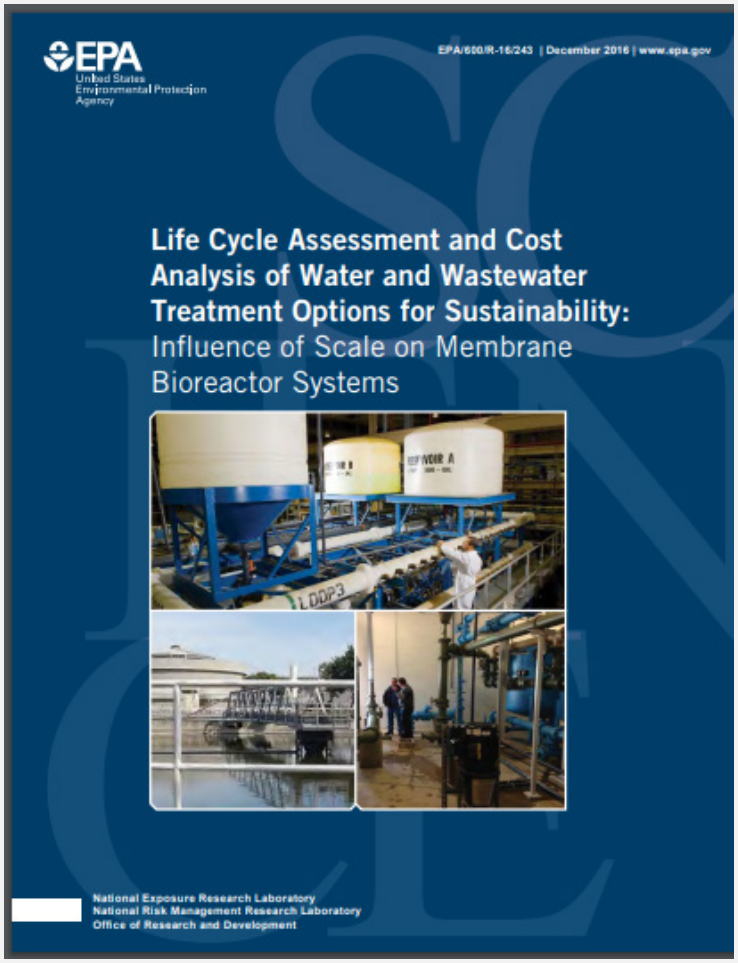

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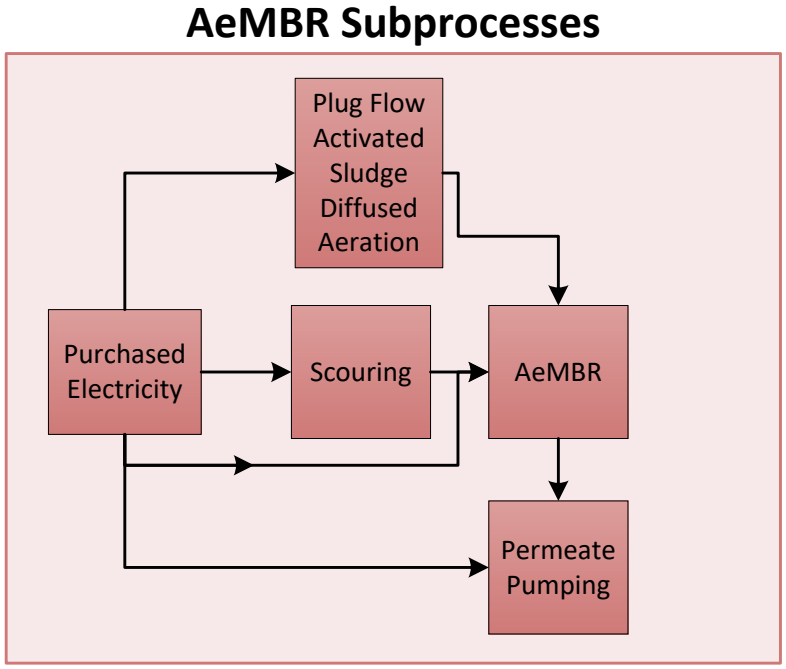
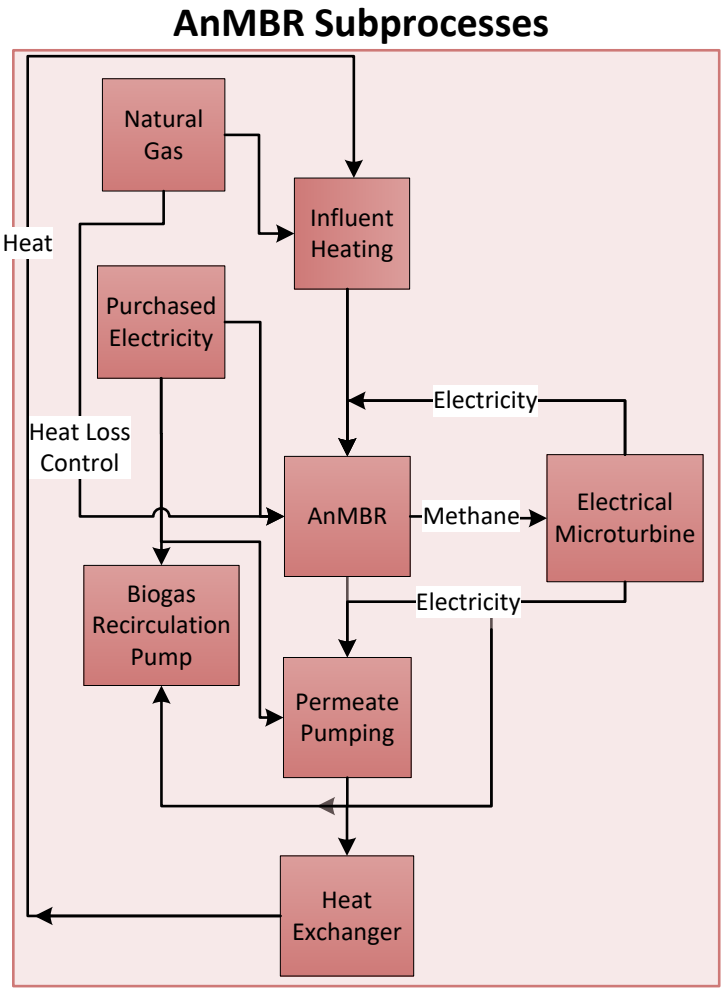
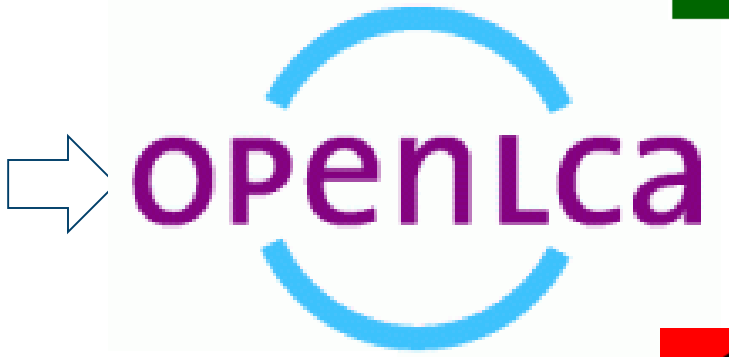
ADDITIONAL SLIDES

MBR Operation



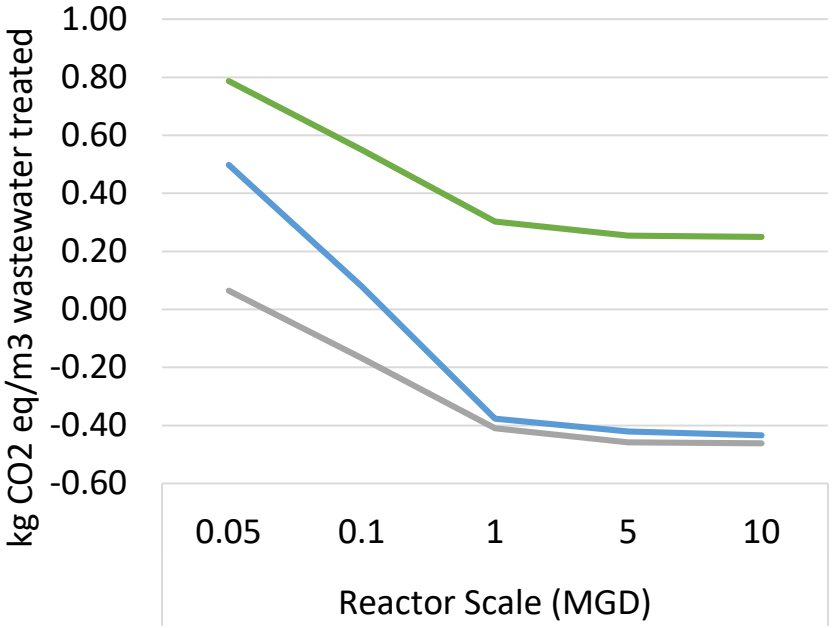


LCA database development

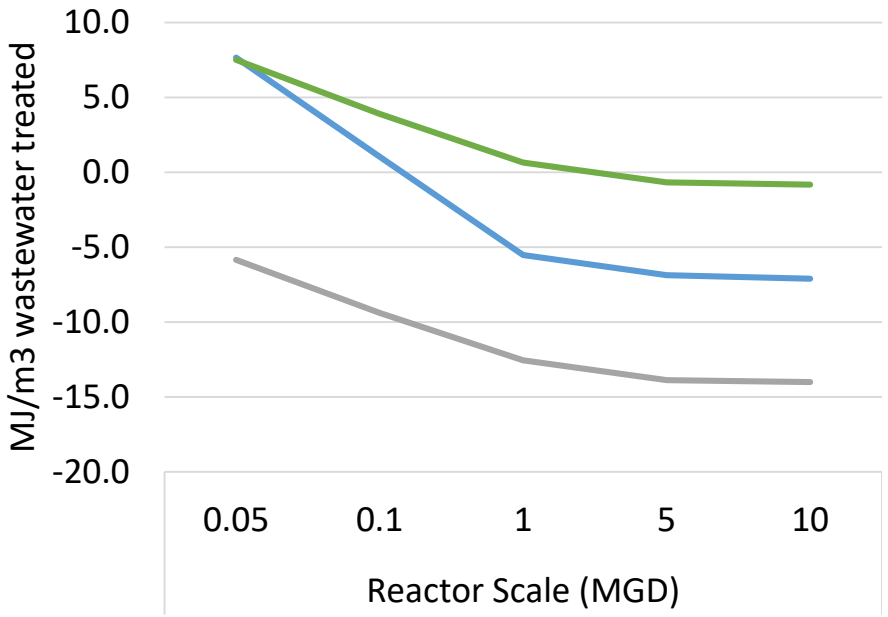


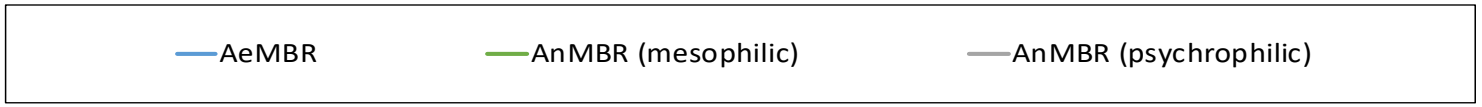
Influence of Reactor Scale

Global Warming Potential

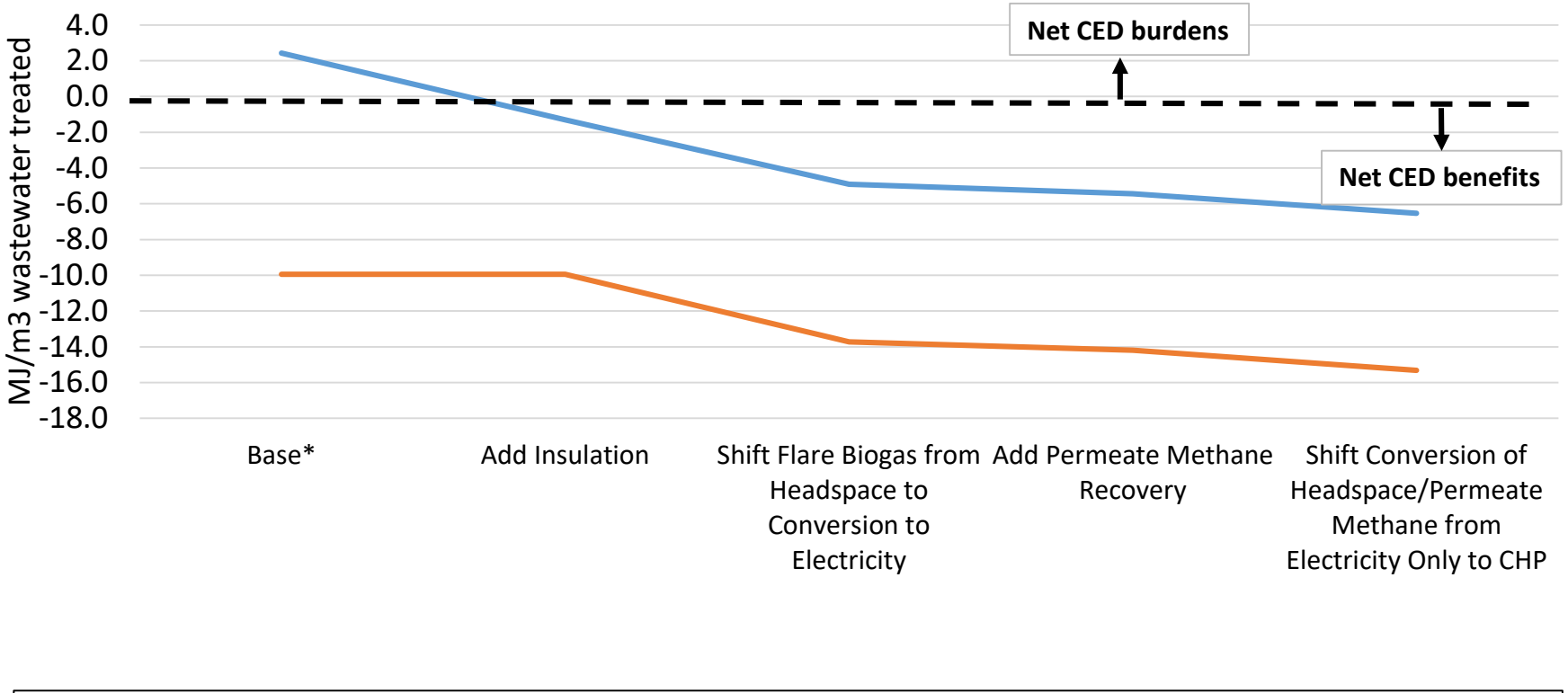


Cumulative Energy Demand





Effect of MBR Improvements Strategies on Energy Demand under Different Climate Conditions



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

Influence of Electrical Grid and Displaced Water Assumptions on GWP