

Supplementary Information

Parameter	Scenario A (Freshwater)	Scenario B (Water Reuse)	Unit	Source
System Parameters				
Annual makeup water volume	50,000.00	50,000.00	m ³ /yr	Input must have an equal value for both scenarios
Cycles of Concentration (COC)	6.00	3.50	-	EPA, 2012, DOE
Tower operating hours per year	8,000.00	8,000.00	hrs/yr	Schulze et al. 2019 (20yr, 6 days x 3 shifts)
System lifetime	20.00	20.00	yr	Schulze et al. 2019
Electricity grid carbon intensity	0.39	0.39	kg-CO ₂ /kWh	US avg EPA eGRID 2023. Change for regional sensitivity
Treatment Energy Intensity				
Treatment energy (primary train)	0.04	0.46	kWh/m ³	A: Ghimire et al. 2021, B: Plappally & Lienhard V, 2012
Treatment energy (sensitivity, UF+RO)	0.08	1.74	kWh/m ³	A: unchanged; B: UF+RO+Cl ₂ worst case from Akhoundi et al. 2020
Chemical dosing energy equivalent	0.03	0.06	kWh/m ³	Akhoundi et al. 2020
Pumping & Distribution Energy				
Pipeline distance to tower	1.00	2.00	km	Slight penalty to reuse because freshwater pipeline infrastructure is already streamlined, whereas additional on-site routing is required for tertiary

				treatment. To-site pumping is attributed to the water supplier.
Pumping energy per km per m ³	0.04	0.05	kWh/m ³ /km	Standard hydraulic estimate; Cincinnati LCA 2019
Tower recirculation pump energy	0.18	0.18	kWh/m ³	Schulze et al. 2019 LCI table. Equal for both scenarios
Fan energy	0.09	0.09	kWh/m ³	Schulze et al. 2019 LCI table. Equal for both scenarios
Water				
Evaporation ratio	0.02	0.02	m ³ /m ³	EPA and WaterSense, 2023. 1% per 10°F cooling range; conservative design assumption
Blowdown ratio (function of CoC)	0.003	0.006	m ³ /m ³	Calculation from LCI
Freshwater withdrawn from nature	1.00	0.00	-	A: 100%; B: reclaimed = 0 freshwater withdrawal
TDS of source water	200.00	800.00	mg/L	Design assumptions baked on: A: EPA, Secondary Drinking Water Standards B: Badruzzaman et al. 2022
Impact Characterization Factors				
GWP factor of electricity	0.39	0.39	kg-CO ₂ -eq/kwh	EPA eGRID 2023 US average; change per region
GWP factor of antiscalant production	3.50	3.50	kg-CO ₂ -eq/kg	Ecoinvent 3.9. Phosphonate/polyacrylate antiscalant proxy
GWP factor of biocide production	1.50	1.50	kg-CO ₂ -eq/kg	Ecoinvent 3.9. Sodium hypochlorite

				production proxy
Direct treatment process emissions	0.0005	0.002	kg-CO ₂ -eq/m ³	THM/DBP from chlorination. Negligible by Akhouni 2020; included for completeness
Water scarcity factor (AWARE2.0)	8.00	8.00	M ³ world-eq /m ³	WULCA AWARE2.0. Seitfudem et al. 2025; set per region
Antiscalant chemical load	1.5	4.5	g/m ³ makeup	Badruzzaman et al. 2022; higher for reuse due to TDS
Biocide chemical load	1	3	g/m ³ makeup	Badruzzaman et al. 2022; Legionella risk higher for reuse
Cost of electricity	0.0895	0.0895	\$/kWh	EIA, electric power prices, US average 2026
Cost of water	1.02	1.02	\$/m ³	OSTI, industrial price, US average 2021
Electricity-associated water consumption	0.0439	0.0439	m ³ /kWh	EIA, electric power sector cooling water 2021

Table S0. Assumptions for wastewater reuse and freshwater cooling tower.

GWP Component	Freshwater (A) [kg CO ₂ -eq/m ³]	Reuse (B) [kg CO ₂ -eq/m ³]	Diff (B-A) [kg CO ₂ -eq/m ³]
Electricity for treatment	0.025	0.201	-0.176
Electricity for pumping	0.015	0.039	-0.023
Electricity for tower operations	0.104	0.104	0.0000
Electricity subtotal	0.145	0.344	-0.199
Antiscalant chemicals	0.0053	0.0158	-0.011
Biocide chemicals	0.0015	0.0045	-0.003
Chemicals subtotal	0.0068	0.0203	-0.014
Direct process emissions	0.0005	0.0020	-0.002
TOTAL GWP	0.152	0.366	-0.214

Table S1. Decomposition of GWP by emission source. Electricity accounts for 93.9% (reuse) and 95.2% (freshwater) of total GWP. Treatment energy drives 80% of the inter-scenario difference.

Impact Category	Freshwater (A)	Reuse (B)	Difference (B-A)	Winner
GWP [kg CO ₂ -eq/m ³]	0.152	0.366	-0.214	Freshwater
Energy Intensity [kWh/m ³]	0.375	0.890	-0.515	Freshwater
Freshwater Displacement [m ³ /m ³]	1.0	0	1.0	Reuse
Water Scarcity [m ³ world-eq/m ³]	0.144	0	0.144	Reuse
Indirect Water (Electricity) [L/m ³]	0.675	1.602	-0.927	Freshwater
Indirect Water (Chemicals) [L/m ³]	0.03	0.08	-0.05	Freshwater

Table S2. Summary of impact assessment results per m³ makeup water. Reuse wins on water metrics; freshwater wins on carbon and energy. Net preference depends on the regional water-scarcity weighting.

Grid Scenario	EF [kg CO ₂ /kWh]	GWP Fresh [kg CO ₂ -eq/m ³]	GWP Reuse [kg CO ₂ -eq/m ³]	Diff
US Coal-heavy (WV)	1.020	0.390	0.930	-0.540
US Average	0.386	0.152	0.366	-0.214
California	0.210	0.086	0.209	-0.123
France (nuclear)	0.047	0.025	0.064	-0.039
100% Renewable	0.000	0.007	0.022	-0.015

Table S3. GWP sensitivity to grid carbon intensity. The GWP gap narrows from -0.540 (coal-heavy) to -0.015 (100% renewable). At zero-carbon electricity, only chemical and direct process emissions remain.

Parameter	Freshwater (A)	Reuse (B)
COC [-]	6.0	3.5
Blowdown (m ³ /m ³ makeup)	0.003	0.006
Antiscalant load [g/m ³]	1.5	4.5
Biocide load [g/m ³]	1.0	3.0
Chemical GWP share [%]	4.3%	6.4%
Grid EF [kg-CO ₂ -eq/kWh]	0.39	0.30

Table S4. Cycles of concentration sensitivity. Lower COC in the reuse scenario increases blowdown and chemical consumption. Chemical-attributed GWP is 6.4% for reuse vs 4.3% for freshwater.