United States Environmental Protection Agency

Nutrient Removal and Resource Recovery

Effect on Life Cycle Cost and Environmental Impacts of Small Scale Wastewater Treatment

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Date

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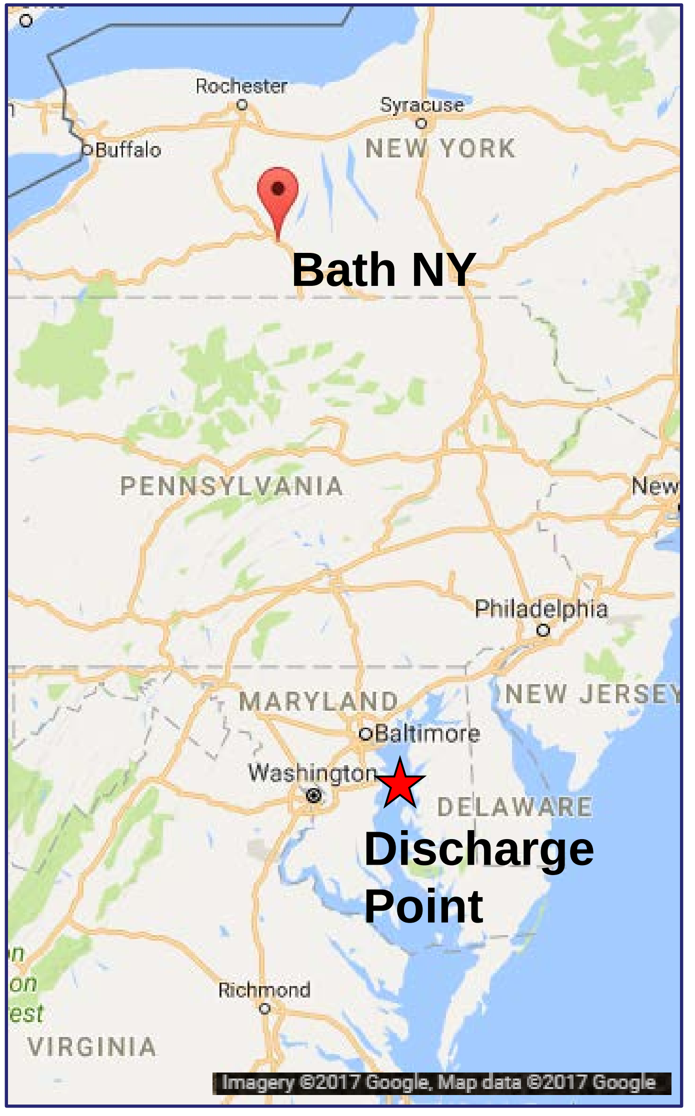
Bath NY Community & Wastewater Treatment

- **<u>Population</u>: 5,600**
- **<u>Flow Capacity</u>: 1 MGD**
- **<u>Legacy WWTP</u>: CAS**
- **<u>Upgraded WWTP</u>: MLE biological treatment**



MGD – Million gallons per day
WWTP – Wastewater Treatment Plant
CAS – Conventional Activated Sludge
MLE – Modified-Ludak Ettinger

Goal & Scope

- **Comparative analysis of legacy and upgraded WWTP**
- **Energy recovery potential and avoided product benefits of Anaerobic Digestion (AD) and land application of compost**
  - *Effect of adding High Strength Organic Waste (HSOW)*
- **Calculate life cycle costs of upgraded system**

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Functional Unit

1 cubic meter of treated wastewater with specified influent characteristics

** Accepting additional HSOW and compost amendment does not increase treatment capacity. Results are normalized to 1 MGD flowrate.*

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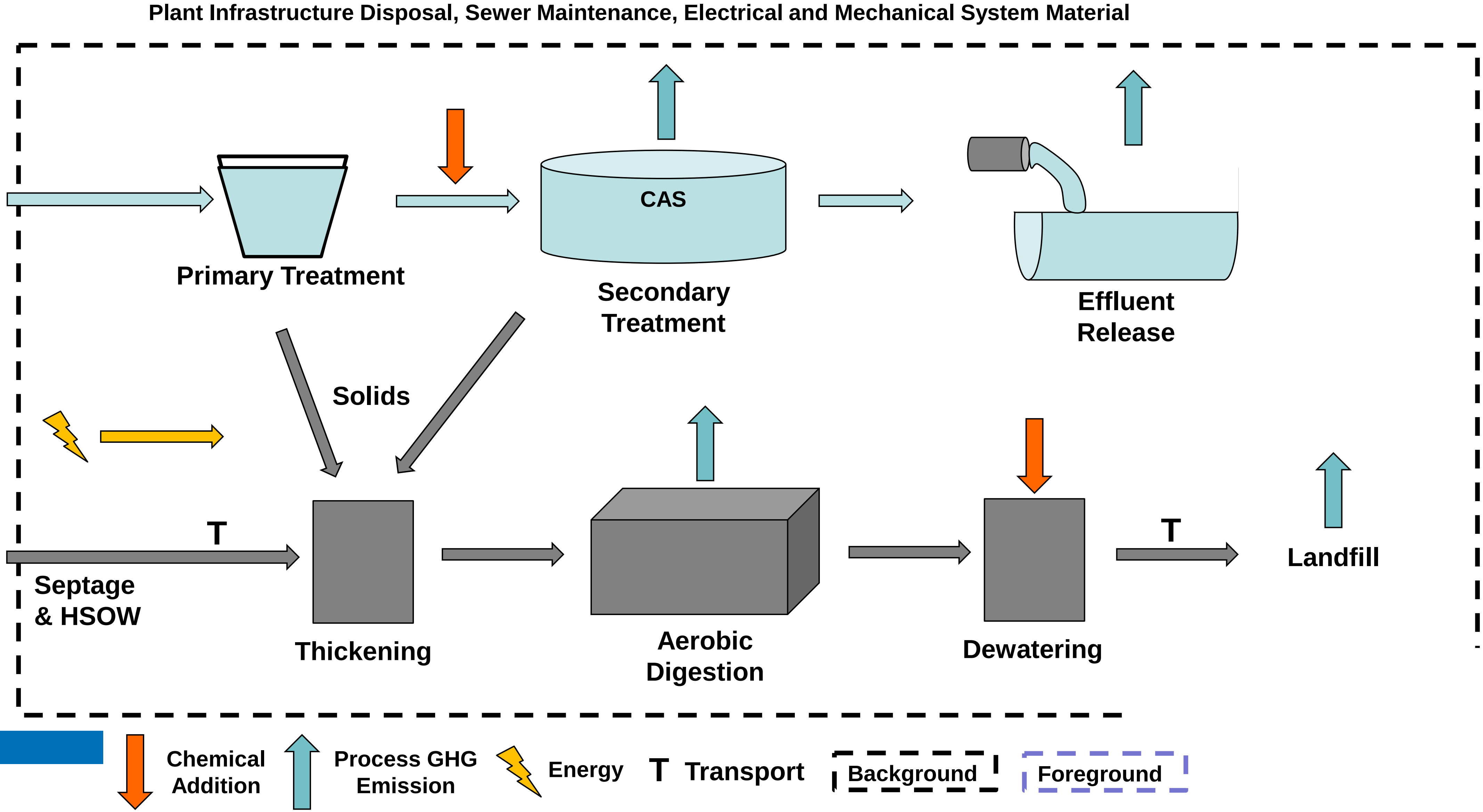
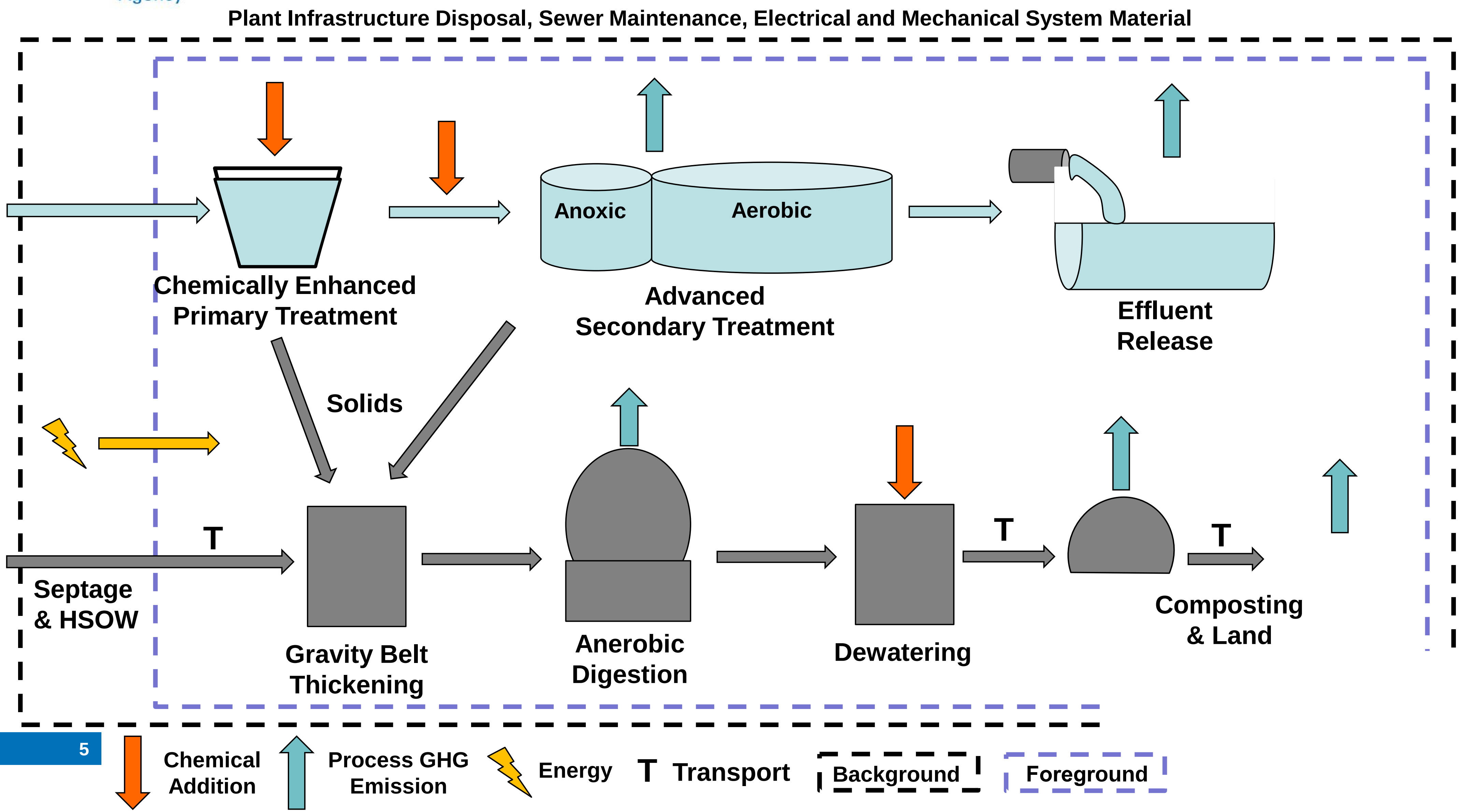
Legacy System Diagram



Upgraded System Diagram



Influent & Effluent Characteristics

Characteristic	Influent	Legacy	Upgraded
		(mg/L)	
Suspended Solids	437	7.9	5
Biological Oxygen Demand	323	8.5	2.3
Total Kjeldahl Nitrogen	56	16	4.4
Ammonia	32	6.7	3.6
Total Phosphorus	8	0.7	0.6
Nitrite	<1	2.8	0.8
Nitrate	<1	13	14
Organic Nitrogen	29	9	0.8
Total Nitrogen	61	31	20

** SPDES – State Pollutant Discharge Elimination System*

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Select LCI Calculations

- **Electricity: calculated using a record of equipment use, horsepower, and run time**
- **Chemicals: via provided dosage rates**
- **Process GHGs**
  - **N_2O: based on TKN influent to secondary (Chandran 2012)**
  - **Methane: based on BOD influent to secondary (IPCC 2006)**
    - **Assigns methane correction factor for specific treatment units (Legacy – Czepiel 1993, Upgraded – Daelman et al. 2013)**

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Select LCI Calculations continued…

- **<u>Biogas Production (Upgraded Plant)</u>**
  - Based on Volatile Solids (VS) destruction assumption (ft^3/day)
- **<u>Landfill Emissions (Legacy Plant)</u>**
  - Regional and national average gas capture performance
  - Degradation via a first-order decay model
- **<u>Composting Emissions (Upgraded Plant)</u>**
  - Methane (0.11%, 0.82%, 2.5% of C)
  - Nitrous Oxide (0.34%, 2.68%, 4.65% of N)
  - Ammonia (1.2%, 6.7%, 12.74% of N)
  - Carbon Monoxide (0.04% of C)

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Life Cycle Costing

Total Costs = Σ (Annual Costs) + Σ (Capital Costs)

Total Capital Costs = Purchased Equipment Costs + Direct Costs + Indirect Costs

Total Annual Costs = Operation Costs + Replacement Labor Costs + Materials Costs + Chemical Costs + Energy Costs

Net Present Value=$\Sigma(\text{Cost}_x/(1+i)^x)$

Sensitivity & Scenario Analysis

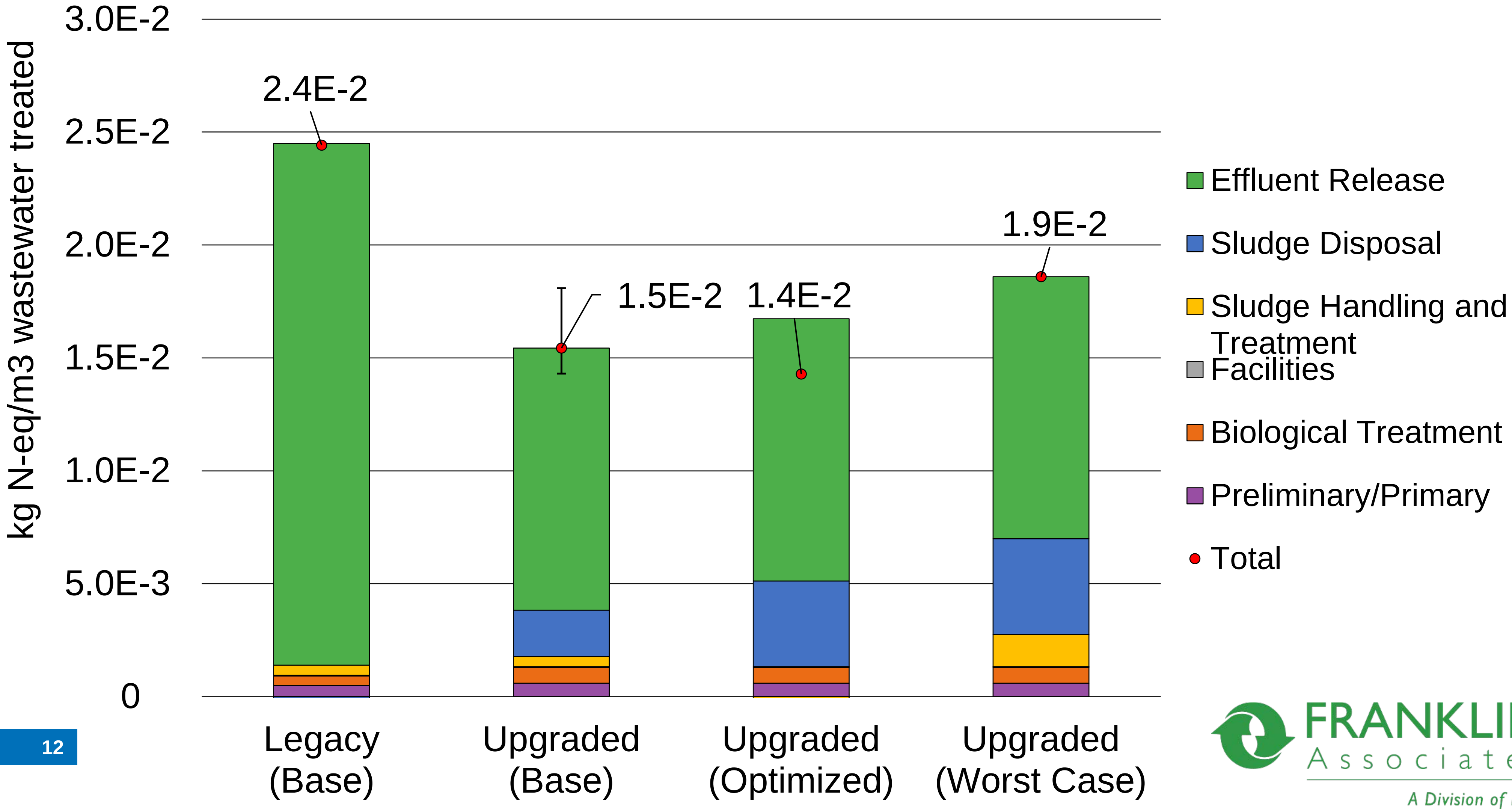
- **High Strength Organic Waste Acceptance**

Scenario Type	Scenario			
Anaerobic Digestion	**Low**	**Base**	**High**	**Units**
Loading Rate	223	271	352	kg VS/m^3/day
Biogas Yield	0.75	0.94	2.18	m^3/kg VS destroyed
Volatile Solids Reduction	45	60	65	%
Methane Content of Biogas	60	65	70	% v/v
Biogas Heat Content	0.55	0.59	0.61	MJ/ft^3
CHP Electrical Efficiency	30	36	42	%
CHP Thermal Efficiency	41	51	43	%

Upgraded Base Scenario Summary

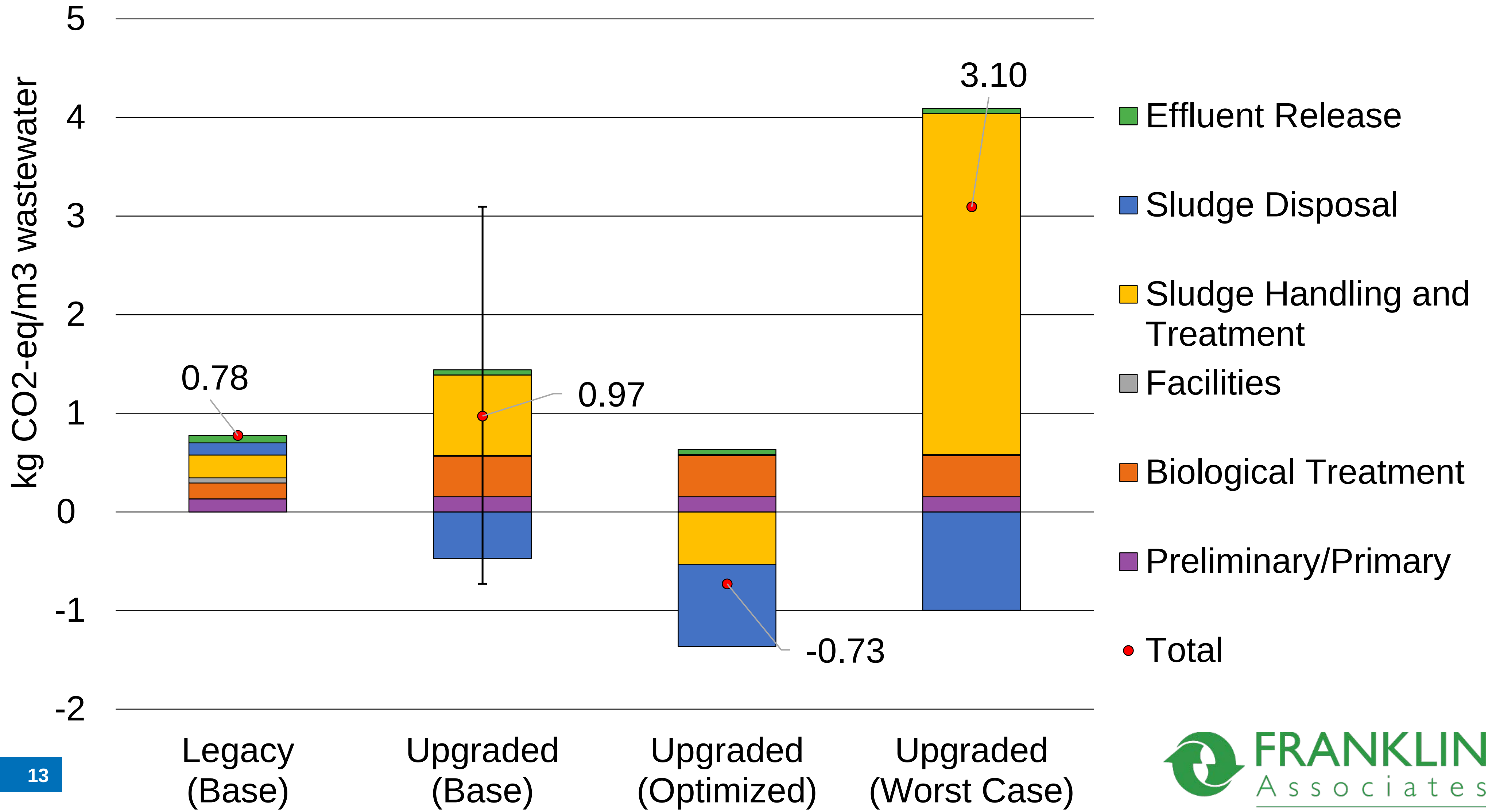
- **Includes all treatment upgrades with <u>no</u> acceptance of additional HSOW**
- **Industry standard biogas yield estimate (conservative)**
- **Middle estimate of potential compost emissions**
- **End-of-Life GHG emission estimates include amendment Carbon and Nitrogen**
- **Other process GHG emissions remain constant across scenarios**

Eutrophication Potential
Process Contribution



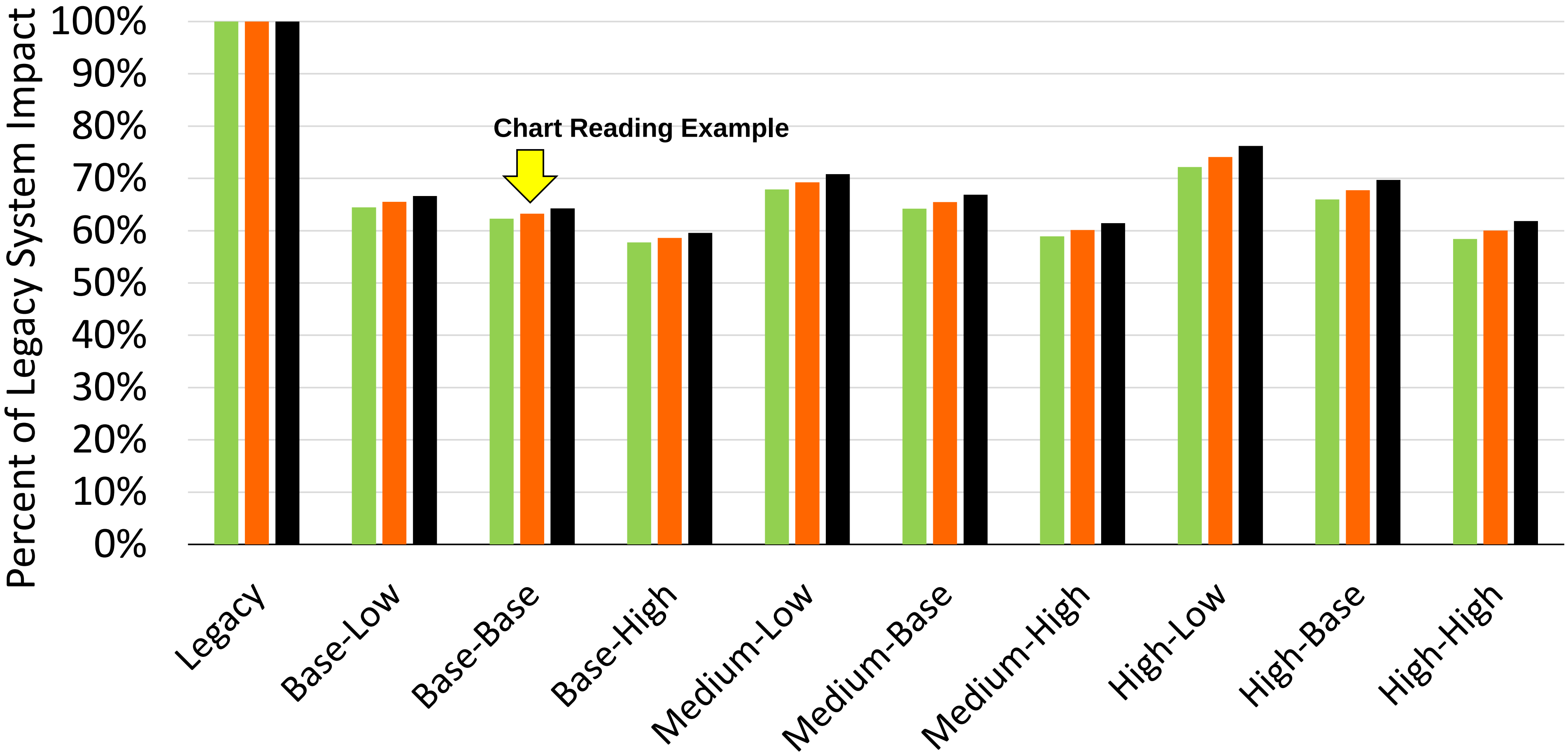
Global Climate Change Potential

Process Contribution



Eutrophication Scenarios

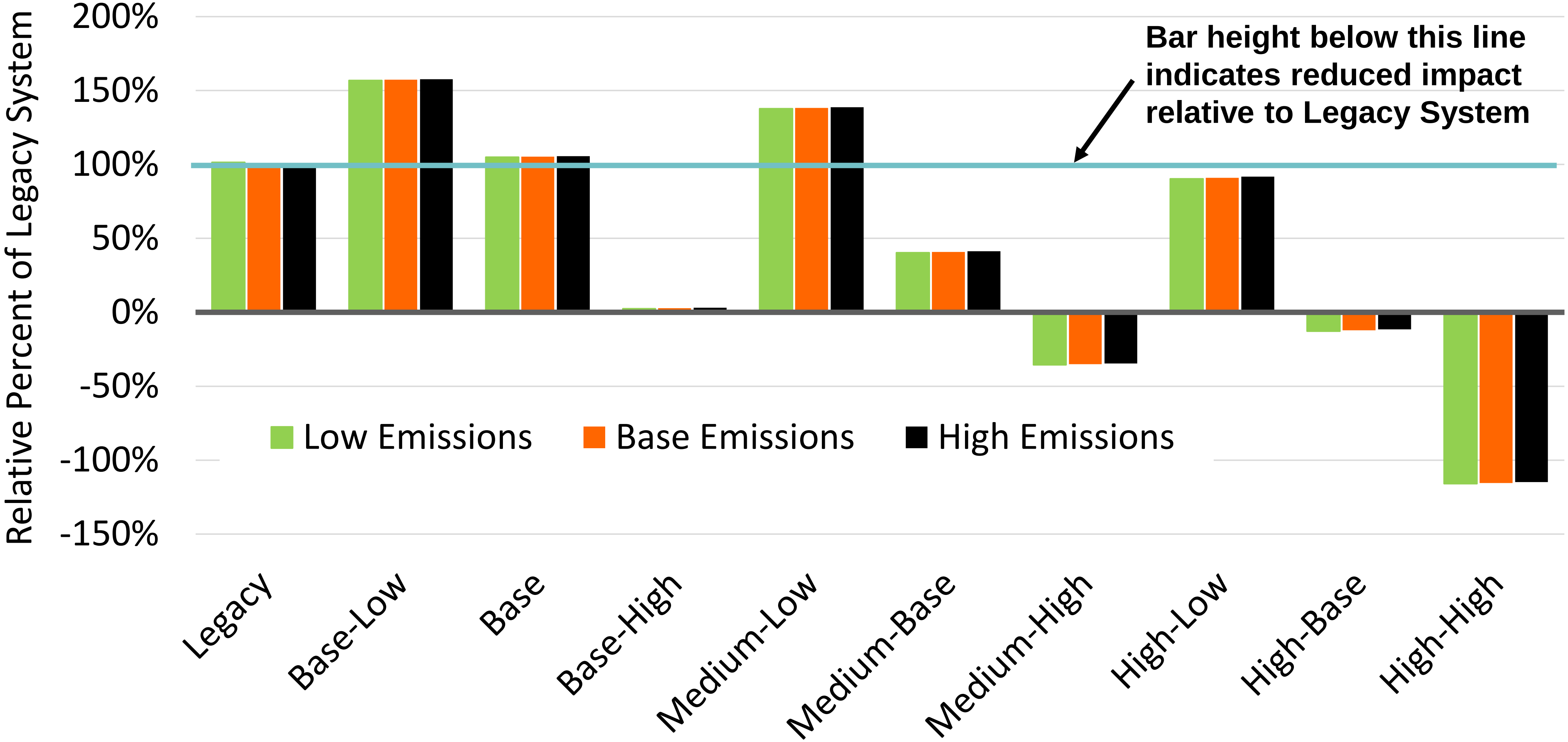
Percent of Legacy System Impact



Scenario Name: Feedstock - AD

Cumulative Energy Demand Scenarios

Percent of Legacy System Impact



Scenario Name: Feedstock - AD

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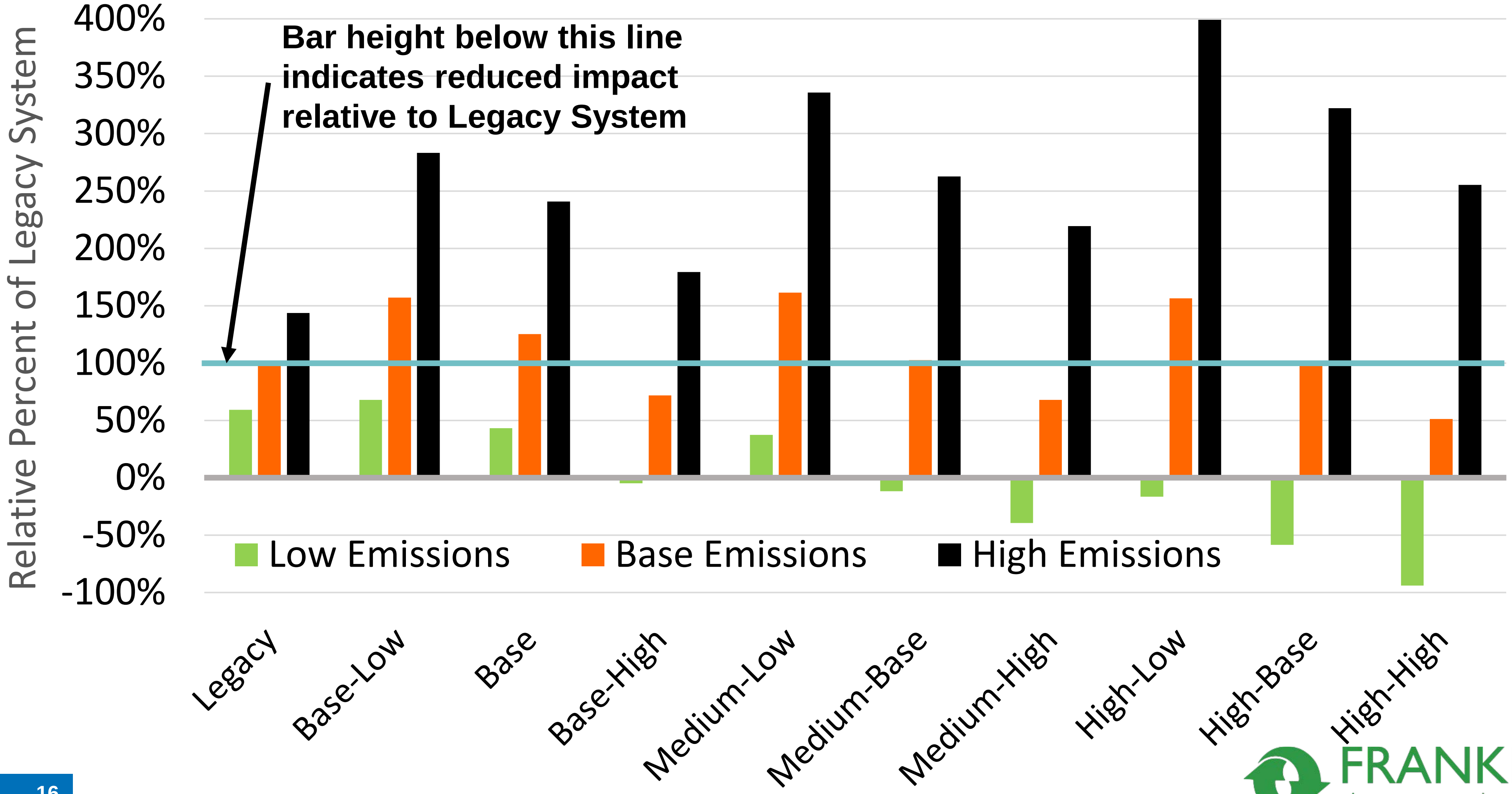
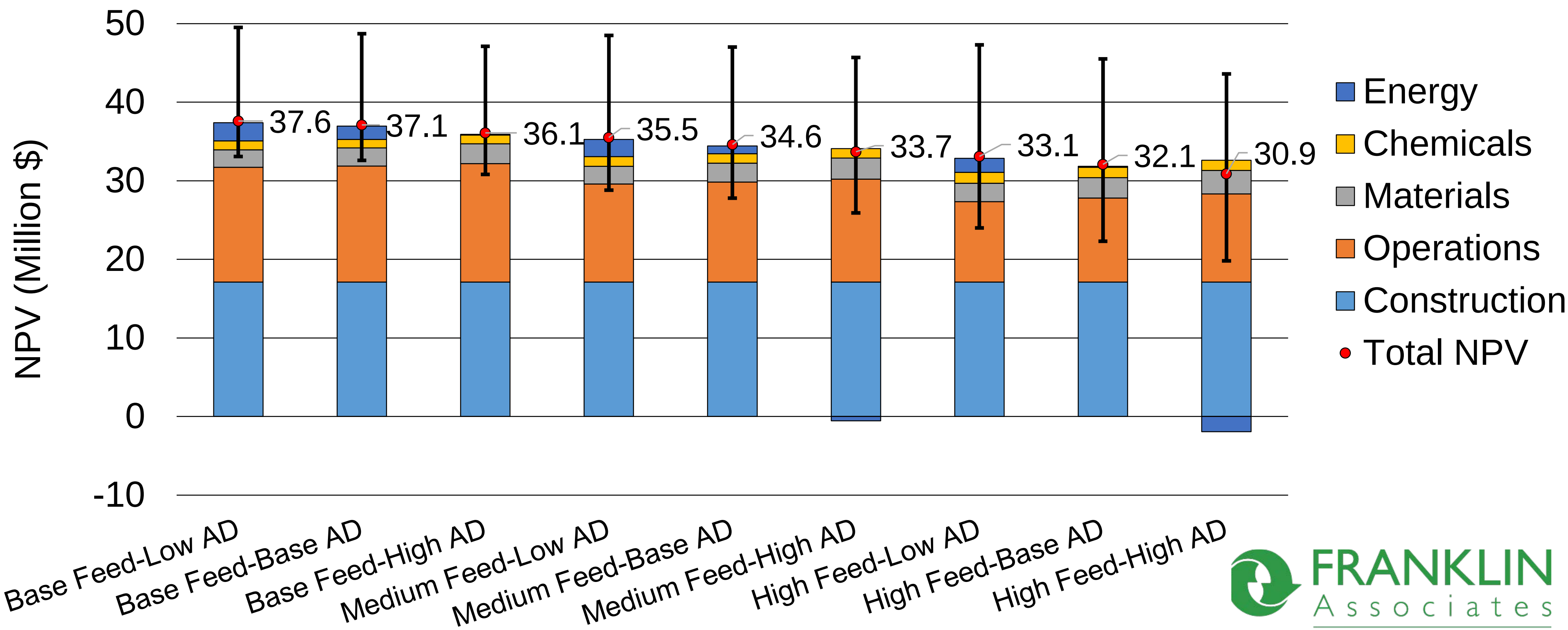
Global Climate Change Potential Scenarios



Scenario Name: Feedstock - AD

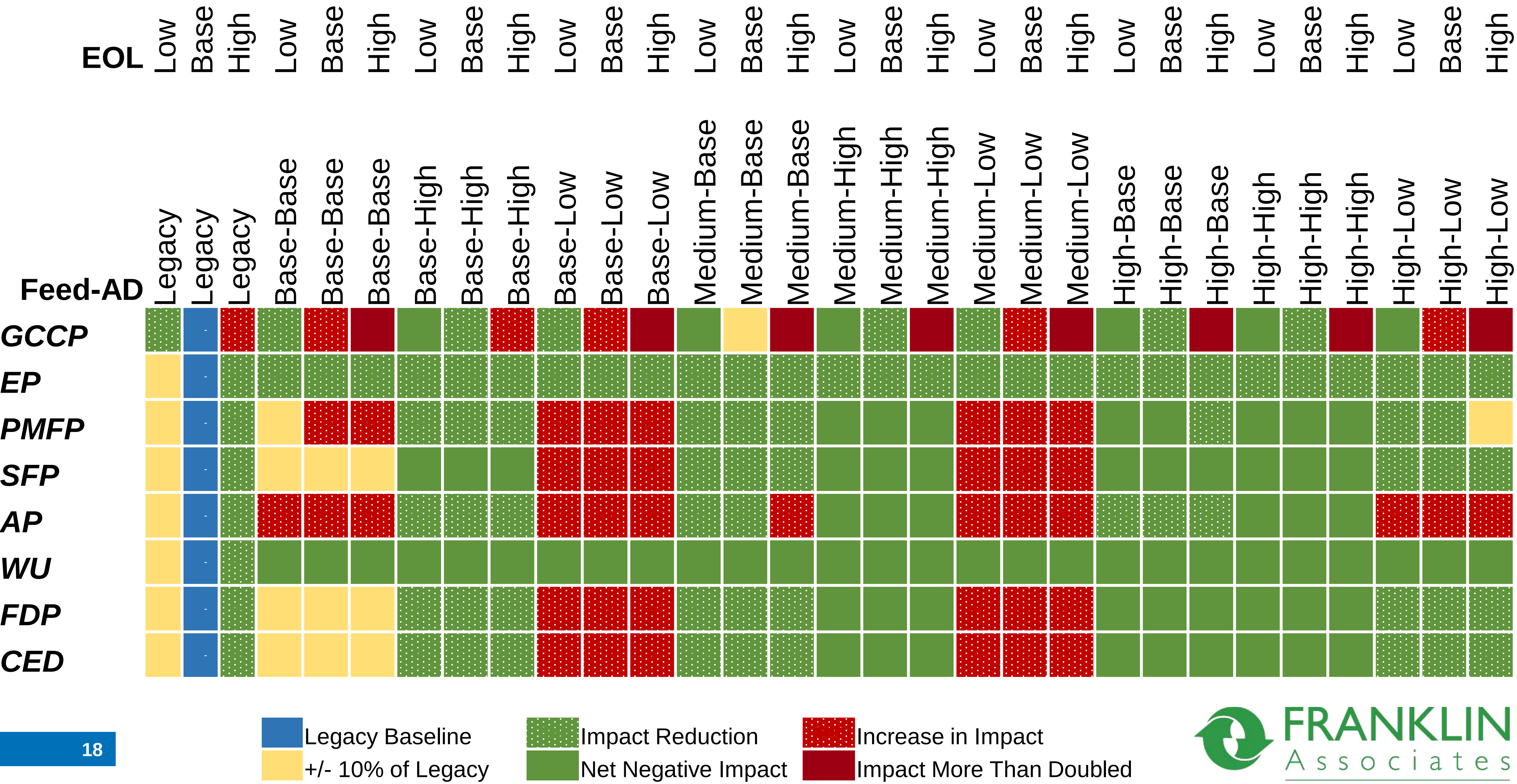
LCCA Results

Cost Scenario	AD + CHP Payback Period (years)								
Low	None	None	378	79	56	34	27	21	16
Base	None	None	None	None	847	162	98	65	45
High	None	None	None	None	None	None	None	243	70



Scenario Name: Feedstock - AD

Summary of Relative Scenario Impacts



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Conclusions

- **Clear Environmental Benefit of HSOW Acceptance**
  - **Maximize use of AD capacity**
  - **Low AD performance (avoidable), can lead to increases in environmental impact**
- **Benefit to Climate Change Potential depends strongly on composting system selection and management**
- **Simple payback of AD is challenging to achieve at small-scale, but the trend is towards decreasing cost**
- **Many impact categories positively influenced by avoided electricity and natural gas consumption**
- **Appropriate use of AD has the potential to reduce environmental impacts of achieving increased nutrient removal**

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The opinions expressed in this presentation are those of the author. They do not reflect EPA policy, endorsement, or action, and EPA does not verify the accuracy or science of the contents of this presentation. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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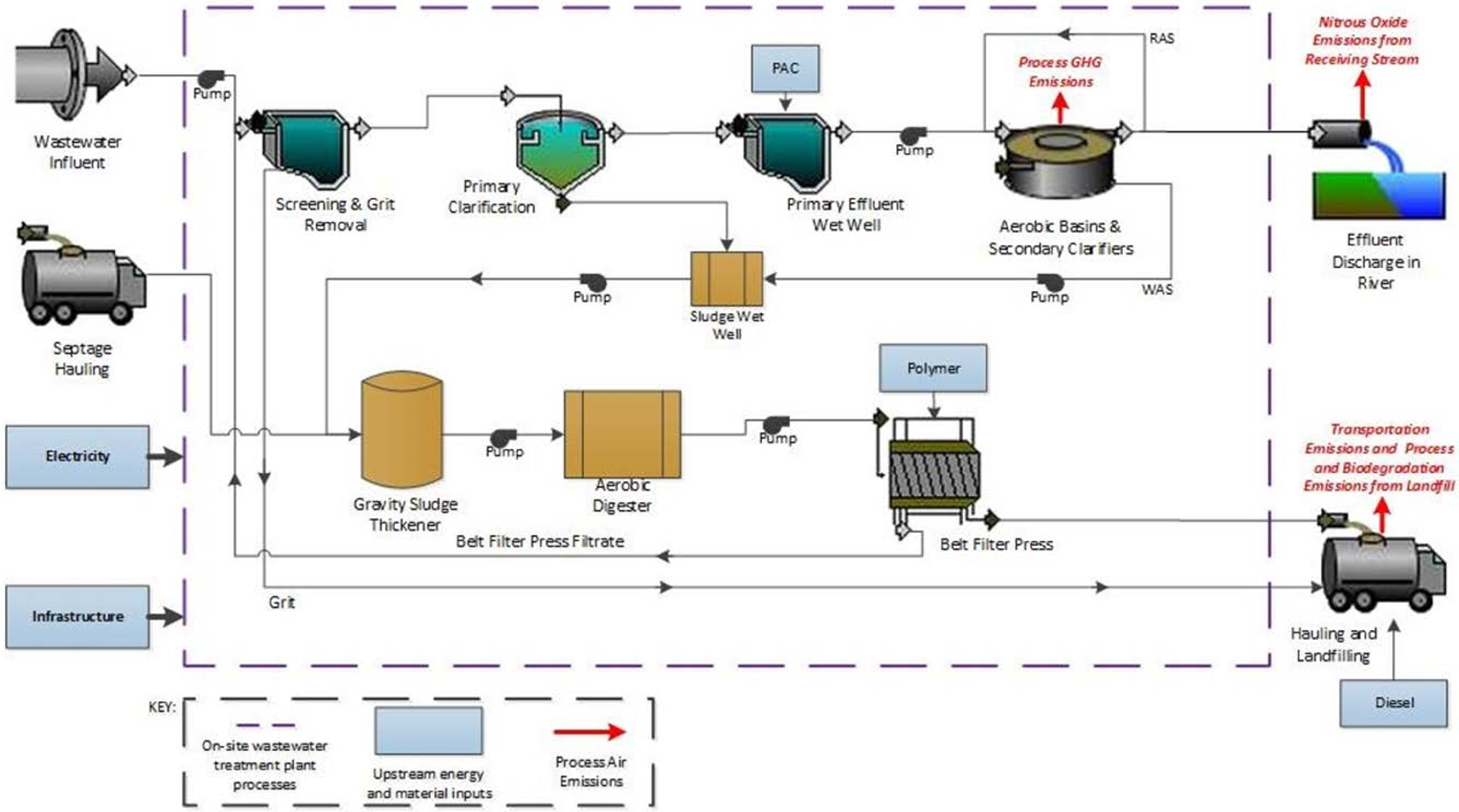
SI. Impact Categories

Metric	Method	Unit
Cost	LCCA	USD 2014
Global Warming Potential	TRACI 2.1	kg CO_2-eq.
Eutrophication Potential	TRACI 2.1	kg N-eq.
Particulate Matter Formation Potential	TRACI 2.1	kg $PM_{2.5}$-eq.
Smog Formation Potential	TRACI 2.1	kg O_3-eq.
Acidification Potential	TRACI 2.1	kg SO_2-eq.
Water Use	ReCiPe	m^3
Fossil Depletion Potential	ReCiPe	kg oil-eq.
Cumulative Energy Demand	Ecoinvent	MJ-eq.

SI. Legacy WWTP Flow Diagram



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SI. Plant Upgrades

- **Chemically Enhanced Primary Clarification**
- **Modified Ludzack-Ettinger Biological Treatment**
  - ***Currently Operational***
- **Gravity Belt Thickening**
- **Anaerobic Digestion**
- **Composting & Land Application**

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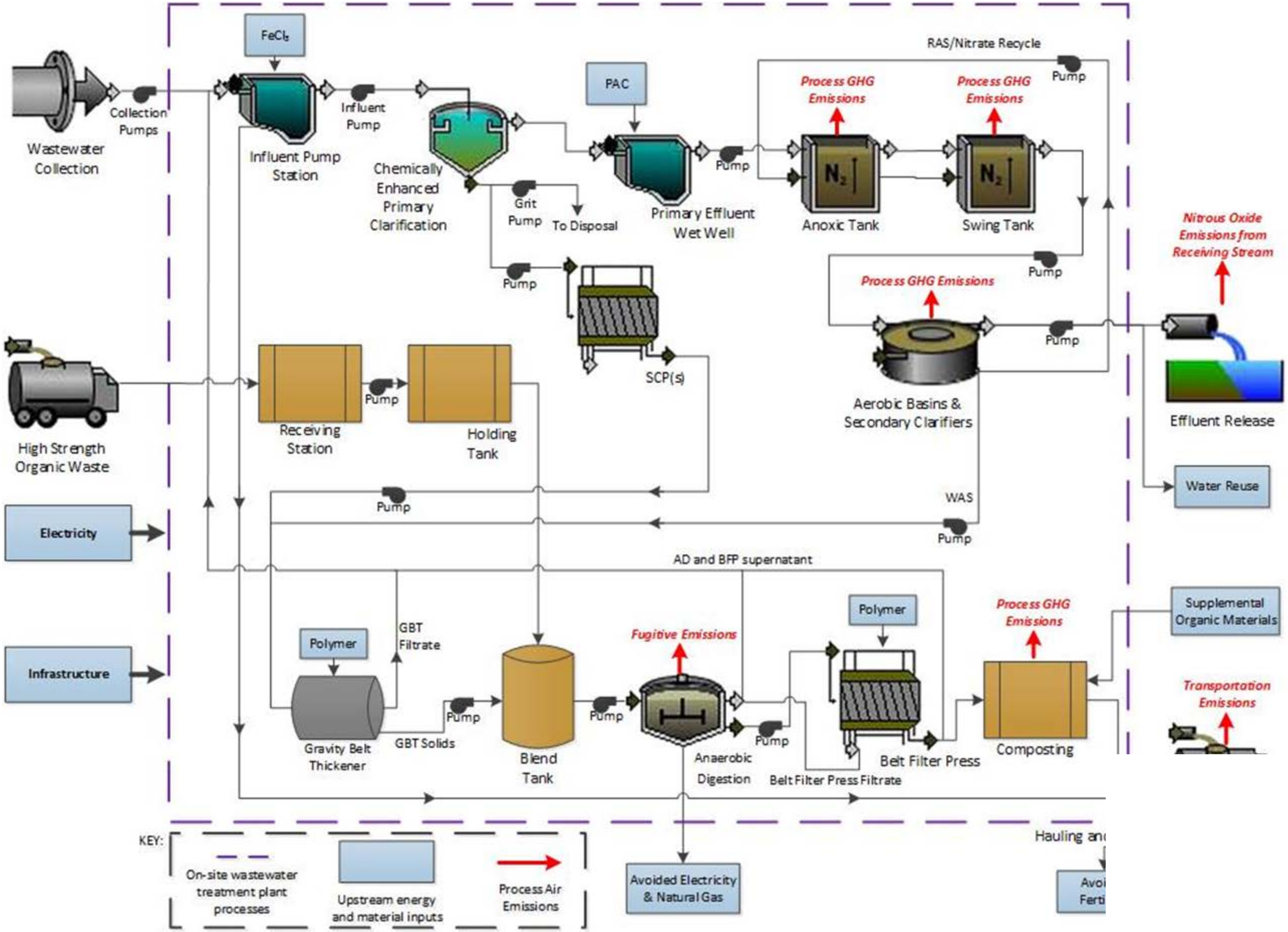
SI. Upgraded WWTP Flow Diagram



SI. Results Process Categories

Category Names	Process
Preliminary/Primary	Wastewater collection; operation and infrastructure; m3 wastewater
Preliminary/Primary	Influent Pump Station; wastewater treatment unit; at updated plant - US
Preliminary/Primary	Screening and Grit Removal - US
Preliminary/Primary	Clear Cove Primary Clarification; wastewater treatment unit; at updated plant - US
Preliminary/Primary	Primary Clarifier; wastewater treatment unit - US
Sludge Handling and Treatment	ClearCove SCP; wastewater treatment unit; at updated plant - US
Preliminary/Primary	Wet Well and Sump Station; wastewater treatment unit; at updated plant - US
Biological Treatment	Pre-Anoxic & Swing tank; wastewater treatment unit; at updated plant - US
Biological Treatment	Aeration Tanks; wastewater treatment unit - US
Sludge Handling and Treatment	Waste Receiving and Holding; wastewater treatment unit; at updated plant - US
Sludge Handling and Treatment	Gravity Belt Thickener; wastewater treatment unit; at updated plant - US
Sludge Handling and Treatment	Sludge Thickener; wastewater treatment unit - US
Sludge Handling and Treatment	Blend Tank; wastewater treatment unit; at updated plant - US
Sludge Handling and Treatment	Anaerobic Digestion; wastewater treatment unit; at updated plant - US
Sludge Handling and Treatment	Aerobic Digester; wastewater treatment unit - US
Sludge Handling and Treatment	Belt filter press; wastewater treatment unit - US
Sludge Handling and Treatment	Biosolids composting; windrow composting; wastewater treatment unit; at updated plant - US
Sludge Disposal	Land application of compost; wastewater treatment unit; at updated plant - US
Sludge Disposal	Sludge Disposal; wastewater treatment unit - US
Effluent Release	Effluent release; wastewater treatment unit; at surface water; m3 wastewater - US
Facilities	Control Building; at wastewater treatment plant - US

SI. LCCA Scenario Parameters

Parameter Value	Low Cost	Base Cost	High Cost
Planning Period (years)	30	30	30
Real Discount Rate (%)	6%	5%	3%
Interest Rate (%)[1]	0%	0%	0%
Electricity Cost ($/kWh)[1]	0.077	0.051	0.077
Electricity Revenue ($/kWh)	0.077	0.051	0.051
Diesel Cost ($/gal)	2	2.7	3.5
Natural Gas Cost ($/MCF)	4.5	3.84	3.84
Septage Disposal Fee ($/gallon)	0.01	7.00E-03	7.00E-03
High Strength Organic Waste ($/gallon)[2]	0.15	0.06	0.03
Compost Revenue ($/yd^3)[3]	10	5	-
Landfill Tipping Fee ($/wet ton)[1]	50.8	50.8	50.8
Fraction of Biogas Heat Valued	Total Heat Potential	Facility Use	Facility Use
Material and Maintenance Escalation	2%	3%	4%
Labor Escalation	1%	2%	3%
Taxes/Salvage Escalation	0%	0%	0%
Operations General Escalation	1%	2%	3%
Fee Escalation	1%	2%	2%
Energy Escalation	2%	2%	3%

SI. New England Regional Grid Mix

Fuel Source	Electrical Grid Mix (%)[1,2]
Biomass	3.10%
Wind	1.90%
Solar	0.40%
Hydro	29%
Nuclear	29%
Gas	31%
Coal	5.50%
Total	100%

Notes/References: [1] U.S. EPA 2016 [2] ISO-NE 2016

SI. Landfill Calculations

Degradable Carbon Remaining (metric tons) = $C_t = C_0 {*} e^{(-k*t)}$

C_t = Degradable carbon remaining at time t
C_0 = Degradable carbon remaining at time 0
k = Degradation rate constant
t = time elapsed

Gas Capture Performance

Parameter	Bath NY Landfill (baseline)	National Average Landfill
Percentage of landfilled C that produces methane	50%	50%
Percentage of methane released w/o treatment	4.50%	29%
Percentage of methane captured for energy recovery	95%	57%
Percentage of methane flared	0%	11%
Percentage of methane oxidized to CO_2	0.50%	3.80%

Carbon remaining after year 100 is considered sequestered

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SI. Calculated Agricultural Emission Rates

Emission Species	Compartment	Emission	Units
Ammonia	air	16.50%	of applied N
Nitrous Oxide	air	1.17%	of applied N
Nitrate	water	10.50%	of applied N
P, sediment	water	10.10%	of applied P
P, soluble	water	3.20%	of applied P
P, soluble	groundwater	0.32%	of applied P
P, sediment	air	2.40%	of applied P

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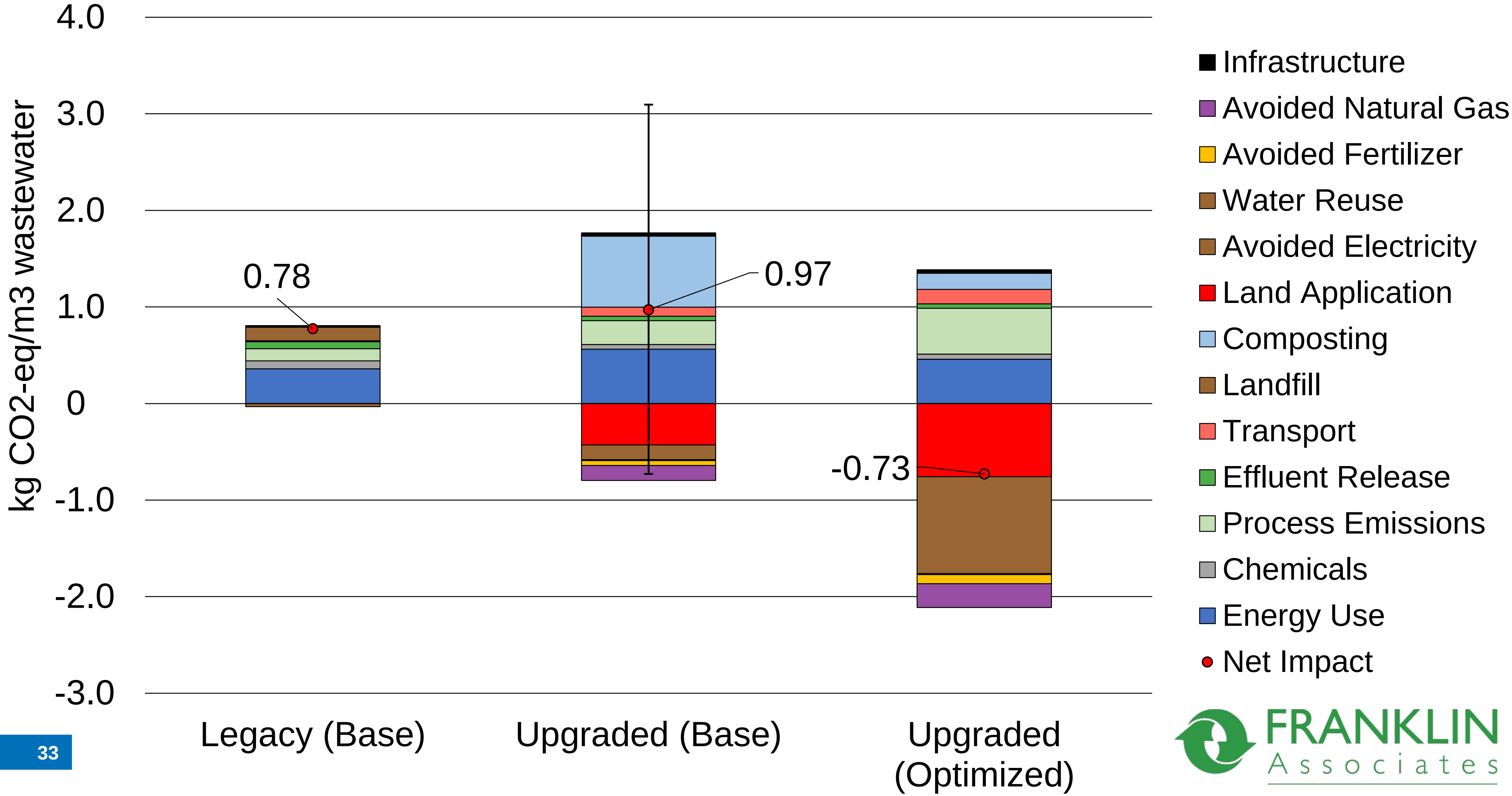
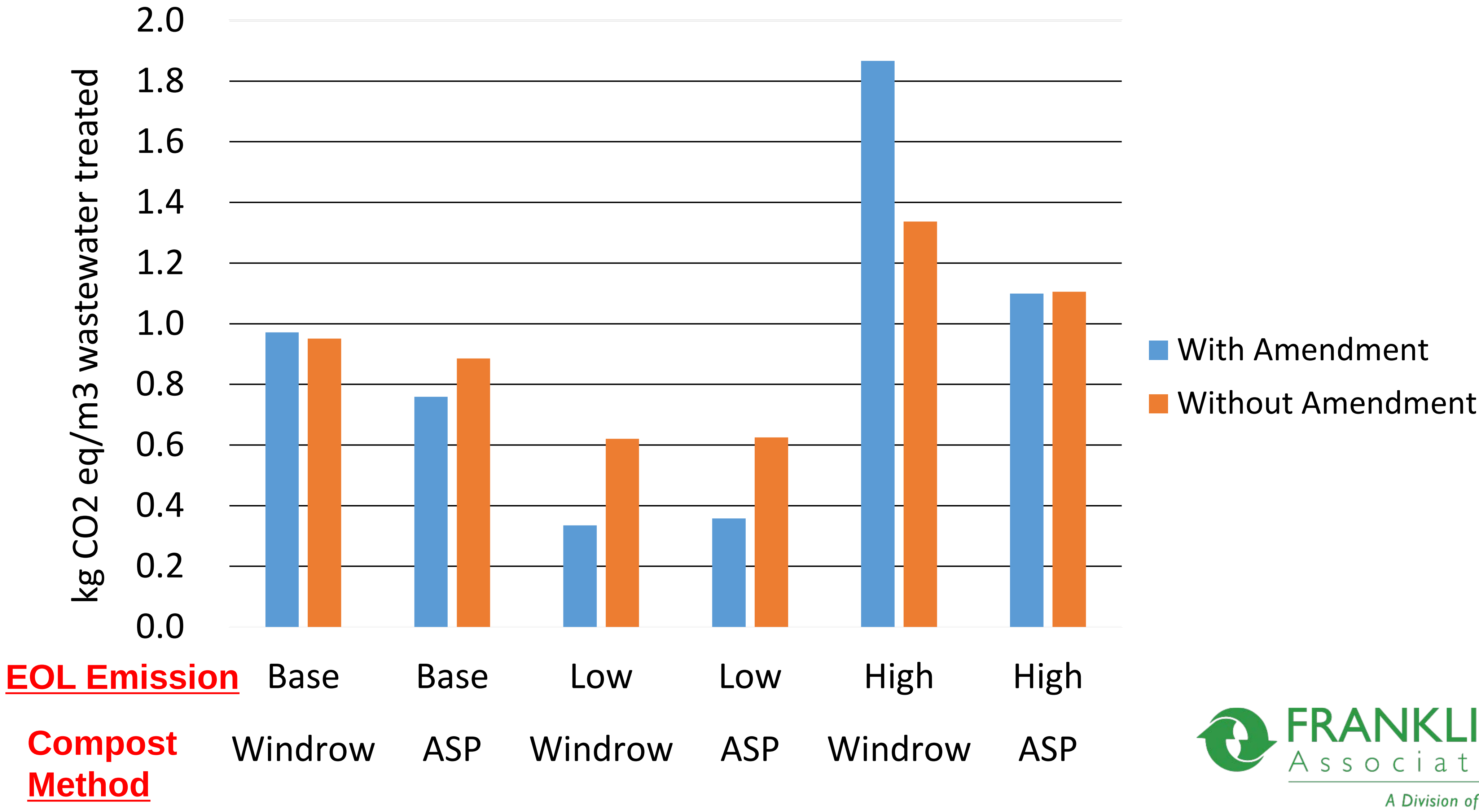
Global Climate Change Potential

Drivers



SI. Amendment Sensitivity



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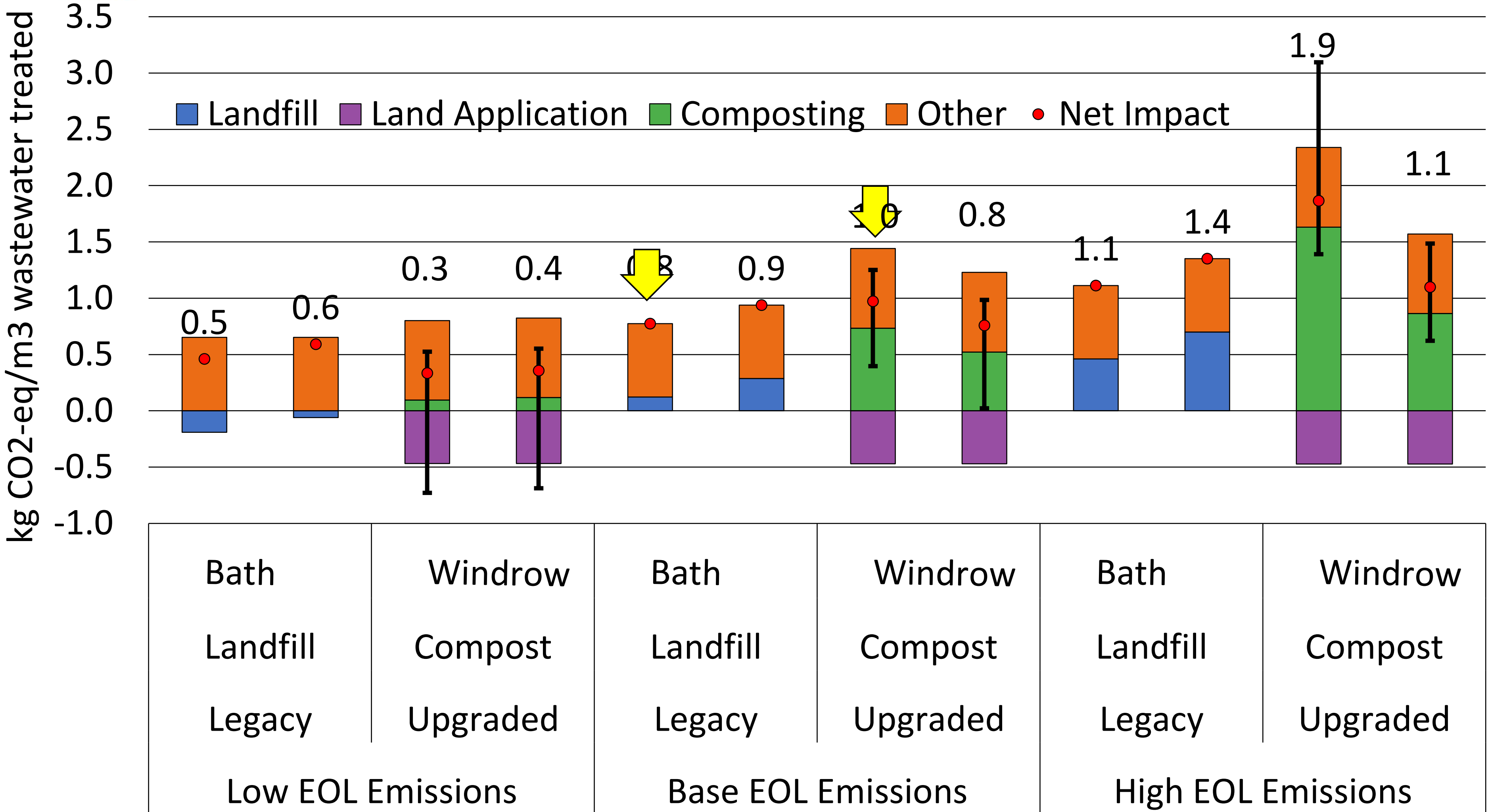
SI. GCCP End-of-Life Sensitivity



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