Bio-Energy with Carbon Capture and Storage (BECCS): Achieving Net Zero and Beyond

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Solutions for Today | Options for Tomorrow

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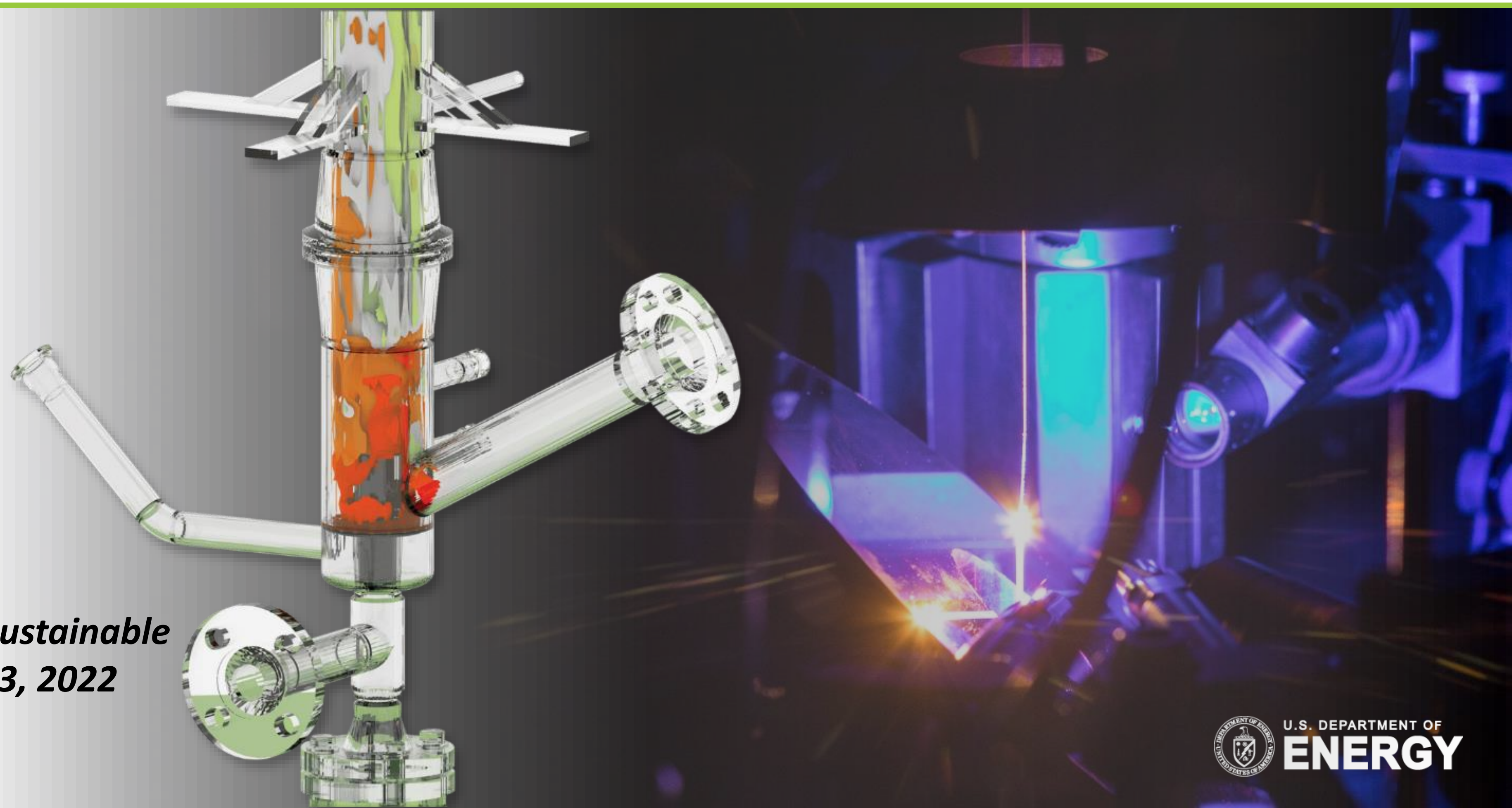

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U.S. DEPARTMENT OF ENERGY

Basis of This Work

Technoeconomic and Life Cycle Analysis of Bio-Energy With Carbon Capture and Storage (BECCS) Baseline

- **Multi-year effort.**
- **Covers hybrid poplar biomass co-firing.**
  - Pelletized.
  - With and without CCS.
  - Alternative Enhanced Oil Recovery scenarios.


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TECHNOECONOMIC AND LIFE CYCLE ANALYSIS OF BIO-ENERGY WITH CARBON CAPTURE AND STORAGE (BECCS) BASELINE

KYLE BUCHHEIT, ERIC LEWIS, KISHORE MAHBUBANI, DERRICK CARLSON

July 23, 2021

Available: https://netl.doe.gov/energy-analysis/details?id=52e9635b-6ac5-4703-b1a2-08710ef81f53

Fundamental Questions

Can you make a coal power plant carbon neutral using biomass and carbon capture?

if so,

How much biomass do you need?

and,

How much will it cost?

Agenda

- Study outline.
- Analyses.
- Results.
- Sensitivities.
- Future Research (2022 and beyond).

Study Outline

- **Objective: Examine the performance, environmental impact, and economics of co-firing biomass in a 650 MW greenfield supercritical pulverized coal (PC) power plant.**
  - Economic Result: Levelized Cost of Electricity (LCOE).
  - Environmental Result: Life Cycle Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI).
- **Co-firing Scenarios: 0, 20, 35, 49, and 100% Biomass (by mass).**
  - Coal: Illinois No. 6 Bituminous.
  - Biomass: Hybrid Poplar grown in the Midwest.
- **All scenarios modeled with and without 90% Carbon Capture and Sequestration (CCS) systems.**

Analyses

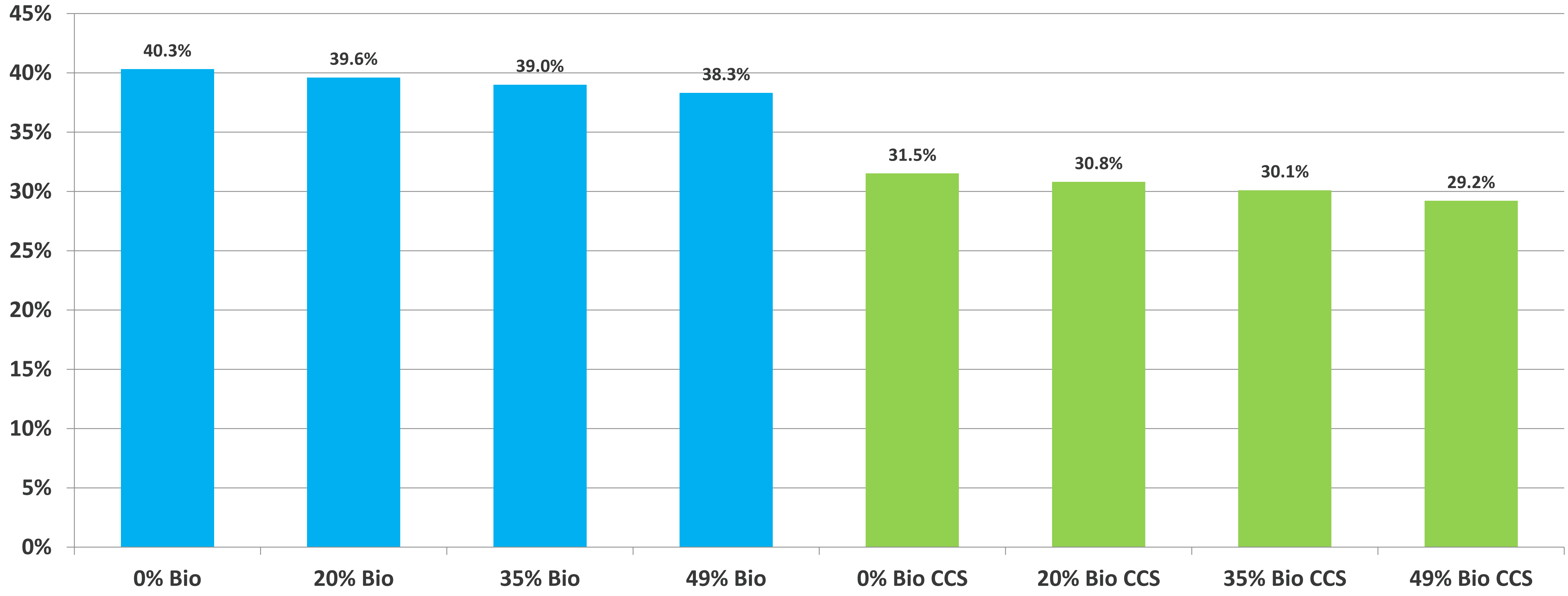
- **Technical Analysis: Aspen Plus model, mass and energy balance used to scale equipment sizes.**

- **Economic Analysis: Capital and operating costs scaled from vendor quotes and previous project data.**

- **Life Cycle Analysis: openLCA model, data from NETL coal and biomass upstream models.**
  - Fuel extraction, processing, and transport; consumables manufacture, and co-product disposition were all modeled in the LCA.

Results: Plant Efficiency

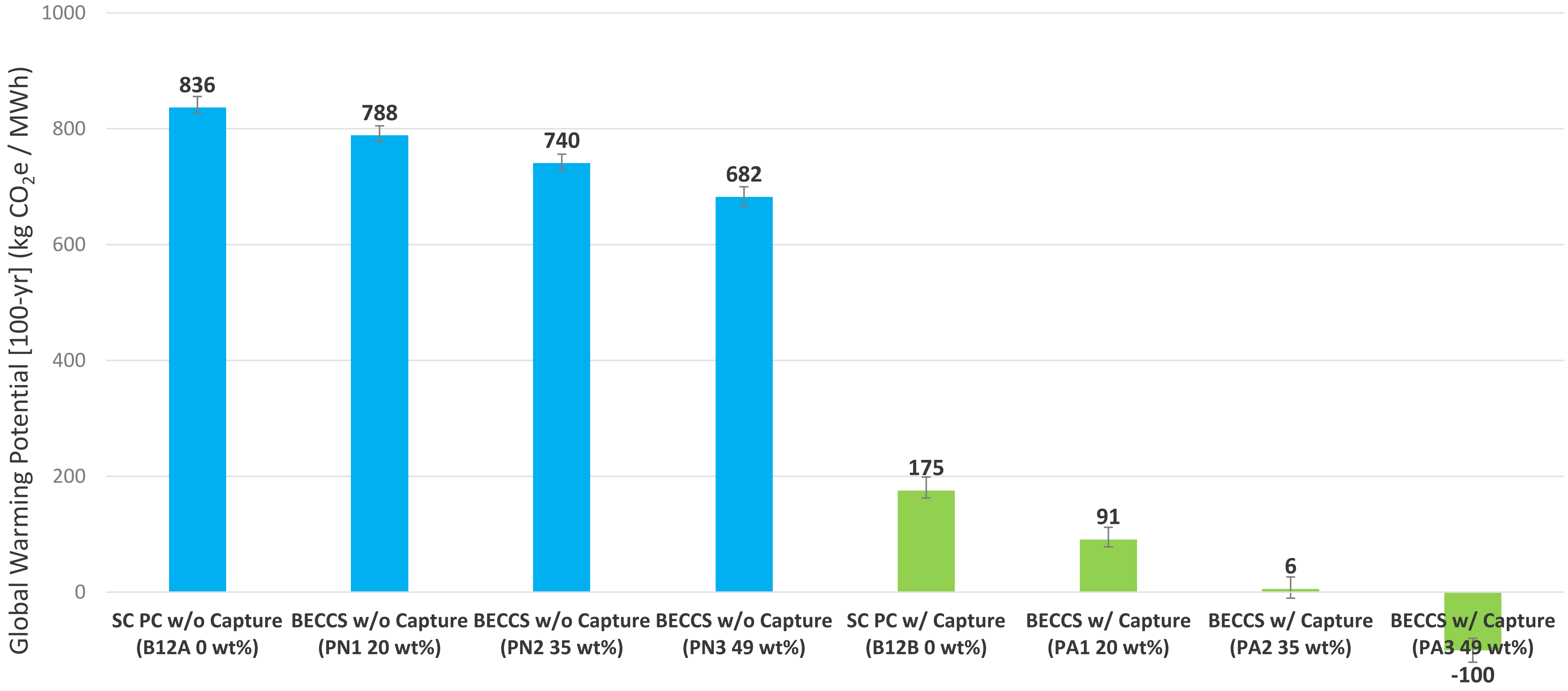
Efficiency % (HHV Basis)



*100% biomass cases were excluded in some cases due to configuration uncertainty for technical scaling to this extent.

Results: Life Cycle Greenhouse Gas (GHG)Analysis

Global Warming Potential (GWP) [100-yr] kg CO_2e/MWh



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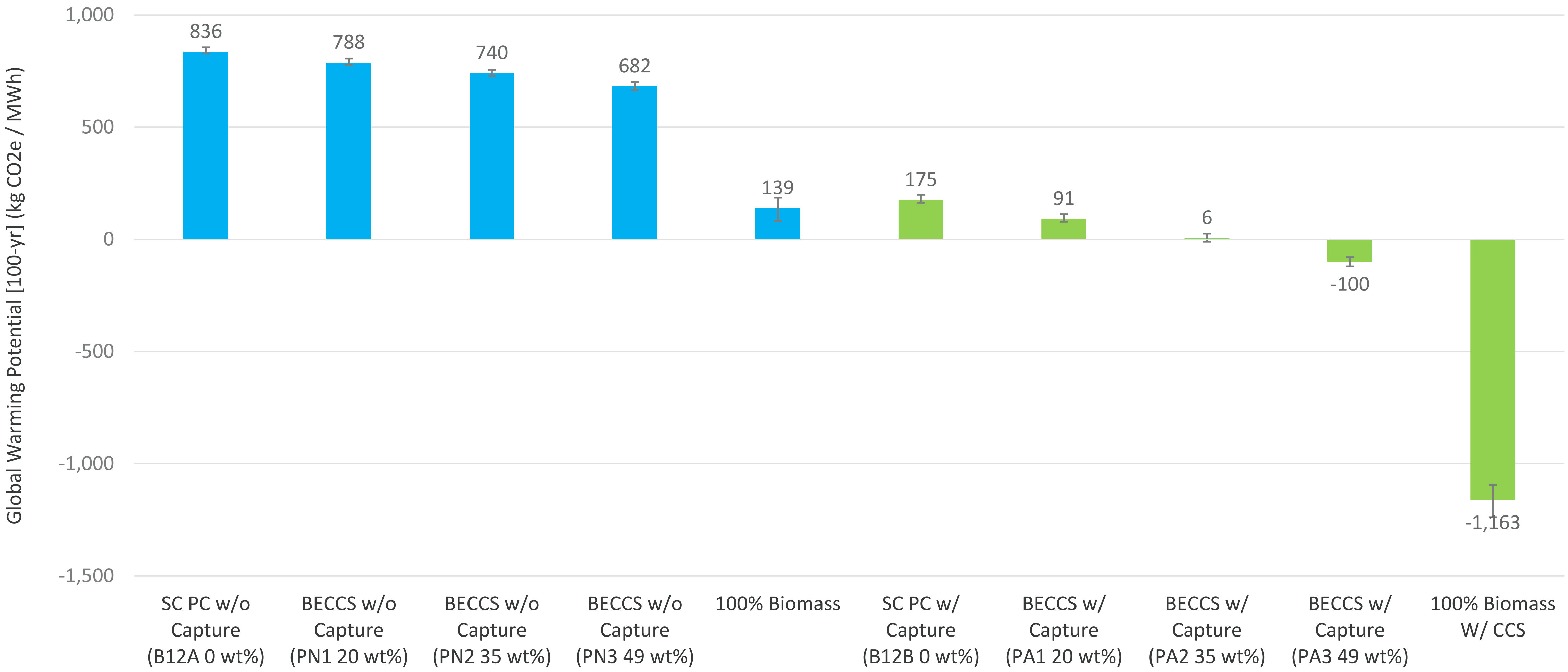

Results: Life Cycle GHG Analysis

Global Warming Potential [100-yr] kg CO_2e/MWh

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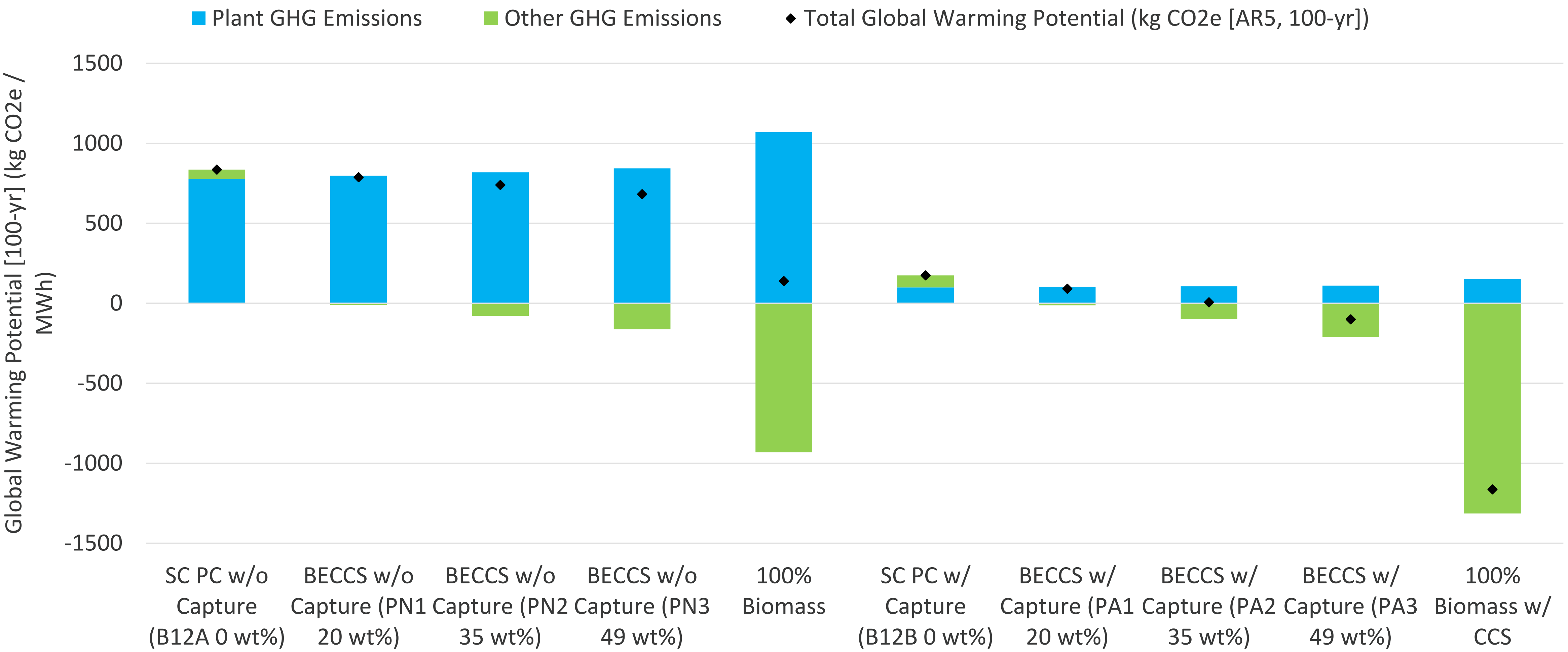
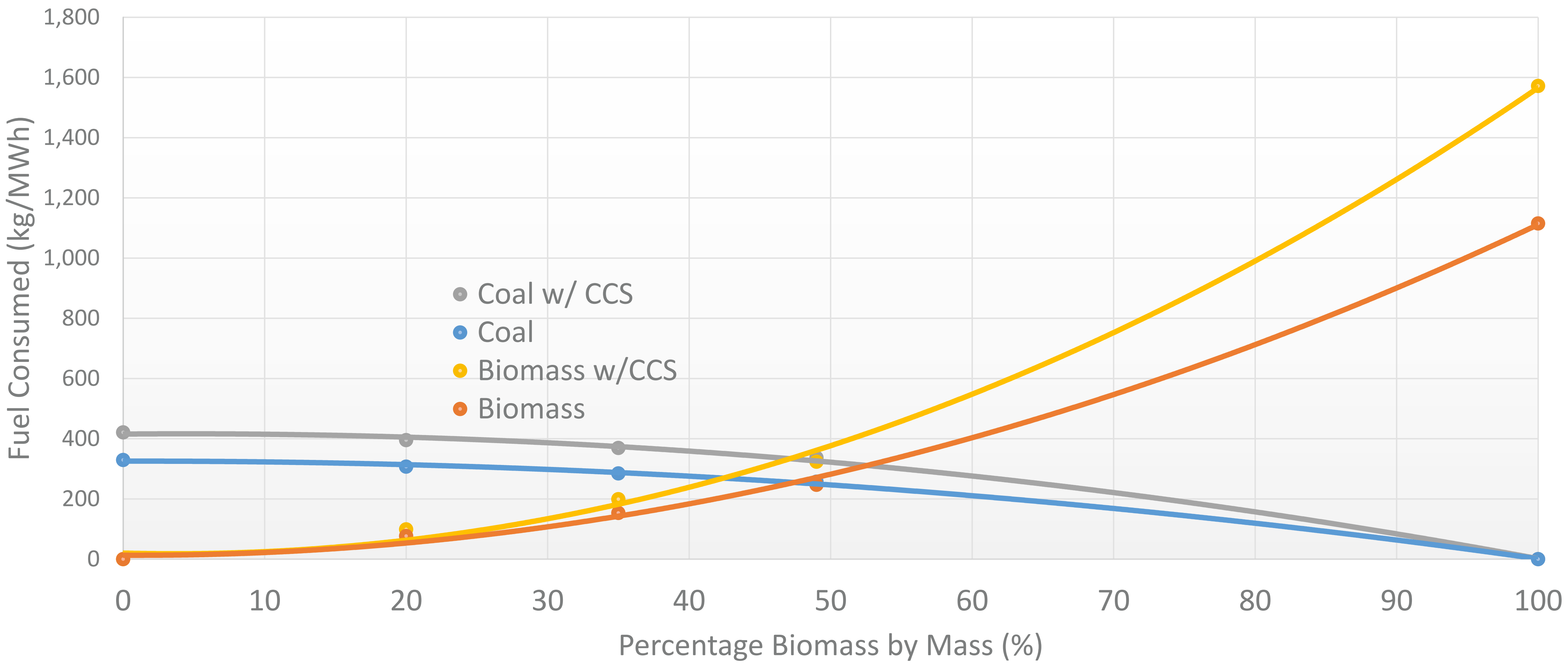


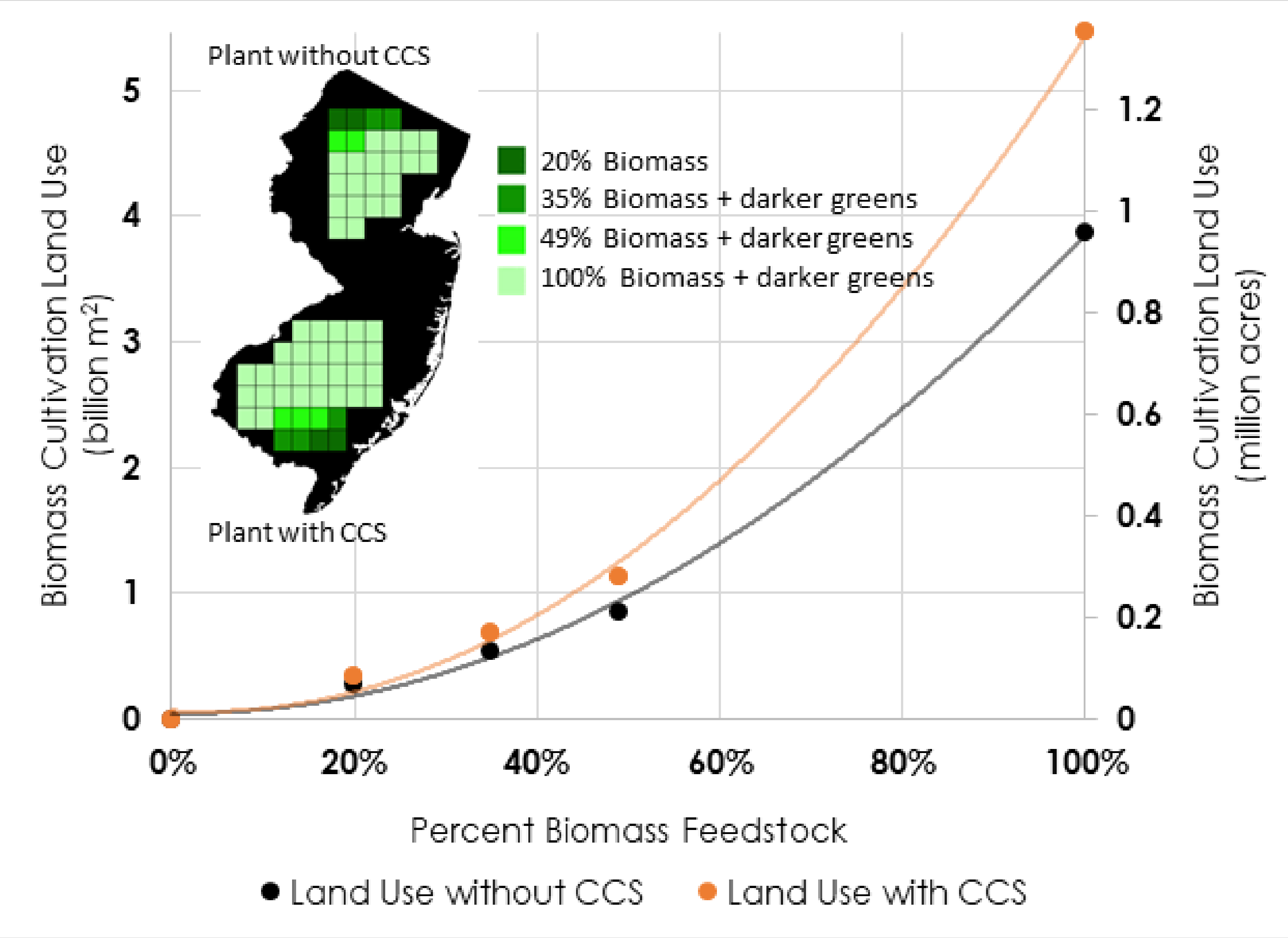
Fuel Mixes for BECCS Scenarios

kg/MWh for Increasing Biomass Scenarios With and Without Capture



BECCS Land Use Requirements

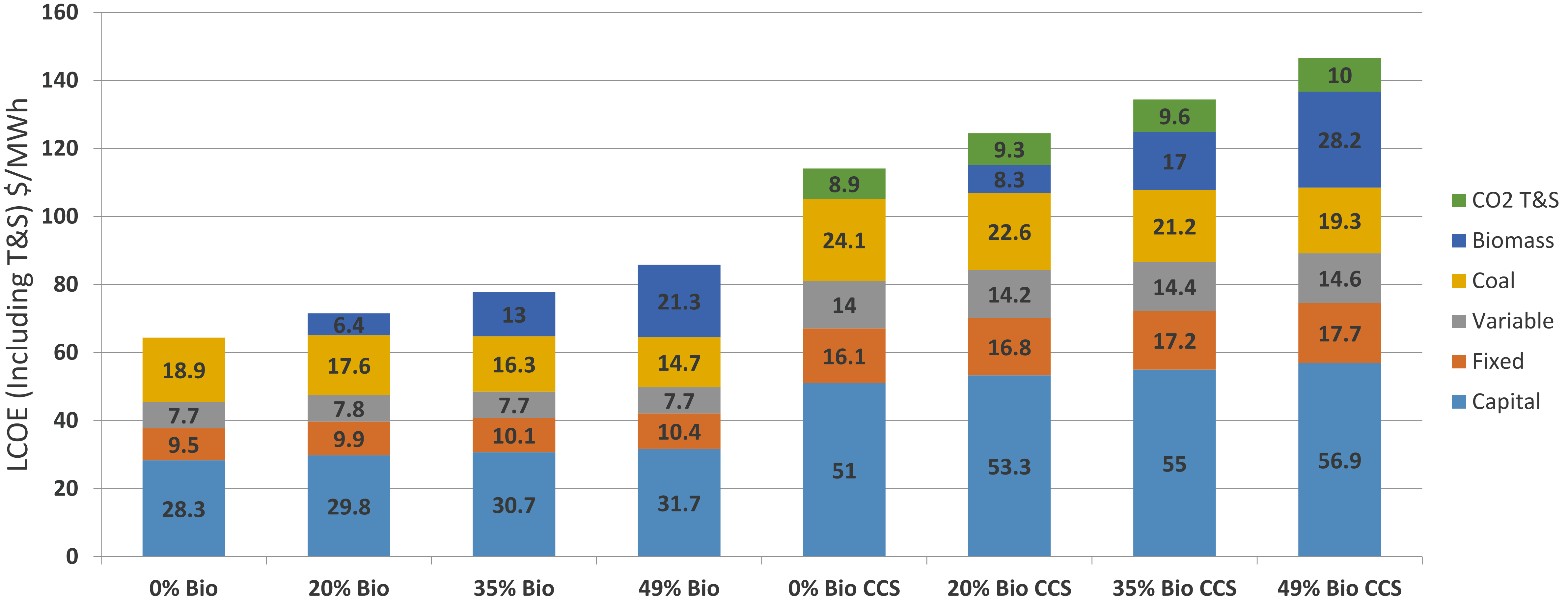
Kg CO_2e/MWh



Effect of Biomass Feedstock Percentage on Land Use for Cultivation Relative to the State of New Jersey (5.6 Million Acres)

Results: Levelized Cost of Electricity

LCOE (Including T&S) $/MWh



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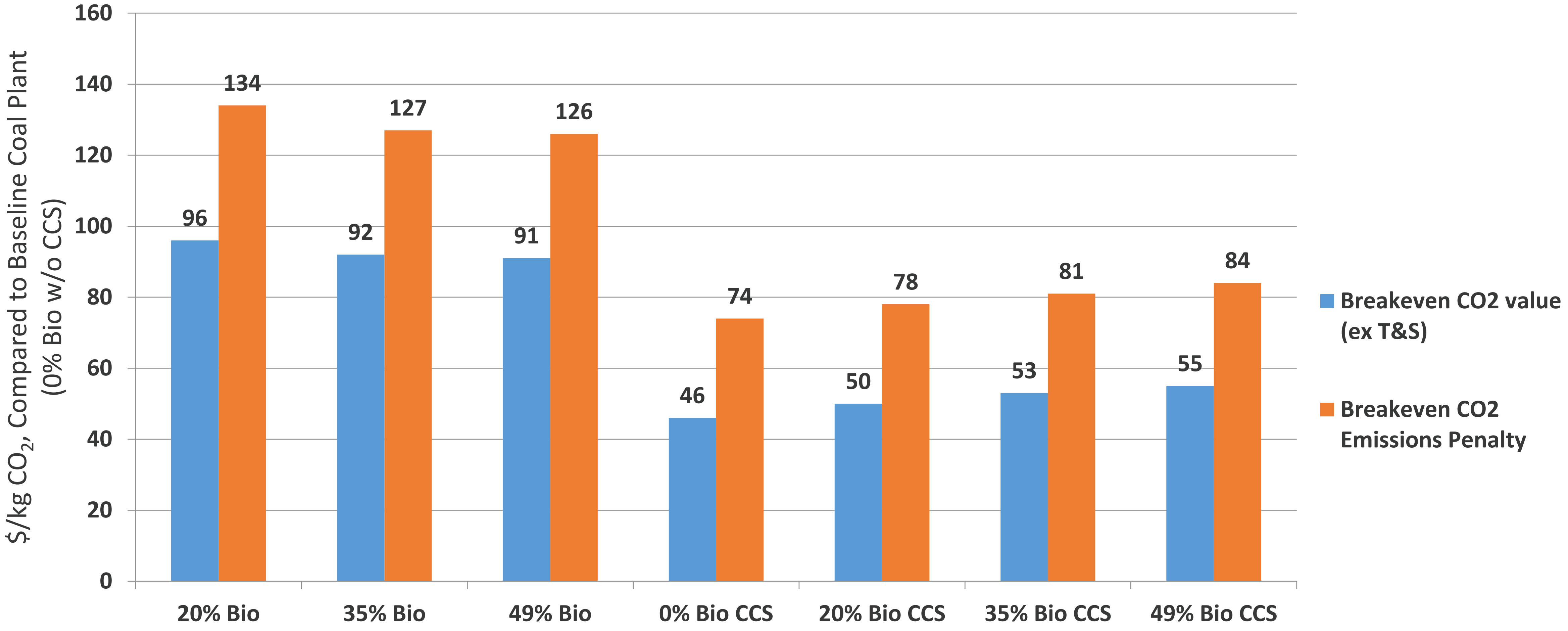
Results: Breakeven CO_2 Cost

$/kg CO_2, Compared to Baseline Coal Plant (0% Bio w/o CCS)



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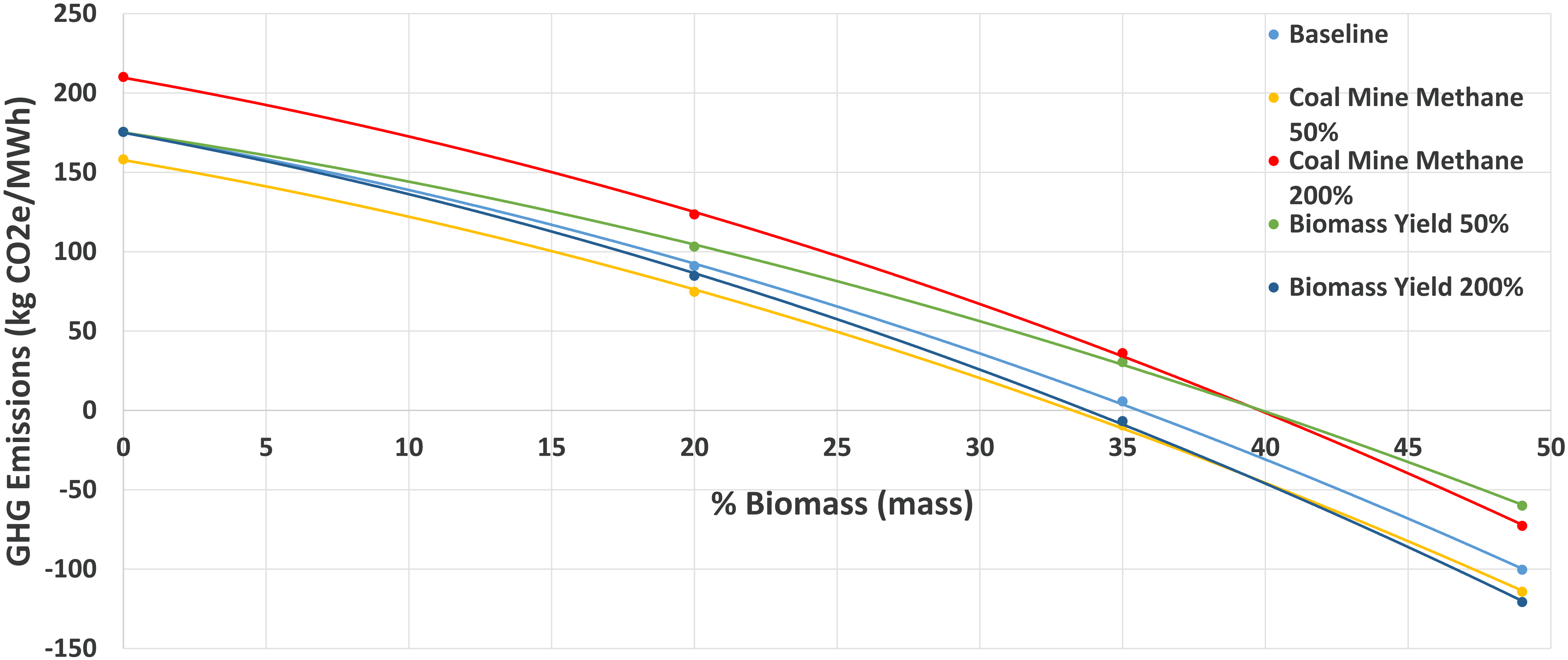
Breakeven Trendlines for GHG Sensitivities

Selected Sensitivity Analyses, All Cases Include CCS



100% Biomass – Heat Map

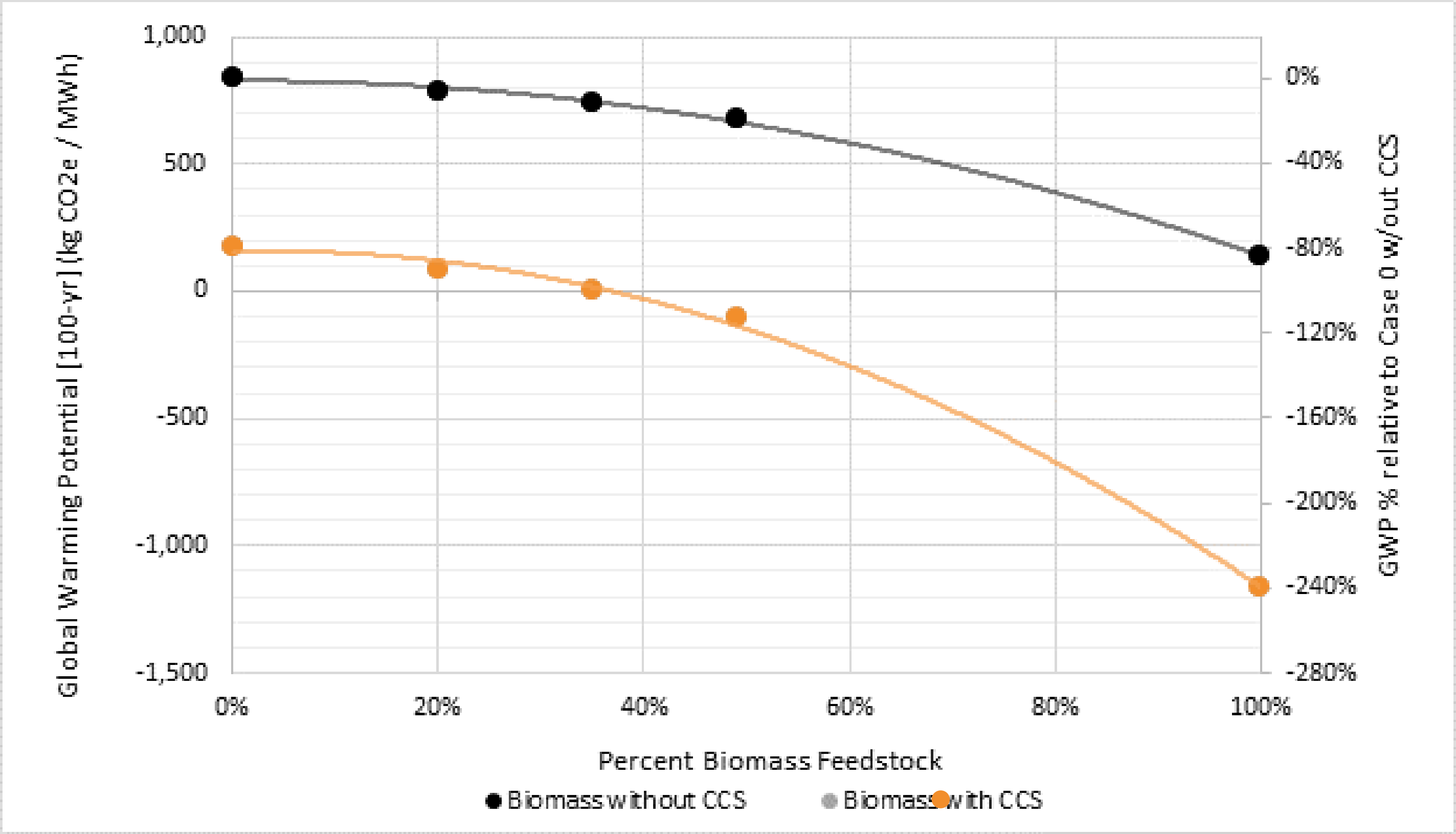
Indicator	100% Coal	100% Coal CCS	20% Bio	20% Bio CCS	35% Bio	35% Bio CCS	49% Bio	49% Bio CCS	100% Bio	100% Bio CCS	Unit
Acidification Potential - TRACI 2.1 (NETL)	5.91E-01	3.31E-01	7.30E-01	5.40E-01	8.70E-01	7.53E-01	1.04E+00	1.02E+00	2.99E+00	3.71E+00	kg SO2e
Eutrophication Potential - TRACI 2.1 (NETL)	1.62E-02	2.07E-02	4.75E-02	6.12E-02	7.87E-02	1.02E-01	1.17E-01	1.53E-01	4.74E-01	6.68E-01	kg Ne
Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	8.16E+02	1.49E+02	7.73E+02	7.15E+01	7.31E+02	-6.57E+00	6.80E+02	-1.04E+02	2.01E+02	-1.08E+03	kg CO2e
Ozone Depletion Potential - TRACI 2.1 (NETL)	4.57E-09	5.87E-09	2.11E-08	2.73E-08	3.79E-08	4.95E-08	5.90E-08	7.76E-08	2.62E-07	3.75E-07	kg CFC-11e
Particulate Matter Formation Potential - TRACI 2.1 (NETL)	1.16E-01	1.23E-01	1.20E-01	1.32E-01	1.24E-01	1.40E-01	1.30E-01	1.51E-01	2.01E-01	2.55E-01	kg PM2.5e
Photochemical Smog Formation Potential- TRACI 2.1 (NETL)	8.82E+00	1.01E+01	1.09E+01	1.28E+01	1.30E+01	1.57E+01	1.57E+01	1.92E+01	4.03E+01	5.51E+01	kg O3e
Water Consumption (NETL)	2.86E+02	3.65E+02	6.03E+03	7.76E+03	1.17E+04	1.52E+04	1.87E+04	2.45E+04	8.35E+04	1.18E+05	kg

Highest value in this analysis for a given indicator.

Lowest value in this analysis for a given indicator.

GWP Reductions with Additional Biomass

Effect of Increasing Biomass on Life Cycle GWP of Power Generation via BECCS



Summary

- **Carbon neutral or carbon negative coal electricity is possible by adding both biomass and CCS systems.**
  - Carbon neutrality occurs near 35% biomass with 90% CCS.
- **CCS systems cause a greater reduction in emissions than biomass but a greater decrease in plant efficiency and a greater increase in cost.**
  - Carbon neutral electricity costs $134/MWh vs. $64/MWh for coal w/o CCS.
- **Increased biomass use decreases GHG but increases every other impact studied.**
  - This is due to biomass agriculture impacts, which might be mitigated by alternative biomass crops or agriculture systems.

CFB Review

Ongoing Analysis of 100 MW CFB With Hybrid Poplar and Forest Residue

- **Circulating fluidized bed (CFB) technologies are favored for combustion and gasification processes.**
  - Globally, CFBs make up 18% of biomass co-firing[1].
  - CFBs fueled by 100% biomass exist but are not prevalent.
- **During CFB's flameless combustion process, a high fluidization velocity allows particles to be carried away by the flue gas. A cyclone separates particles from the gas using a loop seal to return unburned fuel particles and circulating bed material to the lower part of the furnace. Fuels are circulated in the reactor until fully burned.[2]**

Exhibit: Schematic of a CFB[4]

1. (Sugiyono, 2022), https://iopscience.iop.org/article/10.1088/1755-1315/963/1/012007
2. (Banerjee, 2020), DOE: 10.2172/1659115.

CFB Review

Ongoing Analysis of 100 MW CFB with Hybrid Poplar and Forest Residue

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- **Key characteristics of CFBs include:**
  - Load flexibility and high heat transfer rates.
  - Fuel flexibility, ideal for handling high moisture and ash content of low-rank coals and biomass[3].
  - Uniform temperature throughout gasifier (850–950°C)[4].
  - Low NOx emissions due to low temperatures.
- **Old boilers are commonly converted to CFBs[4].**
  - Conversion is cheaper than buying a new boiler.
  - Project schedules are often short (approximately one year).
  - CFB reduces emissions and allows for wider range of fuels.

3. (NETL Website), https://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/fluidizedbed
4. (Vakkilainen, 2017), http://dx.doi.org/10.1016/B978-0-12-804389-9.00010-1

Subcritical Pulverized Coal Retrofit

- **2012 NETL study showed that retrofit of an existing plant to co-fire biomass (10%) increased the cost of electricity by 31%[5].**
- **An updated model will provide the option for conversion of up to 100% biomass plus the addition of CCS.**
- **Systems smaller than the 650MW greenfield plant will be explored as existing plants may be smaller, biomass has a lower heating value than coal, and parasitic loads from the capture system will lower the net output.**
- **The Drax Power Station in the United Kingdom has converted four of its six coal units to operate on biomass[6].**

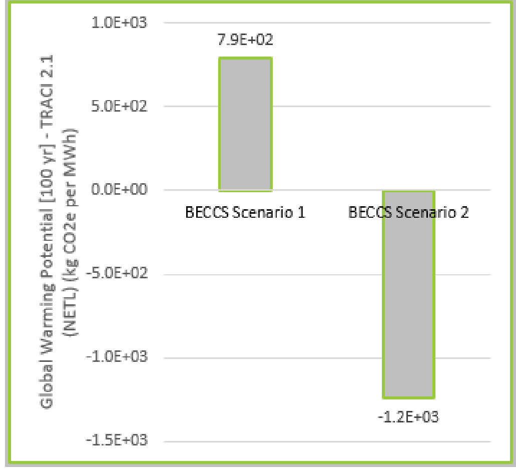
5. Skone, Timothy J., et al. Role of alternative energy sources: pulverized coal and biomass co-firing technology assessment. No. NETL/DOE-2012/1537. National Energy Technology Laboratory (NETL), Pittsburgh, PA, Morgantown, WV, and Albany, OR (United States), 2012.
6. “Drax closer to coal-free future with fourth biomass unit conversion” Drax Press Release. August 20, 2018. https://www.drax.com/press_release/drax-closer-coal-free-future-fourth-biomass-unit-conversion/

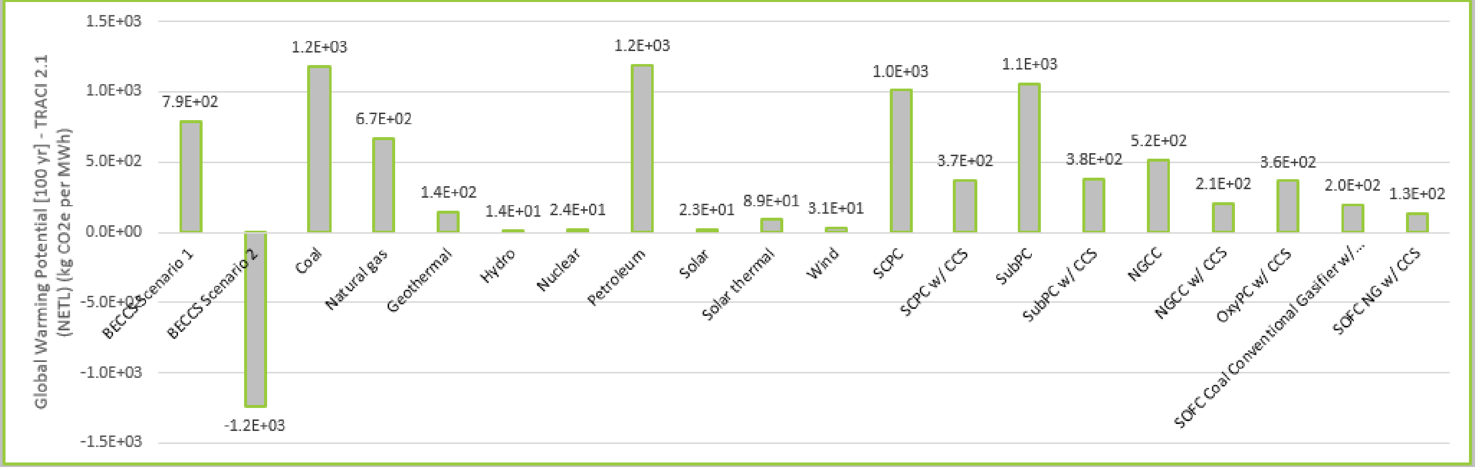
BECCS Screening Tool

Global Warming Potential [100 yr] - TRACI 2.1 (NETL) (kg CO2e per MWh)

Impact Category	Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	**Result 1**	**Result 2**	
	Note: Do not adjust areas in gray	**7.9E+02**	**-1.2E+03**	**kg CO2e per MWh**
	Cells in white can be adjusted			
	Areas in orange are under development in 2021			
	Areas in blue are dropdown menus			

Inputs	BECCS Scenario 1	BECCS Scenario 2	Units	Scaling Factor	Acceptable Range	Default Values	Difference 1	Difference 2
Biomass Type	Hybrid Poplar	Hybrid Poplar						
Coal Type	Subbitiminous	Subbitiminous						
Processing	Pelletization and Drying	Torrefaction						
Moisture Content	10%	5%	%	10%	0%-100%	10%	0%	5%
Coal Transportation	320	600	km	0.006039743	0-3,500	321.868	-1.868	278.132
Harvest Residue	50	50	% of yield	-0.02784	25-100	50	0	0
Biomass Yield	6214	6214	kg per acre-year	-0.000767461	3,000-12,500	6214	0	0
Coal Mine Methane	0.002696	0.002696	cubic meters per kg coal	9363.501484	0.002-0.02	0.002696	0	0
Biomass Transport	1.00x	1.00x	radius change - tied to yield	0.188	0.71x-1.44x	1	0	0
Biomass Mass %	20	100	%			35	-15	65
Carbon Capture	no	yes				yes		
Disposition	Saline Aquifer	EOR				Saline Aquifer		





Future Research

Plans for 2022 and Beyond

- **Torrefaction and other biomass pretreatments.**
  - Alternative drying configurations, torrefaction, biomass/coal briquettes, pelletization, and raw biomass.
- **Biomass harvesting, transportation, and logistics.**
- **Additional biofuels.**
  - Southern yellow pine, switchgrass, forest residue and thinnings, sorghum, cane, eucalyptus, corn stover, willow.
- **Smaller plant sizes and retrofits for subcritical pulverized coal plants.**
- **Increased capture rates up to 99%.**
- **Circulating fluidized bed (CFB) capture systems.**

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Life Cycle Analysis
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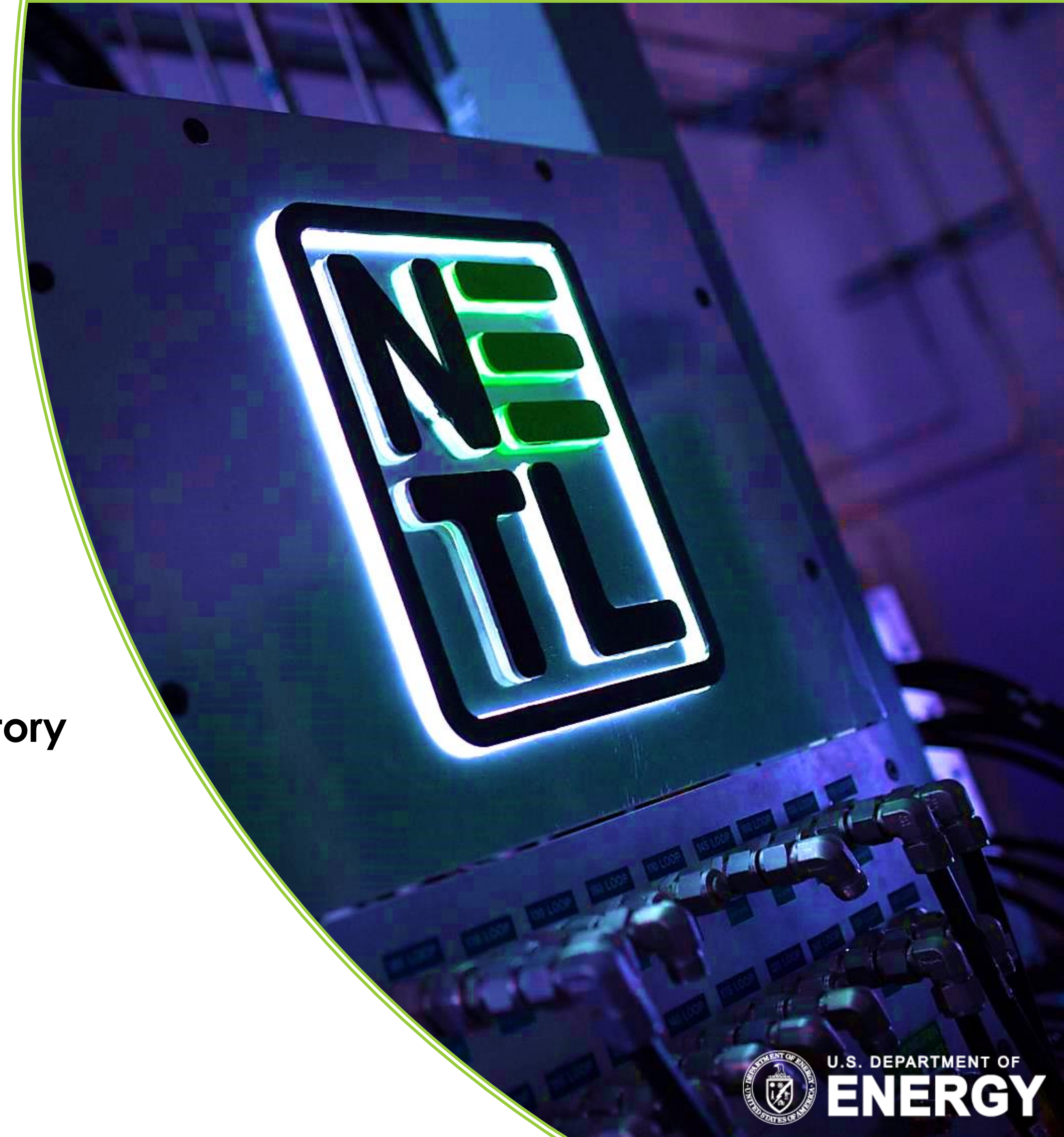
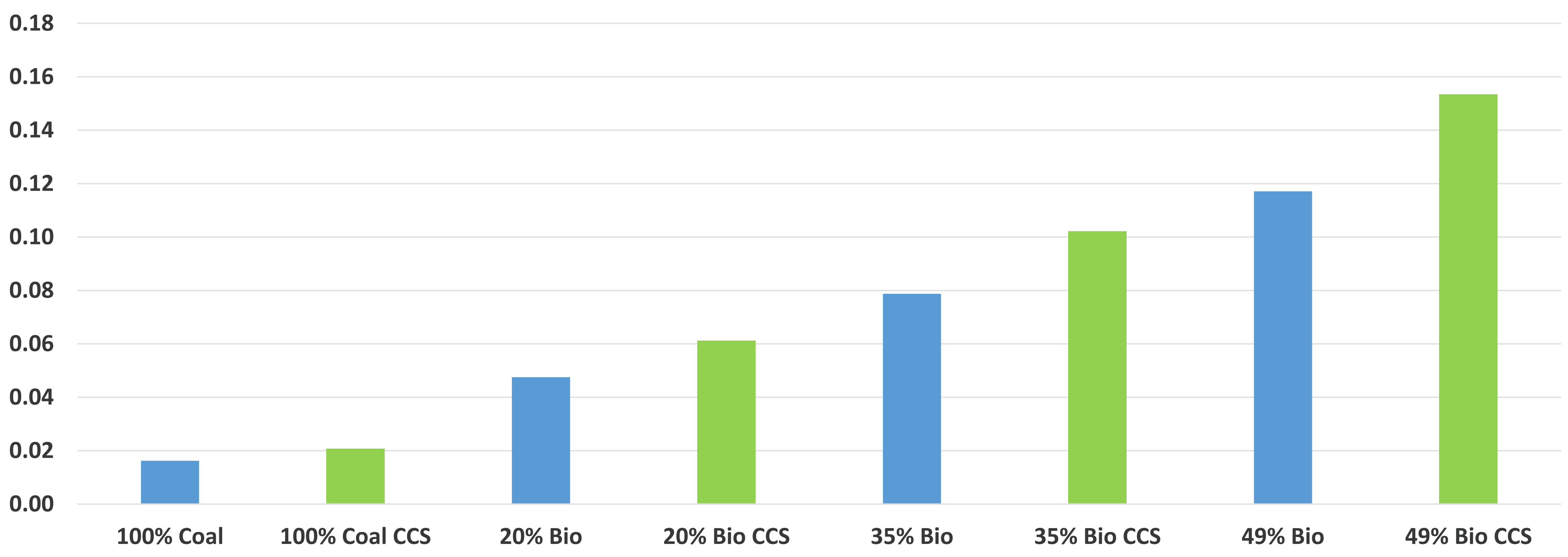


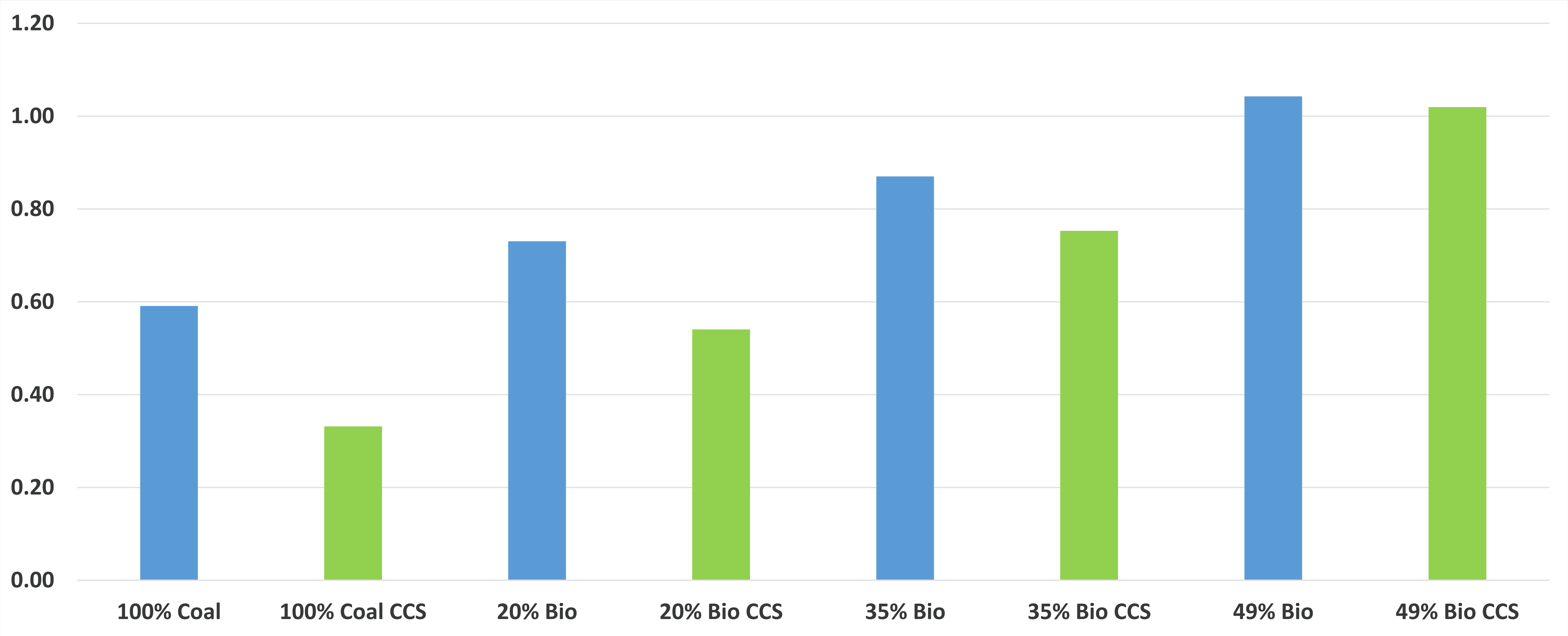
Eutrophication Potential

Kg N-equivalent /MWh



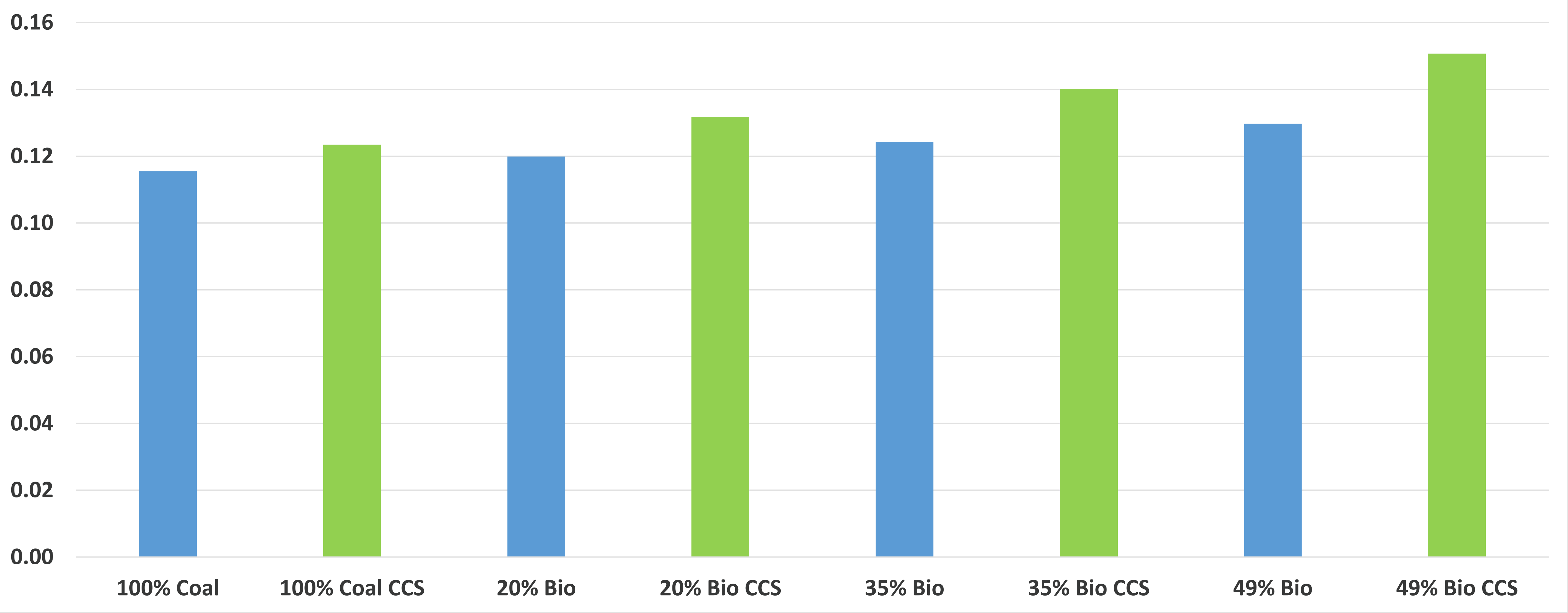
Acidification Potential

Kg SO_2-equivalent /MWh



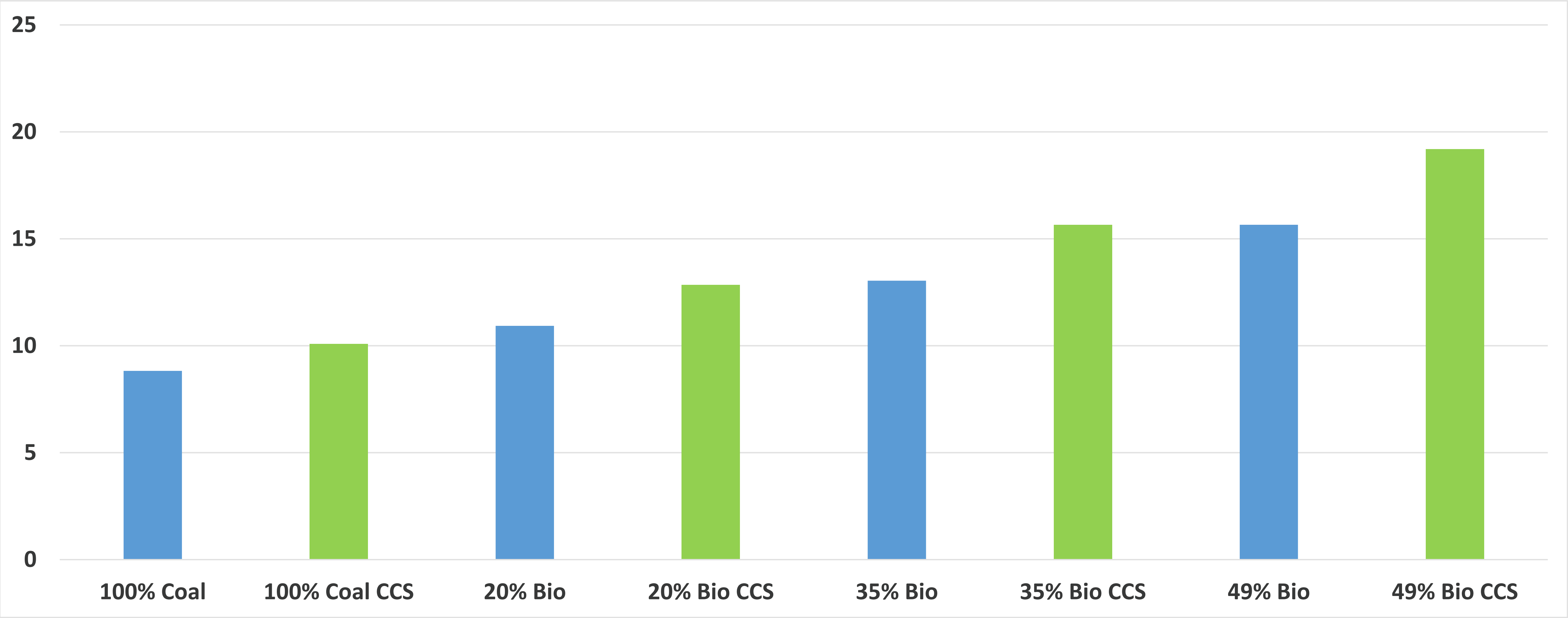
Particulate Matter Formation Potential

Kg PM2.5-equivalent /MWh



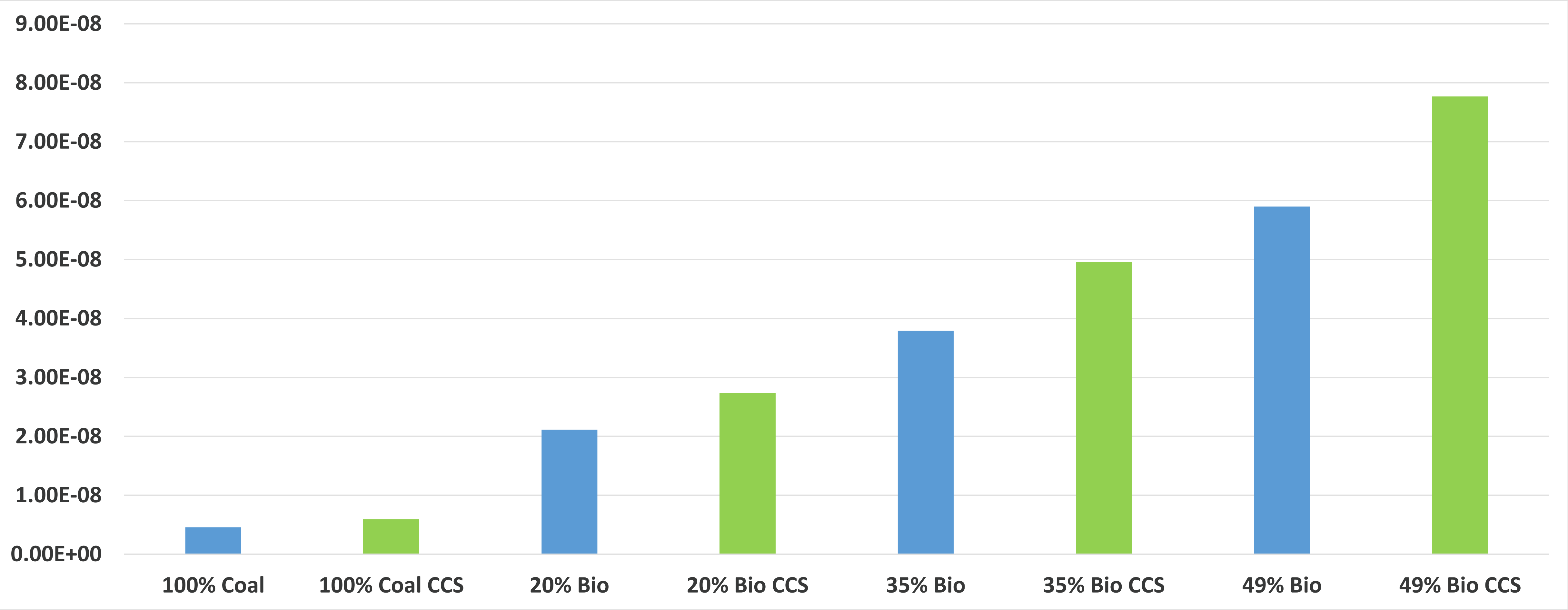
Photochemical Smog Formation Potential

kg O_3-equivalent /MWh



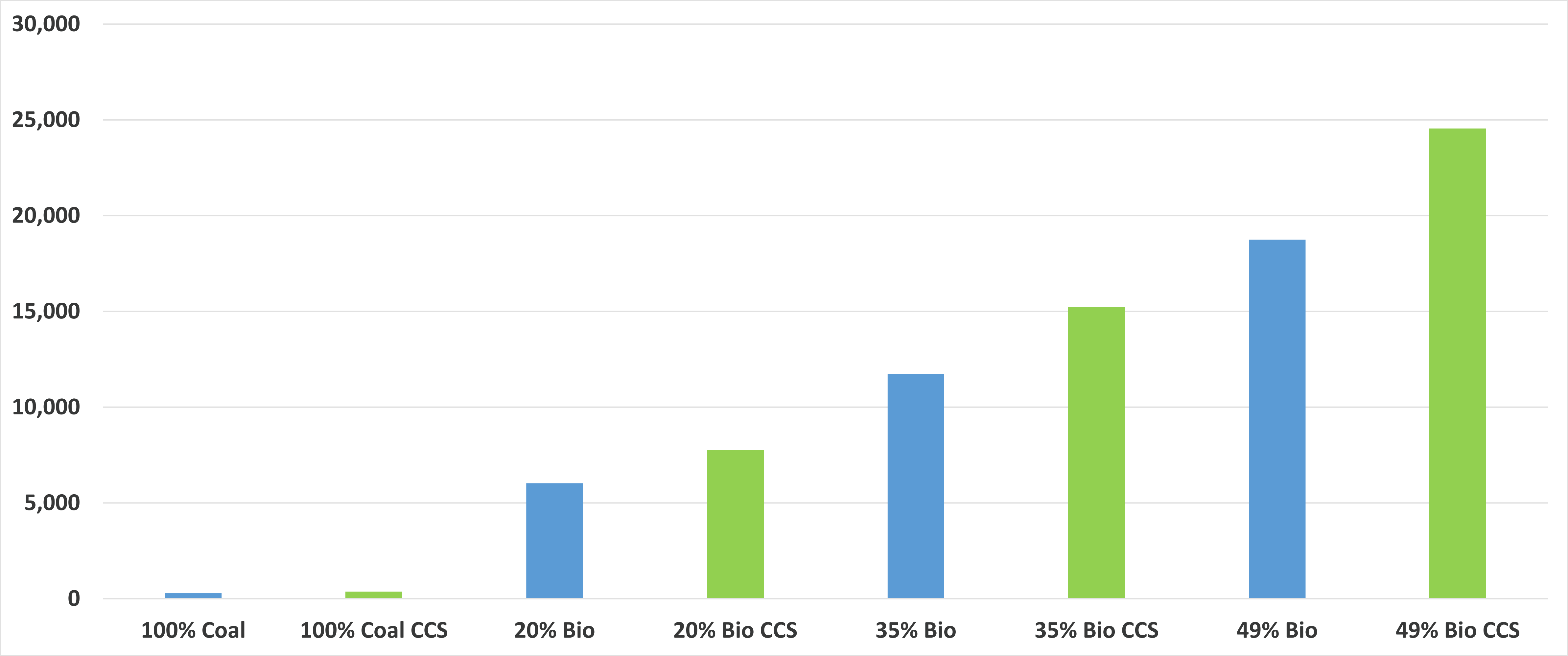
Ozone Depletion Potential

Kg CFC11-equivalent /MWh



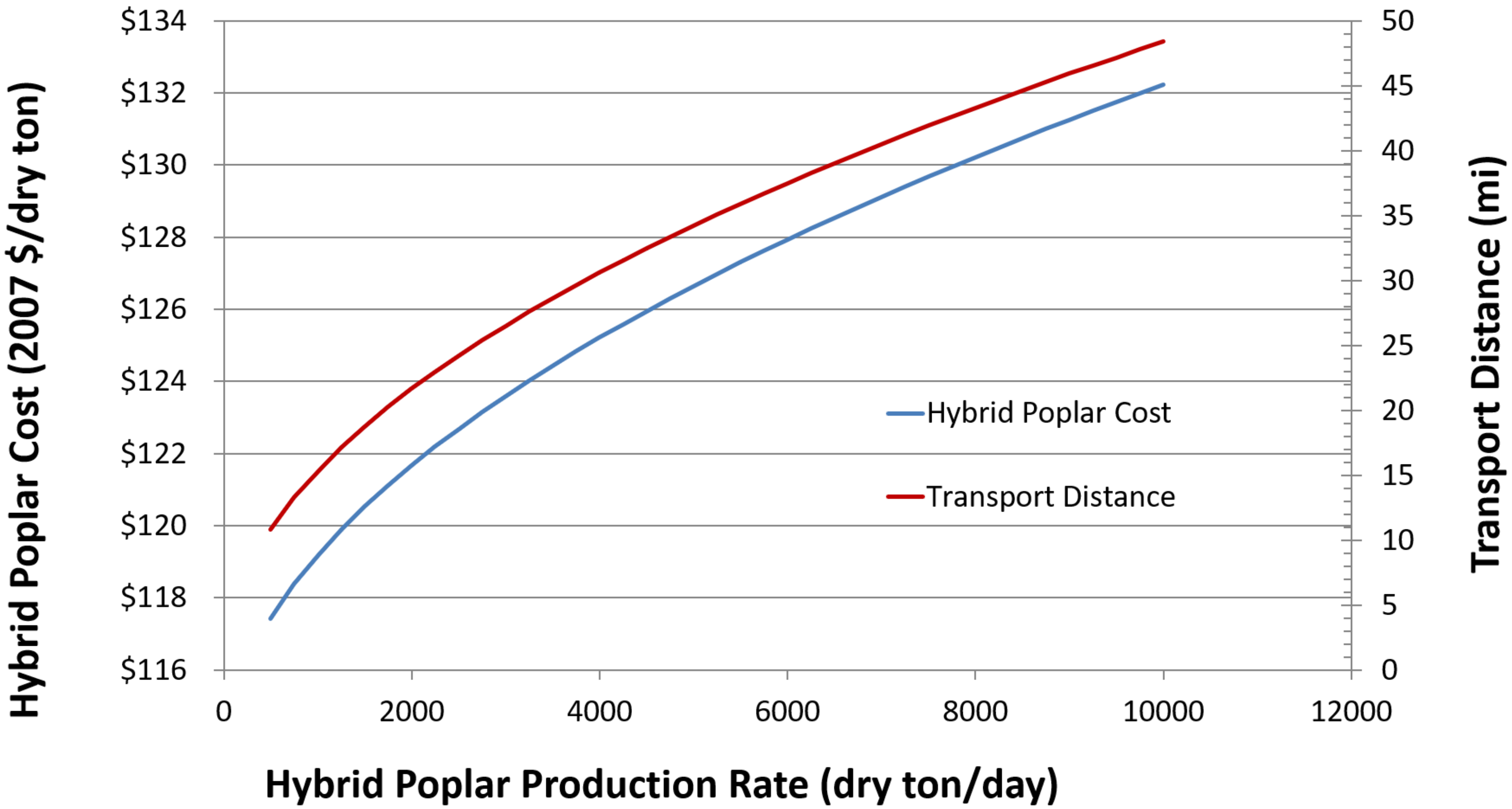
Water Consumption

Kg Water /MWh



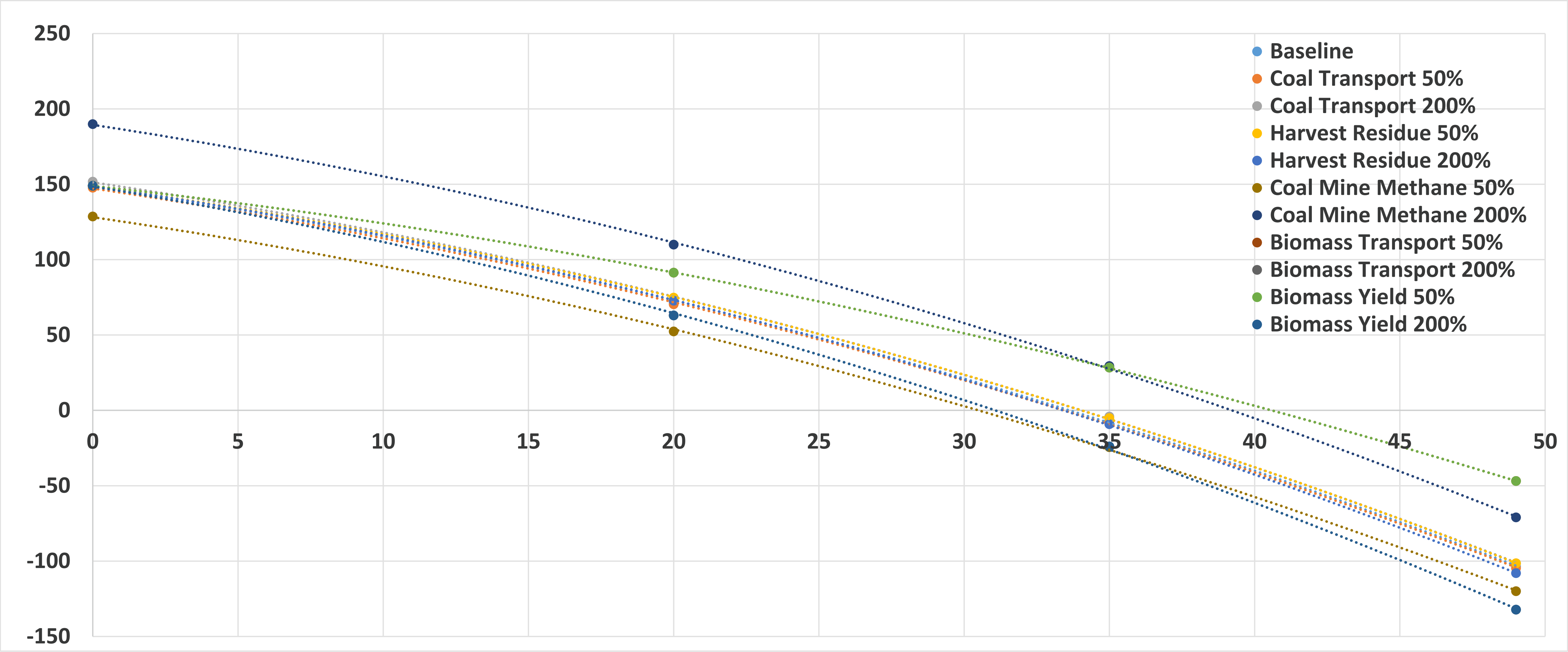
Biomass Transport Distances and Costs

Source: CBPC



Breakeven Trendlines for GHG Sensitivity

49% Biomass w/ CCS

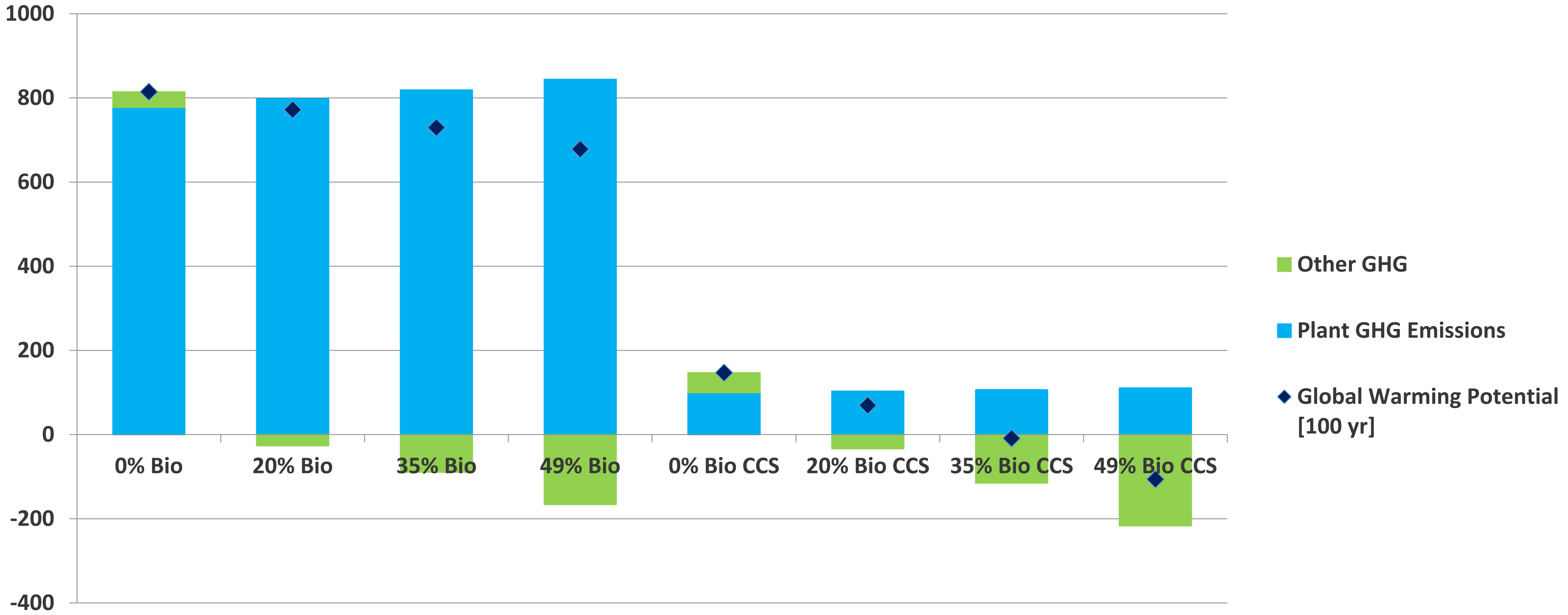


TRACI Impacts Heat Map

Indicator	100% Coal	100% Coal CCS	20% Bio	20% Bio CCS	35% Bio	35% Bio CCS	49% Bio	49% Bio CCS	Unit
Acidification Potential - TRACI 2.1 (NETL)	5.91E-01	3.31E-01	7.30E-01	5.40E-01	8.70E-01	7.53E-01	1.04E+00	1.02E+00	kg SO_2e
Eutrophication Potential - TRACI 2.1 (NETL)	1.62E-02	2.07E-02	4.75E-02	6.12E-02	7.87E-02	1.02E-01	1.17E-01	1.53E-01	kg N e
Global Warming Potential [100 yr] - TRACI 2.1 (NETL)	8.16E+02	1.49E+02	7.73E+02	7.15E+01	7.31E+02	-6.57E+00	6.80E+02	-1.04E+02	kg CO_2e
Ozone Depletion Potential - TRACI 2.1 (NETL)	4.57E-09	5.87E-09	2.11E-08	2.73E-08	3.79E-08	4.95E-08	5.90E-08	7.76E-08	kg CFC-11e
Particulate Matter Formation Potential - TRACI 2.1 (NETL)	1.16E-01	1.23E-01	1.20E-01	1.32E-01	1.24E-01	1.40E-01	1.30E-01	1.51E-01	kg PM2.5e
Photochemical Smog Formation Potential- TRACI 2.1 (NETL)	8.82E+00	1.01E+01	1.09E+01	1.28E+01	1.30E+01	1.57E+01	1.57E+01	1.92E+01	kg O_3e
Water Consumption (NETL)	2.86E+02	3.65E+02	6.03E+03	7.76E+03	1.17E+04	1.52E+04	1.87E+04	2.45E+04	Kg

Results: Life Cycle GHG Breakdown

GWP [100-yr] kg CO_2e/MWh



Fuel Mixes

Fuel Consumed (kg/MWh)