Biogas Utilization in Refuse Power Plants (BURP^2)

Presenters: Marco Hernandez & Lawrence Anyim

FECM 24 (08/09/2024)

Award No: DE-FE0032194

Project Period of Performance: 10/01/22 to 09/30/24

PI: Johannes van der Watt (University of North Dakota)

Project Manager: Heather Hunter

UNIVERSITY OF NORTH DAKOTA

COLLEGE OF ENGINEERING & MINES

PROJECT PARTICIPANTS

University of North Dakota

- College of Engineering and Mines Research Center
- Dept. of Chemical Engineering

Envergex, LLC (Sub-Contractor)

Budget:

$400,000 (UND – $360,000 & Envergex – $40,000)

PROJECT OBJECTIVES

Opportunity: Remediate coal waste piles

Goal: Continue using facilities combusting waste coal, but operate them cleaner

Solution approach: Use biogas for co-firing

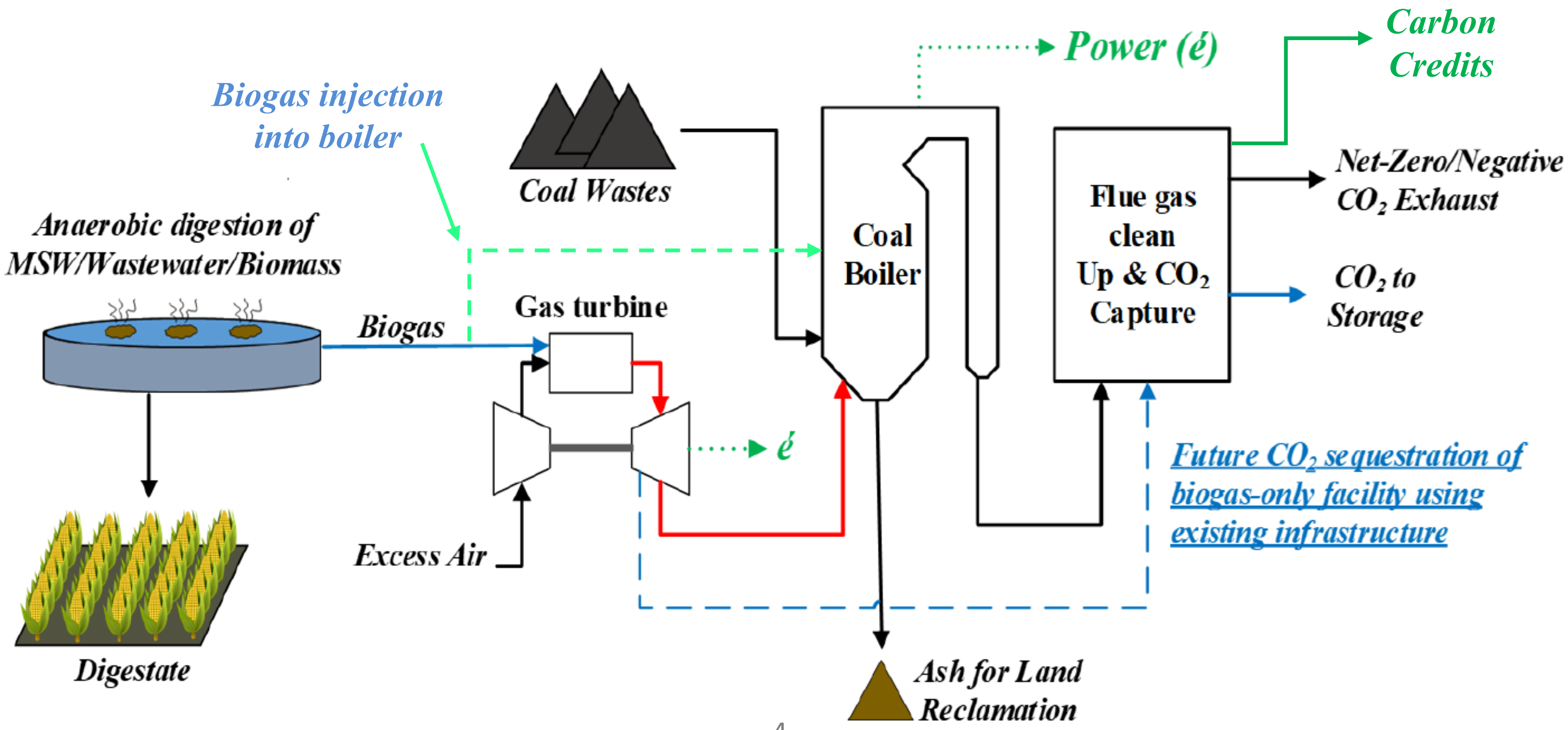
- Employ hot windbox repowering to provide energy for CO_2 capture
- Extend economic life of asset with CCS

Motivation

- Quantify environmental & economic benefits / disadvantages using multiple biogas resources
- Track aggregate quantity of GHG emissions

APPROACH

Clean up coal waste piles and ensure long-term energy sustainability



POTENTIAL BENEFITS

Generate power with net-zero to net-negative CO_2 emissions

- Consider post-combustion CO_2 capture
- Create environmentally friendly waste remediation approach
- Justify added expenses for CCS
- Extend economic life of power plants

Project to aid in determining

- How to leverage existing infrastructure (waste coal remediation)
- How biomass gathering/transportation/road infrastructure affect approach viability
- How to leverage existing biogas resources

POTENTIAL BENEFITS

Project benefits:

- Advance research in fossil fuel conversion/utilization
  - Coal waste remediation and power generation
- Expand UND's fossil research capabilities/facilities
  - Combustion process modeling diversification
  - Carbon Lifecycle modeling – applications expansion
- Support education/training of next gen. engineers/scientists
  - Industry-related projects providing hands-on training to students in the growing field of energy and environmental engineering

PROJECT MILESTONES & SCHEDULE

- **Task 1** – Project Management and Planning
- **Task 2** – Repowering Design Setup
- **Task 3** – Retrofit vs. Greenfield Co-Firing TEAs
- **Task 4** – Integrated Resource Utilization and LCA

Milestone	Task/Subtask	Milestone Title and Description	Completion or Planned Completion Date
	1.1	Update project management plan	09/30/2022
1	2	Design basis for repowering setup	6/30/2023
2	**3**	**TEAs for retrofit and greenfield facilities**	**6/30/2025**
3	**4**	**LCAs for retrofit and greenfield facilities**	**9/30/2025**

CURRENT PROJECT STATUS

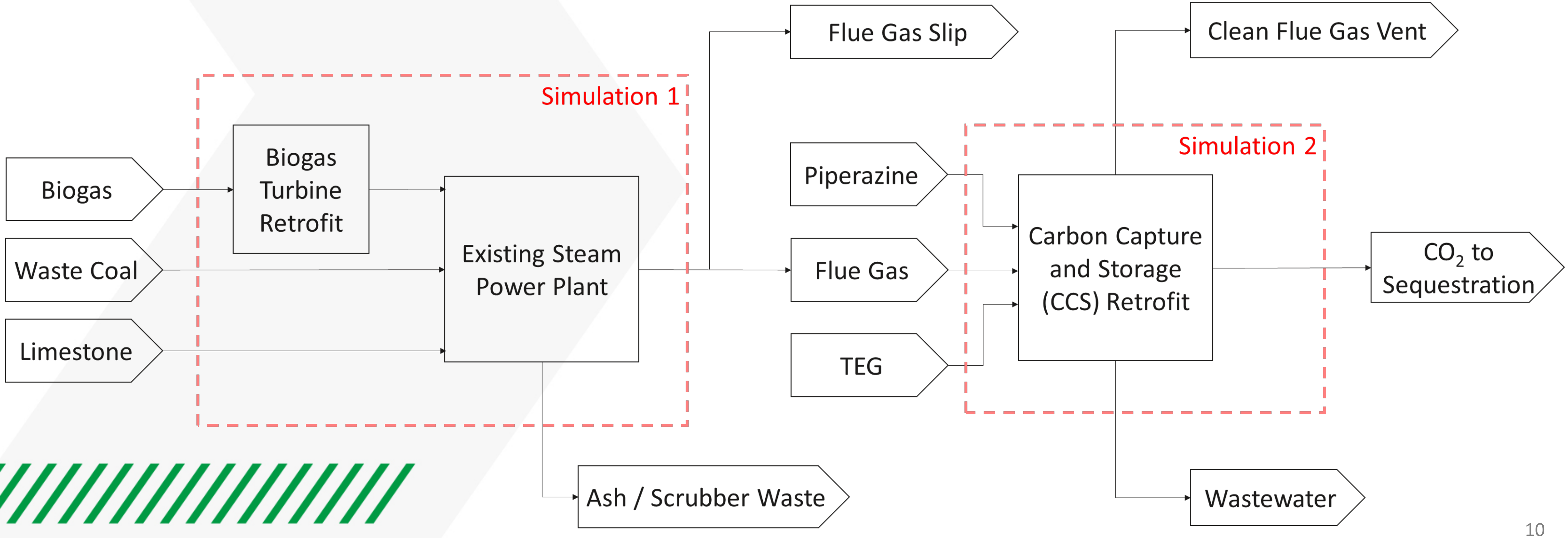
TASK 2 – REPOWERING DESIGN SETUP

- **Task 2** – Repowering Design Setup
  - Select target facilities (waste coal processing and greenfield)
  - Determine minimum size of gas turbine
  - Select biogas sources and CO_2 storage locations
  - Evaluate transportation logistics
  - Scale CO_2 capture system

TASK 2 – REPOWERING DESIGN SETUP

AspenPlus used to optimize process design and specifications for 80 MW-net utility

- Obtained values for flowrates, power output, and utility demands



TASK 3 – RETROFIT AND GREENFIELD TEA

- **Task 3** – Retrofit vs. Greenfield Co-Firing TEAs
  - Class IV – Study of Feasibility (-15/+30%)
  - Use information from Task 2
  - Subtask 3.1 – TEA for optimal retrofit
  - Subtask 3.2 – TEA for Greenfield location

TASK 3 – RETROFIT AND GREENFIELD TEA

NETL's "Quality Guidelines for Energy System Studies: Cost Estimation Methodology for NETL Assessments of Power Plant Performance"[2]

- Equipment Costs
  - Aspen Plus V14 Economic Analyzer
- Turbine Costs
  - Quoted from Gas Turbine World 2023[3]
- Pipeline Installation
  - Cost Estimation from Brown et al.'s Equations for NG Pipeline[4]
  - Pipeline Distance required calculated with GIS support

2 Theis, J. (2021). Quality Guidelines for Energy Systems Studies: Cost Estimation Methodology for NETL Assessments of Power Plant Performance. https://doi.org/10.2172/1567736
3 Jaeger, H. (Ed.). (2023). Gas Turbine World 2023 GTW Handbook . Retrieved 2023, from https://gasturbineworld.zinioapps.com/reader/readsvg/621435/112.
4 Brown, D., Reddi, K., & Elgowainy, A., "The development of natural gas and hydrogen pipeline capital cost estimating equations," International Journal of Hydrogen Energy, 2022, 47(79), 33813–33826. https://doi.org/10.1016/j.ijhydene.2022.07.270

TASK 3 – RETROFIT AND GREENFIELD TEA

- Approach 1 – Cases 2-5
  - Assume 21k kg/hr Biogas Available in Region
  - Scale CCS with Power Generated by Turbine to maintain 80MW-net
  - Increase % of Biogas Utilized
- Approach 2 – Cases 6-9
  - Assume a Constant CCS Size and %
  - Excess Power Generated by increasing Biogas sold
  - Case 9 assumes plant's willingness to derate to 68 MW-net for 90% Capture

BURP² CASE DESCRIPTIONS

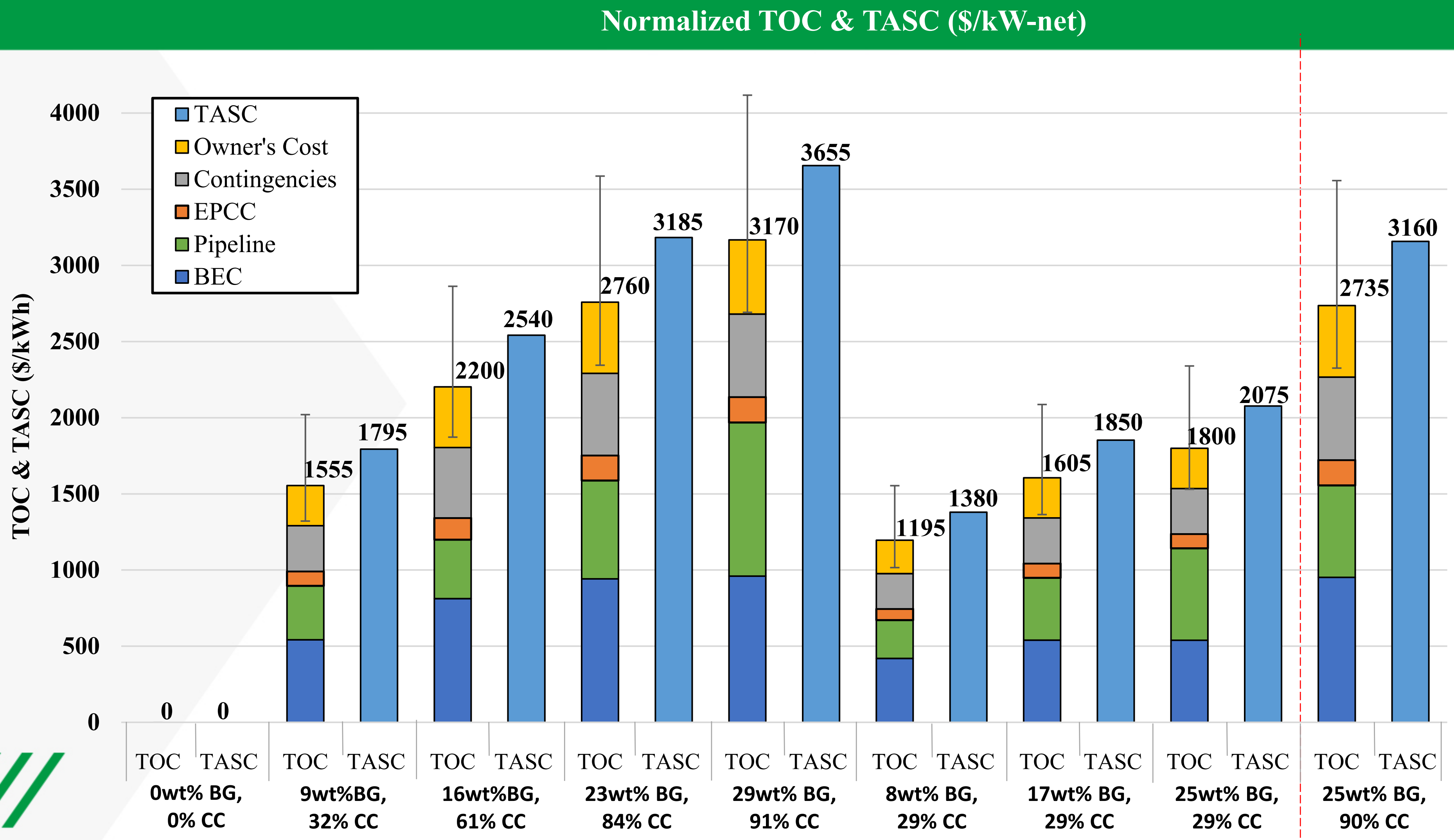
<table>
<tr><th></th><th>Case</th><th>Biogas Type</th><th>Plant Type</th><th>Net power (MW)</th><th>% Biogas (BG) in Feed</th><th>CO_2 Capture (CC) %</th><th>Capture System</th></tr>
<tr><td>Baseline</td><td>0wt%BG, 0%CC</td><td rowspan="9">Each of the retrofit cases co-fired with landfill gas, and biogas from the anaerobic digestion of animal manure, municipal solid waste and wastewater sludge.</td><td rowspan="9">Retrofit</td><td rowspan="8">80</td><td>0</td><td>0</td><td rowspan="13">Amine-based CO_2 capture system</td></tr>
<tr><td rowspan="4">Approach 1</td><td>9wt%BG, 32%CC</td><td>9</td><td>32</td></tr>
<tr><td>16wt%BG, 61%CC</td><td>16</td><td>61</td></tr>
<tr><td>23wt%BG, 84%CC</td><td>23</td><td>84</td></tr>
<tr><td>29wt%BG, 91%CC</td><td>29</td><td>91</td></tr>
<tr><td rowspan="4">Approach 2</td><td>8wt%BG, 29%CC</td><td>8</td><td>29</td></tr>
<tr><td>17wt%BG, 29%CC</td><td>17</td><td>29</td></tr>
<tr><td>25wt%BG, 29%CC</td><td>25</td><td>29</td></tr>
<tr><td>25wt%BG, 90%CC</td><td>68</td><td>25</td><td>90</td></tr>
<tr><td rowspan="4">Greenfield</td><td>35wt%BG-LFG, 95%CC</td><td>Landfill</td><td rowspan="4">Greenfield</td><td rowspan="4">100</td><td rowspan="4">35</td><td rowspan="4">95</td></tr>
<tr><td>35wt%BG-AM, 95%CC</td><td>Animal Manure</td></tr>
<tr><td>35wt%BG-MSW, 95%CC</td><td>Municipal Solid Waste</td></tr>
<tr><td>35wt%BG-WWS, 95%CC</td><td>Wastewater Sludge</td></tr>
</table>

RESULTS: TOTAL AS-SPENT COSTS

Based on net-power output of plant ($/kWh)

BEC varies based on the larger CCS System which means higher CC%

Pipeline Costs increased with increased Biogas amount thus larger effect on TASC



RESULTS: LEVELIZED COST OF ELECTRICITY

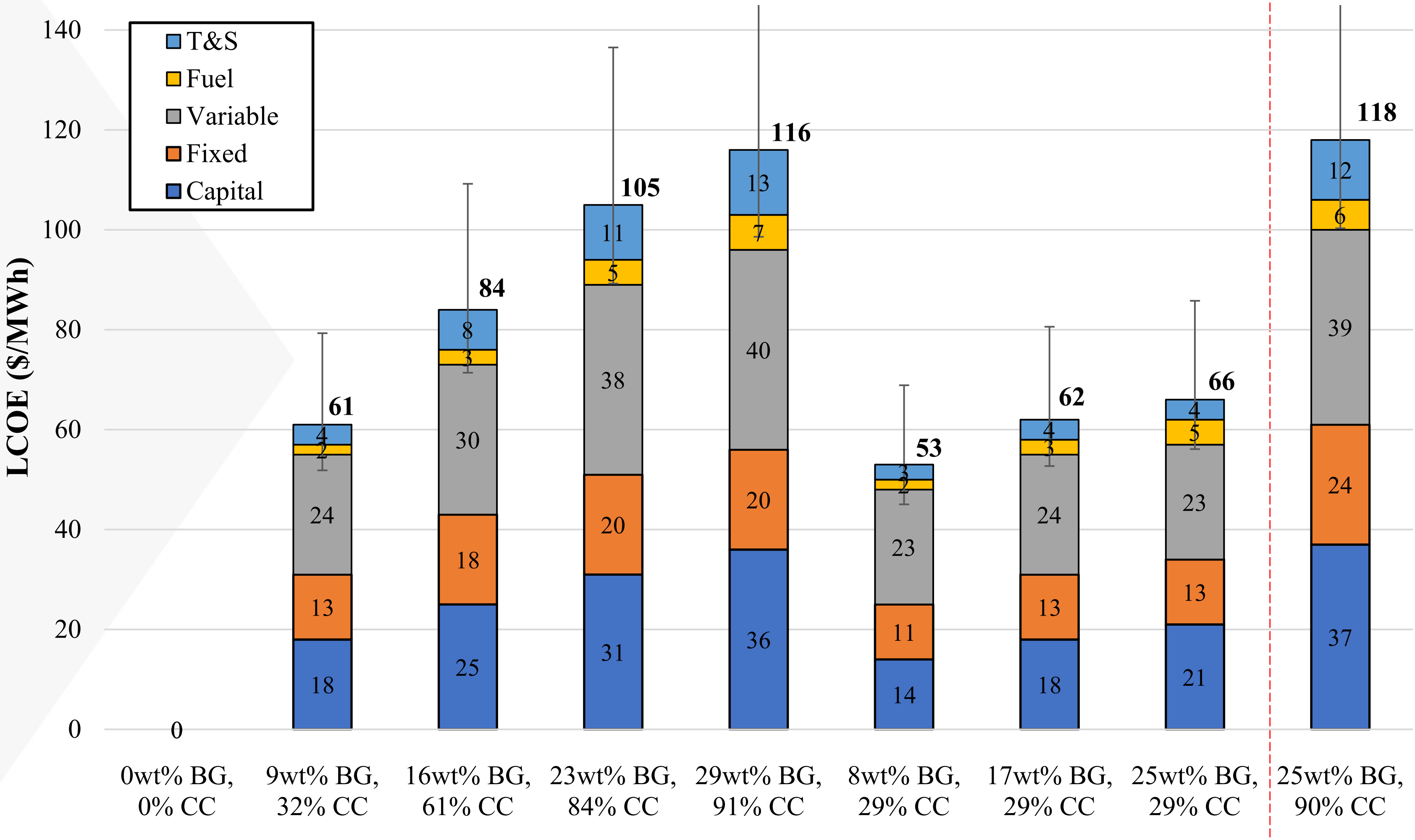
Increasing Biogas as Fuel had small impact on LCOE

Fuel → Increased

Capital Costs of the Pipeline has largest fluctuation and impact on LCOE

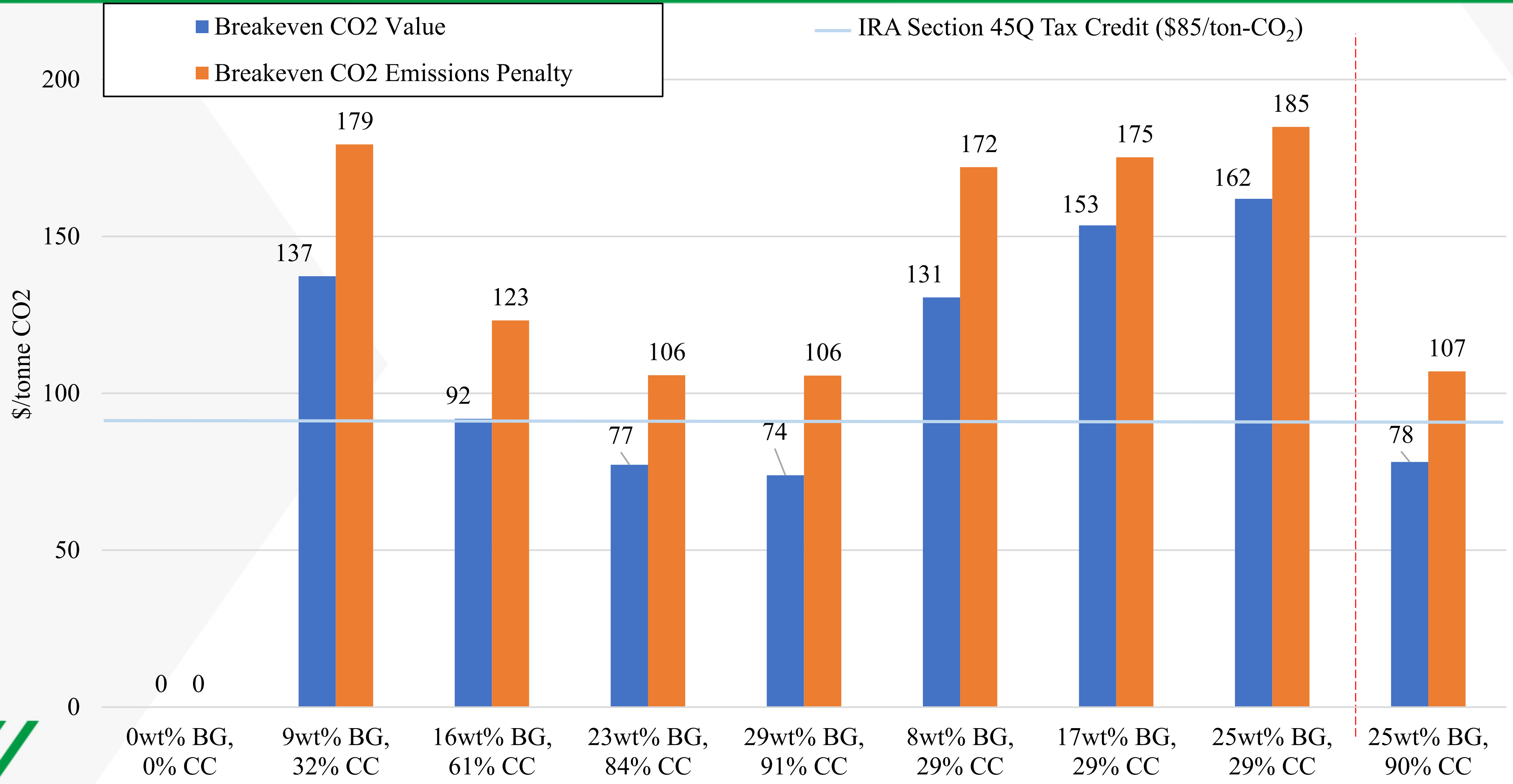
Decreased Rating (68 MW) had highest LCOE

Levelized Cost of Electricity Breakdown ($/MWh)



RESULTS – CO_2 VALUATION

- At <75% Capture, current CO_2 value would **not** breakeven on retrofit
  - IRA Section 45Q eligibility requires 75%[5]
- At >75% Capture, current Tax Credit is above the breakeven value
  - Eligible for 45Q
  - New NSPS Rule requires 95% capture[6]



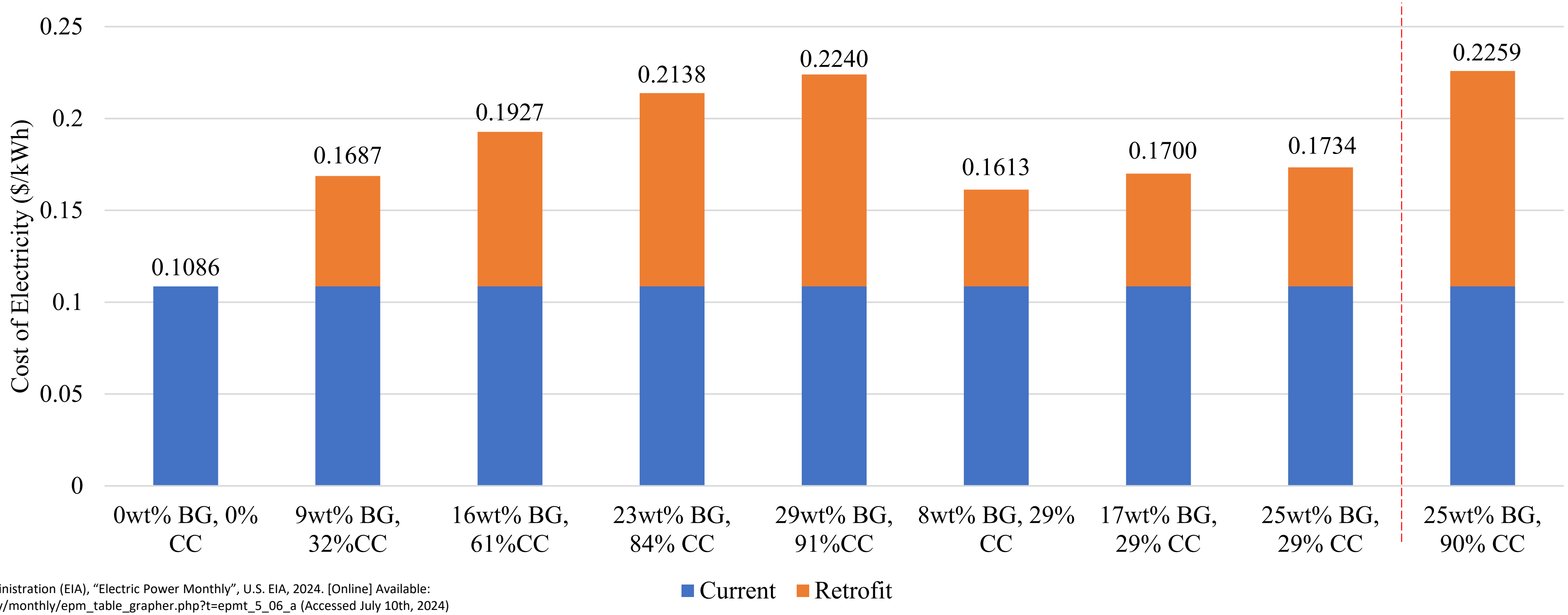
5 Congressional Research Service (CRS), “The Section 45Q Tax Credit for Carbon Sequestration,” CRS, 2023
6 The Federal Register. Federal Register :: Request Access. (n.d.). https://www.federalregister.gov/documents/2024/05/09/2024-09233/new-source-performance-standards-for-greenhouse-gas-emissions-from-new-modified-and-reconstructed

RESULTS – CONSUMER'S ELECTRICITY PRICES

Current West Virginia Cost of Electricity

10.86 ¢/kWh[7]

Retrofit implementation would necessitate consumers willingness to pay for sustainability

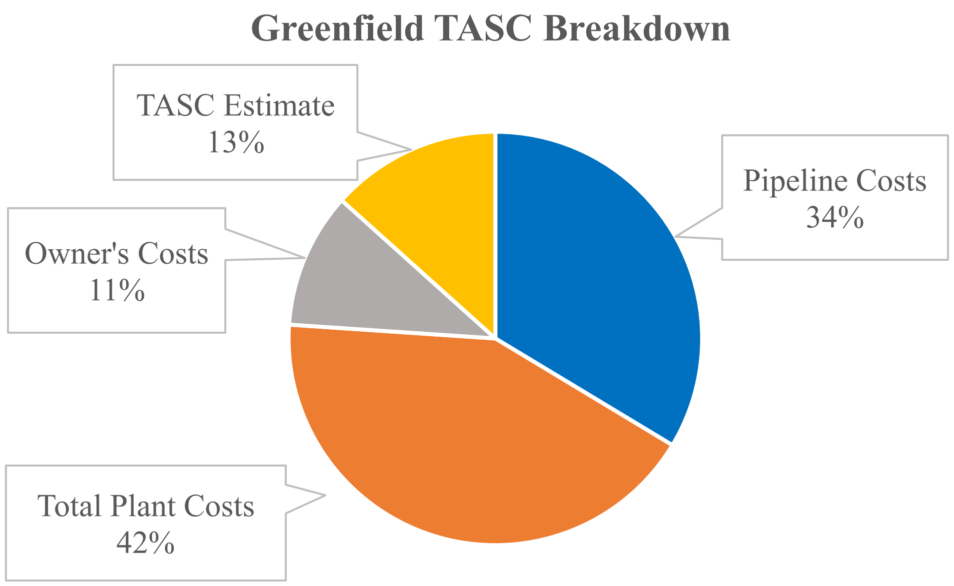


7 U.S. Energy Information Administration (EIA), "Electric Power Monthly", U.S. EIA, 2024. [Online] Available: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_06_a (Accessed July 10th, 2024)

GREENFIELD CO-FIRING TEA

- Case study basis of Harlan County, Kentucky
  - Approximately 8 million tons of waste coal
  - Focused on remediation, a 100 MW-net power plant can remove pile in ~23 years
  - Due to location, pipeline installation close to $370 million

Component	Value ($/MWh)	Percentage
Capital	110	45%
Fixed	50	20%
Variable	50	21%
Fuel	22	9%
Total (Excluding T&S)	**230**	
CO_2 T&S	13	5%
Total (Including T&S)	**243**	



GREENFIELD CO-FIRING TEA

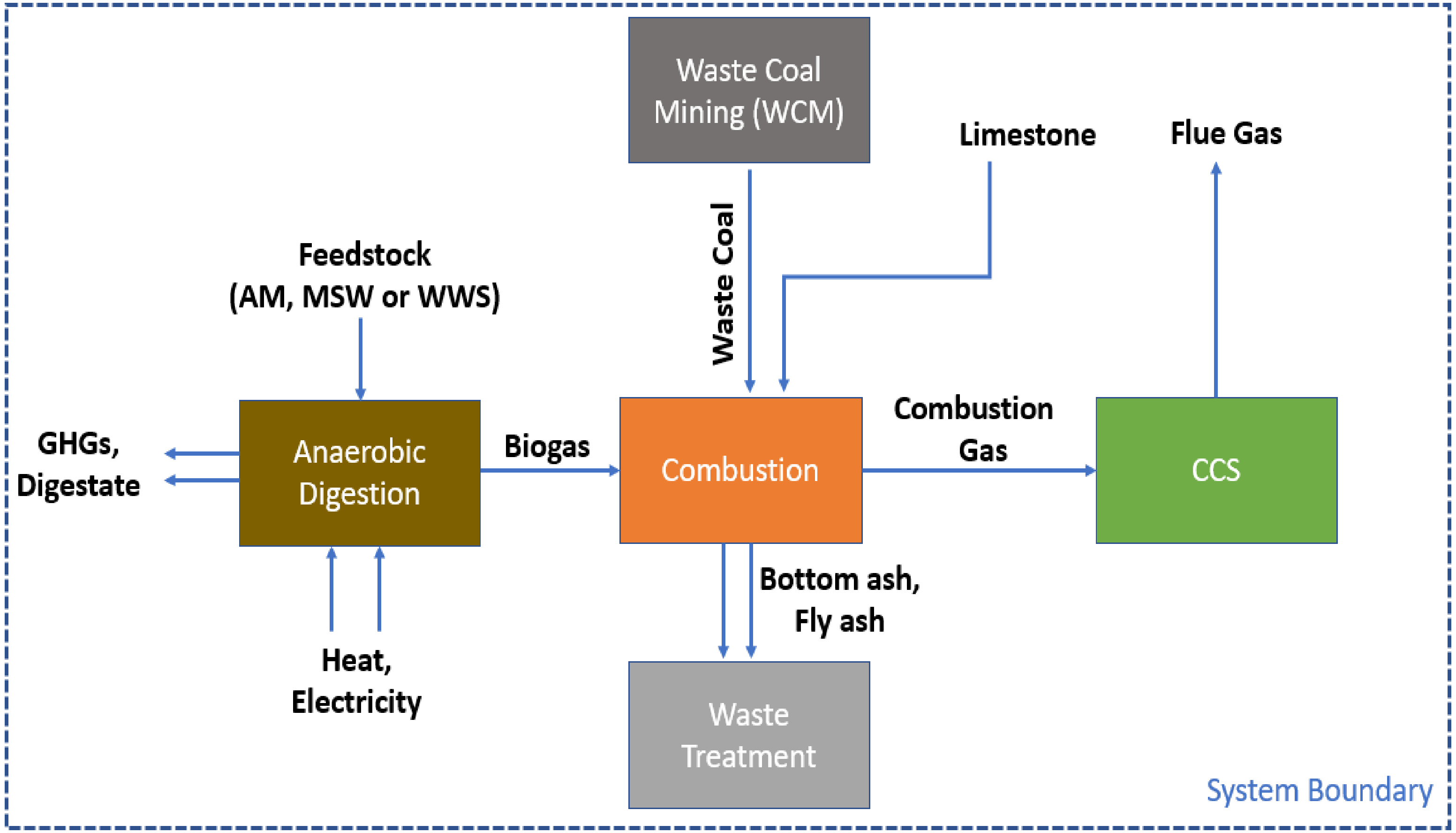
- Primary Issues
  - Location, Economies of Scale, Biogas Availability
- Future Configurations
  - Power plant location closer to biogas
    - Transport Coal to plant rather than transporting biogas (pipeline)
  - 650 MW-net power plant
    - Compare to BECCS to compare technologies on same scale
  - Utilize Natural Gas instead of biogas
    - Compensate for lack of biogas by enriching biogas with natural gas; tri-combustion
    - Renewable natural gas would achieve sustainability goals

TASKS 4 – LIFE CYCLE ASSESSMENT

- **Task 4** – Integrated Resource Utilization and LCA
  - Resources - Availability, location and transportation
  - Biogas - Landfill gas and biogas from anaerobic digestion
  - Impacts - Global warming, acidification, eutrophication, ozone depletion, particulate matter formation and photochemical smog formation potentials.
  - Goal - Determine resources integration strategy to reduce environmental impacts

BURP² LIFE CYCLE ASSESSMENT

- Assessed Global Warming Potential (GWP) using the IPCC 2013 GWP 100a method with the ecoinvent database
- SimaPro PhD 9.1.08 software following ISO 14040-14044 standards
- Functional unit of 1MWh
- AD feedstock: animal manure (AM), municipal solid waste (MSW) and wastewater sludge (WWS)



Basic BURP² LCA flows & system boundary for co-firing with biogas from anaerobic digestion

BURP^2 LIFE CYCLE INVENTORY ANALYSIS

- The life cycle inventory (LCI) includes data from Aspen process simulation of the BURP^2 setup and literature[8,9]

- The BURP^2 cases LCI is based off the net power produced and considers the power needed to operate the system

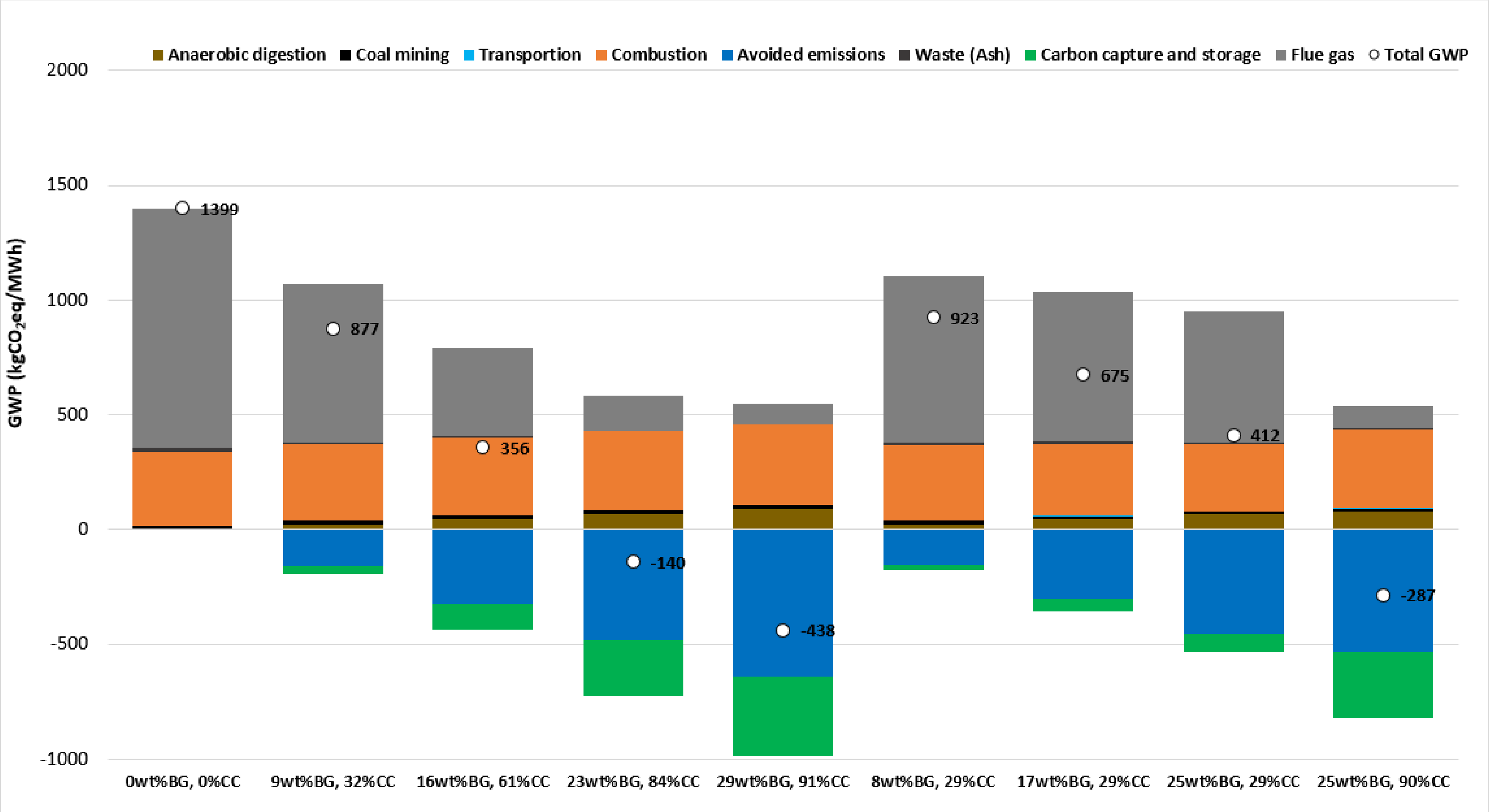
- Retrofit cases 1-8 based on 80 MW-net power while case 9 based on 68 MW-net power produced

- The power plant configuration scenarios are defined based on the co-fired biogas (BG) weight percentage and the amount of CO_2 captured (CC) in each scenario

8 Fecko, P., Tora, B. and Tod, M., 2013. Coal waste: handling, pollution impacts and utilization. In *The coal handbook: towards cleaner production* (pp. 63-84). Woodhead Publishing
9 Rai, S., Hage, D., Littlefield, J., Yanai, G. and Skone, T.J., 2022. Comparative Life Cycle Evaluation of the Global Warming Potential (GWP) Impacts of Renewable Natural Gas Production Pathways. *Environmental Science & Technology*, *56*(12), pp.8581-8589.

BURP² LIFE CYCLE GWP

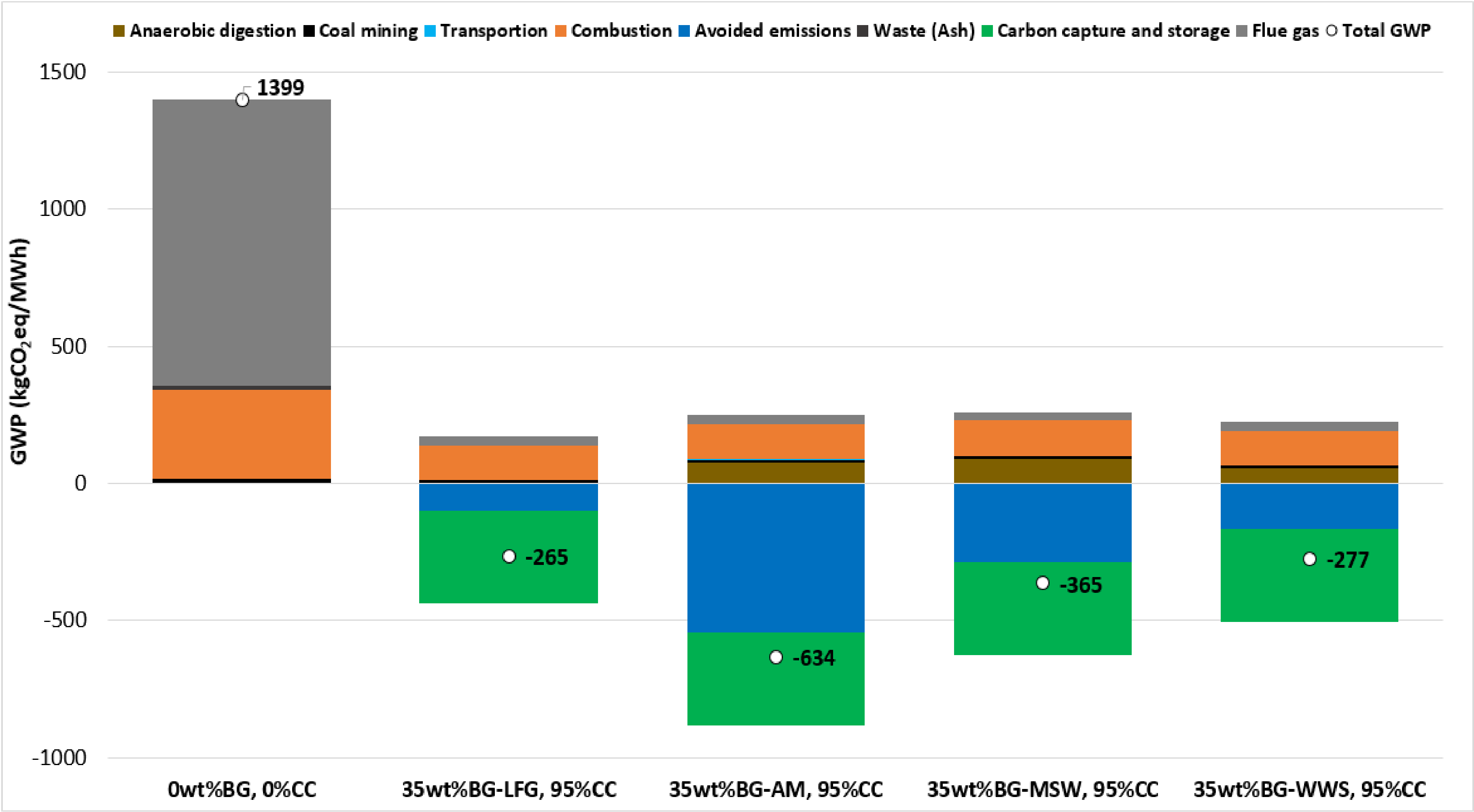
- Life cycle stages GWP - retrofit cases
- Co-firing with animal manure-based biogas showed the least impact compared to the other biogas types
- Results compare favorably with other BECCS LCA reports (938 to 181 $kgCO_2eq/MWh$)[10]



10 Weihs, G. F., Jones, J. S., Ho, M., Malik, R. H., Abbas, A., Meka, W., ... & Wiley, D. E. (2022). Life cycle assessment of co-firing coal and wood waste for bio-energy with carbon capture and storage–New South Wales study. *Energy Conversion and Management*, *273*, 116406

BURP² LIFE CYCLE GWP

- Life cycle stages GWP - preliminary greenfield cases
- Compared the various biogas co-firing cases



SUMMARY

TEA:

- Retrofit implementation necessitates consumer willingness to increase energy prices for greener energy
- Industry wide investment into pipeline infrastructure → increase feasibility for $BURP^2$-related technologies

LCA:

- Replacing 30 wt% waste coal with LFG + 90% CO_2 capture = GWP change from 1400 to -1 $kgCO_{2eq}$/MWh
- Using 23-29 wt% anaerobic digestion-based biogas also achieved negative CO_2 emissions
- Results align well with BECCS LCA report
    - Biogas feed, avoided CH_4 emissions, and CO_2 storage, all contribute to emissions reduction

FUTURE WORK

Task 3

- TEA greenfield
  - Different configurations to solve preliminary issues

Task 4

- LCA greenfield
  - Finalize environmental impact categories assessment
  - Complete resource integration studies

DISCLAIMER & ACKNOWLEDGEMENT

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U.S. Department of Energy

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END

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- Questions?
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