West Virginia Greenhouse Gas Reduction Technical Appendix

Introduction

There are six distinct projects that were assessed for greenhouse gas (GHG) emissions reductions:

1. Power Plant Efficiency Program
2. Small Modular Reactor
3. Clean Hydrogen for Power Generation
4. Natural Gas Power Plant with Carbon Capture
5. Coal Mine Methane Capture
6. State Government Buildings Energy Efficiency Program

Different GHG reduction calculation methodologies were used for each project type, as described in detail in this Appendix. In general, emissions reductions were calculated by comparing a baseline case to a proposed case, as shown in the following equation:

- Emissions Reduced = Baseline Case Emissions – Proposed Case Emissions

For both the baseline and proposed case, total emissions were calculated each year from 2025-2050. The annual emissions in the proposed case were subtracted from the annual emissions in the baseline case to calculate the emissions reduced for those specific years. Cumulative emissions reduced were calculated by summing annual emissions reduced each year. Global Warming Potentials (GWPs) were obtained from the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report to convert emissions reduced into metric tons of carbon dioxide equivalent ($MTCO_2e$).

Cumulative and annual GHG reductions for each project and across projects are in Table 1 and Table 2.

Table 1 Cumulative GHG Emissions Reductions

Year Range	Cumulative GHG Emissions Reductions ($MTCO_2e$)
2025-2030	21,229,239
2025-2050	165,553,134

Table 2 Annual GHG Emissions Reductions

	Annual GHG Reductions ($MTCO_2e$)						
Year	Power Plant Efficiency Program	Small Modular Reactor	Clean Hydrogen for Power Generation	Natural Gas Plant with Carbon Capture	Coal Mine Methane Capture	State Gov. Buildings Energy Efficiency Program	**Total**
2025	-	-	-	1,882,848	-	63,556	**1,946,404**
2026	-	-	-	1,882,848	-	79,444	**1,962,292**
2027	115,750	-	-	1,882,848	224,000	95,333	**2,317,931**
2028	231,500	-	-	1,882,848	448,000	111,222	**2,673,570**

2029	347,250	-	3,293,492	1,882,848	448,000	127,111	**6,098,701**
2030	463,000	-	3,293,492	1,882,848	448,000	143,000	**6,230,340**
2031	468,800	-	3,293,492	1,882,848	672,000	143,550	**6,460,690**
2032	474,600	-	3,293,492	1,882,848	784,000	144,100	**6,579,040**
2033	480,400	-	3,293,492	1,882,848	896,000	144,650	**6,697,390**
2034	486,200	367,550	3,293,492	1,882,848	896,000	145,200	**7,071,290**
2035	492,000	347,442	3,293,492	1,882,848	896,000	145,750	**7,057,532**
2036	497,800	348,833	3,293,492	1,882,848	1,008,000	146,300	**7,177,273**
2037	503,600	350,223	3,293,492	1,882,848	1,008,000	146,850	**7,185,013**
2038	509,400	351,614	3,293,492	1,882,848	1,120,000	147,400	**7,304,754**
2039	515,200	353,005	3,293,492	1,882,848	1,120,000	147,950	**7,312,495**
2040	521,000	354,395	3,293,492	1,882,848	1,120,000	148,500	**7,320,235**
2041	526,800	349,497	3,293,492	1,882,848	1,232,000	149,050	**7,433,687**
2042	532,600	344,598	3,293,492	1,882,848	1,232,000	149,600	**7,435,138**
2043	538,400	339,699	3,293,492	1,882,848	1,232,000	150,150	**7,436,589**
2044	544,200	334,801	3,293,492	1,882,848	1,344,000	150,700	**7,550,041**
2045	550,000	329,902	3,293,492	1,882,848	1,344,000	151,250	**7,551,492**
2046	555,800	331,137	3,293,492	1,882,848	1,344,000	151,800	**7,559,077**
2047	561,600	332,372	3,293,492	1,882,848	1,344,000	152,350	**7,566,662**
2048	567,400	333,607	3,293,492	1,882,848	1,008,000	152,900	**7,238,247**
2049	573,200	334,842	3,293,492	1,882,848	1,008,000	153,450	**7,245,832**
2050	579,000	336,077	3,293,492	1,882,848	896,000	154,000	**7,141,417**
TOTAL	**11,635,500**	**5,839,595**	**72,456,824**	**48,954,048**	**23,072,000**	**3,595,167**	**165,553,134**

Power Plant Efficiency Program

Project Summary

Provide funding to projects that improve the energy efficiency of existing coal-fired power plants.

Assumptions

- **GHG calculation tools used: Energy Policy Simulator (EPS) v3.4.8 tool from Energy Innovation LLC and RMI[1] (used to calculate the baseline scenario forecasts)**
- Project implementation year: 2026
- Project completion year: 2031
- Years project is operational: 20+
- Durability of Reductions: The project will result in permanent reductions as long as the energy efficiency measures remains in place until 2050.
- Uncertainties**:**
    - The actual energy efficiency projects may vary, resulting in different GHG reduction values.
    - Project implementation dates may vary depending on the projects selected.
    - EPS energy sector forecasts carry inherent uncertainty.

Reference Case

The baseline case includes the emissions produced by West Virginia's electric power generation sector. 2021 electric power plant emissions were obtained from "West Virginia EPA's Methodology Report:

[1] https://energypolicy.solutions/home/westvirginia/en

Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990-2021".[2] These emissions were then forecast using the open-source EPS tool which projects changes in GHG emissions for each state based on the expected rise and/or decline of emissions based on expected changes in each state's population, energy use, and fuel sources in the absence of policy actions. The tool does not include the effect of non-CPRG federal incentives (e.g., grants, tax incentives) provided through programs or legislation such as IRA, BIL, and/or CHIPS.

Proposed Case

The proposed case assumes that the baseline case includes power plant energy efficiency improvements. Target efficiency improvement is assumed to be 5% of current efficiency levels[3][4], which will be achieved uniformly over the program period. It is assumed funding allocation, measure implementation, and GHG reductions occur in a uniform manner, which translates to 0% implementation in 2026 and 100% implementation in 2031. It assumes no additional measures will be completed after 2030.

Small Modular Reactor

Project Summary

Develop a small modular reactor (SMR) on DEV-owned property adjacent to the existing Mt. Storm Power Station in Grant County.

Assumptions

General assumptions for this project include the following:

- Project completion year: End of 2034
- Years project is operational: 60
- Durability of reductions: The project will result in permanent reductions as long as the SMR is operational. Additionally, GHG reductions will occur past the 2050 timeframe as the SMR is assumed to be in operation until 2094.
- Uncertainties:
    - While the company has conducted a preliminary siting evaluation for Mt. Storm, it is possible that adverse conditions for the deployment of an SMR at the site could be uncovered during development which could shift back the GHG reduction timeline.
    - The actual MW output and capacity factor of the SMR may vary as these are based on studies of other facilities.
    - Any electricity emission factor forecasts will come with inherent uncertainty. NREL has noted the following on their Cambium 2023 electricity emissions forecasting: "Although we strive to capture relevant phenomena as comprehensively as possible, the models used to create the data are unavoidably imperfect, and the future is highly uncertain."[5]

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[2] https://www.epa.gov/ghgemissions/methodology-report-inventory-us-greenhouse-gas-emissions-and-sinks-state-1990-2021

[3] Page 7: https://www.epa.gov/system/files/documents/2023-05/TSD%20-%20GHG%20Mitigation%20Measures%20for%20Steam%20EGUs.pdf

[4] Page 9: https://sgp.fas.org/crs/misc/R43343.pdf

[5] https://www.nrel.gov/docs/fy24osti/88507.pdf

Reference Case

The baseline case assumes that the electricity generated by the proposed SMR (2,176,299.36 MWh/year – see Proposed Case for calculations) would instead be generated by the regional PJM electric grid. This annual electricity generation is assumed to be constant until 2050. Electricity generation was multiplied by the specific annual electricity emissions factor for that year to calculate annual emissions.

Electricity emissions factors were forecast using NREL's Cambium 2023 Mid-Case Scenario data for the PJM East generation and emissions assessment region (see Table 3).[6][7] The Mid-Case Scenario represents a business-as-usual scenario that considers electric sector policies as they existed in September 2023. The emissions factors reflect the average emission rate of all generation within a region for the specified duration of time and no adjustment is made for imported or exported electricity. Forecast values are available every five years starting in 2025 and ending in 2050. The project team interpolated interim years' emissions factors using this data. Emission factors were converted to $MTCO_2e$ using the IPCC Fifth Assessment Report 100-year GWP values.

Table 3 Electricity Emission Factor Forecasts

Year	$MTCO_2e$/MWh
2025	0.374609
2026	0.340857
2027	0.307104
2028	0.273351
2029	0.239599
2030	0.205846
2031	0.196606
2032	0.187367
2033	0.178127
2034	0.168888
2035	0.159648
2036	0.160287
2037	0.160926
2038	0.161565
2039	0.162204
2040	0.162843
2041	0.160592
2042	0.158341
2043	0.15609
2044	0.153839
2045	0.151589
2046	0.152156
2047	0.152724
2048	0.153291
2049	0.153858
2050	0.154426

[6] https://www.nrel.gov/analysis/cambium.html
[7] https://www.nrel.gov/docs/fy23osti/84916.pdf

Proposed Case

The proposed case assumes electricity production from an SMR produces no GHG emissions, so all baseline emissions are fully reduced to zero. The project team assumed annual electricity production is constant from 2034-2050. The SMR MWh generation value was calculated using the following assumptions:

- Capacity factor: 92.7% (US EIA 2022)[8]
- Net electrical output: 268 MW (output of a typical 300 MW thermal generation plant utilizing air cooled condensers from DEV's 2023 Integrated Resource Planning document filed with the Virginia State Corporation Commission) [9]
- Operations: 24 hours/day, 365 days/year
- Annual MWh produced:
  - 268 MW * 0.927 capacity factor * 24 hrs/day * 365 days/yr = 2,176,299.36 MWh/year

Clean Hydrogen for Power Generation

Project Summary

Natural gas will be used to produce clean hydrogen at large scale using the autothermal reforming (ATR) process. CO_2 generated from the process will be captured and sequestered. The clean hydrogen will fuel Mitsubishi gas turbines with the generated power dispatched into the PJM electric grid.

Assumptions

- **GHG reduction tool used: Proprietary Mitsubishi Power Calculator. The calculator estimates emissions from the combustion of natural gas and from fugitive emissions to the atmosphere.** Emissions are based on typical natural gas composition of 90% CH_4, 5% C_2H_6, 2% C_3H_8, 2% CO_2 and 1% N_2 in volume basis.
- Project completion year/commercial operation year: 2029
- Years project is operational: 30
- Durability of reductions: The project will result in permanent reductions as long as the carbon capture mechanism remains in place and the captured carbon is stored permanently. Additionally, GHG reductions will occur past the 2050 timeframe as the plant is assumed to be in operation until 2060.
- Uncertainties:
  - Operations can be affected by equipment breakdown and thus forced outages do occur. If the project switches the power plant to operate on natural gas in the event of an extended ATR outage, this will limit GHG reductions.

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[8] Electric Power Monthly, February 2024, U.S. Energy Information Administration, Feb. 2024. [Online]. Available: https://www.eia.gov/electricity/monthly/current_month/february2024.pdf

[9] Virginia State Corporation Commission. Case number PUR-2023-00066. (2023, May 1). "2023 Integrated Resource Plan of Virginia Electric and Power Company"

- The expected operating life of the power plant is 30 years, with the first 10 years fueled by hydrogen and the last 20 years fueled by natural gas. However, should the general economics of hydrogen and regulations be favorable, this combined facility will be capable of operations for a period of 30 years sometime in 2030 (i.e. potential operations extend to 2060). Therefore, potential annual emissions reductions are held constant from project completion in 2029 to 2050, but reductions may differ depending on the economic and political landscape surrounding hydrogen production.

Reference Case

In the baseline case, a traditional natural gas fired power plant is used to add 1,231 MW of net power to the PJM grid. Emissions are calculated from the combustion of natural gas and from fugitive emissions to the atmosphere. Annual emissions are held constant from 2029 to 2050. All assumptions and calculations are from the Proprietary Mitsubishi Power Calculator. Inputs, outputs, and assumptions for the calculator are as follows:

- Power Plant Capacity factor: 100%
- Annual Average Output: 1,231 MW
- Annual CO2 emissions from natural gas combustion and fugitive emissions = 3,760,326 $MTCO_2e$/year

Proposed Case

In the proposed case, natural gas is used to produce enough clean hydrogen to add 1,231 MW of net power to the PJM grid. 95-98% of the carbon dioxide generated from the ATR process will be captured using convention technology (using an average of 96.5% for calculation purposes). Pipelines will transport and sequester the CO_2 in appropriate geologic sites in the region. Annual emissions are held constant from 2029 to 2050. All assumptions and calculations are from the Proprietary Mitsubishi Power Calculator. Inputs, outputs, and assumptions for the calculator are as follows:

- Emissions Factor: 1.05 $kgCO_2e$/kg H2 (64% of which is associated with upstream emissions)
- CO_2 capture %: 96.5% (depends upon CO_2 removal technology selected – could be either 98% or 95%, so 96.5% was used as an average)
- Annual CO_2 emissions from combustion and fugitive emissions: 466,834 $MTCO_2$/year (emissions generation from Blue H2 based on Pre-FEED analysis of ATR technologies)

Natural Gas Power Plant with Carbon Capture

Project Summary

Develop an electricity generation plant powered by natural gas that captures and sequesters most of the CO_2 produced during operations.

Assumptions

General assumptions for this project include the following:

1. Project completion year: 2025
2. Years project is operational: 40
3. Durability of reductions: The project will result in permanent reductions as long as the carbon capture mechanism remains in place and the captured carbon is stored permanently.

Additionally, GHG reductions will occur past the 2050 timeframe as the plant is assumed to be in operation until 2065.

4. Uncertainties:
    a. Annual electricity production may vary.
    b. To take a more conservative approach with GHG reduction estimations, an advanced gas fired combined cycle power plant without natural gas capture was used for the baseline case, but an alternative baseline case of using grid electricity instead would result in higher emissions reductions.
    c. Proper maintenance is needed to ensure the 75% carbon removal effectiveness for the life of the project. The project will most likely be able to capture much more than 75% of carbon.
    d. There could be project delays associated with permitting or other issues which could delay the anticipated start date.

Reference Case

The baseline case assumes an advanced gas fired combined cycle power plant without carbon capture would be built. The project team assumed annual natural gas use and emissions are constant from 2025-2050. Baseline assumptions include:

- Net electrical output: 1,200 MW
- Average Operating Capacity Factor: 75%
- Operating hours: 8,760 hours/yr (operating 24/7)
- Net plant heat rate: 6.000 MMBtu natural gas/MWh generated (conservative GE estimate of heat rate for 7HA.03 gas turbines in 2x1 combined cycle configuration)
- Natural gas emissions factor: 117 lbs. CO_2/MMBtu natural gas (US EIA)[10]
- Annual electricity generation: 1,200 MW * 8,760 hours per year * 0.75 capacity factor = 7,884,000 MWh/yr year sent to the grid
- Annual natural gas used: 7,884,000 MWh/yr * 6.000 MMBtu/MWh = 47,304,000 MMBtu/yr natural gas consumed by the power plant
- Annual baseline emissions: 47,304,000 MMBtu/yr * 117 lbs/MMBtu ÷ 2204.6 lbs/MT = 2,510,464 $MTCO_2$/yr

Proposed Case

The proposed case is the same as the baseline case with additional carbon capture and sequestration. The project team assumed annual natural gas use and emissions are constant from 2025-2050. Proposed case assumptions include:

- Net CO_2 capture and sequestration: 75% (the minimum required to qualify for a DOE loan under the provisions of the Inflation Reduction Act)
- Annual proposed emissions: 2,510,464 $MTCO_2$/yr * (1 - 0.75 removal factor) = 627,616 $MTCO_2e$/yr

Coal Mine Methane Capture

Project summary

The project will capture coal mine methane (CMM) from one mine by installing new capture equipment, measurement equipment, pipelines, conditioning equipment, and interconnections to interstate natural

[10] https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the-environment.php

gas transmission pipeline systems. This would represent the first productive use of this source of CMM at these mines as CMM was previously vented to the atmosphere.

Assumptions

- **GHG reduction tool used: DOE's Argonne National Laboratory's R&D GREET model**
- Project completion year: 2027
- Years project is operational: 20+
- Durability of Reductions:
  - The project will result in permanent reductions as long as the CMM capture mechanism remains in place and the methane is used to replace traditional natural gas use.
  - Rigorous industry measurement standards for volume, high frequency composition sampling and calibration, training records for all measurement personnel, and independent 3rd party verification are all processes that CNX will deploy to ensure emission reductions durability.
- Uncertainties**:**
  - There is inherent uncertainty associated with mining pace and duration, geologic conditions, productivity of future waste methane sources, and timing of capture. For example, the composition and production rate of methane may vary from current estimates which would result in differing levels of methane capture from current estimates.

Reference Case

The baseline case consists of current mining operations and emissions and assumes no CMM capture. Estimates for CMM production were generated by using geologic data, current measurement of methane currently being liberated, historical measurement of liberated methane, and assumed future mining based on the plans of the mine operator. Direct methane measurement data from the operating and abandoned Marshall and Marion mines was used to estimate trends in the volume, composition, and change associated with sources of coal mine methane. These measurements are consistent with data the mine operator has reported to EPA and is included in EPA's GHGRP. CMM emissions are expected to increase by eight times over this century.[11] Evidence supports 100% of CMM would be released in the baseline case.[12]

Proposed Case

The proposed case is the same as the baseline case but with a CMM capture system in place. Methane capture calculations are based on current trend of market adoption of CMM emissions abatement, geologic data, and planned future mining activities. Key sources for these calculations include the EPA

[11] Kholod, N., Evans, M., Pilcher, R., et al. (February 2020). Global methane emissions from coal mining to continue growing even with declining coal production. Journal of Cleaner Production, 256. https://www.globalmethane.org/documents/Global_Methane_Emissions_from_Coal_Mining.pdf.

[12] Mucho, T. P., Diamond, W. P., Garcia, F., Byars, J. D., Cario, S. L. (2000). Implications of Recent NIOSH Tracer Gas Studies on Bleeder and Gob Gas Ventilation Design. 2000 SME Annual Meeting, Salt Lake City, Utah, February 28 - March 1, 2000. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., Preprint 00-08, 1-17. https://stacks.cdc.gov/view/cdc/9025; see also Schatzel, S. J., Krog, R. B., Dougherty, H. (2017). Methane emissions and airflow patterns on a longwall face: Potential influences from longwall gob permeability distributions on a bleederless longwall. Transactions of Society for Mining, Metallurgy, and Exploration, 342(1), 51–61. http://transactions.smenet.org/abstract.cfm?articleID=8108&page=51.

Greenhouse Gas Reporting Program[13], Argonne National Lab[14], MSHA[15]. The net GHG emissions in the proposed case also considers the additional energy consumption of the capture and conditioning systems.

State Government Buildings Energy Efficiency Program

Project Summary

Provide funding to projects that improve energy efficiency in state-owned commercial buildings.

Assumptions

- **GHG calculation tools used: Energy Policy Simulator (EPS) v3.4.8 tool from Energy Innovation LLC and RMI[16] (used to calculate the baseline scenario forecasts)**
- Project implementation year: 2025
- Project completion year: 2030
- Years project is operational: 20+
- Durability of Reductions: The project will result in permanent reductions as long as the energy efficiency measures remains in place until 2050.
- Uncertainties**:**
  - The actual energy efficiency projects may vary, resulting in different GHG reduction values.
  - Project implementation dates may vary depending on the projects selected.
  - EPS energy sector forecasts carry inherent uncertainty.

Reference Case

The baseline case includes the emissions produced by West Virginia's commercial and residential buildings sector. 2021 commercial and residential emissions were obtained from "West Virginia EPA's Methodology Report: Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990-2021".[17] These emissions were then forecast using the open-source EPS tool which projects changes in GHG emissions for each state based on the expected rise and/or decline of emissions based on expected changes in each state's population, energy use, and fuel sources in the absence of policy actions. The tool does not include the effect of non-CPRG federal incentives (e.g., grants, tax incentives) provided through programs or legislation such as IRA, BIL, and/or CHIPS.

Proposed Case

The proposed case assumes that the baseline case includes building energy efficiency improvements. Energy efficiency gains in state buildings were modelled only during the 5-year timeframe planned for the program. Efficiency gains will likely continue to improve past the program's end, however, only those directly applicable to the policy measure in this plan are included in the analysis. This approach ensures that a clear connection is maintained between the proposed policies and their predicted emissions reductions. The model assumes a linear ramp up of these programs over 5 years, with 20% of the emissions reduction progress from this policy achieved each year. The model assumes the average cost per kWh of implementing energy efficiency projects to be $0.58/kWh, based on data from the Clean

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[13] https://enviro.epa.gov/query-builder/ghg.

[14] https://greet.anl.gov/

[15] https://www.msha.gov/data-and-reports/statistics/mine-employment-and-coal-production

[16] https://energypolicy.solutions/home/westvirginia/en

[17] https://www.epa.gov/ghgemissions/methodology-report-inventory-us-greenhouse-gas-emissions-and-sinks-state-1990-2021

Power Plan.[18] The total amount of energy that could be saved with the funding for this program was calculated by dividing the total funding for the program by the cost per kWh. The project team assumed that energy efficiency improvements are directly proportional to a reduction in carbon emissions. The estimated emission reductions from the energy efficiency program were subtracted from West Virginia's baseline projected emissions for each projected year to arrive at the reduction in emissions achieved through this program. The project team assumes that no additional measures will be completed after 2030.

[18] https://www.govinfo.gov/content/pkg/FR-2015-10-23/pdf/2015-22842.pdf