

**CPRG IMPLEMENTATION GRANTS COMPETITION
TECHNICAL APPENDIX FOR
Resilient Rapid City: City and Community Partnership Efforts for Reducing GHG Emissions**

Energy use and emission reduction calculations were performed using a simple-math spreadsheet approach (i.e., not using statistical modelling). The calculations use a combination of local and scaled state-level data. Technology energy consumption ratings are based on manufacturers' specifications:

- LED lighting: 0.102 kWh per fixture.
- Heat pumps: coefficient of performance of 3 (air source) and 5 (ground source).
- Solar PV systems: capacity factor of 0.1412.

1. Low-Emission City Facilities and Schools

GHG Reduction Measures: 1) City Building and Facility Retrofits, 2) City-Wide LED Lighting Conversion, School Weatherization, 4) Non-Profit Organization Energy Efficiency, and 5) Water District Net Zero/Low Energy Study.

Emission Reductions (MT CO₂e)	2025-2030 Annual Average	2025-2030 Cumulative	2025-2050 Cumulative
City Facilities Retrofitted	239	1,030	5,812
Municipal Lighting Upgraded	1,630	1,630	7,580
Schools Weatherized	308	1,846	20,058
Non-Profit Buildings Retrofitted	217	1,300	9,645
Water District Pipeline Installed	0	0	152,539
Totals	2,394	5,806	195,634

a. Building Retrofitting and Weatherization

To quantify emissions reductions from performing City and school buildings energy improvements, the methodology compares a building's year-over-year and total energy use and resulting emissions before and after improvements are made.

Baseline building energy use was sourced from the Energy Information Administration (EIA) and allocated by sector and buildings using the National Renewable Energy Laboratory's (NREL) State and Local Planning for Energy (SLOPE) Platform. NREL's ComStock platform was used to allocate total energy use in each building to individual end uses.

Building upgrades include both energy efficiency improvements and switching from systems using fossil fuel energy to heat pumps that can use zero-emissions electricity. The formulas provided here estimate changes in energy consumption and emissions from these two energy sources to either air or ground source heat pumps.

Changes in Total Energy Use

In the formulas below, for the purposes of building retrofit measures:

- The 'Energy Reduction %' was set to 50% to reflect a desired reduction in non-space conditioning energy consumption in these buildings by 50%. Lighting, appliance, and plug load efficiency upgrades are calculated to be able to achieve this reduction as the facilities in question are typically using dated, inefficient technologies.
- The 'Thermal Energy Reduction %' was set to 50% to reflect a reduction in space conditioning energy consumption by 50%. As natural gas space and water conditioning systems are being switched to heat pump systems, the difference in coefficient of performance between these technologies is estimated to easily achieve this 50% reduction; and,
- The COP (coefficient of performance) reflects the increase in efficiency of heat pumps relative to natural gas or electric systems.

b. Electricity

To determine the impact of improved performance on buildings' **non-space conditioning electricity consumption** (i.e., energy used for appliances, lighting, plug load, etc.) the following formula is used:

$$\text{New NonSpace Conditioning Electricity Use (MMBTU)} = (1 - \text{Energy Reduction \%}) \times \text{Baseline NonSpace Conditioning Electricity Use (MMBTU)}$$

To determine the impact of improved performance on buildings' **space-conditioning electricity consumption** (i.e., space heating and cooling and water heating) the following formula is used:

$$\begin{aligned} \text{New Space Conditioning Electricity Use (MMBTU)} = & (1 - \text{Thermal Energy Reduction \%}) \times \\ & \text{Baseline Space Conditioning Natural Gas Use (MMBTU)/COP} + \\ & (1 - \text{Energy Reduction \%}) \times \text{Electricity of Baseline Buildings (MMBTU)} \end{aligned}$$

The final, total electricity consumption after retrofits are complete is calculated as:

$$\text{New Electricity Use (MMBTU)} = \text{New Space Conditioning Electricity Use (MMBTU)} + \text{New NonSpace Conditioning Electricity Use (MMBTU)}$$

c. Natural Gas

To determine the impact of improved performance on buildings' **non-space conditioning natural gas consumption** (e.g., natural gas use for stoves) the following formula is used:

$$\text{New NonSpace Conditioning Natural Gas Use (MMBTU)} = (1 - \text{Energy Reduction \%}) \times \text{Baseline NonSpace Conditioning Natural Gas Use (MMBTU)}$$

To determine the impact of improved performance on buildings' **space conditioning natural gas consumption** (e.g., space heating and hot water heating) the following formula is generally used to show, for example, a *reduction* in natural gas use due to increased insulation:

$$\text{New Space Conditioning Natural Gas Use (MMBTU)} = (1 - \text{Thermal Energy Reduction \%}) \times \text{Baseline Space Conditioning Natural Gas Use (MMBTU)}$$

However, in order to achieve significant emissions reductions, the projects for this PCAP will include completely removing natural gas systems for space conditioning, and replacing them with heat pumps. In this case the following formula is used:

$$\text{New Space Conditioning Natural Gas Use (MMBTU)} = 0$$

The final, total natural gas consumption after retrofits are complete is calculated as:

$$\text{New Natural Gas Use (MMBTU)} = \text{New Space Conditioning Natural Gas Use (MMBTU)} + \text{New NonSpace Conditioning Natural Gas Use (MMBTU)}$$

Changes in Total Emissions

The resulting changes in emissions are calculated by applying the appropriate emissions factors to the change in energy consumption (both electricity and natural gas) calculated above:

$$\text{Net Electricity Emissions (MT CO}_2\text{e)} = \text{Baseline Electricity Use (MMBTU)} - \text{New Electricity Use (MMBTU)} \times \text{Emission Factor of the Grid (MT CO}_2\text{e/MMBTU)}$$

$$\text{Net Natural Gas Emissions (MT CO}_2\text{e)} = \text{Baseline Natural Gas Use (MMBTU)} - \text{New Natural Gas Use (MMBTU)} \times \text{Natural Gas Emission Factor (MT CO}_2\text{e/MMBTU)}$$

The final, total emissions reductions (MT CO₂e) are the sum of electricity and natural gas emissions.

$$\text{Net Emission Reduction (MT CO}_2\text{e)} = \text{Net Electricity Emissions (MT CO}_2\text{e)} + \text{Net Natural Gas Emissions (MT CO}_2\text{e)}$$

d. Municipal Lighting Upgrades

Streetlight upgrades and upgrades to lighting at The Monument and City sports fields replace energy inefficient lighting technologies with LED lighting technologies. To quantify emissions reductions achieved from this switch, the year-over-year and total energy use and resulting emissions before and after lighting improvements are made are calculated.

Baseline lighting energy use was sourced from City facilities management, providing lighting counts and estimated annual energy use. 2,400 streetlights currently use high intensity discharge (HID) lighting. The Monument (3,095 light fixtures) and City sports fields (130 lights) rely on metal halide lamps for most lighting applications.

Changes in Total Energy Use

To determine the impact of improved lighting performance the following formula is used:

$$\text{Change in Electricity Use (MMBTU)} = \text{Existing Lighting Electricity Use (kWh)} - \text{New Lighting Electricity Use (kWh)} \times \text{MMBTU to kWh conversion factor}$$

Changes in Total Emissions

The resulting changes in emissions are calculated by applying the appropriate emissions factors to the change in electricity consumption:

$$\text{Net Emission Reduction (MT CO}_2\text{e)} = \text{Change in Electricity Use (MMBTU)} \times \text{Emission Factor of the Grid (MT CO}_2\text{e/MMBTU)}$$

e. Water District Pipeline Project

The proposed water district pipeline is based on similar existing pipelines that supply Rapid City with water. A study provided the value for the energy required to pump the daily water volume requirement from the source to the City using 5 pump stations. The study calculated that the energy capacity needed to operate the pumps at 10 hours/day would be 57,000 kW.

Changes in Total Energy Use

There is no change in total energy use for this project as it is new infrastructure and will be built to energy efficient standards. The energy source to power the pumps is assumed to be the electricity grid in the baseline case and renewable energy (e.g., solar PV, wind) in the actual project implementation case.

Changes in Total Emissions

Switching energy sources from the electricity grid baseline to renewable energy sources reduces the emissions that would otherwise result from use of grid electricity.

$$\text{Net Emissions Reduction (MT CO}_2\text{e)} = \text{Baseline Electricity Use (kWh)} \times \text{Emission Factor of the Grid (MT CO}_2\text{e/kWh)}$$

Assumptions:

- City Building and Facility Retrofits:
 - 10 city owned buildings by 2030
 - 50% reduction in thermal and plug load energy
 - Inclusion of air source heat pumps
 - Retrofit Costs (Building Energy Retrofit Potential, Pembina Institute)
 - Heat Pump Costs (US EIA Updated buildings sector appliances and equipment costs and efficiencies, June 2023)
 - Energy Costs (EIA, Annual Energy Outlook 2023)
- Municipal Lighting
 - The Monument
 - 3,095 light fixtures to LED lighting
 - Capital Costs: \$4,486,149¹
 - City Streets
 - 2,400 High Intensity Discharge lights to LED lighting
 - 800 older LED to new LED lighting
 - Capital Costs: \$2,980,000²
 - City Sport Fields
 - 130 1500W metal halide lamps to LED lighting
 - Capital Costs: \$5,355,000³
 - Energy Costs (EIA, Annual Energy Outlook 2023)
- School Weatherization
 - North Middle School
 - 25% reduction in energy use due by upgrading lighting and controls by 2026
 - Installation of a geothermal wellfield with electric ground-source chiller/heater by 2028

¹ City estimate

² City estimate

³ City estimate

- Lighting capital costs: \$2,419,000⁴
 - Geothermal costs: \$16,453,000⁵
 - Energy Costs (EIA, Annual Energy Outlook 2023)
- Remaining Schools
 - 25% reduction in thermal and plug load energy from 2029 to 2040
 - Retrofit Costs (Building Energy Retrofit Potential, Pembina Institute)
 - Energy Costs (EIA, Annual Energy Outlook 2023)
- Non-profit Organization Building Retrofits
 - 7 buildings by 2030
 - 35% reduction in thermal and plug load energy
 - Inclusion of air source heat pumps
 - Retrofit Costs (Building Energy Retrofit Potential, Pembina Institute)
 - Heat Pump Costs (US EIA Updated buildings sector appliances and equipment costs and efficiencies, June 2023)
 - Energy Costs (EIA, Annual Energy Outlook 2023)
- Water District Net Zero Study
 - South Dakota School of Mines & Technology study
 - 5 pump stations
 - Estimated energy requirement of 57,100 kW
 - Pumps operate on average 10 hours per day
 - Study Scope Costs: \$592,200
 - Energy Costs (EIA, Annual Energy Outlook 2023)

2. Renewable Rapid City

GHG Reduction Measures: 6) City Water Reclamation Facility Solar PV Pilot and 7) SD Mines Solar Pilot.

Emission Reductions (MT CO ₂ e)	2025-2030 Annual Average	2025-2030 Cumulative	2025-2050 Cumulative
Water Reclamation Facility Solar PV	76	379	1,214
SD Mines Solar PV	50	248	1,110
Totals	126	627	2,324

⁴ Estimated by Skyline Engineering

⁵ Estimated by Skyline Engineering

a. Water Reclamation Facility Solar PV

Rapid City's water reclamation facility uses 480,000 kWh of energy annually. A solar PV installation would offset the facility's emissions.

Changes in Total Energy Use

The total energy used by the facility would not change, but the source of the energy would. The annual energy generation from the system is calculated as:

$$\text{Annual Generation (GWh)} = \text{Installed Capacity (GWh)} \times 8760 \times \text{Capacity Factor}$$

Assuming a conservative solar capacity factor of 0.1412, the installed capacity needed to generate 480,000 kWh of annual energy is roughly 422kW.

Changes in Total Emissions

Emission reductions achieved by using solar PV generated electricity are calculated as:

$$\begin{aligned} \text{Emissions Reduction (MT CO}_2\text{e)} \\ = \text{Emission Factor (MT CO}_2\text{e/GWh)} \times \text{Annual Generation (GWh)} \end{aligned}$$

The emission factor used is that of the electric grid.

Assumptions:

- Water Reclamation Facility Solar PV
 - Install 422 kW of solar PV to cover 480,000 kWhs of annual electricity consumption by 2026
 - Installation costs (NREL, Electricity Annual Technology Baseline)
 - Energy Costs (EIA, Annual Energy Outlook 2023)
- South Dakota School of Mines & Technology
 - Install 50 kW of solar PV in 2026
 - Install and additional 375 kW of solar PV by 2028
 - Installation costs: \$2,801,2506
 - Energy Costs (EIA, Annual Energy Outlook 2023)

⁶ South Dakota School of Mines & Technology estimate

3. Low Waste Rapid City

GHG Reduction Measures: 8) Solid Waste Methane Gas Conversion.

Emission Reductions (MT CO ₂ e)	2025-2030 Annual Average	2025-2030 Cumulative	2025-2050 Cumulative
Landfill Gas Capture	446	2,674	11,588

a. Landfill Gas Capture

The City's solid waste facility can capture methane escaping from the landfill to power facility operations. The facility uses an average of 1,400 MMBTU in thermal energy each month, currently supplied by natural gas.

Changes in Total Energy Use

The total energy use of the facility will not change, just the energy source. The amount of energy needed is calculated as:

$$\text{Annual Natural Gas Consumption (MMBTU)} = \text{Average Monthly Natural Gas Use (MMBTU)} \times \text{Number of Heating Months}$$

Changes in Total Emissions

Emission reductions achieved by switching from natural gas to landfill capture gas are calculated as:

$$\text{Emissions Reduction (MT CO}_2\text{e)} = \text{Natural Gas Emission Factor (MT CO}_2\text{e/MMBTU)} \times \text{Annual Natural Gas Consumption (MMBTU)}$$

Assumptions:

- Landfill gas capture
 - Average monthly natural gas heating consumption: 1,400 MMBTU/months⁷
 - Number of heating months: 6
 - Capital Costs: \$3,306,000⁸
 - Energy Costs (EIA, Annual Energy Outlook 2023)

⁷ "Rapid City Solid Waste Master Plan", City of Rapid City, South Dakota, 2021

⁸ "Technical Memorandum, MRF – Use of Dual Fuel for Heating", City of Rapid City WRF, 2023

4. Total Emission Reductions

The total emission reductions achieved by these projects are tabulated below.

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Water Reclamation Facility Solar PV	76	379	1,214
SD Mines Solar PV	50	248	1,110
Landfill Gas Capture	446	2,674	11,588
Totals	2,966	9,107	209,546