Clean Energy Integration in Natural Gas Compressor Station Operations

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Summary of Findings

Integrating renewable energy into oil and gas operations could reduce emissions and maximize higher-value use of produced hydrocarbons. In this study, analysts from the Joint Institute for Strategic Energy Analysis (JISEA) and the National Renewable Energy Laboratory (NREL) evaluated clean power technologies for a natural gas compressor station in Texas, using NREL's REopt tool. Different configurations of distributed energy resources were evaluated based on the technologies available and the load they can satisfy, available land, and hypothetical carbon pricing. The analysis is part of a collaborative program with industry to understand site-specific energy consumption and prices in the oil and gas supply chain and determine under what conditions clean energy options are economically attractive. This work was sponsored by a consortium including Kinder Morgan, Interstate Natural Gas Association of America Foundation, Extraction Oil & Gas, Baker Hughes, and ConocoPhillips.

Snapshot

- Smaller size renewable energy technologies can be cost-effective; larger systems (generating 50% of the site's annual load) offset significant amounts of CO_2, but at an added cost.
- For grid-connected systems, the low-cost industrial electricity rates (below $0.03/per kilowatt-hour) paid by these facilities frequently reduced the net present value of co-located renewable power installations beyond economic viability.
- A calculated cost of emissions reduction ($/t$CO_2$e) based on renewable energy generated indicates that a carbon cost of $40/t$CO_2$e would result in a break-even point for a renewable energy system generating 50% of the site's load at a case study site.
- New low-carbon power technologies could represent another viable option for generating electricity on-site while decreasing emissions, although they require additional demonstration of their business models.
- Incorporating clean energy technologies and otherwise reducing the amount of fossil fuels used in the petroleum production, transportation, and refining process have the potential to both decrease energy costs and decrease greenhouse gas emissions.

JISEA
Joint Institute for Strategic Energy Analysis

Increasing Importance of Clean Energy in Oil & Gas Operations

Developing oil and gas resources remains critical to our energy and economic future in the next decade. Prudent business practices, which are especially important in times with low oil prices, require minimizing product losses and reducing energy costs along the supply chain. Global pressure toward addressing environmental concerns and the potential advantages of clean energy—reduced impact on the environment, increased operational efficiencies, and conservation of oil and gas resources for the marketplace—are compelling the oil and gas industry to consider implementing clean technologies into their operations (Domonoske 2021). In addition, the rapid decline in the price of clean energy technologies over the past decade (Figure 1) makes them more attractive than ever before, and it is possible that the coupling of conventional generation with renewables could deliver the most feasible and economically attractive solution to decreasing emissions.

One way to meet [pre-pandemic] growing demand for oil and gas and the energy intensity required for operations—while also meeting emissions reduction goals and minimizing environmental burdens—is to integrate clean energy technologies into oil and gas operations (Ericson, Engel-Cox, and Arent 2019). Incorporating clean energy technologies and otherwise reducing the amount of fossil fuels used in petroleum production, transportation, and refining processes have the potential to decrease both energy costs and greenhouse gas emissions, as well as preserve oil and gas resources for their highest-value uses.

In 2019, JISEA established a collaborative program to:

- Support the identification, development, and adaptation of highly reliable, cost-effective clean energy solutions for oil and gas operations
- Perform techno-economic analysis and site-specific optimization of combinations of renewable and conventional generation, storage, and energy conservation
- Demonstrate the most promising technologies for validation of performance in a variety of field environments (while analyzing optimization scenarios), in partnership with industry.

Members of the consortium include Kinder Morgan, Interstate Natural Gas Association of America Foundation, Extraction Oil & Gas, Baker Hughes, and ConocoPhillips. As part of this program, and with supporting funding from the U.S. Department of Energy, the group has explored upstream (Krah et al. 2020), midstream (Elgqvist et al. 2021), and downstream (Krah et al. forthcoming) clean energy, and energy resiliency goals. Specifically, the analysis evaluates solar photovoltaics (PV), wind turbines, and energy storage for clean energy integration into oil and gas operations. The following content describes the techno-economic modeling and results from the midstream case, focusing on compressor stations.

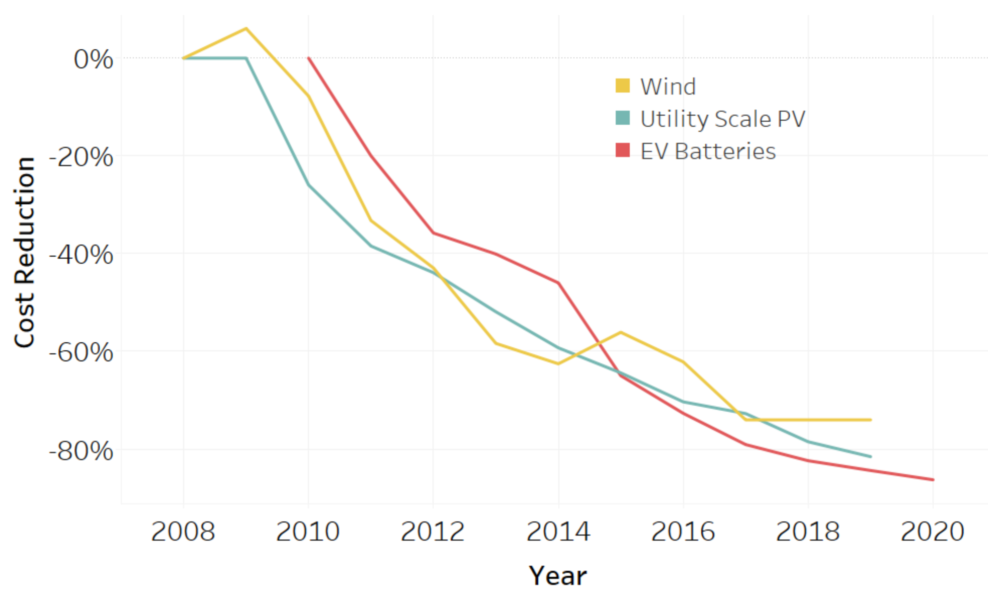

Figure 1. Clean energy technology percent cost reductions since 2008
Source: Natural Resources Defense Council 2021

Methodology

To explore the techno-economics of renewable energy integration into oil and gas operations, JISEA/NREL analysts used NREL's techno-economic decision support model called REopt (National Renewable Energy Laboratory 2021). REopt was developed to optimize energy systems for buildings, campuses, communities, microgrids, and more. The tool recommends the optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings, resilience, and energy performance goals. Formulated as a mixed-integer linear program, REopt provides an integrated cost-optimal energy solution. An overview of inputs and outputs are shown in Figure 2. The technology assumptions used in REopt can be found in the Appendix.

One key input to REopt is the compressor station's electric load (typically 15-minute or hourly data), which must be met by a combination of technologies in each timestep. For this analysis, the utility costs along with distributed solar PV, wind turbines, and battery energy storage systems (BESS) were considered. The model makes decisions about the most cost-optimal combination, size (possibly zero), and dispatch of technologies based on site goals, technology costs and incentives, and utility costs that could be avoided with distributed energy technologies. REopt was also used to evaluate an additional location in the study—a gas processing facility in North Dakota—which showed very similar results to the natural gas compressor station in Texas. Therefore only the results for the Texas site are presented in this paper.

Case Study: Texas Compressor Station

Compressor stations play an important role in transporting natural gas from the well to end users by sustaining the pressure and flow of natural gas. Compressors are built approximately every 40 to 100 miles along a pipeline. As of 2008, there were around 1,400 compressor stations in the United States. The typical unit at a compressor station is rated at least 1,000 horsepower (0.75 megawatts). Larger stations can have up to 16 units rated at 50,000–80,000 horsepower (37–60 megawatts), moving more than 3 billion cubic feet of natural gas per day (U.S. Energy Information Administration 2008).

JISEA/NREL evaluated clean energy options for an all-electric compressor station located in Texas. The site has about 30 acres of land that could be used for solar PV or other energy development. Figure 3 shows the site's 30-minute-interval data for a full year with peaks around 20 megawatts. The load shape indicates three load levels (reflecting two units that are either on or off) and differs from a typical commercial building, highlighting the importance of using actual load data and not simulated data.

The site is classified under the large industrial power rate tariff by the electric utility for its electricity rate, with energy charges of \$0.03/kilowatt-hour. This value is low compared to commercial and residential rates, which vary from \$0.05/kilowatt-hour to over \$0.15/kilowatt-hour (Roberts 2016). The rate has a demand charge component

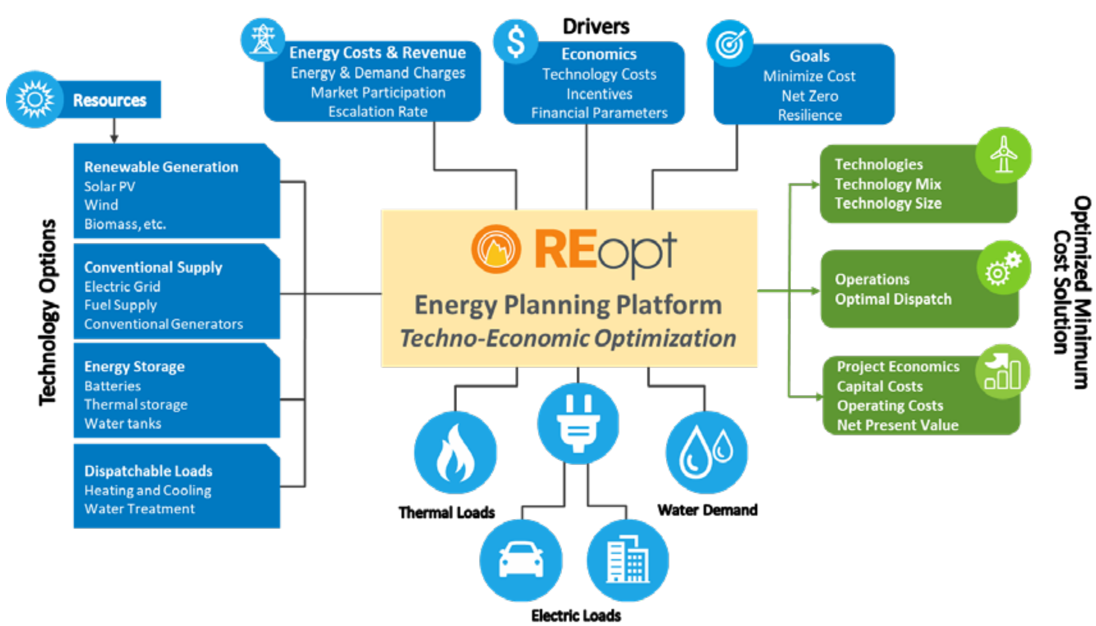

Figure 2. Overview of inputs and outputs for the REopt modeling platform

Compressor stations play an important role in transporting natural gas from the well to end users by sustaining the pressure and flow of natural gas. Note the pictured compressor station was not the one modeled in the study. Photo courtesy of Kinder Morgan

of $8/kilowatt and a fixed charge (which was not included because variable renewable energy generation technologies would not offset this charge).

JISEA/NREL studied the techno-economic potential of PV, wind, and BESS at the Texas compressor station under the following scenarios:

1. Base case life cycle cost of electricity: assumes site continues to purchase all electricity from utility grid
2. Minimum life cycle cost: size of distributed energy systems that would provide the lowest life cycle cost of electricity
3. 50% renewable energy: size of distributed energy systems that would generate 50% renewable energy on an annual basis.

Scenarios 2 and 3 were evaluated with and without full net metering of electricity generated above the site's load and with two methodologies for accounting for emissions reduction (including all renewable electricity generated by the system, or what renewable electricity is actually consumed on site).

Results: Clean Energy Options for Compressor Stations

Results indicate that smaller size renewable energy technologies (generating 5% of the site's load) are cost-optimal (Table 1). A 196-kilowatt PV system coupled with a 360-kilowatt (roughly 2 hour) battery could be cost-effective and would reduce both annual energy ($9,000) and demand charges ($32,000) by reducing grid purchases (kilowatts refer to kilowatts of direct current). The net present value (NPV) over the analysis period (25 years) is $89,000. Larger systems (generating 50% of the site's load) offset significant amounts of CO_2, but at an added cost and with a negative NPV. In scenarios 2 and 3, the model could (but did not) select to build wind turbines driven by the installed cost and wind resource at the location.

The cost of carbon offset could be compared to a carbon tax. The values shown in scenarios 2B and 3B in Table 1 are the break-even numbers, or the cost of carbon that would result in a $0 NPV for the renewable energy

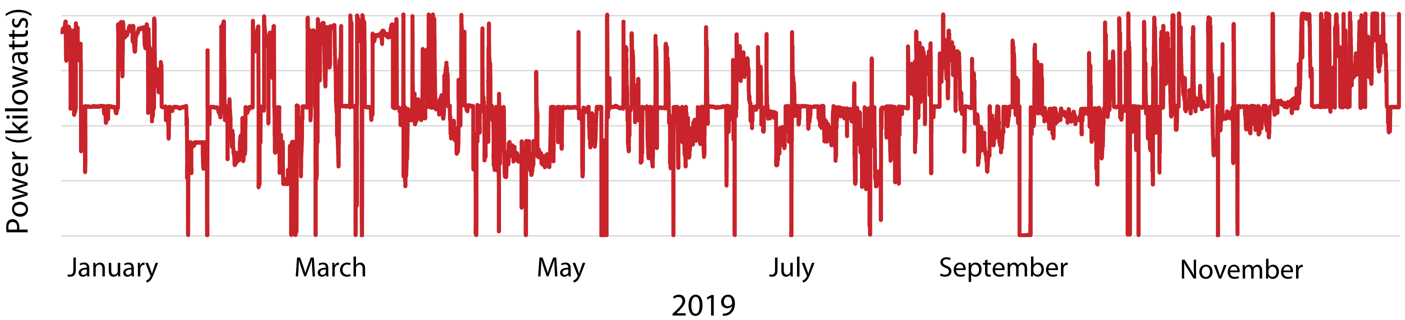

Figure 3. Thirty-minute-interval energy consumption data for a compressor station

systems recommended, based on reduction in grid purchases. According to Greenhouse Gas Protocol (World Resources Institute and World Business Council for Sustainable Development 2021), only emission reductions from reduced grid purchases count toward emissions reduction though reduction from on-site generation can be reported as additional information. For example, if a carbon tax of $69/$tCO_2$e were enacted, it would cost the same to install the 34 megawatts of PV (with a small battery) as it would to pay the carbon tax in the scenario without net metering. If the carbon tax increased to values over $69/$tCO_2$e, it would be more cost-effective to install renewable energy technologies to provide carbon reductions. This break-even point decreases to $38 tCO_2e if the site is able to fully net meter the solar PV system. The table also reports the impact of alternatively calculating these values based on total on-site renewable generation, where the break-even point without and with net metering further decrease to $49/$tCO_2$e and $26/$tCO_2$e, respectively.

If net metering is available (scenario 3), the economics of the 50% renewable energy scenario improve significantly, because the electricity that is generated above the load is compensated at the retail value; the minimum life cycle cost solution (smaller sizes) is not impacted because the resulting electricity generation rarely, if ever, exceeds the site load. Figure 4 shows how the solar PV and battery storage system would be dispatched throughout the year. PV generated above site load could be exported to the utility or curtailed.

Conclusion: Insights for Industry

This study explored the potential for cost-effective clean energy implementation at an all-electric

Table 1. REopt Techno-Economic Results for Installation of Solar and Wind at a Kinder Morgan Compressor Station in Texas

	Scenarios				
	1. Base Case	2. No Net Metering		3. Full Net Metering	
		A. Minimum Life Cycle Cost	B. 50% Renewable Energy Generation	A. Minimum Life Cycle Cost	B. 50% Renewable Energy Generation
PV size (kilowatt-DC)	–	196	34,202	261	34,167
Battery size (kilowatt)	–	362	1,020	378	386
Battery size (kilowatt)	–	628	4,264	671	804
Battery size (hours)	–	2	4	2	2
Wind size (kilowatt)	–	0	0	0	0
Total capital cost (dollars)	$0	$577,780	$37,558,640	$664,635	$36,625,680
Electricity purchases (kilowatt-hour)	104,530,173	104,232,832	67,399,537	104,136,003	68,341,079
Percent renewable energy generated based on generation (%)	0%	<1%	50%	<1%	50%
Reduction in grid purchases (kilowatt-hour)	0	297,355	37,130,650	394,184	36,189,108
Annualized CO_2e offset based on reduction in grid purchases (tCO_2e)	0	116	14,481	154	14,114
Cost of emissions reduction offset based on reduction in grid purchases ($/$tCO_2$e)	–	–	$69	–	$38
Renewable energy generated annually (kilowatt-hour)	0	299,215	52,319,787	398,860	52,265,601
Annualized CO_2e offset based on renewable energy generated (tCO_2e)	0	117	20,405	156	20,384
Cost of emissions reduction based on renewable energy generated ($/$tCO_2$e)	–	–	$49	–	$26
Year 1 energy costs (dollars)	$3,135,905	$3,126,985	$2,021,986	$3,123,974	$1,567,967
Year 1 demand costs (dollars)	$1,838,009	$1,805,752	$1,738,730	$1,803,505	$1,789,661
Year 1 energy savings (dollars)	$0	$8,921	$1,113,920	$11,931	$1,567,938
Year 1 demand savings (dollars)	$0	$32,256	$99,278	$34,503	$48,347
Life cycle cost of electricity (dollars)	$65,634,225	$65,544,807	$78,895,025	$65,543,833	$72,718,192
Net present value (dollars)	$0	$89,411	−$13,260,807	$90,385	−$7,083,973

At the request of the consortium advisory committee members, JISEA/NREL also modeled the techno-economics of an emerging technology that uses the Allam-Fetvedt Cycle, which burns natural gas with pure oxygen. The resulting high-pressure CO_2 is used through the cycle and then captured, along with other industrial gas coproducts (argon and nitrogen) that are salable.

Based on information provided by the company, JISEA/NREL evaluated the economics of a 25-megawatt power plant sited behind the meter at a hypothetical compressor station and able to sell power generation on the Electric Reliability Council of Texas (ERCOT) wholesale market, valued at 2018 ERCOT west hub pricing.

Initial analysis shows potential for the technology to provide cost savings, largely driven by the value of selling gas generation (nitrogen, oxygen, argon, and CO_2) associated with this technology (about 45%). Additional savings come from avoided utility costs and sales to the wholesale market.

compressor station in Texas. The results indicate that smaller size renewable energy technologies are cost-effective; larger systems (generating 50% of the site's load) offset significant amounts of CO_2, but at an added cost. JISEA/NREL calculated the cost of emissions reduction ($/t$CO_2$e) based on renewable energy generated and found that this too improved economics. A technology using the Allam-Fetvedt Cycle could be cost-effective for producing power and reducing emissions, but more information is needed to fully understand its market potential.

As a large energy user, a compressor station benefits from low costs of grid electricity purchases, making the economics of large-scale renewable energy integration challenging. Large-scale renewable energy technology costs continue to decrease across the country. Although there is variability in renewable energy resources across the United States, it is likely that the avoided cost of electricity (coupled with current or existing policy environments) may drive prioritization and implementation of clean energy projects.

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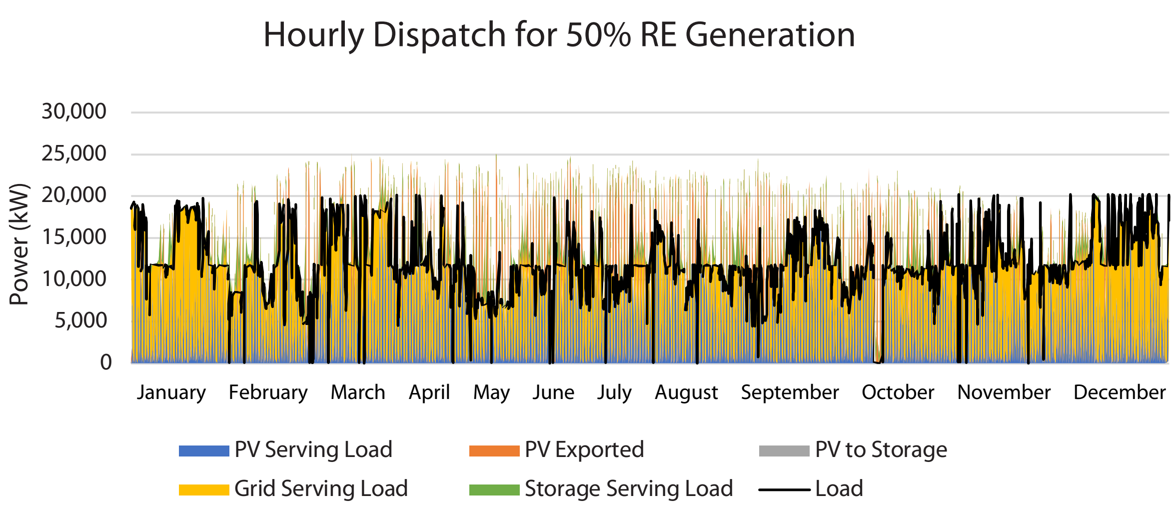

Figure 4. Hourly dispatch of solar PV and battery storage

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Appendix

Economic analysis assumptions

Input	Assumption
Objective	Minimize life cycle cost
Ownership model	Direct ownership
Build year	2020
Analysis period	25 years
Site's discount rate (nominal)	8.3% per NREL Annual Technology Baseline (ATB)[a]
Electricity cost	Entergy Large Industrial Power (per Kinder Morgan)
Natural gas cost	$1.81/MMBtu (September 2020 per Kinder Morgan)
Electricity cost escalation rate (nominal)	2.49% per EIA (2020–2045 for west south-central region – industrial)[b]
Natural gas cost escalation rate (nominal)	3.68% per EIA (2020–2045 for west south-central region – industrial)[b]
Inflation rate	2.5% per NREL ATB[a]

[a] https://atb.nrel.gov/

[b] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2020&region=1-7&cases=ref2020&start=2018&end=2050&f=A&linechart=ref2020-d112119a.3-3-AEO2020.1-7& map=ref2020-d112119a.4-3-AEO2020.1-7&sourcekey=0 and https://www.eia.gov/consumption/commercial/maps.php

Analysis assumptions for solar PV

Input	Assumption
System type	Ground mount, single axis tracking
Technology resource	TMY2 weather file from National Solar Radiation Database (NSRDB)[a]
Installed capacity density	6 acres/MW
Tilt	0
Azimuth	180° (south-facing)
DC-to-AC ratio	1.2
Capital costs	$1.06/W-DC (one-axis tracking utility scale) per NREL ATB[b]
Operating and maintenance (O&M) costs	$13/kW/y per NREL ATB
Incentives	26% Investment Tax Credit (ITC)[c]; 5-year Modified Accelerated Cost-Recovery System (MACRS)[d]

[a] https://rredc.nrel.gov/solar/old_data/nsrdb/

[b] https://atb.nrel.gov/

[c] http://programs.dsireusa.org/system/program/detail/658

[d] http://programs.dsireusa.org/system/program/detail/676

Analysis assumptions for battery storage

Input	Assumption[a]
Battery type	Lithium-ion
DC-DC round-trip efficiency	89.9%
Minimum state of charge	20%
Capital costs	\$420/kWh + \$840/kW
Replacement costs (year 10)	\$200/kWh + \$410/kW
Incentives	26% ITC; 5-year MACRS (assumes grid cannot charge BESS)

[a] https://reopt.nrel.gov/tool/REopt%20Lite%20Web%20Tool%20User%20Manual.pdf

Analysis assumptions for wind

Input	Assumption
Technology resource	AWS Truepower database[a]
Installed capacity density	30 acres/MW
Capital costs	Large (>1,000 kW): \$3.450/W-AC per 2018 Distributed Wind Market Report[b]
O&M costs	\$40/kW/y per NREL distributed wind cost analysis[c]
Incentives	5 year MACRS; Production Tax Credit (PTC) expired in 2019[f]

[a] https://aws-dewi.ul.com/

[b] https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Distributed%20Wind%20Market%20Report.pdf

[c] https://www.nrel.gov/docs/fy17osti/67337.pdf

[f] http://programs.dsireusa.org/system/program/detail/734

Analysis assumptions for emissions

Input	Assumption[a]
Region	SERC Mississippi Valley (SRMV)[a]
Total output emissions rate	809.6 lb CO_2e/MWh; 5.1% grid loss = 0.39 tCO_2e/MWh[b]

[a] https://www.epa.gov/egrid/power-profiler#/SRMV

[b] https://www.epa.gov/sites/production/files/2021-02/documents/egrid2019_summary_tables.pdf

Annual cost (or savings) = net present value (\$)/present worth factor

Annual tCO_2e offset = reduction in grid purchases (MWh) * emissions factor (tCO_2e/MWh)

Cost of emissions reduction = annual cost (\$)/annual tCO_2e offset (tCO_2e)

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