Assessment of an Alternative Renewable Energy-Based Hybrid Microgrid for NJ TRANSITGRID Project

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Summary

New Jersey Transit Corporation (NJ Transit) has issued a Request for Proposal (RFP) for the design and development of a backup power generation project to maintain the operation of critical portions of its transportation infrastructure during commercial grid outages. The project was conceived in response to increasingly frequent and long-lasting power outages caused by severe weather events in the region such as Superstorm Sandy in 2012, and tropical storms Fay and Isaias in 2020, and is supported by the allocation of a $409.8 million resiliency grant from the Federal Transit Administration, plus a 25% match from the State of New Jersey for a total of $512.25 million. The RFP, published in 2021, called for a new Microgrid Central Facility (MCF) on 20 acres of land in Kearny, able to produce up to 140 MW of power that could power approximately 40% of NJ Transit's normal daily commuting load for a period of two weeks (14 calendar days) and operate full-time selling power back to the grid and/or other third parties. Based on several previous NJ Transit documents, including its Industry Briefing Document, it is understood that the MCF is expected to be gas-powered.

In recent years, clean energy technologies have rapidly improved and can now be a financially viable alternative to new natural gas plants. In fact, from 2017 to 2020, the proportion of proposed gas-powered combined cycle (CC) plant projects that could have been economically outperformed by clean energy projects grew from 10% to 70% and by 2021 over 80% of total gas capacity proposed could be economically avoided with clean energy portfolios.[1] The Inflation Reduction Act of 2022 (IRA) created additional monetary incentives to develop clean energy technologies, making these projects more cost-effective. New Jersey's goal to reach 100% clean energy by 2050 further weakens the case for gas CC plants, which produce substantial emissions leading to increased environmental and social costs. In this context, Strategen assessed a potential renewable energy-based hybrid microgrid system featuring solar, energy storage, and a backup gas turbine (S+ES+GT) as a viable alternative to provide critical power to the transit system while reducing exposure to fuel price volatility and minimizing emissions.

For this assessment, Strategen conducted a high-level comparison of a 140 MW CC gas plant and an alternative S+ES+GT system with 97 MW of solar, 76 MW of 4-hour battery storage, and a 32 MW backup gas turbine.[2] The comparison included an analysis of expected costs, revenues, and emissions for both

[1] RMI, 2021. Headwinds for US natural gas power. 2021 Update on the growing market for clean energy portfolios.

[2] Based on empirical data from the Lawrence Berkeley National Laboratory, the solar array is expected to require approximately 300-350 acres (0.47-0.55 square miles) of land, conservatively assuming no gains in efficiency resulting from advancements in

systems through 2050. From a financial perspective, the analysis found that the S+ES+GT system would cost less than the proposed CC power plant and could result in at least $16 million more in profits than the CC over the 2028 to 2050 period, with potentially even higher profits depending on the future price of natural gas.[3] In a modeled high natural gas price scenario, profits from the renewable energy-based microgrid are nearly $127 million higher than those from the CC gas plant.

In addition to the financial comparison, Strategen quantified the environmental and health benefits that would be realized through avoided emissions of carbon dioxide (CO_2) as a driver of climate change, and nitrogen oxides (NO_X) and sulfur dioxide (SO_2) as precursors of pollutants affecting human health. Compared to the CC plant, operation of the S+ES+GT system would result in $346 million in benefits through reduced CO_2 emissions. In a high gas price scenario, the CC would operate less often (assuming it only runs when economically advantageous), so emissions savings would be smaller, with benefits valued at $193 million. The alternative system would also lead to an additional $14.3 million in avoided health and morbidity cost impacts caused by local pollutants in the base case and $7.6 million in the high gas price scenario. Combined, the environmental benefits of reducing CO_2 and local pollutants total $360 million in a base case scenario and more than $200 million in the high gas price scenario.

In assessing the reliability of the alternative clean energy solution, Strategen also recreated the hour-by-hour dispatch of the S+ES+GT option during a sample of historical weather events that disrupted the system and limited solar yields that would otherwise provide power during normal days. Strategen found that the S+ES+GT system would be capable of providing reliable power to serve the transit critical loads during these sample events and over extended periods.

Table 1. Market and Environmental Outcomes of Microgrid Alternatives (2028 – 2050)

	Low Gas & Power Prices		High Gas & Power Prices	
	CC	S+ES+GT	CC	S+ES+GT
Market Profit	$29,054,370	$45,406,783	-$42,199,687	$84,783,153
Avoided Environmental Cost	-	$359,912,240	-	$200,751,733
Total Net Benefit	$29,054,370	$405,319,023	-$42,199,687	$285,534,886
Net Profit Advantage of S+ES+GT	$16,352,413		$126,982,840	
Total Net Advantage of S+ES+GT	$376,264,653		$327,734,573	

Key Takeaways

- The proposed S+ES+GT alternative is technically feasible, can meet NJ Transit's specified operational power needs, and has higher profits, significantly better social and economic benefits, and far fewer long-term risks than a combined cycle plant running on natural gas. This analysis finds that a renewable energy-based microgrid would provide $328 million to $376 million more in future value than the proposed CC plant.
- Solar and energy storage are established and proven technologies, and a combined system featuring solar, 4-hour battery storage, and a backup gas turbine is a feasible alternative for meeting NJ Transit's

technology by the start of the project. See: Lawrence Berkeley National Laboratory, 2022. Land requirements for utility-scale PV: an empirical update on power and energy density.

[3] To provide a range of the possible scenarios, the analysis considered a low and a high natural gas price forecast, based on projections from the U.S. Energy Information Administration.

operational needs during severe weather events and subsequent extended outages, with the ability to power the system for periods lasting two weeks or longer.

- Different ownership options for the microgrid can be pursued (direct ownership or power purchase agreement), but given new tax credit direct payment eligibility for state-owned entities in the IRA, systems under both structures would be able to capitalize on the full credits for solar and storage systems. Further, New Jersey's new Competitive Solar Incentive program for SREC's has added eligibility for projects developed by public agencies.
- The alternative S+ES+GT microgrid would be lower cost than the proposed natural gas CC plant and provide greater future value than the CC, generating at least $16 million more in profit through 2050. In a separately modeled high gas price scenario, profits from the cleaner microgrid are $127 million higher than those from the CC.
- The S+ES+GT alternative would lead to social and environmental benefits valued at nearly $200 to $360 million, through avoided CO_2 emissions and avoided health and morbidity impacts from local pollutants in Kearny and its surrounding areas, which are already defined as pollution overburdened communities by New Jersey's Environmental Justice Law. When accounting for these avoided costs, the S+ES+GT system would result in total net benefits of approximately $285 million to $405 million, providing $328 million to $376 million more in future value than the proposed combined cycle gas plant.
- A new natural gas CC plant would face substantial financial risks in the future from gas price volatility and potential stranded costs. In a high natural gas price scenario, the CC could even result in over $42 million in losses by 2050 due to a combination of stranded costs and higher fuel costs.
- Additional expenditures would be necessary to replace the CC plant with clean energy resources by 2050 or otherwise mitigate its associated emissions. Costly investments in carbon capture and storage, or conversion to run the plant on renewable natural gas (biogas) or green hydrogen, would introduce further risk and uncertainty related to infrastructure needs, fuel costs, and fuel availability. In contrast, the S+ES+GT solution provides a long-term "no-regrets" alternative with technologies that are already proven, commercially ready, and due to their modularity, can be easily upgraded as their efficiency improves.
- NJ Transit's need for reliability would be best met in the long-term by the S+ES+GT solution, rather than relying heavily on the volatile natural gas market and required transition dependent on currently unfeasible fuel systems and other unproven technologies to abate future emissions.
- For all of the above reasons, Strategen recommends that NJ Transit use its FTA/NJ one-time grant money to build a S+ES+GT solution that will meet its 2050 objectives, instead of committing these funds towards a more costly, highly polluting solution that will require major additional funding, from currently uncertain sources, between 2030 and 2050.[4]

Methodology & Assumptions

Strategen performed the analysis using an in-house tool to model the hourly dispatch of both the CC and the S+ES+GT systems. The dispatch was simulated for both a *normal operations scenario* and a *critical operations scenario*. The comparative market analysis and the environmental benefits assessment were

[4] It must be noted that on February 15, 2023, New Jersey Governor Phil Murphy announced an accelerated target of 100% clean energy by 2035, moving up the initial goal by 15 years. To comply, NJ Transit would have to transition a CC gas plant to clean fuels or other abatement technologies in just seven years (2028 to 2035), rather than 22 years (2028 to 2050). This dramatically increases Transit's risk of not achieving the state's target and makes it much more attractive to jettison plans for a gas plant and instead rewrite its RFP to request proposals for a renewable energy-based hybrid microgrid.

conducted based on information and results from analysis of the normal operations scenario, while the reliability assessment was based on analysis of the critical operations scenario.

Normal Operations Scenario

The simulation of normal operations assumed that when not needed for providing backup power to the transit system during significant outage periods, both the CC and S+ES+GT systems would continue to operate, only when it is economically effective to sell power to the grid.[5] The dispatch of each option was modeled based on forecasted prices of natural gas and power, considering two price forecasts from the Energy Information Administration (EIA), intended to represent a range of possible futures.[6] Future energy prices were calculated using these forecasts and historical hourly energy and ancillary service prices,[7] while annual capacity prices were based on projections for PJM.[8] The costs and revenues of the CC and the S+ES+GT systems were calculated for years 2028 through 2050. The costs and efficiency of each system were sourced from the NREL Annual Technology Baseline (ATB)[9] assuming 2027 as the construction year and annualized for comparison to annual revenues. For the 4-hour storage portion, the fixed operations and maintenance costs from NREL include the additional cost of augmenting the system to account for battery degradation resulting from frequent charge and discharge cycles.[10] Solar irradiance for the specific location was included using a typical meteorological year. It was assumed that the alternative S+ES+GT system would be eligible and able to take advantage of benefits from the IRA.[11]

The normal operations scenario was also the source of the emissions benefits assessment. The economic dispatch of the CC over the life of the project was used to calculate CO_2, NO_X, and SO_2 emissions. Heat rates for the CC and GT were sourced from the NREL ATB, and emission rates were sampled from installed power plants in the area as reported to EIA. The cost savings from avoided emissions were calculated using a 3% discount rate.

[5] Although this analysis assumed that the microgrid systems would only be used to meet NJ Transit loads for resiliency during extended outages, in actuality both of these options could also be used for supplying power to the transit system during normal conditions, when financially optimal. In such situations, self-supply would result in savings by reducing the need to purchase power. Therefore, for the purpose of this analysis, estimated revenues from selling to the grid could alternatively be viewed as the value of energy purchase savings instead. In either case, the microgrid systems would create financial benefits, either from selling to the grid or reducing power purchase costs.

[6] The natural gas and power price forecasts considered were from the EIA *Reference* and *Low Oil & Gas Supply* cases for the Mid-Atlantic region from the 2022 Annual Energy Outlook.

[7] Historical energy and ancillary service prices were used to project future prices, based on regional industrial power price projections from EIA's Annual Energy Outlook. The analysis uses historical hourly power prices, scaled based on the forecasted regional prices, but it does not consider a potential increase in hourly price volatility. Increased hourly volatility, resulting from high renewable energy penetration, can increase the value of energy storage arbitrage going forward.

[8] S&P Market Intelligence, 2022. PJM Capacity Prices Projected to Drop Due to Auction Parameter, Market Updates.

[9] The National Renewable Energy Laboratory's Annual Technology Baseline (NREL ATB 2022) includes the capital costs, fixed annual costs, and variable non-fuel costs of different energy generating technologies for three price decline scenarios. Strategen used the medium or "moderate" scenario for the analysis.

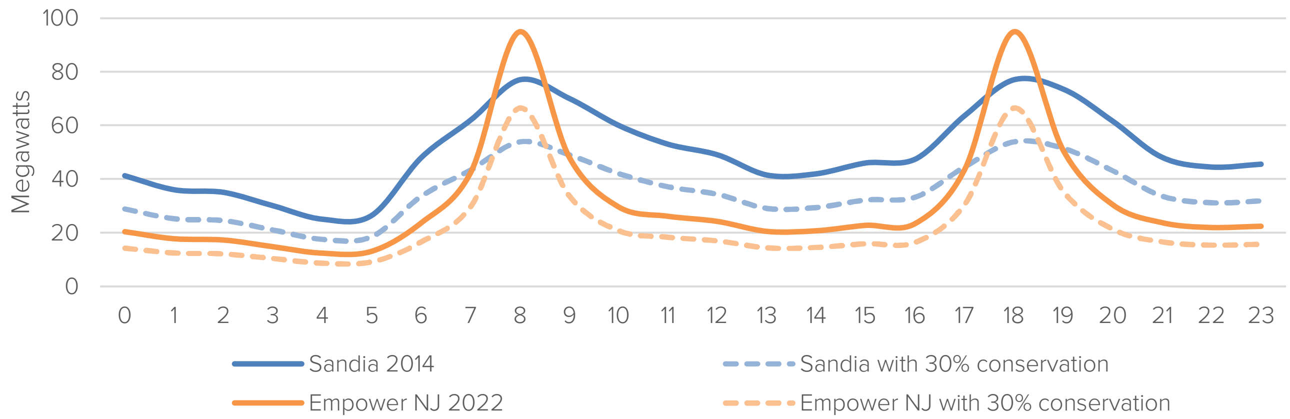
[10] In NREL's 2022 ATB, fixed O&M includes the value needed to compensate for degradation to enable the battery system to have a constant capacity throughout its life. Degradation is a function of the usage rate of the battery and systems might need to be replaced at some point during the analysis period. Considering this, the fixed O&M costs include battery replacement costs, based on assumed battery degradation rates that drive the need for 20% capacity augmentations after 10 and 20 years to return the system to its nameplate capacity. The updates assume that 20% of the cells are replaced in each augmentation, with costs for battery cells and bidirectional inverters dropping 40% in the next 20 years.

[11] The analysis assumes a 30% investment tax credit (ITC) for the solar and storage portions of the system, which provides a dollar-for-dollar reduction in federal income tax liability equal to 30% of the cost of these components, and that the project meets prevailing wage and apprenticeship requirements from the IRA in order to receive the maximum benefits. Without incorporation of these IRA benefits, combined capital costs for the solar and storage portions would be approximately 30% higher.

Critical Operations Scenario

The reliability assessment was modeled to simulate islanded microgrid operations of the S+ES+GT system. The analysis involved dispatching the three components of the system to match the demand profile of NJ Transit's critical load. In this scenario, solar irradiance is scarce, in comparison to normal days, but the storage system is able to charge from the gas turbine and the GT could also be available to power the transit system directly, assuming the system is designed to do so. To approximate the definition of the system's critical load, two load profiles were recreated using input assumptions provided by Empower NJ[12] and two additional profiles were developed for benchmarking, based on data published by Sandia National Laboratories.[13] The S+ES+GT system was tested against each of these load profiles during several historical weather events in 2012, 2019 and 2020.[14]

Figure 1. Estimated Critical Load Shape for NJ Transit System



Market Benefits

According to NJ Transit's 2021 RFP, the project would be built in 2027 and begin operation in 2028.[15] Hence, the analysis used 2027 capital and operations and maintenance (O&M) costs projected by NREL, as well as 2028-2050 natural gas and electricity prices projected by EIA and adjusted for local price profiles to reflect hourly locational marginal prices. During this period, the capital and O&M costs of each system were

[12] Empower NJ provided input assumptions based on a design by its solar engineering consultant that NJ Transit's critical load (to be powered during a blackout) has a peak of 95 MW and daily energy usage of 760 MWh. After assumed energy conservation measures, the daily peak and energy consumption would be reduced by 30%, resulting in 67 MW during the peak and 532 MWh across the day. The assumption of a 30% reduction was developed primarily based on a technical proposal from Jacobs Engineering for the TRANSITGRID project, which provided multiple options for reducing transit system peak loads, including a pathway to achieve at least a 27% reduction (See: Jacobs Engineering, 2015. *Technical Proposal for Design, Engineering, Construction Assistance and Other Technical Services for the NJ TRANSITGRID Project*). To assess the sensitivity of this assumption, Strategen tested the S+ES+GT system against the Empower NJ load profile both with and without a 30% reduction from energy conservation.

[13] Sandia's 2014 TRANSITGRID Feasibility Study contains a graph illustrating the hourly demand of critical loads of the system to be powered during a blackout. This graph informed the shape of the profile considered in Strategen's analysis. Sandia's study suggests a 77 MW peak demand and 1,203 MWh of energy used during the day. Strategen developed and tested an additional scenario, where 30% energy conservation is assumed.

[14] Absent direct input data from NJ Transit on demand profiles for the transit system during emergency events, the four scenarios tested by Stratgen are assumed to approximate the system's critical load. The energy demand of the system during critical hours includes intra-hour variations that were not modeled for this analysis, but the battery component is assumed to be capable of providing fast-response flexibility to supply intra hour variations in demand.

[15] NJ Transit, 2021. NJ Transit request for proposal No. 20-055. NJ TRANSITGRID microgrid project.

assessed annually and compared to the revenues that each could realize in the energy, ancillary services, and capacity markets.

The capital costs of the 140 MW CC gas plant were annualized assuming a shortened financial life in light of New Jersey's clean energy goals.[16] Its revenues were modeled assuming an economic dispatch based on market signals, dispatching every time that the hourly energy prices are above its cost to dispatch. In this model, the plant runs more often, and has higher profits in scenarios where the cost of natural gas is low. The CC is also assumed to participate in the ancillary services market providing primary reserves every hour that it is not scheduled to dispatch energy, and in the capacity market through interconnection to the PJM system. Given the size of the plant, NJ Transit would be required to participate in the Regional Greenhouse Gas Initiative (RGGI), meaning that it would need to purchase allowances for every ton of CO_2 emitted.[17] The monetary impacts of RGGI allowance purchases are included in the analysis and provided in Table 2 below.

The components of the alternative renewable energy-based hybrid microgrid system have the advantage of diverse revenue streams. The energy produced by the 97 MW solar portion of the system can provide power to the grid during normal days, while the energy storage system can provide solar integration, energy arbitrage, and ancillary services in the form of synchronized reserves.[18,19] Both the solar and the storage components can also provide capacity to the PJM market at their respective effective load carrying capability (ELCC) values, and may be eligible to participate in future incentive programs sponsored by the state.[20] The

[16] Although the state's clean energy goals might not necessarily result in the retirement of the CC plant, which might still be used as a reliability asset, its capabilities to generate energy or notable revenues during normal days would be severely limited beyond 2050. In this likely scenario, the CC would risk becoming a stranded asset by 2050. To account for this outcome, the analysis models a shortened financial life for the project, running only until 2050, rather than a full 30-year period. For more information on the topic of stranded power assets see: RMI, 2022. *You Might Be Paying for a Worthless Gas Plant.*

[17] New Jersey reentered RGGI in 2020. The state was previously in the program from 2005 until 2012. Established in 2005, RGGI is a regional cap-and-trade program to reduce CO_2 emissions from power plants. All fossil fuel-fired power plants with a capacity of 25 MW or higher are required to hold enough allowances to cover all of their CO_2 emissions, in order to demonstrate compliance. A CO_2 allowance represents a limited authorization to emit one short ton of CO_2 and the price of allowances is defined each year in an auction with a limited and reducing number of allowances. RGGI has set a goal of reducing emissions an additional 30% compared to 2020 levels by 2030. For this analysis, Strategen assumed a future cost of allowances of $8/ton.

[18] Although the battery storage system may have the potential to earn additional ancillary service revenues through PJM's frequency regulation market today, by responding to short-term changes to ensure the stability of the power system, the future maximum demand for such services is uncertain. While attractive on an opportunistic basis, frequency regulation markets lack depth and risk becoming saturated. That is, as additional new resources enter the market, not every resource will be needed to meet the limited demand for regulation. The PJM independent market monitor, Monitoring Analytics, has already flagged the saturation of the regulation market and diverse flaws in its design, advising against building a business model for storage based on the current regulation market. Therefore, Strategen's conservative analysis does not include potential revenues from the PJM regulation market for a system that would begin operation in 2028. For more information, see, e.g., Utility Dive, 2019. "New Battery Storage on Shaky Ground in Ancillary Service Markets."

[19] Energy storage systems provide numerous additional benefits for the grid as a whole, including leveling peaks in electricity demand, integration of variable energy resources, reducing the curtailment of renewable resources, congestion relief, and deferring the need for transmission and distribution system upgrades. However, absent a market to directly compensate individual resources for these services, Strategen does not quantify the value of these benefits or directly attribute them to the alternative S+ES+GT system assessed in this analysis.

[20] Since 2018, New Jersey's Clean Energy Program has maintained some of the most successful solar incentive programs in the country. In December 2022, the NJ Board of Public Utilities published an order launching the state's successor solar incentive program targeting up to 3,750 MW of new solar generation by 2026, with tranches for solar plus storage projects (NJ BPU, 2022. Order Launching the CSI Program. Docket No. QO21101186). Since the current program is expected to hit its target by 2026, it might not be available by the time NJ Transit's project is online, so this analysis conservatively does not include the program. However, Strategen notes that successor programs might support the business case for clean energy systems like the S+ES+GT system, which would provide additional future value and further make the case for the clean energy solution as a more desirable alternative to a CC gas plant.

gas turbine would also participate in RGGI,[21] but since it will only be used as back-up, it is assumed that it can't participate in PJM's capacity market. The modeling of this alternative system did not include costs associated with energy conservation measures to limit the peak electricity demand of the transit system during critical hours.

The analysis found that the S+ES+GT system could realize profits (revenue net of capital and O&M costs) between $45.4 million and $84.8 million from 2028 to 2050. As explained earlier, these cost ranges are the result of the uncertainty around future costs of natural gas and electricity, and are intended to bookend a range of future possibilities.

Table 2. Costs and Market Revenues of Microgrid Alternatives (2028 – 2050)

	Low Gas & Power Prices		High Gas & Power Prices	
	CC	S+ES+GT	CC	S+ES+GT
Capital & Fixed Costs	$325,693,058	$300,745,634	$325,693,058	$300,745,634
Variable O&M Costs[22]	$29,743,952	$351,381	$16,293,407	$351,381
Fuel or Charging Costs[23]	$330,265,275	$63,096,233	$305,453,324	$75,750,525
RGGI Allowance Costs[24]	$39,277,755	$299,078	$22,599,610	$299,078
PJM Market Revenues[25]	$754,034,410	$409,899,109	$627,839,712	$461,929,771
Market Profit	$29,054,370	$45,406,783	-$42,199,687	$84,783,153
Net Profit Advantage of S+ES+GT	$16,352,413		$126,982,840	

In comparison, the financial impacts of developing a CC power plant could range from $42.2 million in losses to $29 million in profits over the same period. The risk of net losses arises from two primary factors. First, in

[21] Although the gas turbine would not be running during normal grid conditions, in order to account for and estimate the cost of purchasing RGGI allowances, as well as fuel and variable costs that would result from operation during resiliency events, it is assumed that the GT portion of the microgrid would run in 1% of all hours over the period. In actuality, the GT's operations would depend on the frequency and duration of such events.

[22] Although both systems would face predictable fixed costs, the gas plants would also incur additional variable costs per unit of output. Under normal operations, the GT portion of the renewable energy-based microgrid would not be running. However, for proper comparison of the two system options, variable O&M associated with the GT running during extended outage events is included in this table and calculations, assuming that it would run on average in approximately 1% of hours per year. In actuality, the GT may not run at all in some years and may run for more than 1% in other years, depending on the frequency and duration of outage periods.

[23] Both the CC and the GT portion of the renewable energy-based microgrid would incur costs to purchase natural gas, based on how often it is economical to operate the CC and assuming that the GT would run in approximately 1% of hours on average. Under normal operations, the battery portion of the S+ES+GT system could either charge directly from the solar plant or charge from purchased power. However, when the battery is charging from the solar plant, the system would forgo revenues associated with selling that solar generation to the grid. This analysis assumed that it would be more profitable to charge the battery by purchasing power during the lowest priced hours of the day, which typically occur during periods when the solar would not be generating, and then discharge the battery to sell power back to the grid during the highest priced hours. This would take full advantage of energy arbitrage opportunities, while allowing solar generation to be sold back to the grid as well, to earn additional revenues.

[24] The RGGI allowance cost was calculated using an average price of $8 per short ton of CO_2. Since the first auction in 2008, the price of RGGI allowances has ranged between $2.60 and $13.50, with the highest values achieved in the last three years.

[25] In both the base case and the high natural gas price scenario, the combined cycle plant would run more often than the S+ES+GT system, resulting in higher potential PJM market revenues. Although the renewable energy-based microgrid has lower operating costs, the number of hours in which it is able to operate during normal conditions is limited by the availability of sunlight and the GT would only be operating in emergency conditions, meaning that the system has less opportunity to earn revenues through sale of services to PJM.

the high gas price scenario, the CC would not only face higher fuel costs when operating, but would also run less frequently, due to a greater number of hours in which the variable cost to operate the plant would be higher than the expected returns.[26] The result in this scenario is therefore both higher per-MWh operating costs and lower revenues, overall. Second, in both gas price cases examined, the CC plant is assumed to cease operation when New Jersey's 100% clean energy goals take effect in 2050, creating the potential for stranded capital costs if the CC does not earn enough revenue to fully pay off the plant.[27]

NJ Transit may not be focused on stranded capital costs of its gas plant since the plant is being funded by grants, but well before 2050 NJ Transit would need to explore other options, and incur very significant additional investment costs, to provide backup power for the transit system using clean energy. One option would include construction of a new solar and storage microgrid, similar to the system assessed in this analysis. Other investments to keep the CC plant operating with lower emissions, such as incorporation of carbon capture and storage (CCS) technology or conversion of the CC plant to run on green hydrogen[28] or renewable natural gas (RNG), would introduce significant risks associated with uncertainty in future costs, technological advancements, and fuel availability, and retrofitting an asset that is near the end of its traditional useful life. Installation of CCS is currently estimated to cost approximately $900/kW or $126 million in 2050,[29] but this does not include the cost of storage and transportation of the captured carbon and relies on the future development of broader enabling infrastructure that does not yet exist.

Conversion to clean fuels bears particular uncertainty regarding future capital costs, fuel prices, and availability. Further detailed analysis would be necessary to project and estimate the costs associated with switching to these options in 2050. Existing CC technologies are able to burn small volumes (e.g., 10% to 20%) of hydrogen blended with natural gas, but defensible estimates on the costs and timeline for a feasible transition to run on 100% hydrogen are not currently available. Combustion of hydrogen, though carbon-free, also emits NOx, which is harmful to local communities and would require additional abatement costs. Hydrogen also embrittles metal, requiring additional expenses for more frequent replacement of all exposed infrastructure. Regarding fuel prices, the U.S. Department of Energy has set a goal of reducing the cost to produce green hydrogen to $1 per kilogram. If achieved by 2050, this would be equivalent to approximately $7-8 per MMBtu, which is already in the range of natural gas prices in the studied high gas price case, even before accounting for delivery costs.

Availability is also expected to be an issue, as use cases in sectors such as long-haul transportation, aviation, or industrial applications that are more difficult to decarbonize are likely to take priority for using green hydrogen created from renewables through electrolysis. High costs and sufficient availability are both expected to be challenges for RNG as well. Estimates of annual RNG production capability by 2040 range from 1,910 billion cubic feet (bcf) in a low resource potential scenario to 4,510 bcf in a high resource potential

[26] Strategen's analysis assumes that the CC would not be dispatched in hours when it would be uneconomic. That is, the plant would not operate during periods when doing so would result in a loss due to hourly revenues being lower than hourly costs.

[27] The financial analysis performed in this assessment shortens the financial life of the CC system to 23 years, assuming it will shut down by 2050.

[28] For purposes of this analysis, "green hydrogen" refers to hydrogen produced from renewable energy.

[29] NREL, 2022. Annual Technology Baseline, Moderate Costs in 2050. Strategen's estimate is based on the cost difference between a CC plant with 90% CCS and a CC plant without any CCS, with an additional 20% adder to account for the cost of unbundling.

scenario, with only 500 bcf available at a production cost of less than $15 per MMBtu.[30] Such volumes would only be enough to meet between 6% and 15% of annual natural gas demand in the U.S.[31]

Regardless of the option pursued, higher costs associated with CCS or clean fuels would result in higher capital, operating, and dispatch costs, which would limit the ability of the CC plant to earn revenue through generation. Additional uncertainty concerning the potential for sufficient availability of clean fuels would present further risk around the plant's ability to run consistently. Ultimately, a CC plant burning RNG or green hydrogen would be expected to operate more as a peaking resource, given the likely constraints on fuel supply and high fuel prices. As a result, more investments in clean generating resources would be necessary to produce the same amount of power as previously generated from natural gas, or to provide enough reliable power to backup the NJ Transit system during outage events.

Future costs and revenues are more certain for the S+ES+GT alternative, as they are detached from the price of natural gas and potential increases in the cost of carbon in regional markets, and would not be impacted as heavily by New Jersey's clean energy goals. In addition, due to their modularity, solar and storage components can be easily upgraded in small increments as their efficiency improves. The reduced risks associated with the solar and storage system provide further support for "no-regrets" investments in clean energy alternatives that will prevent greater expenditures, and uncertainty, in the future.

Environmental Benefits

In addition to the market benefits, Strategen quantified the environmental and health benefits of avoiding the emission of CO_2 as a driver of climate change, and NO_X and SO_2 as precursors of pollutants affecting human health. The analysis used the social cost of carbon developed by the Interagency Working Group (IWG) on the Social Cost of Greenhouse Gases[32] and EPA's estimates on the benefits of reducing precursors of $PM_{2.5}$ and ozone.[33] Both values were assessed using a 3% discount rate as a conservative estimate of the future impacts of these emissions.

The analysis found that avoided CO_2 emissions from operating the S+ES+GT system instead of the CC system from 2028 to 2050 could save $193 to $346 million in avoided costs associated with climate change impacts. Another $7.6 million to $14.3 million would be saved locally from reducing health and morbidity impacts from local pollutants. This is especially noteworthy given the area's designation as an overburdened community by New Jersey's Environmental Justice Law, already suffering disproportionately from local pollutants. Kearny is part of one of the most pollution overburdened regions in the country, with most of the area above the 80th percentile nationally for the EJScreen Air Toxics Respiratory Hazard Index.[34]

Combining these avoided environmental and health costs with the market benefits discussed earlier, the alternative S+ES+GT system would result in total net benefits of approximately $285 million to $405 million

[30] ICF (for the American Gas Foundation), 2019. Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment.

[31] U.S. Energy Information Administration, U.S. Natural Gas Total Consumption for 2021.

[32] New Jersey has recognized the social cost of carbon as an accepted measure for the cost of carbon emissions, and has used it to show the benefits of CO_2 reductions in its Energy Master Plan and in cost tests for Energy Efficiency and Demand Reduction Programs. https://costofcarbon.org/states/new-jersey

[33] EPA, 2021. Technical Support Document: Estimating the Benefit per Ton of Reducing Directly-Emitted $PM_{2.5}$, $PM_{2.5}$ Precursors and Ozone Precursors from 21 Sectors. The U.S. Environmental Protection Agency (EPA) published its approach for estimating the average avoided human health impacts, and monetized benefits related to emissions of ozone and $PM_{2.5}$ precursors including NO_X and SO_2 from 17 sectors. The values in this analysis are representative for power plants.

[34] United States Environmental Protection Agency. 2022 Version. EJScreen.

over the 2028 to 2050 period, providing $328 million to $376 million more in future value than the proposed combined cycle gas plant.

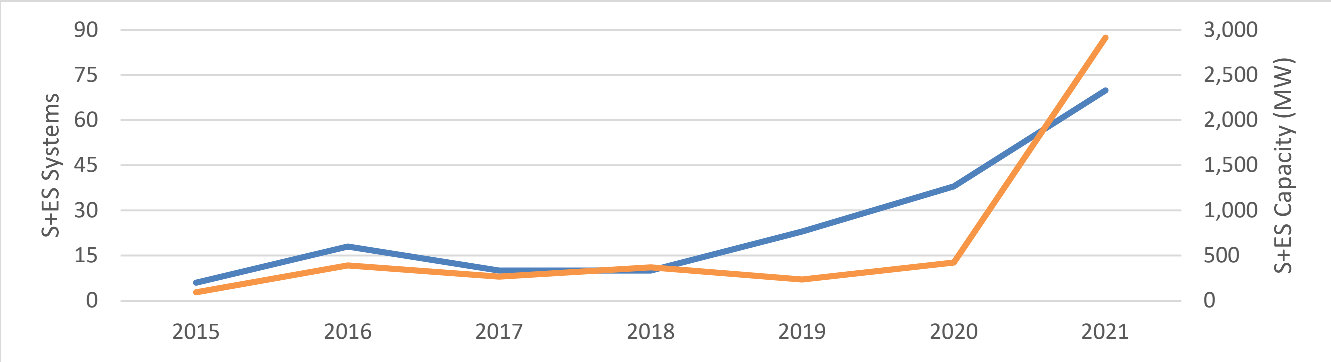
Table 3. Net Benefits of Microgrid Alternatives

	Low Gas & Power Prices		High Gas & Power Prices	
	CC	S+ES+GT	CC	S+ES+GT
Market Profit	$29,054,370	$45,406,783	-$42,199,687	$84,783,153
Avoided Environmental Cost	-	$359,912,240	-	$200,751,733
Total Net Benefit	**$29,054,370**	**$405,319,023**	**-$42,199,687**	**$285,534,886**
Total Net Advantage of S+ES+GT	$376,264,653		$327,734,573	

Project Viability and Resiliency

Both solar and battery energy storage are proven and commercially ready technologies. In 2015, the year the NJ Transit Microgrid was proposed, only six solar plus storage (S+ES) projects with a combined capacity of 96 MW were installed in the U.S. In 2021 alone, 70 S+ES systems were installed with a combined capacity of 2,920 MW, and many more projects are underway. According to the Lawrence Berkeley National Laboratory, there were 280,176 MW of solar plus storage projects in interconnection queues across the U.S. at the end of 2021.[35]

Figure 2. Annual S+ES Installations and Capacity



Several successful projects demonstrate the viability of pairing and operating these solutions. Large-scale battery energy storage systems are increasingly being deployed as regulators and utilities are realizing their value for providing power during critical hours and transitioning to a cleaner electric grid. Notable examples of large scale recent storage projects include the 100 MW Saticoy Energy Storage Site in Oxnard, California, which was selected by Southern California Edison specifically as an alternative to a new natural gas-fired plant, as well as two 100 MW projects in Texas at Bat Cave and North Fork, a 409 MW battery system that Florida Power & Light has paired with its existing Manatee Solar Energy Center, and California's Moss Landing Energy Storage System with its 400 MW battery.

Battery storage, particularly when paired with renewables or other backup generation technologies, can help increase grid resilience by providing power for extended periods of time if the grid goes down. Combined systems offer additional advantages over systems relying solely on fossil fuels during weather events or other outages, as they can reduce the necessary size and usage of backup generators, extend

[35] Lawrence Berkeley National Laboratory, 2022. *Generation, Storage, and Hybrid Capacity in Interconnection Queues.*

limited fuel supply, and provide a layer of backup that does not require refueling. Mitigating the risks associated with reliance on natural gas or other fossil fuels can be especially beneficial if and when fuel supply or pipeline capacity are constrained or fully interrupted during severe weather conditions. It should also be noted that the Federal Emergency Management Agency (FEMA) put out a warning in 2014 against relying on natural gas for emergency power to critical facilities.[36]

In addition to the market and environmental benefits estimated in this analysis, a S+ES+GT alternative featuring 97 MW solar, 76 MW 4-hour storage, and 32 MW gas turbine system could provide resilience for the NJ Transit system's critical loads. With a total footprint of approximately 300-350 acres,[37] development of the project in the region would be viable from a land use perspective as well, through utilization of space owned by NJ Transit or in other nearby open areas.[38]

Resiliency Testing Analysis

In assessing the resiliency of the proposed clean energy alternative, Strategen recreated the hour-by-hour dispatch of the S+ES+GT system during a sample of historical weather events that caused power system blackouts and limited the availability of solar energy. The analysis considered historical solar yields in Hudson County for years 2012, 2019, 2020 and the typical meteorological year, and included Superstorm Sandy (October 30, 2012), NJ Storm Outage (July 22, 2019), Tropical Storm Fay (July 11, 2020), Tropical Storm Isaias (August 04, 2020) and a major NYC snowstorm (December 16, 2020).

The energy dispatch capacity of the S+ES+GT system during these key days and years was tested against four potential critical load profiles of the NJ Transit system. Strategen found that a potential 97 MW solar, 76 MW 4-hour storage, and 32 MW gas turbine system is capable of providing reliable power during severe weather events in three of the four sample load profiles, including both base case profiles developed using data assumptions from Empower NJ and the benchmark profile based on data from Sandia assuming energy conservation measures would be taken to reduce peak loads during such events. In these scenarios, the alternative clean system proved not only capable of powering the transit system during the historical outages, but also during every other hour of the year.

The figure below features sample 3-day snapshots of the S+ES+GT system behavior during two of the tested events, for the base case critical load profile provided by Empower NJ, assuming a 30% reduction in peak load through energy conservation measures. As shown in the graphs, the alternative clean energy solution

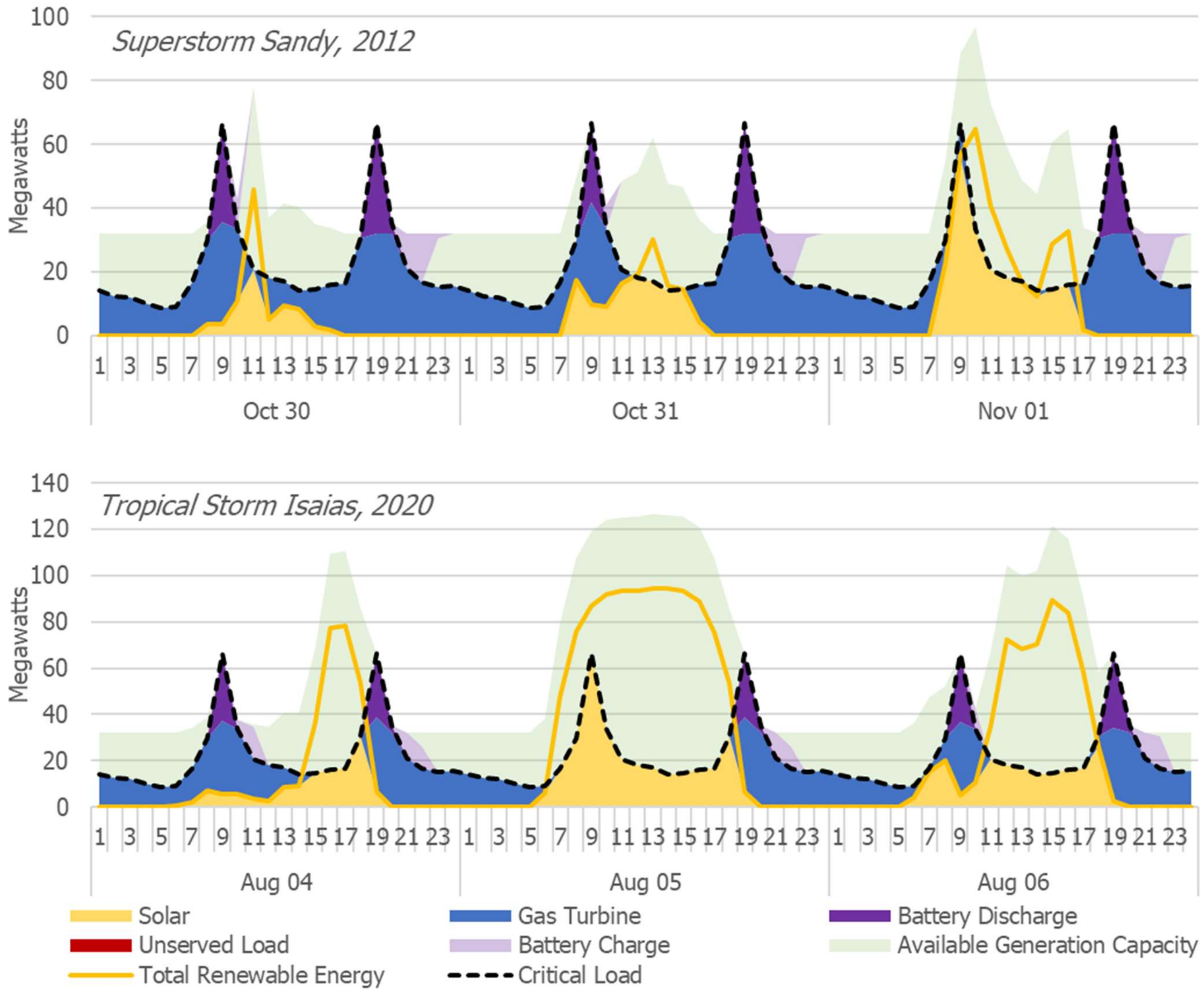
[36] FEMA, 2014. *Emergency Power Systems for Critical Facilities: A Best Practices Approach to Improving Reliability*. "Natural gas, unlike propane and diesel, is not stored on site but rather piped to a site from a local utility. Natural gas supplies can be interrupted during high-wind, flood, or earthquake events. Also, natural gas services are often intentionally shut down prior to a storm event to reduce the risk of fires and explosions. Because of this, natural gas should not be used as a fuel for providing emergency power to critical facilities unless the facility can confirm that natural gas service will not be interrupted."

[37] Although this analysis does not include a specific siting assessment, the geographical footprint of the solar array, which accounts for the vast majority of required land, is estimated to be approximately 300-350 acres (0.47-0.55 square miles), based on data from Lawrence Berkeley National Laboratory. However, gains in efficiency resulting from advancements in technology could potentially reduce this estimate. See: Lawrence Berkeley National Laboratory, 2022. Land requirements for utility-scale PV: an empirical update on power and energy density.

[38] Strategen's analysis did not assess or include potential costs associated with the acquisition of land for solar. Preliminary analysis developed by Empower NJ, and previously shared with NJ Transit, estimated that there are over 500 acres of land already owned by NJ Transit that could potentially be used for solar panels, and even more if panels are sited directly above or adjacent to the tracks. Empower NJ's analysis also identified several nearby sites, totaling more than 1,200 acres, which could possibly provide additional space for solar. These preliminary findings suggest that there is sufficient space available for the development of renewable power sources and that NJ Transit should examine these siting options in considering cleaner alternatives for the TRANSITGRID project.

is able to meet system needs even during the worst conditions of a storm, and could provide power through extended outage periods lasting two weeks or more.[39]

Figure 3. Sample 3-day Energy Dispatch During Blackout (Empower NJ Load Profile, 30% Conservation)



For the load profile based on data from Sandia, assuming no energy conservation measures, the tested S+ES+GT system was, not unexpectedly, insufficient during the most extreme sample events as the design provided by Empower NJ was not modeled to meet those loads. This finding underscores the importance of peak demand reduction measures. When reducing the system's critical energy needs by 30% for the Sandia profile, the S+ES+GT system is capable of supplying all needed energy through the tested events.[40]

[39] The dispatch of the microgrid during blackouts and critical weather events is performed by all parts of the S+ES+GT system. The GT is assumed to only operate during such events, providing most of the power as solar is expected to be limited during storms. Solar is still dispatched and prioritized when available. Energy storage is used to meet system peaks and intra-hour energy variations, and charges from the GT during severe weather events and extended outages.

[40] Strategen did not include the cost of energy conservation measures in this analysis.

Alternatively, the size of the S+ES+GT system could be reconfigured to meet the Sandia profile without the 30% energy conservation, if necessary, as there is no inherent limit on expanding the basic design.

Recommendation

Based on this analysis, the development of a system featuring solar, battery storage, and a backup gas turbine would be a viable and preferred alternative to a new gas-fired CC plant for meeting NJ Transit's critical loads during severe weather-related outages. Offering higher financial benefits, and substantial environmental and health benefits through significantly lower emissions, the S+ES+GT system would offer more future value, while minimizing risks associated with price volatility, stranded costs, and fuel availability associated with converting the CC plant to a clean energy solution. Unlike a gas-fired plant, which will incur additional costs to replace by 2050 or otherwise convert to mitigate its associated emissions, solar and battery storage are already clean and, as proven and commercially ready technologies, they provide greater financial certainty in meeting the system's long-term needs for resilient and reliable backup power during periods of disruption. Strategen, therefore, recommends that NJ Transit invest its FTA/NJ one-time grant money in a renewable energy-based microgrid as a "no-regrets" solution that will meet NJ Transit's 2050 objectives, instead of funding a new combined cycle gas plant that will have limited project life, produce harmful emissions, and will require major additional funding between 2030 and 2050, the source of which is very uncertain, thus creating far greater risk in the future.

About Strategen

Strategen is a globally connected, impact-driven firm on a mission to decarbonize energy systems. A minority and woman-owned business, Strategen is headquartered in Berkeley, California with offices in Portland, Oregon and Brisbane, Australia. Since 2005, Strategen's 60-person multidisciplinary team of economists, business strategists, regulatory and policy experts, and energy modelers has helped clients envision, accelerate, and create a clean energy future.

Relevant Experience

Strategen has first-hand experience assessing clean energy technologies such as storage, solar, and distributed resources, for a diverse range of clients. Through grid and financial asset modeling, Strategen's analyses have supported Integrated Resource Planning, clean technology roadmaps, fossil fuel retirement analyses, and market entry strategies. Strategen's modeling expertise is trusted by associations, utilities, developers, and government agencies to help them assess the value of clean energy and energy storage.

Notably, Strategen is the founder and operator of the California Energy Storage Alliance (CESA), which has helped to advance significant legislation advancing energy storage deployments in California and has supported the development of over 4,000 MW of storage in the state. Strategen has led projects to develop quantitative approaches to valuing benefits of, and needs for, long-duration energy storage in California. Strategen also founded and manages the Green Hydrogen Coalition (GHC) and the Vehicle Grid Integration Council (VGIC), which serve as role models for public-private partnership, collaboration, and market transformation. The team has played a significant and direct role in jump-starting the use of energy storage and green hydrogen throughout the U.S. through regulatory design for market participation, strategic market analysis, and innovative development strategies.

Further, Strategen has worked with several environmental justice and community advocates, policymakers, and non-profits to quantify energy pollution damages and identify technical, market, and policy solutions to reduce reliance on fossil fuels. Strategen has developed fossil fuel retirement strategies across the United

States, underscored by financial analysis. Strategen developed technical reports that accelerated economic retirement of coal assets in Colorado[41] and Arizona,[42] based on detailed financial analyses. Additionally, the team has worked with both NY-BEST[43] and New York's PEAK Coalition[44] to provide custom peaker capacity cost analysis and feasibility assessments around the retirement and replacement of existing peaker plants with energy storage and renewables in environmental justice communities.

For additional information or questions regarding this analysis, please contact Joe Goodenbery, Senior Manager at Strategen Consulting, at *jgoodenbery@strategen.com*.

[41] Strategen, 2016. Colorado Coal Plant Valuation Study, https://coal.sierraclub.org/sites/nat-coal/files/co-report-coal-valuation-study.pdf.

[42] Strategen, 2019. Arizona Coal Plant Valuation Study, https://www.strategen.com/strategen-blog/arizona-coal-plant-valuation-study.

[43] Strategen, 2020. Long Island Fossil Peaker Replacement Study, https://www.strategen.com/strategen-blog/long-island-fossil-peaker-replacement-study.

[44] Strategen, 2021. The Fossil Fuel Endgame: A Frontline Vision to Retire NYC's Peaker Plants by 2030, https://www.strategen.com/strategen-blog/the-fossil-fuel-end-fame-a-frontline-vision-to-retire-nycs-peaker-plants-by-2030.