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PNNL-35717

Power Supply Options for the Marpi Landfill, Saipan

Addendum to 2023 Feasibility Study

April 2024

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Michael D Brown
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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Executive Summary

The Marpi Landfill (“Marpi” or “the landfill”), located on the northern end of the island of Saipan in the Commonwealth of the Northern Mariana Islands (CNMI), is powered by an on-site diesel generator that only operates when the landfill is open and staffed. The CNMI Office of Planning and Development (OPD) aspires to provide the Marpi Landfill with 24-hour power availability despite its remote location and to increase sustainable energy consumption within the CNMI.

Pacific Northwest National Laboratory (PNNL) authored a feasibility study in 2023 that explores alternative power supply options for the landfill. This feasibility study (hereafter referred to as Phase I of this study) culminated in a report named “Power Supply Options for the Marpi Landfill, Saipan.”

In Phase I, the project team investigated and prioritized seven different power supply scenarios (Table ES-1) for the landfill according to Solid Waste (SW) Taskforce priorities. The project team found that Scenario 4 (100 kW of solar photovoltaic [PV] generation, a 75 kW/300 kWh battery energy storage system [BESS], and 160 kW of diesel generation) ranked highest.

Table ES-1. Evaluated scenarios.

Scenario	Resource Mix
1	Solar PV + BESS
2	Wind + BESS
3	Solar PV + Wind + BESS
4	Solar PV + BESS + Diesel Generation
5	Wind + BESS + Diesel Generation
6	Solar PV + Wind + BESS + Diesel Generation
7	Diesel Generation Only

Following the Phase I feasibility study, the SW Taskforce tasked PNNL with assessing additional considerations regarding power supply options for Marpi. The purpose of Phase II of this study is to investigate these additional considerations, as compiled in this addendum. Some of the findings compiled here replace findings from the original report.

The project team evaluated additional considerations regarding power supply options for the landfill, including:

- Modified operations to account for 24/7 power supply,
- Electrified landfill equipment
- Costs for new and replacement distribution lines
- Incorporating the social cost of carbon into the life cycle analysis of each scenario

Modifying landfill operations to allow for 24/7 pumping would allow the landfill to better meet permit requirements since pumps can operate during nights and evenings rather than just during operating hours. Based on guidance from the SW Taskforce, a revised annual load profile was generated, accounting for 24/7 operations and assuming that the operation and storm pumps would need to operate 1.5 times as long during the rainy season to sufficiently

lower leachate levels to meet permit requirements. Given these assumptions, Marpi's expected annual electricity consumption is 182 MWh with a peak load of 109 kW. Additionally, peak loads occur less often because the pump loads are spread throughout the day and night rather than during the hours that the landfill is open.

Further modifying landfill operations to include charging electric alternatives for existing landfill equipment would reduce the landfill's reliance on diesel fuel and reduce on-site air pollution and greenhouse gas emissions. Based on guidance from the SW Taskforce, the 24/7 load profile was further revised to account for charging electric versions of the existing dump truck, payloader, tanker truck, utility trucks, riding mower, and brush cutters. Based on these additional loads, the landfill's expected annual electricity consumption with 24/7 operations and electric landfill equipment is estimated to be 358 MWh, over 2.5 times more than the estimate in the Phase I results, with a peak load of 155 kW.

Table ES-2 summarizes the annual electricity consumption and peak load for the Phase I results, 24/7 operations, and 24/7 operations with electric landfill equipment. These load profiles were used to revise the technical and economic evaluation of the various power supply scenarios from Phase I.

Table ES-2. Evaluated load profiles.

Load Profile	Annual Consumption (MWh)	Peak Load (kW)
Phase I	170	112
24/7 Operations	182	109
24/7 Operations & Electric Landfill Equipment	458	155

Given the changing power requirements for 24/7 operations and 24/7 operations & electric landfill equipment, the component sizing for those two load profiles was reassessed.

Since the annual and peak loads for the 24/7 operations load profile are similar to the results from Phase I, but the peak loads occur less often, the power supply scenarios were either left unchanged, or the BESS was downsized to reduce capital costs and rely on the diesel generator during the occasional high peak loads. Since the annual load for 24/7 operations with electric landfill equipment is over two times larger than the results from Phase I, most of the power supply scenarios were modified to provide uninterrupted power, increasing the solar PV array, diesel generator, and BESS capacities. Because of the increased capacity, some of the configurations will not fit within the footprint identified on landfill property in Phase I. Those configurations would require leasing additional land outside the landfill.

The life cycle cost analysis for each scenario for the updated Phase I results, 24/7 operations, and 24/7 operations & electric landfill equipment were revisited to include the cost of new distribution lines between new generation equipment and existing loads, the cost of replacing existing distribution lines, and the social cost of carbon.

The costs of installing new distribution cable range between \$29k and \$483k, depending on the scenario and load profile. This is because different capacities of solar PV, wind, BESS, and diesel generators generate different amounts of current, which require cables rated for different ampacities, and cables with higher ampacity ratings are more expensive than those with lower ratings. The cost of replacing existing cable (connecting loads to the existing generator) for all load profiles and power supply scenarios is expected to be approximately $802k. This value remains the same across scenarios because the replacement distribution cable is rated for the same ampacity no matter the power supply scenario.

The social cost of carbon for scenarios with diesel generators ranges from $24k to $250k for the Phase I results, $24k to $270k for 24/7 operations, and $97k to $680k for 24/7 operations & electric landfill equipment. The higher costs are a result of the diesel generator operating more frequently to meet the greater loads resulting from increased pump operations and the charging of electrified landfill equipment.

For the updated Phase I results, capital costs increase for all scenarios because of the additional cost of distribution. All operations and maintenance (O&M) costs slightly decrease, solely because an updated real discount rate was used in the calculations. The 25-year levelized cost of energy (LCOE) increases for all scenarios, especially for the scenarios using diesel generators, because of the addition of the social cost of carbon.

For the 24/7 operations results, costs remain the same for Scenario 2 since the cost of distribution is offset by the smaller BESS. For all other scenarios, capital costs increase because of the additional cost of distribution, even accounting for decreases in the capital cost due to the smaller BESS capacity. Annual O&M costs decrease or remain the same because an update in the real discount rate offsets the increased O&M costs associated with increased reliance on the diesel generator. CO_2e emissions fluctuate among the scenarios. Some scenarios have increased emissions because of additional reliance on the diesel generator, whereas Scenario 5 emissions are lower because of reduced wind generation curtailment, as wind generation aligns well with overnight pump loads. Generally, the 25-year LCOE decreases for scenarios utilizing wind and increases for scenarios with solar PV. The LCOE also generally decreases because of the lower capital costs associated with smaller BESS capacities.

For the 24/7 operations & electric landfill equipment results, capital costs significantly increase for all scenarios except Scenario 2 since the component sizing for this scenario does not change. These increases are due to larger solar PV, diesel generator, and BESS capacities. Annual O&M costs increase for all scenarios except Scenario 2. Carbon dioxide equivalent (CO_2e) emissions increase across the board for scenarios reliant on diesel generators because of increased reliance on those generators. Generally, the 25-year LCOE decreases for scenarios including wind and increases for scenarios with solar PV generation. This is because wind power is better suited to meet the larger nighttime loads. Generally, charging the electric landfill equipment will be challenging because not all evaluated landfill equipment, such as the dump truck, currently has a commercially available electric alternative; because charging would mostly happen at night, resulting in nighttime peaks; and because charging landfill equipment more than doubles the annual electricity requirement, requiring large-capacity on-site generation, which will not fit within the footprint of the landfill identified in Phase I.

To assist with decision-making, three prioritization matrices were created to compare the power supply scenarios associated with the updated Phase I results, 24/7 operations, and 24/7 operations & electric landfill equipment according to various stakeholder priorities.

These rankings show that a microgrid that includes a solar PV array, BESS, and diesel generator (Scenario 4) is the favored option for all three load profiles assessed. However, meeting the charging load for the electric landfill equipment with Scenario 4 requires more land than what was identified as available at the landfill. Table ES-3 shows the top 3 power supply scenarios for the updated Phase I results, 24/7 operations, and 24/7 operations & electric landfill equipment.

Table ES-3. Top 3 Ranked Power Supply Scenarios.

Ranking	Updated Phase I results	24/7 operations	24/7 operations & electric landfill equipment
1	Scenario 4: • 100 kW solar PV • 75 kW/300 kWh BESS • 160 kW diesel generator	Scenario 4: • 100 kW solar PV • 100 kW/400 kWh BESS • 160 kW diesel generator	Scenario 4: • 300 kW solar PV • 300 kW/1,200 kWh BESS • 300 kW diesel generator
2	*Tied:* Scenario 6: • 100 kW solar PV • 100 kW wind • 60 kW/120 kWh BESS • 160 kW diesel generator Scenario 7: • 160 kW diesel generator	*Tied:* Scenario 6: • 100 kW solar PV • 100 kW wind • 60 kW/120 kWh BESS • 160 kW diesel generator Scenario 7: • 160 kW diesel generator	Scenario 7: • 300 kW diesel generator
3			Scenario 5: • 100 kW wind • 500 kW/2,000 kWh BESS • 300 kW diesel generator

Acknowledgements

Pacific Northwest National Laboratory (PNNL) would like to acknowledge the Commonwealth of the Northern Mariana Islands (CMNI) Office of Planning and Development (OPD) team, specifically Ricardo Miranda for his support in the development of this addendum report, especially coordinating with stakeholders and providing data. Other key stakeholders from CNMI who collaborated with the PNNL team include Solid Waste Division Director Blas Mafnas, Office of Planning and Development Director Elizabeth Balajadia and Deputy Director Christopher Sablan, Safe Drinking Water Program Manager CDR Travis Spaeth from the Bureau of Environmental and Coastal Quality, and James Benavente from MES, the landfill operator. Adam Klein from the Federal Emergency Management Agency and Pete Gingrass from the U.S. Department of Energy provided key direction and guidance throughout the process. Christopher Niebylski from PNNL provided technical and editorial reviews and strategic guidance. Mark Weimar from PNNL provided economic analysis support.

This feasibility study was funded by the Federal Emergency Management Agency, through its Interagency Reimbursable Work Agreement with the U.S. Department of Energy.

Acronyms and Abbreviations

BESS	battery energy storage system
CNMI	Commonwealth of the Northern Mariana Islands
CO_2e	carbon dioxide equivalent
CUC	Commonwealth Utilities Corporation
DPW	Department of Public Works
EPA	US Environmental Protection Agency
LCOE	levelized cost of energy
O&M	operations and maintenance
OPD	Office of Planning and Development
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
SW	Solid Waste
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

Pacific Northwest National Laboratory (PNNL) conducted a feasibility study in 2023 that evaluated alternative power supply options for the Marpi Landfill (Marpi or the landfill) on the island of Saipan in the Commonwealth of the Northern Mariana Islands (CNMI). This feasibility study (hereafter referred to as Phase I of this study) culminated in a report named "Power Supply Options for the Marpi Landfill, Saipan" (Solana et al. 2023).

The evaluation presented here (Phase II of this study) is meant to supplement Phase I by assessing additional considerations regarding power supply options for Marpi. These include adjusting equipment dispatch in anticipation of 24/7 power supply needs (Section 2.0), evaluating the impact of electrifying landfill equipment (Section 3.0), estimating the cost of new distribution lines between new generation equipment and loads (including the costs of replacing existing lines) (Section 4.0), and calculating the social cost of carbon for each scenario (Section 5.0). The results of these analyses are used to update the life cycle cost analysis of each power supply scenario (Section 6.0) as well as scenario prioritization (Section 7.0). Recommendations and next steps are presented in Section 8.0.

2.0 24/7 Operations at Marpi

As described in Phase I, Marpi is not connected to the Commonwealth Utilities Corporation (CUC) electric distribution grid; instead, it is powered by an on-site diesel generator. The landfill's operating hours are 7:30 a.m.–4:30 p.m. Monday to Saturday (6 a.m.–6 p.m. during or after high rainfall conditions). During operating hours, pumps are used to control leachate and stormwater levels. Pumps are not used outside these hours because the generator is turned off when the landfill is unoccupied.

The power supply options from Phase I of this study are all configured to be capable of providing power 24/7, despite all loads occurring during landfill operating hours. However, it is important to understand how future 24/7 operations, when loads could be spread across hours when the landfill is closed (Sundays and evenings), may impact power supply equipment sizing. As such, the project team developed a revised load profile and modeled the impact on power supply scenarios.

This analysis focuses on the need for 24/7 operations for the Cell 2 and Cell 3 standard leachate and storm pumps. Pump loads at Marpi are not metered, so reliable estimates of these loads do not exist. Operational logger data for Cell 2 standard and storm pumps (spanning August 14, 2023–September 18, 2023) provided by the landfill operator were analyzed to determine daily pump operation hours during the rainy season. The logger data show that the stormwater pump in Cell 2 is in operation 3 h a day on average, with a maximum of 12 h a day, and that the standard pump is in operation 5.4 h a day, also with a maximum of 12 h a day. The logger data indicate that both pumps are turned on and off multiple times throughout the day to control leachate levels. However, the logger data show that the leachate level exceeds the permitted[1] levels for the full extent of time recorded. Through conversation with the Department of Public Works (DPW) and Office of Planning and Development (OPD), it was assumed that

[1] CNMI Solid Waste Management Facility Permit No. SWMF-S-LF-01-2021. This permit requires the manual operation of leachate pumps to make sure that the landfill leachate depth does not at any time exceed 30 cm over the liner.

the standard and storm pumps would need to operate 1.5 times as long during the rainy season to sufficiently lower leachate levels to meet permit requirements. As such, pump operation hours from the logger data were scaled by 1.5 and extrapolated to every month of the rainy season for both Cell 2 and Cell 3 standard and storm pumps, with pump loads randomly assigned throughout the day and night.

Based on the changes to the pumping duty cycles, the landfill's annual consumption is estimated to be 182 MWh, up from the Phase 1 result of 170 MWh, with a peak load of 109 kW, down from 112 kW. The Phase I calculations assumed that the standard pumps run an average of 5 h/day and that the storm pumps run 2 and 3 h/day during the dry and rainy seasons, respectively. Updating these assumptions using logger data and scaling pump loads by 1.5 times during the rainy season lead to an increase in annual electricity consumption. The peak load is similar because pumps still need to operate at maximum capacity during the day when other operational loads are present and during particularly rainy days. However, the peak load occurs much less frequently because the pumps are able to operate during the evening and nighttime to maintain low leachate levels, rather than working at maximum capacity to lower leachate levels during the day.

Figure 1 shows the estimated hourly load profile for a typical year, and Figure 2 shows the estimated hourly load profile for a typical week during both the dry and rainy seasons, respectively. Since the annual and peak loads are similar to the results from Phase I, but the peak loads occur less often, the power supply scenarios were either left unchanged, or the battery energy storage system (BESS) was downsized to reduce capital costs and rely on the diesel generator during peak loads.

Specifically, the BESS was downsized from 350 kW/1,400 kWh to 250 kW/1,000 kWh for Scenario 1, from 300 kW/1,200 kWh to 200 kW/800 kWh for Scenario 2, from 260 kW/1040 kWh to 150 kW/600 kWh for Scenario 3, and from 100 kW/400 kWh to 75 kW/300 kWh for Scenario 4. The life cycle cost analysis for each power supply scenario was updated based on the revised component sizing and by adding the cost of distribution and the social cost of carbon, as discussed in Section 6.2.

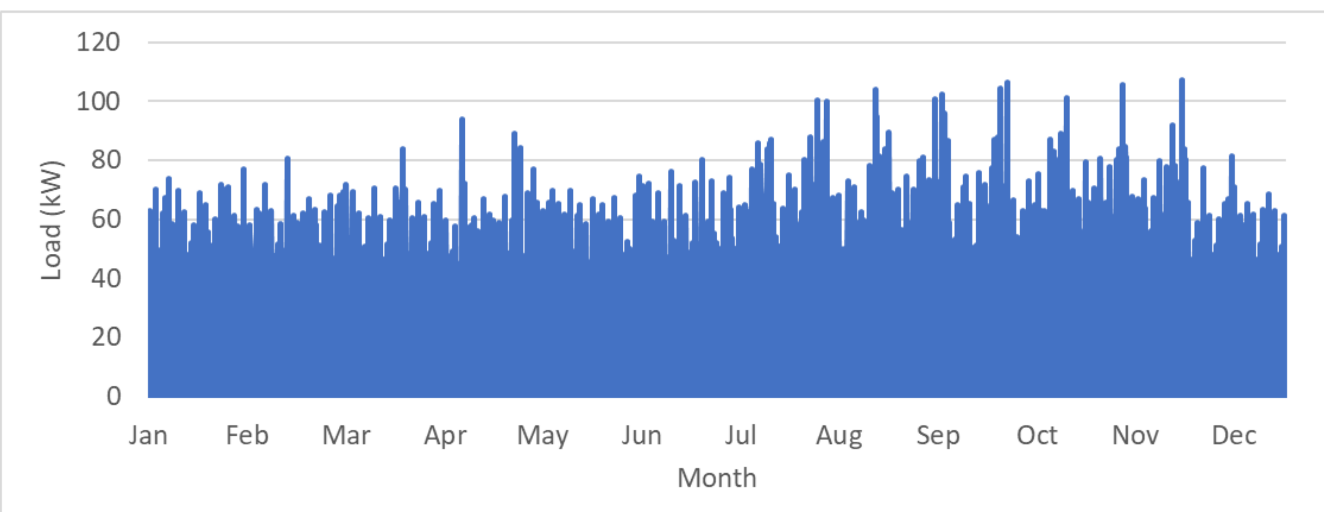

Figure 1. Estimated hourly Marpi Landfill load profile with 24/7 operations.

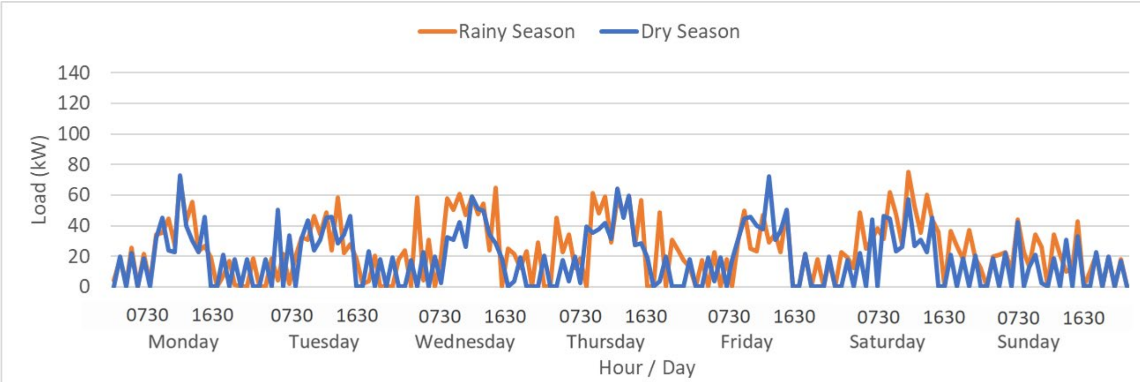

Figure 2. Estimated typical weekly Marpi Landfill load profile with 24/7 operations.

3.0 24/7 Operations & Electric Landfill Equipment

A variety of heavy equipment is required to operate Marpi, including a compactor, a dump truck, two bulldozers, a payloader, a tanker truck, two utility trucks, a riding mower, and three brush cutters. Equipment currently in use at Marpi, usage patterns, and fuel consumption were provided by the landfill operator. Figure 3 shows the existing equipment and usage in hours/day and days/week.

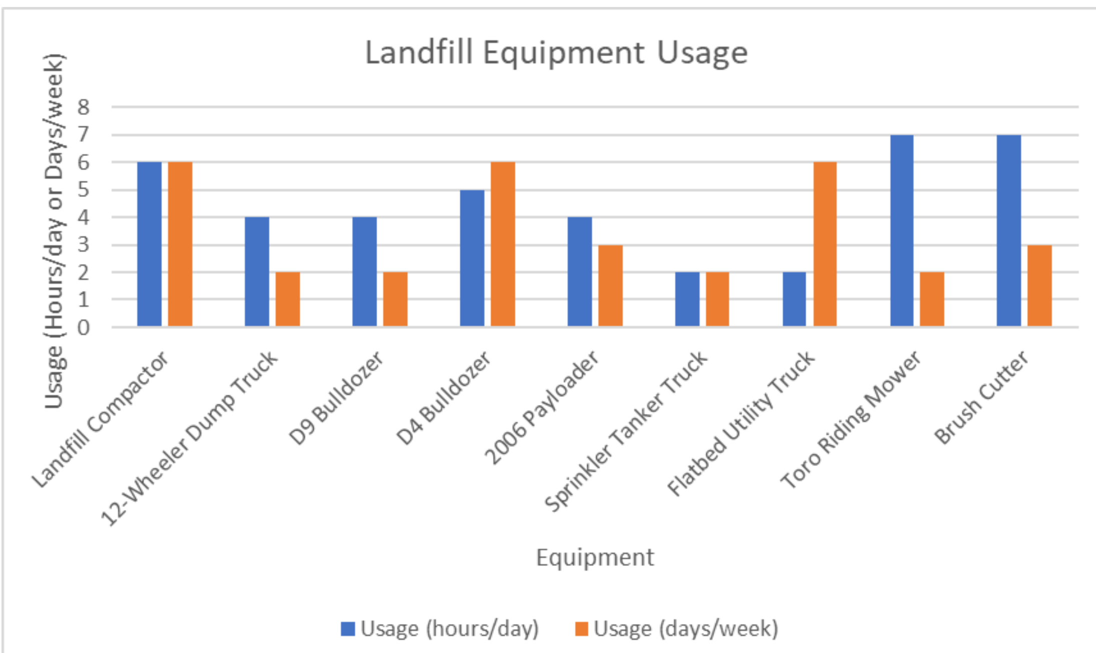

Figure 3. Marpi Landfill equipment and usage.

All landfill equipment currently operates on diesel or gasoline, furthering Marpi's reliance on fossil fuels for daily operations. The Solid Waste (SW) Taskforce expressed interest in exploring alternatives to fossil-fueled heavy equipment at the landfill. As such, the project team evaluated the impact of converting the heavy-duty equipment used at Marpi to electric equivalents, including a revised load profile and power supply scenarios.

OPD and the site operator recommended considering only electric alternatives that are currently available or projected to be available commercially in the near future. Based on this guidance, a subset of the existing equipment was considered for this analysis. Table 1 summarizes this equipment and the number of units in use, the estimated power consumption and daily energy storage of an electric equivalent, the estimated charge time based on charger type, and the commercial availability of the electric alternative.

Table 1. Selected characteristics of electric alternative equipment.

Number of Units	Equipment	Estimated Power Consumption (kW)	Estimated Daily Energy Storage Required (kWh)	Charge Time (hours)	Charger Type	Commercial Availability of Electric Alternative
1	12-Wheeler Dump Truck	113	586	3.9	DC[(a)]	No
1	2006 Payloader	126	654	4.4	DC	Yes
1	Sprinkler Tanker Truck	101	262	13.1	Level 2[(b)]	Yes
2	Flatbed Utility Truck	12	31	1.6	Level 2	Yes
1	Toro Riding Mower	25	229	11.5	Level 2	Yes
3	Brush Cutter	5	48	2.4	Level 2	Yes

(a) DC refers to a direct current fast charger, which requires 400–1000 V electrical service, provides 50–350 kW power output, and costs between \$10,000 and \$40,000 per charger, excluding installation.
(b) Refers to a Level 2 alternating current electric vehicle charger, which requires 208–240 V electrical service, provides 7–19 kW power output, and costs between \$400 and \$6,500 per charger, excluding installation.

This analysis assumed that the electric versions would have similar usage patterns and energy requirements as the fossil-fuel versions. Therefore, the daily fuel use was converted to kilowatt-hours to determine charging requirements for each piece of equipment. Charging was assumed to occur when the landfill is closed (4:30 p.m.–7:30 a.m.), requiring 24/7 power to meet charging requirements.

Adding these charging loads and assuming 24/7 landfill operations, the landfill's annual consumption increases to 458 MWh with a peak load of 155 kW. The annual electricity consumption more than doubles because of the high energy needs of the landfill equipment, especially the payloader and dump truck. The peak load increases by 1.5 and occurs overnight rather than during the day.

Figure 4 shows the resulting hourly load profile for a typical year, and Figure 5 shows the hourly load profile for a typical week during both the dry and rainy seasons. The added overnight load from equipment charging is larger than the typical landfill daytime load, so the load profiles "flip." In other words, the loads are larger at night than they are throughout the day.

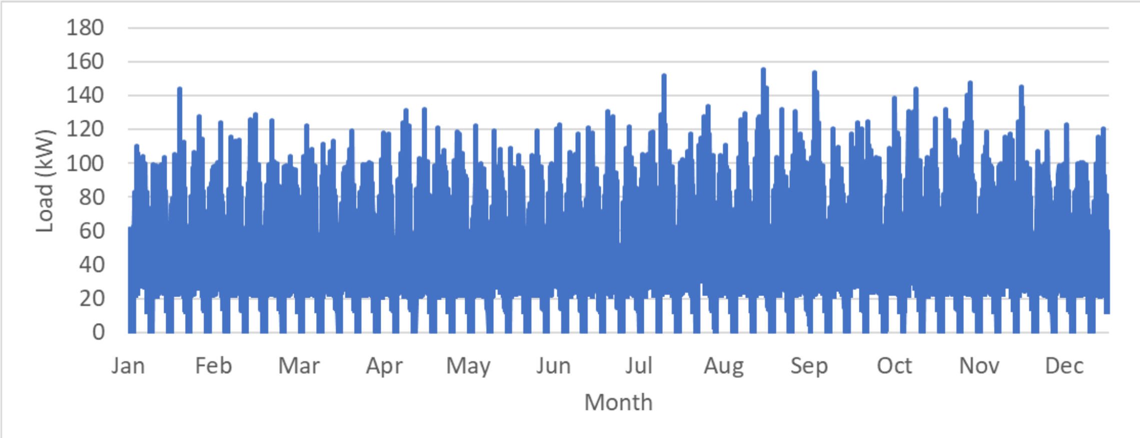

Figure 4. Estimated hourly Marpi Landfill load profile with electric equipment charging.

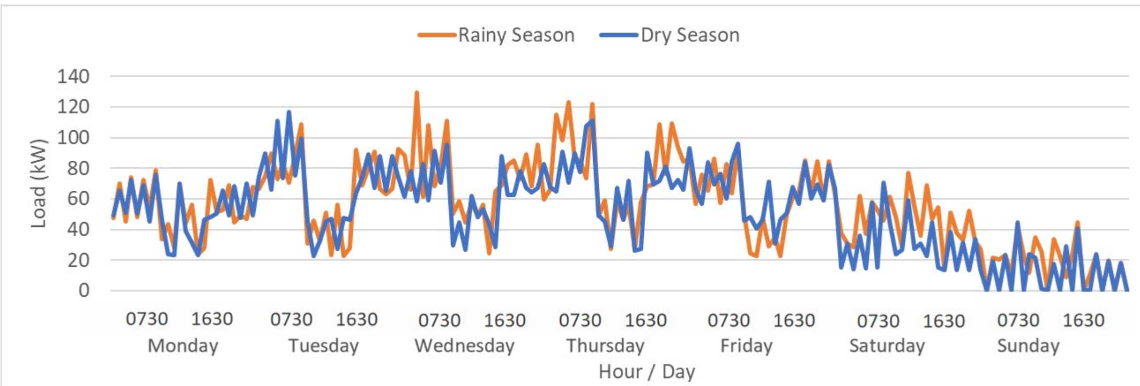

Figure 5. Estimated typical weekly Marpi Landfill load profile with electric equipment charging.

Since the annual load is over two times larger than the results from Phase I, most of the power supply scenarios were modified to provide uninterrupted power, increasing solar photovoltaic (PV) array, diesel generator, and BESS capacities. Because of the increased capacity, some of the scenarios will not fit within the proposed project footprint identified in Phase I. Those scenarios would require additional space.

Additionally, the cost of distribution and the social cost of carbon were added to each modified scenario's life cycle cost analysis, as detailed in Section 6.3.

4.0 Cost of Distribution

The life cycle cost analysis in Phase I of this study included the costs of the energy generation equipment, energy storage, microgrid controls, and backup generator. To better understand the full costs of the project, the project team estimated the cost of new distribution lines between new generation equipment and existing loads, as well as the costs associated with replacing existing distribution lines (between loads and the existing diesel generator), if required in the future. These costs were incorporated into the life cycle cost analysis of each scenario, as discussed in Section 6.0.

The assumptions outlined for this task are related to installation and cost considerations. In terms of installation, it is assumed that all new conduit is required, supported by the observation that no extra empty conduit exists from images of manholes shared by the DPW. The layout of the new conduit avoided paved areas, assuming open trench direct burial of conductor whenever possible (as opposed to directional boring). A typical rocky ground profile is assumed. Regarding materials, copper conductors are used for ampacity calculations. Conductor costs were taken from the U.S. Army Corps of Engineers (USACE 2022a), the Department of Defense (DoD 2023), and the Phase I analysis and are listed in Table 2. The values in this table were further multiplied by an area cost factor[2] of 3.6 based on USACE assumptions for Saipan (USACE 2022b), with the caveat that this factor may not be entirely accurate for common materials like power cable. A 50% contingency factor was also applied to account for uncertainty.

Table 2. Conductor unit costs.

Description	Rated Ampacity (A)	USACE ($/ft)	DoD ($/ft)	Phase I Analysis ($/ft)
4 conductor set of 1/0	130	$49.8	$51.8	$40.6
8 conductor set of 1/0	260	$75.6	$77.7	$61.3
4 conductor set of 4/0	195	$60.2	$64.9	$50.0
8 conductor set of 4/0	390	$93.5	$107.5	$80.0
12 conductor set of 4/0	585	$129.7	$146.4	$110.0
20 conductor set of 4/0	780	$201.9	$224.3	$170.0

Figure 6 shows an overview of the site, including the confirmed and assumed paths of existing conductor and the path of the required new conductor.

[2] USACE area cost factors are a DoD mechanism to adjust U.S.-based construction costs based on location.

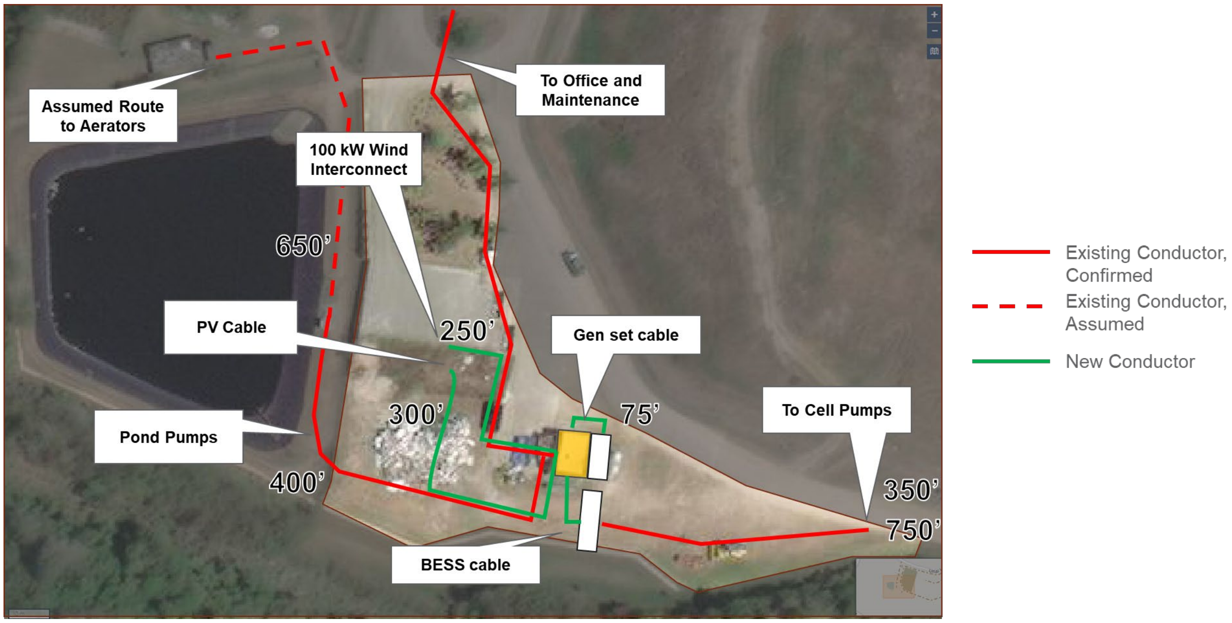

Figure 6. Overview of existing and new electric distribution cable.

The costs for the direct burial of new distribution lines and the replacement of existing distribution lines were calculated for 24/7 operations as well as 24/7 operations & electric landfill equipment. Both the average and highest estimated costs of the three data sources are presented.

As discussed in Section 3.0, electric landfill equipment charging requires larger solar PV, diesel generator, and BESS capacities. These generate more current, requiring more expensive conductors with higher ampacity ratings, increasing the cost of the new generation cable. The cost of the replacement of existing cable remains the same.

Figure 7 and Figure 8 show the average and highest estimated costs for the direct burial of new generation cable for 24/7 operations as well as 24/7 operations & electric landfill equipment, respectively. Figure 9 shows the average and highest estimated costs for the replacement of existing facilities cable, which is the same for both scenarios. This cost will occur if the existing distribution between the loads and breaker box needs to be replaced during the project lifetime.

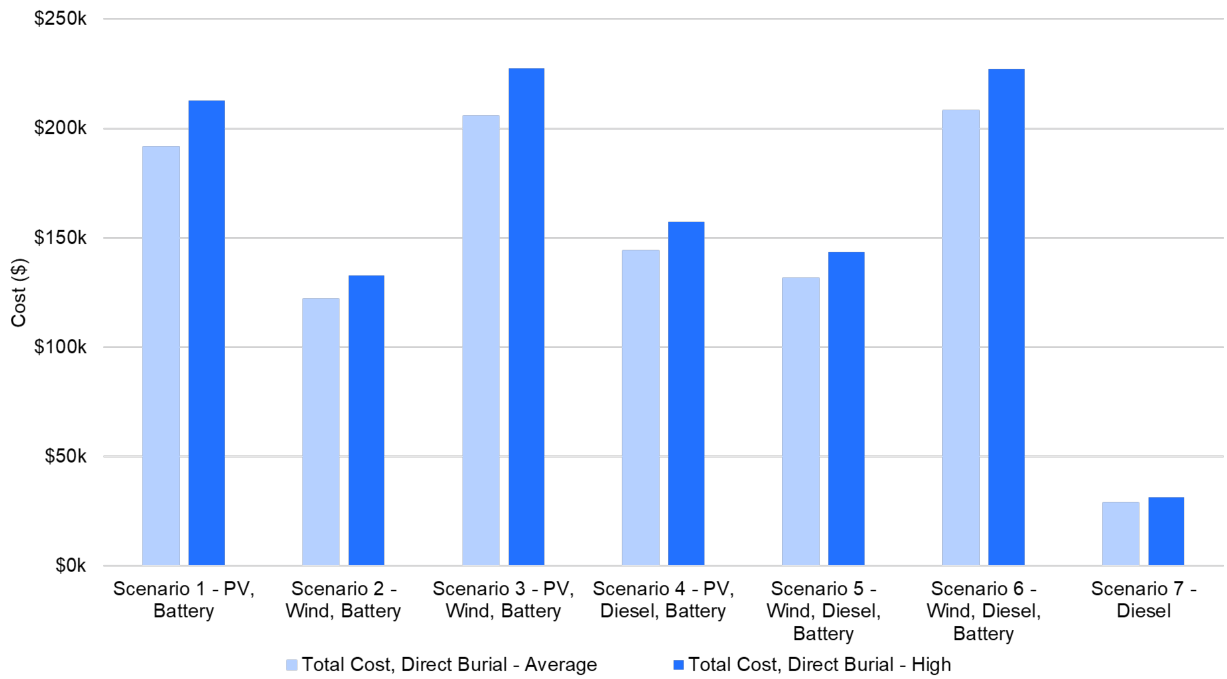

Figure 7. Cost summary for the installation of new distribution cable, 24/7 operations.

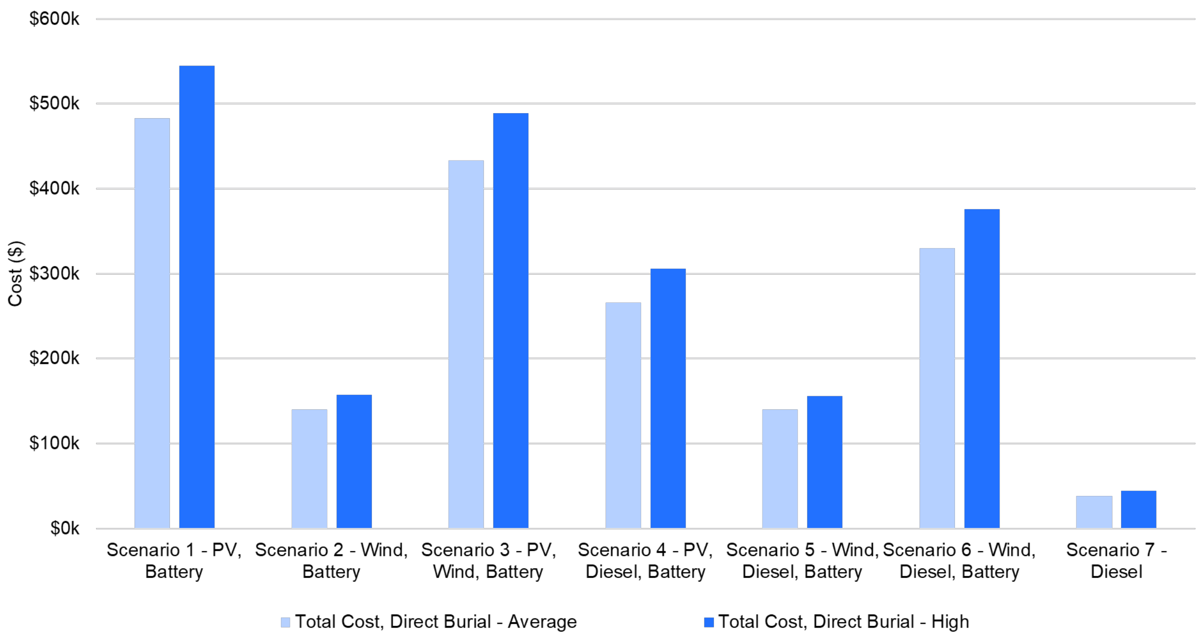

Figure 8. Cost summary for the installation of new distribution cable, 24/7 operations & electric landfill equipment.

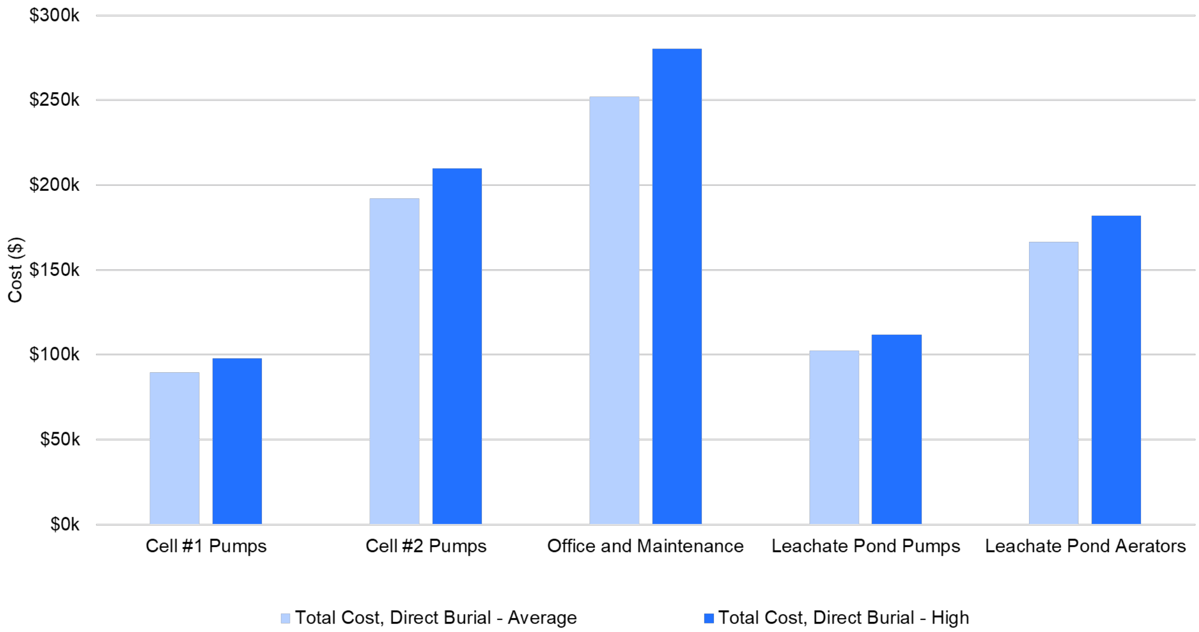

Figure 9. Cost summary for the replacement of existing distribution cable.

The costs for the direct burial of new distribution cable for the Phase I results range between $131k and $220k for Scenarios 1–6. Assuming 24/7 operations slightly decreases those costs, between $122k and $208k for Scenarios 1–6, because smaller BESS capacities require less expensive cable. Adding electric equipment charging more than doubles the cost for scenarios with larger equipment capacities, between $140k and $483k for Scenarios 1–6. This is because electric landfill equipment charging requires larger solar PV, diesel generator, and BESS capacities. These generate more current, requiring more expensive conductors with higher ampacity ratings, increasing the cost of the new generation cable. For Phase I, 24/7 operations, and 24/7 operations & electric equipment charging, the direct burial cost of new distribution cable for Scenario 7 (diesel-only) is $38k. The direct burial cost of replacing existing cable for all load profiles and power supply scenarios is expected to be $802k.

The average direct burial costs of new and replacement cable were used to inform the updated life cycle cost analysis for each power supply scenario, as discussed in Section 6.0.

5.0 Social Cost of Carbon

The SW Task Force prioritized scenarios in Phase 1 using ranked qualitative criteria related to climate and environmental justice considerations; these considerations may also be represented quantitatively by the social cost of carbon. As such, this project team calculated the social cost of carbon for each power supply scenario and incorporated it into each life cycle cost analysis (those from Phase 1 and from the scenarios outlined in Sections 2.0 and 3.0).

The social cost of carbon used for this analysis comes from the Interagency Working Group on Social Cost of Greenhouse Gases. As defined by the Working Group, the social cost of greenhouses gases, such as carbon dioxide, “is the monetary value of the net harm to society associated with adding a small amount of that greenhouse gas to the atmosphere in a given year" (Interagency Working Group on Social Cost of Greenhouse Gases 2021). The Working Group defines the social cost of carbon in 2020 dollars per metric ton of CO_2 equivalent (CO_2e), which was escalated to 2022 dollars using a 2.5% discount rate for this analysis (Table 3).

Table 3. Social cost of carbon.

Year	Social Cost of Carbon (2022$/Ton CO_2e emitted)
2022	89
2023	90
2024	91
2025	93
2026	94
2027	96
2028	98
2029	99
2030	100
2031	102
2032	103
2033	105
2034	107
2035	108
2036	109
2037	111
2038	112
2039	114
2040	116
2041	117
2042	118
2043	120
2044	121
2045	123
2046	125

To calculate the social cost of carbon, the CO_2e emissions associated with each scenario were calculated using a U.S. Environmental Protection Agency (EPA) emissions factor of 0.07421 tons of CO_2e per million British thermal units of fuel consumed by the diesel generator (EPA 2022). The tons of CO_2e were then multiplied by the social cost of carbon and incorporated into the life cycle cost analysis for each power supply scenario in Section 6.0.

6.0 Life Cycle Cost Analysis of Modified Power Supply Scenarios

The life cycle cost analyses for the power supply scenarios from Phase I were modified to include the social cost of carbon and the cost of distribution (Section 6.1). Next, the power supply scenarios from Phase I were updated to account for 24/7 operations at Marpi (Section 6.2) and for electric landfill equipment charging (Section 6.3).

The seven scenarios evaluated and presented in the tables in the following subsections are as follows:

1. Solar PV + BESS
2. Wind + BESS
3. Solar PV + Wind + BESS
4. Solar PV + BESS + Diesel Generator
5. Wind + BESS + Diesel Generator
6. Solar PV + Wind + BESS + Diesel Generator
7. Diesel Generator Only[3]

Each scenario provides certain benefits and challenges, as described in detail in the Phase I report.

6.1 Updated Phase I

Table 4 provides a summary of the updated scenarios from Phase I to include the social cost of carbon and the cost of distribution. Capital costs increase for all scenarios because of the additional cost of distribution. Operations and maintenance (O&M) costs all slightly decrease solely because of an update in the real discount rate used in the calculations (0.45% to 2%). The 25-year levelized cost of energy (LCOE) increases for all scenarios, especially for the scenarios using diesel generators, because of the addition of the social cost of carbon.

Table 4. Summary of the evaluated scenarios (updated Phase I).

Scenario	Solar PV (kW)	Wind Turbine (kW)	Diesel Generator (kW)	Battery (kW/kWh)	Capital Cost ($M)	Annual O&M Costs ($k/yr)	25-year LCOE ($/kWh)	Social Cost of Carbon ($k)	CO_2e Emissions Generated (tons/yr)	% Renewable Energy Curtailed Annually	% Load Not Met Annually
PV/BESS	200	0	0	350/1400	6.0	6	2.56	0	0	50%	0%
Wind/BESS	0	100	0	300/1200	4.9	15	3.66	0	0	37%	34%
PV/Wind/BESS	150	100	0	260/1040	5.5	16	2.47	0	0	61%	0%
PV/BESS/Gen	100	0	160	75/300	2.7	14	1.43	44	22	15%	0%
Wind/BESS/Gen	0	100	160	100/400	3.3	43	1.97	110	54	46%	0%
PV/Wind/BESS/Gen	100	100	160	60/120	3.2	19	1.68	24	12	56%	0%
Diesel Generator	0	0	160	0	0.8	70	1.25	250	122	0%	0%

6.2 24/7 Operations

As described in Section 2.0 above, the power supply scenarios given 24/7 operations were either left unchanged, or some of the equipment was downsized. Table 5 provides a summary of the evaluated scenarios including the cost of distribution and the social cost of carbon.

[3] This scenario differs from current landfill operations in that the diesel generator is configured with the ability to operate 24/7 to meet permit requirements.

Capital costs remain the same for Scenario 2 since the cost of distribution is offset by the smaller BESS. For all other scenarios, capital costs increase because of the additional cost of distribution, even accounting for capital cost decreases due to the smaller BESS capacity. Annual O&M costs decrease or remain the same because an update in the real discount rate balancing offsets the increased O&M costs associated with increased reliance on the diesel generator. CO_2e emissions fluctuate; some increase because of additional reliance on the diesel generator, while Scenario 5 emissions are lower because wind generation is curtailed less owing to a better match with the overnight pump loads. Generally, the 25-year LCOE decreases for scenarios utilizing wind and increases for scenarios with solar PV generation. The LCOE also generally decreases because of the lower capital costs associated with smaller BESS capacities.

Table 5. Summary of the evaluated scenarios (24/7 operations).

Scenario	Solar PV (kW)	Wind Turbine (kW)	Diesel Generator (kW)	Battery (kW/kWh)	Capital Cost ($M)	Annual O&M Costs ($k/yr)	25-year LCOE ($/kWh)	Social Cost of Carbon ($k)	CO_2e Emissions Generated (tons/yr)	% Renewable Energy Curtailed Annually	% Load Not Met Annually
PV/BESS	200	0	0	250/1000	4.7	5	2.00	0	0	45%	0%
Wind/BESS	0	100	0	200/800	3.6	13	2.60	0	0	32%	33%
PV/Wind/BESS	150	100	0	150/600	4.0	14	1.85	0	0	58%	0%
PV/BESS/Gen	100	0	160	100/400	3.0	18	1.52	42	21	24%	0%
Wind/BESS/Gen	0	100	160	100/400	3.3	41	1.81	102	50	36%	0%
PV/Wind/BESS/Gen	100	100	160	60/120	3.2	19	1.58	24	12	52%	0%
Diesel Generator	0	0	160	0	0.8	75	1.2	270	132	0%	0%

6.3 24/7 Operations & Electric Landfill Equipment

As described in Section 3.0, most of the power supply scenarios require increased equipment capacity to provide uninterrupted power given 24/7 operations and charging electric landfill equipment. Because of the increased capacity, some of the scenarios will not fit within the footprint of the landfill identified in Phase I. Those scenarios are indicated in red font in Table 6, which provides a summary of the evaluated scenarios including the cost of distribution and the social cost of carbon.

Capital costs significantly increase for all scenarios except Scenario 2 since the component sizing for that scenario does not change. These increases are due to larger solar PV, diesel generator, and BESS capacities. Annual O&M costs increase for all scenarios except for Scenario 2. CO_2e emissions increase across the board for scenarios reliant on diesel generators because of increased reliance on those generators. Generally, the 25-year LCOE decreases for scenarios including wind and increases for scenarios with solar PV generation. This is because wind power is better suited to meet the larger nighttime loads than solar.

Table 6. Summary of the evaluated scenarios (24/7 operations & electric landfill equipment).

Scenario	Solar PV (kW)	Wind Turbine (kW)	Diesel Generator (kW)	Battery (kW/kWh)	Capital Cost ($M)	Annual O&M Costs ($k/yr)	25-year LCOE ($/kWh)	Social Cost of Carbon ($k)	CO_2e Emissions Generated (tons/yr)	% Renewable Energy Curtailed Annually	% Load Not Met Annually
PV/BESS	500	0	0	600/2400	8.7	12	1.47	0	0	45%	0%
Wind/BESS	0	100	0	300/1200	4.9	15	2.25	0	0	4%	62%

Scenario	Solar PV (kW)	Wind Turbine (kW)	Diesel Generator (kW)	Battery (kW/kWh)	Capital Cost ($M)	Annual O&M Costs ($k/yr)	25-year LCOE ($/kWh)	Social Cost of Carbon ($k)	CO_2e Emissions Generated (tons/yr)	% Renewable Energy Curtailed Annually	% Load Not Met Annually
PV/Wind/BESS	400	100	0	500/2000	10.4	21	1.71	0	0	46%	0%
PV/BESS/Gen	300	0	300	300/1200	7.9	34	1.37	99	48	21%	0%
Wind/BESS/Gen	0	100	300	100/400	4.1	133	1.15	433	211	8%	0%
PV/Wind/BESS/Gen	250	100	300	250/1000	7.9	44	1.41	97	48	34%	0%
Diesel Generator	0	0	300	0	1.5	190	0.97	680	332	0%	0%

7.0 Prioritization of Scenarios

To assist with decision-making, three prioritization matrices were created to compare the power supply scenarios according to various SW Taskforce priorities. The process for generating the prioritization matrices and ranking the scenarios is described in the Phase I report.

The scores for each metric and scenario and the overall scenario ranking scores are presented in Table 7 for the updated Phase I results, Table 8 for 24/7 operations, and Table 9 for 24/7 operations & electric landfill equipment.

These rankings show that a microgrid that includes solar PV generation, a BESS, and a diesel generator (Scenario 4) is the favored option for the updated Phase I results, 24/7 operations, and 24/7 operations & electric landfill equipment. However, meeting the electric equipment charging load with Scenario 4 requires additional land than is available at the landfill. Diesel generators alone (Scenario 7) rank second under both sets of conditions, driven by lower capital costs and lower space requirements. However, Scenario 7 has the highest CO_2e emissions and the highest cost of carbon of any scenario. Scenarios without diesel generation (Scenarios 1–3) are ranked lowest, primarily because of the unreliability of these scenarios in meeting the load and permit requirements.

Table 7. Prioritization of Marpi power supply scenarios (updated Phase I results).

Relative Metric Priority	1	5	1	3	4	1	3	3	1	2	2		
Prioritization Metric	Capital Cost	Annual O&M Costs	25-Year Levelized Cost of Energy	% Load Not Met Annually	Meets Permit Req. for Backup Power	CO_2e Emissions Generated	Area Req.	Diversity of Resources (# of components)	Equipment Hardening Req.	Training Req.	Smart Safe Growth		
Scenario	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Total Score	Rank
PV/BESS	7	1	6	3	7	1	4	5	2	3	2	3.17	4
Wind/BESS	5	3	7	7	7	1	4	5	5	3	5	4.17	7
PV/Wind/BESS	6	4	5	3	7	1	4	2	6	5	5	3.77	6
PV/BESS/Gen	2	2	2	1	1	5	1	2	3	5	4	1.87	1
Wind/BESS/Gen	4	6	4	1	1	6	4	2	4	5	7	3.23	5
PV/Wind/BESS/Gen	3	5	3	1	1	4	4	1	7	7	6	3.00	2
Diesel Generator	1	7	1	1	1	7	1	7	1	2	5	3.00	2

Table 8. Prioritization of Marpi power supply scenarios (24/7 operations).

Relative Metric Priority	1	5	1	3	4	1	3	3	1	2	2		
Prioritization Metric	Capital Cost	Annual O&M Costs	25-Year Levelized Cost of Energy	% Load Not Met Annually	Meets Permit Req. for Backup Power	CO_2e Emissions Generated	Area Req.	Diversity of Resources (# of components)	Equipment Hardening Req.	Training Req.	Smart Safe Growth		
Scenario	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Total Score	Rank
PV/BESS	7	1	6	3	7	1	4	5	2	3	2	3.17	4
Wind/BESS	5	2	7	7	7	1	4	5	5	3	5	4.00	7
PV/Wind/BESS	6	3	5	3	7	1	4	2	6	5	5	3.60	6
PV/BESS/Gen	2	4	2	1	1	5	1	2	3	5	4	2.20	1
Wind/BESS/Gen	4	6	4	1	1	6	4	2	4	5	7	3.23	5
PV/Wind/BESS/Gen	3	5	3	1	1	4	4	1	7	7	6	3.00	2
Diesel Generator	1	7	1	1	1	7	1	7	1	2	5	3.00	2

Table 9. Prioritization of Marpi power supply scenarios (24/7 operations & electric landfill equipment).

Relative Metric Priority	1	5	1	3	4	1	3	3	1	2	2		
Prioritization Metric	Capital Cost	Annual O&M Costs	25-Year Levelized Cost of Energy	% Load Not Met Annually	Meets Permit Req. for Backup Power	CO_2e Emissions Generated	Area Req.	Diversity of Resources (# of components)	Equipment Hardening Req.	Training Req.	Smart Safe Growth		
Scenario	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Total Score	Rank
PV/BESS	6	1	5	3	7	1	7	5	2	3	2	3.40	5
Wind/BESS	3	2	7	7	7	1	4	5	5	3	5	3.93	6
PV/Wind/BESS	7	3	6	3	7	1	7	2	6	5	5	3.97	7
PV/BESS/Gen	4	4	3	1	1	4	7	2	3	5	4	2.87	1
Wind/BESS/Gen	2	6	2	1	1	6	4	2	4	5	7	3.10	3
PV/Wind/BESS/Gen	4	5	4	1	1	4	7	1	7	7	6	3.37	4
Diesel Generator	1	7	1	1	1	7	1	7	1	2	5	3.00	2

8.0 Recommendations and Next Steps

The details and results presented in this addendum are for consideration by the SW Taskforce. Of the power supply options presented here, a microgrid that includes solar PV generation, a BESS, and diesel generation was shown to best meet Marpi, OPD, DPW, and SW Taskforce requirements and goals. Based on landfill operator and DPW inputs, the evaluation found that approximately 100 kW of solar PV generation, a 100 kW/400 kWh BESS, and 160 kW of diesel generation will provide the necessary power requirements for 24/7 continuous landfill operations. Additionally, the amount of solar PV and BESS could be expanded as needed, to meet additional new loads at Marpi. Equipment capacities must be increased to 300 kW of solar PV generation, a 300 kW/1200 kWh BESS, and 300 kW of diesel generation if electric landfill equipment charging is included, with the caveat that the larger solar PV array and BESS will not fit within previously identified space at Marpi.

The next steps for this project include grant research by PNNL as well as decision-making and grant pursuit by the SW Taskforce.

As part of the Phase II scope, PNNL researched specific grants available for Marpi. This list of funding opportunities, including funding amounts, key areas of interest, funding agency eligibility, lead agency responsibilities, and application deadlines was presented to the SW Taskforce as a summary excel spreadsheet as well as a word document narrative along with this addendum.

9.0 References

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Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354

1-888-375-PNNL (7665)

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