Rawhide Operations Study

Platte River Power Authority

Rawhide Unit 1 Cycling Impact
Project No. 109903

Revision Final
09/26/2019

Rawhide Operations Study

prepared for

Platte River Power Authority
Rawhide Unit 1 Cycling Impact
Fort Collins, Colorado

Project No. 109903

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prepared by

Burns & McDonnell Engineering Company, Inc.
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LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
BMcD	Burns & McDonnell Engineering Company, Inc.
CRSP	Colorado River Storage Project
EHS	Equivalent Hot Starts
EPRI	Electric Power Research Institute
FOM	Fixed Operating & Maintenance
GHG	Greenhouse Gas
IRP	Integrated Resource Plan
LAP	Loveland Area Project
MW	Megawatt
MWh	Megawatt-hour
NREL	National Renewable Energy Laboratory
PPA	Power Purchase Agreement
PRPA	Platte River Power Authority
Rawhide	Rawhide Unit 1
RFP	Request for Proposals
Roundhouse	Roundhouse Renewable Energy Project
SCGT	Simply Cycle Gas Turbine
VOM	Variable Operating & Maintenance
WAPA	Western Area Power Administration
ZNC	Zero Net Carbon

STATEMENT OF LIMITATIONS

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1.0 EXECUTIVE SUMMARY

Platte River Power Authority ("PRPA") headquartered in Fort Collins, Colorado, retained the services of Burns & McDonnell Engineering Inc ("Engineer") to study the operational impact of Rawhide Unit 1 ("Rawhide") within a set of Company derived dispatch scenarios. The Company was interested in studying the operational and economic impact to Rawhide based on various levels of wind and solar penetration in the future. These scenarios will help the Company identify the existing operational limits of Rawhide for use in their Integrated Resource Plan ("IRP").

Rawhide is a coal steam turbine generator located in Larimer, Colorado and has an operational capacity of 280 MW. The Company reliably provides the electric service needs of the owner municipalities: Estes Park, Fort Collins, Longmont and Loveland Colorado. Rawhide has superb historical availability and capacity factors while operating as a base-loaded unit.

1.1 Introduction

PRPA has demonstrated a strong commitment to environmental stewardship. As technology develops and opportunities arise, PRPA is committed to evaluating these opportunities to shape a responsible, reliable and cost effective resource mix for the future. The emergence of wind and solar generation, in availability and price reduction, combined with the goal to reduce greenhouse gas ("GHG") emissions necessitates a better understanding of the transition to meet those goals. To accommodate the intermittency and variability of solar and wind resources, traditional baseload resources must respond to be more flexible.

Rawhide has demonstrated to be a reliable and efficient resource for PRPA and its members. As a coal unit, it is designed for cost effective baseload operation with continuous steady production at high capacity factors. How Rawhide can adapt during the transition toward carbon-free generation is estimated in this study.

1.2 Project Summary

Burns & McDonnell developed a dispatch model to estimate Rawhide operational characteristics across the various sensitivities and scenarios while focusing on three years: 2021, 2026, and 2031. Multiple wind and solar generation scenarios were evaluated as part of this analysis with focus on a high wind and solar penetration that parallels PRPA's Zero Net Carbon ("ZNC") scenario developed by Pace Global. Additional scenarios assume that PRPA begins with contracted amounts of wind and solar generation (50 MW and 228 MW capacity respectively) through 2020. Uniform annual increases of wind and solar capacity to achieve a total of 410 MW of wind and 630 MW of solar by 2031 were assumed for the ZNC scenario.

1.3 Results

With the addition of "Roundhouse Renewable Energy Project" ("Roundhouse") at the end of 2020, the operational impact to Rawhide will begin to be notable. The added wind capacity will require careful scheduling to efficiently operate Rawhide. Table 1.1 shows the number of equivalent hot starts ("EHS")[1] estimated for Rawhide with varying factors considered. The table shows a linear increase of wind and solar resources to achieve ZNC by 2031.

Table 1.1: ZNC Unit EHS

Year	Wind	Solar	Equivalent Hot Starts 140 MW Min	100 MW Min	75 MW Min	Peak Load
2021	228	50	75	16	10	700
2022	246	108	99	31	16	710
2023	264	166	125	52	26	720
2024	283	224	149	81	44	731
2025	301	282	171	107	69	742
2026	319	340	189	136	92	753
2027	337	398	208	150	120	765
2028	355	456	217	164	139	777
2029	374	514	239	185	147	789
2030	392	572	251	199	162	801
2031	410	630	265	213	179	814

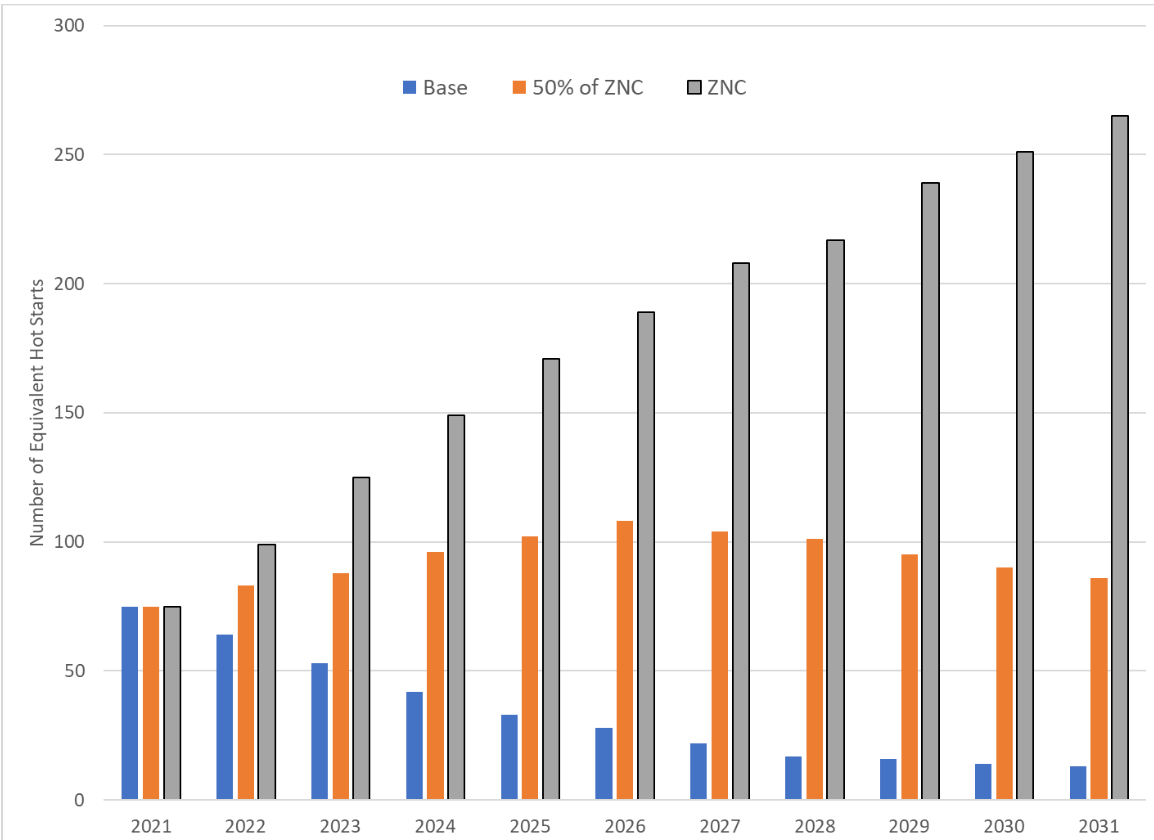
The addition of Roundhouse and Rawhide Solar expansion begins to challenge the operation of Rawhide with no physical modifications made to the coal unit. With a minimum generation capacity of 140 MW, the unit could experience 75 EHS in 2021, without additional corrective or accommodating measures. The number of starts in 2021 decreases to 13 with a 100 MW minimum generation and to 2 starts with a 75 MW minimum. As PRPA increases wind and solar generation to levels modeled and shown in Table 1.1 by 2031, the number of Rawhide's potential cycles increases to approximately 213 EHS with a 100 MW minimum generation limit. Alternatively stated, with 213 EHS, the Unit is cycled off for more than half the days in a year.

Without a demand to market surplus generation or turn down to less than historical generation minimums, the excess must be curtailed at Rawhide (or at another source). The ability to operate Rawhide at lower capacity levels reduces the need for taking the unit offline or curtailing wind and solar resources. Figure 1.1 illustrates the outcome of EHS while maintaining Rawhide at 140 MW minimum generation with varying wind and solar penetration. The ZNC scenario results in increasing number of equivalent hot starts as wind and renewable generation is increased. In the 50% of ZNC scenario, the EHS begin to

[1] EHS = (sum of hot starts) + (sum of cold starts x 5) + (sum of warm starts x 3)

increase each year through 2026, but decrease as demand continues to grow. Increased demand allows increases minimum load requirements.

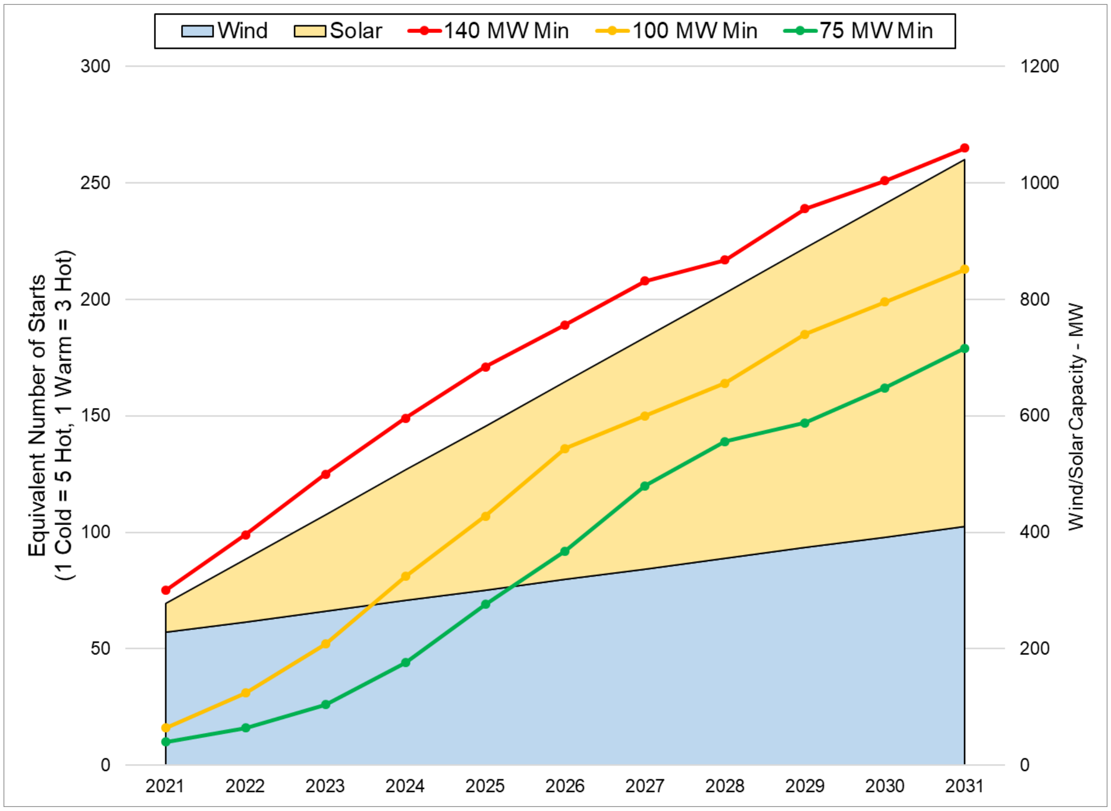
Figure 1.1: EHS at 140 Minimum Generation



Sensitivities over the minimum capacity (minimum loading) of Rawhide were performed at 140 MW, 100 MW and 75 MW. The dispatch model was used to determine the number of cold starts, warm starts, and hot starts for Rawhide across each scenario, sensitivity, and year. Figure 1.2 shows the equivalent starts by year, resulting from increased wind and solar for each minimum generation level applied to the ZNC and base load forecast assumption.

Without lowering the minimum capacity at Rawhide below 140 MW or the inability to market excess generation, the number of hot starts is approximately 60 (75 EHS) in 2021 with the commissioning of the Roundhouse wind project and the Rawhide solar expansion.

Figure 1.2: Equivalent Hot Starts



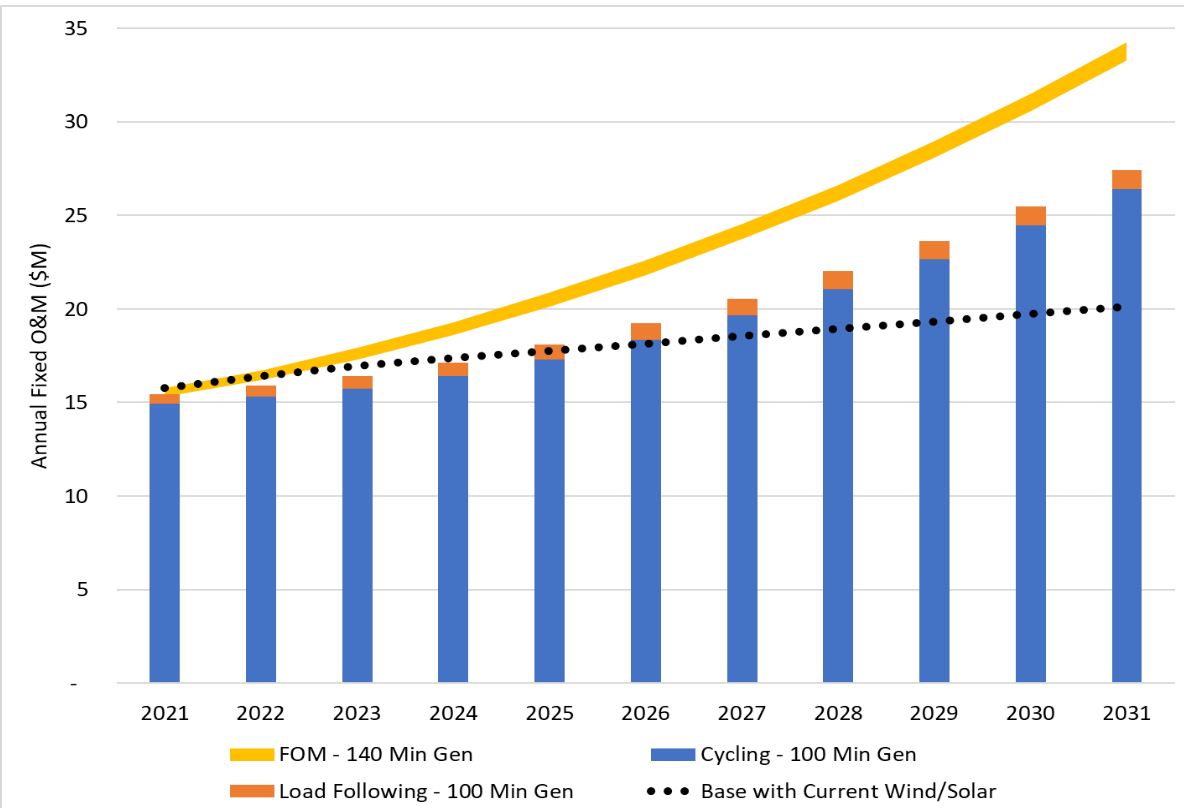
The operational characteristics derived from above (Phase 1 of the Study) were then used in conjunction with relationships developed by the Electric Power Research Institute ("EPRI") to establish a method to forecast Fixed Operating and Maintenance ("FOM") expenditures. FOM estimated in this analysis consists of costs associated with cycling of the unit on and off and additional load-following operation between maximum generation and minimum generation due to increased wind and solar.

As outlined by EPRI[2], FOM expenditure for coal plants is linked to total equivalent operating hours. Increased cycling has the effect of aging a unit. Using actual operating hours from the dispatch model would not capture the increased stresses placed on the unit due to high-cycling operation. A relationship between the number of equivalent hot starts ("EHS") and an equivalent number of operating hours was derived and used within this analysis. In years with high cycling, the number of equivalent operating hours was used as a substitute for the projected operating hours. The cumulative operating hours were then used to forecast FOM expenses for 2019 through 2031. Figure 1.3 illustrates the forecasted annual FOM expenditures possibilities through 2031.

[2] EPRI, "Effects of Cycling on the Operation and Maintenance Cost of Conventional and Combined-Cycle Power Plants"

With a minimum generation capacity of 140 MW, a base load forecast and annual wind and solar increases represented in the ZNC case, shown in yellow, the annual FOM expenditures are expected to surpass $34 million per year after 2031. The width of the yellow line represents the amount of costs associated with load-following operations. The ability to maintain lower minimums of 100 MW and 75 MW at Rawhide may reduce FOM expenditures. The demonstrated ability to reach down to a 100 MW minimum generation at Rawhide will help manage the FOM to approximately $27.4 million in 2031. The portion shown in orange represents the costs associated with load-following operations. The base case FOM estimate with existing wind and solar commitments through 2031 is $20 million for on/off and load-following operations.

Figure 1.3: Fixed O&M



2.0 INTRODUCTION

Platt River Power Authority retained Burns & McDonnell Engineering, Inc. to conduct a quantitative and qualitative analysis of the operational impacts on Rawhide Unit 1 over various levels of future wind and solar energy penetration. This analysis was requested as PRPA begins to develop their 2020 Integrated Resource Plan and continues to study increasing the amount of wind and solar resources within of PRPA's power supply portfolio.

2.1 About Platte River Power Authority

PRPA is a community-owned electric utility that provides wholesale electricity generation and transmission service to four owner municipalities: Estes Park, Fort Collins, Longmont, and Loveland, Colorado. PRPA's service territory contains a population of over 334,000 and had an annual peak demand of 690 megawatts ("MW") in July 2018 and projected energy deliveries to member communities of 3,254,000 megawatt-hours ("MWh"). Of the projected total energy delivered in 2018, 38 percent of PRPA's energy was delivered from renewable resources (hydro, wind, solar) and the remaining 62 percent was delivered from fossil-fueled resources or market purchases[3].

2.2 Existing Portfolio

PRPA currently has 931 MW of capacity from a diverse mix of on-system, off-system, hydro, wind, solar, and fossil resources. PRPA currently recognizes 12.5 percent of nameplate capacity for wind resources and 30 percent of nameplate capacity for solar resources.

2.2.1 Rawhide Unit 1

Rawhide is a coal steam turbine generator located in Larimer, Colorado and has an operational capacity of 280 MW. Rawhide has superb historical availability and capacity factors while operating as a base-loaded unit.

2.2.2 Craig Generating Station

PPRA owns 18 percent of Unit 1 and Unit 2 at the Craig Generating Station (Yampa Project). PRPA's ownership share provides 154 MW of total capacity. The Craig units are operated by Tri-State Generation and Transmission, and Craig Unit 1 is scheduled to be retired on December 31, 2025.

[3] Platt River Power Authority 2018 Strategic Plan

2.2.3 Rawhide Peaking Generation

PRPA owns five natural gas-fired simple cycle gas turbines ("SCGT") at the Rawhide site. Rawhide Unit A, Rawhide Unit B, Rawhide Unit C, and Rawhide Unit D have capacity of 65 MW each and Rawhide Unit F has a capacity of 128 MW. All of the SCGTs provide PRPA with 388 MW of capacity and operate as peaking resources.

2.2.4 Hydroelectric Contracts

PRPA has long-term contracts with the Western Area Power Administration ("WAPA") for output from two hydroelectric projects. PRPA has contracts with firm transmission from the Loveland Area Project ("LAP") and the Colorado River Storage Project ("CRSP") providing 30 MW and 60 MW of summer capacity, respectively.

2.2.5 Existing Wind and Solar Generation

PRPA currently receives energy from four existing wind and solar generating projects and has entered contracts for two future projects. PRPA receives electricity from the wind and solar generating facilities through power purchase agreements ("PPA"). PRPA has PPAs for three existing wind projects: Medicine Bow, Silver Sage, and Spring Canyon. These contracts are for 6 MW, 12 MW, and 60 MW of nameplate capacity and presently receive capacity credit for 12.5 percent of nameplate capacity. PRPA also has a PPA for solar generation from the Rawhide Flats Solar facility. The contract is for 30 MW of nameplate capacity and solar generation presently receives capacity credit for 30 percent of nameplate capacity.

2.2.6 Rawhide Solar Expansion

In February 2018, PRPA issued a request for proposals ("RFP") for at least 20 MW of additional solar generation to be built on PRPA's system between June 2019 and December 2021. The RFP additionally called for up to 5 MWh of energy storage capacity. As part of this analysis, the 20 MW expansion was assumed to be online in 2020.

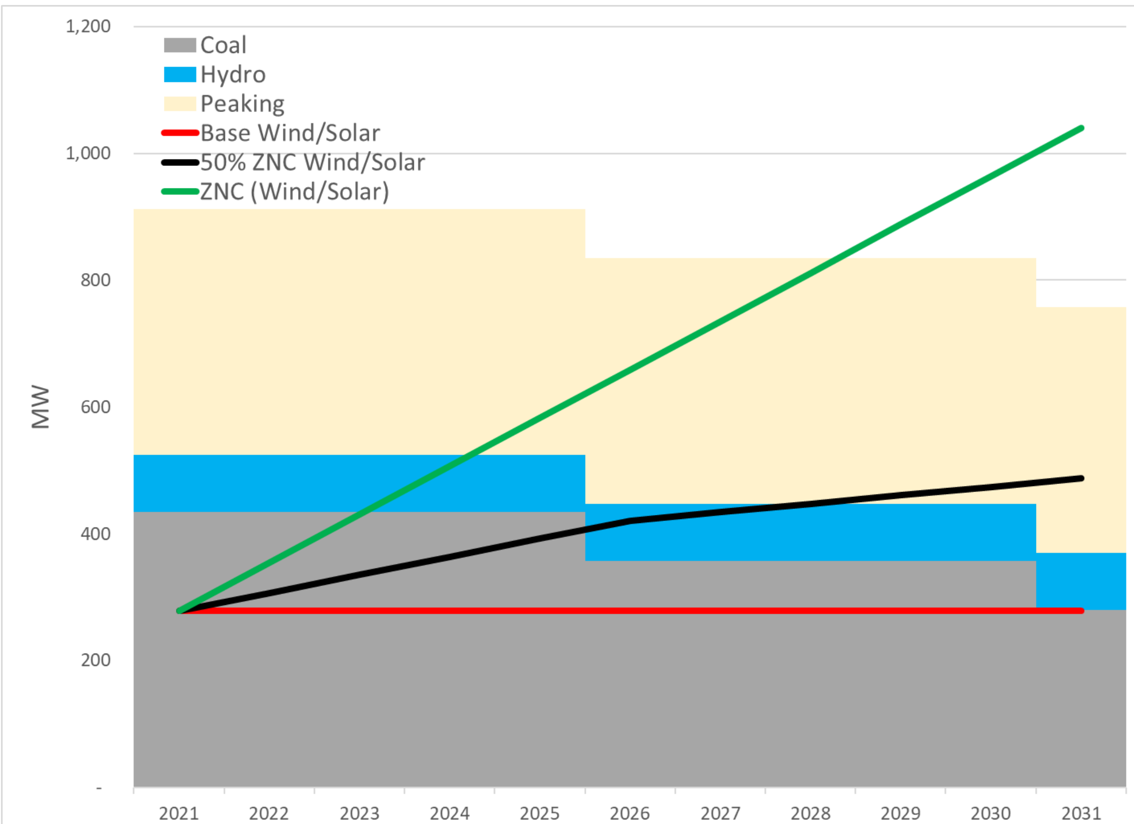
2.2.7 Roundhouse Renewable Energy Project

In January 2018, PRPA signed a PPA for 150 MW of new wind power capacity. The wind project will be developed by Roundhouse Renewable LLC. and will be located twenty miles north of Rawhide Energy Station. The project's 75 wind turbines will be spread 14,000 acres to form the Roundhouse Renewable Energy Project ("Roundhouse"). When completed, the addition of Roundhouse will give PRPA access to a total of 228 MW in wind resources.

2.3 Portfolio Scenarios

By 2021, PRPA anticipates having a total of 228 MW of wind nameplate capacity and 50 MW of solar nameplate capacity in service. The Study designed three scenarios that examined the equivalent hot start outcomes from each. The first scenario keeps the installed wind and solar from 2021 constant through 2031 (228 MW of wind and 50 MW of solar). The second scenario applies half of the respective wind and solar installation as estimated in the Pace Global ZNC study, for each year. The third scenario parallels the ZNC study, it estimates 410 MW of wind capacity and 630 MW of solar capacity by 2031. Figure 2.1 shows the total wind and solar capacity for each scenario.

Figure 2.1: Study Scenarios



For each scenario, Rawhide Unit 1 and hydro generation are assumed to be online through 2031, while Craig Unit 1 is assumed to be retired in 2026 and Unit 2 is retired in 2030.

2.4 Study Objectives

The primary objective of this Study is to provide operational characteristics and impacts to Rawhide Unit 1 across varying levels of wind and solar energy penetration. PRPA has unique issues that drive its decision-making process, and long-term strategic goals. Consistent with typical utility planning, the overall objectives of this Study included the following:

- Evaluate the current condition and operational characteristics of Rawhide Unit 1
- Determine multiple wind and soar integration scenarios to evaluate in this Study
- Analyze the operational and financial impacts of altering the minimum generation capacity of Rawhide Unit 1
- Provide inputs for production cost modeling for use in PRPA's 2020 IRP

To satisfy the Study objectives, Burns & McDonnell utilized a 2-phased approach to complete this Study. The phases were completed in succession and the objectives of each phase are outlined below.

2.4.1 Phase 1 Objectives

The primary goals of Phase 1 were to analyze and identify drivers behind existing operational patterns of Rawhide Unit 1. In addition, Phase 1 consisted of developing multiple wind and solar integration scenarios as a sensitivity on varying levels of wind and solar energy adoption. These scenarios were developed with the goal of representing market conditions for differing operational schema of Rawhide Unit 1.

- Evaluate existing and potential future drivers of Rawhide operational patterns
- Define various wind and solar integration scenarios
- Determine Rawhide operational characteristics across the various scenarios

2.4.2 Phase 2 Objectives

Phase 2 goals consisted of utilizing the outcomes of Phase 1 to determine the impacts of various operating schemes on operational and key unit metrics. Phase 2 additionally involved developing guidance for production cost modeling inputs for PRPA to use in their 2020 IRP. These inputs include the following:

- Availability / forced outage rates
- Unit Start-ups
- Fixed O&M
- Heat Rates
- Cycling Frequency
- Minimum Generation

3.0 PHASE 1 - OPERATIONS ANALYSIS

Burns & McDonnell and PRPA worked in conjunction to develop a range of wind and solar integration scenarios to analyze impacts of varying wind and solar penetration levels and generation portfolios. The following section provides a summary of Phase 1 tasks and results.

3.1 Renewable Integration Scenarios

As part of this Study, Burns & McDonnell worked with PRPA to develop multiple Renewable Integration Scenarios to represent different future outlooks over resource mix and renewable penetration levels. Each scenario includes and classifies hydro generation within the "renewables" definition. The following three scenarios were evaluated in this analysis:

- Existing Portfolio
- Zero Net Carbon
- 50% of ZNC

3.1.1 Existing Portfolio Scenario

The first scenario evaluated in the study maintains PRPA's existing portfolio of renewable energy contracts. This amounts to maintaining 228 MW of wind generation, 50 MW of solar generation and existing hydro. This scenario serves as the baseline case and the minimum level of renewable energy penetration for this study.

3.1.2 Zero Net Carbon Scenario

In 2017, PRPA commissioned Pace Global to determine the least-cost portfolio of generation resources to achieve carbon-neutrality by 2030. The Zero Net Carbon study found a combination of 630 MW of solar generation and 410 MW of wind generation produced the least-cost portfolio to achieve carbon-neutrality. This Renewable Integration Scenario is based on the results of the 2017 study and is the high renewable energy penetration scenario.

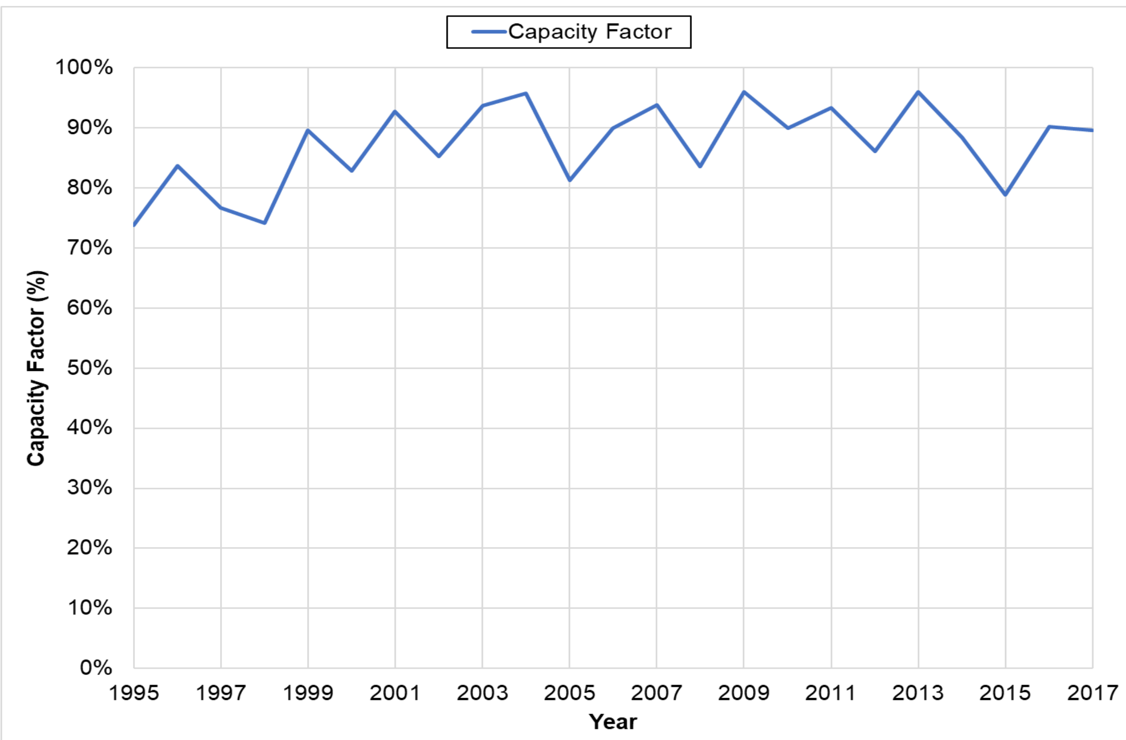
3.1.3 50% of ZNC

The third scenario evaluated in this Study applied half of the annual ZNC wind and solar to form the 50% of ZNC scenario. This scenario includes PRPA reaching a total of 300 MW of wind generation and 188 MW of solar generation by 2031. The energy produced by these resources covers over 50% of PRPA customer's load. This scenario additionally serves as an intermediate renewable penetration scenario.

3.2 Existing Rawhide Operation

A portion of the Phase 1 analysis consisted of determining key drivers of Rawhide Unit 1's existing operational schemes. Based on historical generation patterns, the unit has operated primarily as a baseload unit. Baseload units typically operate at maximum capacity and are operating nearly 100 percent of the time, apart from planned maintenance outages and forced outages. Figure 3.1 presents the capacity factor for Rawhide Unit 1 from 2009 through 2017. Aside from 2015, a year where a major maintenance outage occurred, the capacity factor has remained above 80 percent since 1999. As the amount of wind and solar generation installed near PRPA's system has increased, Rawhide has been relatively unaffected by the increased amount of wind and solar generation to date. As additional wind and solar generation capacity is installed near PRPA's system, the ability to run Rawhide as a baseload unit will become increasingly challenging.

Figure 3.1: Rawhide Historical Capacity Factor



3.2.1 Future Operational Drivers

While Rawhide has historically operated as a baseload unit, increased penetration of intermittent wind and solar generation, will begin to shift the unit to respond like a load-following unit. Particularly in spring months were wind generation is high and electric load is relatively low. Overnight hours will operationally challenge the unit, as electricity use tends to be low and wind generation is up. The minimum generation level of the unit will directly impact the ability of the unit to remain online in a market with high levels of wind and solar penetration. During summer (peak) months, Rawhide will generally operate in a two-shift manner; shifting from minimum generation overnight to maximum generation during the day. The Study reviewed the sensitivity of differing Rawhide's minimum generation levels.

3.3 Dispatch Analysis

Burns & McDonnell developed an Excel dispatch model to estimate Rawhide operational characteristics across the various scenarios. The ability to market surplus Rawhide generation will be a key to minimizing unit starts and cycling in real-time operation. However, the model was designed to stress Rawhide to determine some operating outcomes without the assistance of market imports or exports. This hypothetical operation quantifies the EHS that assists with understanding potential cost implications. Sensitives over the minimum capacity (minimum loading) or Rawhide were performed at 140 MW, 100 MW, and 75 MW. PRPA has traditionally maintained Rawhide operation above 140 MW though testing at the plant has demonstrated that a 100 MW minimum is currently attainable. To achieve 75 MW minimum generation may require significant plant investment along with operational procedure changes. This study includes a 75 MW minimum as a stretch sensitivity to determine the cost implications to O&M.

The model combined the anticipated PRPA resource mix (to include known additions and retirements) and combined varying amounts of wind and solar generation through 2031 to serve only native load. The dispatch model was used to determine the number of cold starts, warm starts, and hot starts for Rawhide across each scenario, sensitivity, and year. The following section describes the development and methodology the model uses to estimate Rawhide operational patterns.

3.3.1 Model Assumptions

The Excel dispatch model developed for this analysis performs a high-level dispatch analysis of PRPA's system. Simplistic risk-aversion logic is included in the model, and Rawhide adheres to specified minimum runtime and minimum downtime inputs. The following assumptions were utilized in the dispatch model:

- Hourly Load - PRPA 2016 hourly load shape
- Base Load Demand Forecast - PRPA's 2016 IRP
- Rawhide Operation Assumptions:
  - Dispatched After Renewables
  - 8 Hour Minimum Runtime

    - 8 Hour Minimum Downtime
    - Hot start: between 8 hours and 24 hours since last shutdown
    - Warm Start: between 24 and 72 hours since last shutdown
    - Cold Start: greater than 72 hours since last shutdown
- An average of existing wind and solar profiles were used for additional wind and solar generation
- CRSP and LAP used historical profiles from 2013 through 2017 to generate an average profile
- Hydro, wind, and solar generation are "must take"
- Craig Unit 1 and Craig Unit 2 are dispatched after Rawhide
    - Craig Unit 1 is retired by 2026
    - Craig Unit 2 is retired by 3031
    - Craig Unit 1 and Craig Unit 2 abide by minimum runtime and minimum downtime inputs
- Natural gas generation meets remaining load not met with renewable or coal generation

3.4 Dispatch EHS Results

The dispatch model evaluated the various scenarios and sensitives from 2021 through 2031. The number of cold starts, warm starts, and hot starts were then used in conjunction with relationships developed by the Electric Power Research Institute ('EPRI") to determine the number of equivalent hot starts across the scenarios and sensitivities. The impacts of plant cycling are captured by calculating the number of Equivalent Hot Starts ("EHS") from the three start categories. As outlined by EPRI[4], one cold start is equivalent to five hot starts and one warm start is equivalent to three hot starts. Table 3.1 contains the number of EHS for each sensitivity, scenario, and year evaluated. Figure 3.2, Figure 3.3, and Figure 3.4 present the number of EHS along with the total amount of installed solar and wind generation on PRPA's system.

[4] EPRI, "Effects of Cycling on the Operation and Maintenance Cost of Conventional and Combined-Cycle Power Plants"

Table 3.1: Dispatch Model Results

Equivalent Hot Starts									
	Base			50% of ZNC			Zero Net Carbon		
Year	140 MW Min	100 MW Min	75 MW Min	140 MW Min	100 MW Min	75 MW Min	140 MW Min	100 MW Min	75 MW Min
2021	75	16	10	75	16	10	75	16	10
2022	64	15	8	83	22	12	99	31	16
2023	53	13	7	88	26	12	125	52	26
2024	42	12	4	96	31	17	149	81	44
2025	33	12	4	102	37	18	171	107	69
2026	28	11	2	108	41	22	189	136	92
2027	22	9	1	104	38	21	208	150	120
2028	17	6	1	101	38	20	217	164	139
2029	16	4	1	95	36	19	239	185	147
2030	14	1	0	90	36	18	251	199	162
2031	13	1	0	86	35	19	265	213	179

3.4.1 Existing Portfolio Results

The baseline scenario evaluated in this study maintains PRPA's existing levels of installed and contracted renewable generation. Figure 3.2 presents the number of EHS at each of the minimum generation levels evaluated along with the amount of solar and wind capacity. The completion of the 150 MW Roundhouse Renewable Energy Project and 20 MW Rawhide Solar expansion will significantly impact Rawhide's operation. The addition of 170 MW of intermittent generation will hinder the ability to continue running Rawhide as a baseload unit, particularly in overnight hours with high levels of wind generation. Reducing the minimum generation level of Rawhide from 140 MW to 100 MW reduces the number of EHS from 75 to 16 in 2021. Decreasing the minimum loading of the unit to 75 MW further reduces the number of EHS to 10 in 2021. In years following 2021, the number of EHS declines for all minimum loading levels. This is due to load growth and PRPA's effectively "growing" into their generation capacity.

Figure 3.2: Equivalent Hot Starts - Existing Portfolio

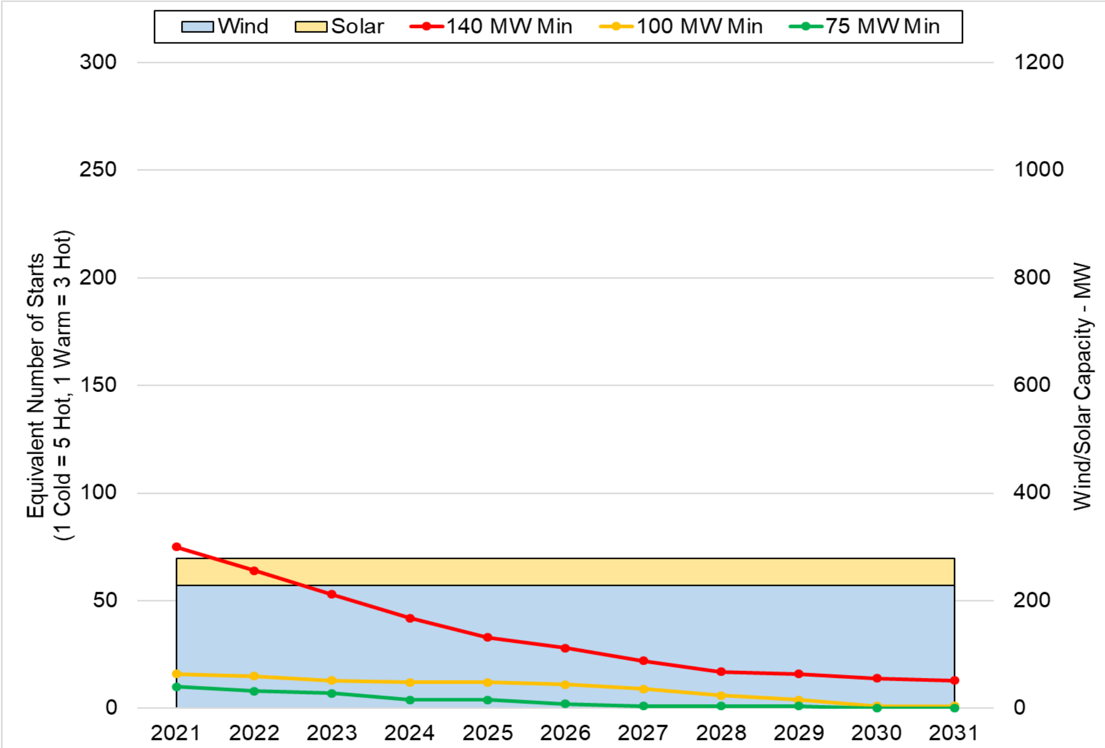


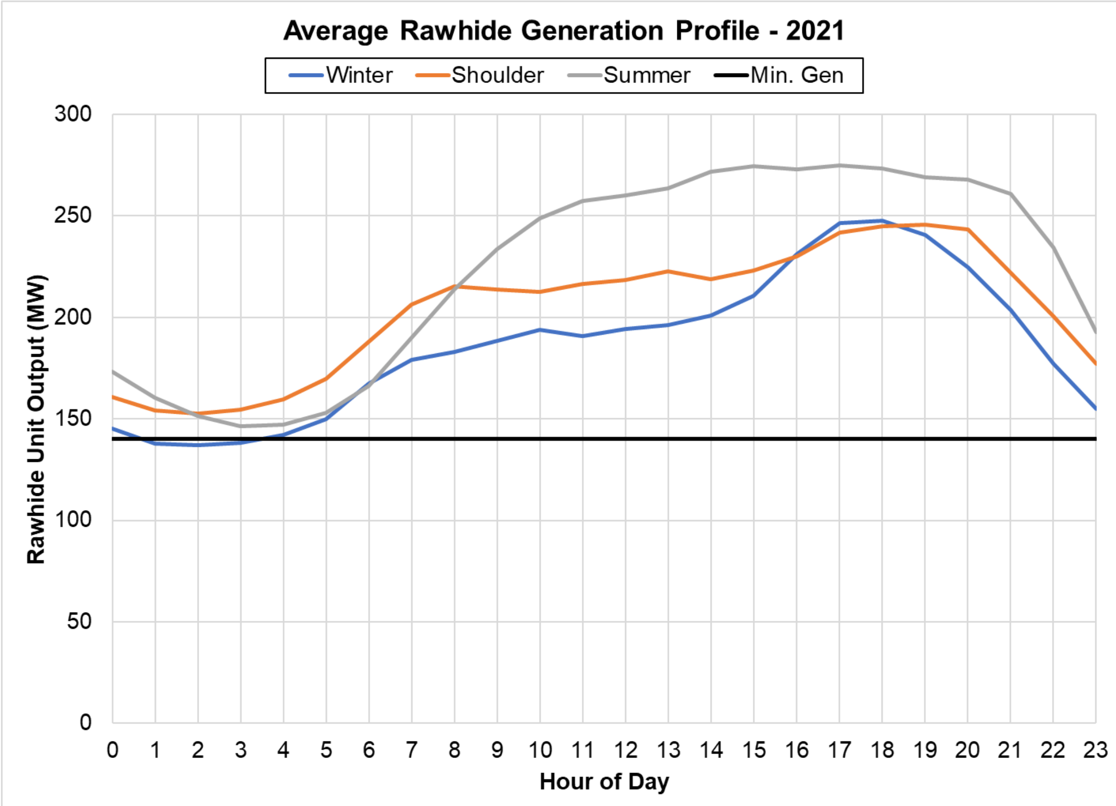
Table 3.2 presents a heatmap of Rawhide starts for 2021. The shoulder and winter months contain larger numbers of starts largely due to high amounts of wind generation in overnight hours paired with low electric load. June and August additionally have elevated number of starts due to significant drops in wind generation during morning hours.

Table 3.2: 2021 Existing Portfolio Heatmap of Rawhide Starts

44% - Carbon-Free		2021 Equivalent Hot Starts by Month											
		1	2	3	4	5	6	7	8	9	10	11	12
TYPICAL DAY (Rawhide Minimum Gen Capacity - 140 MW)	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	1	1	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	1	0	0	1	0
	7	0	0	1	0	0	3	0	0	0	3	0	0
	8	1	0	0	1	1	1	1	2	2	0	5	0
	9	1	1	0	3	0	0	0	2	0	1	1	1
	10	1	0	0	3	0	1	0	1	0	1	1	1
	11	0	0	0	0	0	1	0	1	0	0	1	0
	12	0	0	1	0	0	0	0	0	0	1	0	1
	13	0	0	0	3	1	0	0	0	0	1	0	0
	14	1	3	0	0	0	1	0	1	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	1	2
	16	0	1	0	1	0	0	0	0	0	1	0	1
	17	1	2	1	0	0	0	0	0	0	1	0	1
	18	0	1	0	0	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0	0	0	0
	21	0	0	0	0	0	0	0	0	0	0	0	0
	22	0	0	0	0	0	0	0	0	0	0	0	0
	23	0	0	0	0	0	0	0	0	0	0	0	0
Total - 75		5	9	4	11	2	7	1	8	2	9	10	7

Figure 3.3 shows the average generation profile for Rawhide in the summer, shoulder, and winter months for 2021. On average Rawhide maintains generation levels above 140 MW but lowering the minimum loading of the unit would provide additional flexibility and reduce the number of annual starts. In 2021 Rawhide is forecasted to operate in a load cycling pattern alternating between various generation levels. In summer months, the unit operates at minimum loading during the overnight hours and increases output as solar production declines in the late afternoon. In shoulder and winter months the unit alternates between three generation levels following the load with morning and afternoon peaks.

Figure 3.3: 2021 Existing Portfolio Average Generation Profile



3.4.2 50% ZNC Results

The 50 % ZNC scenario evaluated in this study increases PRPA's wind and solar generation from 228 MW of wind and 50 MW of solar in 2021 to 300 MW of wind and 188 MW of solar in 2031. Figure 3.4 presents the number of EHS at each of the minimum generation levels evaluated along with the amount of solar and wind capacity. At 140 MW minimum generation there is a notable decline in EHS beginning in 2026 due to the retirement of Craig Unit 1. Expanding the amount of intermittent generation to meet 50% of PRPA load with wind and solar generation has significant impacts on Rawhide. As previously shown, presently contracted amounts of wind and solar generation prevent Rawhide from operating as a baseload unit. Increasing the amount of wind and solar generation further challenges the ability of Rawhide to stay online, leading to increased cycling of the unit. Reducing the minimum generation level of Rawhide from 140 MW to 100 MW reduces the number of EHS from 108 to 41 in 2026. Decreasing the minimum loading of the unit to 75 MW further reduces the number of EHS to 22 in 2026. In years following 2026, the number of EHS declines for all minimum loading levels.

Figure 3.4: Equivalent Hot Starts - 50% ZNC

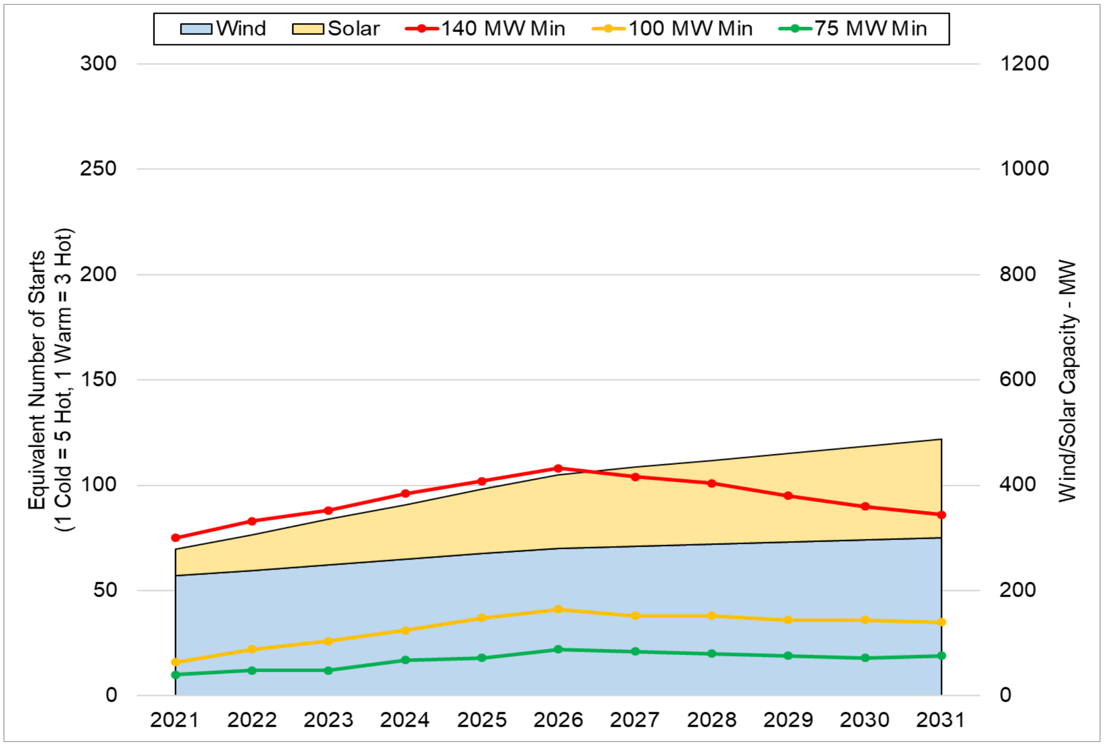


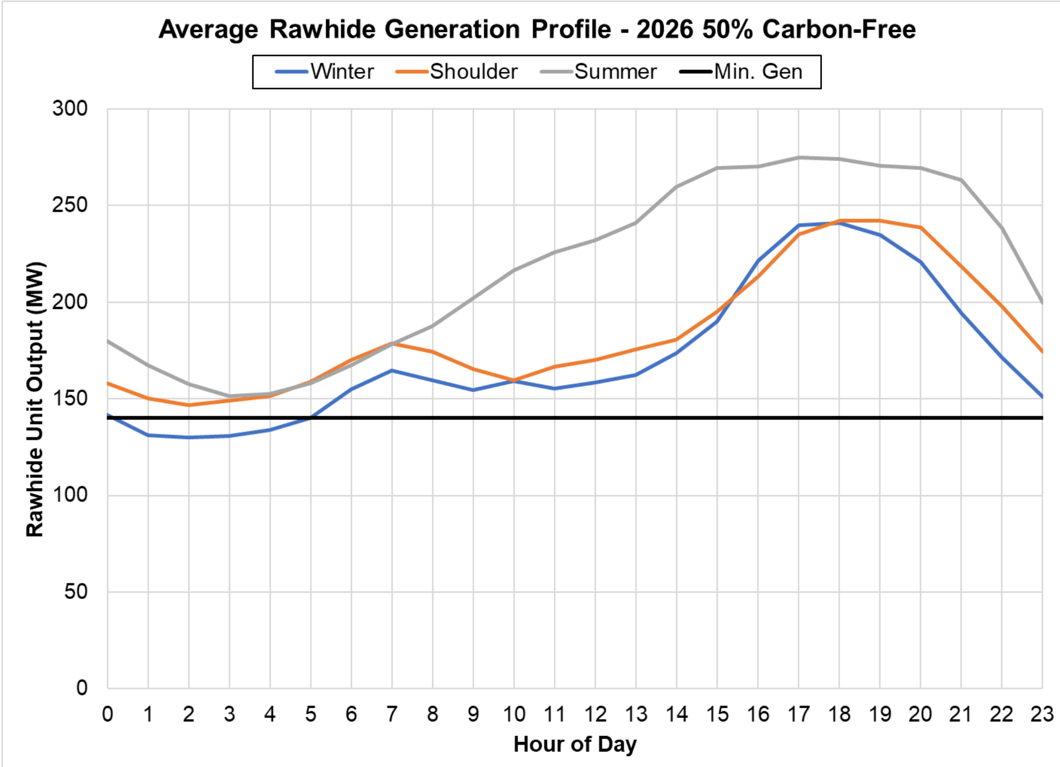
Table 3.3 presents a heatmap of Rawhide starts for 2026. The shoulder and winter months contain larger numbers of starts largely due to high amounts of wind generation in overnight hours paired with low electric load. Lowering the minimum loading of the unit would provide additional flexibility and drastically reduce the number of annual starts. In 2026 Rawhide is forecasted to operate in a load cycling pattern alternating between various generation levels.

Table 3.3: 2026 50% ZNC Heatmap of Rawhide Starts

51% - Carbon-Free		2026 Equivalent Hot Starts by Month											
		1	2	3	4	5	6	7	8	9	10	11	12
TYPICAL DAY (Rawhide Minimum Gen Capacity - 140 MW)	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	1	1	0	0	0	0	0	0	0	0	0
	5	0	0	1	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	1	0	0	2	0
	7	1	0	0	0	0	2	0	0	0	2	1	1
	8	0	0	1	0	0	1	0	1	2	2	2	0
	9	0	0	0	0	1	1	2	1	0	0	3	0
	10	0	0	0	0	1	0	0	4	0	2	2	2
	11	2	0	0	8	0	0	0	0	0	0	0	0
	12	0	0	1	0	0	0	0	1	0	0	1	3
	13	0	0	3	0	0	1	0	0	0	0	1	0
	14	0	4	0	0	0	2	0	0	0	0	1	0
	15	1	1	0	3	4	0	0	1	0	3	0	1
	16	3	0	1	0	1	0	0	0	0	0	1	2
	17	3	2	2	2	0	0	0	0	0	1	1	1
	18	0	1	0	0	0	0	0	0	0	1	0	0
	19	0	0	0	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0	0	0	0
	21	0	0	0	0	0	0	0	0	0	0	0	0
	22	0	0	0	0	0	0	0	0	0	0	0	0
	23	0	3	0	0	0	0	0	0	0	0	0	0
Total - 108		10	12	10	13	7	7	2	9	2	11	15	10

Figure 3.5 includes the average generation profile for Rawhide in the summer, shoulder, and winter months. In the summer and shoulder months, Rawhide is forecasted to maintain generation levels above 140 MW. In the winter months the average generation from Rawhide drops below 140 MW overnight. This is due to the large amount of wind generation during overnight hours while electric load low. In summer months, the unit operates at minimum loading during the overnight hours and increases output as solar production declines in the late afternoon. In shoulder and winter months the unit alternates between three generation levels following the load with morning and afternoon peaks.

Figure 3.5: 2026 50% ZNC Average Generation Profile



3.4.3 Zero Net Carbon Results

The Zero Net Carbon renewable scenario evaluated in this study increases PRPA's wind and solar generation from 228 MW of wind and 50 MW of solar in 2021 to 410 MW of wind and 630 MW of solar in 2031. Figure 3.6 presents the number of EHS at each of the minimum generation levels evaluated along with the amount of solar and wind capacity. Expanding the amount of intermittent generation to the levels specified by Pace Global has significant impacts on Rawhide. As previously shown, existing contracts and installed renewable generation along with a 50 % ZNC portfolio prevent Rawhide from operating as a baseload unit. Increasing the amount of wind and solar generation further challenges the ability of Rawhide to remain online, leading to significant cycling of the unit.

Figure 3.6: Equivalent Hot Starts - Zero Net Carbon

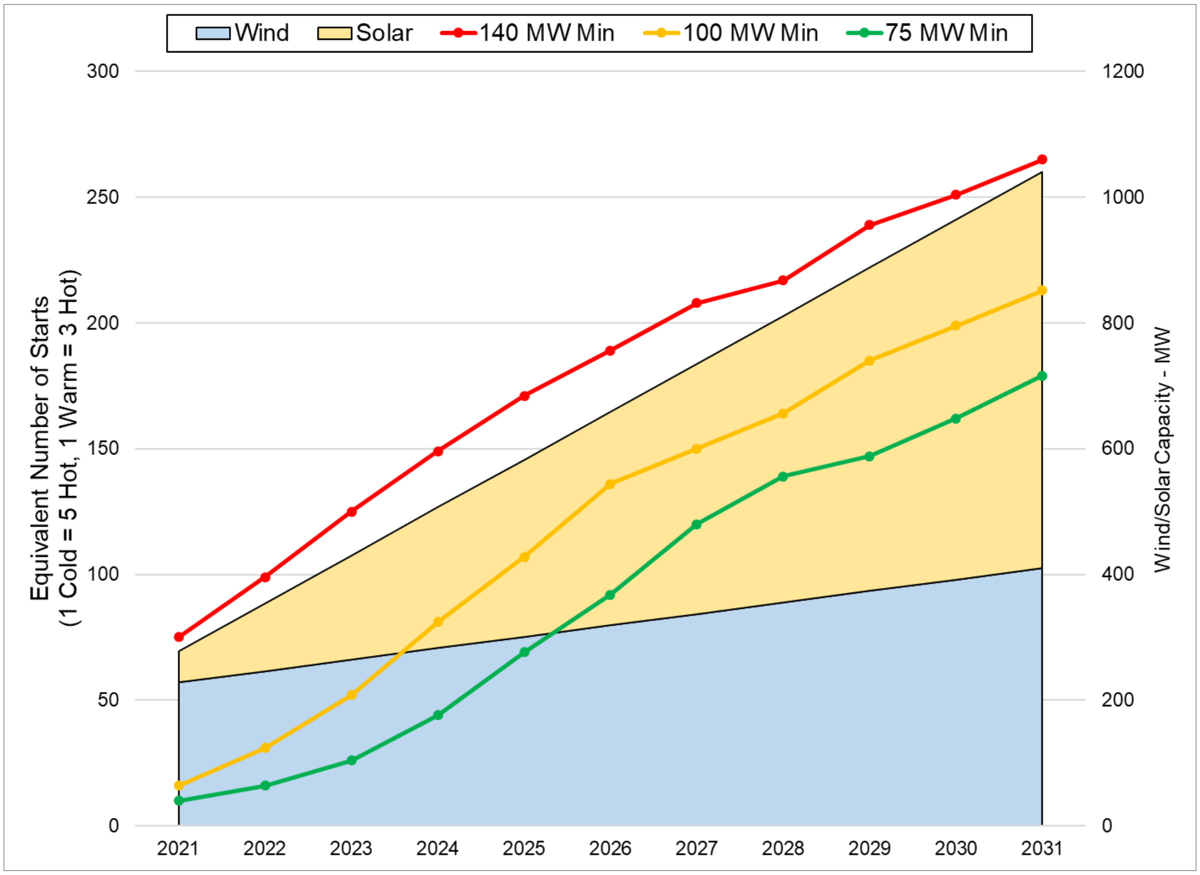


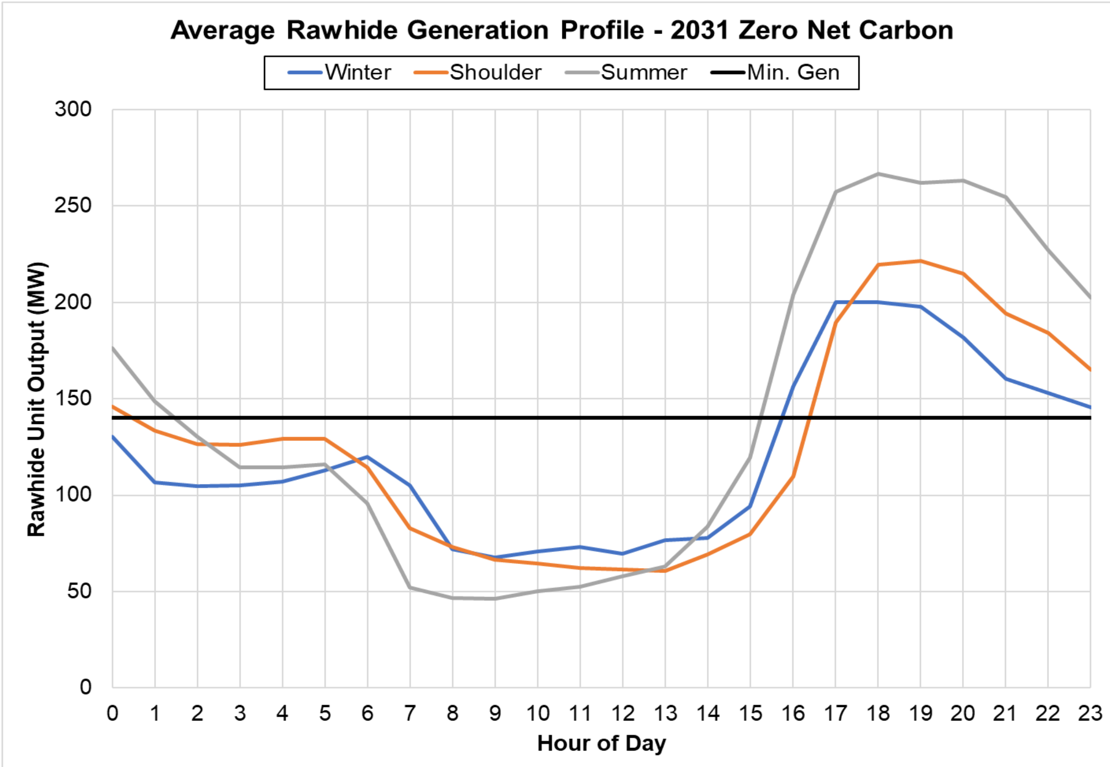
Table 3.4 presents a heatmap of Rawhide starts for 2031. The starts are equally distributed across all months of the year with January, June, and August containing the highest number of starts. In the ZNC portfolio, Rawhide is starting on nearly a daily basis in 2031. Reducing the minimum generation level of Rawhide from 140 MW to 100 MW reduces the number of EHS from 265 to 213 in 2031. Decreasing the minimum loading of the unit to 75 MW further reduces the number of EHS to 179 in 2031.

Table 3.4: 2031 Zero Net Carbon Heatmap of Rawhide Starts

83% - Carbon-Free		2031 Equivalent Hot Starts by Month											
		1	2	3	4	5	6	7	8	9	10	11	12
TYPICAL DAY (Rawhide Minimum Gen Capacity - 140 MW)	0	0	0	1	0	0	0	0	0	0	0	1	0
	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	1	0	0
	4	0	1	1	0	0	0	0	0	0	0	1	0
	5	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	1	0
	7	0	0	0	0	0	0	0	0	0	0	2	3
	8	0	0	0	0	0	0	0	0	0	1	1	0
	9	0	0	0	0	0	0	0	0	0	0	0	0
	10	1	0	0	0	0	2	1	0	1	0	0	1
	11	0	3	0	0	0	0	0	0	1	1	0	0
	12	0	1	1	0	0	0	0	1	1	1	0	0
	13	0	0	0	3	0	0	0	1	0	0	0	1
	14	0	0	0	0	2	2	0	5	0	1	0	0
	15	0	0	0	0	2	2	6	4	5	1	1	5
	16	6	2	3	10	3	9	8	6	10	6	16	3
	17	18	6	15	6	6	9	1	5	1	6	1	5
	18	1	0	0	4	7	1	1	0	0	0	1	0
	19	1	0	1	2	0	0	0	0	0	0	0	2
	20	0	0	0	0	0	3	0	0	0	0	0	0
	21	0	0	0	0	0	0	0	0	0	1	0	0
	22	0	3	0	0	0	0	0	0	0	0	0	1
	23	0	4	0	0	0	0	0	0	0	0	0	0
Total - 265		27	20	22	25	20	28	17	22	19	19	25	21

Figure 3.7 includes the average generation profile for Rawhide in the summer, shoulder, and winter months. This figure illustrates an average daily profile for the seasons shown, actual daily generation (in the model) will not drop below the minimums shown unless minimum uptime and downtime constraints are met. All three average generation profiles have the Unit dropping below the 140 MW minimum loading level between 2 am and 4 pm. The large amount of wind generation along with large amounts of solar generation displace the need for fossil generation during those hours. Rawhide effectively operates in a two-shifting manner in the ZNC scenario; shutting down for overnight and mid-day hours and starting and operating through early-evening peak. Lowering the minimum loading of the unit to the lowest possible level would be required to avoid significant cycling of the unit in a ZNC portfolio.

Figure 3.7: 2031 Zero Net Carbon Average Generation Profile



4.0 PHASE 2 – CYCLING ANALYSIS

Burns & McDonnell simulated three separate scenarios (Base, 50% ZNC, and Zero Net Carbon) to determine the dispatch of the Unit in the market. The scenarios vary wind and solar penetration to determine the effect of generation on the Unit dispatch. The dispatch model, which allowed for the adjustment of Unit minimum load, aimed to provide the annual number of cold, warm, and hot starts and capacity factor for the Unit from 2021 through 2031. Burns & McDonnell approximated the anticipated fixed and variable O&M expenditures associated with the Unit as cycling operation increases. Fixed O&M costs are predicated on the cumulative life of the Unit. Combining historical operation with the dispatch projections, Burns & McDonnell was able to approximate the anticipated fixed O&M expenditures associated with increased cycling and more frequent load-following or ramping operations. Burns & McDonnell provided an outline of events that will affect the variable O&M ("VOM") of the unit. Burns & McDonnell did not extrapolate VOM expenditures for the Unit as a part of this study. A detailed condition assessment of the Unit would be able to provide an outline of VOM expenditures over the life of the Unit but is outside the scope of this report. Burns & McDonnell has identified the consequences of changing operation on major Unit components.

4.1 Approach

In order to determine the cost effects of cycling Burns & McDonnell utilized an EPRI Report[5]. The EPRI Report was written to better understand how cycling will affect steam and combined cycle units. According to the EPRI Report, cumulative operating hours correlate with increased costs associated with the unit's FOM. Cumulative operating hours can be influenced by either unit operation or starts. The occurrence of hot, warm and cold starts has the effect of transforming cumulative actual operating hours to equivalent operating hours; a unit enduring excessive warm and cold starts is aged beyond its actual cumulative operating hours. Since each type of start has a different effect on the unit, all starts must be normalized to EHS for conversion to equivalent operating hours. In years during high cycling operation, the unit may reflect more equivalent operating hours than actual operating hours.

Burns & McDonnell created a dispatch model to approximate the number of EHS, capacity factors and operating hours the Rawhide Unit would experience during varying minimum load and wind and solar penetration scenarios. The dispatch model allowed Burns & McDonnell to approximate the cumulative

[5] *Impact of Cycling on the Operation and Maintenance Cost of Conventional and Combined-Cycle Power Plants*. EPRI, Palo Alto, CA: 2013. 3002000817.

operating hours for the Rawhide unit. The EPRI Report provided the insight and analysis to derive the correlation of equivalent operating hours due to cycling to annual FOM expenses. Burns & McDonnell applied this analysis to determine the anticipated annual FOM at Rawhide across multiple operating scenarios.

4.2 Capacity Factor

Determining the unit's capacity factor for each year provides insight into the type of operation the Unit will experience from 2021 to 2031. Table 4.1 shows the capacity factors generated from the Phase 1 analysis in the base scenario with 228 MW wind and 50 MW of solar with adjustments to the unit's minimum generation.

Table 4.1: Base Model Capacity Factors

	Base		
Year	140 MW Min Capacity Factor	100 MW Min Capacity Factor	75 MW Min Capacity Factor
2021	72.79%	74.70%	74.35%
2022	74.44%	75.80%	75.53%
2023	75.96%	76.97%	76.70%
2024	77.48%	77.86%	77.73%
2025	79.17%	79.15%	79.07%
2026	80.49%	80.31%	80.28%
2027	81.79%	81.51%	81.49%
2028	82.78%	82.50%	82.39%
2029	84.01%	83.89%	83.74%
2030	85.07%	85.03%	84.85%
2031	86.11%	86.09%	85.95%

At the three levels of minimum generation that were analyzed, the Base Model estimates the Unit's capacity factor is estimated to continuously increase from 2021 to 2030. An increase in capacity factor is again observed in 2031 when Craig Unit 2 is retired. The Unit is not anticipated to have a capacity factor below 70 percent and in 2026 the Unit's capacity factor should exceed 80 percent; still in the range of typical baseload generation. Without the addition of wind and solar generation, the Unit will continue to operate as a baseload unit.

Table 4.2 shows the capacity factors generated by the 50% ZNC Model by adjusting the unit's minimum generation.

Table 4.2: 50% ZNC Model Capacity Factors

50% ZNC			
Year	140 MW Min	100 MW Min	75 MW Min
	Capacity Factor	Capacity Factor	Capacity Factor
2021	72.79%	74.70%	74.35%
2022	71.72%	73.68%	73.40%
2023	70.79%	72.73%	72.46%
2024	69.52%	71.52%	71.32%
2025	68.80%	70.73%	70.66%
2026	67.98%	70.01%	69.86%
2027	68.55%	70.56%	70.32%
2028	69.01%	70.79%	70.60%
2029	69.94%	71.55%	71.24%
2030	70.61%	72.01%	71.73%
2031	71.33%	72.53%	72.19%

With each minimum generation limit analyzed, the Unit's capacity factor decreases from 2021 to 2026, but begins to decrease annually from 2026 to 2030. The increased capacity factor coincides with the retirement of Craig Unit 1. Retiring Craig Unit 1 reduces the maximum capacity from Craig Power Plant provided to PRPA from 154 MW to 74 MW. Even with the continuous addition of wind and solar generation, Rawhide will be utilized to fill the void left by the retirements of Craig Unit 1. The Rawhide Unit capacity factor does not recover to the level experienced in 2021 but does exceed 70 percent in all minimum capacity scenarios by 2030, this can be attributed to the load growth projections.

Table 4.3: Zero Net Carbon Model Capacity Factors

Zero Net Carbon			
Year	140 MW Min	100 MW Min	75 MW Min
	Capacity Factor	Capacity Factor	Capacity Factor
2021	72.79%	74.70%	74.35%
2022	68.28%	70.40%	70.22%
2023	63.63%	66.07%	66.14%
2024	59.13%	61.60%	61.88%
2025	56.01%	58.08%	58.38%
2026	53.70%	55.06%	55.47%
2027	51.77%	53.02%	52.99%
2028	50.23%	51.12%	50.99%
2029	48.67%	49.60%	49.74%
2030	47.56%	48.36%	48.44%
2031	46.18%	47.27%	47.26%

Table 4.3 shows the capacity factors generated by the Zero Net Carbon Model by adjusting the unit's minimum generation. Regardless of the Unit's minimum generation, the Unit's capacity factor decreasing

continuously from 2021 to 2031. In 2021 the unit is anticipated to have a capacity factor greater than 70 percent, but by 2029 the capacity factor is anticipated to drop below 50 percent. The Zero Net Carbon scenario contains the most aggressive adoption of wind and solar resulting in the declining operation of Rawhide. The wind and solar adoption outpace the load growth of the PRPA system leading to a reduced capacity factor of the Rawhide Unit.

4.3 Unit Start-ups and Operation

Unit starts will heavily influence the consumption of unit life. Damage from cycling will depend on the number of cold, warm and hot starts the Unit experiences. Cold starts exert the most stress on Units, but any additional starts the Unit experience will reduce the useful life of the Unit. Table 4.4 shows the number of cold, warm and hot starts the Unit will experience from 2021 to 2031 in the Base scenario attributable to economic dispatch. The Unit starts do not account for planned outages or forced outages which would be in addition to the starts in Table 4.4.

Table 4.4: Base Model Detailed Results

Base									
Year	140 MW Min			100 MW Min			75 MW Min		
	Cold	Warm	Hot	Cold	Warm	Hot	Cold	Warm	Hot
2021	-	5	60	-	-	16	-	-	10
2022	-	4	52	-	-	15	-	-	8
2023	-	2	47	-	-	13	-	-	7
2024	-	1	39	-	-	12	-	-	4
2025	-	-	33	-	-	12	-	-	4
2026	-	-	28	-	-	11	-	-	2
2027	-	-	22	-	-	9	-	-	1
2028	-	-	17	-	-	6	-	-	1
2029	-	-	16	-	-	4	-	-	1
2030	-	-	14	-	-	1	-	-	-
2031	-	-	13	-	-	1	-	-	-

The addition of Roundhouse Wind and 20 MW of solar may increase the number of annual cycling at Rawhide. The Base scenario results indicate Rawhide will experience a decrease in starts after 2021 (after Roundhouse and Rawhide Solar). In the 75 MW minimum load scenario the Unit will only incur two additional hot starts due to wind and solar penetration. When the minimum generation of the Unit is assumed to be 100 MW, hot starts at Rawhide are estimated to from 2021 to 2029. Beginning in 2029 and continuing in subsequent years, Rawhide may experience one additional hot start per year. When the minimum generation of the Unit is assumed to be 140 MW, Rawhide is estimated to experience a decrease in hot and warm starts following 2021. Warm starts will only be experienced from 2021 to 2024.

Table 4.5 shows the number of cold, warm and hot starts the Unit will experience from 2021 to 2031 in the 50% ZNC scenario attributable to economic dispatch. The Unit starts do not account for planned outages or forced outages which would be in addition to that starts shown in Table 4.5.

Table 4.5: 50% of ZNC Model Detailed Results

50% ZNC									
Year	140 MW Min			100 MW Min			75 MW Min		
	Cold	Warm	Hot	Cold	Warm	Hot	Cold	Warm	Hot
2021	-	5	60	-	-	16	-	-	10
2022	-	6	65	-	-	22	-	-	12
2023	-	6	70	-	-	26	-	-	12
2024	-	7	75	-	-	31	-	-	17
2025	-	8	78	-	-	37	-	-	18
2026	-	8	84	-	-	41	-	-	22
2027	-	8	80	-	-	38	-	-	21
2028	-	8	77	-	-	38	-	-	20
2029	-	8	71	-	-	36	-	-	19
2030	-	7	69	-	-	36	-	-	18
2031	-	7	65	-	-	35	-	-	19

The 50% ZNC scenario results indicate Rawhide will experience an increase in hot starts regardless of the Unit's minimum capacity, while estimated warm starts will only occur while the minimum capacity is 140 MW. When the minimum generation of the Unit is assumed to be 75 MW, wind and solar penetration will gradually increase the number of hot start events per year from 2021 to 2026. From 2026 until 2031 the Unit will experience approximately 19 hot starts per year through 2031. When the minimum generation of the Unit is assumed to be 100 MW, wind and solar penetration will increase hot starts from 2021 to 2026. After experiencing 41 hot starts in 2026, the number of hot starts per year will decrease and plateau at 35 hot starts per year by 2031. When the minimum generation of the Unit is assumed to be 140 MW, Rawhide is anticipated to experience gradual increase in warm and hot starts after 2021. Warm start will increase until 2025 and hot starts will increase until 2026. After 2025 warm starts will plateau at eight hot starts per year and will only experience a small decrease in 2030 and 2031. Rawhide will experience a maximum number of hot starts in 2026. After 2026 Rawhide will experience fewer hot starts in every subsequent year.

Table 4.6 shows the number of cold, warm and hot starts the Unit will experience from 2021 to 2031 in the Zero Net Carbon scenario attributable to economic dispatch. The Unit starts do not account for planned outages or forced outages which would be in addition to the starts shown in Table 4.6.

Table 4.6: Zero Net Carbon Model Detailed Results

Zero Net Carbon									
Year	140 MW Min			100 MW Min			75 MW Min		
	Cold	Warm	Hot	Cold	Warm	Hot	Cold	Warm	Hot
2021	-	5	60	-	-	16	-	-	10
2022	-	7	78	-	-	31	-	-	16
2023	-	9	98	-	-	52	-	-	26
2024	-	9	122	-	5	66	-	-	44
2025	-	12	135	-	7	86	-	1	66
2026	-	15	144	-	8	112	-	4	80
2027	-	16	160	-	8	126	-	6	102
2028	-	17	166	-	8	140	-	8	115
2029	-	23	170	-	9	158	-	8	123
2030	-	24	179	-	12	163	-	8	138
2031	-	24	193	-	14	171	-	8	155

The Zero Net Carbon scenario results indicate Rawhide will experience an increase in warm and hot starts in every year after 2021 regardless of the Unit's minimum generation limit. When the minimum generation of the Unit is assumed to be 75 MW, the Unit will experience an increase of hot starts in 2021 and warm starts in 2027. When the minimum generation of the Unit is assumed to be 100 MW, the Unit will experience an increase of hot starts in 2021 and warm starts in 2024.

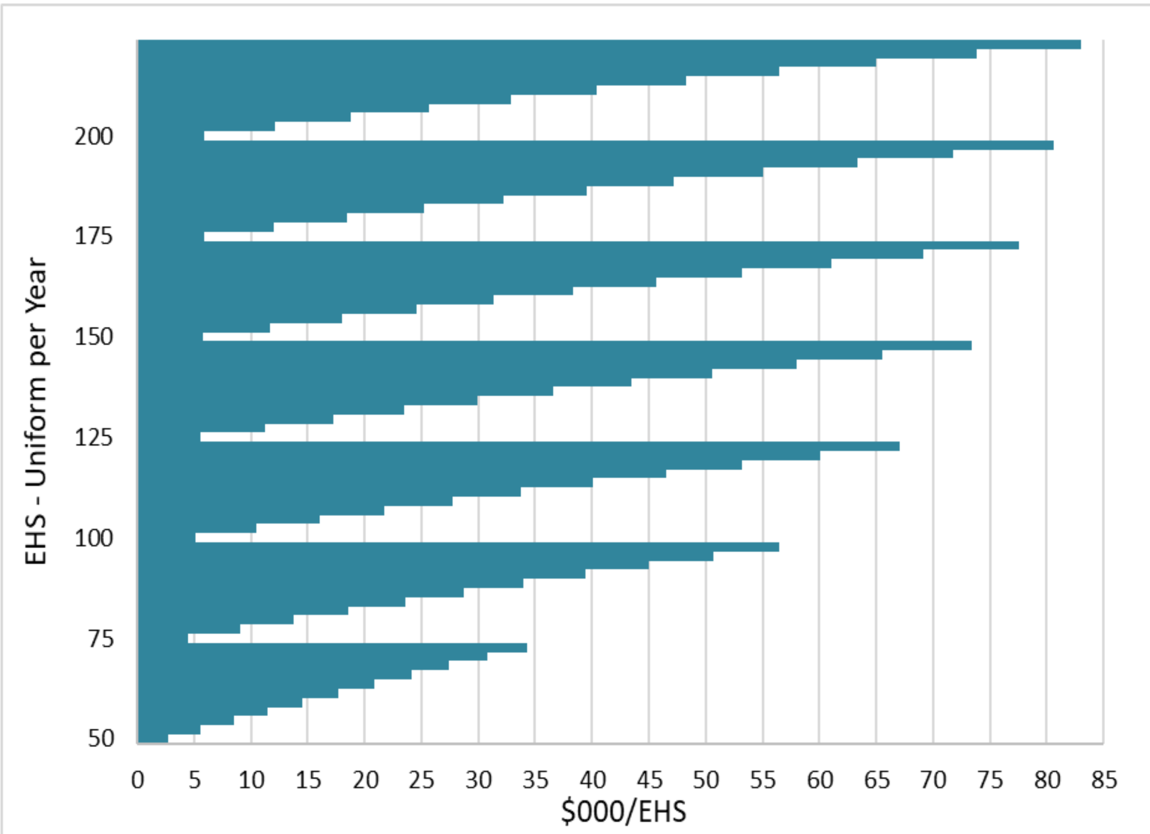
Burns & McDonnell does not anticipate Rawhide experiencing any cold starts as a result of changed operations assuming load grows at the rate PRPA anticipates. If load growth is slower than anticipated Rawhide may experience cold starts due to changed operations. The Unit will experience cold starts coming out of outages, but no additional cold starts should be expected due to dispatch in a market with increasing wind and solar penetration. Cycling operations may require the Unit to operate outside of design parameters which can lead to component failures. The component failure and subsequent effect on availability and reliability is discussed in Appendix B.

4.4 Fixed O&M Forecast

Burns & McDonnell was able to determine a relationship between cumulative operating hours and annual fixed O&M expenditures. Cumulative operating hours were determined by combining historical operating hours with forecasted operating hours determined by the dispatch model. Annual operating hours used in the calculation were either based on actual annual operating hours or annual equivalent operating hours. Equivalent operating hours were determined by converting cold, warm and hot starts into the equivalent number of operating hours the starts impressed on operation. All starts were normalized to hot starts for the conversion. Burns and McDonnell assumed one cold start is equivalent to five hot starts and one warm start is equivalent to three hot starts. The relationship between equivalent hot starts and cost per

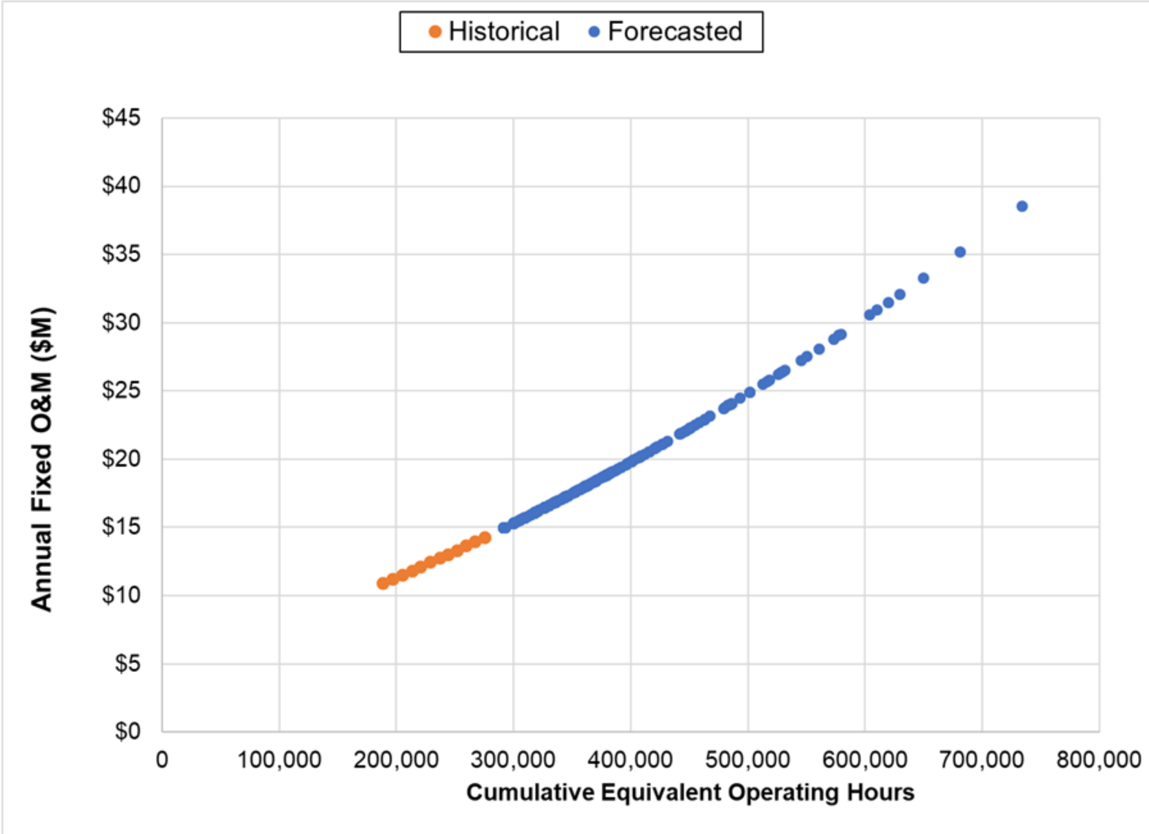
EHS for the study period is displayed in Figure 4.1. The figure illustrates the potential incremental cost implications due to increasing equivalent hot starts as derived from the study. The estimates shown in the figure are for 2021 to 2031 with varying annual EHS. The chart shows that the accumulation of EHS by year results in increasing costs per start. For example, in the first year with 100 EHS, the average start is approximately $5,000 per EHS. By 2031, the effect of accumulated aging due to EHS increases the average per start cost above $65,000 in the 100 EHS case shown below.

Figure 4.1: Estimated Cost per EHS



Burns & McDonnell compared the actual annual operating hours and annual equivalent operating hours and selected the greater of the two values to be the representative operating hours for a given year. With annual operating hours Burns & McDonnell was able to determine forecasted cumulative operating hours for the Unit. With the forecasted cumulative operating hours Burns & McDonnell was able to project the approximate fixed O&M expenditures for the Unit. The forecasted fixed O&M trend is presented with historical fixed O&M costs in Figure 4.2.

Figure 4.2: Historical and Forecast Annual Fixed O&M



Actual operating hours are time-limited within a calendar year. In contrast equivalent operating hours, due to cycling, are theoretically unlimited. Since equivalent operating hours are not bounded by time, starts due to cycling can result in significantly more equivalent operating hours within a calendar year. More equivalent operating hours can exponentially increase the anticipated FOM expenses associated with units and can be seen in Figure 4.2. Thus, if Rawhide experiences more cycling the annual FOM will escalate significantly faster than during normal operation. The rate of escalation will be dependent on the level of cycling required by the unit, but cycling will consume more unit life than normal operation.

Additional maintenance costs will be incurred if the Unit has increased ramp-rates while following load. "Load-follow" cycling will not have the same effect as cycling the Unit on and off but will result in higher damage versus baseload operation. Burns & McDonnell only considered significant load changes as part of the study since minor load changes will not exert significant transients on the Unit leading to additional Unit damage. The costs associated with load following directly correlates to the magnitude of the load change. Burns & McDonell considers significant load changes to be any load change greater than 17.5 percent of the gross dependable capacity of any Unit. Additionally, Burns & McDonnell captured load following scenarios when the Unit pauses load following for up to two hours and the combination of the load changes before and after the pause are greater than 17.5 percent of the gross dependable capacity of the Unit.

In order to determine the cost effects of load following, Burns & McDonnell utilized data from a National Renewable Energy Laboratory ("NREL") Report[6] written to better understand how significant load following affects steam cycle units. The NREL Report provided load following costs based on the individual Units within the study. The report splits the load following costs into quartiles based on the study population. The 25th percentile load following cost represents the break point between the lowest cost and second lowest cost quartiles within the study population. The 75th percentile load following cost represents the break point between the highest cost and second highest cost quartiles within the study population. Burns & McDonnell's analysis utilized the median load following cost from the NREL Report. Table 4-7 displays the load following costs from the NREL Report, which have been escalated to 2019 dollars ("2019$").

Table 4-7: Coal-Fired Boiler Significant Load Following Cost (2019$)

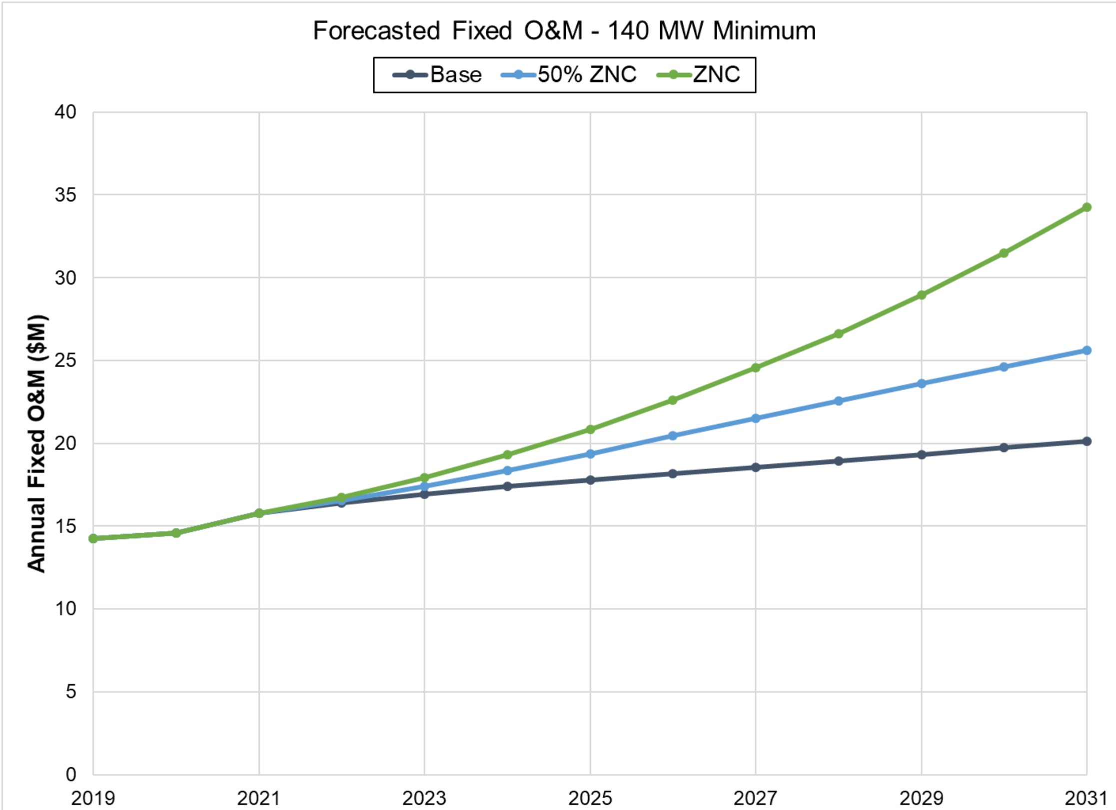
Load Following Cost	25th Percentile	Median	75th Percentile
O&M Cost ($/MW Cap.)	2.18	3.82	4.39

4.4.1 FOM – 140 MW Minimum Generation

Currently, Rawhide Unit 1 is operating with a minimum capacity or turn-down of 140 MW. The Unit runs economically and reliably well above this capacity within the mix of resources. The increase in wind and solar generation may require a strategy that allows the Unit to respond with increased cycling. Figure 4.3 shows the projected FOM expenditure outcome with due to the three renewable scenarios studied. The ZNC scenario may result in the largest number of cumulative EHS by 2031. FOM expenditures are in excess of $34 million. At 50% ZNC, FOM is $25.5 million by 2031 and $20 million at the Base or current committed level of wind and solar with no additions beyond 2020.

[6] *Power Plant Cycling Costs*. NREL, Golden, CO: 2012.

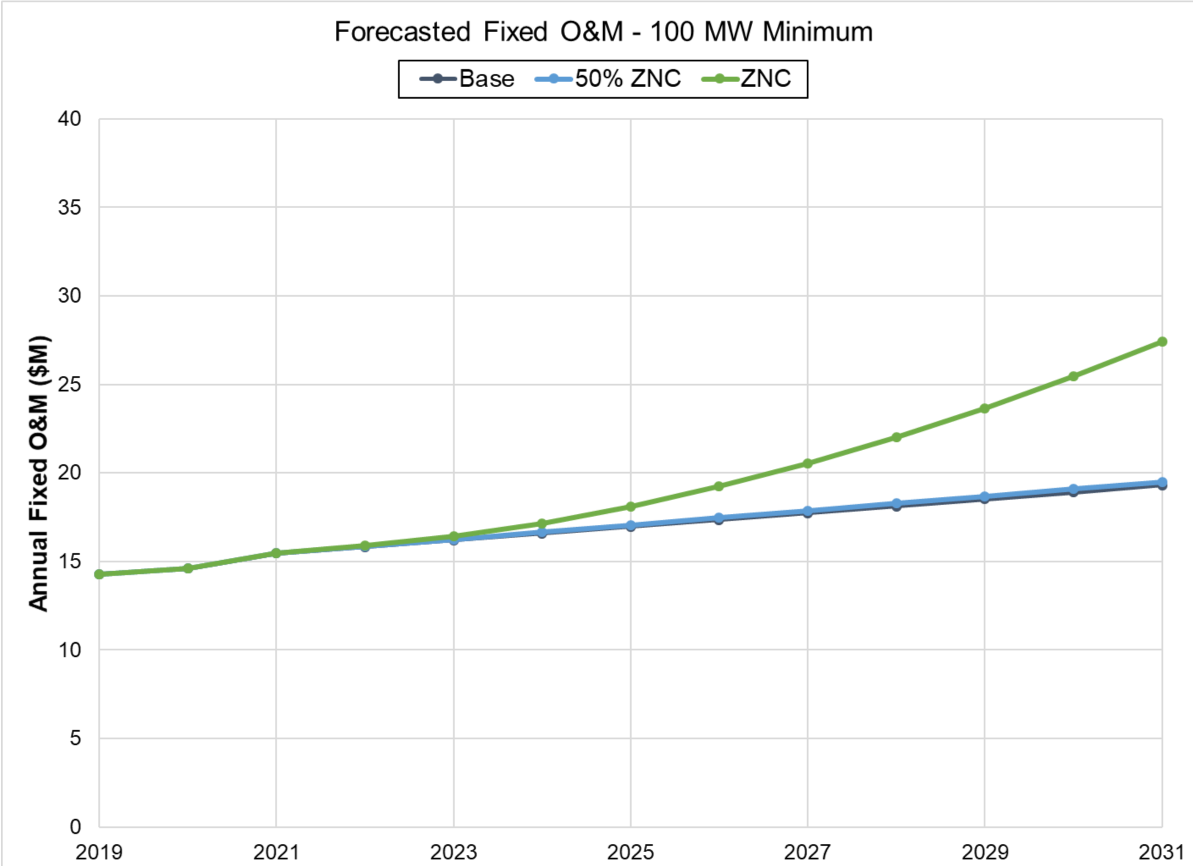
Figure 4.3: FOM – 140 MW Minimum Generation



4.4.2 FOM – 100 MW Minimum Generation

If a 100 MW minimum generation capacity can be achieved on Unit 1, FOM can be reduced. Figure 4.4 shows the estimated FOM costs with a 100 MW minimum on Unit 1. There are less EHS at Unit 1 with a lower minimum, the high wind and solar case (ZNC) yields and estimated FOM of $27.4 million. The 50% ZNC scenario is approximating the Base scenario; both amount to approximately $19.5 million in FOM by 2031.

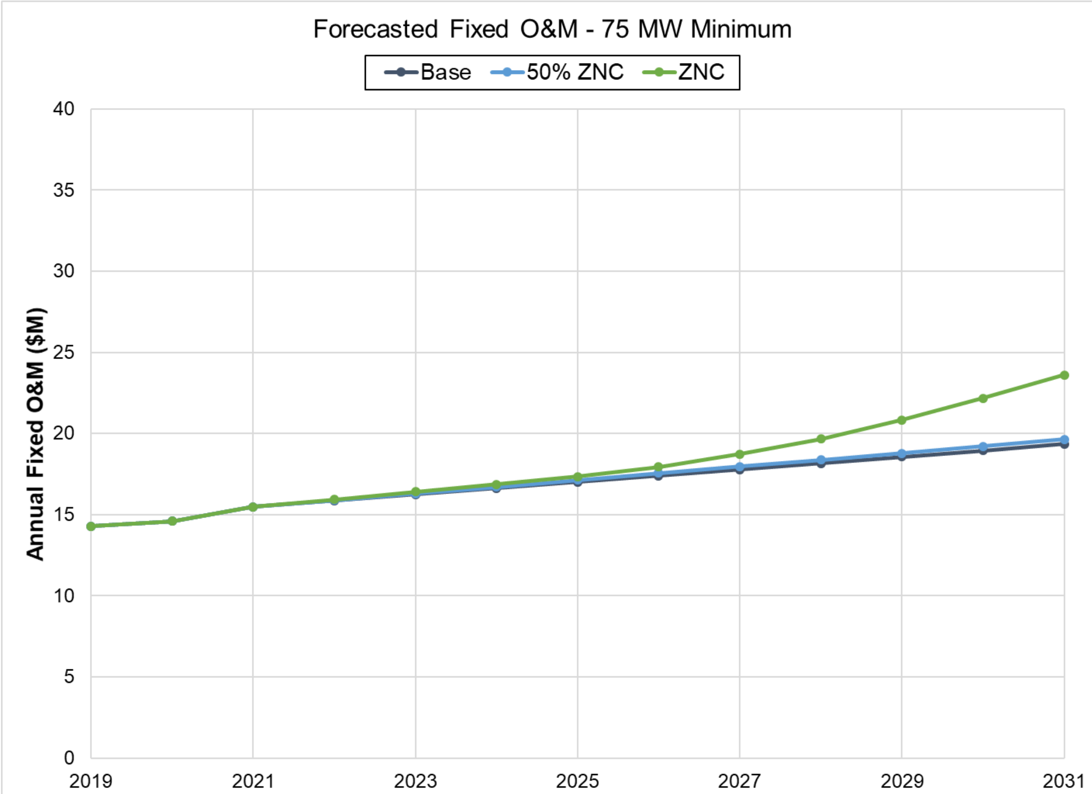
Figure 4.4: FOM – 100 MW Minimum Generation



4.4.3 FOM – 75 MW Minimum Generation

Figure 4.5 shows a smaller difference in FOM between ZNC and the 50% ZNC and Base scenarios with a 75 MW minimum generation capacity on Unit 1. This study did not address the technical viability or economics of achieving a 75 MW minimum, but as shown in the chart, FOM expenditures can be reduced. A high penetration of wind and solar shown in the ZNC scenario, combined with the ability to turn-down to 75 MW at Unit 1 can result in reduced FOM. Expenditures are closer to $20 million for FOM in 2031 while with this lower minimum capability.

Figure 4.5: FOM – 75 MW Minimum Generation



4.5 Variable O&M Discussion

As the Rawhide unit begins to cycle more frequently VOM expenditures will escalate. Unit cycling will decrease the useful life of most Unit components. Due to cycling boiler and turbine overhauls will require more resources to conduct a successful outage repairing or replacing many of the damaged components. Without dedicating adequate resources, the unit will be unable to reach the unit's maximum operational potential. Also, during cycling operation normal maintenance items, such as boiler tube and pump/valve repairs, will require additional resources to offset any damage incurred by the cycling operation.

Operating the Unit in low load or cycling scenarios will require plant operator to be more knowledgeable about the Unit. Additional training may need to be administered to plant operators for more effective and efficient startups and shutdowns. Units that have provided baseload generation do not experience many starts or shut down during a calendar year. Without proper training operators will not be prepared to make proper decisions during startup and shutdown which are highly dynamic environments. Operators are critical in adjusting the Unit and handling emergencies during unit startup and shutdown. Automation will reduce the requirements for operators but changing from baseload to cycling operation will require operators to increase their knowledge of the unit.

Burns & McDonnell anticipates operating expenditures on chemicals and limestone to decrease as the unit increases cycling. Chemicals used for water treatment, and limestone used for SO_2 reduction, are only necessary during operation of the Unit. With increased cycling water treatment chemicals will be used less frequently. Water treatment is necessary to reduce the risk of boiler tube failures. Without the continuous pumping of feedwater into the Unit, the use of water treatment chemicals is unnecessary. As the unit experiences a decrease in operating hours, due to cycling, less limestone will be necessary to stay under the SO_2 emission limit for the unit.

As a boiler approaches the end of design life PRPA must determine whether to continue Unit operation beyond the design life or operate the Unit until failure. If PRPA decides to continue unit operation milestone projects will take place to upgrade Unit components. Many of the milestone projects are large capital projects that will be substantially more than the average VOM expenditures associated with the Unit. If PRPA decides to run the Unit until failure, VOM expenditures drop below the historical average since maintenance will likely be neglected. Once Unit starts operating until failure only essential components and components that pose a safety threat are replaced.

5.0 CONCLUSIONS

Equivalent hot starts will contribute to the aging of the Unit. Increasing wind and solar generation to a total of 410 MW of wind and 630 MW of solar by 2030 will result in escalating FOM expenditures due to cycling.

- By 2031, with no operational or technical changes made to Rawhide Unit 1, the Unit may observe FOM costs in excess of $34 million per year by 2031 under the high wind and solar scenario explored in this study. It's not reasonable nor prudent to operate with EHS (See Table 5.1) at the levels determined in this scenario.

- After 2021, a trajectory build-out of wind and solar in line with the ZNC scenario may require actions to maintain EHS at minimum.

- Wind and solar integration representative of the ZNC scenario will effectively age Rawhide Unit 1 beyond its actual years.

- After 2021,150 EHS (arbitrarily selected) per year will result in approximately $30 million of fixed operating and maintenance expenses.

- Maintaining below 100 EHS can reduce annual FOM to $26.8 by strategically reducing the minimum generation of Rawhide.

5.1 Managing EHS

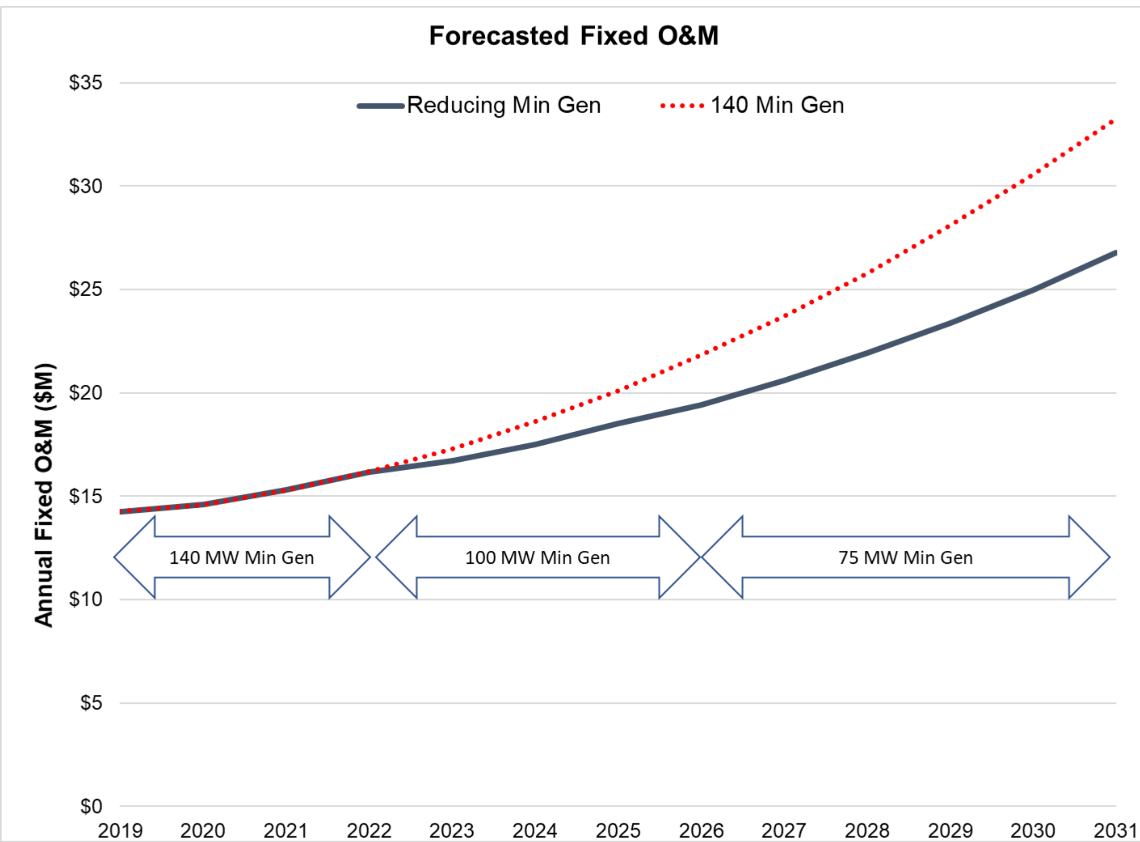
The ability to minimize equivalent hot starts can result in reduced FOM. The ability to reduce minimum generation to 100 MW may be viable in the short term. Achieving 75 MW may require significant retrofits to the Unit, but there is an opportunity and time through 2025. Table 5.1. Figure 5.1 illustrates a potential path for keeping EHS below 100 per year. Even on the road to ZNC, the ability to achieve 75 MW minimum generation will reduce EHS below 100 through 2026 and below 150 through 2029.

Table 5.1: EHS Paths

Year	Wind	Solar	EHS 140 MW Min	EHS 100 MW Min	EHS 75 MW Min	EHS
2021	228	50	75	16	10	75
2022	246	108	99	31	16	99
2023	264	166	125	52	26	52
2024	283	224	149	81	44	81
2025	301	282	171	107	69	107
2026	319	340	189	136	92	92
2027	337	398	208	150	120	120
2028	355	456	217	164	139	139
2029	374	514	239	185	147	147
2030	392	572	251	199	162	162
2031	410	630	265	213	179	179

Figure 5.1 demonstrates that FOM expenditure trajectory can be reduced by achieving lower minimum generation. Annual FOM reaches $26.8 million per year with the ability to turn down minimum generation. The ZNC scenario with 140 MW minimum generation at Rawhide increases cumulative equivalent operating hours and FOM expenditures are approximately $33.3 million per year after 2031.

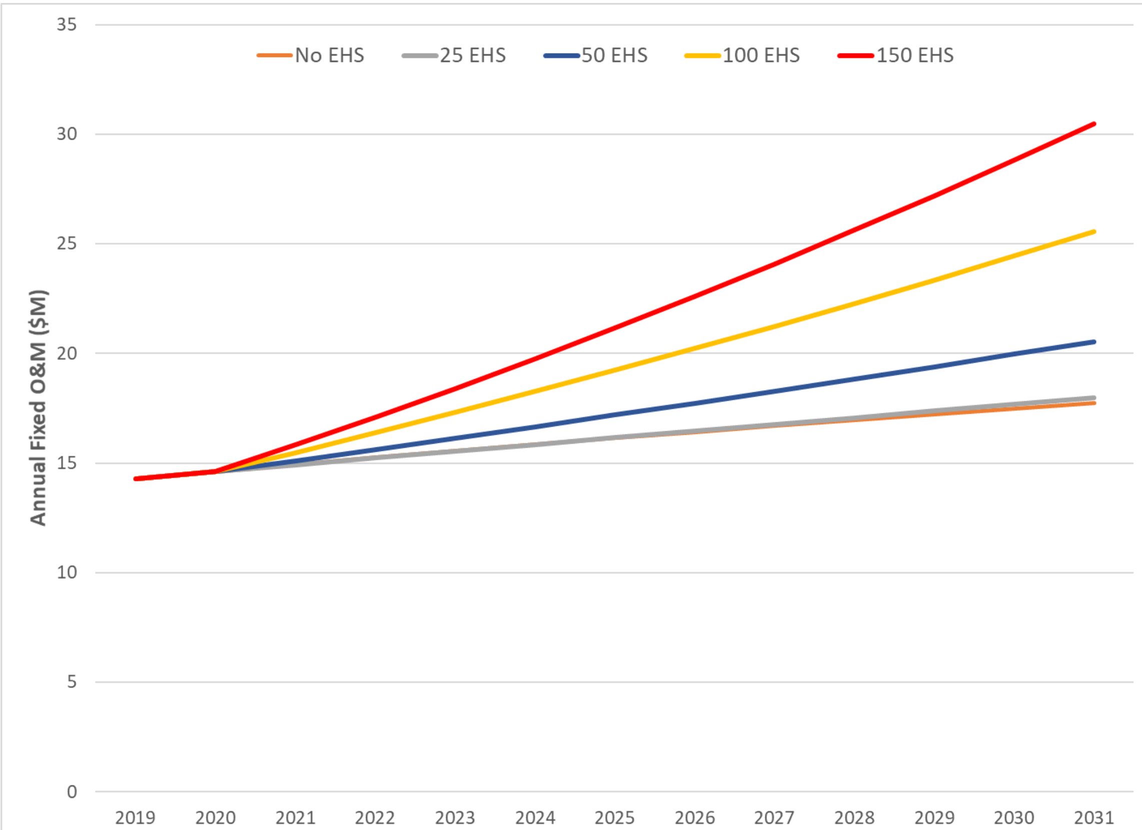
Figure 5.1: Min Gen Adjustments (Reduce FOM)



5.2 Accelerated Equivalent Hours Due to Cycling

The ability to reach a 100 MW minimum at Rawhide Unit 1 will maintain annual EHS below 150 until 2026. Further lowering the minimum generation to 75 MW will help keep EHS below 150 per year through 2029.

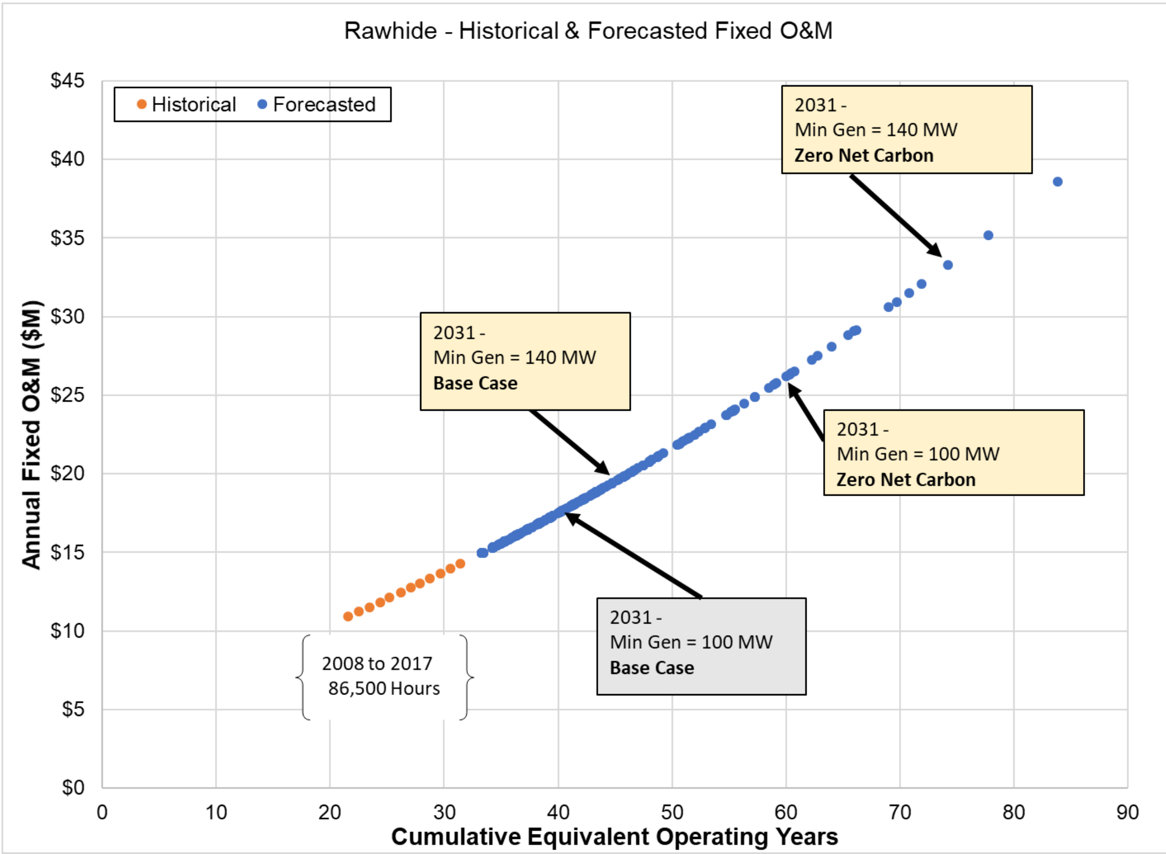
Figure 5.2: Uniform Annual EHS



5.3 Accelerated Aging

Through 2017, Rawhide Unit 1 has accumulated approximately 300,000 hours of runtime. The unit's actual operation from 2008 to 2017 was approximately 86,500 hours. In Figure 5.3, we call out the cumulative operating years that correspond to each of the three scenarios studied with a 140 MW and 100 MW minimum turn-down. By 2031, in the ZNC scenario, the cumulative equivalent operating years may reach approximately 75 with a 140 MW minimum. This number of hours is absurdly high; a unit with an annual capacity factor of 85% would run 7,446 hours per year. By contrast, in a high wind and solar case such as ZNC, the ability to turn down to 100 MW minimum has the effect of reducing equivalent years down to 60. Commissioned in 1984, the Unit's actual age in 2031 will be 48 years.

Figure 5.3: Aging Due to EHS



APPENDIX A RAWHIDE SENSITIVITIES

Figure 5.4: Historic O&M

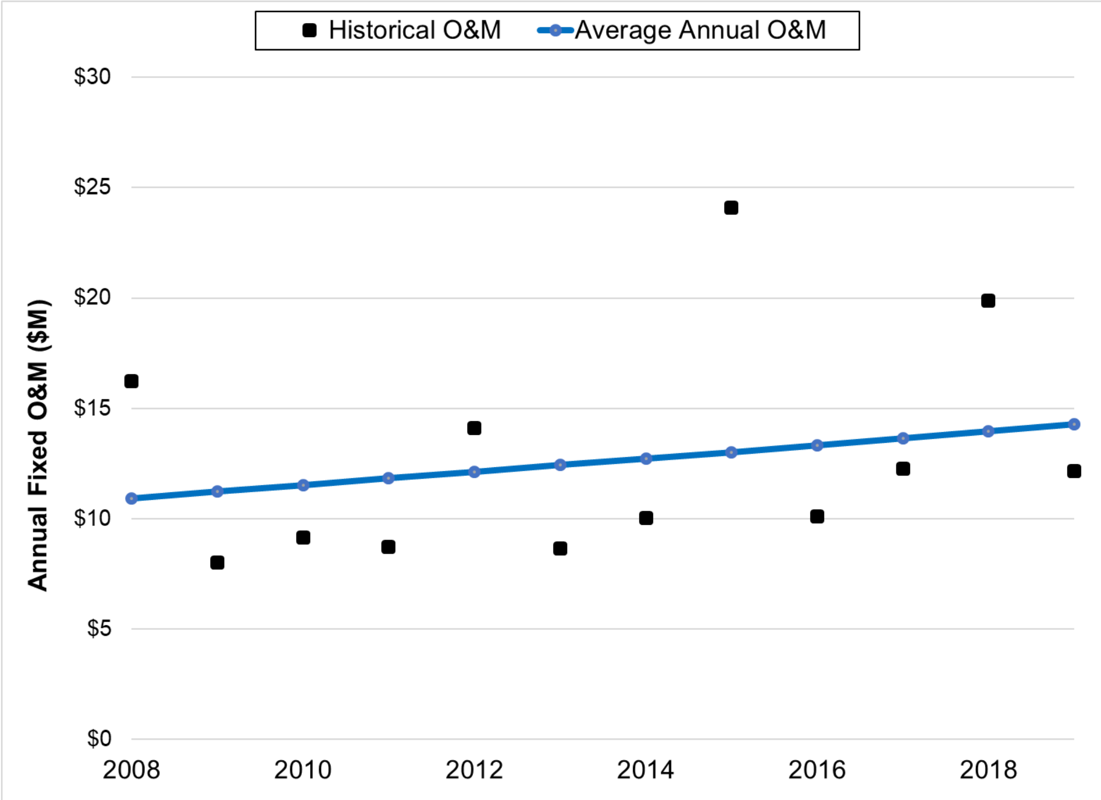


Figure 5.5: Historic & Predicted O&M (Base Scenario)

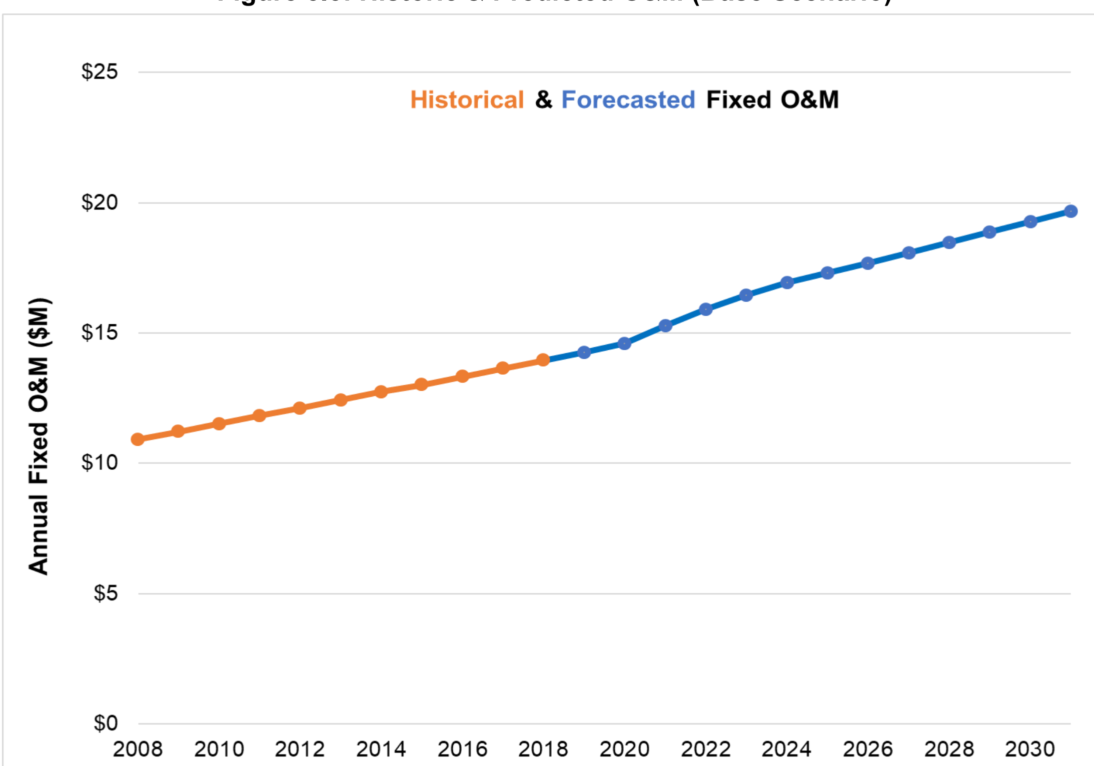


Figure 5.6: 140 MW Minimum Gen (Vary Wind/Solar)

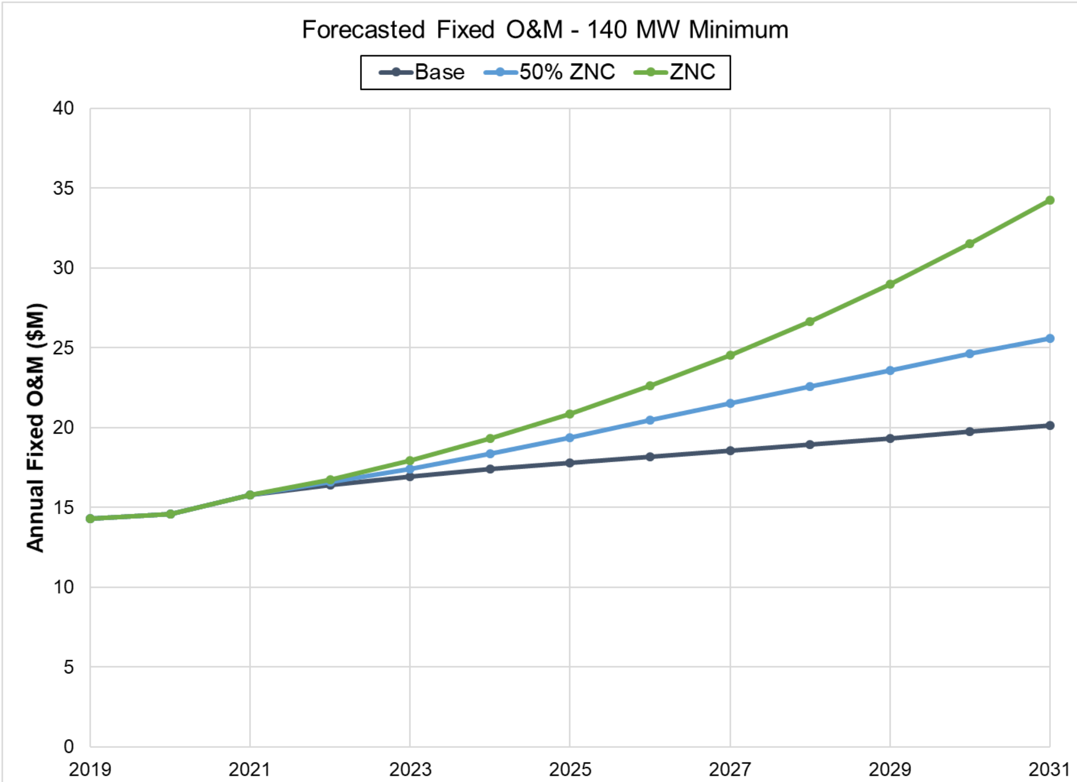


Figure 5.7: ZNC (Vary Minimum Generation)

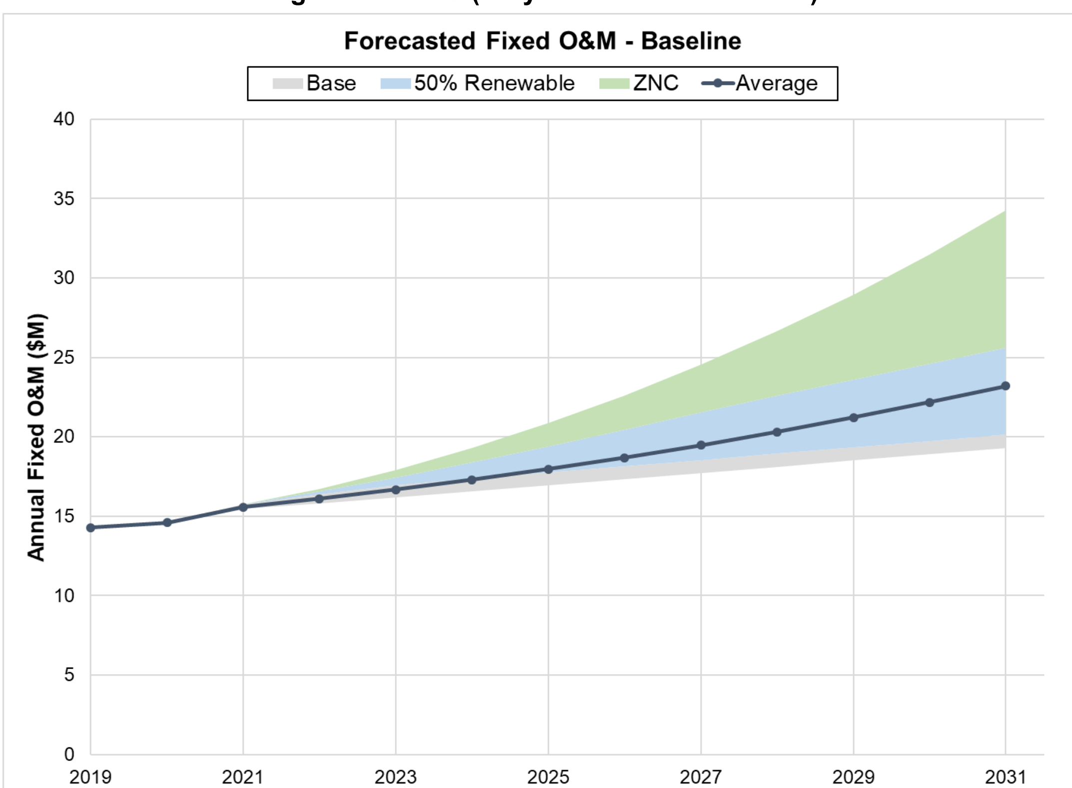


Figure 5.8: ZNC/140 Minimum Gen (Vary Load)

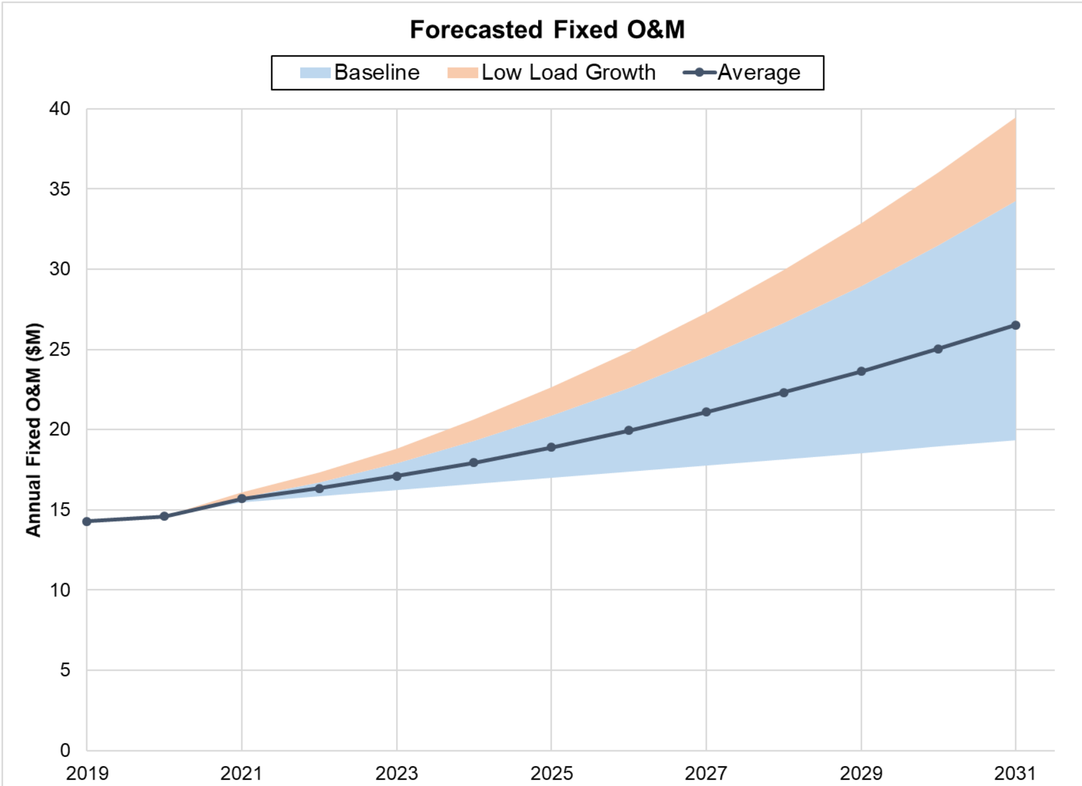
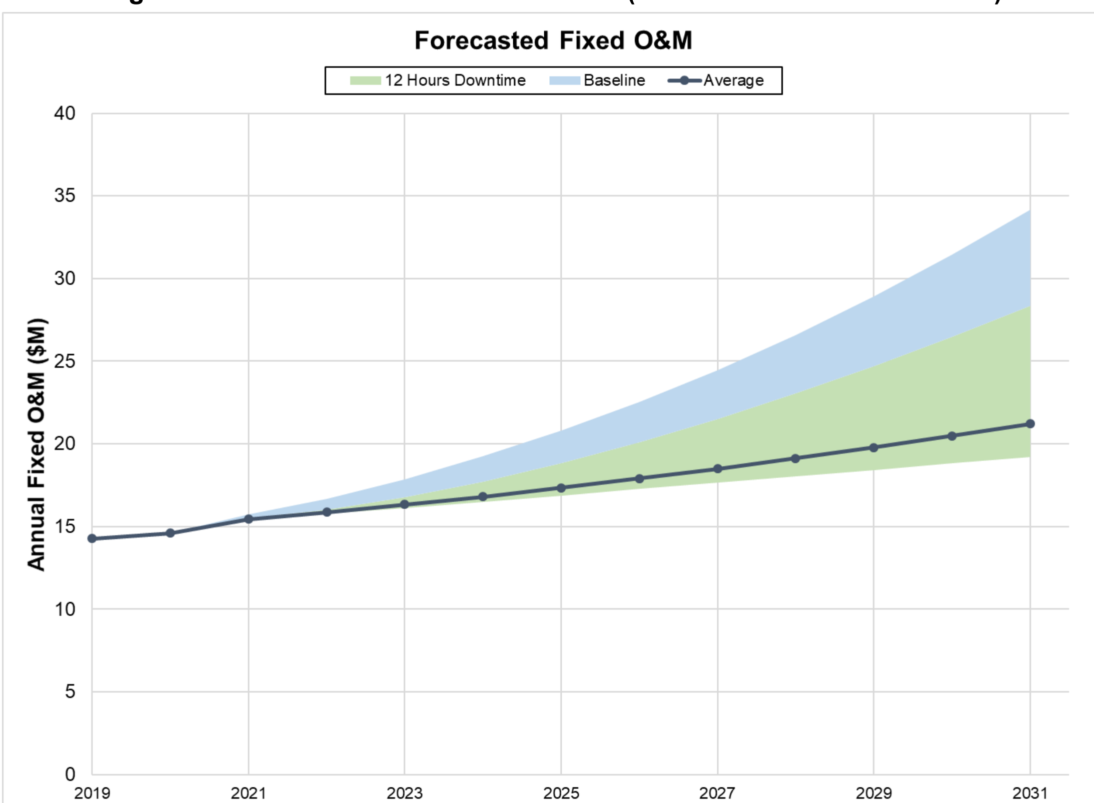


Figure 5.9: 140 MW Minimum Generation (12 Hour Minimum Downtime)



APPENDIX B RAWHIDE SYSTEM COMPONENT COMMENTARY

Availability & Forced Outage Rates

Coal-fired units commonly experience failures due to corrosion, thermal fatigue, creep and creep fatigue, erosion, hydrogen damage, short term overheating and flow accelerated corrosion. Without reducing the operational minimum load or introducing cycling, units will experience less available and reliable operation as components age and reach the end of useful life. As units reduce the operational minimum load or begin cycling operation components within the unit fail at a higher rate. In particular corrosion, thermal fatigue, and creep and creep failure rates increase as a result of the changed operations.

As units start minimum load or cycling operations, many of the effects of the changed operations are unrecognizable in the short-term. As the unit continues minimum load or cycling operations, the effects become more prominent. Minimum load or cycling operations will expose the unit to more failure risks and reduces the unit availability and reliability certainty. Over time, unit failures will reduce the availability and reliability of the unit, although the severity of the decrease will be dependent on specific component failures. Burns & McDonnell did not conduct a detailed analysis of Rawhide component failure risks. Utilizing Burns & McDonnell's industry experience and industry reports on cycling and low load operation, Burns & McDonnell can identify areas of concern resulting from changing the unit from baseload to intermediate generation. The following sections outline failure mechanisms that have been experienced throughout the industry specifically related to minimum load or cycling operations resulting in decreased availability and reliability.

Boiler

Internal and external corrosion is common within all utility boilers. Internal corrosion is associated with boiler water contaminants. Steam attemperators, used to control superheat temperature, introduce impurities into the superheated steam and is the largest driver of internal corrosion in the boiler. Superheated steam supplied by the steam drum has where impurities remaining in feedwater are left during evaporation. Steam attemperators siphon off feedwater from the boiler feed pumps and inject the water into the superheated steam. Since the steam attemperator water does not go through the steam drum before injection, impurities, usually removed from superheated steam, will be present in steam directed to the HP and IP steam turbines. The impurities can contribute to equipment degradation in the boiler and steam turbine. External corrosion caused by corrosive combustion products, a reduced atmosphere in the furnace, moisture between insulation and component, and acid formation when the flue gas temperature falls below acid dew point. Reducing the operational minimum load will increase the rate of external corrosion of back-end boiler equipment. As units operate at lower loads, the flue gas exiting the boiler is often cooler than the design temperature. When the exiting flue gas temperature falls below the acid dew point, equipment on the back end of the boiler experience accelerated corrosion leading to an earlier than expected component replacement.

Cycling will increase the frequency of thermal fatigue on components within the boiler. Large utility boilers are susceptible to thermal fatigue due to temperature differential stresses that develop between components or between the bulk and surface materials of thick-walled components. Cracks stemming from thermal fatigue are prevalent in pipe to drum connections, tube to header connections, and thick-walled components such as the steam drum and headers. Cracking in the boiler does not require wholesale replacements of components, but repairs are made while the boiler is offline reducing the availability and reliability of the unit.

Creep is a time dependent deformation and ultimate fracture at elevated temperatures under the application of a load. Creep and creep fatigue are dependent on the strain range resulting from thermal and mechanical fatigue during normal operation, startup and shutdown. During cycling operations, a boiler experiences a wider range of thermal and mechanical loads contributing to fatigue. The combination of thermal and mechanical failure mechanisms results in failures sooner than expected with each mechanism acting independently. Creep and creep fatigue are mostly seen in the superheater, reheater and associated headers. Similar to cracking in the unit, creep failures often can be repaired without a wholesale replacement of a component but will require the unit to be brought offline to conduct the repair.

During cycling operations, waterwall tubing will experience increased loading and unloading resulting in more stress cycling. Corrosion fatigue is common around tube attachment since large hoop stresses develop there during transient operations. Waterwall erosion is heavily influenced by the feedwater supplied to the boiler. During cycling operations managing the water chemistry process becomes difficult as the chemistry of the condensate and feedwater is constantly changing. Feedwater with more impurities is likely to leave deposits of minerals and corrosive products inside the waterwall tubes.

At lower loads the steam drum may be unable to remove all moisture from steam directed to the superheater due to insufficient steam velocity. Failing to remove all moisture from the steam does not jeopardize the steam drum but can have a significant effect on the superheater.

Superheater and reheater tubes may be constructed of materials that are ill-equipped for the desired low load or cycling operating conditions. Excessive stresses in the superheater and reheater tubes may be experienced during large load changes from inconsistent heating and expansion throughout the boiler. The superheater and reheater headers are susceptible to cracking if a temperature gradient develops as the unit cycles.

Economizer tubes experience the most damage from cycling during stop-start operations. Thermal fatigue is most commonly experienced in the system when cold water passes through a warm economizer header. The introduction of cold water into the warmer economizer header leads to thermal and fatigue in the header. During boiler startup, feedwater within the economizer is often oxygen-rich. The excess oxygen causes pitting corrosion within the tubes. The exterior of the economizer tubes is susceptible to corrosion if the flue gas passing over the tubes falls be the acid dew point. When flue gas falls below the acid dew point SO_x condenses on the tubes.

During cycling operations, the steam attemperators are cycled more frequently. When spray water is injected into the superheated steam the piping downstream of the steam attemperators are susceptible to damage due to material quenching. The spray nozzles used to inject spray water experience significant thermal fatigue during cycling operations. Without steam attemperators operates may struggle to manage the outlet steam temperature of superheater steam directed to the HP or IP turbines.

Steam Turbine

Fatigue in steam turbines is cause by either high-cycle or low-cycle fatigue mechanisms. High-cycle fatigue is usually a byproduct of vibration issues, while low cycle fatigue stems from unit stop-starts or thermal transients. High-cycle fatigue from LP last-stage blade stall flutter can contribute to significant decreases in unit availability and reliability since a large outage would be required to remedy the failure. At lower loads, blade flutter is possible due to the interaction of aerodynamic forces and high back pressure. During lower negative flow can affect the last stage bucket and can cause high vibration stresses. The vibration stresses can lead to a failure in the form of liberation. When operating the unit at lower loads operators must consider blade flutter and avoid the operational region to mitigate failure concerns. Low-cycle fatigue is caused by a deviating from design temperatures and pressures rate of change. As the unit fluctuates between minimum and full-load, crack propagation in the turbine rotor, casing, diaphragm ledges, control valve girth welds, steam chest transitions and ligaments between bolt stud holes in horizontal flanges can occur. The turbine rotor responds to temperature changes within the turbine at a faster rate than much of the surrounding stationary hardware. The varying response time between the turbine rotor and surrounding hardware can result in “rotor-long” and “rotor-short” situations. When there is temperature variation within the turbine, the warmer component will develop surface tension stresses as the material is cooled and attempts to contract but is prevented by the bulk material. The bulk material will be subjected to compressive stresses during the thermal cycle. Inversely, the surface will experience compressive stresses when warmer steam is admitted to a cooler component while the bulk material will experience tensile stresses. Either type of thermal cycling will consume the fatigue life of the material and surface cracking will develop. Replacing turbine equipment, especially turbine rotors, can be expensive and requires long lead times reducing the availability and reliability of the unit.

During lower load operation steam temperatures often drop in the main and reheat steam lines, often called droop. Steam temperature droop will result in an increase of steam moisture levels. Steam moisture levels are designed between six and eight percent. Steam temperature droop can increase the steam moisture levels as high as 15 percent. At elevated steam moisture levels, steam turbines are more likely to experience water droplet erosion and lower loads exposes more turbine stages to damage. Damage sustained by water droplet erosion deteriorate fatigue properties.

Thermal cycling of steam units may lead to solid particle erosion ("SPE") within the steam turbine. Thermal expansion and extraction within the superheater and reheater boiler tubes can cause the exfoliation of iron oxide particles into the superheated steam. SPE most commonly affects turbine components such as control valves, nozzle blocks, and the leading stages of HP and IP turbines. At low load conditions the oxide particles have very high velocities which leads to the oxide materials wearing the turbine components. The damage sustained by SPE will reduce the endurance limit of turbine components. SPE will also limit the maximum output of the turbine which will affect the availability of the steam turbine.

Generator

Low load or cycling operation will subject generators to several failure mechanisms, singularly or combined. Insulation degradation is driven by relative movement or restricted relative movement. In the stator, insulation degradation is primarily driven by the effects of relative movement between the coils and the stator core. Thermal expansion is the primary driver of this relative movement and correlates with the amount of current flowing through the stator windings. Insulation looseness can also be a byproduct of the curing process used during installation. Expansion and contraction of stator coils directly affects the looseness of wedges, accelerating the loosening damage. In some cases, the stator coils can expand as much as 30 percent as compared to the core. When insulation degradation results in a short, a rotor or stator rewind is required to repair the generator. Stator winding insulation is responsible for the most forced generator outages

The end-winding structure has shown a greater susceptibility to damage and cycling-induced damage. The cantilever aspect of the end-winding structure permits local and global vibration which is increased with thermal expansion and contraction that loosens the bonds of the integral coil-to-coil blocking.

The rotor bore is susceptible to crack propagation if the unit begins stop-start cycles. Cracks would begin to propagate due to a variation of centrifugal stress within the shaft in areas where there are pre-existing defects. Crack propagation from bore defects are manageable and predictable which allows the operator to conduct an analysis of the effects of stop-start operations. If managed correctly the rotor bore should not plague the turbine with availability or reliability concerns.

Balance of Plant (BOP) Equipment

Cycling of BOP equipment reduces the overall useful life of the components and leads to failure sooner than anticipated. Many BOP systems have redundant components that allow for the system to operate while repairs or replacements are taking place avoiding availability and reliability concerns. Other components, such as the boiler feed pump and condenser, can limit the overall plant output due to equipment failures thus reducing the availability of the unit. BOP equipment will experience similar failure mechanisms as the boiler and steam turbine when exposed to cycling operations. Operating at lower loads will put additional stresses on BOP equipment since the components will operate outside of the design parameters. In particular lower loads will put additional stress on boiler feed pump recirculation valves which are critical during boiler startup.

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