Zero Net Carbon Portfolio Analysis

Prepared for:

Platte River Power Authority

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TABLE OF CONTENTS

BACKGROUND 3
OVERVIEW 3
ZERO NET CARBON 3
PROJECT INPUTS 4
METHODOLOGY 4
CARBON REDUCTION GOALS 7
ACCOUNTING FOR ZERO NET CARBON 7
MODELING APPROACH 10
AURORA OVERVIEW 10
LONG-TERM CAPACITY EXPANSION PLAN 10
ZERO NET CARBON (ZNC) MODELING PROCESS 11
PORTFOLIO ANALYSIS 13
EXISTING INSTALLED CAPACITY 13
THE 2016 IRP RECOMMENDED PORTFOLIO 13
CONSTRUCTING THE ZERO NET CARBON PORTFOLIO 15
WIND AND SOLAR ECONOMICS 15
VALUE OF STORAGE 17
ZERO NET CARBON PORTFOLIO 18
EVALUATION OF COST IMPACT 21
MARKET PURCHASES AND SALES 22
RISKS OF A ZERO NET CARBON (ZNC) PORTFOLIO 24
CONCLUSIONS AND RECOMMENDATIONS 26
APPENDIX A: MARKET ASSUMPTIONS 30
STANDARD ASSUMPTION EXHIBITS 30

EXHIBITS

Exhibit 1: 2030 ZNC Example with Imports and Exports Exchanged at a Rate of 1,803 lb/MWh 8
Exhibit 2: 2030 ZNC Example with Imports and Exports Exchanged at a Rate of 1,434 lb/MWh 9
Exhibit 3: ZNC Portfolio Carbon Output by Year 9
Exhibit 4: ZNC Modeling using AURORA Long-Term Optimization 11
Exhibit 5: 2030 Integrated Resource Plan (Capacity by Generation Type) 13
Exhibit 6: 2018 Platte River Portfolio Composition (Nameplate Capacity) 14
Exhibit 7: Generation for IRP Portfolio 15
Exhibit 8: All in Wind and Solar Costs 16
Exhibit 9: Wind vs. Solar All in Costs $/MWh 17
Exhibit 10: Levelized Cost of Energy 18
Exhibit 11: Capacity Comparison (2018 vs. 2030) 19
Exhibit 12: Portfolio Buildout for ZNC Portfolio 20
Exhibit 13: Generation for ZNC Portfolio 20
Exhibit 14: Financial Overview (Nominal Dollars) 21
Exhibit 15: Annual Costs for the ZNC Portfolio (Nominal Dollars) 22
Exhibit 16: Market Sales and Purchases for ZNC and IRP Portfolios 23
Exhibit 17: Capacity Mix of ZNC Portfolio 27
Exhibit 18: Cost of Alternative Portfolios Nominal ($000s) 28
Exhibit 19: Total Portfolio Cost (shown in Nominal Dollars) 28
Exhibit 20: Existing Plant Operating Parameters 30
Exhibit 21: New Technology Options ($2018) 30
Exhibit 22: National Gas Prices (Nominal Dollars) 31
Exhibit 23: Coal Prices (Nominal Dollars) 31
Exhibit 24: Emission Prices (Nominal Dollars) 32
Exhibit 25: Carbon Accounting for all Portfolios 32
Exhibit 26: Energy and Peak Demand (MW) 33

BACKGROUND

OVERVIEW

Pace Global, a Siemens business ("Pace Global"), has prepared this report as an independent assessment of the implications of Platte River Power Authority (Platte River) achieving and maintaining a "zero net carbon" ("ZNC") target for its generation supply portfolio by 2030. In this report, the term "carbon" is used to expediently describe carbon dioxide, or CO_2.

Platte River Power Authority (Platte River) is a not-for-profit wholesale electricity generation and transmission provider that delivers safe, reliable, environmentally responsible, and competitively priced energy and services to its owner communities of Estes Park, Fort Collins, Longmont, and Loveland, Colorado for delivery to their utility customers.

ZERO NET CARBON

Platte River engaged Pace Global in 2017 to analyze the system cost to convert to a portfolio that will yield ZNC for its generating system by 2030. This approach differs from a zero-carbon portfolio in that traditional fossil-fueled resources are held in the portfolio to ensure system stability and reliability. To achieve zero net carbon, any carbon produced by fossil resources is offset through generation from excess renewable resources that is then sold to the regional power market, thus achieving a "net" zero carbon emission overall. The table below summarizes the key definitions for the different portfolio constructs.

Zero Carbon Portfolio	A portfolio where energy is produced and delivered to end-users using generation types that yield no carbon output. This type of portfolio includes only resources such as wind, solar, and battery storage. This system would not include any carbon producing generation or power imports and would operate largely in isolation of the regional grid.
Zero Net Carbon (ZNC) Portfolio	A portfolio where both zero carbon and carbon producing generation technologies can be used. However, the portfolio offsets any carbon produced either by producing and selling excess carbon-free generation (such as wind and solar) off system, or by purchasing carbon offsets.
Carbon Offset	An action or activity that compensates for the emission of carbon dioxide or other greenhouse gases to the atmosphere

PROJECT INPUTS

Platte River, through guidance from its owner communities, provided high-level assumptions for this study, including:

Objective Statement:

Evaluate a least-cost portfolio of generation resources that can achieve and sustain zero net carbon by 2030.

Key Assumptions:

- All coal plants exit service by 2030 (Rawhide and Craig)
- Maintain required resource adequacy / reserve margin of 15%
- Maintain existing hydro power positions
- Maintain existing renewable positions and add as necessary to meet ZNC targets
- Retain existing CTs as a “free capacity option”; however, the units are not required to run
- Consider 4-hour lithium-ion battery energy storage with a peak credit of 75% as a resource option
- Determine the least-cost feasible generation mix that achieves the ZNC target considering a range of technology options (e.g. solar, wind, gas combined cycle, combustion turbines, reciprocating engines, battery storage)

METHODOLOGY

In preparing this report, Pace Global developed a portfolio for Platte River that fulfills the zero net carbon target by 2030, ***at the least-cost***, while simultaneously maintaining a minimum planning reserve margin within existing transmission transfer capability limits. A wide range of technology options were considered as candidate technologies, including solar and wind as renewable options, battery energy storage, and several gas-fired technologies (simple cycle combustion turbines, combined-cycle combustion turbines, and reciprocating engines).

Pace Global used AURORAxmp® (AURORA)—a chronological dispatch model which uses hourly production simulation—to assess portfolio options that can achieve ZNC by 2030. The AURORA model has the capability to assess construction and retirement options for generation units based on economic assessments under a variety of constraints. Many utilities use AURORA, and Pace Global has used it for more than 15 years in modeling the U.S. electric utility industry. Platte River also used AURORA for its 2016 Integrated Resource Plan (IRP).

For this project, Pace Global modeled Platte River as a sub-region within the broader Colorado power market. The model was run on an hourly basis with the generation dispatched against the Platte River system load and allows for economically beneficial, off-system sales and purchases. While this approach does not address intra-hour intermittency, it is an industry-accepted approach for long-term planning purposes.[1]

Pace Global's basic modeling approach included the following steps:

1. Define the marginal carbon emission rate of the existing regional power "market"—1,803 lb/MWh was used as the marginal carbon emission rate for the regional power market based on the published eGrid Rockies data for non-baseload generation.[2]
2. Establish a starting level of renewable energy requirements as a percentage of Platte River's load. This is done because the AURORA cannot simultaneously solve for both the emission reductions required to hit net zero carbon emissions and the least-cost portfolio, so model iteration is required.
3. Solve for the least-cost mix of generation technologies based on capital costs, and fixed and variable operations and maintenance costs using hourly production modeling over the forecast horizon.
4. Assess the results to determine if ZNC is achieved each year beginning in 2030.
5. Modify the renewable generation capacity as a percentage of load and repeat steps 3 and 4 until ZNC is achieved in 2030 and then maintained beyond 2030.[3]

Pace Global developed assumptions, described in the body of this report and in the attached appendices. The key assumptions include:

- Capital cost projections which reflect rapid declines in renewable and storage costs[4]
- Fuel cost projections for coal, natural gas, and transportation[5]
- A carbon price trajectory that reflects a carbon regulatory future post 2024 but exhibits relatively low prices for carbon (under $10 per ton in real $2018 dollars through 2050)

Platte River provided additional modeling assumptions including:

- Wind and solar PPA costs and capacity factors
- Transmission, integration, and congestion costs associated with PPA purchases

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[1] Intra-hour analyses would support refinement the results to assess the relative value of short term energy storage versus fast ramping, fossil fueled technologies for responding to the intra-hour production intermittency from wind and solar generation. This study, however, was designed to assess whether energy storage or fast ramping, fossil fueled technologies are more economic for longer term support for renewable intermittency.

[2] The 1,803 lb/MWh marginal market emission rate was held constant over life of the study. However, Pace Global determined that even if the market emission rate were 1,434lb/MWh "net zero" carbon emissions would still be achieved in year 2030 with the recommended portfolio. Pace Global assumed that any purchases or sales by Platte River would not be large enough to impact baseload generation units of the broader regional market, but rather would impact the output and resulting emission of intermediate or peaking generation units in the region. Under this approach, each renewable MWh that Platte River sells into the market serves to "offset" the generation of an existing fossil fueled generation unit in the broader regional market, and results in a reduction of 1,803 lb/MWh to the overall market emissions.

[3] Increments of 3% increase in renewable capacity were used to assess zero net carbon of each portfolio option – the iteration process was stopped when zero net carbon was achieved. Using smaller increments would have allowed us to meet the standard without over-achieving in each year but we do not expect a material change in buildout and associated costs.

[4] For several technologies, capital costs and operating parameters for thermal units were provided by Platte River based on estimates provided to them from HDR Engineering. However, Pace Global determined these HDR Engineering developed costs were reasonably comparable to Pace Global's independently developed estimates.

[5] Using fuel and O&M data, power prices are solved for in the modeling.

- Energy efficiency assumptions
- Transmission costs within Colorado
- Plant operating parameters
- In addition to identifying the least-cost zero net carbon portfolio, Pace Global also modeled and compared the least-cost ZNC portfolio to the cost of the recommended portfolio defined in Platte River's 2016 IRP.[6]

By design, this analysis considered wind and solar generation and lithium-ion battery energy storage as the only zero-emission options. Other generation and storage options were briefly considered and dismissed due to their higher costs (e.g., fuel cells), higher risk of development (e.g., pumped storage and geothermal) or technological maturity (e.g., solar thermal). The analysis also did not review the costs and benefits associated with incremental energy and demand reduction investments beyond those included in Platte River's IRP filings. This study was primarily designed to assess the costs of a ZNC portfolio to aid in future planning decisions for Platte River and its member-owners.

[6] The recommended portfolio in the 2016 IRP was modeled using current assumptions for consistency with the assumptions used for the zero net carbon assessment.

CARBON REDUCTION GOALS

Zero net carbon action plans are being considered by cities and utilities across the globe. There are widely accepted definitions of "Zero Net Carbon" or "carbon-neutrality" used in cities in Colorado and internationally. According to the Carbon Neutral Cities Alliance, a collaboration of cities that have ambitious carbon-neutral plans, the definition of ZNC is offsetting carbon emissions by "generating excess renewable energy and providing it to consumers outside the city or purchasing carbon offsets, which are tradable units that represent abatement of greenhouse gas emissions"[7]. For this study, generating excess renewable energy to offset gas, coal, and market purchases is used to calculate ZNC starting in 2030 for Platte River's generating system.

ACCOUNTING FOR ZERO NET CARBON

For this Platte River study, Pace Global's models achieved zero net carbon by selling surplus carbon-free power (wind and solar) into the market to offset emissions generated by fossil-fuel plants. Exhibits 1 and 2 illustrate the accounting methodology to produce ZNC (where net carbon emissions equal zero or less).

Net carbon emissions are calculated by summing the product of the energy for each generation type (Column a) and its associated carbon emissions rate (Column b) and then adjusting for the carbon associated with making market sales and purchases. All market exports and imports are assumed to generate an emission rate of 1,803 lb/MWh.[8] This rate is the publicly available eGrid Rockies emission rate for non-baseload generation. The general formula is shown below.

Net carbon emissions =

$$\sum(\text{Energy}_{\text{unit type}} \times \text{Emissions rate}_{\text{unit type}})/2000 - (\text{Market sales} \times 1{,}803\ \text{lb/MWh})/2000 + (\text{Market purchases} \times 1{,}803\ \text{lb/MWh})/2000$$

In Exhibit 1, 386,269 tons of carbon are generated to meet Platte River's system demand. If net exports reduce emissions by at least 386,269 tons of carbon, zero net carbon-neutrality is achieved. Since all coal retires in 2030, carbon is produced solely from the gas-fired resources (the sum of CT and CC carbon in the example above). As evidenced by the negative value for the accounting tons of carbon, this portfolio has enough carbon-free energy (hydro, wind, solar) sales to more than offset all the carbon from thermal generation and market purchases. The goal is for the total accounting tons of carbon to be less than or equal to zero in 2030 and beyond. Exhibit 1 utilizes the actual carbon-neutral portfolio that was determined as the least-cost ZNC portfolio by the analysis. In all years after 2030, the total accounting tons of carbon must be less than or equal to zero.

7 Fort Collins: https://www.fcgov.com/climateaction

8 https://www.epa.gov/energy/egrid,USEPA, eGRID2014, January 2017

Exhibit 1: 2030 ZNC Example with Imports and Exports Exchanged at a Rate of 1,803 lb/MWh

	(a) 2030 Annual Generation (MWh)	(b) Emissions Rate (lb/MWh)	(c) Accounting Tons of Carbon
Coal	0	2,087	-
CT[9]	18,713	1,351	12,641
CC[10]	941,129	794	373,628
Hydro	611,793	0	-
Solar	1,026,798	0	-
Wind	1,385,805	0	-
Total Plant Generation	**3,984,238**		**386,269**
Exports	586,287	(1,803)	-528,537
Imports	47,658	1,803	42,964
Net Carbon Emissions			**(99,305)** [11]

Source: Pace Global

[9] Simple Cycle Combustion Turbine (CT)

[10] Combined Cycle Combustion Turbine (CC)

[11] The requirement that the balance must be zero in every year from 2030 on results in a range of negative balance values in each year of the remaining planning horizon. Using smaller iterations for the optimization could have resulted in an outcome closer to zero but the additional effort did not justify getting more granular as we did not expect a material change in buildout and associated costs

In Exhibit 2, the same calculation method is used except that the current benchmarked carbon emission rate of 1,803 lb/MWh is lowered to 1,434lb/MWh. Under this assumption, the portfolio would still achieve the ZNC goal in 2030. If the market emission rate dropped further than 1,434 lb/MWh (which would decrease the value of renewable exports) additional renewable energy would need to be considered in the portfolio.

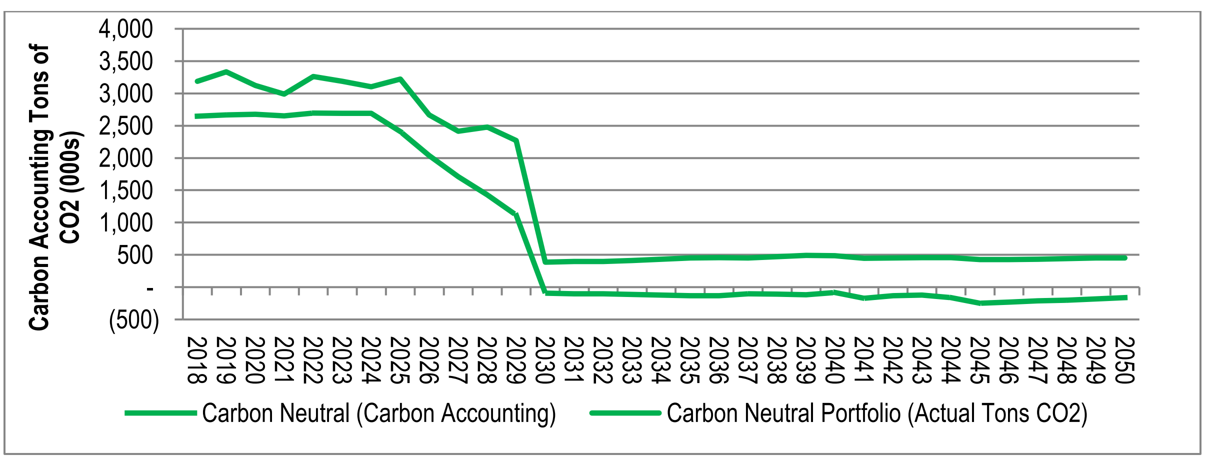
Exhibit 2: 2030 ZNC Example with Imports and Exports Exchanged at a Rate of 1,434 lb/MWh

	(a) 2030 Annual Generation (MWh)	(b) Emissions Rate (lb/MWh)	(c) Accounting Tons of Carbon
Coal	0	2,087	-
CT	18,713	1,351	12,641
CC	941,129	794	373,628
Hydro	611,793	0	-
Solar	1,026,798	0	-
Wind	1,385,805	0	-
Total Plant Generation	**3,984,238**		**386,269**
Exports	586,287	(1,434)	-420,446
Imports	47,658	1,434	34,177
Net Carbon Emissions			**0**

Source: Pace Global

As can be seen from Exhibit 3, ZNC is achieved in every year beyond 2029.

Exhibit 3: ZNC Portfolio Carbon Output by Year



Source: Pace Global

MODELING APPROACH

AURORA OVERVIEW

Pace Global performed the modeling and construction of the ZNC portfolios using AURORA, an EPIS product for power modeling simulations. This was achieved through a specific feature in the model called the "Long-Term Capacity Expansion Plan (LTCE)." The goal of the modeling was to define the least-cost portfolio that achieved the ZNC target for each year from 2030 to 2050. The two portfolios modeled include 1) Platte River's IRP Portfolio and 2) the Zero Net Carbon Portfolio.

Pace Global used Aurora's hourly chronological dispatch capabilities to define the ZNC portfolio that provided the least-cost mix of resources to achieve the target emissions within the transmission limitations and resource adequacy requirements. The simulation model was defined on a zonal basis by assigning separate areas for each of the entities considering joining the Mountain West Structure. The transmission system capability to transfer power between each of the areas was then added to the model structure. These were compared to the existing IRP Portfolios. In the next section we will review the modeling approach to achieve the ZNC target.

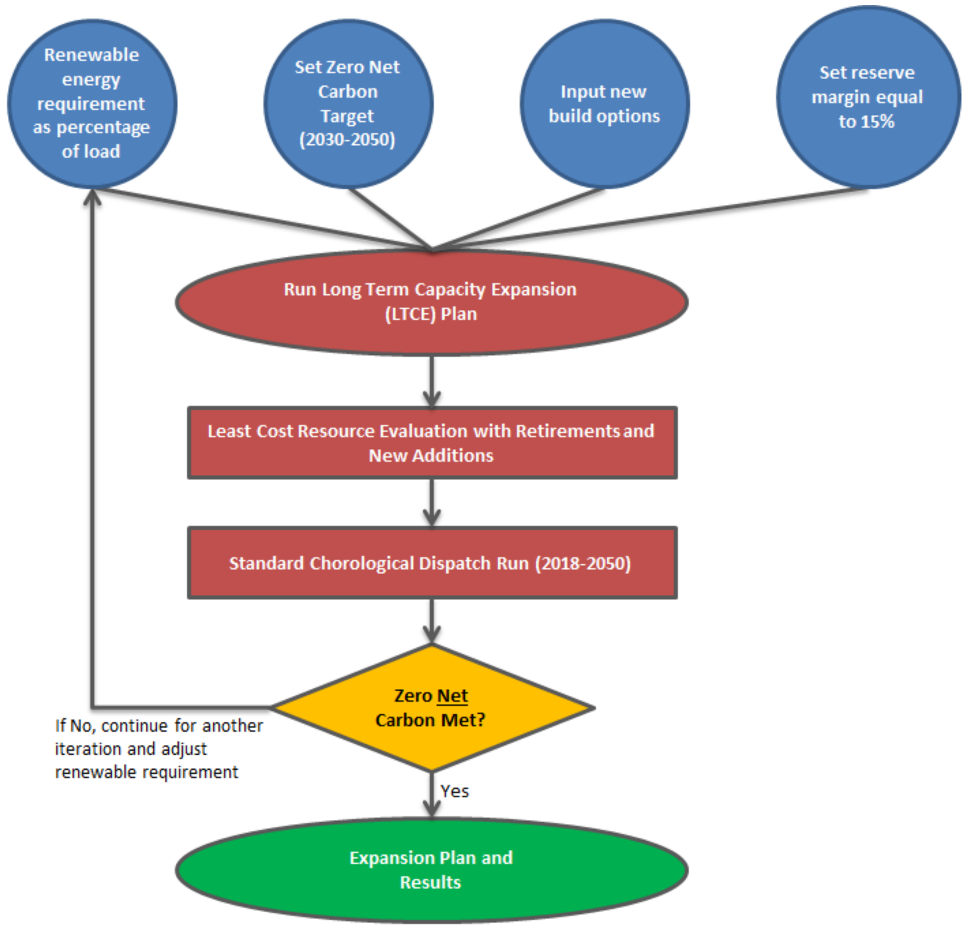
LONG-TERM CAPACITY EXPANSION PLAN

As a first step, new and existing resource parameters such as production costs and heat rates are defined as well as projected energy requirements, commodity price projections, and reserve margin targets. A mixed-integer program is used to make least-cost resource build and retirement decisions. The primary target objective is to minimize overall system costs for Platte River. The secondary target is to achieve the carbon-neutral goal, which was a unique approach used by Pace Global within the long-term capacity modeling framework. The process is described below.

ZERO NET CARBON (ZNC) MODELING PROCESS

Pace Global used the following modeling process to define the least-cost ZNC portfolio. The process uses iteration to converge on the least-cost ZNC portfolio. The following description provides an elaboration and further detail behind the process steps described in the Background section of this study.

Exhibit 4: ZNC Modeling using AURORA Long-Term Optimization



Source: EPIS, LLC and Pace Global

- Set an initial renewable energy requirement on a MWh basis as a percentage of load over time. The AURORA model is not designed to specifically model the ZNC constraint, so a starting point for renewables as a percentage of load was established to begin model iterations. The renewable assets consist of both Platte River's existing assets as well as potential new wind and solar builds.
- Require that zero net carbon be met for each year between 2030 and 2050. Beginning in 2025, renewable builds ramp up to achieve the target in 2030. This allows for thermal or renewable units to be built economically while adhering to the ZNC goal.
- Create a pool of supply resources for Platte River to build based on least-cost optimization and subject to minimum reserve margin constraints.

- Set the minimum reserve margin for Platte River at 15%.
- Solve for the least-cost portfolio for the starting renewable energy requirement.
- After the buildout is constructed, simulate a dispatch each hour from 2018-2050.
- Check the dispatch results to see if ZNC goal is achieved by the process described in the "Accounting for Zero Net Carbon" section. If over or under the limit, adjust the starting renewable percentage accordingly and repeat the previous steps.

After the modeling results were complete and buildout for the ZNC portfolio was solved to achieve the target in 2030 and throughout all years of the study, the two portfolios (the ZNC and the IRP) were compared. The key metrics reviewed were annual cost impacts from 2018-2050, market exposure, and generation mix.

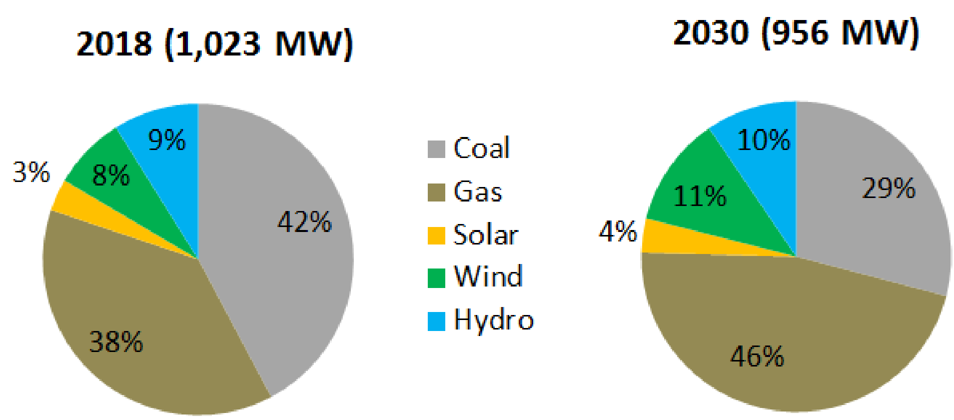
PORTFOLIO ANALYSIS

EXISTING INSTALLED CAPACITY

Platte River's current installed nameplate capacity is approximately 1,023 MW, of which about 20% or 200 MW is carbon-free capacity, including hydro, wind, and solar contracted capacity. In terms of thermal capacity, Platte River maintains ownership interest in the Rawhide and Craig coal plants with total installed coal generating capacity of 434 MW. The remaining thermal capacity is natural gas-fired peaking capacity. With the total expected peak demand of approximately 670 MW, Platte River enjoys a healthy reserve margin of 38% after adjusting for the peak credit of wind and solar capacity.

By 2030, the system capacity falls from 1,023 MW to 956 MW under the IRP portfolio. This contrasts with the ZNC portfolio shown later.

Exhibit 5: 2030 Integrated Resource Plan (Capacity by Generation Type)



Source: Platte River Power Authority

THE 2016 IRP RECOMMENDED PORTFOLIO

In its 2016 IRP, the recommended portfolio buildout changed over time because both Craig Units retired by 2030 and the Rawhide coal plant retired in 2047. The five peaking units and the hydro units did not retire during the study. The existing wind contracts end for Medicine Bow in 2029, Silver Sage in 2030, and Spring Canyon in 2040. The Rawhide solar contract ends in 2042.

Exhibit 6: 2018 Platte River Portfolio Composition (Nameplate Capacity)

Plant	Technology	2018 Planning Capacity MW (Current)	Capacity Factor %	2030 Capacity MW (IRP)	Capacity Factor %
Rawhide	Coal	278*	87%	278	83%
Craig Unit 1 and 2	Coal	154	68%	0	
CT 1-4	Gas	260	<1%	260	<1%
FA Unit	Gas	128	<1%	128	<1%
CRSP	Hydro	60	77%	60	77%
LAP	Hydro	31	77%	31	77%
Medicine Bow	Wind	6		0	
Silver Sage	Wind	12	32%	0	
Spring Canyon	Wind	60	39%	60	39%
Rawhide Solar	Solar	30	19%	30	19%
Community Solar	Solar	4.1	19%	4.1	19%
New Wind	Wind	0		50	39%
New RICE	Gas	0		55	13%
New 1x1 CC	Gas	0		0	
Total Nameplate Capacity (MW)		**1,023**		**956**	
Total Effective Summer Capacity		**931**		**836**	
Peak Demand (MW)		**673**		**685**	
Reserve Margin based on Effective Summer Capacity*		**38%**		**22%**	

** Platte River holds 2 MW of Rawhide's total 280 MW capacity for spinning reserves in planning scenarios*

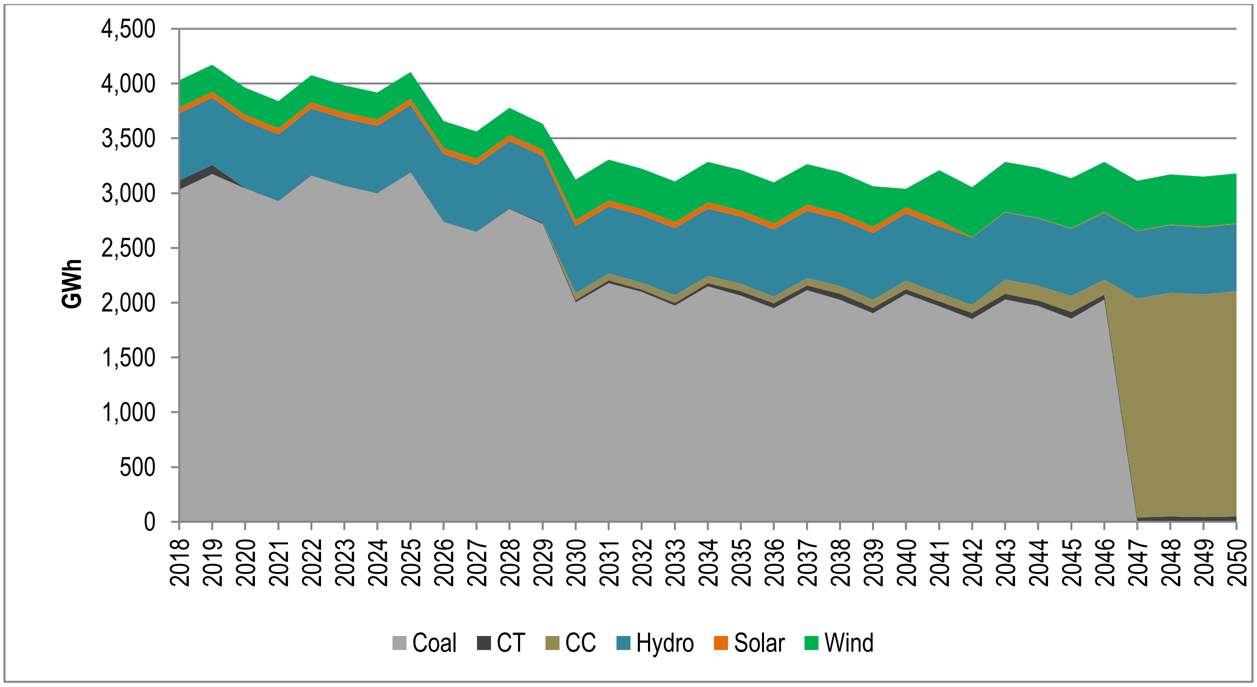
*** The assumed peak credit for wind is 12.5% and solar is 30%*

Source: Platte River Power Authority

As shown in Exhibit 7, Platte River continues to rely on fossil-fueled generation under the IRP portfolio. Coal generation progressively decreases over time, first with the retirement of Craig units in 2030 and then the Rawhide unit in 2047. Generation from wind grows through the term of the plan and in the out years, and a new combined cycle gas plant replaces the generation lost from Rawhide's retirement.[12] The IRP Portfolio also indicates that Platte River shifts from net-exporter to net-importer status by 2030.

[12] To replace capacity and keep the required reserve margin above the 15% levels, 50 MW of wind is added in 2030 and 85 MW in 2040. A 55 MW RICE unit is added in 2030 and again in 2043. Finally, to replace Rawhide capacity, a new 1x1 combined cycle plant with 286 MW capacity is added in 2047. This analysis was completed before consideration of the renewable bids that could add more renewable generation to the IRP mix.

Exhibit 7: Generation for IRP Portfolio



Source: Pace Global

CONSTRUCTING THE ZERO NET CARBON PORTFOLIO

WIND AND SOLAR ECONOMICS

As shown in Exhibit 8, there are four important components that determine the total cost of wind and solar. Starting in 2018, the all-in wind and solar costs are similar. Wind has a lower starting PPA price but higher transmission costs. Solar PPA costs are projected to decline relative to wind costs due to a steep expected decline in capital costs but also continued availability of investment tax credits at the 10% level. By 2030, the all-in cost for solar is slightly lower than wind.

The transmission charge represents firm point-to-point transmission charges associated with contracted wind plants located outside the immediate Platte River System. Solar is assumed to be located inside (or relatively near) the Platte River system so limited incremental transmission fees are incurred. The transmission charge is calculated using the average firm-to-firm point charges in the PSCo and WAPA areas.

The integration charge represents system balancing costs incurred within PSCo's balancing authority. Two of the balancing authority charge types specifically apply to renewables, and are used to develop the integration cost assumption. Quantifying additional renewable impact costs, such as grid impacts, were beyond the scope of the study.

Exhibits 8 and 9 show wind vs. solar "all-in" costs on a $/MWh basis. In the ZNC Portfolio, all-in solar is more economic than wind on an energy basis despite wind having a lower resource cost on a $/MWh basis. This is largely because of the transmission charges associated with contracted wind. Thus, the model favors more solar than wind in the least-cost portfolio. However, some wind is added since relying on solar alone is less economic given its lower peak credit for solar, and because solar is largely available during hours when demand is lower with potential for curtailment. Furthermore, transmission constraints also limit building solar alone. Building a combination of solar and wind allows energy exports to spread out over a larger number of hours given that solar and wind availability are not coincident.

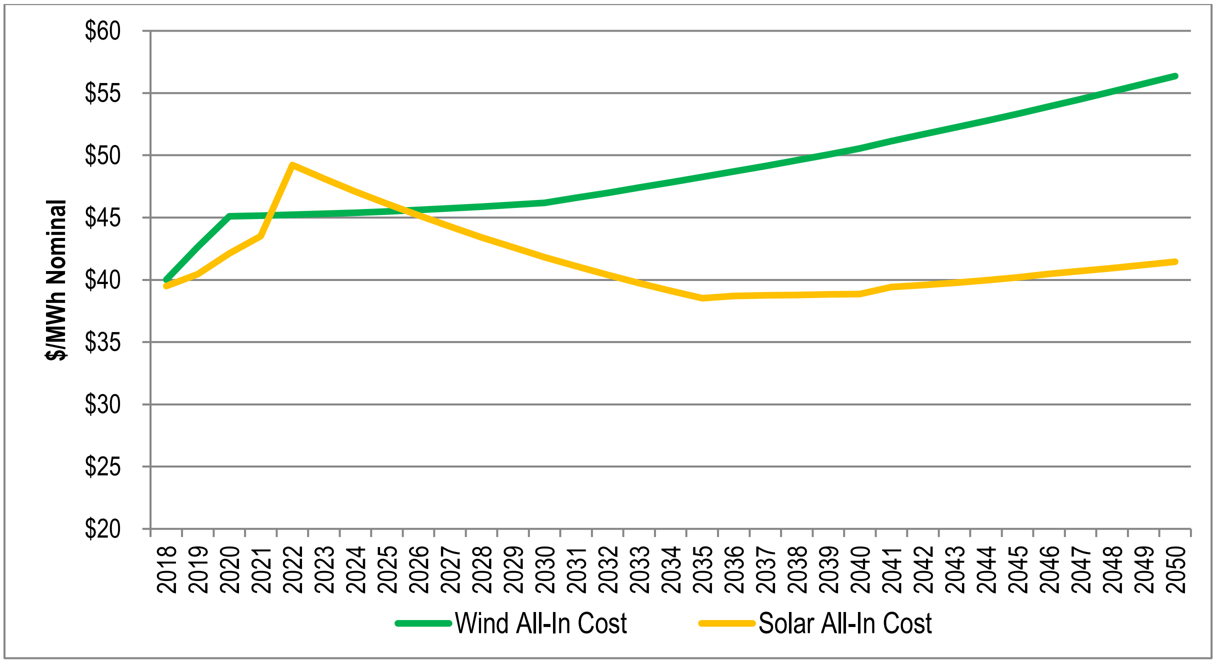
Exhibit 8: All-in Wind and Solar Costs

Renewable Costs[13] $/MWh	**Wind**	**Solar**
PPA in (2018)	$23.00	$32.50
PPA in (2030)	$24.61	$32.95
Transmission (2018/2030)	$12.52/$15.87	$2.50/$3.17
Integration (2018/2030)	$4.50/$5.71	$4.50/$5.71
Congestion Costs	$0.00	$0.00
Total (2018)	$40.02	$39.50
Total (2030)	$46.19	$41.82

Source: Platte River Power Authority and Pace Global

[13] The PPA prices assume the current ITC and PTC provisions but do not include safe harboring assumptions. Safe harbor provisions could extend wind and solar tax credits by an additional two years.

Exhibit 9: Wind vs. Solar All-in Costs $/MWh



Source: Platte River Power Authority and Pace Global

VALUE OF STORAGE

The capability and price of energy storage continue to improve, making it an increasingly viable component for power systems. Battery energy storage economics have improved both as a standalone technology and in combination with solar and thermal resources, although the total market penetration remains relatively low. An HDR storage study commissioned by Platte River indicated that lithium-ion battery energy storage costs are expected to decline by approximately 20% over the next five years. Much of the recent utility scale battery energy storage applications were driven more by mandates and the desire for utilities to gain experience with this technology. With improving economics, the installations and roles for batteries are expected to continue to expand.

For the ZNC portfolio analysis, battery storage (four-hour duration) was considered as a long-term capacity expansion option. Based on Platte River's study and expertise, the battery energy storage peak credit was assumed to be 75% for a long-duration battery. Based on the hourly modeling conducted for this study, battery storage resources proved uneconomic relative to other resources such as intermittent renewables and thermal generation capacity. Other sources of value for storage that would require intra-hour modeling, (e.g., fast ramping, frequency, and voltage control) were not analyzed.[14]. As storage technology matures

[14] For example, short duration battery energy storage resources (one-hour storage duration) can serve to reduce Platte River's integration charges. However, currently there is not enough precedence in vertically integrated utility regions to utilize battery energy storage purely for ancillary service needs. If ancillary services (integration services) are not procured and the battery fails to perform, the imbalance charges can be significant

and there is wider adoption, battery storage can also be considered a part of the portfolio mix for ancillary service needs.

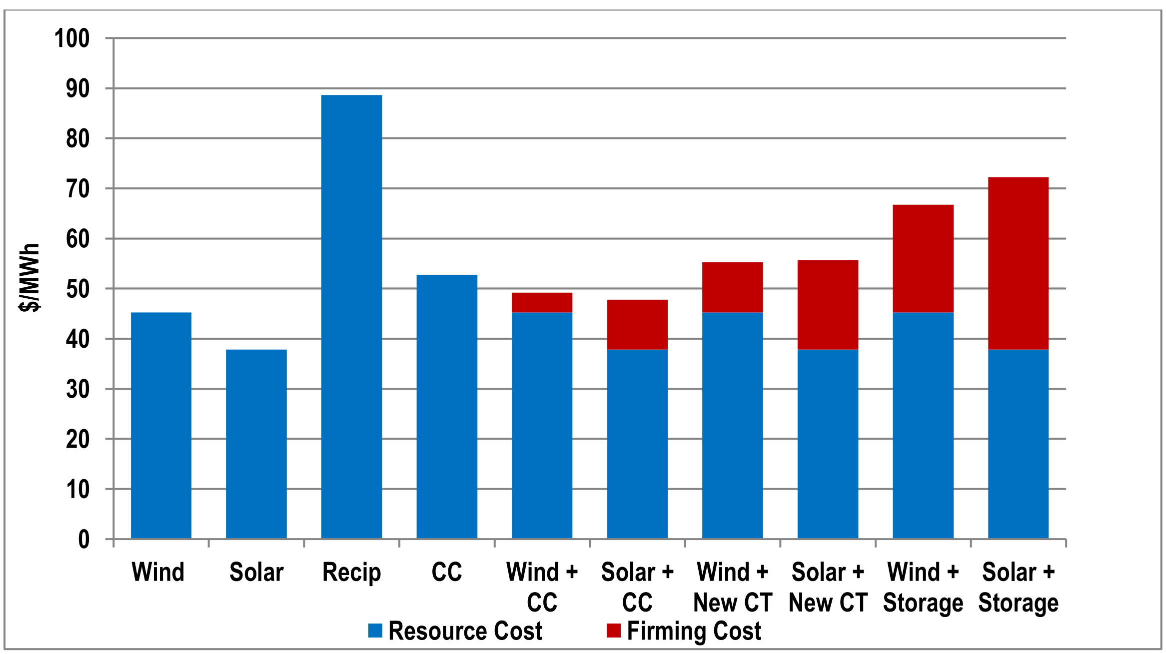
ZERO NET CARBON PORTFOLIO

Exhibits 11 and 12 show the construction of the ZNC portfolio over time. In 2025, wind and solar resources enter the portfolio and by 2030, 950 MW of renewables are added. A 1x1 7FA CC is added in 2030 upon the retirement of the coal resources. The combined cycle resources are added primarily to meet the reserve margin needs of the system. Wind and solar are built to help meet the ZNC goal with the long-term capacity expansion functionality ensuring an optimal mix based on modeled constraints.

There are several reasons why an additional thermal unit was built in 2030 as opposed to other technology options such as reciprocating engines, combustion turbine, battery, wind, solar, or additional coal. In order to meet the ZNC goal, all coal generation will need to be retired before 2030. It is difficult to reach the ZNC goal with a coal unit online since it yields a higher marginal emission rate than the market marginal rate of 1,803 lb/MWh. If coal generation were included in the portfolio, even more renewable resources would be required to offset carbon output, further increasing portfolio cost.

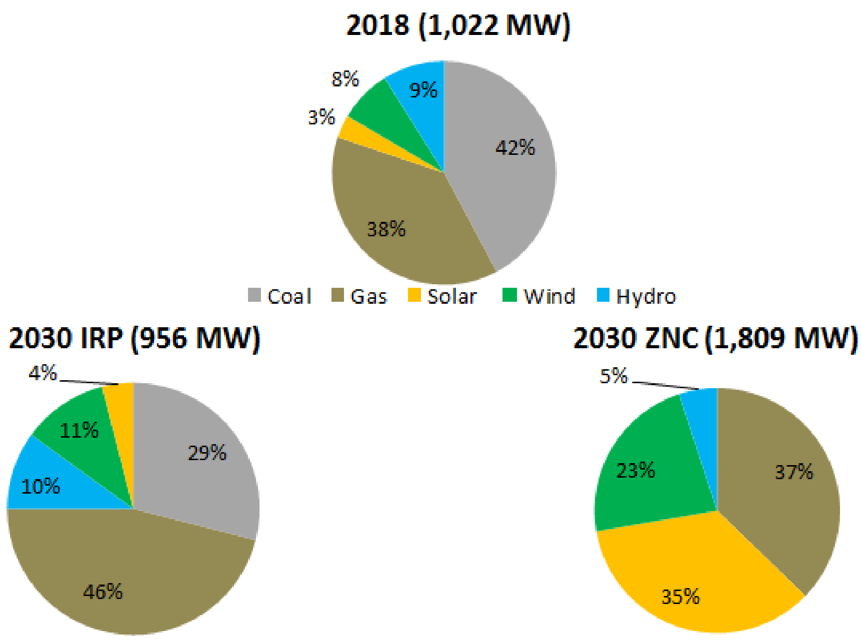
An efficient combined cycle natural gas unit with a full load heat rate of 6,800 Btu/kWh and low fixed costs adds portfolio flexibility and is more able to meet the resource adequacy needs of Platte River's system once significant amounts of baseload coal capacity retire. In addition, when wind and solar generation is unavailable, a combined cycle plant is the most efficient option to provide firming for the renewables relative to reciprocating engines, batteries, or combustion turbines. By 2050, 1,456 MW of new capacity is projected to be added (286 MW of natural gas, 500 MW of wind, and 670 MW of solar).

Exhibit 10: Levelized Cost of Energy



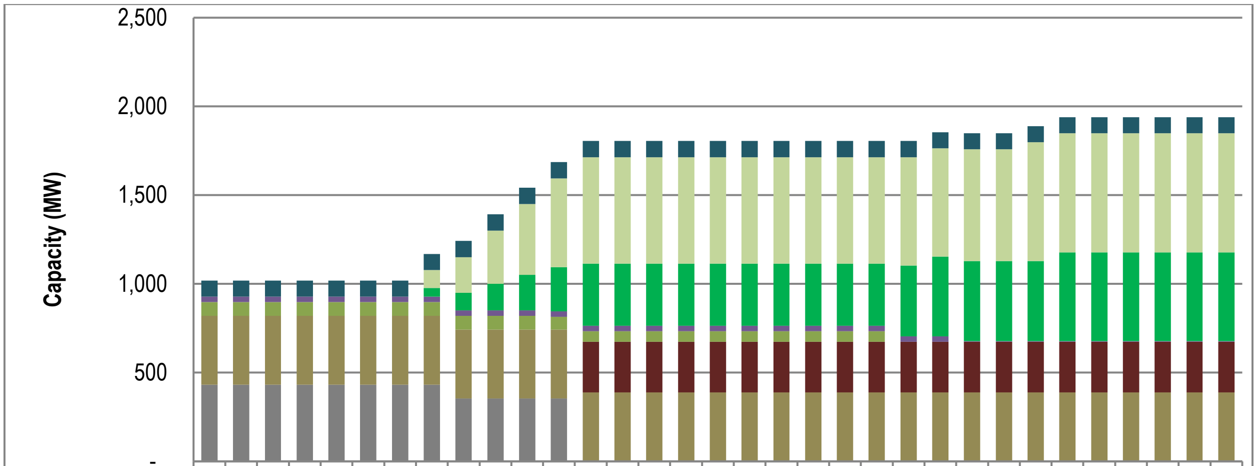
As shown in Exhibit 11, in 2030, almost twice as much capacity is needed in the ZNC portfolio as compared to the IRP portfolio. The portfolio mix for the ZNC portfolio is shown on a year-by-year basis in Exhibit 12.

Exhibit 11: Capacity Comparison (2018 vs. 2030)



Source: Pace Global

Exhibit 12: Portfolio Buildout for ZNC Portfolio



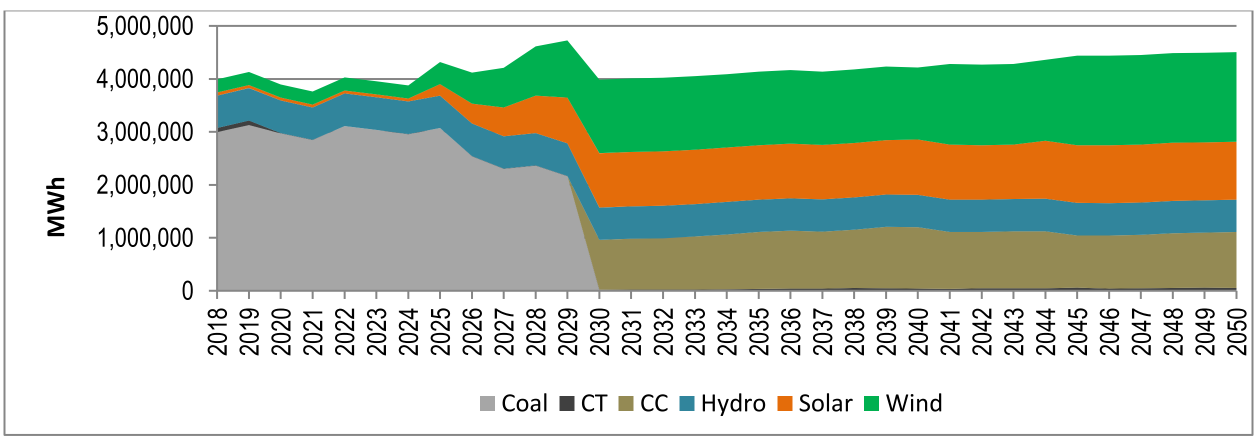
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Hydro	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91
Solar_New								100	200	300	400	500	600	600	600	600
Wind_New								50	100	150	200	250	350	350	350	350
Solar_Existing	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Wind_Existing	78	78	78	78	78	78	78	78	78	78	78	72	60	60	60	60
CC_New													286	286	286	286
CT	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388
Coal	432	432	432	432	432	432	432	432	355	355	355	355				

	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Hydro	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91
Solar_New	600	600	600	600	600	600	610	610	630	630	670	670	670	670	670	670	670
Wind_New	350	350	350	350	350	350	400	450	450	450	450	500	500	500	500	500	500
Solar_Existing	30	30	30	30	30	30	30	30	4	4	4	4	4	4	4	4	4
Wind_Existing	60	60	60	60	60	60											
CC_New	286	286	286	286	286	286	286	286	286	286	286	286	286	286	286	286	286
CT	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388
Coal																	

Source: Platte River Power Authority and Pace Global

Exhibit 13 shows the generation mix over time as the portfolio evolves to meet the ZNC goals. By 2030, carbon-free energy accounts for 75% of the total energy generated by serving Platte River. After the retirement of all coal capacity in 2030, wind constitutes the largest portion of the generation mix, followed by combined cycle generation, and finally solar and hydro. Although more solar capacity is added in the ZNC portfolio, wind provides more energy because of its higher average capacity factor (40% relative to solar's 20%).

Exhibit 13: Generation for ZNC Portfolio



Source: Platte River Power Authority and Pace Global

EVALUATION OF COST IMPACT

Exhibit 14 details the breakdown of Platte River's total system production cost. For this analysis, production costs include new thermal and renewable amortized capital costs, fuel costs, variable O&M costs, fixed O&M costs, emission costs, starts costs, and market sales and purchase costs. In AURORA, the total fuel consumed, generation profile, variable cost, start costs, and market exposure change depending on how Platte River-owned generation resources are dispatched. The fixed components are a function of new-build capital costs and ongoing fixed O&M expenses and are dispatch-independent.

The 2018 projected total costs are approximately $105 million, net of market sales. Fuel expense constitutes a large portion of the costs as the portfolio is still dominated by thermal resources. However, by 2030, total costs increase to $175 million in the IRP portfolio. This is due to increases in fuel and emission costs, fixed O&M costs, and Platte River becoming a net energy importer.

In 2030, the total production cost for the ZNC portfolio is $210 million—approximately 20% higher than the IRP portfolio production cost. A large portion of the cost increase is attributable to the capital expenses involved in bringing on new renewables to meet the ZNC goals. In the ZNC portfolio, Platte River is a net energy exporter due to the additional renewable generation required to offset the carbon emissions from thermal resources. From a capacity perspective, Platte River's ZNC portfolio total nameplate generating capacity is almost double that of the IRP portfolio.

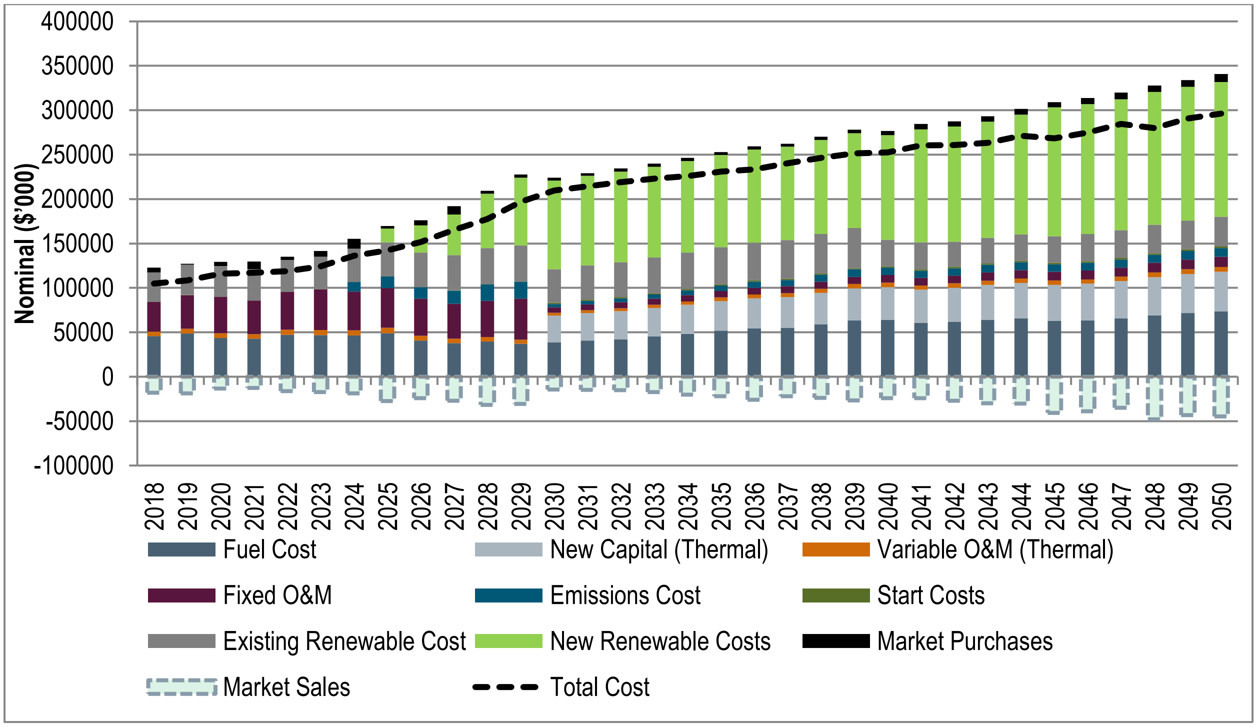
Exhibit 14: Financial Overview (Nominal Dollars)

	Units	2018 Base Portfolio	2030 ZNC	2030 IRP
Fuel Cost	$/1000	45,705	38,644	38,918
New Capital (Thermal)	$/1000	-	30,116	7,062
Variable O&M (Thermal)	$/1000	5,164	3,296	5,442
Fixed O&M	$/1000	33,240	6,278	35,316
Emissions Cost	$/1000	-	3,512	19,568
Start Costs	$/1000	102	1,191	80
Existing Renewable Cost	$/1000	33,347	37,882	37,882
New Renewable Costs	$/1000	-	99,967	8,135
Market Sales	$/1000	(18,031)	(14,471)	(6,994)
Market Purchases	$/1000	5,332	3,191	29,380
Total Cost	**$/1000**	**104,859**	**209,606**	**174,789**
Resource Generation	MWh	3,988,260	3,984,238	3,125,238
Market Sales MWh	MWh	(734,171)	(586,287)	(142,409)
Market Purchases MWh	MWh	134,892	47,658	462,780
Annual Energy Requirement	MWh	3,267,429	3,445,610	3,445,610
Fuel Consumption	MMBtu	31,585,870	7,139,180	21,419,238
Fuel Cost	$/MMBtu	1.45	5.41	1.82

Source: Platte River Power Authority and Pace Global

Exhibit 15 shows the annual stream of production costs for the portfolios. Renewable capital costs are first incurred in 2025 as new resources are required. These costs progressively increase over time, first to meet the ZNC goals in 2030, and then to meet energy demand into 2050 with projected 0.6% growth. Over time, costs increase from $105 million in 2018 to $296 million in 2050, net of market sales.

Exhibit 15: Annual Costs for the ZNC Portfolio (Nominal Dollars)



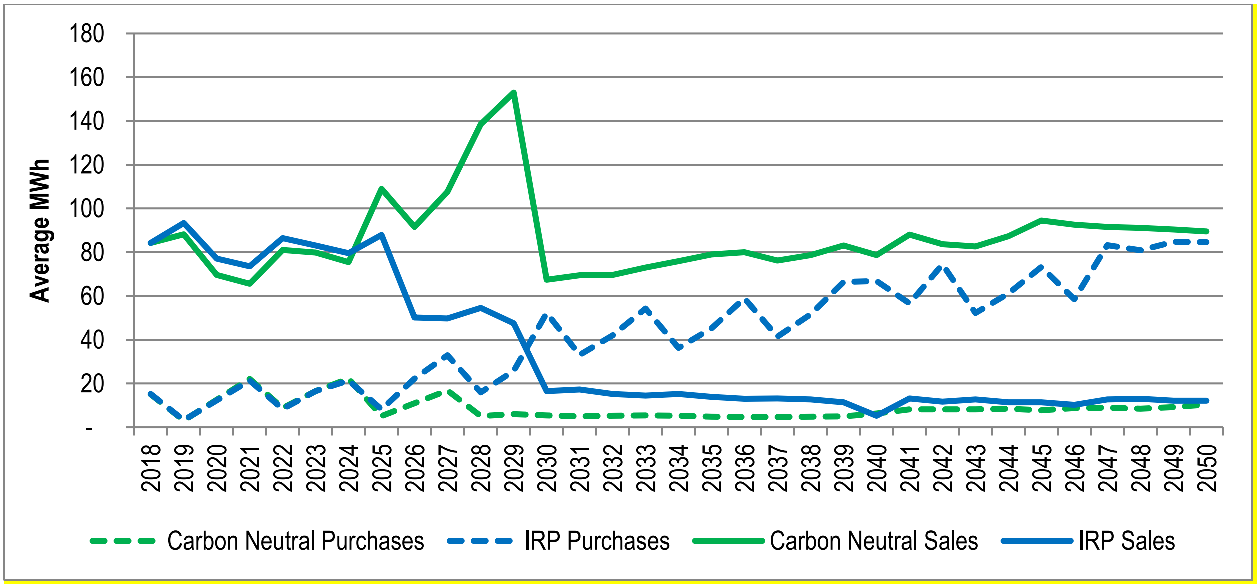
Source: Platte River Power Authority and Pace Global

MARKET PURCHASES AND SALES

Currently, Platte River relies on limited market purchases and is a net energy exporter. The existing portfolio consists of adequate baseload resources and a reserve margin of approximately 38%. However, in the IRP portfolio, the reserve margin dips over time to approximately 22% with the retirement of Craig Units 1 and 2. This results in higher market purchases in the 2030 timeframe, and decreasing market sales[15]. In the ZNC portfolio, as renewables are added Platte River's net exports rise sharply until its coal units exit service in 2030, and then settle to a level comparable to today's levels. Overall, the ZNC portfolio maintains Platte River's long energy position through time at roughly the same export levels as experienced today.

[15] Note that the year over year fluctuations in sales and purchases reflect coal maintenance schedules.

Exhibit 16: Market Sales and Purchases for ZNC and IRP Portfolios



Source: Platte River Power Authority and Pace Global

RISKS OF A ZERO NET CARBON (ZNC) PORTFOLIO

There are additional risks that should be considered before moving to a ZNC portfolio and there are also means of mitigating some of these risks. For completeness, some of the additional risks and mitigation measures are addressed below.

Risks of ZNC Portfolio Strategy

1. There is significant uncertainty around incremental "integration" costs with much higher renewable penetration levels:
    a. System requirements to take on high levels of renewables are not currently known and may require additional investment in more flexible generation resources.
    b. If the whole region (Platte River only is assumed in the reference portfolio) starts to integrate more renewables at a similar rate to Platte River, there will be more sellers of excess renewables, fewer buyers of excess renewables, lower sales prices in the market, lower carbon offset value, and more renewables with higher investment will have to be built to achieve net zero carbon. At some point the needed sales may have no market.
    c. If the entire region builds more renewables, the integration costs could be higher due to higher demand for ancillary services such as load following, regulation, and inertial response. The higher costs can be in the form of higher integration charges from PSCo or through additional technology investment to self-provide such services.
    d. The ZNC portfolio has a significant long position. If other entities within Colorado or the broader WECC market pursue the same strategy, it may expose the portfolio to declining or possible negative wholesale power prices as currently seen in many parts of California and the Pacific Northwest.
2. Higher rates may be required to achieve net zero carbon. There is a balance between the desire to achieve ZNC standards and the cost implications of achieving the standard.
3. Committing too soon to a high percentage of renewables may sacrifice future opportunities for renewable cost reductions and technological improvements. With expectations of declining capital costs on renewable and storage resources, there is value in the optionality to wait instead of committing to the entire investment early on. Diversification of the resource mix through staging the timing of the investment is a prudent strategy.
4. Selling excess power in a bilateral market faces more market risks than in a liquid, RTO based market.

Risk Mitigation Opportunities for ZNC Strategy

The following steps could be taken to mitigate some of the risks stated above.

1. RTO membership can reduce risks associated with market sales: Joining an RTO could lower risk by:
    - Reducing transmission wheeling charges within the RTO footprint and increasing the sales opportunities for Platte River's excess renewables at lower costs (assuming others do not follow the same strategy).
    - RTO membership can also help lower the integration costs by tapping into a more liquid, deeper and more diverse pool of resources available within the larger Mountain West Transmission Group footprint.
    - Pace Global has begun to consider the implications of Platte River joining the Mountain West Transmission Group and will continue to evaluate it as more information surrounding the RTO becomes available.
2. Using renewables as a fuel price risk hedge: Moving to a renewables-heavy portfolio can inherently de-risk the portfolio from uncertainty in fuel and emission costs.
3. Provide grid flexibility through low cost gas resources: flexible gas-fired resources can provide diversity in terms of meeting grid flexibility needs and resilience in the event of periods of extended cloud cover or low winds.
4. Define optimal project locations to minimize grid impacts based on available transmission and wind and solar resources: This approach (including incentives or tariff structures) could provide signals to developers to assist in optimizing the location of wind and solar resources based on availability of transmission and land and avoid costly grid interconnection costs.
5. Work with member utilities to maximize installation of cost-effective distributed solar: The solar installations can be utility-scale solar connected to the transmission or distribution system but may also include community and rooftop solar in favorable locations on the grid.
6. Monitor and track the cost of storage to provide grid integration services: As battery storage costs decline, grid integration services may become more cost effective.
7. Utilize cost-effective demand response and energy efficiency: Identifying low cost DR and EE programs can serve to more economically meet energy, capacity, and ancillary service needs.

CONCLUSIONS AND RECOMMENDATIONS

Pace Global reached the following conclusions and recommendations:

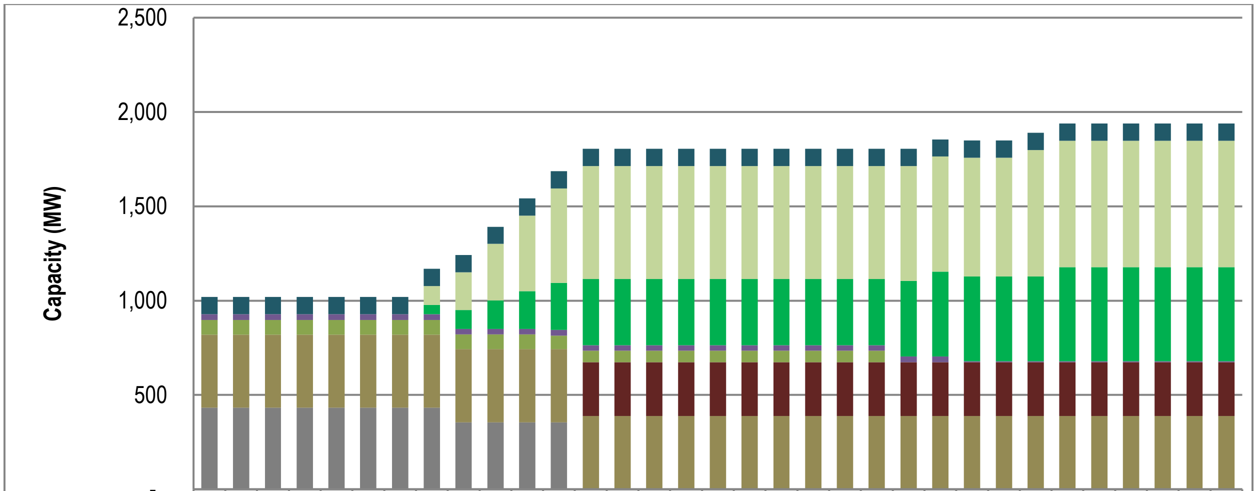
1. **A portfolio strategy to reach net zero net carbon is achievable, but will require additional investment, costs, and the assumption of additional market risk.**

2. With the zero net carbon portfolios defined in this analysis, **Platte River would deliver approximately 75% of the energy it produces with carbon-free resources.** The remaining 25% of its energy needs are met with fossil-fueled generation and its carbon emissions are offset with sales of renewable energy to the market during the times when total generation exceeds Platte River's total load requirements.

3. **Some new fossil-fueled generation (approximately 286 MW of new, natural gas-fired, combined cycle capacity) is required** to economically meet reserve adequacy and stay within transmission limits in 2030. In instances when a resource is needed to meet both renewable energy and minimum reserve margin constraints, wind and solar must be paired with combined cycle generation to provide firming and are collectively more economic compared to combined cycle plants alone. Renewables paired with a combined cycle unit is the most cost-effective option for firming at this time.

4. **The remaining load and incremental capacity needed to offset emissions from fossil generation is met through renewable capacity consisting of approximately 600 MW of new solar and 350 MW of new wind.** Over 200 MW of this incremental renewable capacity in 2030 will be sold into the market as an offset to Platte River's emissions from its new and existing natural gas-fired plants. The ZNC portfolio mix is shown in Exhibit 17.

Exhibit 17: Capacity Mix of ZNC Portfolio



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Hydro	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91
Solar_New								100	200	300	400	500	600	600	600	600	600
Wind_New								50	100	150	200	250	350	350	350	350	350
Solar_Existing	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Wind_Existing	78	78	78	78	78	78	78	78	78	78	78	72	60	60	60	60	60
CC_New													286	286	286	286	286
CT	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388
Coal	432	432	432	432	432	432	432	432	355	355	355	355					

	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Hydro	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91
Solar_New	600	600	600	600	600	610	610	630	630	670	670	670	670	670	670	670
Wind_New	350	350	350	350	350	400	450	450	450	450	500	500	500	500	500	500
Solar_Existing	30	30	30	30	30	30	30	4	4	4	4	4	4	4	4	4
Wind_Existing	60	60	60	60	60											
CC_New	286	286	286	286	286	286	286	286	286	286	286	286	286	286	286	286
CT	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388	388
Coal																

5. Including lithium-ion **battery energy storage** in the modeled portfolios led to higher predicted production costs without materially reducing carbon production; therefore, battery storage **was not selected as an economic technology** in the modeled portfolios.[16]

6. As shown in Exhibit 19, the current portfolio costs are approximately $105 million. In the ZNC portfolio, **costs are 20% higher than the IRP Portfolio in 2030.** Overall on a **Net Present Value basis, costs of the ZNC portfolio are 8 percent higher than the IRP portfolio over the 2018-2050 planning horizon and 10% higher over the 2030-2050 timeframe.**

[16] Some battery storage might be economic for intra-hour intermittency. This was not modeled. A 75% peak credit was assumed for battery energy storage.

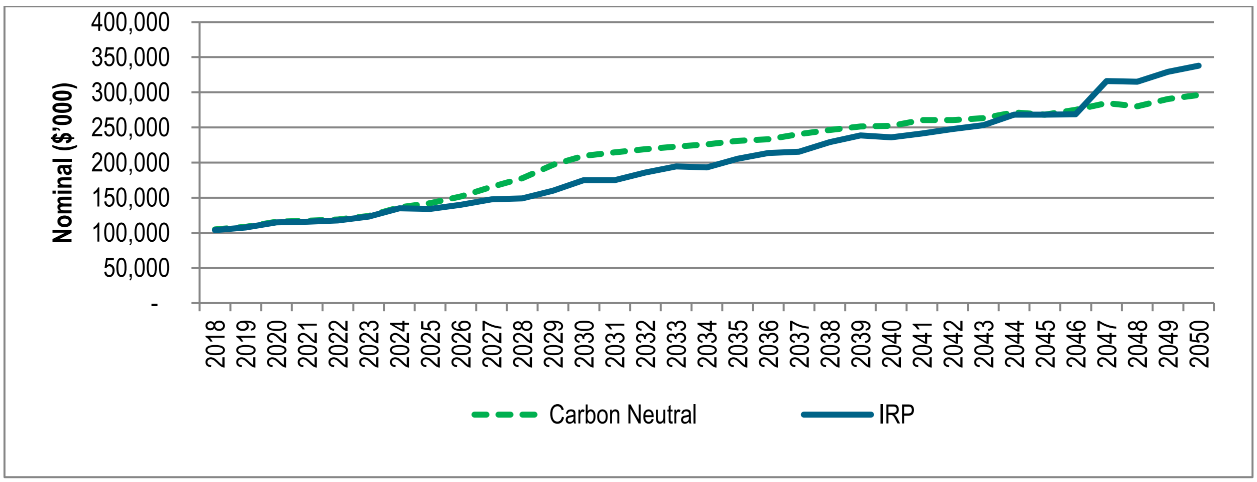
Exhibit 18: Cost of Alternative Portfolios Nominal ($000s)

	2030 Annual Cost	% Change	2050 Annual Cost	% Change
ZNC Portfolio	$209,606	20%	$296,214	-12%
IRP Portfolio	$174,788		$337,926	

	2018 - 2050 NPV	% Change	2030 - 2050 NPV	% Change
ZNC Portfolio	$2,938,219	8%	$2,495,799	10%
IRP Portfolio	$2,717,718		$2,278,986	

Source: Pace Global

Exhibit 19: Total Portfolio Cost (shown in Nominal Dollars)



Source: Pace Global

7. **The incremental cost to achieve a zero-carbon emissions target would be much higher than for meeting zero net carbon.**
   a. Fossil generation has a lower levelized cost of production than renewable generation plus storage firming costs throughout the planning horizon. Replacing fossil generation with higher cost renewables plus storage would raise costs appreciably.
   b. Fossil-fueled generation receives a full 100% credit for its rated output capacity. However, due to their intermittent output and the timing of their production, solar generation receives a 30% capacity credit toward reserve margin while wind receives a 12.5% capacity credit. This means Platte River would need to replace gas-fired capacity in the carbon-neutral portfolios by multiples of 3.3 to 8.0 times renewable capacity (solar and wind, respectively) in order to receive a comparable capacity credit for resource adequacy and reserve margin requirements.

   c. Even with significantly higher renewable generation capacity additions, energy storage or other higher cost zero-carbon generation would still be needed to support the intermittent operation of the wind and solar. All of these factors would yield higher portfolio costs than the ZNC portfolio.

8. Several recent publications suggest that **a gradual increase in renewables is more prudent to ensure reliability and resiliency of the grid and to minimize impacts.** For example, a recent study commissioned by the DOE[17] suggests that adequate market price signals under current market regulations may not be in place to ensure resiliency and reliability of the grid currently provided by fossil fuel base. In addition, a study funded by Hawaiian Electric Company, in support of their move to the state's 100% Renewable Portfolio Standard (RPS) by 2045[18], suggests that some form of firm, dispatchable generation[19] is needed to support renewables for purposes of grid resiliency and reliability.

9. Within the last decade, there has been significant technological and price improvement in wind and solar technology. Batteries will almost certainly assist in the transition towards zero-carbon generation options. However, batteries currently are costlier than alternatives for many applications, have limited storage capability, and cannot store energy indefinitely, but many of these risks may be resolved over time. In addition, technologies such as hydrogen fuel cells, solar thermal, and non-battery storage options are being tested around the world, and may offer a material change to the economics and availability of additional forms of renewable energy and storage. For this reason, **preserving optionality and flexibility in its resource plans is an important strategy consideration for Platte River.** Committing too early to any one technology could lessen the ability to adapt when these technologies mature.

10. **A prudent path for Platte River would be to agree on carbon reduction targets with its members, and develop a strategy that progresses toward the desired reductions while preserving the ability to benefit from continuing technological advancements and price reductions.**

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[17] Staff Report to the Secretary on Electricity Markets and Reliability, August

[18] Hawaii PUC DOCKET NO. 2014-0183, Hawaiian Electric Companies' PSIP Update Report, filed December 23, 2016, Appendix P, Page P-89.

[19] This could be fossil, bio-fuel or geothermal generation

APPENDIX A: MARKET ASSUMPTIONS

STANDARD ASSUMPTION EXHIBITS

Exhibit 20: Existing Plant Operating Parameters

Plant Name	Primary Fuel	Heat Rate Average	Plant Capacity	CO_2 Emission Rate
		Btu/KWh	*MW*	*lb/MWh*
Craig (CO) 1	Coal	10,100	77	2,119
Craig (CO) 2	Coal	10,100	77	2,119
Rawhide CT Unit 1	Natural Gas	12,995	65	1,541
Rawhide CT Unit 2	Natural Gas	12,995	65	1,541
Rawhide CT Unit 3	Natural Gas	12,995	65	1,541
Rawhide CT Unit 4	Natural Gas	12,995	65	1,541
Rawhide FA Unit	Natural Gas	11,364	128	1,351
Rawhide Coal Unit	Coal	9,950	278	2,088
Spring Canyon Wind Farm	Wind	-	60	-
Medicine Bow	Wind	-	6	-
Rawhide Solar	Sun	-	30	-
Community Solar	Sun	-	4	-
Silver Sage Wind	Wind	-	12	-
LAP	Water	-	30	-
CRSP	Water	-	85	-

Source: Platte River

Exhibit 21: New Technology Options ($2018)

Technology Options	Block Size (MW)	Full Load Heat Rate Btu/kWh***	Capital Cost $/kW	FOM $/kW	VOM $/MWh
1x1 7FA.05, Water Cooled	**286**	**6,680**	**1,220**	**9.4**	**2.7**
1x1 7FA.05, ACC	281	6,838	1,353	9.7	2.7
6x0 9 MW Recip. Engines	55	8,619	1,553	16.4	6.3
2x0 LM6000	71	9,431	1,586	12.9	3.9
2x1 LM6000 CC, Water Cooled	91	7,237	2,186	25.7	6.2
2x1 LM6000, ACC	89	7,405	2,366	26.2	6.5
2x1 7FA.05, Water Cooled	573	6,670	1,089	5.4	2.6
2x1 7FA.05, ACC	561	6,838	1,200	5.7	2.5
Lithium-ion Battery 4MWh*	1	N/A	2,206	29	1
Wind*	**50**	**N/A**	***See PPAs***	***See PPAs***	***See PPAs***
Solar*	**10**	**N/A**	***See PPAs***	***See PPAs***	***See PPAs***

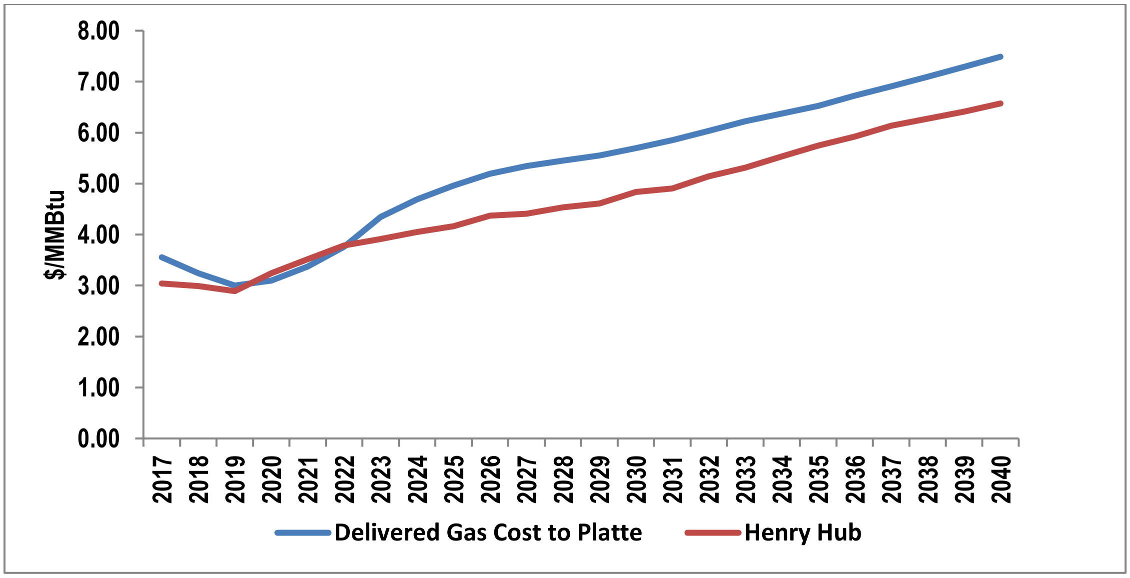
*See Battery Technology Section. The Cost assumptions are Pace Global

** See Wind vs. Solar Economics Section

*** This represents summer heat rate from HDR

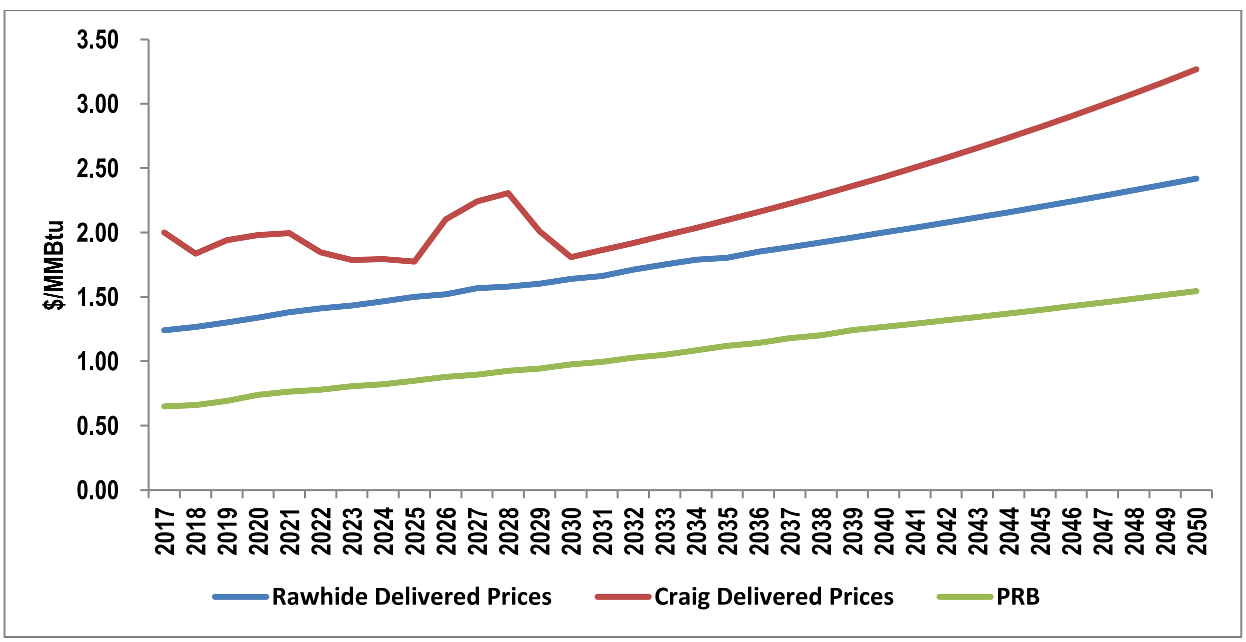
Source: HDR and Pace Global

Exhibit 22: National Gas Prices (Nominal Dollars)



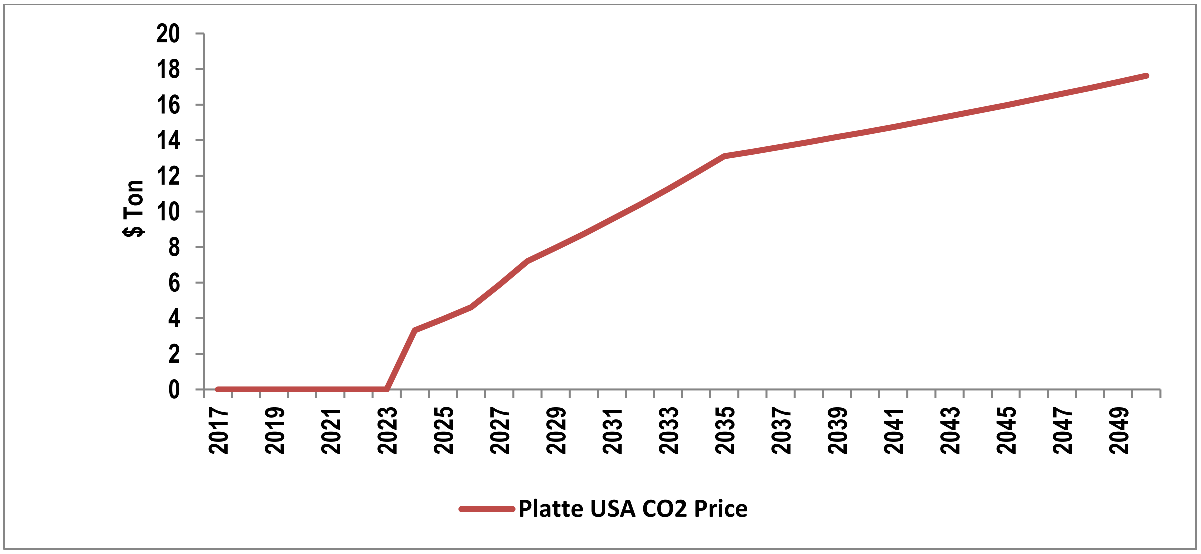
Source: Pace Global

Exhibit 23: Coal Prices (Nominal Dollars)



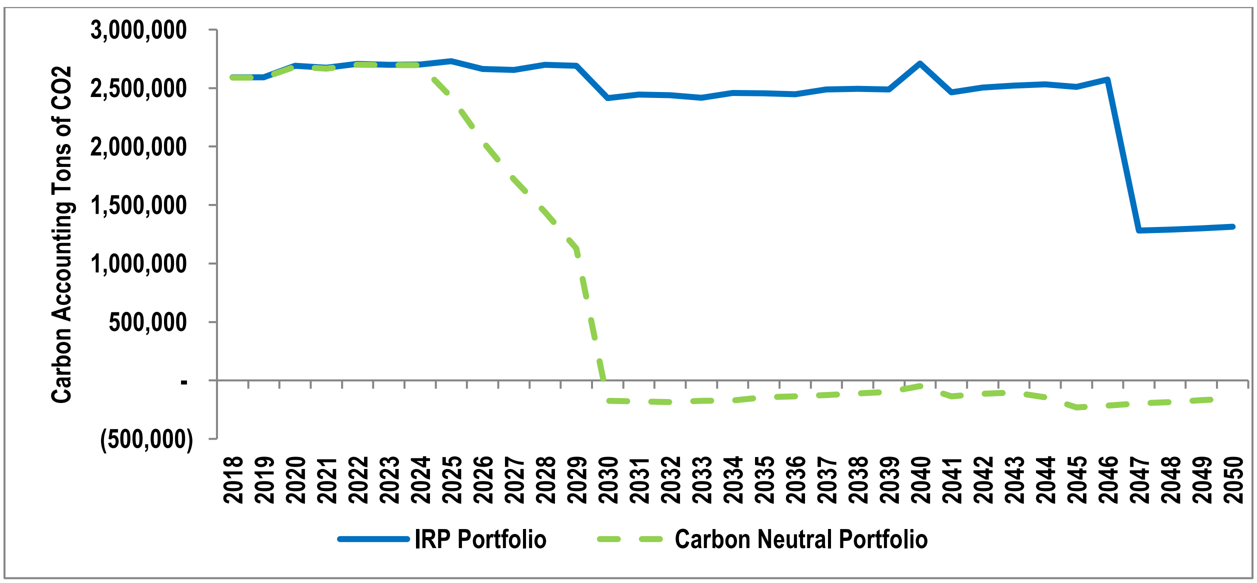
Source: Pace Global

Exhibit 24: Emission Prices (Nominal Dollars)



Source: Pace Global

Exhibit 25: Carbon Accounting for all Portfolios



Source: Pace Global

Exhibit 26: Energy and Peak Demand (MW)

Year	WECC - Colorado	
	Average Energy Requirement (MW)	Peak Demand (MW)
2017	7,423	10,966
2018	7,532	11,080
2019	7,659	11,224
2020	7,756	11,275
2021	7,847	11,400
2022	7,953	11,572
2023	8,046	11,650
2024	8,137	11,750
2025	8,241	11,905
2026	8,337	12,000
2027	8,443	12,154
2028	8,538	12,267
2029	8,635	12,388
2030	8,736	12,470
2031	8,846	12,627
2032	8,957	12,746
2033	9,064	12,886
2034	9,174	13,021
2035	9,285	13,145
2036	9,389	13,243
2037	9,504	13,401
2038	9,601	13,514
2039	9,714	13,628
2040	9,833	13,785
2017-2020 CAGR	1.5%	0.9%
2021-2040 CAGR	1.2%	1.0%
2017-2040 CAGR	**1.2%**	**1.0%**

Year	Platte River	
	Average Energy Requirement (MW)	Peak Demand (MW)
2017	378	665
2018	381	673
2019	381	673
2020	381	673
2021	382	674
2022	382	674
2023	383	676
2024	384	677
2025	384	679
2026	385	680
2027	385	681
2028	386	682
2029	387	684
2030	388	685
2031	388	686
2032	389	686
2033	390	688
2034	391	690
2035	393	693
2036	394	696
2037	396	699
2038	398	703
2039	400	706
2040	402	710
2041	405	714
2042	407	719
2043	410	723
2044	412	728
2045	415	733
2046	418	737
2047	420	742
2048	423	748
2049	427	753
2050	430	759
2017-2020 CAGR	0.3%	0.4%
2021-2040 CAGR	0.3%	0.3%
2017-2050 CAGR	**0.6%**	**0.6%**

Source: Pace Global

