ENERGY STRATEGIES

Analyzing the Cost of Small Modular Reactors and Alternative Power Portfolios

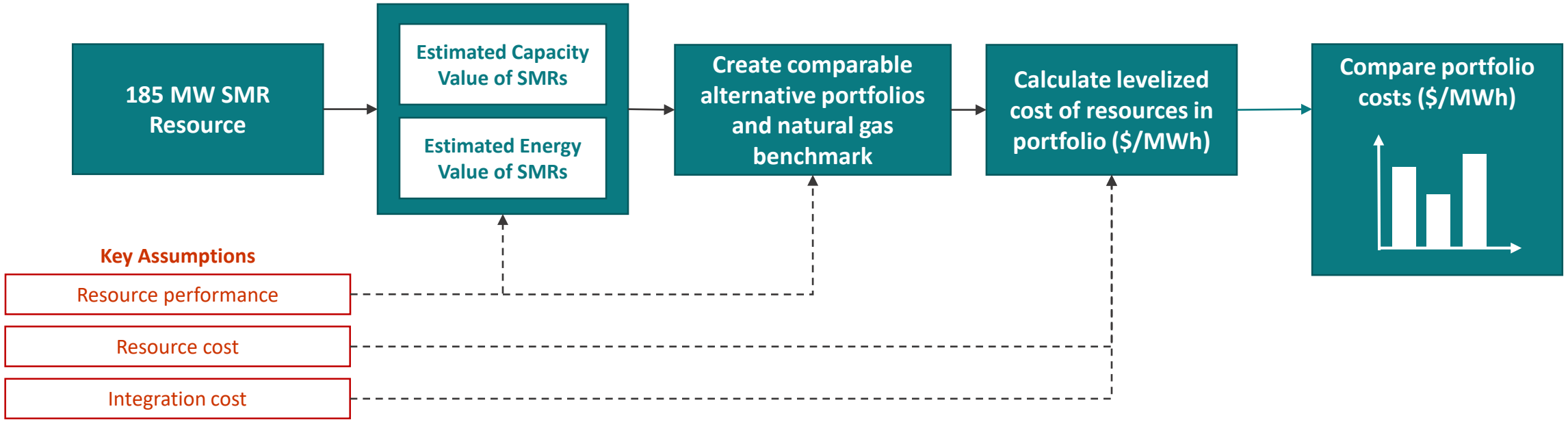
Prepared for Healthy Environment Alliance of Utah (HEAL Utah)

May 2019

Background & Purpose

- **HEAL Utah commissioned Energy Strategies to conduct an independent study comparing the cost of small modular reactors (SMR) with comparable portfolios made up of other low or non-carbon emitting resources, such as wind, solar, and energy storage**
  - NuScale Power is developing 600 MW of SMR nuclear technology (12 SMR units that are 50 MW each) located at the Idaho National Laboratory, with an expected operational date in 2026
  - Utah Associated Municipal Power Systems (UAMPS) members are considering participation in 185 MW of this capacity
  - This analysis compares the cost of alternative resource portfolios that would provide similar grid services and environmental attributes as 185 MW of SMRs, focusing primarily on energy and capacity value
  - The analysis also includes market purchases and new thermal generation in the alternative portfolios
  - An all natural gas "benchmark" portfolio was created for reference purposes
- **The study seeks to create data surrounding the relative costs of the SMR resources and alternatives by:**
  - Developing alternative energy resource portfolios that have comparable energy and capacity values
  - Developing total cost estimates for each portfolio
- **Energy Strategies conducted this analysis objectively and independently**
  - Energy Strategies does not take a position regarding UAMPS member's resource decisions nor does it advocate for or against any of the portfolios evaluated in this analysis
  - This analysis does not make assumptions with regards to the long-term needs of UAMPS members, but instead focuses on cost tradeoffs between specific resource portfolios

Study Method



- **Cost comparison is founded on resource-specific levelized cost of energy (LCOE) values**
  - Total portfolio LCOEs are calculated based on total energy associated with portfolio, but also take into account fixed levelized cost of resources that we assume provide no energy value and are to be used for capacity purposes only (energy storage and simple cycle combustion turbine)
- **LCOE combines capital costs, fixed and variable operation and maintenance costs, expected energy output (capacity factor), and other costs over the generator's anticipated lifetime to calculate the "average price" of energy from that resource on a levelized basis**

High-Level Study Assumptions

- **185 MW SMR is a carbon-free generation asset that may supply a portion of UAMPS members' capacity and energy needs starting in 2026**
  - SMR may be able to provide additional services, such as certain ancillary services and renewable integration; however, these additional benefits are not considered in this analysis
- **The study assumes that UAMPS members receive power from the SMRs and alternative portfolios through Network Integration Transmission Service on PacifiCorp's system and, therefore, transmission service costs for all alternatives are comparable and not considered in the analysis**
  - Interconnection costs are discussed but do not factor into the overall cost analysis given the significant uncertainty and case-by-case nature of these costs
  - The study does assume an integration cost consistent with PacifiCorp's Integrated Resource Plan (IRP) cost assumptions, but no other ancillary services are included in this assessment
- **Most data was gathered from a single publicly-available source: PacifiCorp's 2019 IRP assumptions**
  - Resource performance and levelized cost of energy assumptions for the alternative resources was sourced from PacifiCorp's 2019 IRP materials
  - Energy Strategies includes a cost sensitivity to capture possible deeper declines in renewable energy and storage costs not captured in the PacifiCorp IRP assumptions
- **All portfolios were designed to match the energy and capacity values of the 185 MW SMR portfolio**
  - Alternative portfolios were not optimized for least-cost
  - The capacity contribution and energy content of the alternative resources is based on PacifiCorp IRP assumptions. While these values are not specific to UAMPS member load and resource portfolio, they serve as a reasonable proxy for this study
- **Interconnection costs for the SMR and alternative portfolios are not explicitly included in the analysis, but estimated cost impacts are addressed**
  - The SMR units will require the Antelope Transmission Projects to interconnect and deliver SMRs to UAMPS members
  - Alternative resources may also require new transmission upgrades to interconnect, but these upgrade costs are not known at this time
- **This study did not analyze UAMPS members' entire resource portfolio, nor is it focused on the cost of accomplishing certain clean energy goals, such as 80% or 100% renewables**
  - The study considers the SMR units in isolation and assumes they will continue to be a part of a broader resource mix that includes non-renewable dispatchable resources
  - If UAMPS members do adopt aggressive GHG reduction goals (or are forced to), and emission reduction goals are drastic (versus marginal) the analysis of SMR economics relative to other options should be performed under this specific policy context

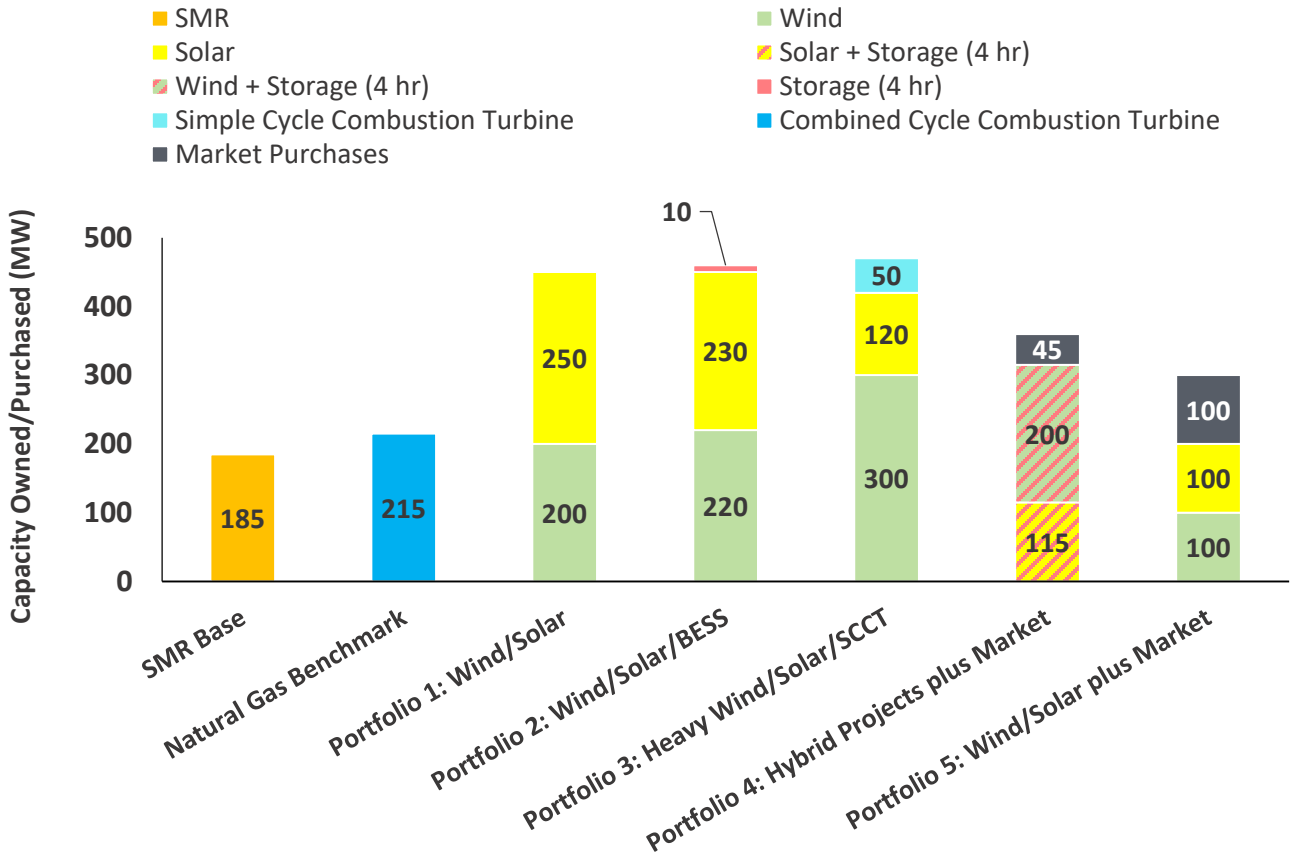
Key Study Findings

1. **On a levelized cost basis, the alternative resource portfolios, including those that are emissions-free, were approximately 40% ($24-$28/MWh) less costly than the SMR generation assumed in the Base Case of this study**
   - This means that the SMRs will cost at least $35 million per year more than the alternative portfolios
2. **On a present value basis, the alternative portfolios offer between $298M - $355M in savings compared to the SMR Base Case portfolio**
   - This estimate is based on cost differentials starting in 2026 and continuing for 20 years of portfolio operation
3. **Even after considering a $45/MWh low-end LCOE sensitivity for the SMR technology, the alternative portfolios are still less expensive than SMRs**
   - The average cost of the alternative portfolios is $40/MWh, which means that the alternative options are more than 10% less expensive than the lower-bound SMR cost estimate
   - Based on a $90/MWh high-end cost sensitivity for SMR resources, the SMR portfolio is more than twice as expensive as any of the alternative portfolios
4. **Deeper capital cost declines for solar, wind, and battery energy storage resources as reported by NREL may reduce the costs of studied portfolios with these resources by 7 – 19%, which further increases the likelihood that these resources would be less costly than the SMR project**
5. **Even with a carbon allowance price based on the Energy Information Administration's 2018 Annual Energy Outlook forecast, the SMR Base Case portfolio is slightly more expensive than the natural gas benchmark**
   - Adding a carbon price to the alternative portfolios that include market purchases or natural gas capacity resources does not significantly change their cost

SMR & Alternative Portfolios

Portfolio Composition by Nameplate Capacity

- **Resource Assumptions**
  - SMR located at Idaho National Lab in Idaho
  - Solar located near Milford, Utah
  - Wind located in Wyoming
  - Battery energy storage system (BESS) assumed to be a 4-hour capacity resource
  - Combined cycle combustion turbine (CCCT) assumed at 5,050’ at Hunter power plant location
  - Simple cycle combustion turbine (SCCT) assumed at 5,050’ at Hunter power plant location
  - Market purchases assumed to be at Four Corners
- **Alternative resource portfolios and natural gas benchmark were developed to match energy and capacity value of the SMR portfolio**
- **GHG Considerations**
  - Portfolios 1 and 2 are completely GHG-free, while Portfolio 3 includes SCCT as a capacity resource that would drive minimal GHG emissions
  - Portfolios 4 and 5 include “brown” market power purchases that would cause these portfolios to have material GHG emissions; ~170,000 metric tons and 375,000 metric tons, respectively, of CO_2 per year
  - Natural Gas Benchmark portfolio contains a CCCT which runs at a relatively high capacity factor and thus would produce material GHG emissions; ~500,000 metric tons of CO_2 per year
  - While not considered in this analysis, GHG emissions associated with these portfolios could be offset through the procurement of unbundled renewable energy credits (RECs) to meet voluntary renewable goals

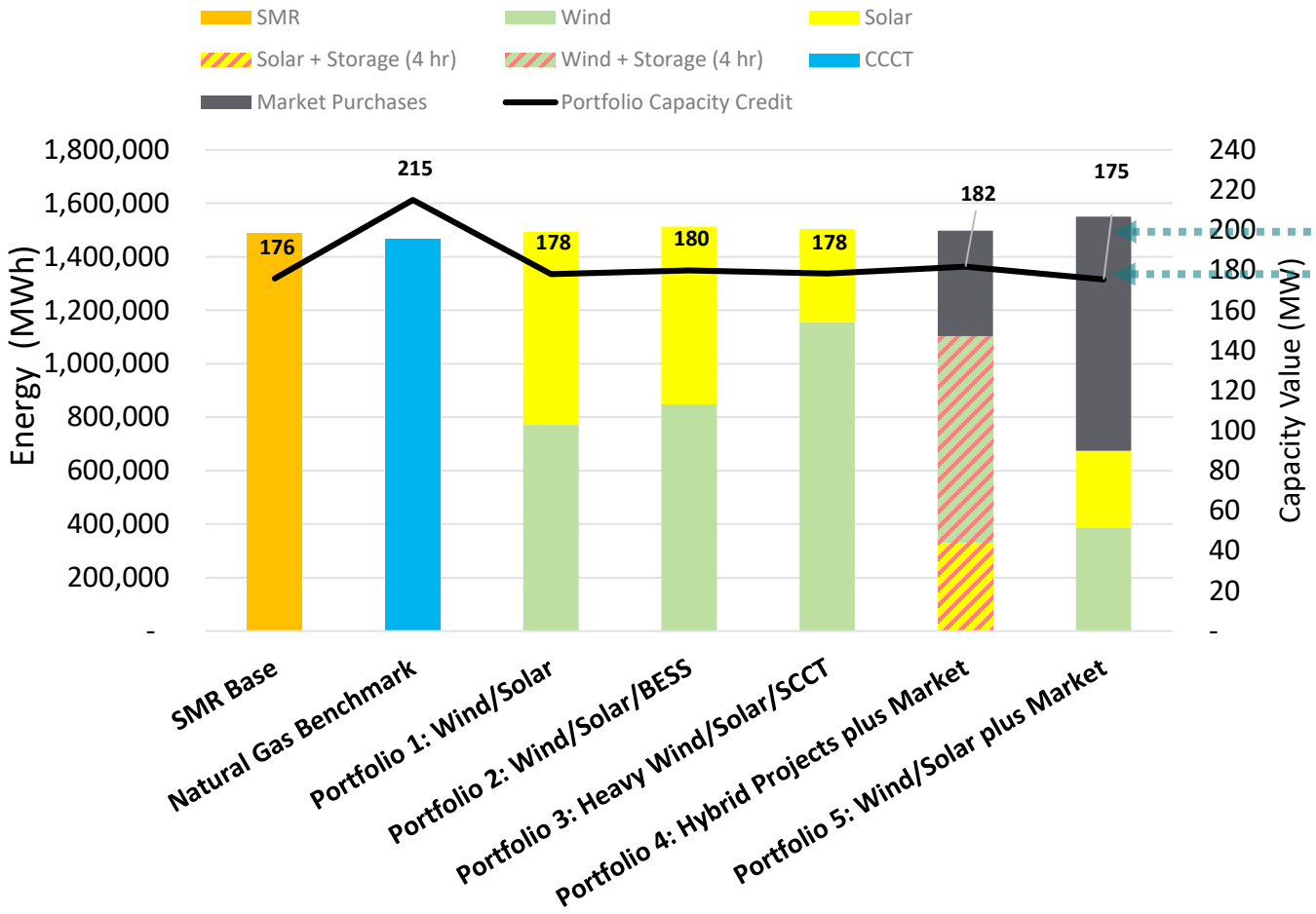


Energy and Capacity Value Assumptions

- **Each resource type was assigned a capacity value and capacity factor in order to develop comparable portfolios comprised of various resource types**
  - ❖ Capacity value reflects the resource's ability to reliably serve system peak demand
  - ❖ Capacity factor is the amount of energy output the resource will provide

Resource Type	Capacity Value	Capacity Factor	Data Source/Assumption
SMR	95%	92%	• Capacity value based on assumed summer de-rate and capacity factor based on "The Economics of Small Modular Reactors" by SMR Start (September, 2017) • Capacity factor based on "Examination of Federal Financial Assistance in the Renewable Energy Market" prepared by Scully Capital and KutakRock for the DOE Office of Nuclear Energy (October, 2018)
CCCT	100%	78%	PacifiCorp 2019 IRP Supply Side Resource Assumptions
Wind	21%	44%	PacifiCorp 2019 IRP Supply Side Resource Assumptions
Solar	54.4%	33%	PacifiCorp 2019 IRP Supply Side Resource Assumptions
Solar + Storage (4-hr)	65%	33%	PacifiCorp 2019 IRP Supply Side Resource Assumptions; Assumed addition of storage results in 10% increase in capacity value
Wind + Storage (4-hr)	31%	44%	PacifiCorp 2019 IRP Supply Side Resource Assumptions; Assumed addition of storage results in 10% increase in capacity value
Storage (4-hr)	85%	0%	Based on NREL Report: The Potential for Energy Storage to Provide Peaking Capacity in California under Increased Penetration of Solar Photovoltaics (March 2018); No energy content assigned – value is entirely capacity driven
SCCT	100%	0%	Capacity value based on WECC *Pro Forma* Capital Cost Model; No energy content assigned – value is entirely capacity driven
Market Purchases	100%	100%	Assumes firm capacity contract with 100% availability

Portfolio Composition by Energy and Capacity Value



- **Multiple resource types were drawn upon to form alternative portfolios that, combined, have comparable energy and capacity value to the SMR portfolio**
- **Energy content is consistent**
- **Capacity value is consistent**

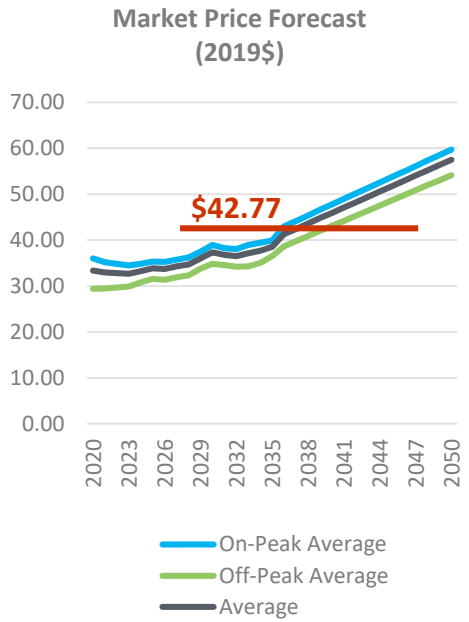
Portfolio Costs

Levelized Cost Assumptions

Keegan - Are we sure NuScale's price ($65) includes PTC for SMR?

- **SMR cost is based on publicly-available materials from the project developer and UAMPS**
- **Other resource cost estimates are sourced from PacifiCorp's IRP, Lazard, OTC Global**
  - Costs in this analysis do not include Production Tax Credits (PTC) for wind; but do include 10% Investment Tax Credits (ITC) for solar
  - Forward market prices are derived from Energy Strategies long-term forecasting models combined with futures pricing published by OTC Global
- **LCOE values were adjusted for capacity factors and inflation but not for tax treatment or cost of capital**

Resource Type	Cost*	Unit	Source	Notes
SMR	$66.30	$/MWh	UAMPS and NuScale materials	Cost after DOE support funding, cost of capital associated with municipality customers, and tax support including production tax credits (PTCs)
CCCT	$45.56	$/MWh	PacifiCorp 2019 IRP Supply Side Table	Energy and capacity resource
Wind	$33.28	$/MWh	PacifiCorp 2019 IRP Supply Side Table	No PTC
Solar	$39.50	$/MWh	PacifiCorp 2019 IRP Supply Side Table	10% ITC
Solar + Storage (4-hr)	$48.49	$/MWh	PacifiCorp 2019 IRP Supply Side Table	10% ITC for solar only
Wind + Storage (4-hr)	$37.95	$/MWh	PacifiCorp 2019 IRP Supply Side Table	No PTC/ITC
Storage (4-hr)	$160.24	$/kW-year	Lazard LCOS, Version 4.0	No ITC
SCCT	$82.00	$/kW-year	PacifiCorp 2019 IRP Supply Side Table	Capacity resource
Market Purchases	$42.77	$/MWh	Energy Strategies forecast/OTC Global	Used Four Corners as proxy market, 20-year price average



*All costs are in 2019$

Integration Cost Assumptions

- **Integration costs are used to represent the cost required to incorporate the resource output into the overall resource mix of the balancing area on a sub-hourly basis**
- **Schedule 3/3a "Regulation and Frequency Response" charges from PacifiCorp's tariff were used to estimate potential integration costs for resources**
  - Escalated costs at 3% per year
  - Assumed "committed scheduling" construct for all new resources, and assumed the SMR was a non-variable resource and all other non-dispatchable resources were variable resources
  - Energy storage and combustion turbines were not assigned an integration cost
- **Estimated values were checked against integration costs in PacifiCorp's IRP for consistency**

Schedule 3/3a Costs (Committed Scheduling) ($/MW-yr)				
	VER		Non-VER	
2019	$	5,631	$	1,794
2020	$	5,744	$	1,830
2021	$	5,858	$	1,866
2022	$	5,976	$	1,904
2023	$	6,095	$	1,942
2024	$	6,217	$	1,981
2025	$	6,341	$	2,020
2026	**$**	**6,532**	**$**	**2,081**

Rates escalated in real-terms to anticipate future cost increases

Used to calculate $/MWh costs

Resource Type	Integration Cost ($/MWh)	
SMR	$	0.26
Wind	$	1.69
Solar	$	2.26
Solar + Storage (4-hr)	$	2.26
Wind + Storage (4-hr)	$	1.69
Storage (4-hr)	$	-
CCCT/SCCT	$	-
Market Purchases	$	-

Integration costs in PacifiCorp's IRP are all less than $1/MWh, confirming the conservative nature of this estimate

Levelized Portfolio Cost

- **Total portfolio cost includes cost of energy and capacity resources and resource integration costs**
  - ❖ Interconnection/transmission costs not included

SMR portfolio levelized cost in the Base Case was $24 - $28/MWh higher than alternative portfolios analyzed

Present Value Savings Relative to SMR Base Case

- **Differences in the present value cost between portfolio represent the estimate savings (or costs) between portfolio choices**
- **Present value analysis was performed for 20 years, capturing total costs from 2026-2045**
  - Differences in costs between SMR Base Case and each portfolio were totaled, then discounted at 4.91% (real discount rate)
  - Present values brought back to today (2019)
- **By assuming a 20-year timeframe, analysis of savings is a conservative estimate**
  - SMR LCOEs are "locked in" for 40 years, while wind, solar and energy storage resources would need to either repower or be replaced after 20-30 years
  - Given that these resources are declining in costs, not increasing, the LCOE value of the alternative portfolios in year 30 or 40 would likely be lower than what is captured in year 20 of this analysis

- **Alternative portfolio 1 (wind and solar) offers the highest level of savings compared to the SMR Base Case, $355M**
  - Even though this portfolio would require the installation of more MWs of resource capacity (e.g. >400 MW of wind/solar vs 185 MW of SMR), there are substantial cost savings that can be realized due to the lower per unit cost of wind and solar resources
- **Natural Gas Benchmark portfolio offers significant savings over the SMR portfolio, though not as great as other alternative portfolios analyzed**

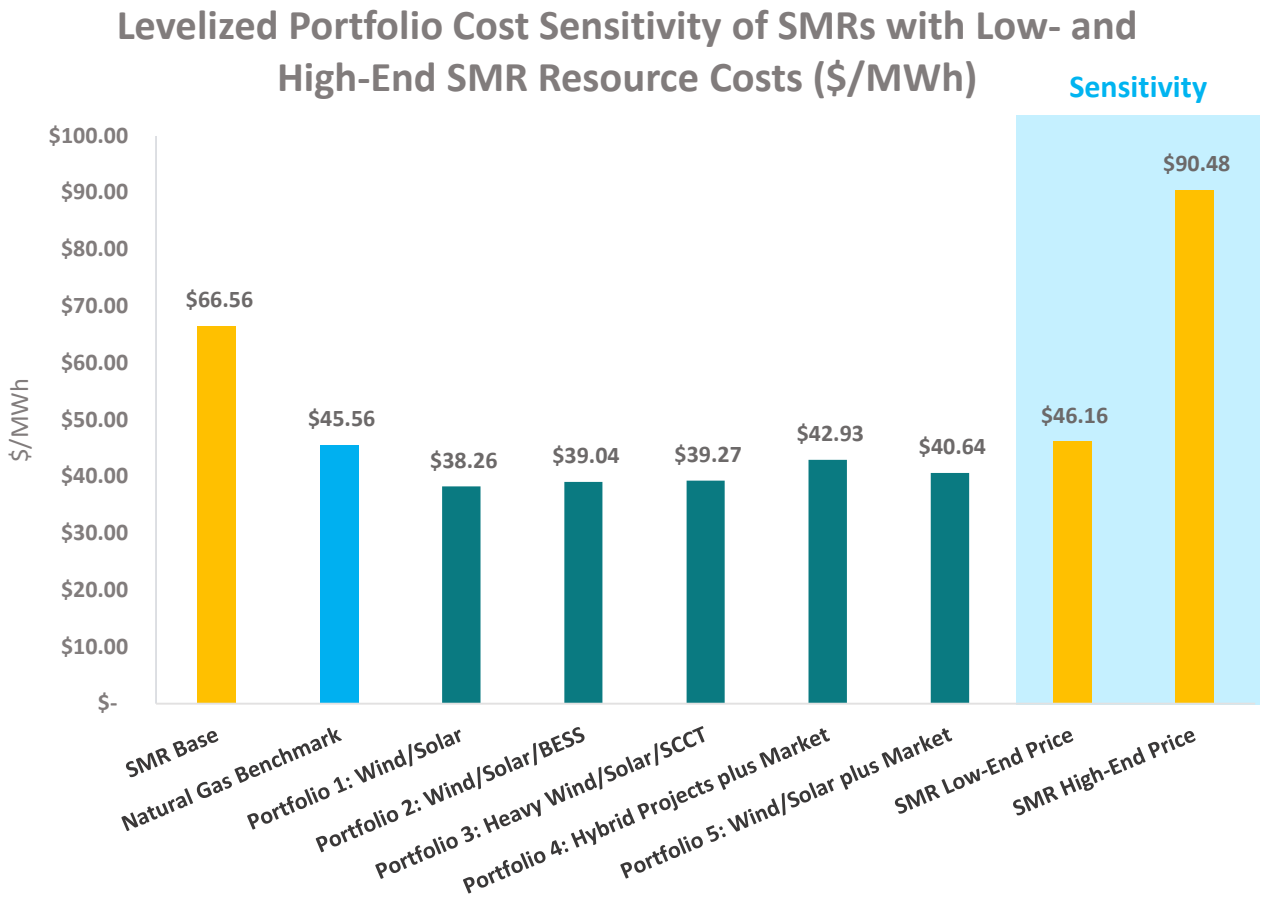
Present Value Savings Relative to SMR Base Case Over 20 Years Starting in 2026 ($M)

Portfolio	Present Value of Savings Relative to SMR Base Case ($M)
Natural Gas Benchmark	$259
Portfolio 1: Wind/Solar	$355
Portfolio 2: Wind/Solar/BESS	$350
Portfolio 3: Heavy Wind/Solar/SCCT	$345
Portfolio 4: Hybrid Projects plus Market	$298
Portfolio 5: Wind/Solar plus Market	$338

Sensitivities

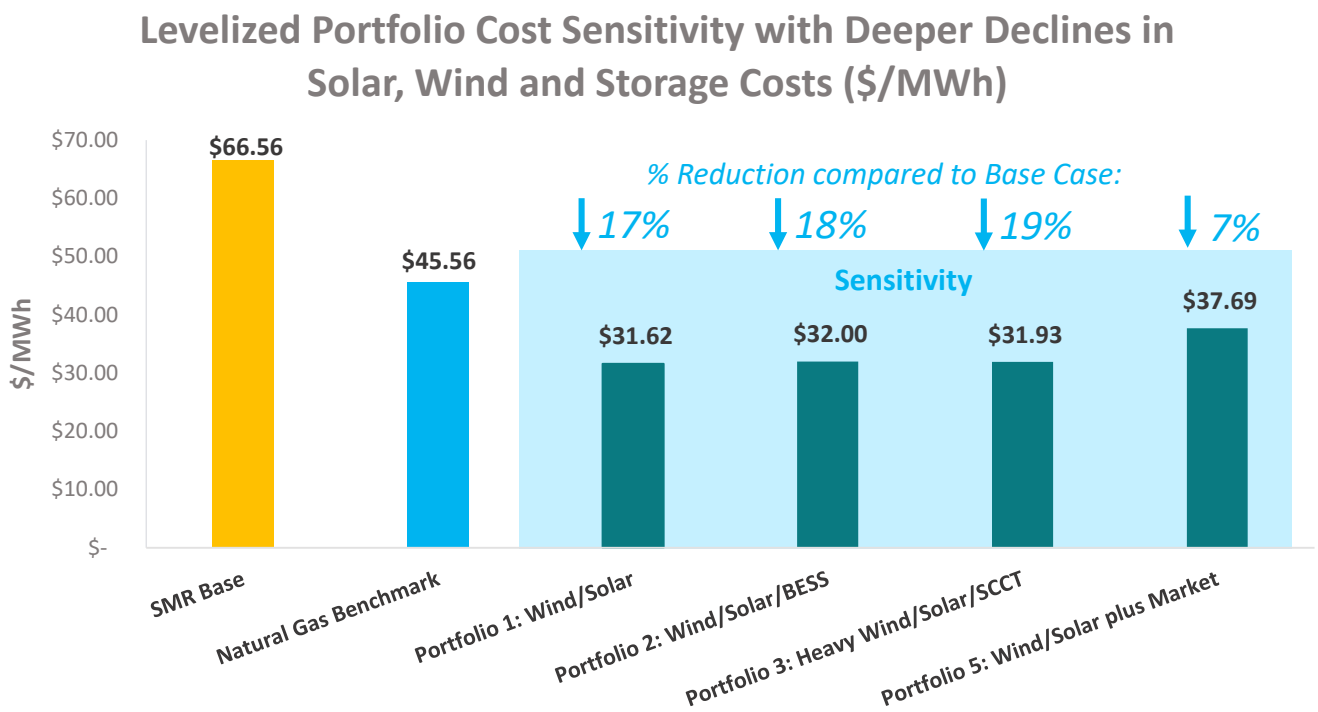
SMR Cost Sensitivity

- **SMR technology has not been demonstrated in a commercial application and there is uncertainty surrounding the actual cost of the future SMR project**
- **This analysis evaluated two alternative SMR LCOE cost scenarios:**
  - **$45/MWh**: Low-end cost represents low ranging SMR cost as reported in recent NuScale/UAMPS presentations
  - **$95/MWh**: High-end cost represents PacifiCorp's 2019 IRP cost assumption for SMR
    - *Adjusted in this analysis (to $90/MWh) to account for a slightly lower capacity factor*
- **High-end SMR cost is more than twice the cost of the wind/solar alternative portfolio 1**
- **Low-end SMR cost is on par with the cost of the natural gas benchmark**



Deeper Cost Reductions for Renewables and Storage

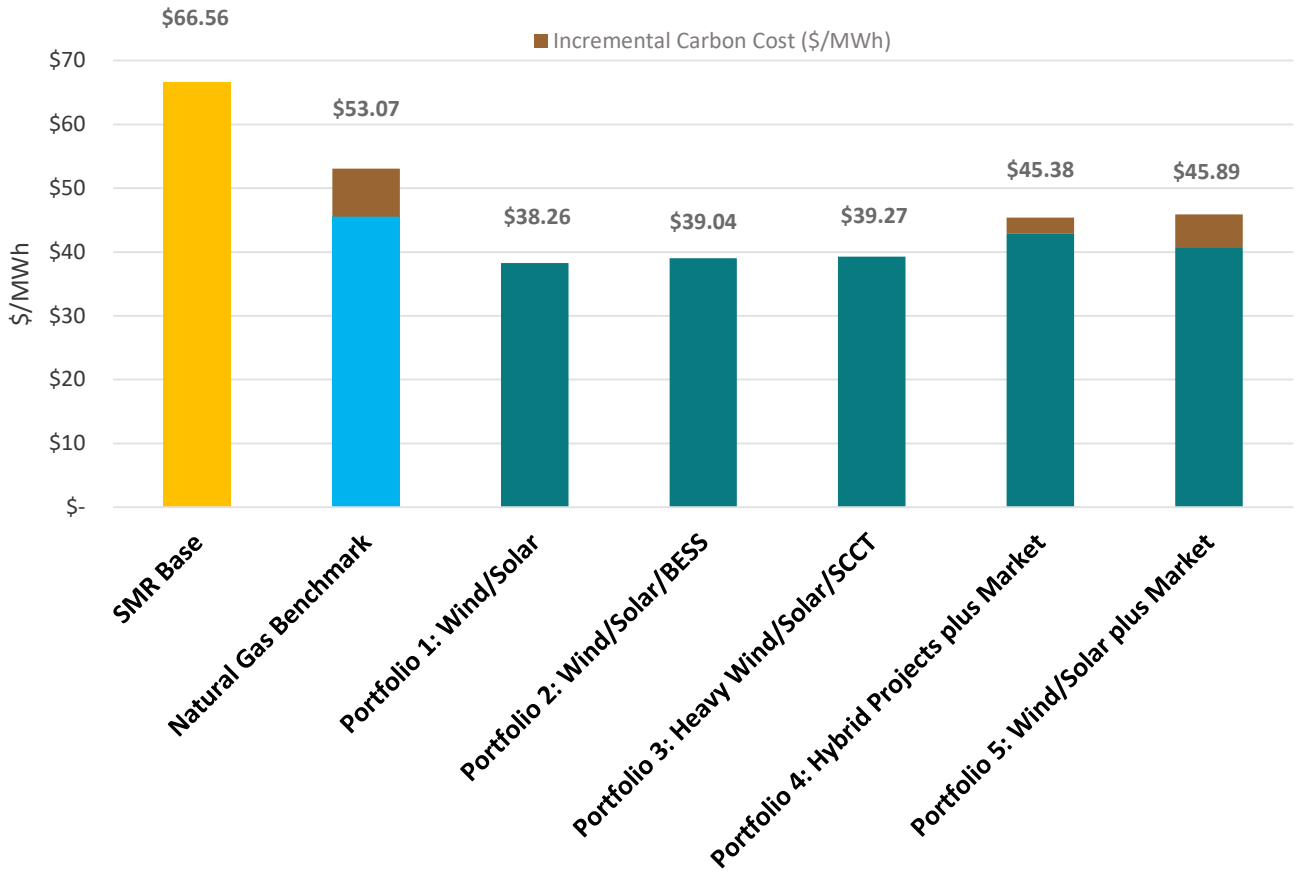
- **This study used PacifiCorp's 2019 IRP resource cost projections in its Base Case analysis which do account for future costs declines; however, these are a "mid" level costs and given extreme historic decreases in costs, it is prudent to account for a future where these cost declines are lower than current forecasts**
- **Reduced costs for renewables were imputed based on capital expenditure ranges developed by NREL's 2018 Annual Technology Baseline (ATB)**
  - An LCOE was derived from NREL's capital expenditure projection using the WECC 2017 *pro forma* capital cost model
- **Deeper cost reduction sensitivity development approach:**
  - The imputed low-end solar capital cost in 2026 was 13% less than its mid-level cost, thus resulting in a solar resource LCOE sensitivity of $34/MWh
  - Wind lower-bound cost compared a mid-level 2023 capital cost against a low-end 2026 cost to account for the PacifiCorp IRP's assumed 2023 installation year; resulting in a wind resource LCOE sensitivity of $25/MWh
  - Storage cost declines were projected by comparing a January 2019 Joule report's BESS cost forecast for 2026 to Lazard's 2020 base BESS cost; resulting in a BESS levelized cost of storage sensitivity of $122/kW-year



Carbon Price Sensitivity

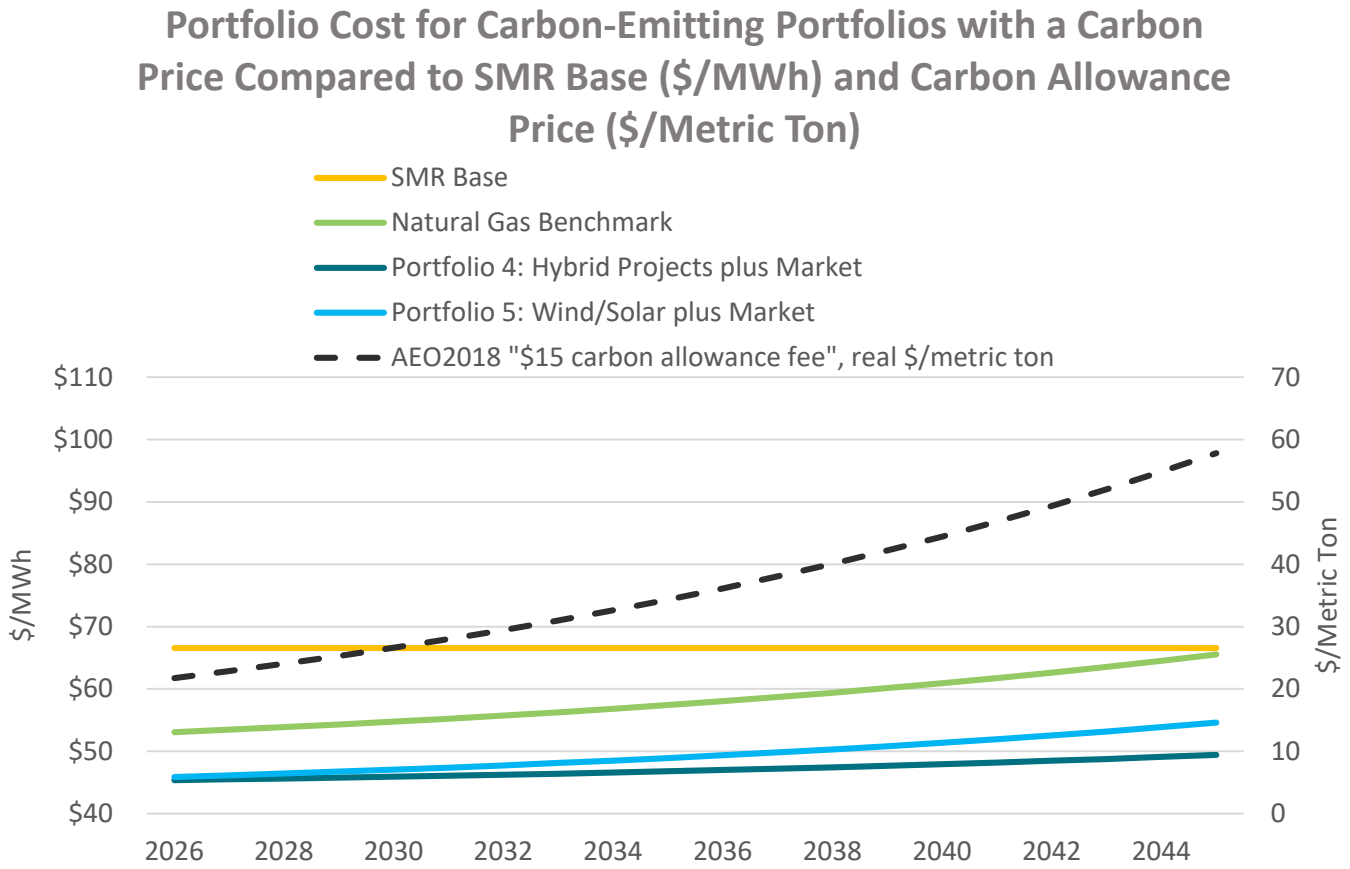
- **Many load-serving entities, including PacifiCorp, consider a future carbon price in their resource planning processes as a way to capture future risk associated with potential regulation**
- **Therefore, this analysis also considered a carbon price as a sensitivity to the Base Case analysis**
  - ❖ Utilized Energy Information Administration's 2018 Annual Energy Outlook (AEO) carbon price forecast for a $15 Carbon Allowance price, which was surveyed as a medium carbon price sensitivity in PacifiCorp's 2019 IRP process
- **Carbon pricing was applied to resources with emissions**
  - ❖ Natural Gas Benchmark: CCCT resource
    - ➢ 117 lbs of CO_2/MMBTU with a heat rate of 6510 Btu/kWh as reported by PacifiCorp's 2019 IRP supply side assumptions
  - ❖ Portfolio 4 and 5: Market Purchases
    - ➢ 0.427 Metric Tons/MWh, which is the California Air Resources Board emissions rate for WECC-wide unspecified power

Levelized Portfolio Cost Sensitivity with AEO 2018 "$15 Carbon Allowance Price" ($/MWh)



Carbon Price Sensitivity (continued)

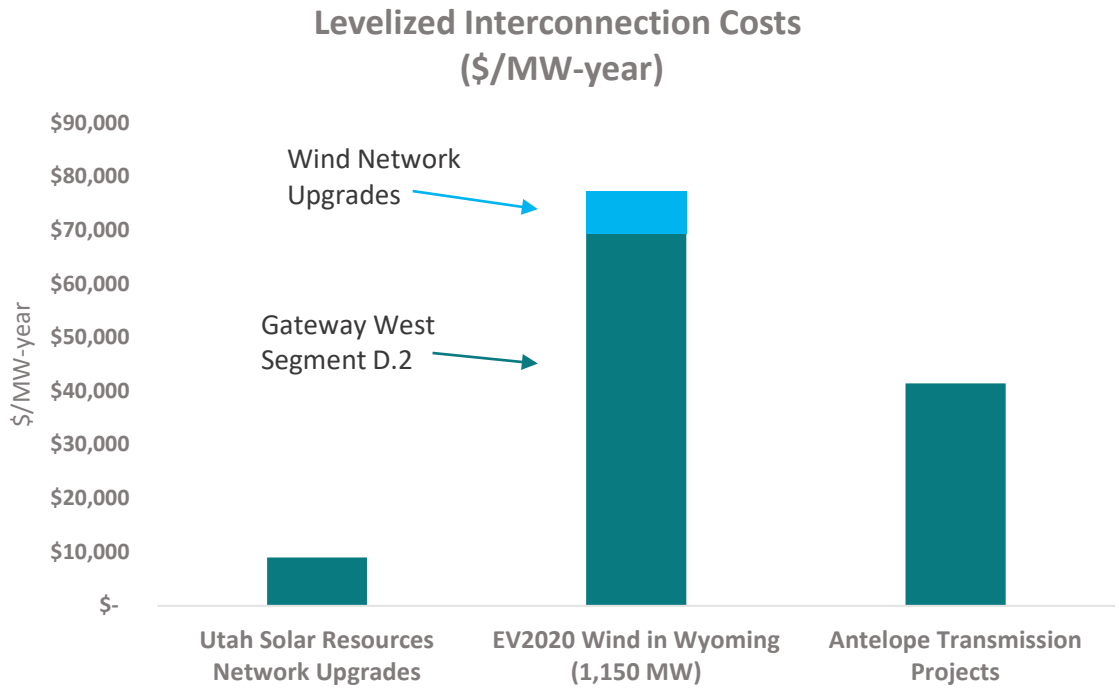
- **Over a 20-year time horizon, annual carbon cost impacts on each portfolio will increase at different rates depending on their respective carbon emissions rates**
- **Relative to the SMR Base portfolio, the natural gas benchmark is projected to become more expensive shortly after 2045 (in real terms)**
- **However, even with the incremental carbon cost associated with market purchases in portfolios 4 and 5, these portfolios costs are still significantly lower than the SMR Base Case at the end of the 20-year time horizon that starts in 2026 on a levelized basis**
- **Given that these portfolios have relatively low carbon intensity, including carbon costs does not significantly change the economic efficiency of these options compared with SMR resources**



Interconnection & Transmission Cost Assessment

Interconnection & Transmission Costs

- **Interconnection costs were not considered in the cost analysis portion of the study**
- **However, PacifiCorp's transmission customers will ultimately pay the costs for network transmission upgrades required to connect new generation to grid**
  - ❖ Transmission customers include load associated with PacifiCorp, UAMPS, and UMPA service territories
- **Studies performed by PacifiCorp and Northern Tier Transmission Group indicate the 345-kV Antelope Transmission Project is required for the 600 MW SMR interconnection**
  - ❖ The project is beyond the point of interconnection of the facility, so it will likely be a Network Upgrade
- **Recent solar projects in Utah have completed interconnection studies that indicate lower network upgrade costs compared to costs required to bring Wyoming EV2020 wind online and costs potentially associated with the SMR interconnection**
  - ❖ Network upgrade costs identified in an interconnection study give an indication of the network transmission costs necessary to deliver the resource to load
- **Interconnection and transmission cost analysis for this study used WECC *Pro Forma* Transmission Cash Flow model with capital cost input data compiled by Energy Strategies**
- **Results indicate that network upgrade costs are highly dependent on location and ratepayers are potentially less impacted by Utah solar**



Data source:
- Utah Solar: Energy Strategies PPA database and research/review of interconnection studies in PacifiCorp interconnection queue.
- EV2020 transmission costs based on public information from PacifiCorp testimony and estimate Segment D.2 cost at $739 million
- Antelope Transmission Project costs are estimated using WECC Capital Cost Calculator and assume 97 miles of 345-kV single circuit lines at $2.11 million per mile (excluding substation costs)

Findings & Recommendations for Additional Analysis

Base Case Findings

- **On a levelized cost basis, the alternative resource portfolios, including those that are carbon-free, were at least $24/MWh less costly than the SMR generation assumed in the Base Case of this study**
  - The average cost of the alternative portfolios was roughly 40% less than the SMR resource option.
  - Compared with SMR generation, wind, solar and BESS (along with market purchases and a small SCCT) represent lower cost options for UAMPS' members to add resources to meet energy needs while *incrementally* reducing total GHG emissions in its overall resource portfolio
- **On a present value basis, the alternative portfolios offer between $298M – $355M savings over a 20-year time horizon staring in 2026 compared to the SMR Base Case portfolio**
  - The wind and solar only portfolio (alternative portfolio 1) offers the highest potential savings
  - The natural gas benchmark portfolio, without a future carbon price, offers a $259M savings compared to the SMR Base Case portfolio on a present value basis
- **Integration costs are not a significant factor in the cost analysis as they add roughly $2/MWh to the cost of the alternative portfolios**
  - The development of these cost assumptions were very conservative and including them in the cost analysis does not change the conclusion outlined above, which is that portfolios of wind and solar are lower cost compared to the SMR resource option

Additional Findings from Sensitivity Analysis

- **Cost sensitivity analyses reveal that the "Base Case" findings are robust:**
  - Based on a $45/MWh low-end levelized cost sensitivity for SMR resources, the alternative portfolios are still roughly 10% cheaper than SMRs. An all-natural gas portfolio is roughly the same price as the SMR assuming this lower-bound SMR cost.
  - Based on a $90/MWh high-end levelized cost sensitivity for SMR resources, the SMR portfolio is more than twice as expensive as any of the alternative portfolios, and approximately $45/MWh more costly than the all-natural gas portfolio
- **If renewable and storage resources experience deeper capital cost reductions, there may be additional "upside" cost savings associated with the alternative portfolios**
  - Deeper cost declines for future solar, wind, and BESS resources may reduce the costs of portfolios with these resources by 7 – 19%
  - If these lower renewable and storage costs are achieved, the portfolios with these resources may cost less than half as much as the SMR portfolio
- **Including a carbon price does not change any of the Base Case findings because:**
  - (1) the alternative portfolios require no or low carbon-emissions, and
  - (2) the natural gas benchmark portfolio is much less costly to begin with, so it has "headroom" to absorb the incremental carbon cost through 2045

Recommendations for Additional Analysis

- **Portfolio cost-effectiveness in the context of achieving specific emissions reduction goals**
  - This study did not analyze UAMPS members' entire resource portfolio, nor did it focus on the cost of accomplishing certain clean energy goals, such as 80% or 100% renewables or achieving specific carbon reductions. The study considers the SMR units in isolation and assumes they will continue to be a part of a broader resource mix that includes non-renewable, dispatchable resources.
  - While not considered in this study, other Energy Strategies analyses suggest that the total cost of serving load with 80-100% renewables using wind, solar, energy storage, and balancing with market purchases/sales may cost more than a $65/MWh SMR resource. The cost for a small entity to completely eliminate carbon is an area of ongoing research.
  - This leads to the conclusion that, if UAMPS members adopt aggressive GHG reduction goals or are required to by legislative fiat, and those reduction goals are aggressive (versus incremental or marginal), the analysis of SMR economics relative to other options should be studied under this specific policy context and the results of that analysis may indeed have different conclusions than the resource-to-resource comparison considered in this study
- **Accounting for the ancillary benefits offered by SMRs and other portfolios**
  - Integration benefits of SMRs have not been considered, nor were investment risk, among other potential costs and benefits across the portfolios
  - A more thorough analysis could include a line-by-line accounting of all portfolio costs and benefits
- **Consideration of transmission upgrade costs required for various portfolios**
  - The Antelope Transmission Projects represent a significant upgrade, although its costs would eventually be borne by all of PacifiCorp's transmission customers
  - Regardless, any increase in UAMPS' member transmission rates could be incorporated in the economic analysis of the generation project (as could any transmission rate impact associated with other resources requiring substantial Network Upgrades)
- **Reliability impacts**
  - While we believe reasonable parameters were used to approximate the capacity credit for renewable resources, additional work could be performed to estimate more granular capacity credit assumptions
- **Operational modeling**
  - It would be informative to evaluate the SMR resources and the alternative portfolios as a part of the UAMPS' generation mix through hourly production cost modeling or another analysis method that captures the variable nature of wind and solar generation.

ENERGY STRATEGIES

THANK YOU

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