Southwest Power Pool

FUTURE ENERGY AND RESOURCE NEEDS STUDY (FERNS) RESULTS

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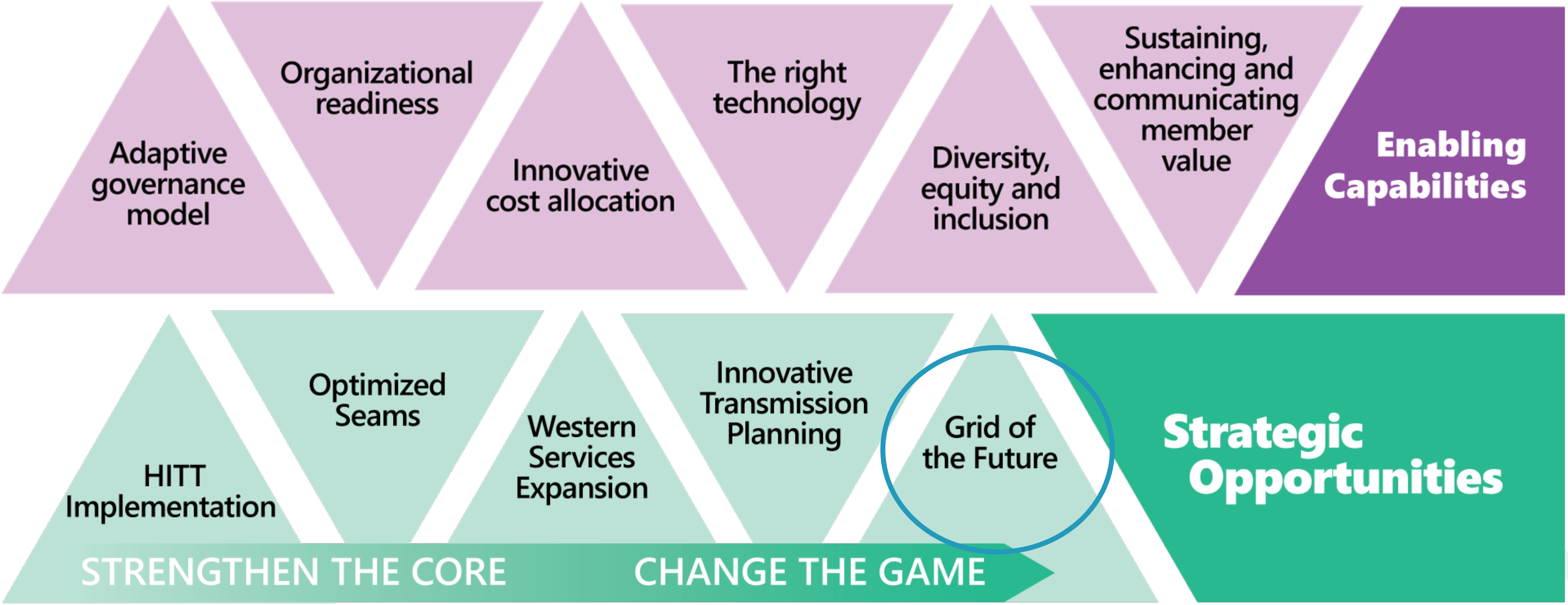
spp.org/about-us/strategic-plan/

STRATEGIC PLAN ALIGNMENT

PURPOSE OF THIS PRESENTATION: Review FERNS Study key results and findings.



FERNS STUDY OVERVIEW

Purpose

- What is the most cost-effective future resource mix to meet system needs through 2050?
- How do the costs (operational and investment) of these systems vary across future scenarios?
- What are the shortcomings of the current resource adequacy framework in a highly electrified and decarbonized future?

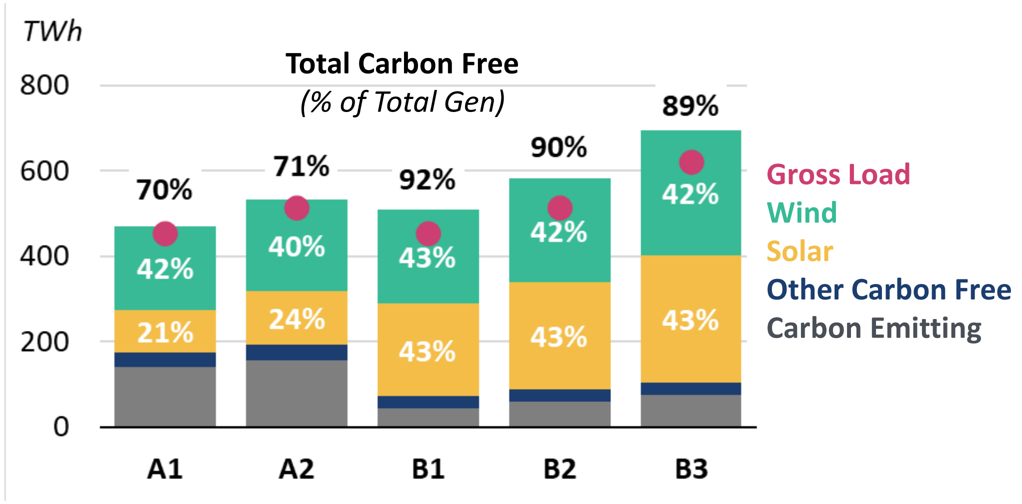
Approach

- Zonal capacity expansion model of SPP for each of the five FERNS scenarios (recognizing interconnection with neighbors)
- Study horizon from 2023 through 2050
- Coordination with SPP Staff and stakeholder groups (e.g. ITP, CPP) on all study inputs

FERNS Study Scenarios

Electrification \ Carbon Free Resource Shares	Low	Moderate	High
Low		A1	B1
Moderate		A2	B2
High			B3

SPP-Wide Decarbonization Share by 2050



Note: Total (%) shows % of total generation from carbon free resources

KEY FINDINGS FROM FERNS SIMULATIONS

In scenarios with high load growth and high shares of renewable generation, SPP is projected to maintain resource adequacy in a cost-effective and affordable manner if fossil-fuel generation capacity is retained (or replaced) for reliability purposes and sufficient new resources, including storage, are added to the SPP system.

A projected $88–$263 billion of generation investments will be needed to support SPP's load growth through 2050. This is possible without significant rate increases (in inflation-adjusted terms) due to load growth and fuel-cost savings, especially if federal tax credits (or similar renewable generation support) remain available.

Between 70% and 90% of SPP's annual energy is projected to be generated from renewable resources by 2050, though conventional generation is expected to continue to serve a large share of SPP's resource adequacy needs, representing 40–60% of the region's accredited capacity. This is a function of technology costs, natural gas prices, and the availability of tax credits (or similar policies).

Solar generation is projected to outcompete wind generation. By 2050, 20–48 GW of new wind generation is expected to be added, which compares to 42–130 GW of new solar generation. As solar generation expands, 22–59 GW of battery storage is projected to be cost-effective (and often co-located) to maintain resource adequacy.

KEY FINDINGS FROM FERNS SIMULATIONS

4–21 GW of new regional transmission capacity (between SPP zones) is projected to be cost-effective by 2050, necessary to support the delivery of generation to load centers.

Resource adequacy challenges evolve over time to be more frequent during: (a) winter months (particularly in high electrification futures) and (b) the early evening hours (after sunset). This implies that winter planning reserve margins will need to be significantly higher than summer reserve margins, due to low solar capacity values and high temperature-correlated fossil outages in the winter.

SPP has sufficient available land to accommodate the projected 60–180 GW of wind and solar generation capacity additions through 2050 in all scenarios evaluated.

The effective load carrying capability (ELCC) value of solar and short-duration storage resources is projected to decline over time, while the ELCC of wind resources increases slightly. Even the ELCC of 8-hour storage declines in the high renewable generation scenarios, indicating a need for long-duration storage. Interties with neighboring regions offer valuable resource adequacy and extreme-weather resilience benefits to the SPP footprint.

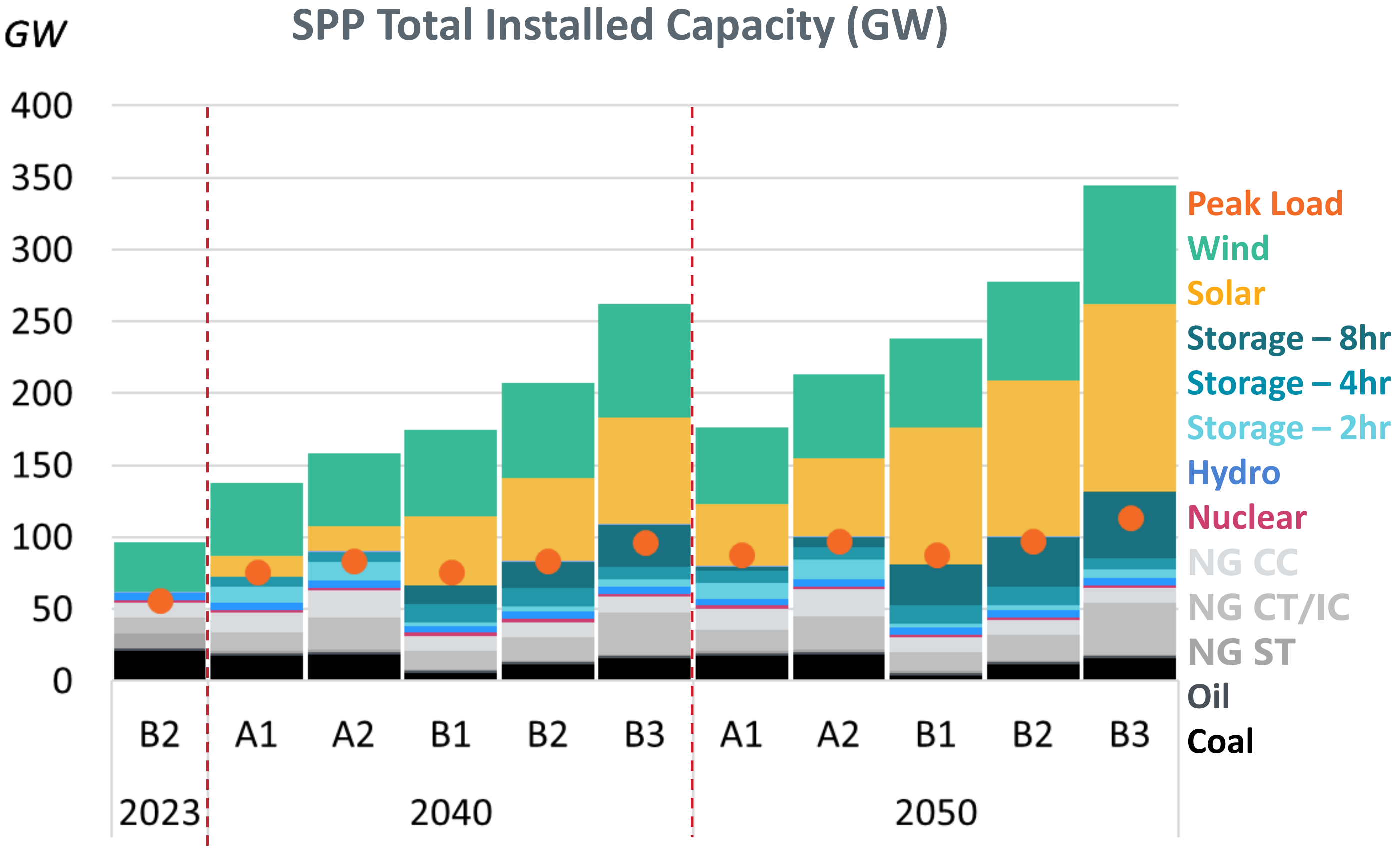
SPP is projected to become a more significant net exporter by 2050, particularly in the high renewable generation scenarios, due to the high-quality of renewable generation in the region.

CAPACITY BUILDOUT ACROSS SCENARIOS

Electrification	Carbon Free Resource Shares: Moderate	Carbon Free Resource Shares: High
Low	A1	B1
Moderate	A2	B2
High		B3

The extent to which SPP will electrify and decarbonize will lead to different optimal resource solutions as shown through scenario analysis:

- Through the 2020s: In the near term, all scenarios have comparable capacity buildout driven by already scheduled retirements and planned builds currently in the interconnection queue
- In the 2030s: High decarbonization scenarios replace fossil capacity with low-cost renewables and storage resources, with more resources needed for higher electrification scenarios
- In the 2040s: Longer duration storage becomes a key resource adequacy asset for the high decarbonization scenarios paired with renewables (primarily solar). Moderate decarbonization scenarios rely on more fossil, shorter duration storage assets, and much less solar by 2050



Note: Only select later years, 2040 and 2050, are highlighted in this chart. For full capacity buildout by year see FERNS report.

INTERZONAL SPP TRANSMISSION EXPANSION BY SCENARIO

Electrification \ Carbon Free Resource Shares	Moderate	High
Low	A1	B1
Moderate	A2	B2
High		B3

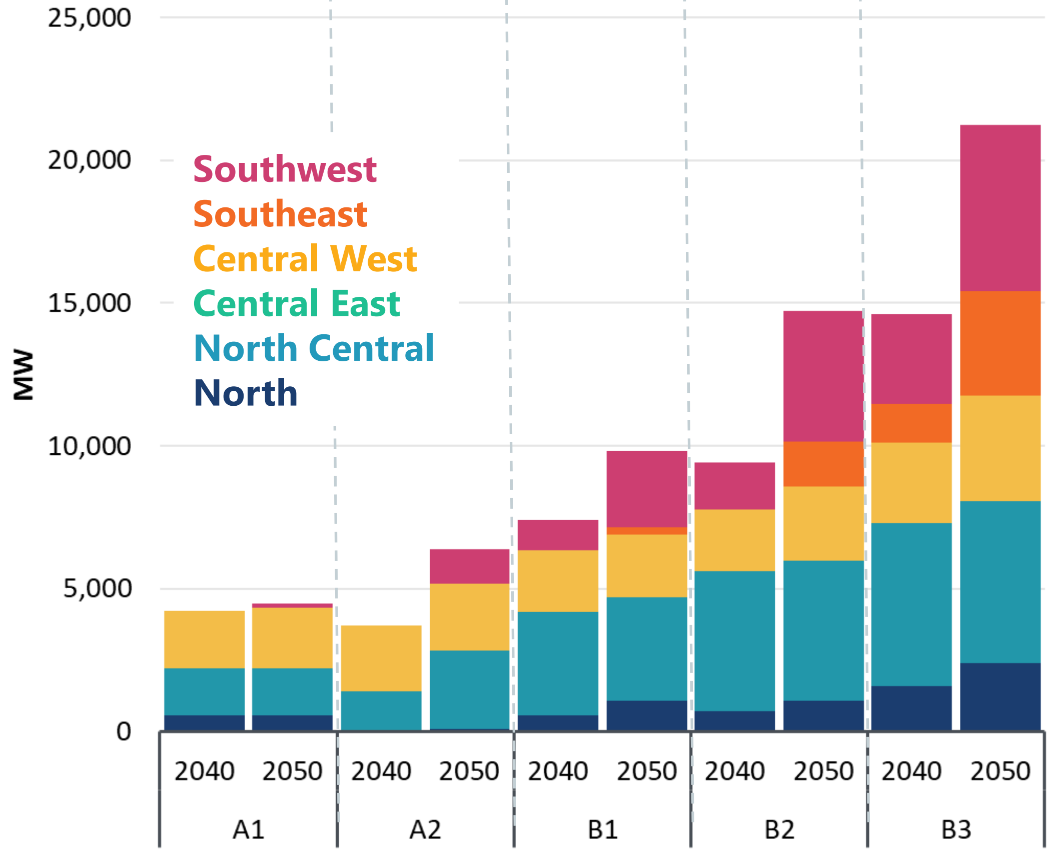
The need for additional SPP interzonal transmission (relative to assumed import/export limits of LOLE zones) varies significantly with electrification and decarbonization trajectories:

- Moderate carbon-free scenarios (A1, A2) result in the lowest demand for additional interzonal transmission because load is met by local dispatchable fossil generators
- In high decarbonization scenarios (B1, B2, B2), it is more cost effective to locate (the lower-cost) renewables in high resource-quality regions (Southern and Central zones) and invest in transmission infrastructure when renewables are not zonally located with load.
- The optimal level of transmission expansion is a function of both transmission costs and generation costs

A portion of these expansion levels will be addressed by SPP's 2024 ITP proposed transmission investments, which total $7.7 billion. FERNS modeling was completed before ITP 2024 release.

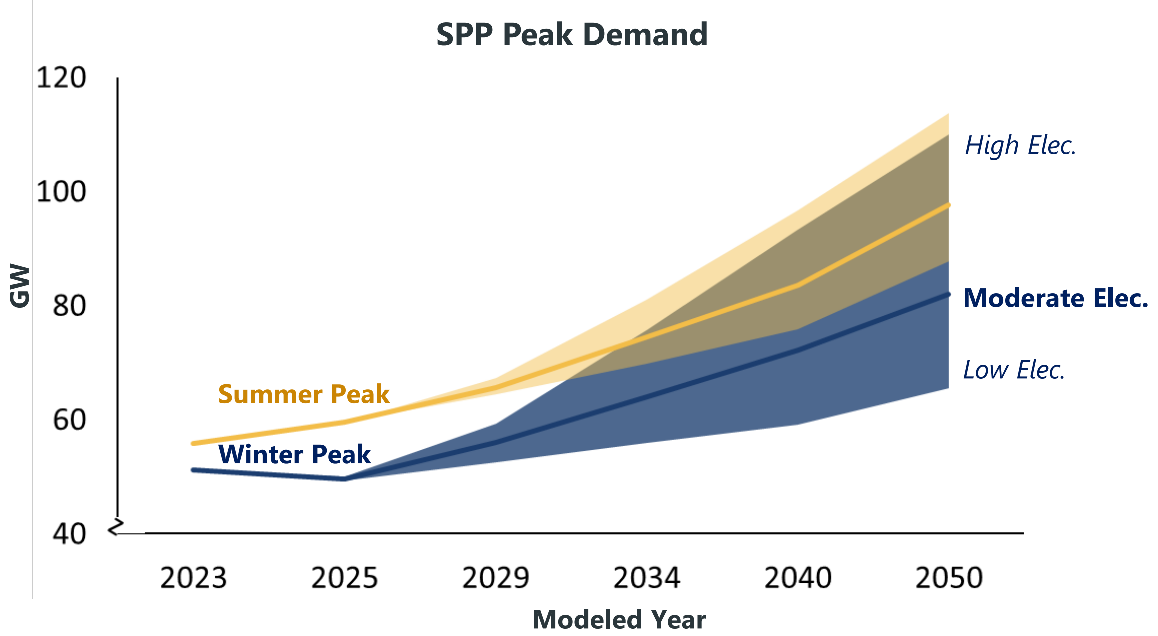
SPP Cumulative Economic Interzonal Incremental Transmission

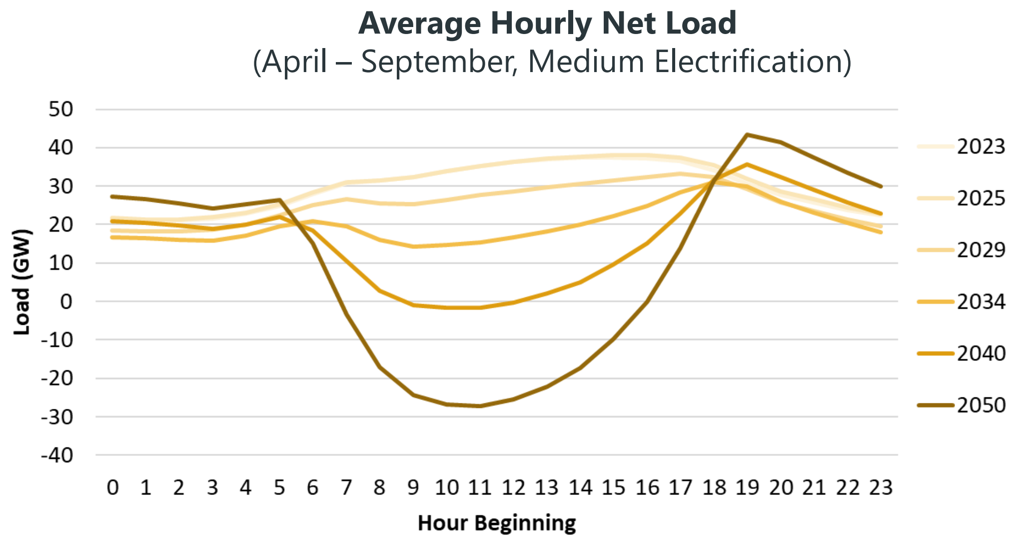
(MW of added zonal import/export capability by 2050)

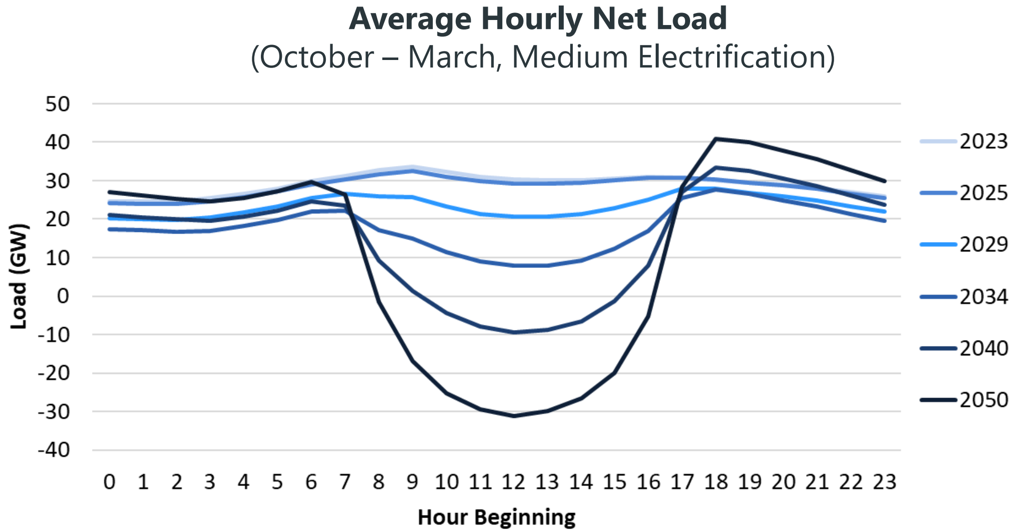


FUTURE SYSTEM NET LOAD CONDITIONS

- SPP system conditions will evolve with increased electrification and renewable penetration
- Electrification will increase SPP gross peak load by 1.4x – 1.8x by 2050 in the electrification scenarios
- Preliminary capacity expansion results show evolving system needs. At the right are the proxy year SPP-wide net load shapes broken into two seasons:







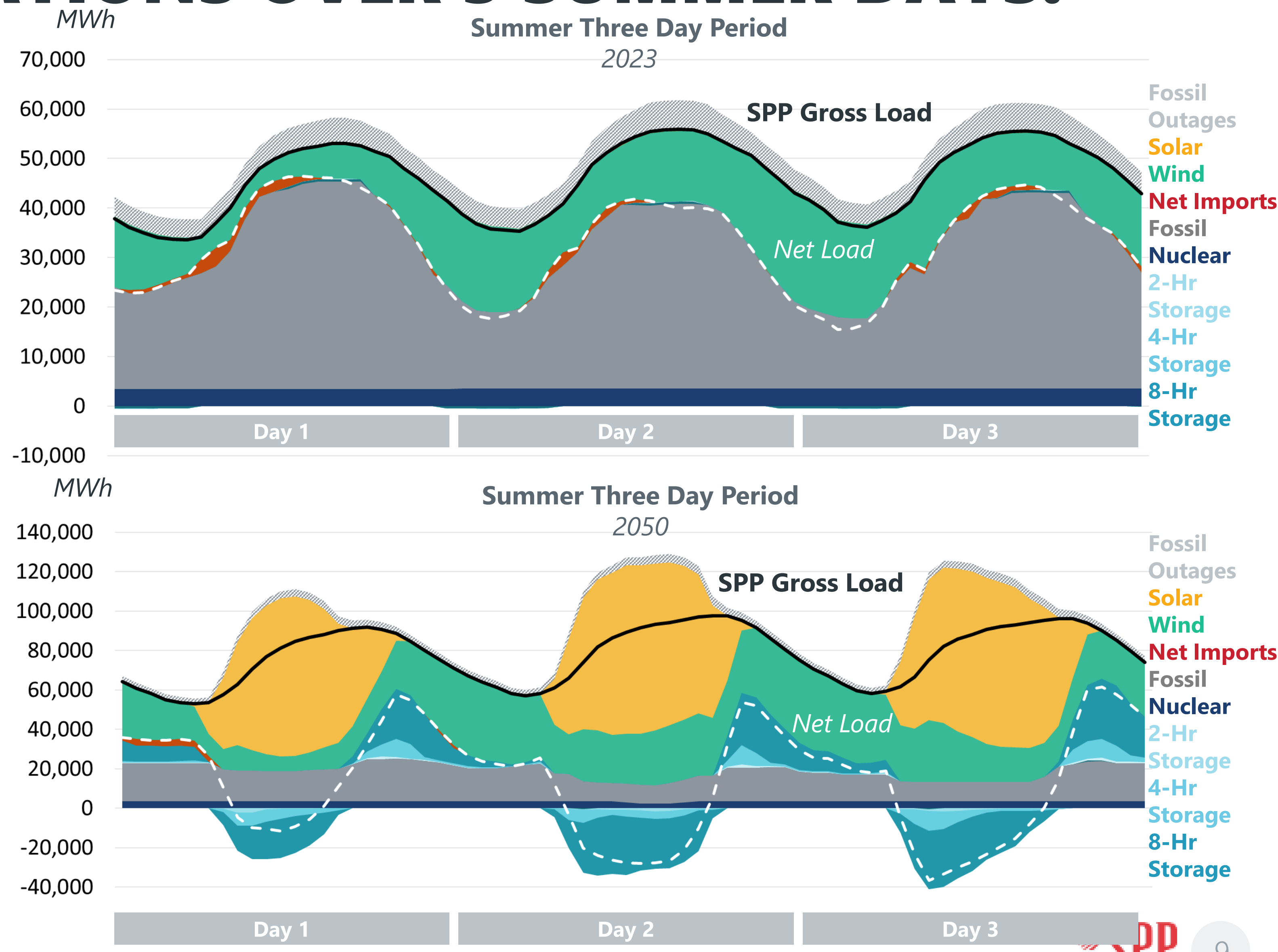
Note: Results show average 24-hour seasonal shapes of system gross load minus variable renewable generation (solar, wind) plus fossil outages, without any battery storage impacts. Results show the B2 scenario with medium electrification and high carbon-free resource share reaching ~90% by 2050.

SPP

SPP HOURLY OPERATIONS OVER 3 SUMMER DAYS: 2023 VS. 2050 (B2)

As SPP decarbonizes, fossil operations are displaced by renewables and mid-duration storage:

- Solar increases penetration and "duck curve" net load shape
- Longer duration storage enters in later years to charge during high solar hours and serve load during low renewable output periods (e.g., overnight)
- Coal continues operations as a base load generation, but could be displaced by gas depending on price dynamics



Note: Vertical axis differ across figures. Net load is gross load net of renewable generation (not storage and not accounting for fossil outages because they are shown individually in the chart.

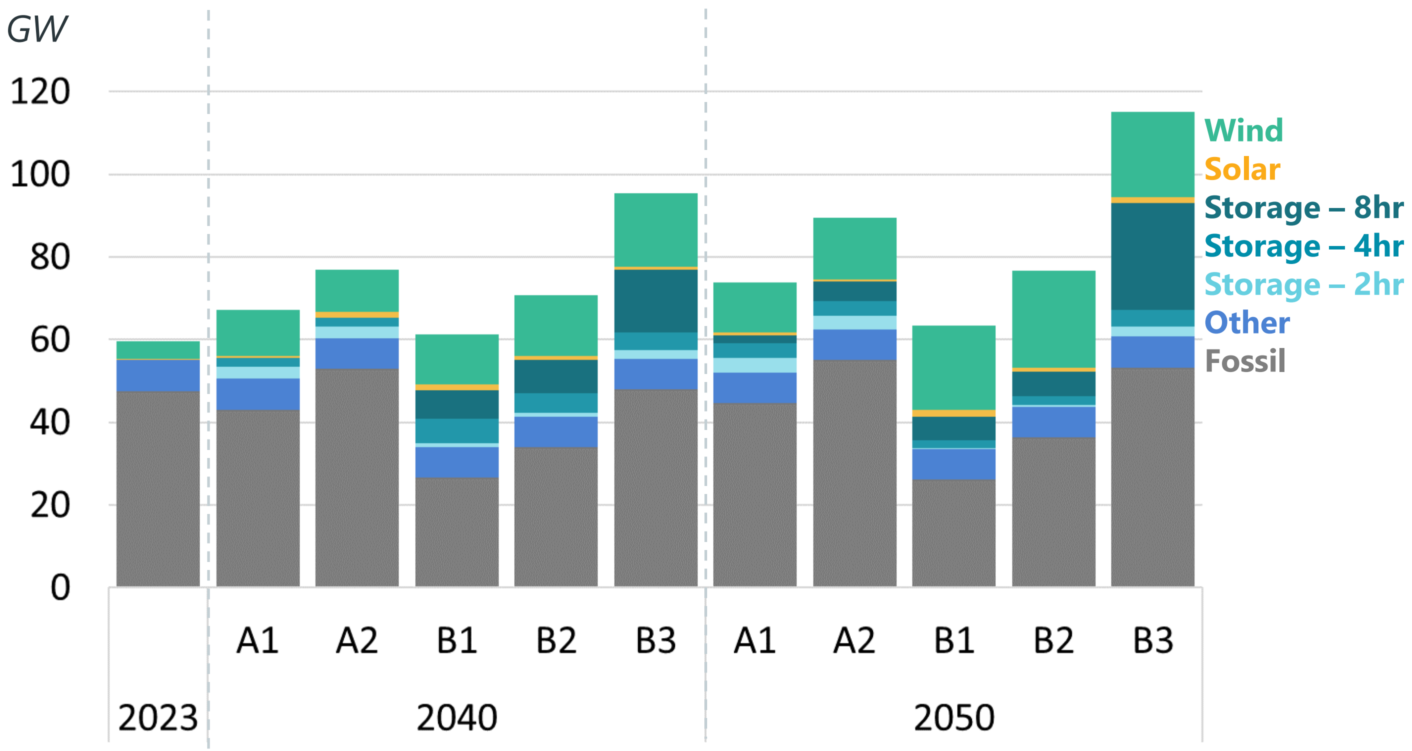
AVAILABLE CAPACITY DURING 100 TIGHTEST HOURS

Electrification	Carbon Free Resource Shares: Moderate	Carbon Free Resource Shares: High
Low	A1	B1
Moderate	A2	B2
High		B3

Across all scenarios, SPP will continue to rely on fossil resources during challenging system hours. The chart shows the available resource capacity during the top 100 RA risk hours:

- Today in the 2020's: SPP primarily serves load during risk hours (high summer load and winter risk days) with thermal resources, supplemented by low quantities of wind and nuclear generation
- Through 2040: While fossil continues to dominate, wind resources increase their contributions in peak hours across all scenarios, with high renewable B scenarios also relying on battery storage
- By 2050: Fossil resources still contribute to 41% to 62% of rated capacity in RA risk hours, even in scenarios with 90% clean energy generation

SPP Available Capacity During 100 Highest RA-Risk Hours (GW)



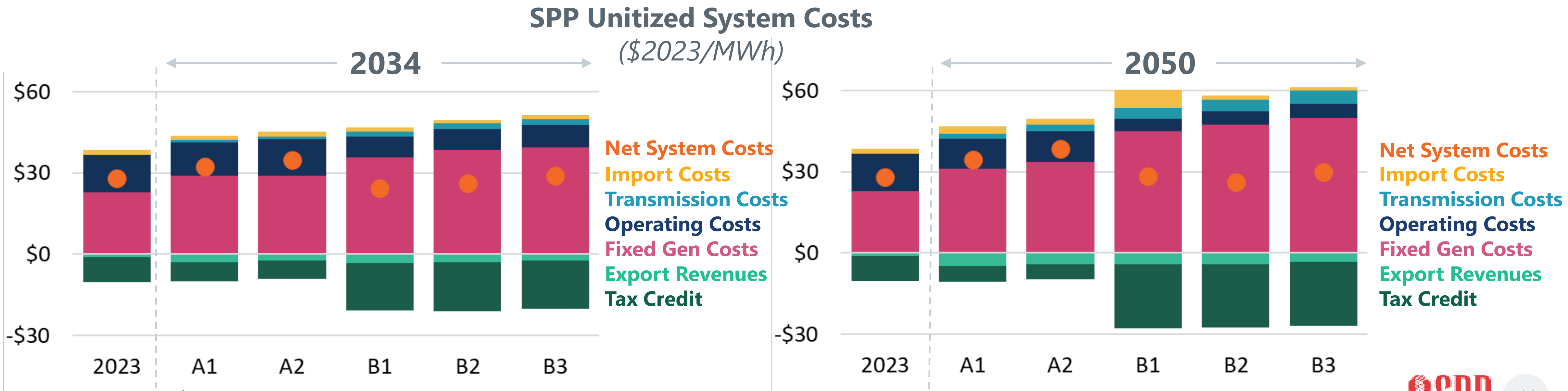
Note: Only select later years, 2040 and 2050, are highlighted in this chart.

Electrification	Carbon Free Resource Shares: Moderate	Carbon Free Resource Shares: High
Low	A1	B1
Moderate	A2	B2
High		B3

$/MWH COSTS ACROSS SCENARIOS

Per unit system costs (total annualized cost divided by total annual load, in inflation-adjusted 2023 dollars) show only modest increases in Scenarios A1 – A2 and no increases in Scenarios B1 – B3:

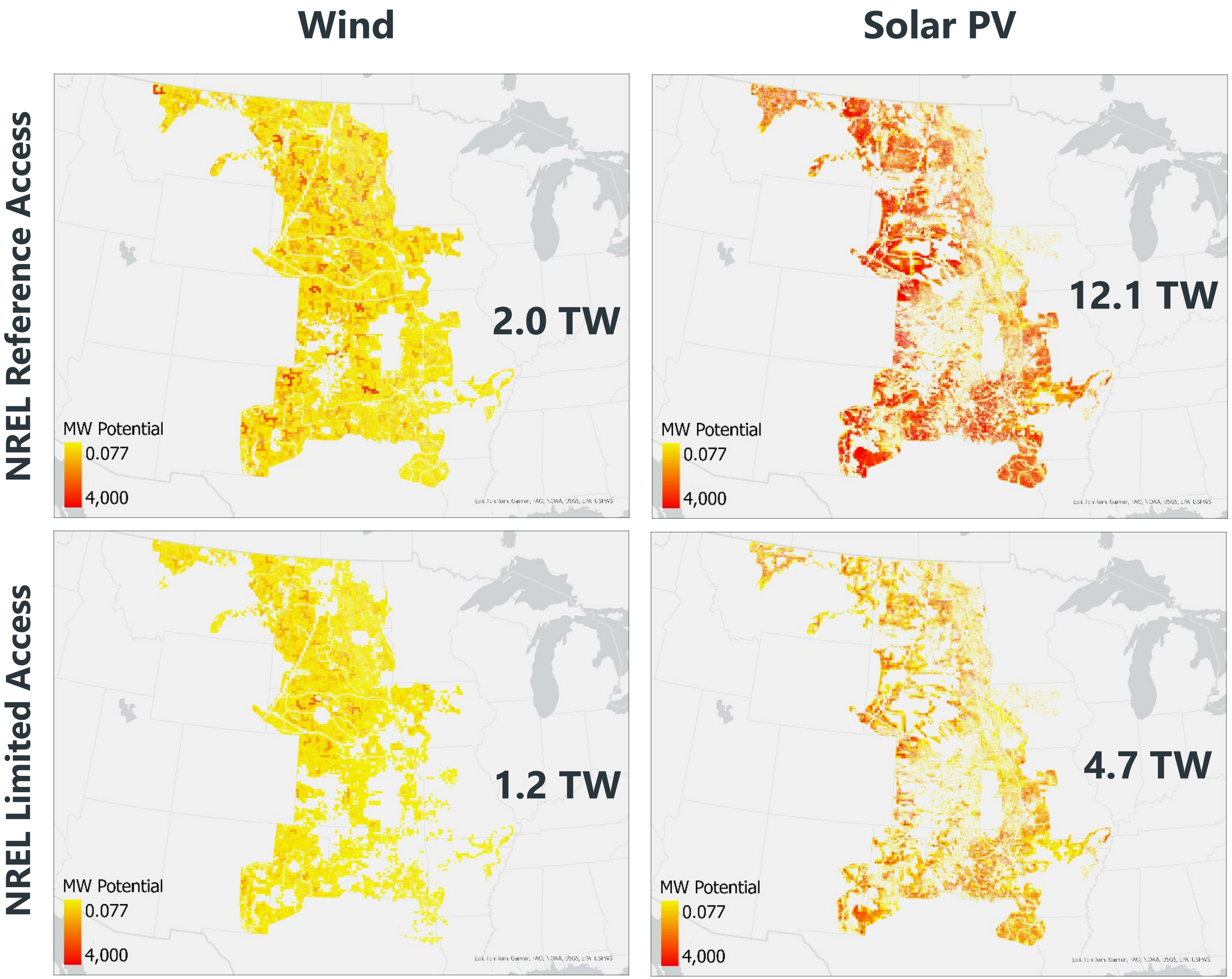
- Moderate carbon-free resource scenarios (A1, A2) have slight $/MWh cost increases driven by additional fossil fixed and operational investments, while B scenarios have no cost increases due to the higher value of tax credits
- On a per-MWh basis, differences in electrification scenarios do not drive significant differences in system costs
- This suggests SPP could achieve high levels of decarbonization and electrification with minimal rate impacts



Note: costs are in $2023 dollars and allocated over MWh of SPP system gross load. Fixed costs recovery of existing generation not included.

LAND USE STUDY

- FERNS includes a land use analysis to ensure generation expansion results are within physical constraints
- Used detailed land-impact and -availability data from NREL Geospatial Data and The Nature Conservancy's Power of Place data
- All FERNS zonal capacity buildout scenarios will likely be well within these calculated low-impact potential estimates



APPENDIX

ADDITIONAL FERNS INPUTS AND RESULTS

SUMMARY OF MODELING INPUTS

Data Element	Description and Source Notes (may differ by year modeled)
	Transmission Modeling Inputs
Energy Zones	Six SPP-internal energy zones consistent with 2023 LOLE Study zones (North, North Central, Central West, Central East, Southwest, and Southeast)
Transmission Topology and Limits	Interface limits between each internal zone and the rest of SPP consistent with 2023 LOLE study limits (ATC and FCITC); the simulations will optimally expand the internal transmission limits based on SPP transmission cost estimates
Imports and Exports	Fixed import and export limits with neighboring regions provided by SPP staff. Hourly energy transfers based on simplified modeling of external zones to capture regional variations in load, renewables (over the same 15 weather years and cold snaps) and associated diversity benefits
	Demand-Side Modeling Inputs
Load Growth	Low, moderate, and high scenarios developed by Evolved Energy Research (EER) for SPP FERNS Demand Electrification that represents a range of electrification scenarios and 15 weather years
Hourly Load Shapes	Hourly shapes developed by EER for SPP FERNS Demand Electrification that vary by weather year, SPP zone, end-use, and scenario for 2023, 2025, 2029, 2034, 2040, 2050

SUMMARY OF MODELING INPUTS

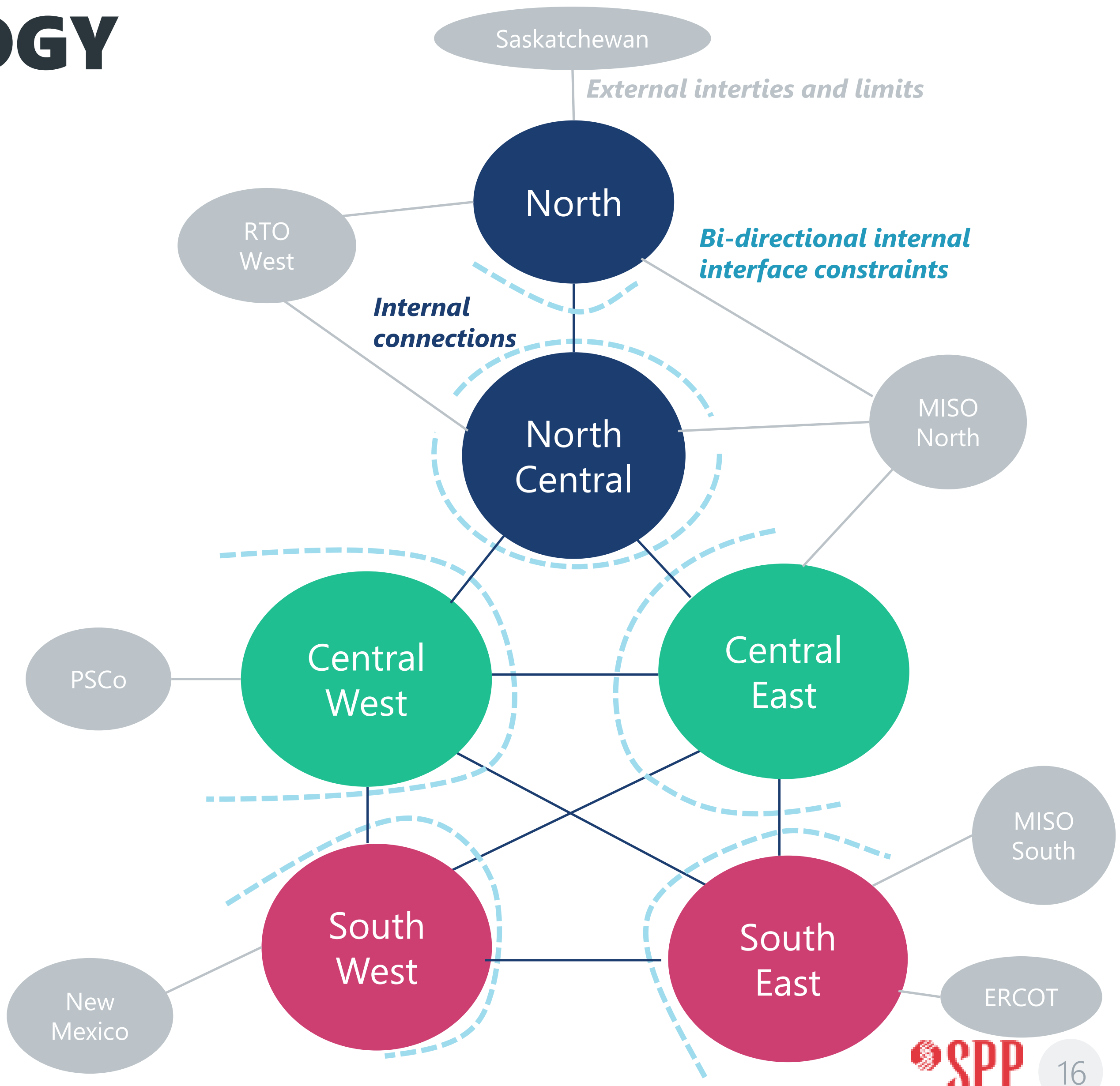
Data Element	Description and Source Notes (may differ by year modeled)
Supply-Side Modeling Inputs	
Existing Generator Data	SPP data (2025 ITP) for existing unit capacities, heat rates, and additional operational characteristics by region
Scheduled Additions/Retirements (near term)	SPP data (2025 ITP) and Interconnection Queue studies to identify resource decisions already made (as model input) by capacity, location, date. (Necessary additional future generation additions and retirement decisions are optimized by the model)
Cost Trajectory for New Generation	Capital, fixed, and variable cost projections for new generators by resource type and SPP zone from SPP IHS forecasts; zonal costs and intra-zonal transmission adders as function of resource availability and transmission headroom/cost by zone informed by SPP interconnection studies
Hourly Renewable Generation	Hourly renewable profiles for all SPP zones and external regions, for all 15 weather years available in the load dataset, based on Imperial College London (Renewables.ninja) dataset and benchmarked to National Renewable Energy Laboratory (NREL) regional values
Fuel Prices	Natural gas, coal, and oil prices (by SPP zone) from SPP IHS forecasts and 2024 and 2025 ITP; additional fuel types supplemented from other public sources like the NREL.
Market and Policy Inputs	
Reserve Margin and RA framework	FERNS uses an hourly approach to determine resource adequacy needs (based on hourly loads, operating reserves, renewable profiles, and generation outages associated with 15 weather years and cold snaps). FERNS defines RA requirements as hourly load plus a 5% capacity (operating reserve) margin, which needs to be maintained across the full range of challenging system conditions (such as heat waves, cold snaps, renewable droughts, and high generation outages). A $50,000/MWh “resource adequacy violation charge” represents tradeoffs between adding generation capacity or allowing for load shedding (or operating reserve depletion) approximately once in ten years during the most challenging hours across all weather years.
Tax Credits and Clean Energy Policies	IRA-based PTC for solar and wind (and ITC for battery storage) or equivalent (state or corporate) support, assumed for the entire study horizon in Scenarios B1, B2, and B3. Assumed eliminated for Scenarios A1 and A2. No other clean energy policies are assumed for the SPP footprint.

EXTERNAL ZONAL TOPOLOGY

In addition to internal SPP zones, we model interties for 8 external zones with dynamic hourly transmission flows to/from SPP to capture economic and resilience benefit of interregional diversity

- Intertie limits were provided by SPP staff for import and export directions. SPP internal limits based on 2023 LOLE study.
- Each external zone is modeled with simplified aggregate load and resource mix, reflecting hourly differences in net-load variance to capture geographic diversity during the modeled weather years
- Future expansions of external resource capacity and transmission capabilities is an input assumption (i.e., not optimized by the model)

SPP Zones and Interties to Neighboring Systems



RESOURCE ADEQUACY APPROACH

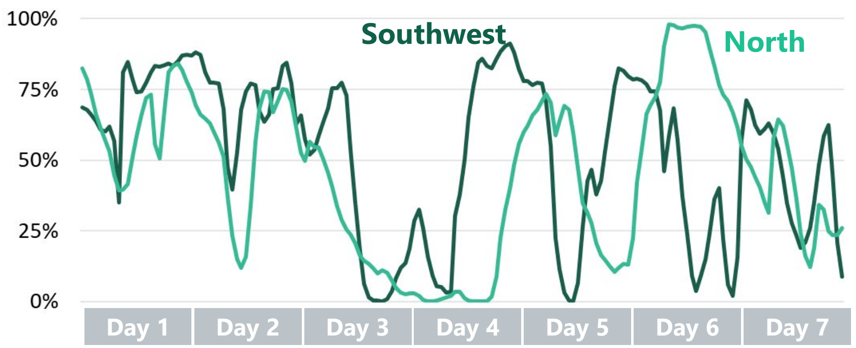
Conventional approach to considering resource adequacy in expansion modeling:

- Based on forecasted normalized summer peaks plus planning reserve margins
- Capacity accreditations based on ELCC values (specified as a function of resource shares)
- Challenge: requires a lot of assumptions (about the nature of future resource adequacy challenges, ELCCs, and planning reserve margin) that will change significantly in an increasingly decarbonized and electrified future

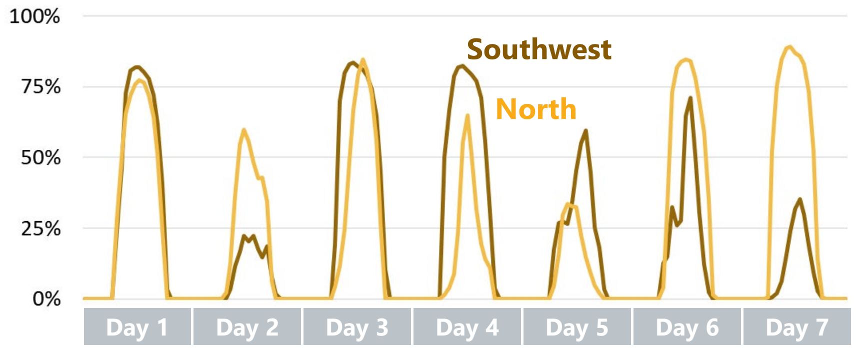
FERNS "dynamic" hourly approach to resource adequacy:

- Create a proxy weather year based on load and renewable data for 15 weather years and added cold snaps to approximate the expected future challenges SPP may experience
  - Heat waves, cold snaps, renewable droughts
  - Realistic seasonal, daily, hourly variations
- Each model year is represented by 26 three-day periods that capture representative hourly conditions across all weather years. The 26 periods consist of 6 periods for each of the four seasons, one summer peak period, and one winter extreme weather period
  - Each 3-day period has a different probabilistic weight consistent with 8760 hours in 15 weather years
- The simulation balances supply and demand in every hour, including operating reserve requirements. This identifies when resource adequacy challenges could occur in the future
  - Future risk likely concentrated in certain months and hours outside of summer peaks
  - The model will choose generation investments and technologies capable of meeting needs
- The results inform when the existing RA frameworks may need to be modified in the future (but will need to be confirmed through probabilistic LOLE analyses with SERVM)

Example: Hourly Wind Profiles
(March 2020 Week in North and Southwest Regions)



Example: Hourly Solar Profiles
(March 2020 Week in North and Southwest Regions)



Note: Renewable profile shown for a sample week in March 2020 to highlight hourly and geographic variation in the 15-year dataset. Profile expressed as hourly generation % of nameplate capacity.

SPP

FERNS RESOURCE ADEQUACY APPROACH

Brattle's capacity expansion modeling employs our **Weather and Resource Adequacy Sampling (WRAS)** tool to create a weather-reflective proxy year with appropriately probability weighted multi-day periods:

- The tool selects probability-weighted proxy year periods based on multi-variable "k-means clustering" algorithm for gross load, net load (adjusted for weather-correlated forced fossil outages), and solar/wind profiles
- Each FERNS proxy year is comprised of 26 three-day periods (6 per season, summer peak, winter storm period). Each period is weighted based on the frequency of periods with similar conditions during the entire 15-year sample to capture multi-day events
- Weather representative proxy year eliminates the need for planning reserve margin and allows for hourly accreditation approach + operating reserve margin

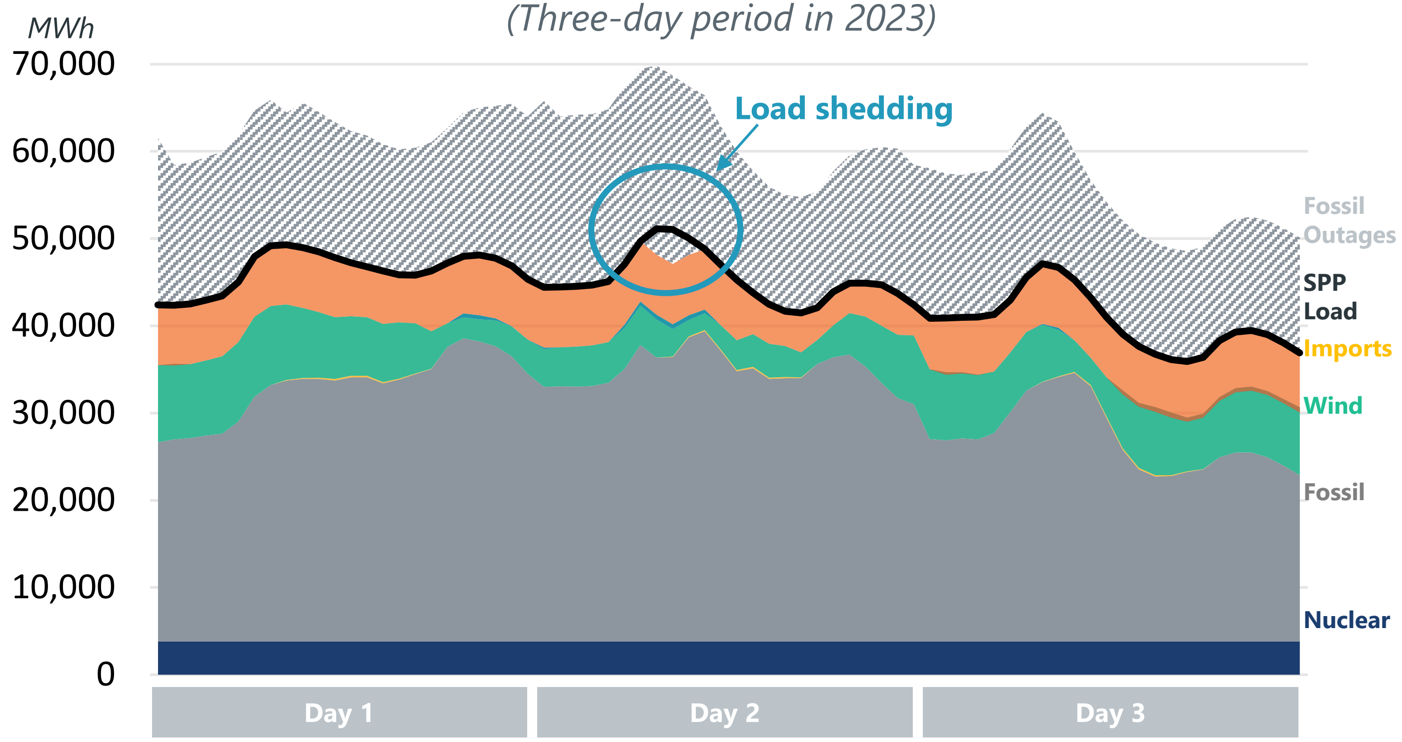
The WRAS approach is computationally efficient, while accurately representing the full set of renewable and load conditions that drive resource adequacy challenges and unveiling the resource adequacy and energy market value of different resource types, including storage

RA VIOLATIONS / POTENTIAL LOAD-SHED EVENTS

- The FERNS modeling effort simulates weather-reflective resource adequacy challenges on an hourly basis. It uses a high "resource adequacy violations charge" to ensure that the frequency of operating reserve depletions or load shed events roughly meets the 1-in-10-year LOLE resource adequacy standard:
  - The simulations use a $50,000/MWh RA violation charge to represent tradeoffs between adding generation capacity or allowing for load shedding (or operating reserve depletion) during the most challenging hours across all simulated weather years
  - The RA violation charge needs to exceed typical estimates of the Value of Lost Load (VOLL) because the 1-in-10-year RA standard is more stringent than what could be justified economically with VOLL
- The highest RA risks occur during the three-day cold-snap period (representing Uri-like severe winter storms, assumed to occur once every 5-10 years):
  - RA violations (between none and 8,900 MW as shown in the table) occur only during the winter storm periods
  - Other than in 2023, these violation of SPP RA criteria are not associated with load shed events due to energy imports available from neighboring regions (who do not experience the severe challenges at exactly the same time)

SPP Winter Risk Period

(Three-day period in 2023)

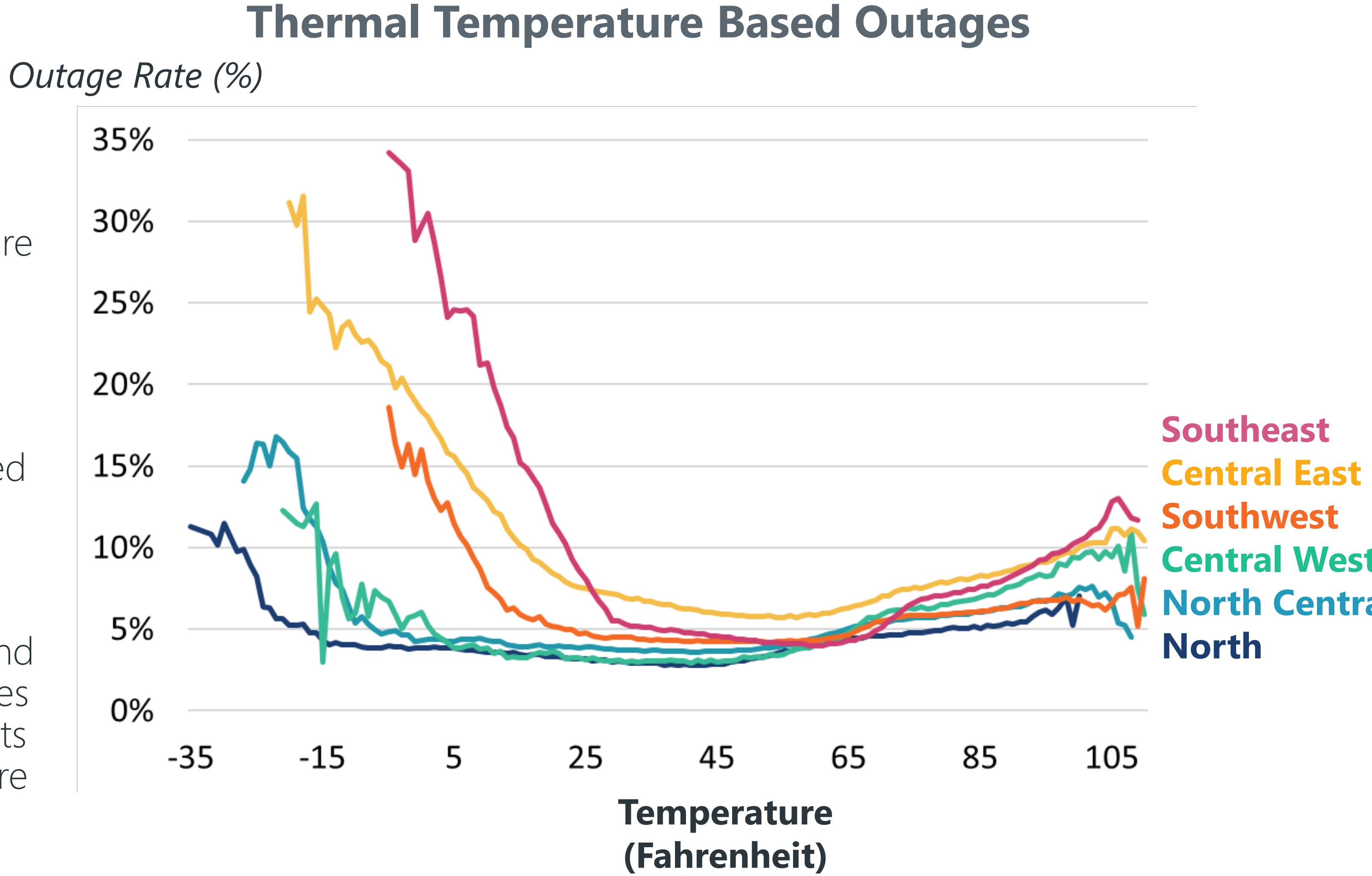


Max Hourly Violation of SPP Installed Capacity Requirement (MW)

Year	A1	A2	B1	B2	B3
2025	8,902	7,606	7,246	6,421	5,970
2029	3,736	5,488	1,698	1,849	2,255
2034	3,523	3,455	0	0	0
2040	1,826	3,190	0	0	0
2050	616	1,610	0	0	0

WEATHER-CORRELATED THERMAL GENERATION OUTAGES

- FERNS modeling accounts for weather-dependent thermal outages, which vary by zone:
  - SPP provided LOLE zonal temperature and outage relationships that we mapped to 2006-2020 hourly temperature curves by FERNS zone
  - Outage rates are the same for all thermal units within a zone; no forced outages for solar or wind assets are modeled
  - Thermal plants located in southern zones like Southeast, Central East, and Southwest are more prone to outages at cold temperatures relative to plants in northern zones that are often more winterized



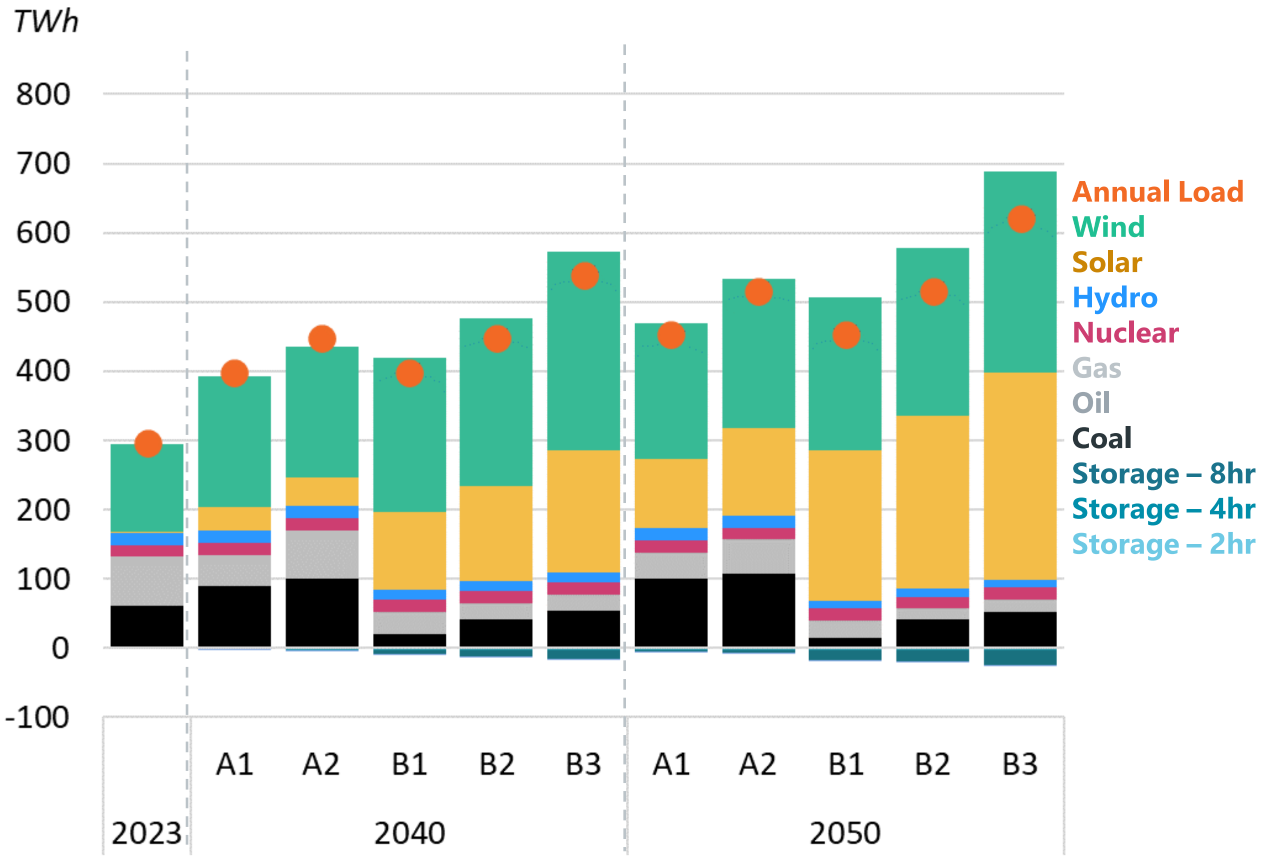
GENERATION OUTPUT ACROSS SCENARIOS

Electrification	Carbon Free Resource Shares	
	Moderate	High
Low	A1	B1
Moderate	A2	B2
High		B3

Electrification and decarbonization scenarios lead to different optimal use of the generation fleet:

- Through the 2020s: In the near term, all scenarios have comparable buildout with less generation in lower electrification scenarios
- In the 2030s: By the 2030's, high decarbonization scenarios deploy mostly new solar resources in SPP, while moderate decarbonization buildout continues to rely more heavily on fossil resources to meet electrification load
- In the 2040s: High decarbonization scenarios continue to deploy renewables for local demand and for cost-effective exports to neighboring regions. High decarb scenarios result in ~90% carbon-free while moderate decarbonization results in ~70% carbon-free generation by 2050

SPP Annual Energy Generated (TWh)



Note: Total SPP generation exceeds annual load in years when SPP is a slight net exporter to neighboring regions. This occurs in later years when SPP is highly renewable saturated.

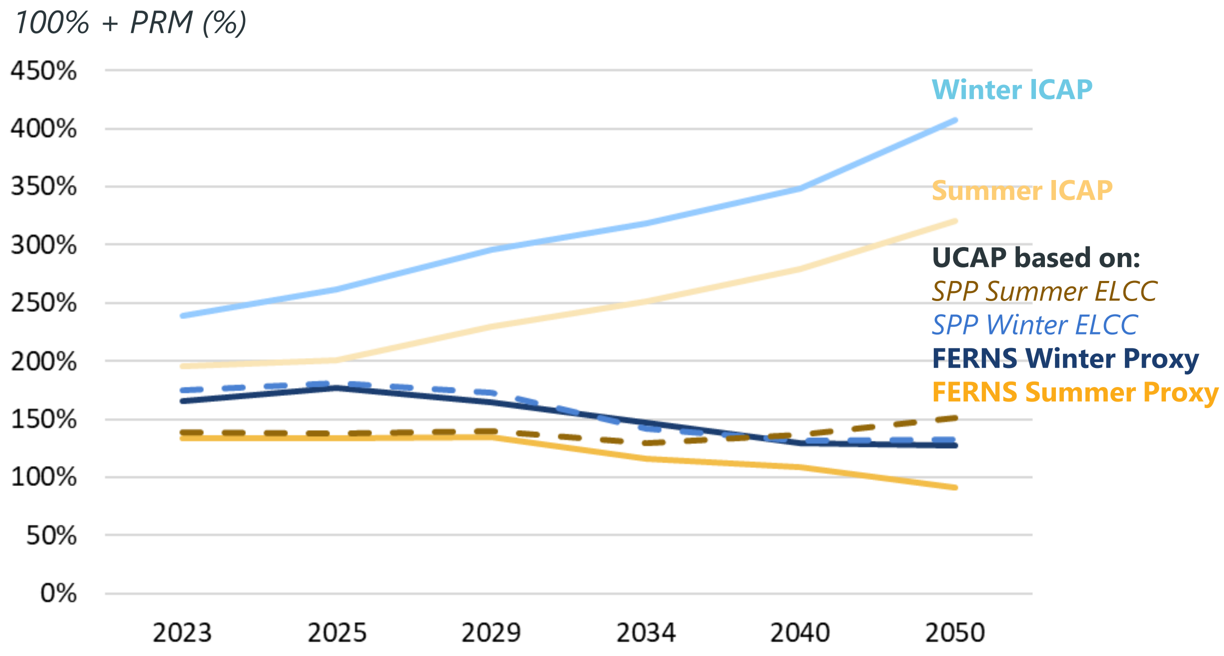
SPP SEASONAL PLANNING RESERVE MARGINS (SCENARIO B2)

We estimate implied future planning reserve margins (relative to weather-normalized peak load) for FERNS Scenario B2, using three methods to estimate rated capacity:

- Based on installed nameplate capacity (ICAP)
- With SPP's 2029 ELCC values from the Future Resource Mix Study (Scenario ELCCs selected based on FERNS annual capacity)
- With proxy ELCC from FERNS simulation results (contributions during top 100 hours)

Irrespective of "reserve margins", all model results meet system-wide and zonal resource adequacy needs on an hourly basis.

Implied Seasonal Planning Reserve Margin (+100%)



Note: SPP ELCC values come from [Future Resource Mix Study](), May 2024. 100% means the capacity is equal to peak load in that year (i.e. 0% PRM).

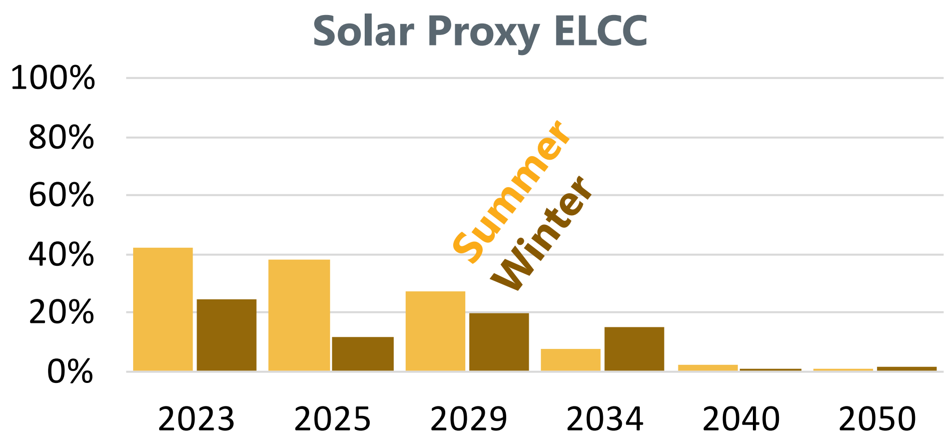
<u>Note</u>: PRMs are expressed as % of seasonal weather-normalized peak load. They decline (even below 100%) as RA violations shift into evening hours with lower gross load (but high net loads).

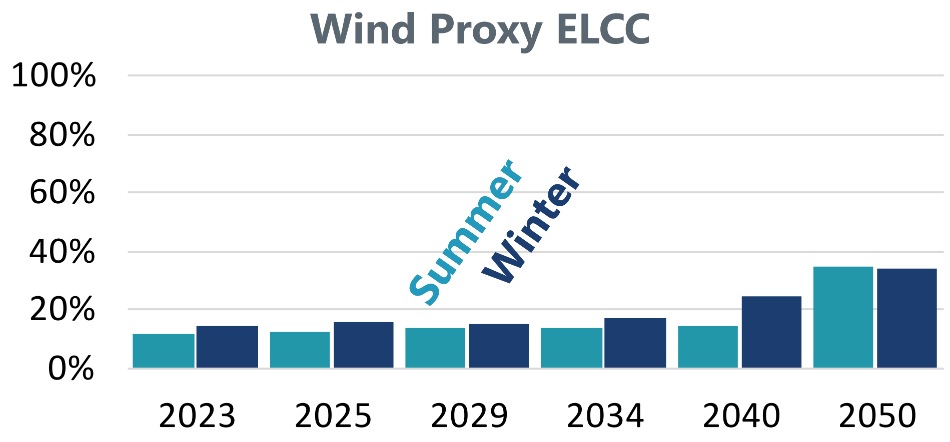
SEASONAL PROXY ELCC VALUES FOR WIND AND SOLAR (SCENARIO B2)

Proxy ELCC values are calculated based on the simple average of resource performance during the top 100 resource-adequacy risk hours (with highest net load, adjusted for generation outages) in each modeled year:

- Through the 2020s: Renewable ELCC proxy values remain relatively high, although wind generation has already mostly saturated the market
- In the 2030s: Solar ELCC proxy values begin to decline as more is added; wind ELCC values have plateaued. Winter ELCC values can increase with shifting RA-risk hours and correlated fossil outages
- In the 2040s: Solar proxy ELCC values continue to decline as SPP solar generation investments accelerates in the 2040s. Electrification drives winter RA risk and increases proxy ELCCs for wind generation

<u>Note</u>: These proxy ELCCs are only approximate and do not replace more detailed ELCC modeling.



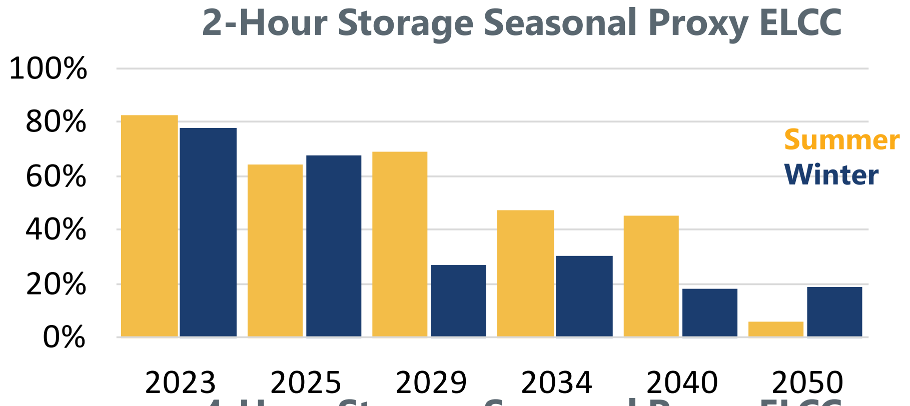


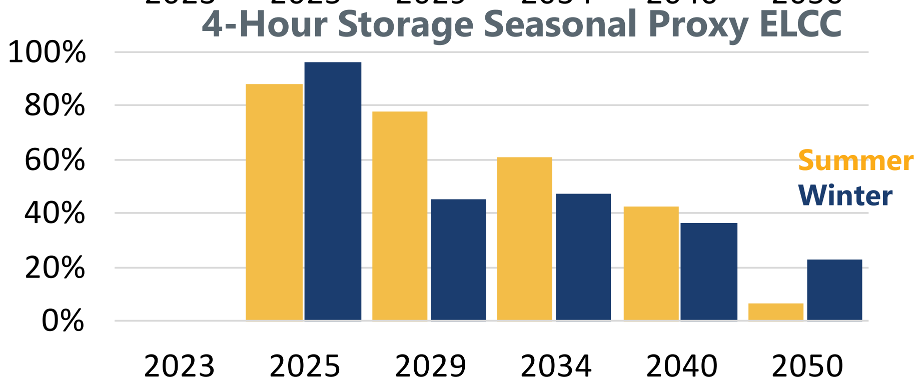
SEASONAL PROXY ELCCS FOR STORAGE (SCENARIO B2)

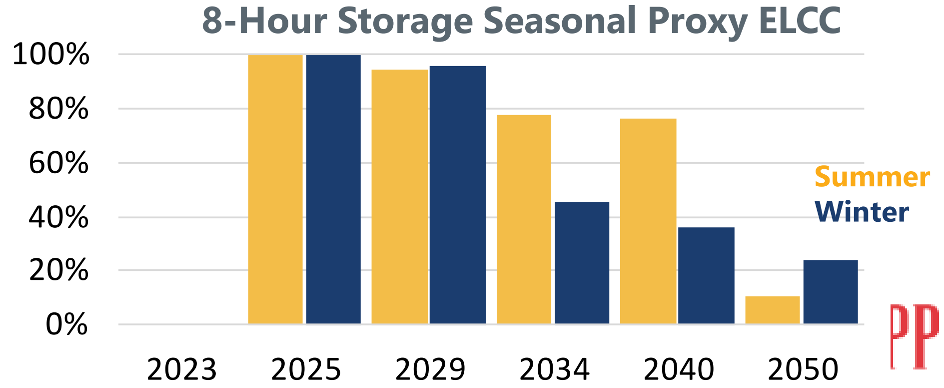
Storage proxy ELCC values decline over the next decade. FERNS models 2hr, 4hr, and 8hr battery storage assets:

- Through the 2020s: Storage has the highest proxy ELCC values
- In the 2030s: Storage ELCC values begin decline quickly for shorter-duration batteries. 8hr storage (with only limited deployment) maintains high proxy ELCC values
- In the 2040s: Even 8hr storage shows declining proxy ELCC values, suggesting that longer duration storage may be a more cost-effective resource (FERNS modeling did not include battery storage with durations greater than 8hrs)

<u>Note</u>: These proxy ELCCs are only approximate and do not replace more detailed ELCC modeling.

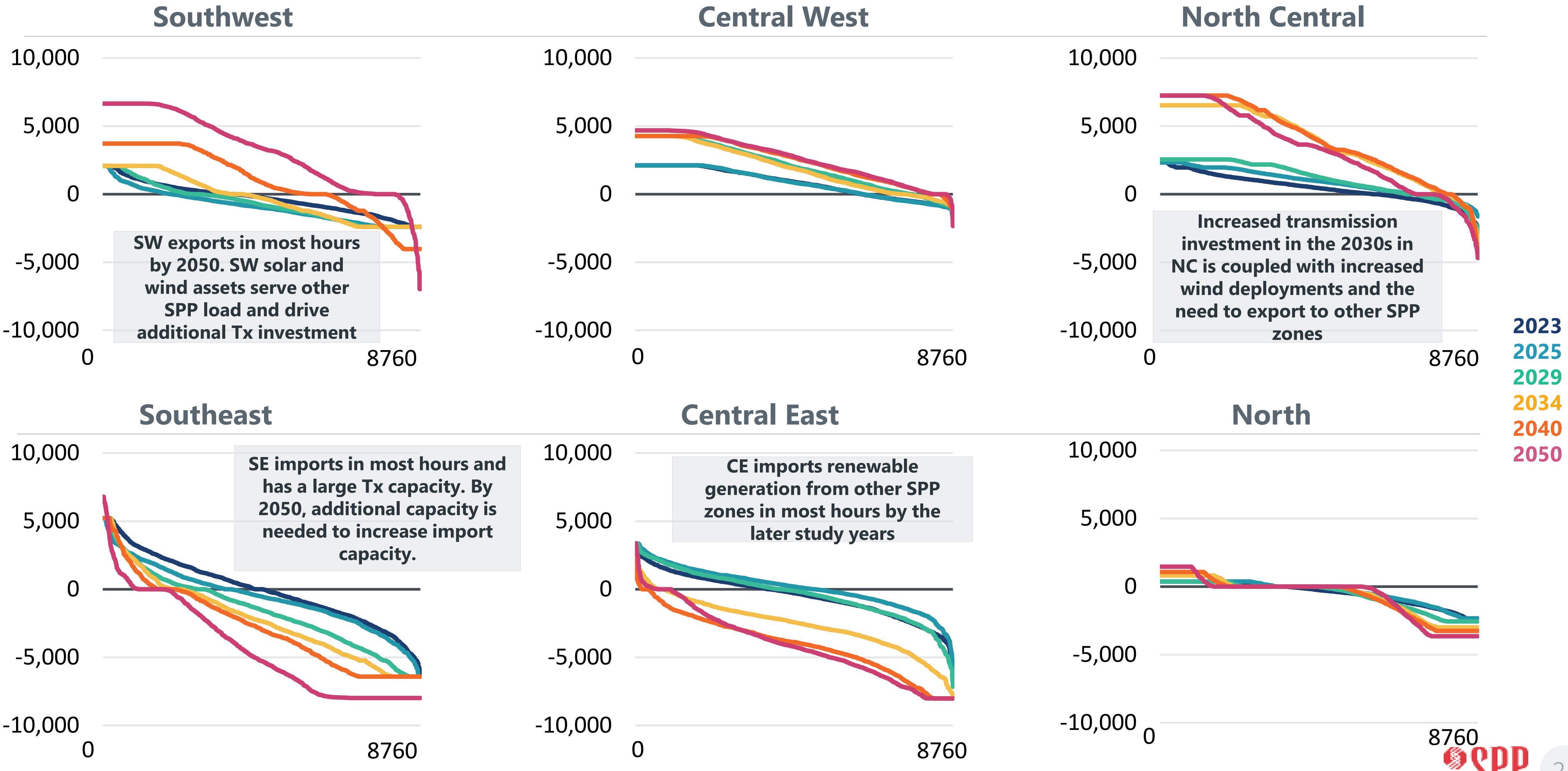






ZONAL INTERFACE DURATION CURVE (SCENARIO B2)

HOURLY MW INTERNAL FLOWS (POSITIVE = ZONAL EXPORT)



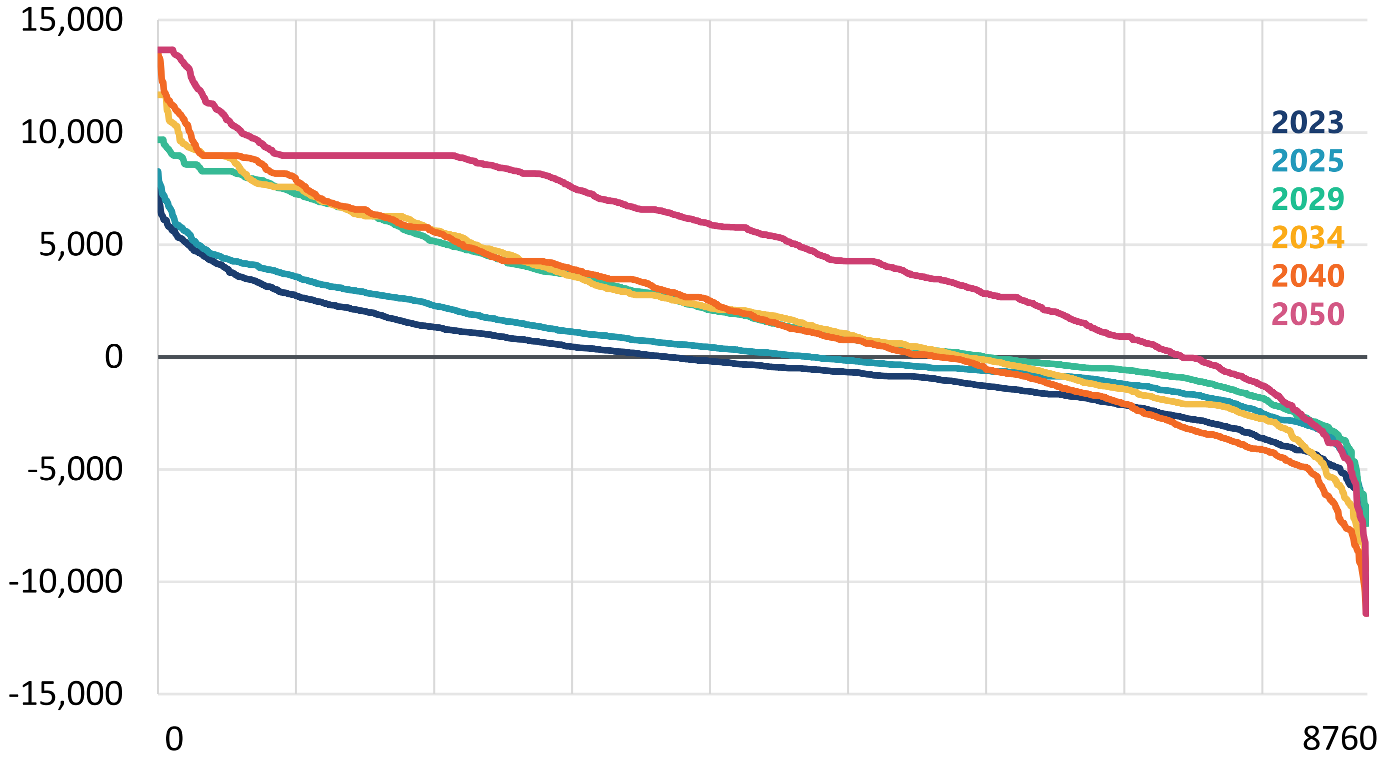
RELIANCE ON NEIGHBORING REGIONS (SCENARIO B2)

SPP has transfer capability with all neighboring regions, with large connections to MISO and the West

- Through the 2020s: SPP is a slight net exporter, exporting from other regions in just over half the hours throughout the year
- In the 2030s: Through the 2030's as SPP continues to deploy solar and wind resources, SPP begins to export more generation to neighboring regions
- In the 2040s: By 2050, SPP exports in most hours throughout the year as neighboring regions import low-cost renewables

We do not model economic expansion of external interfaces, which are the same across all scenarios.

SPP Net Imports and Exports across all interties (MW)
(Positive = net flow out of SPP; Negative = net flow into SPP)



Note: Net imports shown across interfaces between SPP and all neighboring regions

FORECASTED CUMULATIVE INVESTMENT NEEDS BY SCENARIO

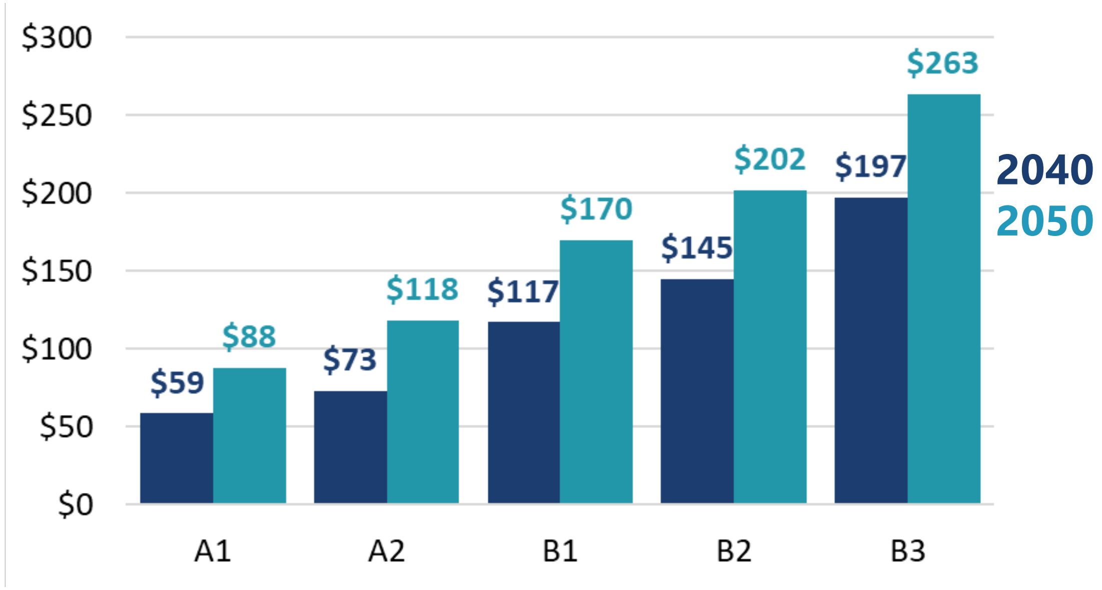
	Carbon Free Resource Shares	
Electrification	Moderate	High
Low	A1	B1
Moderate	A2	B2
High		B3

Through 2050, between $88 and $263 billion of additional generation investment is required to meet SPP's future system needs:

- Total generation (capital) investment is highest in high carbon-free and highly electrified scenarios
- This is primarily due to the significant generation capacity additions needed to maintain resource adequacy in high-load scenarios
- With continued tax credits (or similar state or corporate clean-energy support), high renewable generation investments yield lower total costs
- As a result, total system costs (see next slides) vary much less than capital investment costs

SPP Cumulative Generator Capex Investment Needs (2023-2050)
($2023 billion)

$2023 billion



Note: Costs are in $2023 dollars. Includes only incremental CAPEX based on net additions. Does not net out value of tax credits. Excludes all transmission costs including those associated with zonal generator interconnection.