ACEP Railbelt Decarbonization Project
Wind-Solar Scenario Addendum

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Intro Slide

Project page and full report

The analysis presented in this slide deck is an addendum to a larger project which was published in January 2024.

- The full report looks at different scenarios for a fully decarbonized Railbelt electric grid in 2024.
  - Railbelt Decarbonization Project Full Report: https://www.uaf.edu/acep/files/media/ACEP_Railbelt_Decarbonization_Study_Final_Report.pdf
    - Executive summary: https://www.uaf.edu/acep/files/media/ACEP_Railbelt_Decarbonization_Study_Final_Report__ExecutiveSummary.pdf
- Each scenario featured a large amount of Wind and Solar alongside an emerging carbon-free technology or project that has been proposed to meet a large share of demand (Nuclear, Tidal, and Hydroelectric).
- Our analysis looked at costs associated with building and operating these future systems alongside an estimate for costs associated with electrical stability.
- This addendum came about due to interest in our analysis for a decarbonized grid that only adds new generation as variable renewable energy: Wind and Solar

Key Takeaways

- The Wind/Solar scenario (W/S) focuses solely on new wind and solar sources of generation and was developed in response to feedback
- W/S achieves 77% fossil-free generation, less than W/S/Hydro and W/S/Nuclear
- Much higher levels of inverter-based generation and North-South intertie flows result in more hours with stability challenges compared to the other low carbon (LC) scenarios
- The stability mitigations employed in the other LC scenarios also worked in W/S and were relied upon during more hours of the year
- W/S costs are in the same ballpark as all the other scenarios

New Wind/Solar Scenario

Scenario	New wind and solar	Large non-wind or non-solar power project
Business As Usual (BAU)	No	No
Wind/Solar/Hydro	Yes	Yes
Wind/Solar/Tidal	Yes	Yes
Wind/Solar/Nuclear	Yes	Yes
Wind/Solar	Yes	No

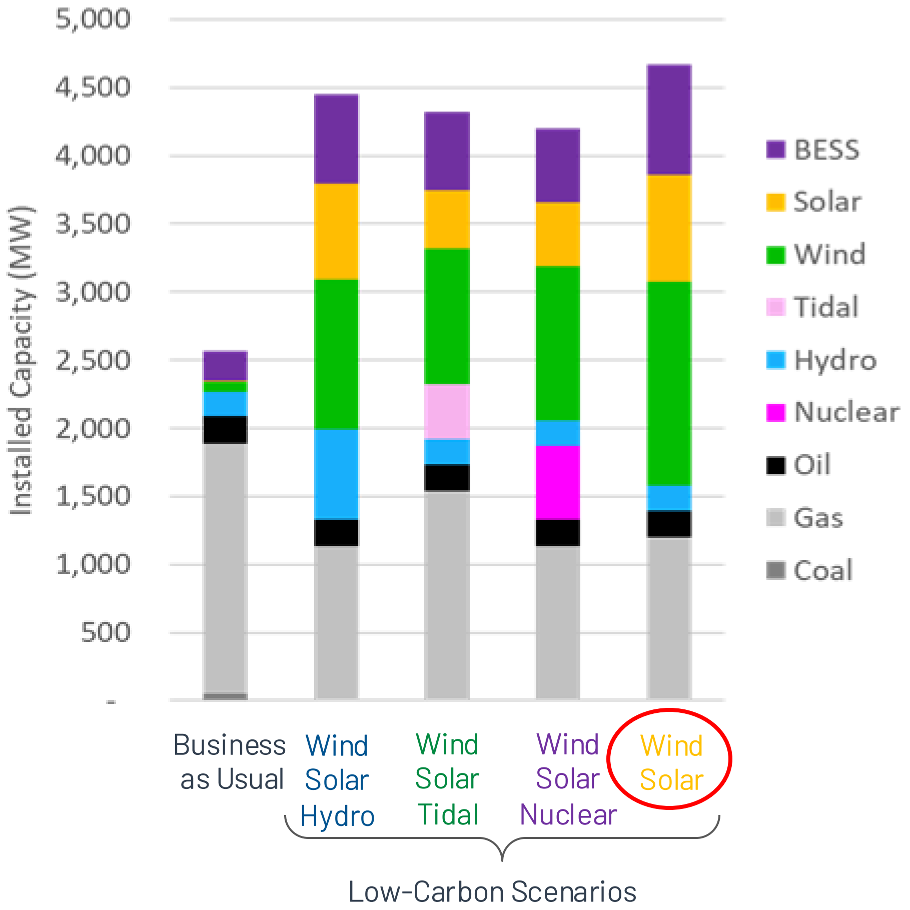
Low carbon scenarios

This scenario used the same input assumptions as the other low carbon scenarios, except no new non-wind or non-solar source of power.

Installed Capacity By Resource Type

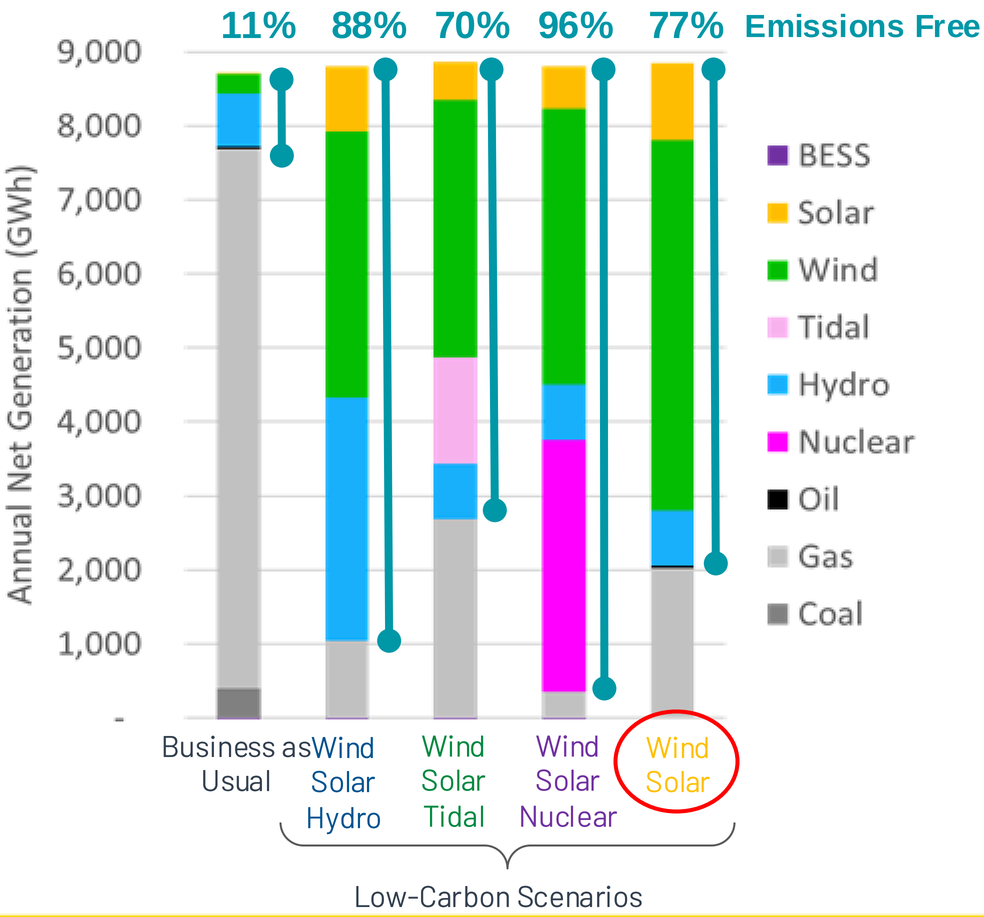
- Low-Carbon vs. BAU:
  - Much greater total capacity
  - Slightly reduced fossil capacity

- Wind/Solar vs. Other Low-Carbon Scenarios
  - Slight increase in total capacity



Annual Generation by Resource Type

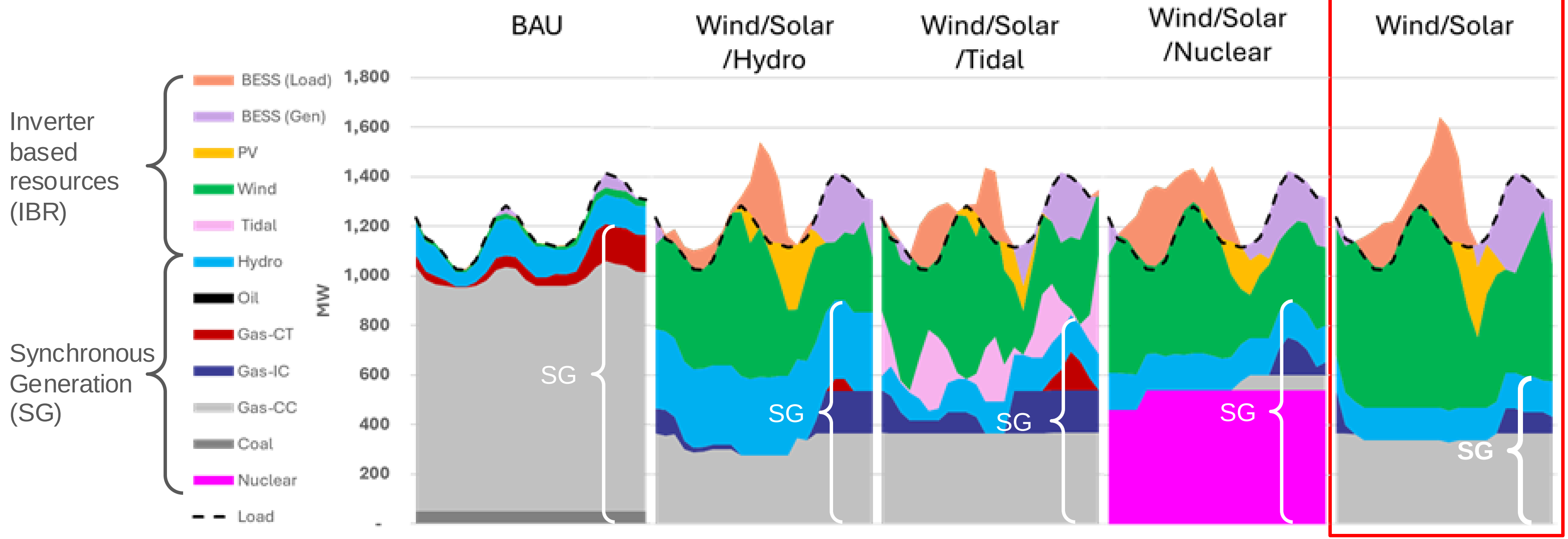
- Low-Carbon vs. BAU:
  - Much lower fossil generation
- Wind/Solar vs. Other Low-Carbon Scenarios
  - More fossil generation than W/S/Hydro and W/S/Nuclear
- Curtailment stays below 10% across all scenarios



Representative Daily Generation & Operations

"Typical" Winter Day

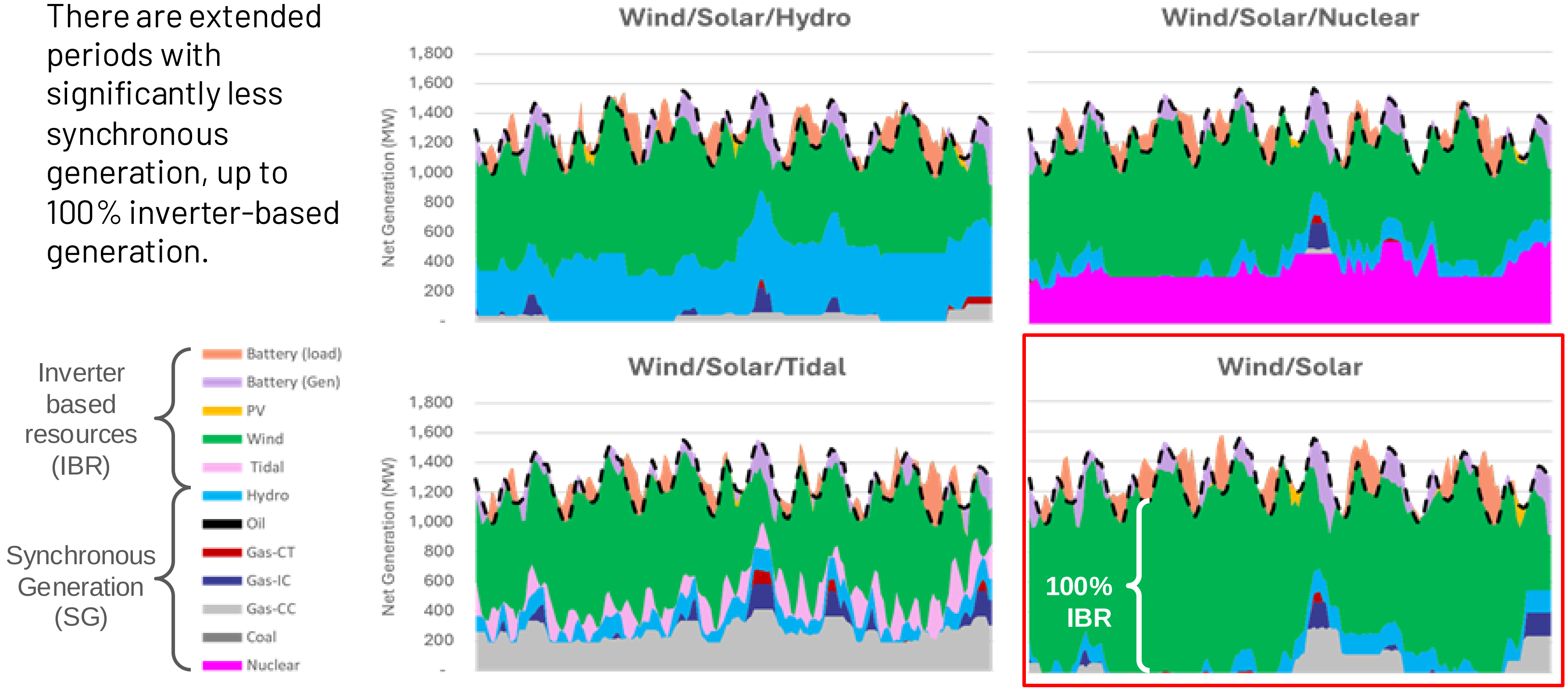
On a normal day, there is less synchronous generation (which is mostly supplied by fossil fuel) compared to other Low-Carbon Scenarios.



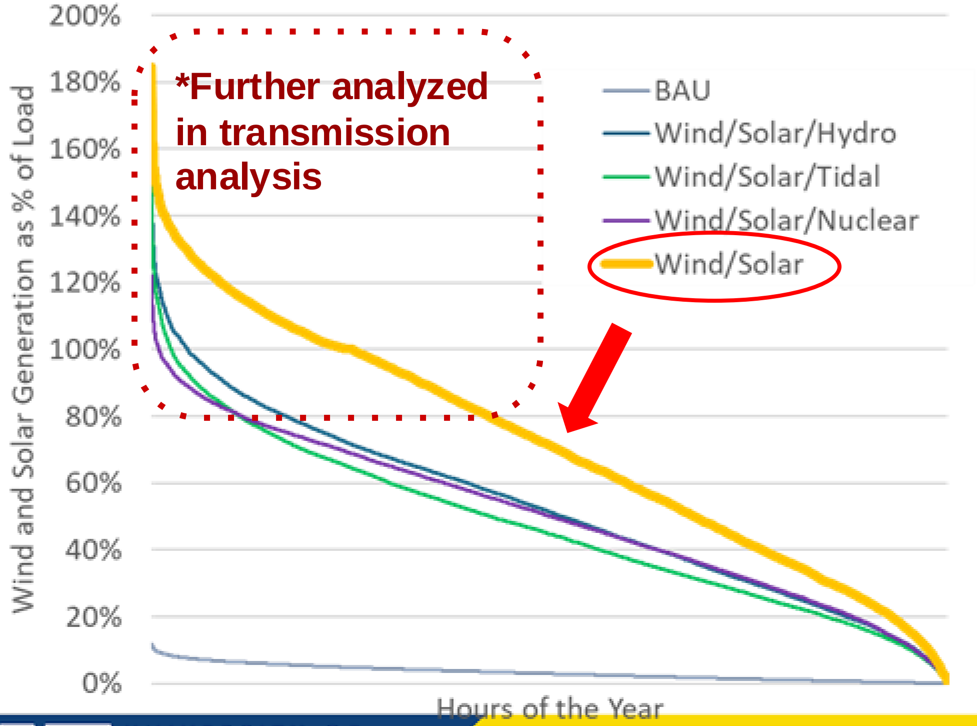
Note: BESS load is when the battery is charging, primarily from PV and wind. BESS Gen is when battery is providing energy to grid.

Highest Renewable Week Generation & Operations

There are extended periods with significantly less synchronous generation, up to 100% inverter-based generation.



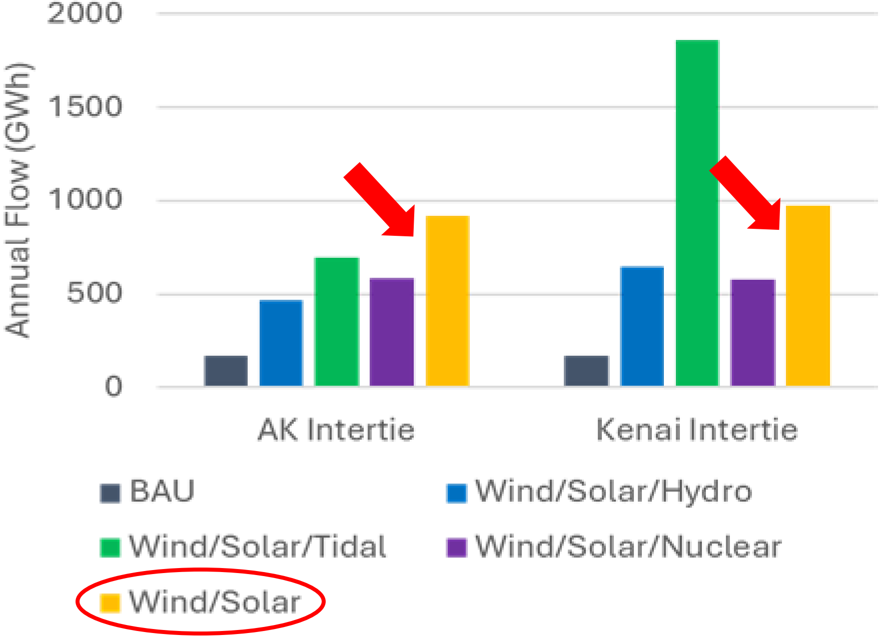
Annual Wind and Solar Generation Share Distribution

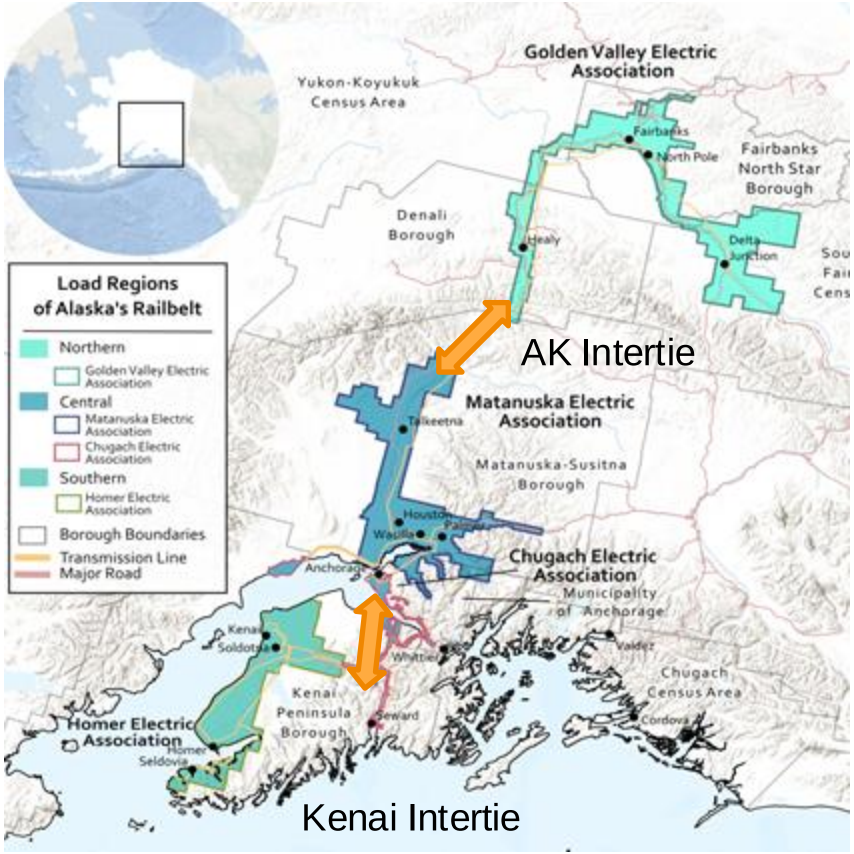


- Low-Carbon Scenarios have periods with very high and very low wind and solar generation
- Wind/Solar spends much more time at high wind and high solar generation, >100% for much of the year (battery charging)
- Periods of high wind and high solar generation were evaluated in further detail* in the transmission analysis.

Intertie Use

- AK Intertie: increase in use
- Kenai Intertie: increase in use compared to W/S/Hydro and W/S/Nuclear





Transmission Analysis

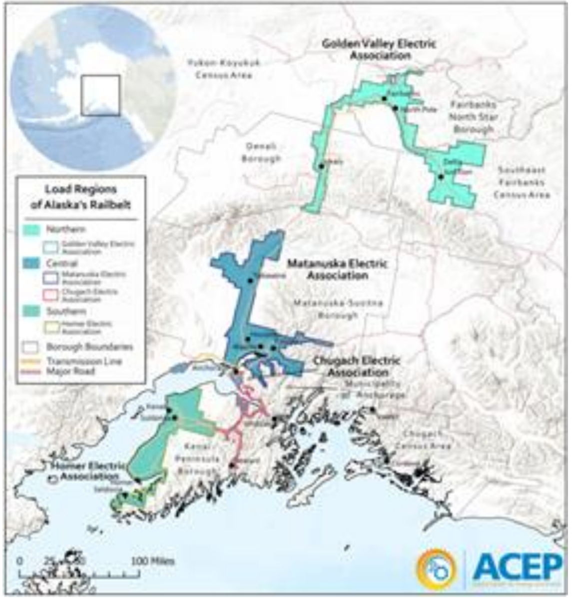
Summary of Changes for the W/S Scenario

Grid Operations

- The most challenging hours for stability have changed
- The highest flows on the interties have changed, particularly the Kenai intertie flow direction

Additional Contingency

- An additional contingency was evaluated because it was more severe due to higher North → South flows on the interties
- This contingency was not analyzed for any other scenario



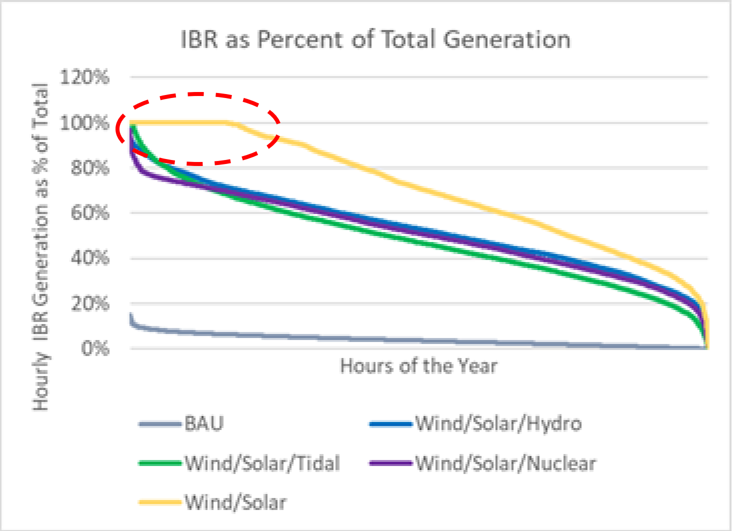
Grid Operations - IBR Penetration

Inverter based resources (IBR) in the Wind & Solar Scenario

- More dominated by IBR than the previously studied scenarios
- There are thousands of hours with a 100% IBR Railbelt!

Implications

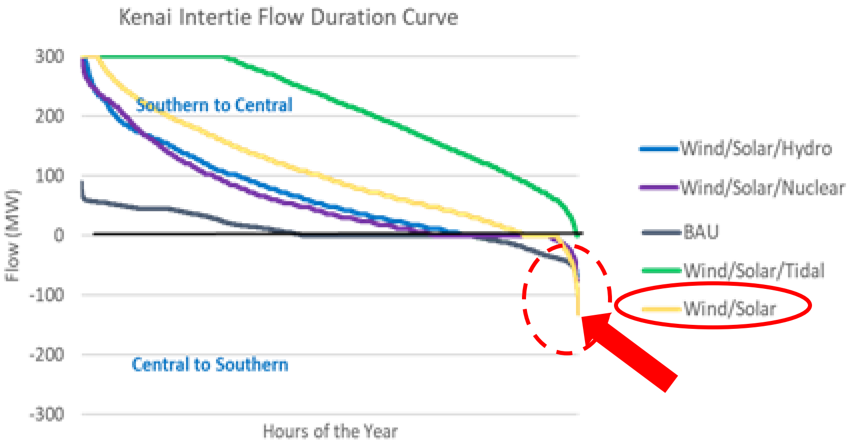
- Historically, synchronous machines have provided critical stability services
- Grid forming inverters (GFM) technology plays a critical role in providing stability similar to all scenarios
- Conventional electric machinery options like synchronous condensers also exist

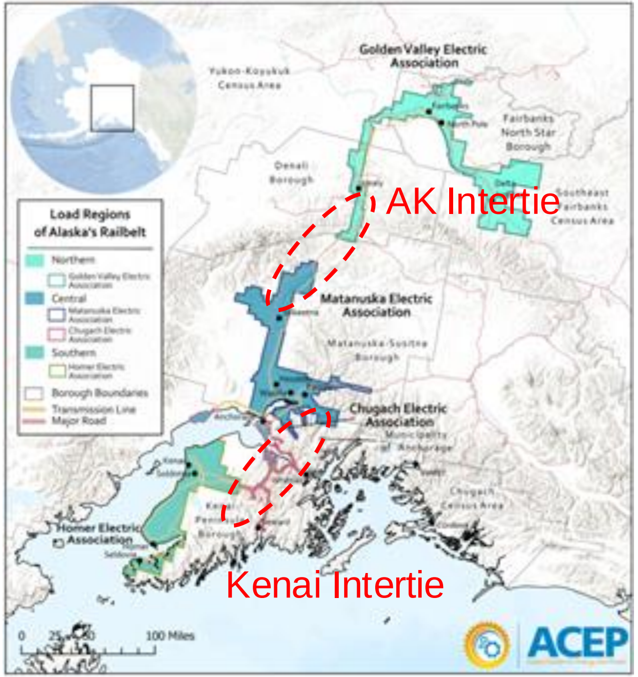


Grid Operations - Intertie Flows

Intertie Flows in the W/S Scenario

- Periods of increased southern flow, particularly on the Kenai intertie
- This flow pattern stresses the Railbelt differently, introducing new violations and different critical contingencies





Intertie Locations

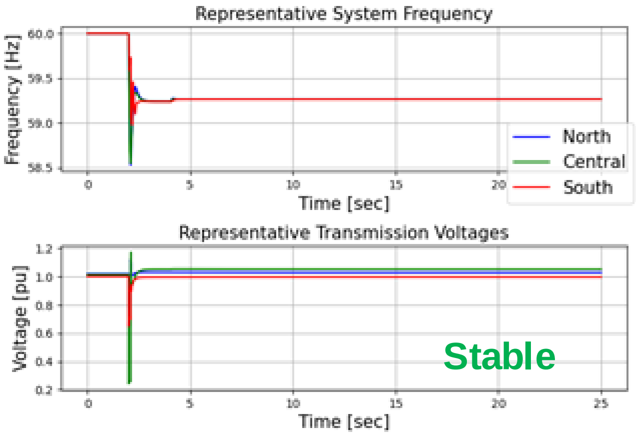
W/S Scenario Intertie Loss

- The mitigations used for the other scenarios - strategic transmission upgrades and additions of GFM BESS - were found to be effective in stabilizing the most challenging hours from the W/S Scenario
- Similar to the other scenarios, the GFM batteries played a crucial role in providing essential support in instances of intertie loss
- Identifying the most impactful locations for GFM BESS helped reduce the total BESS MVA needed for stability

Additional Contingency: 230kV Line in the Central Area

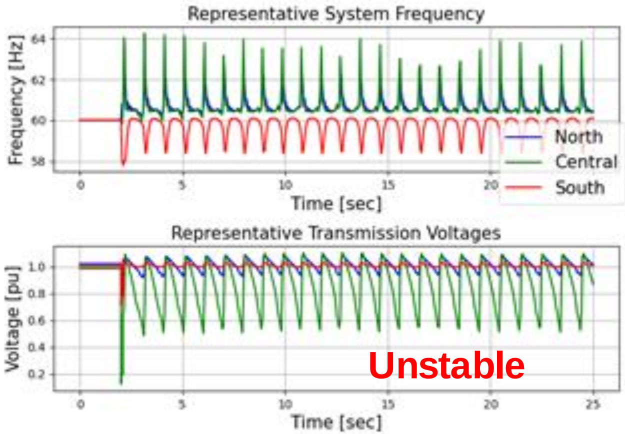
- The loss of a 230kV line can force power in a "roundabout" path that weakens the connection between the North and South areas
- During periods of high power flows from North to South in combination with a loss of a particular transmission line in Central, the system can lose synchronism
- Mitigated with a new substation

Contingency with High **South to North** Flows



These graphs are pre-mitigation. This scenario has high North to South flows (right graph) which is why the additional contingency was analyzed.

Contingency with High **North to South** Flows



Mitigation Options: Equipment v. Operations

- For major new violations, operational mitigations were considered in addition to equipment reinforcements (new transmission or new resources)
- Operational mitigation was not cost-effective due to high fuel burn

Contingency	Violation	Equipment Mitigation	Operational Mitigation
Loss of the 138kV line in the North	Thermal (69kV system in the North)	New Transmission (second 138kV line in North)	Dispatch the North Pole fossil plant during winter peak periods in the North (additional 1142 hours)
Loss of the 230kV line in Central	Thermal (115kV system in Central) Voltage (115kV system in Central)	New Transmission (new substation at Lorraine*)	Dispatch the George Sullivan fossil plant during winter peak periods in the North (additional 1077 hours)
	Dynamic Instability (Loss of synchronism on Railbelt)	New Transmission (new substation at Lorraine*) OR Additional Battery (300 MVA Battery at Teeland)	Restrict the flow from the North to South to a maximum of 50 MW at the Kenai Intertie (~100 hours)

*Lorraine substation project has already been proposed (#15-0481) in 2017

Summary of Battery Reinforcements for Stability

GFM Battery reinforcements for stability provide:

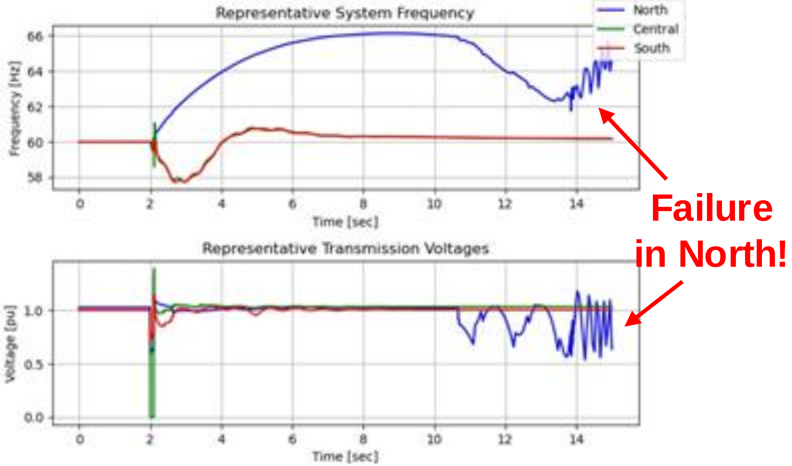
- High quality voltage support (fast, continuous reactive capability)
- Inertia, of the quality of synchronous machinery
- Sustained contingency response (~30 minutes)

Total Batteries (MVA)	BAU	Hydro	Nuclear	Tidal	Wind/Solar
Northern	30	304	331.24	40	275
Central	15	152.6	569.45	50	250
Southern	5	216	216	300	400
Total	50	807.6	1116.69	390	925

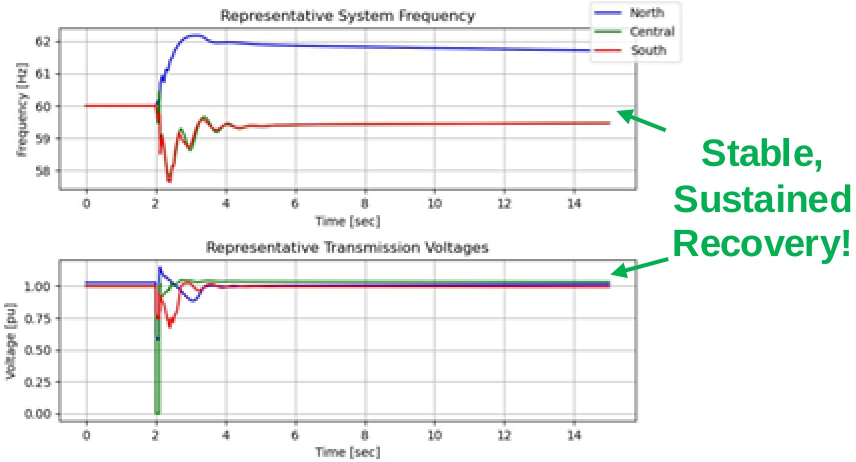
Lessons Learned From the Other Scenarios

Summary	GFL only	SC addition	GFL tuned	GFM
Stability	System collapsed	Stable except for Hour #7763	Stable	Stable
Synchronous MVA needed	System collapsed	564 - 624 MVA	290 - 494 MVA	No need for synchronous condensers
Worst case underfrequency load sheding	System collapsed	398.7 MW	282.2 MW	255.9 MW

Loss of the AK Intertie for Hour 7763, GFL with SC Addition

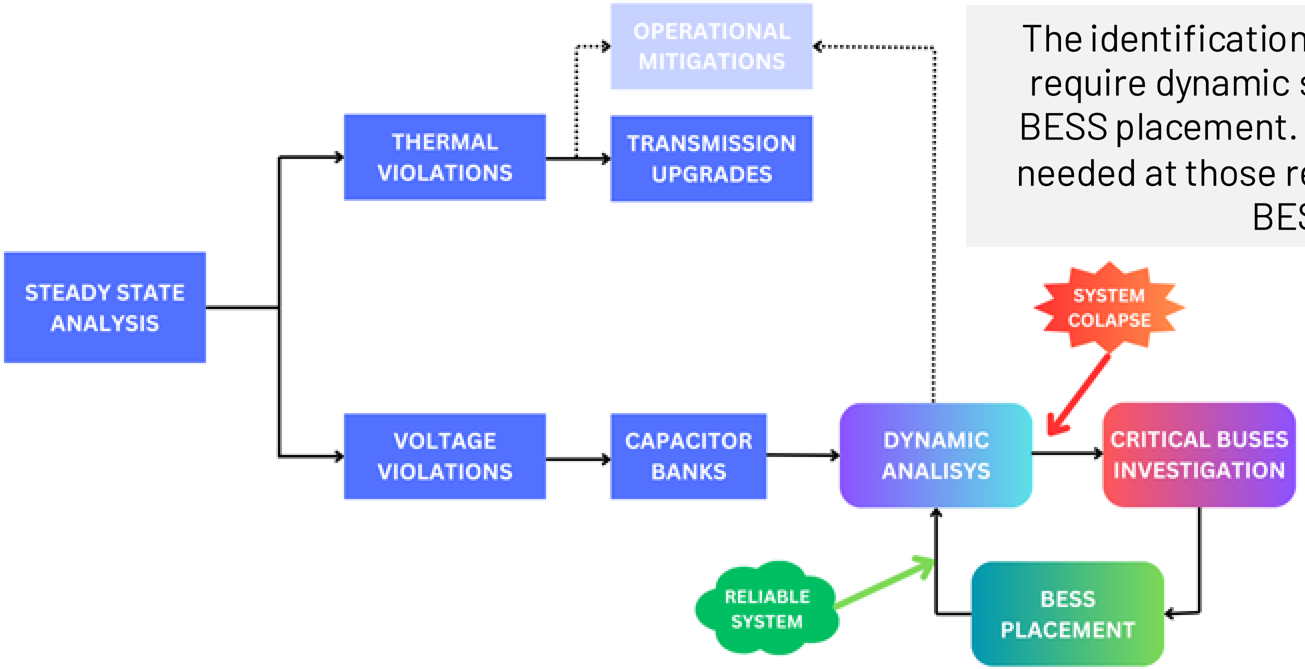


Loss of the AK Intertie for Hour 7763, GFM Included



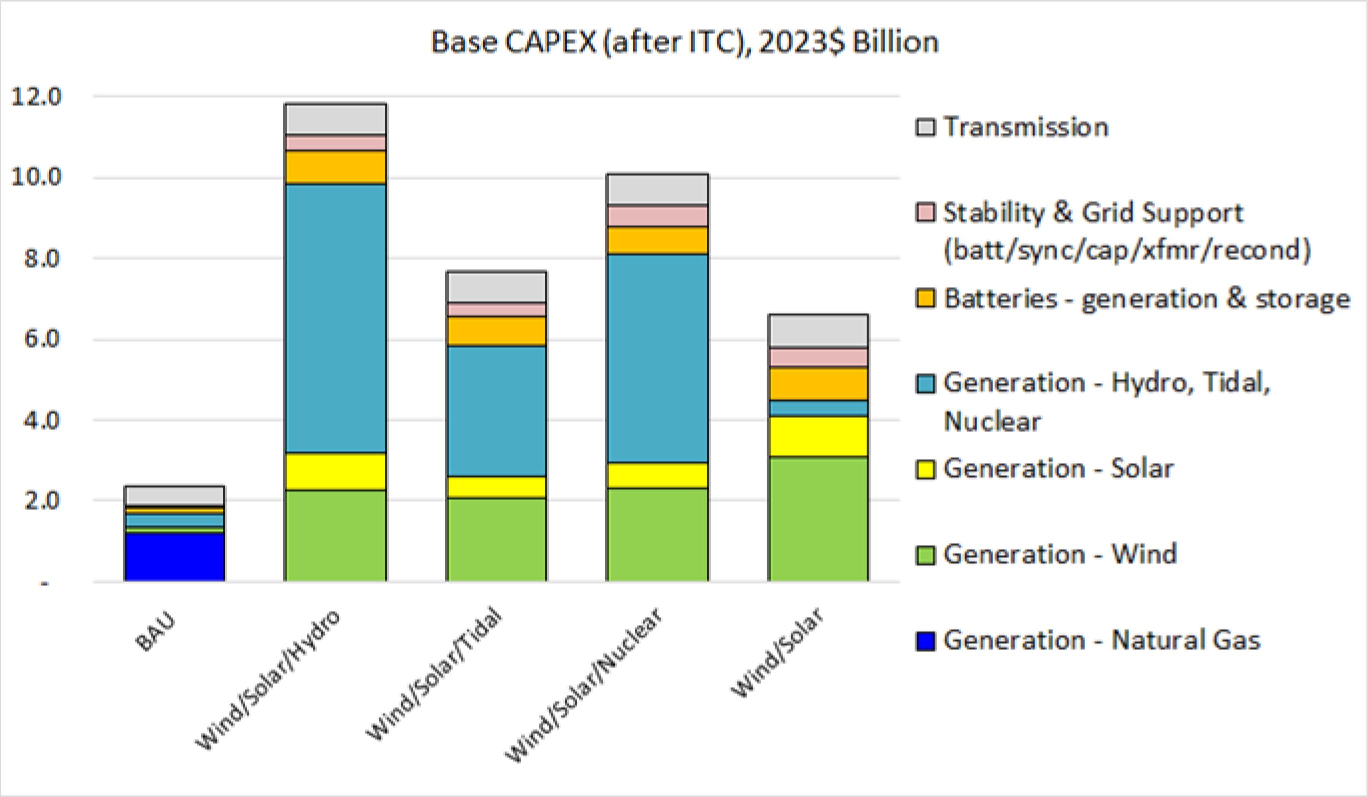
GFM inverter technology showed to be effective in replacing the reliability services from retiring synchronous plants. GFM BESS for dynamic support was used on the new Wind and Solar scenario.

GFM Batteries: Location & Size



The identification of the locations which require dynamic support led to the GFM BESS placement. The amount of support needed at those regions defined the GFM BESS sizes.

Required Capital Investment



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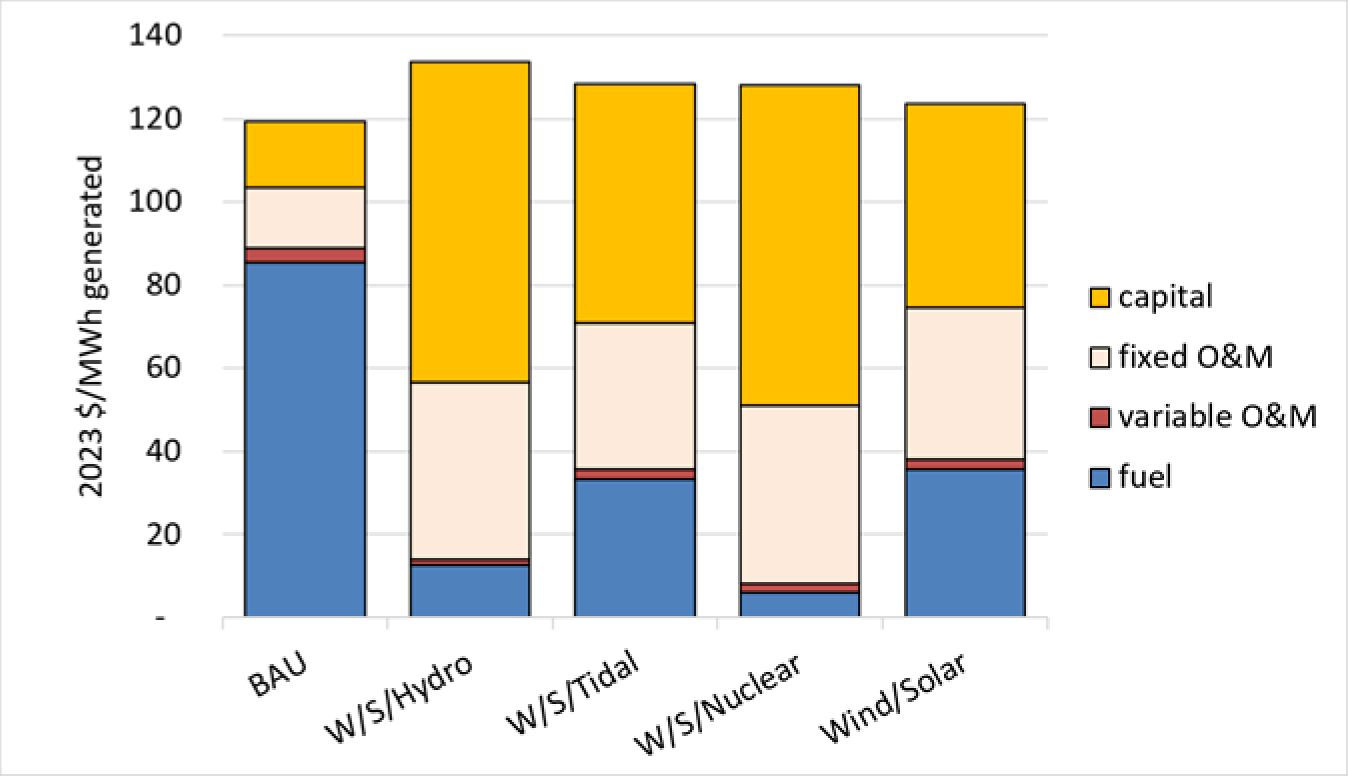
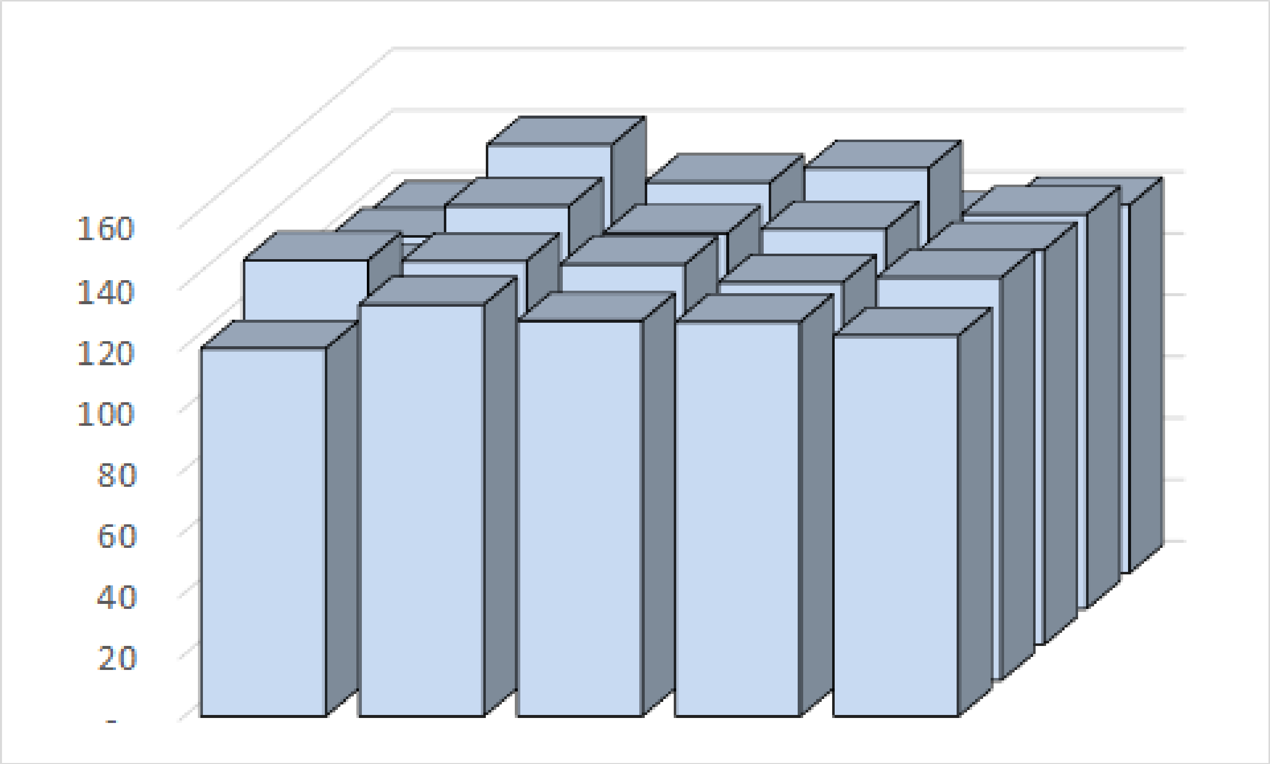
Base Case Generation & Transmission Cost of Service



Costs are all in the same ballpark range



Recap of Sensitivity Cases

S1: High Fuel
Fuel costs are 20% higher

S2: High interest
Debt interest rate is 6% (vs 5%)

S3: High-Cost Renewables
Hydro,Tidal, Nuclear CAPEX is 20% higher, interest rate = 6%

S4: Low-cost renewables
Hydro, Tidal, Nuclear CAPEX is 20% lower, interest rate = 4%

Cost per MWh generated	BAU	W/S/Hydro	W/S/Tidal	W/S/Nuclear	Wind/Solar
Base	119	134	128	128	124
S1 High Fuel	137	136	135	129	131
S2 High interest	121	143	134	135	128
S3 High-cost renewables	121	151	138	143	128
S4 Low-cost renewables	118	119	119	115	119

Change from Base, $/MWh	BAU	W/S/Hydro	W/S/Tidal	W/S/Nuclear	Wind/Solar
Base	-	-	-	-	-
S1 High Fuel	17	3	7	1	7
S2 High interest	1	9	5	7	4
S3 High-cost renewables	1	17	10	15	4
S4 Low-cost renewables	-1	-15	-9	-13	-4

Percent change from Base	BAU	W/S/Hydro	W/S/Tidal	W/S/Nuclear	Wind/Solar
Base	0%	0%	0%	0%	0%
S1 High Fuel	14%	2%	5%	1%	6%
S2 High interest	1%	7%	4%	5%	4%
S3 High-cost renewables	1%	13%	8%	12%	4%
S4 Low-cost renewables	-1%	-11%	-7%	-11%	-3%

Percent change from BAU	BAU	W/S/Hydro	W/S/Tidal	W/S/Nuclear	Wind/Solar
Base	0%	12%	8%	7%	4%
S1 High Fuel	0%	0%	-1%	-5%	-4%
S2 High interest	0%	18%	10%	12%	6%
S3 High-cost renewables	0%	25%	14%	18%	6%
S4 Low-cost renewables	0%	1%	1%	-3%	1%

Key Takeaways

- The Wind/Solar scenario (W/S) focuses solely on new wind and solar sources of generation and was developed in response to feedback
- W/S achieves 77% fossil-free generation, less than W/S/Hydro and W/S/Nuclear
- Much higher levels of inverter-based generation and North-South intertie flows result in more hours with stability challenges compared to the other low carbon (LC) scenarios
- The stability mitigations employed in the other LC scenarios also worked in W/S and were relied upon during more hours of the year
- W/S costs are in the same ballpark as all the other scenarios

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Thank you!

For more information, see our project website