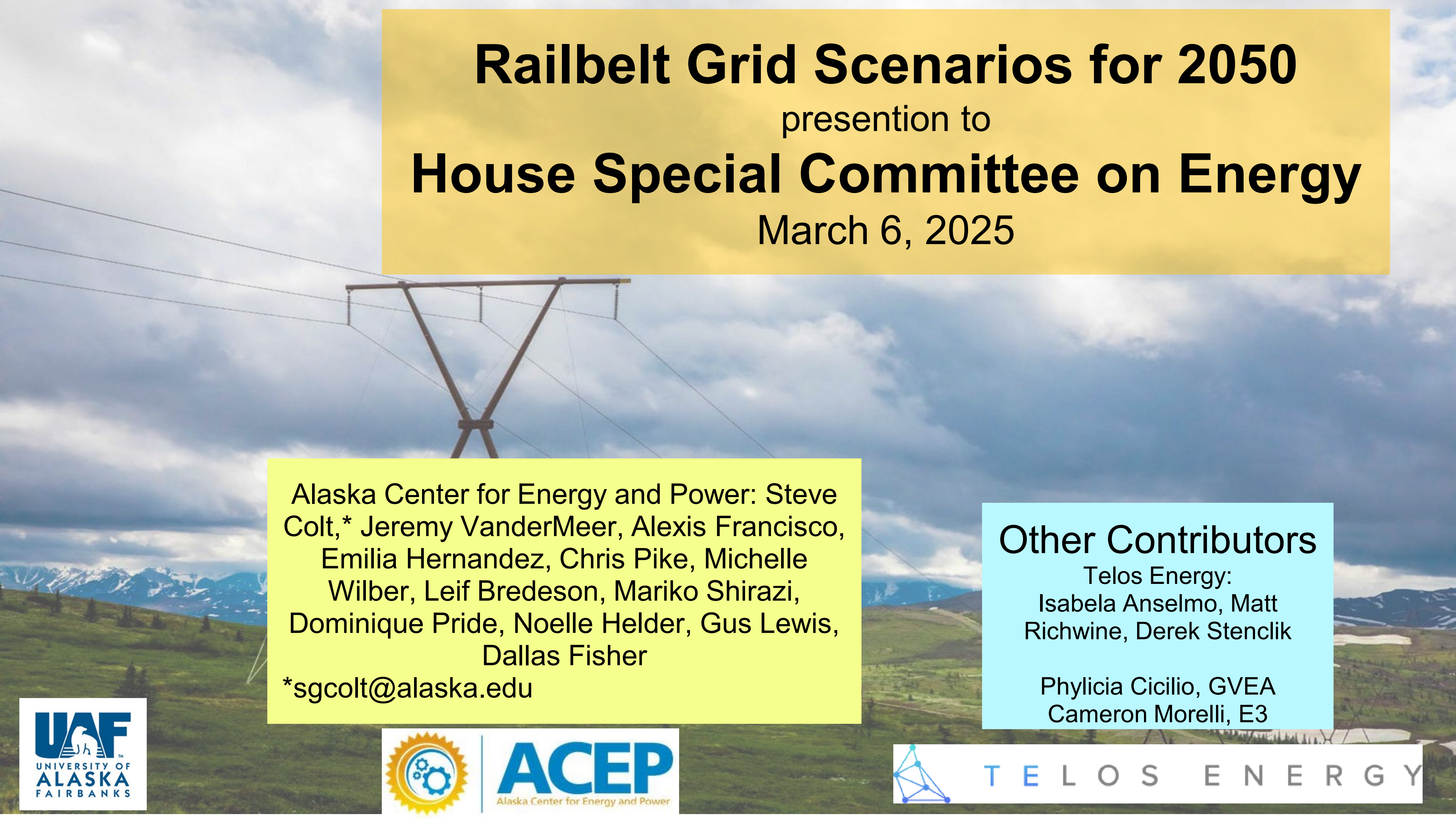

Railbelt Grid Scenarios for 2050

presention to

House Special Committee on Energy

March 6, 2025

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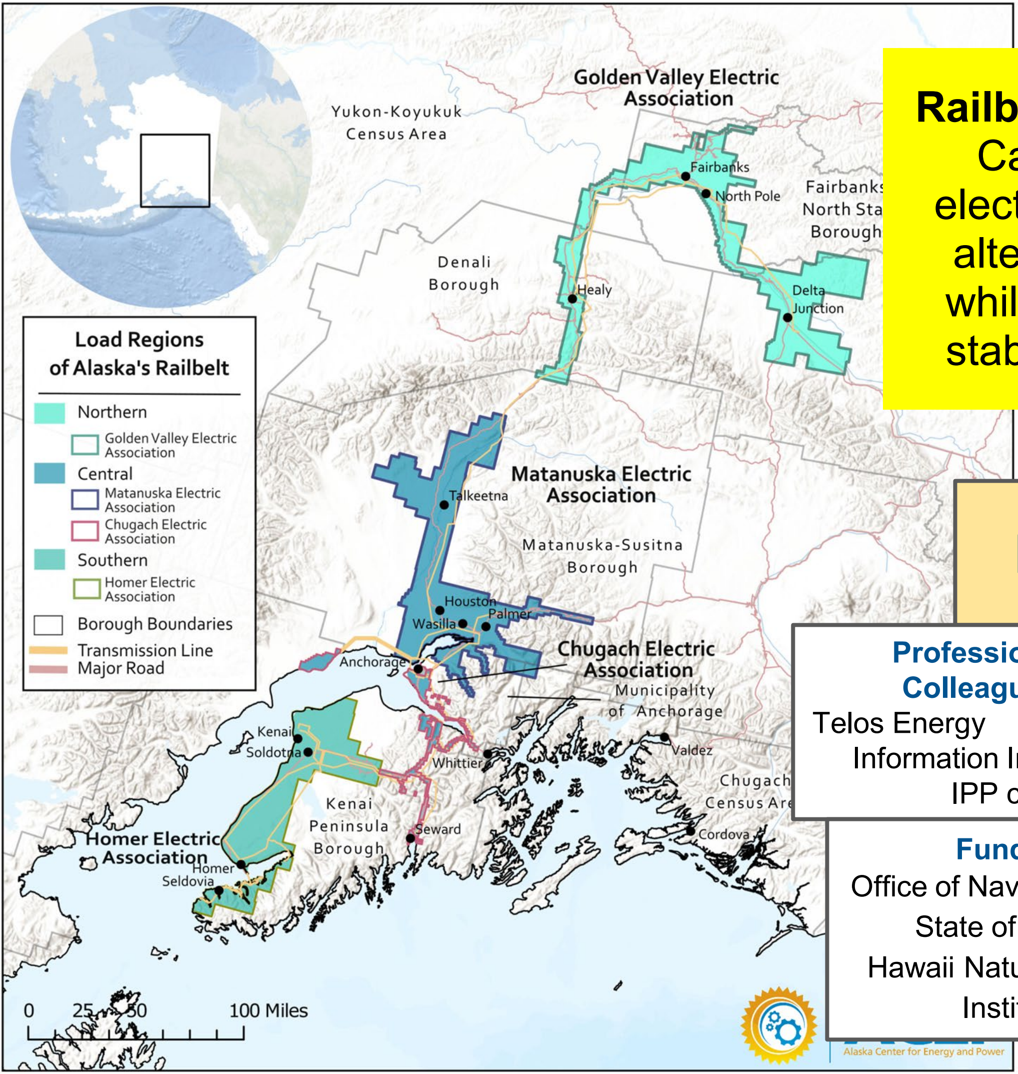
TELOS ENERGY



Railbelt 2050 Scenarios Project:
Can we meet a much larger electricity demand in 2050 using alternative generation sources while maintaining reliability and stability? What might this cost?

Partners

Public
Virtual May 2022
Fairbanks Sep 2023
Anchorage & Zoom, Jan 2024
Legislature, Jan 2024

Professional Colleagues
Telos Energy
Information Insights
IPP community

Utilities - Technical Advisory Group
Alaska Energy Authority
Chugach Electric Association
Golden Valley Electric Association
Homer Electric Association
Matanuska Electric Association
Railbelt Regional Coordination
Seward Electric System

Funding
Office of Naval Research
State of Alaska
Hawaii Natural Energy Institute

Approach

Scenario Development

Determining what components to consider for 2050.

i.e. resources, electrification and grid integration strategies.

Load Forecast

Projected 2050 load, including effects of EV's heat pumps, and rooftop solar

Resource Selection and Sizing

Identifying where resources are available and hourly generation profiles.

Generation Analysis

PLEXOS BY ENERGY EXEMPLAR

Hourly simulation of dispatch, fuel burn, starts-stops, runtimes

Reliability Analysis

SIEMENS PSSE

Evaluating power flow, frequency and voltage stability, response to contingencies

Economic Analysis

Required investment cost and average cost of service

$

Hourly Load

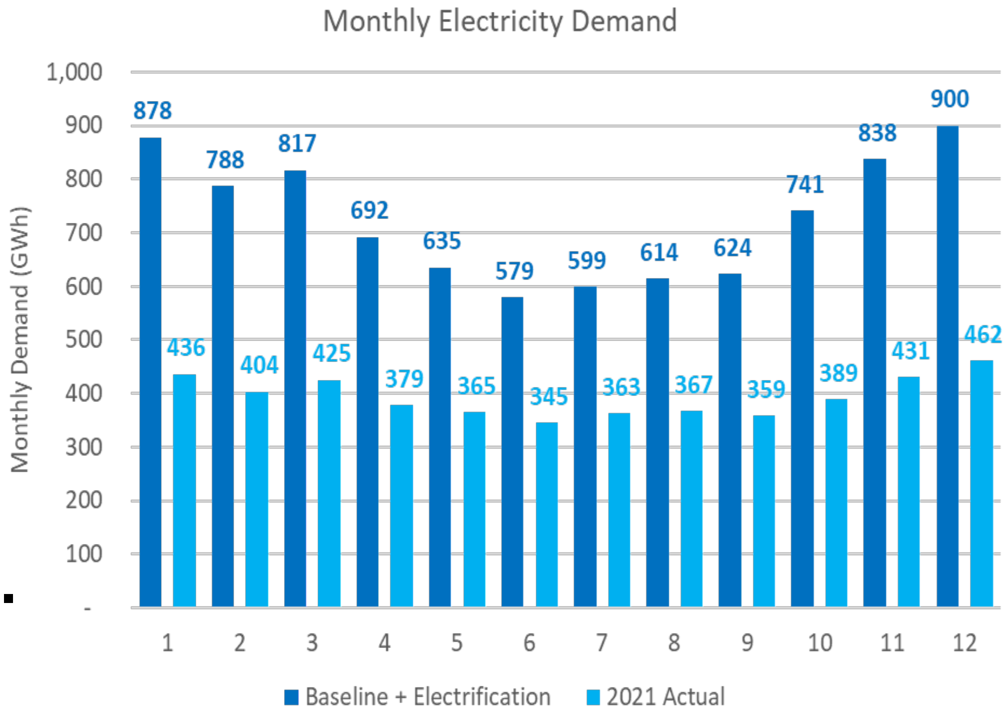
Hourly Resource Availability

Hourly Dispatch

Challenging hours

Electricity Demand (“Load”)

Challenge: Meet hourly 2050 Projected electricity demand = Twice the 2021 demand, and more winter-peaking. Maintain reliability.



5 Scenarios

BAU: Build Dixon Diversion, 30 MW Little Mt. Su Wind, HVDC to Beluga, Upgrade Kenai intertie. Add thermal capacity as needed.

Wind/Solar: Build wind, solar & storage. Upgrade both Kenai and Anchorage-Fairbanks transmission to 230 kV.

Wind/Solar/Hydro: Build Susitna-Watana 475-600 MW hydro, plus wind, solar & storage. Transmission upgrades same as W/S.

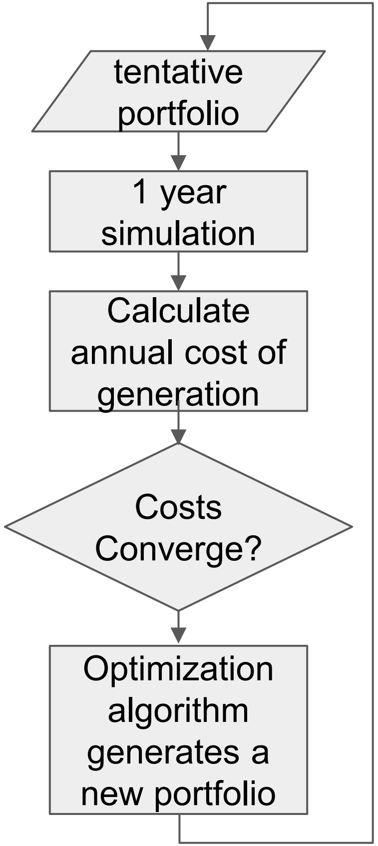
Wind/Solar/Tidal: Build 400 MW tidal project in Lower Cook Inlet, plus wind, solar & storage. Transmission upgrades same as W/S.

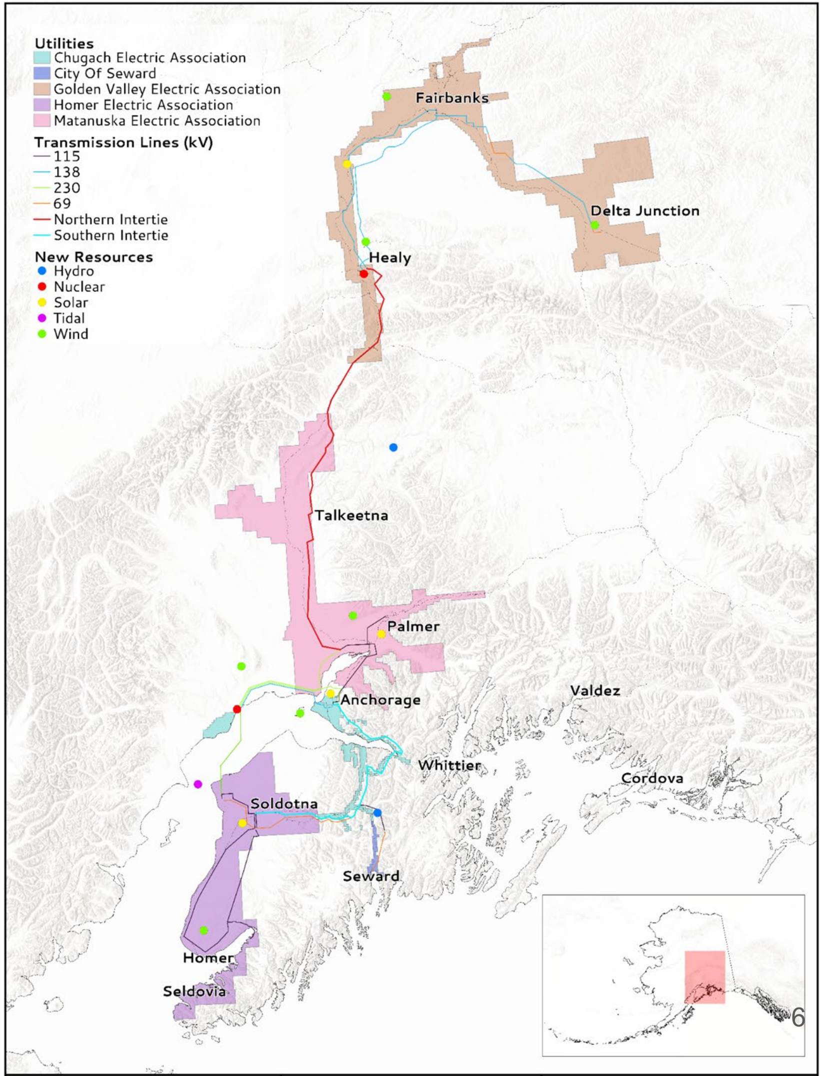
Wind/Solar/Nuclear: Build 2 small modular reactors (308+231 MW), plus wind, solar & storage. Transmission upgrades same as W/S.

Scenarios are **illustrative, not optimal**. We make **no recommendations**.

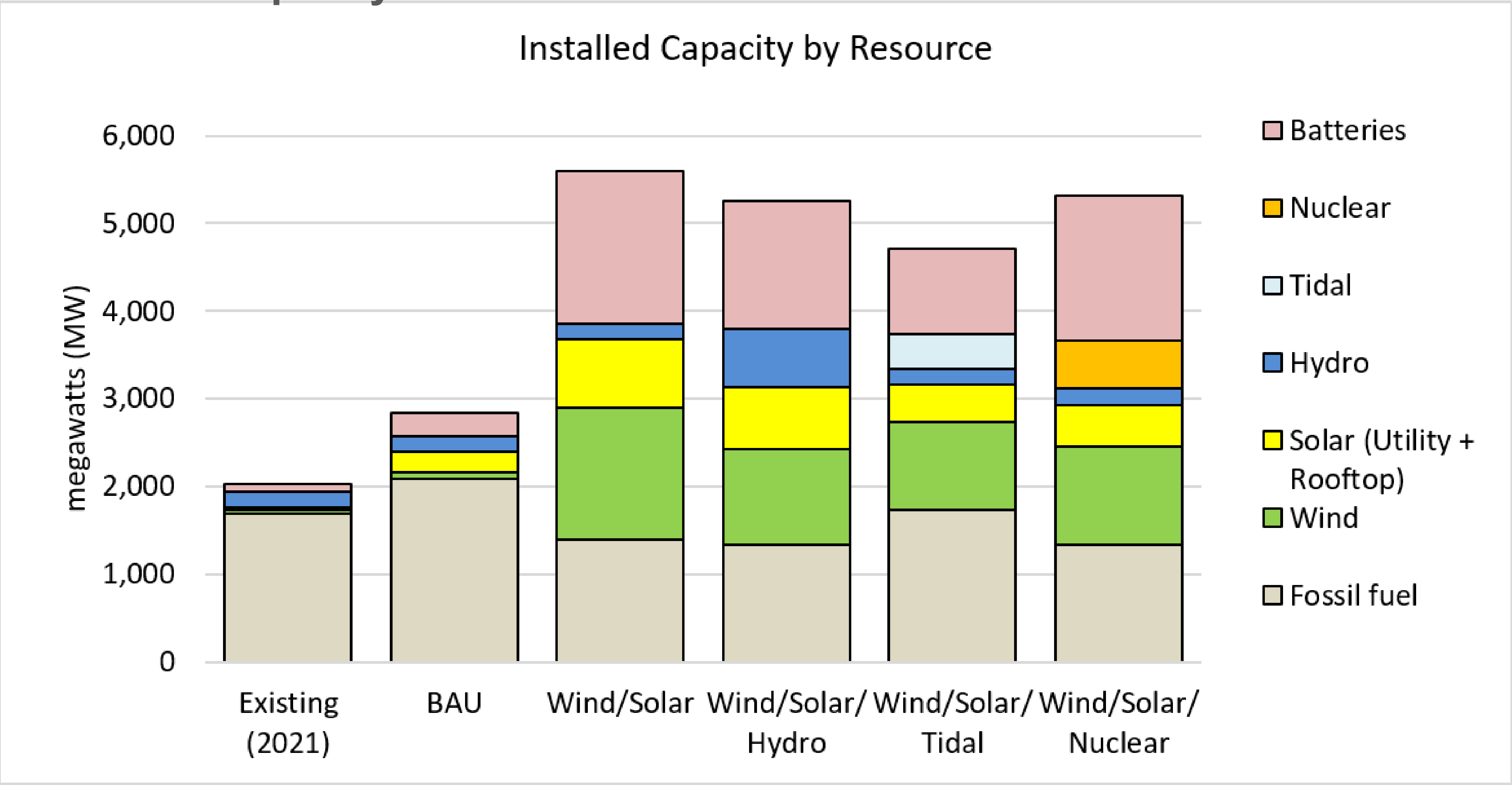
Resource selection and sizing based on availability and cost

Resource Type	Project
Hydro	Susitna-Watana, Grant Lake, Bradley Lake, Eklutna Lake, Cooper Lake
Wind	Delta Wind, Eva Creek, Fire Island, Homer, Houston, Little Mount Susitna, Shovel Creek
Utility Solar	Fairbanks, Houston, Nenana, Point Mackenzie, Sterling, Willow
Rooftop Solar	Northern, Central, Southern
Tidal	Cook Inlet
Nuclear	Healy, Beluga

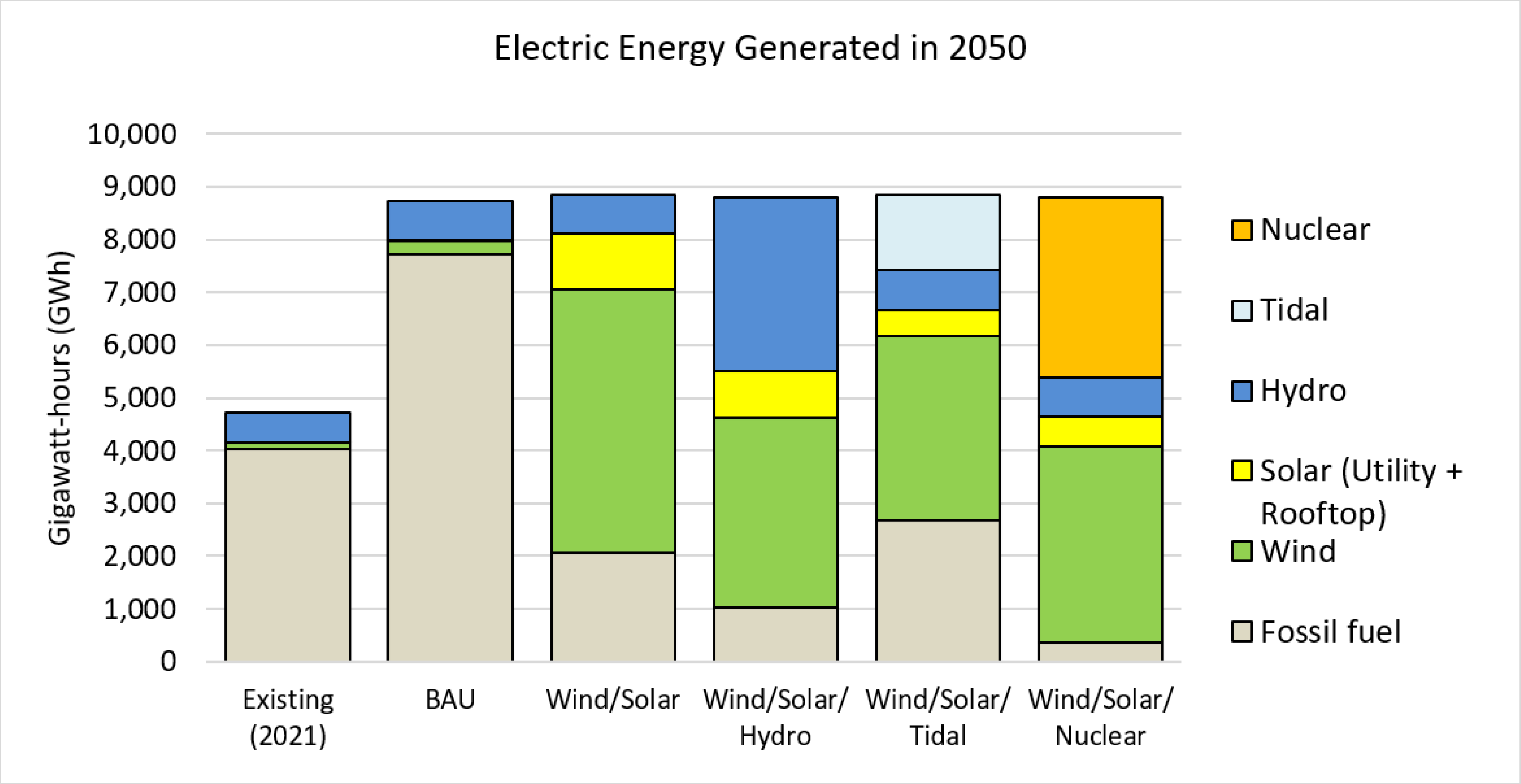




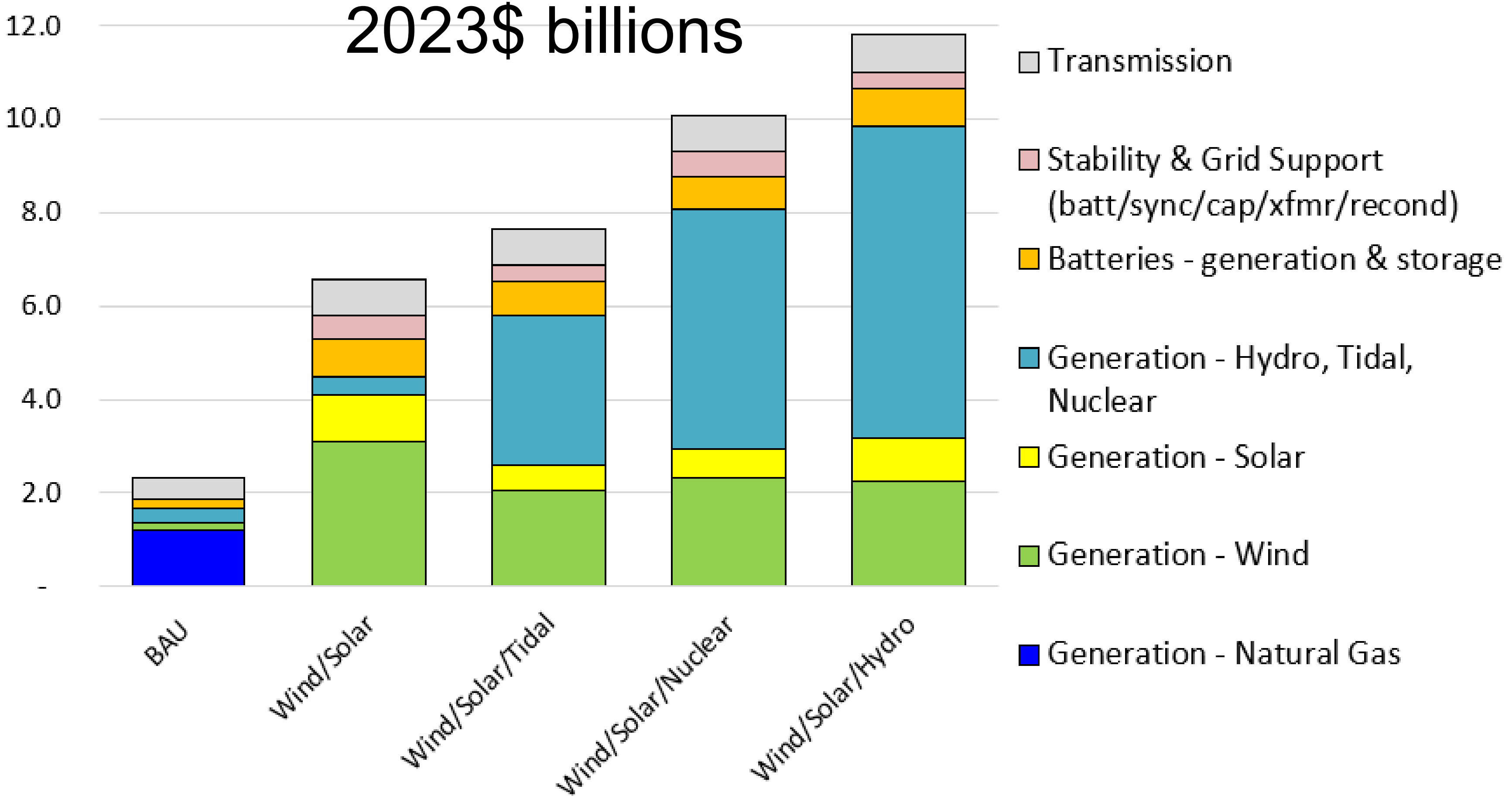
Installed Capacity in 2050



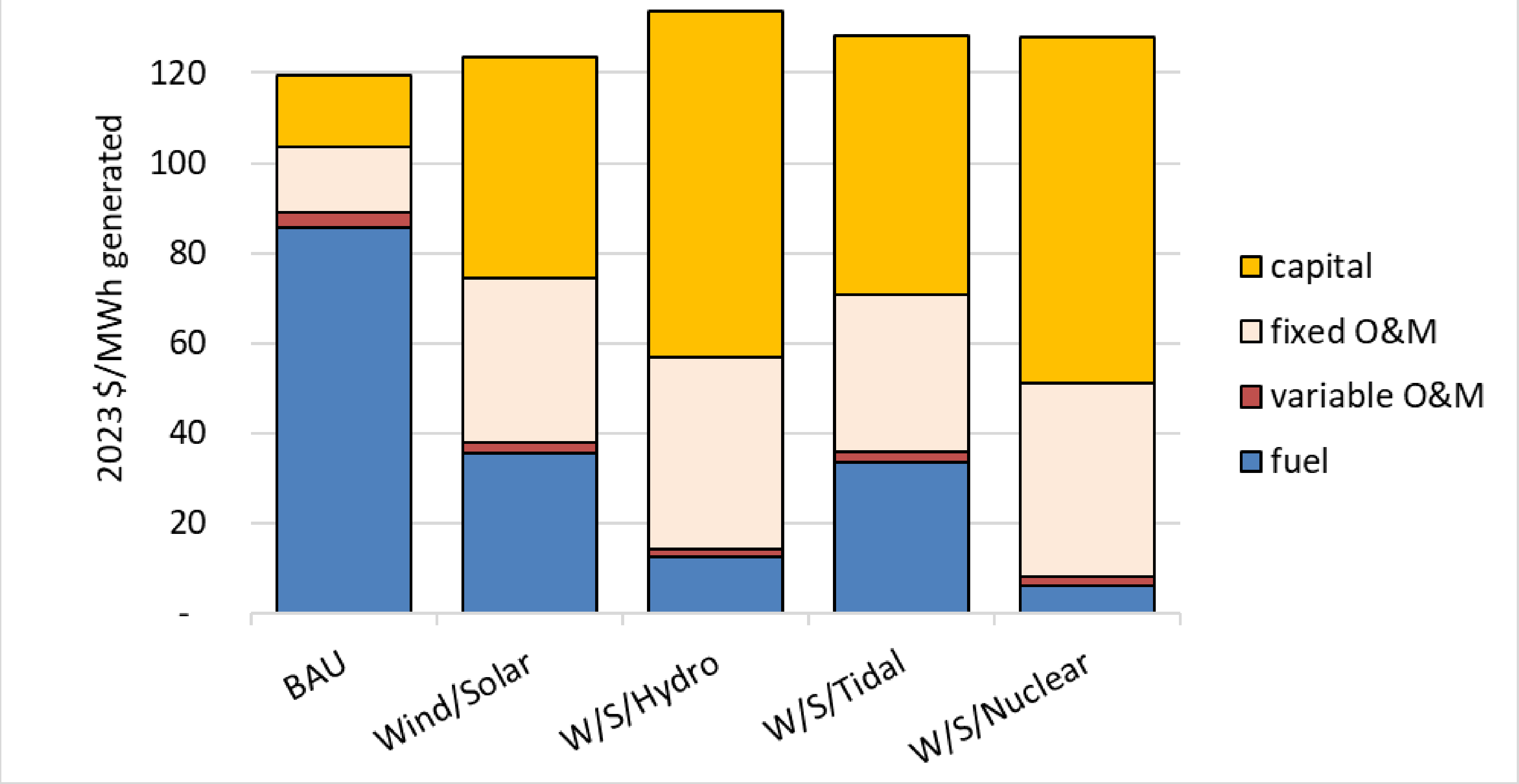
Annual Generation in 2050



Capital Investment (after 30% ITC), 2023$ billions

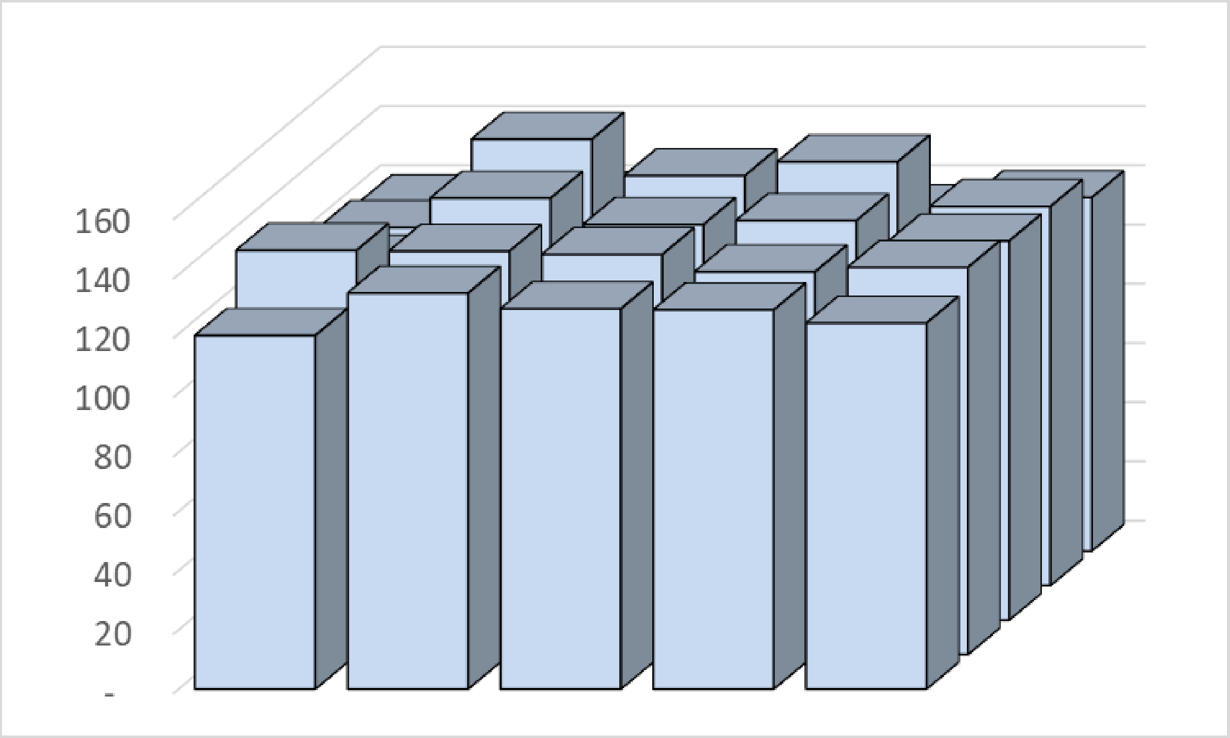


G&T Average Cost of Service – base case ($14/mmbtu gas, $20 oil, $4.19 coal)



G&T Cost of Service sensitivity cases (inputs +/- 20%)

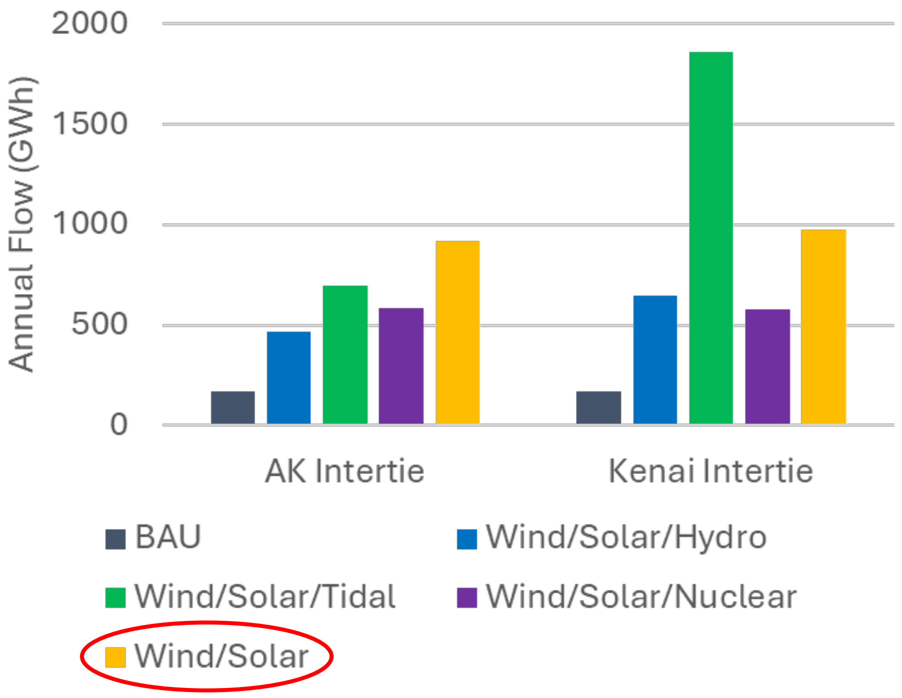
G&T Cost of service across 25 sensitivity cases is in same ballpark

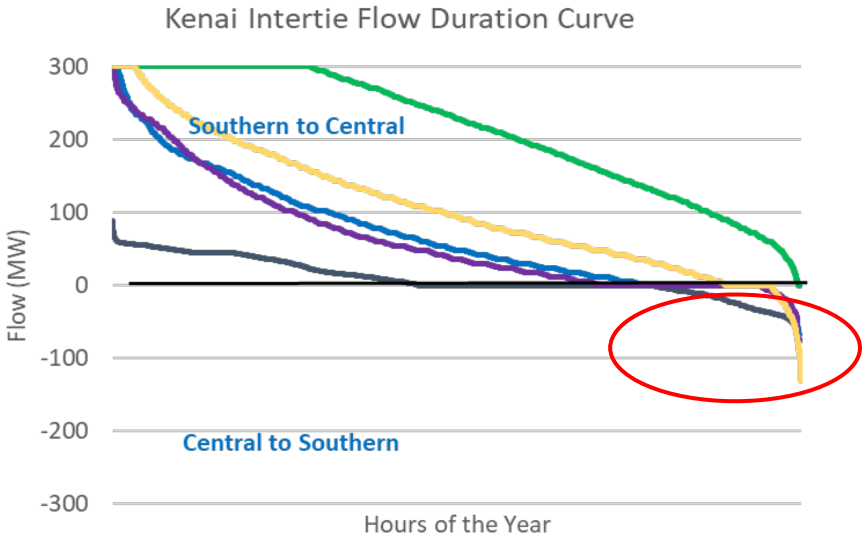


Generation & Transmission Cost of Service, $ per MWh

Transmission & Stability Summary

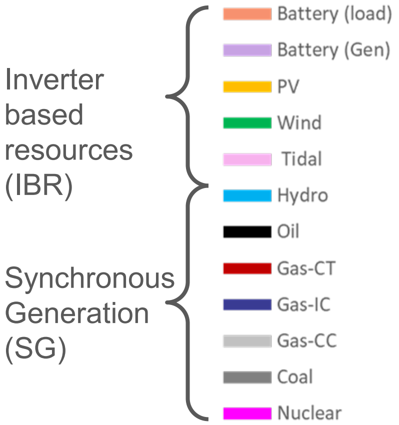
Intertie Utilization up 5-20 fold

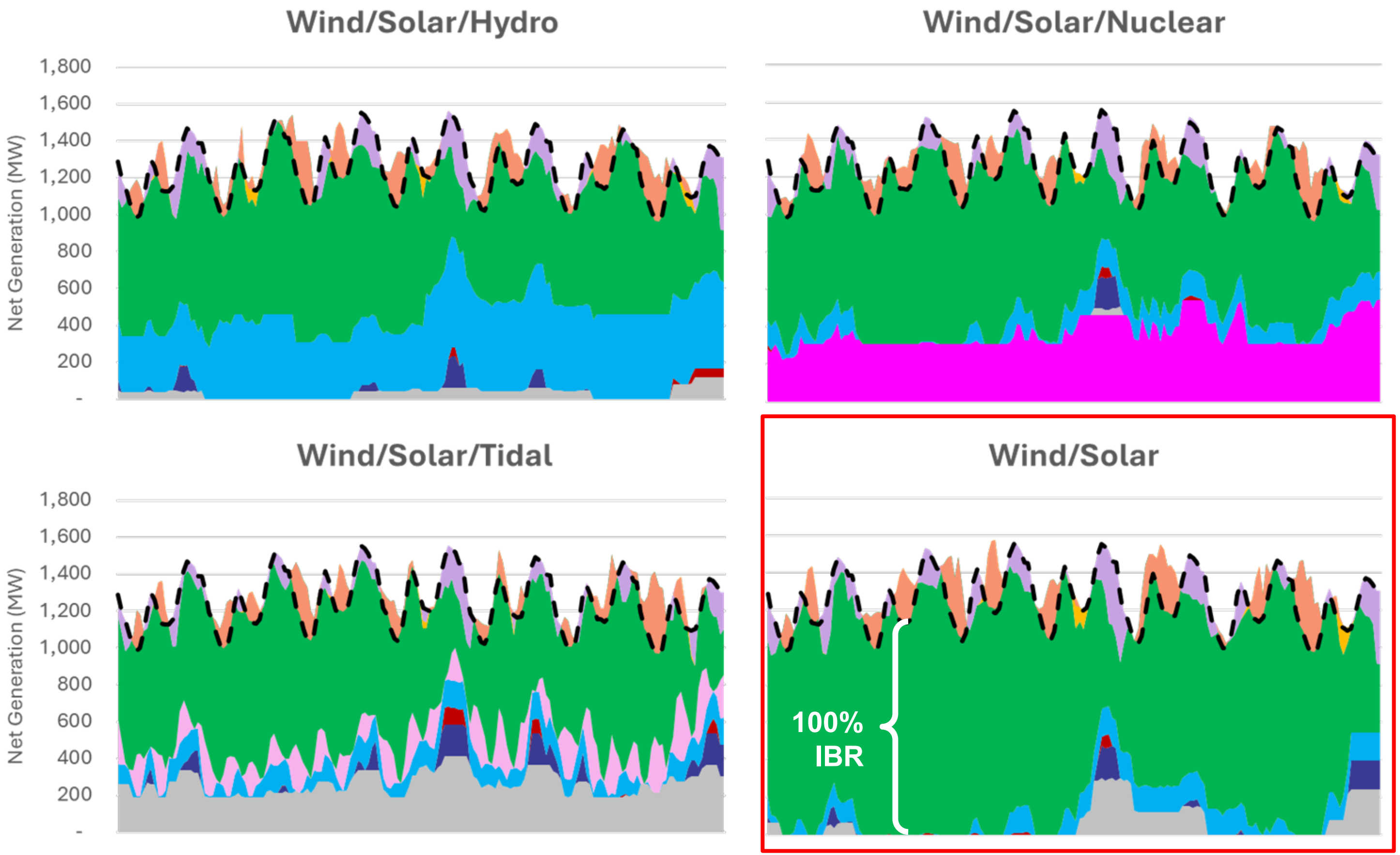




Highest Renewable Week Generation & Operations

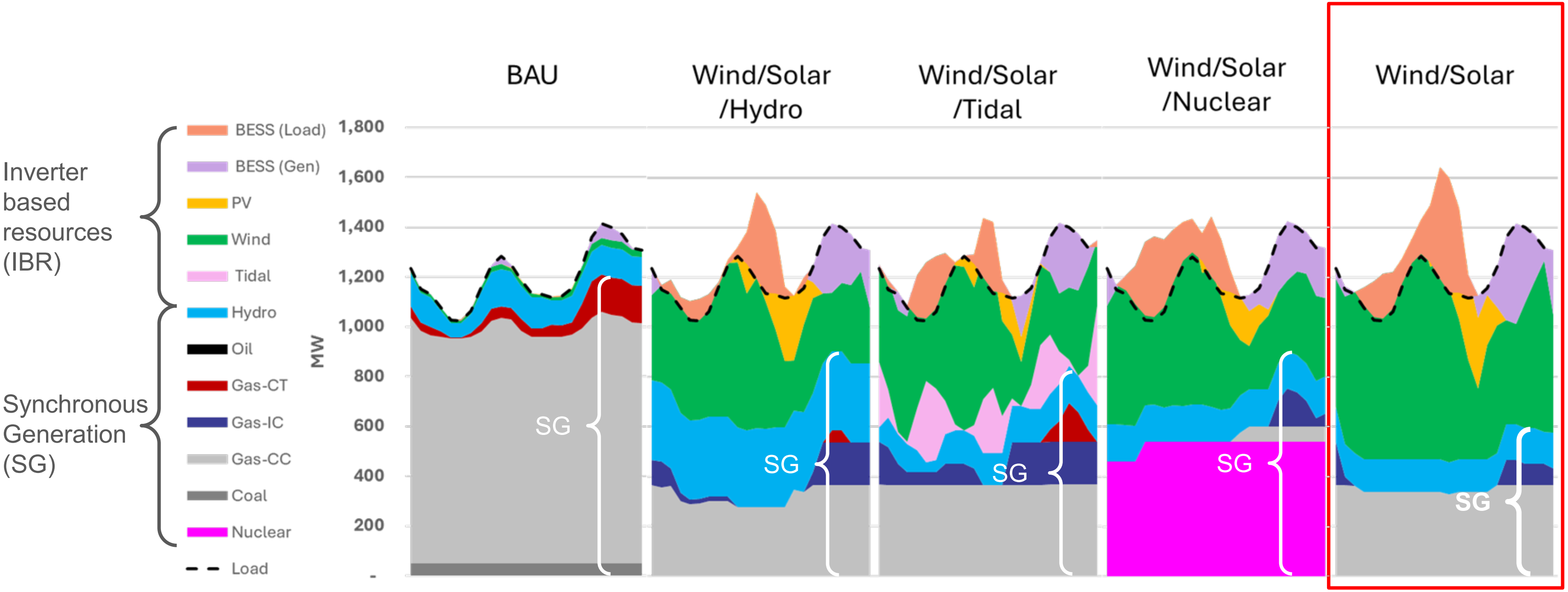
There are extended periods with significantly less synchronous generation, up to 100% inverter-based generation.





Representative Daily Generation & Operations

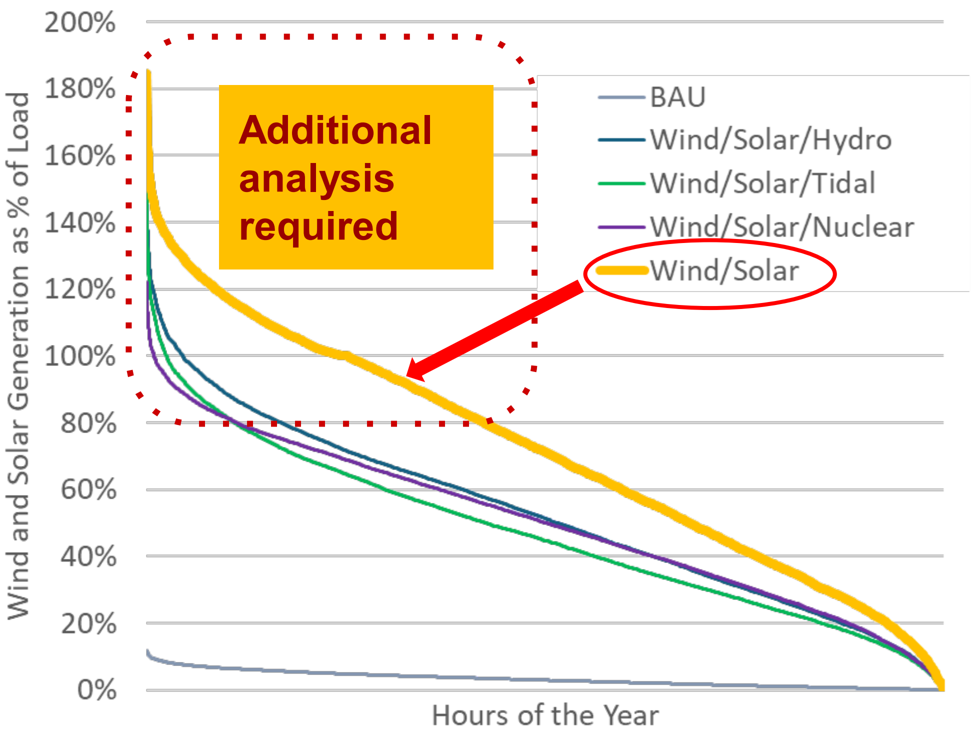
"Typical" Winter Day



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

Challenge: less Synchronous Generation (SG) with renewables.
Can Inverter-Based Resources (IBR's) effectively replace SG?

Annual Wind and Solar Generation as % of Load



- 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 solar generation, >100% for much of the year (battery charging)
- Periods of high wind and solar generation must be evaluated in further detail for transmission reliability.

Transmission Analysis

Grid Operations and stability

- Historically - synchronous machines provided critical stability services
- Decarbonization scenarios - high IBR, low synchronous generation
    - IBR with conventional controls: limited inertia and reference dependence
    - High generation in one area and none in others

Challenges

- Voltage violations
- Thermal overloading
- System crash- dynamics

Mitigation Options

- Operational (redispatch) - considered
- Upgrades and resource additions - primary

Equipment added for stability & reliability

	BAU	Wind/Solar/ Hydro	Wind/Solar/ Tidal	Wind/Solar/ Nuclear	Wind/Solar
30-min batteries (MVA, MW)	50	808	390	1,117	925
# of transformers	20	23	31	41	22
Capacitors (MVAr)	0	91	75	185	330
Synch Condensers (MVAr)	0	0	358	90	0
miles of reconductoring	2	122	224	231	119
New substations, xformers, $ billion					0.08
Capital cost, $ billion	**0.0**	**0.4**	**0.4**	**0.6**	**0.5**

Operational Mitigation Options also considered

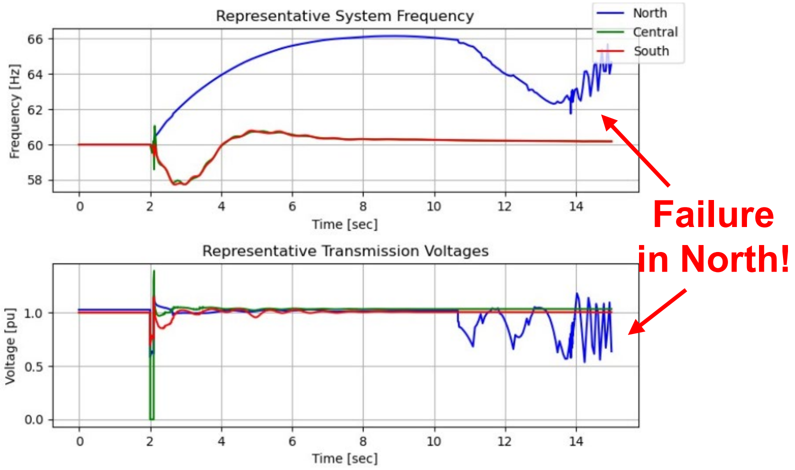
- For major **new** violations in the wind/solar scenario, operational mitigations were also considered in addition to new transmission or new equipment
- Operational mitigation was did not cost-effective due to high fuel burn

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)

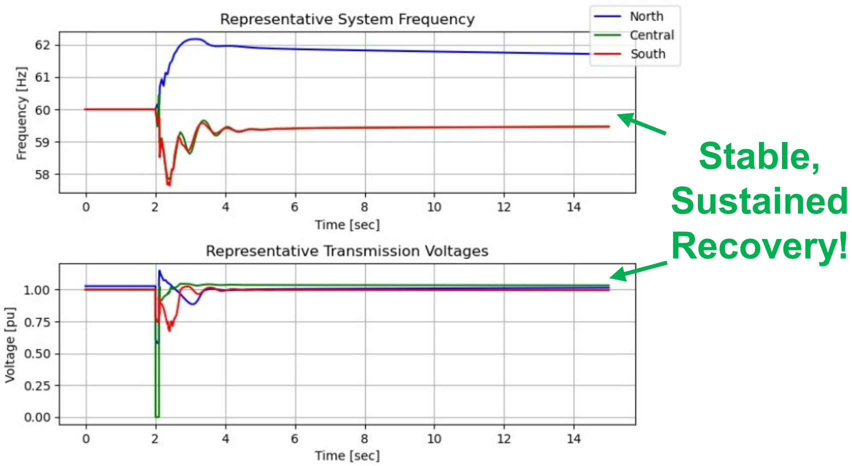
Grid-Forming Inverters

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 with batteries (GFM+BESS) for dynamic support was used the new Wind and Solar scenario.

“Conclusions”

- A renewables-based grid in 2050 is possible, but it will likely still require significant sources of firm dispatchable generation, such as fossil, hydro, or nuclear, in addition to large amounts of wind and solar.
- A renewables-based grid in 2050 would be operated very differently than it is today, with region-wide economic dispatch and extensive use of batteries and fossil fuel generators to follow load and to handle intermittent wind and solar output. Additional flexibility of natural gas supply would be needed that does not exist today.
- Interregional power flows would greatly increase as renewable generation is sited in the best places.
- Maintaining the stability and the reliability of the relatively weak Railbelt grid will be a challenge with fewer synchronous generators online to provide inertia and grid strength. That challenge can be met, but doing so will require significant resources and the use of new and emerging technologies such as grid-forming inverters. Alaska’s experience operating rural microgrids should prove useful.
- The cost of electricity in the renewables-based scenarios is in the same ballpark as the cost of reliance on fossil fuels, but the cost structure would be quite different, shifting from fuel to capital and O&M.
- Steve Colt’s ***Bonus Conclusion*:** Renewables can offer significant energy at zero marginal cost – opening up major new possibilities for load growth.

The End,Thank You

Full Study:
https://www.uaf.edu/acep/files/media/ACEP_Railbelt_Decarbonization_Study_Final_Report.pdf
And
https://www.uaf.edu/acep/files/projects/Wind_Solar-addendum-presentation.pdf

Some additional material is provided on the following slides

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Sensitivity cases detailed results

S1 High Fuel: fossil fuels cost 20% more than base

S2: High Interest: 6% vs 5%

S3: High-cost renewables: High interest *and* Susitna, tidal & nuclear are 20% more expensive to build

S4: Low-cost renewables: Low interest rate *and* Susitna, tidal & nuclear are 20% less expensive to build

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

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

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

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

Comparison of ACEP Railbelt 2050 study to NREL RPS Cost Analysis

	ACEP	NREL
Title	Alaska's Railbelt Electric System: Decarbonization Scenarios For 2050 (Feb 2024, addendum April 2024)	Achieving an 80% Renewable Portfolio in Alaska's Railbelt: Cost Analysis (Fall 2024)
Research focus	Assess alternative generation scenarios for reliability, stability & cost	Cost assessment of renewable generation portfolio
Generation mix target	100% zero-carbon by 2050 (soft goal)	80% renewable by 2040 (hard constraint in some)
Time horizon	2050 only	2024-2040, with annual results
Nuclear & Tidal energy	Included	Not included
Load growth projections	Almost doubles by 2050 to 8,500 GWh/yr	Increases by about 20% by 2040 to 4,860 GWh/yr
Generation expansion	Partial optimization based on scenario assumptions	Determined by PLEXOS capacity expansion tool
Scope of operational modeling	PLEXOS hourly dispatch + PSS/E power flow (events)	PLEXOS hourly dispatch
Cost assessment	Comparing projected average cost of service ($ per MWh) among scenarios	Comparing Railbelt-wide costs between scenarios and by category

Additional Details regarding Transmission& Reliability Analysis of the Wind/Solar Scenario

- Changes in most challenging hours and flow directions
- Increase in number of hours with 100% inverter-based resources
- GFM batteries remain effective
- New contingency emerged due to increased North-to-Central (Southward) flows on AK Intertie

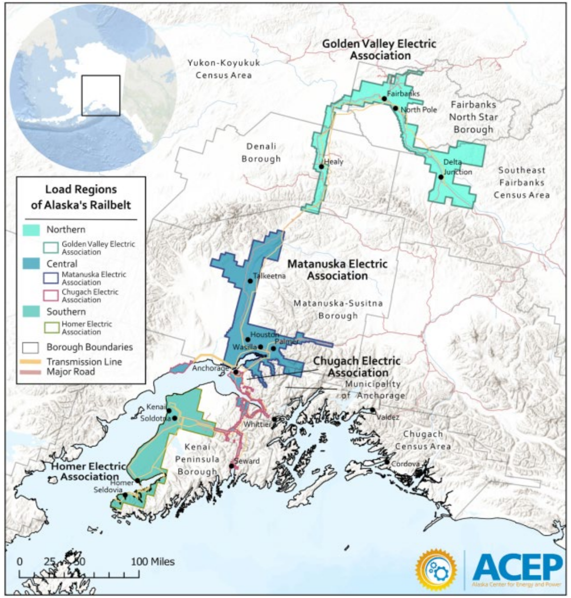
Transmission Analysis
Summary of Changes for the Wind/Solar Scenario

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



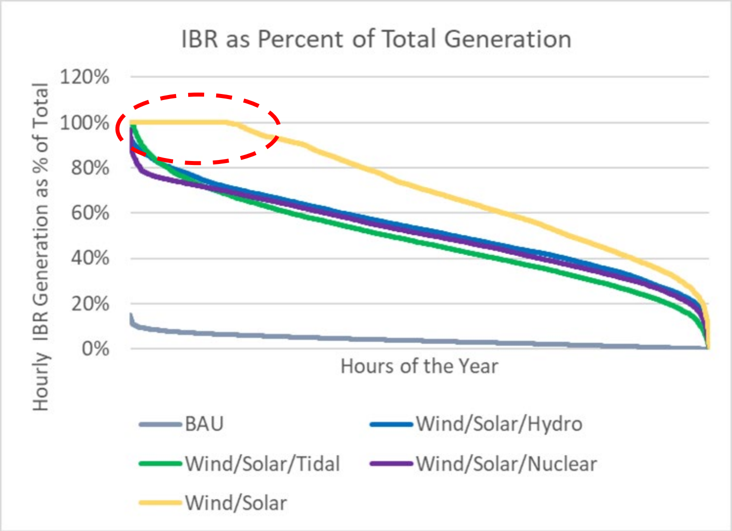
Grid Operations - IBR Penetration

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

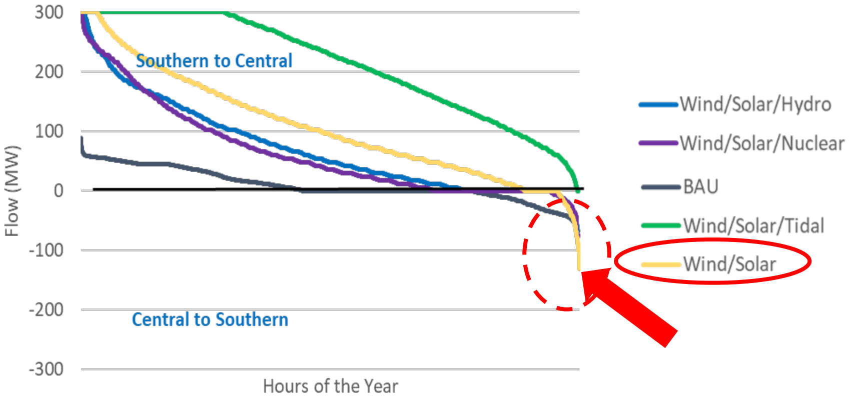


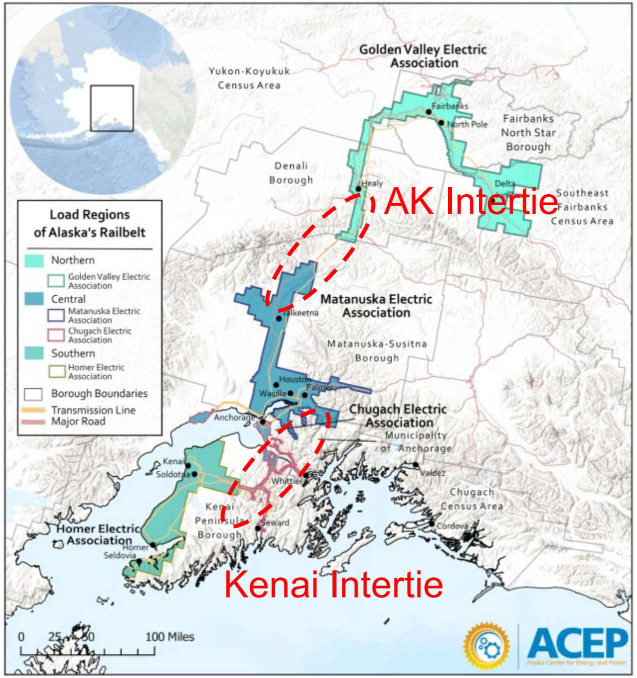
Grid Operations - Intertie Flows

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

Kenai Intertie Flow Duration Curve





Intertie Locations

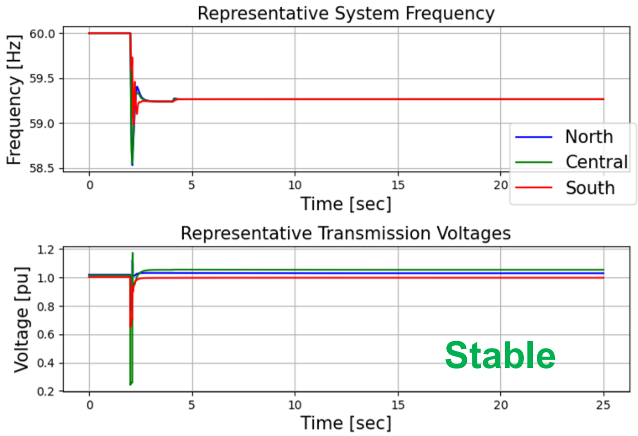
W/S Scenario: GFM batteries and intertie loss

- 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