Alaska Railbelt Wind Integration Study

Alaska Energy Authority Webinar

February 20, 2025

Energy+Environmental Economics

Jimmy Nelson, Director
Arne Olson, Senior Partner

Who is E3?

Thought Leadership, Fact Based, Trusted.

130+ full-time consultants

30+ years of deep expertise

Engineering, Economics, Mathematics, and Public Policy Degrees

San Francisco

New York

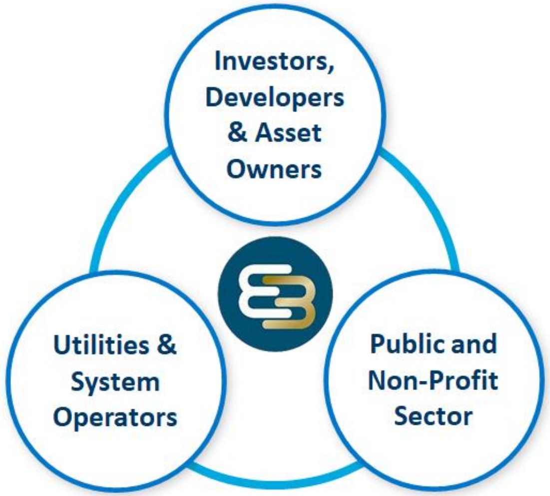
Boston

Calgary

Denver

E3 Clients

300+ projects per year across our diverse client base



E3 Practice Areas

Climate Pathways

- Climate and energy policy analysis
- Long-term energy & climate scenarios
- Electrification and low-carbon fuels
- Future of gas

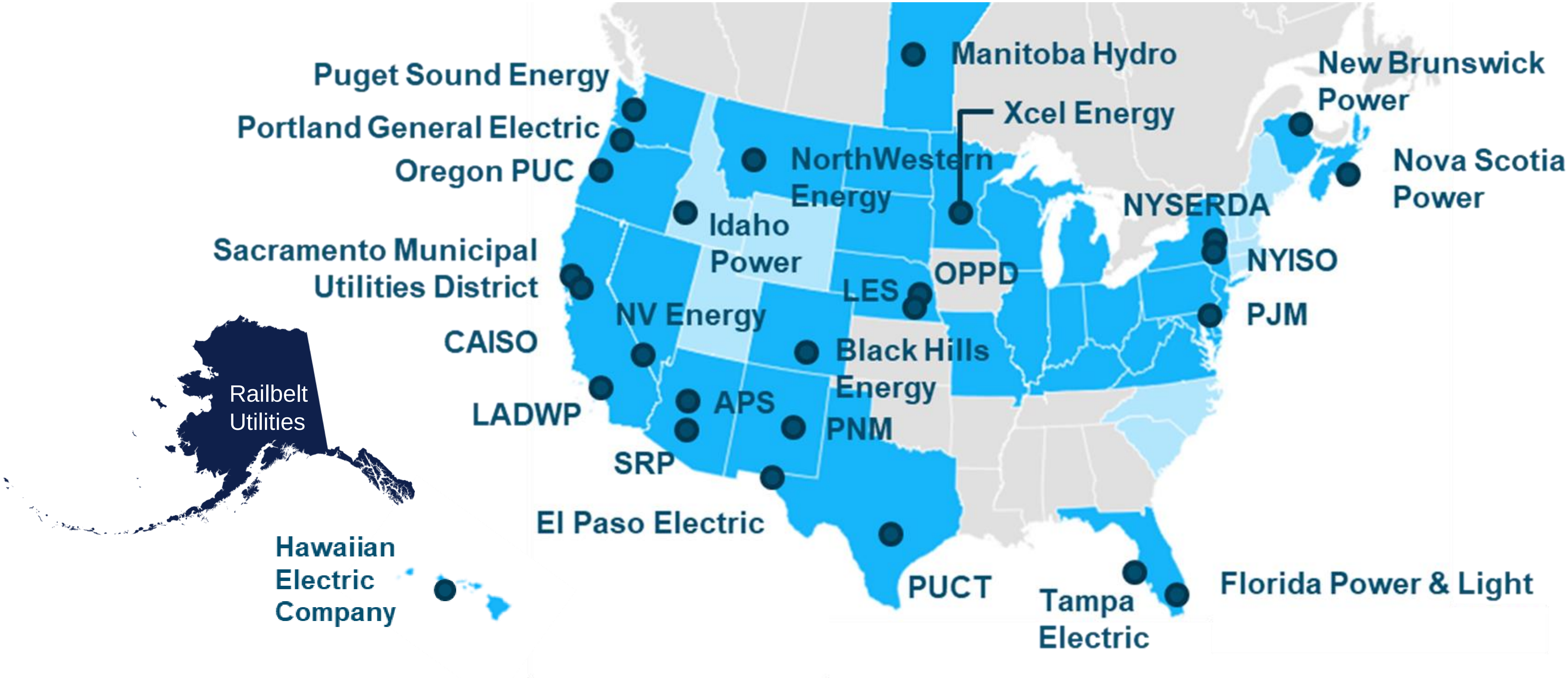
Asset Valuation, Markets & Transmission

- Asset valuation & due diligence for energy technologies
- Electricity market price forecasting
- Market design
- Transmission planning

Integrated System Planning

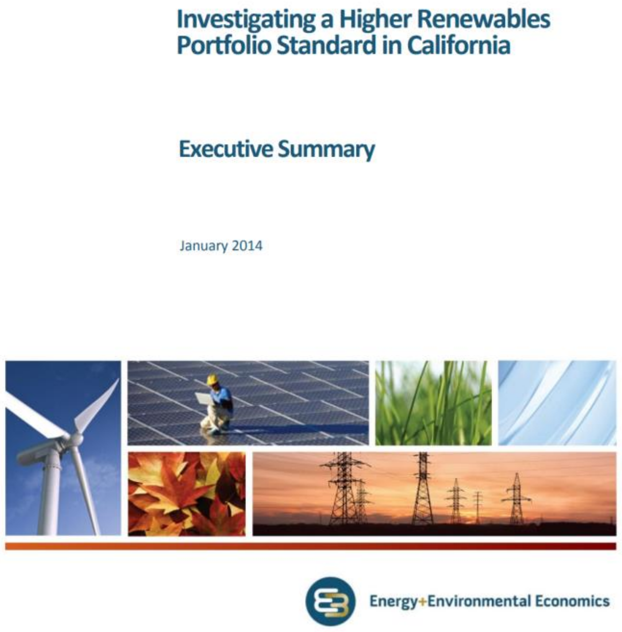
- System planning and analysis
- Utility resource procurement
- DER valuation
- Rate design
- Electrification and grid modernization

E3's System Planning Support Across North America



E3's 50% RPS study: 2014

The question: how can the system operators in California handle 50% renewables?



The answer: let operators curtail renewables if necessary

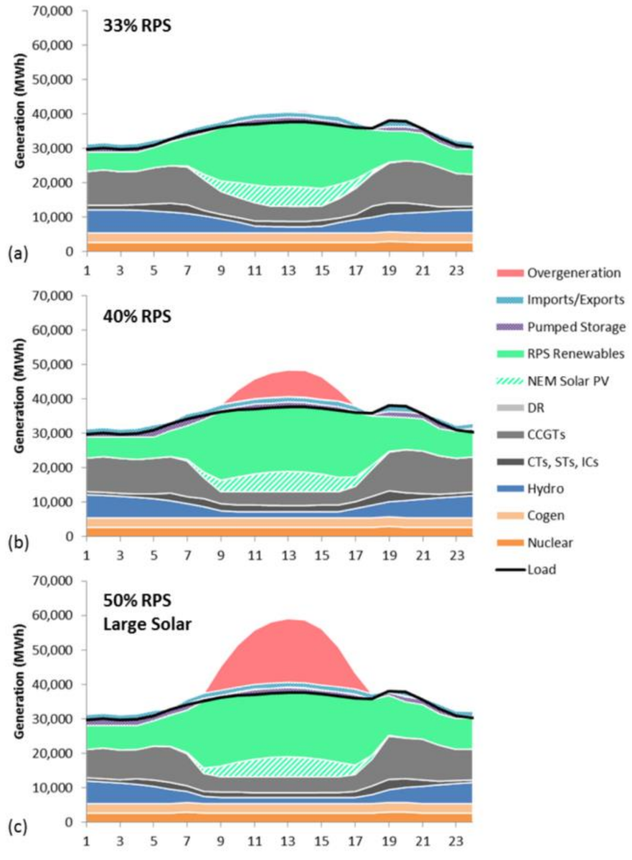


Figure 1: Generation mix calculated for an April day in 2030 with the (a) 33% RPS, (b) 40% RPS, and (c) 50% RPS Large Solar portfolios showing overgeneration

Operational Flexibility Drivers

Lower operational flexibility (Operator has less control)	Higher operational flexibility (Operator has more control)
Inflexible load	Flexible Load
Non-dispatchable solar and wind	Dispatchable / curtailable solar and wind
Run-of-river/inflexible hydro	Dispatchable Hydro
Inflexible thermal: Must-run, slow ramp rate, small dispatchable range, etc.	**Flexible thermal:** quick start, quick ramping, large dispatchable range
Small system, fewer ties, or big ties relative to load	Larger system, more ties
Storage with dispatch limitations	Storage operated to maximize system benefit

Alaska Railbelt project team

E3 Team

Jimmy Nelson

Project manager

Arne Olson

Senior Partner

Chen Zhang

Lead Modeler

Saamrat Kasina

Sam Kramer

Alex Gonzalez

Chris Herman

Railbelt Utilities

- Golden Valley Electric Association (GVEA)
- Chugach Electric Association (CEA)
- Matanuska Electric Association (MEA)
- Homer Electric Association (HEA)

Electric Power Systems, Inc. (EPS)

- James Cote and Rich Meier

Energy+Environmental Economics

Wind Integration Study Scope and Modeling

Research questions

With 300 MW more wind in the Railbelt by 2030…

Can reliability be maintained?

By how much would operational costs (fuel, variable, and start costs) be reduced?

How much would CO_2 emissions be reduced?

What level of wind curtailment would be expected?

How can the Railbelt's transmission, generation, and storage resources be used to balance wind variability and uncertainty?

How could Railbelt operations evolve to accommodate more wind?

Railbelt studied using detailed production cost modeling

Industry standard production cost modeling, customized to the Railbelt

- E3 used the PLEXOS (industry standard) production cost model to perform unit commitment and dispatch of the Railbelt system
- Hourly and 5-minute simulation of a year of chronological data

PLEXOS

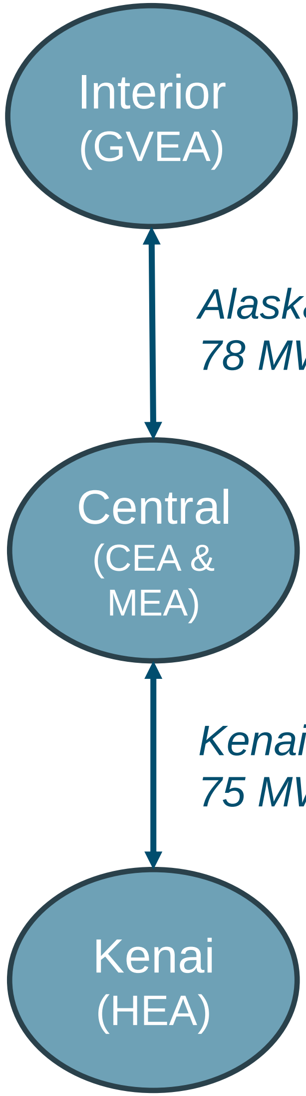
Modeling focuses on near-term: 2025-2030. Near present-day Railbelt infrastructure represented in model.

- Present-day resources online, except Healy 2 is retired
  - The retirement of Healy 2 is assumed in this study but the unit has not yet retired. The retirement timeline is not well defined due to shortages of natural gas in the Cook Inlet region.
- Natural gas assumed to be available as needed
- CEA/MEA battery storage (Tesla) online, no other resource additions
- GVEA battery used for spinning reserves only
- Current solar resources not modeled due to relatively small capacity
- Transmission capacity at current levels: no upgrades or additional lines

Modeled topology and wind capacity

Shovel Creek Wind
140 MW
42% capacity factor

Also includes Eva Creek Wind, 25 MW



Alaska Intertie:
78 MW in both directions

Little Mount Susitna Wind
160 MW
47% capacity factor

Also includes Fire Island Wind, 18 MW

Kenai Intertie:
75 MW in both directions

Railbelt modeled as a single load balancing area

- **In current operations, CEA and MEA have a joint balancing agreement but HEA and GVEA resources are balanced separately.**
- **Reflecting possible future dispatch coordination, the Railbelt utilities recommended that E3 model the Railbelt as a single load balancing area.**
- ***Impact:* The single load balancing area assumption is an evolution of Railbelt operations that results in more flexibility in the model than is available currently. The additional flexibility from coordinated operations in PLEXOS makes it easier to integrate wind than it would be with current levels of coordination.**

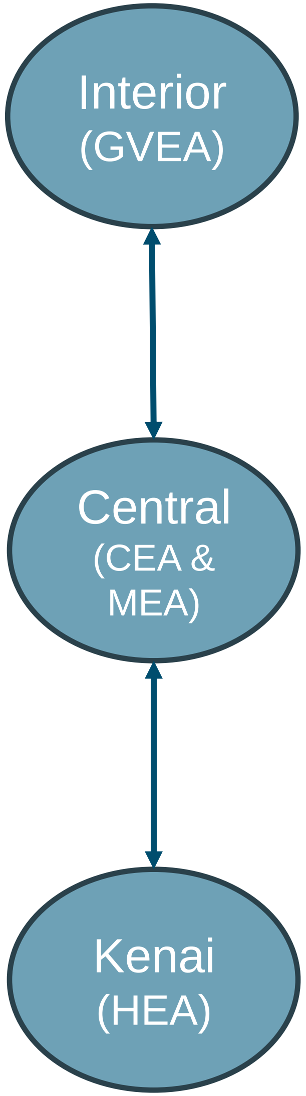
- **To implement the single load balancing area in E3's Railbelt PLEXOS model:**
  - All zones (Interior, Central, and Kenai) are balanced simultaneously in real-time
  - Wheeling charges are not included on transfers between zones
  - Scheduling of energy and regulating reserves is seamlessly coordinated Railbelt-wide (while respecting transmission constraints between zones)
    - Consistent with current practice, contingency reserves held in each region

Scheduling constraints and forecast errors are modeled

	1st stage: Day-Ahead Schedule		2nd stage: Real-Time Dispatch
Goal of Stage	Perform day-ahead scheduling of combined cycles, coal, and gas fuel		Evaluate production costs and reliability
Timestep	Hourly, solved a day at a time		5-minutes, solved a day at a time
Load and Wind	Day-ahead <u>forecast</u> profiles; balancing reserves held for forecast error and variability		Real-time actual (not forecast) profiles; balancing reserves released to be dispatched
Unit Schedules	All units free to be economically committed, subject to generator limits	→ Commitments	Coal and combined cycle unit commitment schedule from first stage cannot be changed
Gas Supply	Gas nominated economically each hour	→ Gas nominations	Gas consumption must be within +/- 10% of day-ahead nomination

Stability requirements

- **EPS, Inc. performed a stability analysis with 300 MW of new wind**
- **EPS found that certain thermal and hydro units – described on the right – need to be online in each area to maintain voltage and inertia stability.**
  - E3 has included the EPS stability requirements in every timestep in our modeling to ensure system stability
- ***Further study needed: There may be opportunities to maintain stability without as much committed thermal and hydro generation***
  - *Batteries, synchronous condensers, etc.*



At least one North Pole unit must be online

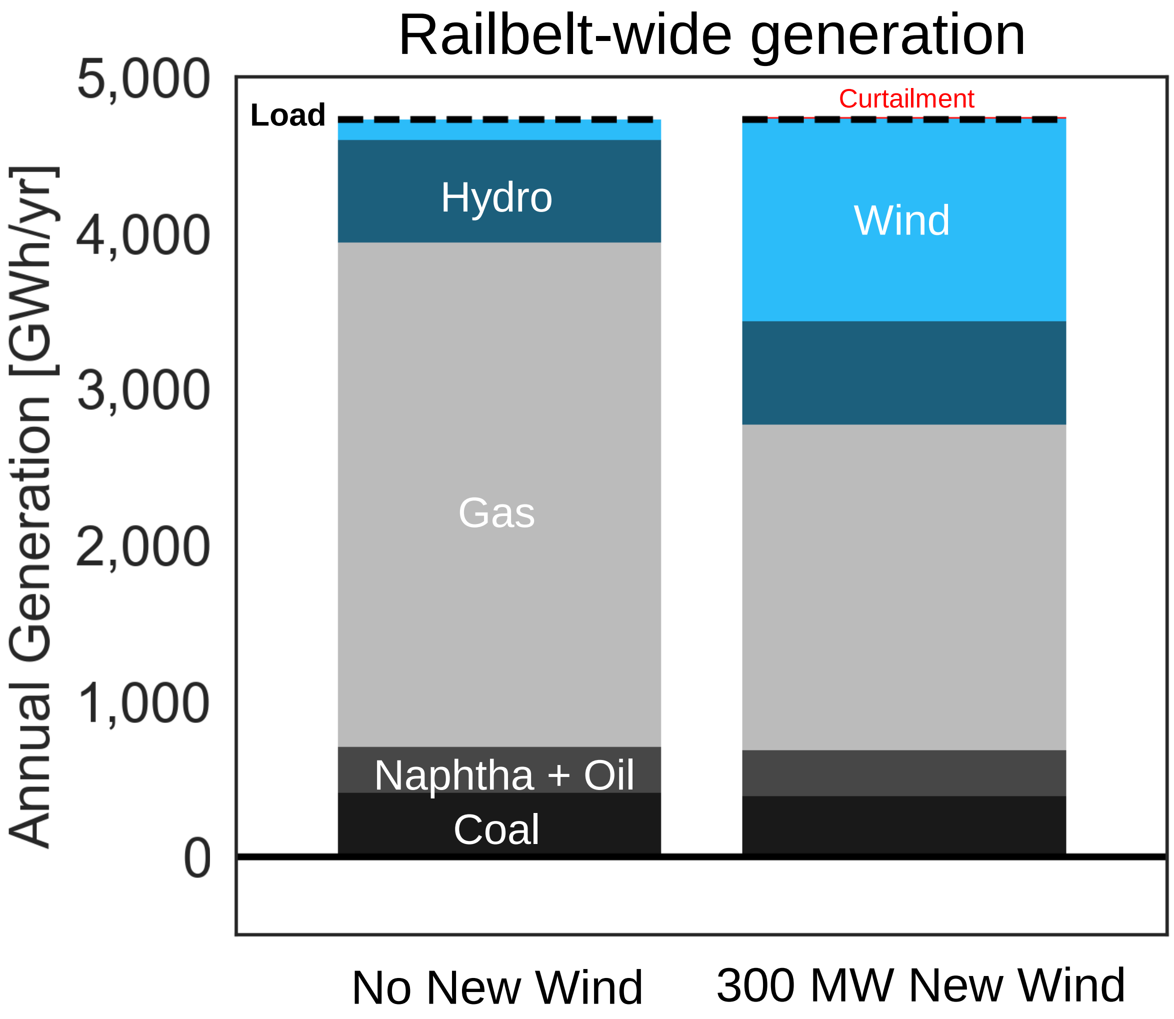
Eklutna Generation Station + Eklutna Hydro: as MEA load increases, more units must be online

At least one large combined cycle (Southcentral or Sullivan) must be online

Requirement 1: Nikiski or Soldotna must be online
Requirement 2: 2 units must be online (Nikiski, Soldotna, Bradley Units)

300 MW New Wind: Base Results

Wind predominantly displaces gas



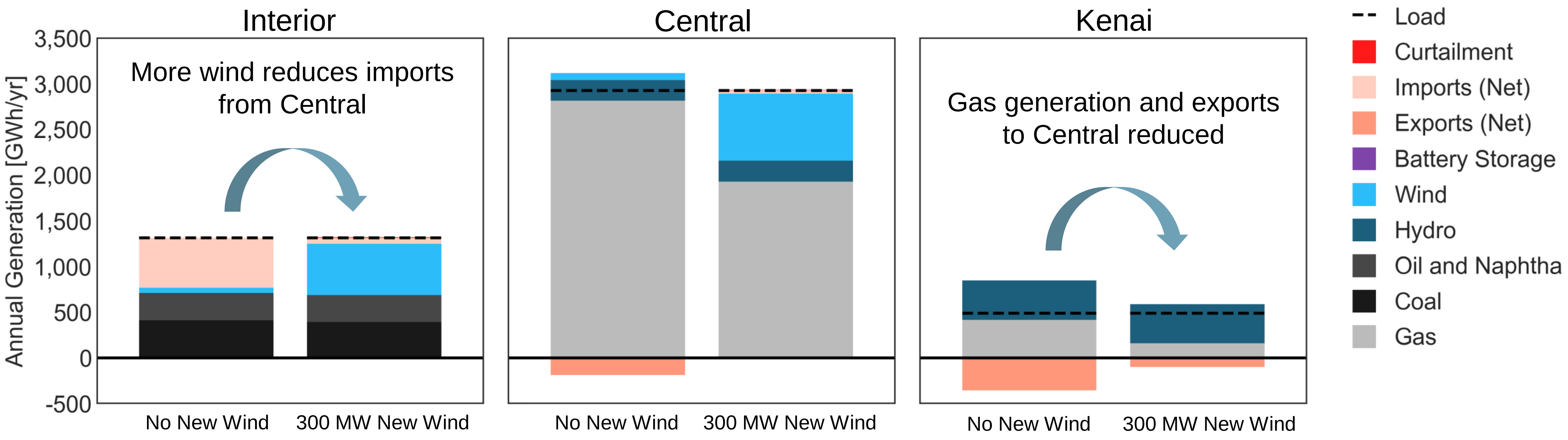
All load served – system is reliable on the 5-minute timescale:
No unserved energy observed in any 5-minute interval in any zone across an entire year

New wind offsets predominantly gas generation

On an annual basis, coal and naphtha/oil are largely unchanged

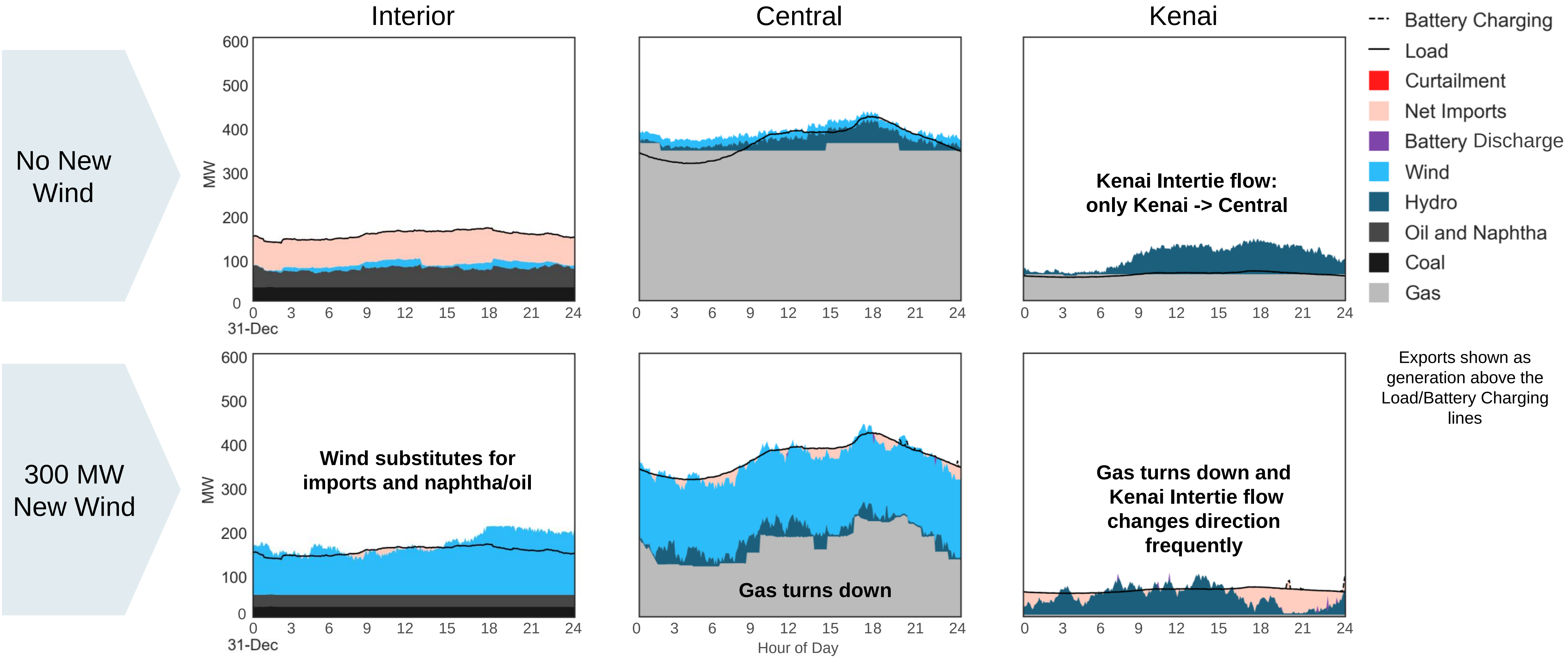
Wind curtailment is low:
13 GWh of wind curtailment is observed in +300 MW Wind case, which represents 1% of wind production potential

Annual imports and exports change with more wind



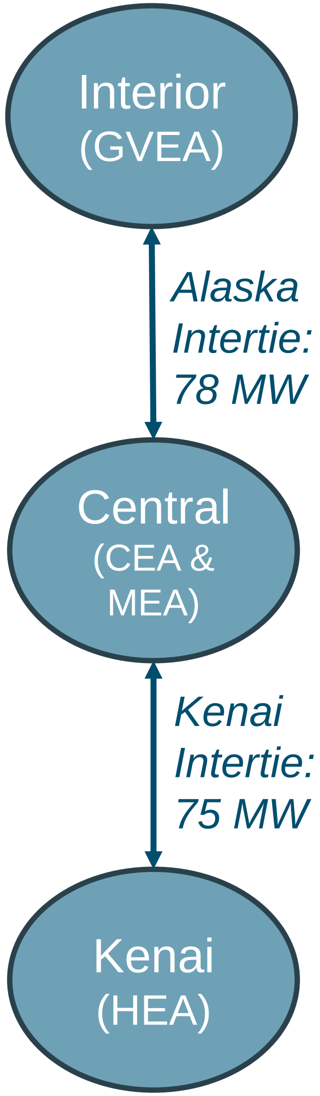
Generation is shown by the physical location of the resource, not by ownership.

Thermal generation turns down when wind is abundant



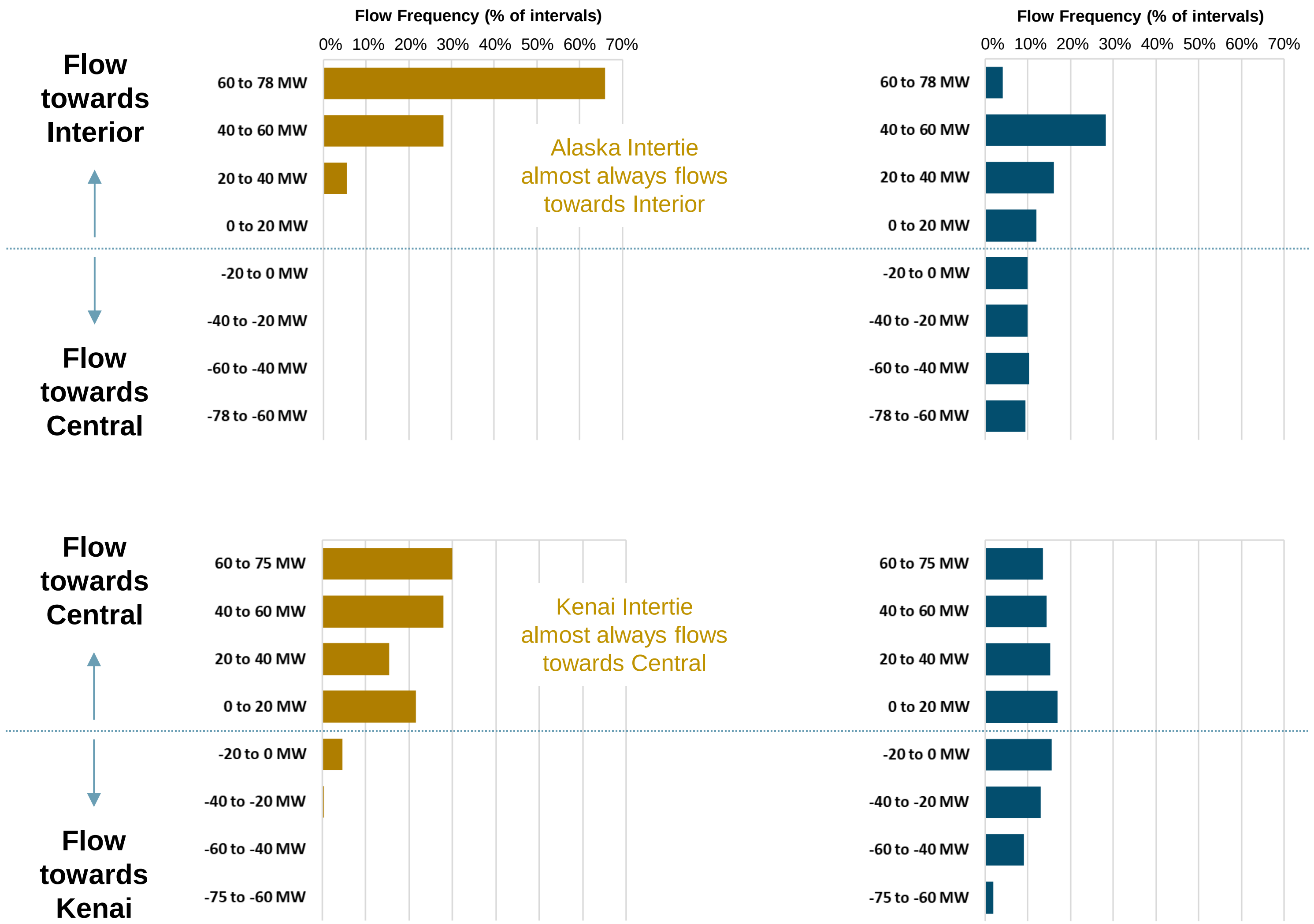
Exports shown as generation above the Load/Battery Charging lines

Intertie flows become more variable with more wind



No New Wind

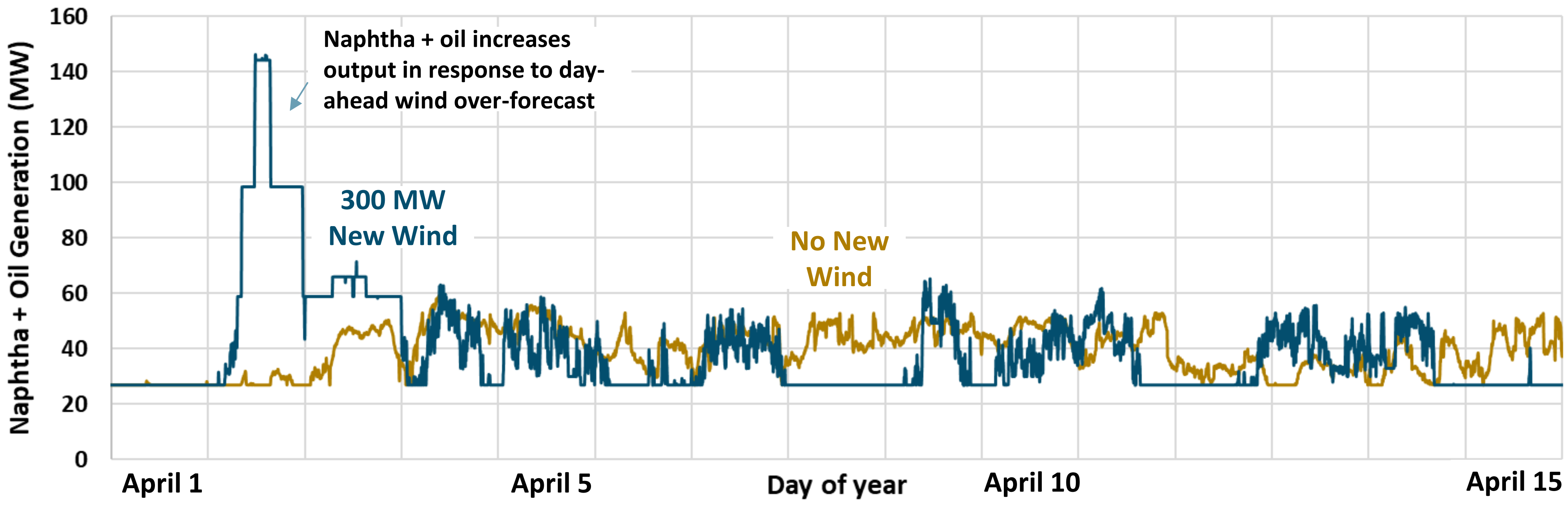
300 MW New Wind



Alaska Intertie flow with more wind is much more variable and frequently flows towards Central

Kenai Intertie flow with more wind is much more variable and sometimes flows towards Kenai zone

Naphtha and Oil: No New Wind vs. 300 MW New Wind



Reliability results

How reliability is modeled

- 5-minute real-time modeling ensures that over 100,000 individual 5-minute intervals can balance load and resources, and that impact of wind variability on power system operations is considered. Day-ahead scheduling with load and wind forecast errors between day-ahead scheduling and real-time dispatch ensures that the impact of forecast errors is represented.
- Contingency and regulation reserves are held at all times to ensure that adequate capacity is available to address contingency events and to balance the system via automatic generation control.
  - The study approximates the need for balancing within each 5-minute dispatch interval using **simulated** 5-minute wind production data; additional study and operational experience are required to determine the correct level of regulation reserves to balance wind fluctuations within each 5-minute interval.
- Voltage and inertial stability are ensured through commitment of certain thermal and hydroelectric units.
- Gas fuel availability limited in real-time dispatch to near (+/- 10%) of day-ahead schedule

Reliability results

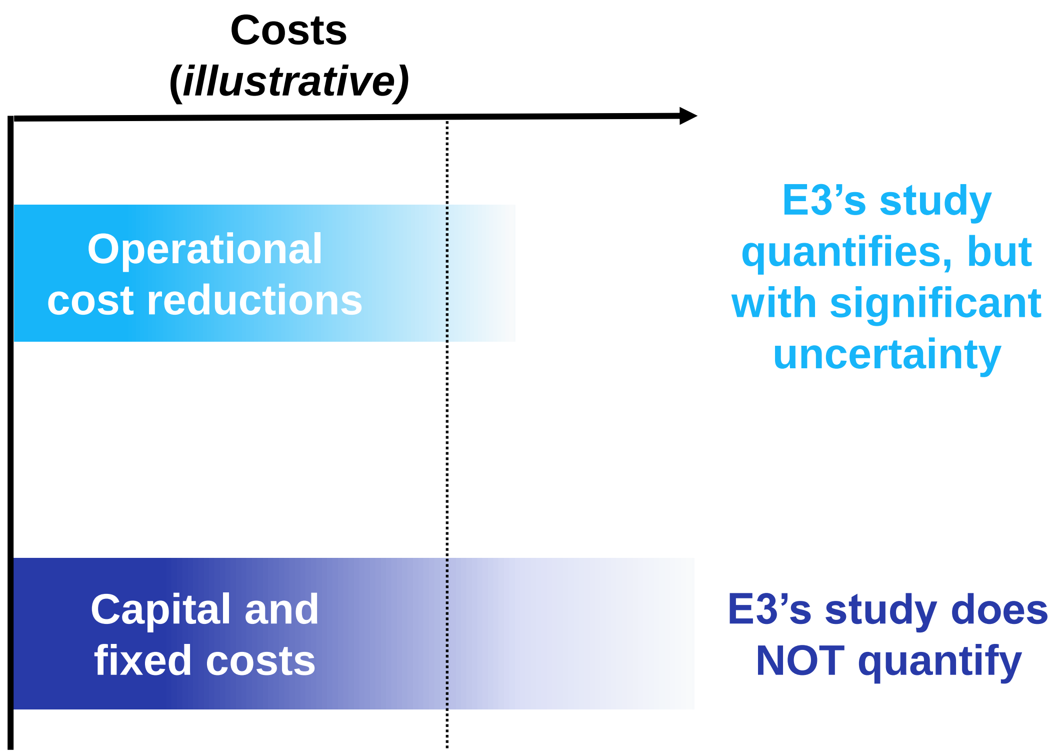
- At the resolution of 5-minute dispatch, the Railbelt system can be reliably operated with 300 MW of new wind. No loss of load events are observed over an entire year of 5-minute operations.
- Minimal levels of regulation shortages are observed, within reasonable bounds for 5-minute production simulation.
- No contingency reserve (spin/non-spin) shortages are observed
- Required units always committed by the model
- Minor / infrequent gas violations are within acceptable bounds (Railbelt staff input)

Energy+Environmental Economics

Cost + Emissions + Sensitivities

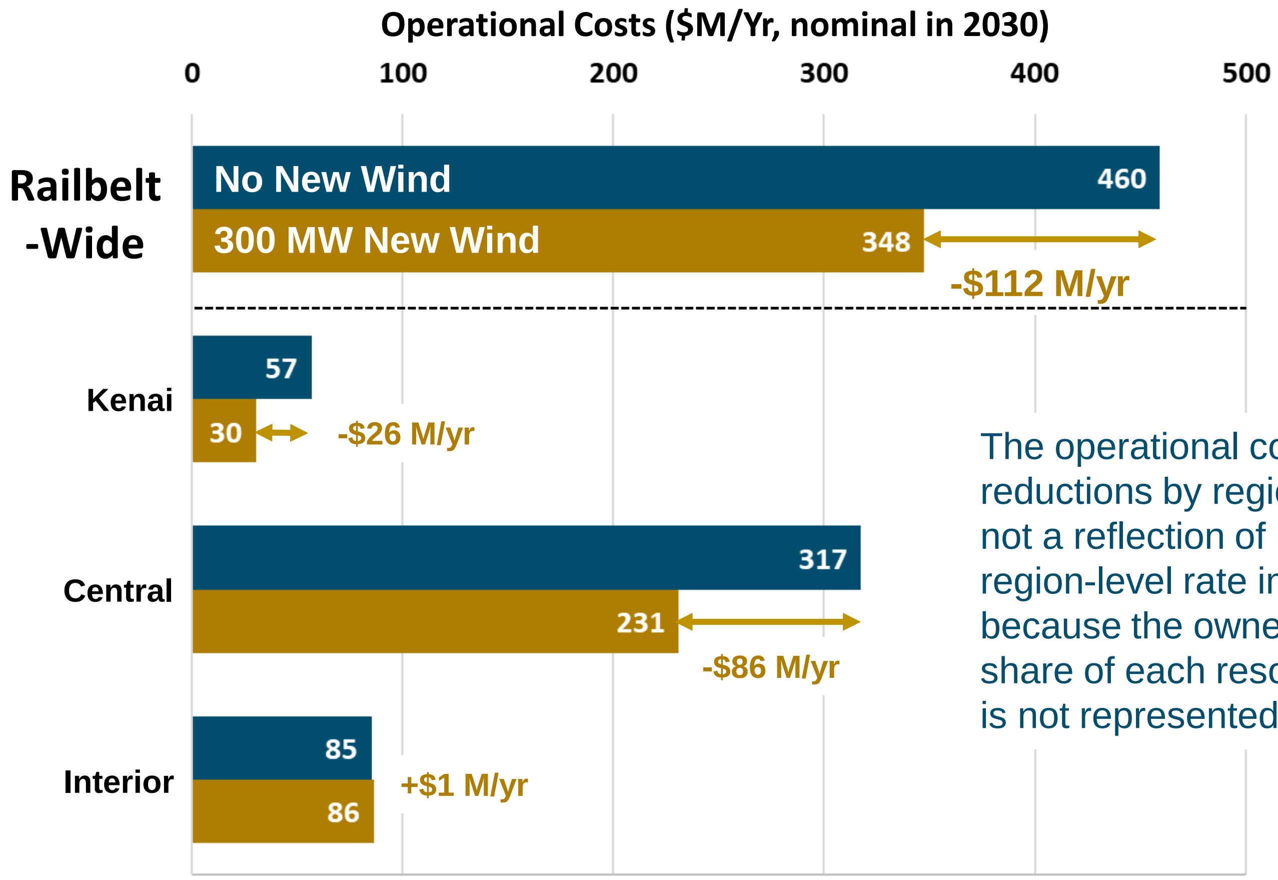
E3's study does not determine if wind is cost-effective

- E3's production cost study quantifies reductions in operational costs (fuel, start, and variable maintenance costs) that could result from the addition of 300 MW of wind to the Railbelt
- Wind capital and fixed maintenance costs are <u>not</u> included in the operational cost reductions. The Railbelt utilities would need to pay the wind PPA price plus the cost of any infrastructure upgrades (e.g. substations and transmission lines) that are required to connect the wind projects.
- In addition, the study assumes that Railbelt operations have evolved to be more flexible than they are in current practice; the costs and benefits of this evolution are not quantified



A cost-effective resource has benefits that exceed costs over the project lifetime; E3's study does not determine cost-effectiveness

Base case operational cost reduction from wind is $95/MWh in 2030



The operational cost reductions by region are not a reflection of region-level rate impacts because the ownership share of each resource is not represented

Operational costs are reduced by $112 M/yr Railbelt-wide in **2030**

On average, energy production from new wind decreases operational costs by **$95 per MWh** in 2030, which is calculated by dividing the annual operational cost reduction ($112 M/yr) by the annual production potential from 300 MW of wind (1,180 GWh/yr)

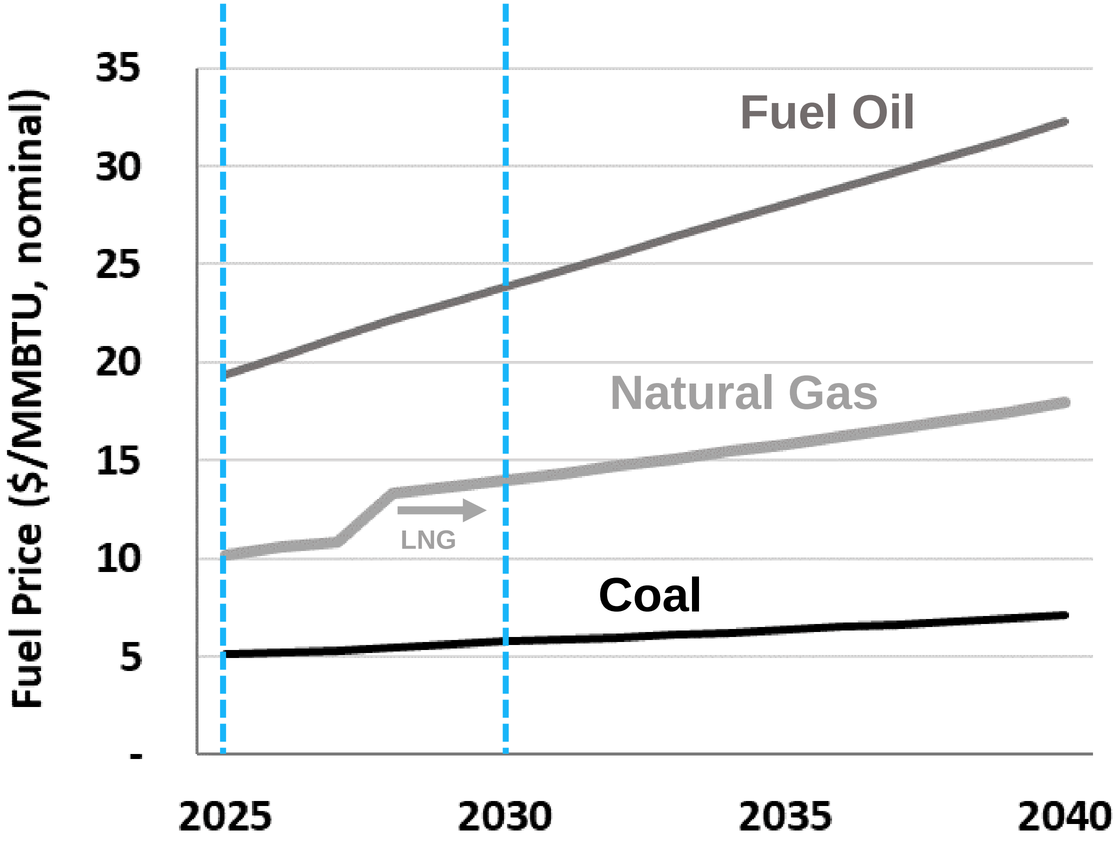
- Operational cost reductions on this slide are for a single year (2030)
- Fuel cost changes would impact reductions in other years

2025 Fuel Price Sensitivity

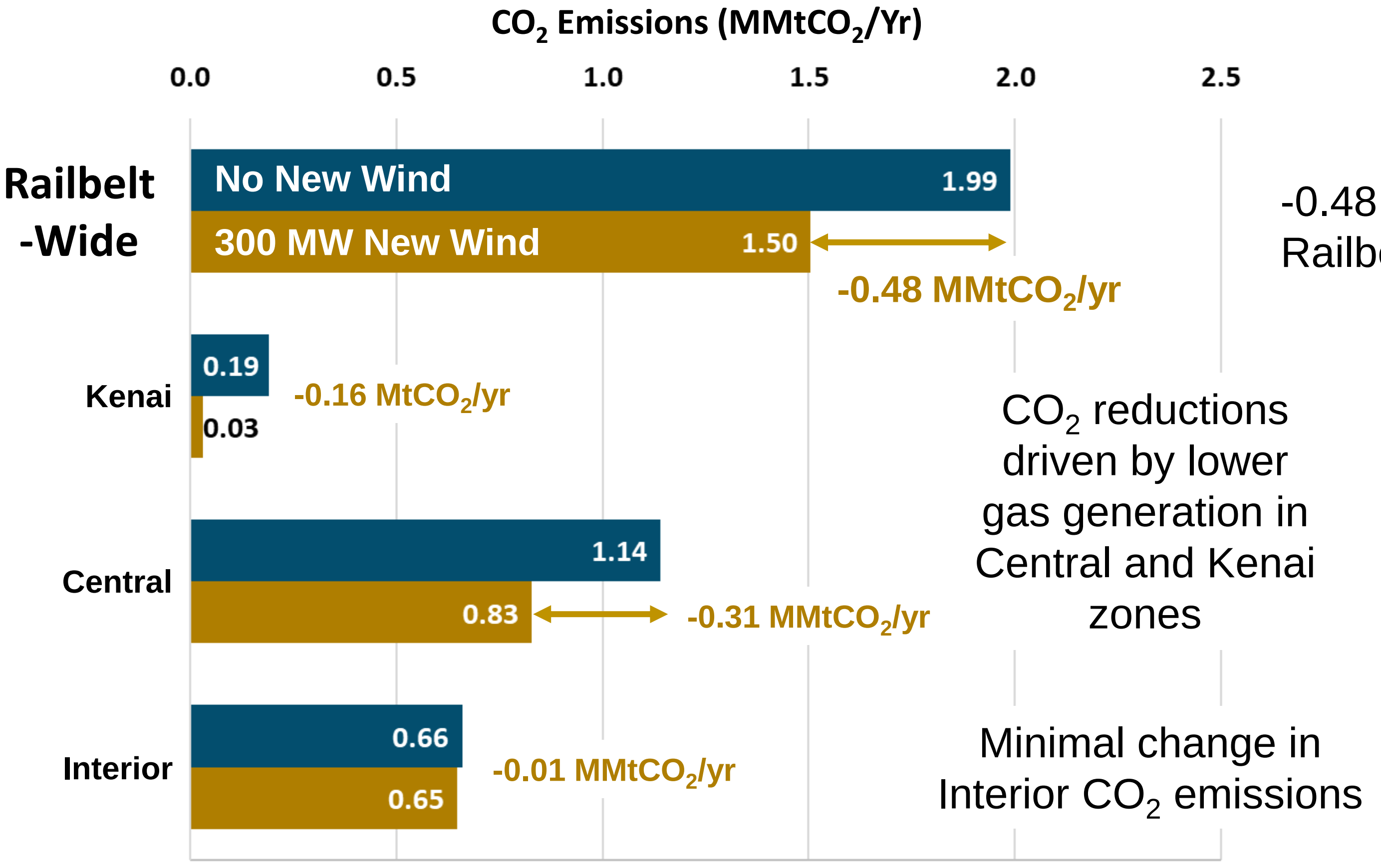
+ The main way in which wind creates value on the Railbelt grid is by avoiding thermal fuel consumption.
  - The price of the fuel that is avoided will strongly influence the economics of new wind.
+ Impending gas supply challenges make future gas fuel costs uncertain
+ Railbelt staff advised E3 to use Liquified Natural Gas (LNG) pricing forecast for 2030
+ 2025 Fuel Price Sensitivity shows impact of lower, near-term non-LNG pricing
+ Fuel price projections from 2024 NREL report, converted to nominal dollars using a 2% inflation rate
  - https://www.nrel.gov/docs/fy24osti/85879.pdf.

Wind operational cost reduction in **2025 = $70/MWh**

Wind operational cost reduction in **2030 = $95/MWh**



Wind avoids CO_2 emissions predominantly from gas



-0.48 $MMtCO_2$/yr is a 24% decrease in Railbelt emissions

On average, energy production from new wind decreases emissions by **0.41 tCO_2 per MWh** in 2030, which is calculated by dividing the annual reductions (0.48 $MMtCO_2$/yr) by the annual production potential from 300 MW of wind (1,180 GWh/yr)

Sensitivity study highlights value of operational flexibility in the context of more wind

Sensitivity	Operational costs relative to base 300 MW New Wind (negative indicates cost reduction)	Notes
Increasing the flexibility of gas fuel scheduling allows gas plants to better participate in balancing wind	-$14 M/yr	Cost of, or limits to, increasing gas scheduling flexibility not explored
Increasing transmission capacity (Central <> GVEA: 78 -> 200 MW and HEA <> Central: 75->175 MW) allows for more efficient dispatch of resources and facilitates reserve procurement across the interties	-$13 M/yr	Operational cost reduction does not include cost of new transmission
Replacing the GVEA battery with a modern 2-hour duration battery allows for easier balancing of wind, especially reserves for wind variability	-$9 M/yr	Operational cost reduction does not include cost of new battery
Removing thermal commitment requirements increases system flexibility, reducing operational costs. However, system not operable without further developments.	-$14 M/yr	Feasibility and cost of ensuring stability without thermal commitment not studied
Decreasing thermal commitment flexibility by committing all thermal resources day-ahead increases operational costs and wind curtailment	+$15 M/yr	Railbelt operators can change commitments on the operating day if necessary, so this is a bookend sensitivity

Operational cost reduction range in 2030

Depending on the level of flexibility in the Railbelt system, wind could be more or less effective at reducing operational costs.

$82/MWh	**$95/MWh**	**$106/MWh**
Lower thermal commitment flexibility	Base Case	More gas supply flexibility

We model an evaluation from current dispatch practices therefore the values shown here are not reflective of savings that could be realized immediately

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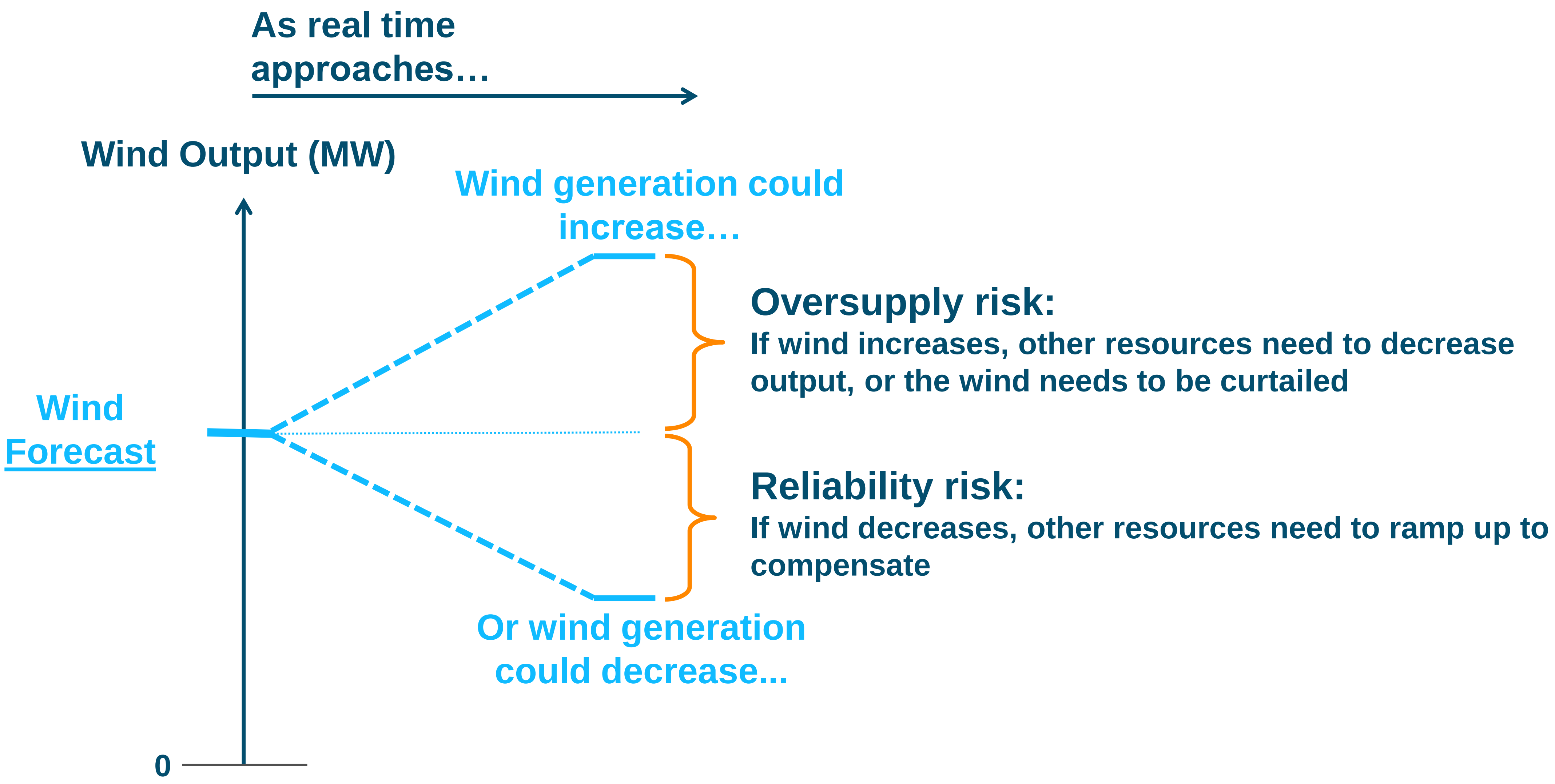
Scheduling and Operations

System balancing and uncertainty



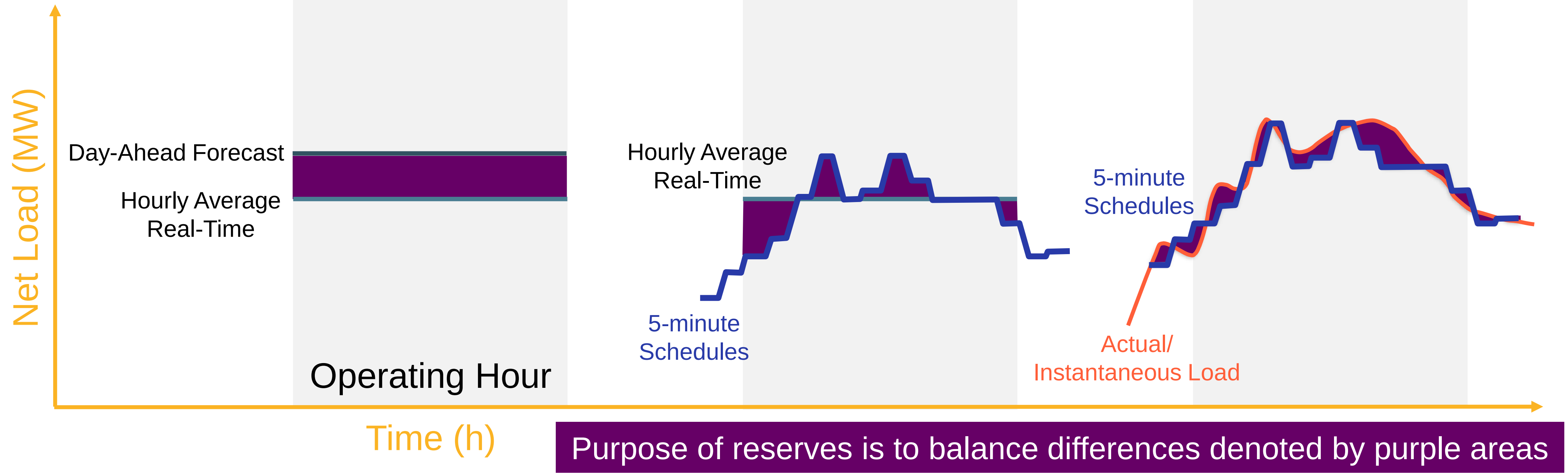
Reserves bridge between operating timeframes

E3 models these three reserves to balance wind and load

Day-Ahead Forecast Error Reserves prepare for differences between day-ahead forecasts and average real-time load

Within-Hour Regulation Reserves hold ramping capability for ramps between hourly averages and 5-minute scheduling intervals

5-minute Regulation Reserves hold capacity for automatic generation control dispatch



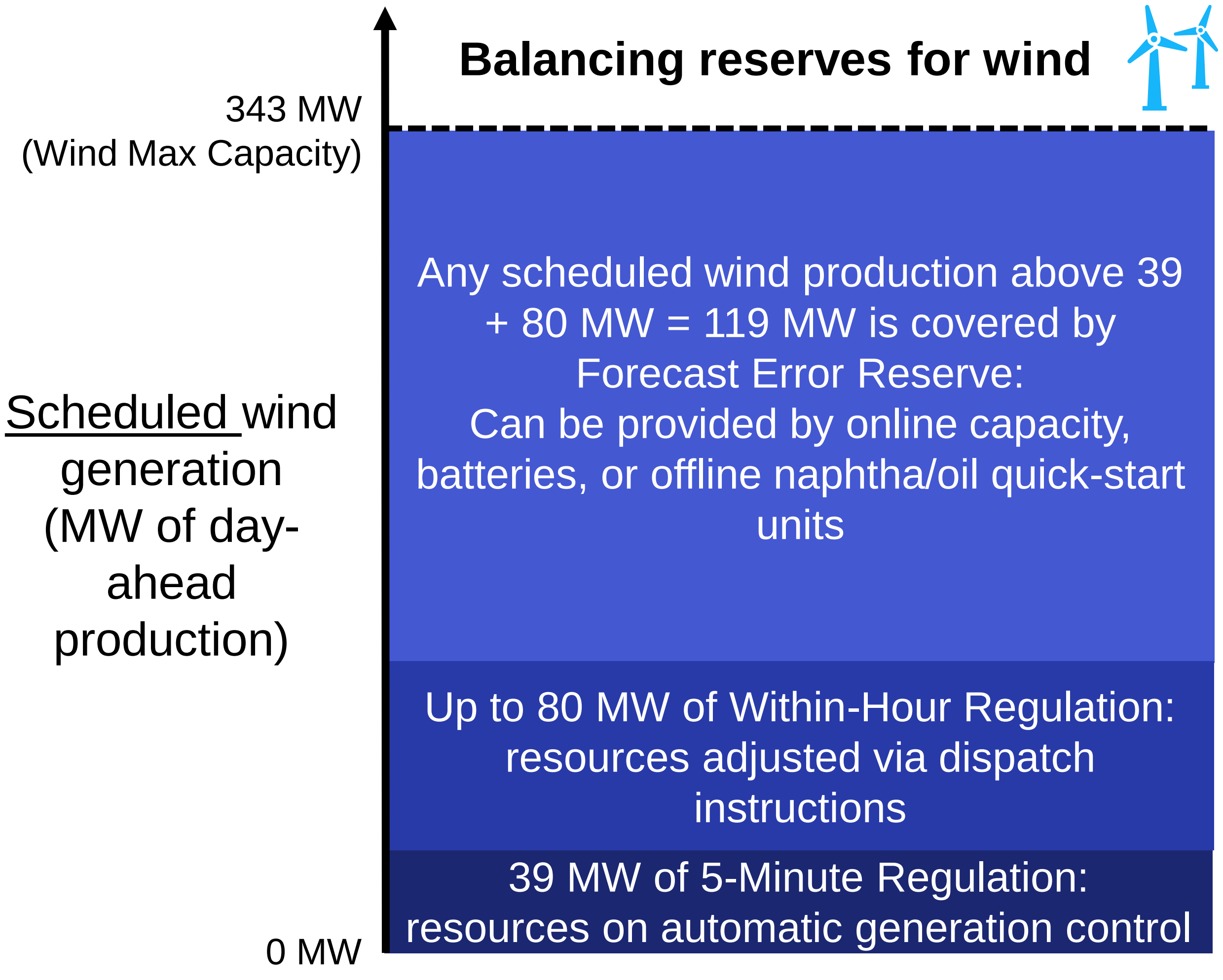
Purpose of reserves is to balance differences denoted by purple areas

Adapted from Makarov, Y. V., *et al*., 2009. Operational Impacts of Wind Generation on California Power Systems. *IEEE Transactions on Power Systems* 24 (2), 2009, 1039-1050.

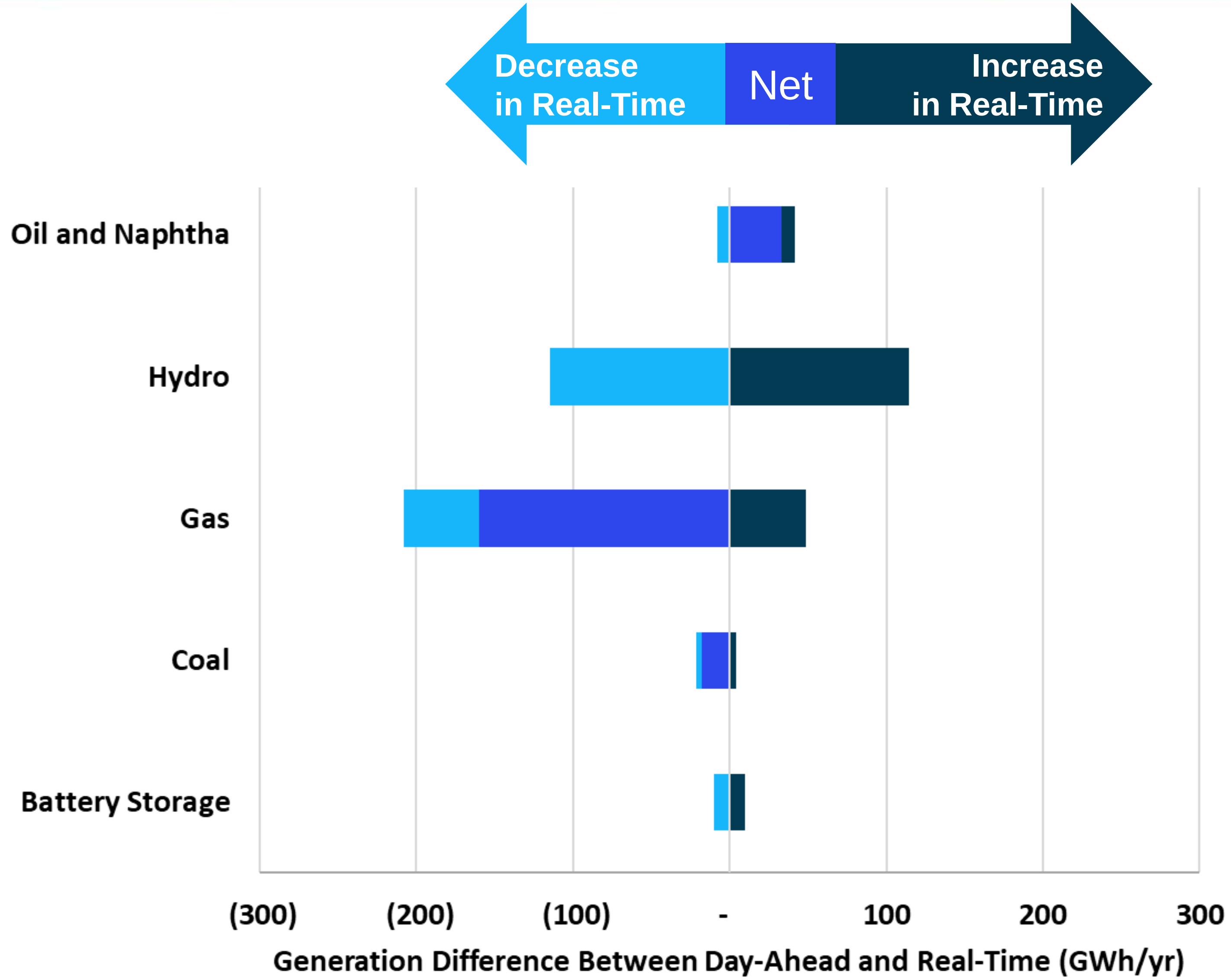
Balancing reserve capacity held to address wind variability and uncertainty

+ **In the day-ahead timeframe, E3 assumes all wind generation must be backed up by other resources**
  - Only the scheduled wind production is covered by reserves – no need to hold 300+ MW of reserves on a day without wind!
  - Wind can be curtailed when oversupply is a concern
  - Wind balancing reserves are dividing into three timeframes in day-ahead unit commitment to ensure efficient and reliable real-time operation

Synthetic wind data used; further study on within 5-minute wind drops necessary



Thermal, hydro, and batteries adjust during wind forecast errors



Wind forecast errors cause generation differences in other resources

Oil/Naphtha ramped up in tail events

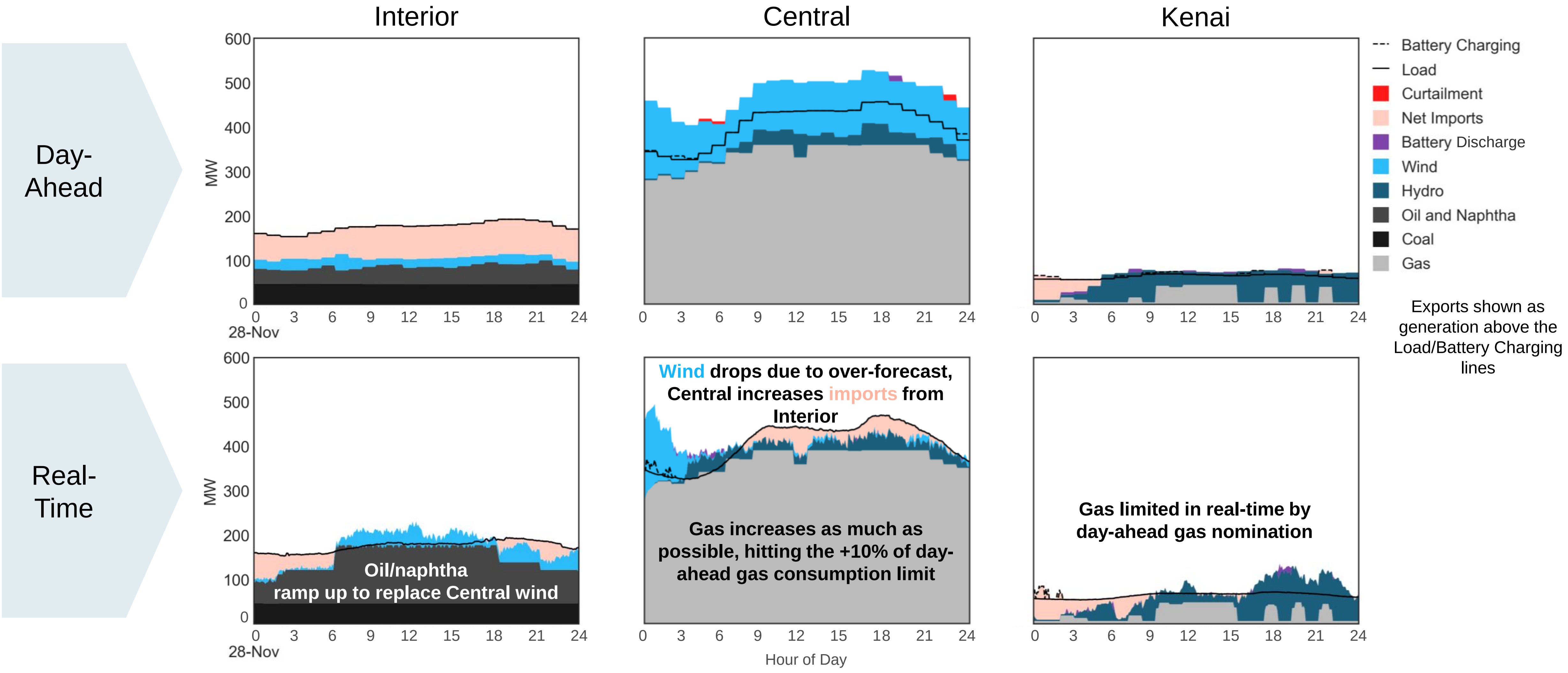
Hydro flexibility used frequently for balancing

Gas increases are limited by gas nominations; decreases driven in-part by day-ahead load over-forecast

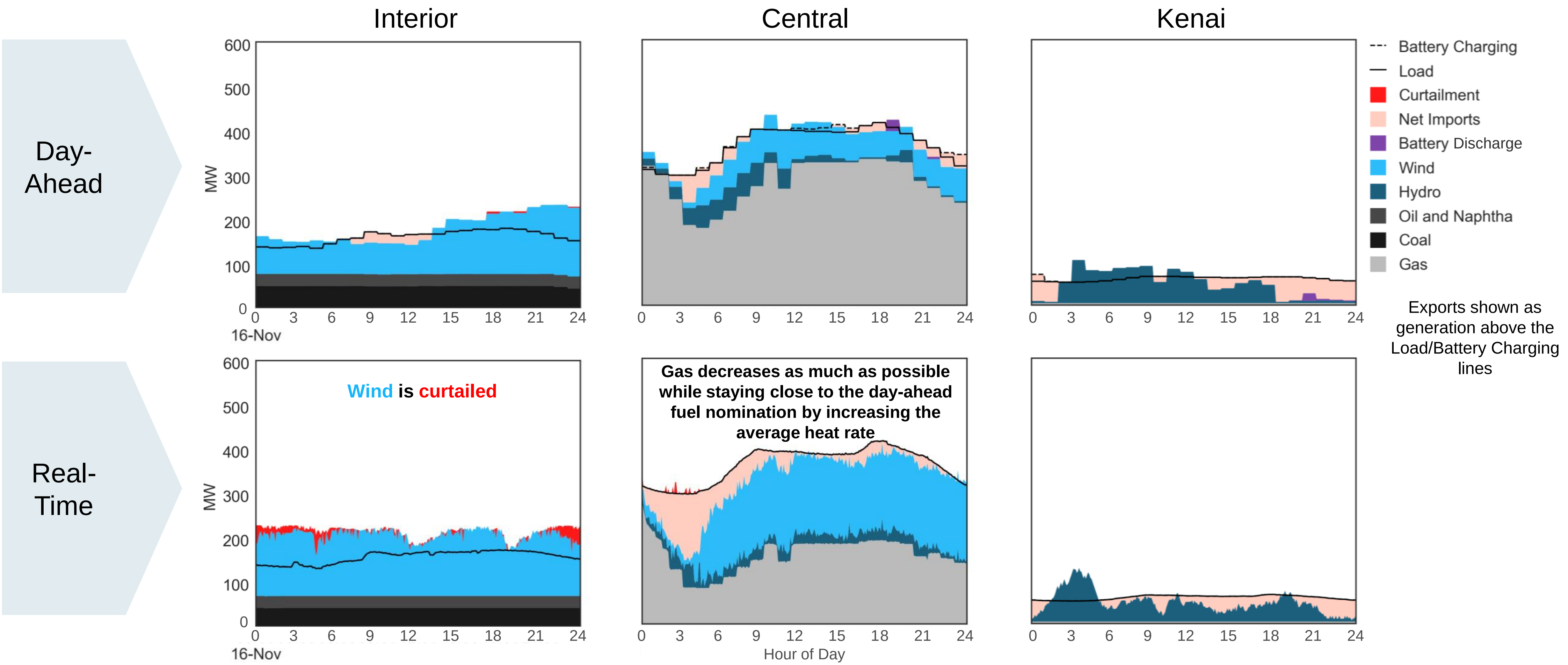
Coal ramps infrequently due to low cost and limited flexibility

Batteries used infrequently for balancing due to limited energy capacity and role in providing reserves

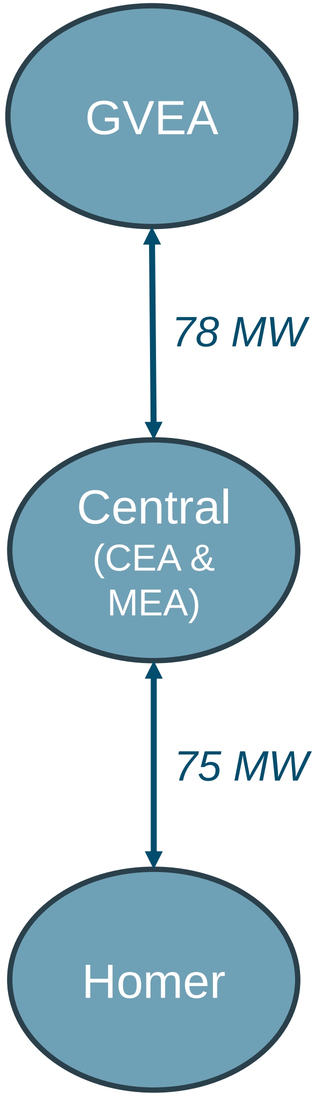
How does the system perform when wind is over-forecasted?

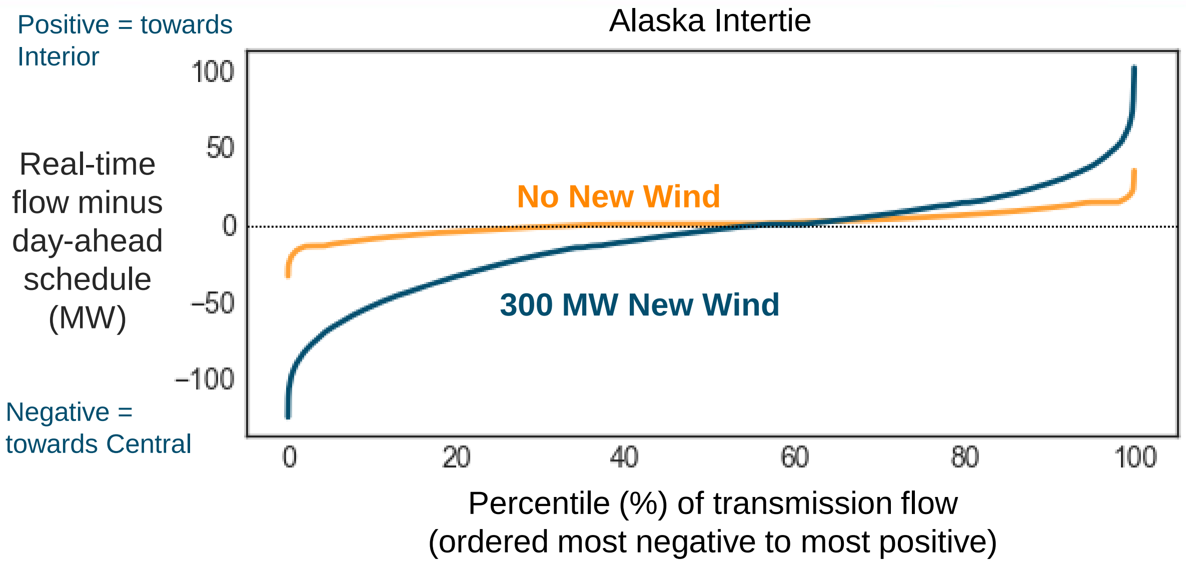


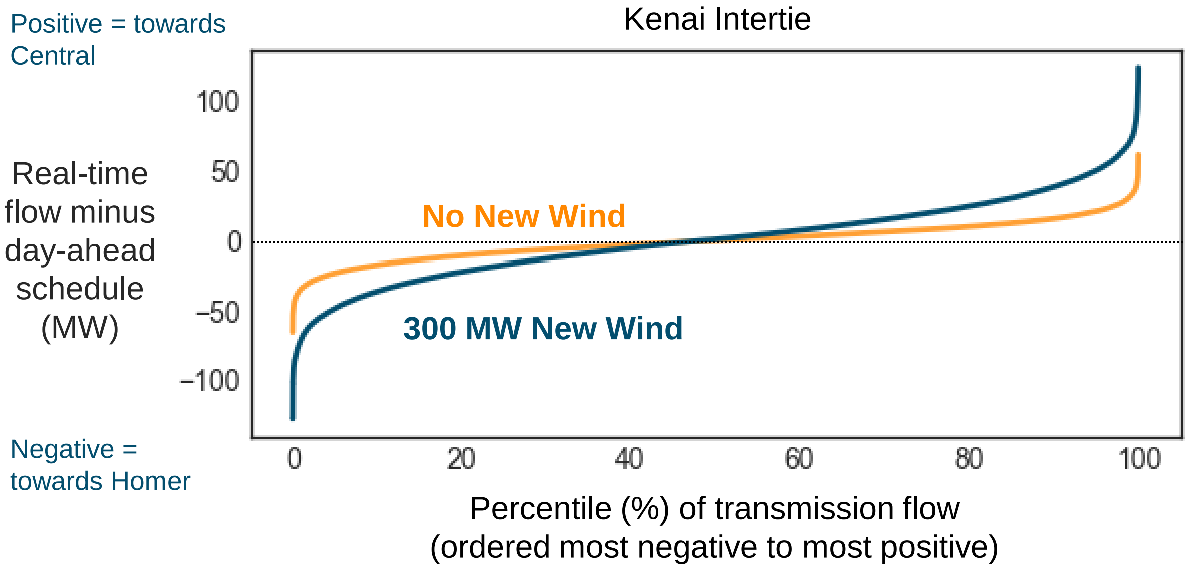
How does the system perform when wind is under-forecasted?



How does wind forecast error impact transmission scheduling and flows?







Transmission is important to balance wind forecast errors: With more wind, transmission flows deviate more frequently in real-time from their day-ahead schedules

The flexibility of Bradley hydro and the Homer battery is used to balance wind, resulting larger changes in flows between day-ahead schedules and real-time dispatch with more wind capacity

System operations discussion

- **Railbelt system operations are represented in this study as more flexible than current practice. While no single aspect of system flexibility is central to the ability to absorb more wind energy on the Railbelt system, our results are based on operational practices that are an evolution from current practice.**
- **Increasing system flexibility could reduce Railbelt production costs even without the addition of more wind generation, but the benefits of additional operational flexibility will increase with more wind generation.**
- **The following enhancements to Railbelt operations should be considered:**
  - Coordinated, Railbelt-wide unit commitment and dispatch
  - Transmission scheduling without wheeling charges
  - Co-optimization of energy and reserves on transmission lines
  - Use day-ahead wind forecasts in unit commitment
  - Scheduling upward and downward regulation reserve capacity separately, potentially on different resources
  - Differentiating wind balancing needs by the length of the balancing service required (day ahead forecast error, within-hour variability, 5-minute regulation)

Results summary: +300 MW of wind

System is reliable – load can be met in every 5-minute interval across a year
- Further study of regulation needs within 5-minute intervals recommended

Fuel and other operational costs reduced by \$82 – 106 per MWh of wind production potential in 2030 (scales with fuel prices). Cost reduction does not include wind PPA and interconnection costs.

Wind reduces CO_2 emissions by reducing predominantly gas generation

Wind curtailment is observed, but infrequently (1% of wind potential).

Optimal dispatch of batteries, hydro, thermal, and transmission allows for almost all wind to be absorbed. GVEA naphtha/oil used to balance extreme wind forecast errors.

Increasing operational flexibility would support wind integration
- Further study needed to prioritize operational changes

Thank You

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Appendix

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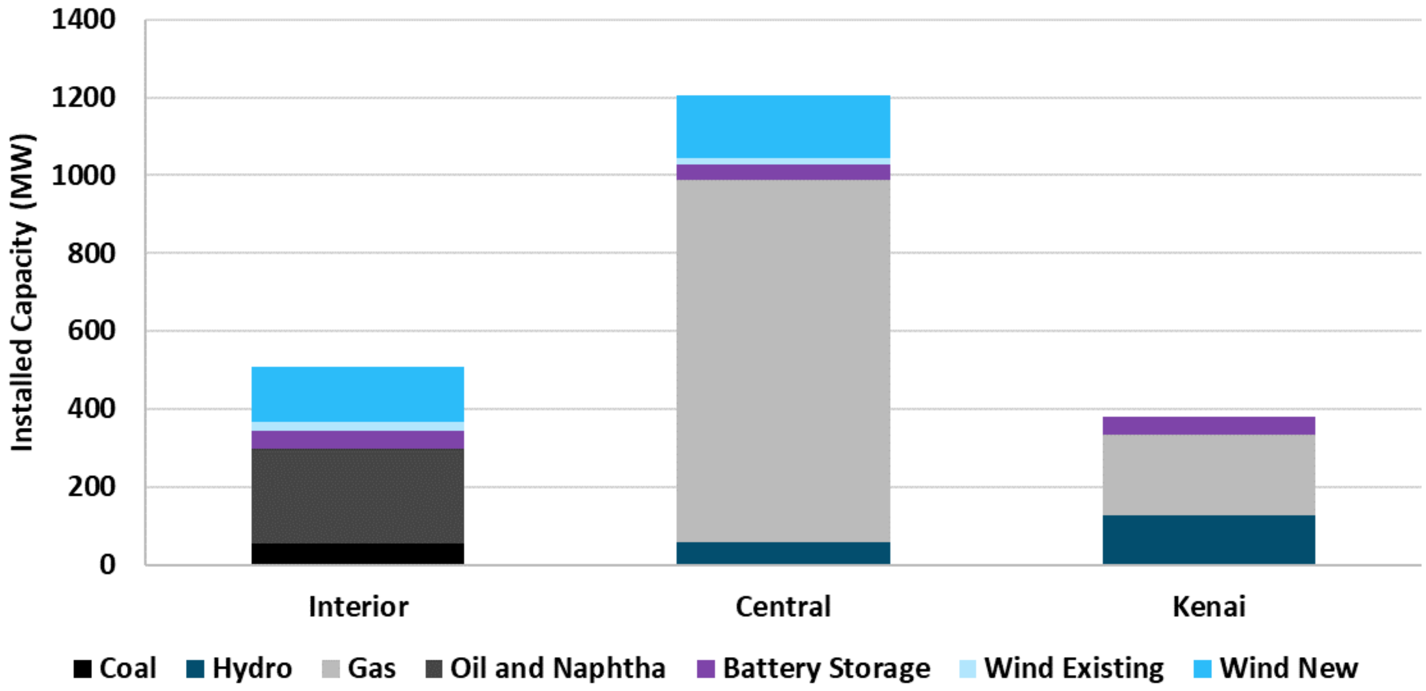
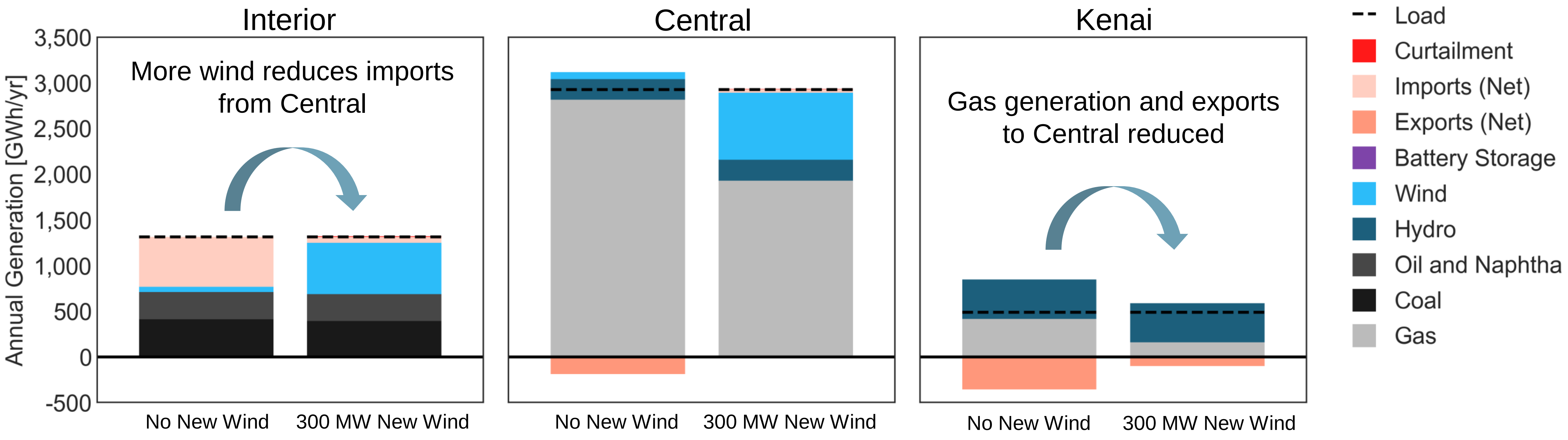
Resource Capacity



Base Wind Results

+300 MW of wind in the Railbelt

No New Wind vs. Base Wind: Generation



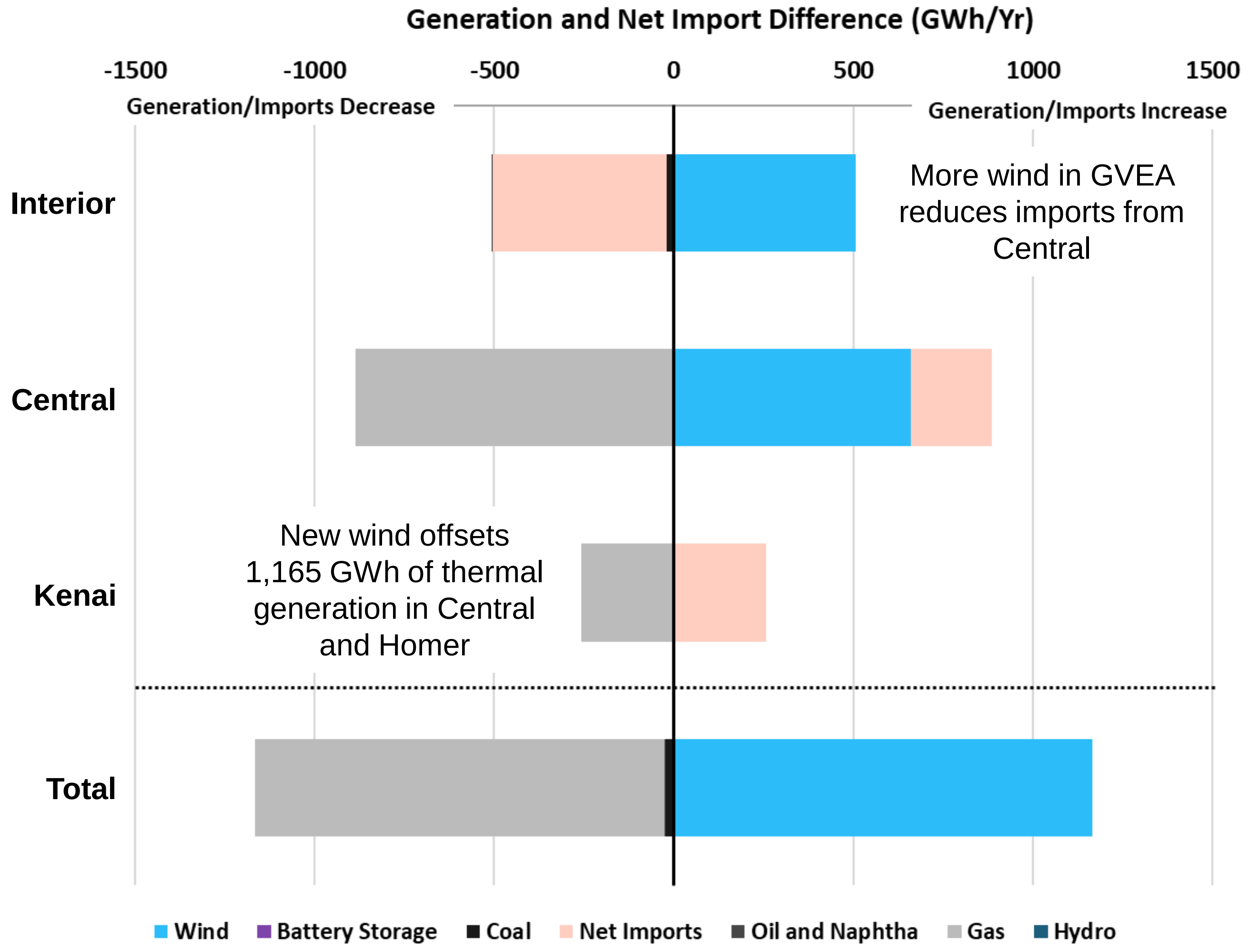
Wind curtailment is low:
13 GWh of wind curtailment is observed in the Base Wind case, which represents 1% of wind production potential

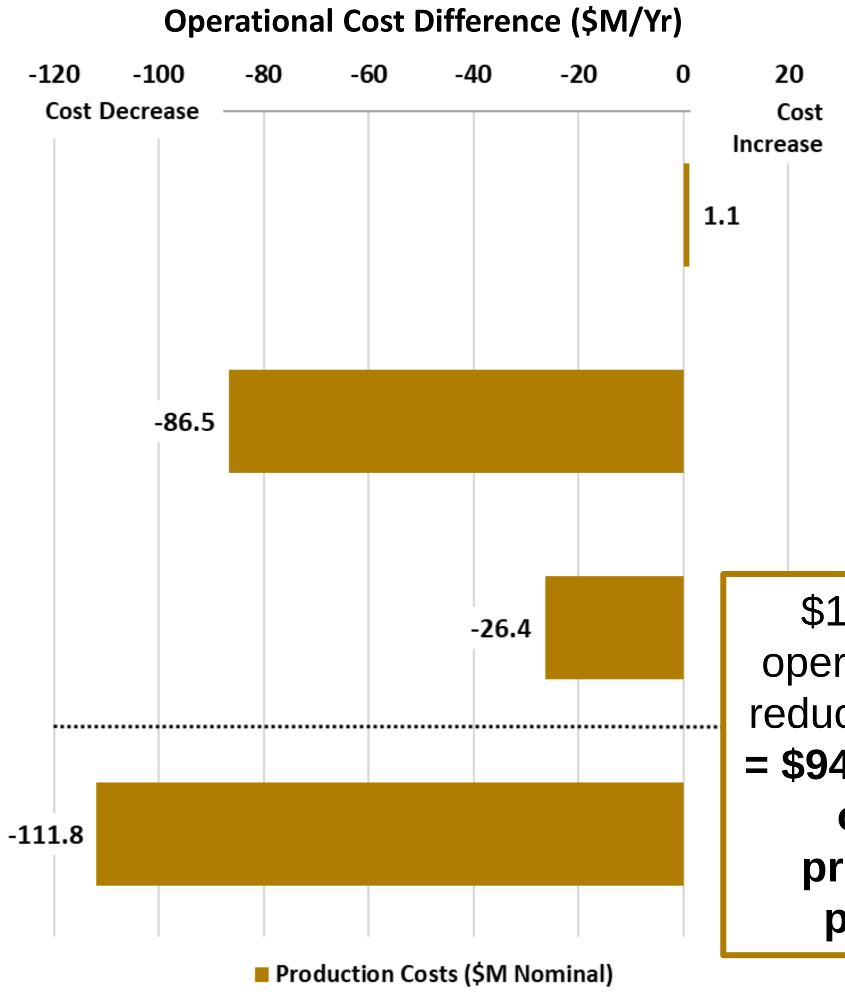
☑ ***No unserved energy observed in any 5-minute interval in any zone***

Generation is depicted based on the physical location of the resource.

How does additional wind change generation, transmission flow, and production costs?

Difference = 300 MW New Wind – No New Wind

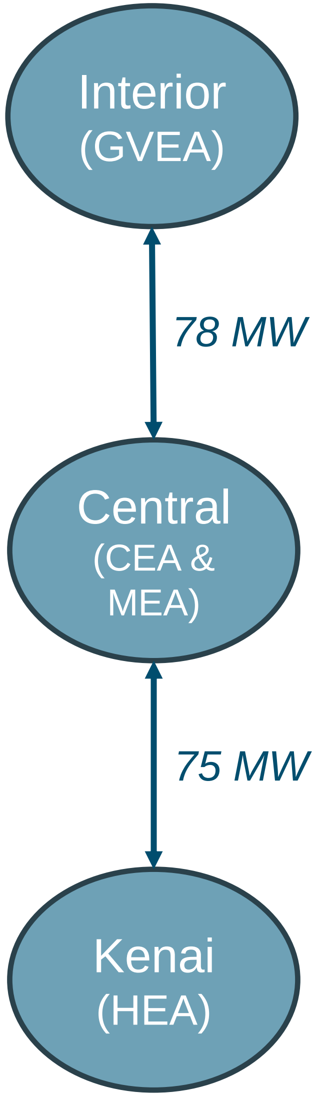




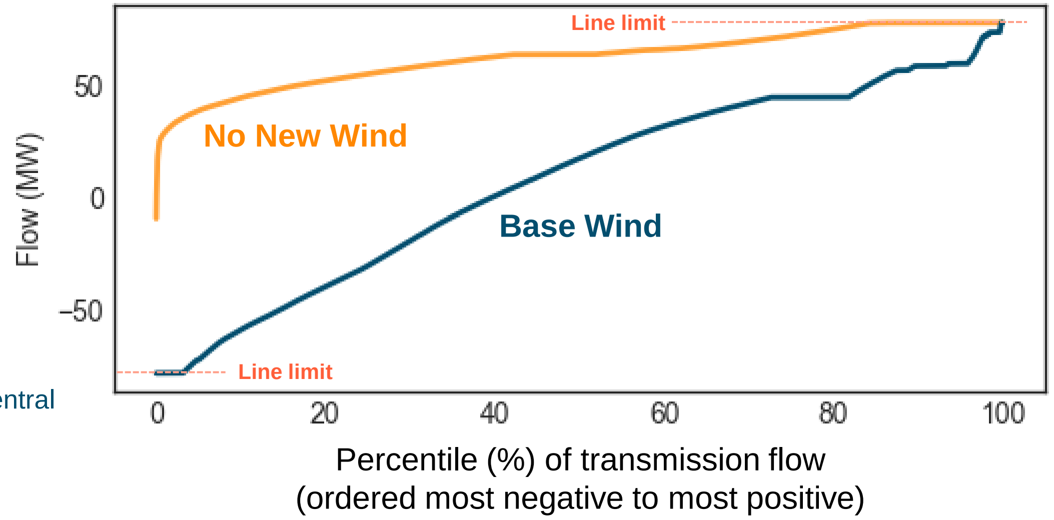
Production cost difference does NOT include cost of new wind

$112M/yr of operational cost reduction in **2030 = $94.8 per MWh of wind production potential**

How do transmission flows change with more wind?



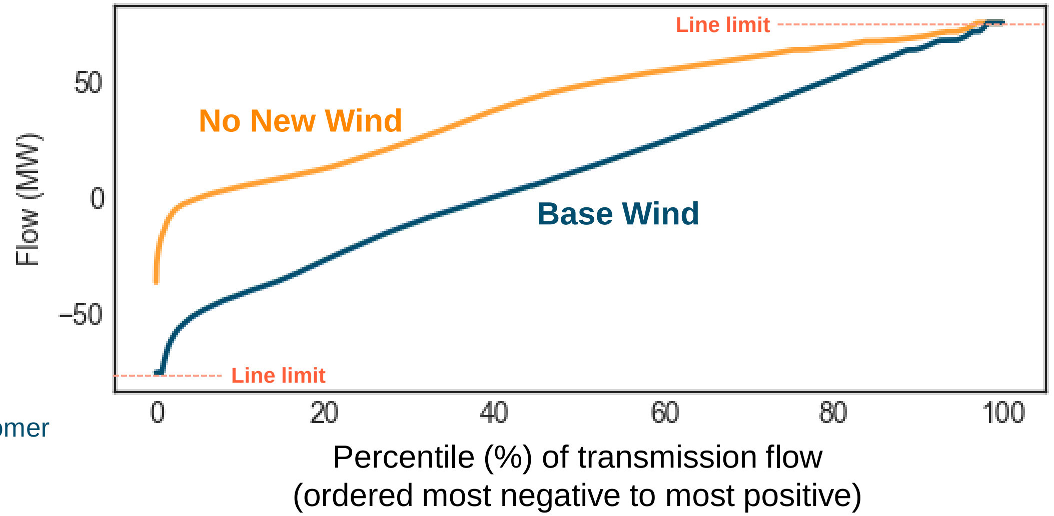
Positive = towards Interior



Negative = towards Central

The addition of Shovel Creek Wind in the Interior reduces imports from Central and results in exports to Central in ~40% of hours.

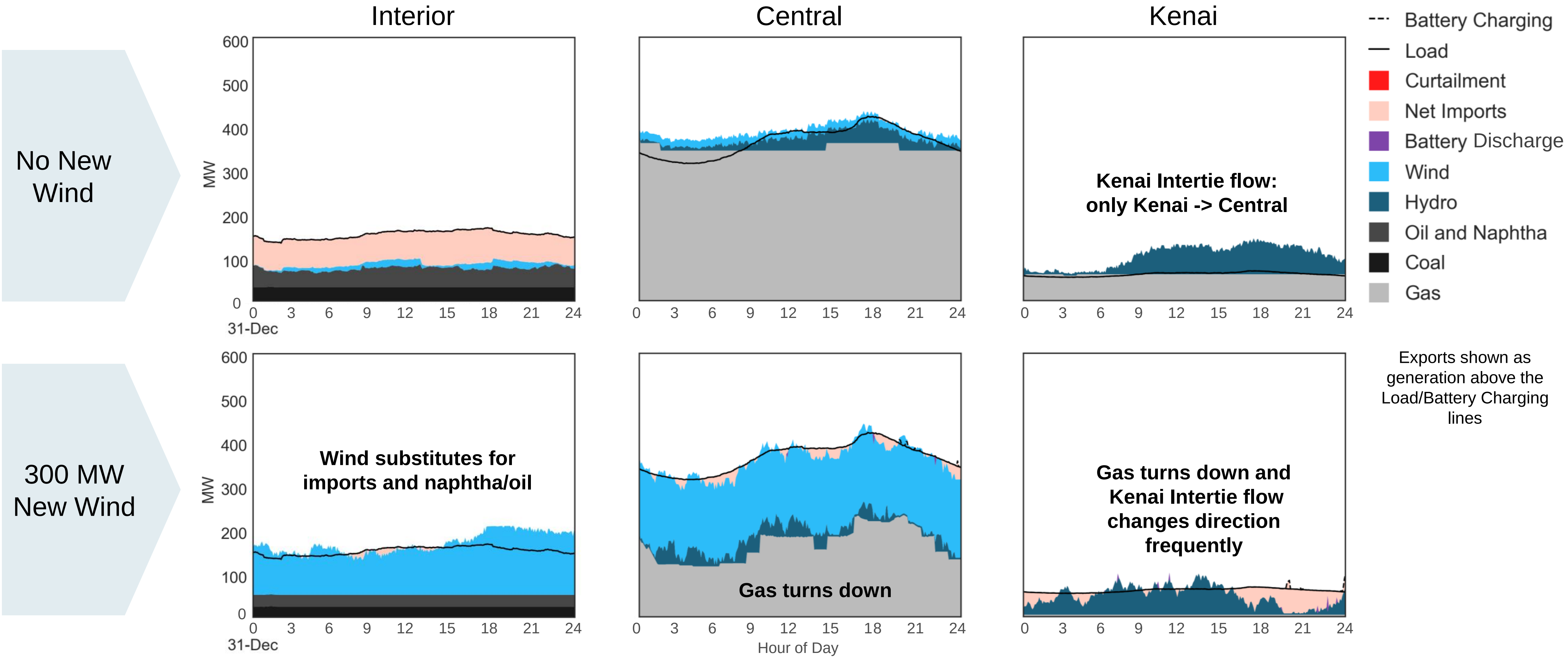
Positive = towards Central



Negative = towards Homer

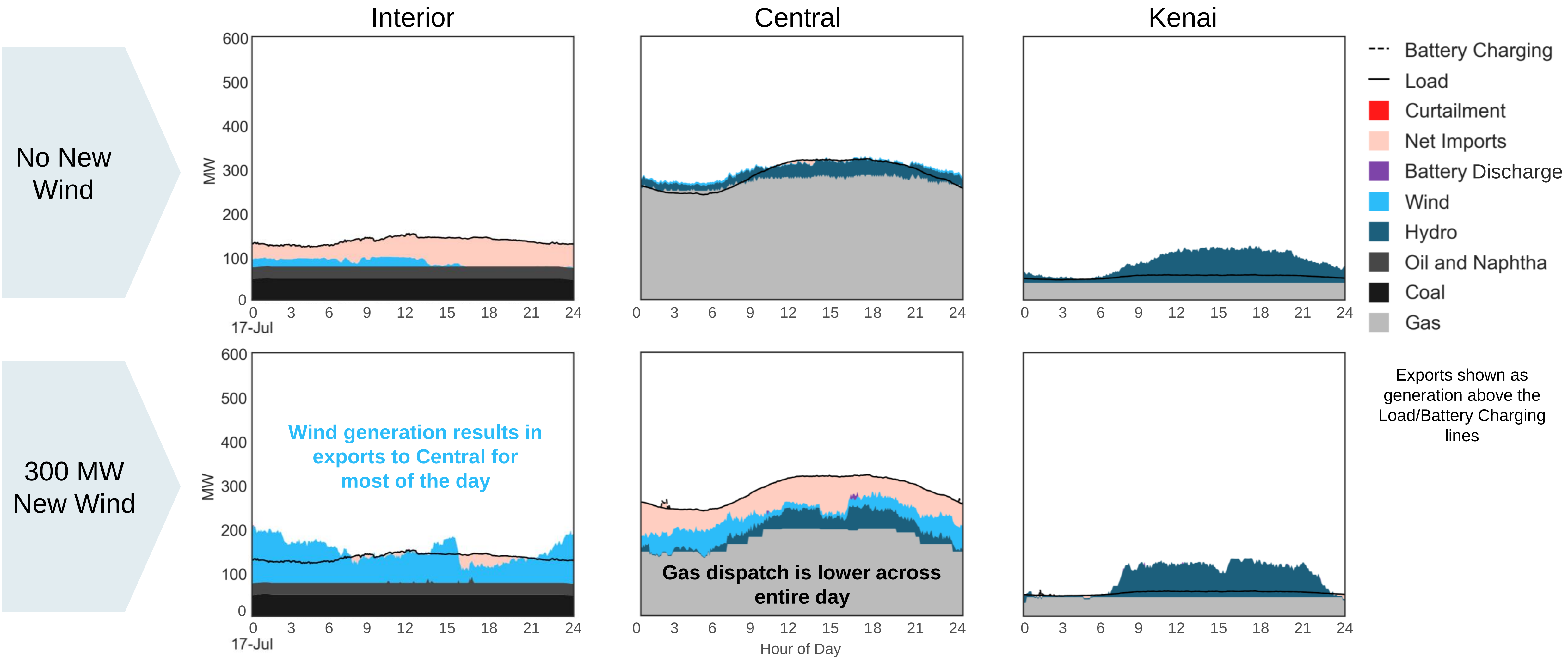
With more wind, energy and balancing capacity compete for space on the Kenai Intertie. The lowest cost Railbelt-wide is frequently to turn down HEA gas and use the Kenai Intertie for wind balancing from Bradley hydro and the HEA battery.

How does system dispatch change on a day with abundant wind generation?



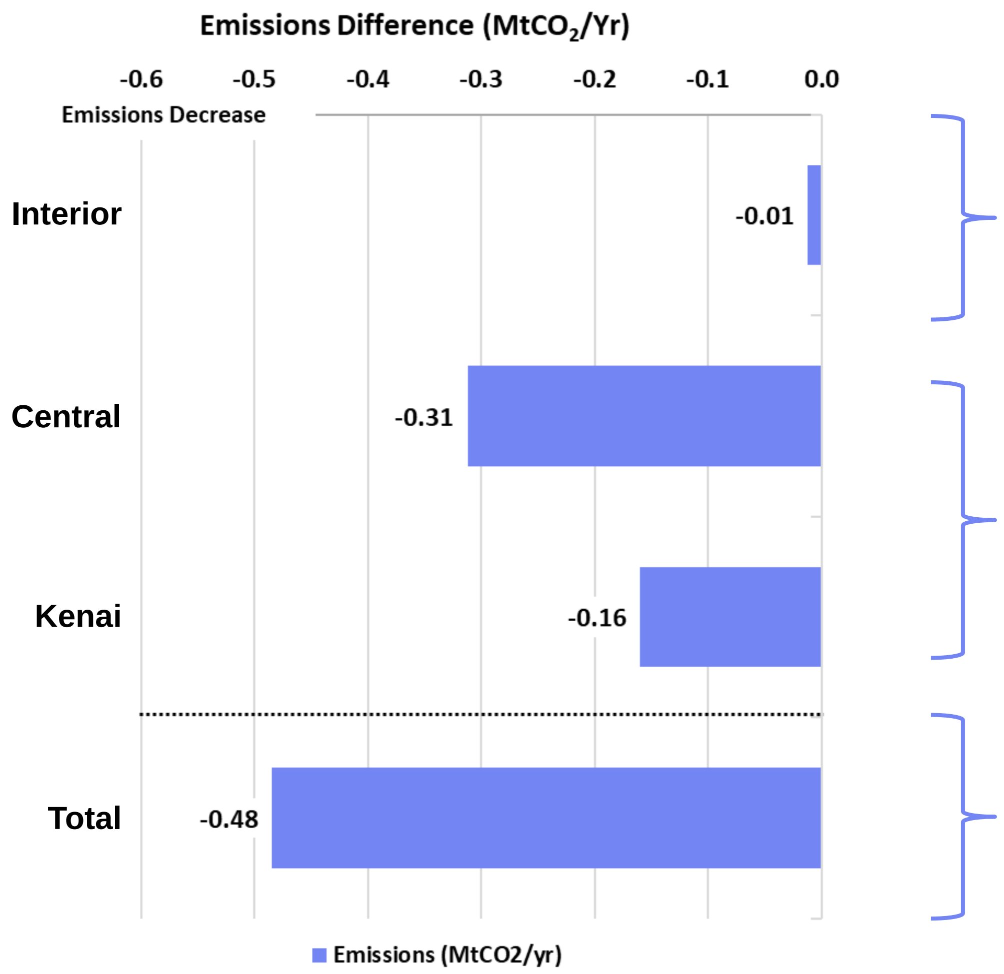
Exports shown as generation above the Load/Battery Charging lines

How does system dispatch change on a day with intermediate wind generation?



By how much are GHG emissions reduced with more wind?

Difference = 300 MW New Wind – No New Wind



Minimal change in Interior CO_2 emissions

CO_2 reductions driven by lower gas generation in Central and Kenai

-0.48 $MtCO_2$/yr is a 24% decrease in Railbelt emissions relative to the No New Wind case emissions of 1.99 $MtCO_2$/yr

-> 0.41 tCO_2 reduced per MWh of wind production potential

Energy+Environmental Economics

Scheduling Considerations: Base Wind

Production cost model simulation stages

1st stage: Commitments

- Goal: Set up the 2nd stage (called Real-Time Dispatch) for success: reliable and economic dispatch
- Timestep granularity: hourly, solved a day at a time
- Uses load and wind day-ahead forecasts
- Gas nominated on hourly basis

Information passed to real-time stage:

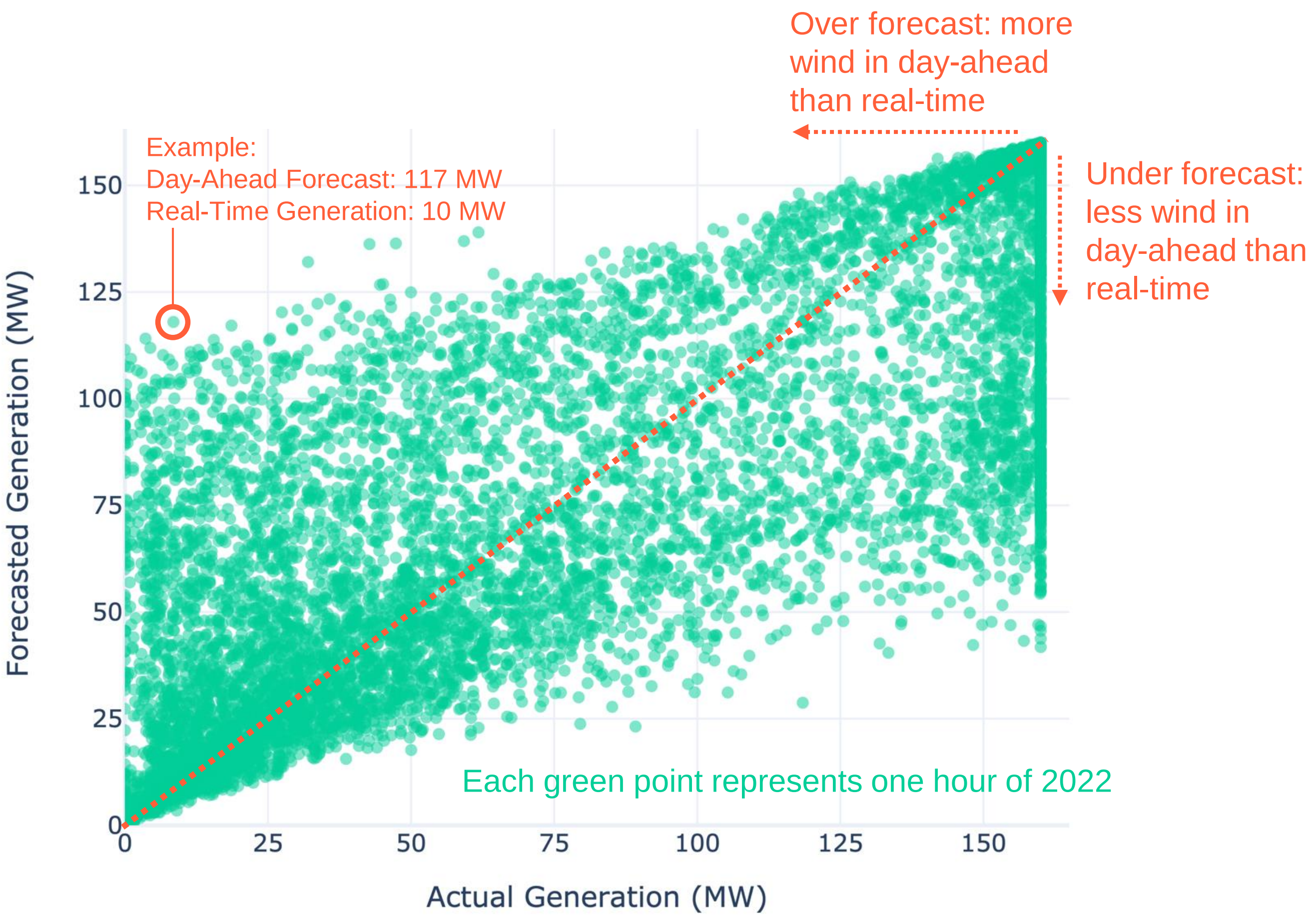
- Hourly unit commitment schedule of slow units
- Gas nomination schedule

2nd stage: Real-Time Dispatch

- Goal: Evaluate production costs and reliability
- Timestep granularity: 5-min, solved a day at a time
- Must adhere to gas nominations and slow-moving unit commitment schedules from 1st stage.
  - Gas nominations have +/-10% flexibility band per current gas contracts
- Uses real-time load and wind data (not forecasts)

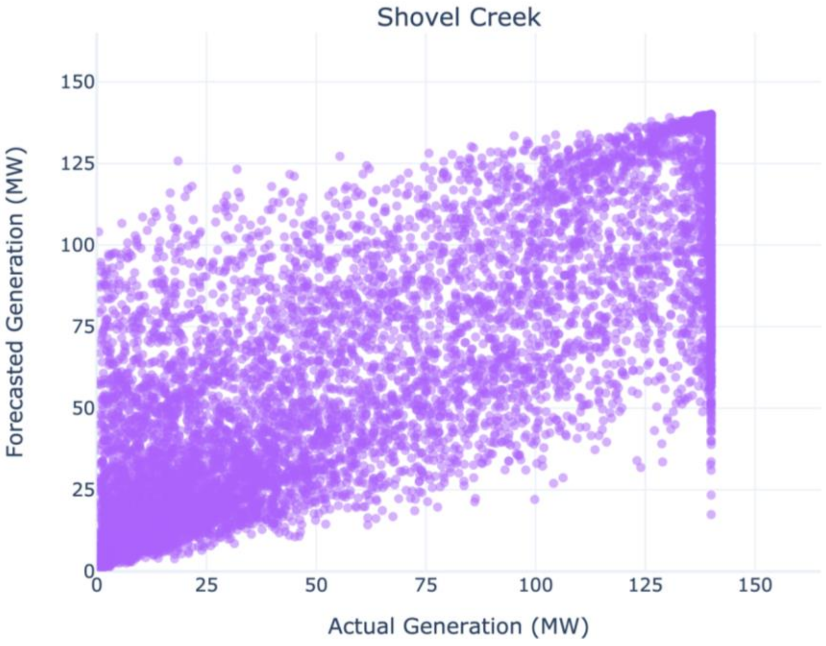
Wind day-ahead forecast results: Forecast vs. Actual

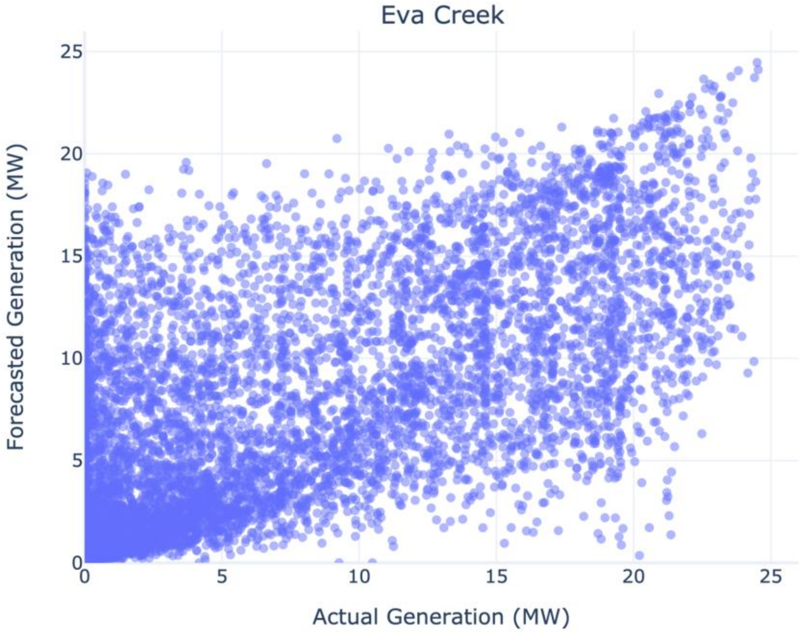
Simulated forecast error distribution for Little Mt. Susitna

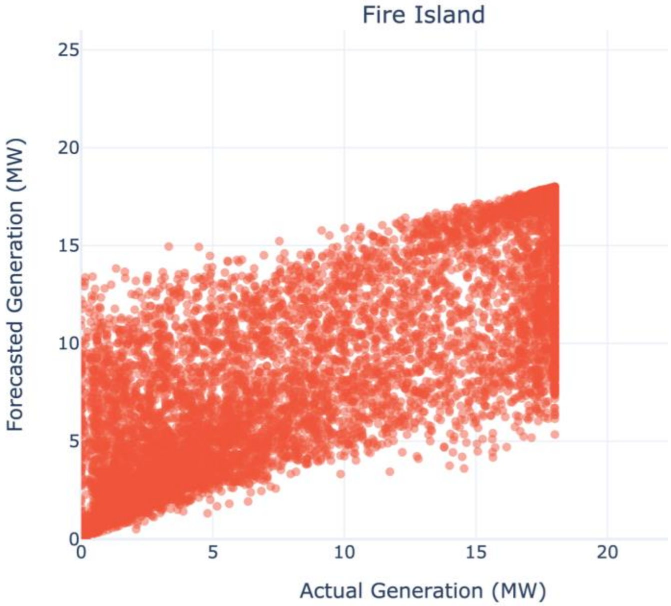


Wind day-ahead forecast results: Forecast vs. Actual

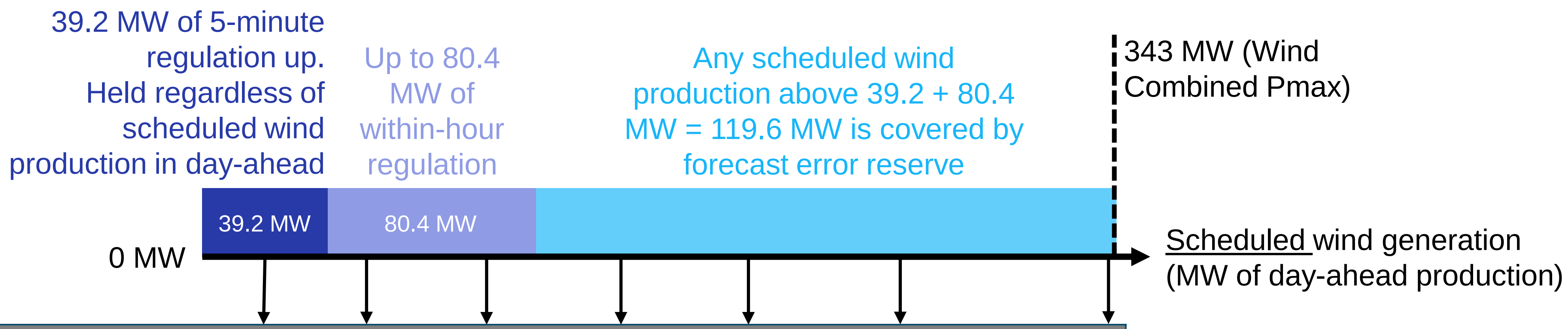
Simulated forecast error distributions







Wind reserve summary: Day ahead

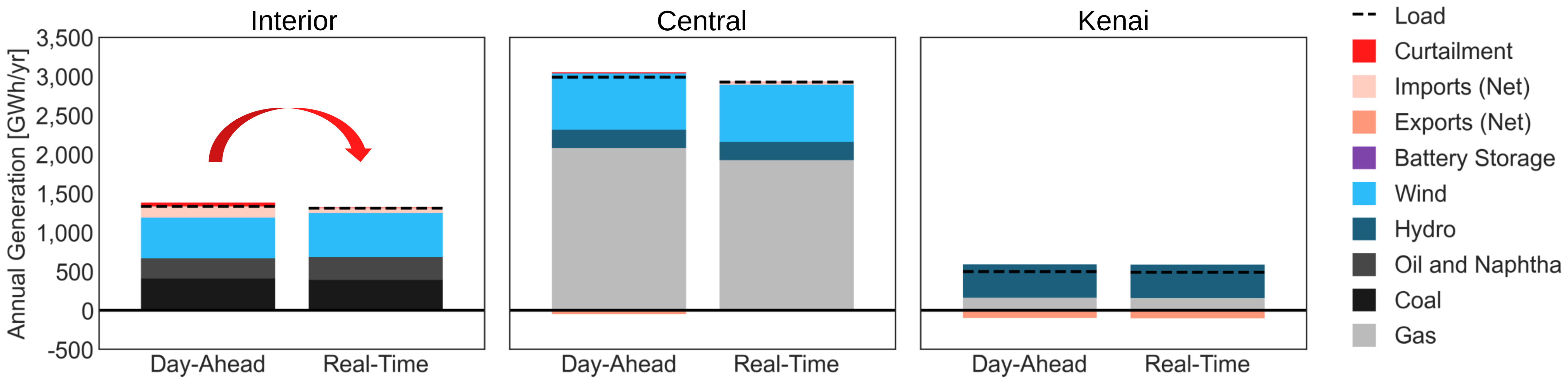


Example scheduled wind MW	20	50	100	150	200	250	343
5-minute regulation up	39.2	39.2	39.2	39.2	39.2	39.2	39.2
Within-hour regulation	0	10.8	60.8	80.4	80.4	80.4	80.4
Forecast error	0	0	0	30.4	80.4	130.4	223.4

Generation Results: Day-Ahead Schedule vs. Real-Time

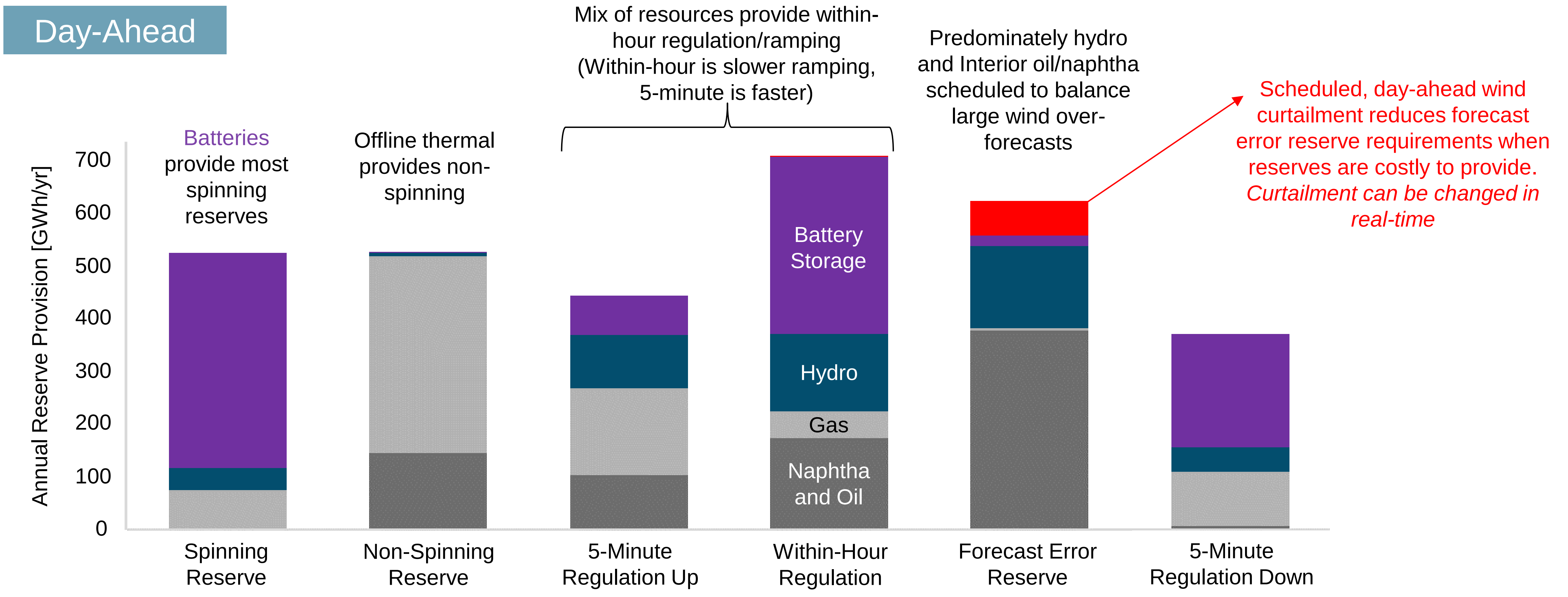
More day-ahead wind curtailment is scheduled in day-ahead than is ultimately necessary in real-time

Small load over-forecast in Central means slightly less load needs to be served in real-time, partially explaining lower gas generation in Central in real-time



Which resources are scheduled day-ahead to manage net load imbalances?

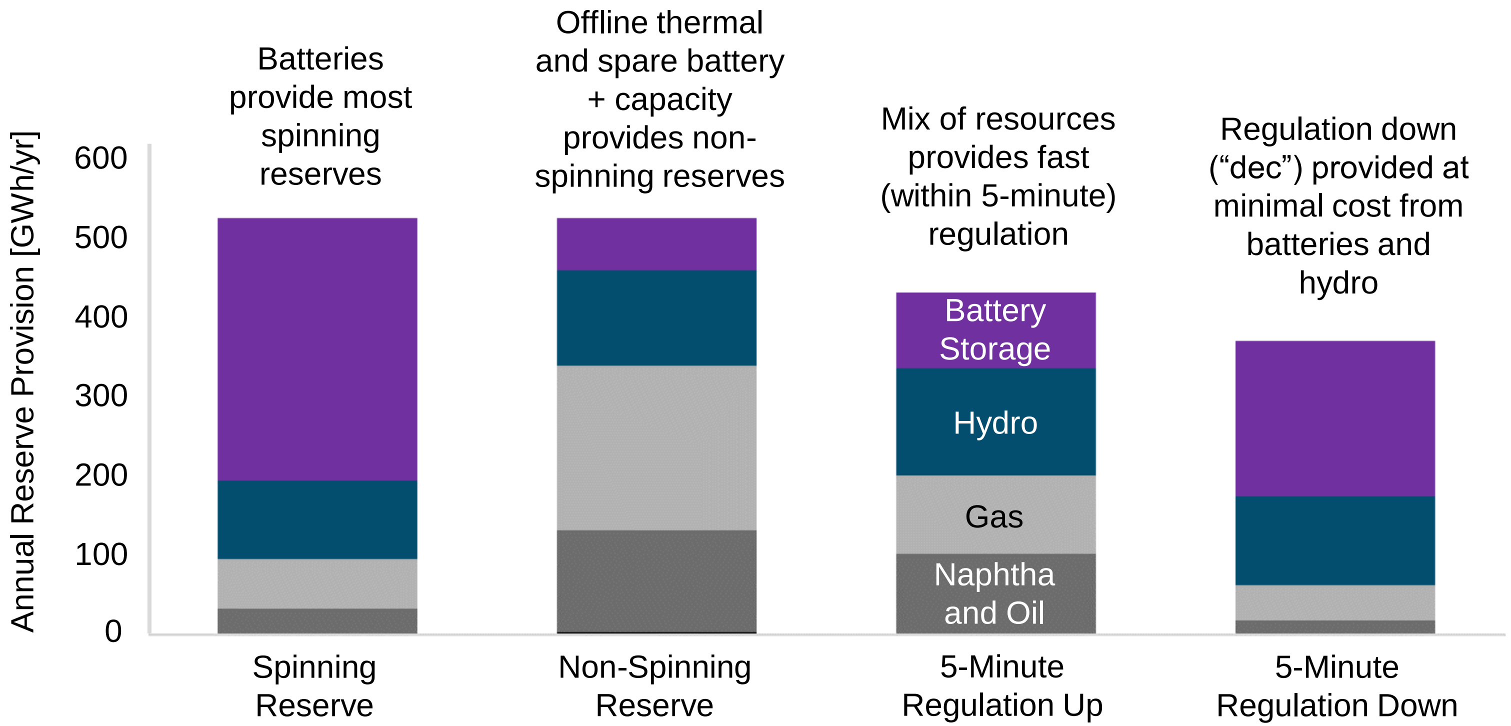
The plot below shows which resources are scheduled to provide each reserve over an entire year



Which resources provide operational reserves in real-time?

The plot below shows which resources are scheduled to provide each reserve over an entire year

Real-Time



De-Minimus reserve shortages:
Regulation Up 5-min shortages: 0.016 GWh (Interior), 0.002 GWh (Central), 0 GWh (Kenai)

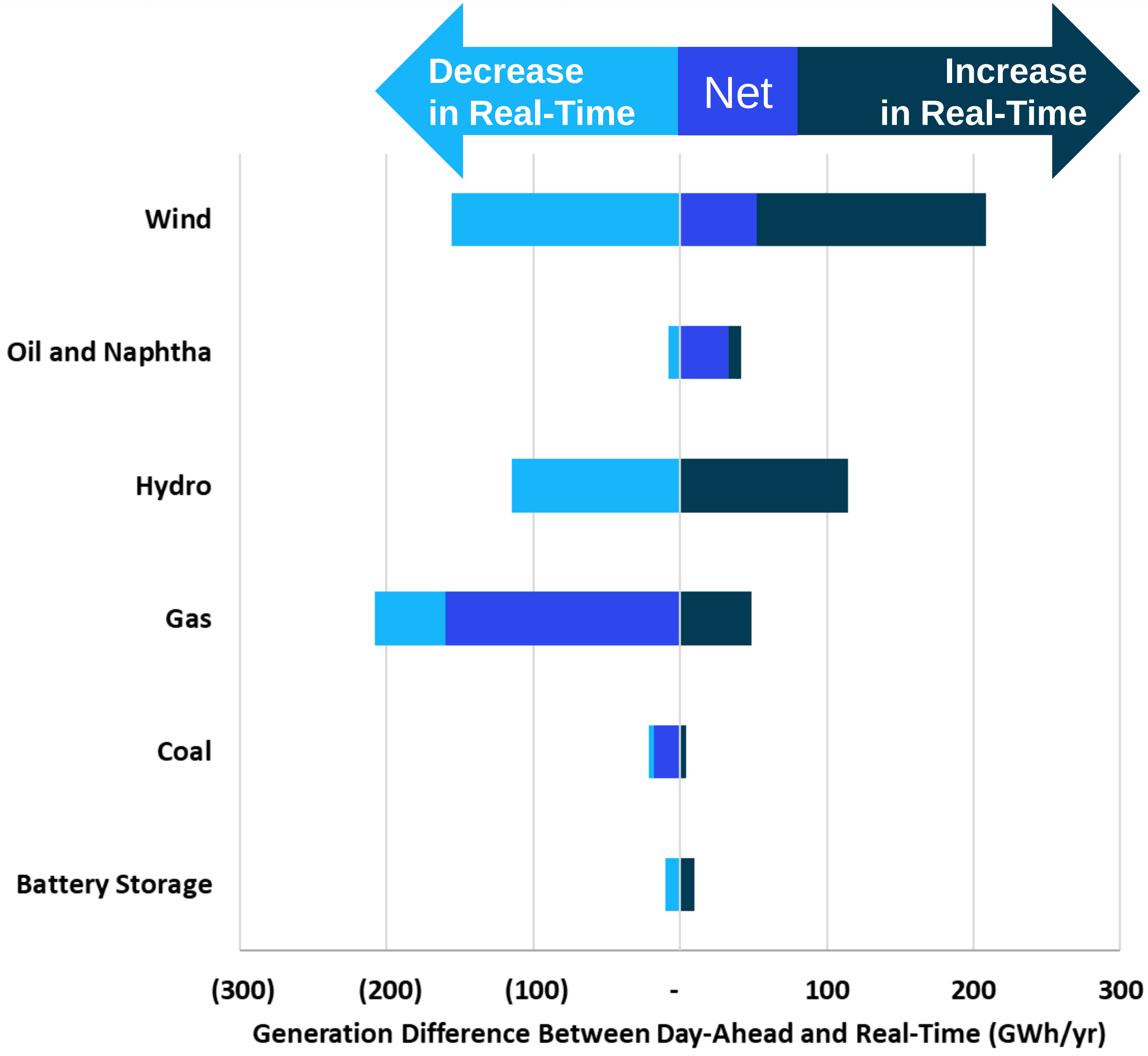
No shortages for any other reserve in real-time

How often are generators started?

- Compared to the No New Wind case, generators are started more frequently in the 300 MW New Wind case to help with integrating variable wind generation and balancing the system.

Generator Category	# units starts per year	
	No New Wind	Base Wind
Interior Oil and Naphtha	166	320
Central Combined Cycle	-	8
Central Steam, Reciprocating Engine, and Combustion Turbine	636	2,221
Kenai Gas	204	776

How does wind forecast error impact resource scheduling and dispatch?



Wind forecast errors drive generation differences in other resources. Net generation increase is caused by a reduction of curtailment in real-time dispatch relative to the day-ahead schedule.

Oil/Naphtha ramped up in in tail events

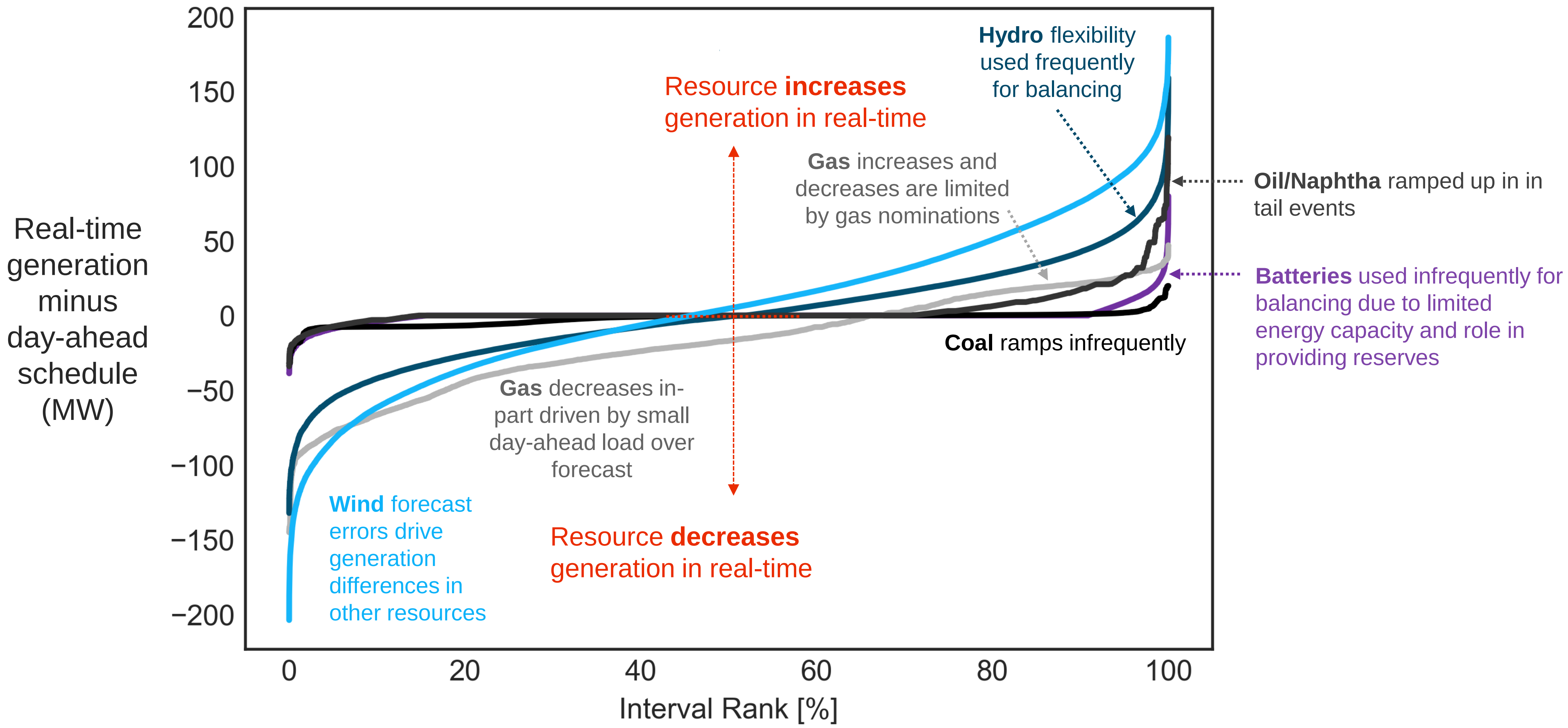
Hydro flexibility used frequently for balancing

Gas increases limited by gas nominations; decreases driven in-part by day-ahead load over-forecast

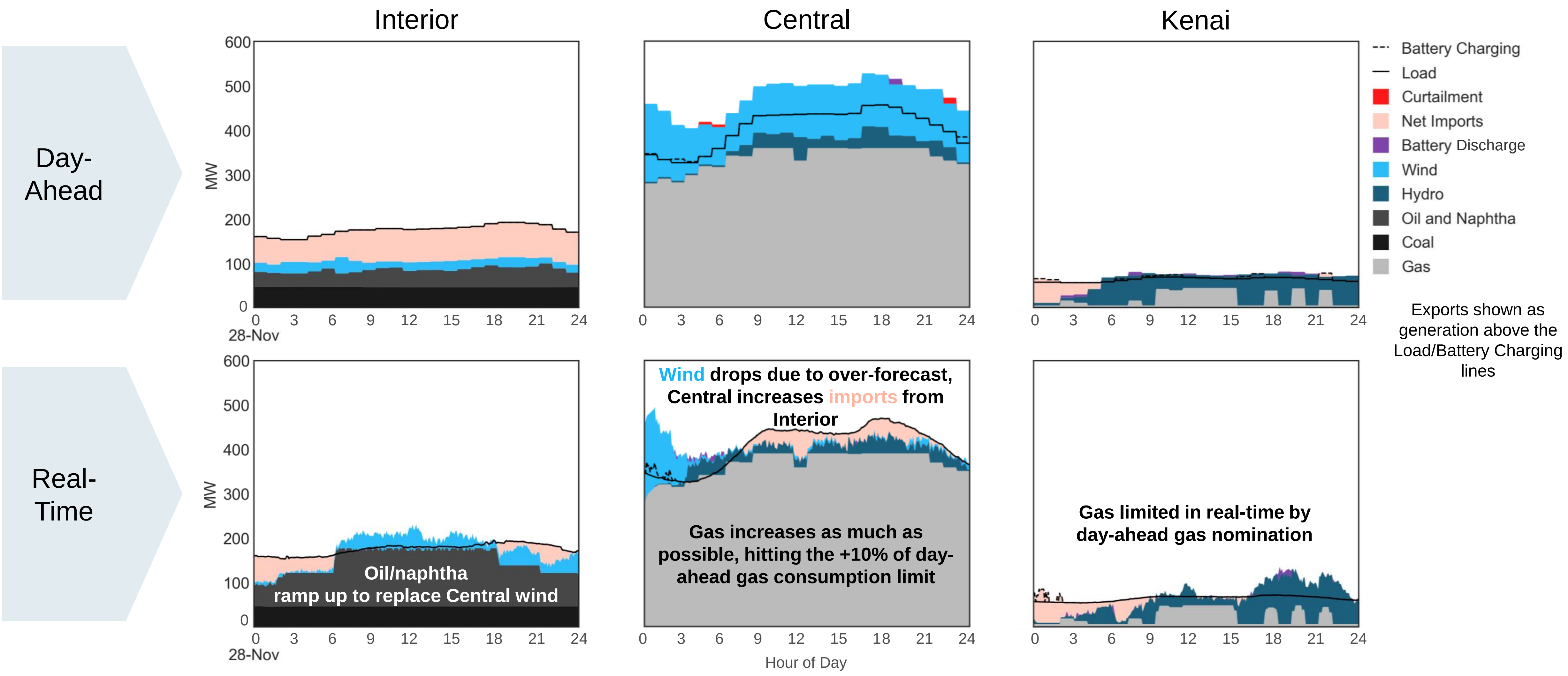
Coal ramps infrequently due to low cost and limited flexibility

Batteries used infrequently for balancing due to limited energy capacity and role in providing reserves

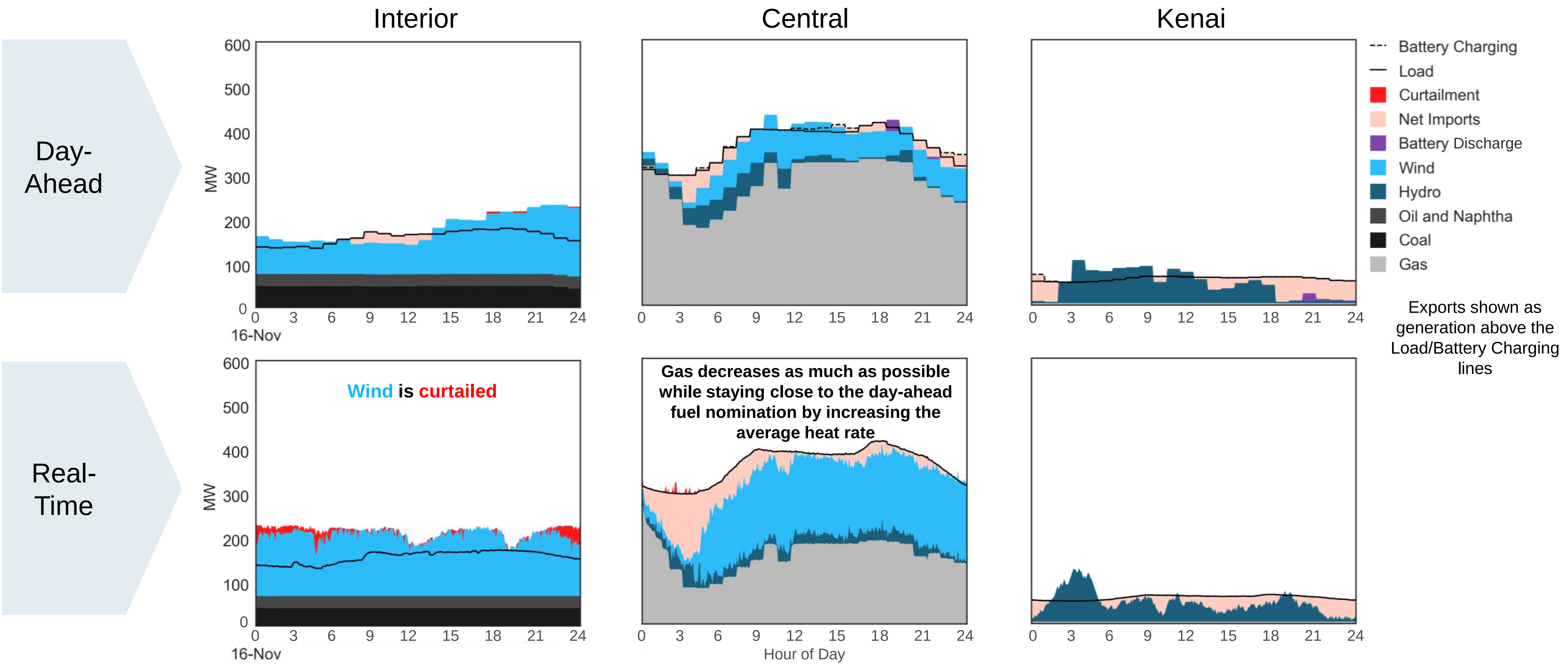
How does wind forecast error impact resource scheduling and dispatch?



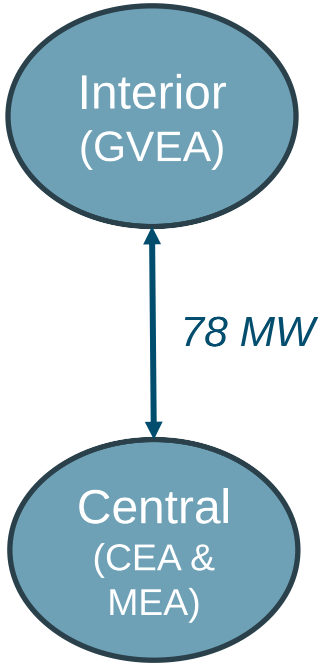
How does the system perform when wind is over-forecasted?

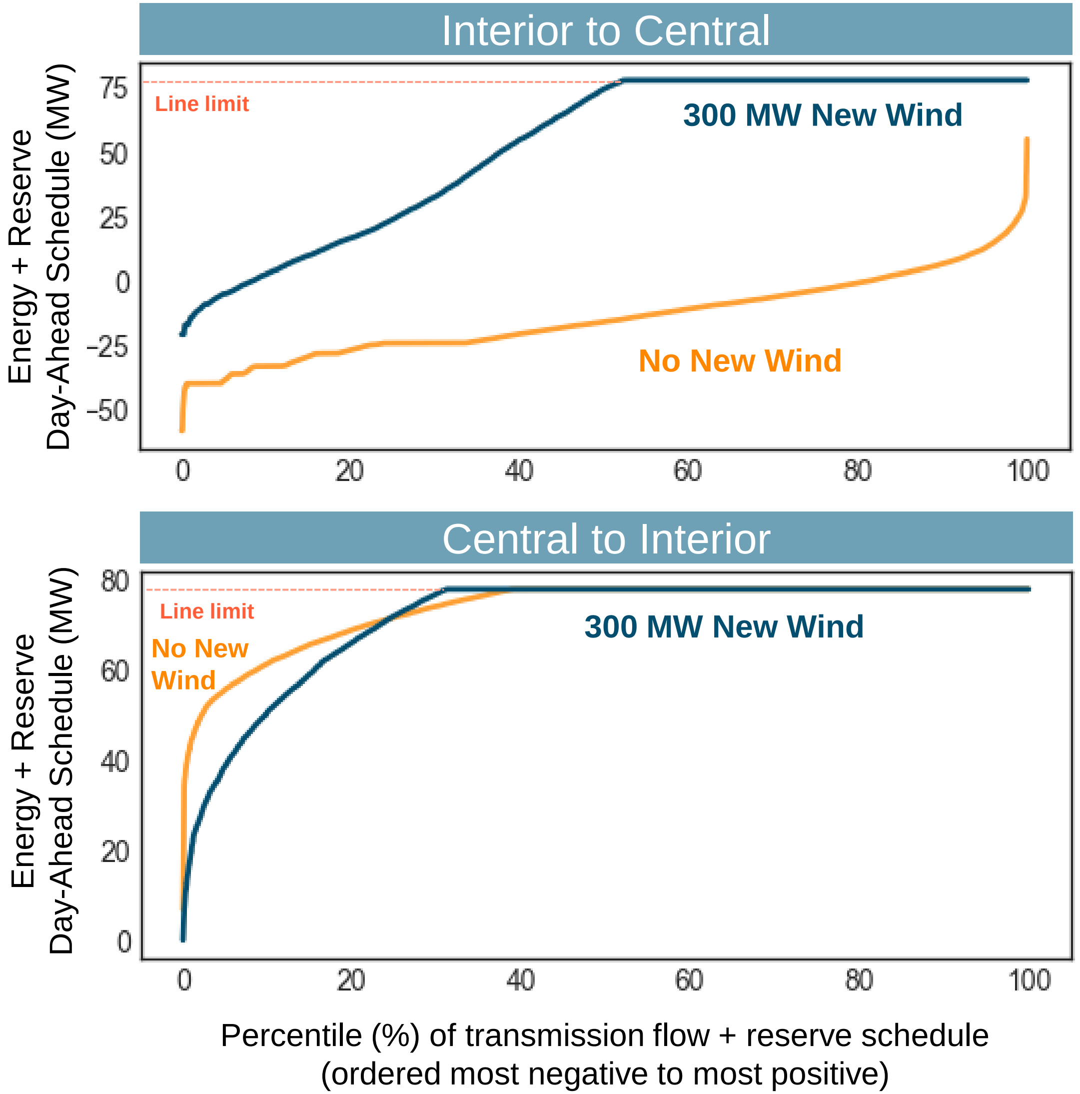


How does the system perform when wind is under-forecasted?



Alaska Intertie Utilization in Day-Ahead Scheduling

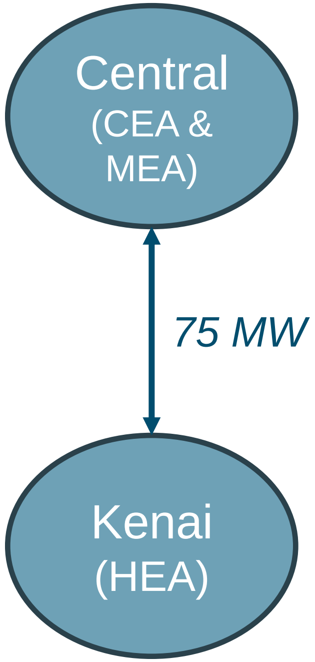




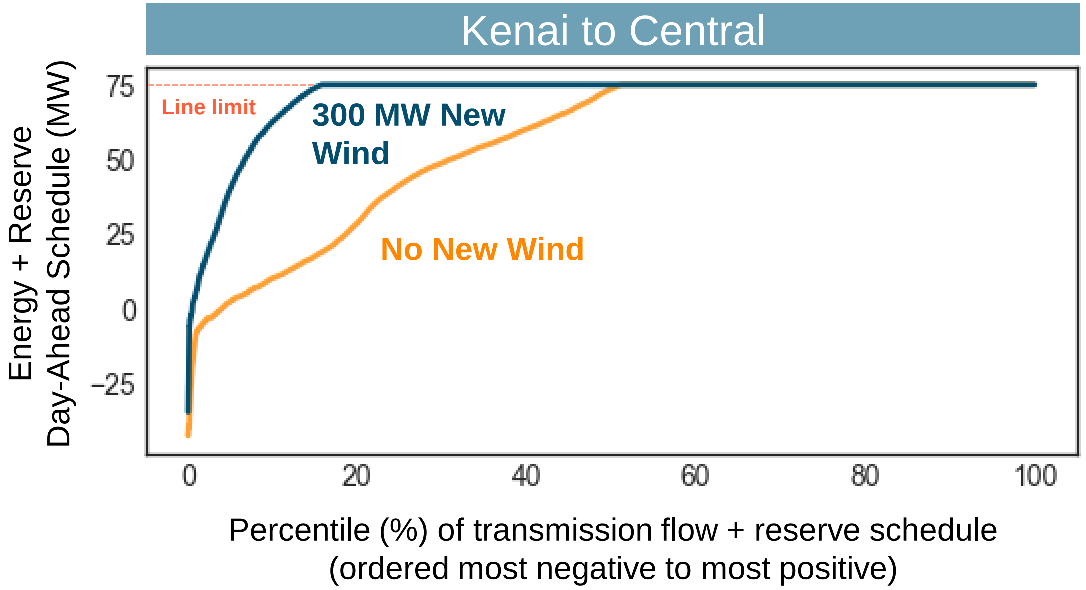
No New Wind: load + wind variability and uncertainty relatively low, resulting in low utilization of the Interior -> Central direction
300 MW New Wind: Interior helps to balance Little Mount Susitna in Central, increasing utilization

Fuel cost difference (Central gas is less expensive than Interior oil/naphtha) drives high intertie utilization in Central-> Interior direction without new wind.
Utilization with 300 MW of New Wind shifts towards reserves in many hours due to Interior wind displacing Central gas imports, as well as the need to balance Interior wind.

Kenai Intertie Utilization in Day-Ahead Scheduling

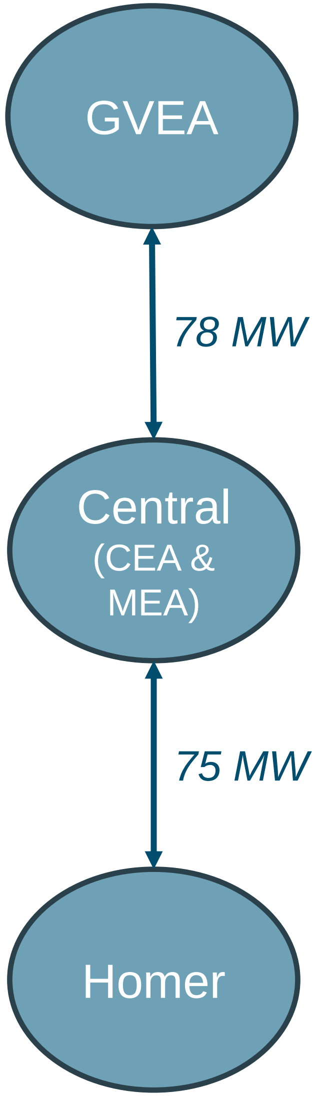


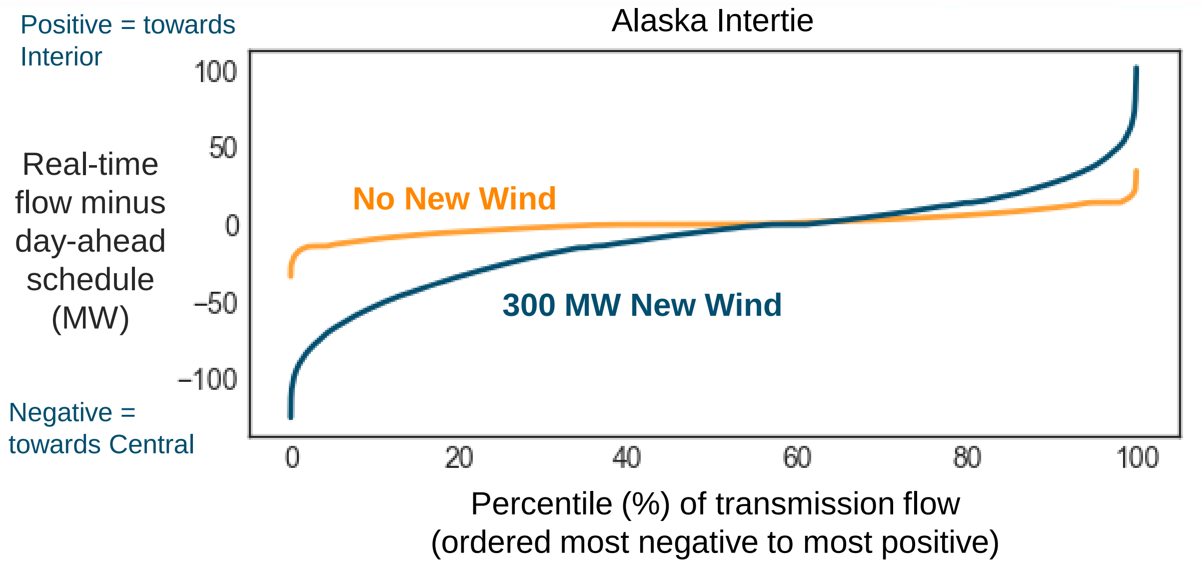
Balancing needs in 300 MW New Wind are much higher in Central and the Interior relative to No New Wind, resulting in frequent transmission reservation for reserves from Kenai -> Central/Interior.



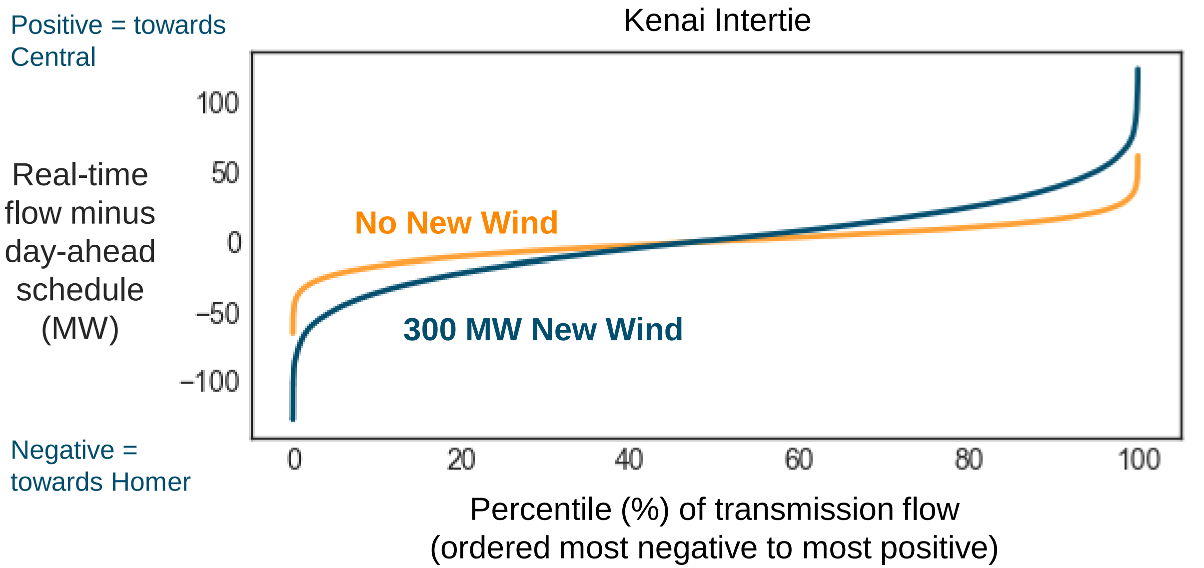
E3 did not model reserve-transmission limits in the Central -> Kenai direction due to the low reserve needs in the Kenai zone

How does wind forecast error impact transmission scheduling and flows?





Transmission is important to balance wind forecast errors: With more wind, transmission flows deviate more frequently in real-time from their day-ahead schedules



The flexibility of Bradley hydro and the Homer battery is used to balance wind, resulting larger changes in flows between day-ahead schedules and real-time dispatch with more wind capacity

How do gas flexibility limitations impact wind balancing?

Modeling of gas nominations:

- Real-time gas consumption in Central and Homer are limited to +/- 10% (90% to 110%) of the day-ahead schedule in every hour
- The model is allowed to violate the gas consumption constraints, but this option is available only during periods where reliability is in jeopardy.

Wind over-forecasts: How to balance while staying within the upper bound (110%) of day-ahead gas nomination in real-time?

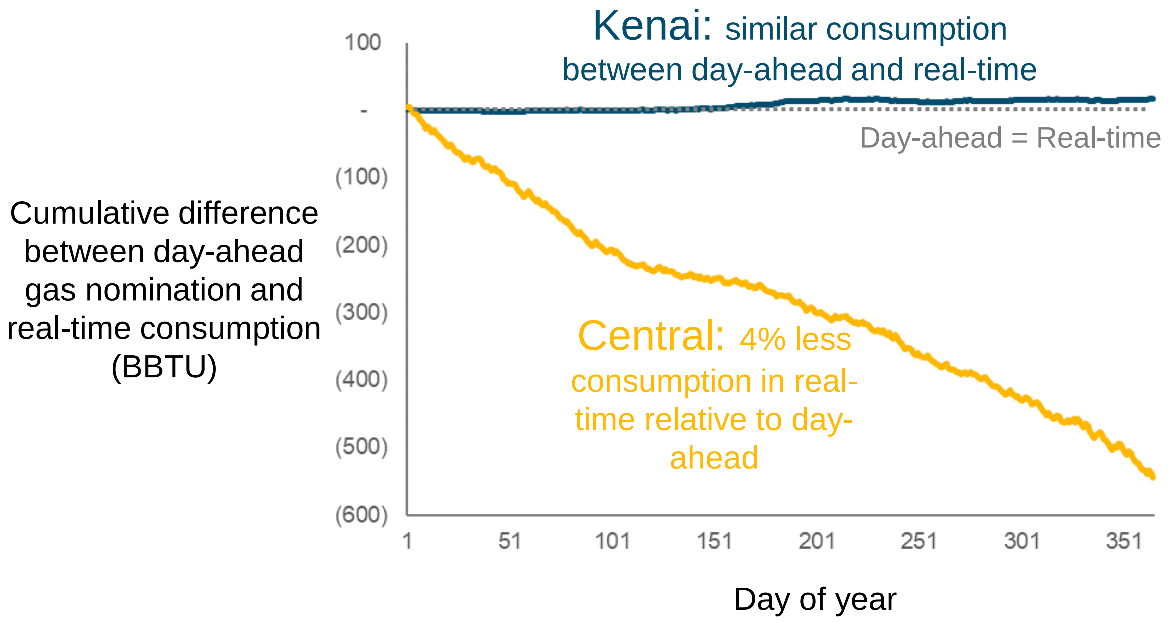
- Hydro (especially Bradley) flexibility can shift energy to the periods of the day when the system is short.
- Reliance on GVEA oil/naphtha units to dispatch up to compensate for wind over-forecasts.
  - These two measures, in combination with the ability to increase gas consumption by 10% in Central and Homer relative to Day Ahead, can balance wind forecast errors with minimal gas consumption outside the 10% band.
- The max hourly violation observed in NG Homer reaches 8% above the +10% limit (118% of the day ahead nomination for the hour). Gas consumption in real-time in each day is within 10% of the day-ahead nomination. Railbelt staff have indicated that this level of deviation from the day-ahead nomination is acceptable.

Wind under-forecasts: How to balance while staying within the lower bound (90%) of day-ahead gas nomination in real-time?

- System is re-dispatched to make as much use of wind as possible in real-time, moving hydro to lower wind hours and ramping gas down to 90% of day-ahead consumption
- When the system has exhausted all ways to reduce non-wind generation, wind is curtailed in real-time. This strategy is used infrequently (1% of wind is curtailed in real-time)

Gas nominations – cumulative deviation over the year

Annual Gas Consumption	Central	Homer
Day-ahead annual gas consumption (BBTU)	15,499	1,994
Real-time annual gas consumption (BBTU)	14,955	2,010
Annual difference (BBTU)	-544	16
Difference (%)	-4%	+1%



Small load over-forecast in Central explains much of the lower gas consumption in Central in real-time

Base Wind results summary

Production costs reduced by $95/MWh of wind production potential in 2030 ($83/MWh in $2023)

GHGs reduced by 0.41 tCO_2 / MWh of wind production potential

System is reliable: No unserved energy, de-minimus reserve shortages

Wind curtailment is observed, but infrequently (1% of wind potential). Wind forecast errors result in system rebalancing between day-ahead and real-time

Thermal plants help to balance wind, but gas nomination, transmission, and stability limits can limit participation. Central and Homer gas consumption are reduced with more wind. GVEA oil and naphtha generators are used to ramp up when wind is over-forecasted.

Hydro flexibility important for wind balancing

Batteries important for reserves (especially spinning) but limited energy capacity results in somewhat modest role in addressing wind forecast errors

Transmission system used in a much more flexible manner with more wind

Sensitivity Results

Energy+Environmental Economics

Sensitivity Summary

Sensitivity Name	Changes from Base Wind case
GVEA Battery Replacement	Replaces existing GVEA battery with a 2-hour battery of the same capacity
Transmission Reinforcement	Adds capacity on the Alaska intertie and increases capacity between Homer and Central to reflect an additional transmission path. Also removes GVEA stability constraint as this is likely to not be required at higher line voltages.
Kenai Tie Outage	Islands Bradley/Homer for one month – two weeks in February and two weeks in July
Gas Scheduling Flexibility	Removes gas nomination limits, allowing full optimization of gas consumption in real-time
Commit All Day-Ahead Sensitivity	Restricts real-time commitment flexibility
Wind Regulation Sensitivity	Includes new wind as an option for providing real-time (within 5-minute) regulation
Relax Stability Commitment Constraints	Removes the stability-related thermal commitment constraints
2025 Fuel Price Sensitivity	Quantifies operational cost reductions from additional wind with near-term (2025) fuel prices

GVEA battery replacement sensitivity

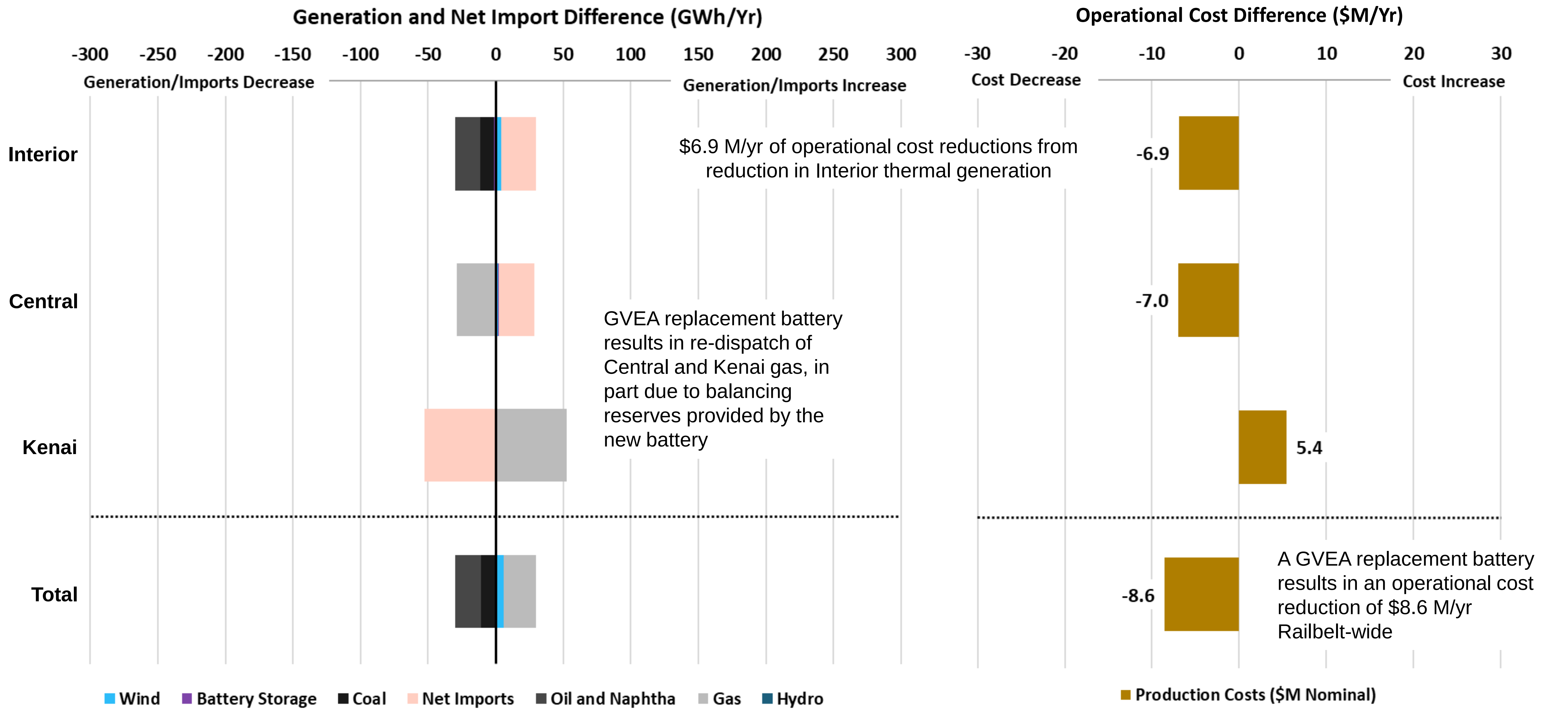
GVEA Batt Replacement Sensitivity

- **GVEA is considering a replacement for their current battery system**
- **This sensitivity explores the operational cost reductions from a replacement battery with the Base Wind portfolio (+300 MW wind relative to the current system)**

- **In this sensitivity:**
  - The existing 46MW/6MWh Fairbanks battery is replaced with a 2-hour battery.
  - Instead of only providing spinning reserves, the replacement battery can provide all types of reserves
  - The replacement battery can provide energy arbitrage whereas the existing battery is limited to exclusively provide reserves

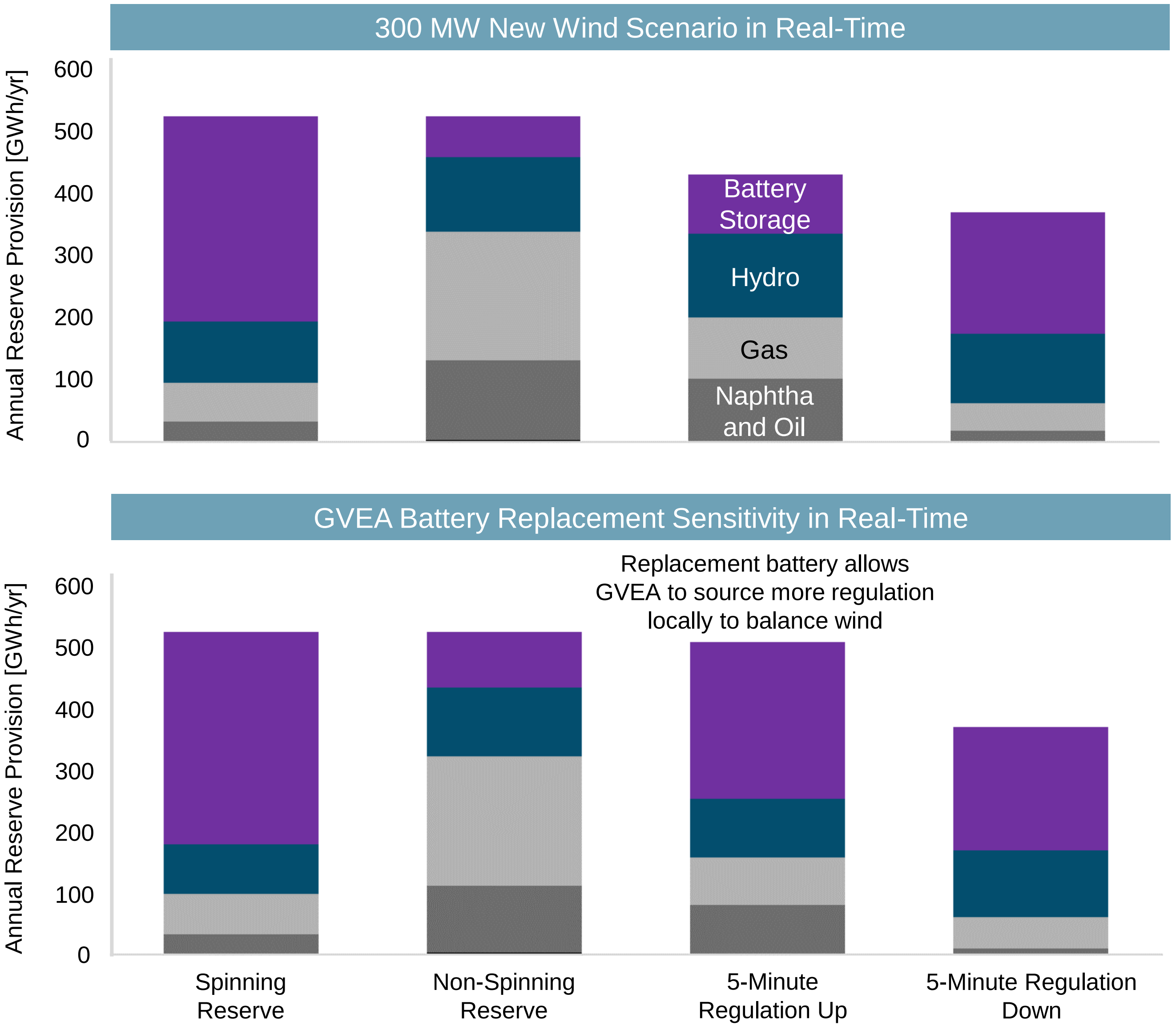
GVEA battery replacement results

Difference = GVEA Battery Replacement Sensitivity - Base Wind



Which grid services does the replacement battery provide?

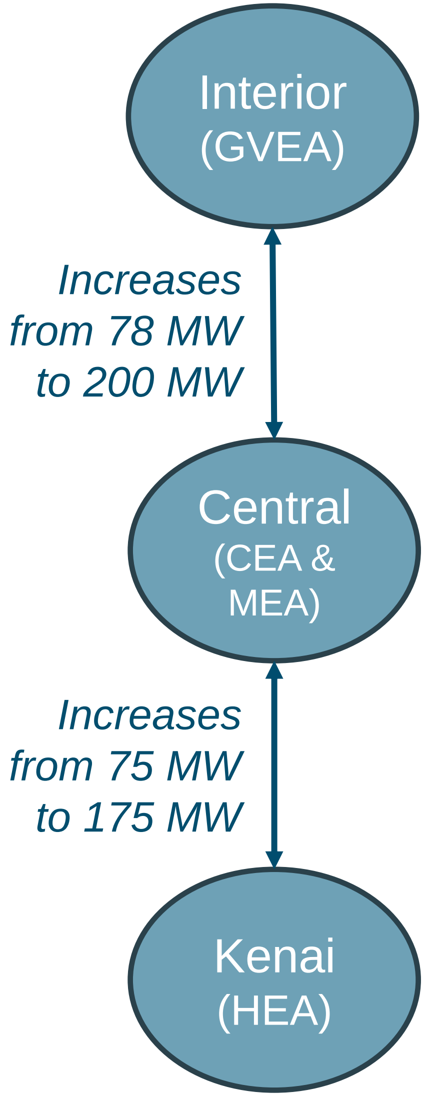
GVEA Battery Replacement Sensitivity



Replacement battery charges and discharges whereas current battery does not

	Annual Charge (GWh)	Annual Discharge (GWh)
Fairbanks Battery (Base Wind)	0	0
Replacement Battery (Sensitivity)	8.2	7.1

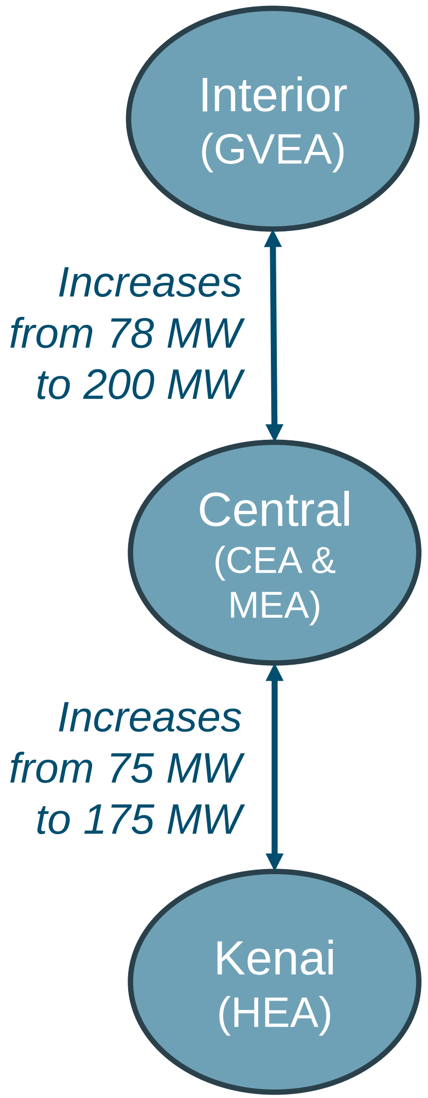
Transmission Reinforcement Sensitivity

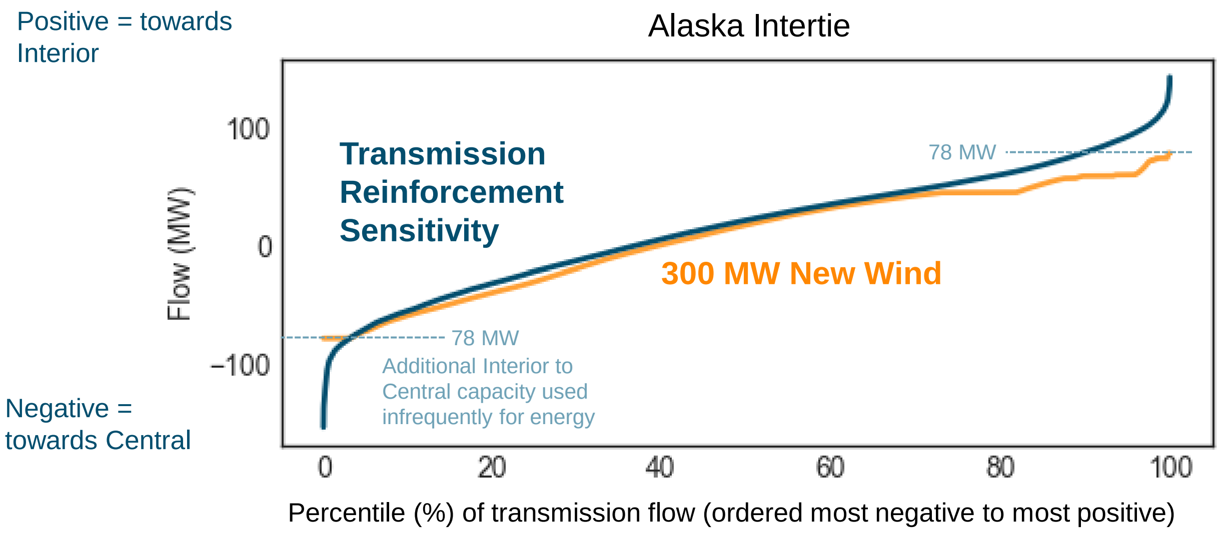


- **The Transmission Reinforcement Sensitivity adds capacity between Central and Kenai, and also between Central and Interior.**
- **The sensitivity also assumes that the Interior stability requirement (requiring commitment of at least one North Pole unit) is no longer necessary with higher voltage transmission between Central and Interior**
  - This assumption should be explored/confirmed with further study
- **Context and Caveats:**
  - This sensitivity does not add new resources to the Base Wind case, so the combined impact of more transmission and additional resources is not quantified
  - This sensitivity does not address many of the potential reliability-related benefits of more transmission capacity
  - This sensitivity does not model increased contingency reserves that may be needed when the lines are flowing at levels above their current rating. The need for more contingency reserves would decrease the benefits of more transmission capacity relative to the results shown here

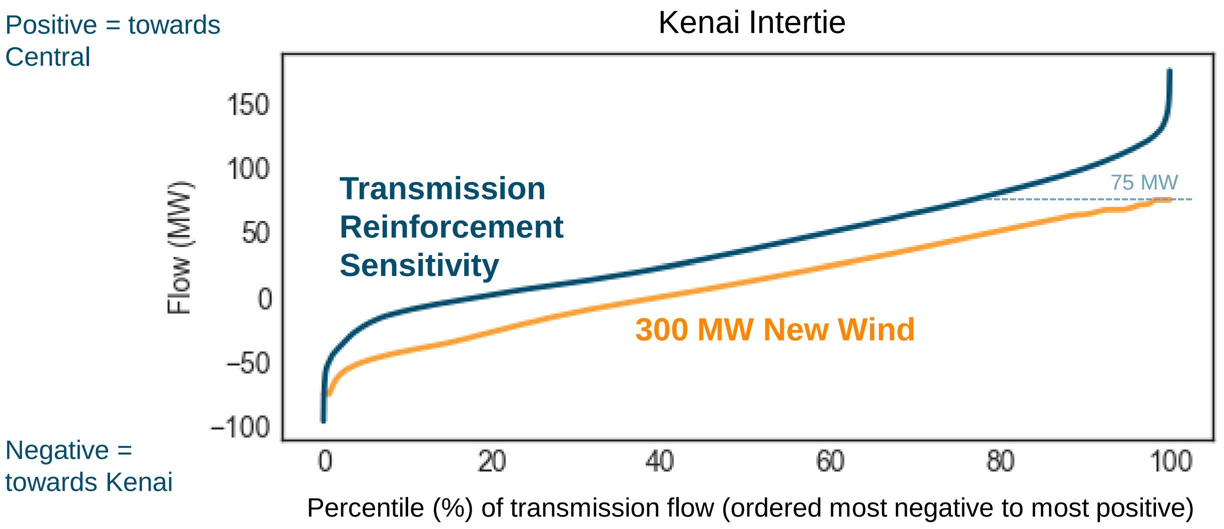
How do transmission flows change with more transmission capacity?

Transmission Reinforcement Sensitivity





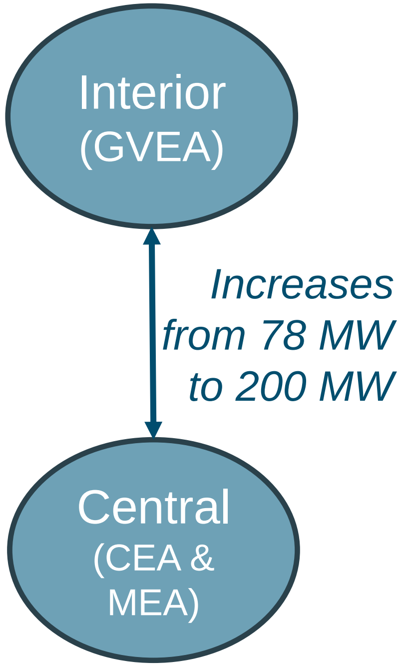
Additional transmission enables higher Central -> Interior flows in ~25% of intervals



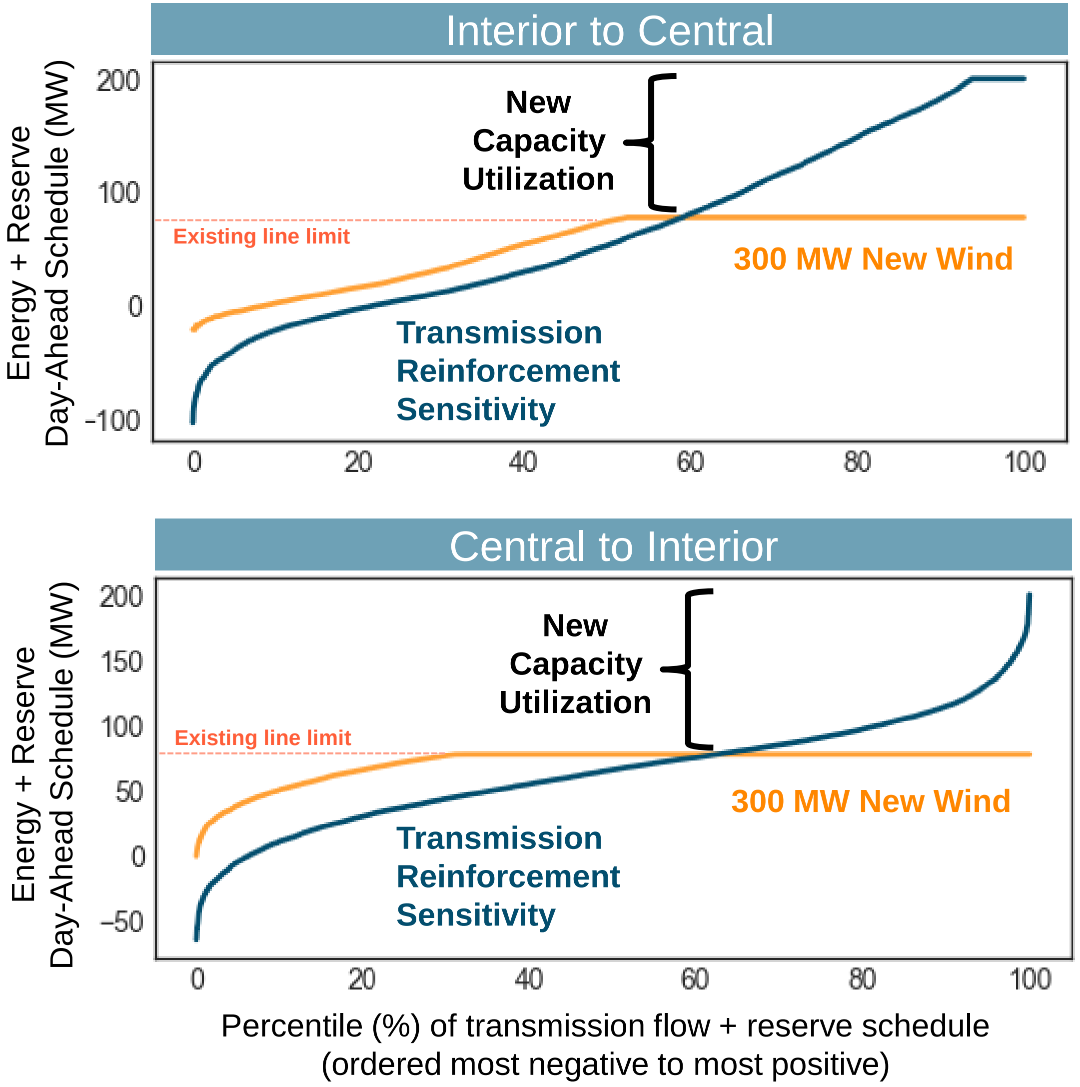
More transmission capacity between Kenai and Central creates space for both energy and reserves, enabling both Nikiski combined cycle and Bradley hydro to economically export energy to Central, increasing flows in the Kenai -> Central direction

Alaska Intertie Utilization in Day-Ahead Scheduling

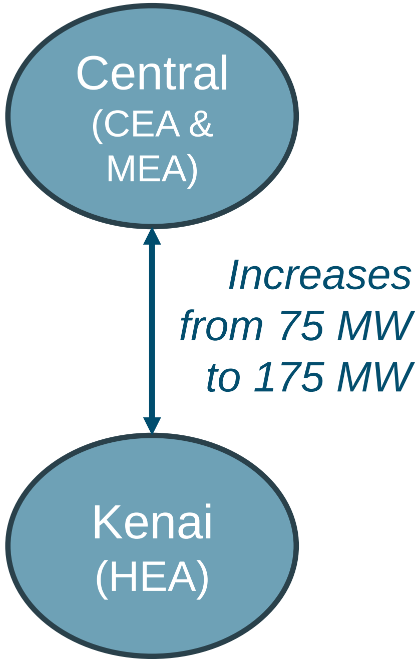
Transmission Reinforcement Sensitivity



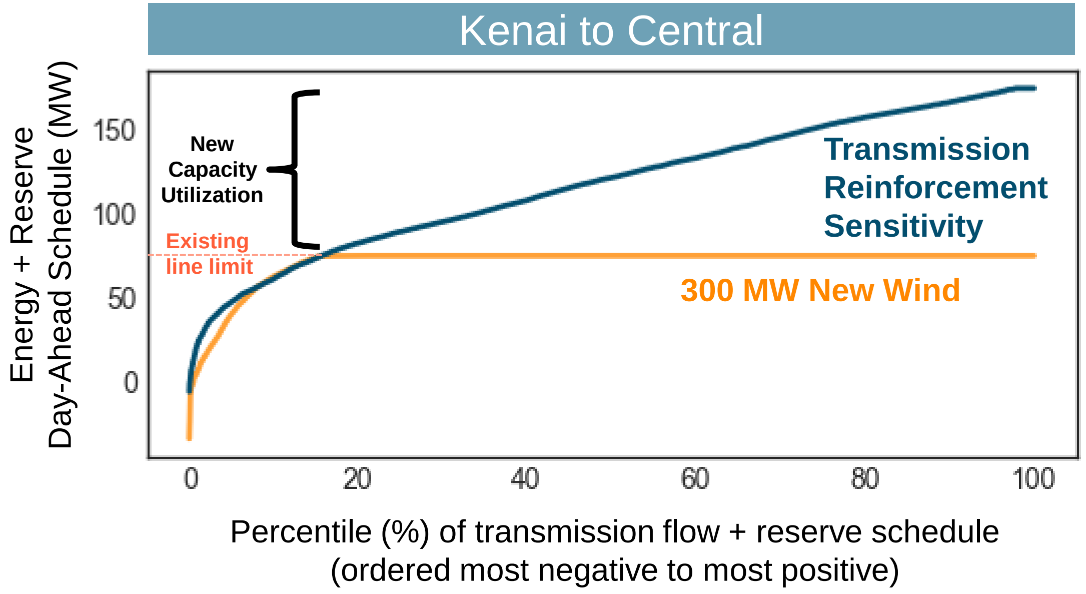
Additional transmission headroom provides more flexibility for Interior and Central to balance wind and share reserve capacity.



Kenai Intertie Utilization in Day-Ahead Scheduling



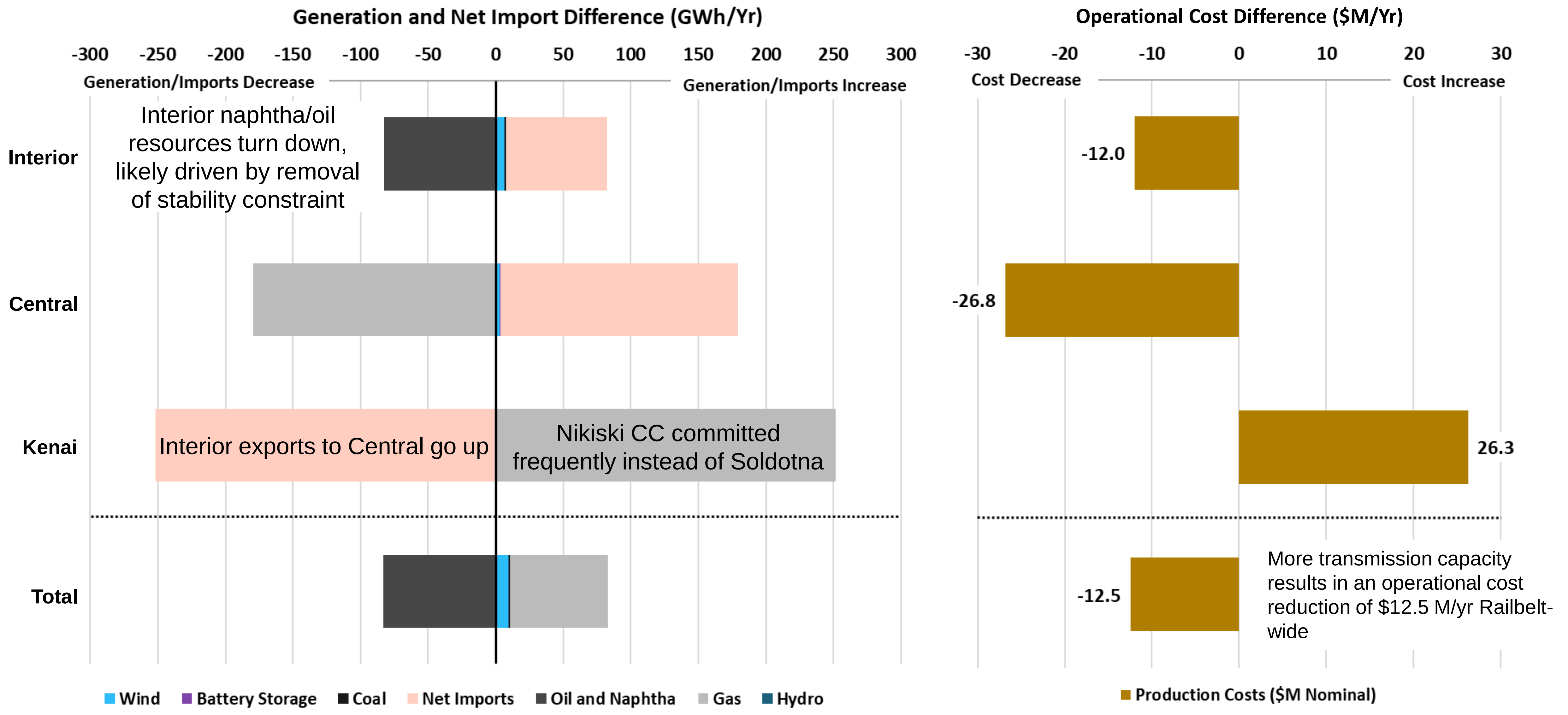
Additional transmission headroom allows for more energy export from the Kenai zone (e.g., Nikiski CC) and more transmission capacity used to provide reserves.



E3 did not model reserve-transmission limits in the Central -> Kenai direction due to the low reserve needs in the Kenai zone

How does resource dispatch and production cost change with more transmission capacity?

Difference = Transmission Reinforcement Sensitivity - Base Wind



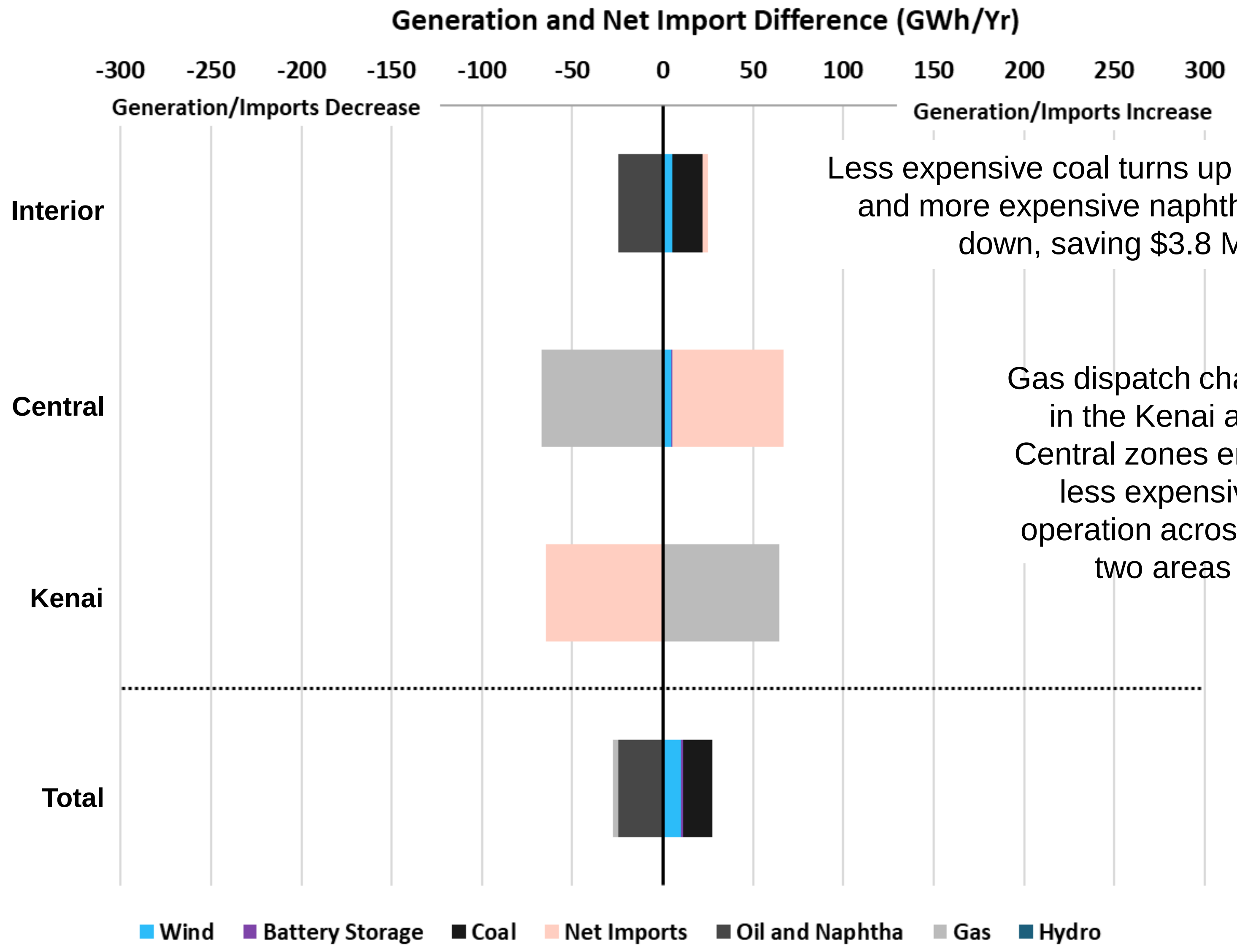
Gas Scheduling Flexibility Sensitivity

+ **As a bookend to explore the cost and dispatch impact of gas nomination limitations, the gas nomination constraints are removed in the Gas Scheduling Flexibility Sensitivity, thereby allowing gas to be dispatched more flexibly. The gas nomination constraints (removed in this sensitivity) include:**
  - Real-time gas consumption must be within +/- 10% of the day-ahead nomination
  - Day-ahead reserve limits require forecast error and within-hour regulation reserve provision from gas plants to be at most 10% of their level of generation
  - Day-ahead restriction that offline gas resources cannot contribute to forecast error reserve

+ **This case represents a limit to the value of additional gas contract flexibility; it is likely that physical and contractual limits will make only a portion of this value achievable**
  - However, to the extent that the PLEXOS single load balancing area dispatch is more efficient that current practice, the Gas Scheduling Flexibility Sensitivity may underestimate the near-term benefits of more gas scheduling flexibility with higher levels of wind.

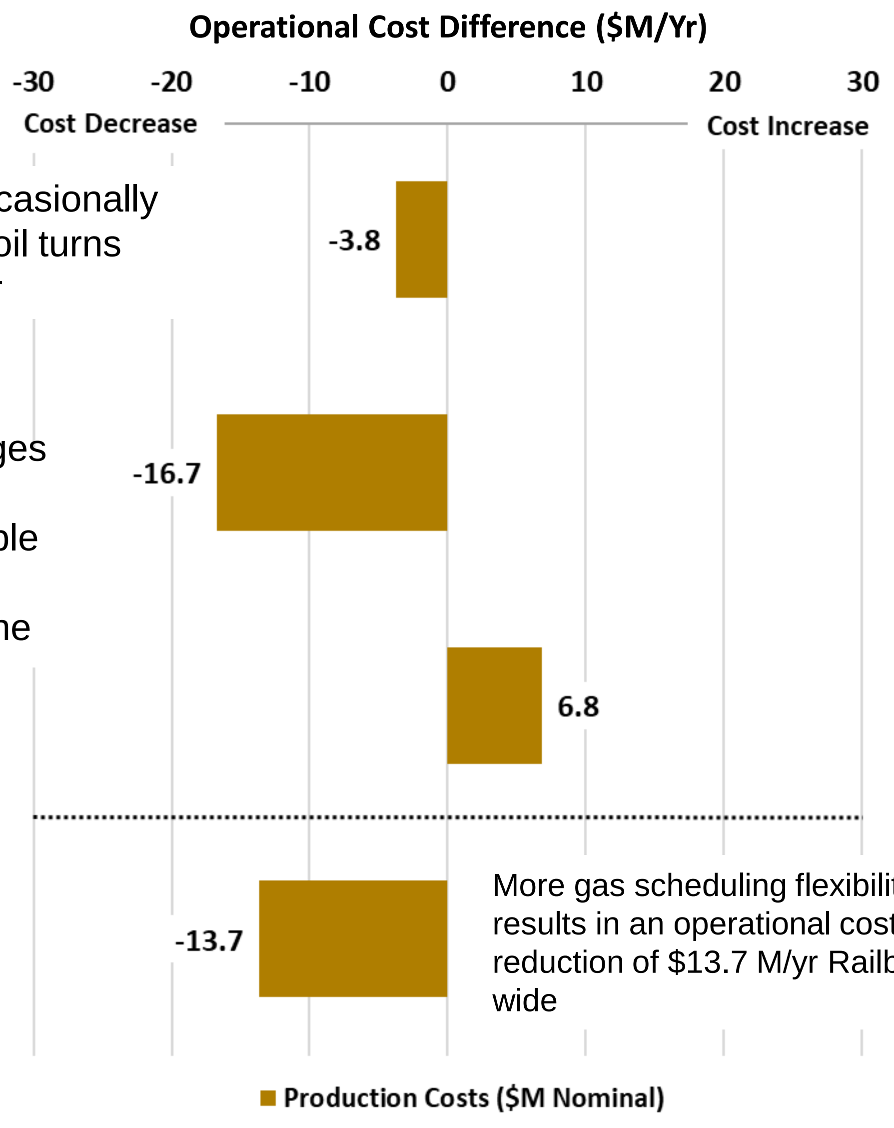
What is the value of more gas supply flexibility?

Difference =
Gas Scheduling Flexibility Sensitivity
- Base Wind



Less expensive coal turns up occasionally and more expensive naphtha/oil turns down, saving $3.8 M/yr

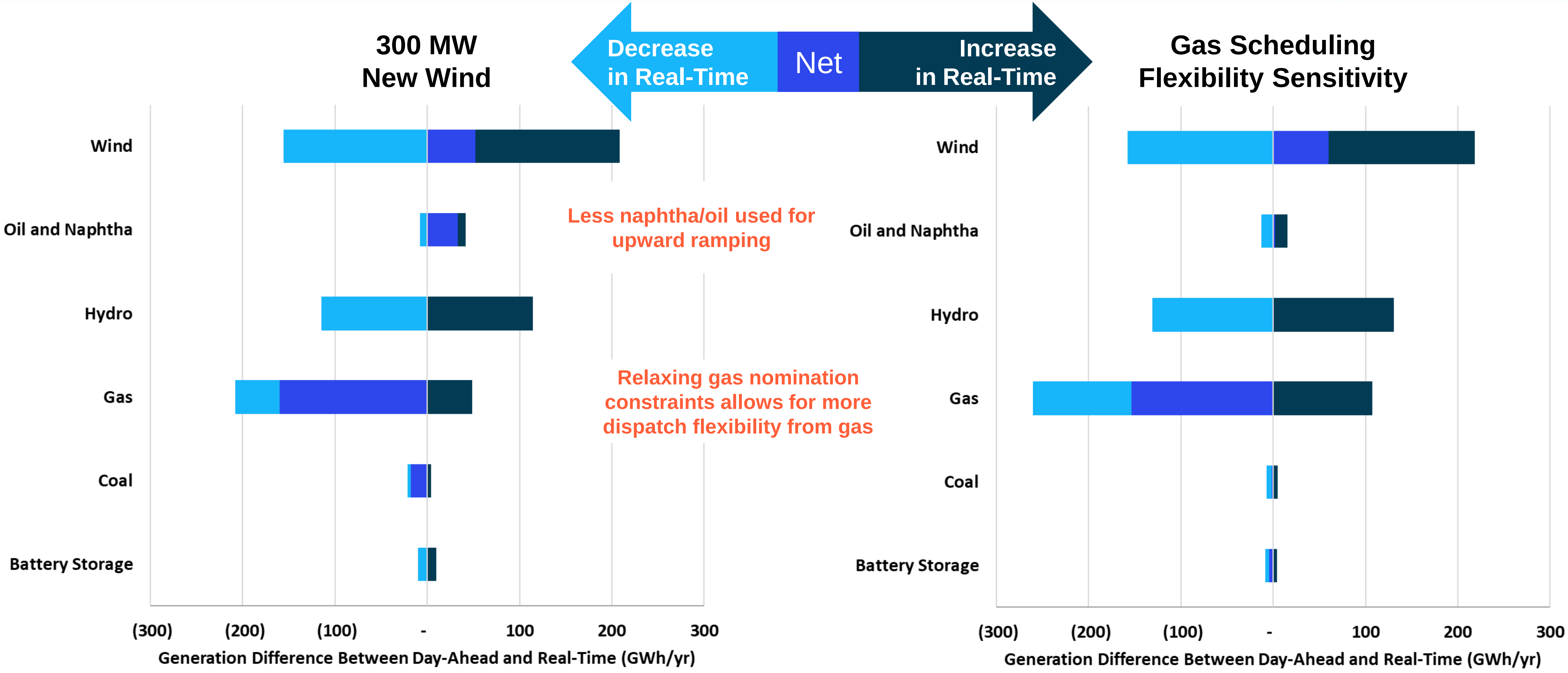
Gas dispatch changes in the Kenai and Central zones enable less expensive operation across the two areas



More gas scheduling flexibility results in an operational cost reduction of $13.7 M/yr Railbelt-wide

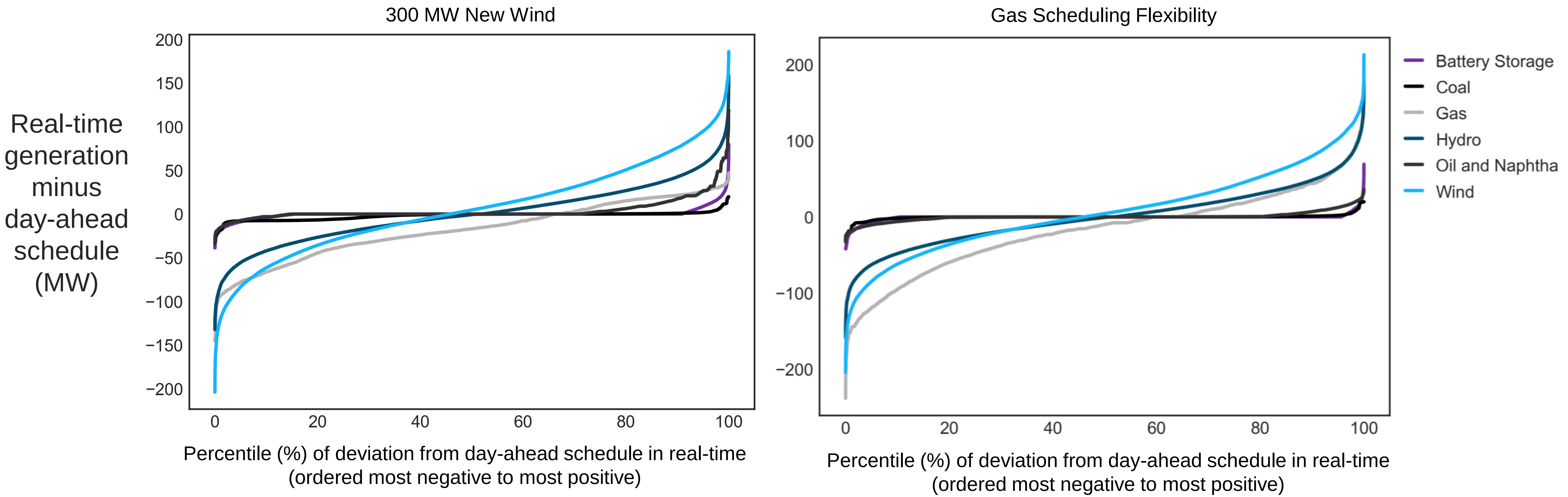
How does more gas supply flexibility change system dispatch?

Gas Scheduling Flexibility Sensitivity



Detailed Day-Ahead to Real-Time comparison

Gas Scheduling Flexibility Sensitivity



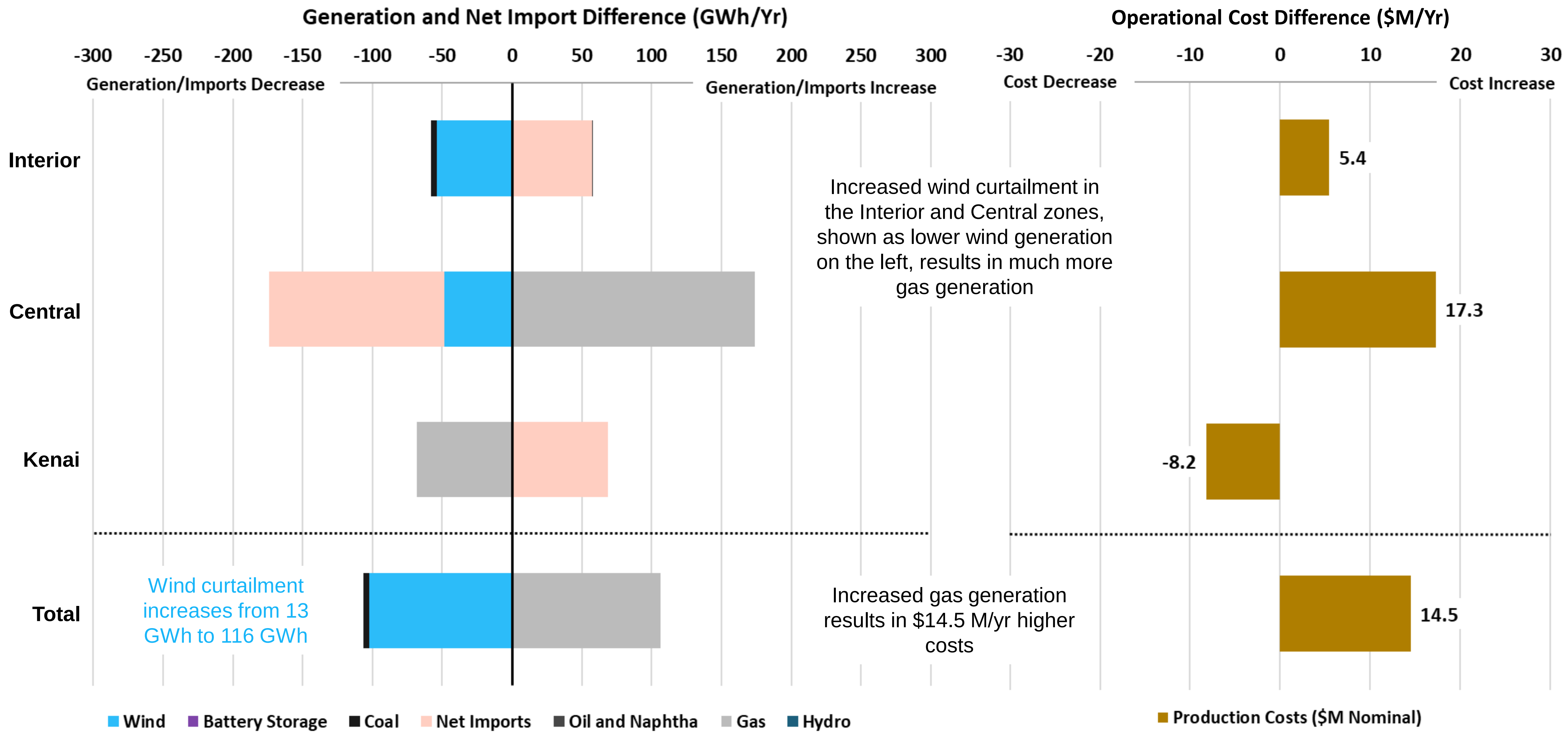
Commit All Day-Ahead Sensitivity Background

Commit All Day-Ahead Sensitivity

- **As a default assumption, E3 requires combined cycle and coal plants to be committed in the day-ahead timeframe, but allows quick start gas and oil plants to be turned on in real-time.**
  - However, real-time gas consumption from quick-start gas plants is limited by the day-ahead gas nomination, severely restricting the ability of quick-start gas to turn on in real-time
- **While Railbelt operators can turn on quick start generators in real-time if necessary, current operational practice typically schedules units on an hourly basis, with some adjustment within the hour.**
- **The Commit All Day-Ahead Sensitivity enforces day-ahead commitment schedules for *all* thermal units in the real-time stage.**
  - Because the day-ahead stage in E3's model is at hourly resolution, resources in the Commit All Day-Ahead Sensitivity do not change their commitment within the hour.
  - This sensitivity reflects an aspect of present-day Railbelt operational practice by not changing thermal resource schedules on a 5-minute basis. It is somewhat restrictive relative to current operational practice because quick-start resources can be started or stopped by operators if necessary.

How does day-ahead resource commitment impact the generation mix and costs?

Difference =
Commit All Day-Ahead Sensitivity
- Base Wind



Commit All Day-Ahead Sensitivity: Reliability

Commit All Day-Ahead Sensitivity

- **Commit All Day-Ahead Sensitivity results indicate lower reliability than the 300 MW New Wind case, highlighting the importance of re-commitment in real-time to balance wind**
  - Higher 5-minute regulation up shortages
    - 1.7 GWh/Yr in Commit All Day-Ahead Sensitivity vs. 0.004 GWh/Yr in Base Wind
  - Higher gas nomination violations (consumption above 110% of day-ahead gas nominated), potentially resulting in unserved energy events or other reliability issues if additional gas cannot be provided in real-time
    - Fuel consumption over 110% of hourly day-ahead gas nomination: 31,000 MMBTU/Yr in Commit All Day-Ahead Sensitivity vs. 600 MMBTU/Yr in Base Wind
      - At an 8 MMBTU/MWh heat rate, this is ~4 GWh/Yr of energy from gas (vs. 0.075 GWh/Yr in the Base Wind case – an acceptable level of violation per Railbelt staff)
  - Minimal changes in unserved energy, dump energy (overgeneration), and spinning reserve shortages (similar reliability between the two cases on these metrics)

Kenai Tie Outage Sensitivity Setup

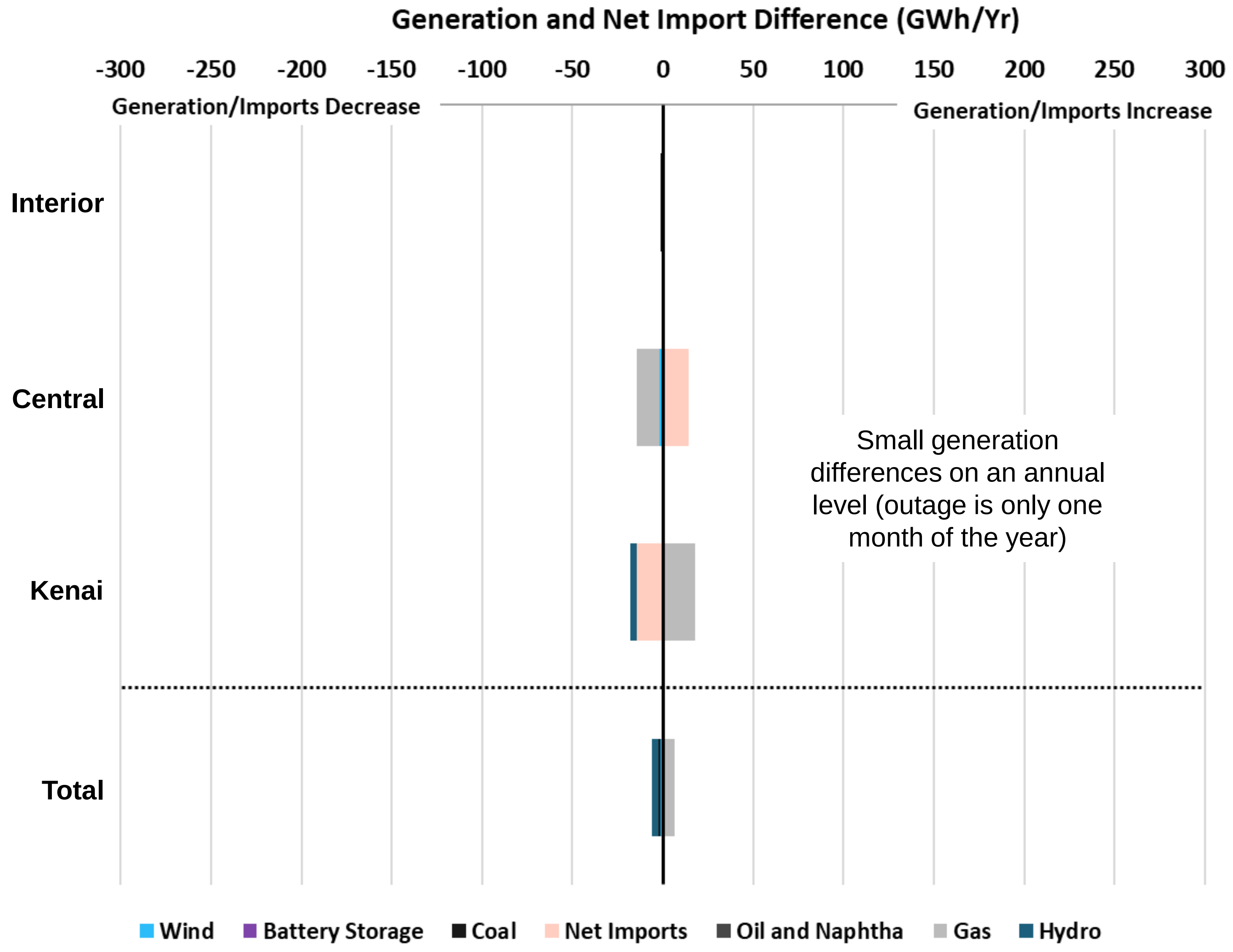
- **Purpose: stress test to explore Railbelt operations when Bradley Hydro and Homer are cut off from the rest of the Railbelt grid**
- **Sensitivity assumptions**
  - Four-week tie outage: two consecutive weeks in Feb and two consecutive weeks in July
  - Only one of the Bradley lake units can be on to ensure system stability
  - Homer carries its own reserves
  - Homer's contingency reserves change from their load share of 60 MW to 40 MW
  - The full capacity of Homer's battery is allowed to provide reserves
  - GVEA and Central share 60 MW of contingency reserve (same as base case) but without contributions from Homer resources (including Bradley)
  - Bradley hydro budget reduced while tie is out (when Bradley is only serving Homer), shifting some water to adjacent periods when tie is in
- **Note: in all other cases, the Kenai tie is modeled as in-service for all hours of the year. Input from Railbelt staff has highlighted that the Kenai tie is usually out for maintenance for 4 weeks per year; this outage is not captured in E3's runs. The Kenai tie outage sensitivity models an outage of 4 weeks per year and thus shows the incremental cost of additional outages when compared to the Base Wind case.**

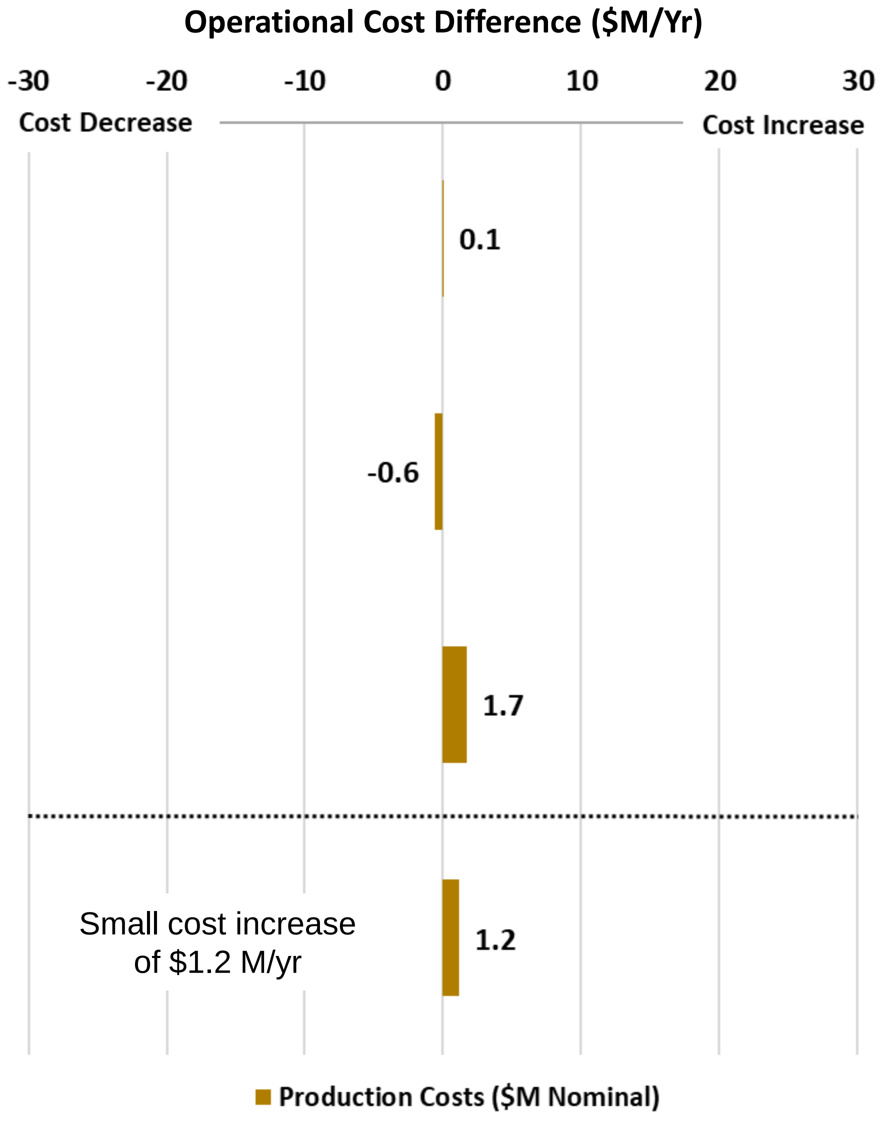
Summary of Kenai Tie Outage Impacts

+ **Kenai Tie Outage doesn't cause any unserved energy**
  - Unserved reserve is also de-minimus, 7 MWh of unserved GVEA and Central 5min Regulation Up Reserve
+ **No daily gas violations (>110% of day-ahead nomination) for any day that the Kenai tie is out**
  - However, we do not have an extreme wind over-forecast day in the 1 month of days that the Kenai tie is out
  - De-minimus hourly gas violation
+ **Relative to the Base Wind case, 1 month of Kenai tie outage per year:**
  - Increases production costs by $1.2 M / yr
  - GHG emissions slightly increase from the Base Wind case (increase of 0.02 MMT/yr)

How do Kenai Tie outages impact the generation mix and costs?

Difference = Kenai Tie Outage Sensitivity - Base Wind

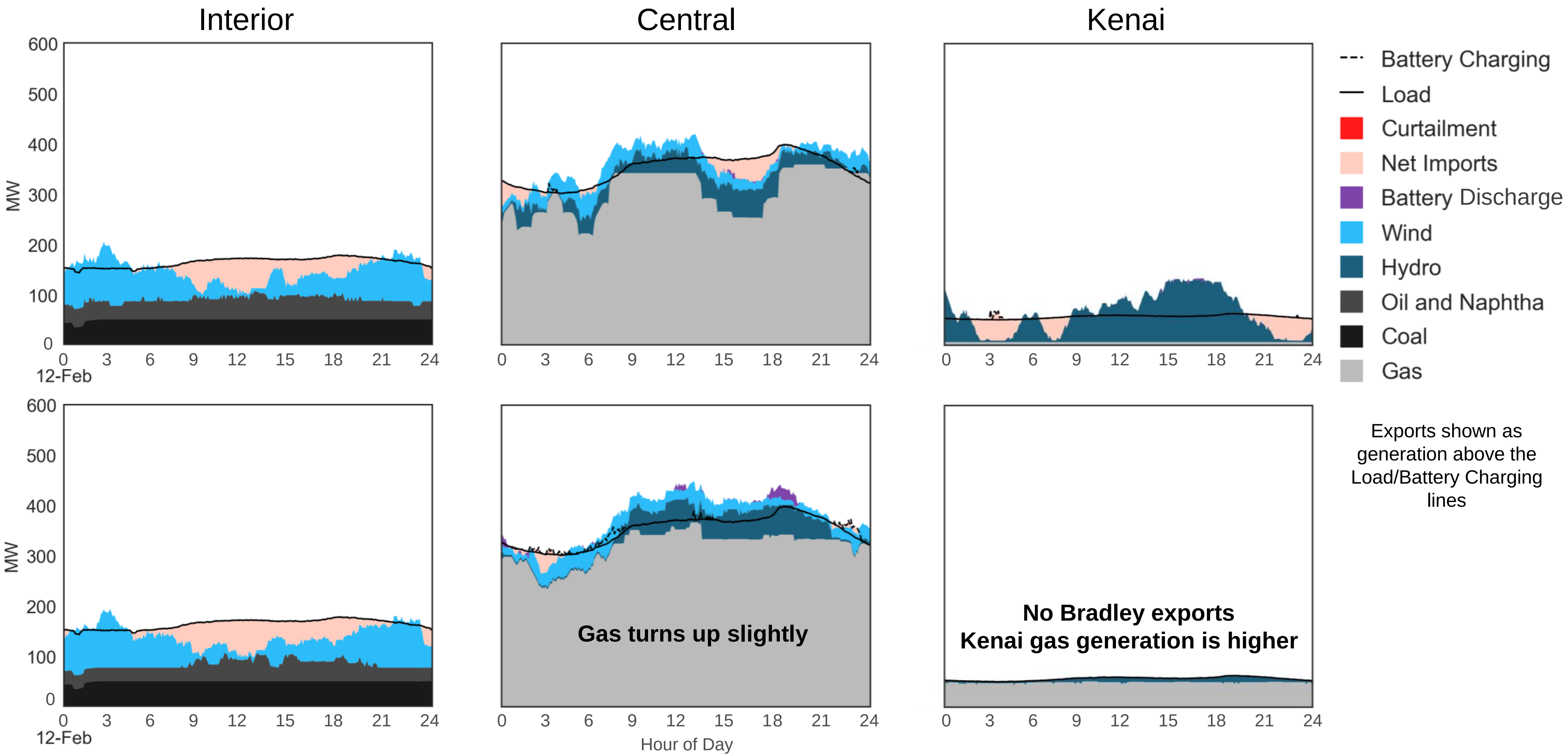




How does dispatch change when the Kenai Tie is out?

300 MW New Wind

Kenai Intertie Out



Exports shown as generation above the Load/Battery Charging lines

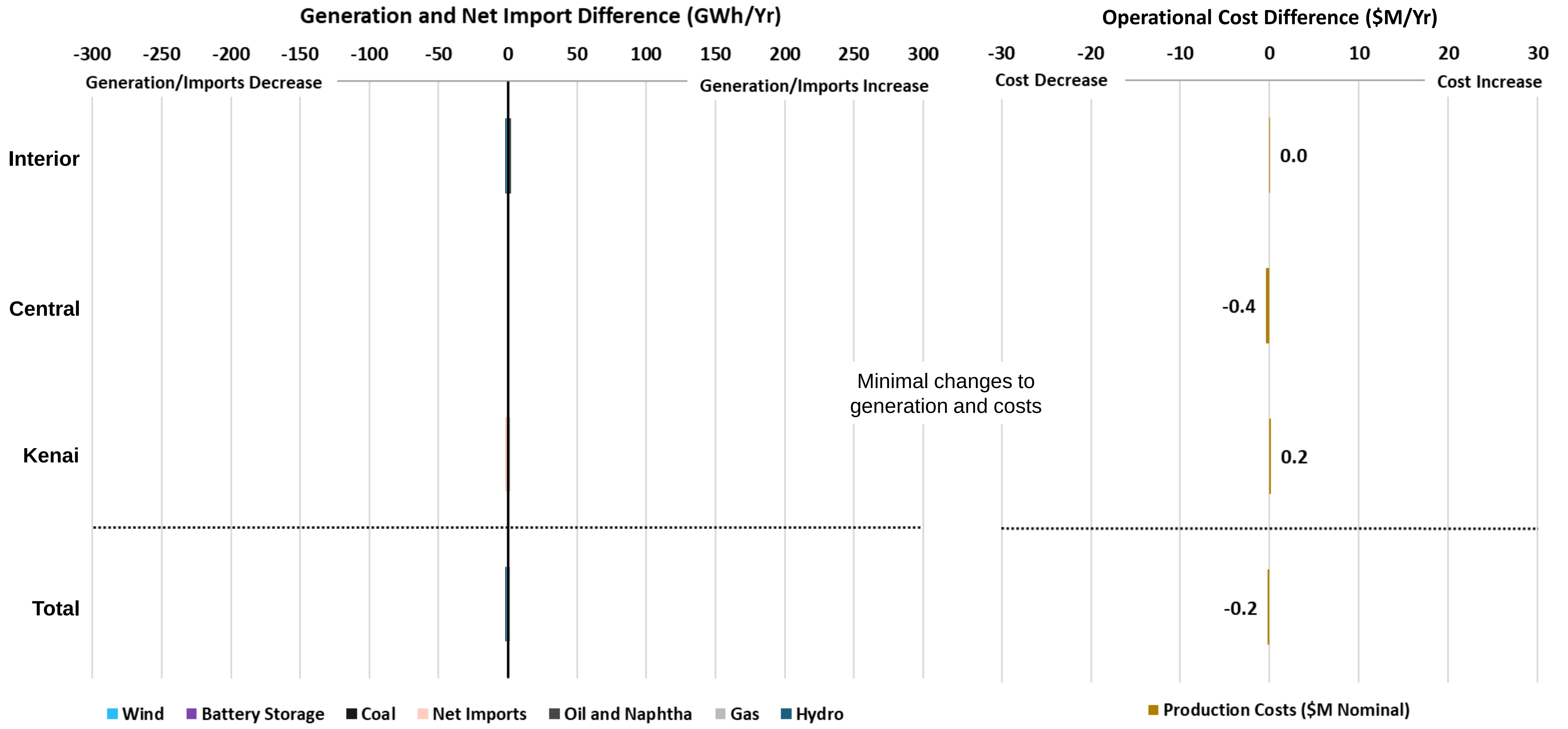
By how much would operational costs be reduced by enabling wind to provide regulation?

Wind Regulation Sensitivity

- **Modern wind plants have the technical capabilities to curtail and un-curtail very quickly and can respond to AGC signals or operator dispatch**
- **However, unlike conventional power plants, wind resources have a variable fuel supply, making control of this resource more complex but also potentially valuable**
- **In this sensitivity we explore the operational cost reductions that could result from wind providing short-duration balancing services within each 5-minute dispatch interval.**
  - We have included wind curtailment in the base case as an option in each 5-minute interval and have also included the option to under-schedule wind in day-ahead if economical
- **In the Wind Regulation Sensitivity, Little Mount Susitna and Shovel Creek are modeled as being able to provide 5-minute regulation up and down, whereas in the Base Wind case they are not modeled as being able to do so.**

How does regulation from wind impact the generation mix and costs?

Difference = Wind Regulation Sensitivity - Base Wind



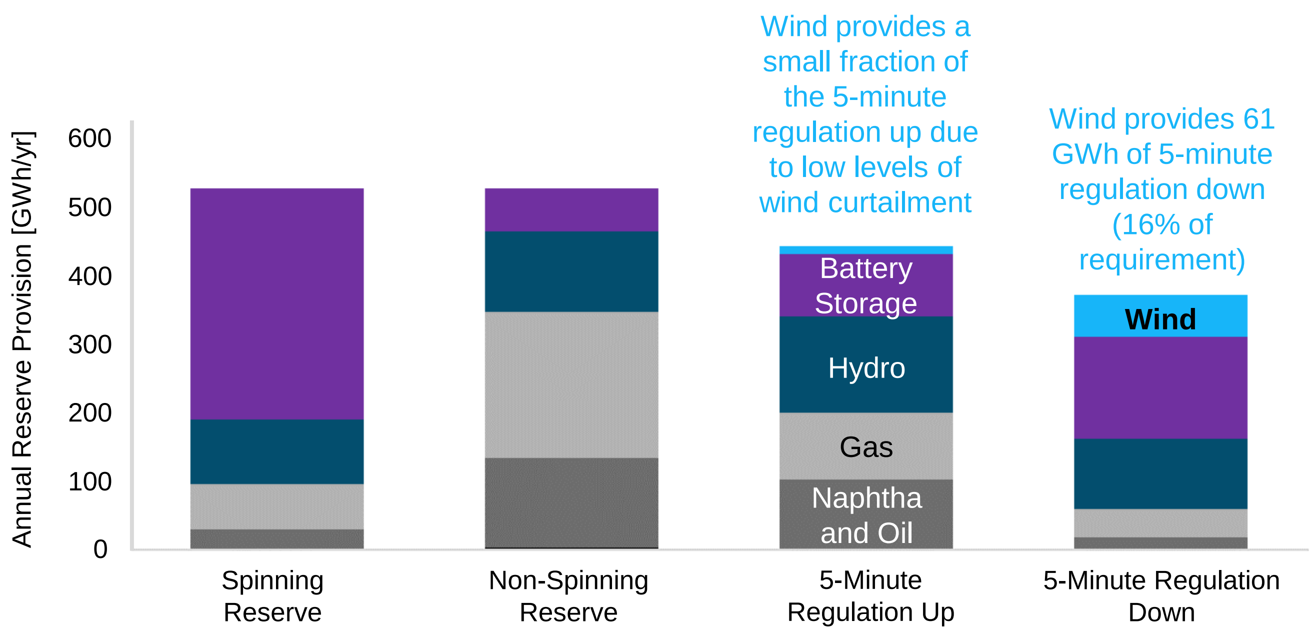
Wind Regulation Sensitivity results discussion

Wind Regulation Sensitivity

- **Wind providing 5-minute regulation has a minimal impact on the generation mix and operational costs – why?**
  - The wind regulation sensitivity focuses narrowly on the value of wind providing within 5-minute balancing. In the Base Wind case, wind provides flexibility by being under-scheduled (i.e. pre-curtailed) in the day-ahead timeframe. Doing so reduces the forecast error reserve that must be provided by other units. The value of under-scheduling wind is captured in the Base Wind case and therefore is not an incremental value in the Wind Regulation Sensitivity.
  - In the near-term, there may be additional operational cost reductions from wind dispatch flexibility relative to those shown here if coordination between Railbelt utilities is not as efficient as it is modeled in this study
  - The impact of wind flexibility depends on the GVEA stability constraints and Central gas nomination limits. These constraints can result in headroom on thermal units for zero or low marginal cost, thereby reducing the benefit observed in the model for other sources of flexibility.
  - To provide regulation *up*, wind must be curtailed. There is minimal wind curtailment in the Base Wind case, implying that there would be infrequent opportunities for wind to provide cost-effective regulation in the upward direction
  - Wind can provide regulation *down* without having to pre-curtail output. The 5-minute regulation down reserve is provided at minimal cost by batteries, hydro, and to a lesser extent thermal resources – there isn't much additional value that results from wind providing regulation down.

How much regulation is provided by wind?

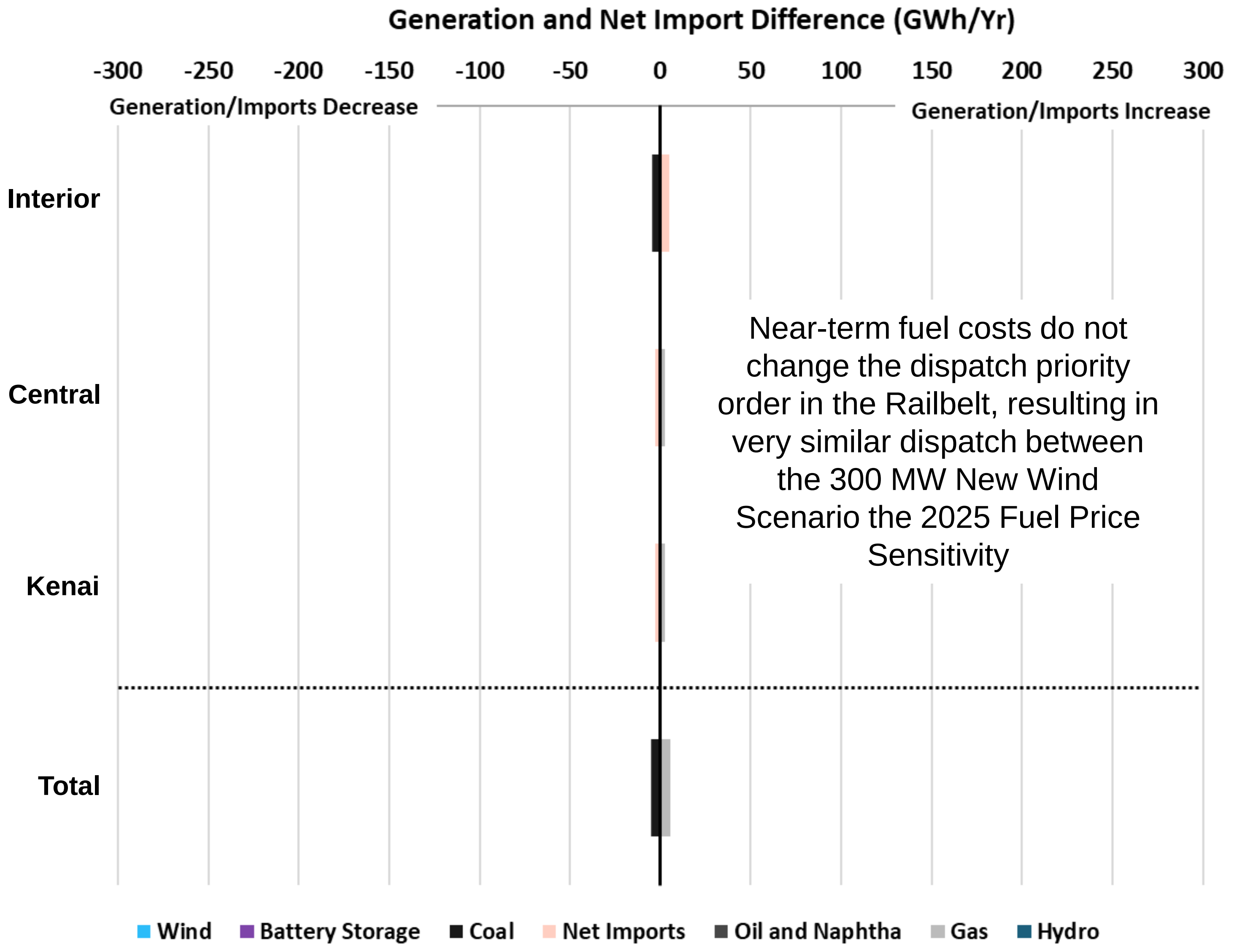
Wind Regulation Sensitivity



2025 Fuel Price Sensitivity

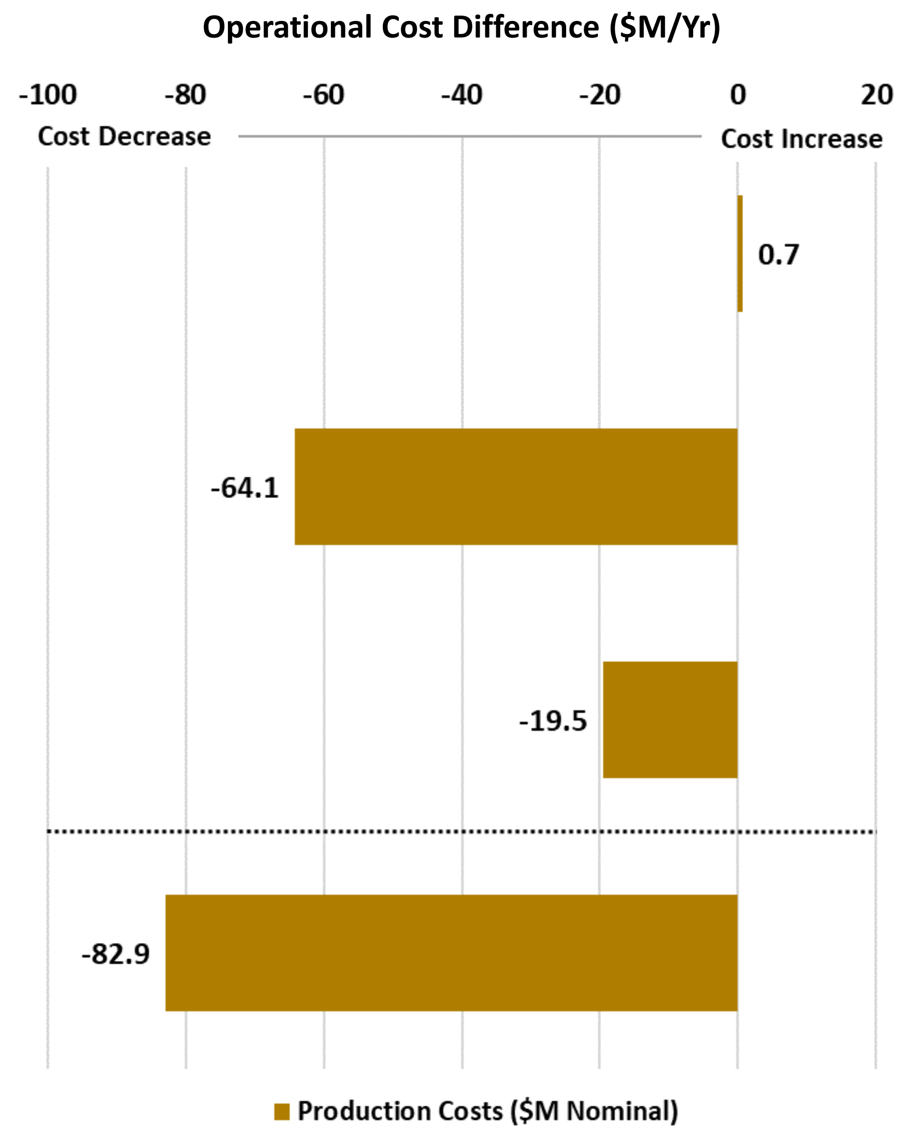
Difference = 2025 Fuel Price Sensitivity - Base Wind

- The 2025 Fuel Price Sensitivity quantifies operational cost reductions from additional wind with lower near-term (2025) fuel prices
- Only the fuel prices (natural gas, coal, oil, naphtha) are adjusted in this sensitivity – all other model assumptions remain the same



No New Wind vs. Base Wind w/ 2025 fuel price

2025 Fuel Price Sensitivity



Difference =
2025 No New Wind –
2025 Fuel Price
Sensitivity

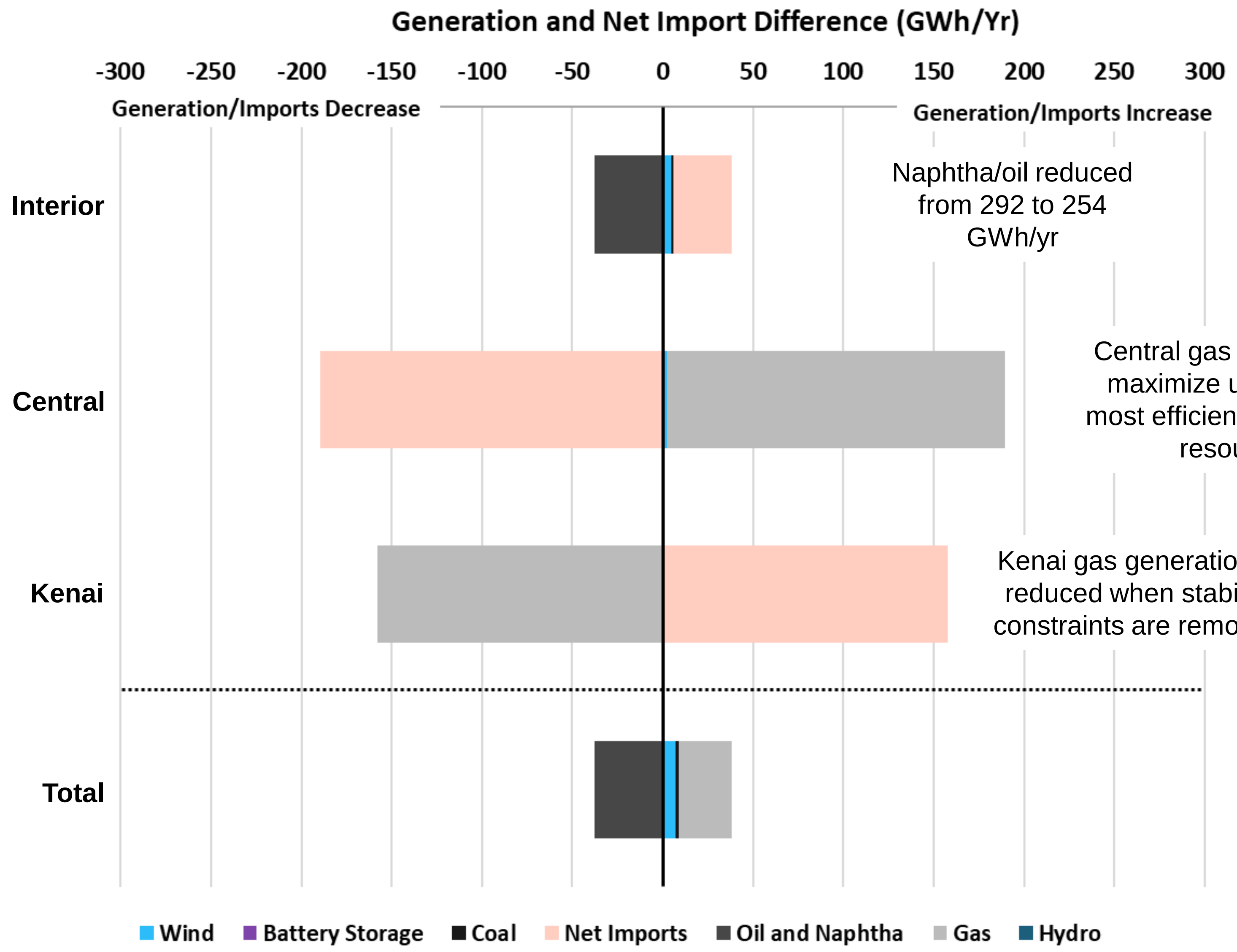
- E3 performed a No New Wind model run with 2025 fuel prices to quantify the operational cost reduction from new wind in 2025.
- Adding 300 MW of wind in the Railbelt results in a cost decrease of $82.9 M/yr using 2025 fuel prices, which is equivalent to an operational cost reduction of $70.2 per MWh of wind production potential.
  - This cost reduction is lower than the 2030 value of $94.8 per MWh of wind production potential.
- Inflation note: the cost figures above are in nominal dollars (i.e. with inflation included). E3 assumes a 2% inflation rate per year (10.0% over the 5 years between 2025 and 2030); the inflation between 2025 and 2030 represents a portion of the difference in cost between the cases.

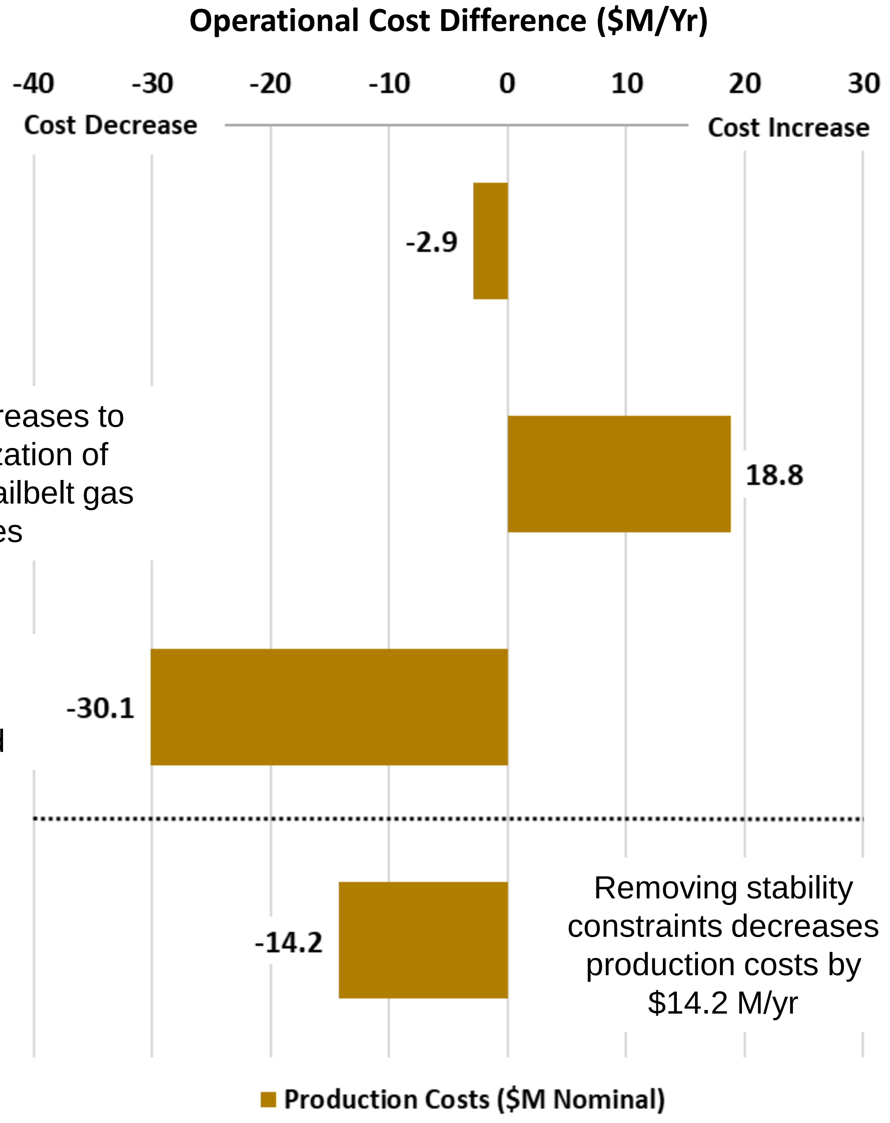
Relax stability constraints sensitivity

- **Stability studies performed by EPS, Inc. identified stability issues (voltage and inertia) when operating the Railbelt grid with low levels of online thermal generation**
- **To ensure system stability, E3 enforces the following generator commitment requirements from the EPS study in all runs except for the Relax Stability Constraints Sensitivity:**
  - GVEA: One North Pole Unit
  - Central: One combined cycle (Southcentral or Sullivan), and a load-varying level of Eklutna Generation Station + Eklutna Hydro units
  - Homer: At least one thermal (Nikiski or Soldotna) and at least two units total (Nikiski, Soldotna, Bradley Hydro Unit1, Bradley Hydro Unit2)
- **The Relax Stability Constraints Sensitivity removes (i.e. does not enforce) the stability commitment rules described above**
- **The Relax Stability Constraints Sensitivity identifies possible operational cost reductions if the stability-related grid services (voltage and inertia) could be provided without thermal commitments (i.e. from batteries, wind, power electronics, synchronous condensers etc.)**
  - This study does not investigate the feasibility of maintaining stability with minimal levels of thermal commitment, nor does it quantify costs of enabling voltage or inertia-related capabilities of non-thermal resources.

How do stability constraints impact the generation mix and costs?

Difference = Relax Stability Constraint Sensitivity - Base Wind





Energy+Environmental Economics

Numeric results appendix

Generation: All Cases

GWh

	No New Wind	Base Wind	Transmission Reinforcement	Kenai Tie Outage	Gas Scheduling Flexibility	Commit All Day-Ahead	GVEA Battery Replacement	Wind Regulation	No New Wind 2025 Fuel Price	2025 Fuel Price	Relaxed Stability Requirement
Wind	132	1,299	1,308	1,297	1,309	1,196	1,305	1,298	132	1,298	1,306
Battery Storage	(0)	(2)	(2)	(2)	(1)	(1)	(2)	(2)	(0)	(2)	(2)
Hydro	658	658	658	654	658	658	658	658	658	658	658
Gas	3,230	2,089	2,161	2,095	2,086	2,194	2,112	2,089	3,233	2,094	2,118
Oil and Naphtha	295	292	209	292	267	292	273	293	293	291	254
Coal	413	393	394	392	409	389	383	392	413	389	394

Operational Costs: All Cases

All in nominal $ million

	No New Wind	Base Wind	Transmission Reinforcement	Kenai Tie Outage	Gas Scheduling Flexibility	Commit All Day-Ahead	GVEA Battery Replacement	Wind Regulation	No New Wind 2025 Fuel Price	2025 Fuel Price	Relaxed Stability Requirement
Total	459.5	347.7	335.2	348.8	334.0	362.2	339.1	347.4	348.5	265.7	333.4
GVEA	85.3	86.4	74.4	86.4	82.6	91.8	79.4	86.4	71.4	72.1	83.5
Central	317.5	230.9	204.2	230.3	214.2	248.2	223.9	230.5	235.2	171.1	249.7
Homer	56.7	30.3	56.6	32.1	37.1	22.2	35.7	30.5	41.9	22.4	0.2

Emissions: All Cases

Million metric tonne

	No New Wind	Base Wind	Transmission Reinforcement	Kenai Tie Outage	Gas Scheduling Flexibility	Commit All Day-Ahead	GVEA Battery Replacement	Wind Regulation	No New Wind 2025 Fuel Price	2025 Fuel Price	Relaxed Stability Requirement
Total	1.99	1.50	1.54	1.52	1.45	1.54	1.49	1.50	1.99	1.52	1.53
GVEA	0.66	0.65	0.61	0.65	0.65	0.66	0.62	0.65	0.66	0.64	0.64
Central	1.14	0.83	0.74	0.83	0.77	0.88	0.81	0.83	1.14	0.83	0.90
Homer	0.19	0.03	0.19	0.05	0.03	0.00	0.07	0.03	0.19	0.05	0.00

Fuel Consumption: All Cases

Billion BTU

	No New Wind	Base Wind	Transmission Reinforcement	Kenai Tie Outage	Gas Scheduling Flexibility	Commit All Day-Ahead	GVEA Battery Replacement	Wind Regulation	No New Wind 2025 Fuel Price	2025 Fuel Price	Relaxed Stability Requirement
Natural Gas (Central)	20,741	14,955	13,263	14,940	13,789	15,896	14,555	14,933	20,758	14,960	16,259
Natural Gas (Homer)	3,778	2,010	3,776	2,132	2,417	1,478	2,379	2,021	3,789	2,031	16
Oil and Naphtha	2,285	2,362	1,863	2,366	2,179	2,599	2,120	2,364	2,273	2,358	2,219
Coal	5,147	4,959	4,975	4,950	5,113	4,925	4,842	4,953	5,144	4,915	4,974
Landfill Gas	818	752	774	744	816	731	762	747	818	745	756