2019 TAG Meeting #5: Resource adequacy and gas planning standard

PUGET SOUND ENERGY

February 7, 2019 TAG #5

Welcome

- Opening remarks
- Safety message
- Introductions

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Meeting objectives

- PSE provides TAG members an opportunity for a resource adequacy dialogue focusing on the following:
  - The Northwest Power and Conservation Council's (NWPCC) power supply adequacy assessment
  - PSE's electric capacity need and effective load carrying capacity
  - Energy+Environmental Economics' (E3) results from a Pacific Northwest resource adequacy study
- PSE presents the gas planning standard

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Action items from prior IRPAG and TAG meetings

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Open action items from previous IRPAG and TAG meetings

Action item #	Description (and meeting reference)	PSE action	Status
1	Identify contact for PSE's carbon reduction goals. (IRPAG #1, May 30, 2018)	PSE will include a listening session at the March 18, 2019 IRPAG meeting #3.	In progress
2	Include carbon impact in scenarios or sensitivities. (IRPAG #1, May 30, 2018 and TAG #2, October 11, 2018)	PSE will model various carbon impacts.	In progress
3	Investigate converting the gas emission rate to a percentage. (TAG #2, October 11, 2018 and TAG #3, December 6, 2018, and January 9, 2019)	PSE will include gas emission rate as a percentage and details on methodology in the draft IRP and final IRP. PSE will consider distributing the details before the draft IRP.	In progress*

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*Note: * denotes items that will be included in the draft and final IRP.*

Open action items from previous IRPAG and TAG meetings

Action item #	Description (and meeting reference)	PSE action	Status
4	Provide a description of the difference between the 2017 and 2019 combined heat and power potential prior to the May 15, 2019 Draft IRP. (TAG #3, December 6, 2018)	PSE will provide the description by March 29, 2019.	In progress
5	Follow up with a TAG member regarding posting communication received prior to the revision of TAG guidelines. (TAG #3, December 6, 2018, TAG #4, January 9, 2019)	Irena Netik reached out to the TAG member by phone and the communication identified will be posted to www.pse.com/irp.	In progress
6	Consider methodology for posting TAG questions and answers publicly. (TAG #4, January 9, 2019)	PSE is still considering this request and developing a proposal for a communication approach.	In progress

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Open action items from previous IRPAG and TAG meetings

Action item #	Description (and meeting reference)	PSE action	Status
7	Include E3's regional resource adequacy study at a future TAG meeting. (TAG #4, January 9, 2019)	Resource adequacy will be discussed at TAG #5 on February 7, 2019 and will include E3's regional resource adequacy study.	In progress
8	Host a presentation on the Energize Eastside project and invite TAG members. (TAG #4, January 9, 2019)	The presentation is being planned and will be communicated to TAG members.	In progress
9	Consider providing an energy efficiency dialogue around policy and implementation of energy efficiency. (TAG #4, January 9, 2019)	PSE is still developing a proposed approach.	In progress

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Open action items from previous IRPAG and TAG meetings

Action item #	Description (and meeting reference)	PSE action	Status
10	Add line miles and project status to the planned major projects list and include cost ranges. (TAG #4, January 9, 2019)	To be included in the draft IRP and final IRP. Cost ranges will be included if publically available.	In progress*
11	Include several previous IRP load forecasts in the IRP and compare those forecasts to actuals for multiple years. (TAG #4, January 9, 2019)	To be included in the draft and final IRP.	In progress*
12	Convert the gas planning standard into the electric planning standard equivalent. (TAG #4, January 9, 2019)	PSE reconsidered this request and instead will be highlighting the differences in the standards at TAG #5.	In progress

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*Note: * denotes items that will be included in the draft and final IRP.*

Open action items from previous IRPAG and TAG meetings

Action item #	Description (and meeting reference)	PSE action	Status
13	Verify the calculation used to develop the EV load as a percentage of load in 2035. (TAG #4, January 9, 2019)	To be included in the draft IRP and final IRP.	In progress*
14	Share draft generic resource assumptions with the TAG prior to the February 9 TAG meeting. (TAG #4, January 9, 2019)	Distributed to TAG members prior to the February 9 TAG meeting #5.	Complete*
15	Share a comparison of the 2017 IRP electric resource costs with the 2019 IRP electric resource costs prior to the February 9 TAG meeting (TAG #4, January 9, 2019)	Distributed to TAG members prior to the February 9 TAG meeting #5.	Complete*

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*Note: * denotes items that will be included in the draft and final IRP.*

Open action items from previous IRPAG and TAG meetings

Action item #	Description (and meeting reference)	PSE action	Status
18	Add a recommendation for time-of-day rate analysis to the 2019 IRP action plan. (TAG #4, January 9, 2019)	PSE will add a recommendation for time-of-day rate analysis to the 2019 IRP action plan.	In progress*
19	Develop responses to NWEC's questions concerning TAG #3 material. (TAG #4, January 9, 2019)	PSE answered NWEC's questions on January 15, 2019.	Complete

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*Note: * denotes items that will be included in the draft and final IRP.*

Open action items from previous IRPAG and TAG meetings

Action item #	Description (and meeting reference)	PSE action	Status
20	Distribute reliability data to TAG members as provided to the WUTC prior to the February 9 TAG meeting. (TAG #4, January 9, 2019)	Provided to TAG members on January 23 via email. The report is available at: https://www.utc.wa.gov/regulatedIndustries/utilities/energy/Pages/electricReliabilityReports.aspx	Complete
21	Finalize meeting notes from TAG #4. (TAG #4, January 9, 2019)	PSE distributed meeting notes on January 23; stakeholders provide feedback by January 30; PSE will post the final meeting notes to www.pse.com/irp on February 6, 2019.	In progress

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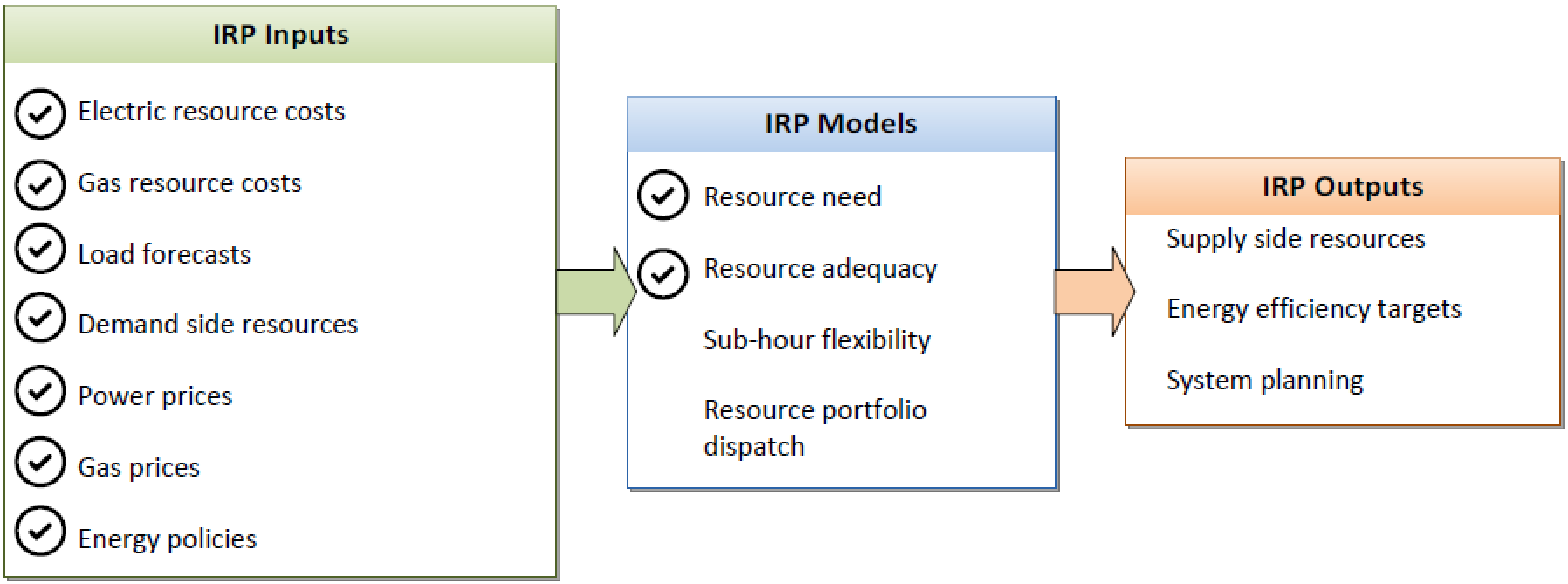
IRP analytical process overview

- PSE has established an analytical framework to develop its **20-year forecast of demand side resources and supply side resources** that appear to be cost effective to meet the growing needs of our customers.



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Overview of electric resource adequacy

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February 7, 2019 TAG #5

Importance of resource adequacy

Key questions:

- How much peak capacity is needed to meet peak planning standards?
- How will different kinds of resources contribute to meet the planning standards?

Resource adequacy modeling

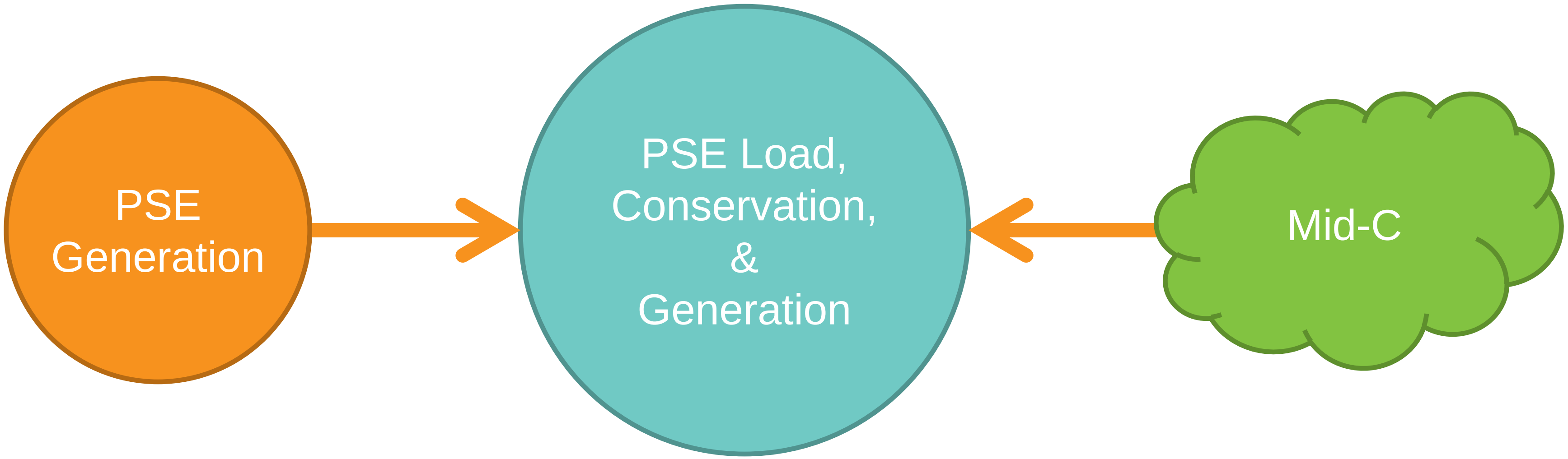
Statistical analysis to ensure that adequate generation resources are available to meet demand

Thousands of scenarios to capture combined effects of uncertainty from several sources

- Temperature/hydro conditions, forced outages, renewable generation, market via regional resource adequacy, macroeconomic forces…

Resources are added to meet ensure that PSE plans system to reliability criteria

PSE's portfolio



Firm transmission to Mid-C power trading hub for short-term capacity market purchases is treated as a resource.

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Planning for resource adequacy

Regional planning standard: 5% LOLP

- Used by Northwest Power and Conservation Council (NWPCC)
- Consistent with WUTC guidance in 2015 IRP

What does this mean?

- Loss of load probability of any firm shortage in a given year, e.g., net demand exceeds firm supply in at least one hour
- 5% is a one-in-twenty chance in a given year
- Does not reflect magnitude or duration of shortages

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Visualizing reliability standards

- Imagine planning for road maintenance
- Standard: 5% chance of tire-damaging pothole or worse in a given year

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Visualizing reliability standards

- Hairline cracks can be easily repaired with sealant
- Important to observe, but not an immediate concern

Visualizing reliability standards

- Most potholes can be repaired by filling with asphalt/concrete…

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Visualizing reliability standards

- … road collapse may not be solved by additional asphalt/concrete alone

Visualizing reliability standards

- Loss of load (road?) probability (LOLP) → chance of road having at least one pothole or worse in a given year

Counted equally!

Visualizing reliability standards

Each box = 33.3% LOLP due to road loss in left-most cases

Visualizing reliability standards

- Expected unserved energy (EUE) → average volume of road lost by pothole or worse in a given year

- EUE is then 1/3 of volume of road collapse in first scenario
- LOLP is 33.3% because only one scenario has road loss

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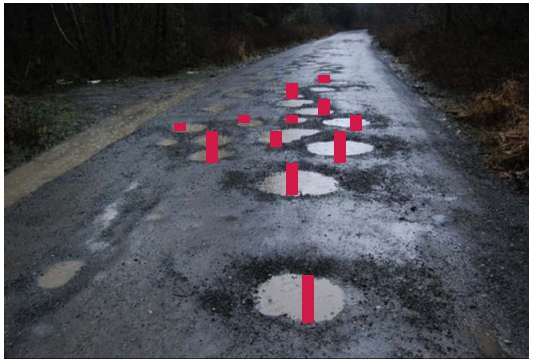
Visualizing reliability standards

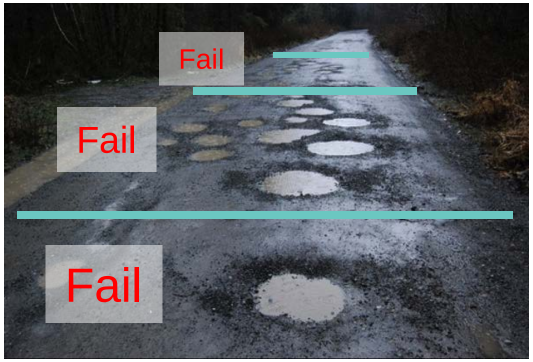
Loss of Load Hours (LOLH):

Average width of all potholes per road



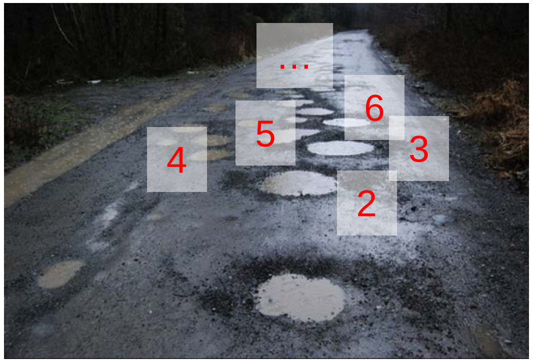
Loss of Load Expectation (LOLE):

Expected number of road segments with potholes per road



Loss of Load Events (LOLEV):

Average number of potholes per road



Visualizing reliability standards

- How does this relate to power system reliability?

Condition	Characterization	Power System
Hairline cracks	No immediate need to patch – transparent to user	Can use operating reserves for the first hour of an event
Potholes	Low time duration, shallow outages	May be able to patch up with energy-limited resources
Road collapse	Prolonged outages	Probably better to enhance structurally (baseload)

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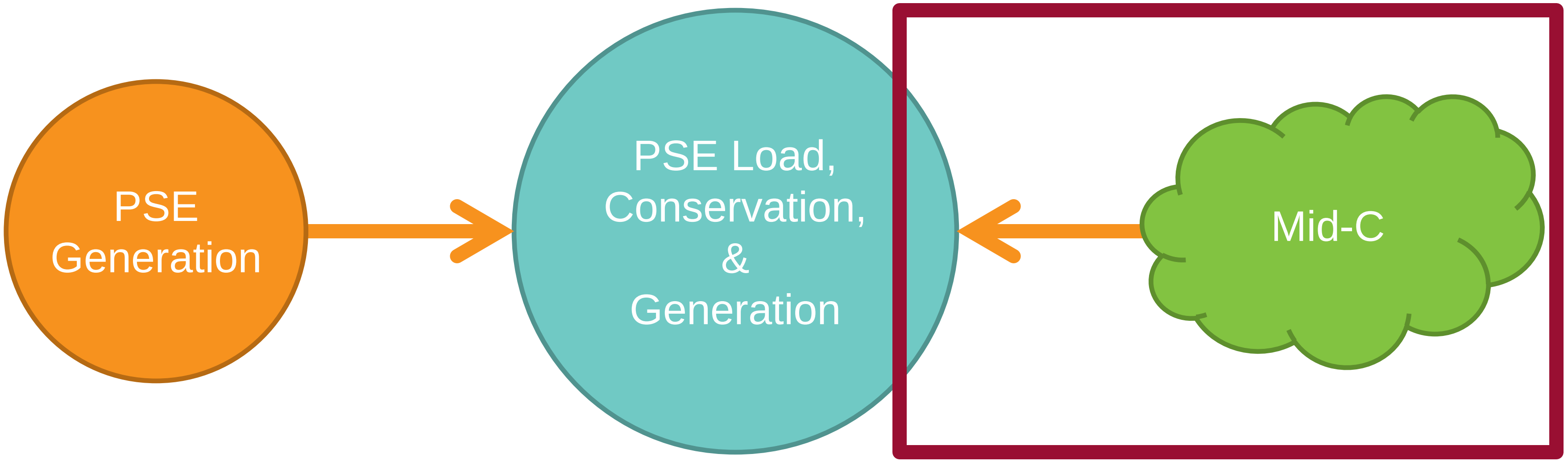
PSE's portfolio



PSE currently relies on 1500 MW of firm transmission to Mid-C for peak planning, so adequacy of region is critical.

Regional electric adequacy assessment

February 7, 2019 TAG #5

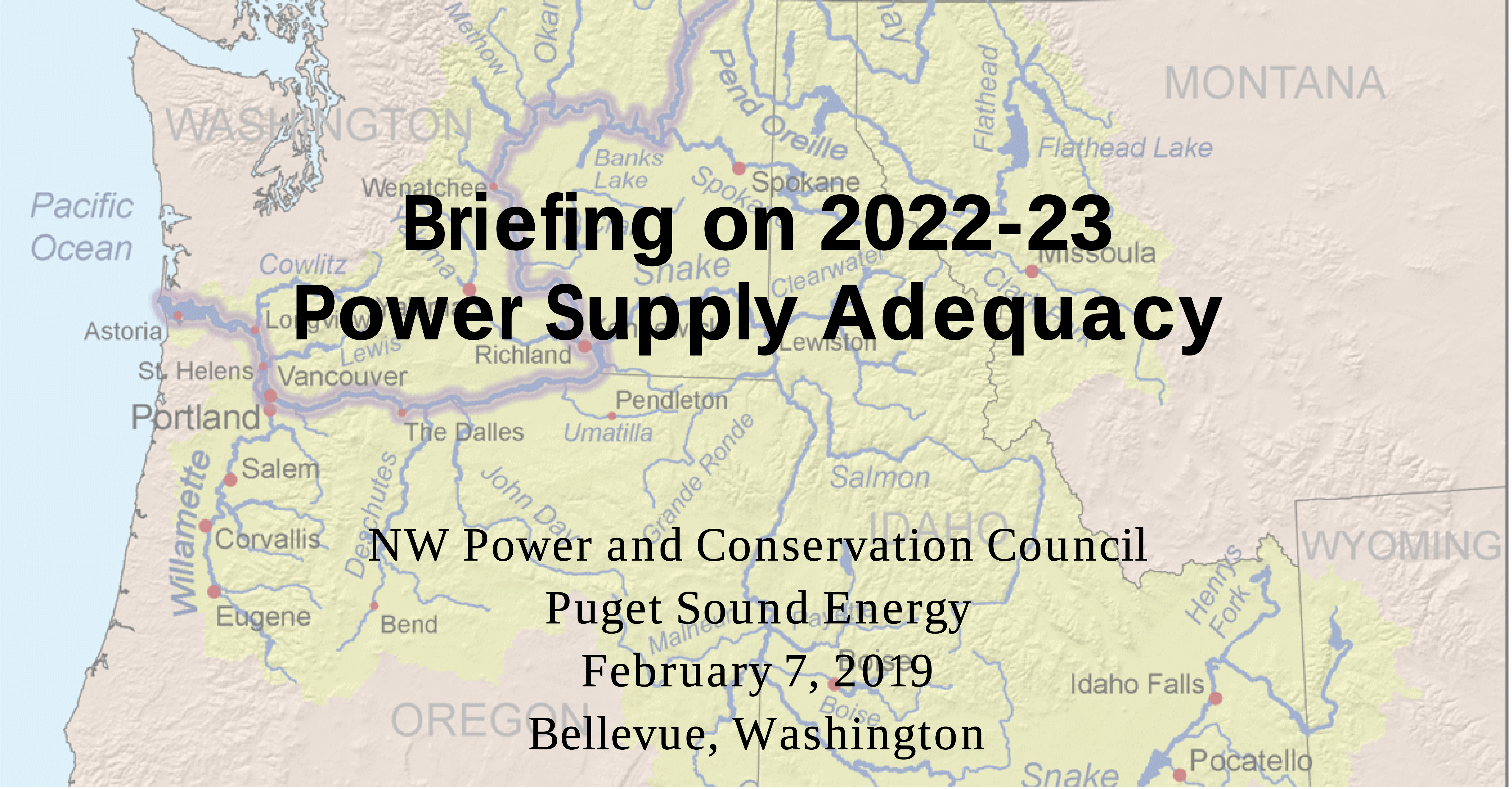
Briefing on 2022-23 Power Supply Adequacy

NW Power and Conservation Council

Puget Sound Energy

February 7, 2019

Bellevue, Washington



2023 and 2035 Load Forecasts

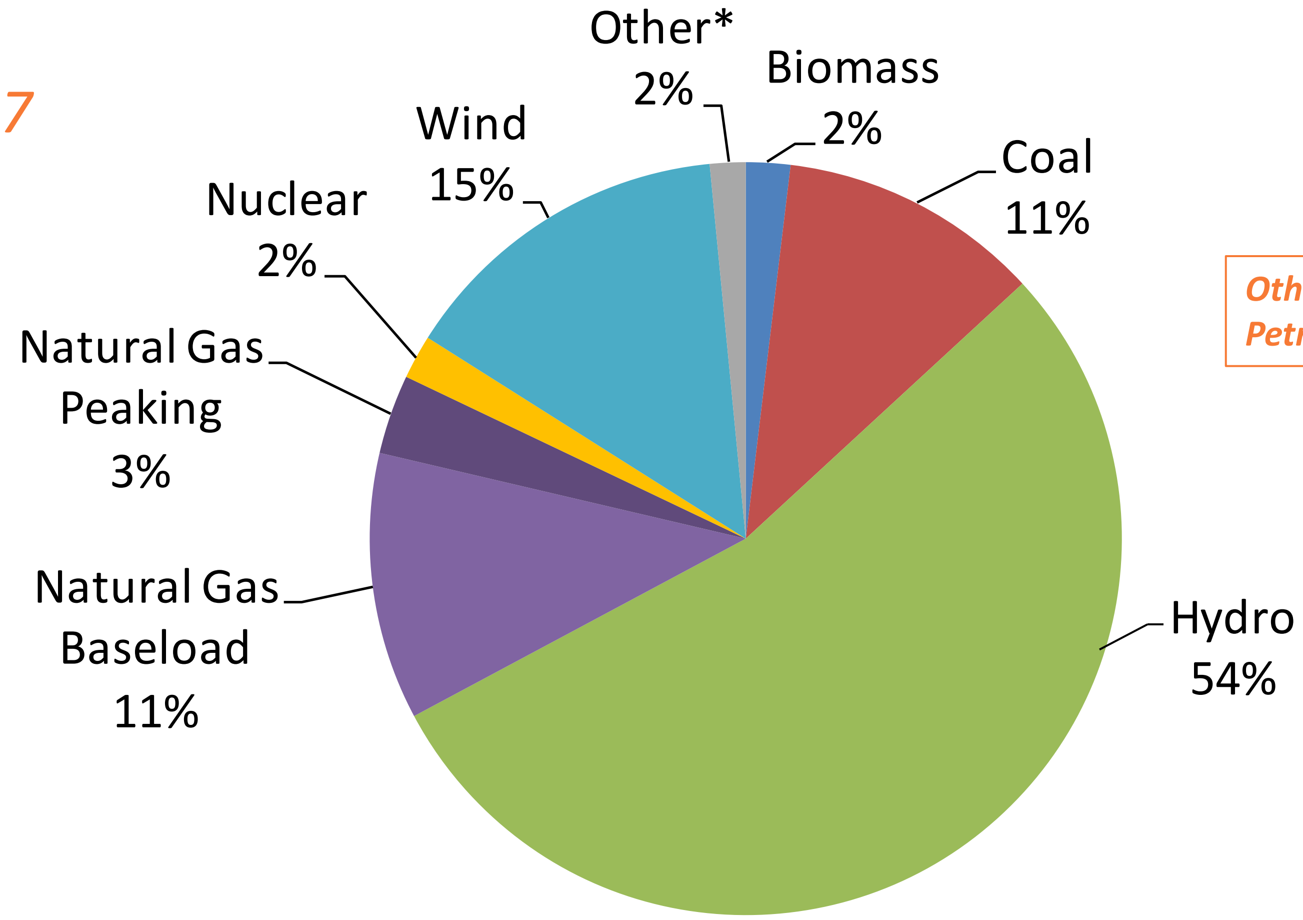
Load[1]	2023	2035
Annual average load (aMW)	21,353	21,487
Winter average peak (MW)	33,649	33,437
Summer average peak (MW)	26,755	27,535

Annual Average Growth Rates (%) 2016 through 2035 (7th Power Plan)	With EE	No EE
Low	-0.043	0.59
Med	-0.030	0.89
High	0.27	1.12

[1]2023 and 2035 load forecasts based on newer data than the 7th plan forecasts and growth rates.

Resource Nameplate Capacity (63,500 MW)

2017



Other* - Geothermal, Petroleum, Solar, Storage

Large Coal Plants Serving NW Load[1]

Plant Name	Capacity (MW)	2023	2035
Boardman	522	Out	Out
Centralia 1	670	Out	Out
Centralia 2	670	In Service	Out
Colstrip 1	154	Out	Out
Colstrip 2	154	Out	Out
Colstrip 3	518	In Service	In Service
Colstrip 4	681	In Service	In Service
Bridger 1	530	In Service	In Service
Bridger 2	530	In Service	In Service
Bridger 3	530	In Service	In Service
Bridger 4	530	In Service	In Service

[1]Jim Bridger plants 1 and 2 may be retired prior to 2035.

Market Availability from the Southwest[1]

Month	SW Surplus (MW)	S-to-N Tie Cap 95th Percentile	Available to NW (MW)
Jan	16,529	3,425	3,425
Feb	15,937	3,425	3,425
Mar	17,316	2,450	2,450
Oct	21,923	2,450	2,450
Nov	20,264	3,425	3,425
Dec	17,929	3,425	3,425

[1]SW surplus estimated by Energy GPS consultants. South-to-North intertie capacity provided by BPA. For adequacy assessment market supply was limited to 2500 MW during winter months only.

Resource Adequacy Assessments

Year	LOLP	Retired Plants
2018-20	< 5%	
2021	6+%	Boardman, Centralia 1
2022	7%	Colstrip 1 & 2, Pasco and N Valmy 1
2023	7%	
2035[1]	9%	Centralia 2

[1]Retirement of Bridger 1 & 2 (1,060 MW) would significantly increase LOLP.

2023 LOLP Heat Map (%)

SW Import (MW)	1500	2000	2500	3000[1]
High Load (+2%)	14.3	12.1	10.1	7.8
Med Load	11.0	8.6	6.9	5.1
Low Load (-2%)	8.0	6.4	4.9	3.5

[1]The “3000 MW import” case represents the maximum amount of market import capability from California. This is based on the Bonneville Power Administration’s recommendation to use 3400 MW as the maximum S-to-N transfer capability for the transmission interties and accounts for approximately 400 MW of space required for firm capacity imports.

2023 Estimated[1] Capacity Need (MW)

SW Import (MW)	1500	2000	2500	3000
High Load (+2%)	1650	1500	1100	600
Med Load	1400	1050	650	50
Low Load (-2%)	950	550	0	0

[1]The amount of additional capacity needed in 2023 to maintain adequacy (i.e. an LOLP of 5%) is estimated by using a surrogate dispatchable resource, in this case a combined cycle combustion turbine. GENESYS studies were run for the "2500 MW import medium load" case and for the "1500 MW import high load" case to estimate nameplate capacity needed to get to 5% LOLP. Other values were estimated using linear interpolation and are rounded to the nearest 50 MW.

Potentially Available Resources

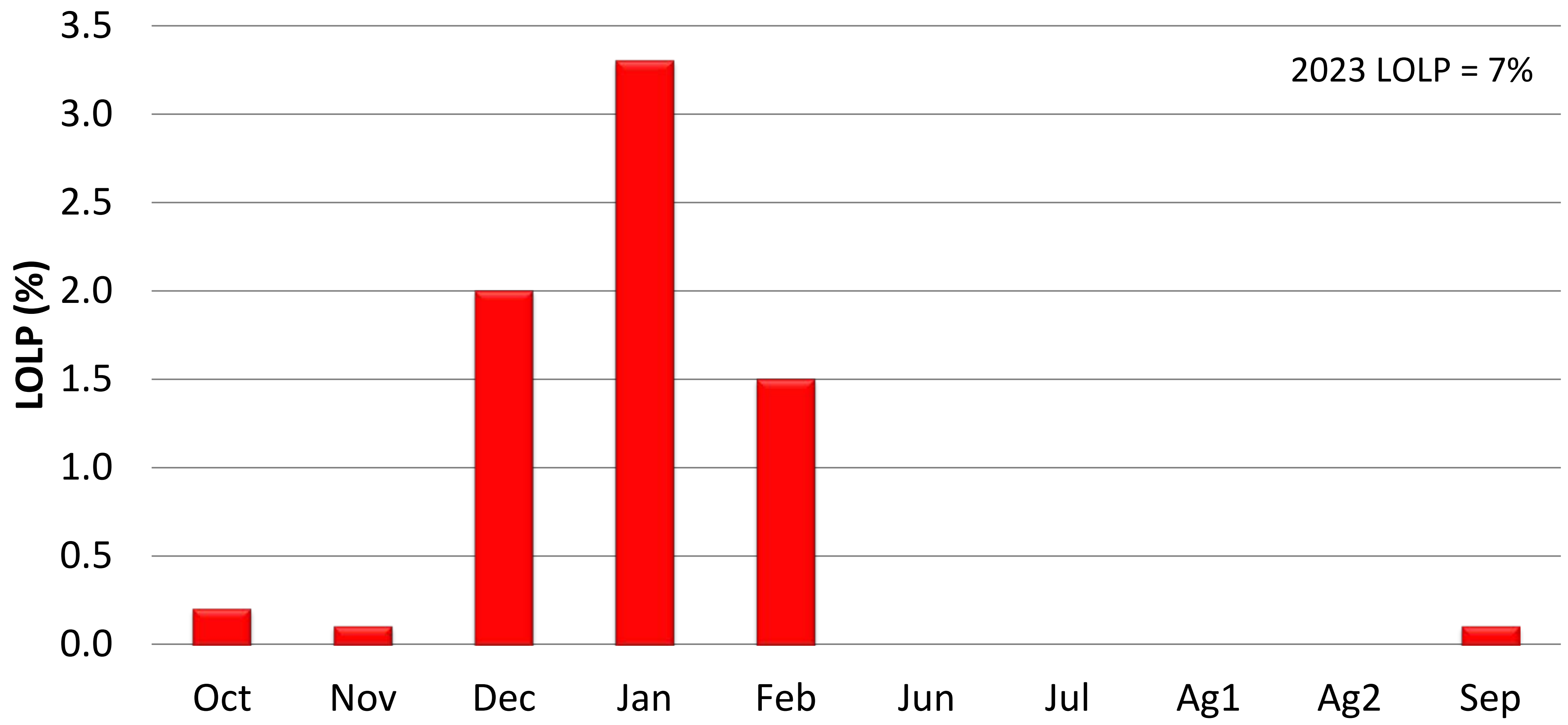
Source: PNUCC 2018 NRF, Table ES-1 Planned Resources

Nameplate (MW)	**2021**	**2022**	**2023**
Solar	0	266	266
Hydro	29	29	29
Wind	540	540	540
Capacity[1]	809	809	809
Battery	39	39	89
Demand Response[2]	400		

[1]Fuel source is unspecified.

[2]Available demand response for 2021 is the potential estimated in the Council's 7th power plan minus DR already implemented.

2023 Monthly LOLP[1]



[1]Sum of monthly LOLP values is equal to or greater than the annual LOLP value because curtailments across multiple months can occur in the same year.

Simulated Curtailment Statistics

Statistic	Value	Comments
Events per year	0.14	1.4 events per 10 years
Frequency of events	1 per every 7 years	Common standard 1 in 10 years
Average event duration	21 hours	16 hours most frequent duration[1]
Average event magnitude	42,500 MW-hours	≈ 2000 MW/hour over 21 hours
Average annual shortfall	≈ 6000 MW-hours	42,500 MW-hours once every 7 years
Average shortfall hours/year	3.0 hours	21 hours once every 7 years

[1]Anticipated shortfalls are spread over the WECC-defined peak hours of the day (16 hours) using hydro storage in order to minimize impacts and facilitate solutions.

Temperature Sensitivity Studies
(Medium Load, 2500 SW Import)

Temp Years >>>	Ref Case 1929-2016	1929-2005	1987-2016
LOLP (%)	6.9	7.3	7.3
CVAR_E (MW-Hour)	121883	122915	87118
CVAR_P (MW)	3216	3192	3297
EUE (MW-Hour)	6190	6253	4522
LOLH (Hour)	3.0	3.1	2.5
LOLEV (Event/year)	0.14	0.15	0.12
Capacity Needed[1] (MW)	650	660	930

[1]Capacity needed is the amount of added capacity required to reduce the peak-hour curtailment duration curve LOLP to 5%, divided by the CCCT associated system capacity contribution (about 1.9).

2023 NERC Adequacy Metrics

Metric	Definition
LOLEV (events/year)	**Loss of load events** = Total events divided by total number of games (event = contiguous set of curtailment hours)
EUE (MW-hours)	**Expected Unserved Energy** = Total curtailment energy divided by the total number of games
NEUE (ppm)	**Normalized Expected Unserved Energy** = EUE divided by average annual load in MW-hours times 1,000,000
LOLH (hours/year)	**Loss of load hours** = Total curtailment hours divided by total number of games

SW Import (MW)	1500	2000	2500	3000	3500
LOLEV (events/year)	0.28	0.20	0.14	0.10	0.07
EUE (MW-hours)	11,450	8,440	6,190	3,908	2,516
NEUE (ppm)	61	45	33	21	13
LOLH (hours/year)	5.1	3.9	3.0	1.9	1.3

While NERC is NOT likely to establish metric thresholds (i.e. a standard), a commonly accepted threshold for LOLEV is 1-event-in-10 years or LOLEV = 0.1

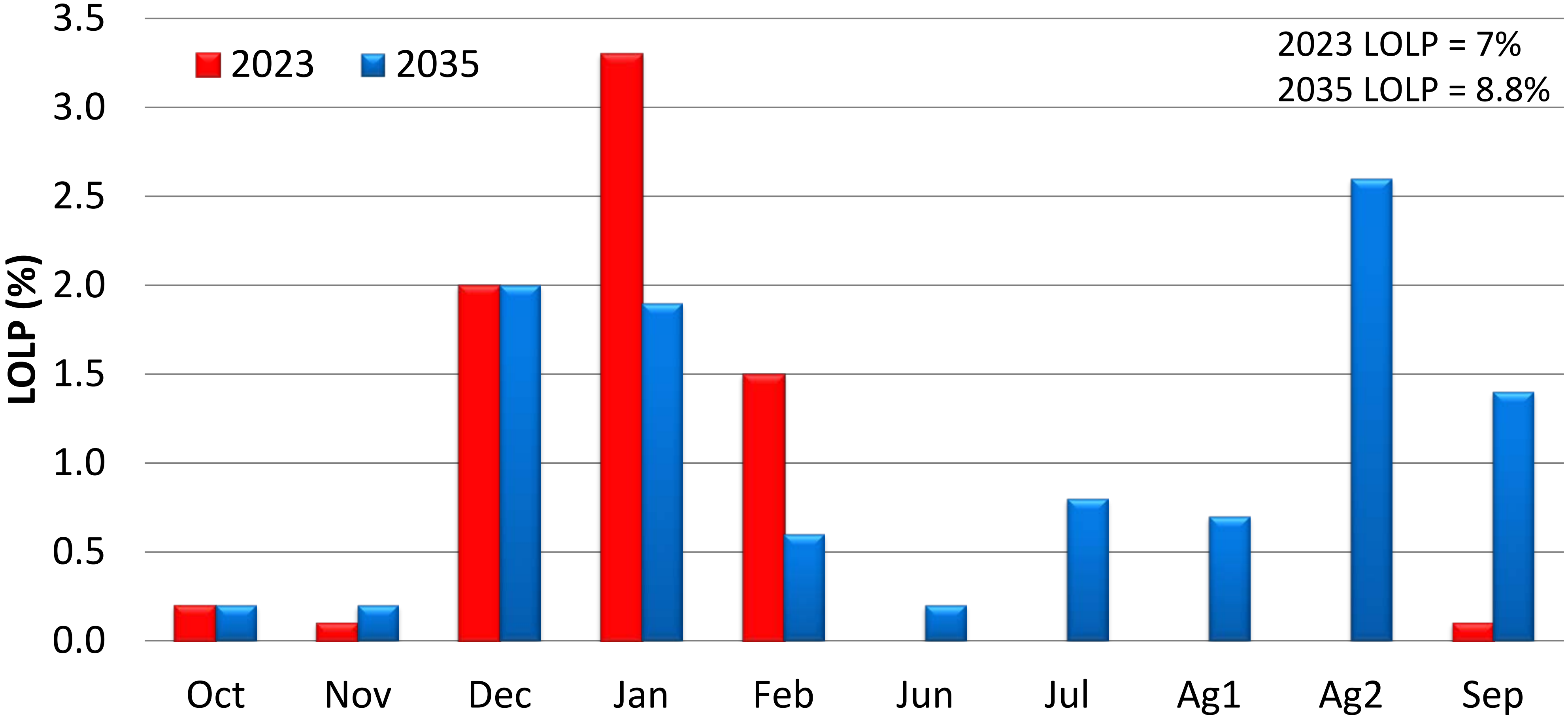
2023 and 2035 Adequacy Metrics

(Medium Load, 2500 SW Import, no new resources)

	2023	2035
LOLP (%)	6.9	8.8
LOLH (Hour)	3.0	2.3
LOLEV (Event/year)	0.14	0.18
EUE (MW-hours)	6,190	3,150
Capacity Needed (MW)[1]	650	750

[1]Capacity needed for adequacy only increases by 100 MW even though Centralia 2 (630 MW) is retired by 2035. This is partially due to the shift in loads, with summer peaks growing more rapidly than winter peaks, reflecting different needs in the summer. Also, the characteristics of potential shortfalls change with lower duration (LOLH) and magnitude (EUE) but slightly higher frequency (LOLEV).

2023 and 2035 Monthly LOLP[1]



[1]Sum of monthly LOLP values is equal to or greater than the annual LOLP value because curtailments across multiple months can occur in the same year.

Appendix

Biomass Resources (MW)

Biomass One 1 & 2	25
Clearwater Paper 1	75
Freres Lumber (Evergreen)	10
Georgia-Pacific	32
Georgia-Pacific Cons	52
H.W. Hill (Roosevelt	10
H.W. Hill Expansion	26
International Paper	22
Kettle Falls Generat	50.7
Nippon Paper Industr	18
Seneca Saw Mill	18.9
Spokane Waste-to-Energy	21
Misc Biomass Resources	28.3

Coal Resources (MW)

Boardman	522
Centralia 1	670
Centralia 2 (PSE)	380
Colstrip 1	154
Colstrip 2	154
Colstrip 3	518
Colstrip 4	680.8
Hardin Generating St	119
Jim Bridger 1	530
Jim Bridger 2	530
Jim Bridger 3	530
Jim Bridger 4	530
North Valmy 1	127
North Valmy 2	134
Yellowstone Energy	6.8

Gas Resources (MW)

Alden Bailey	11	Highwood Generating	14
Basin Creek 1 - 9	16.5	Kettle Falls GT	11
Beaver 1 - 7	521	Lancaster (Rathdrum	281
Beaver 8	24	Langley Gulch	330
Bennett Mountain	180	March Point 1 - 4	145
Boulder Park 1-6	25	Mill Creek/Dave Gate	46.5
Carty Generating Sta	440	Mint Farm	303
Chehalis Generating	514	Northeast 1	31
Coyote Springs 1	242	Northeast 2	31
Coyote Springs 2	291	Port Westward 2	219.6
Danskin (Evander And	180	Port Westward CC 1A	402
Danskin (Evander And	46.5	Rathdrum (Boekel Rd)	83
Danskin (Evander And	46.5	Rathdrum (Boekel Rd)	83
Encogen 1-4	179	River Road Generation	235
Frederickson 1	79.5	Rupert Cogeneration	10
Frederickson 2	79.5	Salmon 1	2.8
Frederickson Power 1	249.4	Salmon 2	2.8
Fredonia 1	111	Sumas Cogeneration S	125
Fredonia 2	111	Tenaska Washington P	245
Fredonia 3	58.5	U.S. Bankcorp IC1 -	6.4
Fredonia 4	58.5	U.S. Navy (Puget Sou	12
Glenns Ferry Cogener	10	U.S. Navy (Submarine	10
Goldendale CC 1A & 1	289	Whitehorn Generating	59.5
Hermiston Generating	236	Whitehorn Generating	59.5
Hermiston Generating	236		

Other Resources (MW)

Nuclear	Capacity	Type
Columbia Generating	1150	
Geo Thermal		
Neal Hot Springs	28.5	
Raft River	13	
Independent Power Plants		
Centralia 1	670	Coal
Centralia 2	290	Coal
Gray's Harbor	650	Gas
Hermiston Power	630	Gas
Klamath Cogeneration	585	Gas

Lunch break

PSE electric capacity need and planning margin (planning standard)

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PSE’s resource adequacy modeling

Calculate capacity needed for 5% LOLP

- Align with most recent NWPCC Adequacy Assessment
- Update PSE resources and contracts
- Capacity need is basis of planning “reserve” margin for portfolio modeling

Determine peak capacity contributions for new resources

- ELCC—Effective Load Carrying Capability
- Input to portfolio model

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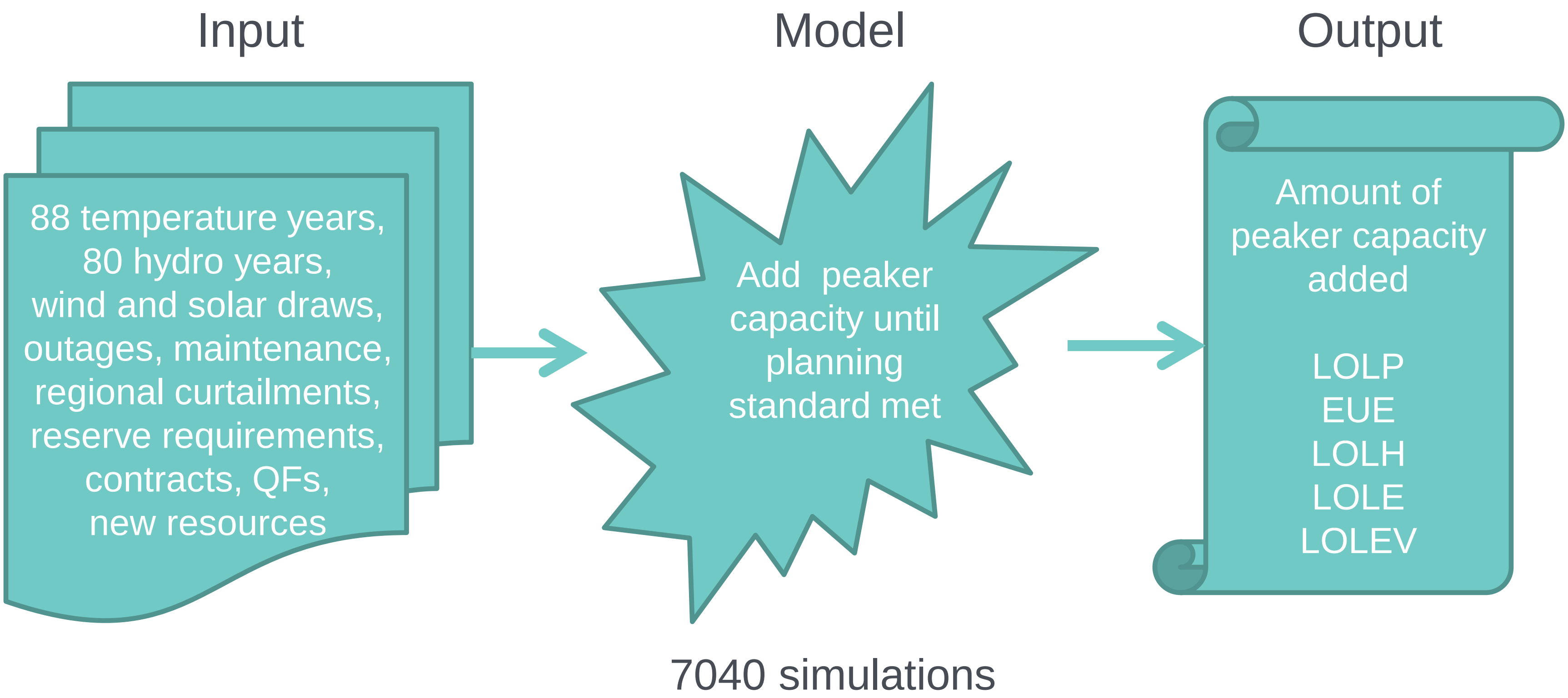
Model framework



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Reasonableness of Historic Temp Data

1987-2016 Coldest temp during peak hours: 10° F

1929 to 1986 number of peak hours: 138,624 hours

1929 to 1986 number of peak hours colder than 10° F: 14 hours

Data set shows…

Likelihood of temperature being colder than 1987 – 2016: 0.01%

Conclusion

- In PSE’s analysis, it is possible, but highly unlikely that we would experience temperatures as extreme as in 1949/50.

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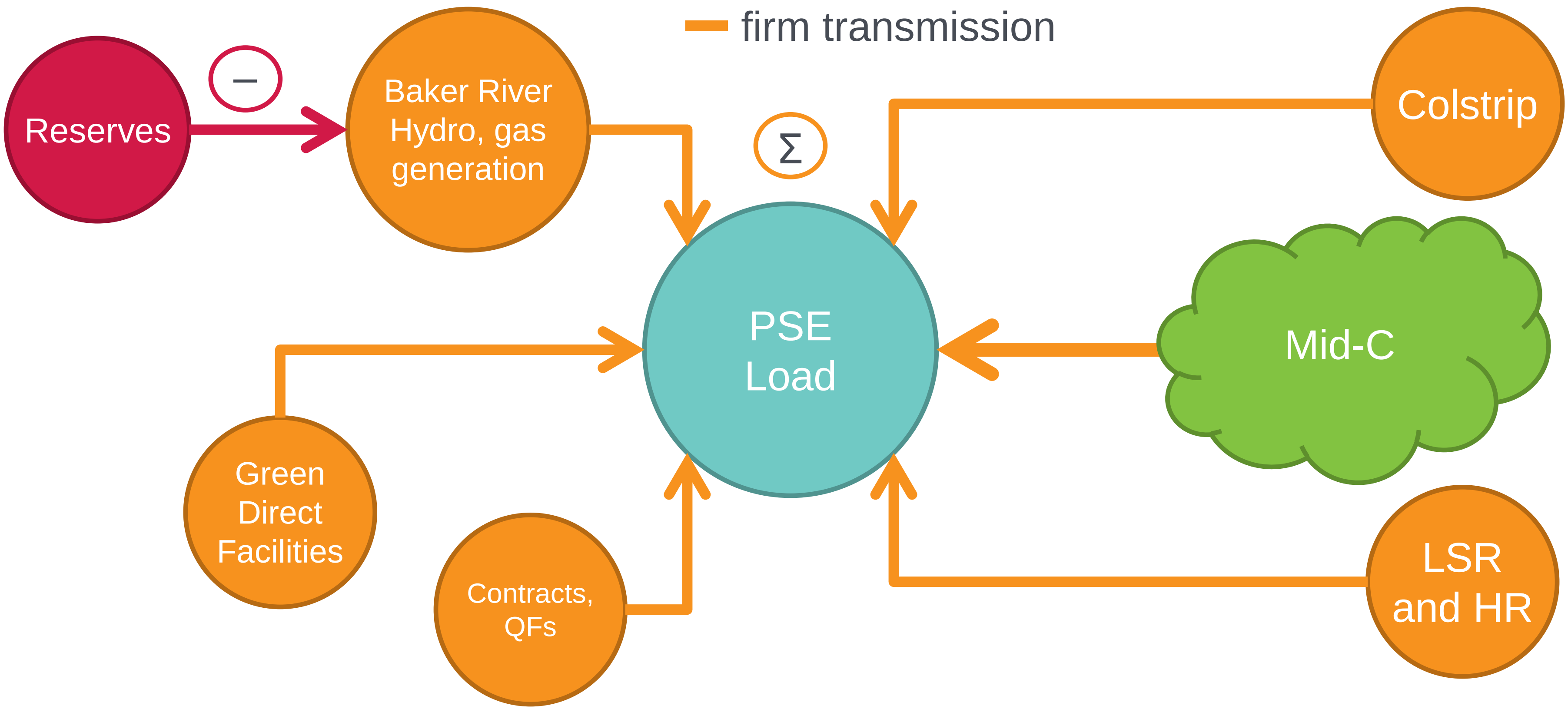
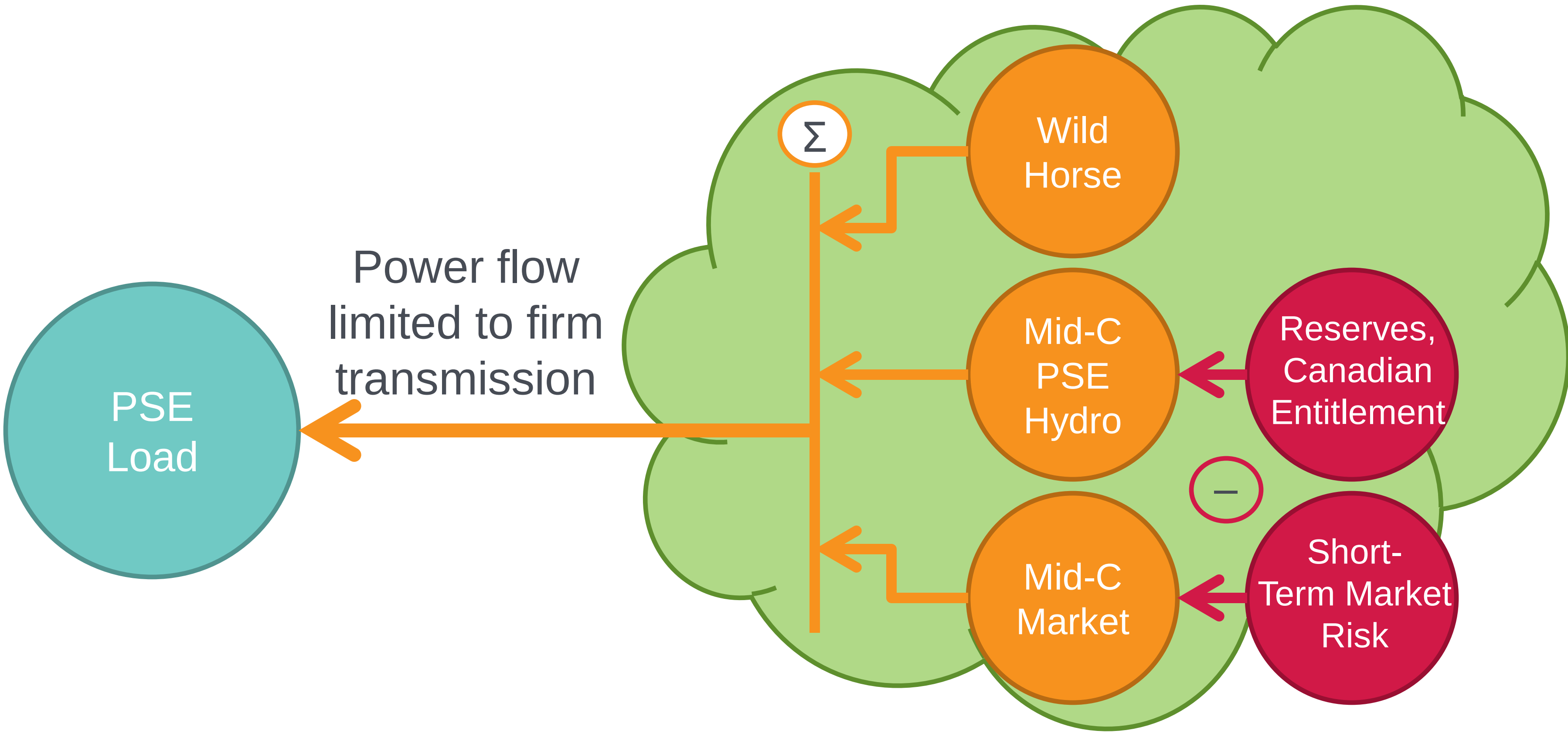
Model framework



Model framework



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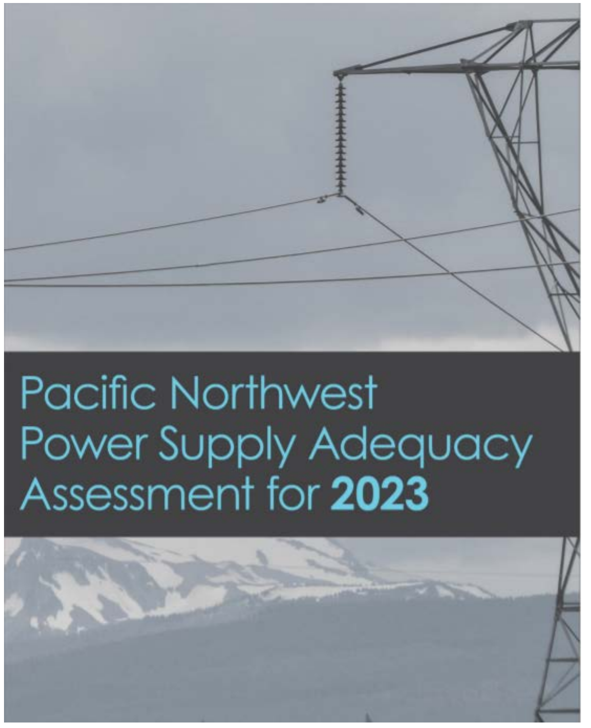
Regional view from GENESYS

- GENESYS base case* regional model used for 2019 IRP, from NWPCC Adequacy Assessment for 2023
  - LOLP: 4.86%
  - EUE: 3942 MWh

- Key assumption in regional model: economics drive joint coordination of resources in the Pacific Northwest
- No consideration of firm transmission rights
- All PNW transmission resources can be fully utilized up to modeled limits by any entity

- * 3400 MW CA import limit, updated PSE resources, add new Green Direct renewables



Resource need at 5% LOLP

Study year October 2022 – September 2023

698 MW resource need for 5% LOLP

Reliability metrics at 5% LOLP:

Metric Name	Base System, No Added Resources	System at 5% LOLP, 698 MW Added
LOLP	40.94%	4.99%
EUE	1932 MWh	205 MWh
LOLH	5.91 hours/year	0.47 hours/year
LOLE	1.29 days/year	0.09 days/year
LOLEV	1.66 events/year	0.10 events/year

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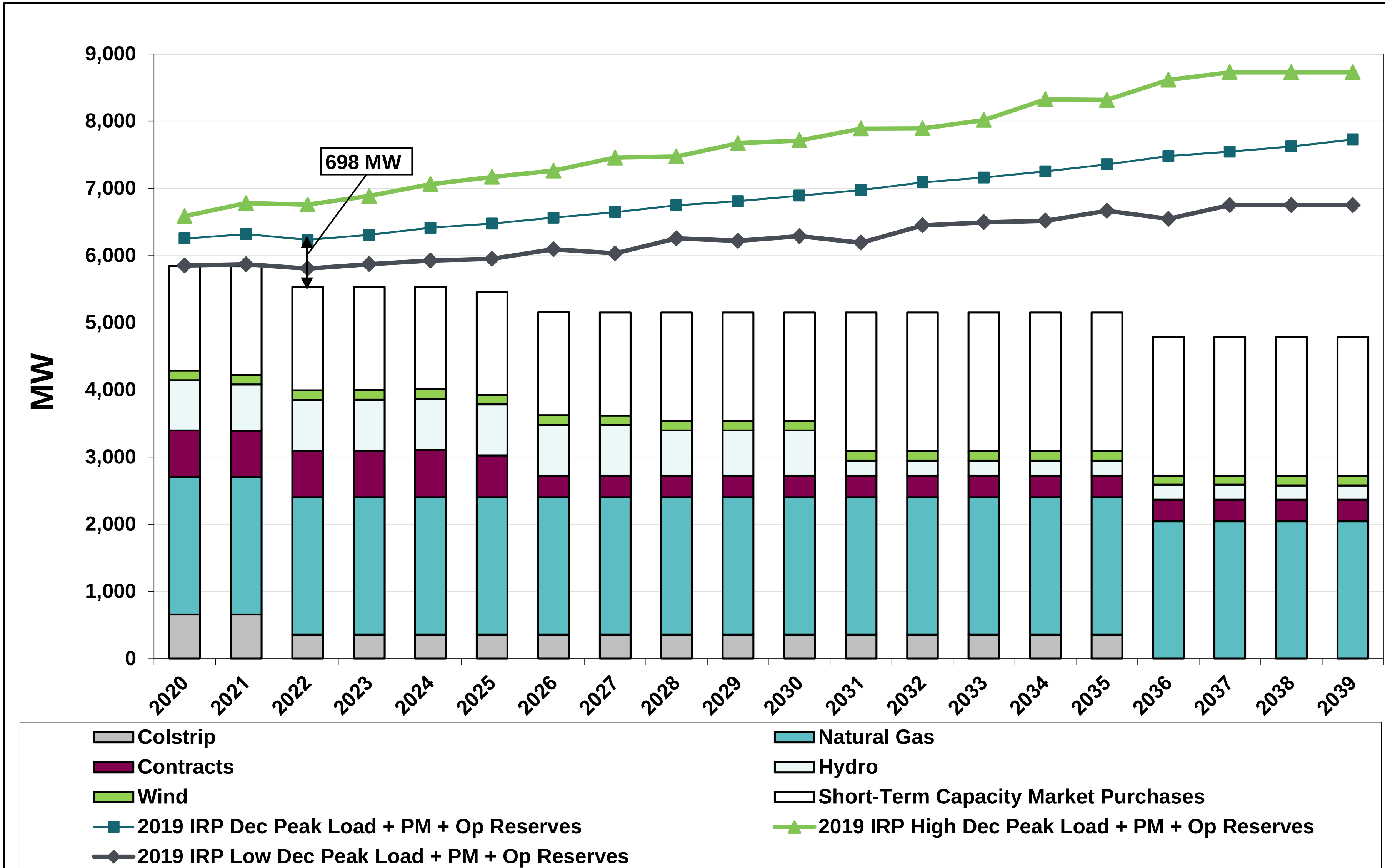
Draft electric peak capacity resource need



Effective load carrying capacity

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Peak capacity contributions

Effective Load Carrying Capability (ELCC), proportion of change in capacity by adding (or removing) another resource

Principle: on a statistical basis, the test system should generally not be worse off by substituting capacity for another resource type

Calculating ELCC

Solve for resource need to achieve 5% LOLP: ($Need_1$)

Add or remove a resource (Change) of nameplate

Solve again for resource need to hit target metric ($Need_2$)

ELCC = $-(Need_2 - Need_1)/Change$

Example:

- Base case, $Need_1$ = 500 MW
- Add 100 MW nameplate renewable
  - $Need_2$ = 475 MW
- ELCC = –(475 MW – 500 MW)/100 MW = 25%

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Renewable resource ELCCs

- Capturing correlations in wind data lowered value in onshore Washington state resources, increased value for Montana and offshore Washington wind
- Updated solar data shows peak value through diversity

Resource	Nameplate (MW)	IRP 2017 Peak Capacity Solve to 5% LOLP Relative to New Peaker	IRP 2019 Peak Capacity Solve to 5% LOLP Relative to Perfect Capacity
Existing Wind	823	11%	8%
Skookumchuck	131	40%	37%
Green Direct 2 Solar	150	N/A	18%
Generic Montana Wind	100	49%	53%
Generic Washington Wind	100	16%	4%
Generic Offshore WA Wind	100	51%	42%
Generic Washington Solar	100	0%	10%

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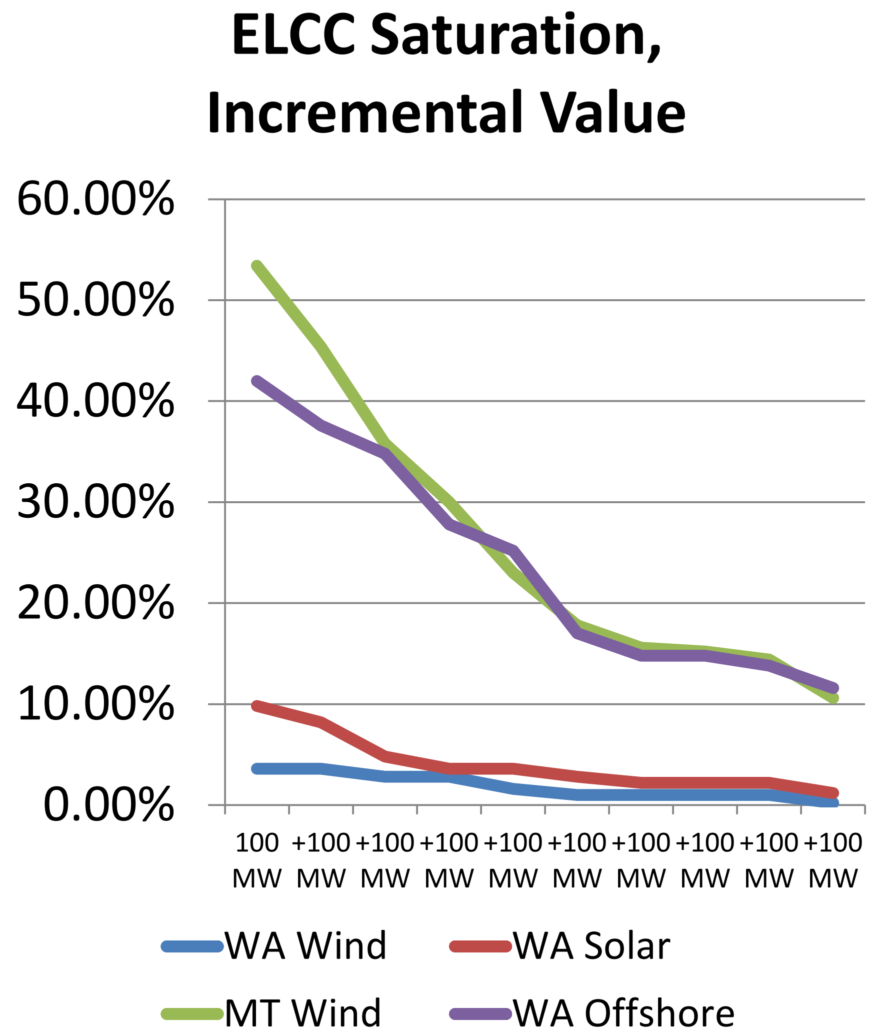
ELCC saturation analysis

Diversity matters!

ELCC declines as more of the same resources are added

Will include saturation curves in 2019 IRP



PSE PUGET SOUND ENERGY

ELCCs, batteries and demand response

Resource adequacy problems in the region are driven by low hydro conditions (*road collapse* not *potholes*)

Energy Limited Resources	Nameplate (MW)	IRP 2017 Peak Capacity EUE at 5% LOLP	IRP 2019 Peak Capacity EUE at 5% LOLP
Lithium-Ion Battery 2 hr, 82% RT efficiency	25	60%	21%
Lithium-Ion Battery 4 hr, 87% RT efficiency	25	88%	42%
Flow Battery 4 hr, 73% RT efficiency	25	76%	39%
Flow Battery 6 hr, 73% RT efficiency	25	N/A	50%
Demand Response 3 hr duration, 6 hr delay	100	77%	40%

Update for 2019: Improved alignment with GENESYS

PUGET SOUND ENERGY

ELCCs, pumped storage and solar+battery

Pumped storage: large projects, operationally complex

Solar + battery: better when they're together

- 100 MW of solar = 10 MW of peak capacity
- 25 MW of 2 hr li-ion battery = 5 MW of peak capacity
- Together = 20 MW of peak capacity

Energy-Limited Resources	Nameplate (MW)	Peak Capacity EUE at 5% LOLP
Pumped Storage 8 hr, 80% RT efficiency	500	42%
Pumped Storage 8 hr, 80% RT efficiency	300	49%
Eastern WA Solar + Li-Ion 25 MW/50 MWh 82% RT efficiency	100 (Solar)	20%

PSE PUGET SOUND ENERGY

15 minute break

PUGET SOUND ENERGY

E3 Regional Resource Adequacy Study

PUGET SOUND ENERGY

February 7, 2019 TAG #5

Energy+Environmental Economics

Resource Adequacy in the Pacific Northwest

Serving Load Reliably under a Changing Resource Mix

Puget Sound Energy

2019 Integrated Resource Plan TAG Meeting #5

February 7, 2019

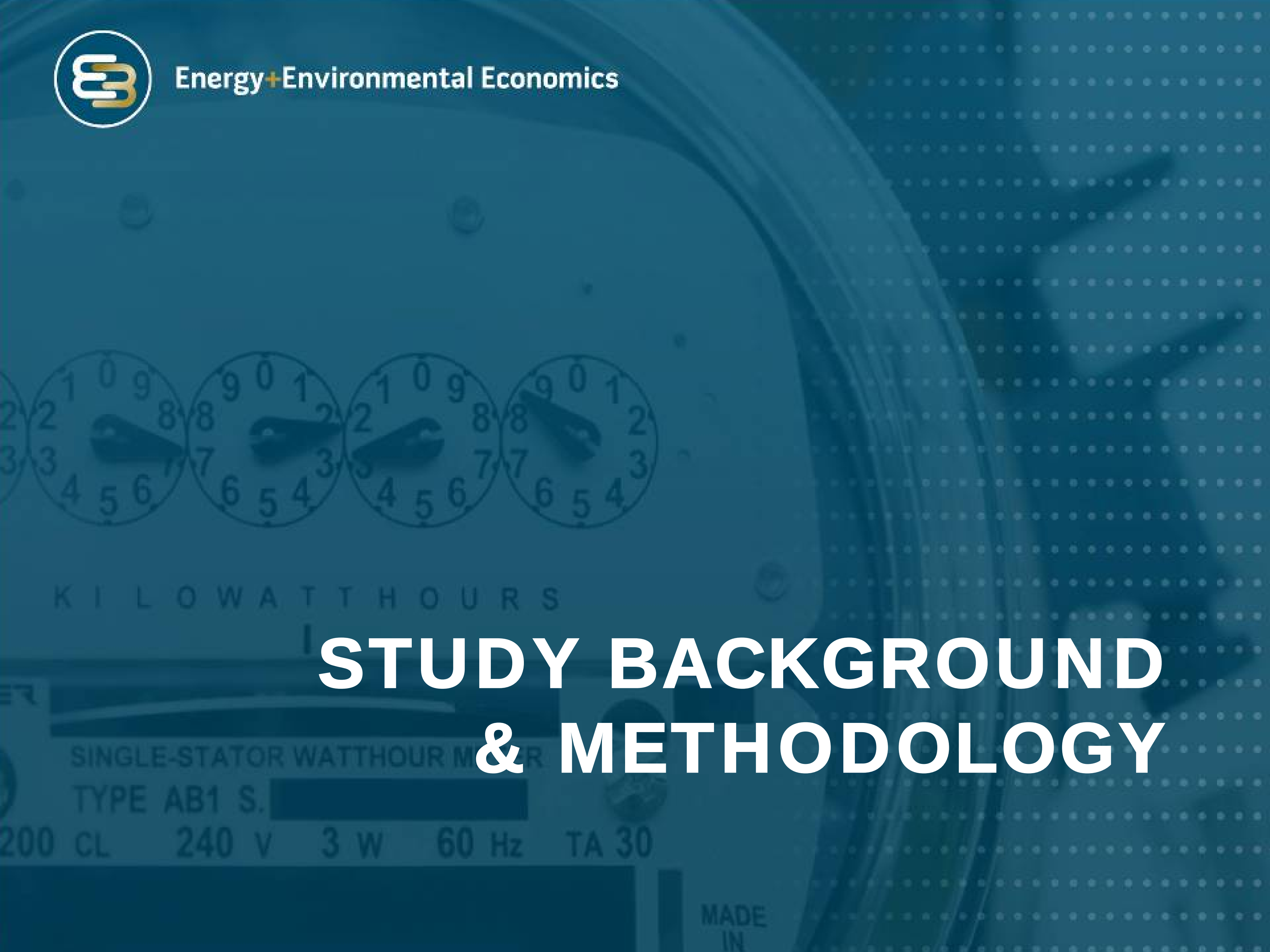
Bellevue, Washington

Arne Olson, Sr. Partner

Outline

+ **Study Background & Methodology**
+ **Results**
  - 2018
  - 2030
  - 2050
  - Capacity contribution of wind, solar, storage and demand response
+ **Key Findings**

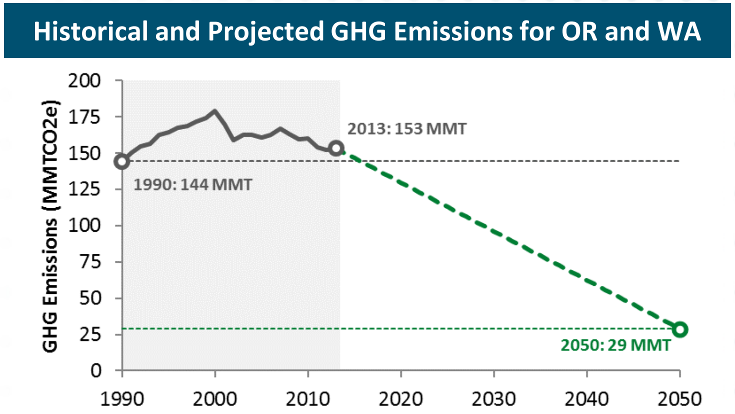
Energy+Environmental Economics

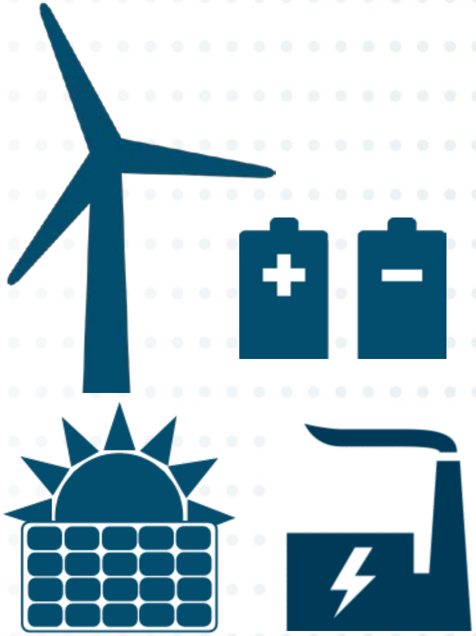


STUDY BACKGROUND & METHODOLOGY

About This Study

- **The Pacific Northwest is expected to undergo significant changes to its generation resource mix over the next 30 years due to changing economics and more stringent policy goals**
  - Increased penetration of wind and solar generation
  - Retirements of coal generation
  - Questions about the role of new natural gas generation
- **This raises questions about the region's ability to serve load reliably as firm generation is replaced with variable resources**
- **This study was sponsored by 13 Pacific Northwest utilities to examine Resource Adequacy under a changing resource mix**
  - How to maintain Resource Adequacy in the 2020-2030 time frame under growing loads and increasing coal retirements
  - How to maintain Resource Adequacy in the 2040-2050 time frame under stringent carbon abatement goals





Study Sponsors

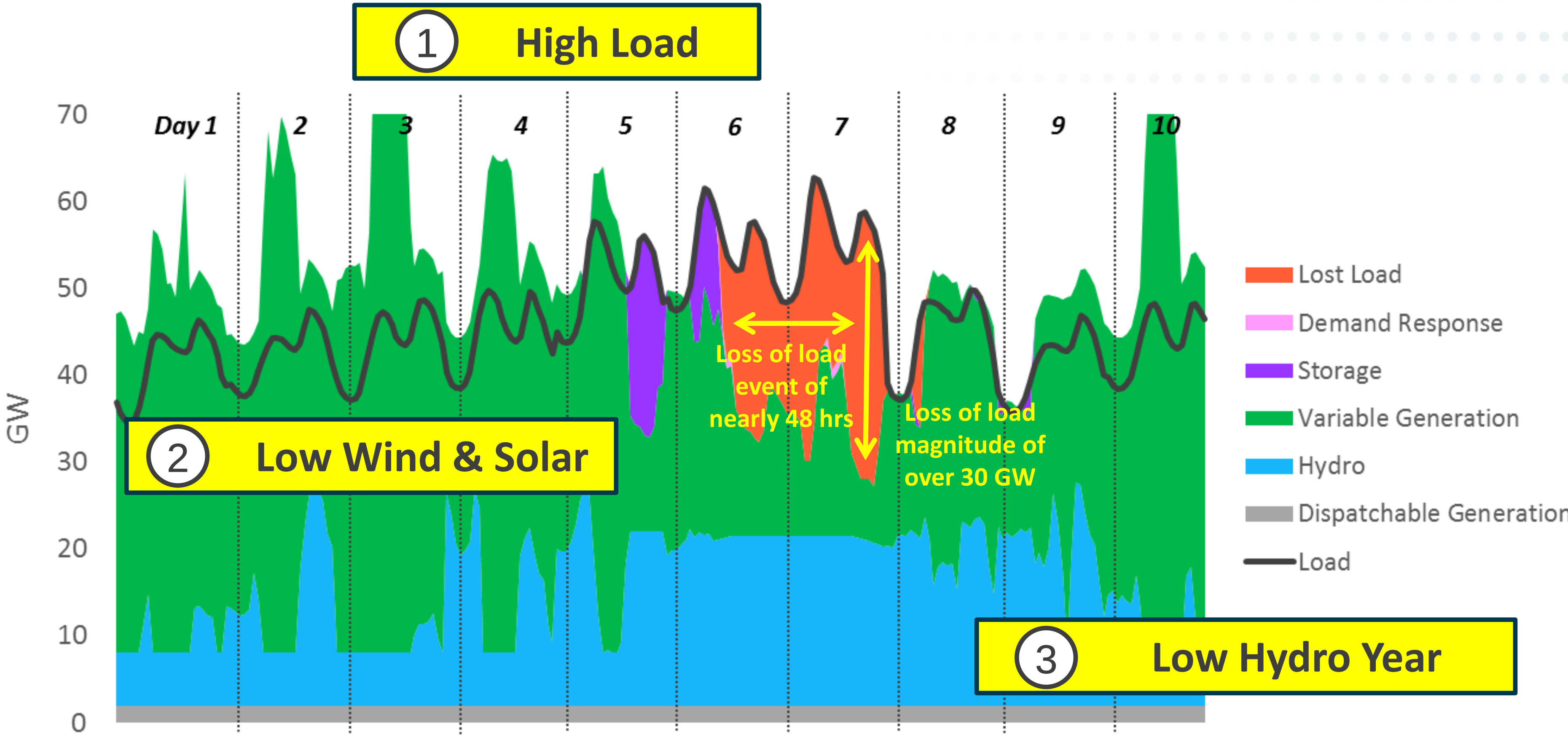
+ **This study was sponsored by Puget Sound Energy, Avista, NorthWestern Energy and the Public Generating Pool (PGP)**

  - PGP is a trade association representing 10 consumer-owned utilities in Oregon and Washington.

E3 thanks the staff of the Northwest Power and Conservation Council for providing data and technical review

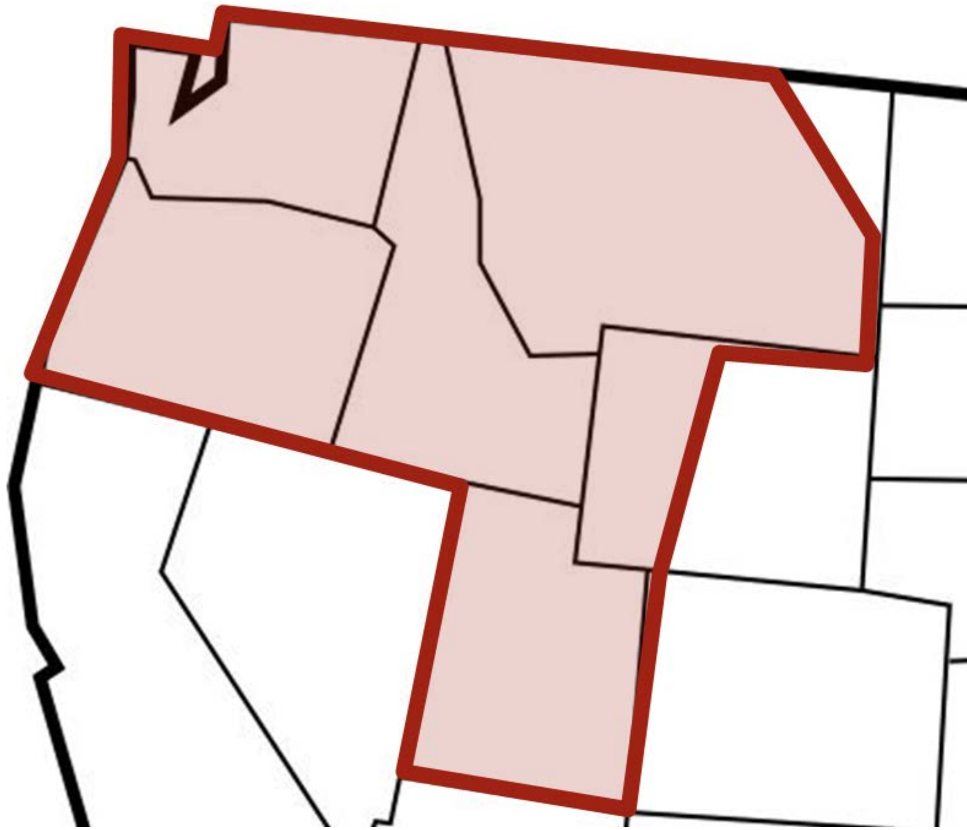
Three Reliability Challenges on a Deeply-Decarbonized Grid

- The most challenging conditions in a deeply-decarbonized Pacific Northwest grid occur when a multi-day cold snap coincides with low wind, solar and hydro production



Study Region – The Greater NW

- **The study region consists of the U.S. portion of the Northwest Power Pool (excluding Nevada)**
- **It is assumed that any resource in any area can serve any need throughout the Greater NW region**
  - Study assumes no transmission constraints or transactional friction
  - Study assumes full benefits from regional load and resource diversity
  - The system as modeled is more efficient and seamless than the actual Greater NW system



Balancing Authority Areas include: Avista, Bonneville Power Administration, Chelan County PUD, Douglas County PUD, Grant County PUD, Idaho Power, NorthWestern Energy, PacifiCorp (East & West), Portland General Electric, Puget Sound Energy, Seattle City Light, Tacoma Power, Western Area Power Administration

Individual utility impacts will differ from the regional impacts

- **Cost impacts in this study are presented from a societal perspective and represent an aggregation of all costs and benefits within the Greater NW region**
  - Societal costs include all investment (i.e. “steel-in-the-ground”) and operational costs (i.e. fuel and O&M) that are incurred in the region
- **Cost of decarbonization may be higher or lower for individual utilities as compared to the region as a whole**
  - Utilities with a relatively higher composition of fossil resources today are likely to bear a higher cost than utilities with a higher composition of fossil-free resources
- **Resource Adequacy needs will be different for each utility**
  - Individual systems will need a higher reserve margin than the Greater NW region due to smaller size and less diversity
  - Capacity contribution of renewables will be different for individual utilities due to differences in the timing of peak loads and renewable generation production

The study considers Resource Adequacy needs under multiple scenarios representing alternative resource mixes

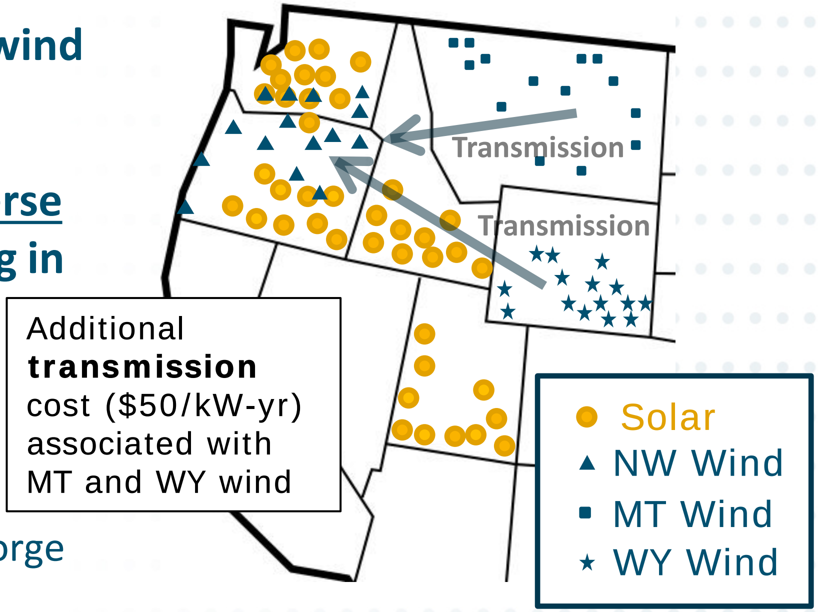
2018-2030 Scenarios	Carbon Reduction % Below 1990[1]	GHG-Free Generation %[2]	CPS %[3]	Carbon Emissions (MMT)
2018 Case[4]	-6%	71%	75%	63
2030 Reference Case[4]	-12%	61%	65%	67
2030 Coal Retirement	30%	61%	65%	42

2050 Scenarios	Carbon Reduction % Below 1990[1]	GHG-Free Generation %[2]	CPS %[3]	Carbon Emissions (MMT)
Reference Case	16%	60%	63%	50
60% GHG Reduction	60%	80%	86%	25
80% GHG Reduction	80%	90%	100%	12
90% GHG Reduction	90%	95%	108%	6
98% GHG Reduction	98%	99%	117%	1
100% GHG Reduction	100%	100%	123%	0

[1]Greater NW Region 1990 electricity sector emissions = 60 MMT/yr.
[2]GHG-Free Generation % = renewable + hydro + nuclear generation, minus exports, divided by total wholesale load
[3]CPS % = renewable + hydro + nuclear generation divided by retail electricity sales
[4]2018 and 2030 cases assumes coal capacity factor of 60%

New wind and solar resources are added across a geographically diverse footprint

- **The study considers additions nearly 100 GW of wind and 50 GW of solar across the six-state region**
- **The portfolios studied are <u>significantly more diverse</u> than the renewable resources currently operating in the region**
  - Each dot in the map represents a location where wind and solar is added in the study
  - NW wind is more diverse than existing Columbia Gorge wind
- **New renewable portfolios are within the bounds of current technical potential estimates, but are nearly an order of magnitude higher than other studies have examined**
- **The cost of new transmission is assumed for delivery of remote wind and solar generation but siting and construction is not studied in detail**



NREL Technical Potential (GW)

State	Wind
WA	18
OR	27
CA	34
ID	18
MT	944
WY	552
UT	13
Total	**1588**

https://www.nrel.gov/docs/fy12osti/51946.pdf

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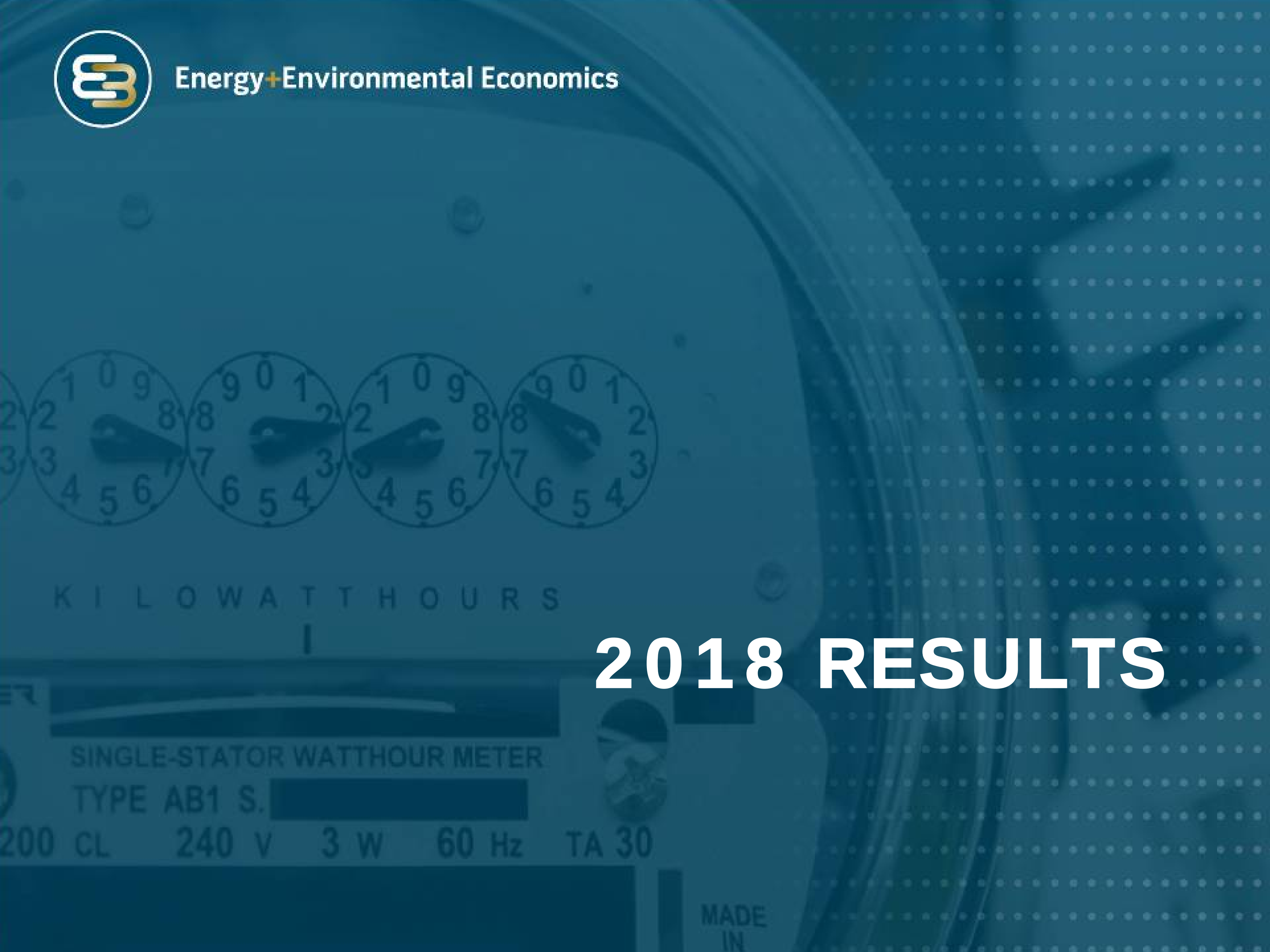
2018 RESULTS



2018 system is in very tight load-resource balance

- A planning reserve margin of 12% is required to meet 1-in-10 reliability standard
- The 2018 system does not meet 1-in-10 reliability standard (2.4 hrs./yr.)
- The 2018 system does meet Northwest Power and Conservation Council standard for Annual LOLP (5%)

	Reliability Metrics
Annual LOLP	3.7%
LOLE (hrs./year)	**6.5**
EUE (MWh/year)	5,777
EUE norm (EUE/Load)	0.003%
1-in-2 Peak Load (GW)	43
Required PRM to meet 2.4 LOLE	12%
Required Firm Capacity (GW)	48

2018 Load and Resource Balance

	2018
Load (GW)	
Peak Load	43.0
PRM (%)	*12%*
PRM	5.0
Total Load Requirement	48.0

Resources / Effective Capacity (GW)	
Coal	11.0
Gas	12.0
Bio/Geo	1.0
Imports	3.0
Nuclear	1.0
DR	0.3
Hydro	18.0
Wind	0.5
Solar	0.2
Storage	0.0
Total Supply	47.0

	Nameplate Capacity (GW)	ELCC* (%)	Capacity Factor (%)
Hydro	*35*	*53%*	*44%*
Wind	*7.1*	*7%*	*26%*
Solar	*1.6*	*12%*	*27%*

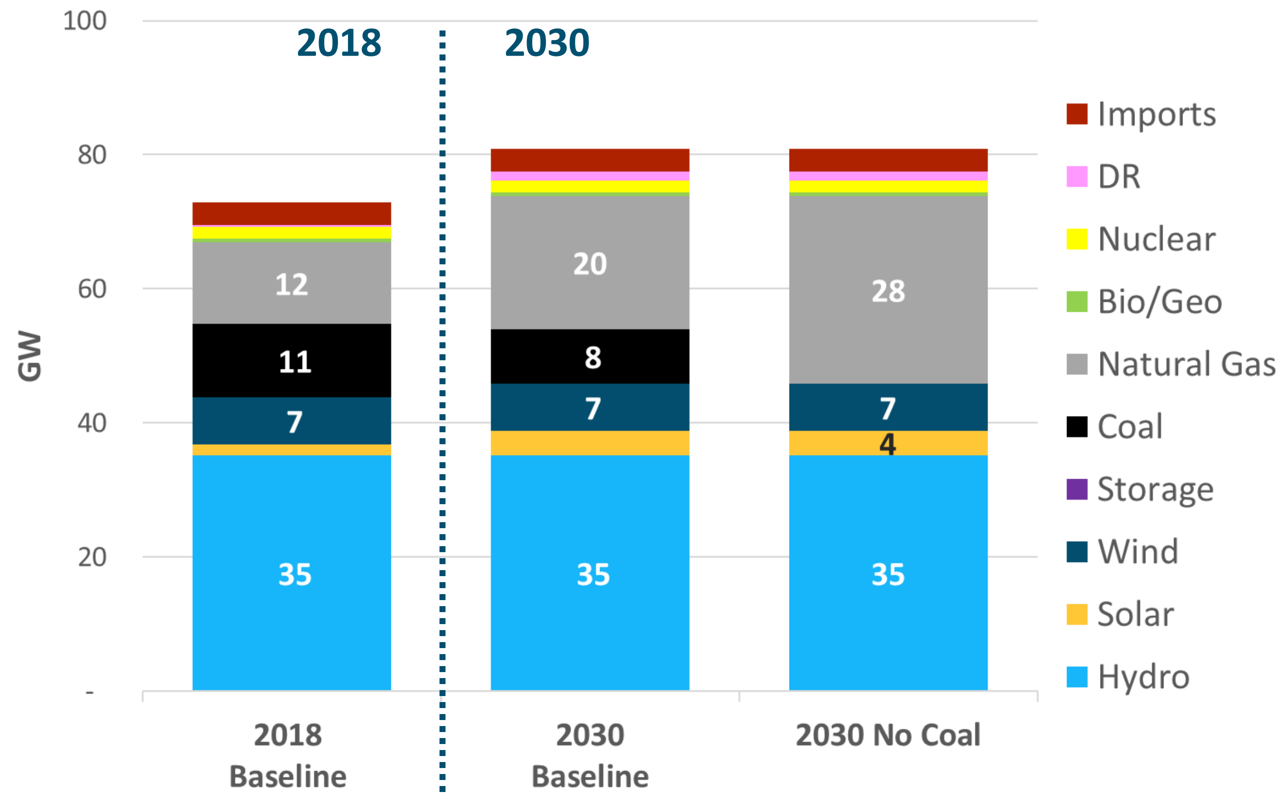
Wind and solar contribute little effective capacity with ELCC* of 7% and 12%

**ELCC = Effective Load Carrying Capability = firm contribution to system peak load*

Energy+Environmental Economics

2030 RESULTS

2030 Portfolios



GHG Free Generation (%)	61%	61%
Carbon (MMT CO2)	67	42
% GHG Reduction from 1990 Level	-12%*	31%

5 GW net new capacity by 2030 is needed for reliability (450 MW/yr)

With planned coal retirements of 3 GW, 8 GW of new capacity by 2030 is needed (730 MW/yr)

If all coal is retired, then 16 GW new capacity is needed (1450 MW/yr)

*Assumes 60% coal capacity factor

The Northwest system will need 8 GW of new effective capacity by 2030

- The 2030 system does not meet 1-in-10 reliability standard (2.4 hrs./yr.)
- The 2030 system does not meet standard for Annual LOLP (5%)
- Load growth and planned coal retirements lead to the need for 8 GW of new effective capacity by 2030

	2030 with No New Capacity	2030 with 8 GW of New Capacity
Annual LOLP (%)	**48%**	2.8%
LOLE (hrs/yr)	**106**	2.4
EUE (MWh/yr)	178,889	1,191
EUE norm (EUE/load)	0.07%	0.0004%

2030 Load and Resource Balance

	2030
Load (GW)	
Peak Load (Pre-EE)	50.0
Peak Load (Post-EE)	47.0
PRM	*12%*
PRM	5.0
Total Load Requirement	52.0

Resources / Effective Capacity (GW)		Nameplate Capacity (GW)	ELCC (%)	Capacity Factor (%)
Coal	8.0			
Gas	20.0			
Bio/Geo	0.6			
Imports	2.0			
Nuclear	1.0			
DR	1.0			
Hydro	19.0	*35.0*	*56%*	*44%*
Wind	0.6	*7.1*	*9%*	*26%*
Solar	0.2	*1.6*	*14%*	*27%*
Storage	0.0			
Total Supply	52.0			

8 GW new gas capacity needed by 2030

Wind and solar contribute little effective capacity with ELCC* of 9% and 14%

**ELCC = Effective Load Carrying Capability = firm contribution to system peak load*

2050 RESULTS

Scenario Summary

Greater NW System in 2050

2018 | 2050

- Natural Gas
- Imports
- Coal
- Storage
- DR
- Solar
- Wind
- Bio/Geo
- Nuclear
- Hydro

Carbon (MMT CO2)	50
CPS (%)[1]	63%
GHG Free Generation (%)[2]	60%
Annual Renewable Curtailment (%)	Low
Annual Cost Delta ($B)	Base
Additional Cost ($/MWh)	Base
% GHG Reduction from 1990 level	16%
Gas Capacity Factor (%)	46%

2050 Reference Scenario

Additions	Retirements
2 GW Wind	
4 GW Solar	
20 GW Gas	
	11 GW Coal

9 GW net increase in firm capacity

Total cost of new resource additions is $4 billion per year (~$30 billion investment)

[1]CPS+ % = renewable/hydro/nuclear generation divided by retail electricity sales

[2]GHG-Free Generation % = renewable/hydro/nuclear generation, minus exports, divided by total wholesale load

Scenario Summary
Greater NW System in 2050

2018 | 2050

4-hr

23 GW of Wind, 11 GW of solar and 2 GW of storage reduce carbon 60% below 1990

Gas generation retained for reliability

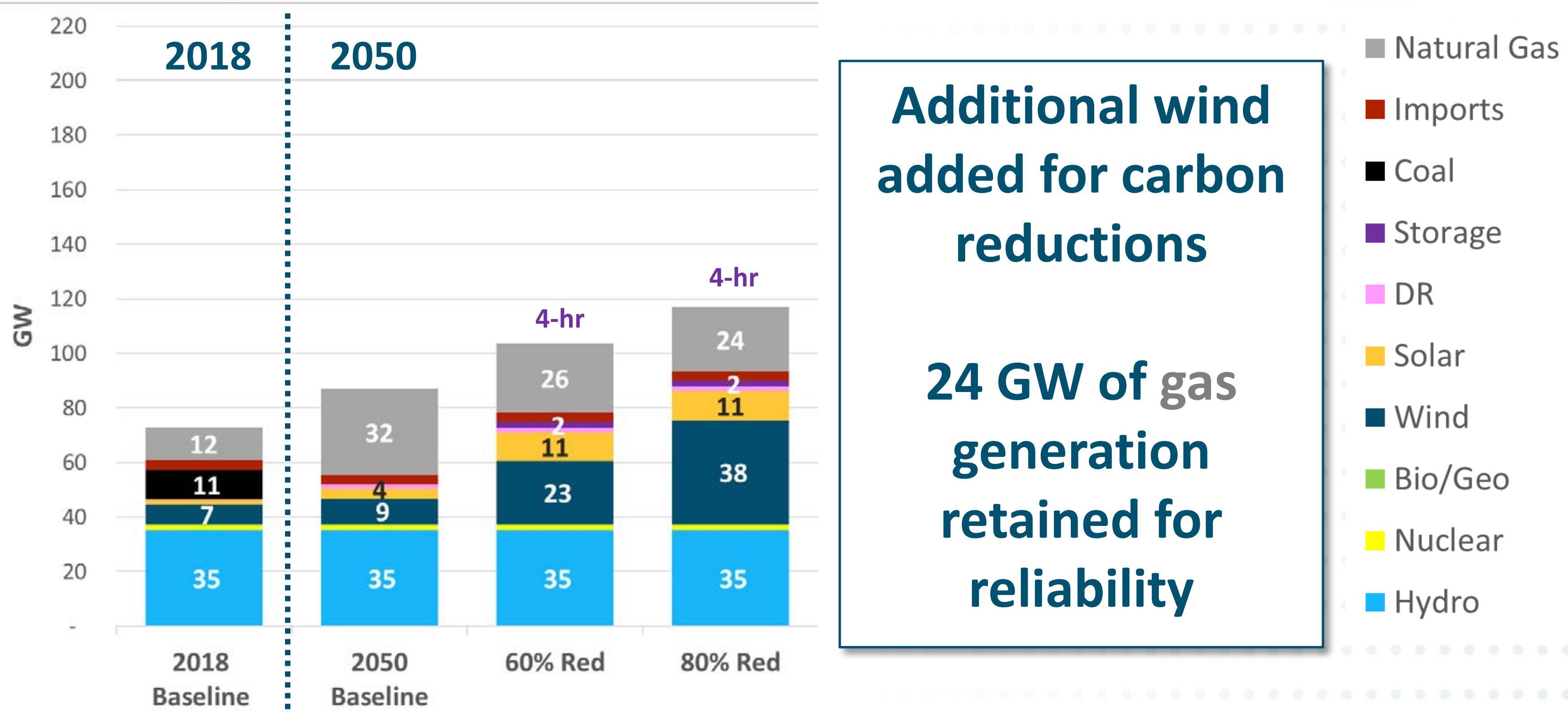
- Natural Gas
- Imports
- Coal
- Storage
- DR
- Solar
- Wind
- Bio/Geo
- Nuclear
- Hydro

	2018	2050
Carbon (MMT CO2)	50	25
CPS (%)[1]	63%	86%
GHG Free Generation (%)[2]	60%	80%
Annual Renewable Curtailment (%)	Low	Low
Annual Cost Delta ($B)	Base	$0 - $2
Additional Cost ($/MWh)	Base	$0 - $7
% GHG Reduction from 1990 level	16%	60%
Gas Capacity Factor (%)	46%	27%

[1]CPS+ % = renewable/hydro/nuclear generation divided by retail electricity sales
[2]GHG-Free Generation % = renewable/hydro/nuclear generation, minus exports, divided by total wholesale load

Scenario Summary

Greater NW System in 2050



Additional wind added for carbon reductions

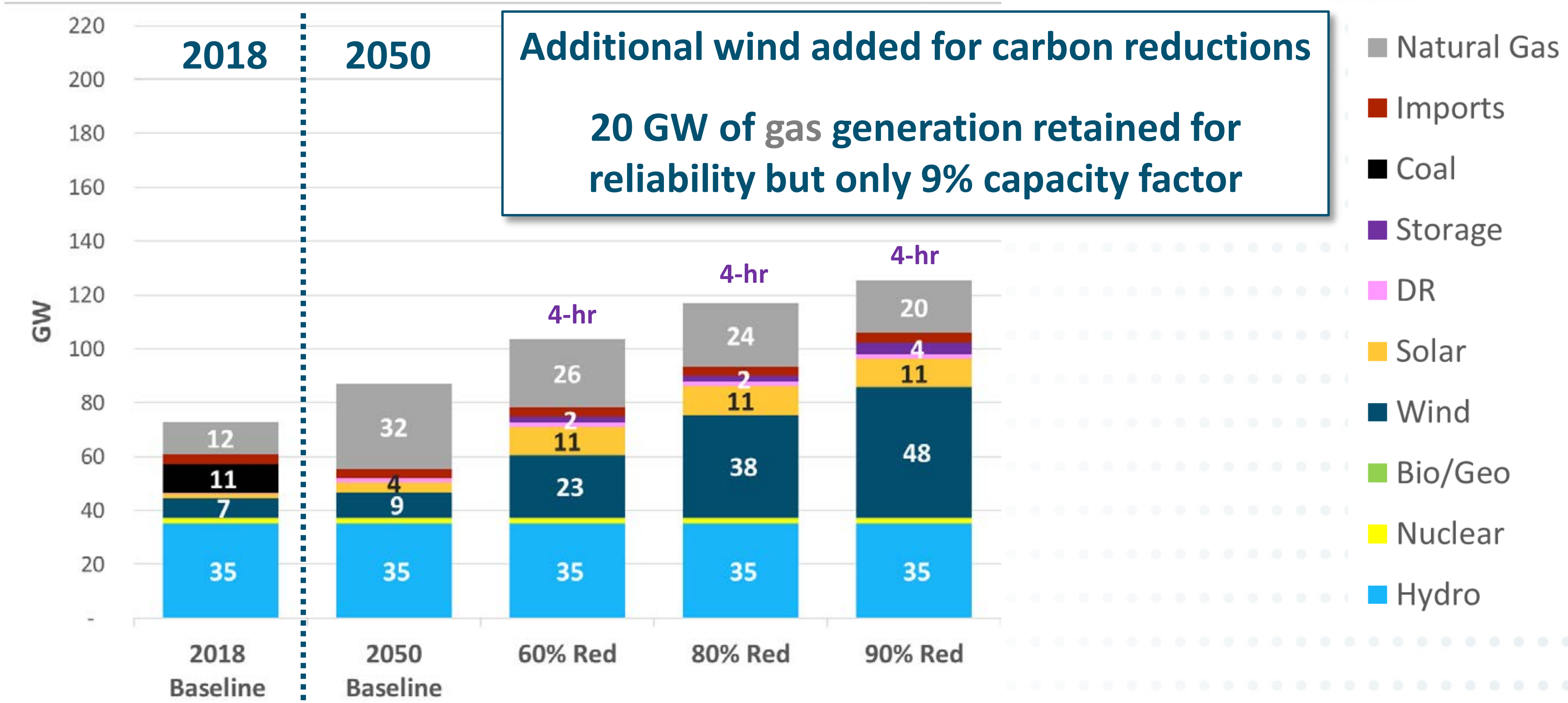
24 GW of gas generation retained for reliability

	2050 Baseline	60% Red	80% Red
Carbon (MMT CO2)	50	25	12
CPS (%)[1]	63%	86%	100%
GHG Free Generation (%)[2]	60%	80%	90%
Annual Renewable Curtailment (%)	Low	Low	4%
Annual Cost Delta ($B)	Base	$0 - $2	$1 - $4
Additional Cost ($/MWh)	Base	$0 - $7	$3 - $14
% GHG Reduction from 1990 level	16%	60%	80%
Gas Capacity Factor (%)	46%	27%	16%

[1]CPS+ % = renewable/hydro/nuclear generation divided by retail electricity sales

[2]GHG-Free Generation % = renewable/hydro/nuclear generation, minus exports, divided by total wholesale load

Scenario Summary
Greater NW System in 2050



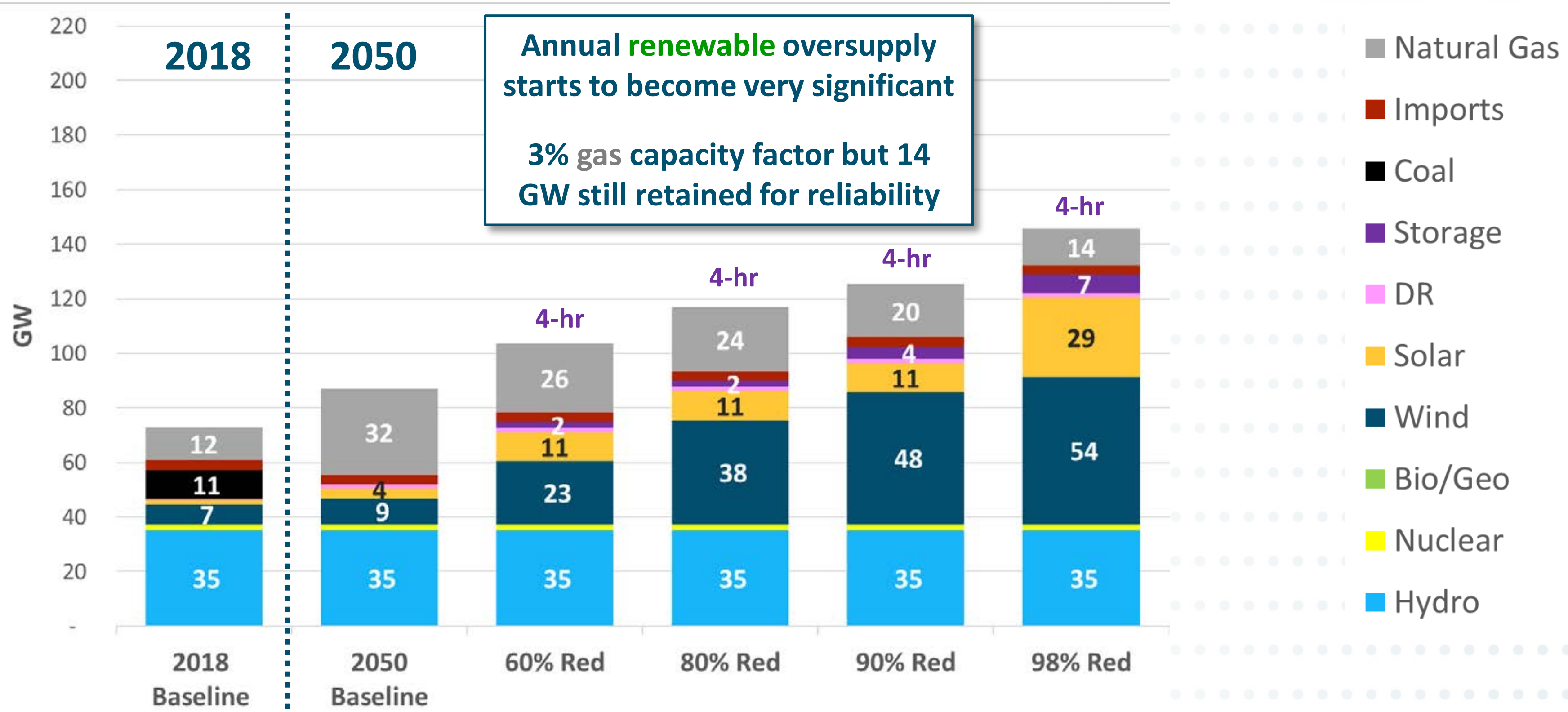
Carbon (MMT CO2)	50	25	12	6
CPS (%)[1]	63%	86%	100%	108%
GHG Free Generation (%)[2]	60%	80%	90%	95%
Annual Renewable Curtailment (%)	Low	Low	4%	10%
Annual Cost Delta ($B)	Base	$0 - $2	$1 - $4	$2 - $5
Additional Cost ($/MWh)	Base	$0 - $7	$3 - $14	$5 - $18
% GHG Reduction from 1990 level	16%	60%	80%	90%
Gas Capacity Factor (%)	46%	27%	16%	9%

[1]CPS+ % = renewable/hydro/nuclear generation divided by retail electricity sales

[2]GHG-Free Generation % = renewable/hydro/nuclear generation, minus exports, divided by total wholesale load

Scenario Summary

Greater NW System in 2050

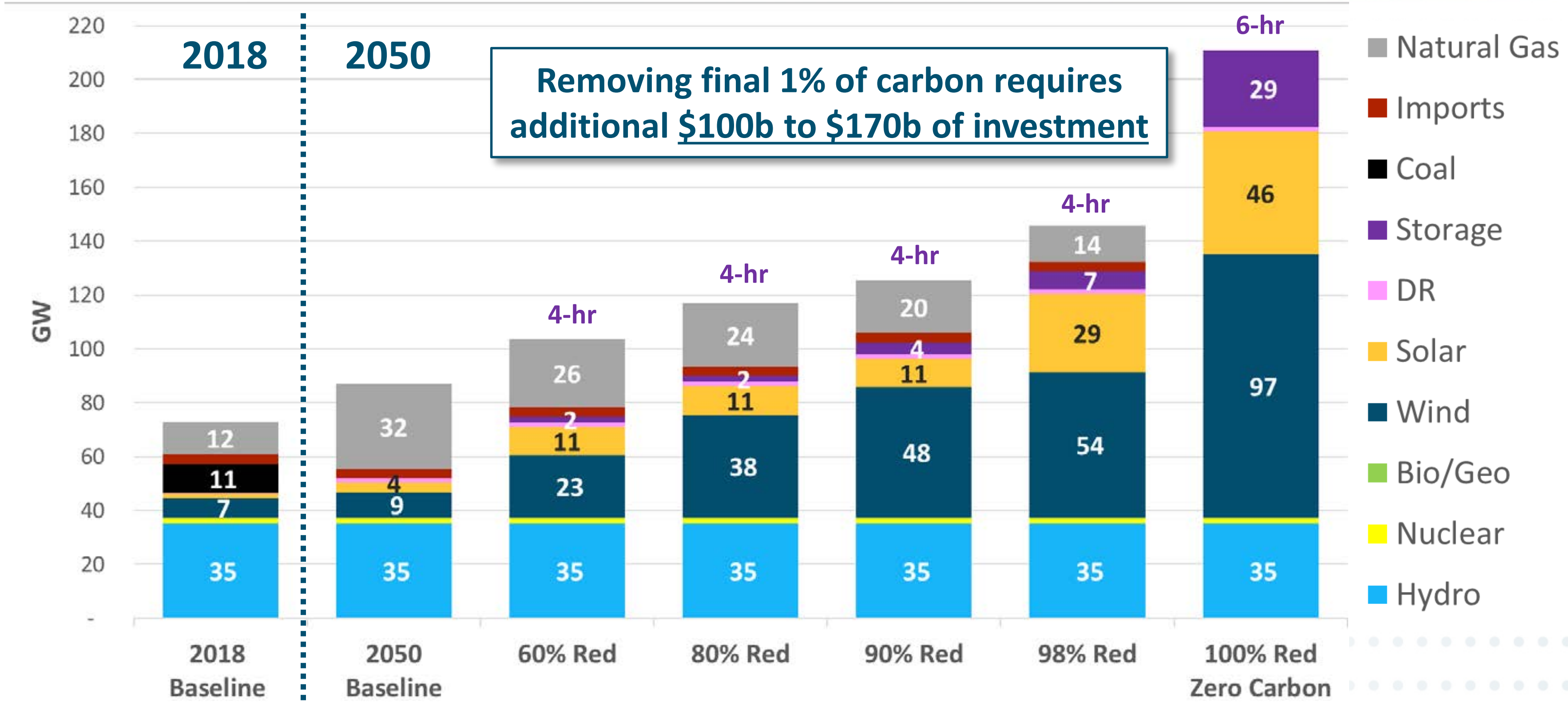


Carbon (MMT CO2)	50	25	12	6	1
CPS (%)[1]	63%	86%	100%	108%	117%
GHG Free Generation (%)[2]	60%	80%	90%	95%	99%
Annual Renewable Curtailment (%)	Low	Low	4%	10%	21%
Annual Cost Delta ($B)	Base	$0 - $2	$1 - $4	$2 - $5	$3 - $9
Additional Cost ($/MWh)	Base	$0 - $7	$3 - $14	$5 - $18	$10 - $28
% GHG Reduction from 1990 level	16%	60%	80%	90%	98%
Gas Capacity Factor (%)	46%	27%	16%	9%	3%

[1]CPS+ % = renewable/hydro/nuclear generation divided by retail electricity sales

[2]GHG-Free Generation % = renewable/hydro/nuclear generation, minus exports, divided by total wholesale load

Scenario Summary
Greater NW System in 2050

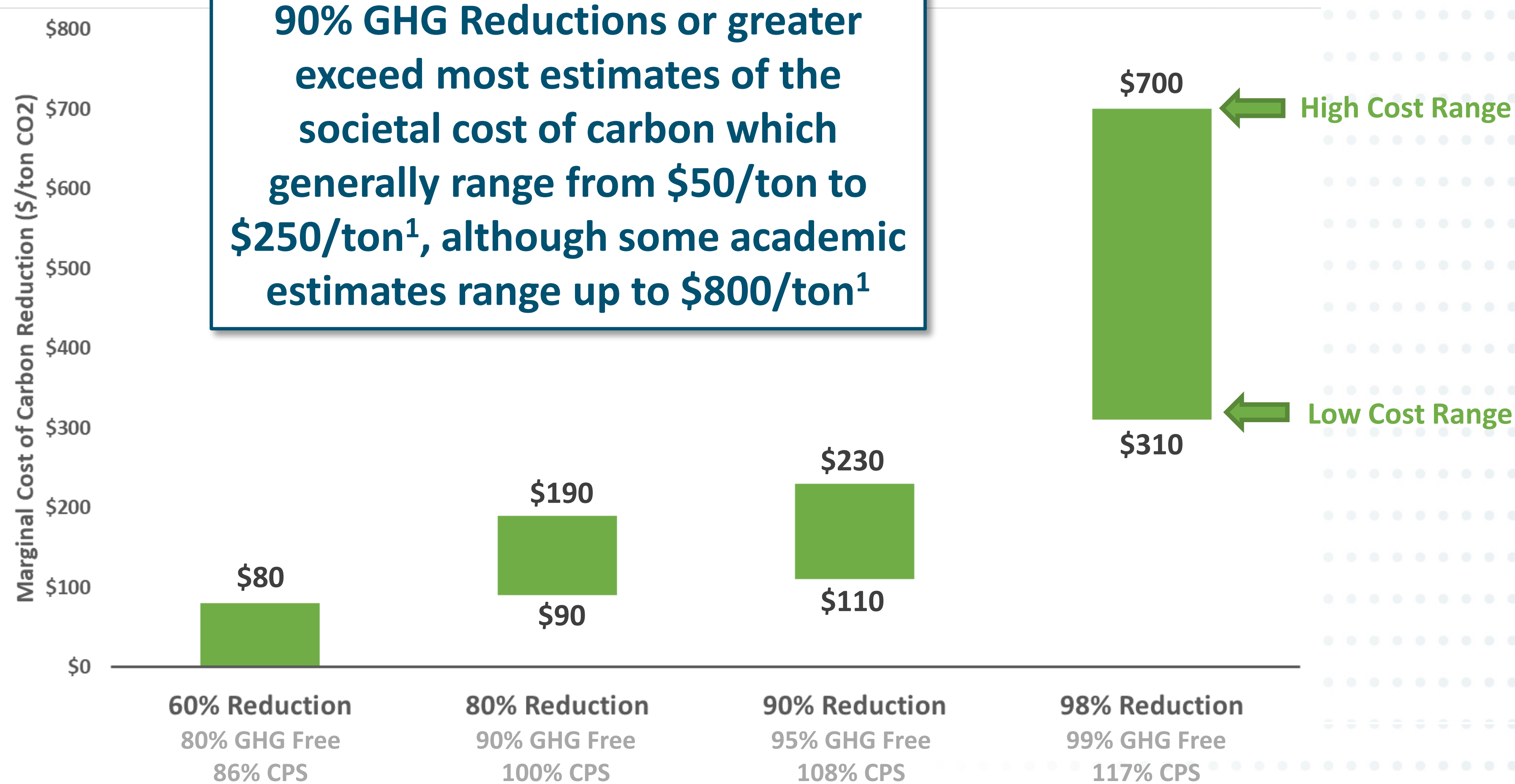


Carbon (MMT CO2)	50	25	12	6	1	-
CPS (%)[1]	63%	86%	100%	108%	117%	123%
GHG Free Generation (%)[2]	60%	80%	90%	95%	99%	100%
Annual Renewable Curtailment (%)	Low	Low	4%	10%	21%	47%
Annual Cost Delta ($B)	Base	$0 - $2	$1 - $4	$2 - $5	$3 - $9	$16 - $28
Additional Cost ($/MWh)	Base	$0 - $7	$3 - $14	$5 - $18	$10 - $28	$52 - $89
% GHG Reduction from 1990 level	16%	60%	80%	90%	98%	100%
Gas Capacity Factor (%)	46%	27%	16%	9%	3%	0%

[1]CPS+ % = renewable/hydro/nuclear generation divided by retail electricity sales
[2]GHG-Free Generation % = renewable/hydro/nuclear generation, minus exports, divided by total wholesale load

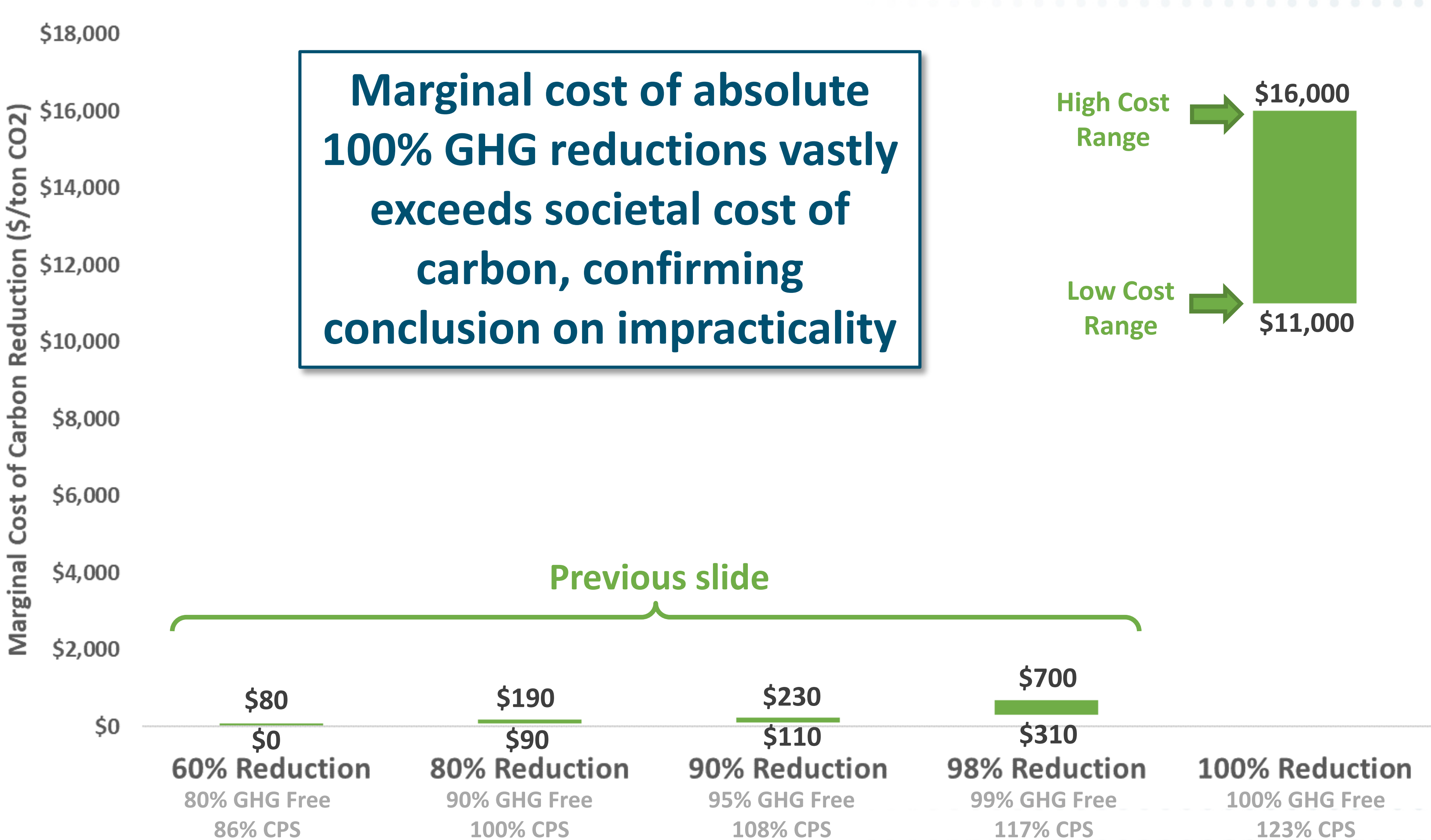
Marginal Cost of GHG Reduction

Marginal cost of CO2 reductions at 90% GHG Reductions or greater exceed most estimates of the societal cost of carbon which generally range from $50/ton to $250/ton[1], although some academic estimates range up to $800/ton[1]

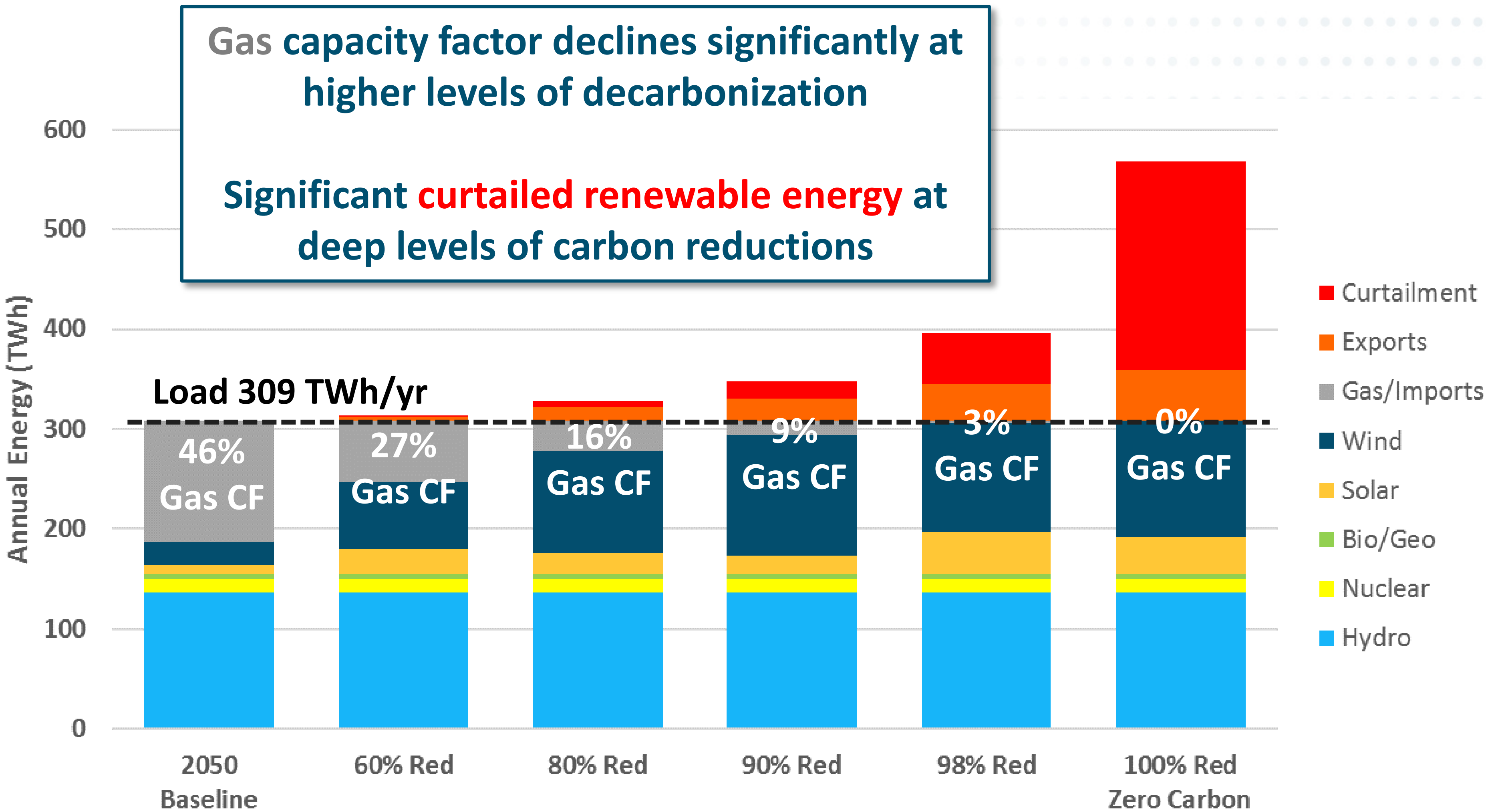


[1] https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html; https://www.nature.com/articles/s41558-018-0282-y

Marginal Cost of GHG Reduction

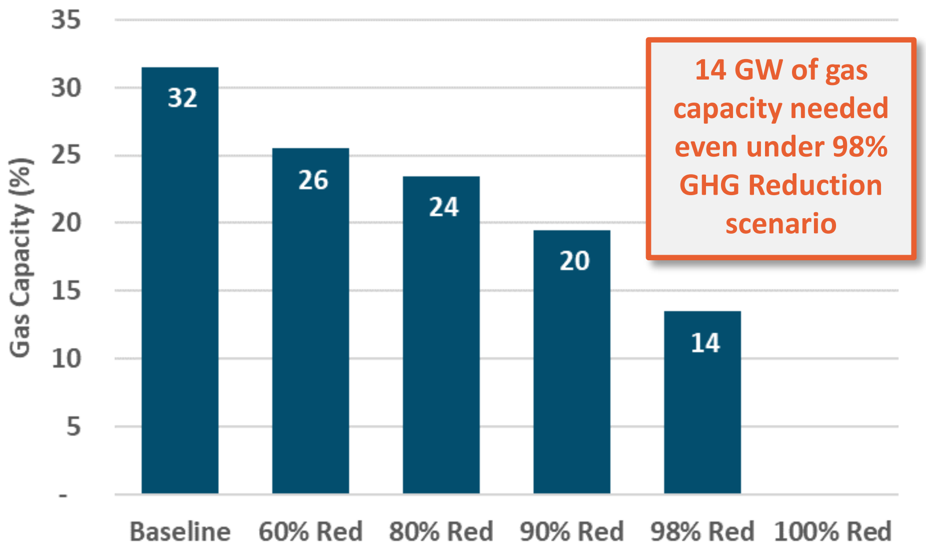


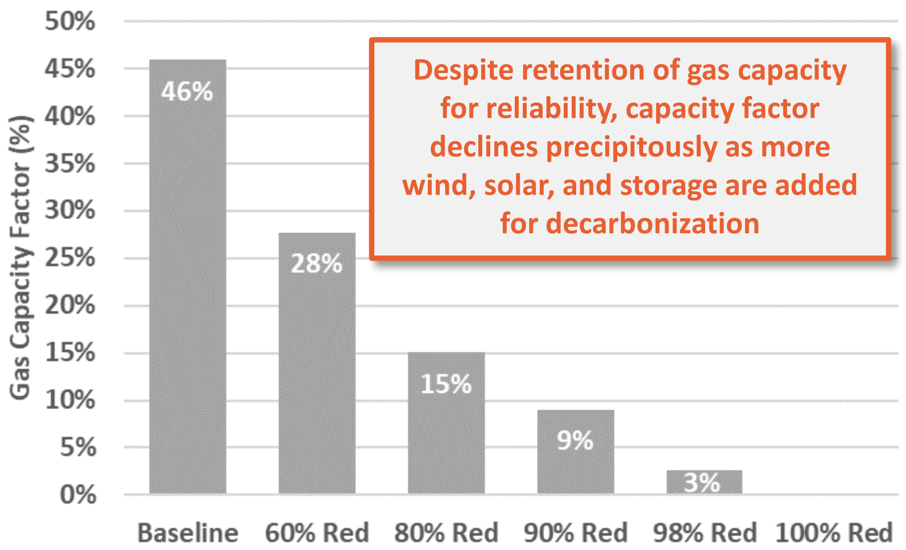
2050 Annual Energy Balance



Firm capacity is still needed for reliability under deep decarbonization despite much lower utilization

- Natural gas *energy production* declines substantially as the GHG increases
- Natural gas *capacity* is part of the least-cost mix of resources to reduce carbon emissions to 1 million tons by 2050
- All scenarios except 100% GHG reductions select more gas capacity than exists on the system today (12 GW)





2050 Load and Resource Balance

	2050		
	80% Reduction	90% Reduction	100% Reduction
Load (GW)			
Peak (Pre-EE)	65	65	65
Peak (Post-EE)	54	54	54
PRM (%)	*9%*	*9%*	*7%*
PRM	5	5	4
Total Load Requirement	59	59	57

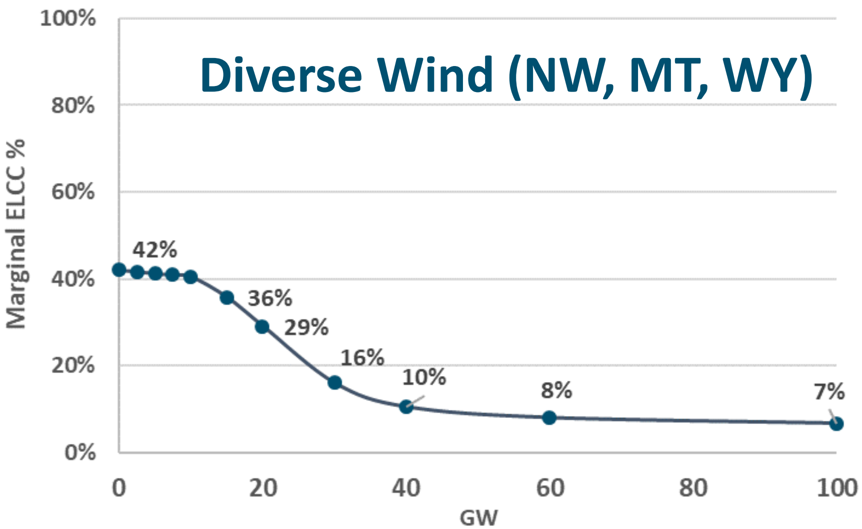
Resources / Effective Capacity (GW)			
Coal	0	0	0
Gas	24	20	0
Bio/Geo	0.6	0.6	0.6
Imports	2	2	0
Nuclear	1	1	1
DR	1	1	1
Hydro	20	20	20
Wind	7	11	21
Solar	2.0	2.2	7.5
Storage	1.6	1.8	5.8
Total Supply	59	59	57

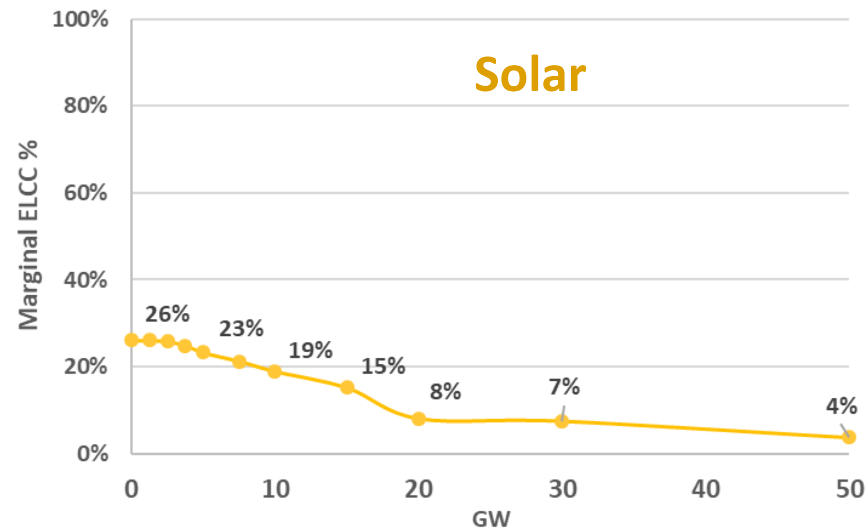
Wind ELCC* values are higher than today due to significant contribution from MT/WY wind

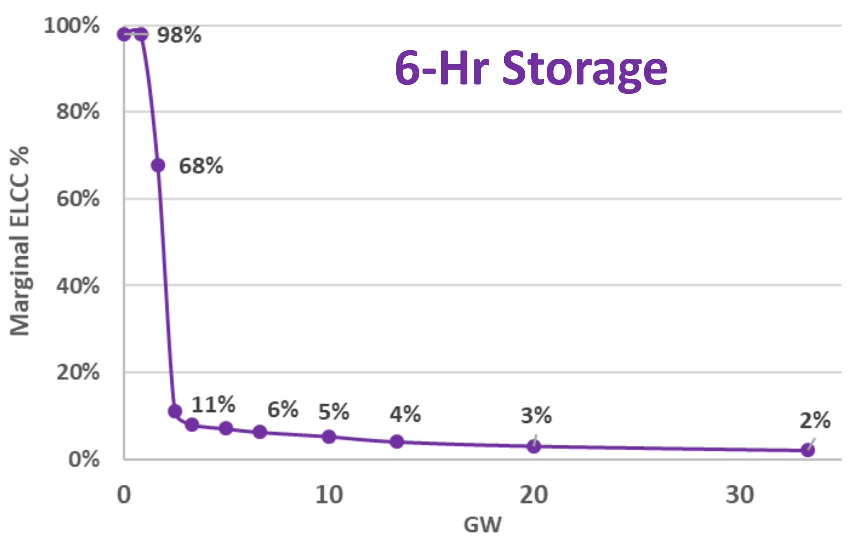
Nameplate Capacity (GW)			ELCC (%)			Capacity Factor (%)		
80% Red.	90% Red.	100% Red.	80% Red.	90% Red.	100% Red.	80% Red.	90% Red.	100% Red.
35	*35*	*35*	*58%*	*58%*	*57%*	*44%*	*44%*	*44%*
38	*48*	*96*	*19%*	*22%*	*22%*	*35%*	*36%*	*37%*
11	*11*	*46*	*19%*	*21%*	*16%*	*27%*	*27%*	*27%*
2.2	*4.4*	*29*	*71%*	*41%*	*20%*	*N/A*	*N/A*	*N/A*

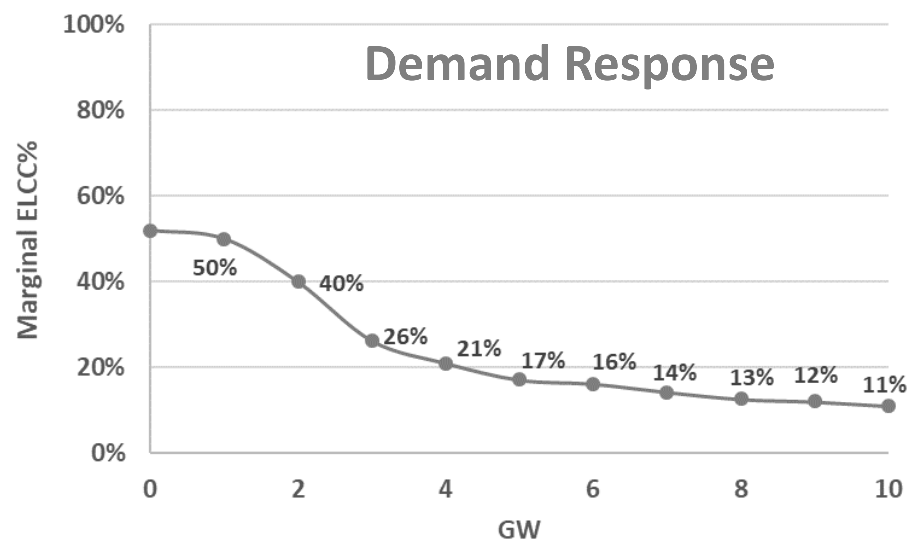
**ELCC = Effective Load Carrying Capability = firm contribution to system peak load*

Effective capacity from wind, solar, storage, and demand response is limited due to saturation effects



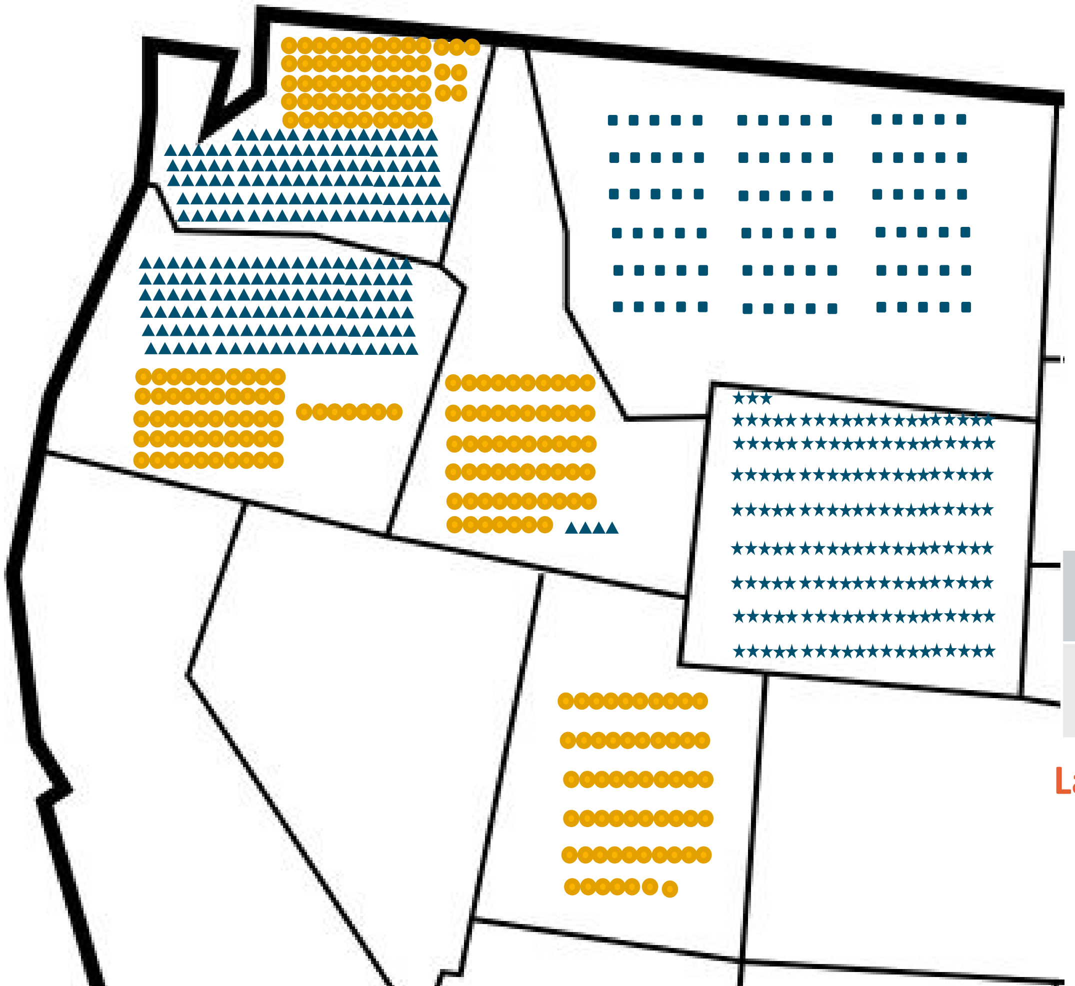






ELCC = Effective Load Carrying Capability = firm contribution to system peak load

Renewable Land Use
100% Reduction in 2050



Technology	Nameplate GW
● Solar	46
▲ NW Wind	47
■ MT Wind	18
★ WY Wind	33

	Solar Total Land Use (thousand acres)	Wind - Direct Land Use (thousand acres)	Wind - Total Land Use (thousand acres)
80% Clean	84	94	1,135 – 5,337
100% Red	361	241	2,913 – 13,701

Land use in 100% Reduction case ranges from

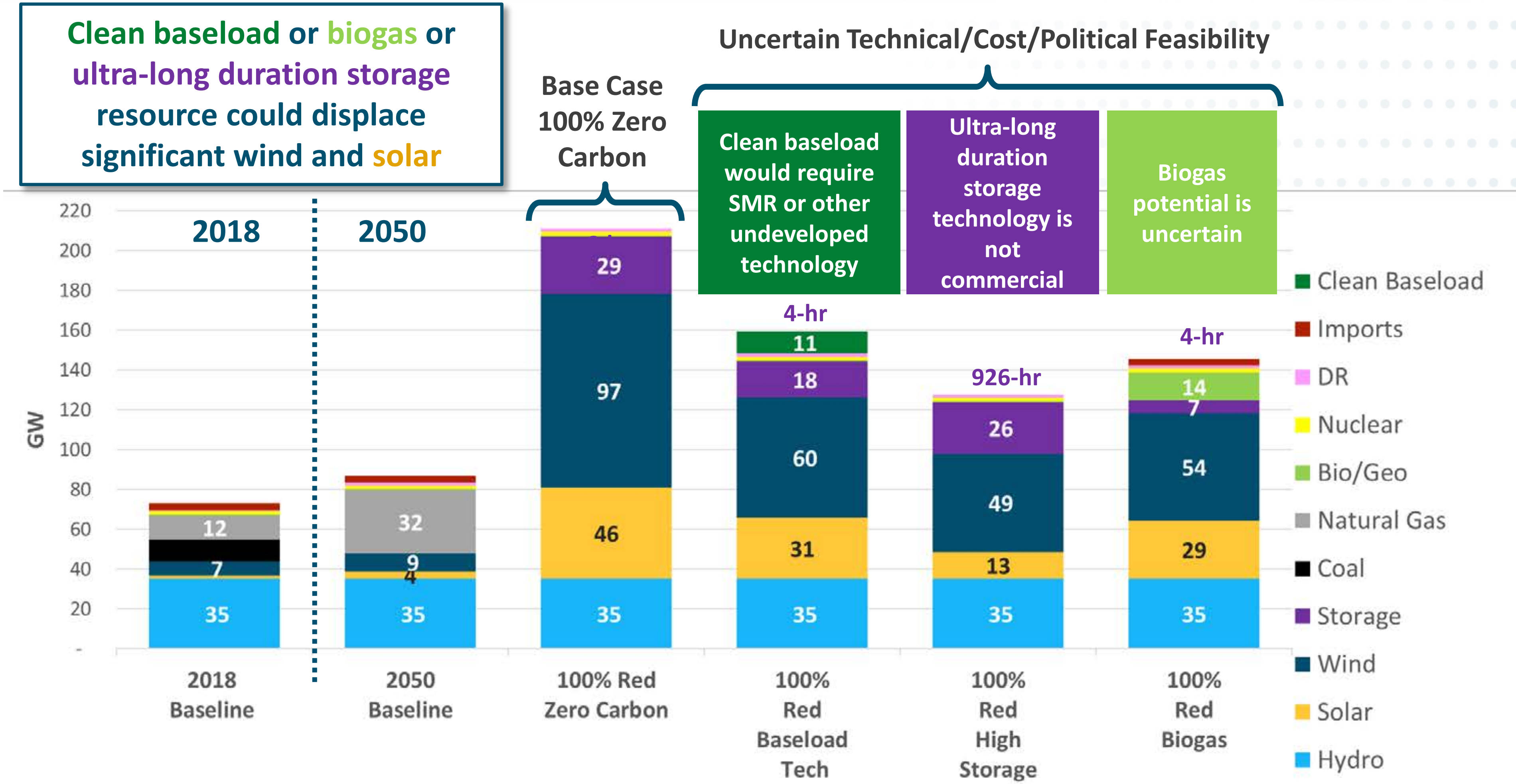
20 to 100x

the area of Portland and Seattle combined

Each point on the map indicates 200 MW.
Sites not to scale or indicative of site location.

Portland land area is 85k acres
Seattle land area is 56k acres
Oregon land area is 61,704k acres

100% Reduction Portfolio Alternatives in 2050



	2050 Baseline	100% Red Zero Carbon	100% Red Baseload Tech	100% Red High Storage	100% Red Biogas
Carbon (MMT CO2)	50	0	0	0	0
Annual Cost Delta ($B)	Base	$16- $28	$14-$21	$550-$990	$4 - $9
Additional Cost ($/MWh)	Base	$52-$89	$46-$69	$1,800-$3,200	$14 - $30

Energy+Environmental Economics

KEY FINDINGS

Key Findings (1 of 2)

1. **It is possible to maintain Resource Adequacy for a deeply decarbonized Northwest electricity grid, as long as sufficient <u>firm capacity</u> is available during periods of low wind, solar and hydro production**
   - Natural gas generation is the most economic source of firm capacity, and adding new gas *capacity* is not inconsistent with deep reductions in carbon emissions
   - Wind, solar, demand response and short-duration energy storage can contribute but have important limitations in their ability to meet Northwest Resource Adequacy needs
   - Other potential low-carbon firm capacity solutions include (1) new nuclear generation, (2) gas or coal generation with carbon capture and sequestration, (3) ultra-long duration electricity storage, and (4) replacing conventional natural gas with carbon-neutral gas
2. **It would be <u>extremely costly and impractical</u> to replace all carbon-emitting firm generation capacity with solar, wind and storage, due to the very large quantities of these resources that would be required**
3. **The Northwest is anticipated to need <u>new capacity in the near-term</u> in order to maintain an acceptable level of Resource Adequacy after planned coal retirements**

Key Findings (2 of 2)

4. **Current planning practices risk underinvestment in new capacity required to ensure Resource Adequacy at acceptable levels**

   - Reliance on "market purchases" or "front office transactions" reduces the cost of meeting Resource Adequacy needs on a regional basis by taking advantage of load and resource diversity among utilities in the region
   - However, because the region lacks a formal mechanism for counting physical firm capacity, there is a risk that reliance on market transactions may result in double-counting of available surplus generation capacity
   - Capacity resources are not firm without a firm fuel supply; investment in fuel delivery infrastructure may be required to ensure Resource Adequacy even under a deep decarbonization trajectory
   - The region might benefit from and should investigate a formal mechanism for sharing of planning reserves on a regional basis, which may help ensure sufficient physical firm capacity and reduce the quantity of capacity required to maintain Resource Adequacy

The results/findings in this analysis represent the Greater NW region in aggregate, but results may differ for individual utilities

Thank You!

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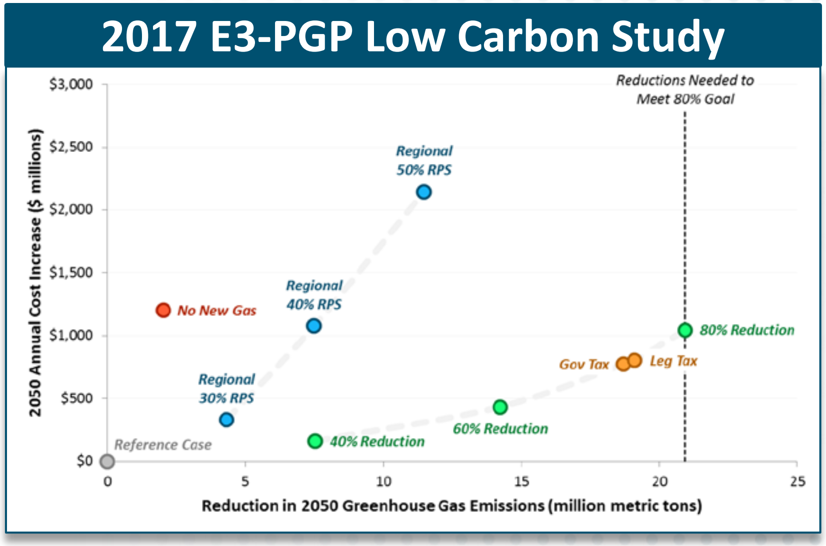
Relationship to Prior E3 Work

+ **In 2017-2018, E3 completed a series of studies for PGP and Climate Solutions to evaluate the costs of alternative electricity decarbonization strategies in Washington and Oregon**
  - The studies found that the least-cost way to reduce carbon is to replace coal with a mix of conservation, renewables and gas generation
  - Firm capacity was assumed to be needed for long-run reliability, however the study did not look at that question in depth



https://www.ethree.com/projects/study-policies-decarbonize-electric-sector-northwest-public-generating-pool-2017-present/

+ **This study builds on the previous analysis by focusing on long-run reliability**
  - How much capacity is needed to serve peak load under a range of conditions in the NW?
  - How much capacity can be provided by wind, solar, storage and demand response?
  - What combination of resources would be needed for reliability under low or zero carbon?
+ **The conclusions from this study broadly align with the previous results**

Long-run Reliability and Resource Adequacy

- **This study focuses on long-run (planning) reliability, a.k.a. Resource Adequacy (RA)**
  - A system is "Resource Adequate" if it has sufficient capacity to serve load across a broad range of weather conditions, subject to a long-run standard for frequency of reliability events, for example 1-day-in-10 yrs.
- **There is no mandatory or voluntary national standard for RA**
  - Each Balancing Authority establishes its own standard subject to oversight by state commissions or locally-elected boards
  - North American Electric Reliability Council (NERC) and Western Electric Coordinating Council (WECC) publish information about Resource Adequacy but have no formal governing role
- **Study uses a 1-in-10 standard of no more than 24 hours of lost load in 10 years, or no more than 2.4 hours/year**
  - This is the most common standard used across the industry

This study utilizes E3's Renewable Energy Capacity Planning (RECAP) Model

- **Resource adequacy is a critical concern under high renewable and decarbonized systems**
  - Renewable energy availability depends on the weather
  - Storage and Demand Response availability depends on many factors
- **RECAP evaluates adequacy through time-sequential simulations over thousands of years of plausible load, renewable, hydro, and stochastic forced outage conditions**
  - Captures thermal resource and transmission forced outages
  - Captures variable availability of renewables & correlations to load
  - Tracks hydro and storage state of charge

RECAP calculates reliability metrics for high renewable systems:

- **LOLP:** **Loss of Load Probability**
- **LOLE:** **Loss of Load Expectation**
- **EUE:** **Expected Unserved Energy**
- **ELCC:** **Effective Load-Carrying Capability for hydro, wind, solar, storage and DR**
- **PRM:** **Planning Reserve Margin needed to meet specified LOLE**

Information about E3's RECAP model can be found here:
https://www.ethree.com/tools/recap-renewable-energy-capacity-planning-model/

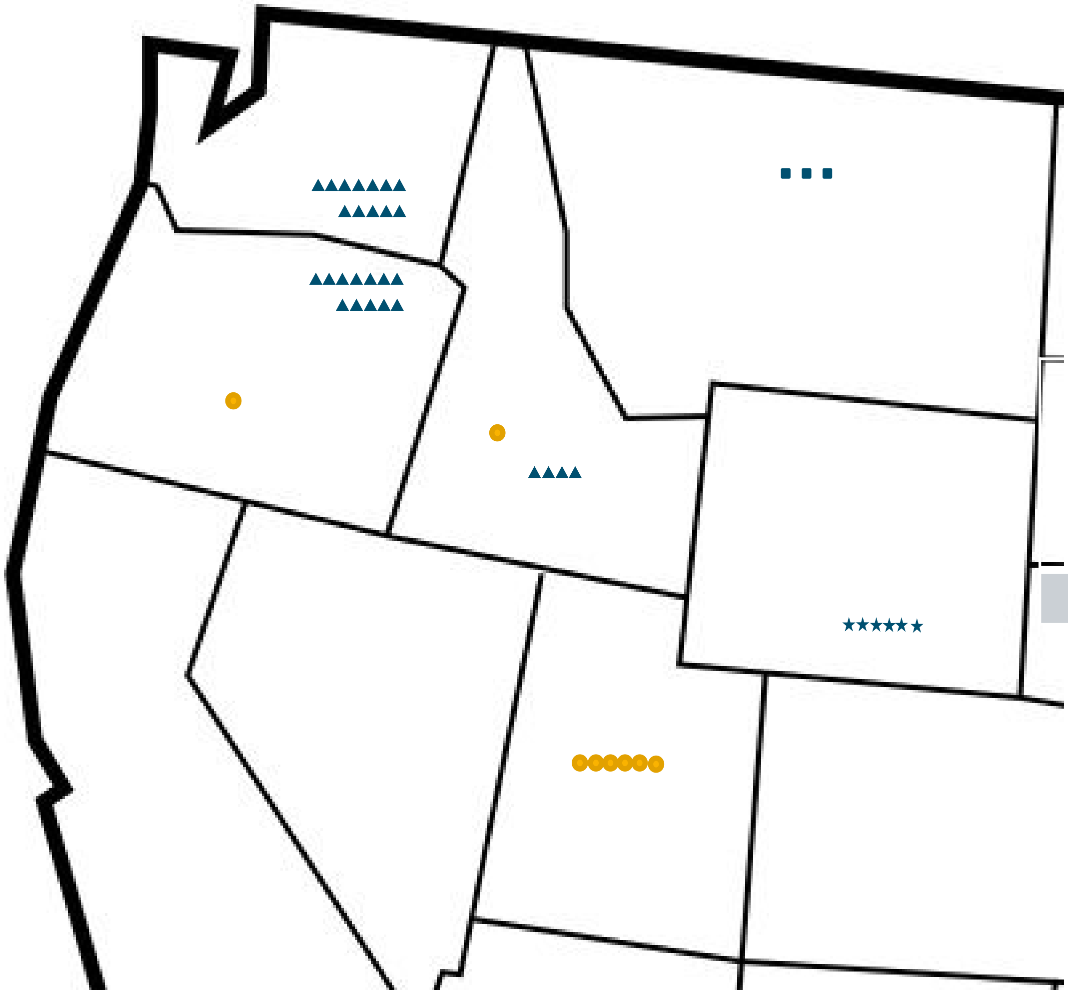
RECAP calculates a number of metrics that are useful for resource planning

- **Annual Loss of Load Probability (aLOLP) (%):** is the probability of a shortfall (load plus reserves exceed generation) in a given year
- **Annual Loss of Load Expectation (LOLE) (hrs/yr):** is total number of hours in a year wherein load plus reserves exceeds generation
- **Annual Expected Unserved Energy (EUE) (MWh/yr):** is the expected unserved load plus reserves in MWh per year
- **Effective Load Carrying Capability (ELCC) (%):** is the additional load met by an incremental generator while maintaining the same level of system reliability (used for dispatch-limited resources such as wind, solar, storage and demand response)
- **Planning Reserve Margin (PRM) (%):** is the resource margin above 1-in-2-year peak load, in %, that is required in order to maintain acceptable resource adequacy

Additional metric definitions used for scenario development

- **GHG Reduction %** is the reduction below 1990 emission levels for the study region
  - The study region emitted 60 million metric electricity sector emissions in 1990
- **CPS %** is the total quantity of GHG-free generation divided by retail electricity sales
  - "Clean Portfolio Standard" includes renewable energy plus hydro and nuclear
  - Common policy target metric, including California's SB 100
- **GHG-Free Generation %** is the total quantity of GHG-free generation, *minus* exported GHG-free generation, divided by total wholesale load
  - Assumed export capability up to 6,000 MW
- **Renewable Curtailment %** is the total quantity of wind/solar generation that is not delivered or exported divided by total wind/solar generation

Renewable Land Use
2018 Installed Renewables



Technology	Nameplate GW
● Solar	1.6
▲ NW Wind	5.3
■ MT Wind	0.6
★ WY Wind	1.2

	Solar Total Land Use (thousand acres)	Wind - Direct Land Use (thousand acres)	Wind – Total Land Use (thousand acres)
Today	12	19	223 – 1,052

Land use today ranges from

1.6 to 7.5x

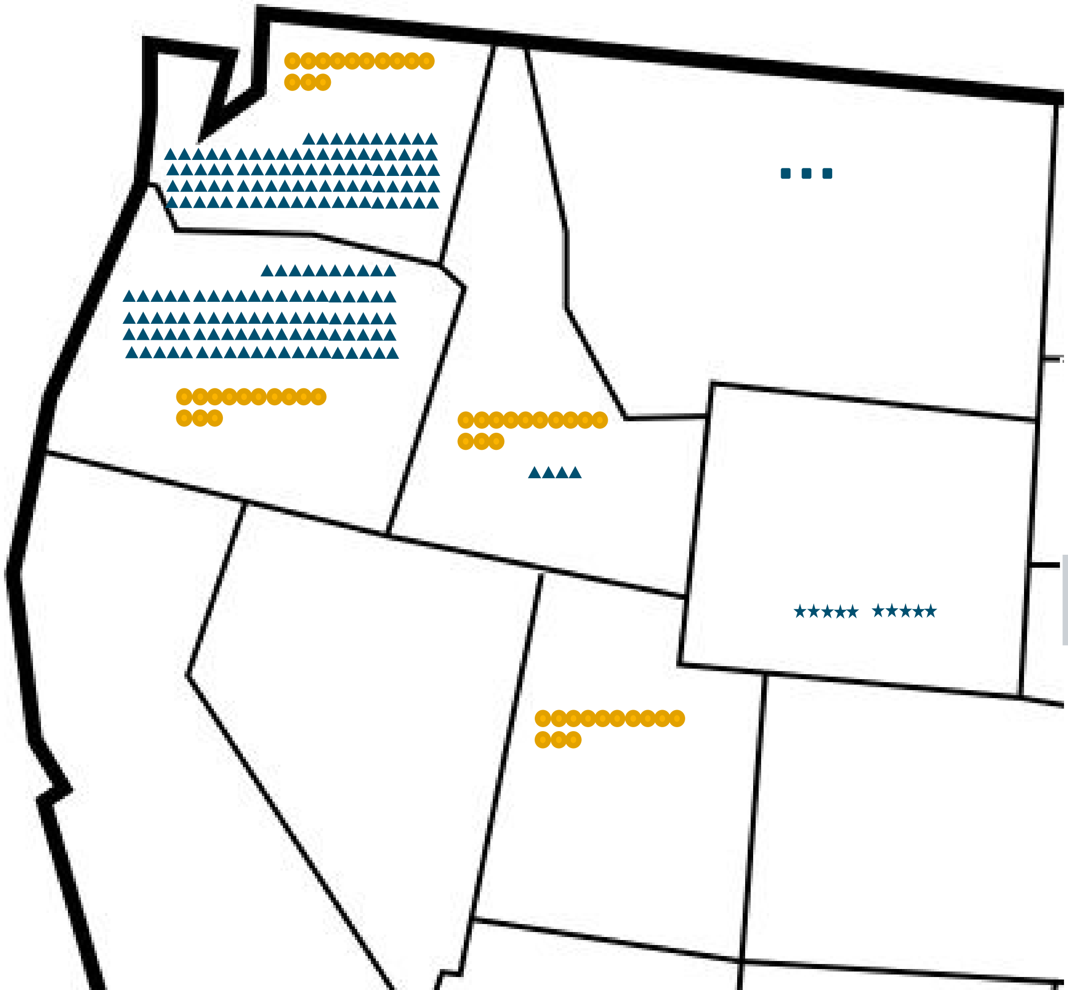
the area of Portland and Seattle combined

Each point on the map indicates 200 MW.
Sites not to scale or indicative of site location.

Portland land area is 85k acres
Seattle land area is 56k acres
Oregon land area is 61,704k acres

Renewable Land Use

80% Reduction in 2050



Technology	Nameplate GW
● Solar	11
▲ NW Wind	36
■ MT Wind	0
★ WY Wind	2

	Solar Total Land Use (thousand acres)	Wind - Direct Land Use (thousand acres)	Wind - Total Land Use (thousand acres)
80% Red	84	94	1,135 – 5,337

Land use in 80% Reduction case ranges from

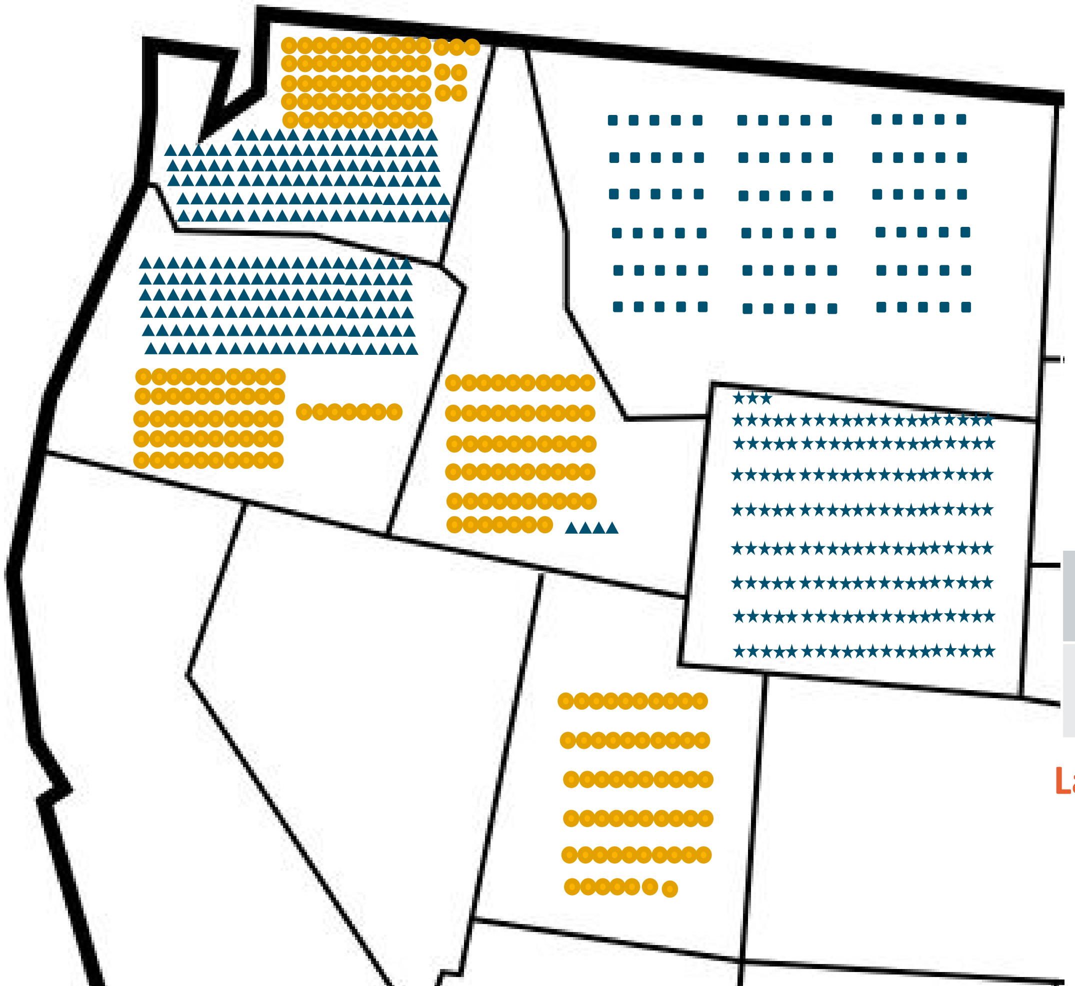
8 to 37x

the area of Portland and Seattle combined

Each point on the map indicates 200 MW.
Sites not to scale or indicative of site location.

Portland land area is 85k acres
Seattle land area is 56k acres
Oregon land area is 61,704k acres

Renewable Land Use
100% Reduction in 2050



Technology	Nameplate GW
● Solar	46
▲ NW Wind	47
■ MT Wind	18
★ WY Wind	33

	Solar Total Land Use (thousand acres)	Wind - Direct Land Use (thousand acres)	Wind - Total Land Use (thousand acres)
80% Clean	84	94	1,135 – 5,337
100% Red	361	241	2,913 – 13,701

Land use in 100% Reduction case ranges from

20 to 100x

the area of Portland and Seattle combined

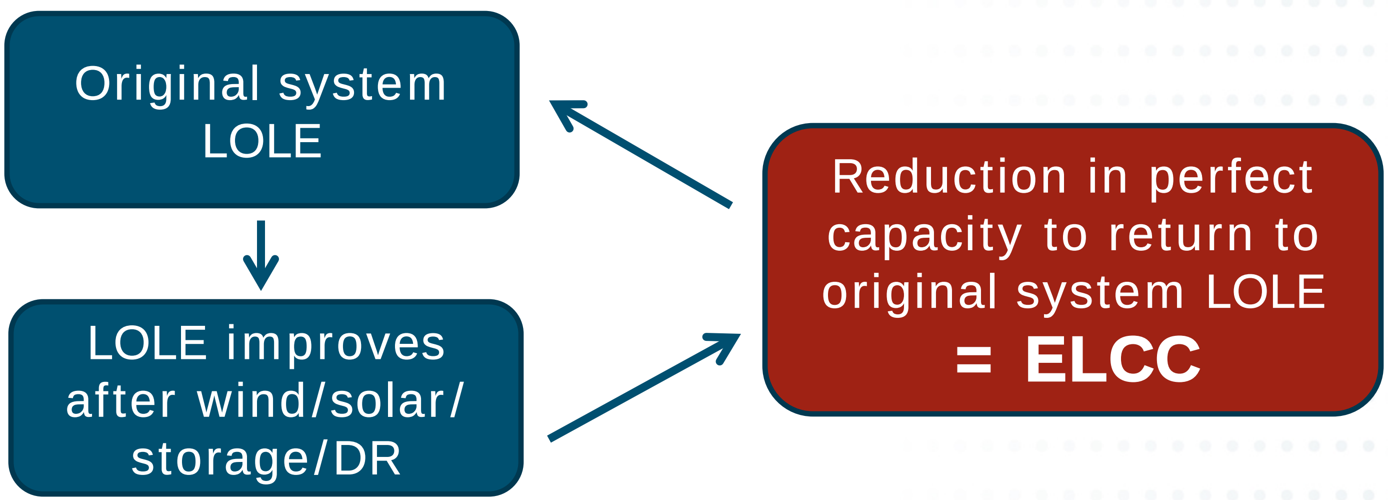
Each point on the map indicates 200 MW.
Sites not to scale or indicative of site location.

Portland land area is 85k acres
Seattle land area is 56k acres
Oregon land area is 61,704k acres

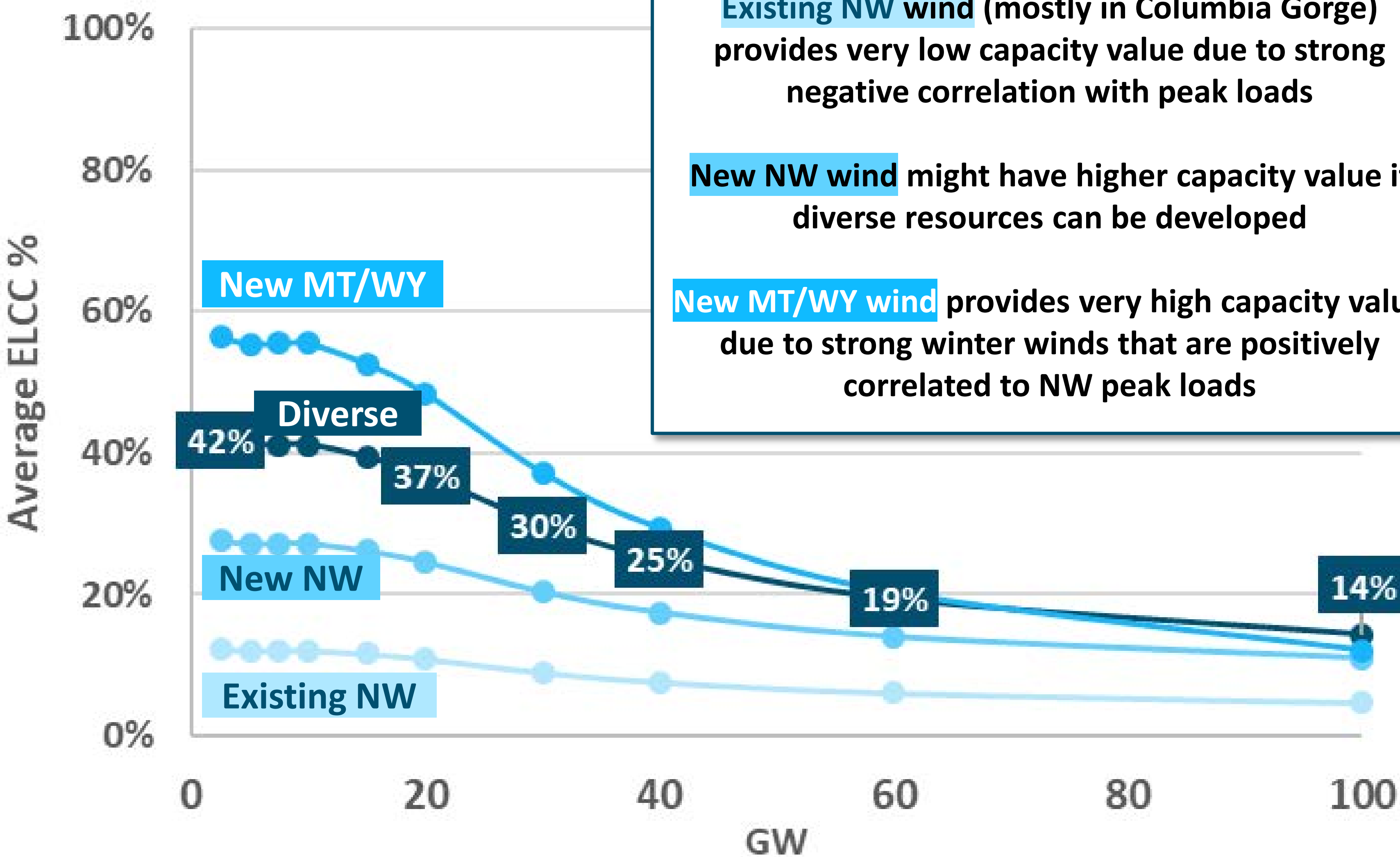
"ELCC" is used to determine effective capacity contribution from wind, solar, storage and demand response

- Effective load carrying capability (ELCC) is the quantity of 'perfect capacity' that could be replaced or avoided with dispatch-limited resources such as wind, solar, hydro, storage or demand response while providing equivalent system reliability

- The following slides present ELCC values calculated using the <u>2050 80% GHG Reduction Scenario</u> as the baseline conditions



Wind ELCC varies widely by location



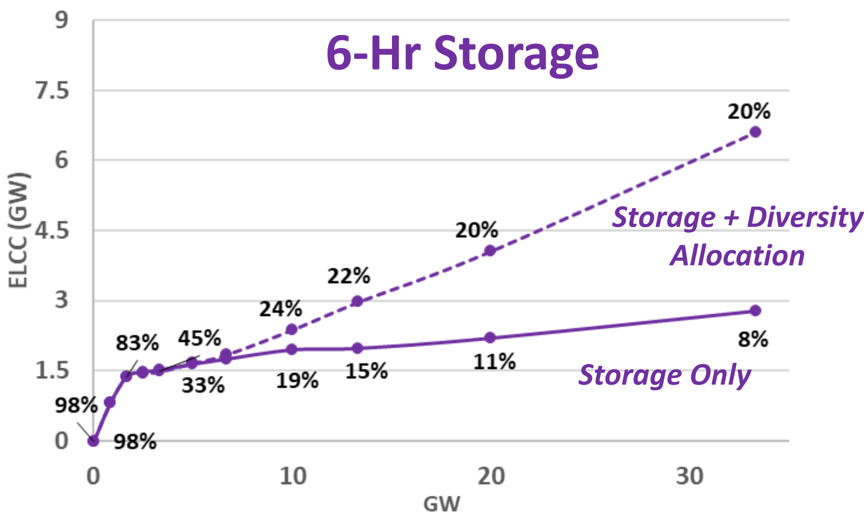
Existing NW wind (mostly in Columbia Gorge) provides very low capacity value due to strong negative correlation with peak loads

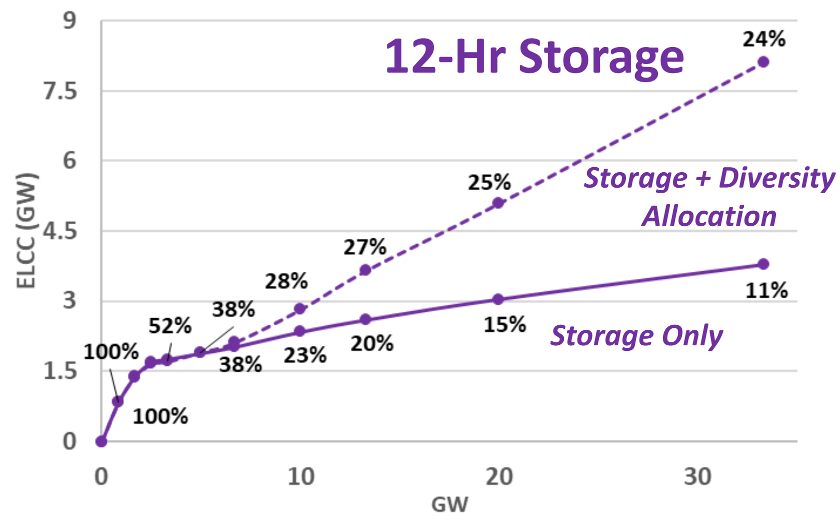
New NW wind might have higher capacity value if diverse resources can be developed

New MT/WY wind provides very high capacity value due to strong winter winds that are positively correlated to NW peak loads

Value of Storage Duration

+ **Increasing the duration of storage provides additional ELCC capacity value, but there are still strong diminishing returns even for storage up to a duration of 12-hours**





PSE gas planning standard

February 7, 2019 TAG #5

Gas planning standard overview

- WUTC recommendation
- Background: PSE’s gas planning standard
- Methodology for developing the standard
- Update with more recent temperature data
- Comparison with other gas utility planning standards

WUTC recommendation

WUTC acceptance letter for 2017 IRP, p. 15:

> “(WUTC) Staff recommends that PSE consider revisiting its peak gas day standard in the next IRP to see if it needs to be updated.”

PUGET SOUND ENERGY

Background: design peak day planning

Electric utility capacity planning

- Peak capacity need as a Planning Reserve Margin - a buffer over a normal peak hour load to attain a resource adequacy metric
- Example: PSE's electric planning standard is 5% LOLP, which resulted in a Planning Reserve Margin of 13.5% in the 2017 IRP

Gas industry uses *different language*

- Gas utilities typically define a design peak planning standard in terms of firm load at a target Heating Degree Day (HDD)
- HDD = 65 - Average Daily Temperature
  - Example: Average Daily Temperature = 13º
  - 65 – 13 = 52 HDD

PSE's Design Peak Day Planning Standard

PSE PUGET SOUND ENERGY

Methodology

2005 IRP (LCP): PSE's performed a benefit/cost analysis to establish the temperature threshold for the design peak day planning standard

Benefits: Primarily avoided cost of lost load

Cost: Portfolio cost associated with higher planning standards

Reliability of gas service is very important

- Service must be manually restored to firm customers
- If PSE lost 10% of its firm customers, it could take 12-14 days to get service fully restored.

Estimating the Value of Reliability

Begin with a planning standard; e.g., 50 HDD (15º F)

What if temperature is colder, such as 51 HDD (14º F)?

- Estimate how many customers lost
- Estimate how many days to restore service
- Multiply number of customers out, per day, by value of lost load
- Multiply by likelihood of experiencing the colder temperature

= Probability weighted value of lost load

Repeat for 51 HDD to 52 HDD, etc., through 55 HDD

Results from benefit/cost analysis

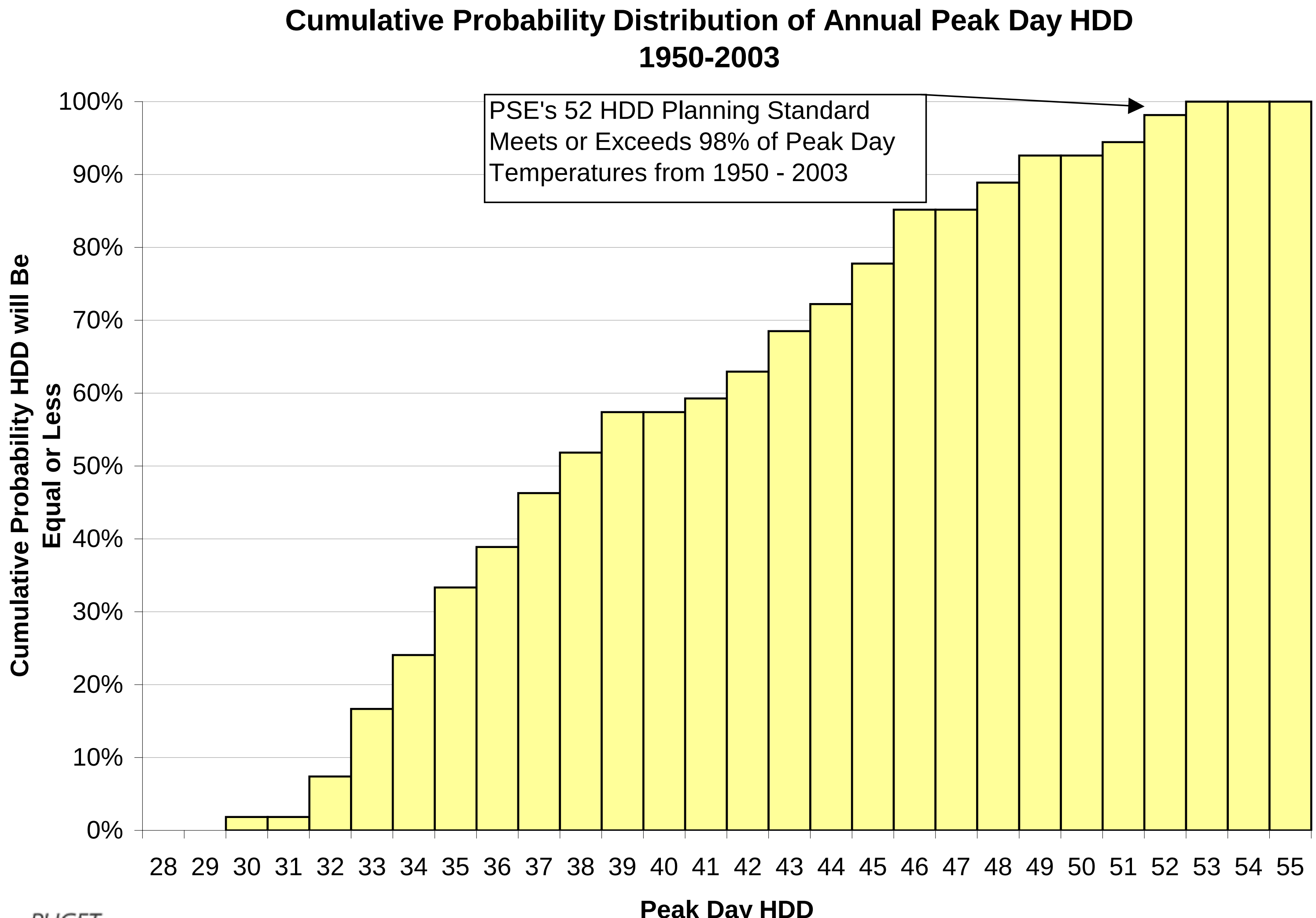
Exhibit I-4
Incremental Benefits and Costs of Reliability

Planning Standard	Incremental Benefit	Incremental Cost	Benefit/Cost Ratio
48 HDD (17° F)	$ 5,195,876	$238,645	21.8
49 HDD (16° F)	$ 3,332,322	$260,798	12.8
50 HDD (15° F)	$ 2,026,693	$423,036	4.8
51 HDD (14° F)	$ 1,169,251	$209,789	5.6
52 HDD (13° F)	$ 535,076	$455,153	1.2
53 HDD (12° F)	$ 145,373	$1,684,778	0.1
54 HDD (11° F)	$ -	$2,531,502	-
55 HDD (10° F)	$ -	$2,831,158	-

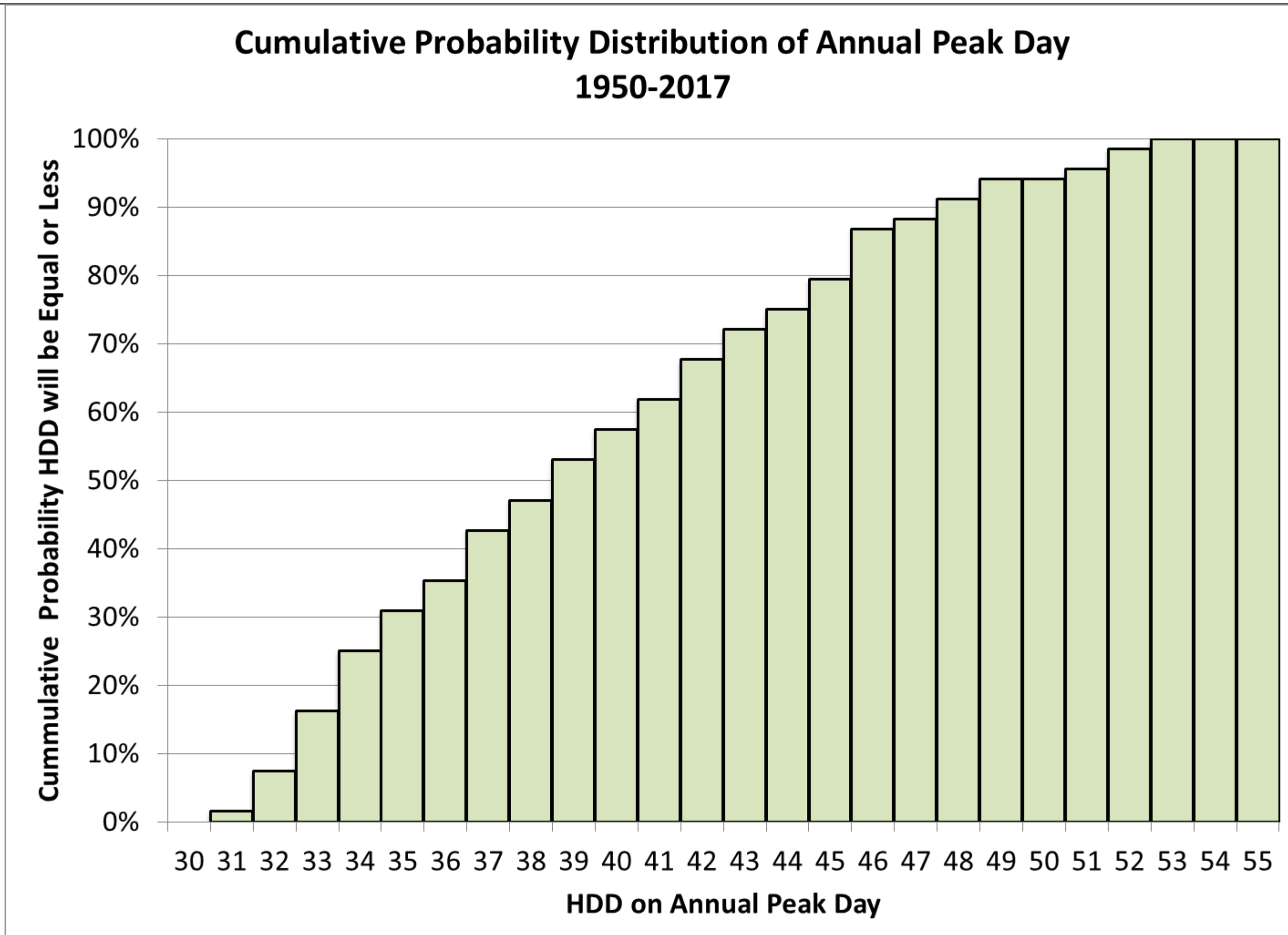
Source: PSE's 2005 Least Cost Plan

PSE PUGET SOUND ENERGY

Implied temperature criteria



Update to implied temperature criteria



Comparison of standards

Electric

- Target: 5% LOLP
- Time step: hourly
- Uncertainty in loads due to economic growth
- Uncertainty in loads due to temperature across year
- Forced outage rates on capacity resources
- Service restored when supply adequate

Gas

- Target: 53 HDD—2% temperature exceedance
- Time step: daily
- Uncertainty in peak loads due to peak temperatures on peak day
- No consideration of supply resource failure
- Service restored based on relight constraint

PUGET SOUND ENERGY

PNW gas utility peak day planning standards

PNW Gas Utility	Peak Capacity Design Standard
NW Natural	NW Natural will plan to serve the highest firm sales demand day in any year with 99% certainty: 99th percentile of annual peak days over last 100 years.
Cascade Natural	Coldest day during the past 30 years.
Avista Corp	Adjust the middle day of the five-day cold weather event to the coldest temperature on record for a service territory, as well as adjusting the two days on either side of the coldest day to temperatures slightly warmer than the coldest day.
Fortis NG	1 in 20 years temperature based on annual peak days over last 60 years.
PSE	98th percentile of annual peaks days from 1950-2017

PUGET SOUND ENERGY

Next steps

Next steps

Date	Action
February 21	PSE posts draft meeting notes with action items on IRP website and distributes draft meeting notes to TAG members
February 28	TAG members review meeting notes and provide comments to PSE
March 7	PSE posts final meeting notes on IRP website: www.pse.com/irp

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THANK YOU

IRP comment period

PUGET SOUND ENERGY

February 7, 2019 TAG #5