Scenario Results – Part 1

FSSTF

10/25/2019

Overview – Scenario Results

Part 1 (October FSSTF)

1. Phase 1 sensitivities based on stakeholder feedback
   a. Pipeline disruption concurrent with event peak load
   b. 14-day pipeline disruption
   c. Initial oil inventory level at 50%
   d. Portfolio sensitivity with additional renewable replacement of retirements (Escalated 3)

2. RTO-wide scenarios using Relevant Risk data from Historical Cold Snap Events

Part 2 (November FSSTF)

3. Locational scenarios using Relevant Risk data from Historical Cold Snap Events

4. RTO-wide and locational scenarios using Relevant Risk data for summer event

3. Scenario with data from October 1, 2019 Operational Event

4. Address feedback from October FSSTF

Goals of Scenario Analysis

Inform stakeholders about:	Phase 1	Phase 2	
		Phase 1 sensitivities based on stakeholder feedback	Additional scenarios using Relevant Risk data from historical cold snaps
1. Potential impacts of fuel/energy/resource risk events	✓	✓	✓
2. Factors that contribute to fuel/energy/resource security	✓	✓	✓
3. Risk of occurrence of selected scenarios			✓
4. Analysis framework that could be applied to **risks in other seasons** and **other resource portfolios**	✓	✓	✓

Phase 1 Sensitivities based on Stakeholder Feedback

Scenario Analysis Approach

Approach	Winter Load	Renewable Profiles	Relevant Risk Forced Outages	Other Forced Outages
Phase 1 & Phase 1 Sensitivities based on Stakeholder Feedback **(Phase 2)**	Typical • 50/50 peak (134,976 MW) • 2011/12 load profile Extreme Winter • 95/5 peak (147,721 MW) • 2017/18 load profile 14 day study period	2017/18 winter profiles, scaled to nameplate capacity in portfolio	Modeled sensitivities for fuel delivery risks: oil refueling, non-firm gas availability, pipeline disruptions	Forced outage rates using GADS cause codes not used in relevant risks or sensitivities
Historical Relevant Risk Events **(Phase 2)**	Load shapes consistent with selected cold snaps	Profile from cold snap, scaled to nameplate capacity in portfolio	Relevant Risk Forced Outages Rates from cold snap scaled to portfolio	
			Sensitivities for discrete occurrences of risks outside of historical forced outage dataset	

Portfolios: Announced (25.8% IRM), Escalated 1 (15.8% IRM), Escalated 2 (15.8% IRM), Escalated 3 (15.8% IRM)

Review: Phase 1 Scenarios

Dispatch	Retirement	Winter Load	Non-Firm Gas	Refueling	Pipeline Disruption (med. impact)	Pipeline Disruption (high impact)	Forced Outages
Economic	Announced	Typical 50/50 134,976 MW	62.5% Avail.	Moderate	Looped 1	Looped 1	Five-Year Avg.
Max. Emergency	Escalated 1	Extreme 95/5 147,721 MW	0% Avail.	Limited	Looped 2	Looped 2	Modeled Outages
	Escalated 2				Single 1	Single 1	
					Single 2	Single 2	

324

combinations

Phase 1 Sensitivities based on Stakeholder Feedback

Adjust following **input assumptions**, one at a time, for selected scenarios:

1. Pipeline disruption concurrent with event peak load (days 6 - 10)
2. 14-day pipeline disruption
3. Initial oil inventory level at 50%
4. Portfolio sensitivity with additional renewable replacement of retirements (Escalated 3)

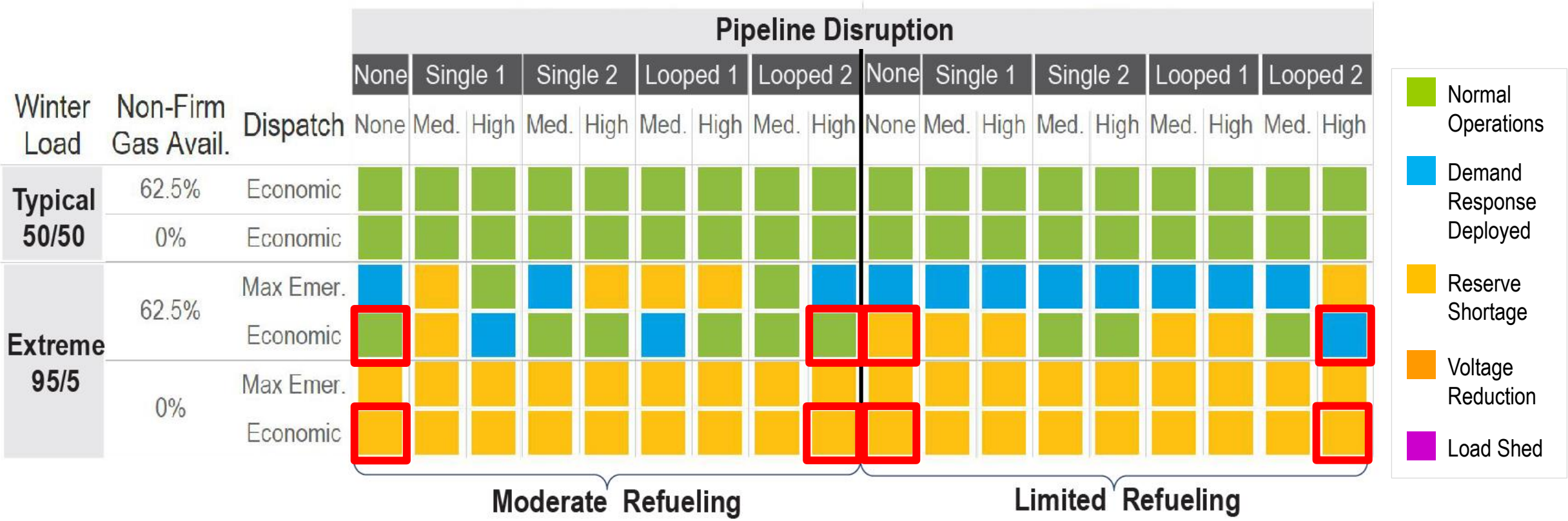
56

sensitivities

Outputs consistent with Phase 1 results presented for each scenario:

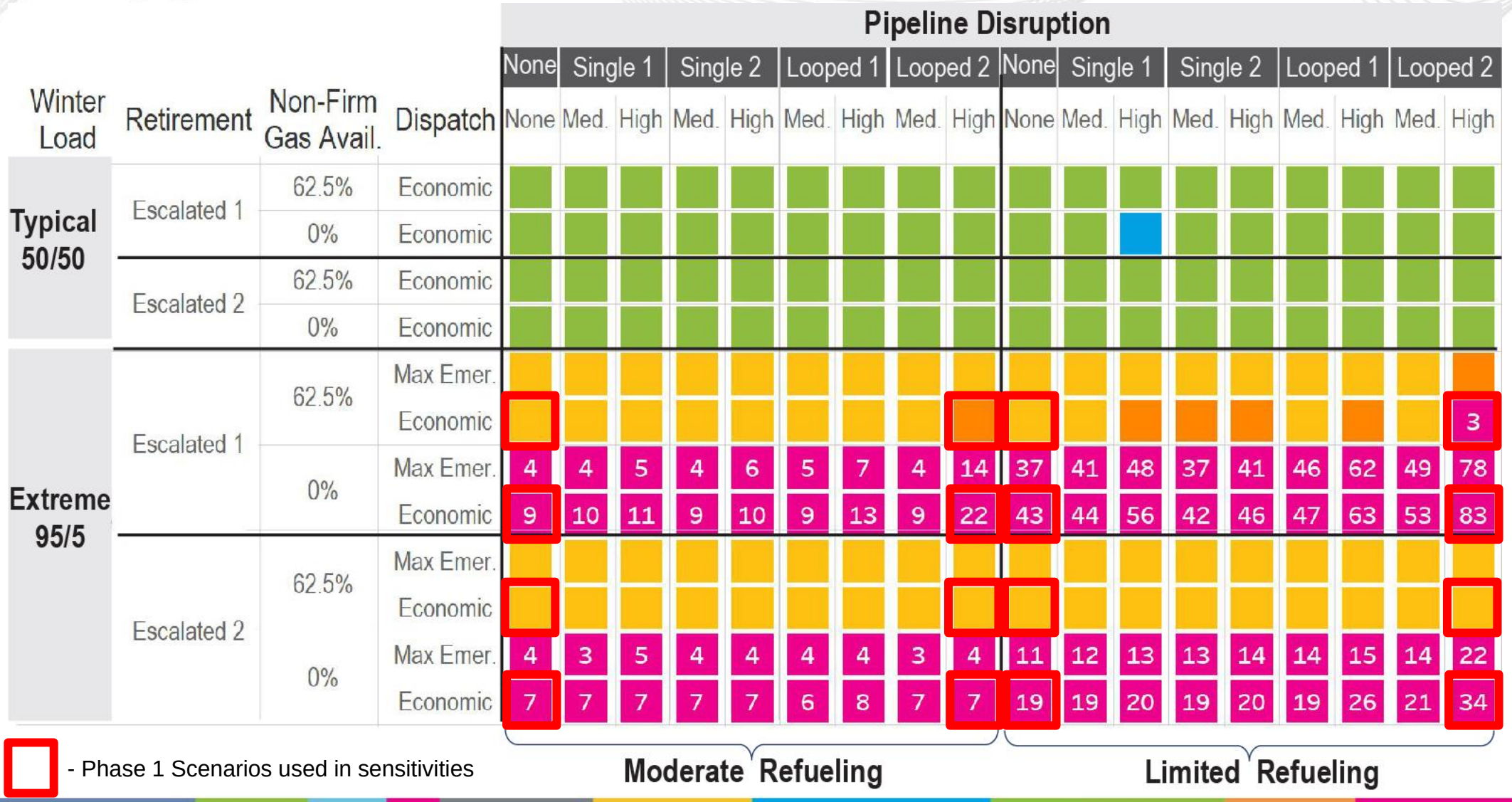
Normal Operations	**No Emergency Procedures** Normal economic dispatch
Demand Response Deployed	**Pre-Emergency Action** Demand response deployment
Reserve Shortage	**Emergency Warning** An operational reserve shortage is triggered when 10-minute Synchronized Reserves are less than the largest generator in PJM. Depending on system conditions, a reserve shortage will trigger additional emergency procedures such as voltage reduction warnings and manual load shed warnings.
Voltage Reduction	**Emergency Action** Voltage reduction action enables load reductions by reducing voltages at the distribution level. PJM estimates a 1-2% load reduction resulting from a 5% load reduction in transmission zones capable of performing a voltage reduction.
Load Shed	**Emergency Action** Manual load shed action enables zonal or system-wide load shed. This is the last step of all emergency procedure actions.

Phase 1 Announced Retirement Models for Sensitivities



- Phase 1 Scenarios used in sensitivities

Phase 1 Escalated Retirement Models for Sensitivities



- Phase 1 Scenarios used in sensitivities

Phase 1 Sensitivities based on Stakeholder Feedback: **Pipeline Disruption Concurrent with Peak Load***

Sensitivity	Related Phase 1 Scenario #	Portfolio	IRM	Dispatch	Winter Load	Non-Firm Gas Availability	Infrastructure Disruption	Disruption Severity	Disruption Duration	Refueling	Initial Oil Inventory Level
1	45	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Moderate	85%
2	54	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Limited	85%
3	63	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Moderate	85%
4	72	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Limited	85%
5	153	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Moderate	85%
6	162	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Limited	85%
7	171	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Moderate	85%
8	180	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Limited	85%
9	261	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Moderate	85%
10	270	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Limited	85%
11	279	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Moderate	85%
12	288	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Limited	85%

*Peak of 147,721 MW occurs on Day 10 with Extreme Winter load shape

Phase 1 Sensitivities based on Stakeholder Feedback:
Pipeline Disruption Concurrent with Peak Load*

Emergency Procedure **Hours**

Phase 1: Pipeline Disruption D1-5

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling Looped 2 High	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic		
		0%	Economic		
	Escalated 1	62.5%	Economic		3
		0%	Economic	22	83
	Escalated 2	62.5%	Economic		
		0%	Economic	7	34

Sensitivity #1-12: Pipeline Disruption D6-10

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling Looped 2 High	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic		
		0%	Economic		
	Escalated 1	62.5%	Economic	2	10
		0%	Economic	37	68
	Escalated 2	62.5%	Economic		
		0%	Economic	9	27

- **No increase in emergency procedures in sensitivities with Announced Retirement portfolio**
- **Some increase in emergency procedure hours in sensitivities with Escalated Retirement portfolios**

☐ - Scenarios to be compared slide 13

Sensitivity Scenario Summaries in Appendix I

Phase 1 Sensitivities based on Stakeholder Feedback:
Pipeline Disruption Concurrent with Peak Load*

Emergency Procedure **GWh**

Phase 1: Pipeline Disruption D1-5

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling: Looped 2 High	Limited Refueling: Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic		
		0%	Economic		
	Escalated 1	62.5%	Economic		2
		0%	Economic	30	204
	Escalated 2	62.5%	Economic		
		0%	Economic	21	104

Sensitivity #1-12: Pipeline Disruption D6-10

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling: Looped 2 High	Limited Refueling: Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic		
		0%	Economic		
	Escalated 1	62.5%	Economic	1	16
		0%	Economic	80	224
	Escalated 2	62.5%	Economic		
		0%	Economic	34	103

- **No increase in emergency procedures in sensitivities with Announced Retirement portfolio**
- **Some increase in emergency procedure GWh in sensitivities with Escalated Retirement portfolios**

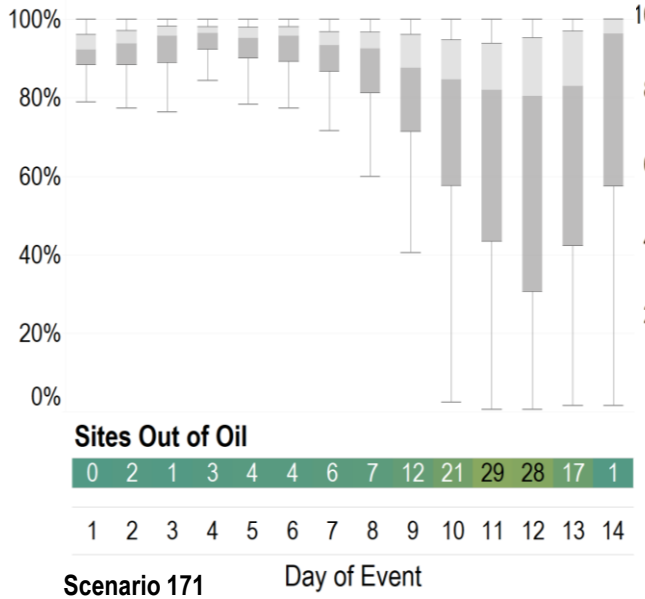
□ - Scenarios to be compared slide 13

Sensitivity Scenario Summaries in Appendix I

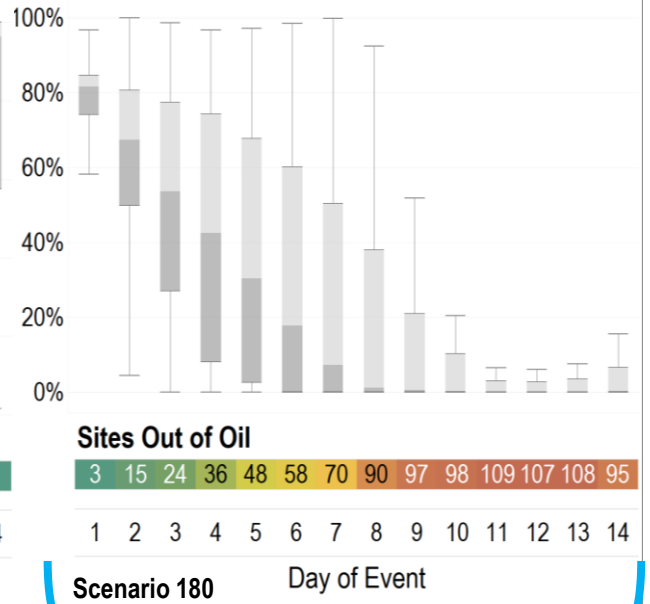
Phase 1 Sensitivities based on Stakeholder Feedback: **Pipeline Disruption Concurrent with Peak Load***

Phase 1: Pipeline Disruption D1-5

Moderate Refueling



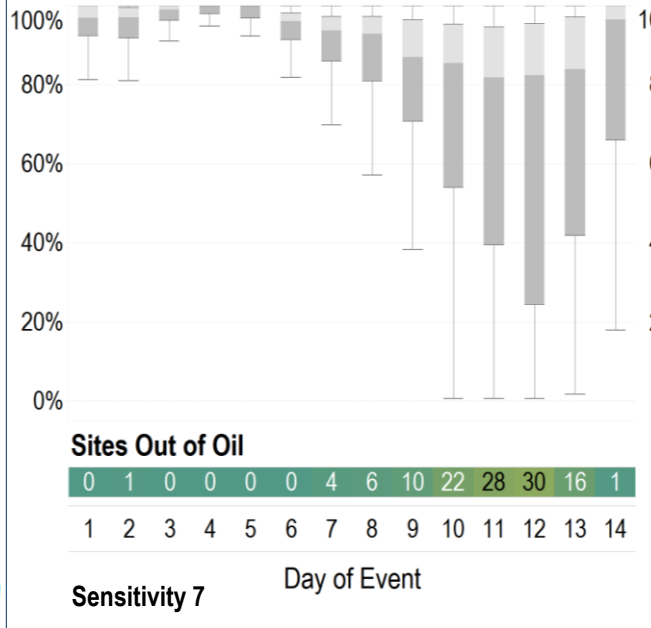
Limited Refueling



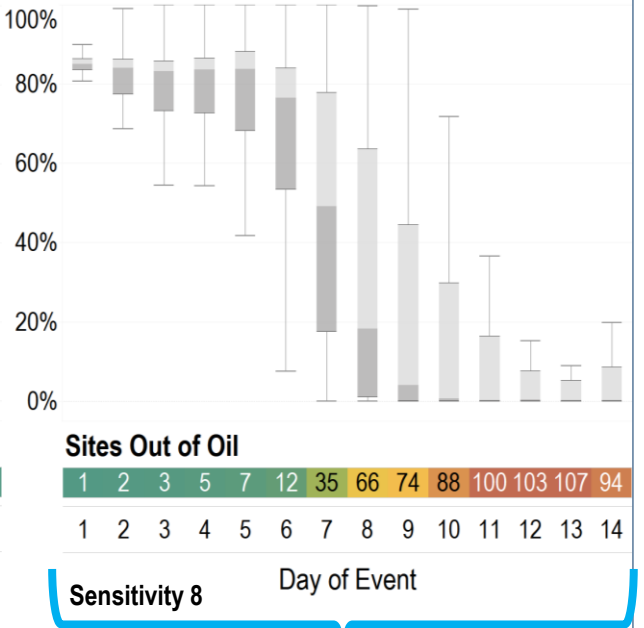
Onsite inventories depleted during pipeline disruption, before peak load of scenario

Sensitivity #1-12: Pipeline Disruption D6-10

Moderate Refueling



Limited Refueling



Onsite inventory depletion occurs later in scenario with pipeline disruption + peak load

Phase 1 Sensitivities based on Stakeholder Feedback: **14-day Pipeline Disruption**

Sensitivity	Related Phase 1 Scenario #	Portfolio	IRM	Dispatch	Winter Load	Non-Firm Gas Availability	Infrastructure Disruption	Disruption Severity	Disruption Duration	Refueling	Initial Oil Inventory Level
13	45	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Moderate	85%
14	54	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Limited	85%
15	63	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Moderate	85%
16	72	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Limited	85%
17	153	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Moderate	85%
18	162	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Limited	85%
19	171	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Moderate	85%
20	180	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Limited	85%
21	261	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Moderate	85%
22	270	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Limited	85%
23	279	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Moderate	85%
24	288	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Limited	85%

Phase 1 Sensitivities based on Stakeholder Feedback:
14-day Pipeline Disruption
Emergency Procedure **Hours**

Phase 1: Pipeline Disruption D1-5

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling Looped 2 High	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic		
		0%	Economic		
	Escalated 1	62.5%	Economic		3
		0%	Economic	22	83
	Escalated 2	62.5%	Economic		
		0%	Economic	7	34

Sensitivity #13-24: Pipeline Disruption D1-14

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling Looped 2 High	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic		
		0%	Economic		
	Escalated 1	62.5%	Economic	2	23
		0%	Economic	63	144
	Escalated 2	62.5%	Economic		
		0%	Economic	18	61

- **Increase in pre-emergency procedures in sensitivities with Announced Retirement portfolio**
- **Increase in emergency procedure hours in sensitivities with Escalated Retirement portfolios**

Sensitivity Scenario Summaries in Appendix I

Phase 1 Sensitivities based on Stakeholder Feedback:
14-day Pipeline Disruption
Emergency Procedure **GWh**

Phase 1: Pipeline Disruption D1-5

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling Looped 2 High	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic		
		0%	Economic		
	Escalated 1	62.5%	Economic		2
		0%	Economic	30	204
	Escalated 2	62.5%	Economic		
		0%	Economic	21	104

Sensitivity #13-24: Pipeline Disruption D1-14

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling Looped 2 High	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic		
		0%	Economic		
	Escalated 1	62.5%	Economic	2	26
		0%	Economic	159	547
	Escalated 2	62.5%	Economic		
		0%	Economic	45	207

- **Increase in pre-emergency procedures in sensitivities with Announced Retirement portfolio**
- **Increase in emergency procedure GWh in sensitivities with Escalated Retirement portfolios**

Sensitivity Scenario Summaries in Appendix I

Phase 1 Sensitivities based on Stakeholder Feedback: **Initial Oil Inventory Level at 50%**

Sensitivity	Related Phase 1 Scenario #	Portfolio	IRM	Dispatch	Winter Load	Non-Firm Gas Availability	Infrastructure Disruption	Disruption Severity	Disruption Duration	Refueling	Initial Oil Inventory Level
25	37	Announced	28.5%	Economic	Extreme	62.5%	None	None	None	Moderate	50%
26	46	Announced	28.5%	Economic	Extreme	62.5%	None	None	None	Limited	50%
27	55	Announced	28.5%	Economic	Extreme	0%	None	None	None	Moderate	50%
28	64	Announced	28.5%	Economic	Extreme	0%	None	None	None	Limited	50%
29	145	Escalated 1	15.8%	Economic	Extreme	62.5%	None	None	None	Moderate	50%
30	154	Escalated 1	15.8%	Economic	Extreme	62.5%	None	None	None	Limited	50%
31	163	Escalated 1	15.8%	Economic	Extreme	0%	None	None	None	Moderate	50%
32	172	Escalated 1	15.8%	Economic	Extreme	0%	None	None	None	Limited	50%
33	253	Escalated 2	15.8%	Economic	Extreme	62.5%	None	None	None	Moderate	50%
34	262	Escalated 2	15.8%	Economic	Extreme	62.5%	None	None	None	Limited	50%
35	271	Escalated 2	15.8%	Economic	Extreme	0%	None	None	None	Moderate	50%
36	280	Escalated 2	15.8%	Economic	Extreme	0%	None	None	None	Limited	50%
37	45	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Moderate	50%
38	54	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Limited	50%
39	63	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Moderate	50%
40	72	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Limited	50%
41	153	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Moderate	50%
42	162	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Limited	50%
43	171	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Moderate	50%
44	180	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Limited	50%
45	261	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Moderate	50%
46	270	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Limited	50%
47	279	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Moderate	50%
48	288	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Limited	50%

Phase 1 Sensitivities based on Stakeholder Feedback:
Initial Oil Inventory Level at 50%
Emergency Procedure **Hours**

Phase 1: Initial Oil Inventory Level at **85%**

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling: None	Moderate Refueling: Looped 2	Limited Refueling: None	Limited Refueling: Looped 2
				None	High	None	High
Extreme (95/5)	Announced	62.5%	Economic				
		0%	Economic				
	Escalated 1	62.5%	Economic				3
		0%	Economic	9	22	43	83
	Escalated 2	62.5%	Economic				
		0%	Economic	7	7	19	34

Sensitivity #25-48: Initial Oil Inventory Level at **50%**

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling: None	Moderate Refueling: Looped 2	Limited Refueling: None	Limited Refueling: Looped 2
				None	High	None	High
Extreme (95/5)	Announced	62.5%	Economic				
		0%	Economic				
	Escalated 1	62.5%	Economic				5
		0%	Economic	9	23	65	105
	Escalated 2	62.5%	Economic				
		0%	Economic	7	7	30	44

- **Some increase in pre-emergency procedures in sensitivities with Announced Retirement portfolio**
- **Some increase in emergency procedure hours in sensitivities with Escalated Retirement portfolios**

☐ - Scenarios to be compared in following slides

Sensitivity Scenario Summaries in Appendix I

Phase 1 Sensitivities based on Stakeholder Feedback:
Initial Oil Inventory Level at 50%
Emergency Procedure **GWh**

Phase 1: Initial Oil Inventory Level at **85%**

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling None None	Moderate Refueling Looped 2 High	Limited Refueling None None	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic				
		0%	Economic				
	Escalated 1	62.5%	Economic				2
		0%	Economic	20	30	107	204
	Escalated 2	62.5%	Economic				
		0%	Economic	18	21	66	104

Sensitivity #25-48: Initial Oil Inventory Level at **50%**

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling None None	Moderate Refueling Looped 2 High	Limited Refueling None None	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic				
		0%	Economic				
	Escalated 1	62.5%	Economic				3
		0%	Economic	22	37	173	311
	Escalated 2	62.5%	Economic				
		0%	Economic	22	21	111	166

- **Some increase in pre-emergency procedures in sensitivities with Announced Retirement portfolio**
- **Some increase in emergency procedure GWh in sensitivities with Escalated Retirement portfolios**

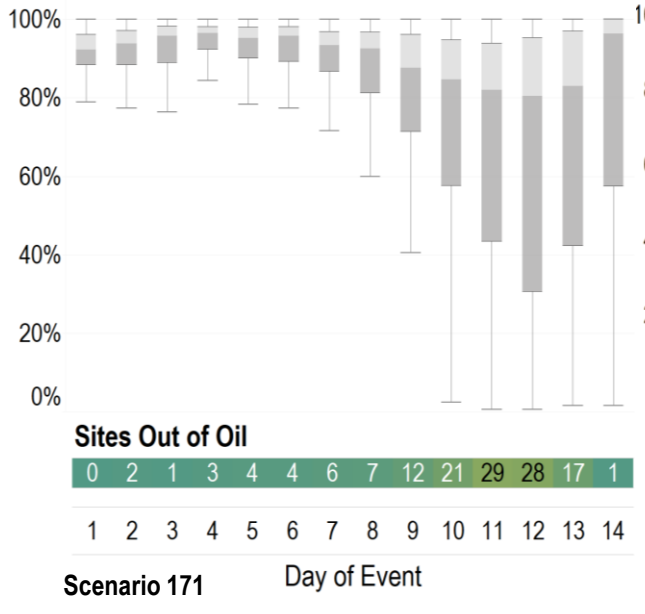
☐ - Scenarios to be compared in following slides

Sensitivity Scenario Summaries in Appendix I

Phase 1 Sensitivities based on Stakeholder Feedback: **Initial Oil Inventory Level at 50%**

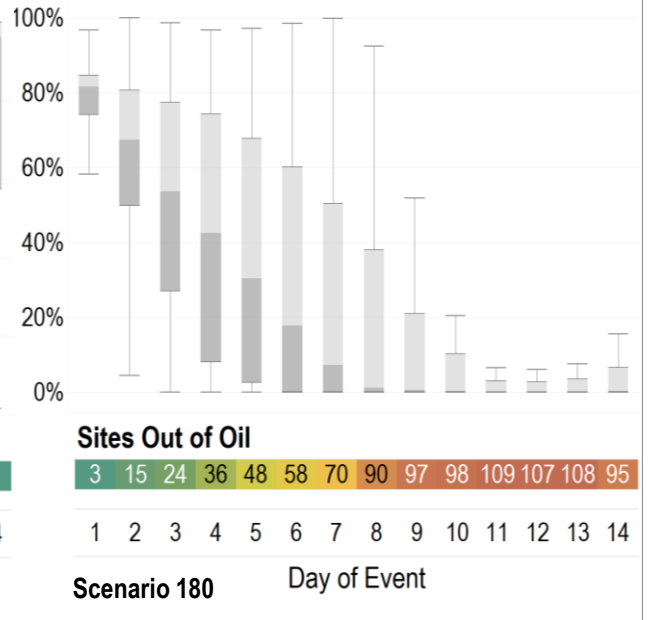
Phase 1: Initial Oil Inventory Level at **85%**

Moderate Refueling



Scenario 171

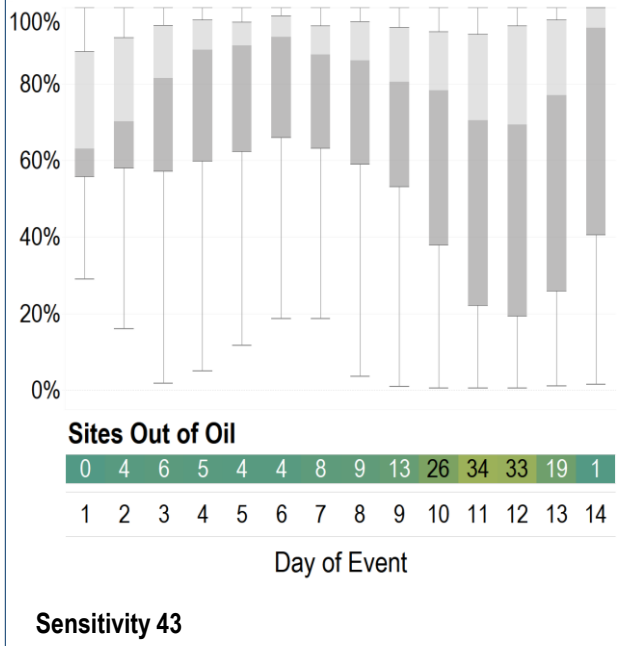
Limited Refueling



Scenario 180

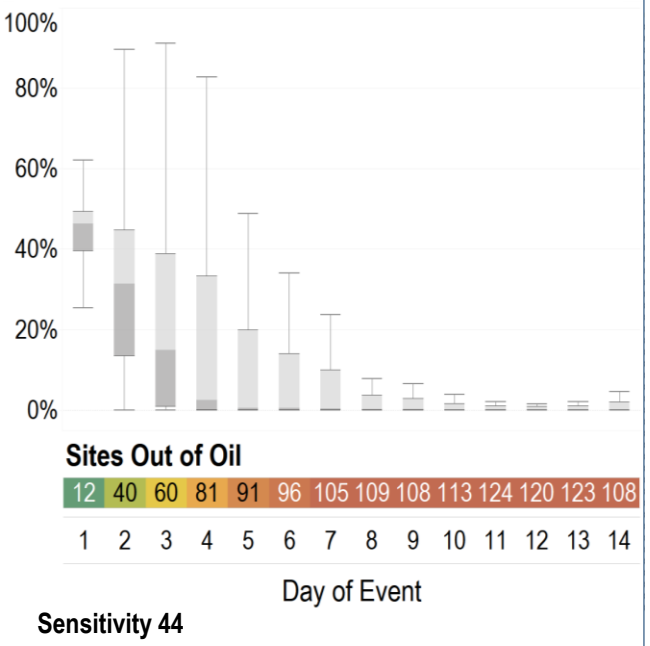
Sensitivity #25-48: Initial Oil Inventory Level at **50%**

Moderate Refueling



Sensitivity 43

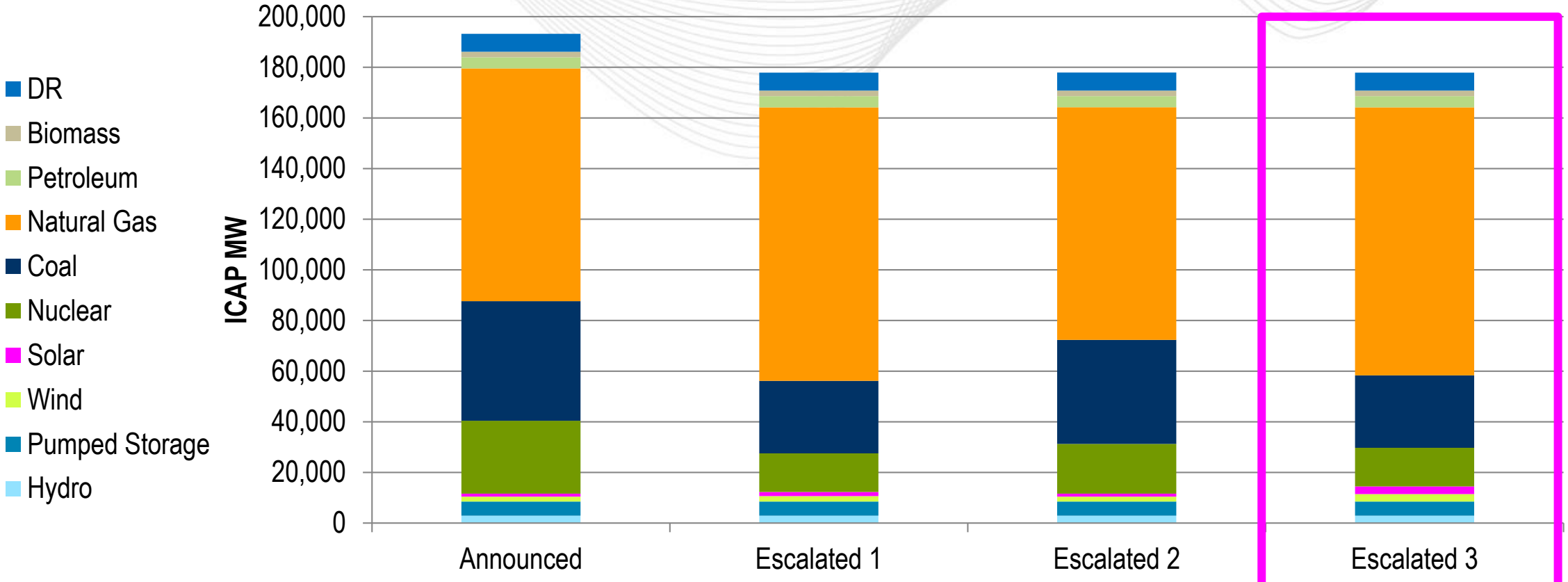
Limited Refueling



Sensitivity 44

More rapid onsite fuel depletion in sensitivities with lower initial inventory levels

Addition of Escalated 3 Portfolio for Sensitivity



	Announced	Escalated 1	Escalated 2	Escalated 3
Wind (ICAP / nameplate)	1,945 / 14,962	2,163 / 16,638	1,945 / 14,962	2,940 / 22,613
Solar (ICAP / nameplate)	1,153 / 3,034	1,613 / 4,245	1,153 / 3,034	3,023 / 7,956

Note: Appendix IV includes comparison of portfolios used in PJM analysis to portfolios used in 2018 NERC Generation Retirement Scenario Assessment

Phase 1 Sensitivities based on Stakeholder Feedback: **"Escalated 3" Portfolio**

Sensitivity	Related Phase 1 Scenario #	Portfolio	IRM	Dispatch	Winter Load	Non-Firm Gas Availability	Infrastructure Disruption	Disruption Severity	Disruption Duration	Refueling	Initial Oil Inventory Level
49	145	Escalated 3	15.8%	Economic	Extreme	62.5%	None	None	None	Moderate	85%
50	154	Escalated 3	15.8%	Economic	Extreme	62.5%	None	None	None	Limited	85%
51	163	Escalated 3	15.8%	Economic	Extreme	0%	None	None	None	Moderate	85%
52	172	Escalated 3	15.8%	Economic	Extreme	0%	None	None	None	Limited	85%
53	153	Escalated 3	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Moderate	85%
54	162	Escalated 3	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Limited	85%
55	171	Escalated 3	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Moderate	85%
56	180	Escalated 3	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Limited	85%

Phase 1 Sensitivities based on Stakeholder Feedback: "Escalated 3" Portfolio

Emergency Procedure **Hours**

Phase 1 Portfolios

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling None None	Moderate Refueling Looped 2 High	Limited Refueling None None	Limited Refueling Looped 2 High
Extreme (95/5)	Announced	62.5%	Economic				
		0%	Economic				
	Escalated 1	62.5%	Economic				3
		0%	Economic	9	22	43	83
	Escalated 2	62.5%	Economic				
		0%	Economic	7	7	19	34

Sensitivity #49-56: Escalated 3 Portfolio

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling None None	Moderate Refueling Looped 2 High	Limited Refueling None None	Limited Refueling Looped 2 High
Extreme (95/5)	Escalated 3	62.5%	Economic				3
		0%	Economic	6	13	29	51

Renewable ICAP in portfolios and renewable profiles (scaled to nameplate MW) contributed to the reduced severity observed between scenarios with Escalated 1 and Escalated 3 portfolios, which include the same numbers of retirements with a different mix of replacement resources.

Sensitivity Scenario Summaries in Appendix I

Phase 1 Sensitivities based on Stakeholder Feedback: "Escalated 3" Portfolio

Emergency Procedure **GWh**

Phase 1 Portfolios

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling: None / None	Moderate Refueling: Looped 2 / High	Limited Refueling: None / None	Limited Refueling: Looped 2 / High
Extreme (95/5)	Announced	62.5%	Economic				
		0%	Economic				
	Escalated 1	62.5%	Economic				2
		0%	Economic	20	30	107	204
	Escalated 2	62.5%	Economic				
		0%	Economic	18	21	66	104

Sensitivity #49-56: Escalated 3 Portfolio

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling: None / None	Moderate Refueling: Looped 2 / High	Limited Refueling: None / None	Limited Refueling: Looped 2 / High
Extreme (95/5)	Escalated 3	62.5%	Economic				1
		0%	Economic	8	16	53	129

Renewable ICAP in portfolios and renewable profiles (scaled to nameplate MW) contributed to the reduced severity observed between scenarios with Escalated 1 and Escalated 3 portfolios, which include the same numbers of retirements with a different mix of replacement resources.

Sensitivity Scenario Summaries in Appendix I

Overview – Scenario Results

Part 1 (October FSSTF)

✓ 1. Phase 1 sensitivities based on stakeholder feedback
   a. Pipeline disruption concurrent with event peak load
   b. 14-day pipeline disruption
   c. Initial oil inventory level at 50%
   d. Portfolio sensitivity with additional renewable replacement of retirements (Escalated 3)

2. RTO-wide scenarios using Relevant Risk data from Historical Cold Snap Events

Part 2 (November FSSTF)

3. Locational scenarios using Relevant Risk data from Historical Cold Snap Events

4. RTO-wide and locational scenarios using Relevant Risk data for summer event

3. Scenario with data from October 1, 2019 Operational Event

4. Address feedback from October FSSTF

Scenarios using Relevant Risk data from Historical Cold Snap Events

Risk Assessment Review

June

- Why current focus on winter?
- Relevant Risk filtering and identification

July

- Historical Cold Snap data
- Historical Pipeline Disruption frequency data

August

- Historical Pipeline Disruption impact data
- Historical Wind and Solar Intermittency
- Historical Relevant Risk data
- Discussion of scenario analysis approach

September

- Review of Relevant Risk data as input to scenario analysis

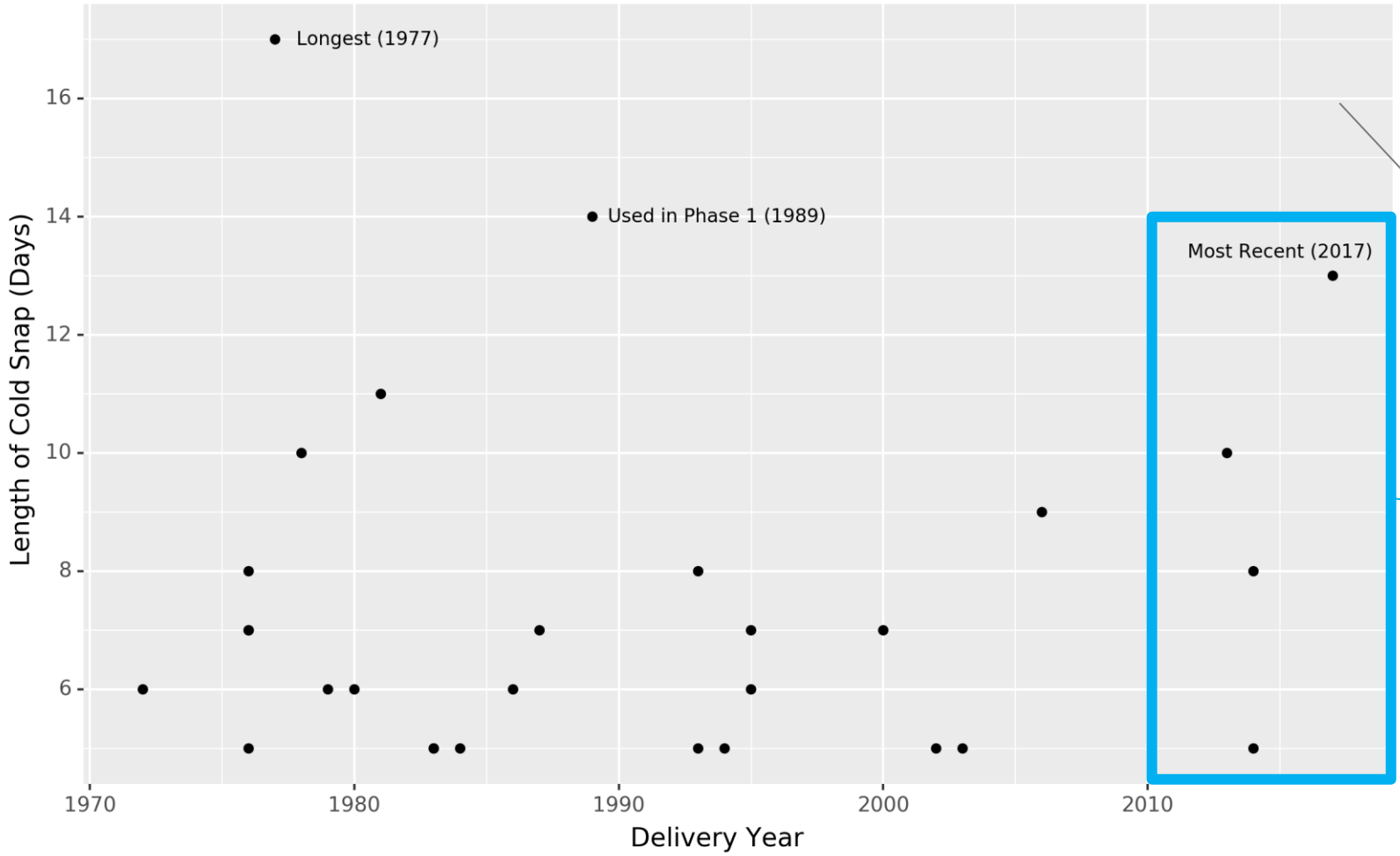
October

Preliminary results

Relevant Risks for Winter Scenarios

Relevant Risks	
Long Duration Cold Snap	Covered in July
Short Duration Cold Snap	
Natural Gas Pipeline Disruptions	Covered in July / August
Solar Intermittency	Covered in August
Wind Intermittency	
Coal Refueling (Bridge Failure)	Covered in August
Coal Refueling (Lock and Dam Failure)	
Coal Refueling (Rail Failure)	
Coal Refueling (River Freezing)	
Coal Unavailability (Coal Quality)	
Natural Gas Unavailability Non-Firm Units	
Oil Refueling (Oil Terminal)	
Oil Refueling (Truck Restrictions)	
Nuclear Regulatory Shutdown (Fuel Related)	
Nuclear Regulatory Shutdown (Non-Fuel Related)	
Nuclear Unavailability (High Winds)	
Hydro Unavailability (Freezing Rivers)	
River Freezing (Cooling Water Impacts)	
Ice Storm (Transportation Impacts)	

Cold Snaps



29 identified cold snaps in 47 winter periods (1972 – 2018)

- Definition: 5 or more contiguous days where average RTO wind-adjusted temperature (WWP) in each day is less than 21.5°F
- Average occurrence: 0.6 Cold Snaps per Delivery Year (Winter)
- Average Length: 7.5 days

4 Cold Snaps with available data for calculating:

- Fuel specific Relevant Risk Forced Outage Rates (RR-FOR)
- Wind & Solar capacity factor profiles

Fuel Specific Risk Analysis Reference

Cold Snaps Analyzed:

Cold Snap	Start	Stop	Duration
1*	Jan. 21, 2014	Jan. 30 2014	10 Days
2	Jan. 6, 2015	Jan. 10, 2015	5 Days
3	Feb. 13, 2015	Feb. 20, 2015	8 Days
4	Dec. 26, 2017	Jan. 7, 2018	13 Days

Winter Peak Hours:

AM Peak	PM Peak
HE08 & HE09	HE19 & HE20

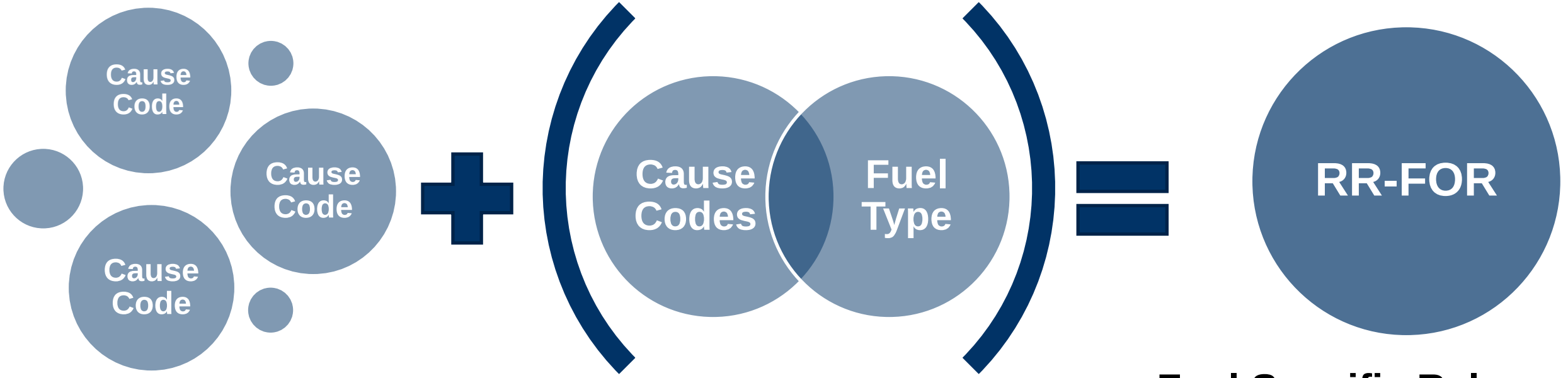
Forced Outage Rate:

$$\text{FOR} = \frac{\text{MW Forced Out}}{\text{Total Installed Nameplate}}$$

For coal, natural gas, nuclear, hydro, and oil resources, the forced outage rate serves as an indicator of the degree of unavailability for a set of resources

* *2014 winter data is considered in this analysis. Forced outages from the peak week of the 2013/14 winter (which contained Jan. 6-8, 2014, Polar Vortex 1) are not included in the development of the Capacity Model in the Reserve Requirement Study. Note that Jan. 6-8, 2014 does not fall under the cold snap criteria defined for this analysis.*

Fuel Specific Relevant Risk Forced Outage Rate (RR-FOR)



Fuel Specific Cause Codes

Common Cause Codes

Fuel Specific Relevant Risk Forced Outage Rate

Relevant Risk Forced Outage Rate Summary by Fuel Type

		Average RR-FOR* (% of MW Out)				
		(1) Jan 21-30, 2014	(2) Jan 6-10, 2015	(3) Feb 13-20, 2015	(4) Dec 26, 2017 - Jan 7, 2018	Four Most Recent Cold Snaps
Oil	Off Peak	1.909%	0.122%	0.957%	0.022%	0.768%
	Peak	1.979%	0.118%	1.266%	0.006%	0.850%
	All Hours	1.921%	0.121%	1.008%	0.020%	0.782%
Nuclear	Off Peak	0.001%	0.012%	0.062%	0.003%	0.017%
	Peak	0.001%	0.012%	0.069%	0.003%	0.018%
	All Hours	0.001%	0.012%	0.063%	0.003%	0.017%
Hydro	Off Peak	0.717%	0.273%	0.209%	0.246%	0.372%
	Peak	0.721%	0.275%	0.215%	0.250%	0.377%
	All Hours	0.718%	0.273%	0.210%	0.247%	0.373%
Gas**	Off Peak	15.101%	3.755%	6.466%	2.456%	7.040%
	Peak	15.117%	3.576%	6.540%	2.306%	6.982%
	All Hours	15.104%	3.725%	6.479%	2.431%	7.031%
Coal	Off Peak	0.684%	0.374%	0.461%	0.131%	0.392%
	Peak	0.699%	0.334%	0.537%	0.125%	0.405%
	All Hours	0.687%	0.367%	0.474%	0.130%	0.394%

** Does not include additional random forced outages generated by Monte Carlo simulation*

*** Gas forced outage MW from RR-FOR capped at MW of non-firm gas in portfolio*

Cold Snaps Analyzed:

Cold Snap	Start	Stop	Duration
1	Jan. 21, 2014	Jan. 30 2014	10 Days
2	Jan. 6, 2015	Jan. 10, 2015	5 Days
3	Feb. 13, 2015	Feb. 20, 2015	8 Days
4	Dec. 26, 2017	Jan. 7, 2018	13 Days

Winter Peak Hours:

AM Peak	PM Peak
HE08 & HE09	HE19 & HE20

Capacity Factor:

$$\mathrm{CF} = \frac{\text{Actual Hourly Output}}{\text{Total Installed Nameplate}}$$

For solar and wind resources, capacity factor serves as an indicator of how effectively the resources are performing

Scenario Analysis Approach

Approach	Winter Load	Renewable Profiles	Relevant Risk Forced Outages	Other Forced Outages
Phase 1 & Phase 1 Sensitivities based on Stakeholder Feedback **(Phase 2)**	Typical • 50/50 peak (134,976 MW) • 2011/12 load profile Extreme Winter • 95/5 peak (147,721 MW) • 2017/18 load profile 14 day study period	2017/18 winter profiles, scaled to nameplate capacity in portfolio	Explicitly modeled sensitivities for fuel delivery risks: oil refueling, non-firm gas availability, pipeline disruptions	Forced outage rates using GADS cause codes not used in relevant risks or sensitivities
Historical Relevant Risk Events **(Phase 2)**	Load shapes consistent with selected cold snaps	Profile from cold snap, scaled to nameplate capacity in portfolio	Relevant Risk Forced Outages Rates from cold snap scaled to portfolio	
			Sensitivities for discrete occurrences of risks outside of historical forced outage dataset	

Portfolios: Announced (25.8% IRM), Escalated 1 (15.8% IRM), Escalated 2 (15.8% IRM), Escalated 3 (15.8% IRM)

Load Shapes based on Historical Cold Snaps

- A 2023/2024 hourly load shape is derived based on the weather of each historical cold snaps
  - Therefore, 29 hourly load shapes are derived
- The procedure to derive the hourly load shapes is consistent with the PJM Load Forecast model and considers
  - A peak load forecast model employed to determine the “peak load” of each load shape
  - An hourly load forecast model employed to determine the relationship between the hourly loads (the “shape”) in each load shape
  - The forecasted “shape” is then adjusted so that the shape’s peak is equal to the forecasted “peak load”

Approach to Historical Cold Snap + Relevant Risk Scenarios

Set 1: Four most recent cold snaps with related RR-FOR and wind/solar capacity factor profiles from same period

Set 2: Scenarios for remaining 25 cold snaps paired with RR-FOR and wind/solar capacity factor profiles from each of the four cold snaps

		Fuel Specific RR-FOR				**Wind & Solar Capacity Factor Profiles**			
		CS-1	CS-2	CS-3	CS-4	CS-1	CS-2	CS-3	CS-4
Cold Snap	CS-1								
	CS-2								
	CS-3								
	CS-4								
	Remaining 25								

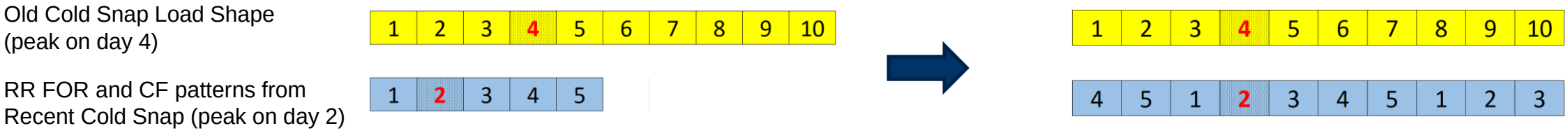
- Monte Carlo for other forced outages (non RR-FOR) in each scenario
- Approach could be applied to any portfolio – in this case will be using Phase 1 & Phase 1 sensitivity portfolios
- 0 MWs of Planned Outages are assumed in all scenarios
- Results: Loss of load expectation (LOLE) metric

Stochastic Elements in Simulation

- Load Shapes: technically, 47 winter load shapes (one for each year in the period 1972-2018) are examined. Each one of them is assumed to be equally likely.
  - For winters without Cold Snaps, the reported LOLE is assumed to be zero
  - For the rest of the winters, the reported LOLE is the sum of the LOLE for each of the Cold Snaps in the winter
- Random Forced Outages (excluding those associated with Relevant Risks)
  - Modeled using Monte Carlo (1,000 replications)

Stochastic Elements in Simulation

- Relevant Risks Forced Outages Rates (RR-FOR) / Renewables Capacity Factors (CF)
  - For the 4 most recent Cold Snaps, the corresponding hourly RR-FOR and CF patterns are used (e.g., for the 12/26/2017 – 01/07/2018 Cold Snap, the RR- FORs and CFs from the same period are used)
  - For the 25 older Cold Snaps, the hourly patterns from the 4 most recent Cold Snaps are used, with each one of them assumed to be equally likely.
    - Daily Peaks are aligned to determine the positioning of the hourly patterns. Data from the most recent cold snaps is used on a rolling basis to fill up data gaps. For example:

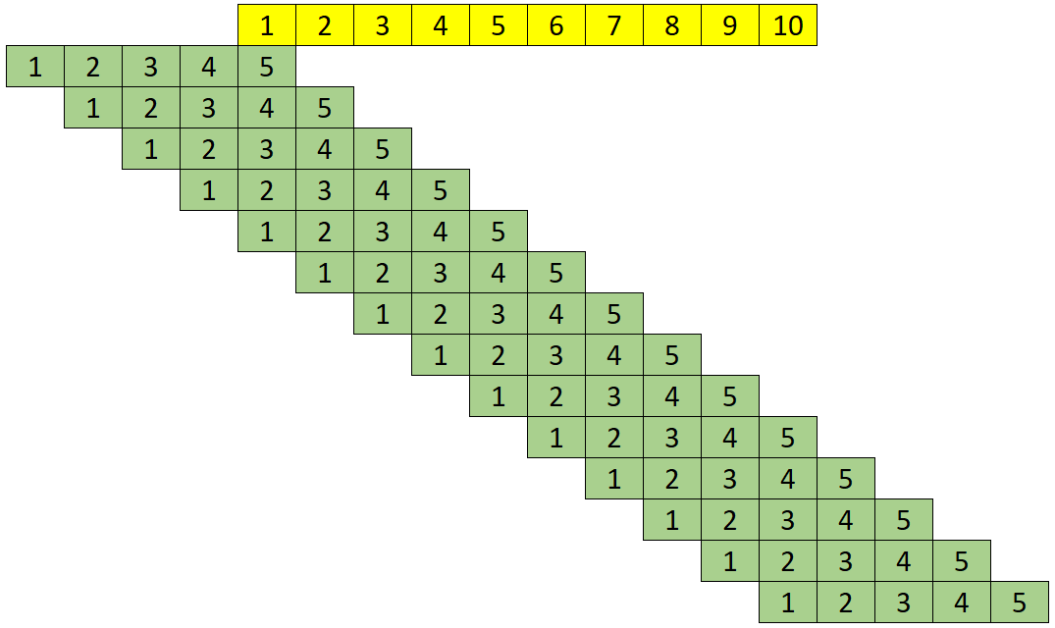


Stochastic Elements in Simulation

- Disruption timing during Cold Snap:
  - Disruptions of size X MW (where X is varied from 0 MW to 10,000 MW) are also simulated
    - The size of the disruption is not stochastic
  - The duration of the disruption is assumed to be 5 days (not stochastic)
  - The timing of the disruption is modeled stochastically by considering all potential overlapping patterns between the disruption and the Cold Snap (with each potential overlapping pattern assumed equally likely)

Stochastic Elements in Simulation

- Disruption timing during Cold Snap:
  - For example, for a 10 day Cold Snap (in yellow below), PJM simulated all overlapping patterns



There are 14 potential overlapping patterns between the disruption (in green) and the Cold Snap (in yellow).

The overlapping patterns include partial and full overlaps. They range from “first day of snap coincides with last day of disruption” to “last day of snap coincides with first day of disruption”.

Stochastic Elements in Simulation

- Therefore, the total number of scenarios examined for a Cold Snap of, for example, 10 days under a disruption of size X is
  - If the Cold Snap is one of the four most recent Cold Snaps:

    1,000 (Random FOR) x 1 (RR-FOR and CF) x 14 (Timing of Disruption) = 14,000
  - If the Cold Snap is one of the older Cold Snaps:

    1,000 (Random FOR) x 4 (RR-FOR and CF) x 14 (Timing of Disruption) = 56,000

LOLE Results

- First, LOLE is calculated for each of the Cold Snaps under a Disruption of size X MW (where X is varied from 0 MW to 10,000 MW)
  - These graphs and tables are shown in the Appendix
- The above results are then aggregated by year (if a year did not have a Cold Snap, the LOLE is assumed to be zero). A total of 47 LOLE values (one for each year in the period 1972-2018) are then averaged.
  - These are the results shown in the upcoming slides

LOLE Results

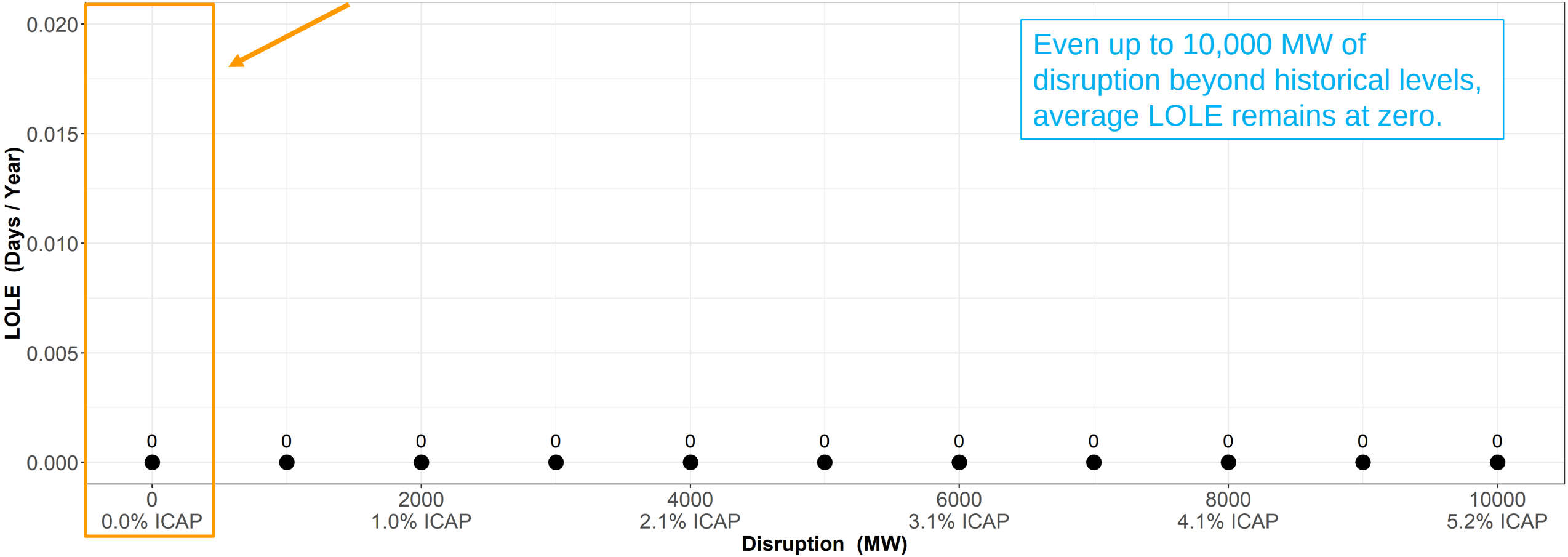
- The LOLE results under a 0 MW Disruption capture the impact of Relevant Risk Forced Outages, Wind/Solar Capacity Factors, and random Forced Outages without any additional disruption.

Clarification of LOLE results

- The LOLE results are expressed in days/year
- The LOLE values reported for each portfolio in this analysis are **in addition** to the LOLE outside of the winter period
  - For instance, a portfolio with reserves at the IRM has an LOLE equal to 0.1 days/year (from the Summer period) **plus** the LOLE reported in this analysis.

LOLE vs Disruption - Announced Retirements (28.5% ICAP Reserves)

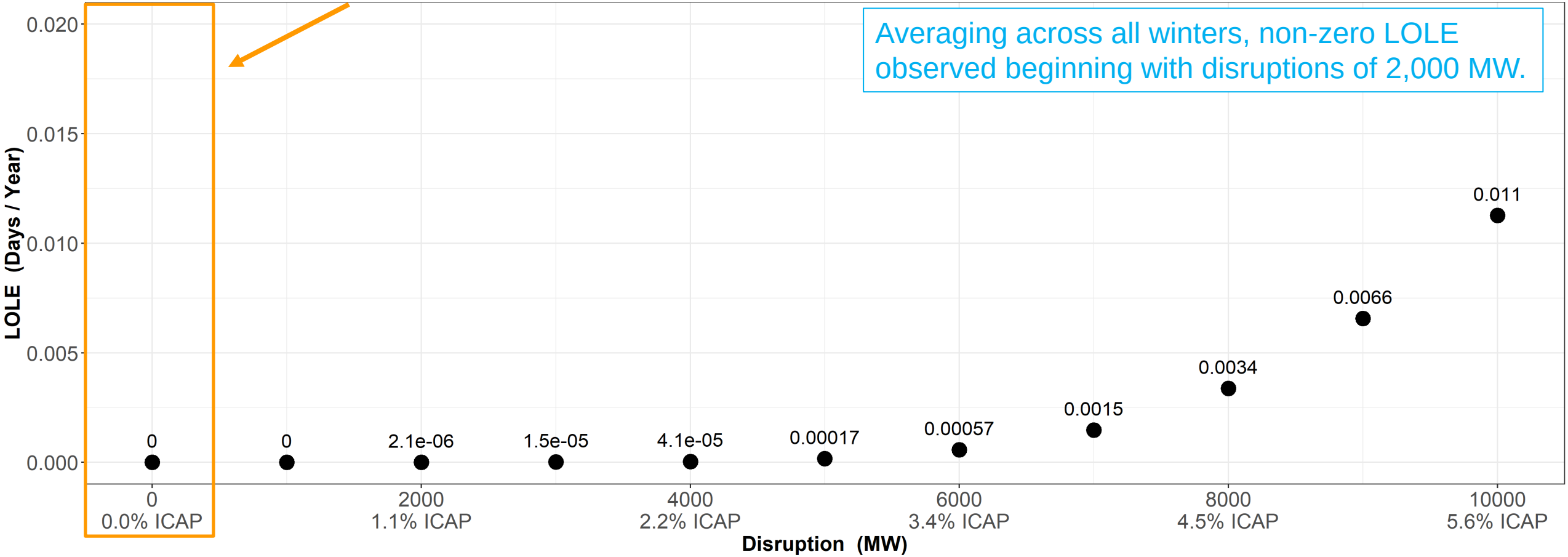
Results considering RR-FOR and other random forced outages with no additional disruptions.



Even up to 10,000 MW of disruption beyond historical levels, average LOLE remains at zero.

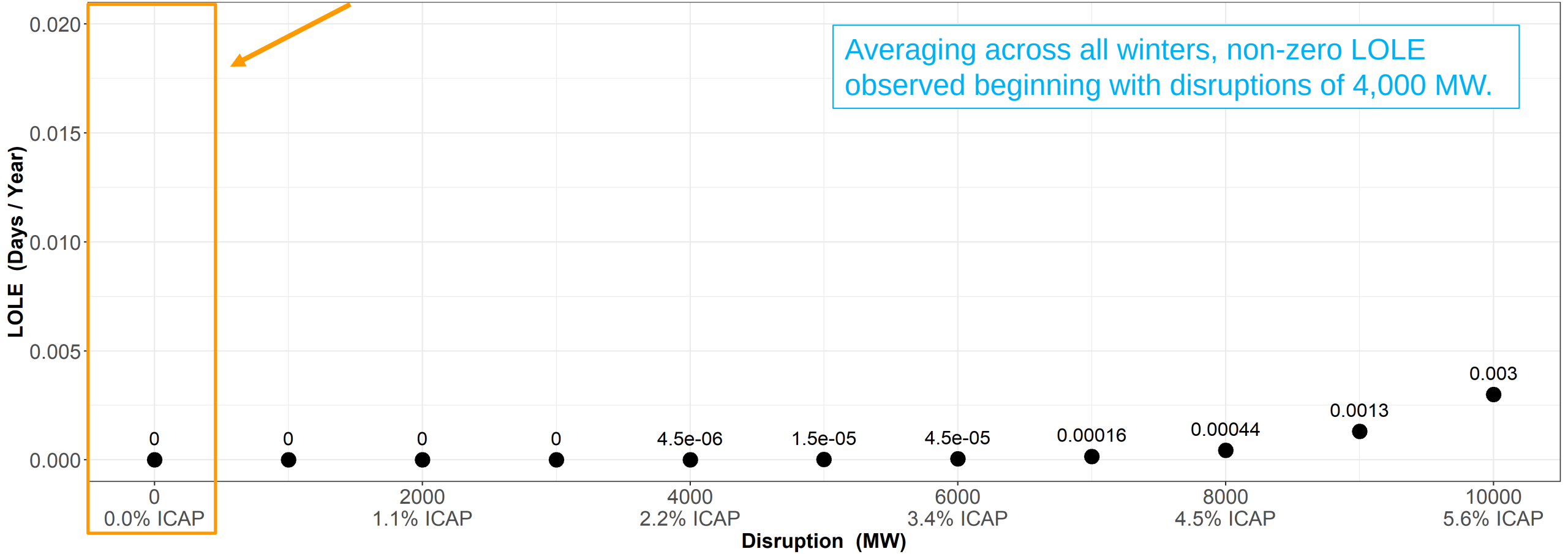
LOLE vs Disruption - Escalated Retirements #1 (15.8% ICAP Reserves)

Results considering RR-FOR and other random forced outages with no additional disruptions.



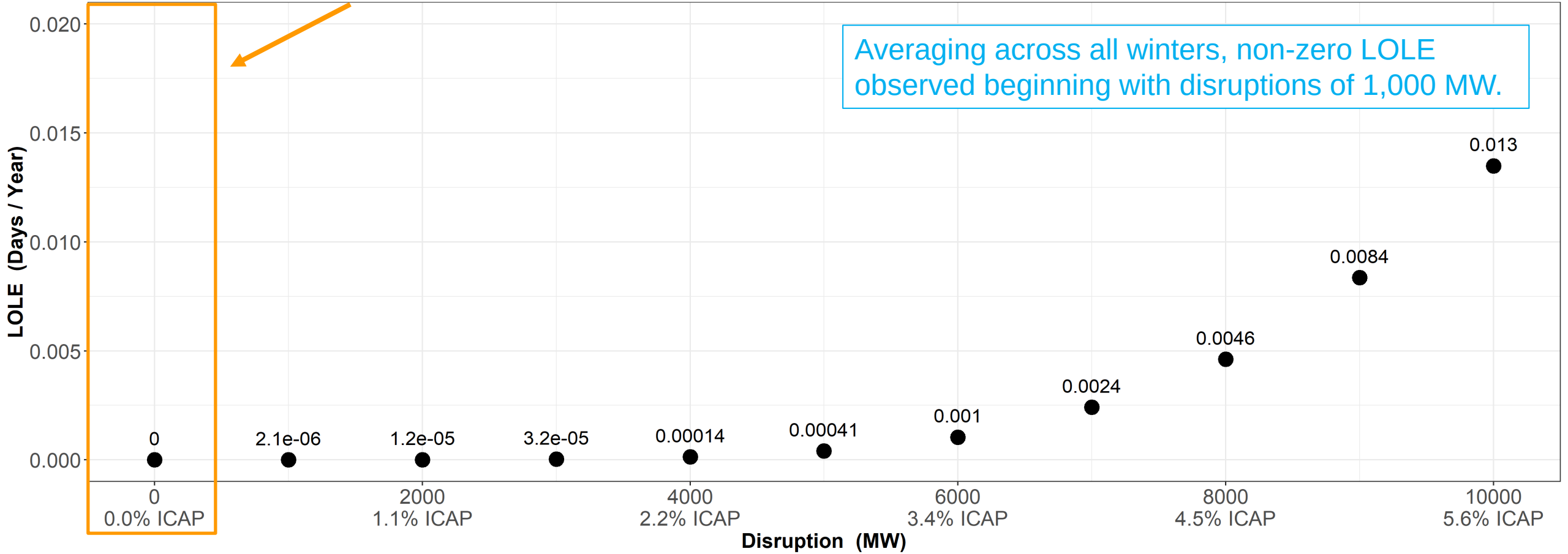
LOLE vs Disruption - Escalated Retirements #2 (15.8% ICAP Reserves)

Results considering RR-FOR and other random forced outages with no additional disruptions.



LOLE vs Disruption - Escalated Retirements #3 (15.8% ICAP Reserves)

Results considering RR-FOR and other random forced outages with no additional disruptions.



Example Disruptions

Intended to provide context for "Disruption (MW)" axis in LOLE results slides

Disruption Type	Worst Case Potential Loss (MW)	Assumptions
Natural Gas Pipeline Contingency with Electric System Impact*	4,945	Worst case; units with dual fuel or alternate pipeline are not able to switch.
Regulatory Event Impacting Nuclear Generation	32,300	All nuclear units in the PJM footprint are required to come offline concurrently.
Regional Event Impacting Nuclear Generation	10,000 - 16,000	A localized event, such as severe weather pattern, requires nuclear generation in a localized region to come offline concurrently.
Coal Barge Disruption	12,800	River freezing, or similar, leads to fuel delivery issues impacting all coal units that rely exclusively on barge fuel deliveries. Assumes coal piles are already running low.
Coal Rail Disruption	9,600	Rail failure, or similar, leads to fuel delivery issues impacting all coal units that rely exclusively on rail fuel deliveries. Assumes coal piles are already running low.
Coal Truck Disruption	3,200	Trucking availability, or similar, leads to fuel delivery issues impacting all coal units that rely exclusively on truck fuel deliveries. Assumes coal piles are already running low.
Non-Coal Barge Disruption	2,800	River freezing, or similar, leads to fuel delivery issues impacting all non-coal units that rely exclusively on barge fuel deliveries.
Non-Coal Truck Disruption	3,800	Trucking availability, or similar, leads to fuel delivery issues impacting all non-coal units that rely exclusively on truck fuel deliveries.
Wind Turbine Shutdown Due to Operating Limits	3,800	Extreme low temperatures, or similar, requires wind turbines in a localized region being forced to come offline concurrently.

** Historical impact of pipeline disruptions on generation discussed at July FSSTF*

Overview – Scenario Results

Part 1 (October FSSTF)

✓ 1. Phase 1 sensitivities based on stakeholder feedback
   a. Pipeline disruption concurrent with event peak load
   b. 14-day pipeline disruption
   c. Initial oil inventory level at 50%
   d. Portfolio sensitivity with additional renewable replacement of retirements (Escalated 3)

✓ 2. RTO-wide scenarios using Relevant Risk data from Historical Cold Snap Events

Part 2 (November FSSTF)

3. Locational scenarios using Relevant Risk data from Historical Cold Snap Events

4. RTO-wide and locational scenarios using Relevant Risk data for summer event

3. Scenario with data from October 1, 2019 Operational Event

4. Address feedback from October FSSTF