Fuel Security
Phase 1 Analysis Results

Special MRC
November 1, 2018
Next Fuel Security Special MRC: November 26

Please send fuel security-related questions to:

natalie.tacka@pjm.com
Note: The analysis is neither meant to be predictive of future conditions nor meant to imply that analyzed scenarios are unavoidable.
Conclusions

- There is **NO** immediate threat to the reliability of the PJM RTO.
- PJM is reliable in the announced retirements and escalated retirements cases under all typical winter load scenarios.
- PJM is reliable in the announced retirements cases under all extreme winter load scenarios.
- By design, PJM created stressed scenarios that were intended to discover the point(s) at which an assumption or combination of assumptions begin to impact the system’s ability to reliably serve customers. The stressed scenarios resulted in a loss of load under extreme, but plausible conditions.
- In the stressed scenarios, assumptions that are contributing factors to the level of load shed include combinations of:
  - The level of retirements and replacements
  - The level of non-firm gas availability
  - The ability to replenish oil supplies
  - The location, magnitude and duration of pipeline disruption
  - Pipeline configuration
Focus

1. Define fuel security considering risks in fuel delivery to critical generators
2. Reaffirm the value of markets to achieving a cost-effective, fuel-secure fleet of resources
3. Identify fuel security risks with a primary focus on resilience
4. Establish criteria to value fuel security in PJM markets

Approach

1. Phase 1: Analysis
   Identify potential system vulnerabilities and develop criteria to address them
2. Phase 2: Modeling
   Model incorporation of vulnerabilities into PJM’s markets
3. Phase 3: Ongoing Coordination
   Address specific security concerns identified by federal and state agencies

Timing

- May–November 2018
  Analysis
- May 2018–December 2019
  Phase 3 ongoing coordination
- 2019/2020
  Phase 2: Assess market design in 2019 and target solution filed with FERC early 2020
Understanding the Study

14-Day Study Period

- Storage: <1 day
- Solar: <1 day
- Wind: <1 day
- Other Renewables: <1 day
- Hydro: <1 day
- Natural Gas: <1 day
- Oil: <1 day
- Coal: 50+ days
- Nuclear: 50+ days

Total Capacity: 84,823 MW
Approach Overview

Study Cases

Retirements

Announced (2023/24)

Weather Scenarios

Typical 50/50 Winter

Disruptions

Fuel delivery infrastructure disruption sensitivities

Deterministic Analysis

Dispatch simulation for study case duration

Detailed transmission analysis for selected peak hours

Outcomes

Evaluation of current capabilities of resources to mitigate fuel delivery infrastructure risk

Inform development of “fuel secure” definition

Probabilistic Analysis

Locational/regional fuel secure MW methodology to mitigate risks, if needed

Locational/regional loss of load hours statistics
Winter Load in 14-Day Periods

All-time winter peak: 143,338 MW, 2/20/15

Study peak: 147,721 MW

Study peak: 134,976 MW

MW

150,000
130,000
110,000
90,000
70,000

1 2 3 4 5 6 7 8 9 10 11 12 13 14

Day

Typical
Extreme

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### Key Model Assumption Ranges

<table>
<thead>
<tr>
<th>Category</th>
<th>Assumption</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weather/Load</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 days</td>
<td>90 days</td>
</tr>
<tr>
<td><strong>Forced Outage Rate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>22%, 40,200 MW</td>
</tr>
<tr>
<td><strong>Initial Oil Tank Capacity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Oil Refueling</strong></td>
<td>0 trucks/day</td>
<td>60 trucks/day</td>
</tr>
<tr>
<td></td>
<td>Sites &lt; 100 MW</td>
<td>10 trucks</td>
</tr>
<tr>
<td></td>
<td>Sites &gt; 100 MW</td>
<td>40 trucks</td>
</tr>
<tr>
<td><strong>Gas Availability, Non-Firm</strong></td>
<td>0 MW</td>
<td>10,000 MW, 62.5%</td>
</tr>
<tr>
<td></td>
<td>0 MW</td>
<td>16,000 MW</td>
</tr>
<tr>
<td><strong>Pipeline Disruptions</strong></td>
<td>0 days</td>
<td>90 days</td>
</tr>
<tr>
<td><strong>Retirements</strong></td>
<td>0 MW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Announced</td>
<td>12.652 MW, 25.8% IRM</td>
</tr>
<tr>
<td></td>
<td>Escalated 2</td>
<td>28.270 MW, 15.8% IRM</td>
</tr>
<tr>
<td></td>
<td>Escalated 1</td>
<td>44.868 MW, 15.8% IRM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>53,736 MW</td>
</tr>
<tr>
<td>Dispatch</td>
<td>Retirement</td>
<td>Winter Load</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Max. Emergency</td>
<td>Escalated 1</td>
<td>Extreme 95/5 147,721 MW</td>
</tr>
<tr>
<td>Escalated 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>Announced</td>
<td>Typical 50/50 134,976 MW</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

300+ combinations
Announced Retirements Analysis
## Emergency Procedures Summary

### Announced Retirement Models

<table>
<thead>
<tr>
<th>Winter Load</th>
<th>Non-Firm Gas Avail.</th>
<th>Dispatch</th>
<th>Pipeline Disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme 95/5</td>
<td>62.5% Max Emer. Economic</td>
<td>None Med. High Single 1 Med. High Single 2 Med. High Loop 2</td>
<td></td>
</tr>
</tbody>
</table>

- **A**: Normal Operations
- **B**: Demand Response Deployed
- **C**: Reserve Shortage
- **D**: Voltage Reduction
- **Load Shed**

**Legend:**
- **Moderate Refueling**
- **Limited Refueling**
Announced Retirements Scenario Model: Example

**Generation & Load**

**Demand Response**

**Emergency Procedures**

**Price**

**Case Name**

**Zonal LMP**

**Oil Inventory**

Prices do not represent forecasts of actual prices.
Announced Retirements Scenario Model A

System Overview

- Generation (MW)
- Forecasted Demand (MW)
- Deployed Demand Response (MW)
- Reserve Shortage (MW)
- Voltage Reduction (MW)
- Load Shed (MW)
- Price ($)  

Prices do not represent forecasts of actual prices.

No Emergency Procedures
Announced Retirements Scenario Model B

- Generation (MW)
- Forecasted Demand (MW)
- Deployed Demand Response (MW)
- Reserve Shortage (MW)
- Voltage Reduction (MW)
- Load Shed (MW)
- Price ($)
Announced Retirements Scenario Model C

More demand response; more reserve shortage

Prices do not represent forecasts of actual prices.
Announced Retirements Scenario Model D

System Overview

- Generation (MW)
- Forecasted Demand (MW)
- Deployed Demand Response (MW)
- Reserve Shortage (MW)
- Voltage Reduction (MW)
- Load Shed (MW)
- Price ($)

Load:
- Extreme

Refueling:
- Limited

Disruption:
- Loop 2 High

Non-Firm Avail:
- 0%

Retirement:
- Announced

Dispatch:
- Max Emergency

Hourly Zonal Average LMP [$]

Limited reserve shortage

Prices do not represent forecasts of actual prices.
Escalated Retirements Analysis
Methodology, Escalated Retirement 1

**Retirement**

\[
\text{2021 Market Efficiency Planning Model} \quad \text{Net Energy Revenue} \quad + \quad \text{2021/2022 Capacity Auction} \quad \text{Capacity Revenue} \quad - \quad \text{Avoidable Cost Rate} \quad \text{(Fixed costs)} \quad = \quad \text{Forecasted Profit & Loss}
\]

**Replacement**

\[
\text{Replacement for 2023 Delivery Year} \quad \rightarrow \quad \text{Facility Service Agreement Units Commercial Probability} \quad \rightarrow \quad 15.8\% \ IRM
\]
Natural gas is 96% of replacement megawatts
Methodology, Escalated Retirement 2

Retirement

- 2021 Market Efficiency Planning Model
  - Net Energy Revenue
- 2021/2022 Capacity Auction
  - Capacity Revenue
- Avoidable Cost Rate (Fixed costs)
  - Forecasted Profit & Loss

15.8% IRM

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Escalated Retirement 2 Portfolio

MW

<table>
<thead>
<tr>
<th>Region</th>
<th>Nuclear</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>2,335</td>
<td>3,490</td>
</tr>
<tr>
<td>South</td>
<td>946</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td>6,147</td>
<td>2,700</td>
</tr>
<tr>
<td>Total</td>
<td>9,428</td>
<td>6,190</td>
</tr>
</tbody>
</table>

- **Total MW Retired:** 15,618
  - **Nuclear:** 9,428 MW (60%)
  - **Coal:** 6,190 MW (40%)
## Emergency Procedures Summary

### Escalated Retirement Models

<table>
<thead>
<tr>
<th>Winter Load</th>
<th>Non-Firm Gas Avail.</th>
<th>Dispatch</th>
<th>Pipeline Disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical 50/50</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retired</td>
<td>62.5%</td>
<td>Economic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Escalated 1</td>
<td>62.5%</td>
<td>Economic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>Economic</td>
<td></td>
</tr>
<tr>
<td>Escalated 2</td>
<td>62.5%</td>
<td>Economic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>Economic</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Extreme 95/5</th>
<th>Non-Firm Gas Avail.</th>
<th>Dispatch</th>
<th>Pipeline Disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Escalated 1</td>
<td>62.5%</td>
<td>Max Emer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>Economic</td>
<td></td>
</tr>
<tr>
<td>Escalated 2</td>
<td>62.5%</td>
<td>Max Emer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>Economic</td>
<td></td>
</tr>
</tbody>
</table>

### Demand Response Deployed

- **Normal Operations**
- **Reserve Shortage**
- **Voltage Reduction**
- **Load Shed**

### Load Shedding

- **Moderate Refueling**
- **Limited Refueling**
Escalated Retirements 1 Scenario Model E

No Emergency Procedures; higher prices

Prices do not represent forecasts of actual prices.
Increased demand response, reserve shortage, voltage reduction and load shed
Significant demand response, reserve shortage, voltage reduction, and load shed
Emergency Procedures Summary

Impact of Assumptions

PJM

Winter Load

Non-Firm Gas Avail.

Dispatch

Max Emer. Economic

Max Emer. Economic

32%

Low Demand

Response Deployed

Reserve Shortage Voltage Reduction Load Shed

Pipeline Disruption

None Single 1 Single 2 Looped 1 Looped 2 None Single 1 Single 2 Looped 1 Looped 2


J 5 3 1

H1

H2

5

3

22

83

Moderate Refueling Limited Refueling

Normal Operations

Load Shed
Conclusions and Next Steps

Conclusions, Background and Assumptions

Announced Retirements Analysis

Escalated Retirements Analysis

Conclusions and Next Steps
Conclusions

• There is **NO** immediate threat to the reliability of the PJM RTO.

• PJM is reliable in the announced retirements and escalated retirements cases under all typical winter load scenarios.

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• By design, PJM created stressed scenarios that were intended to discover the point(s) at which an assumption or combination of assumptions begin to impact the system’s ability to reliably serve customers. The stressed scenarios resulted in a loss of load under extreme, but plausible conditions.

• In the stressed scenarios, assumptions that are contributing factors to the level of load shed include combinations of:
  – The level of retirements and replacements
  – The level of non-firm gas availability
  – The ability to replenish oil supplies
  – The location, magnitude and duration of pipeline disruption
  – Pipeline configuration
While there is NO imminent threat, Fuel Security is an important component of ensuring reliability – especially if multiple risks come to fruition. The findings underscore the importance of PJM exploring proactive measures to value fuel security attributes, and PJM believes this is best done through competitive wholesale markets.

To continue stakeholder engagement, PJM will:

1. Host a follow-up Special Markets & Reliability conference call on Nov. 26, 2018 at 1–3 p.m. to address questions that may arise as stakeholders review the study results further after today’s presentation.

2. Publish a paper detailing the background, method/approach, analysis results, conclusions and next steps in mid-December 2018.

3. Schedule a Special Markets & Reliability meeting after the scheduled Markets & Reliability meeting on Dec. 20, 2018 to discuss the additional detail provided in the white paper.

4. Introduce a Problem Statement and Issue Charge for stakeholder consideration in first quarter 2019 with any potential market rule changes targeted to be filed with FERC in early 2020.

As part of Phase 3 work efforts, PJM will continue to work with key agencies within the federal government and impacted industries to further define fuel security assumptions and scenarios defined by the Department of Energy.
Appendix
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumption</td>
<td>Input variable that is assumed to be true in the study, based on research and discussion with experts and industry groups.</td>
</tr>
<tr>
<td>Probabilistic Analysis</td>
<td>Aims to provide a realistic estimate when some variables are unknown. A multi-area reliability simulation was used to assess system adequacy to serve load by performing loss of load expectation analysis.</td>
</tr>
<tr>
<td>Deterministic Analysis</td>
<td>Analysis of various combinations of input assumptions performed using dispatch simulation analysis and reliability transfer analysis.</td>
</tr>
<tr>
<td>Security Constrained Economic Dispatch Analysis</td>
<td>Deterministic analysis tool used to perform security constrained unit commitment and security constrained economic dispatch analyses over a time horizon to simulate and model scenarios</td>
</tr>
<tr>
<td>Reliability Transfer Analysis</td>
<td>Deterministic analysis tool used to perform contingency analysis to calculate CETL/CETO.</td>
</tr>
<tr>
<td>Typical Winter Load</td>
<td>Winter load level of 134,976 MW, which has probability of occurring every other year (50:50)</td>
</tr>
<tr>
<td>Extreme Winter Load</td>
<td>Winter load level of 147,721 MW which has probability of occurring once every 20 years (95:5)</td>
</tr>
<tr>
<td>Locational Disruption</td>
<td>Gas pipeline break. Categorized by location and pipeline design into Looped 1, Looped 2, Single 1 and Single 2. Looped pipeline design consists of a parallel pipeline delivery system while single pipeline design consists of a single pipeline delivery system.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Non-Firm Gas Availability</td>
<td>Interruptible gas</td>
</tr>
<tr>
<td>DR Deployment</td>
<td>Demand Response Deployment; this action is a pre-emergency action</td>
</tr>
<tr>
<td>Reserve Shortage</td>
<td>Reserve Shortage is triggered when 10 min Synchronized Reserves are less than the largest generator in the RTO; depending on system conditions a reserve shortage will trigger additional emergency procedures such as a voltage reduction warnings and manual load shed warnings. These warnings are classified as emergency procedures.</td>
</tr>
<tr>
<td>Voltage Reduction Action</td>
<td>Voltage reduction action enables load reductions by reducing voltages at the distribution level; PJM estimates a 1-2% RTO load reductions resulting from a 5% load reductions in transmission zones capable of performing a voltage reduction.</td>
</tr>
<tr>
<td>Manual Load Shed Action</td>
<td>Manual load shed action enables zonal or system wide load shed. This is the last step of all emergency procedure actions.</td>
</tr>
<tr>
<td>eFORd</td>
<td>Expected forced outage rate</td>
</tr>
<tr>
<td>LOLH</td>
<td>Loss of load hours</td>
</tr>
</tbody>
</table>
### External Coordination & Outreach Update

| Outreach                              | Information Collected                                                                 | Study Impact                                                   |
|---------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------
| PJM Generation Owner Surveys          | Unit-specific information and statistics                                               | Baseline data and unit-specific study inputs                   |
| Direct Generation Owner Conversations | Detailed information about oil refueling operations                                      | On-site oil inventories and oil refueling assumptions           |
| Natural Gas Pipelines & Industry Groups| Operating information and reliability details                                           | Study scenario development and natural gas supply assumptions/disruptions |
| Renewable Resource Industry Groups    | Operating information and disruption details                                           | Study scenario development and dispatch                         |
| DR Representative & Industry Groups   | Operational information and expected customer response                                 | Baseline data and unit-specific study inputs                   |
| Coal Industry Groups                  | Supply chain and transportation logistics information                                   | Study scenario development and refueling assumptions             |
| Nuclear Industry Groups               | Operational information and logistics                                                  | Baseline data and unit-specific study inputs                   |
| Department of Energy                  | Information on physical/cyber threat actors and capabilities to impact gas pipelines. PJM will work with DOE to determine level of information sharing with PJM stakeholders (and define risk scenarios). | **Phase 3 Input:** Disruption events for extreme cyber and physical threats  
PJM will work with gas pipelines to assess impacts. |
## Assumptions

<table>
<thead>
<tr>
<th>Category</th>
<th>Typical</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study Year</strong></td>
<td>2023/24</td>
<td>2023/24</td>
</tr>
<tr>
<td><strong>Weather Scenario</strong></td>
<td>14 days</td>
<td>14 days</td>
</tr>
<tr>
<td><strong>Load Scenario</strong></td>
<td>50/50 - 1 in 2 (135k peak)</td>
<td>95/5 - 1 in 20 (147k peak)</td>
</tr>
<tr>
<td><strong>Load Profile</strong></td>
<td>2011/12 winter</td>
<td>2017/18 winter</td>
</tr>
<tr>
<td><strong>Dispatch</strong></td>
<td>Economic</td>
<td>Economic &amp; Optional Block Load (Max Emergency)</td>
</tr>
<tr>
<td><strong>Scheduled Interchange</strong></td>
<td>Total interchange with neighboring systems limited to +/-2,700 MW</td>
<td>Total interchange with neighboring systems limited to +/-2,700 MW</td>
</tr>
<tr>
<td><strong>Interruptable Gas Availability</strong></td>
<td>62.5%</td>
<td>62.5% &amp; 0%</td>
</tr>
<tr>
<td><strong>Oil Tank Starting Inventory</strong></td>
<td>85%</td>
<td>85%</td>
</tr>
<tr>
<td><strong>Oil Refueling (&gt;100 MW site)</strong></td>
<td>40 trucks and 10 trucks (sensitivity) daily refueling rate (Oil inventory at each site will be capped at max tank capacity) In model, refueling was applied every 12 hours, with assumed daily mmBtu divided up accordingly</td>
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</tr>
</tbody>
</table>
## Assumptions (cont.)

<table>
<thead>
<tr>
<th>Category</th>
<th>Typical</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oil Refueling (&lt;100 MW site)</strong></td>
<td>10 trucks and 0 trucks (sensitivity) daily refueling rate (Oil inventory at each site will be capped at max tank capacity). In model, refueling was applied every 12 hours, with assumed daily mmBtu divided up accordingly</td>
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</tr>
<tr>
<td><strong>Fuel Prices</strong></td>
<td>2023 futures prices adjusted by day-to-day fluctuations in price (volatility)</td>
<td>2023 futures prices adjusted by day-to-day fluctuations in price (volatility)</td>
</tr>
<tr>
<td><strong>Disruption (medium impact)</strong></td>
<td>5 day 50-100% break + 9 day no impact</td>
<td>5 day 50-100% break + 9 day no impact</td>
</tr>
<tr>
<td><strong>Disruption (high impact)</strong></td>
<td>5 day 100% break + 9 day 20% derate</td>
<td>5 day 100% break + 9 day 20% derate</td>
</tr>
<tr>
<td><strong>Expected Forced Outages</strong></td>
<td>Historical 5 year average discounting gas and oil fuel supply outages</td>
<td>Regression model expected outage rates discounting gas and oil fuel supply outages</td>
</tr>
<tr>
<td><strong>Renewable Modeling</strong></td>
<td>2017/2018 Cold Snap Profile</td>
<td>2017/2018 Cold Snap Profile</td>
</tr>
<tr>
<td><strong>Demand Response</strong></td>
<td>7,092 MW modeled locationally based on MW cleared by zone and nodal modeling</td>
<td>7,092 MW modeled locationally based on MW cleared by zone and nodal modeling</td>
</tr>
<tr>
<td><strong>Distributed Energy Resources</strong></td>
<td>Impacts of DER are explicitly accounted for in the load forecast</td>
<td>Impacts of DER are explicitly accounted for in the load forecast</td>
</tr>
<tr>
<td>Category</td>
<td>Typical</td>
<td>Extreme</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>Energy Efficiency is explicitly accounted for in the load forecast</td>
<td>Energy Efficiency is explicitly accounted for in the load forecast</td>
</tr>
<tr>
<td><strong>Retirement Sensitivity</strong></td>
<td>Two separate retirements scenarios were analyzed. As part of the economic analysis, PJM and IMM nuclear and coal units &quot;at-risk&quot; economic retirement analysis including relevant input from NEI and ACCCE as well as latest nuclear cost estimates published by EPA. A separate analysis was performed retiring coal and nuclear generation down to IRM without replacement.</td>
<td>Two separate retirements scenarios were analyzed. As part of the economic analysis, PJM and IMM nuclear and coal units &quot;at-risk&quot; economic retirement analysis including relevant input from NEI and ACCCE as well as latest nuclear cost estimates published by EPA. A separate analysis was performed retiring coal and nuclear generation down to IRM without replacement.</td>
</tr>
<tr>
<td>Replacement Sensitivity</td>
<td>IRM ≥ 15.8%. Replacement resources reflective of PJM Interconnection Queue. Replacement Combined Cycle Natural gas resources will be modeled as firm supply and transport. Replacement Combustion Turbine Natural Gas resources will be modeled as dual fuel with interruptible gas.</td>
<td>IRM ≥ 15.8%. Replacement resources reflective of PJM Interconnection Queue. Replacement Combined Cycle Natural gas resources will be modeled as firm supply and transport. Replacement Combustion Turbine Natural Gas resources will be modeled as dual fuel with interruptible gas.</td>
</tr>
</tbody>
</table>
Typical Winter Load (50/50)

- **Peak = 134,976 MW**
  Winter 2023/24 forecast
- Average 50/50 winter hourly load shape from 2011/12

Extreme Winter Load (95/5)

- **Peak = 147,721 MW**
  Median of three historical cold snaps in last 45 years
- 1989 peak 95th percentile
- 1994 peak 99th percentile
- 2017/18 peak 82nd percentile
- 2017/18 winter hourly load shape
Demand Response

Estimated Capacity Performance Demand Response (CP DR) = 7,092 MW for 2023/24

- CP DR is reduced by three-year average 32 percent replacement rate.
- CP DR will be used for both Base Case and Extreme Weather Case.
- DR will be modeled in the simulation prior to a load shed event consistent with existing procedures.

CP DR amount cleared in the 2021/22 Base Residual Auction + Fixed Resource Requirement (FRR)

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Refueling Approach

Study refueling based on transportation method and maximum on-site inventory

- **Transportation for base studies** will be the assumed limiting factor rather than fuel.

**Starting Coal Inventory** – unit-specific seasonal inventory target

**Starting Oil Inventory** – 85 percent of max tank capacity

- **Oil refueling sensitivities** will be run modeling a range of 10 to 40 truck deliveries per day for sites > 100 MW and 0 to 10 trucks per day for sites < 100 MW to determine the magnitude of impact refueling has.
<table>
<thead>
<tr>
<th>Day</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
<th>Day 8</th>
<th>Day 9</th>
<th>Day 10</th>
<th>Day 11</th>
<th>Day 12</th>
<th>Day 13</th>
<th>Day 14</th>
</tr>
</thead>
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</tr>
<tr>
<td><strong>Typical and Extreme Winter</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>50% or 100% firm capacity reduction*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>All firm capacity available</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>100% firm capacity reduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20% firm capacity reduction**</td>
<td></td>
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</tr>
</tbody>
</table>

* Firm capacity reduction level depends on pipeline design redundancy.

** 20% of capacity remains unavailable due to assumed PHMSA (Pipeline Hazardous Material and Safety Administration) requirements.
Lack of Fuel Gas Reductions

Data source: NERC GADS
### Extreme (95/5) Case
Generator Outage Model Update

- **Goal** – % generator forced outage rate
- **Using** Jan. 2014 through 2018 data

<table>
<thead>
<tr>
<th>Category</th>
<th>Key Variables</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit Characteristic</strong></td>
<td>Age</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Weather</strong></td>
<td>Wind Adj. Temp.</td>
<td>–</td>
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<tr>
<td></td>
<td>Persistent Cold Weather</td>
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<tr>
<td><strong>Utilization</strong></td>
<td>Run hours</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Basepoint Volatility</td>
<td>✓</td>
</tr>
</tbody>
</table>

- 95/5 weather in 1989
- 2017/18 cold snap
- 2023/24 cold snap

www.pjm.com
Natural Gas Generation Trends

Fuel trends for recently commercial and queue natural gas generators since 2017

**Combined Cycle — 95%**
- 90% Firm
- 10% Non-Firm
- 90% Non-Dual Fuel
- 10% Dual-Fuel

17,000 MW

**Combustion Turbine — 5%**
- 40% Firm
- 60% Non-Firm
- 10% Non-Dual Fuel
- 90% Dual-Fuel

800 MW
## Natural Gas Delivery Disruption Scenarios

<table>
<thead>
<tr>
<th>Pipeline</th>
<th>Single-Fuel Disruption (MW)</th>
<th>Dual-Fuel Disruption (MW)</th>
<th>Total Disruption (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Firm</td>
<td>Firm</td>
<td></td>
</tr>
<tr>
<td>Looped 1</td>
<td>2,690</td>
<td>3,094</td>
<td>5,784</td>
</tr>
<tr>
<td>Looped 2</td>
<td>3,015</td>
<td>4,483</td>
<td>4,100</td>
</tr>
<tr>
<td>Retirement Scenario Total</td>
<td>+ 435</td>
<td>+ 435</td>
<td>+ 225</td>
</tr>
<tr>
<td></td>
<td>1,468</td>
<td>3,450</td>
<td>4,918</td>
</tr>
<tr>
<td>Single 1</td>
<td>1,821</td>
<td>3,004</td>
<td>4,277</td>
</tr>
<tr>
<td>Retirement Scenario Total</td>
<td>+ 774</td>
<td>+ 774</td>
<td>+ 774</td>
</tr>
<tr>
<td></td>
<td>1,183</td>
<td>2,595</td>
<td>3,778</td>
</tr>
<tr>
<td>Single 2</td>
<td>330</td>
<td>750</td>
<td>1,080</td>
</tr>
</tbody>
</table>
Limited reserve shortage, voltage reduction and load shed
Increased demand response, reserve shortage, voltage reduction and load shed
Escalated Retirements 1 Scenario Model I

System Overview

- Generation (MW)
- Forecasted Demand (MW)
- Deployed Demand Response (MW)
- Reserve Shortage (MW)
- Voltage Reduction (MW)
- Load Shed (MW)
- Price ($) 

Prices do not represent forecasts of actual prices.

Load: Extreme
Refueling: Moderate
Disruption: Looped 2 High
Non-Firm Avail: 62.50%
Retirement: Escalated 1 (32 GW)
Dispatch: Economic

No load shed; fewer voltage reduction actions
No voltage reduction actions; fewer reserve shortage hours.
Interchange and load distribution (2023/24 RTEP case)

- PROMOD 2023/24 Market Efficiency Case
- Flowgates
- Reactive interface limits
- Winter peak load
- eFORD
- Fuel supply/replenishment data
- Fuel prices
- Fuel supply disruptions
- Generation data by fuel type

**PLEXOS simulation for the X day duration**

- Day 1 peak hour
- Day 1 to Day 1-X
- Day X peak hour

- Dispatch

- **2023/24 Fuel Security RTEP Case**
  - Transfer analysis (CETL) in TARA
  - N-1 contingency analysis in TARA

- Import limit into LDA
- LOLH Analysis

- Voltage and thermal limits for day 1 and day X
- Unavailable MW vs. LOLH

- Unserved energy
- Generation output by fuel type/unit-specific info.
- Impacts to reserves
- DR Deployment
- Impacts to Prices
Reliability Transfer Analysis
Expected Loss of Load Hours Analysis
Loss of Load Hours (LOLH)
Mid-Atlantic Zone | Typical vs. Extreme (Announced Retirements)

TOTAL UCAP (MW) | 73,992
IMPORTS BASE (MW) | 3,603
IMPORTS EXTREME (MW) | 1,532
PEAK LOAD BASE (MW) | 47,392
PEAK LOAD EXTREME (MW) | 52,809
RTO RESERVE MARGIN | 25.8%