Planning Under Uncertainty: The Future of Long-Term Transmission Planning

Transmission Operations and Planning
Innovating Grid Operations, Shaping Strategic Planning

View from The TOP
Transmission Operations & Planning R&D
Public Webinar Series

August 12, 2026

For Q&A:
Go to slido.com and enter code: **EPRI-LTTP**

REC This webcast will be recorded

Recordings & materials posted at: https://top.epri.com/view-from-the-top

Agenda

01

Introduction & Background

Dinesh Dhungana, EPRI

02

ISO/RTO Perspective

Emmanuele Bobbio, PJM

03

Utility Perspective

Brant Werts, Duke Energy

04

Relevant EPRI Research, Methods, and Tools

Eric Swanger, EPRI

05

Q&A

Open discussion with all speakers

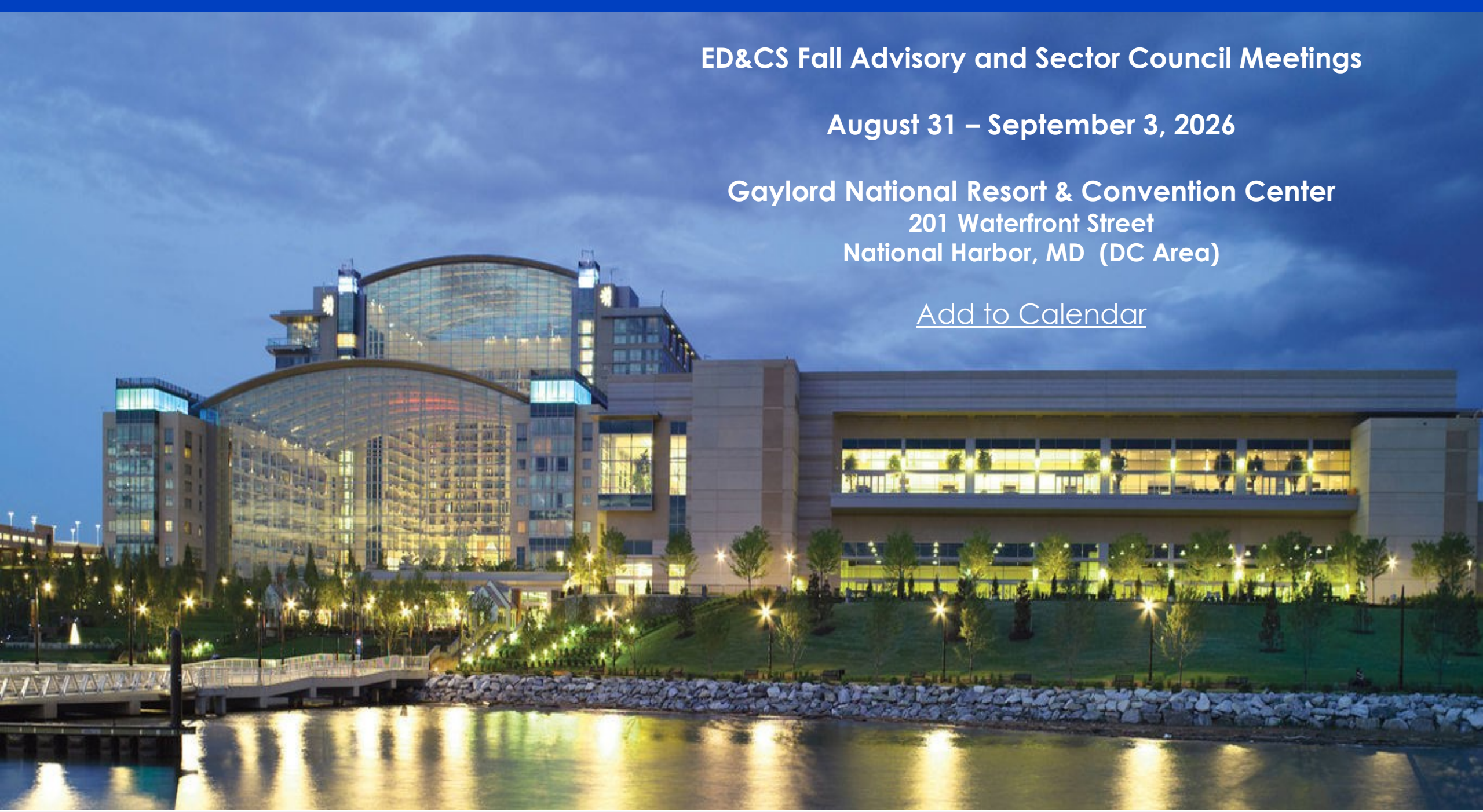
Transmission Operations & Planning

- EPRI's Transmission Operations & Planning (TOP) program conducts collaborative research to support reliable, resilient, and economic planning and operation of the bulk electric power system for transmission owners and system operators

- **Focus Areas**
  - Transmission Operations
  - Transmission Planning
  - Bulk System Integration of Renewables and Distributed Energy Resources
  - Electricity Market Design and Operation

- **Value to Industry**
  - Deliver leading-edge research, software tools, and technical guidance
  - Leverage global collaboration across utilities, ISOs, and subject-matter experts
  - Help the industry manage rapid system change, including renewables, large loads, and climate-driven risks

Learn more about TOP: https://top.epri.com/



ED&CS Fall Advisory and Sector Council Meetings

August 31 – September 3, 2026

Gaylord National Resort & Convention Center

201 Waterfront Street
National Harbor, MD (DC Area)

Add to Calendar

Long-Term Transmission Planning – Key Observations

Historic Approach

- Transmission investments primarily driven by localized reliability needs
- Planning and investment decisions largely focused on resolving specific thermal, voltage, and stability constraints within individual regions or utility footprints
- While this approach maintained system reliability, it often overlooked broader economic, interregional, and system-wide optimization opportunities

Persistent Transmission Deficiencies

- Transmission congestion continues across all regions
- Limited transfer capability between neighboring regions reduces resilience, resource adequacy, and operational flexibility
- Existing constraints contribute to growing interconnection queues and prevent the grid from operating at maximum efficiency

Need for More Transmission

- Rapid load growth, including large loads and electrification
- Aging infrastructure and changing resource mix

FERC Order 1920: A New Bar for Long-Term Transmission Planning

Compliance filings for O1920 are underway across FERC-jurisdictional planning regions

01

Long-Term Horizon

Regional planning across a horizon of no less than 20 years, reassessed and revised at least once every five years

02

Diverse Scenarios

At least three plausible and diverse long-term scenarios, built on Commission-identified categories and best available data

03

Stress Tested

Sensitivity analyses for extreme weather and multiple concurrent outages across a wide area

What it means for planners

Scenario and benefit work cuts across multiple spatial and temporal dimensions, requiring integrated tools, processes, and best available data

Transmission value must be assessed across planning processes, with benefits weighed alongside reliability and resilience impacts

AESO Optimal Transmission Planning Framework

How planning worked before

1. Zero-congestion standard
2. Rule-based trigger
3. Cost not weighed

FROM RULE-BASED
TO VALUE-BASED

1	**Forecast multiple futures**	Develop LTO scenarios for demand, generation, policy, technology, and market conditions.
2	**Model the market and network**	Use zonal capacity-expansion and nodal security-constrained dispatch models.
3	**Test need and value**	Identify reliability, economic, legislated, and multi-value needs; compare costs and benefits.
4	**Choose and stage investments**	Select preferred or least-regret alternatives, publish the LTP, and use milestones before construction.

Source- AESO OTP Framework, January 2026

Planning Under Uncertainty: The Future of Long-Term Transmission Planning

Emmanuele Bobbio
Principal Economist

EPRI

August 12, 2026

Agenda

Background

Current Regional Transmission Expansion Planning (RTEP) process

Long-Term Regional Transmission Planning (LTRTP) process

Planning under uncertainty

RTO-specific considerations and next steps

Background

The electricity system will be critical to support the long-term economic development of the United States

Data Centers	**Electrification (electric vehicles, heat pumps, etc.)**	**State and Federal policies**

PJM anticipates large-scale transformation of the electricity system in its region

70 GW of added load by 2038	**15 GW of generation retired** since 2022

In PJM planning is the art of dealing with uncertainty – no need for planning without uncertainty	PJM is ***enhancing the long-term planning process*** and other planning processes to support this transformation ***proactively and holistically by proceduralizing and creating tools to manage uncertainty and support decision making***

Today's RTEP Process

The current RTEP process develops cases 5 and 8-year out to trend needs and right-size solutions

PJM governing documents provide PJM with the ability to study multiple scenarios and sensitivities to assess uncertainty and identify robust solutions

- 2024 RTEP, 2022 Window 3 *(3 sensitivities on the location of new generation in the west)*
- 2025 RTEP, Window 1 *(5 scenarios for planned and unplanned generation, deactivations, and policies)*
- 2026 RTEP, Window 1 *(2 scenarios and 5 sensitivities on siting opportunities, cost of gas, generation deactivations, policies, etc.)*

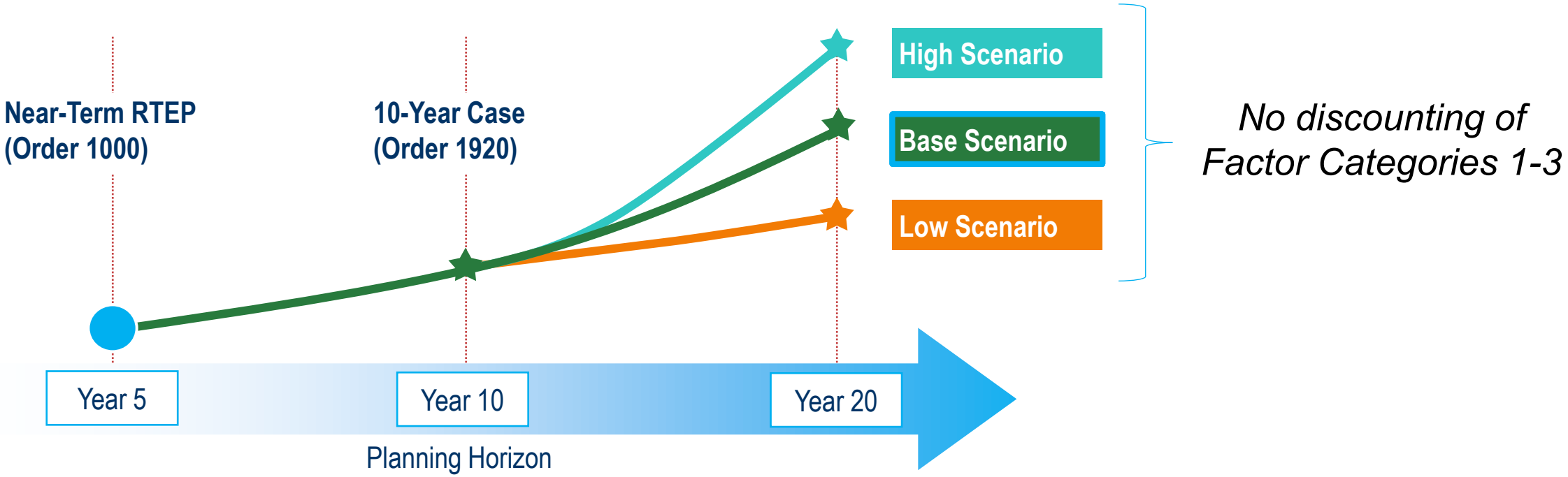
Uncertainty can be managed through **inputs** (scenarios/sensitivities)
or **outputs** (solution selection/plan development)

PJM has approved >$22 billion of transmission investments since 2024

Long-Term Regional Transmission Planning (Order 1920)

The large-scale transformation and the increased role of policies requires a longer-term planning horizon

Order 1920 institutes the Long-Term Regional Transmission Planning process with a minimum planning horizon of 20 years using at least three scenarios and extreme weather sensitivities



Manage Uncertainty at PJM – Key Aspects

OBJECTIVE:	maintain reliability economically under uncertainty (“more efficient or cost effective”)

LEVERS:

Scenario selection to identify relevant reliability needs, and other economic and policy needs

Portfolio selection using multiple futures to identify a contingent/flexible plan that is robust to uncertainty (guarantees reliability under different futures)

- Trigger parts of the contingent plan that are needed to meet expected needs *in time* (wait on other parts of the plan)
- Trigger additional parts of the contingent plan as they become needed
- Adjust the plan as new information arrives (reevaluation)

Develop tools and business practices for scenario and portfolio selection

RTO-Specific Considerations and Next Steps

Multiple jurisdictions

PJM does not plan generation

Develop tools and business practices to systematize long-term, proactive planning under uncertainty

Enhance transmission solicitation process for flexibility

Multi-Value Strategic Transmission Planning –

Planning Under Uncertainty

Brant Werts, Duke Energy - Grid and Operations Planning

DUKE ENERGY®

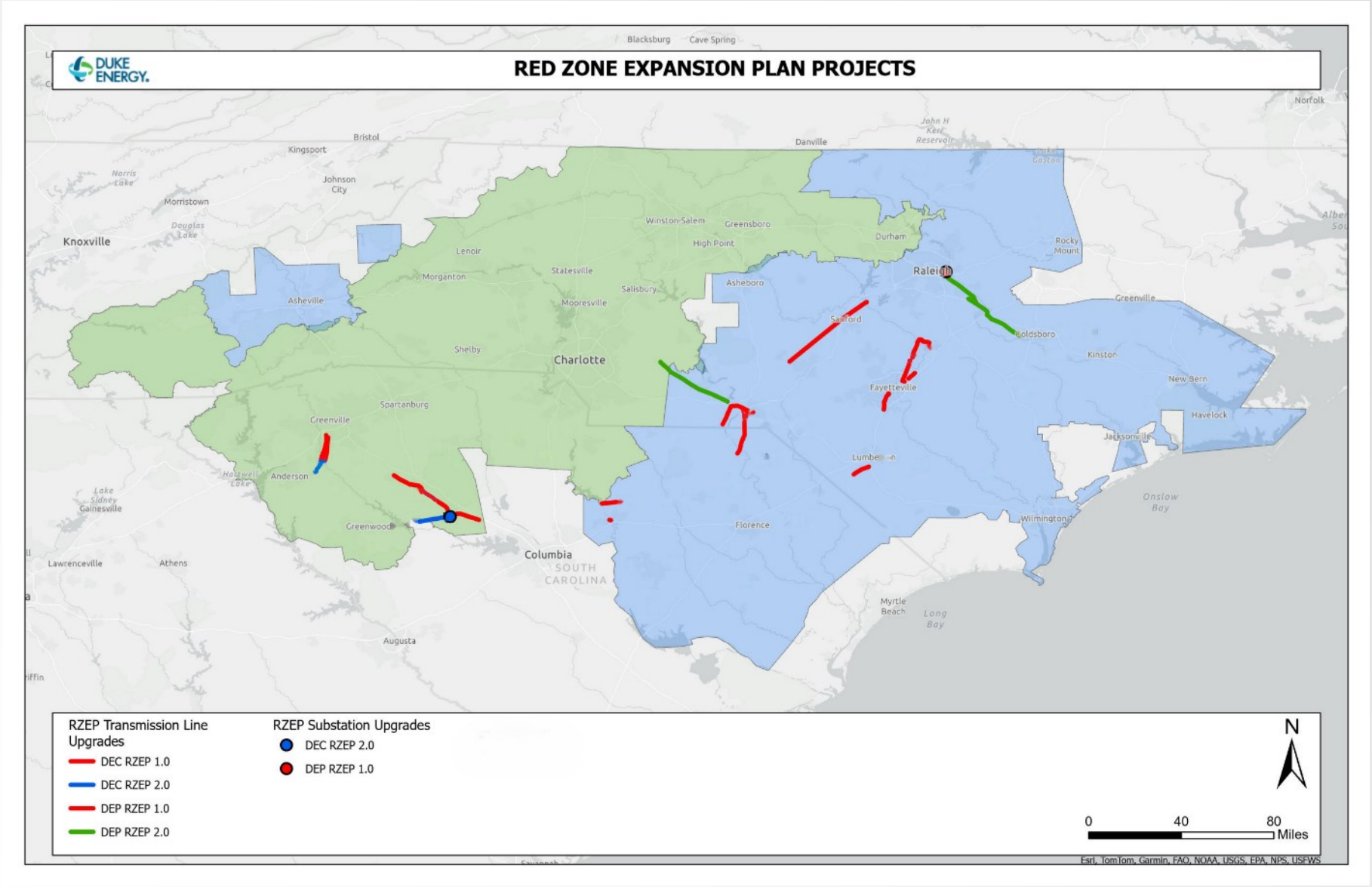
BUILDING A SMARTER ENERGY FUTURE®

AUGUST 12, 2026

Multi-Value Strategic Transmission Planning – Planning Under Uncertainty

- **Roadmap for Integrating Resource Planning and Transmission Planning**
- **Multi-Value Strategic Transmission (MVST) Planning**
- **Uncertainty Challenges in Modeling**
- **Recommendations to Address Uncertainty in Solutioning**

Proactive Planning Roadmap Started with Red Zone Expansion Plan



2024 MVST Study Scope

- Study Criteria
- Case Development
- Study Methodology
- Technical Analysis and Study Results
- Assessment and Problem Identification
- Solution Development (includes GETs eval)
- Benefits Determination
  1. Avoided capacity costs
  2. Generation capacity savings from reduced losses
  3. Congestion and fuel savings
  4. Energy savings from reduced losses
  5. Avoided customer outages
  6. Avoided transmission investment
- Selection of Recommended Projects

Scenario Development ➔Three Scenarios - Resource Plan Portfolio Based

Scenario 1:

Resources added by January 1, 2034 -> 2034 Summer Cases								
Portfolio	**Solar**	**Battery**	**CC**	**CT**	**Onshore**	**PSH**	**SMR**	**Offshore**
P1	19,800	9,540	4,077	2,124	2,250	1,834	-	2,400
DEC	8,100	2,780	2,718	2,124	600	1,834	-	-
DEP	11,700	6,760	1,359	-	1,650	-	-	2,400
Resources added by January 1, 2035 - 2034/35 Winter Cases								
Portfolio	**Solar**	**Battery**	**CC**	**CT**	**Onshore**	**PSH**	**SMR**	**Offshore**
P1	20,775	9,540	4,077	2,124	2,250	1,834	600	2,400
DEC	8,850	2,780	2,718	2,124	600	1,834	600	-
DEP	11,925	6,760	1,359	-	1,650	-	-	2,400

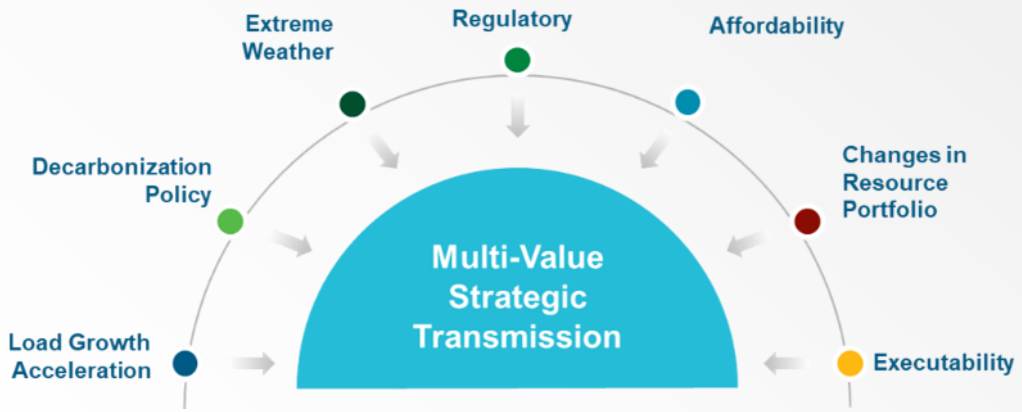
Scenario 2:

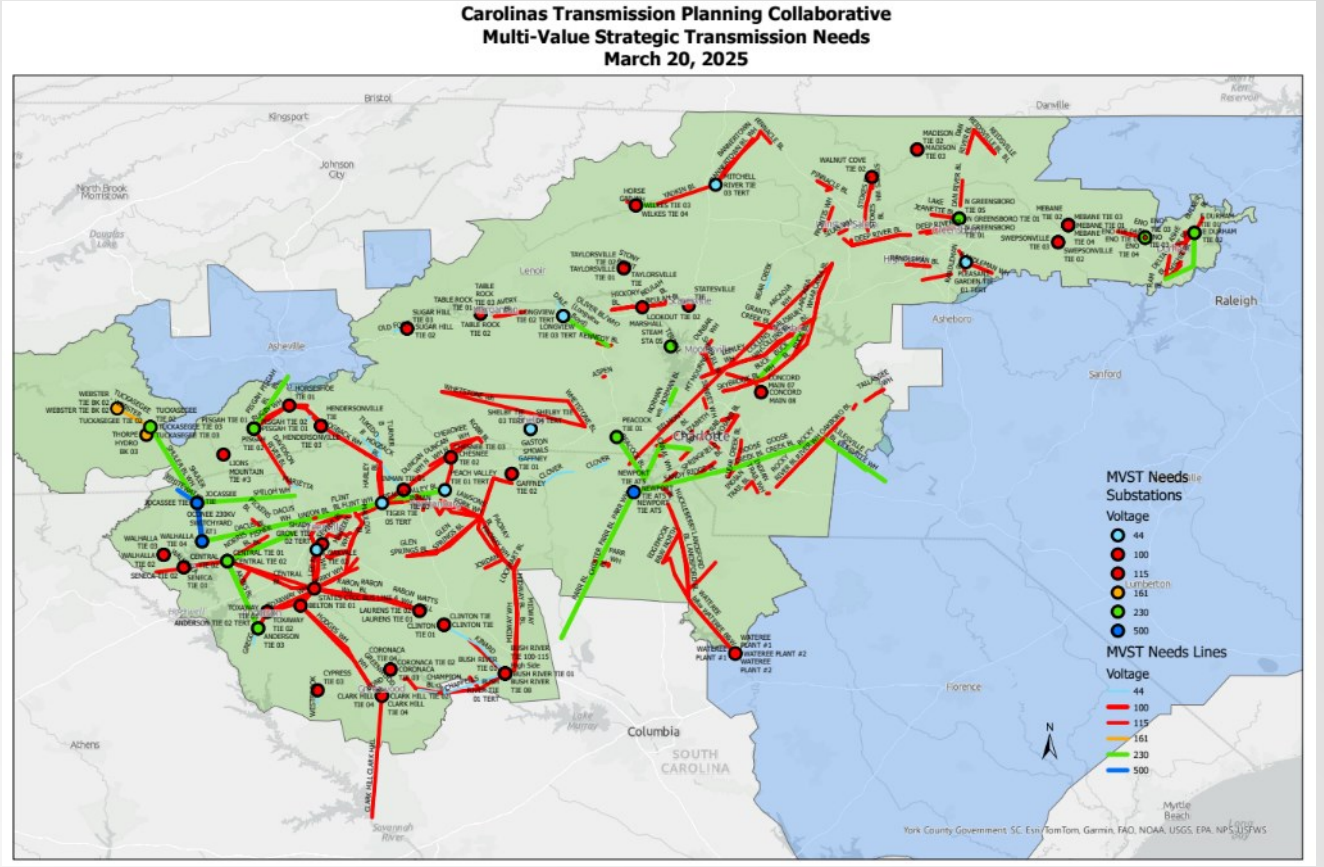
Resources added by January 1, 2034 -> 2034 Summer Cases								
Portfolio	**Solar**	**Battery**	**CC**	**CT**	**Onshore**	**PSH**	**SMR**	**Offshore**
P3	10,800	3,060	6,800	2,124	1,650	1,834	-	2,400
DEC	4,500	1,540	4,077	2,124	-	1,834	-	-
DEP	6,300	1,520	2,718	-	1,650	-	-	2,400
Resources added by January 1, 2035 - 2034/35 Winter Cases								
Portfolio	**Solar**	**Battery**	**CC**	**CT**	**Onshore**	**PSH**	**SMR**	**Offshore**
P3	12,600	5,100	6,800	2,124	2,100	1,834	600	2,400
DEC	5,250	1,740	4,077	2,124	450	1,834	600	-
DEP	7,350	3,360	2,718	-	1,650		-	2,400

MVST Supports Faster Generator and Load Interconnection

Leveraging a Multi-Value Strategic approach to planning transmission projects

- Forward-looking / proactive planning approach that is scenario-based to account for different possible futures
- Represents holistic planning that avoids one-off assessments and piecemeal planning and allows for meaningful stakeholder input
- Ensures projects that provide multiple benefits are prioritized over those with lower impact





Accounting for Resource Uncertainty in MVST Models

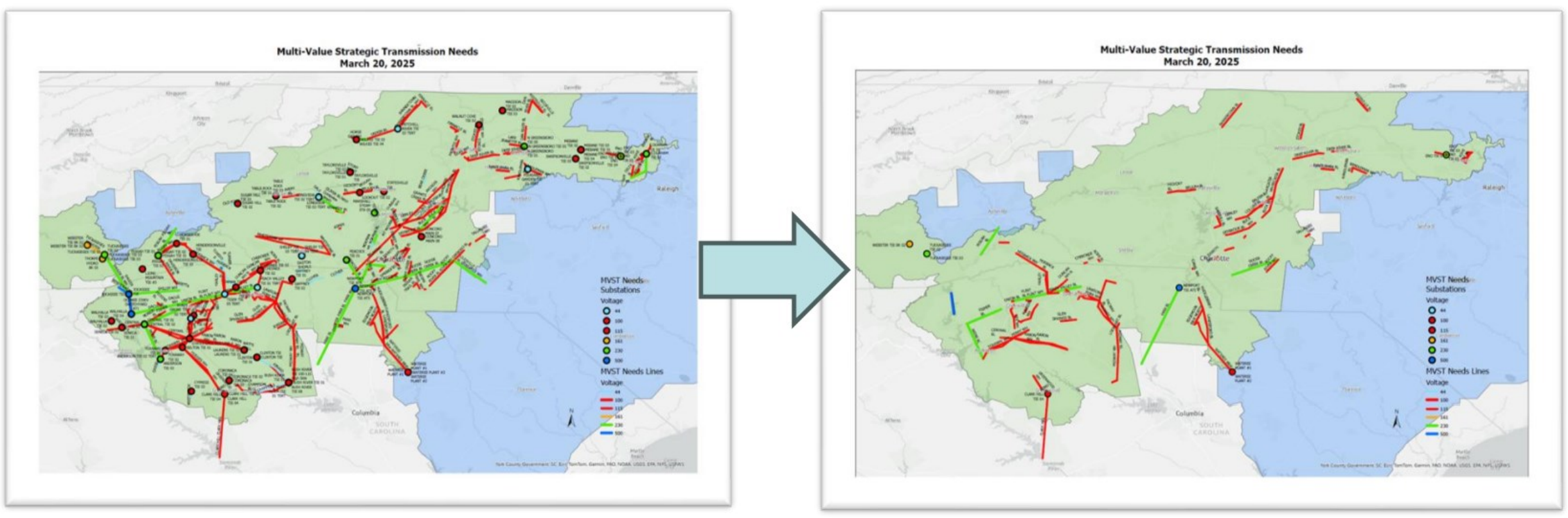
Where Uncertainty Enters the Models

- Siting, size, and in-service timing of individual resources are not firm over a 10- to 20-year horizon
- Interconnection queue positions shift as projects withdraw, resize, or relocate
- Large load additions vary in magnitude, location, and ramp rate
- Retirement timing moves with economics, policy, and reliability needs

How MVST Accounts for It

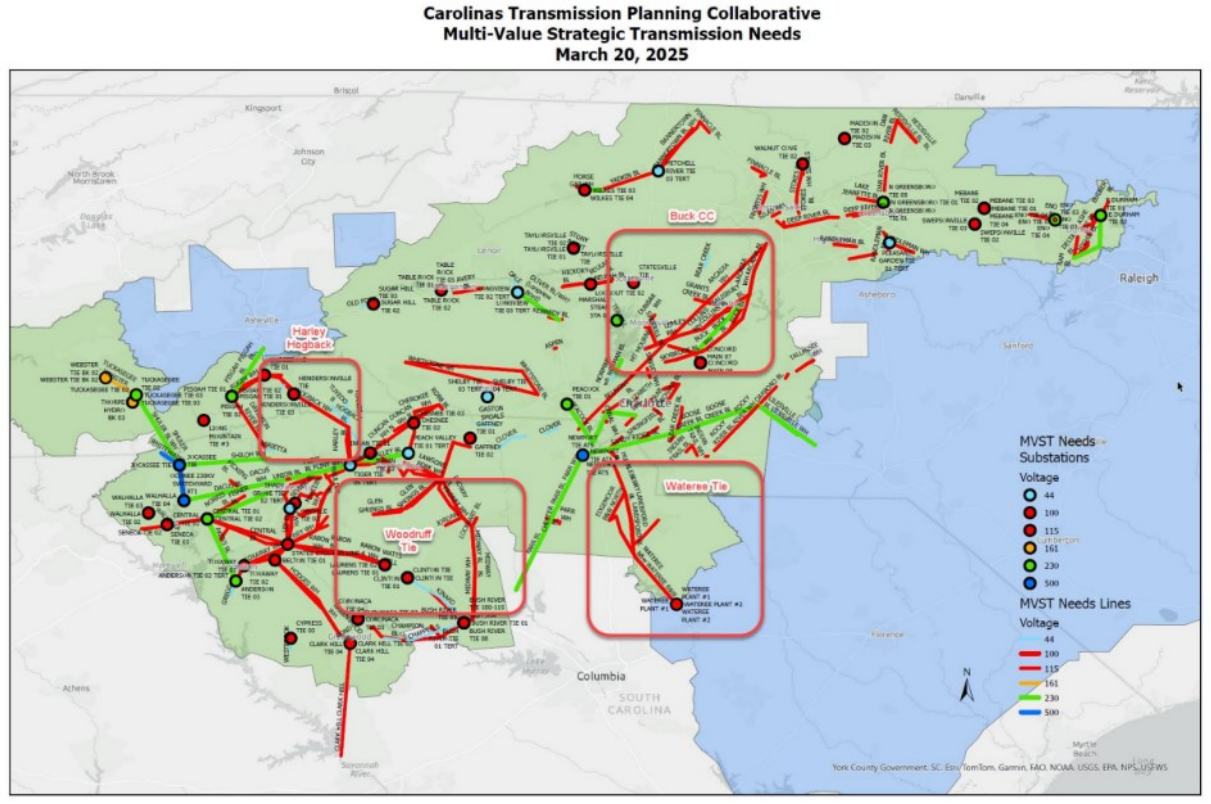
- Develop diverse, plausible scenarios rather than planning to a single expected future
- Treat resource siting probabilistically – zones and corridors instead of single fixed points
- Apply sensitivities that test resource timing, mix, and load placement independently

Application of Selection Criteria

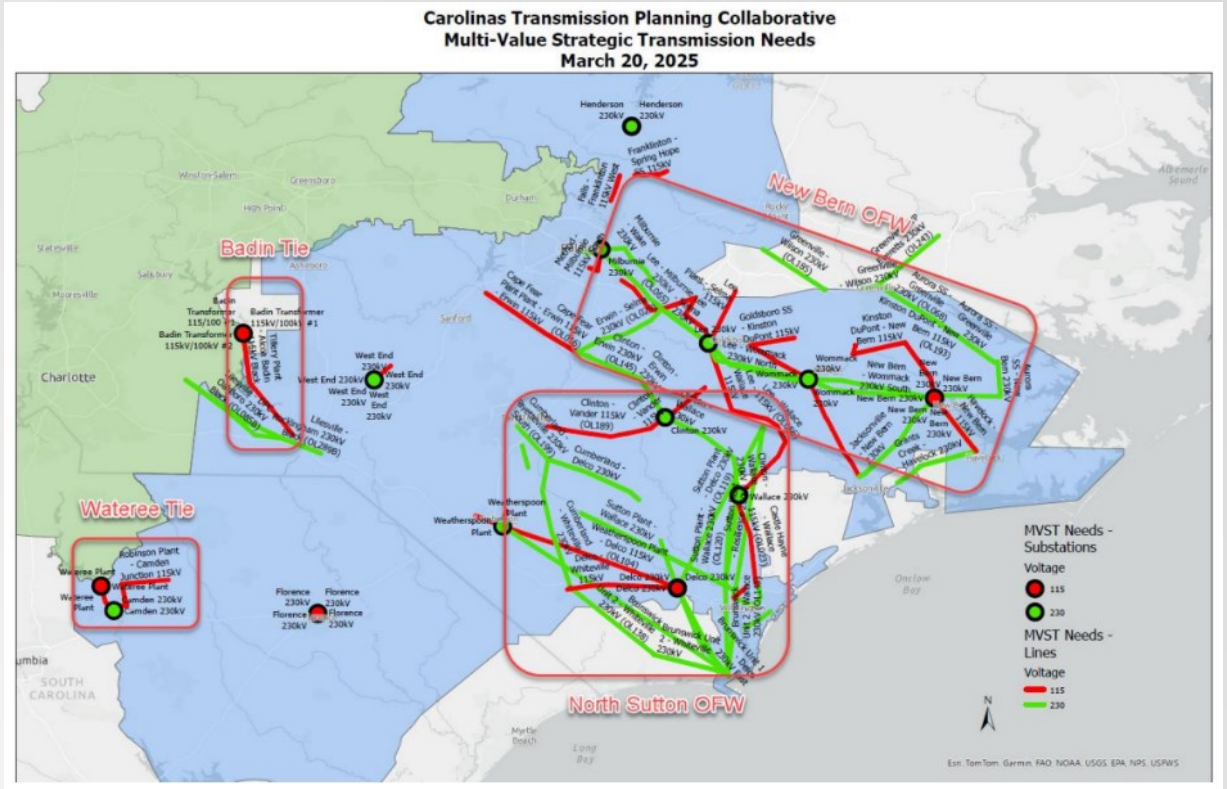


Broad Solutions from a Corridor Perspective

Duke Energy Carolinas Corridors



Duke Energy Progress Corridors



Identifying Solutions Most Likely to Be Needed

Testing Solutions Across Futures

- Evaluate candidate projects against the full set of scenarios and sensitivities
- Prioritize no-regrets projects that perform well across a wide range of project drivers

Designing for Flexibility

- Focus on corridor-based solutions absorb shifts in resource siting without a full redesign
- Right-size upgrades and preserve optionality in right-of-way usage and substation designs

Managing the Trade-offs

- Balance the risk of over-building against any consequences of starting late
- Revisit assumptions each study cycle as queue and load positions firm up

BUILDING A **SMARTER** ENERGY FUTURE®

Relevant EPRI Research, Methods, and Tools

EPRI and Member Collaborative on Order 1920 Readiness

Five industry members — representing RTOs, utilities, and power authorities — worked with EPRI to assess technical and organizational readiness for long-term regional transmission planning under FERC Order 1920

01 Capability Catalog

Established a catalog of Order 1920 technical capabilities across scenario development, benefit calculations, and solution assessment

02 Member Discussions

Individualized discussions with each member on current tools, data, models, and planning processes

03 Gaps Analyses

Compared existing capabilities against Order 1920 requirements to pinpoint technical and organizational readiness gaps

04 Action Plans

Member-specific, prioritized next steps to close gaps ahead of the first Order 1920 compliance cycle

Insights from the collaborative were consolidated into an EPRI whitepaper that is publicly available

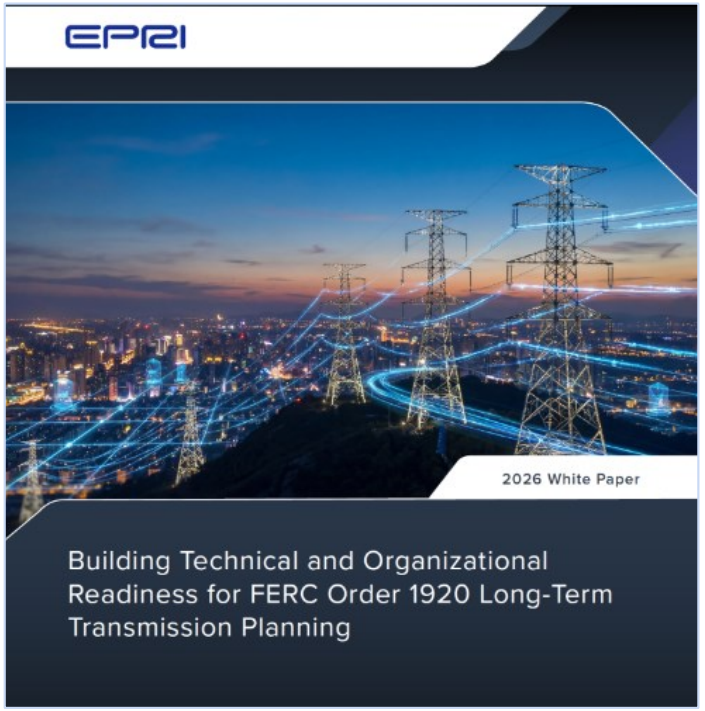
Building Technical & Organizational Readiness for FERC Order 1920 Long-Term Transmission Planning

Product ID: 3002036287

Insights from the Order 1920 Readiness Whitepaper

The whitepaper assists with understanding uncertainty by associating future policy, technology, weather, and economic factors with consistent, scenario-based analyses and sensitivities for long-term transmission planning

Guidance around three core sub-processes



Scenario Development

- Frameworks defining scenario diversity and plausibility
- Technoeconomic and capacity expansion modeling for consistent resource and load assumptions
- Layered fidelity: coarse tools bound uncertainty, detailed models refine feasibility
- Zonal-to-nodal translation, with extreme weather and interregional coordination considered early

Benefit Calculations

- Aligned assumptions across capacity expansion, resource adequacy, production cost, and transmission models
- Deliberate sequencing to avoid double counting and keep scenarios comparable
- Each required benefit computed with existing models, trading off fidelity, burden, and data
- Resilience valued via event libraries and probabilistic weighting

Solution Assessment

- Right-sizing built into planning workflows: end-of-life assets, upgrade versus replacement
- ATTs modeled explicitly: dynamic line ratings, advanced conductors, power flow control, switching
- Optimal portfolios coordinate multiple technologies, not one solution

EPRI Transmission Planning Workflows and Analytics

Long-Term Planning

Advanced and Risk-Based Reliability Analysis

- Scenario Selection and Development via a High-Level Screening Tool
- Probabilistic Contingency Assessment and Tool
- Node-breaker Modeling, Automatic Contingency Generation, and Contingency Screening & Ranking

Probabilistic Resilience Assessment

- Resilient System Investment Framework (RSIF)
- Resilience Case Studies

Coordinated G&T Expansion Planning

- Tools for Coordinated Expansion Planning
- Improved Methods for Planning
- Case Studies

Strategic Network Planning

- FERC Order 1920
- ISSP, Climate READi
- FERC Order 896/TPL-008

Emerging Planning Needs Analytics

HVDC Planning and Integration

- Provide support to planners and operations engineers for HVDC transmission planning and integration

EHVAC 765kV Planning

- Modeling and technology specific insights
- Coordination with design teams
- Assessing value from holistic planning

Grid Enhancing Technologies

- Helps planners design GETs solutions
- Software Tool for Optimized Transmission Solution Design

Optimization-based Transmission Hosting Capacity Tool

- Identifying Point of Interconnections (POIs)
- System Enhancement needs

The Path Forward: Holistic, Multi-Value Transmission Planning

Organizational readiness for long-term planning uncertainty:

01 **Self-Evaluation**

02 **Process Evolution**

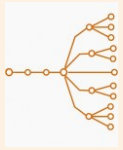
03 **Technical Readiness**

04 **Continued Adaptation**

Move beyond project-by-project reliability fixes toward holistic, multi-value transmission planning

Coordinate across boundaries

Expand regional and interregional coordination — the highest-value opportunities often sit across market and regional seams



Plan for many futures

Use long-term, scenario-based planning for load growth, a changing resource mix, extreme weather, and emerging demands

Plan the system, not the project — value multiple benefits together, coordinate across seams, and test decisions against a range of futures

TOGETHER…SHAPING THE FUTURE OF ENERGY®

www.epri.com