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National Transmission Planning Study

NTP Study Team

October 16, 2024

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Maria Robinson
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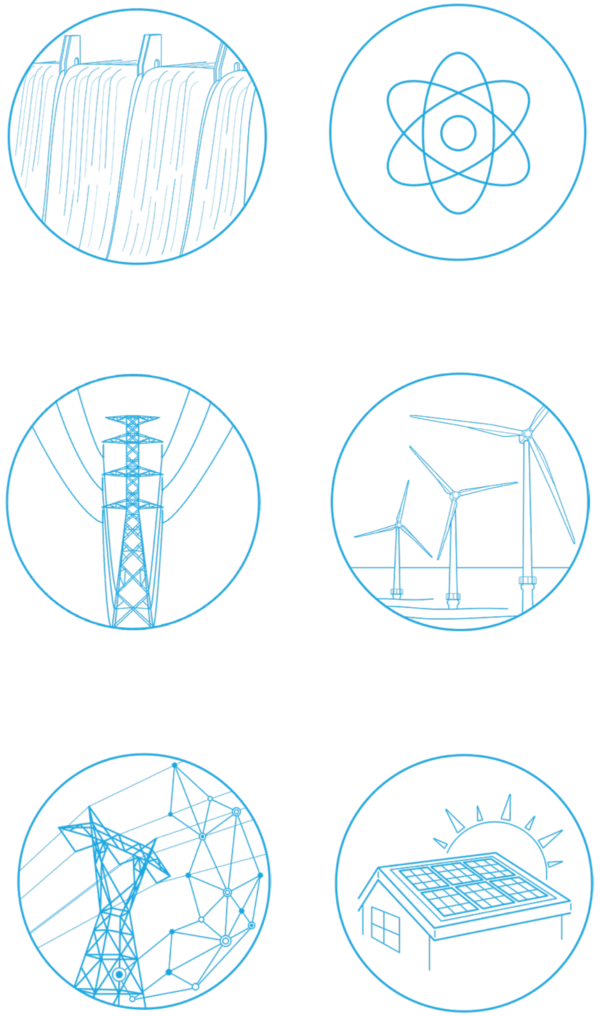
U.S. Department of Energy

GDO Mission and Goals



Ensure **resource adequacy** by supporting **critical generation sources** and expanding and enhancing **electricity markets**.

Catalyze the development of new and upgraded **high-capacity electric transmission lines** and an improved **distribution system** nationwide.

Prevent **outages** and enhance the **resilience** of the electric grid.

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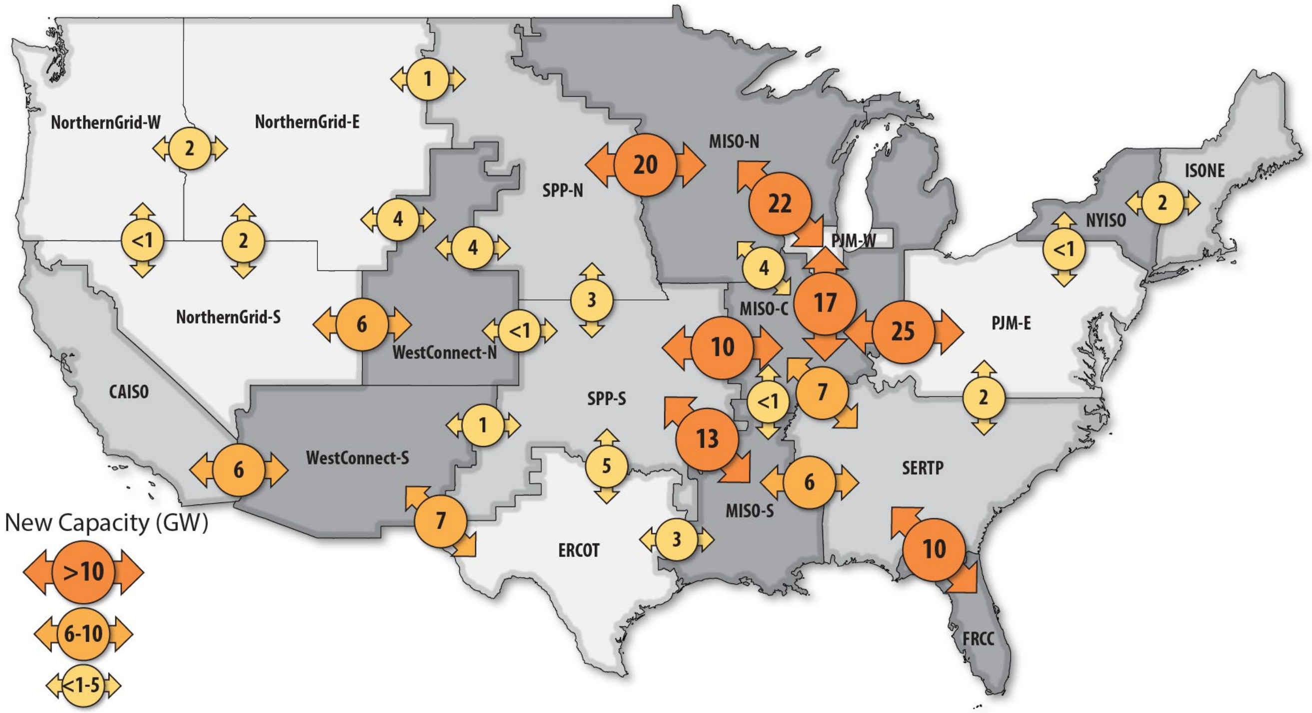
NTP Study Findings Summary

- **Grid Reliability:** Improving interregional transmission can enhance grid reliability, particularly in response to extreme weather events, as it allows more resources to be shared across regions and energy to be moved from where it is available to where it is needed.
- **Consumer Savings:** A substantial expansion of the transmission system throughout the entire contiguous United States delivers the largest benefits to consumers and would save the U.S. **$270-$490 billion** through 2050, with approximately **$1.60 to $1.80** in system cost savings for every dollar spent on transmission.
- **Integrating new, cleaner generation onto the grid:** Expanded transmission enables the grid connection of new generation projects, balancing the variability of wind and solar resources and accommodating growing energy demands while maintaining system reliability and energy affordability.



High Opportunity Transmission (HOT) interfaces represent potentially beneficial transmission capacity expansion between regions found across many future power system scenarios. Transmission projects that align with these HOT interfaces could be strong candidates for further study and serve as a starting point for accelerated transmission expansion.

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Patrick Harwood

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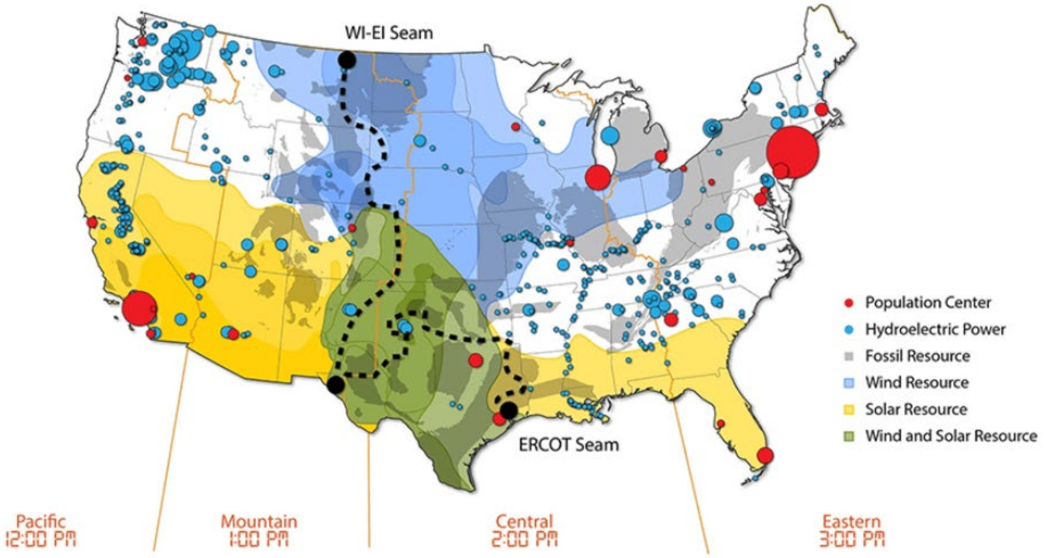
Project Team

- The NTP Study was led by the U.S. Department of Energy's Grid Deployment Office, in partnership with the National Renewable Energy Laboratory (NREL) and Pacific Northwest National Laboratory (PNNL).
- This study builds on past projects and expertise at NREL and PNNL with the support and direction of DOE's Office of Electricity and Grid Deployment Office.

NREL Transforming ENERGY

Pacific Northwest NATIONAL LABORATORY



U.S. DEPARTMENT OF ENERGY

Office of Electricity

North American Energy Resilience Model

NTP Study Goals

The National Transmission Planning Study combines innovative methods with state-of-the-art industry practices to analyze the role and value of transmission in future power systems.

Specifically, the study sought to:

- Develop new national grid-scale planning tools and methods that can be used by industry, especially when planning for interregional transmission capacity needs;
- Identify potential transmission solutions that will provide broad-scale benefits to electric customers under a wide range of potential futures;
- Inform planning processes for regional and interregional transmission; and
- Identify interregional and national strategies to maintain grid reliability as the grid transitions, including to a reliance on low- and zero-carbon energy resources.

What the Study Does and Does Not Do

What the study does do

- Link several long-term and short-term power system models to test multiple transmission buildout scenarios.
- Provide information that can be used in existing planning processes.
- Test transmission options that lie outside current planning processes.
- Assess a range of economic, reliability, and resilience indicators for each transmission scenario considered.
- Provide companion reports describing opportunities and challenges to realizing potential transmission benefits identified by the study.

What the study does not do

- Replace existing regional and utility planning processes.
- Site specific locations or provide approvals for individual transmission lines.
- Address the detailed environmental impacts or other land use issues of potential future transmission lines.
- Develop detailed plans of service or provide results that are as granular as planning done by utilities.
- Provide a roadmap for developing specific projects.

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Final Report Structure

- **Executive Summary** – High-level findings and next steps for how to build on the analysis.
- **Chapter 1: Introduction** – Background, context and study design, including modeling and scenario framework.
- **Chapter 2: Long-Term U.S. Transmission Planning Scenarios** – Methods for capacity expansion and resource adequacy, key findings from the scenario analysis and economic analysis, and High Opportunity Transmission interface analysis.
- **Chapter 3: Transmission Portfolios and Operations for 2035 Scenarios** – Methods for translating zonal scenarios to nodal-network-level models, network transmission plans for a subset of the scenarios, and key findings from transmission planning and production cost modeling.
- **Chapter 4: AC Power Flow Analysis for 2035 Scenarios** – Methods for translating from zonal and nodal production cost models to AC power flow models and describes contingency analysis for a subset of scenarios.
- **Chapter 5: Stress Analysis for 2035 Scenarios** – How the future transmission expansions perform under stress tests.
- **Chapter 6: Conclusions** – High-level findings and study limitations across the six chapters.

NTP Study Companion Reports

- **Interregional Renewable Energy Zones (March 2024)** connects the NTP Study scenarios to ground-level regulatory and financial decision making—specifically focusing on the potential of interregional renewable energy zones.

- **Barriers and Opportunities To Realize the System Value of Interregional Transmission (June 2024)** examines issues that prevent existing transmission facilities from delivering maximum potential value and offers a suite of options that power system stakeholders can pursue to overcome those challenges between non-market or a mix of market and non-market areas, and between market areas.

- **Western Interconnection Baseline Study (September 2024)** uses production cost modeling to compare a 2030 industry planning case of the Western Interconnection to a high renewables case with additional planned future transmission projects based on best available data.

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Broad Stakeholder Engagement

Public Input

Existing Convenor Groups

Technical Review Committee

Tribal Outreach

NESCOE New England States Committee on Electricity

NARUC National Association of Regulatory Utility Commissioners

NASEO National Association of State Energy Officials

EIPC Eastern Interconnection Planning Collaborative

OMS

Southeastern Association of Regulatory Utility Commissioners

WESTERN Conference of Public Service Commissioners

National Governors Association

TVA Tennessee Valley Authority

MISO misoenergy.org

University of Michigan

Southeastern Regional Transmission Planning

CEBA

EPRI Electric Power Research Institute

Bonneville Power Administration

Organization of PJM States, Inc. (OPSI)

The Brattle Group

SPP Southwest Power Pool

Federal Energy Regulatory Commission

Wildlife West Virginia Division of Natural Resources

PacifiCorp

US Army Corps of Engineers

American Clean Power

NEI Nuclear Energy Institute

California ISO

ISO New England

DEQ Montana

Oregon Department of Energy

Xcel Energy

eia

Smart Wires

ESIG Energy Systems Integration Group

Penn Law

The Nature Conservancy

LS Power

New York ISO Independent System Operator

ercot

APEX Clean Energy

pjm

Southern Company

New York State Public Service Commission

NYSERDA

NRDC Natural Resources Defense Council

Columbia University

Oceti Sakowin Power

Southern Ute Indian Tribe

Navajo Nation

Confederated Tribes of the Umatilla Indian Reservation

Many others…

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Technical Review Committee

- Four public meetings (including this one)
- Three plenary TRC meetings
- Six Modeling Subcommittee meetings
- Four Government Subcommittee meetings
- Two Land Use and Environmental Exclusions subcommittee meetings
- Four rounds of regional meetings
- Two sets of office hours

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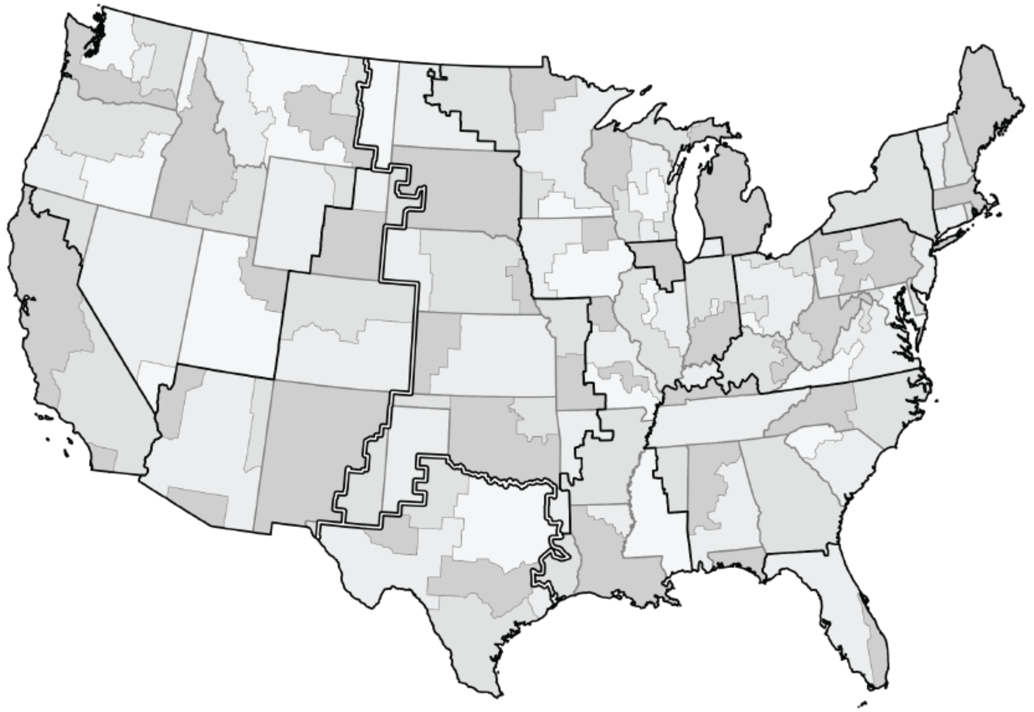
Multimodel analysis for a low-cost, reliable transmission system of the future



Zonal Resolution
Long-Term Scenarios through 2050

- Capacity Expansion
- Economic Analysis
- Resource Adequacy

Nodal Resolution
2035 Transmission Portfolios

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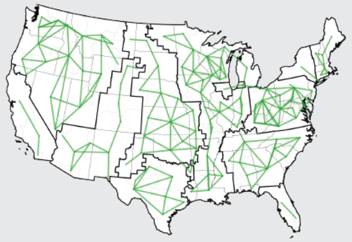
Scenarios: Transmission Frameworks

Reference Transmission Framework

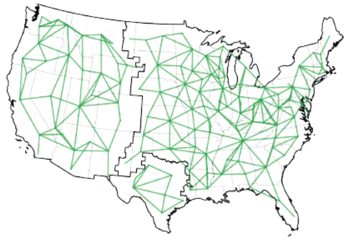
Limited (Lim)



- No new interregional transmission
- Total annual transmission expansion limited to recent observed maximum

Accelerated Transmission Framework

Alternating Current (AC)



- Expansion allowed within interconnections
- No new DC connections

Point-to-Point (P2P)

- Expansion allowed across the country
- Includes long-distance point-to-point HVDC options

Multi-Terminal (MT)

- Expansion allowed across the country
- Includes multi-terminal HVDC options between neighboring zones

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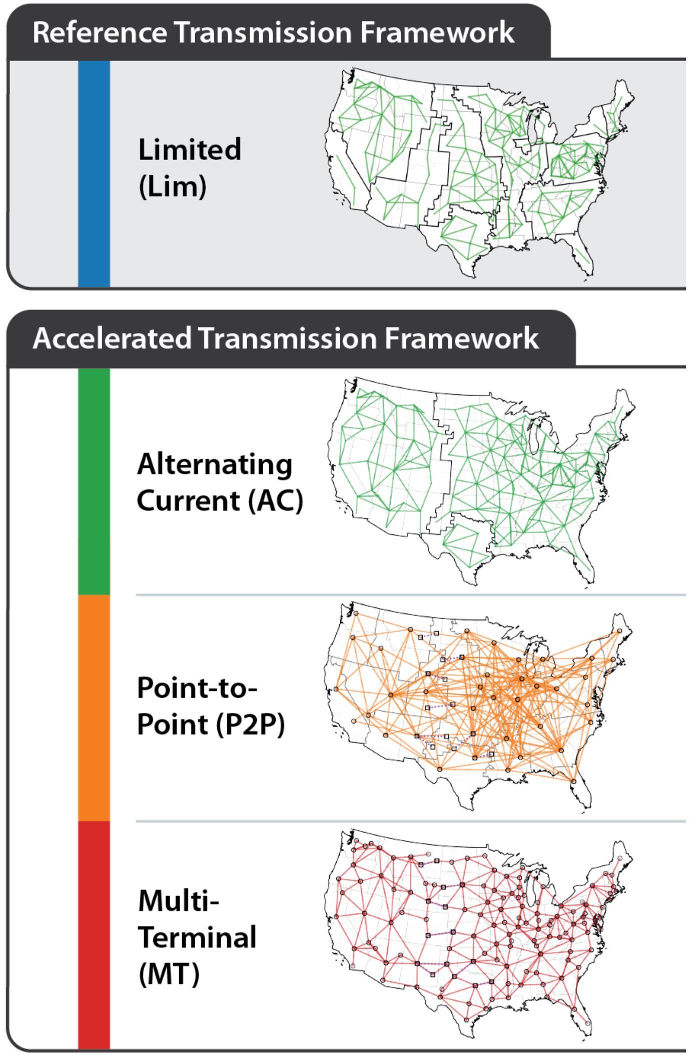
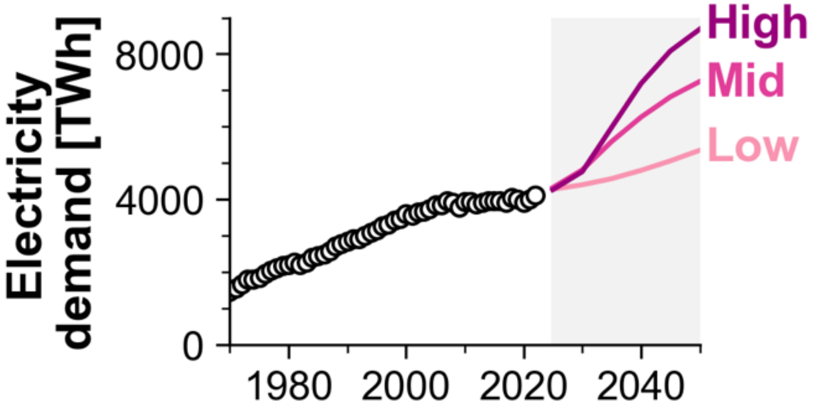
Scenarios: Transmission X Demand X Emissions Targets = 36 Core Scenarios



X 3 Demand Growth



X 3 Emissions Targets
Current policies
90% CO_2 reduction by 2035
100% by 2045

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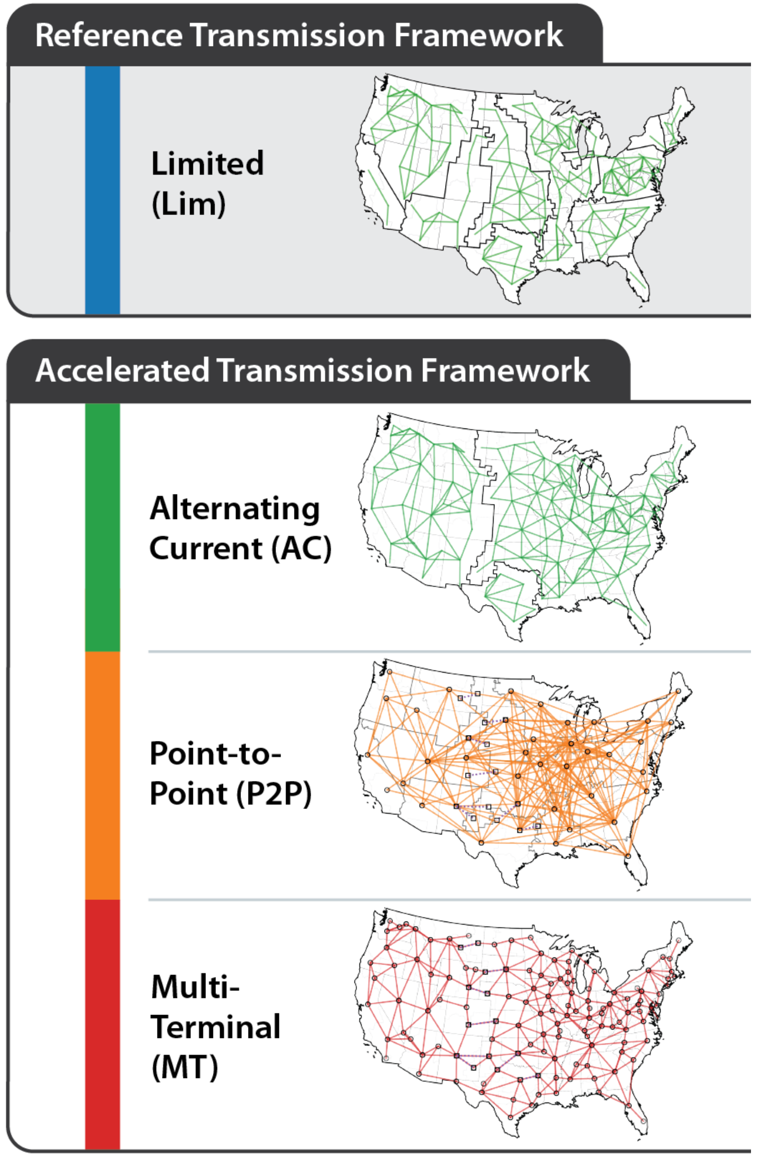
Goal is to understand role of transmission across many possible futures.

Scenarios: Sensitivities



╳ 15 Sensitivities*

Sensitivity
PV + battery low cost
Wind low cost
Electrolyzer low cost
+Nuclear SMR +DAC
No interface expansion limit
Transmission cost 2x
No resource adequacy sharing
Siting limited for PV and wind
CCS high cost
Many challenges
No H2
No CCS
No H2 or CCS
No H2 or new nuclear
Climate

**Full set of sensitivities modeled for the central (90% by 2035, Mid-Demand) case only*

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Executive Summary

6 Principal Findings + 22 Supporting Key Takeaways

1. Transmission expansion under current policies
2. Benefits of transmission
3. Amount of transmission expansion
4. Grid reliability
5. Promising interregional transmission
6. Advancements in planning approaches

Items 2–5: 90% emissions reductions by 2035

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Principal Findings Under Current Policies

Current Policies Definition

- Includes legislated energy policies as of **June 2023**
  - State renewable portfolio and clean energy standards
  - Inflation Reduction Act

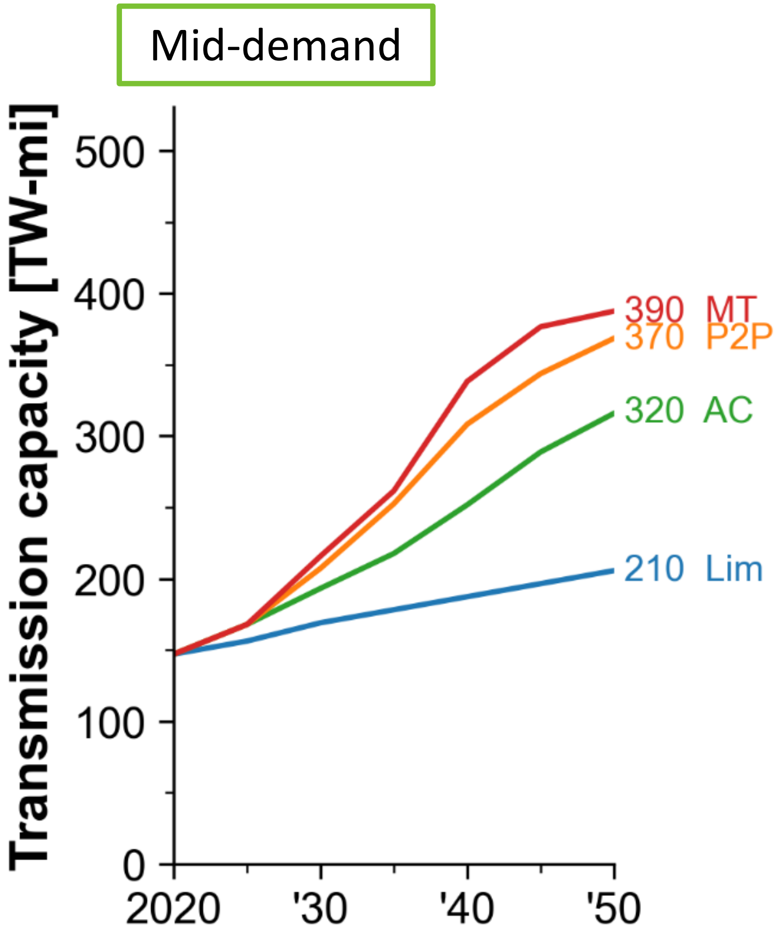
- Excludes
  - Newer policies (e.g., Clean Air Act section 111 rules, newer state policies)
  - Non-binding state targets
  - Corporate voluntary targets

Principal Finding

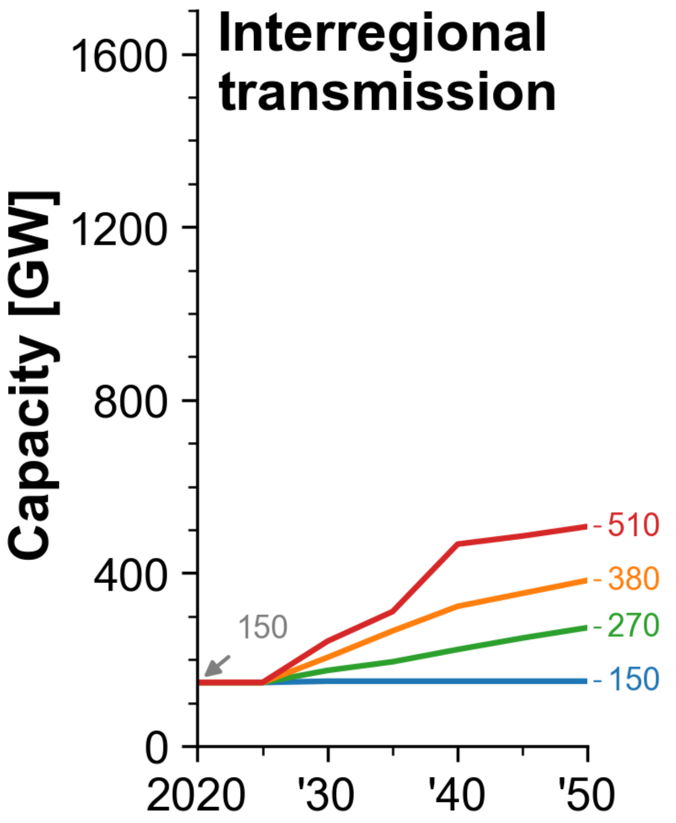
The lowest-cost U.S. electricity system portfolios that meet future demand growth and reliability requirements include substantial expansion in transmission.

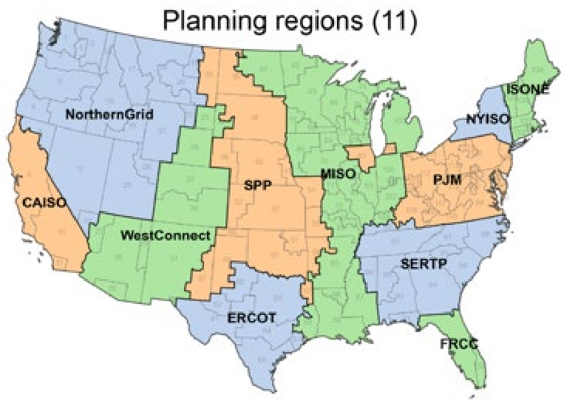
Key Takeaway

The total transmission system of the contiguous United States expands **2.1** to **2.6 times** the size of the 2020 system by 2050 and interregional transmission grows 1.9 to 3.5 times.



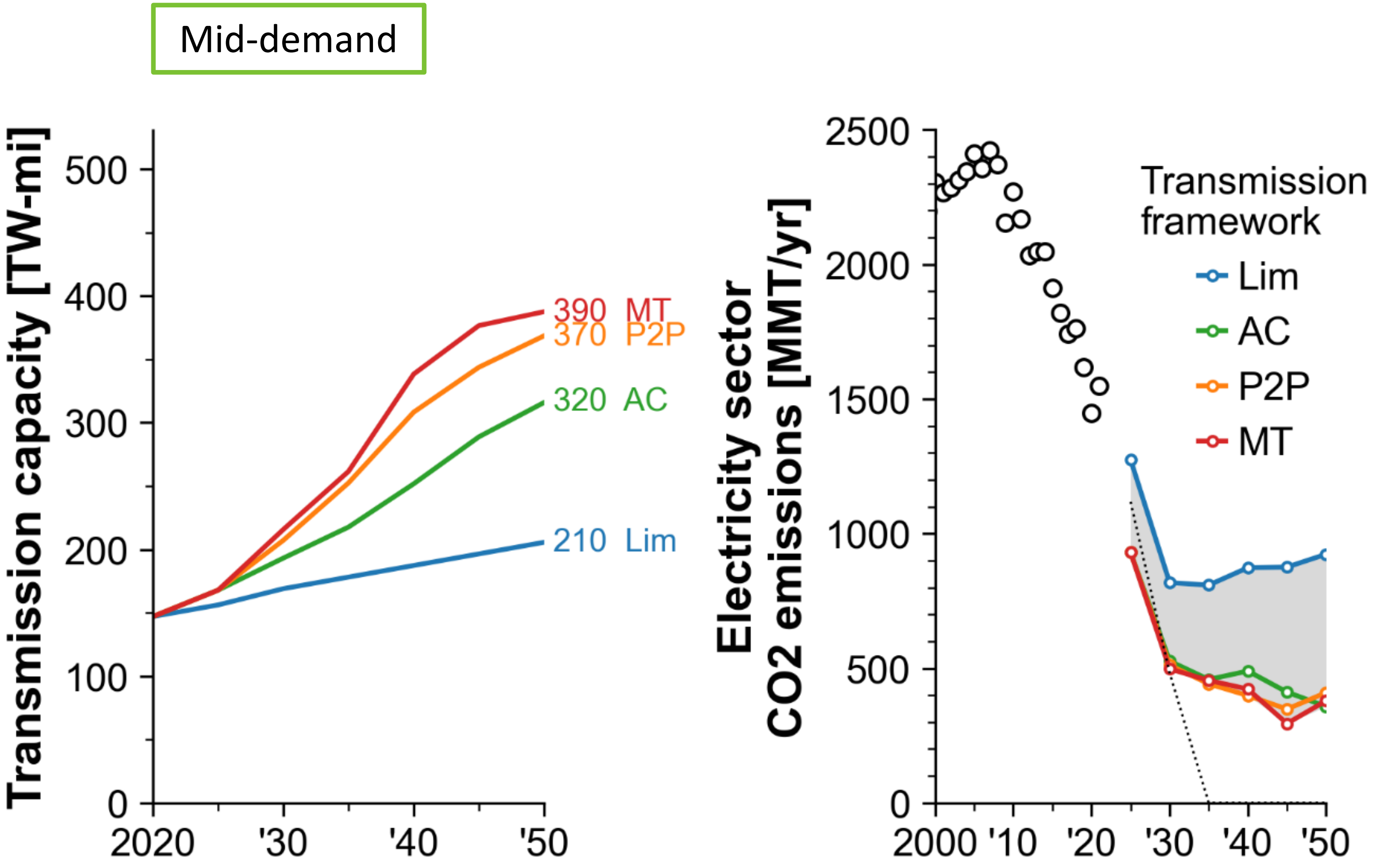
*Total transmission includes local (VRE interconnection), regional, and interregional transmission





Key Takeaway

Accelerating transmission deployment beyond historical rates reduces power system CO_2 emissions by **10** to **11 billion metric tons** (43% to 48%) through 2050.



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Principal Findings Under Central Decarbonization Scenario

Central Decarbonization Scenario

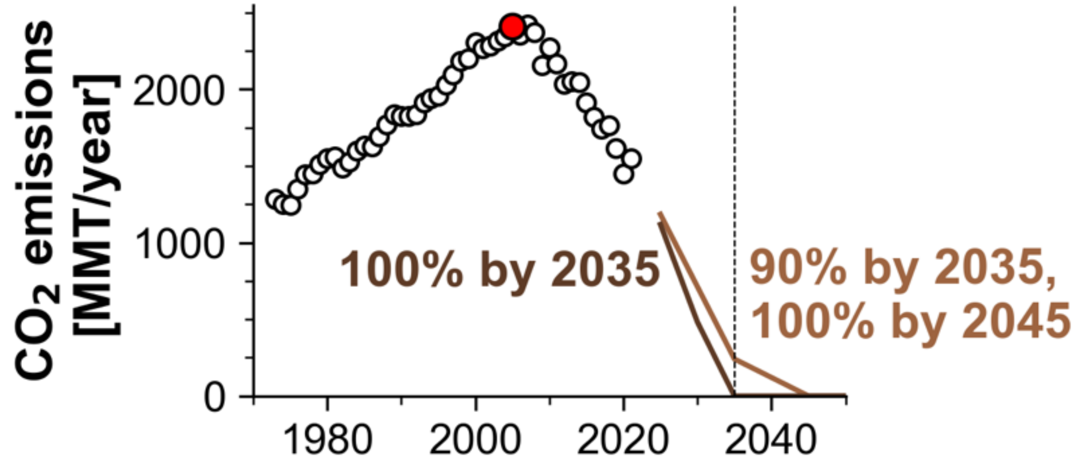
90% emissions reductions (from 2005 levels) by 2035; 100% by 2045

- Implemented as a national annual limit on power sector CO_2(e)
- Emissions can be offset by negative emissions technologies when allowed
- Limit applies to direct CO_2 and upstream methane emissions

← Demand growth →

Emissions constraint (↑ ↓)

Low demand Current policies	Mid demand Current policies	High demand Current policies
Low demand 90 by 2035, 100 by 2045	Mid demand 90 by 2035, 100 by 2045	High demand 90 by 2035, 100 by 2045
Low demand 100 by 2035	Mid demand 100 by 2035	High demand 100 by 2035



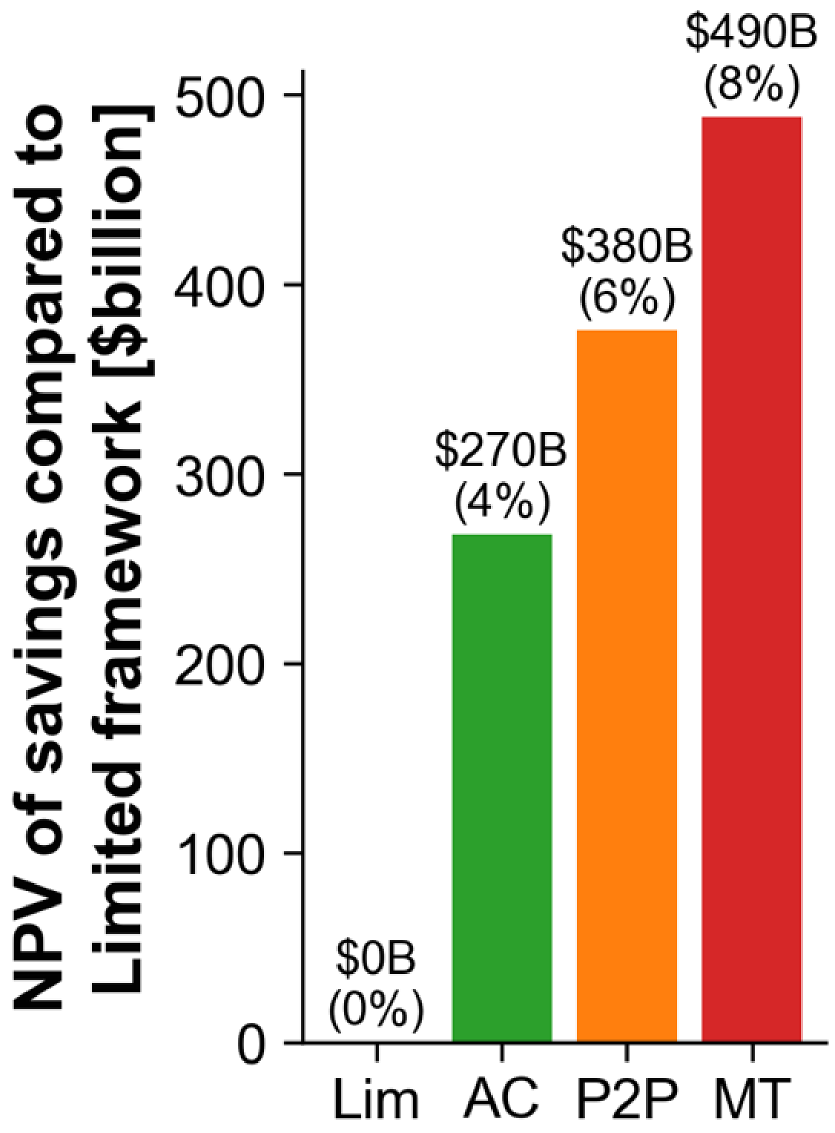
- Includes existing state and federal policies
- Nodal analyses focus on 2035 portfolios

Principal Finding

The study finds hundreds of billions of dollars of net benefits from large-scale transmission expansion compared to historic rates of transmission deployment.

Key Takeaway

Accelerated transmission expansion leads to national electric system cost savings of **$270 to $490 billion** through 2050.



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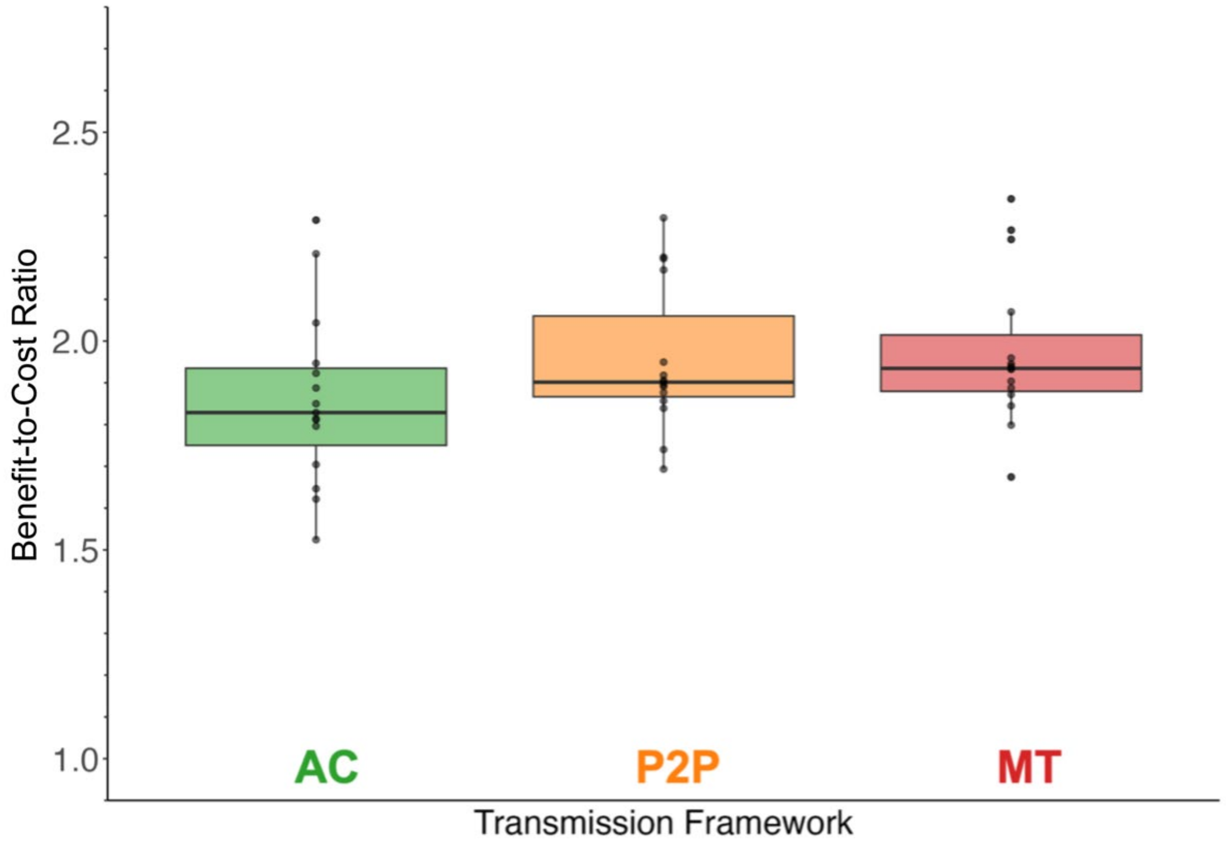
Key Takeaway

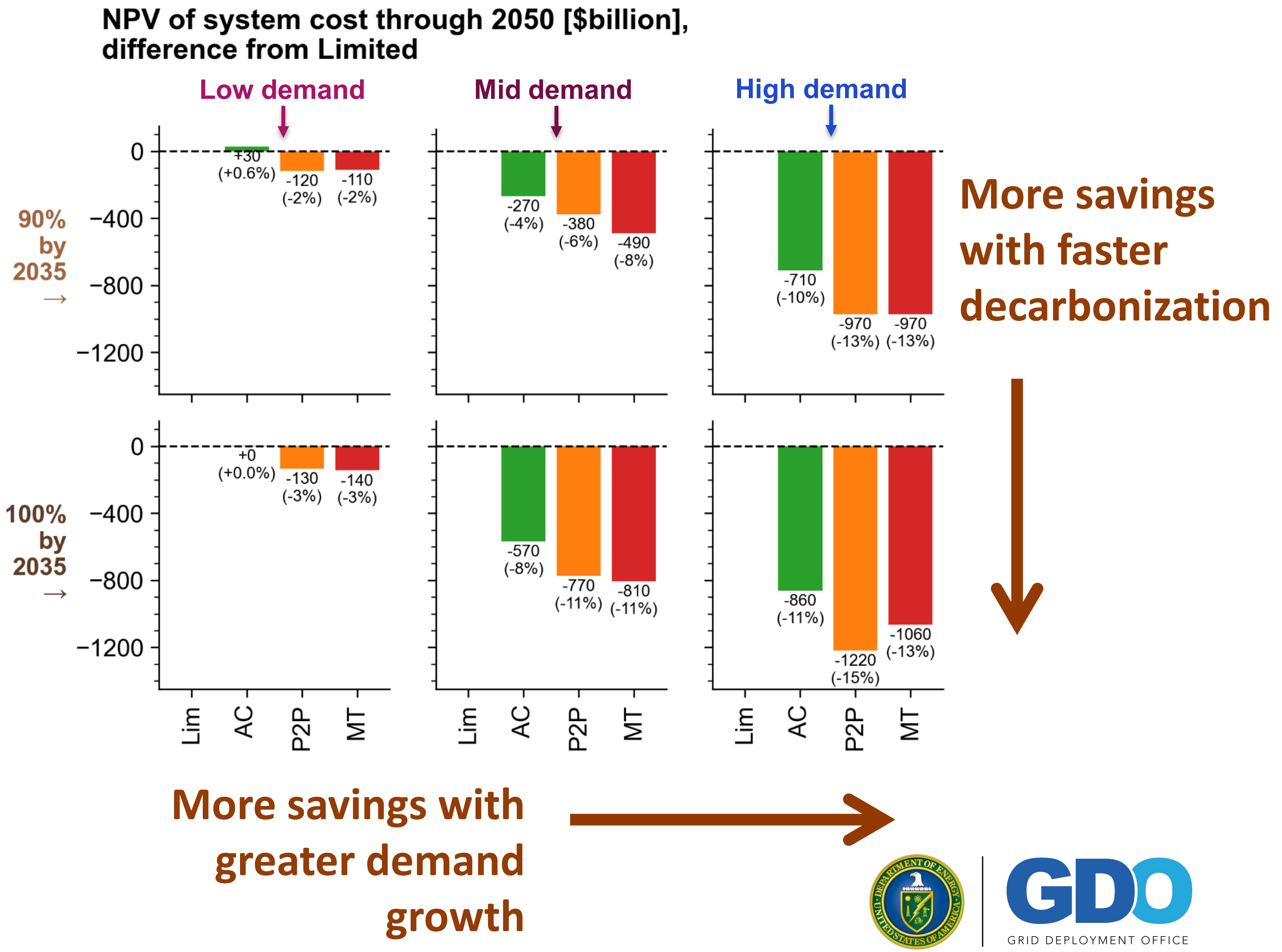
Incremental investments in transmission are more than compensated by reduced electric system costs for fuel, generation and storage capacity, and other costs.

Approximately **$1.60 to $1.80 is saved for every dollar spent** on transmission.



Key Takeaway

The benefits of transmission expansion to system costs scale with the level of electricity demand and rate of decarbonization.

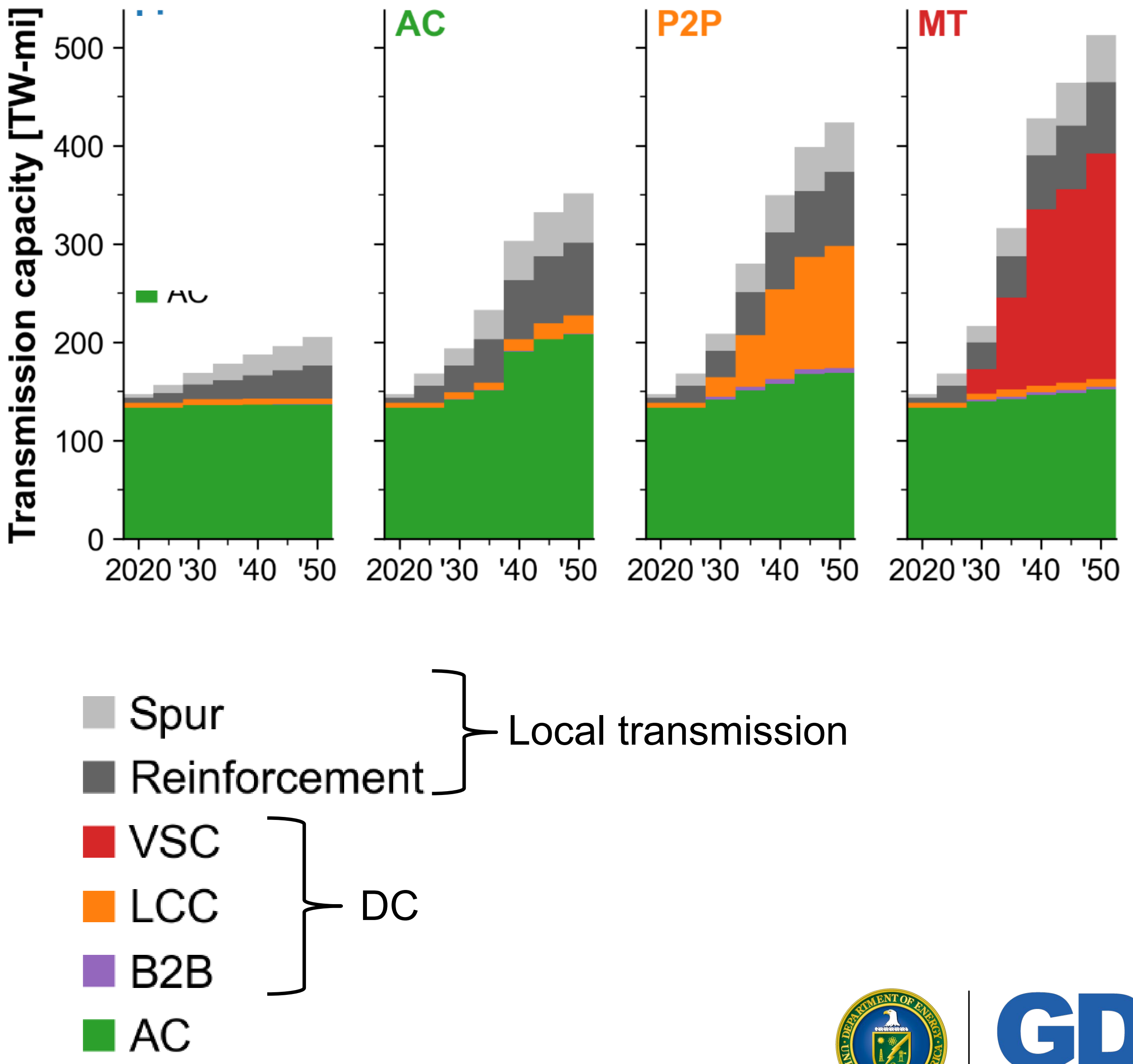


Principal Finding

A substantial expansion of the transmission system throughout the entire contiguous United States delivers the largest benefits across a wide variety of scenarios.

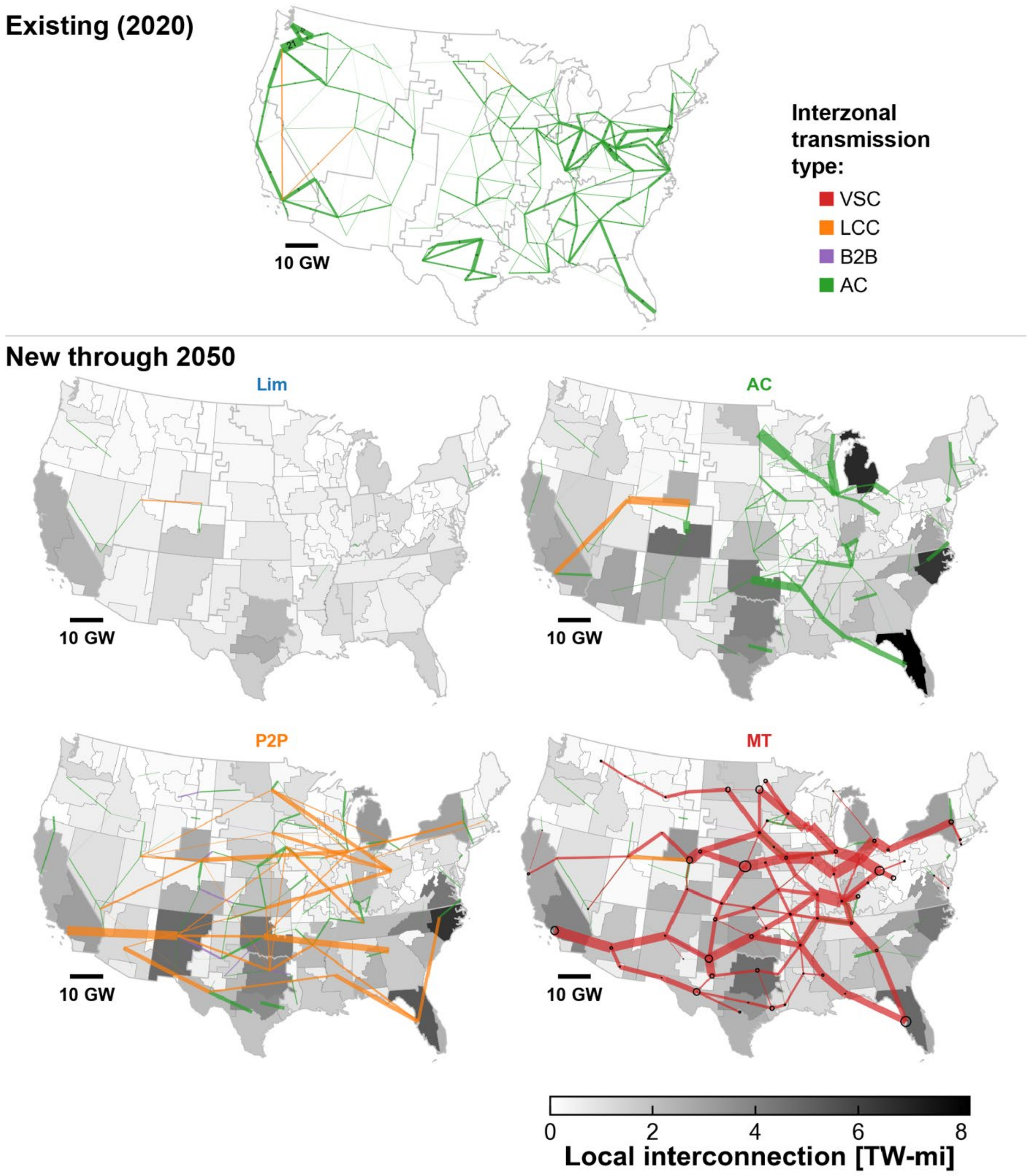
Key Takeaway

The U.S. transmission system expands **2.4 to 3.5 times** the size of the 2020 system by 2050 in scenarios that achieve 90% emissions reductions by 2035 with lowest total power sector costs.



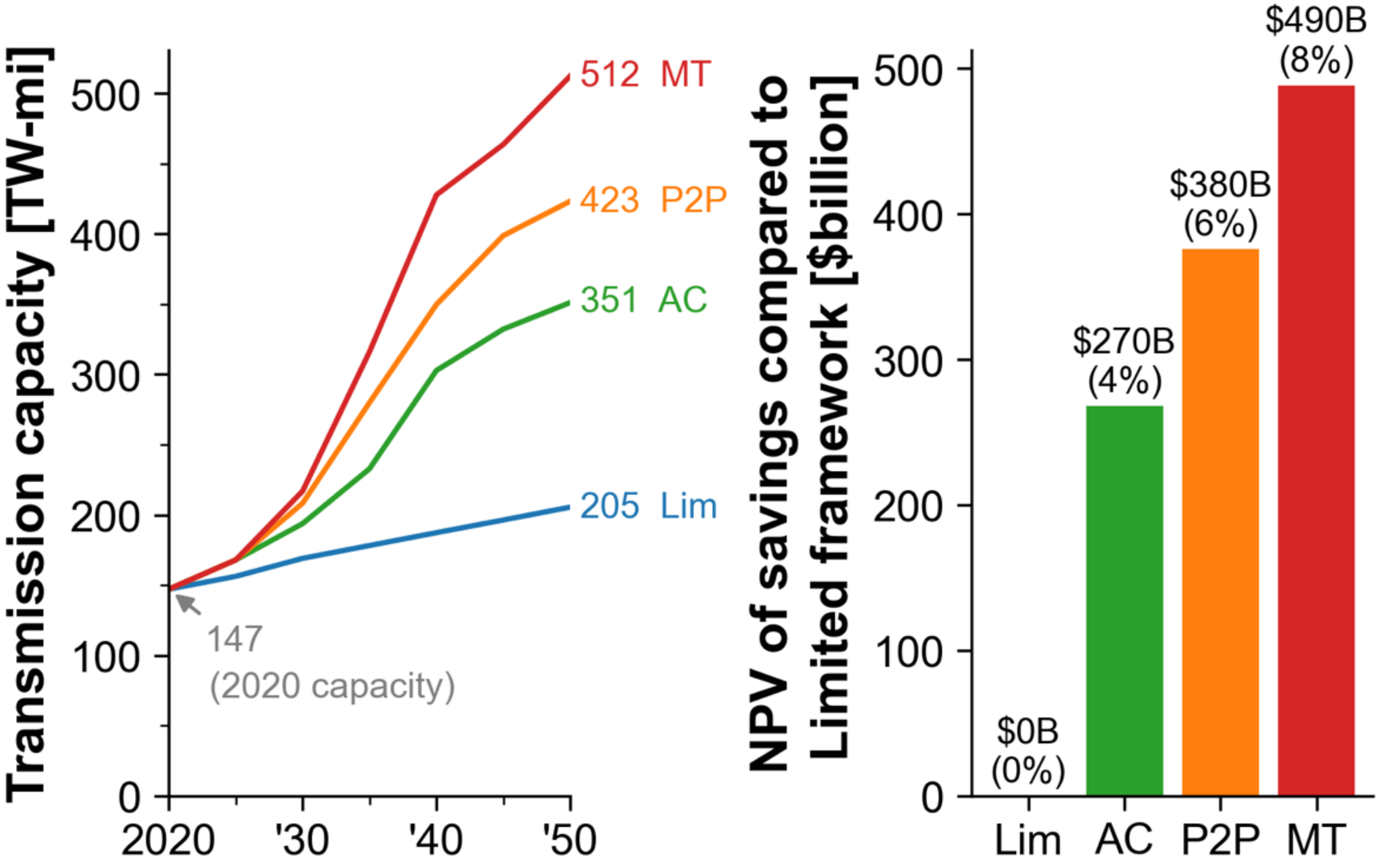
Key Takeaway

Transmission expansion occurs at all scales—including local, regional, and interregional—and for all regions of the country. Expansion of new long-distance transmission is concentrated in the central part of the country.



Key Takeaway

The use of high-voltage direct current (HVDC) transmission technologies, including advanced MT converters, results in the greatest benefits to consumers across the transmission options studied.



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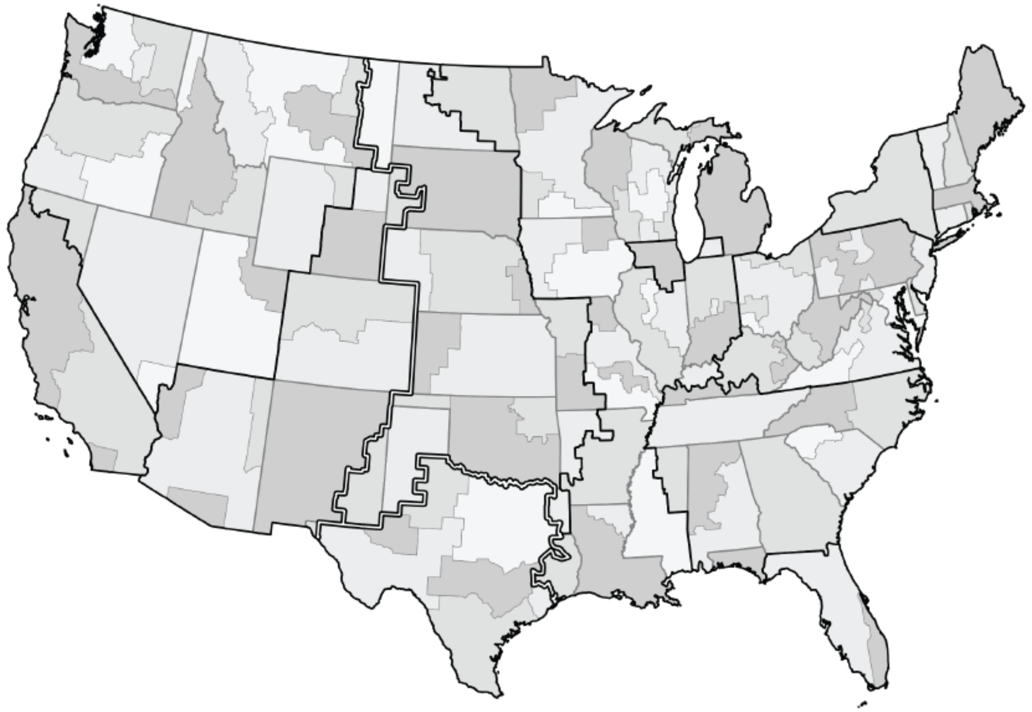
Principal Finding

Grid reliability can be maintained in future low-carbon grid scenarios with the lowest-cost solutions relying on coordinated transmission utilization between regions during periods of greatest stress.

Multimodel analysis for a low-cost, reliable transmission system of the future



Zonal Resolution
Long-Term Scenarios through 2050

- Capacity Expansion
- Economic Analysis
- Resource Adequacy

Nodal Resolution
2035 Transmission Portfolios

- Production Cost
- Power Flow
- Stress Analysis

Key Takeaway

All 96 modeled future grids in the study—including those with about 90% of annual generation from variable resources—**meet or exceed resource adequacy standards**.

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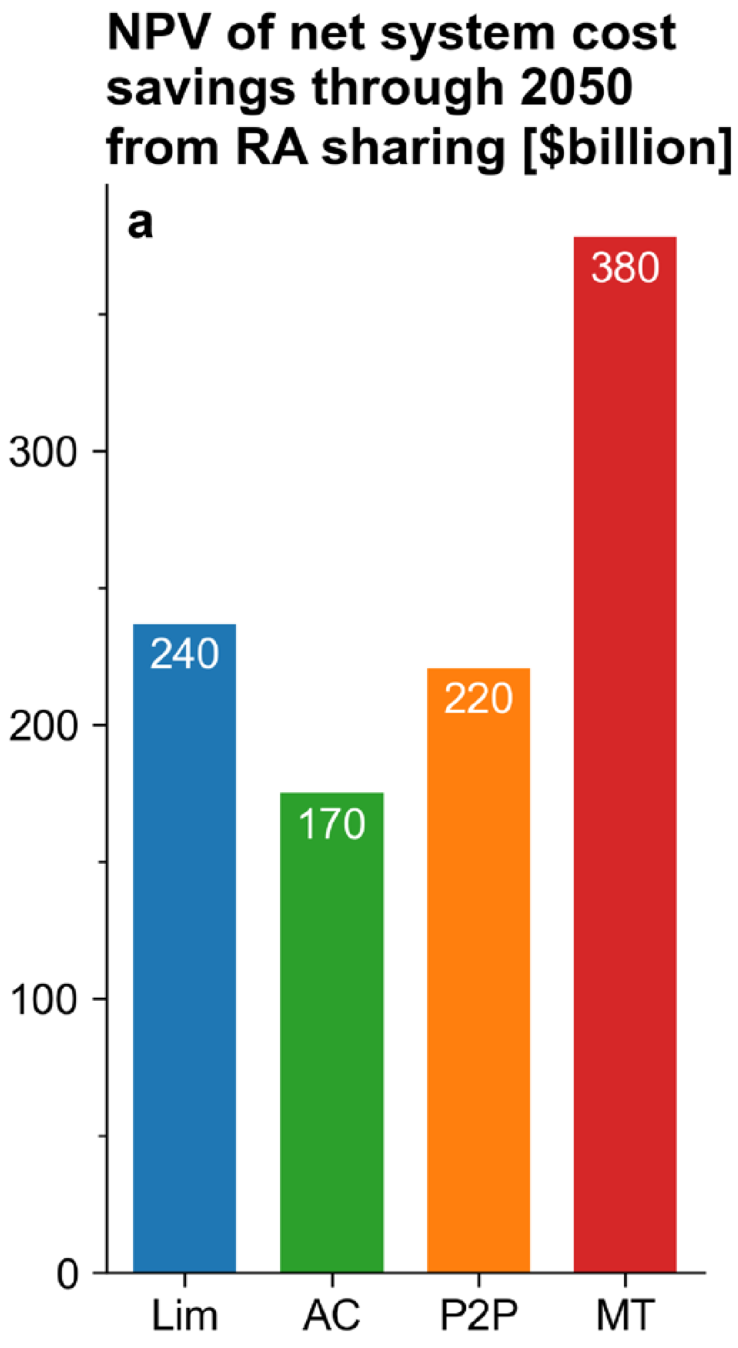
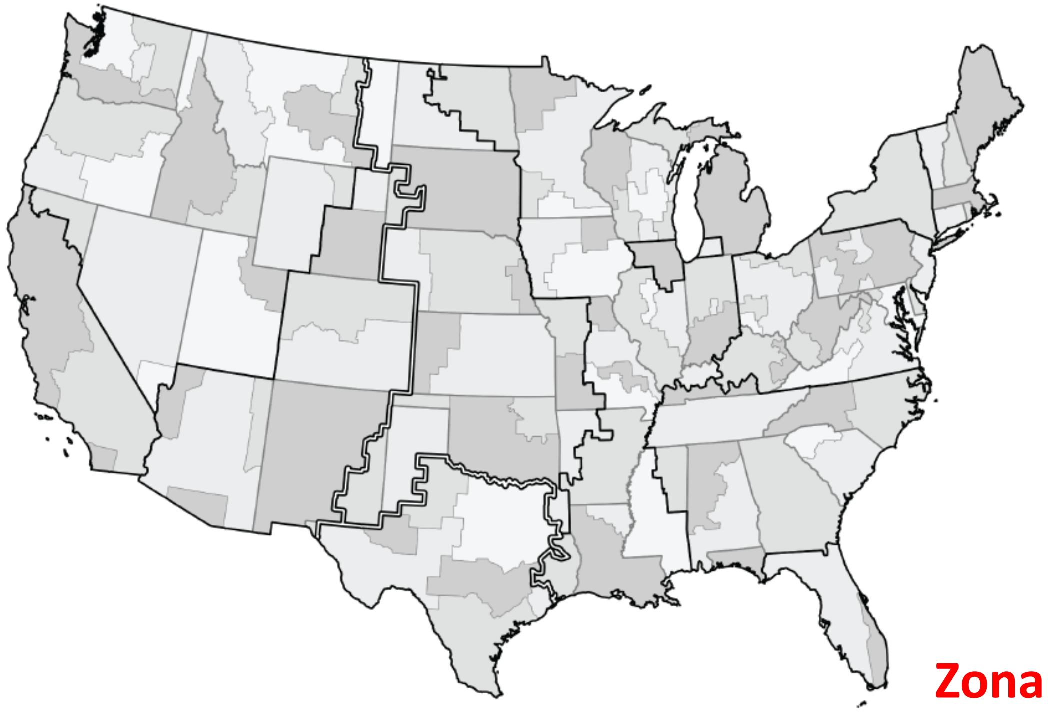
Key Takeaway

When transmission regions coordinate to achieve resource adequacy, system costs through 2050 are lowered by **$170 to $380 billion**.



When the **benefit of resource adequacy** is not considered, substantially less transmission is built.

Multimodel analysis for a low-cost, reliable transmission system of the future



Zonal-to-Nodal translation

Zonal Resolution
Long-Term Scenarios through 2050

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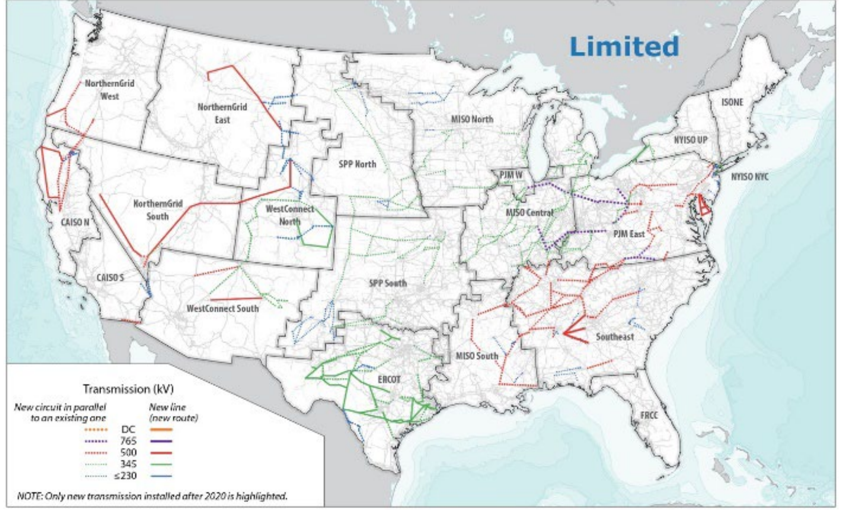
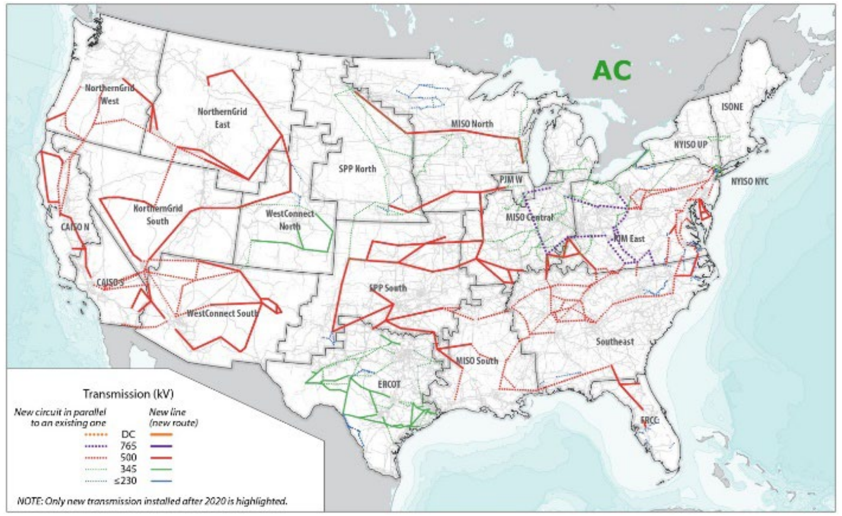
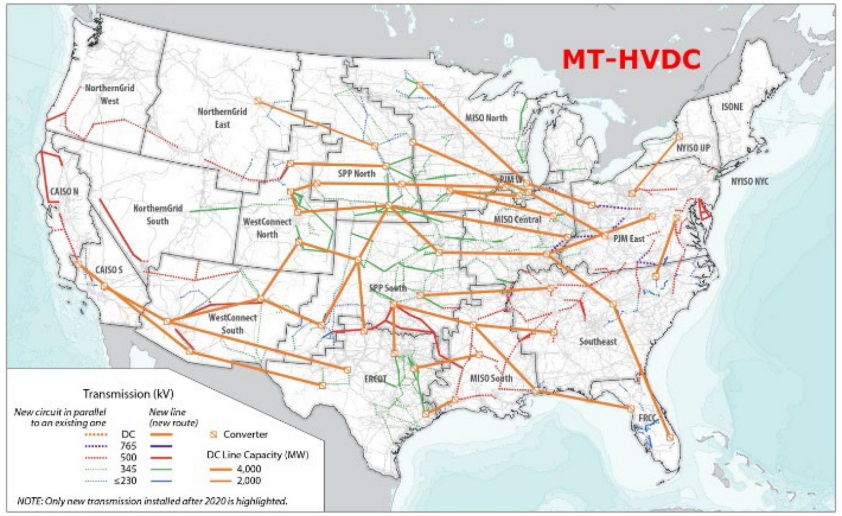
Common Themes in Nodal Network Models

1. **Reinforcement** (or equivalent reconductoring) of existing transmission lines occurs **in most regions**
2. **Increased meshing** improves contingency performance and collects large amounts of remote RE
3. **Intraregional transmission uses existing voltage levels** (with high-capacity configurations)
4. New wind, solar, and storage integrated with weaker HV/EHV transmission network infrastructure requires **specific network topologies to collect resources**
5. With HVDC at scale, **AC and HVDC networks will need to coexist**

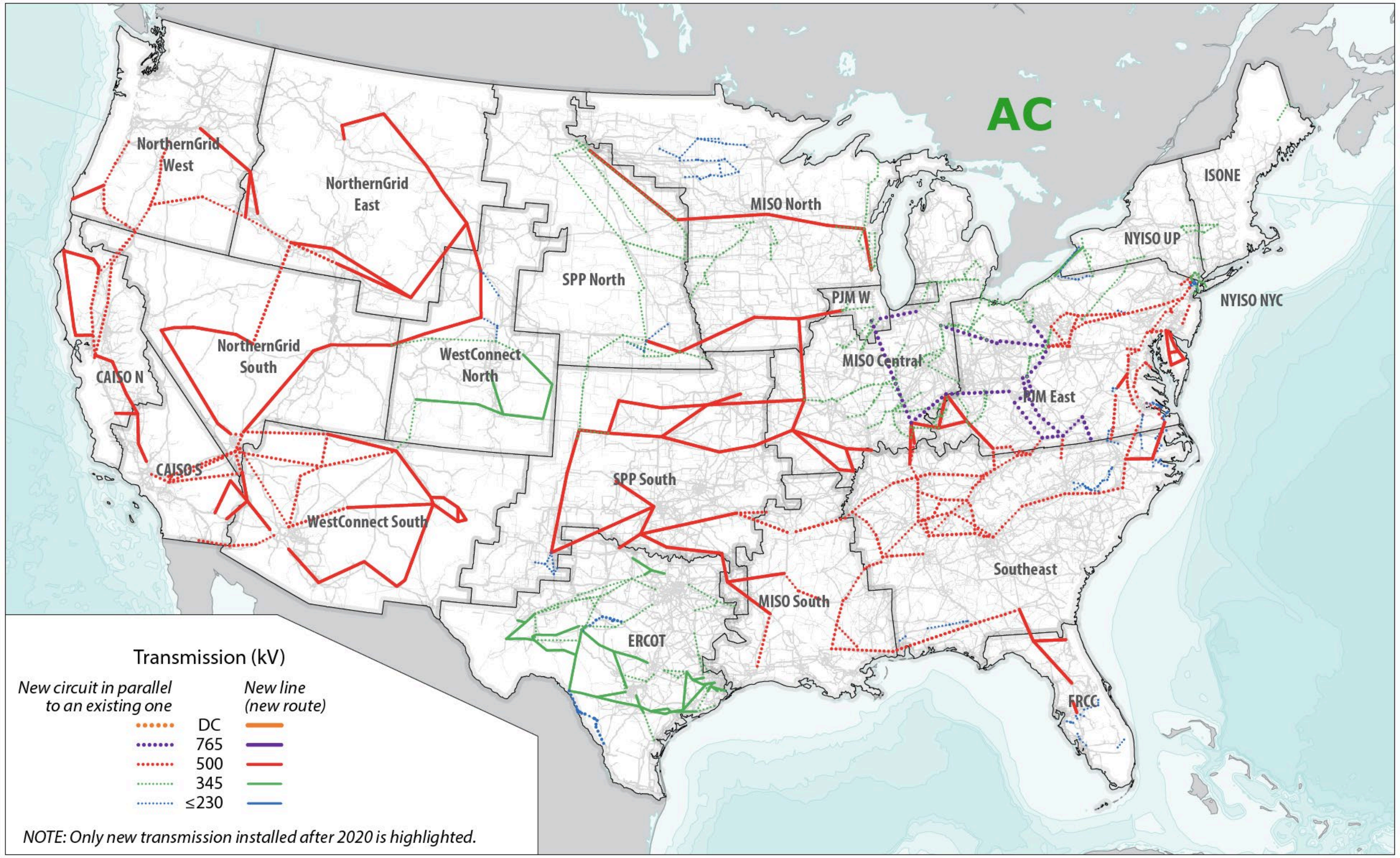




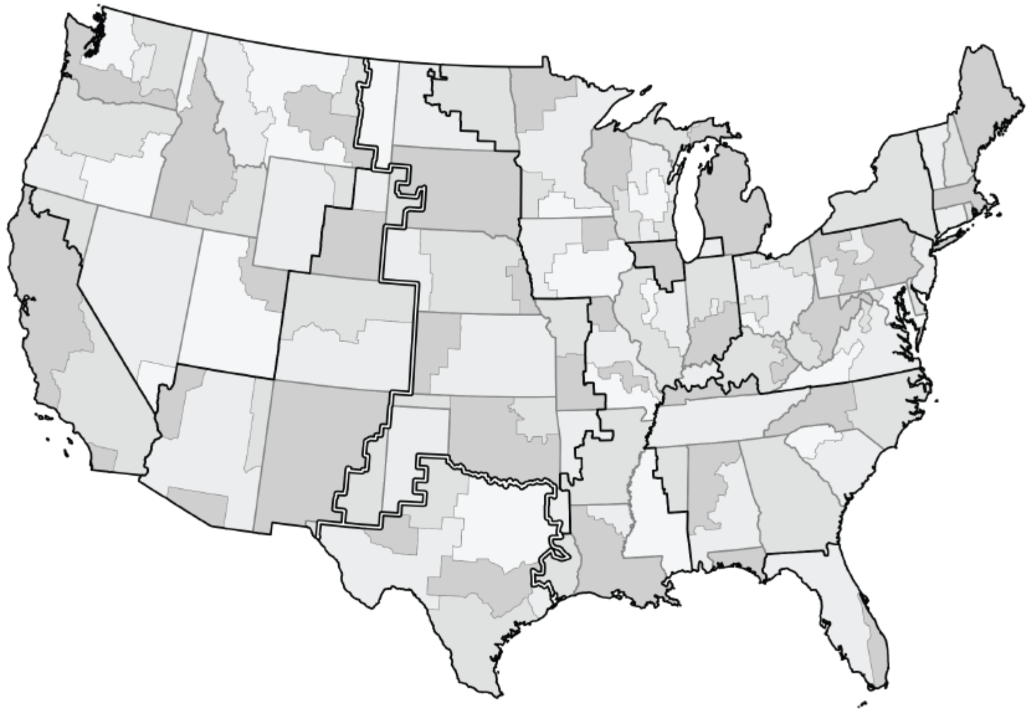


Key Takeaway

High-resolution grid simulations demonstrate hourly demand and supply can be balanced in power systems with very high shares of renewable energy. In scenarios with larger transmission expansion, imports and exports between regions play a substantial role in helping grid operators balance supply and demand in all hours.



Multimodel analysis for a low-cost, reliable transmission system of the future



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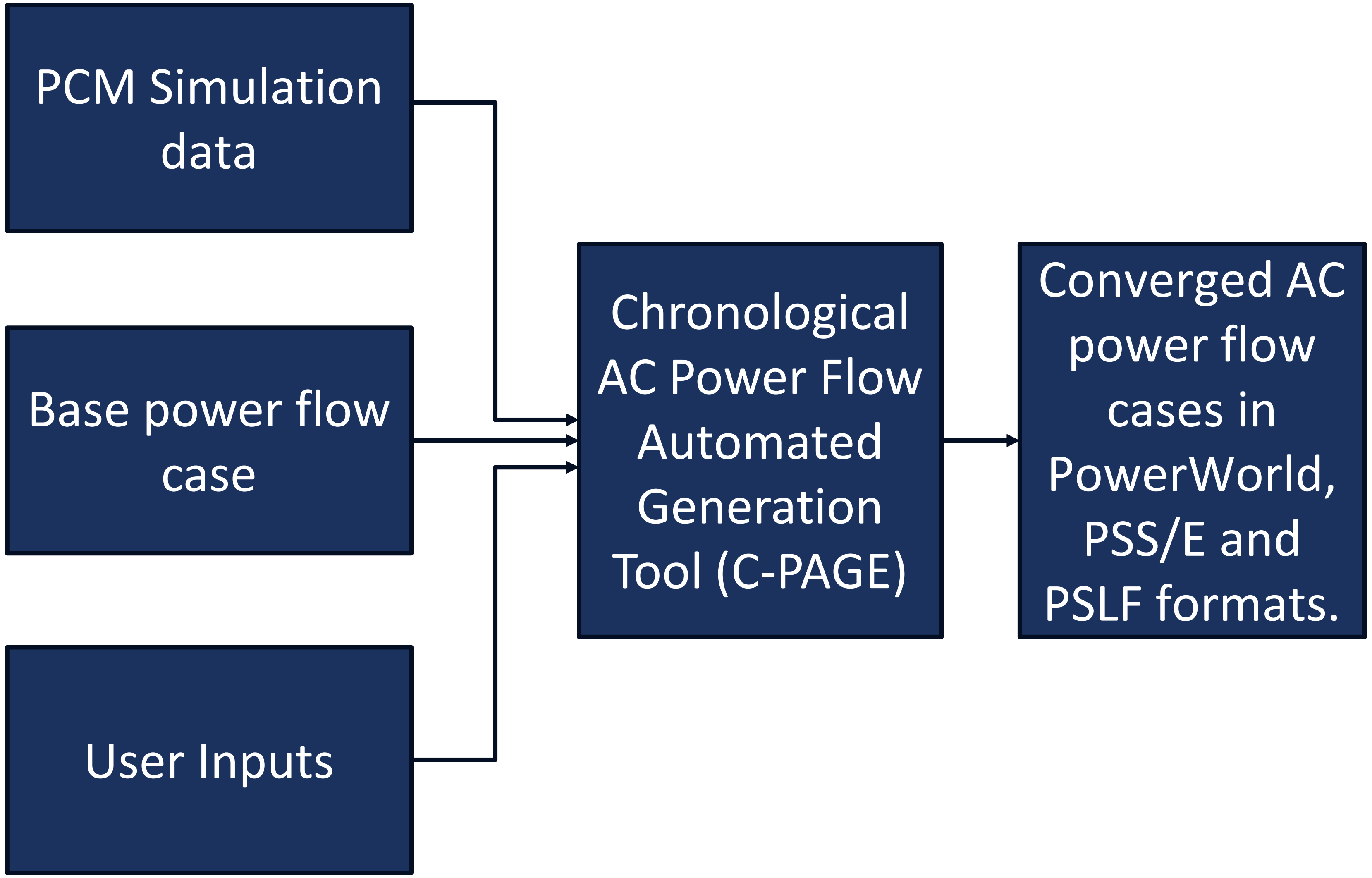
Chronological AC Power Flow Automated Generation Tool



Open-source IEEE Paper:
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9416491

Key Takeaway

Power Flow Analyses for the Western Interconnection demonstrate:

- Highly decarbonized systems can **withstand selected typical contingencies** on new-build transmission lines—even when lines are highly loaded.
  - Outage of two parallel new 500 kV lines that deliver 3,300 MW of power from a wind farm to load centers
  - Outage of two of three new parallel lines that connect 2,500 MW of energy storage to the grid
- Energy storage provides most of the primary frequency response for the modeled large power plant contingencies.
  - Loss of 2600 MW of generation at a power plant

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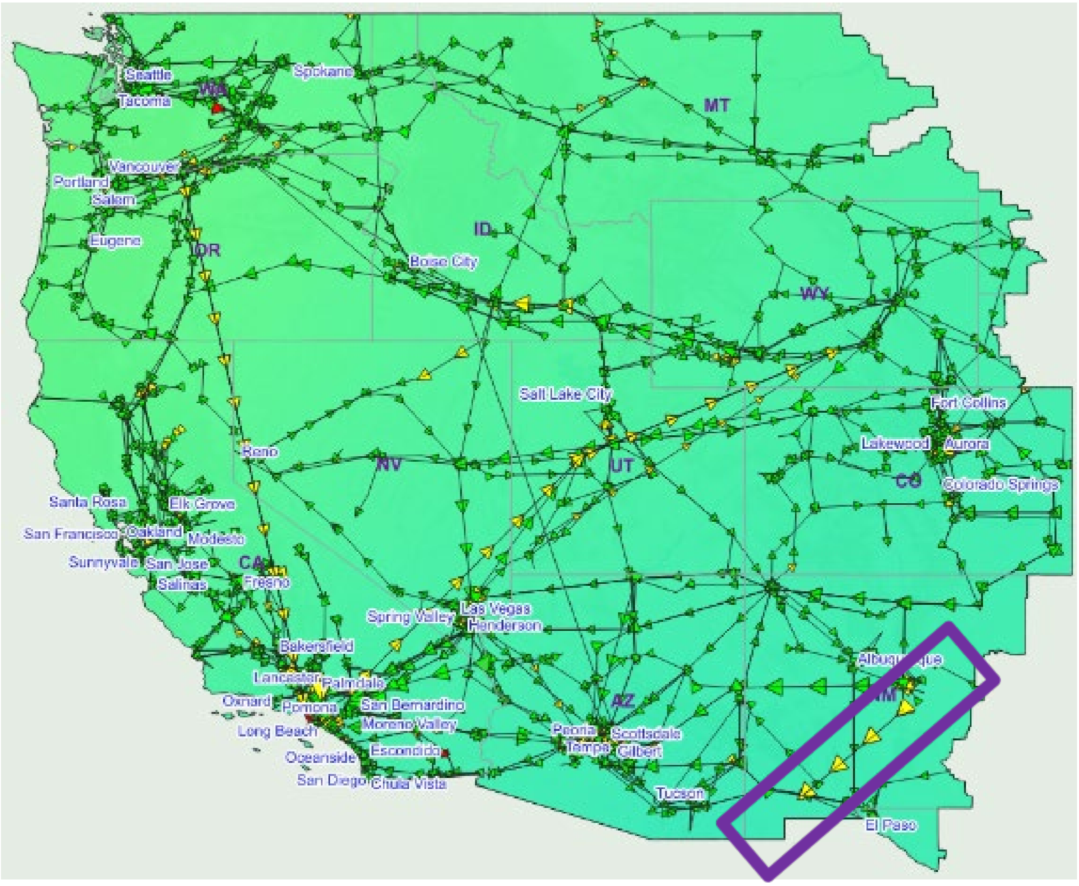
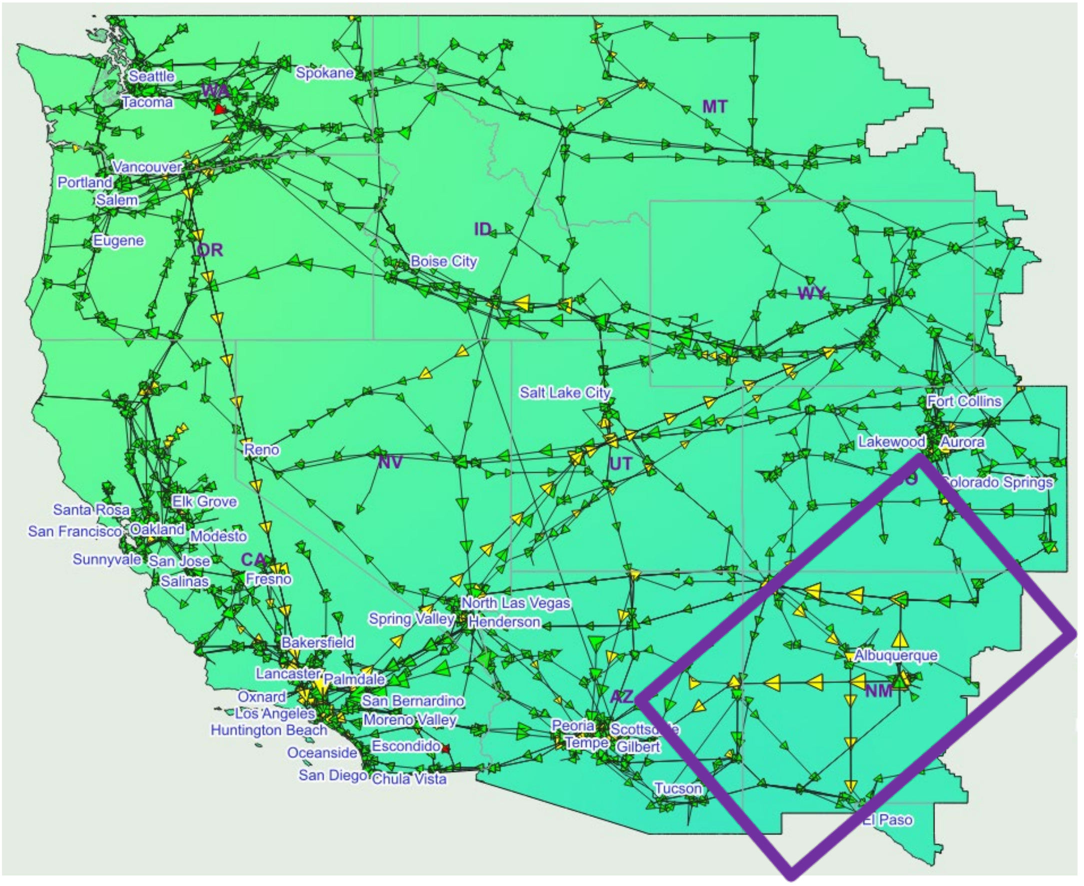
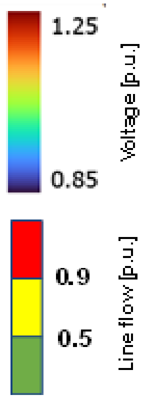
Voltage Profiles and Real Power Flows

Pre-Contingency: Inter-regional AC



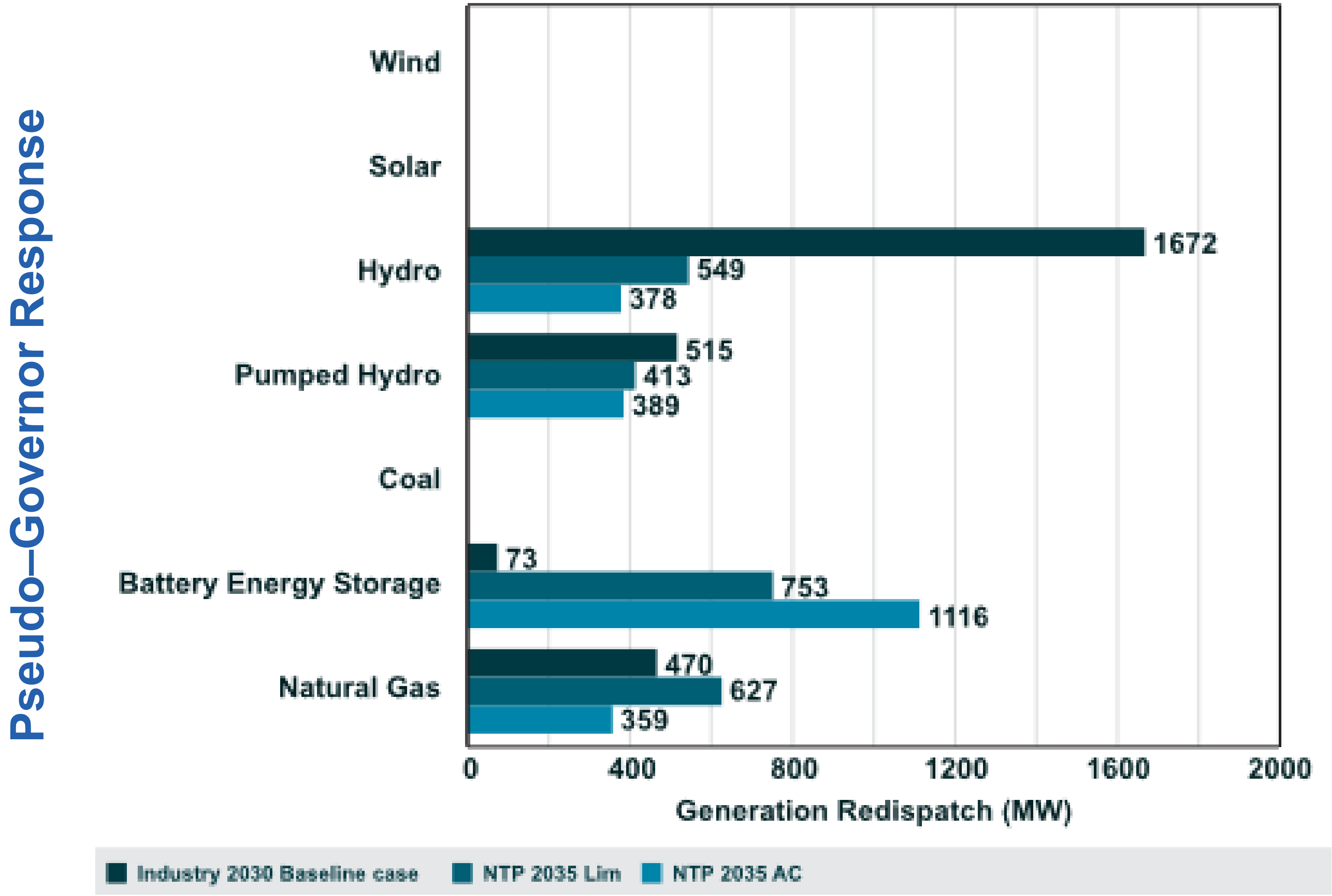
Post –Contingency: Inter-regional AC





- Good voltage profiles across WECC are obtained for different imported hours from PCM.
- Overall, no additional voltage violation in post contingency cases beyond what is observed in the pre-contingency cases.

Generation Redistribution to Make Up for the Loss of 2,600 MW, Pseudo-Governor Response



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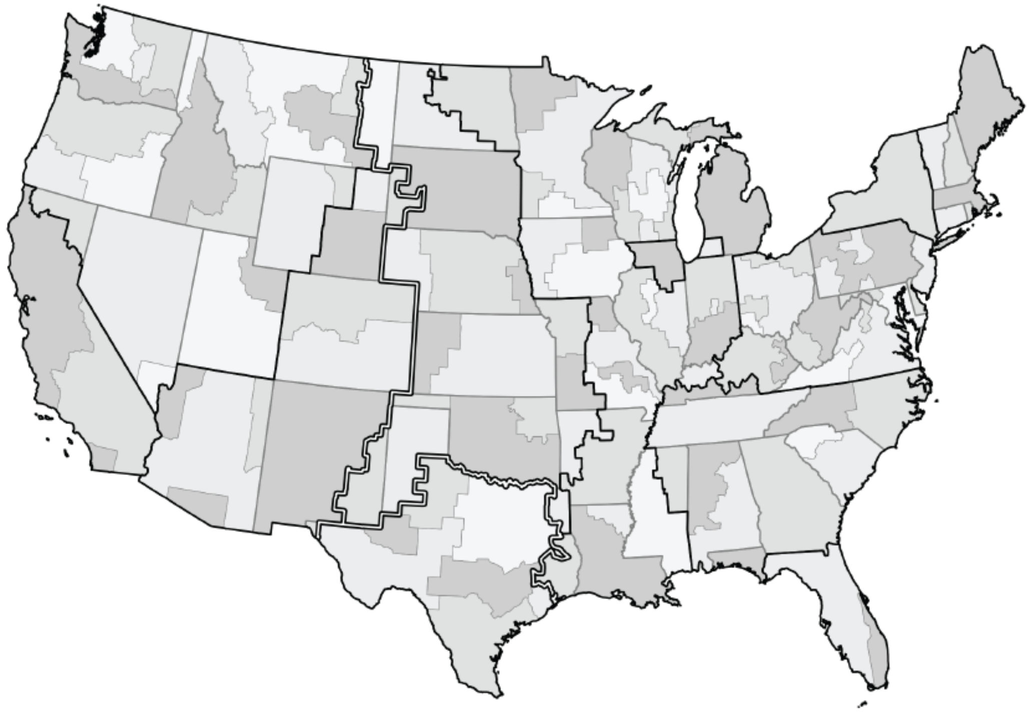
Multimodel analysis for a low-cost, reliable transmission system of the future



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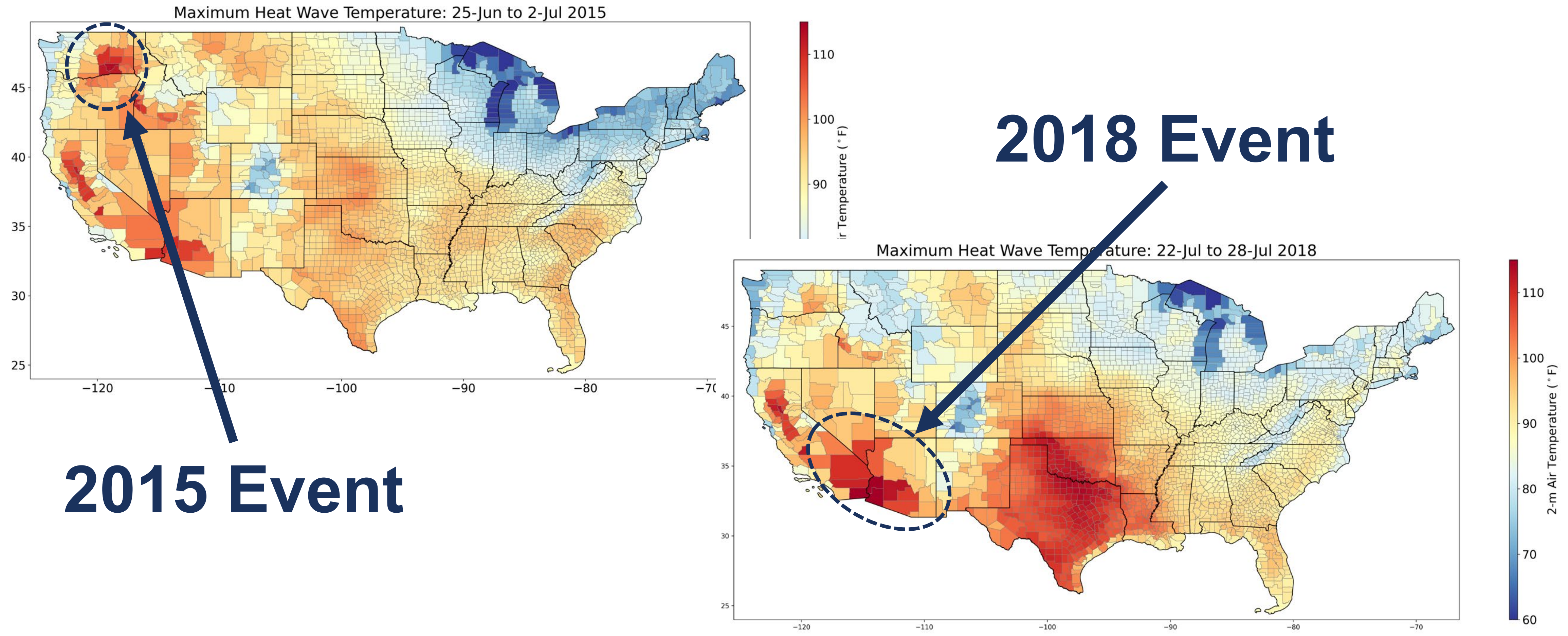
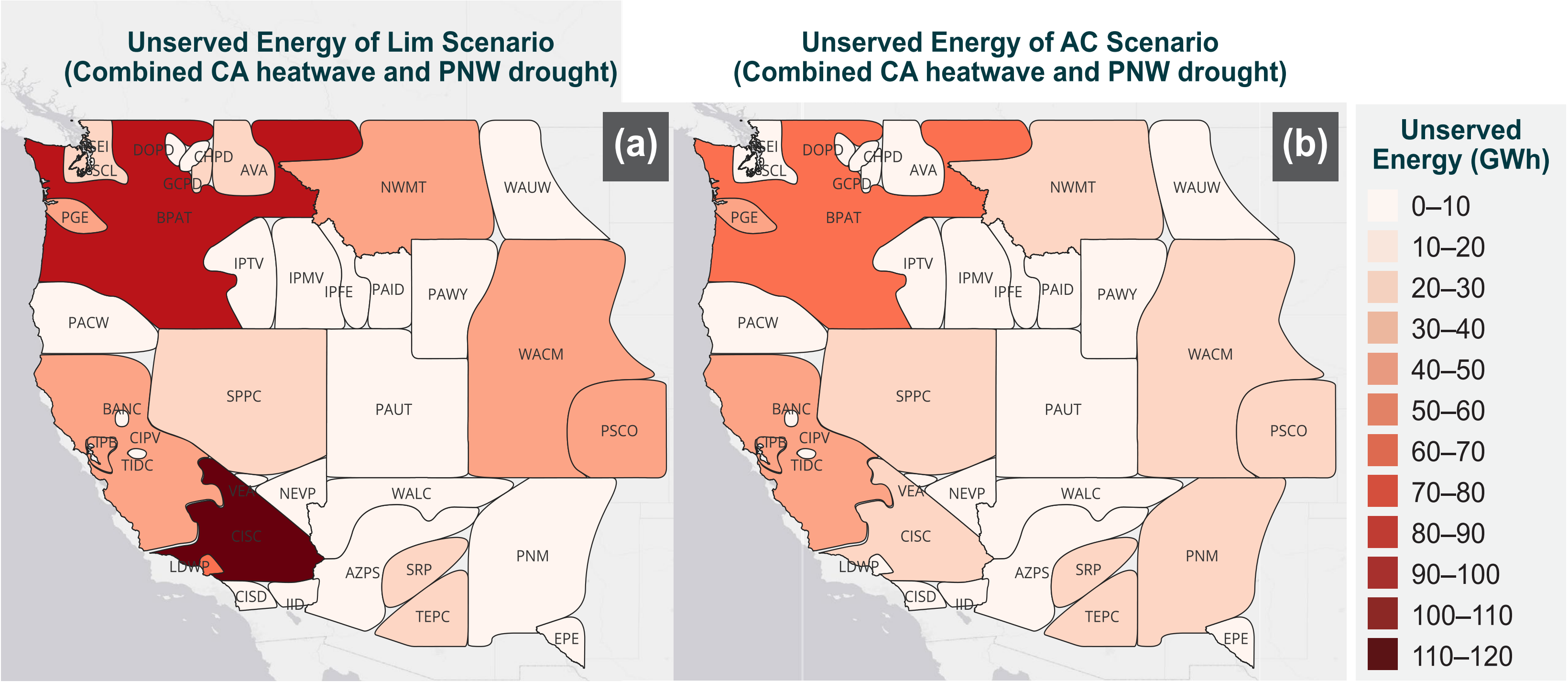
Selecting Heatwave Events to Study



Temperatures in Eastern Washington exceeded 112°F during the 2015 heat wave. Well above average temperatures extended across much of the west. The 2018 heat wave event was more localized to the central California valley and desert southwest where maximum temperatures exceeded 110°F.

Key Takeaway

- Interregional transmission can decrease the potential for and amounts of unserved energy during extreme weather events.
- Additional data (potential extreme events, technology advancements, and demand uncertainty) can support planning and enable broader participation/collaboration.



Unserved Energy during CA Heat Wave and PNW Drought

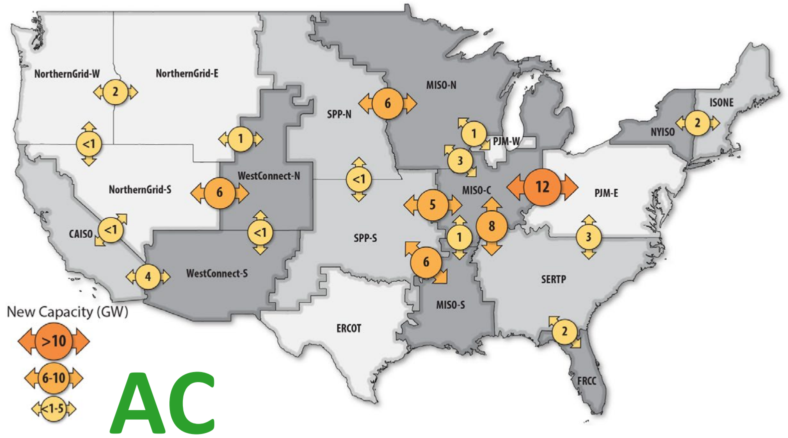
Principal Finding

The NTP Study identifies several examples of transmission that could be promising candidates for more in-depth consideration by planners and developers.

High Opportunity Transmission

HOT interfaces represent transmission capacity expansion [2020-2035] results between regions across many scenarios. Transmission projects that align with these HOT interfaces could be strong candidates for further study and serve as a starting point for accelerated transmission expansion.

What new transmission capacity is present in at least 75% of the 15 (+1) sensitivities?



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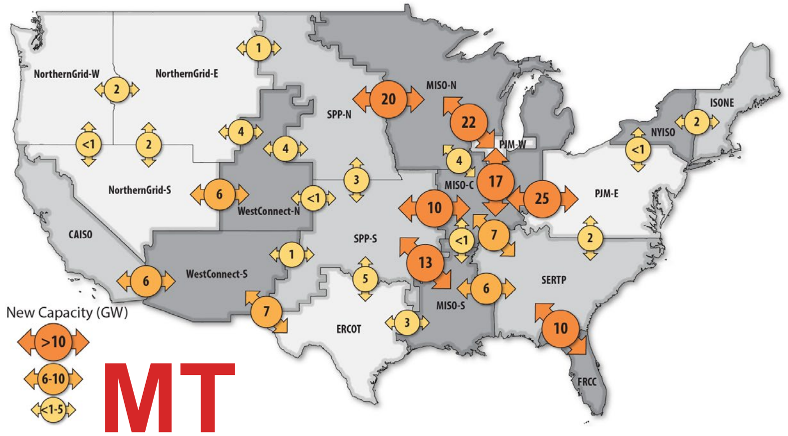

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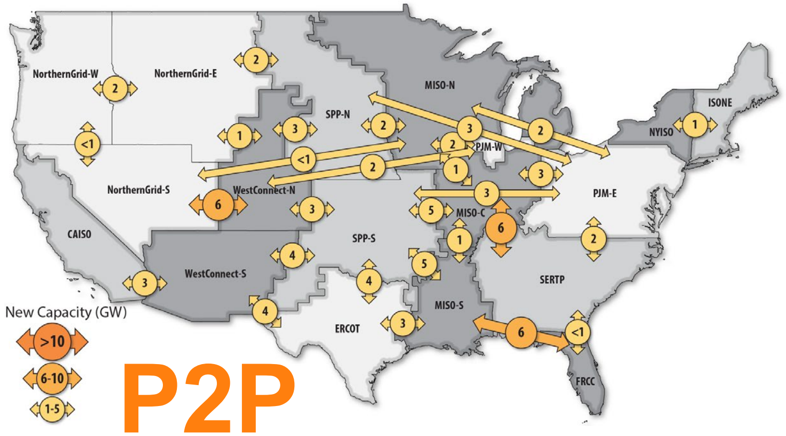

P2P

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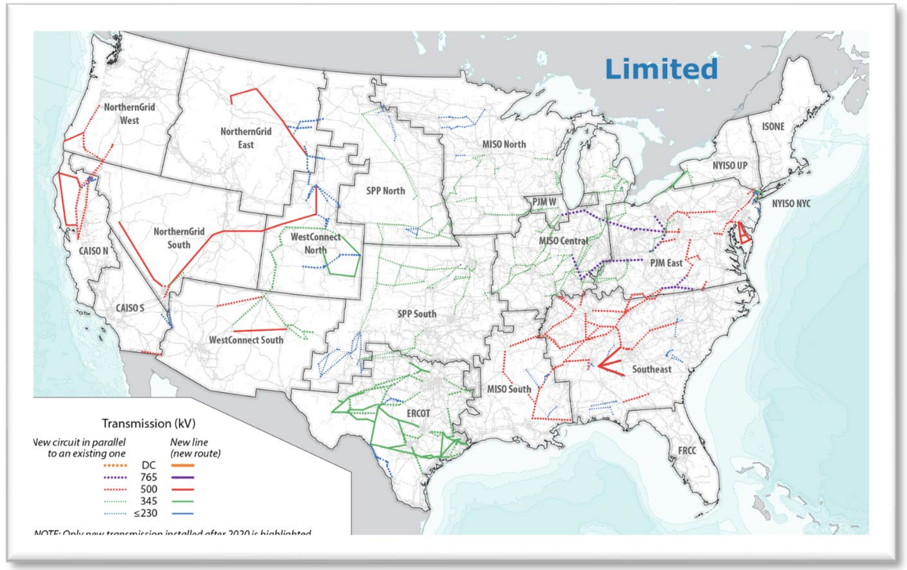
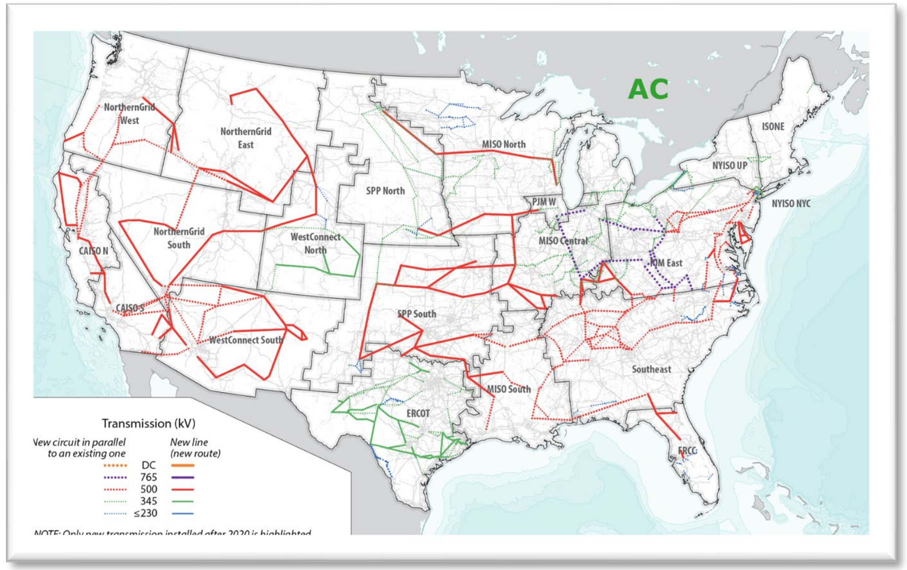
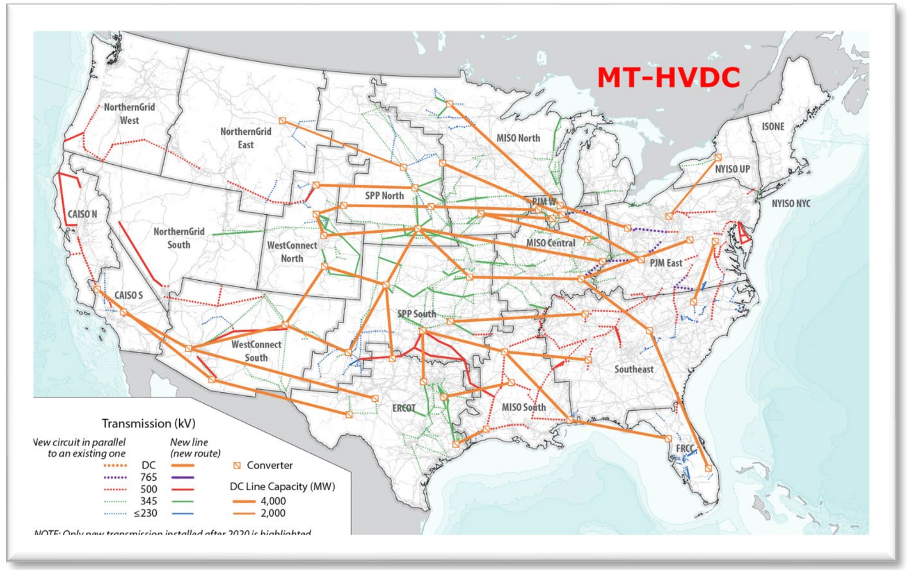
Transmission Portfolios

- Transmission portfolios that deliver broad-scale benefits to consumers were developed using laboratory and industry tools.
- The portfolios demonstrate new interregional transmission + intraregional transmission upgrades can help meet the flexibility requirements of high renewable energy power systems.







These do not represent proposed routes or detailed siting considerations.

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Principal Finding

Regardless of future policy, market, and technology conditions…

Grid planning at the national or multi-regional scale requires enhanced institutional coordination, accessible data, and new grid modeling approaches—all of which have been advanced through the NTP Study in partnership with technical and planning experts.

Jeff Dennis

Deputy Director for Transmission
Grid Deployment Office
U.S. Department of Energy

Next Steps – Turning the Findings into Action

Share the findings and analytical tools developed by the labs with transmission planning entities, RTOs/ISOs, utilities, and states to help **advance planning of interregional transmission**

Encourage examination by planners of **high opportunity transmission options** identified in the NTP Study

Inform DOE's use of financing and permitting tools:

- E.g., Transmission Facilitation Program, NIETC Designation, 2026 Needs Study, etc.
- NTP study results may help GDO shape programs and applicant submissions, but results do not affect selections processes.

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Available DOE Transmission Planning Assistance

Program	Lead DOE Office	Principal Researcher	Eligible Applicants	Assistance Mechanism
Grid Resilience Technical Assistance Consortium	GDO	Universities and others	SEOs, PUCs, and Utilities	Initial Partnership Intermediary Agreement – Not currently open
Tribal Nation Transmission Program	GDO	NREL	Tribal Nations	Direct Lab Funding – Ongoing
Wholesale Electricity Market Studies and Engagement Program	GDO	Applicant Selects	States, Tribes, and RTO/ISOs	Rolling Application Rounds – Not currently open
State Technical Assistance Program	EERE/OE	NREL, LBNL, PNNL	PUCs and SEOs	Direct Lab Funding – Ongoing, with future cohorts for deep dive efforts
Clean Energy to Communities Program	Various	NREL	Local governments, Tribes, electric utilities, and community-based organizations	Direct Lab Funding – Ongoing
Technical Support Service	Various	NREL	State, Local, and Tribal	Direct Lab Funding – Ongoing
DOE State Energy Program (SEP) Direct Technical Assistance	SCEP	National Labs	State Energy Offices	Direct Lab Funding - Ongoing and Quarterly Submission Rounds
Utility and Grid Operator TA	EERE	NREL, LBNL, PNNL	Utilities and Grid Operators	Direct Lab Funding - Ongoing and Periodic Submission Rounds

How can we help you realize the benefits in the NTP Study?

Thank you

www.energy.gov/gdo/national-transmission-planning-study