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Transmission Planning

Jarrad Wright

and many amazing researchers at NREL

National Renewable Energy Laboratory

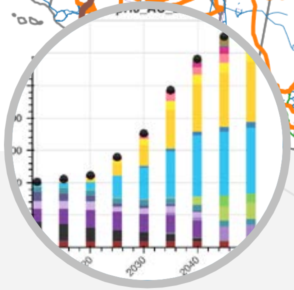
October 8, 2024

Agenda

1. Transmission as a priority
2. Transmission at the National Renewable Energy Laboratory (NREL)
3. Case studies
4. Tools
5. Future directions

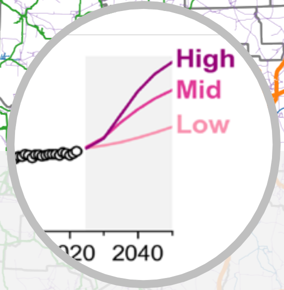
Agenda

Various factors drive the changing need for transmission

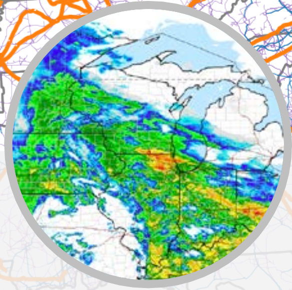


Resource mix

Aging infrastructure



Demand growth



Extreme events

Distributed resources

Images by NREL; Background based on Homeland Infrastructure Foundation-Level Data(HIFLD)

The two largest drivers for further transmission expansion:

Electricity demand

Changing resource mix

Annual U.S. electricity load growth (2021–2050)

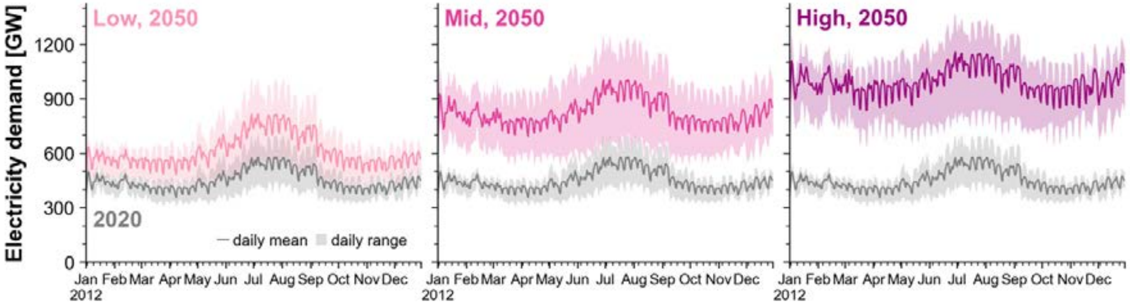
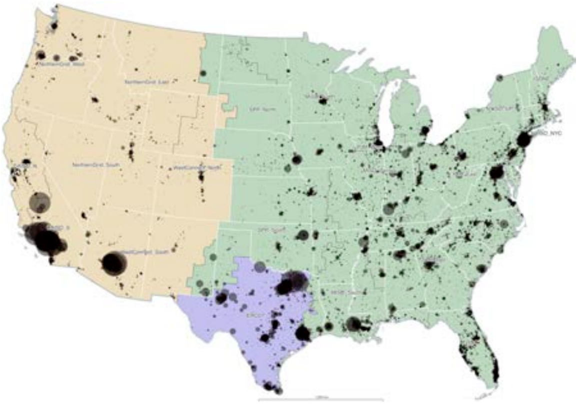


Image by NREL (NTP Study, 2024)



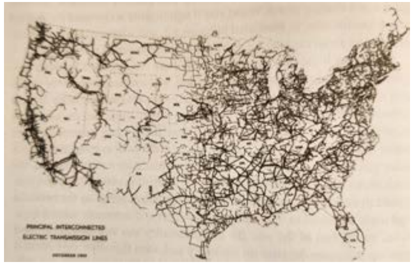
Spatial distribution of load (CONUS)

Image by NREL (NTP Study, 2024)

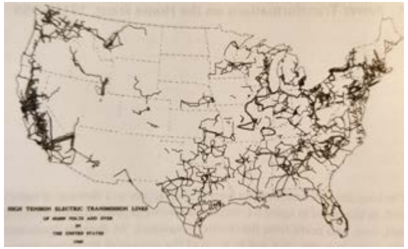
Spatial disaggregation of future generation/storage capacity (CONUS)

Image by NREL (NTP Study, 2024)

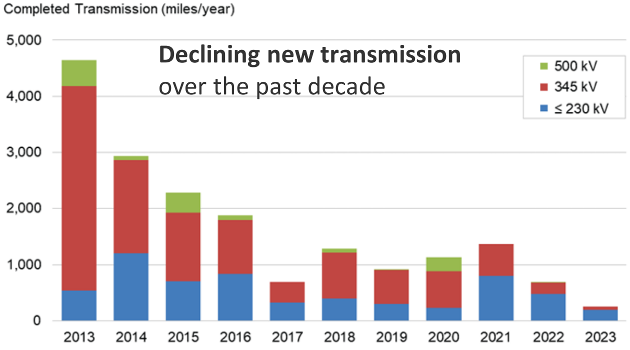
1946



1949



1960



2022

Bulk transmission infrastructure is aging

Images (1946, 1949, 1960) from J. Cohn ("The Grid"); NREL (2022) (map based on Homeland Infrastructure Foundation-Level Data (HIFLD) data);
Plot from Wiser et al. 2024. *Land-Based Wind Market Report: 2024 Edition*

Large transmission has occurred in stages … it's aging again.

- Quick deployment of large-scale interregional transmission is possible. (It has been done before.)

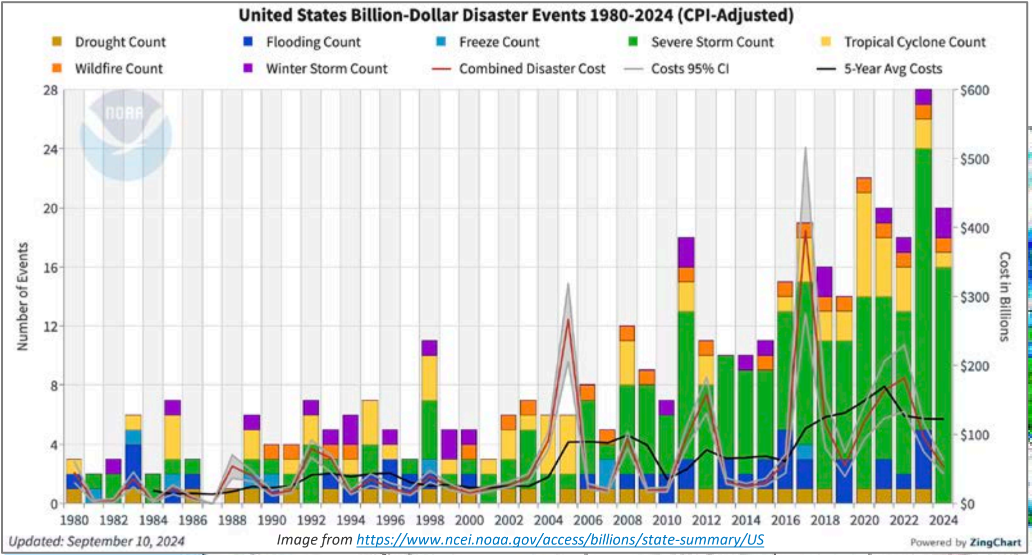


Image from https://www.ncei.noaa.gov/access/billions/state-summary/US

The impact of weather is greater than in previous decades.

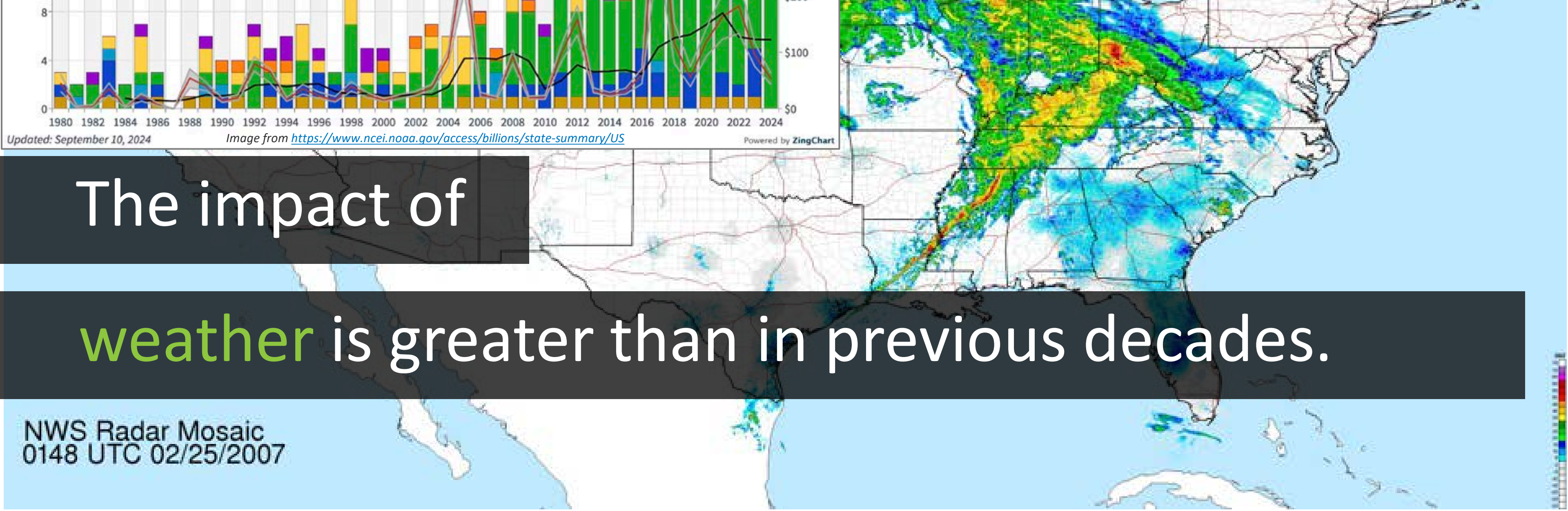
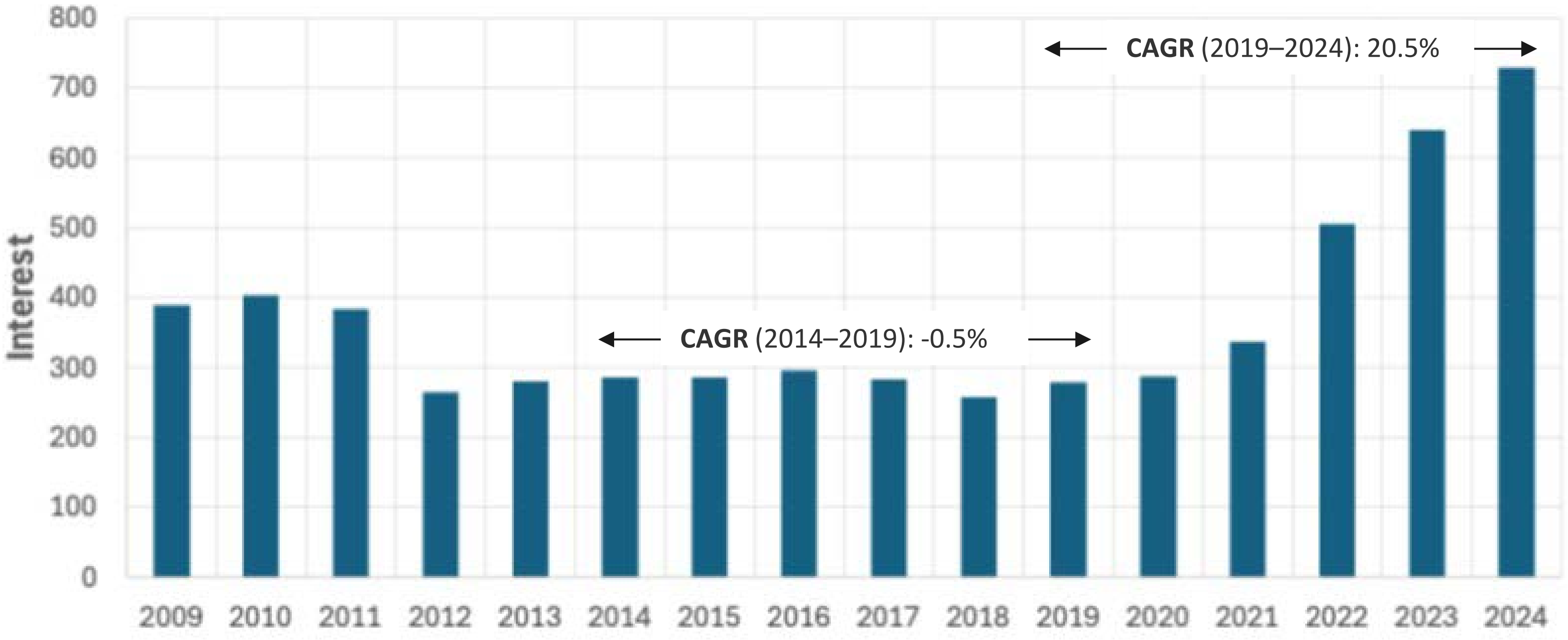


Image from the National Weather Service

25 February 2007 Winter Storm/Blizzard

General interest in "transmission planning"



NOTE: CAGR: Compound Annual Growth Rate; "Interest" is defined as search interest relative to the highest point for the given region and time. (The graphic presented is aggregated annual relative interest, that is, peak monthly popularity = 100).

Source: Based on Google Trends data (https://trends.google.com/, prompt: *"transmission planning",* context: *U.S. only*)

Increased focus on transmission policy in recent years

Financing

- **Billions of dollars of public and private sector funds invested up to 2024**
- **Why?**
  - Kick-starting investments (overcoming hurdles)
  - Enhancing grid flexibility
  - Improving resiliency
  - Improve access
  - Strengthening and modernizing grids.
- **Through IIJA/BIL/IRA and related programs:**
  - GRIP
  - TFP
  - DOE Energy Infrastructure Reinvestment Program
  - USDA Empowering Rural America Program.

Supply Chain

- **More than $4 billion in tax credits across >100 projects in 35 states**
- **Why?**
  - Accelerating domestic clean energy manufacturing and reducing GHG emissions from industrial facilities.
- **Through Qualifying Advanced Energy Project Credit (48C) Round 1.**

Permitting

- **Coordinating federal agencies to reduce permitting times, highlight strategic corridors, simplify environmental reviews for Tx lines, and provide grants to address state/local siting/permitting challenges**
- **Implemented through programs:**
  - CITAP
  - NIETCs
  - Categorical exclusions for Tx line upgrades
  - TSED grants.

IIJA – Infrastructure Investment and Jobs Act; BIL – Bipartisan Infrastructure Law; IRA = Inflation Reduction Act;

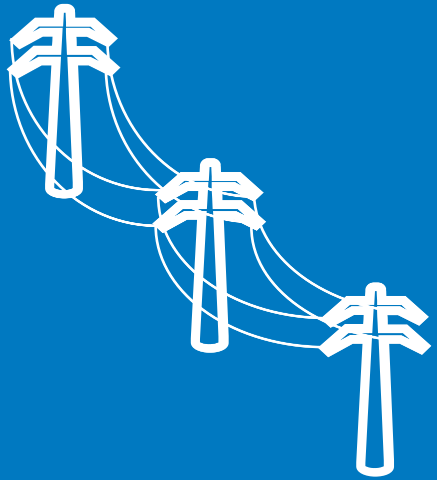
CITAP = Coordinated Interagency Transmission Authorizations and Permits Program; GRIP = Grid Resilience and Innovation Partnership; NIETC = National Interest Electric Transmission Corridor;
TFP = Transmission Facilitation Program; TSED = Transmission Siting and Economic Development

Source: The White House, "Federal Initiatives and Incentive Programs for Upgrading the Nation's Electric Transmission Grid," June 2024. https://infocastinc.com/resources/ti-2024/post-event/Whitney-Muse.pdf

Agenda

1. Transmission as a priority
2. **Transmission at NREL**
3. Case studies
4. Tools
5. Future directions

NREL considers transmission from multiple perspectives



Transmission research at NREL spans many topics, including:

- Planning and operations
- Electricity and gas market interactions
- Testbeds for hardware
- Dynamic interactions with inverter-based resources (IBRs)
- Cyber-resilience
- Interactions with distribution networks and distributed energy resources
- Impacts on the broader economy.

Transmission planning models integrate data and expertise across NREL for impactful integrated and multimodel planning at various geographical scales.

Aiming to answer important transmission policy, economic, deployment, and engineering questions

Interregional and national multivalue transmission planning

- HVDC value and operations
- GETs and transmission upgrades
- Project-level constraints (siting, supply chain, corridor limits).

Integrated workflows

- Seamless tool linkages
- Quick, replicable assessments of economic viability for major opportunities
- Analysis to support state/ISO/RTO/regional decision-making.

Interconnection studies

- Interconnection study workflows
- Methods and data to address queue challenges.

HVDC = High-Voltage DC; GETs = Grid Enhancing Technologies;
ISO = Independent System Operator; RTO = Regional Transmission Organization

Industry linkages and collaborations improve the quality of our research and help address real-world challenges

Image by NREL

Collaboration on Large Projects

ISO/RTOs

Developers

Academia

Industry experts

Professional Organizations

IEEE

ESIG

CIGRE

Numerous others

Research Partnerships

Utilities

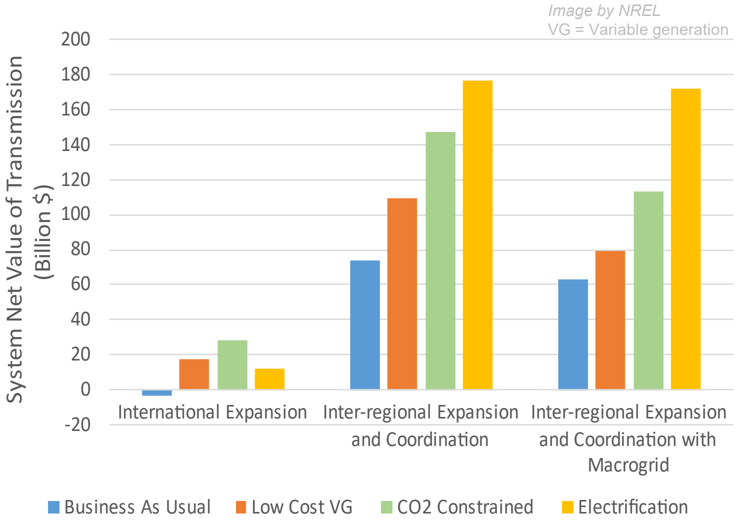
Governments

Other entities

ISO = Independent System Operator; RTO = Regional Transmission Organization; IEEE = Institute of Electrical and Electronic Engineers; ESIG = Energy Systems Integration Group; CIGRE = Conseil International des Grands Réseaux Electriques

Agenda

North American Renewable Energy Integration Study (NARIS)

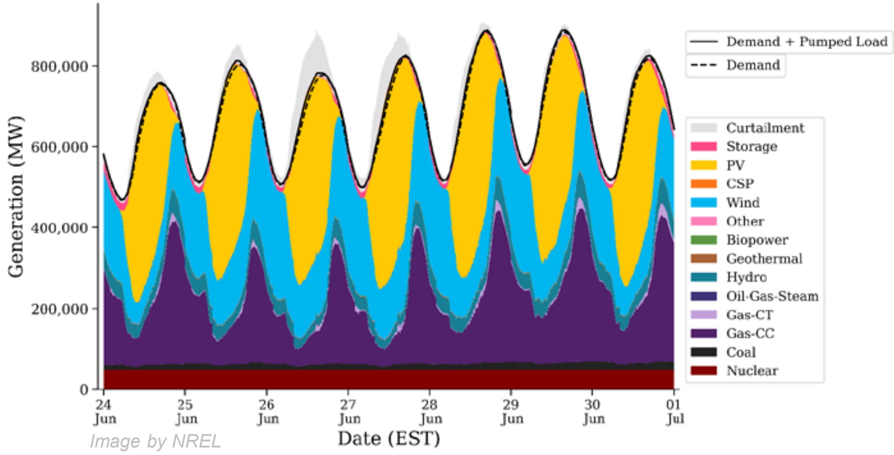


Informing stakeholders on key issues:

- A future low-carbon grid can maintain system adequacy at reasonable cost.
- Benefits of transmission and international collaboration in the future grid could be hundreds of billions of dollars.
- Variable renewable energy (VRE) likely plays a large role in future.

New open-source tools and data:

- Results of modeling for >40 scenarios
- 5-minute wind resource data (including Canada and Mexico)
- Open-source resource adequacy tool.

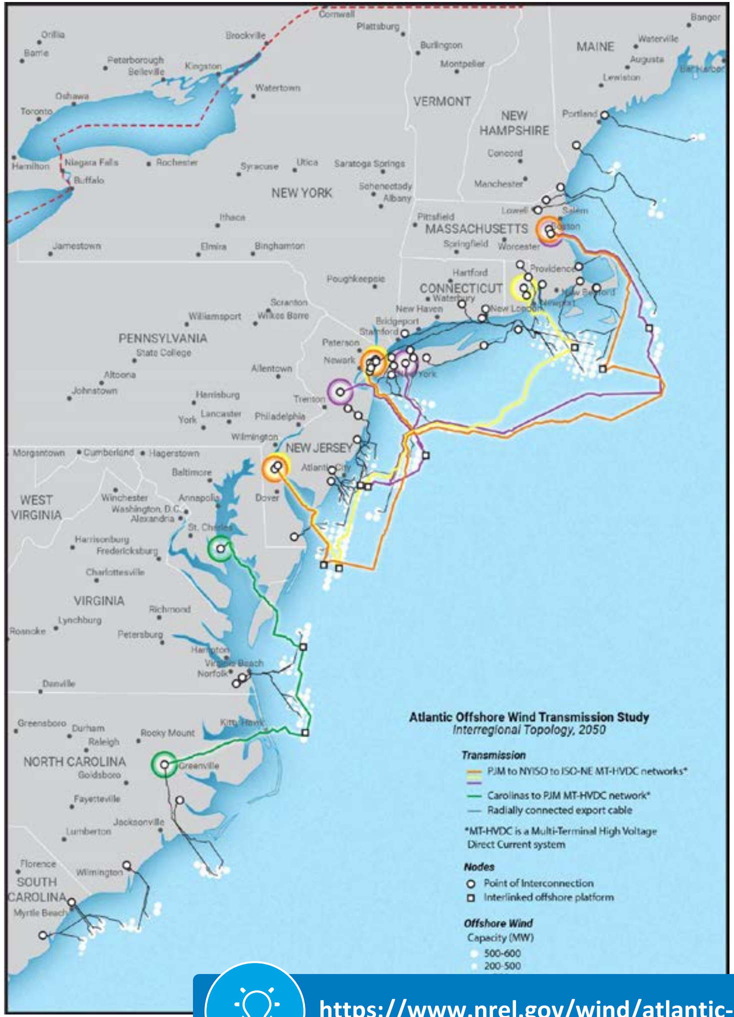


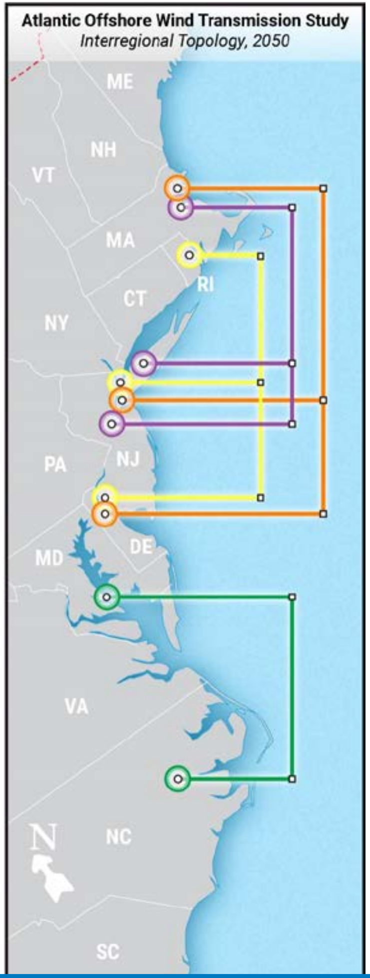
https://www.nrel.gov/analysis/naris.html

Atlantic Offshore Wind Transmission Study

Analysis of offshore wind transmission deployment **through 2050 with 85 GW** in the Atlantic, while respecting ocean co-uses

- Offshore transmission can be planned while considering ocean co-uses and environmental constraints.
- Benefits of offshore transmission networking outweigh the costs by 2 to 1 or more.
- Offshore transmission contributes to grid reliability during contingencies.
- Early implementation of HVDC technology standards is essential for future network solutions.





Images by NREL

https://www.nrel.gov/wind/atlantic-offshore-wind-transmission-study.html

National Transmission Planning Study

Interregional transmission can provide benefits such as lowering emissions, significant cost savings, and supporting reliability in highly decarbonized future systems.

Six principal findings:

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

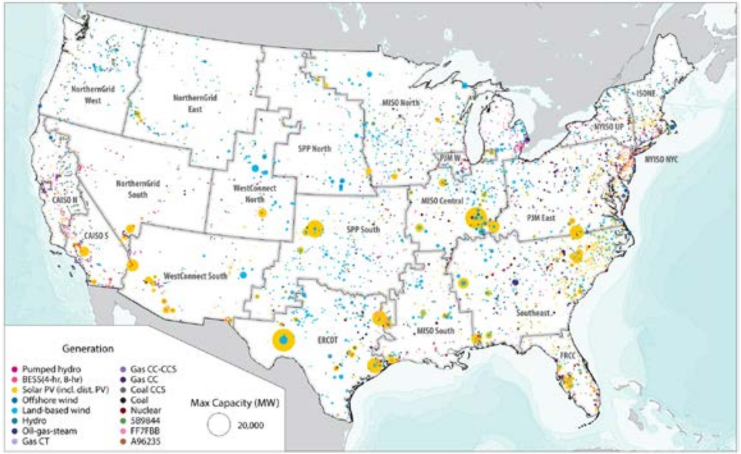
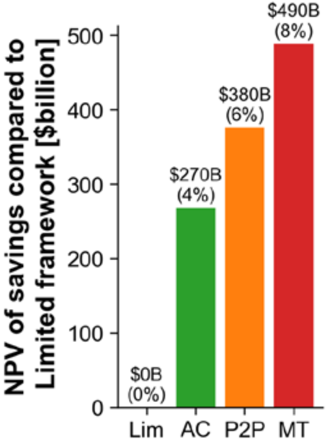


Image by NREL



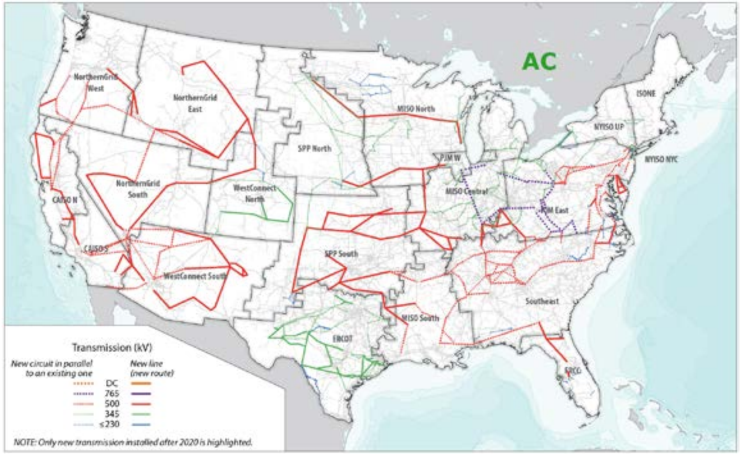


Image by NREL

Access the study including +22 supporting key takeaways: **https://www.energy.gov/gdo/national-transmission-planning-study**

NOTE: NPV = Net Present Value; P2P = Point-to-Point; AC = Alternating Current; MT = Multi-terminal HVDC

Agenda

Coupled capacity expansion and resource adequacy

2 → Disaggregate capacity into individual units
→ Apply hourly failure and recovery probabilities

System design

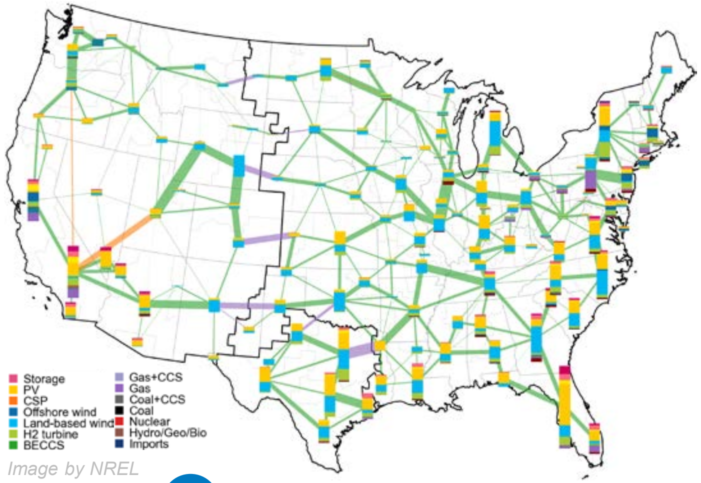


Image by NREL

1 **Co-optimize** generation/transmission/storage

ReEDS

PRAS

7y × 8760h × *N* samples

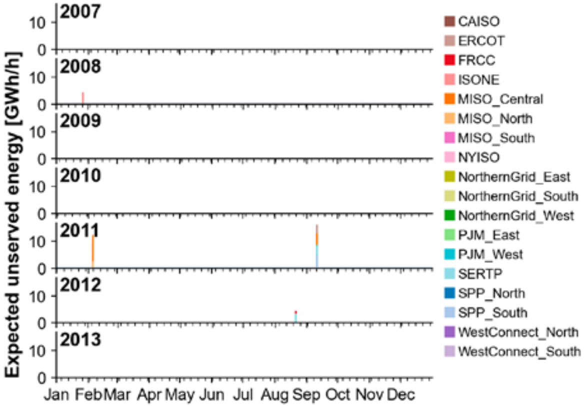


Image by NREL

3 Provide multiyear chronological hourly dispatch with probabilistic outages over many samples (Monte Carlo)

4 **"Stress periods"**

← Identify days with highest risk of unserved energy and include them in ReEDS

Public repositories of ReEDS and PRAS

ReEDS: https://github.com/NREL/ReEDS-2.0
PRAS: https://github.com/NREL/PRAS

Iterate between ReEDS/PRAS until **desired reliability level** (expected unserved energy)

ReEDS

R2X

Disaggregation of resources
(example: AC (2035))

Interregional zonal Tx expansion
(example: AC (2035-2020))

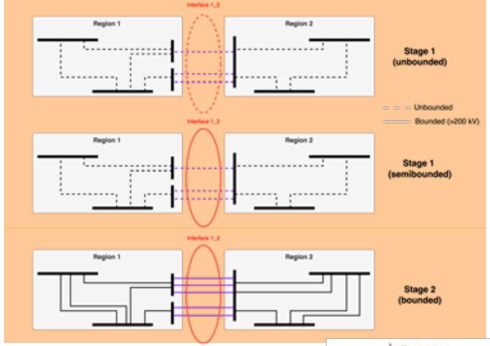
Performance assessment [nodal production cost modelling (PCM)]

(balancing supply-demand, curtailment, network utilization)

Transmission constraints

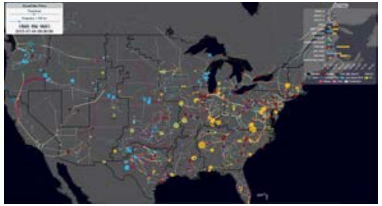
(increasingly tighter representation)

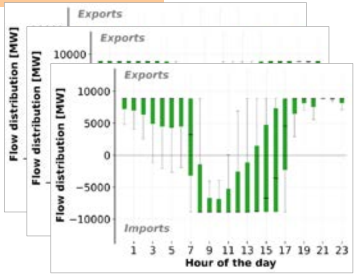
Sienna



Visualization

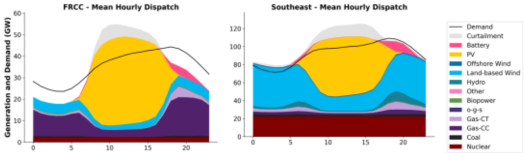
(debugging, planning, sharing)





Interface flows

(example)



Stacks

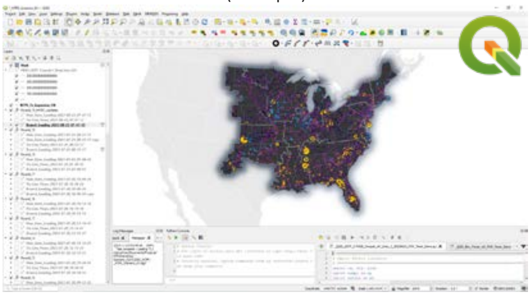
(example)

Interactive Tx expansion [power flow, contingency]

(quick, iterative, planner in-the-loop)

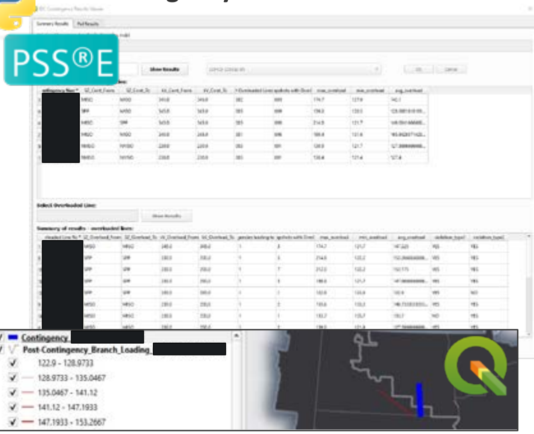
Iterative and interactive Tx expansion

(example)



Contingency assessment (example)

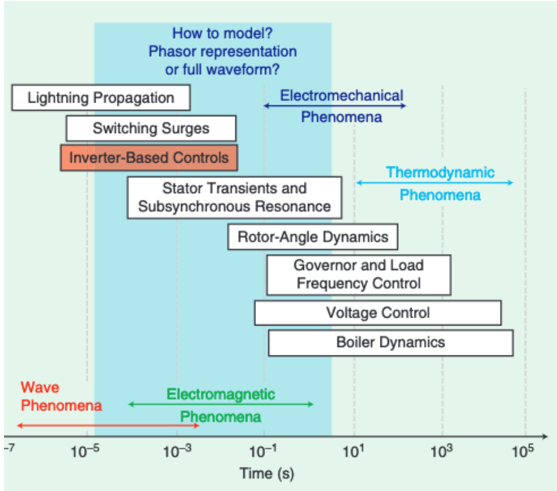
PSS®E



Tx expansion optimality assessment

Images by NREL

Dynamics of inverter-based resources (IBRs) at-scale



Traditional transient simulation tools fall into two categories:

- Phasor-based single-frequency (i.e., QSP)
- Waveform analysis (i.e., EMT)

Same conclusions but faster (144 bus system)

Improved single-frequency simulation methods are needed to represent IBRs

- Analysts need to be able to:
  - Model details needed
  - Switch modeling details quickly
  - Limit effort and computational cost.
- **Sienna\Dyn** employs lossless averaging techniques to enable similar detail as EMT tools with less computation time.

Sienna\Dyn

Dynamic response simulations

EMT = electromagnetic transient;
PSID = PowerSimulationsDynamics.jl; QSP = quasi-static phasor

Agenda

Push the boundaries on what is possible for transmission planning and operations at scale

Large-scale modeling

- What tools/methods does industry need?
- What future interregional transmission portfolios are likely needed?
- Can we site transmission routes earlier with increased confidence?
- How do we represent extreme events in models to better understand risk?
- How can we integrate correlated outages into planning models?

Data and model management

- Can we better integrate and create improved bidirectional interfaces between modeling tools? (CEM/RA/PCM/ powerflow dynamics)
- Can regularly updated databases be made available, to whom and how?

Advanced transmission

- Can offshore transmission options be better integrated into existing planning models more consistently?
- How should dynamic-line ratings (DLRs) and reconductoring be represented in planning models?
- What is the role of transmission in resource adequacy?

Thank you

www.nrel.gov

NREL/PR-6A40-91471

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NREL Transforming ENERGY

Join us Nov. 12, 2024, 10 a.m. MT

Presented by Michael Blonsky and Jeff Maguire