Interconnections Seam Study

Overview

Gregory Brinkman, Joshua Novacheck, Aaron Bloom, and James McCalley

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Disclaimer

- This material includes unpublished preliminary data and analysis that has not been peer-reviewed and is subject to change.
- The study results have been submitted to the journal *IEEE Transactions in Power Systems* for possible publication.
  A preprint of the article has been posted to nrel.gov.
- This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the DOE Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office and the DOE Office of Electricity, in support of the Grid Modernization Initiative.

Continental Power Systems…

First Proposed in 1923

Continental Transmission Studies

Chicago Tribune

1923

Tying the Seasons to Industry

Bureau of Reclamation

1952

Super Transmission System

Bonneville Power Administration

1979

Interconnection of the Eastern and Western Interconnections

Western Area Power Administration

1994

East/West AC Intertie Feasibility Study

U.S. Department of Energy

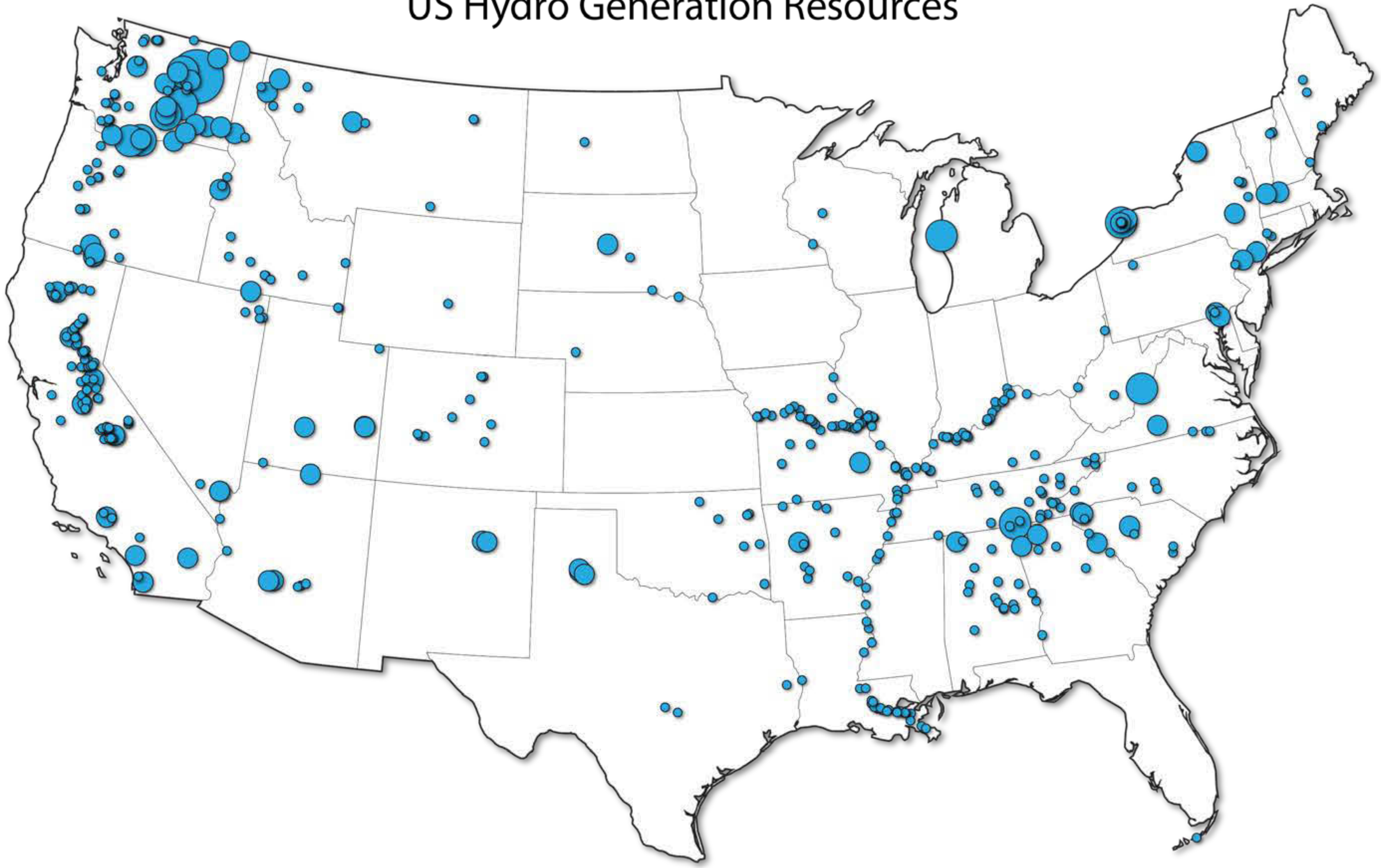
2002

National Transmission Study

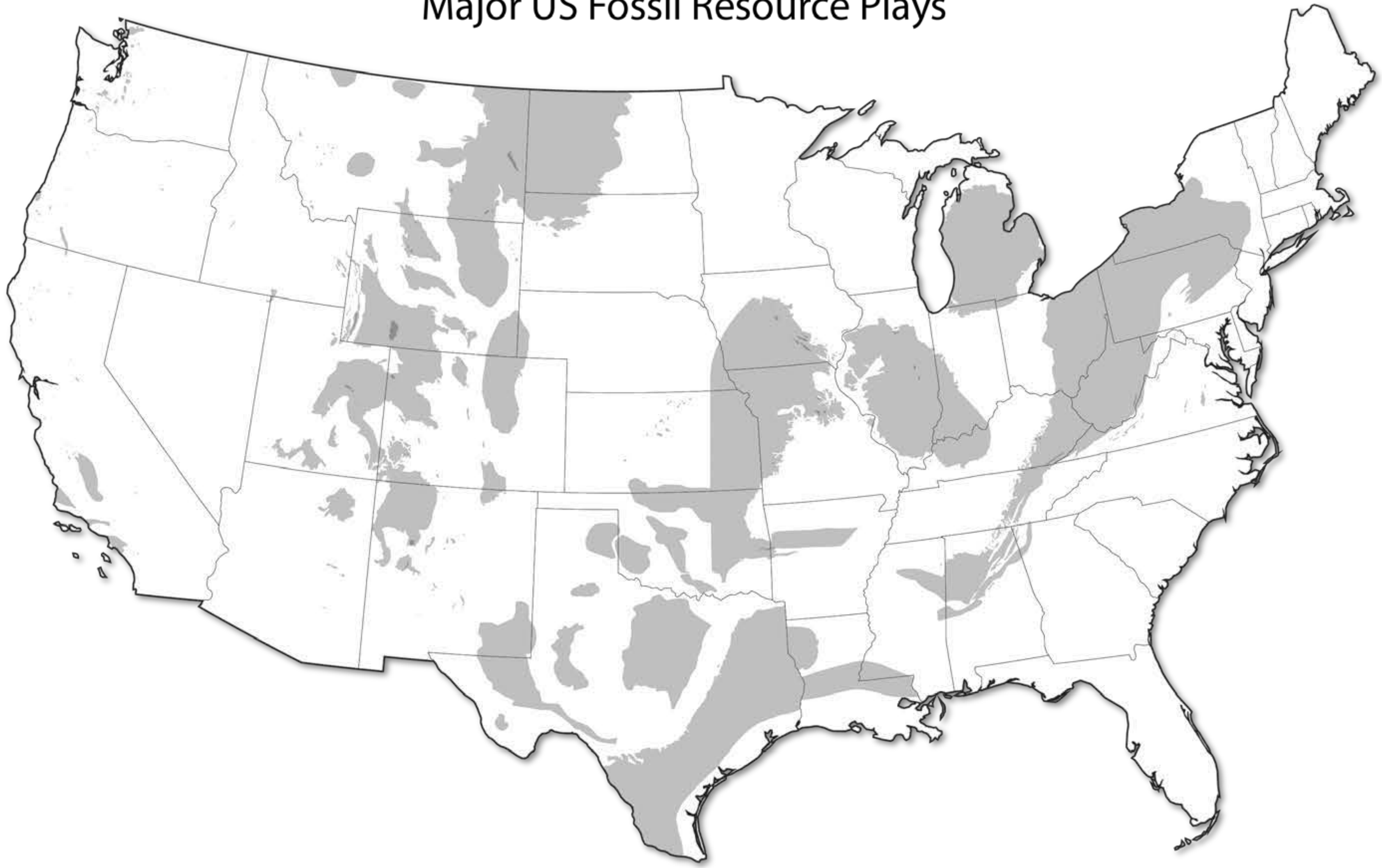
What about

Now?

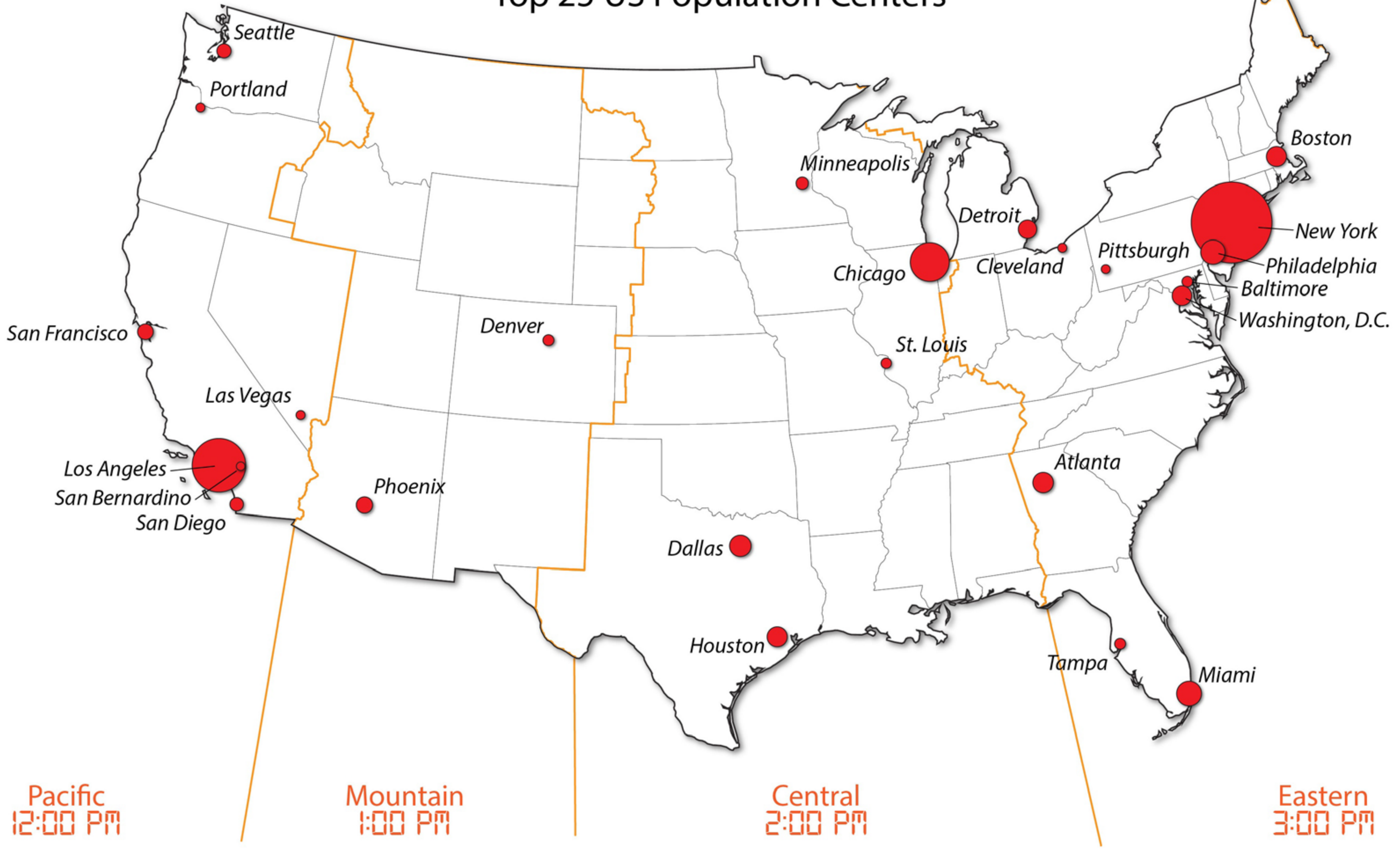
US Hydro Generation Resources



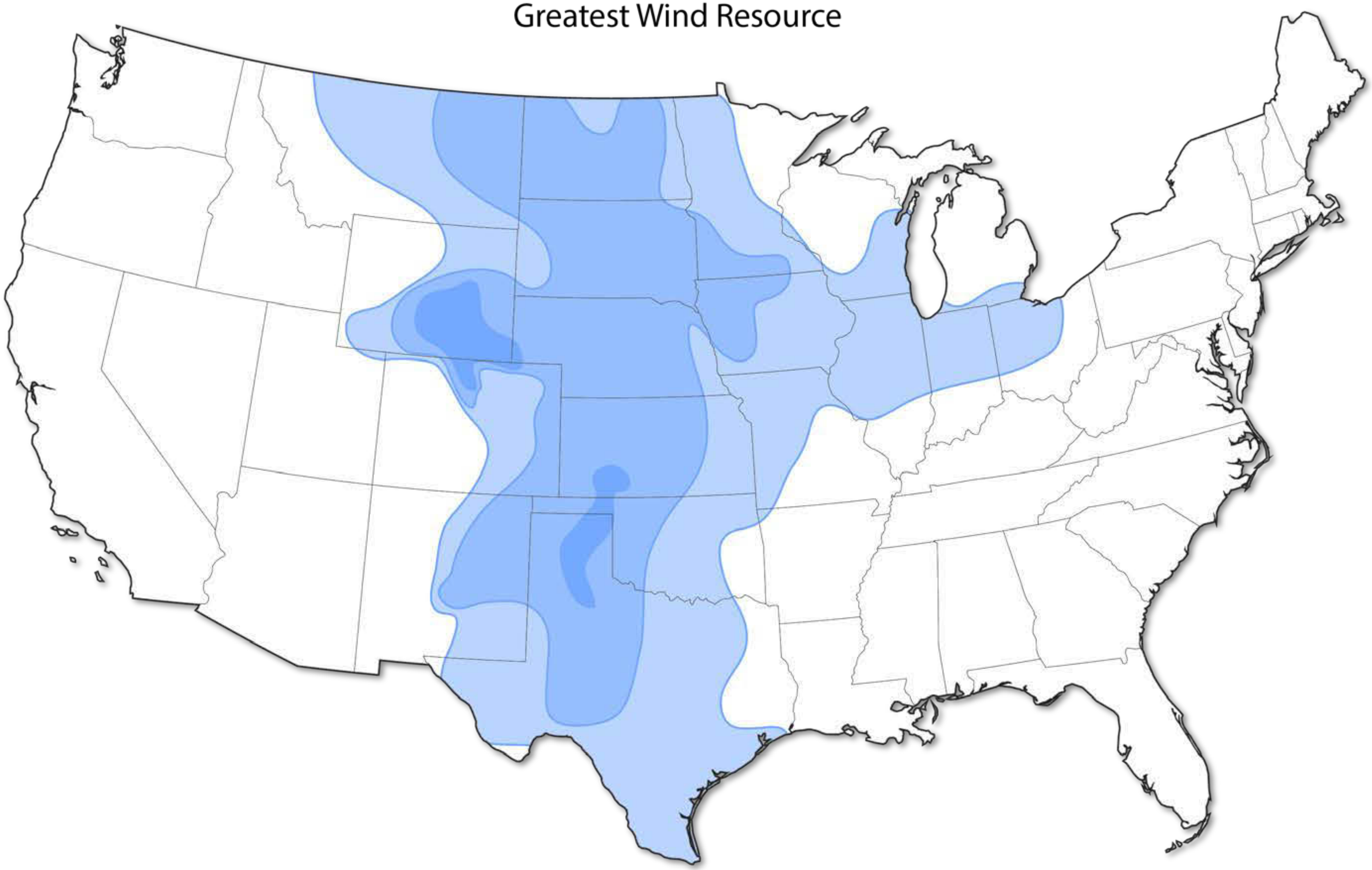
Major US Fossil Resource Plays



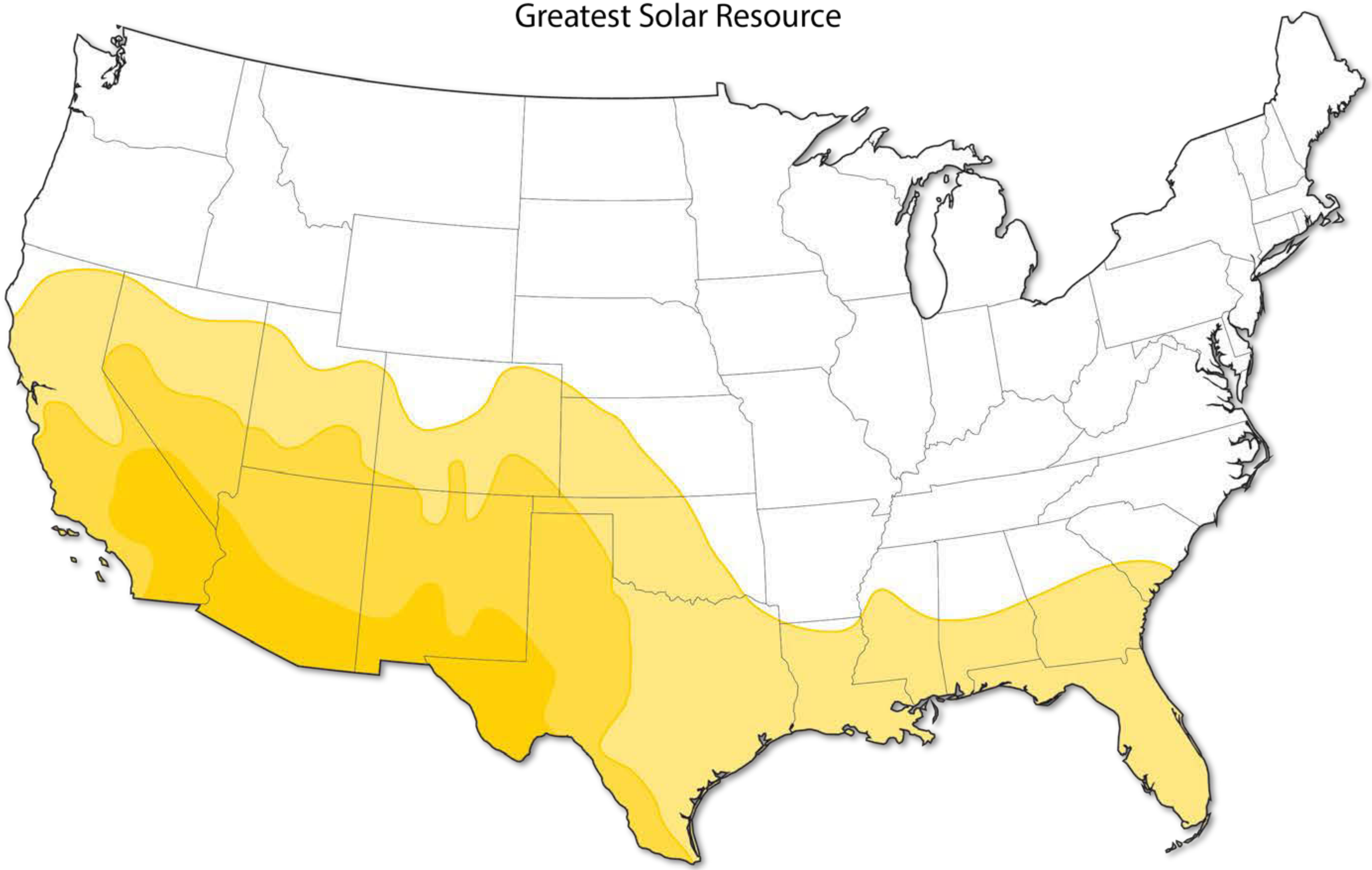
Top 25 US Population Centers

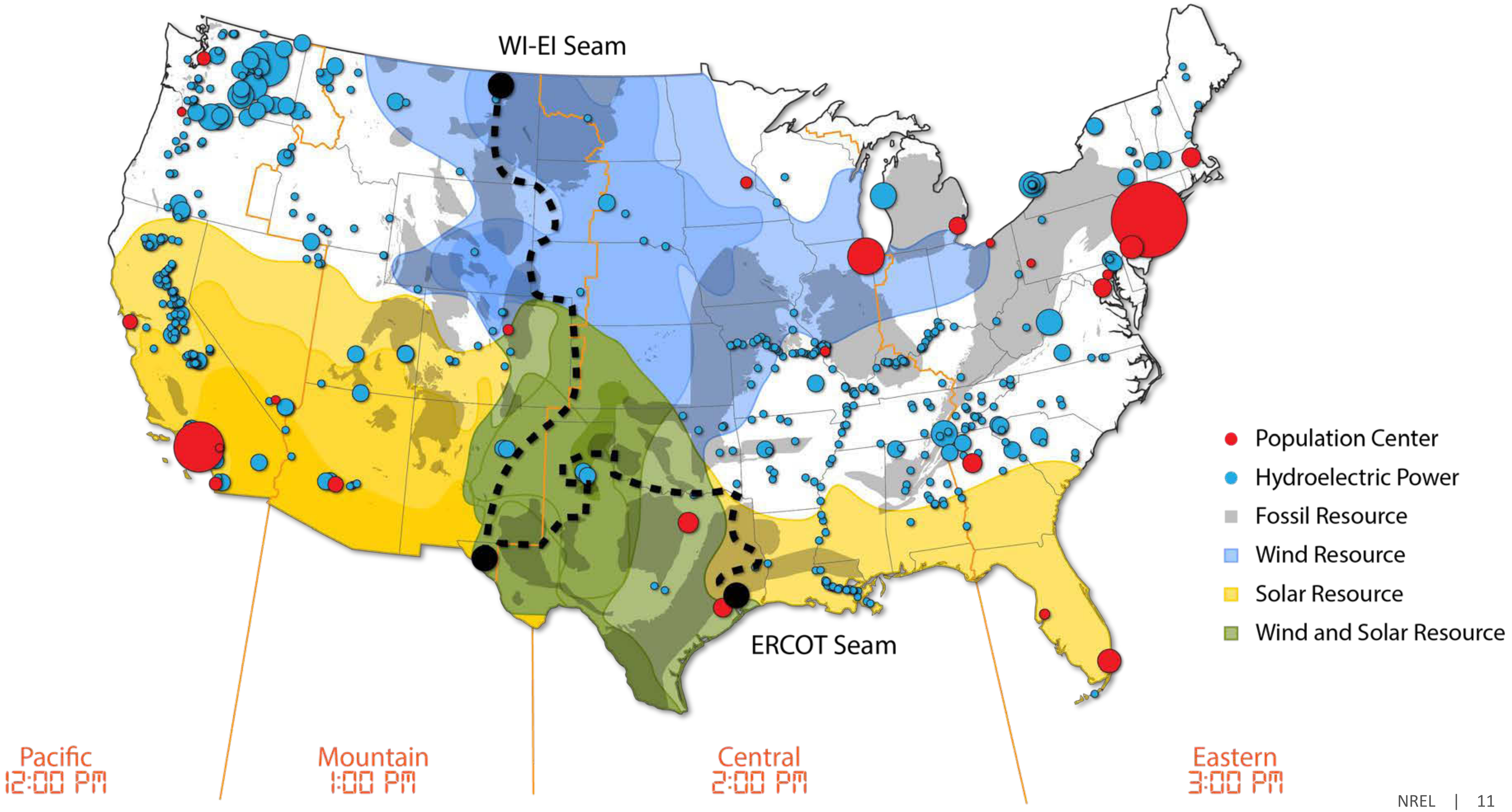


Greatest Wind Resource



Greatest Solar Resource




WI-EI Seam
ERCOT Seam
Population Center
Hydroelectric Power
Fossil Resource
Wind Resource
Solar Resource
Wind and Solar Resource
Pacific
12:00 PM
Mountain
1:00 PM
Central
2:00 PM
Eastern
3:00 PM

Generation and Transmission Technologies

Wind

The single largest source of renewable energy capacity in the US

Solar PV

The fastest growing renewable energy resource

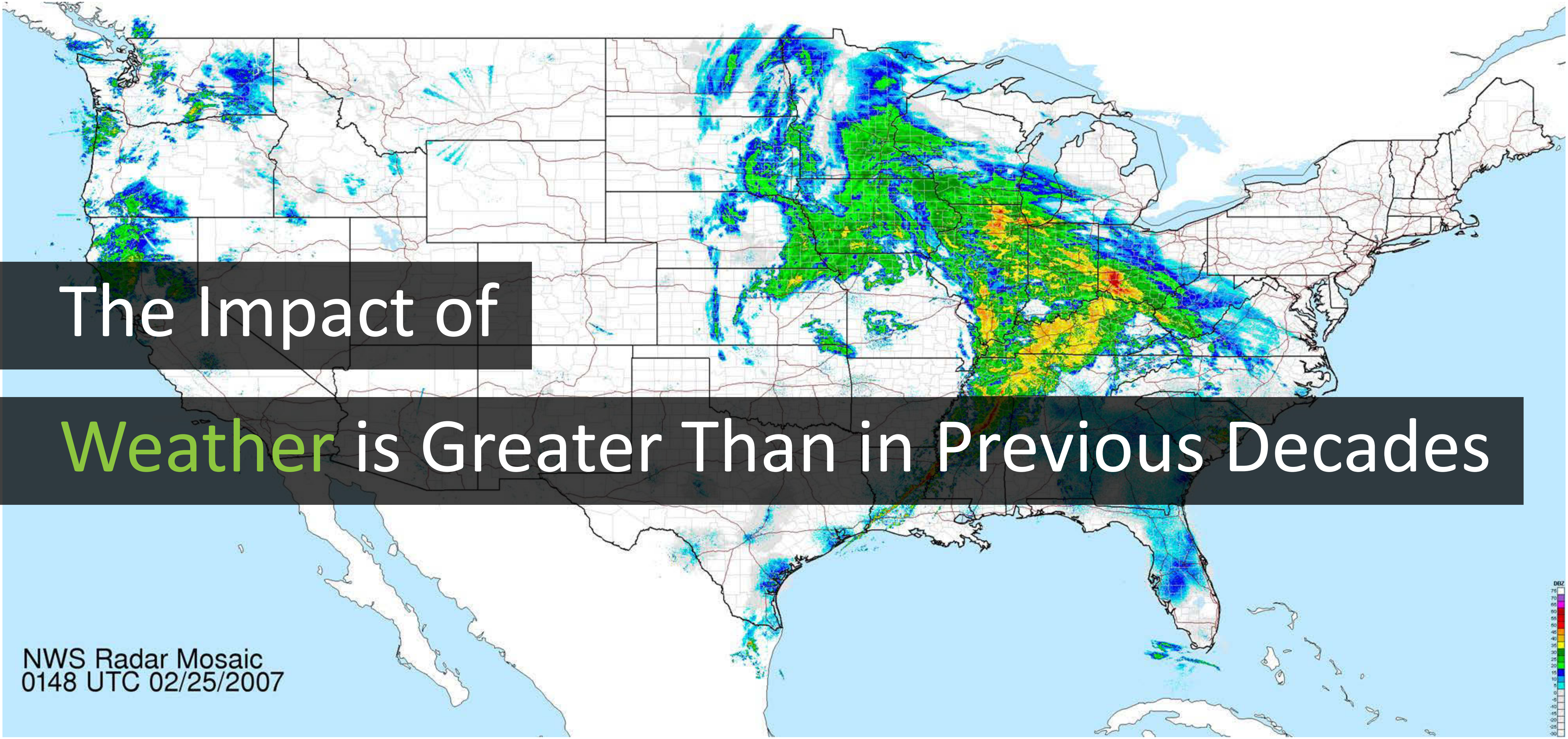
HVDC

Controllable, directional, electricity transmission, with large scale deployment worldwide

HVAC

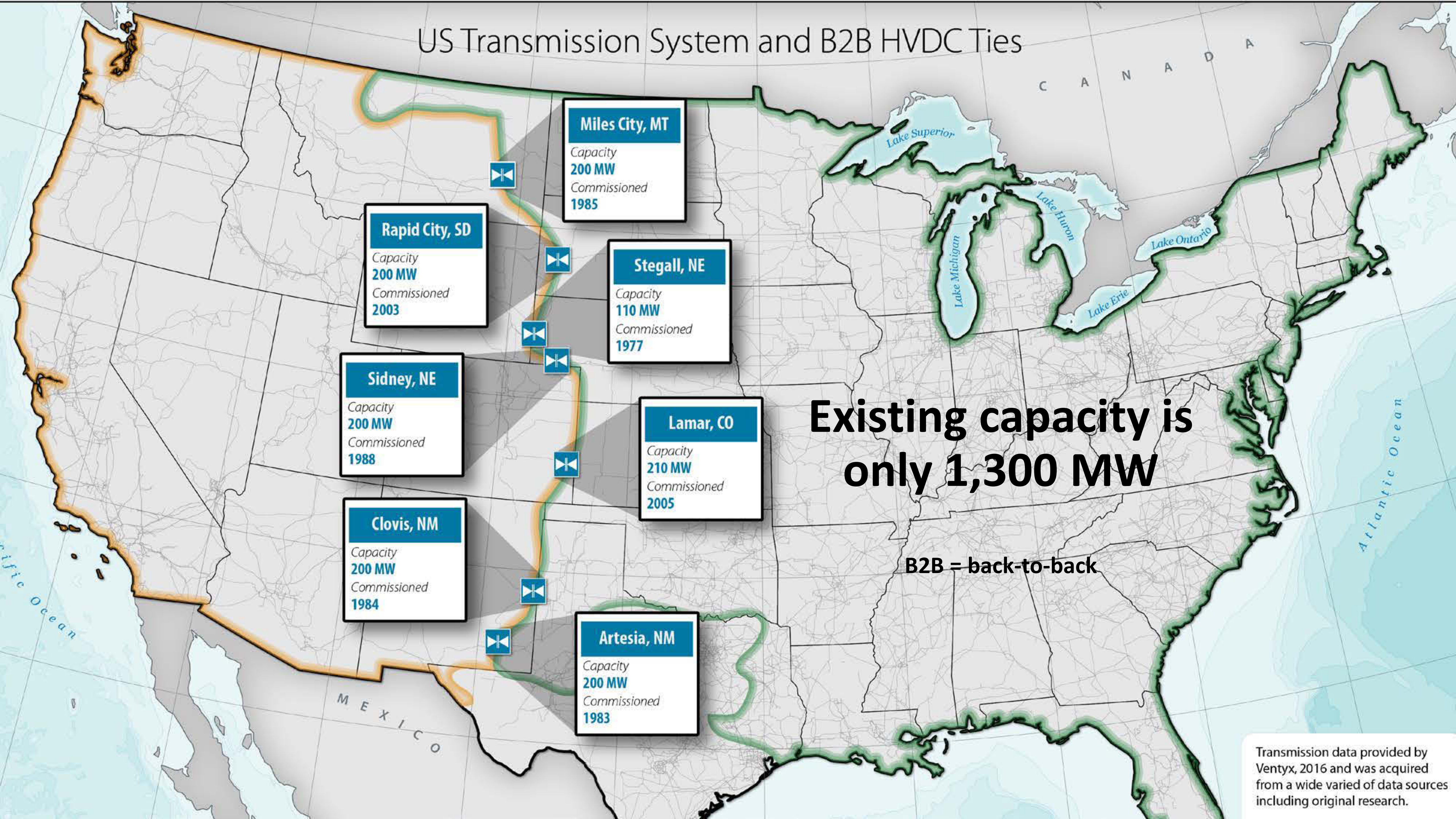
The backbone of existing American Transmission

The Impact of Weather is Greater Than in Previous Decades



New Computational Capabilities

- Parallel computing environments, complex algorithms, and artificial intelligence offer new capabilities
- 100,000 node transmission models can be simulated for an entire year, in a single day
- The dawn of Exa-scale computing


US Transmission System and B2B HVDC Ties
Miles City, MT
Capacity
200 MW
Commissioned
1985
Rapid City, SD
Capacity
200 MW
Commissioned
2003
Stegall, NE
Capacity
110 MW
Commissioned
1977
Sidney, NE
Capacity
200 MW
Commissioned
1988
Lamar, CO
Capacity
210 MW
Commissioned
2005
Clovis, NM
Capacity
200 MW
Commissioned
1984
Artesia, NM
Capacity
200 MW
Commissioned
1983
Existing capacity is only 1,300 MW
B2B = back-to-back
CANADA
MEXICO
Lake Superior
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
Atlantic Ocean
Transmission data provided by Ventyx, 2016 and was acquired from a wide varied of data sources including original research.

The Interconnections Seam Study

SPP Southwest Power Pool

MISO

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Western Area Power Administration

IOWA STATE UNIVERSITY

Pacific Northwest NATIONAL LABORATORY

Study Objective

Through the Interconnections Seam Study, NREL joins national lab, university, and industry partners to evaluate the benefits and costs of options for continental transmission across the U.S. electric grid that would create a more integrated power system that could drive economic growth and increase efficient development and utilization of the nation's abundant energy resources, including solar, wind, and natural gas.

- Visit the Seam Study webpage to learn more
- View a preprint of the article submitted to *IEEE Transactions in Power Systems*
- View study visualization animations on YouTube

Comprehensive Economic and Resource Adequacy Analysis

CGT-Plan (Planning/Expansion Model)

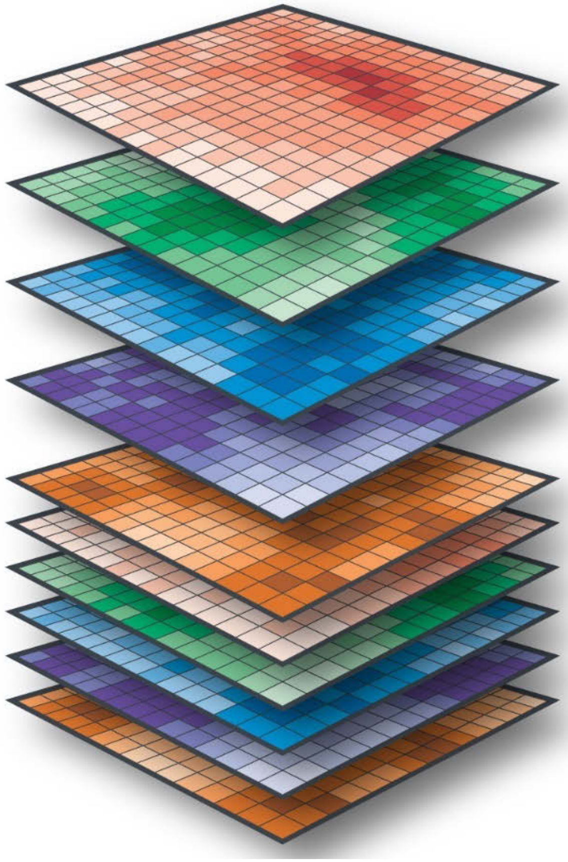
- Iowa State University
- Capital and operating costs 2024-2038
- Generation and transmission system for 2038

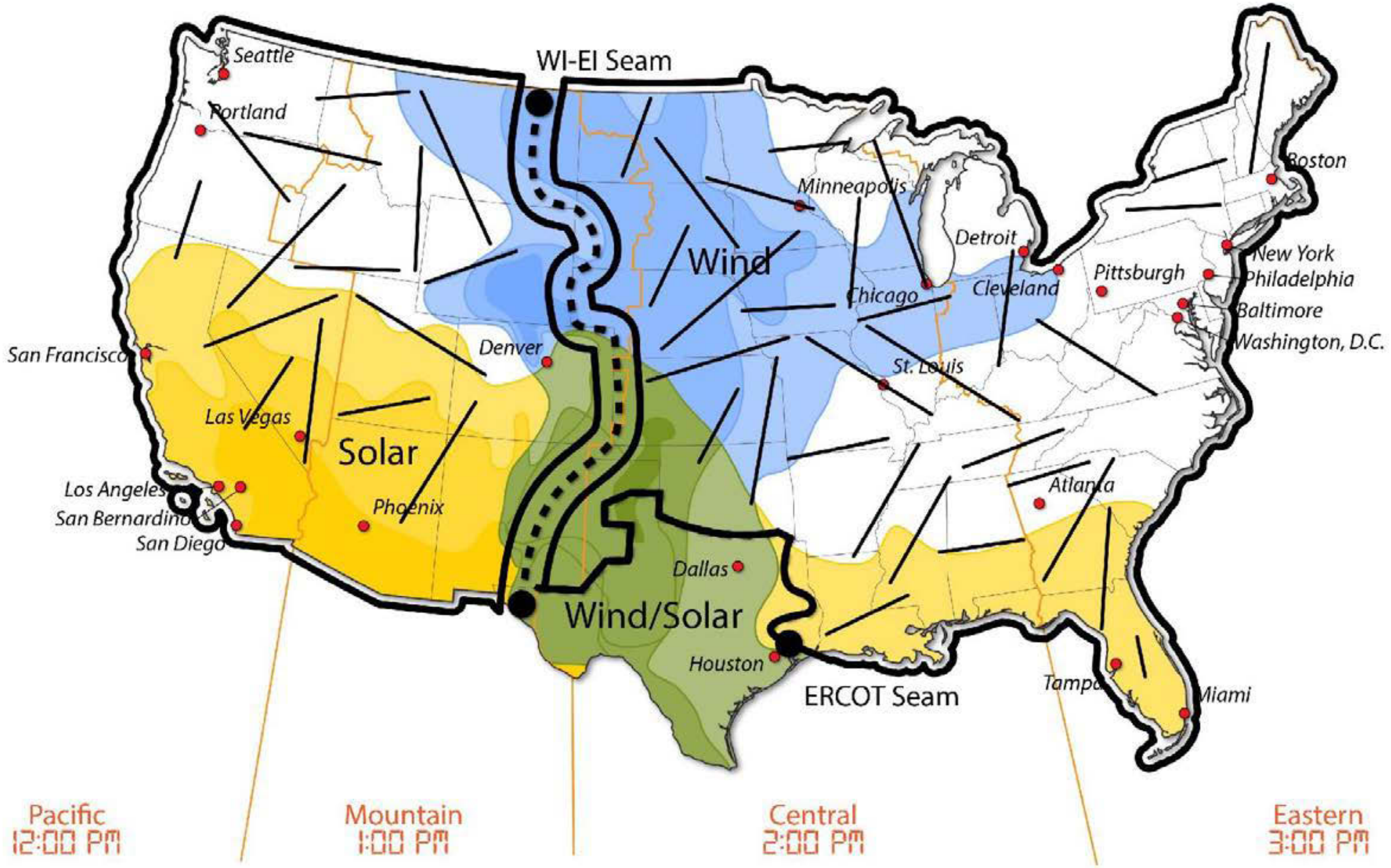
PLEXOS (Production Cost Model)

- NREL
- Operating costs 2038
- Hourly unit commitment and economic dispatch

PSSE (Steady-State AC Analysis)

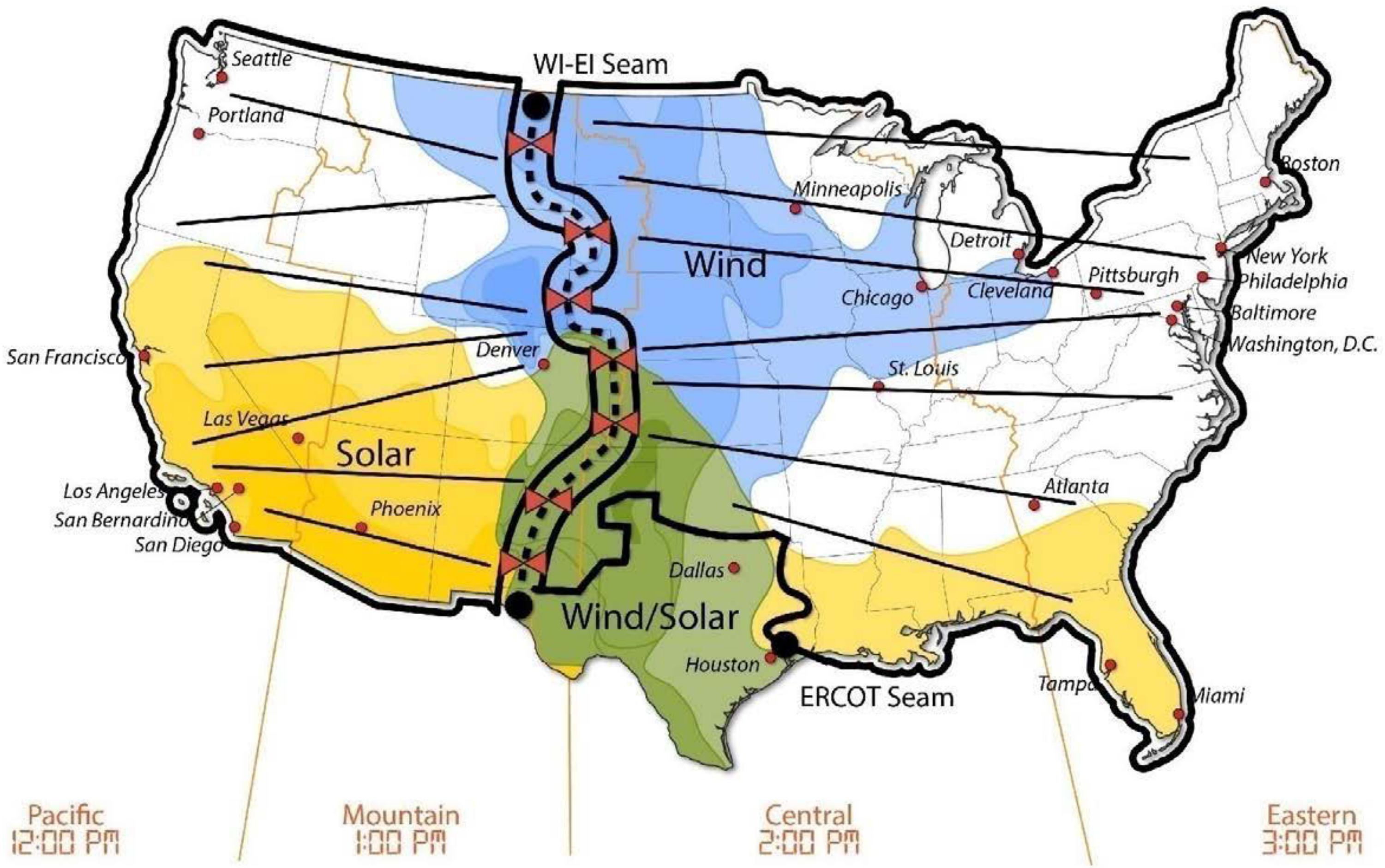
- PNNL
- Develop a capability for future work
- Preliminary analysis of AC power flow impacts





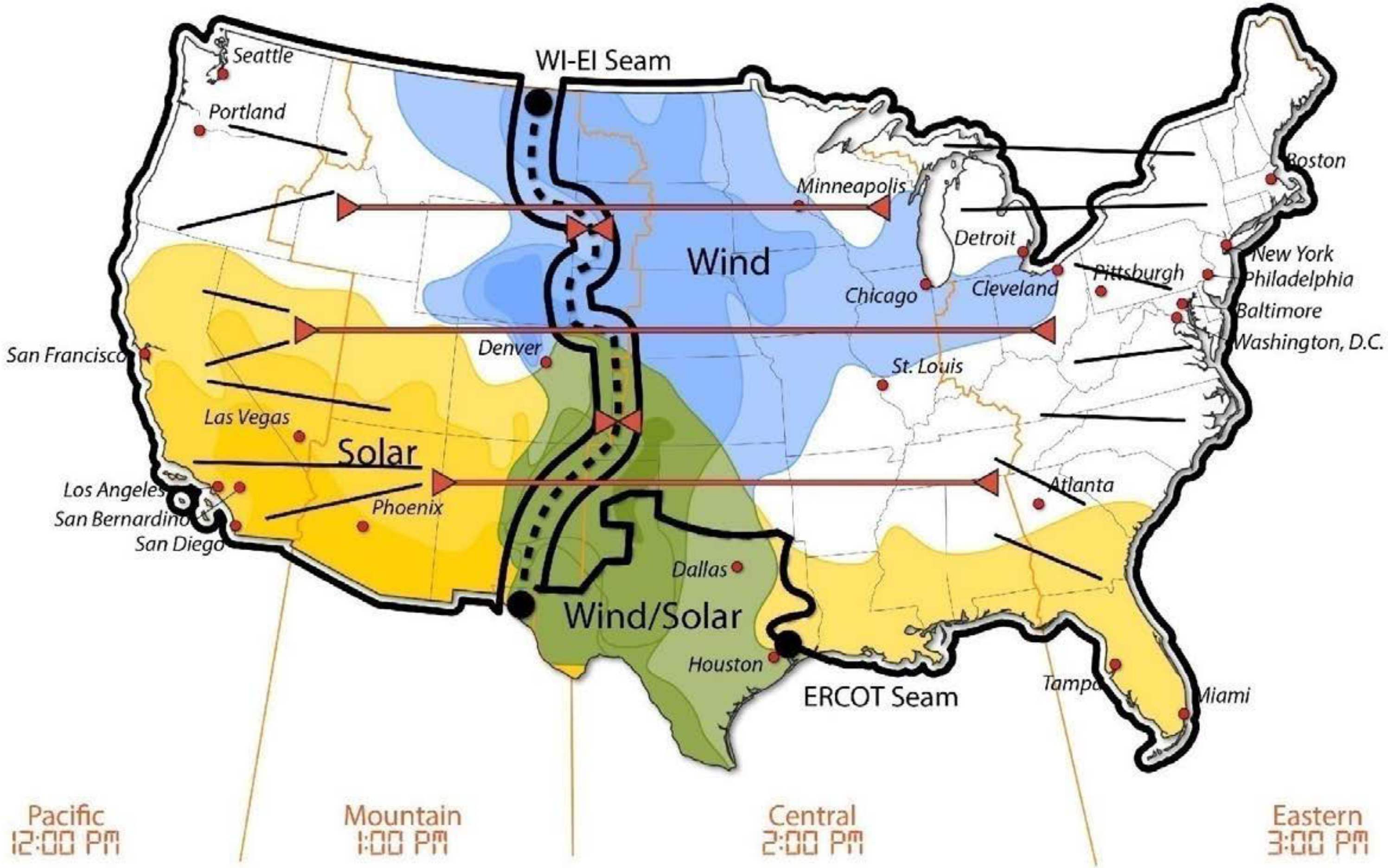
Design 1 (D1)

Existing B2B facilities are replaced at their current (2017) capacity level and new AC transmission and generation are co-optimized to minimize system-wide costs.



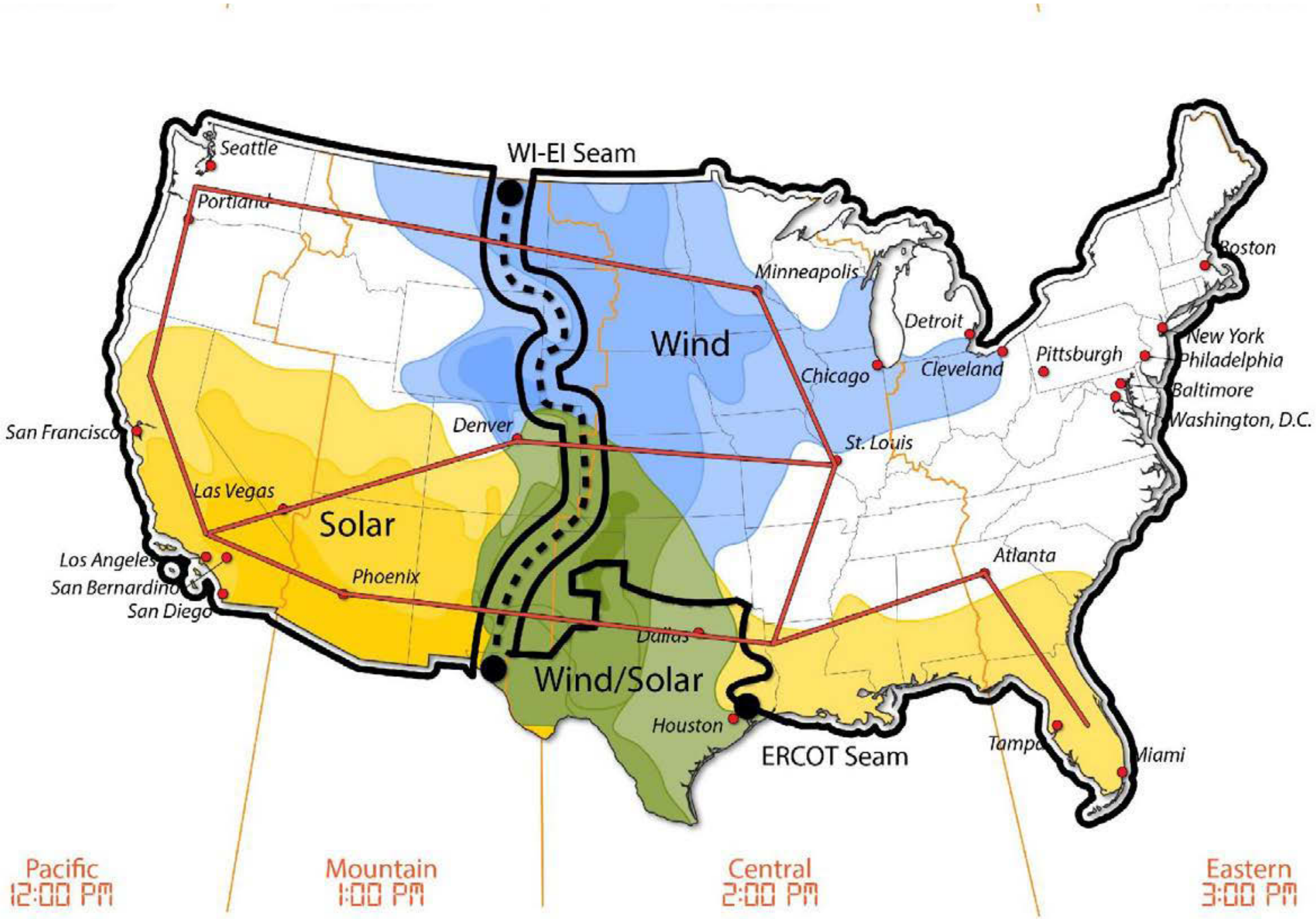
Design 2a (D2a)

Existing B2B facilities are replaced at a capacity rating that is co-optimized along with other investments in AC transmission and generation.



Design 2b (D2b)

Three HVDC transmission segments are built between the Eastern Interconnection and Western Interconnection and existing B2B facilities are co-optimized with other investments in AC transmission and generation.



Design 3 (D3)

Macrogrid (a nationwide HVDC transmission network) is built and additional AC transmission and generation are co-optimized to minimize system costs.

Scenarios

Scenario	Key Assumption Differences
Base Case	AEO 2017 gas price, existing state RPS laws
Low Gas Price	AEO 2017 High Gas Resource (gas prices regionally and temporally varying around $4/mmbtu)
High Gas Price	AEO 2017 Low Gas Resources (gas prices varying around $6/mmbtu)
High AC Trx Cost (1.5x)	50% higher than base transmission cost. Base transmission cost from [16]
High AC Trx Cost (2x)	Double the base transmission cost
No Retirements	Model does not retire any generating units beyond announced retirements
Low-Cost Renewables	ATB 2017 Low Cost projections for wind and solar
High VG	Least-cost generation mix when using a carbon cost from $3/tonne in 2024 to $45/tonne in 2038**

Description of the Scenarios*

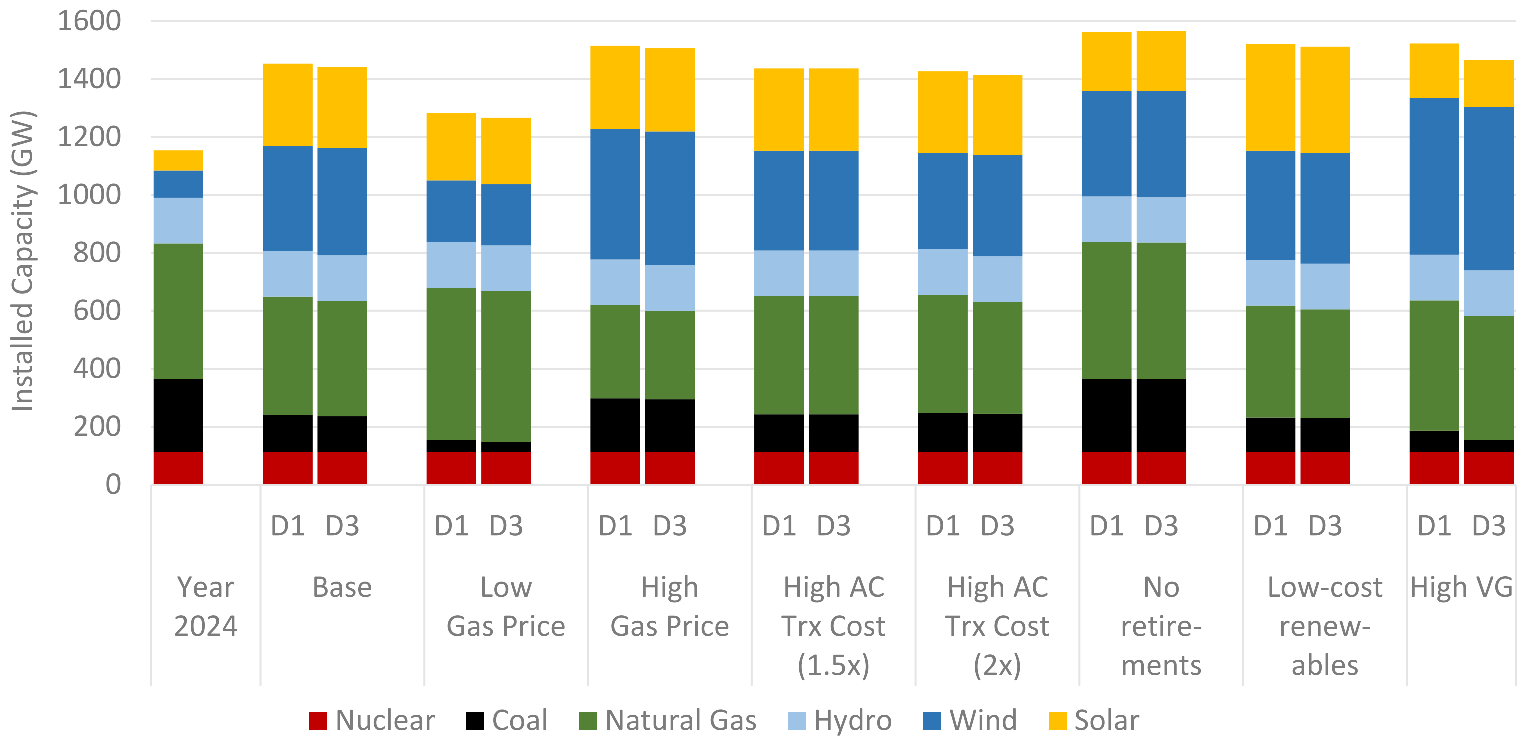
*Acronyms used here include Energy Information Administration (EIA) Annual Energy Outlook (AEO); Renewable Portfolio Standard (RPS); Annual Technology Baseline (ATB) (atb.nrel.gov); Variable Generation (VG); Transmission (Tx)

**: The study Technical Review Committee recommended this approach (consistent with cost estimates in [17]) as a proxy for potential growth in wind and solar in light of uncertainty in traditional deployment forecasts [18].

- The four conceptual transmission designs were studied under eight different grid environments
- A total of 32 total capacity expansion model runs were made
- Scenarios vary in terms of technology cost, fuel price, and policy assumptions
- Refer to preprint article for numbered references

System Characteristics and Operation

Generation Capacity for Selected Scenarios and Designs



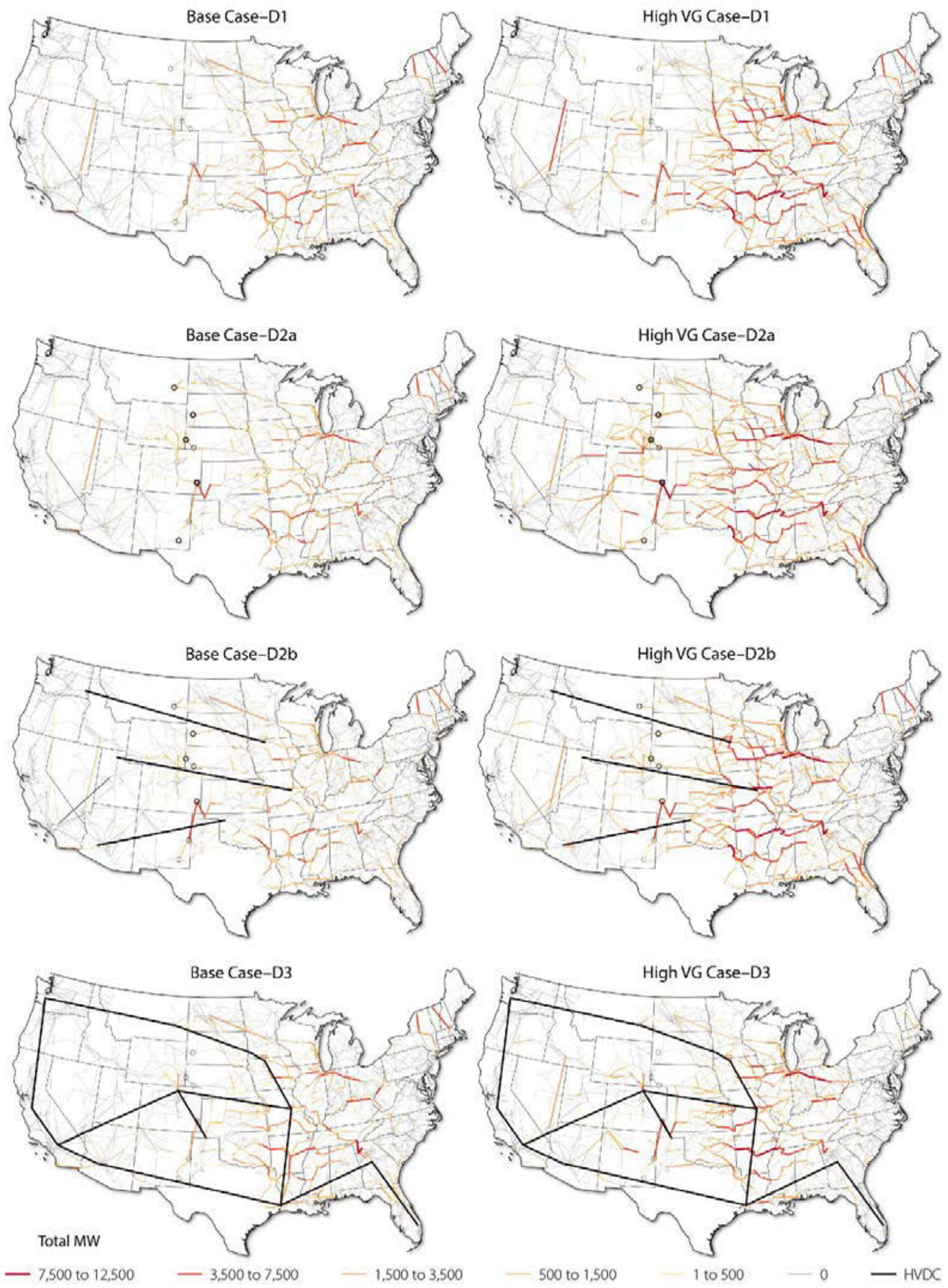
D1 = No new cross-seam transmission

D2a = B2B expansion

D2b = B2B expansion + 3 HVDC lines

D3 = HVDC Macrogrid

Transmission Builds for Selected Scenarios and Designs



Transmission Investment Summary

Base Scenario

Design→	D1	D2a	D2b	D3
HVDC-B2B (GW)	0	6.7	6.3	0
HVDC-Line (GW-miles)	0	0	14,487	29,062
AC Line (GW-miles)	18,409	19,357	17,778	16,076

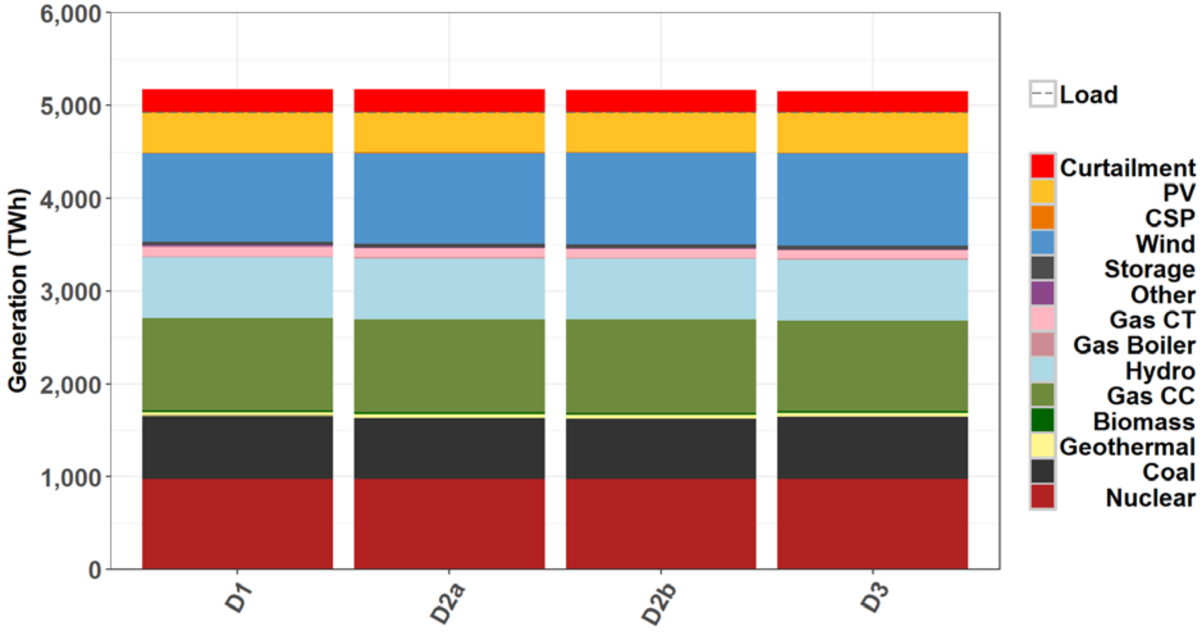
High VG Scenario

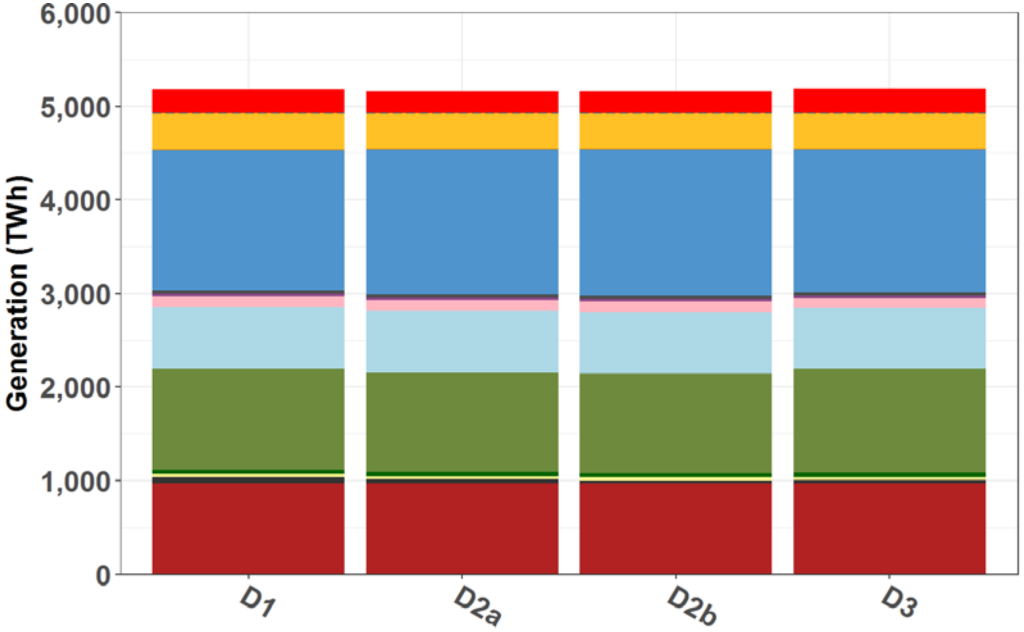
Design→	D1	D2a	D2b	D3
HVDC-B2B (GW)	0	25.7	7.5	0
HVDC-Line (GW-miles)	0	0	31,335	63,156
AC Line (GW-miles)	52,737	60,141	50,964	43,190

Note: New transmission investments are identified for B2B in terms of GW increased capacity between B2B terminals, and for lines in terms of GW-miles (which is the GW capacity multiplied by the path distance).

Annual Generation of 2038 Systems

	Base Case				High VG			
	D1	D2a	D2b	D3	D1	D2a	D2b	D3
Fossil Fuel	36%	36%	36%	36%	26%	25%	25%	25%
Wind and Solar	28%	29%	29%	29%	38%	39%	39%	39%
Zero-carbon	63%	63%	63%	64%	73%	74%	74%	73%

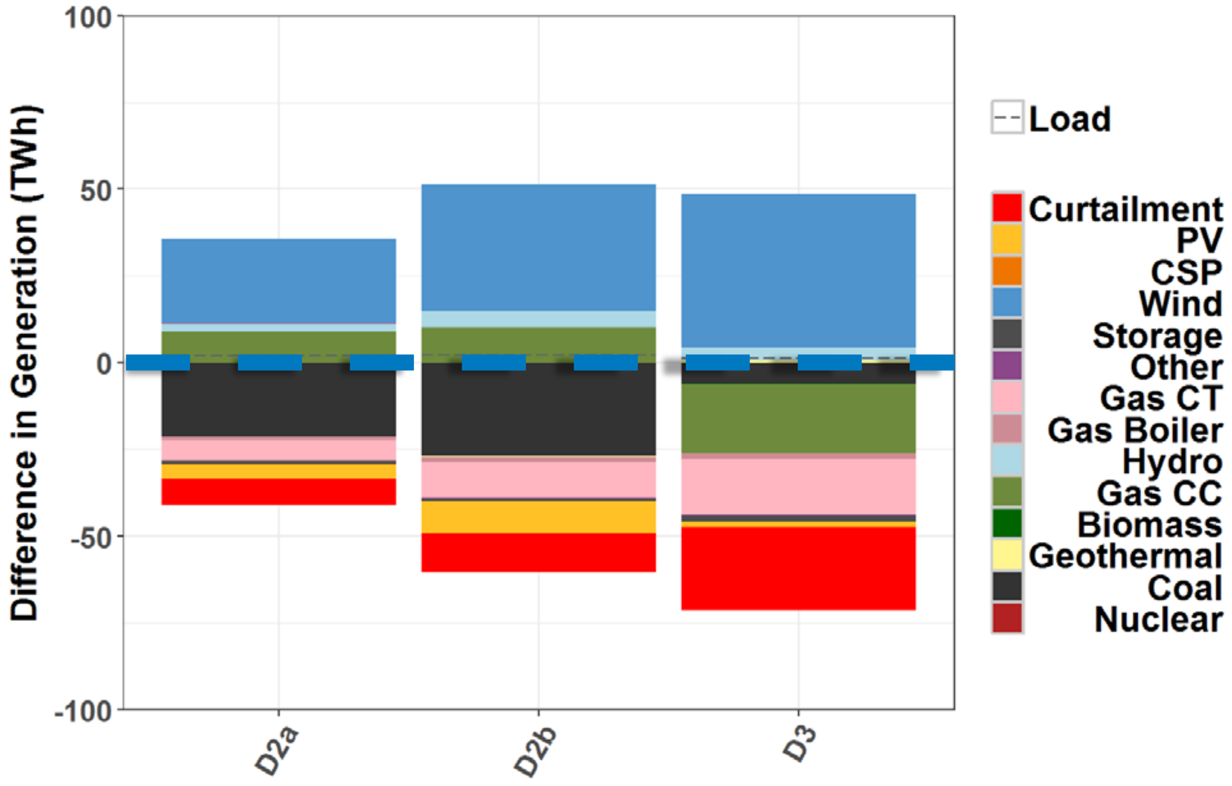




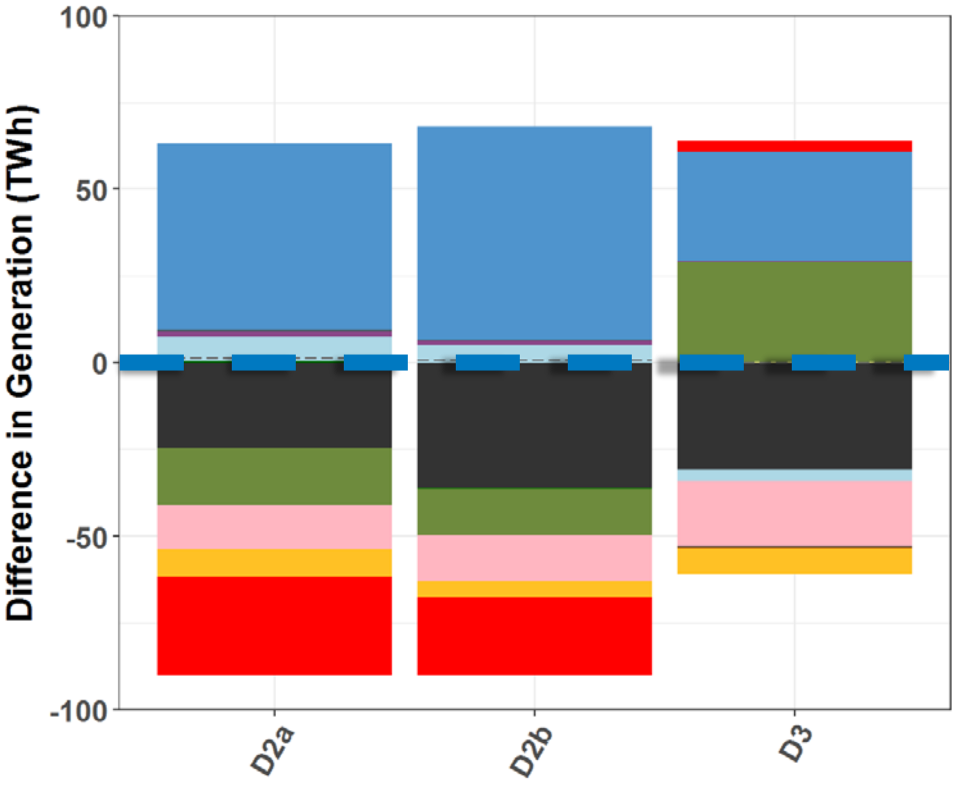
Zero-carbon includes renewables and nuclear generation. Results from PLEXOS unit commitment and economic dispatch

2038 Generation Difference from D1

Base Case



High VG



Results from PLEXOS unit commitment and economic dispatch

What could it cost?

What are the benefits?

Net Cost Relative to Design 1

- Net cost (negative indicates savings) considers the difference in costs between each design and Design 1 for that scenario

Scenario	ΔD2a	ΔD2b	ΔD3
Base Case	-2.6	-4.5	-2.9
Low Gas Price	-2.9	-4.2	-2.4
High Gas Price	-4.7	-9.5	-5.9
High AC Trx Cost (1.5x)	-2.2	-5.4	-4.6
High AC Trx Cost (2x)	-2.1	-5.5	-5.5
No retirements	-1.2	-1.6	-0.8
Low-cost renewables	-2.9	-4.8	-3.0
High VG	-18.3	-28.8	-23.0

Note: D2a, D2b, and D3 results are shown as savings relative to D1. Emission costs included in the High VG scenario are not included in Net Costs.

Benefit-Cost Ratio

$$\text{Benefit-Cost Ratio} = \frac{\text{Change in Total Non-Transmission Costs}}{\text{Change in Transmission Investment Costs}}$$

- Non-Transmission Costs include: Generation Investment, Fuel, Fixed O&M, Variable O&M, Carbon, Regulation Up/Down, and Contingency costs

Scenario	ΔD2a	ΔD2b	ΔD3
Base Case	2.02	1.66	1.36
Low Gas Price	1.81	1.52	1.22
High Gas Price	1.76	1.84	1.46
High AC Trx Cost (1.5x)	1.87	1.45	1.29
High AC Trx Cost (2x)	2.26	1.52	1.37
No retirements	1.98	1.72	1.33
Low-cost renewables	2.53	1.77	1.56
High VG	2.09	2.89	1.80

Note: D2a, D2b, and D3 results are shown as savings relative to D1. Emission costs included in the High VG scenario are not included in Net Costs.

Cost Breakdown

Summary of Benefit/Cost Results from CGT-Plan Model

Base Scenario

Capacity or Cost Item	D1	ΔD2a	ΔD2b	ΔD3
Transmission Investment Cost, $B	40.03	2.57	6.76	8.19
Generation Investment Cost, $B	555.23	3.6	10.44	4.17
Operational cost, $B	2376.50	-8.79	-21.70	-15.30
35-yr Net Cost change, $B	-	-2.62	-4.5	-2.94
35-yr B/C ratio	-	2.02	1.66	1.36

High VG Scenario

Capacity or Cost Item	D1	ΔD2a	ΔD2b	ΔD3
Transmission Investment Cost, $B	71.69	16.79	15.6	28.86
Generation Investment Cost, $B	741.38	6.83	8.02	7.95
Operational Cost, $B	2563.3	-41.97	-52.45	-59.85
35-year Net Cost change , $B	NA	-18.35	-28.83	-23.04
35-year B/C Ratio	NA	2.09	2.89	1.80

Note: D1 results are shown as absolute costs; D2a, D2b, and D3 results are shown relative to D1.
In the High VG case, carbon costs are included in the optimization but not the net costs or B/C ratio

Key Findings

- The power system can balance generation and load.
  - Additional transmission enabled lower total installed capacities, especially in the High VG scenario.
- There are substantial positive benefit-cost ratios for increasing the transfer capability between the interconnections.
- Cross-seam transmission has a substantial impact on the location of wind and solar generation additions.
  - Wind shifts to the Eastern Interconnection and solar to the Western Interconnection.
- Additional benefits and costs may exist (e.g., frequency response and resilience to extreme events).

Caveats and Future Work

- **Caveats**
  - The study provides initial valuations of increasing transmission capacity between the interconnections, but it should not be referenced as reporting final ready-to-build designs.
  - The study does not take the place of regional planning studies.
  - The study does not obviate the need for state and federal siting review.
  - The study does not consider the impact on wholesale rates set by the Federal Energy Regulatory Commission (FERC) or North American Electric Reliability Corporation (NERC) reliability standards under Federal Power Act Sections 203, 205, and 206.
- **Potential Future Work**
  - Potential reliability and resilience assessment via AC power flow studies with steady-state and stability modeling
  - Consideration of system resilience and security requirements related to weather and extreme conditions
  - Evaluation of natural gas delivery infrastructure and gas-electric operational coordination.

Thank you

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NREL/PR-6A20-78161

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