HVDC Macro Grid Design – a Strategic US Infrastructure Investment




Annual Transmission Summit

Midwest Governor's Association

Organization of MISO States

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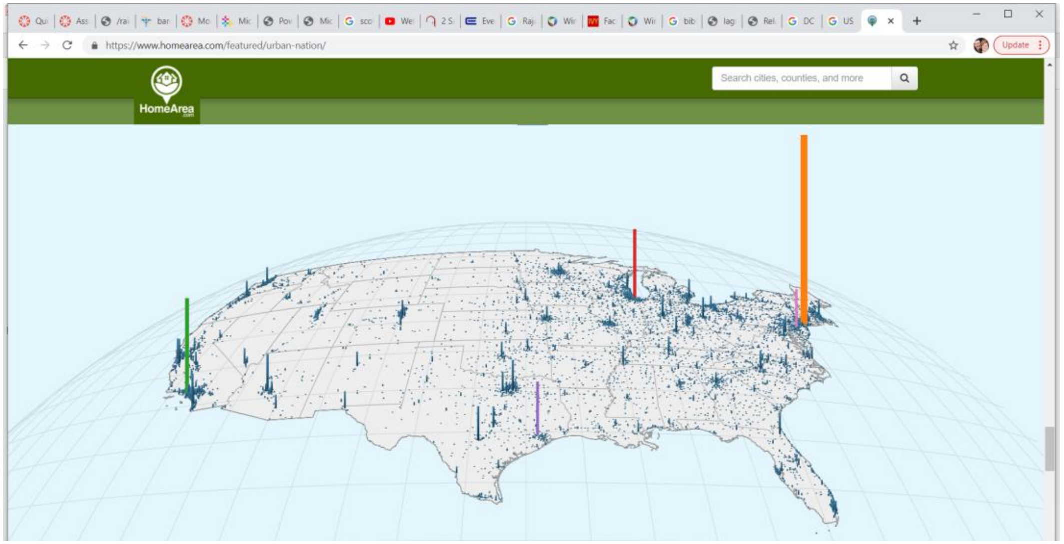
Overview

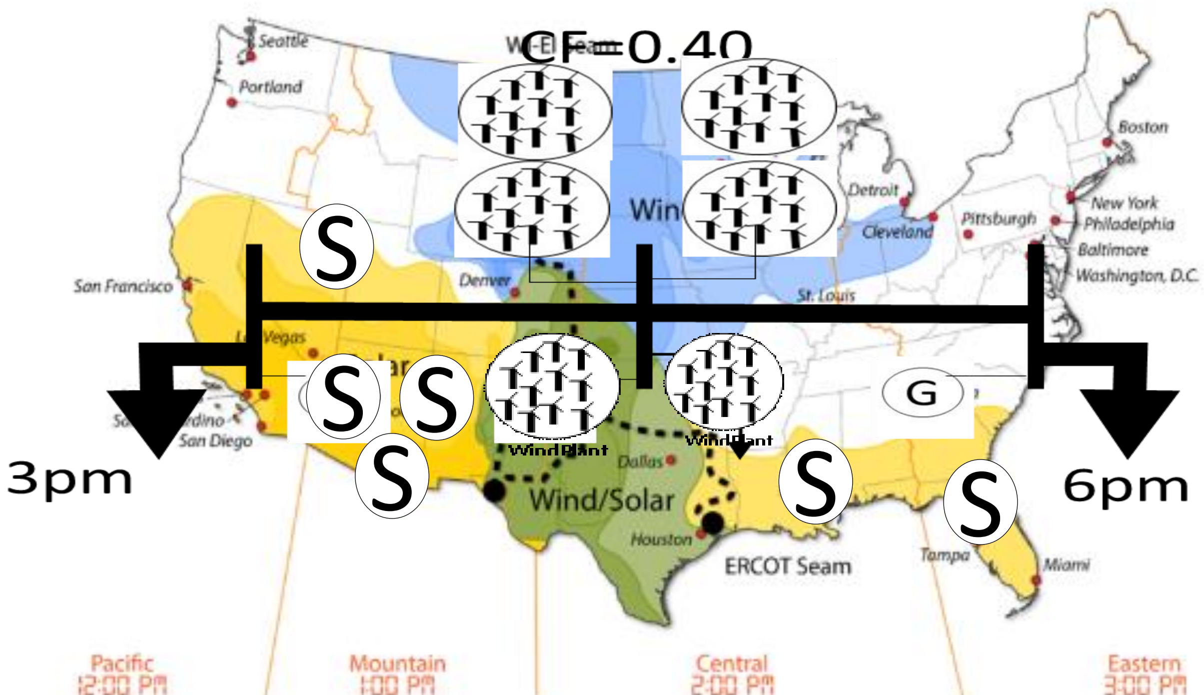
1. Motivation & objective
2. Power system design tool
3. Data, assumptions, design concepts
4. Results, benefits & an operational visual
5. Recent studies and activities
6. Takeaways – how will the macro grid change the BPS?

1. A. Figueroa Acevedo, A. Jahanbani, H. Nosair, A. Venkatraman, J. McCalley, A. Bloom, D. Osborn, J. Caspary, J. Okullo, J. Bakke, and H. Scribner, "Design and Valuation of High-Capacity HVDC Macrogrid Transmission for the Continental US," IEEE Transactions on Power Systems, Vol. 36, No. 4, July, 2021, Available: https://ieeexplore.ieee.org/document/8977392.
2. A. Bloom, J. Novacheck, G. Brinkman, J. McCalley, A. Figueroa-Acevedo, A. Jahanbani-Ardakani, H Nosair, A. Venkatraman, J. Caspary, D. Osborn, and J. Lau, "The Value of Increased HVDC Capacity Between Eastern and Western U.S. Grids: The Interconnections Seam Study," IEEE Transactions on Power Systems." Available: www.nrel.gov/docs/fy21osti/76850.pdf, https://ieeexplore.ieee.org/document/9548789.
3. A. Bloom (chair), "Transmission Planning for 100% Clean Electricity,: Energy Systems Integration Group, Feb., 2021, https://www.esig.energy/wp-content/uploads/2021/02/Transmission-Planning-White-Paper.pdf.
4. Q, Zhang, J. McCalley, V. Ajjarapu, J. Renedo, M. Elizonda, A. Tbaileh, "Primary frequency support through North American Continental HVDC Interconnections with VSC-MTDC Systems," IEEE Trans. Pwr Sys, 2020. vol. 36, no. 1, Jan. 2021. https://ieeexplore.ieee.org/document/9154589.
5. https://acore.org/mgi-library/: ACORE Macro Grid Initiative Library: Relevant materials highlighting the benefits of the Macro Grid.

Intro: Motivation for Seam Study



www.homearea.com/featured/urban-nation/



Midwestern wind with large loads at the coasts.
Little transmission to the east; almost none to the west.

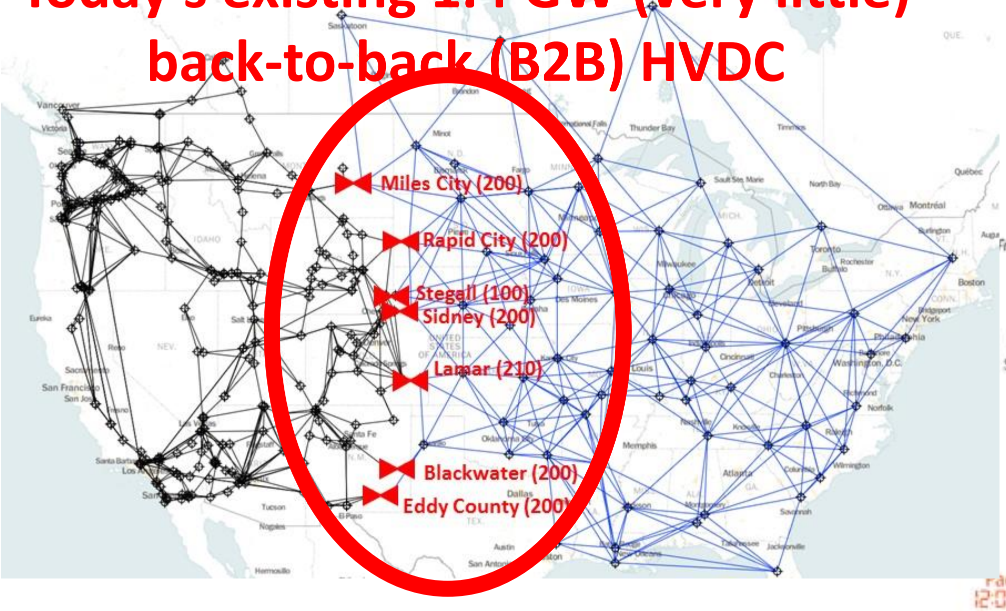
Solar potential is in the south, but better in SW than SE.

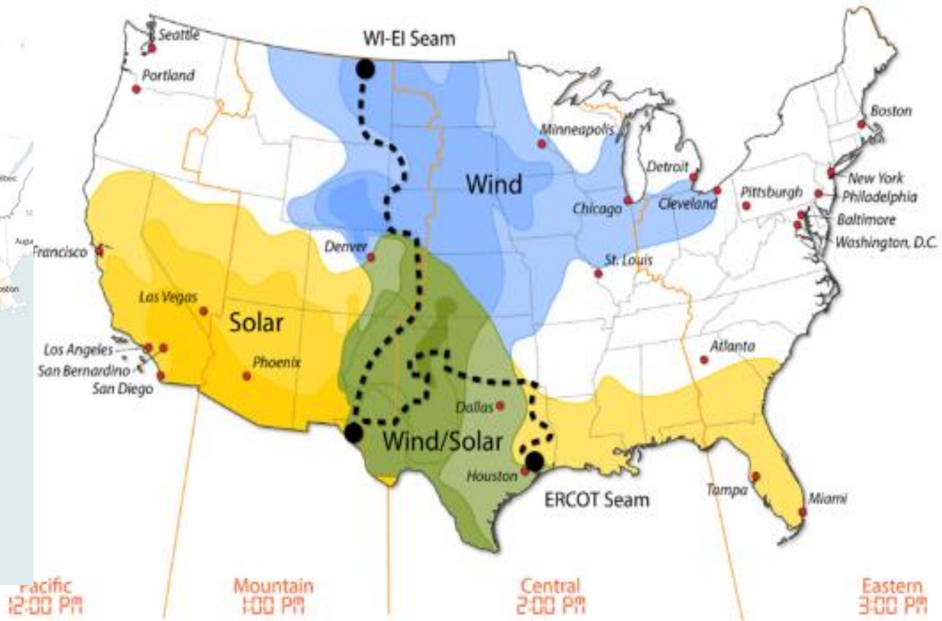
High western solar at hour 8am or 3pm could contribute to eastern peaks at 11am or 6 pm.

Interconnections Seam Study: Objective

Given a high-renewable future for electric energy production, what is the economic value of increasing cross-seam transmission over 2024-2038?

Today's existing 1.4 GW (very little) back-to-back (B2B) HVDC





<u>Rationale</u>: Cost of the transmission build is significantly exceeded by **direct economic energy & capacity savings** due to:

1. **<u>Resource quality</u>**: reduced $/MWhr for wind/solar (accessing high-quality renewables)
2. **<u>Daily energy</u>**: lower cost of daily energy & op. reserves (sharing across time zones)
3. **<u>Peaking capacity</u>**: reduced capacity-build for planning reserves (sharing between regions peaking on different days of the year)

Power System Design Tool: Co-optimized Expansion Planning

Exploratory, not predictive.

TODAY

2024

2029

2034

2039

Identifies transmission & generation investments over time period (~5-35yrs) to minimize net present worth of

- investment costs plus
- operational costs

subject to assumed future conditions

Data

Time-synchronized wind, solar, and load data

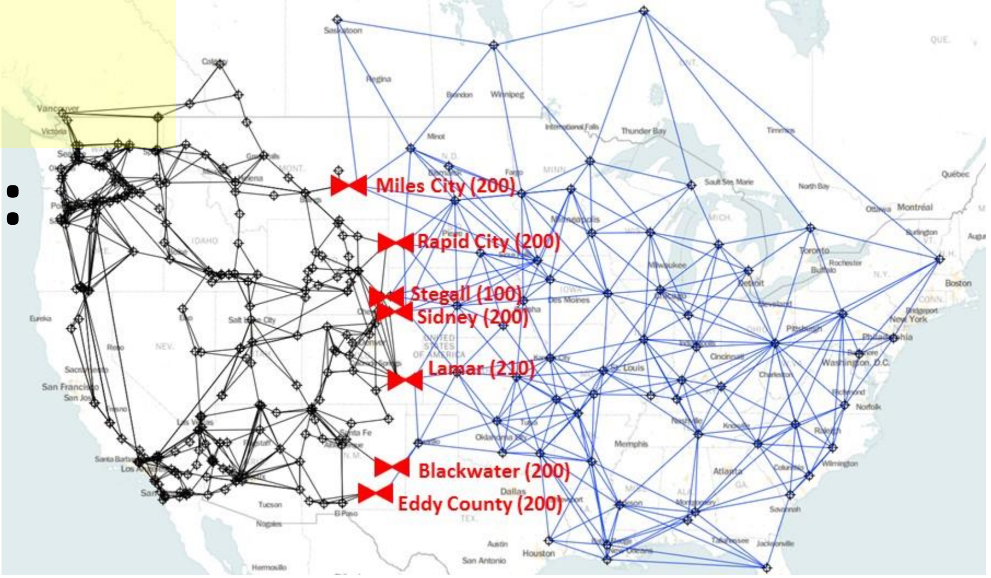
- Wind: 2012 Wind toolkit www.nrel.gov/grid/wind-toolkit.html
  (From WRF, 100-m, 3 wind technologies, 3 wind-bins)
- Solar: 2012 NSRDB https://nsrdb.nrel.gov/
- Load: 2012 FERC Form 714 and RTOs

Transmission and Generation, reduced from:

- WECC TEPPC 2024-Western Interconnection*
- MMWG 2026-Eastern Interconnection **

* M. Bailey, B. Brownlee, K. Moyer, and H. Zhang, “Planing for Energy Futures: The WECC Interconnection-wide Transmission Expansion Experience,” IEEE Power Engineering Society General Meeting, 2014. Also, see www.wecc.org/SystemAdequacyPlanning/Pages/Datasets.aspx.

** https://rfirst.org/ProgramAreas/ESP/ERAG/MMWG



<u>Other data sources</u>:

- Fuel cost forecasts according to AEO 2017 (med-gas)
- Demand growth per NEEM & E3 (WI) per state
- Gen investment base costs & maturation rates from NREL ATB ‘16
- Transmission base costs according to EIPC/B&V
- Gen & trans regional cost multipliers from EIPC/WECC

Assumptions

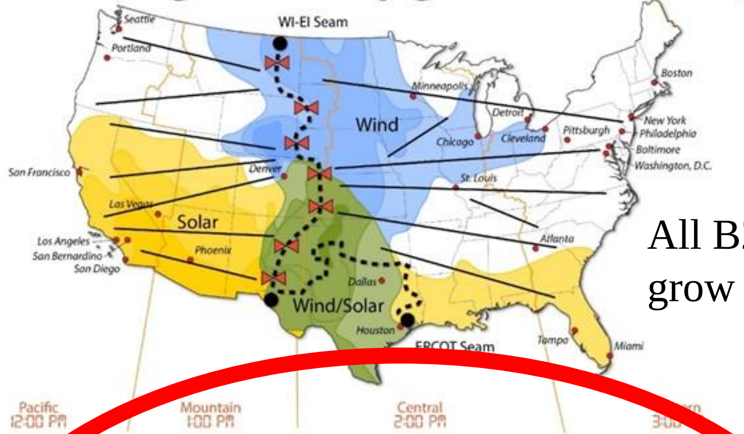
1. DG growth per AEO 2016, 3% per yr
2. Gen capacity investment limited to 40GW/yr: 15 year limit of 600GW
3. Retire gen unit if zero energy or reserves contribution
4. Spur transmission cost approximated based on distance from wind/solar site to closest bus
5. O&M/investment costs assessed at NPV w/ real DR=5.7%.
6. Run for 15 yrs w/ 7 investment periods (every other yr)

7. State renewable portfolio constraints not enforced
8. Escalating cost of CO_2 at $3/MT/year 2024-2038.

Design concepts

Design 1: No CS Transmission

Design 2a: Upgrade existing



All B2B ties may grow w/o constraint.

Design 2b: Upgrade existing + 3 lines

- 3 line design with B2B investments allowed.
- Lines must have equal capacity.

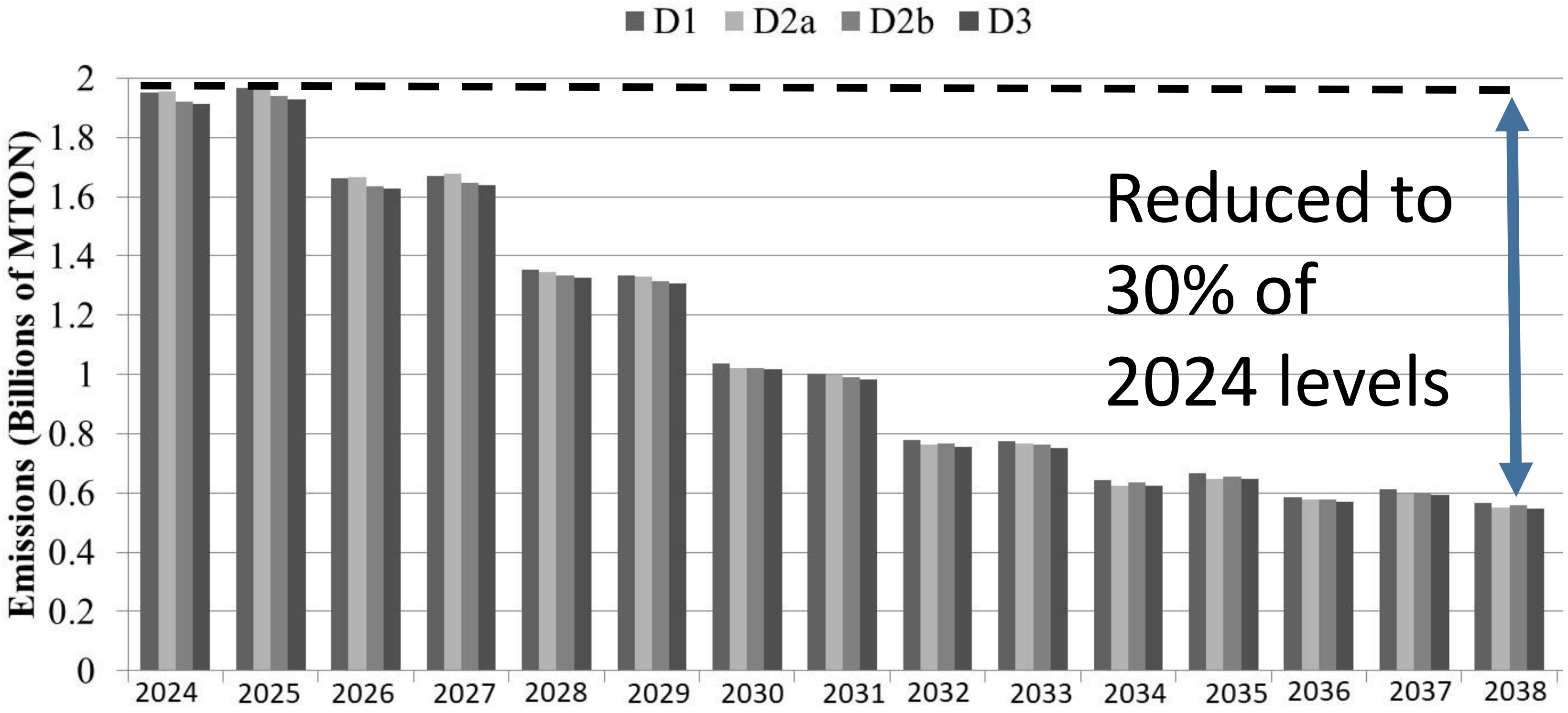
Design 3: Macrogrid

All segments have equal capacity

Common to all transmission designs

All designs resulted in

- 600 GW investment (~392GW wind, 170GW PV, 38GW gas)
- Retirement of 250-300GW coal
- 50% renewable energy production in 2038
- Reduction of CO_2 to 30% of 2024 levels

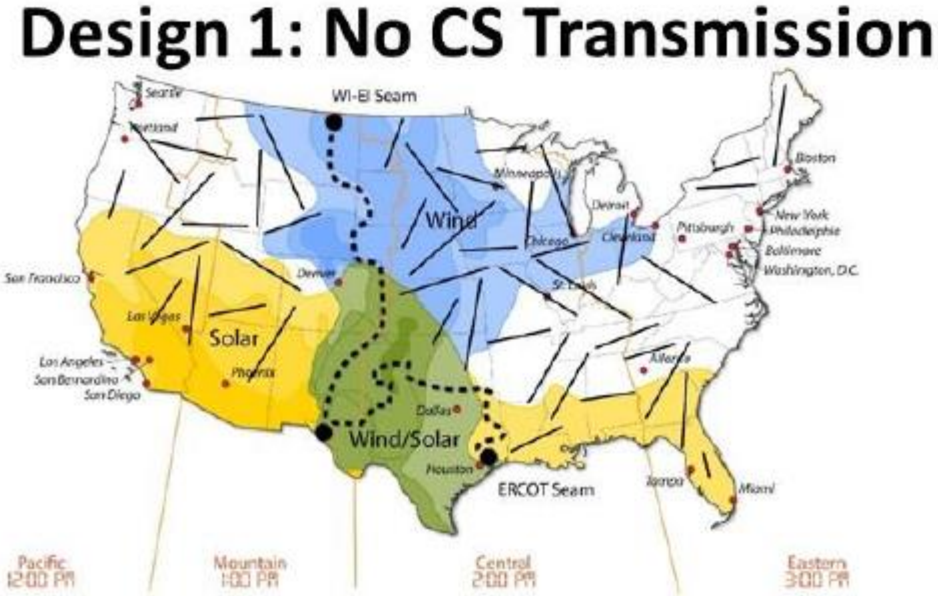


Results: 50% renewables, 2024-2038, Designs 1, 3

Relative to D1, 32 GW of cross-seam capacity causes

← 26 GW solar investment to move westward

→ 37 GW wind investment to move eastward



Results: 50% renewables, 2024-2038, Designs 1, 3

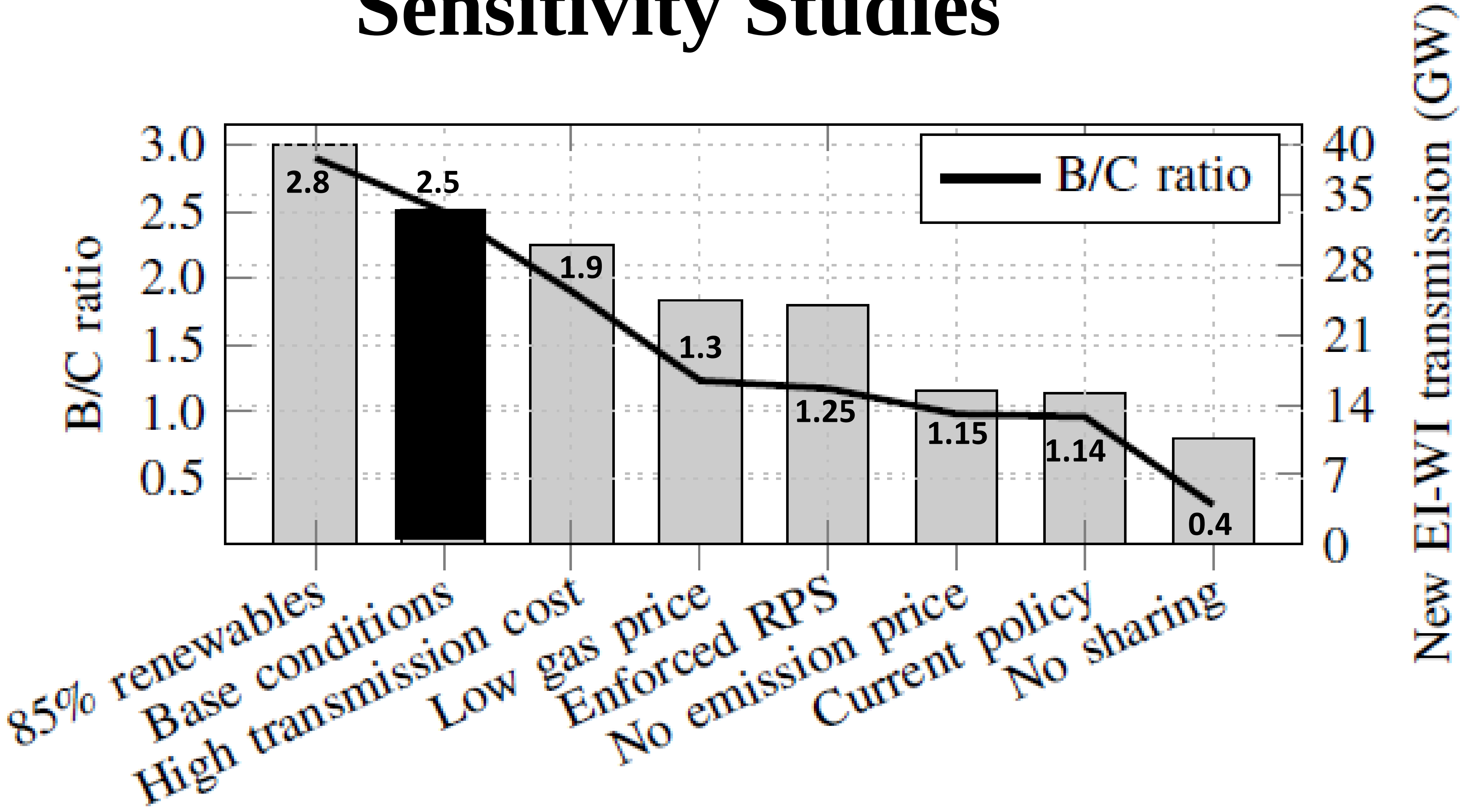
$B	Design 1	Design 3	Δ
Total Line Investment	62.2	80.1	+18.9
Gen Investment	704.0	700.5	-3.5
O&M	1507.5	1463.1	-44.4
35-yr B/C Ratio (orange/blue)	-	-	2.52

$$\frac{\text{GenRelatedSavings}}{\text{IncreasedTransCost}} = \frac{\Delta \text{O\&M} + \Delta \text{GenInv}}{\Delta \text{Trans}} = \frac{44.4 + 3.5}{18.9} = 2.52$$

Capacity (GW)	Design 1	Design 3	Δ
Invested AC transmission	228.9	195.1	-33.8
Invested DC transmission	0	125.8	125.8
Total invested gen (wind, solar, gas),	600 (386/177/37)	600 (392/170/38)	0 (6/-7/1)
Retired generation	240	294	54
2038 creditable capacity	838.5	794.1	-44.4

- DC reduces AC investment
- Gen investment <u>amounts</u> don't change (locations do!)
- DC retires more gen & reduces creditable capacity…due to reserve sharing.

Sensitivity Studies



Summary of benefits

- Direct economic savings; macro-grid pays for itself
  1. **<u>Resource quality</u>**: reduced $/MWhr for wind/solar (accessing high-quality renewables)
  2. **<u>Daily energy</u>**: lower cost of daily energy & op. reserves (sharing across time zones)
  3. **<u>Peaking capacity</u>**: reduced capacity-build for planning reserves (sharing between regions peaking on different days of the year)
- Non-quantified benefits (NQBs):
  - Reliability benefits associated with improved control:
    - Transient frequency response
    - Transient stability
    - Voltage control and stability
    - Additional damping
  - Benefits of interregional sharing
    - Decreased cost of extreme events due to high winds, extreme temp, floods, droughts)
    - Increased adaptability to permanent changes (nuclear, gas)
  - Savings in interconnection cost to “collect” renewables

Watch it operate…

A sped-up sequence of 24 hour periods.

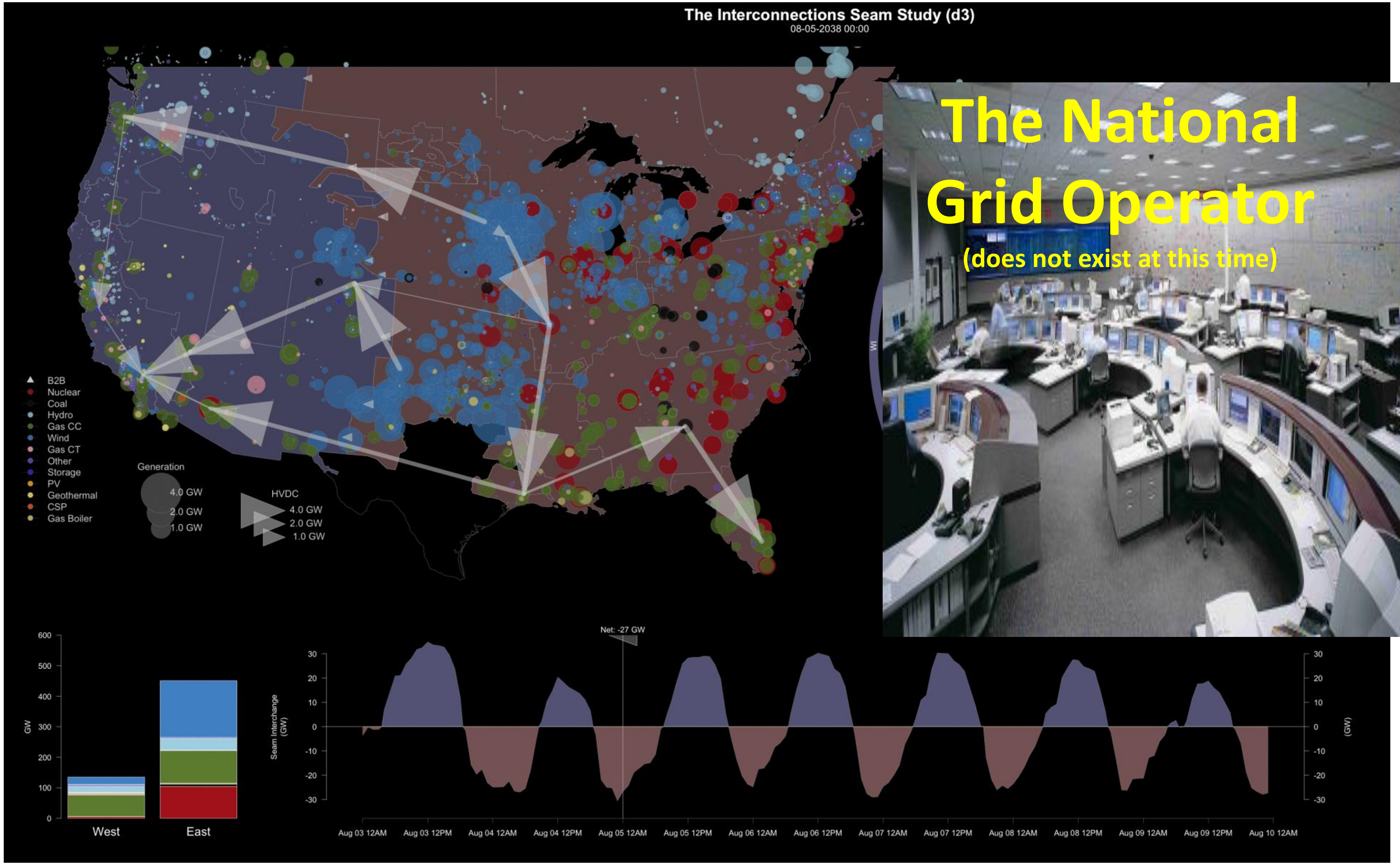
- Blue dots=wind;
- Yellow=solar.

Daytime is lighter, w/solar;

Flow is W→E

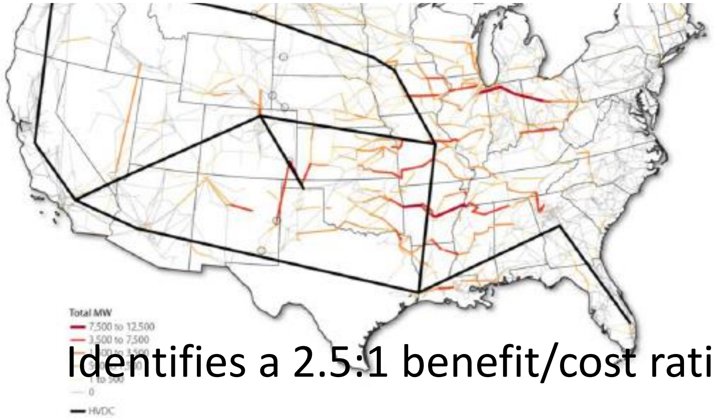
Nighttime is darker, w/wind;

Flow is E→W



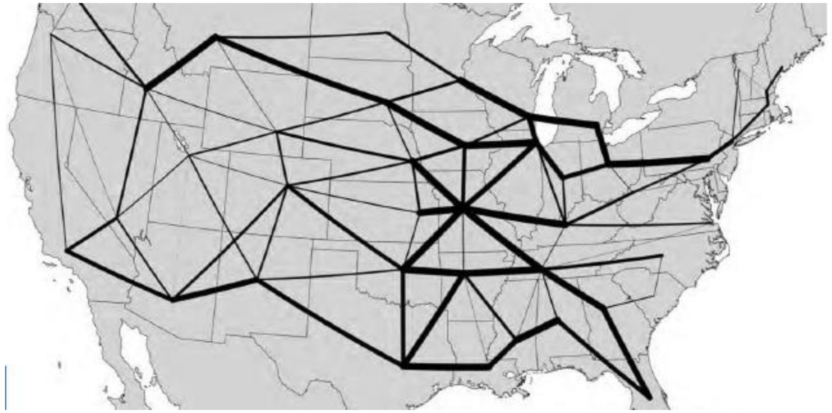
Recent Studies

Interconnections Seam Study, 2018
www.nrel.gov/analysis/seams.html



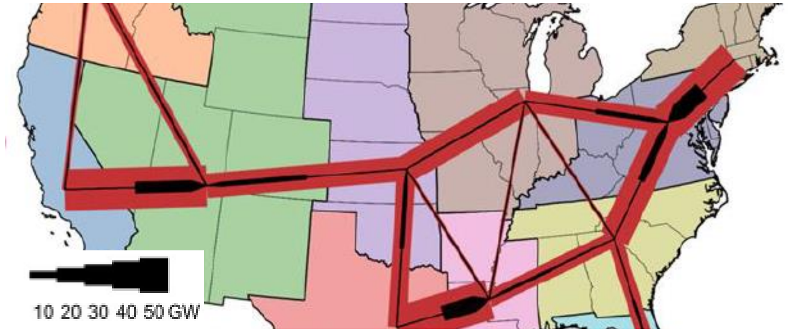
Identifies a 2.5:1 benefit/cost ratio.

Zero by Fifty, 2021
www.vibrantcleanenergy.com/wpcontent/uploads/2020/11/ESIG_VCE_11112020.pdf

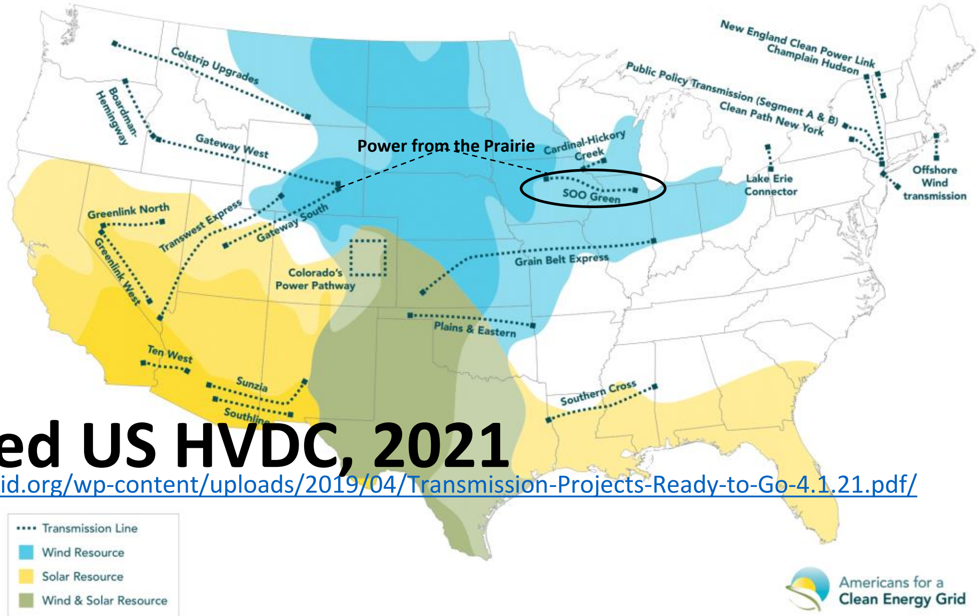


Finds that it a macro grid is NOT built, it costs an additional $1 Trillion to get to 100% clean energy by 2050.

MIT – Decarbonization value of transmission, 2020
https://doi.org/10.1016/j.joule.2020.11.013



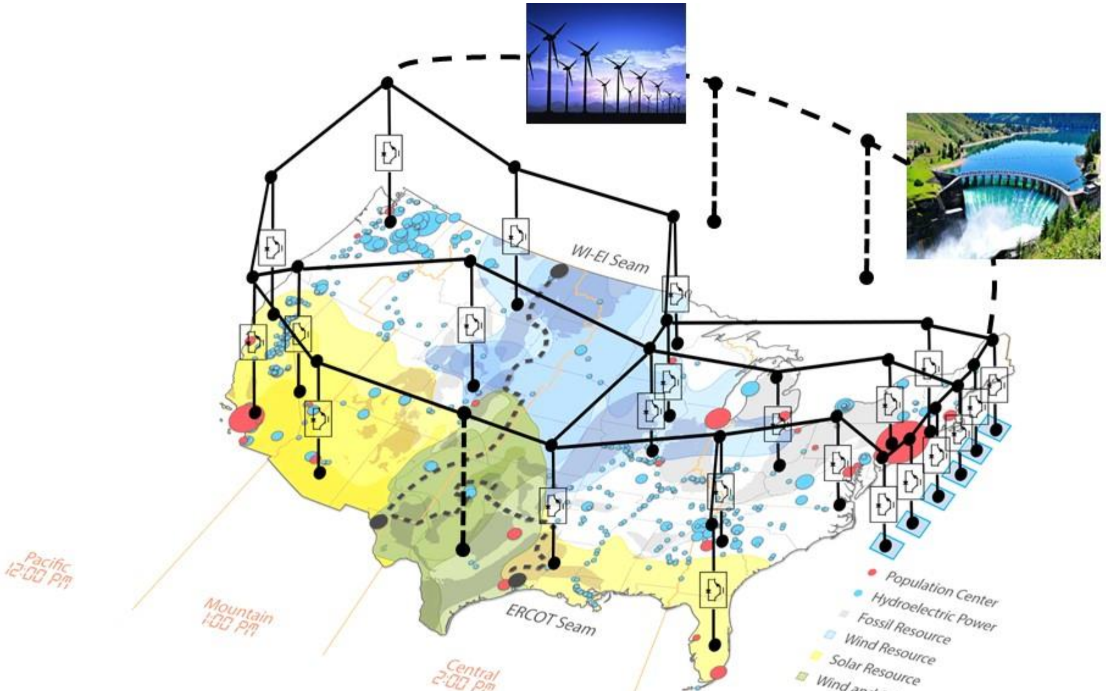
Finds that an "every state for itself" approach has a levelized capital/O&M cost of $135/MWh which can be halved with interregional transmission expansion.



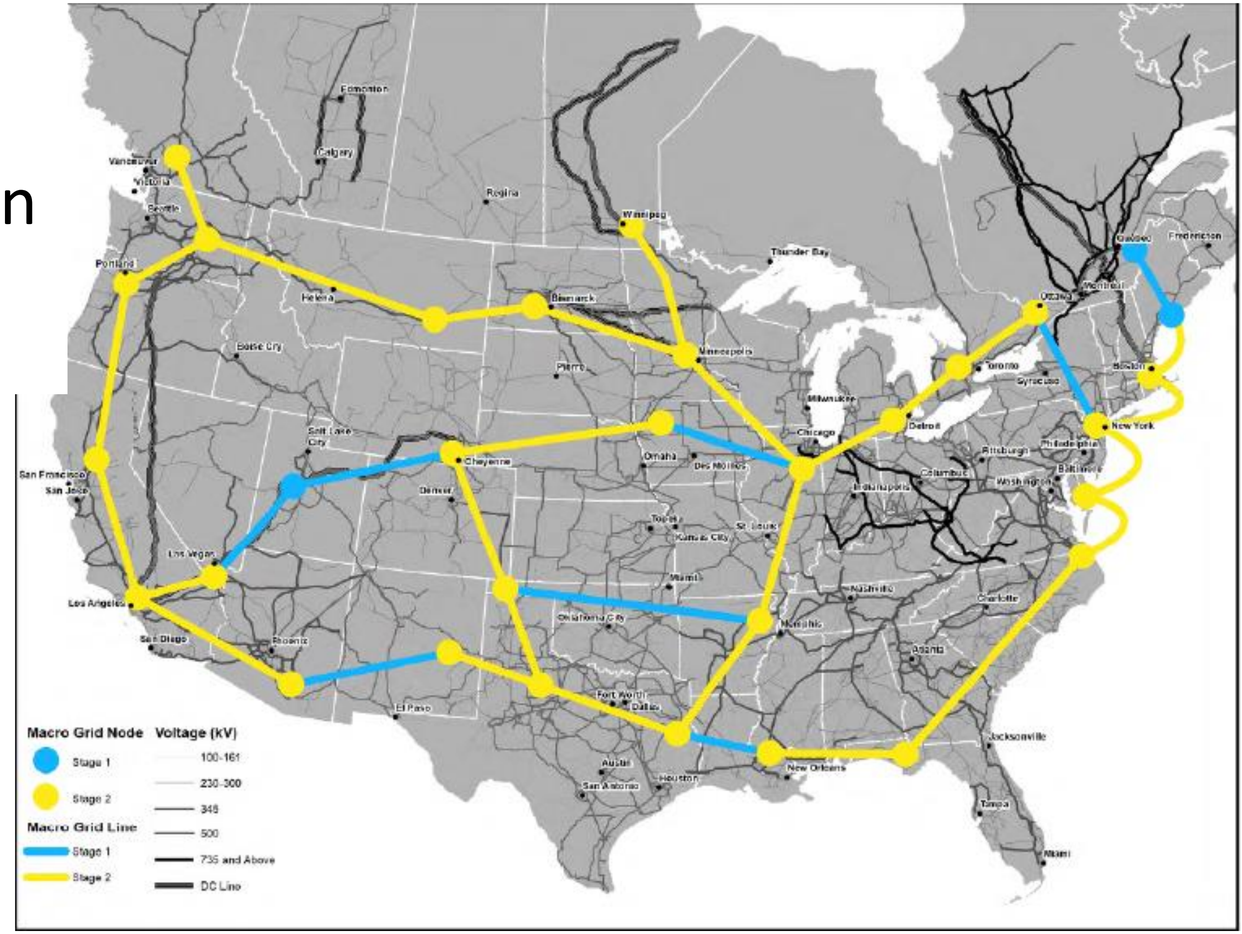
Proposed US HVDC, 2021
https://cleanenergygrid.org/wp-content/uploads/2019/04/Transmission-Projects-Ready-to-Go-4.1.21.pdf/

Recent Activities

- ESIG held 10 hrs of discussions in 12/20 with 50 experts to consider transmission for 100% clean energy & macro grid design
  www.esig.energy/transmission-planning-for-100-clean-electricity
- ESIG funding Macro Grid Scoping Project
- Much offshore work ongoing with some studying relation to Macro Grid



*National Offshore Wind Research & Development Consortium



- DOE (OE) kicking off NREL/PNNL transmission-focused study
  - Will study MacroGrid
  - To directly involve RTO planners
  - RTOs must be involved in multiregional studies

Takeaways: How will the Macro Grid Change the BPS?

1. ***Dispatch of Energy and Ancillary Services***: The most economically attractive resources for energy & ancillary services can be dispatched to cover energy demand across 4 time zones to serve all regions.
2. ***Continental deliverability***: Energy, capacity, and ancillary services are deliverable from any region of the country to any other region, not just between neighbors.
3. ***Better grid management; improved reliability & resilience***:
   - *Diversity*: The Macro Grid provides access to resources everywhere; effectively diversifying what is available to a particular region.
   - *Control*: Macrogrid terminals offer very large control opportunities for grid management enhancing system security during routine & high-consequence events.
4. ***AC & DC nodes***: Utility-scale wind & solar plants can be AC- or DC- connected. The ability to connect wind/solar plants at DC changes fundamentals of converters & collection circuits used at these plants.
5. ***Ultra-wide area monitoring***: A central operator sees the nation's entire grid and coordinates with regional grid operators.
6. ***Scale***: Macrogrid is the only approach that has the SCALE necessary to meet societal decarbonization objectives. Incremental approaches (local build-outs, packing more onto existing lines & ROW, use of advanced technology, DER, energy efficiency, etc.) are necessary, but insufficient.

Final comment**: Nation-wide benefit: economic development; energy prices/manufacturing competitiveness; CO_2 abatement costs; infrastructure flexibility; reliability; resilience; adaptability.**