Design and Valuation of High-Capacity HVDC Transmission to Connect Eastern and Western US Electric Grids

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Acknowledgements

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Presentation Outline

PART 1

- Introduction
- Data, assumptions, and tools

  ➔Co-optimized expansion planning application GTD-Plan
- Design concepts and results
- Sensitivities

PART 2: A conclusion

- Non-quantified benefits
- Path forward

Introduction

North American HVDC Interconnection Seam Study: A regional partnership funded by the U.S. DOE's Grid Modernization Initiative, 3/16-8/18

STUDY PARTICIPANTS

- National Renewable Energy Lab (NREL)
- Pacific Northwest National Lab (PNNL)
- Oak Ridge National Lab (ORNL)
- Argonne National Lab (ANL)
- Iowa State University (ISU)
- Southwest Power Pool (SPP)
- Mid-Continent ISO (MISO)
- Western Area Power Authority (WAPA)
- Western Electric Coordinating Council (WECC)

Technical Review Committee

Alberta Independent System Operator
Basin Electric Power Company
Black Hills Energy
Energy Exemplar
El Paso Electric
Electric Power Research Institute
Electric Reliability Council of Texas
Great River Energy
Hydro Quebec
Independent System Operator of Ontario
LS Power
Manitoba Hydro
Minnesota Power
National Grid
National Rural Electric Cooperative Association
NB Power
NextEra
NS Power
Public Service of New Mexico
SaskPower
Solar Energy Industry Association
TransCanyon
Tri-State Generation and Transmission
Utility Variable Integration Group
Western Electric Coordinating Council
Xcel Energy

Disclaimer: Results/conclusions/perspectives communicated in this webinar are those of ISU researchers and are not necessarily embraced by any study participant or technical review committee member organization.

Introduction

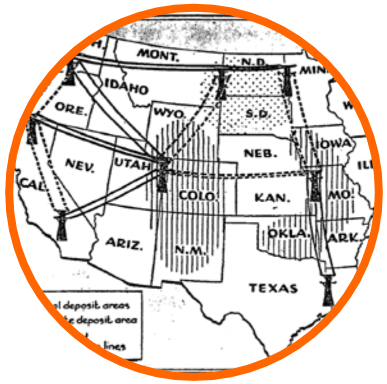
There has been interest for a long time!

Chicago Tribune

1923

Tying the Seasons to Industry

"This is neither prophecy, propaganda, nor rhapsody, but the assured goal of scientific and economic forces at work."
- Chicago Tribune, 1923



Bureau of Reclamation

1952

Super Transmission System

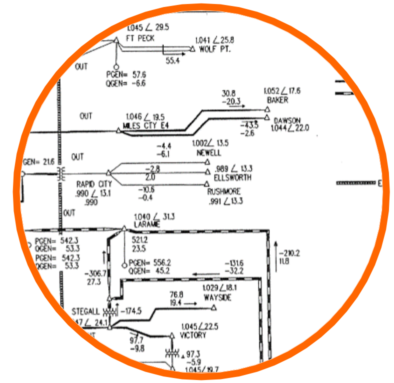
"Such a power system will inevitably come."
- Bureau of Reclamation, 1952

Bonneville Power Administration

1979

Interconnection of the Eastern and Western Grids

"If power transfers of over 500 MW would result in significant benefits, the feasibility of the intercom-nection should be pursued."
- BPA, 1979



Western Area Power Admin

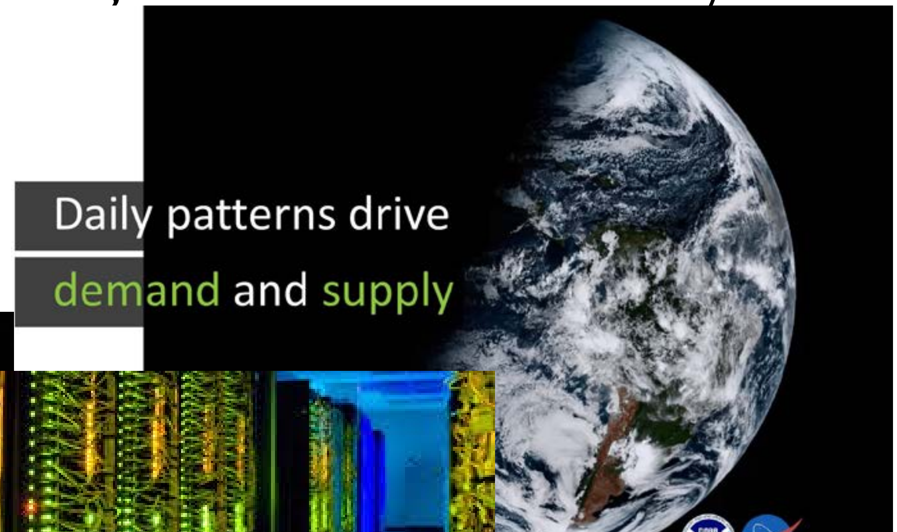
1994

East/West AC Intertie Feasibility Study

"The systems as they exist today… are more robust than… the late 1960s and 1970s."
- WAPA, 1994

Introduction

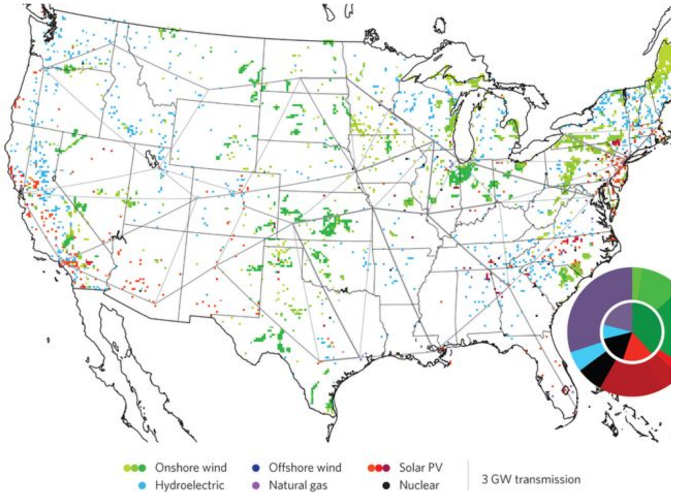
If it looked good in the past, what about today?



- 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

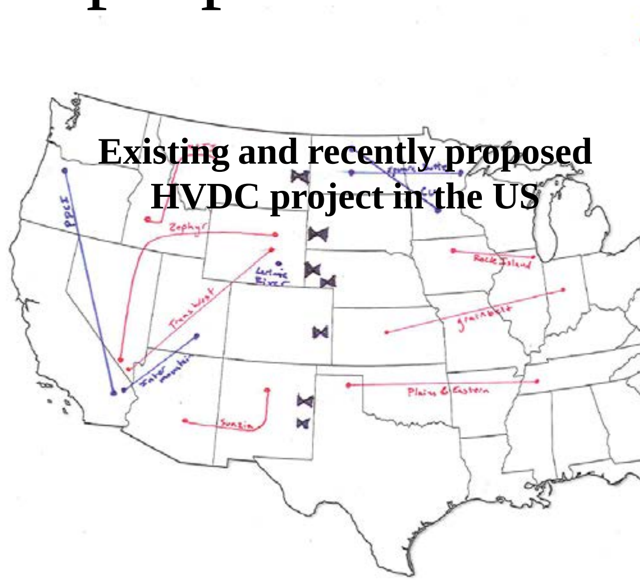
Introduction

Some recent proposals and studies

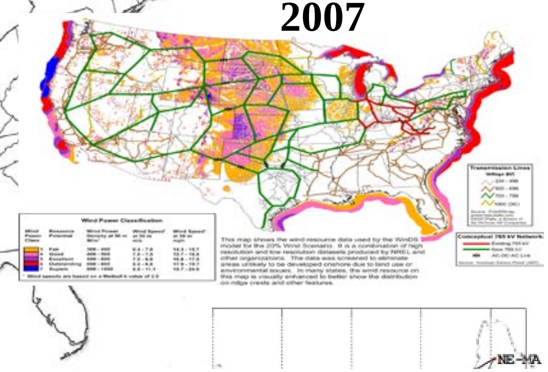


A. MacDonald, C. Clack, A. Alexander, A. Dunbar, J. Wilczak & Y. Xie, “Future cost-competitive electricity systems and their impact on US CO_2 emissions, Nature Climate Change 6, 2016, pp. 526-531.

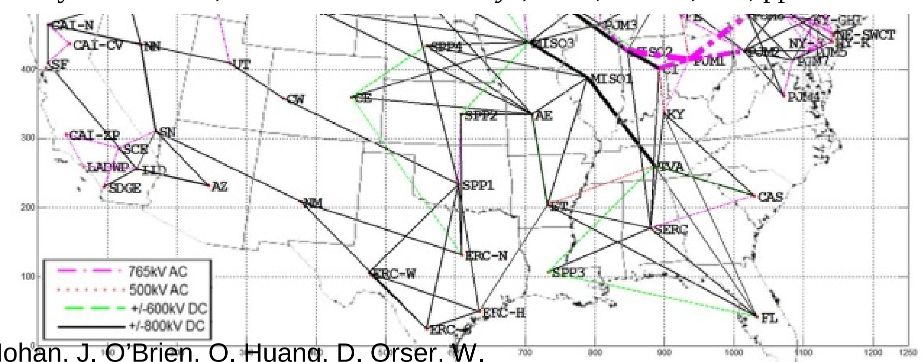
Existing and recently proposed HVDC project in the US

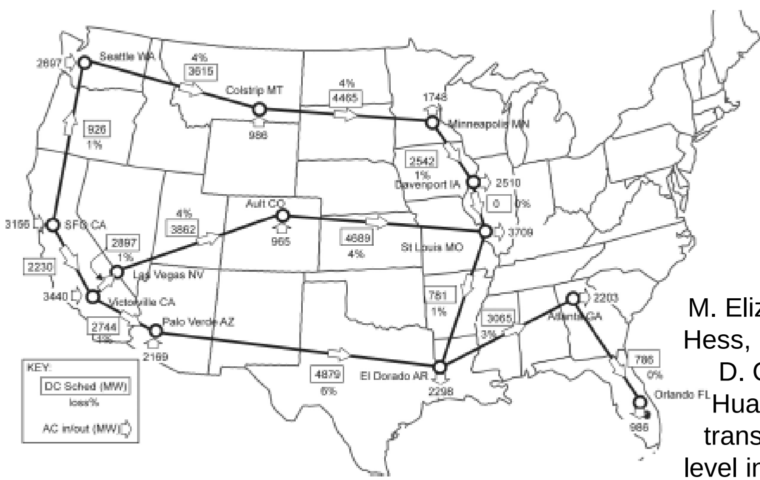


AEP 765kV Design, 2007



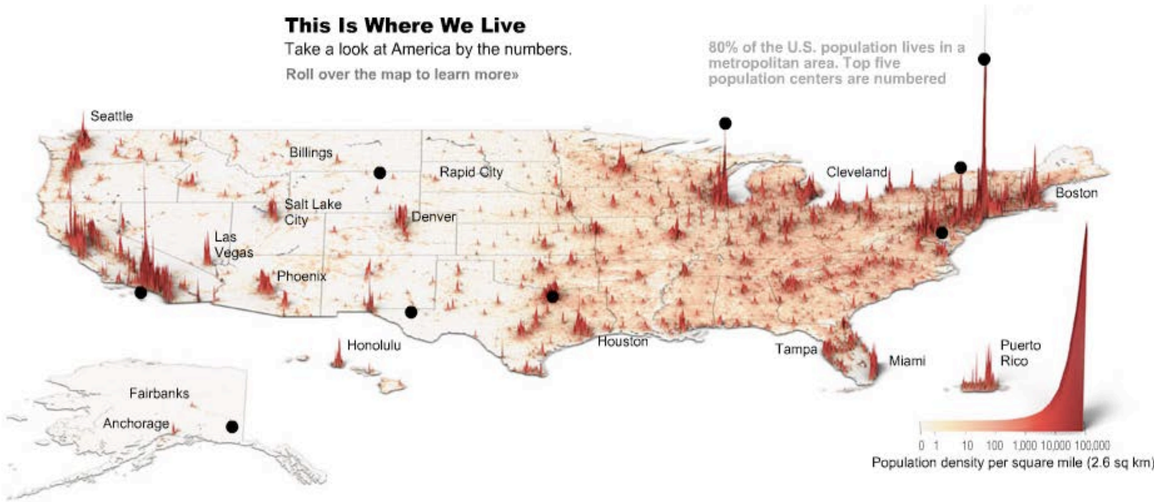
Y. Li and J. McCalley, “Design of a high capacity inter-regional transmission overlay for the U.S.,” *IEEE Trans on Pwr Sys*, 2015, Vol 30, Is 1, pp. 513-521.



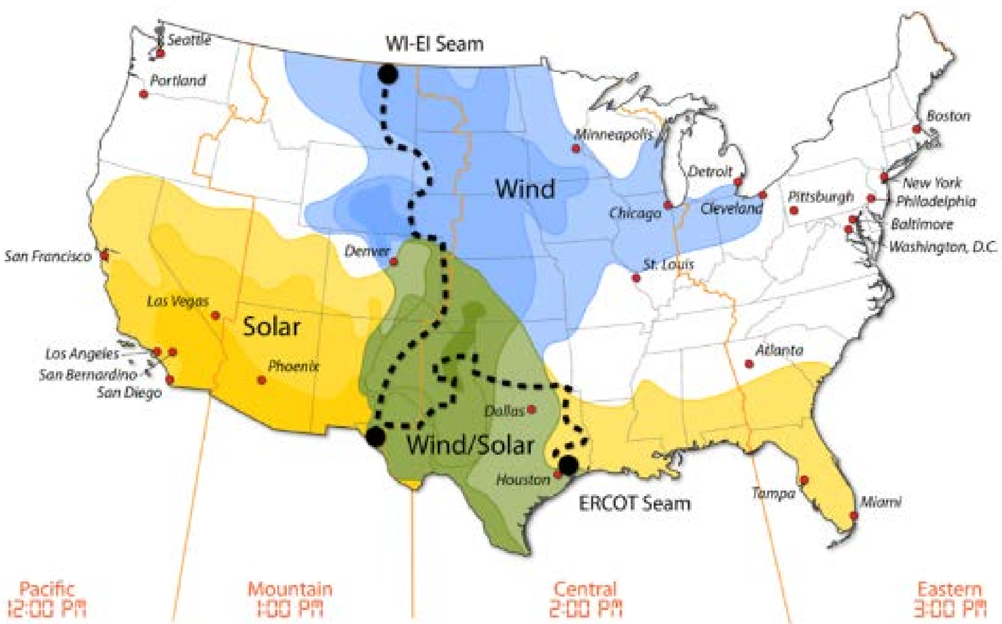


M. Elizondo, N. Mohan, J. O’Brien, Q. Huang, D. Orser, W. Hess, H. Brown, W. Zhu, D. Chandrashekhara, Y. Makarov, D. Osborn, J. Feltes, H. Kirkham, D. Duebner, and Z. Huang, “HVDC Macrogrid modeling for power-flow and transient stability studies in North American Continental-level interconnections,” CSEE Journal of Power and Energy Systems, V 3, I4, 2017.

Introduction



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



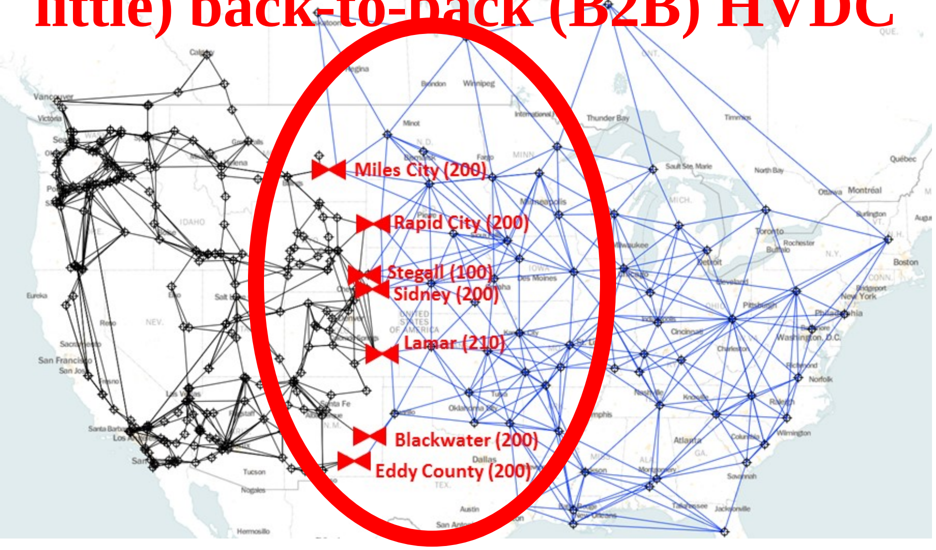
Solar potential is in the south, but better in SW than SE.

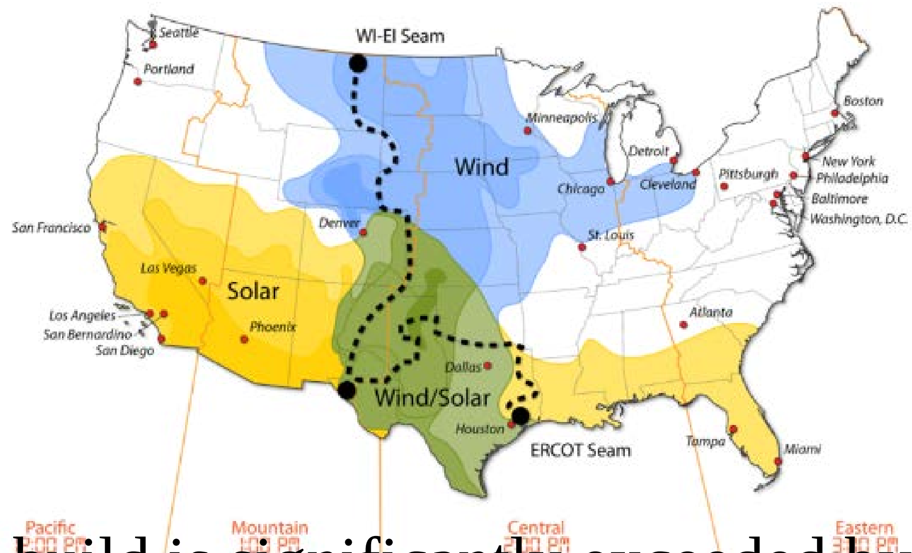
High western solar at hour 8am or 3pm could contribute to eastern peaks at 11am or 6 pm.

Introduction

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

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)

Data, assumptions, and tools

➔ Research-grade and commercial tools

CGTD-Plan (ISU)

- Capital/operating costs 2024-2038
- Gen/transmission system 2038

PLEXOS

- Operating costs 2038
- Hourly unit commitment and economic dispatch

PSSE

- Preliminary analysis of AC power flow impacts

Data, assumptions, and tools
➔ Consistent data between modeling domains

- Wind: 2012 Wind toolkit www.nrel.gov/grid/wind-toolkit.html
  (100 m tower data with 3 wind technologies and 3 wind bins)
- Solar: 2012 NSRDB https://nsrdb.nrel.gov/
- Transmission and Generation:
  - WECC TEPPC 2024-Western Interconnection
  - MMWG 2026-Eastern Interconnection
- Load: 2012 FERC Form 714 and RTOs

Other data sources:

- 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

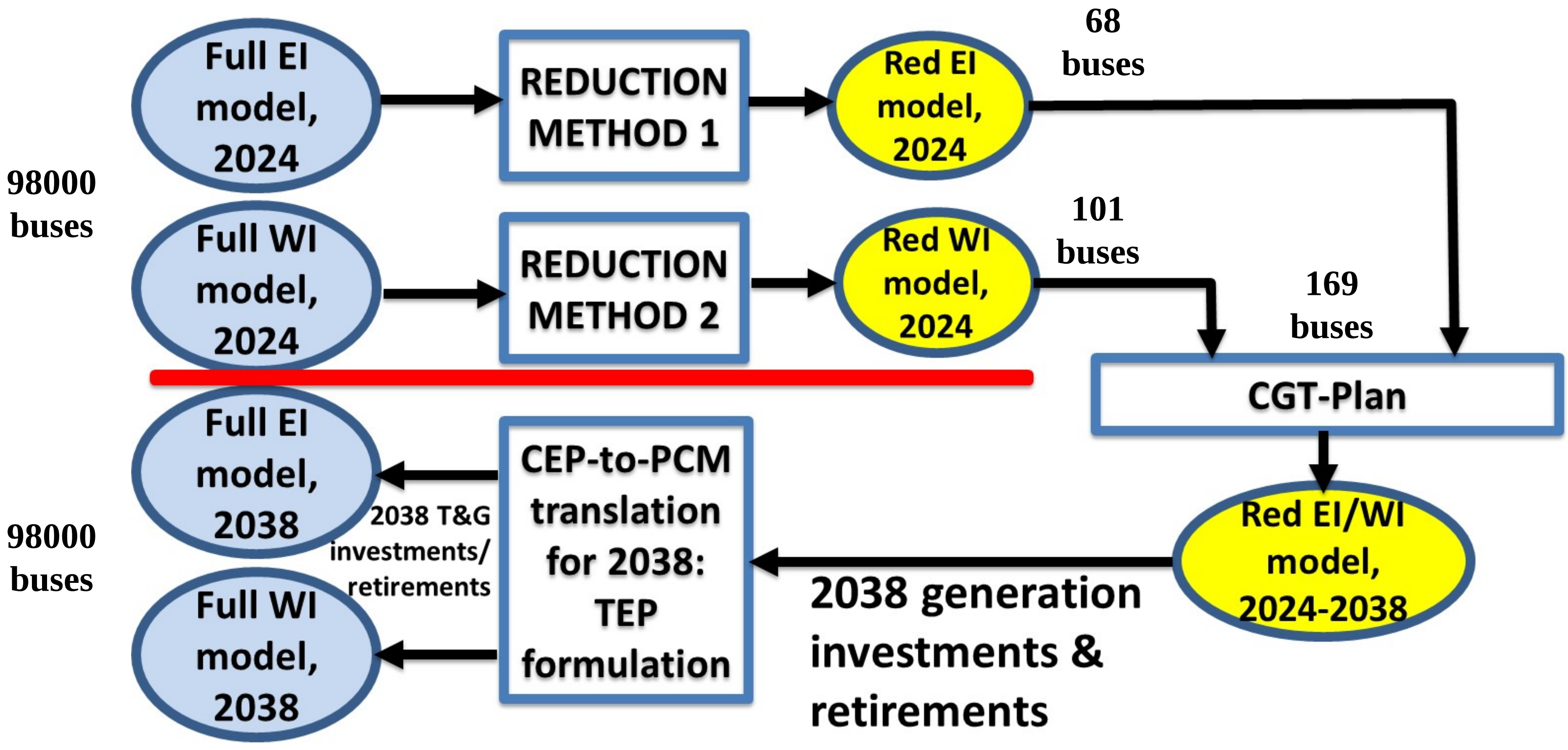
Data, assumptions, and tools

➔ Key Assumptions for Expansion Planning Studies

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

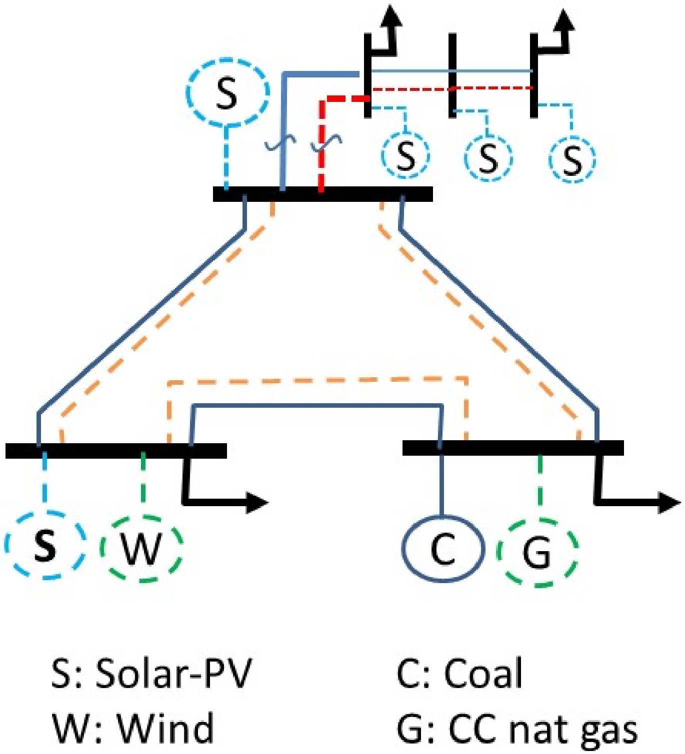
Data, assumptions, and tools

➔ Reduction and translation



Data, assumptions, and tools

➔Co-optimized expansion planning application GTD-Plan



MIN NET PRESENT VALUE

- GTD Investment costs
- + Fixed O&M Costs
- + Var O&M Costs + Fuel Costs
- + Demand Response/EE Cost
- + Environmental Costs

WITH ASSUMPTIONS ON THE FUTURE…

investment costs, load growth, fuel cost, wind, solar, hydro performance

SUBJECT TO CONSTRAINTS ON:

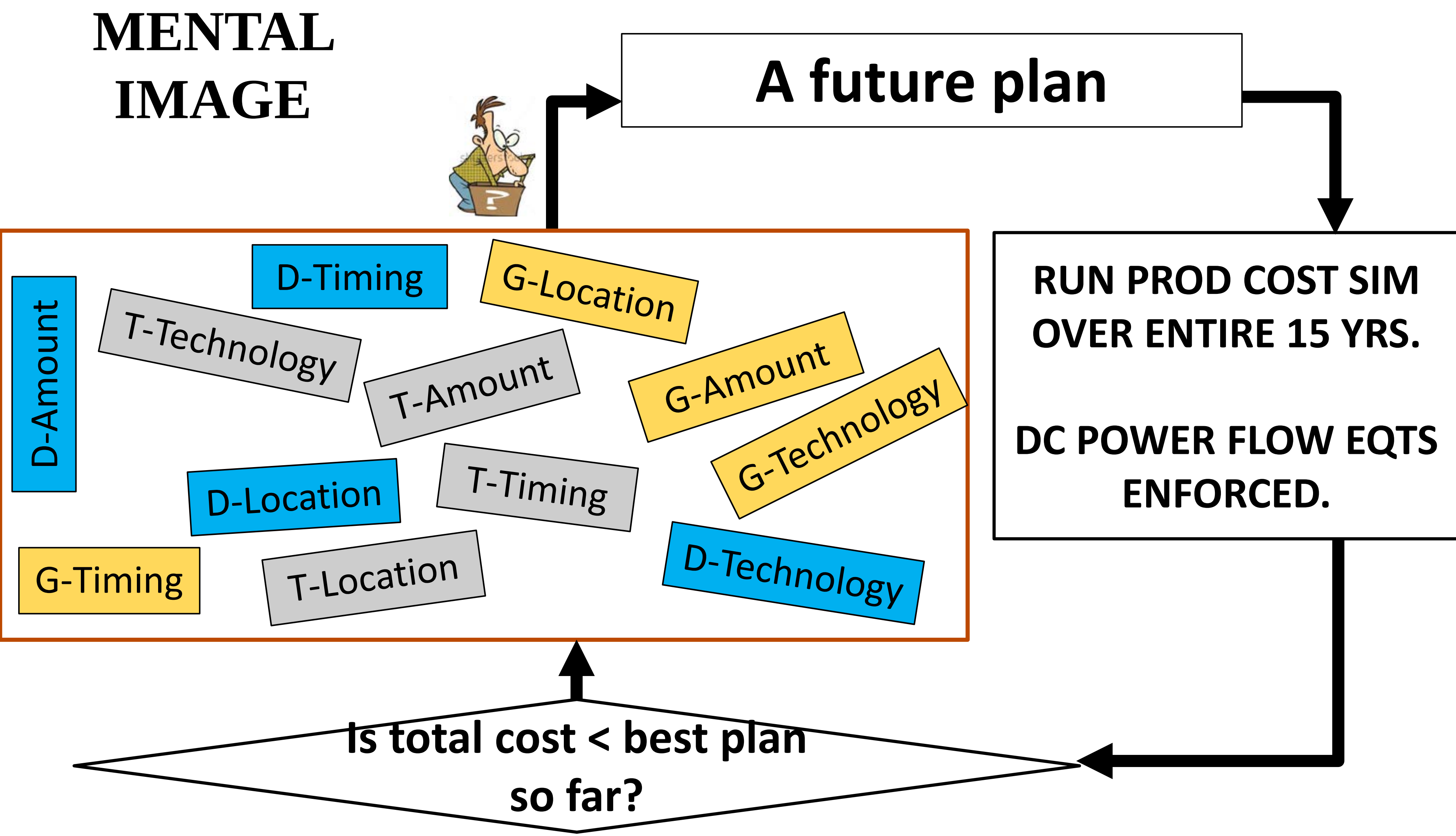
network, operations, investments, environmental

Year 1	**Year 2**	…	**Year 15**

➔Identifies GTD investments (what, when, where, how much) to minimize NPV of investments + operations over 15-yr period

Data, assumptions, and tools

➔Co-optimized expansion planning application GTD-Plan



Data, assumptions, and tools

➔Flexibility constraints

1. Regulation reserves, RU, RD

$$\sum_{\substack{k\in\\ \text{Thermal,}\\ \text{Hydro}}} \mathrm{RU}_k > f\left(\sigma_{\text{NetLoad}}^{\text{1 min,up}}\right) \qquad \sum_{\substack{k\in\\ \text{Thermal,}\\ \text{Hydro}}} \mathrm{RD}_k > f\left(\sigma_{\text{NetLoad}}^{\text{1 min,down}}\right)$$

2. Contingency reserves, CR

$$\sum_{\substack{k\in\\ \text{Thermal,}\\ \text{Hydro}}} \mathrm{CR}_k > \Delta P_{\text{Max}}$$

These constraints imposed system-wide.

They are valued at each unit's cost to supply energy.

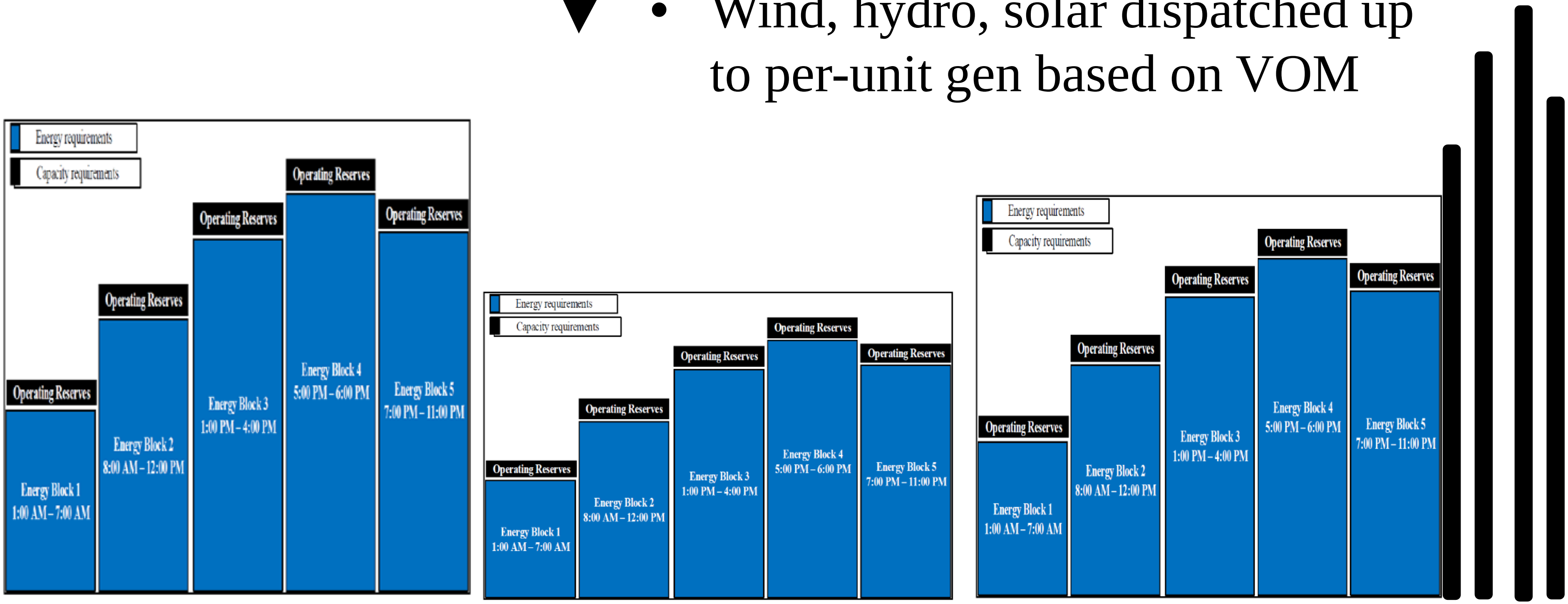
Data, assumptions, and tools

➔Development of operating blocks

$P_{wind}(t,y)$ $P_{hyd}(t,y)$
$P_{solar}(t,y)$ $P_{load}(t,y)$
$t=1,8760;\ y=1,20$

8760hr profiles of wind, hydro, solar, load

- Blocks defined by time-of-day
- Wind, hydro, solar dispatched up to per-unit gen based on VOM

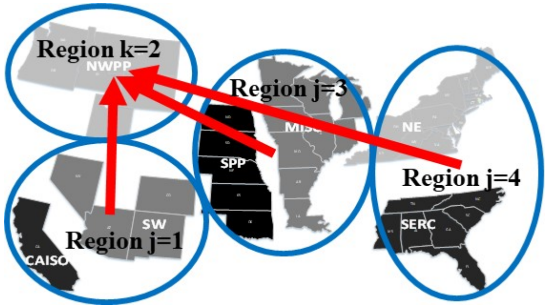


Summer Winter Shoulder Regional peaks

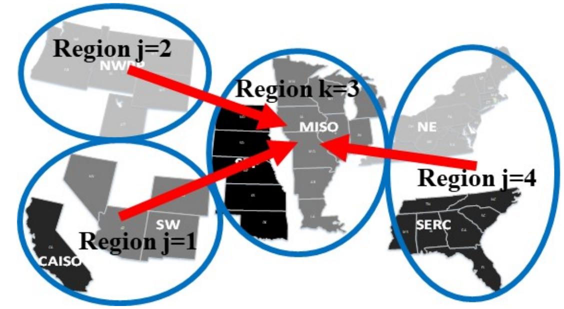
19 op blocks/yr: semi-chronological - captures avg diurnal & seasonal variations of wind, solar, hydro, and load.

Data, assumptions, and tools

➔Annual planning reserves



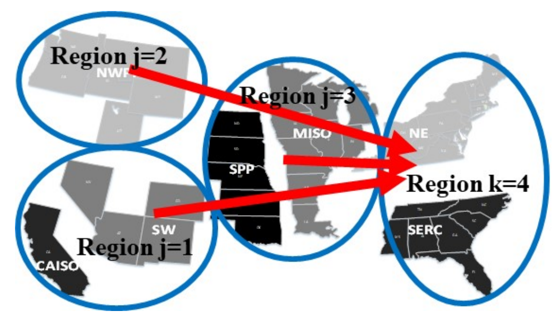
Northwest Annual Peak
Jan 3 @ 10pm EST



Midwest Annual Peak
Aug 3 @ 5pm EST

4 additional 1-hour blocks
Each represents a regional peak
All load scaled by 1.15
Peaking resources at capacity value
Nonpeaking resources at capacity factor

Southwest Annual Peak
Aug 11 @ 11pm EST



East Annual Peak
Aug 21 @ 5pm EST

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

Renewables	State RPS	CO_2 cost
40%	Enforced	Zero
50%	Not enforced	Increases at $3/mton/yr

Results: 40% renewables, 2024-2038

ECONOMICS, NPV $B	Design 1	Design 2a	Delta	Design 2b	Delta	Design 3	Delta
Line Investment Cost	23.50	26.69	3.19	31.50	8.00	37.70	14.20
Generation Investment Cost	493.60	494.70	1.10	492.50	-1.10	494.20	0.60
Fuel Cost	855.10	852.70	-2.40	851.20	-3.90	845.60	-9.50
Fixed O&M Cost	416.40	415.60	-0.80	413.70	-2.70	413.80	-2.60
Variable O&M Cost	81.00	81.10	0.10	81.20	0.20	81.20	0.20
Carbon Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Regulation-Up Cost	31.60	30.97	-0.63	31.13	-0.47	30.02	-1.58
Regulation-Down Cost	45.10	44.20	-0.90	44.42	-0.68	42.85	-2.26
Contingency Cost	23.90	23.42	-0.48	23.54	-0.36	22.71	-1.20
Total Non-Xm Cost (Orange)	1947.01	1943	-4.01	1937.7	-9.01	1930.38	-16.34
15-yr B/C Ratio (Orange/Blue)			1.26		1.13		1.15

The below row provides annualized (over 20 yrs) perpetuity cost for the CP designs. Interpretation is that CP designs 2a, 2b, & 3 will see the above 15-year B/C plus a savings each year over 20 years equal to the annualized perpetuity cost in yellow.

Perpetuity (Annualized 20-yr) Cost	72.32	70.88	-1.45	69.94	-2.39	68.71	-3.62

CAPACITY, GW	Design 1	Design 2a	Delta	Design 2b	Delta	Design 3	Delta
Total gen invested (W/S/G)	461 (225/209/27)	459 (229/202/28)	-2.0 (7/-4/1)	458 (232/201/25)	-5.0 (10/-3/-3)	465 (230/209/26)	4.0 (8/-3/-1)
Total gen retired	202	212	10	226	14	222	20
Total 2038 creditable capacity	857.5	846	-11.5	822.5	-35	830.1	-27.4
Total AC Xm invested	92	95	3	89	-3	84	-8
Total DC Xm invested	0	7	7	20	20	58	58

Results: 40% renewables, 2024-2038, Designs 1, 3

Billion $	Design 1	Design 3	Δ
Total Line Investment	23.5	37.7	+14.2
Gen Investment	493.6	494.2	+0.6
O&M	1453.1	1436.2	-16.9
15-yr B/C Ratio (orange/blue)	-	-	1.15

$$\frac{\text{GenRelatedSavings}}{\text{IncreasedTransCost}}$$

$$= \frac{\Delta\text{O\&M} + \Delta\text{GenInv}}{\Delta\text{Trans}}$$

$$= \frac{16.9 - 0.6}{14.2} = 1.15$$

Capacity (GW)	Design 1	Design 3	Δ
Invested AC transmission	92	84	-8
Invested DC transmission	0	58	58
Total invested gen (wind, solar, gas),	461 (225/209/27)	465 (230/209/26)	4 (8/-3/1)
Retired generation	202	222	20
2038 creditable capacity	857	830	-27

DC reduces AC inv

Gen inv don't change (locations do!)

DC retires more gen & reduces cred cap…due to reserve sharing.

Results: 50% renewables, 2024-2038

ECONOMICS, NPV $B	Design 1	Design 2a	Delta	Design 2b	Delta	Design 3	Delta
Line Investment Cost	61.21	73.89	12.68	74.88	13.67	80.1	18.89
Generation Investment Cost	704.03	703.32	-0.71	696.99	-7.04	700.51	-3.52
Fuel Cost	753.8	738.98	-14.82	737.3	-16.5	736.12	-17.68
Fixed O&M Cost	455.6	450.2	-5.4	448.95	-6.65	450.23	-5.37
Variable O&M Cost	64.5	63.9	-0.6	64.27	-0.23	64.39	-0.11
Carbon Cost	171.1	164.2	-6.9	162.6	-8.5	162.5	-8.6
Regulation-Up Cost	33.29	31.63	-1.66	29.96	-3.33	26.63	-6.66
Regulation-Down Cost	4.76	4.52	-0.24	4.29	-0.47	3.81	-0.95
Contingency Cost	24.41	23.19	-1.22	21.97	-2.44	19.52	-4.89
Total Non-Xm Cost (Orange)	2,211.49	2,179.94	-31.55	2,166.33	-45.16	2,163.71	-47.78
15-yr B/C Ratio (Orange/Blue)	-	-	2.48	-	3.30	-	2.52

The below row provides annualized (over 20 yrs) perpetuity cost for the CP designs. Interpretation is that CP designs 2a, 2b, & 3 will see the above 15-year B/C plus a savings each year over 20 years equal to the annualized perpetuity cost in yellow.

Perpetuity (Annualized 20-yr) Cost	72.32	70.88	-1.37	69.94	-2.51	68.71	-4.19

CAPACITY, GW	Design 1	Design 2a	Delta	Design 2b	Delta	Design 3	Delta
Total gen invested (W/S/G)	600 (386/177/37)	600 (392/172/36)	0 (-6/5/1)	600 (393/172/35)	0 (7/-5/-2)	600 (392/169/38)	0 (7/-6/1)
Total gen retired	240	285	45	287	47	294	54
Total 2028 creditable capacity	838.5	809.5	-29.0	792.0	-46.5	794.1	-44.4
Total AC Xm invested	228.9	251.3	22.4	234.8	-5.9	195.1	-33.8
Total DC Xm invested	0	25.6	25.6	35.9	35.9	125.8	125.8

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

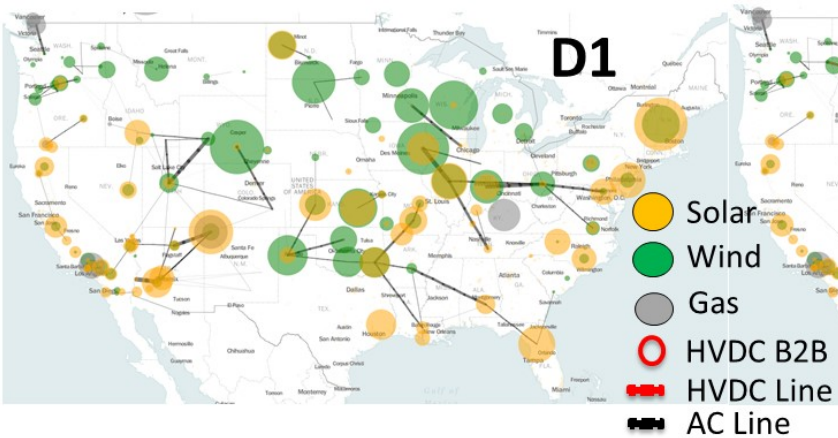
	Design 1	Design 3	Δ
Total Line Investment	62.2	80.1	+18.9
Gen Investment	704.0	700.5	-3.5
O&M	1507.5	1463.1	-44.4
15-yr B/C Ratio (orange/blue)	-	-	2.52

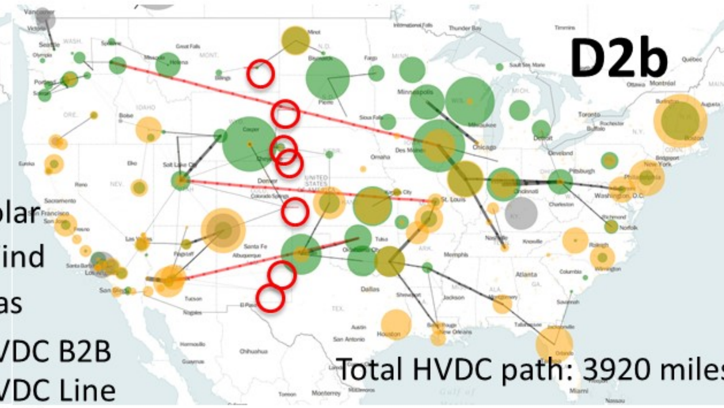
$$\frac{\text{GenRelatedSavings}}{\text{IncreasedTransCost}} = \frac{\Delta \text{O\&M} + \Delta \text{GenInv}}{\Delta \text{Trans}} = \frac{44.4 + 3.5}{18.9} = 2.52$$

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 (386/172/36)	600 (392/169/38)	0 (7/-6/1)
Retired generation	240	294	54
2038 creditable capacity	838.5	794.1	-44.4

- DC reduces AC inv
- Gen inv don't change (locations do!)
- DC retires more gen & reduces cred cap…due to reserve sharing.

Results: 40% renewable, 2024-2038

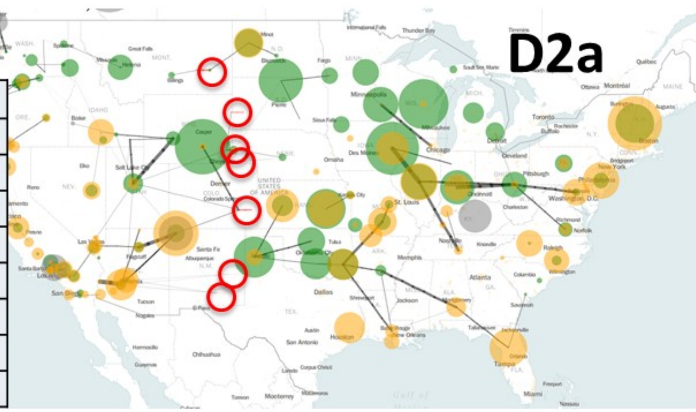


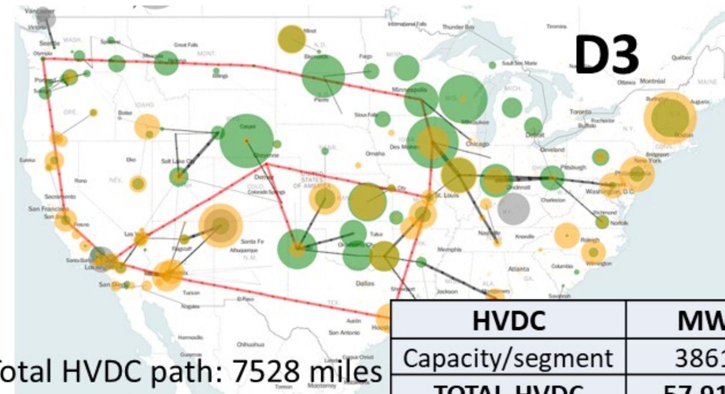


Total HVDC path: 3920 miles

HVDC Investment	MW
MC-ACDC	1774.7
RC-ACDC	915.8
STEGAL-ACDC	1493.6
SIDNEY-ACDC	848.8
LAMAR-ACDC	1021.3
BLACKWATER-ACDC	93.8
EDDYACDC	176.3
Cross-Tx. HVDC/line	3×4779.0
TOTAL	**20,661.3**

B2B Facility	MW
MC-ACDC	1634.9
RC-ACDC	1009.4
STEGAL-ACDC	1518.4
SIDNEY-ACDC	851.2
LAMAR-ACDC	1355.0
BLACKWATER-ACDC	114.5
EDDYACDC	198.9
TOTAL	**6682.3**

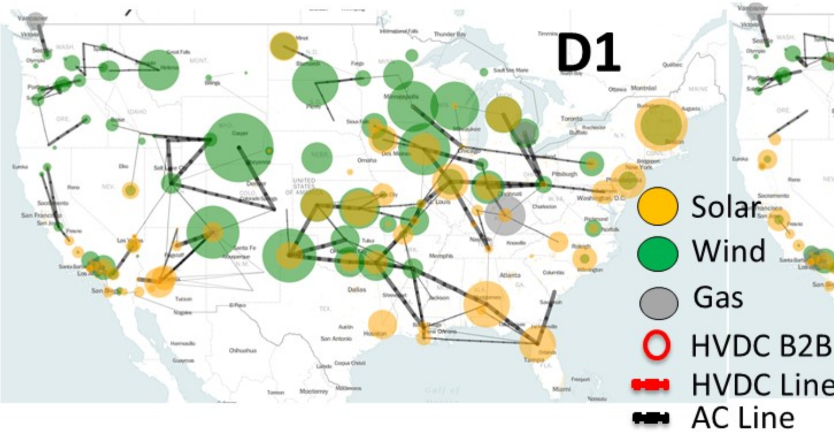


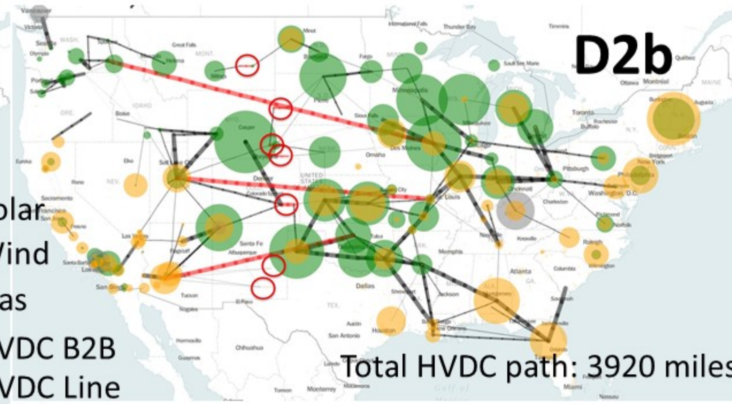


Total HVDC path: 7528 miles

HVDC	MW
Capacity/segment	3861
TOTAL HVDC	**57,915**

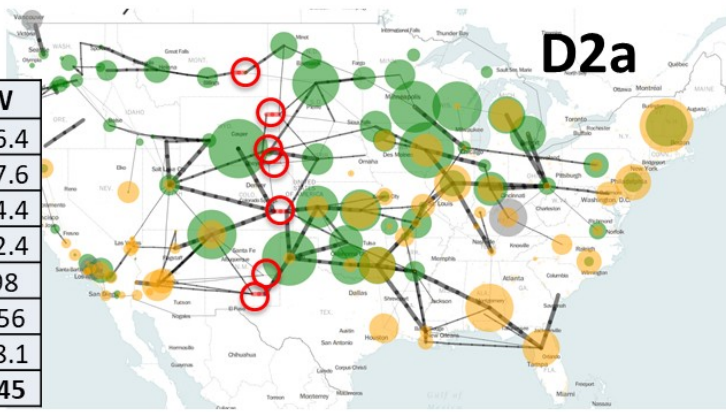
Results: 50% renewable, 2024-2038

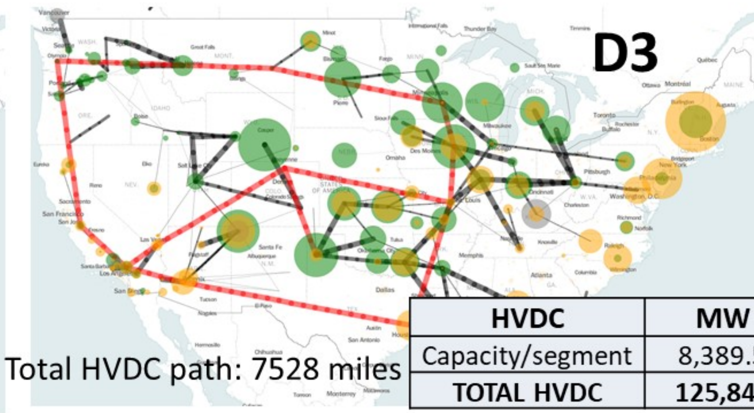




HVDC Investment	MW
MC-ACDC	1119.4
RC-ACDC	1389.0
STEGAL-ACDC	1681.9
SIDNEY-ACDC	1054.9
LAMAR-ACDC	2074.9
BLACKWATER-ACDC	34.4
EDDYACDC	138.4
Cross-Tx. HVDC/line	3×9481.3
TOTAL	**35,937**

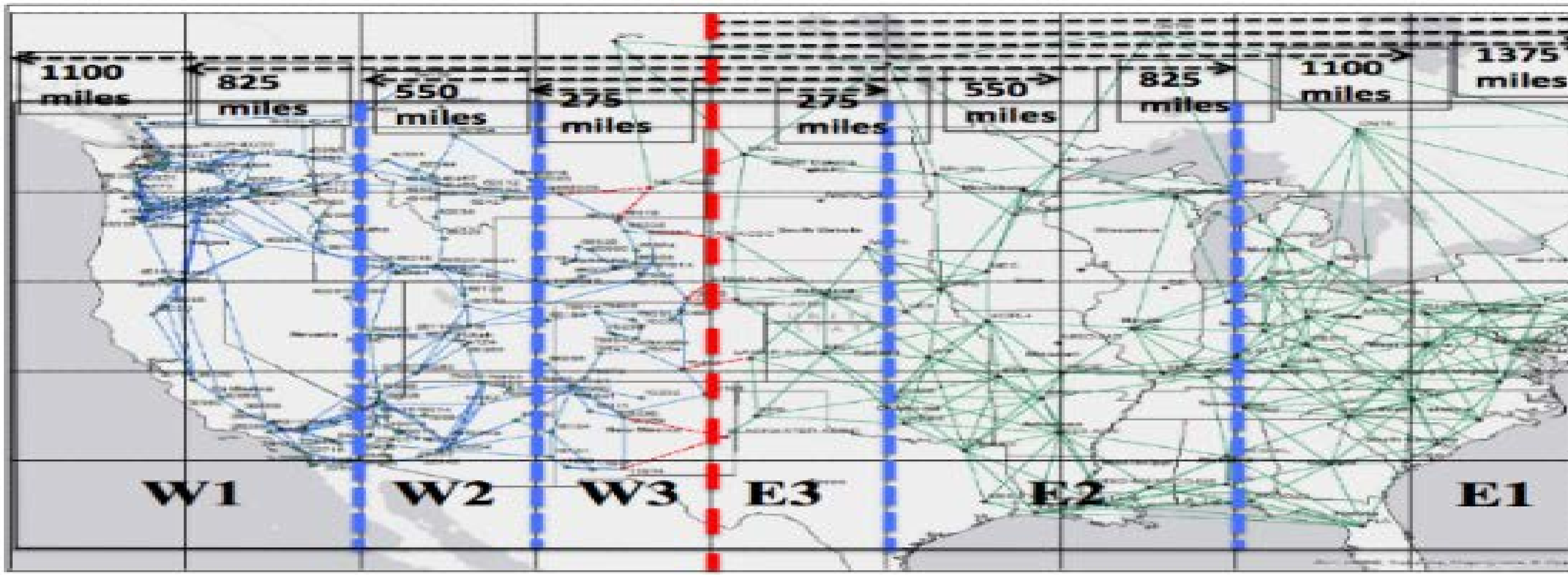
B2B Facility	MW
MC-ACDC	2,636.4
RC-ACDC	3,387.6
STEGAL-ACDC	4,864.4
SIDNEY-ACDC	1,042.4
LAMAR-ACDC	7,298
BLACKWATER-ACDC	358.56
EDDYACDC	1,458.1
TOTAL	**21,045**

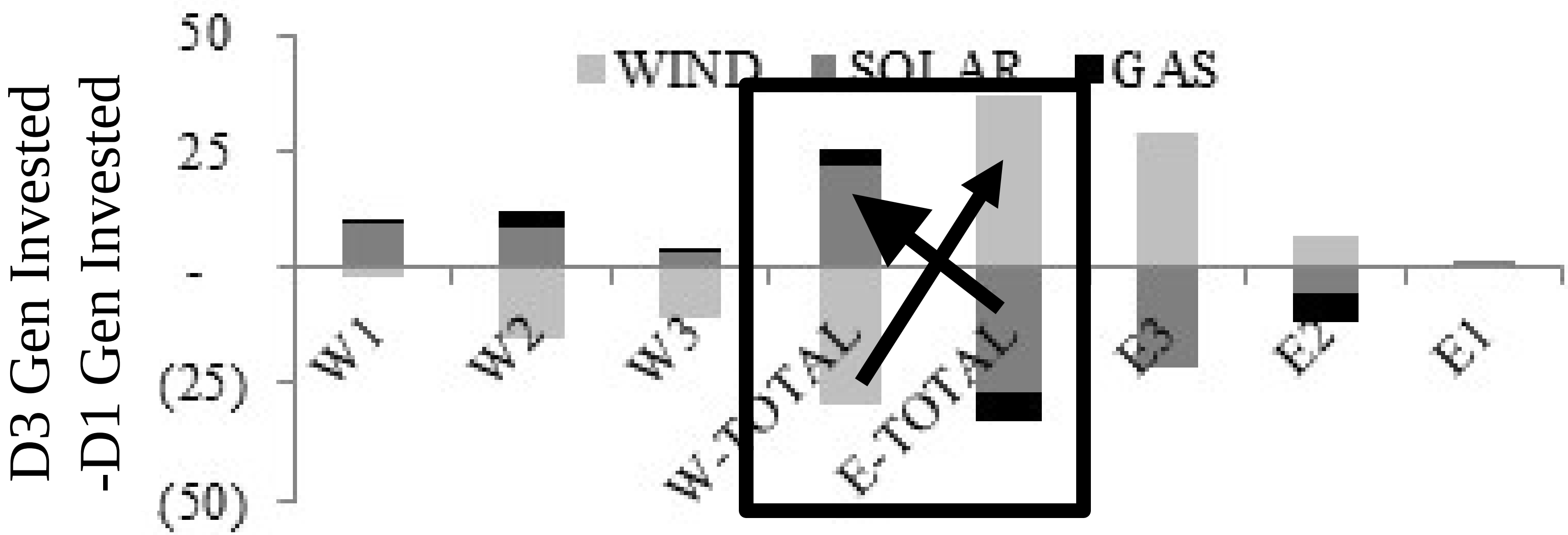




HVDC	MW
Capacity/segment	8,389.5
TOTAL HVDC	**125,842**

Results: 50% renewable, 2024-2038





Cross-seam transm moves wind/gas eastward; solar westward

Sensitivity to 50% case, Design 3

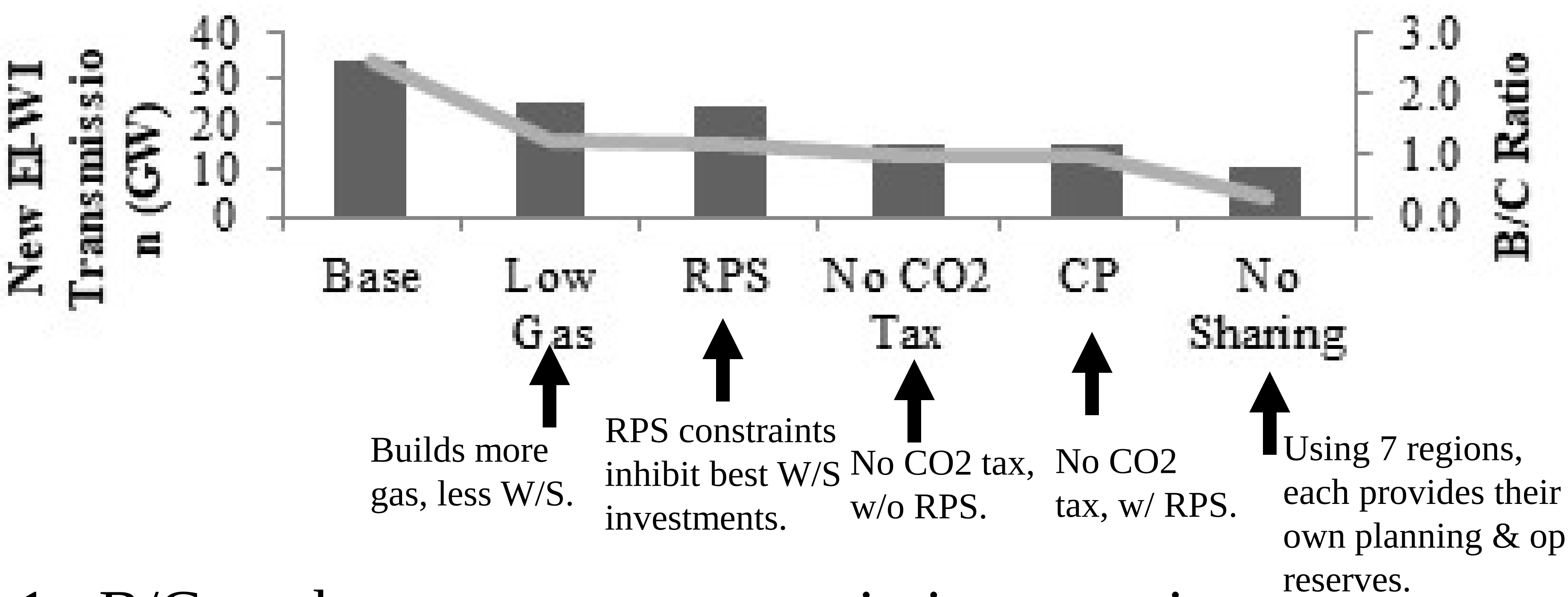
Design 3: 50, 65 ,74, & 85% renewables

	7per, w/cap	2per, w/o cap		
	$3/mt/yr	$3/mt/yr	$10/mt/yr	$67/mt/yr
% Renewable Penetration (energy)	50%	65%	74%	85%
Total gen invested (W/S/G), GW	600 (392/169/38)	792 (479/276/37)	1051 (638/362/51)	1258 (808/386/64)
Total gen retired, GW	294	348	380	458
Total AC Xm invested, GW	195	258	435	601
Cross-seam capacity, GW	25	23	26	35

Renwble pen cannot exceed 85% as higher requires more op-rsrvs than model has.

- Remaining 15% energy from nuclear & gas.
- All coal and oil, and some gas, are retired.
- AC Xm increases to facilitate wind/solar.
- Cross-seam Xm does not change much because 2nd-tier quality W/S being used.

Sensitivity to 50% case, Design 3



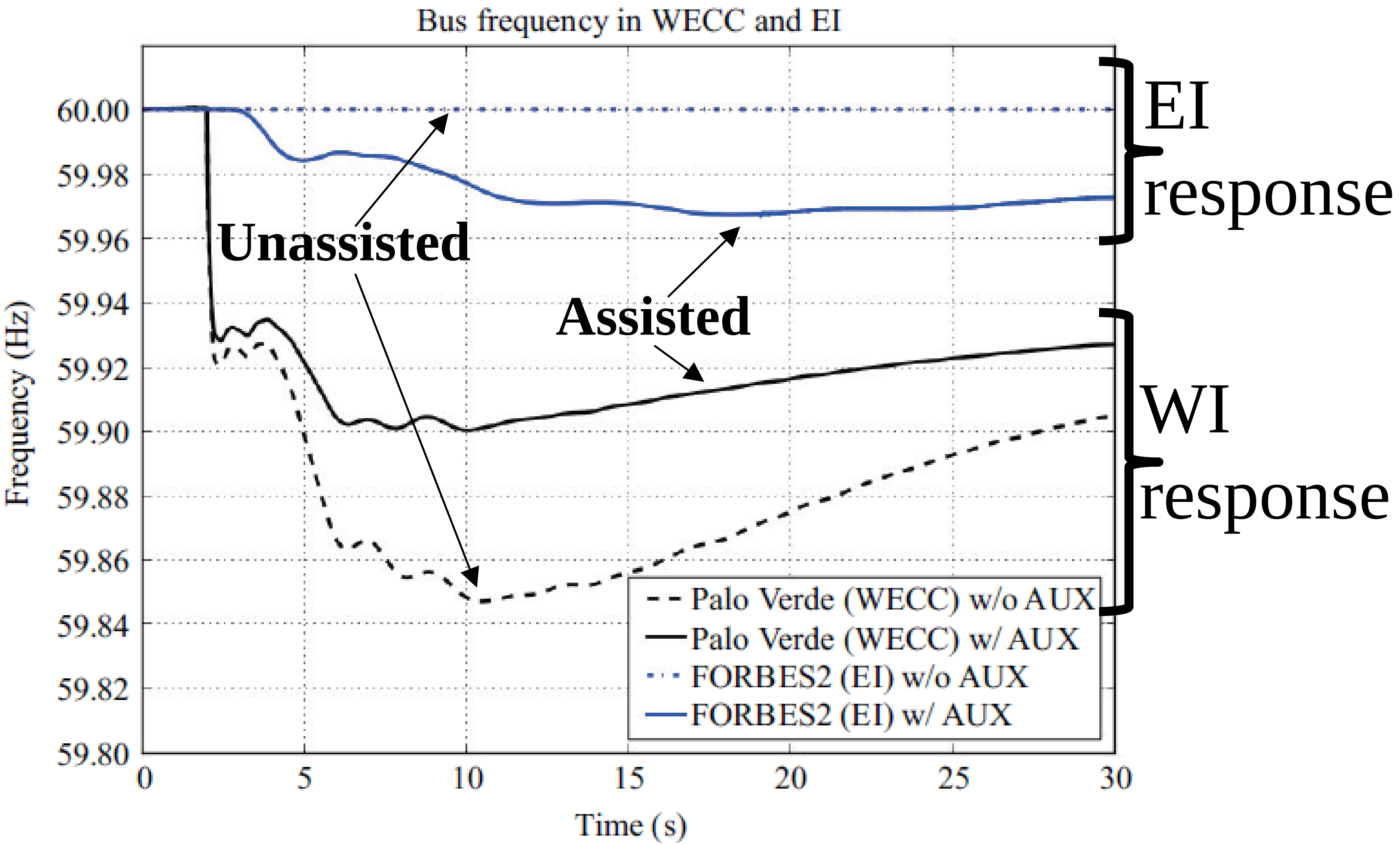
1. B/C tracks cross-seam transmission capacity
2. Base condition is best, with B/C=2.5
3. All sensitivities invest > 10 GW
4. The no-sharing sensitivity has B/C ~ 0.9
5. Other four sensitivities have B/C > 1

➔ Cross seam transmission pays for itself, + NQBs

Non-quantified benefits (NQBs)

- Post-2038 operational savings, 1-4$B/yr
- Additional reliability improvements via HVDC:
  - Improved system frequency response
  - Better local voltage control
- Efficient on/off-ramps nationwide making least-cost resources available at load centers, providing great flexibility for large changes in regional gen capacity
- National economic stimulus via 400,000 new jobs throughout 15 yr period

Improved reliability: trip Palo Verde (2700 MW)



Used with permission. Ref: M. Elizondo, et al., "HVDC Macrogrid Modeling for Power Flow and Transient Stability Studies in North American Continental-level Interconnections," CSEE Journal of Power and Energy Systems, Vol. 3, No. 4, Dec., 2017.

Path forward – Step 2a

140 attendees;
Website contains slides and video showing all presentations;
Available at:
https://register.extension.iastate.edu/transgridx/symposium-information/documents

Path forward – Step 2b

Governors' Wind & Solar Energy Coalition

November 9, 2018

The Honorable Neil Chatterjee, Chairman
The Honorable Cheryl A. LaFleur
The Honorable Richard Glick
The Honorable Kevin McIntyre

Federal Energy Regulatory Commission
888 First Street, NE
Washington, DC 20426

Subject: *Interconnection Seams Study*

To address these concerns, we suggest the Commission, in cooperation with the U.S. Department of Energy, consider convening a series of meetings in partnership with the states, regional transmission organizations, members of Congress, and the private sector to discuss the Interconnection Seams Study and to identify the nation's transmission needs, including integration of the nation's major grids, as well as multi-state and inter-regional transmission challenges.

It is our hope that these proposed meetings will show how a unified transmission system could benefit our states' economies — creating jobs and strengthening national security and resilience. A strong national transmission system will support the economic growth our states and the nation need.

• • •

Steve Bullock
Chair and
Governor of Montana

John Carney
Vice Chair and
Governor of Delaware

Jeff Colyer
Former Vice Chair and
Governor of Kansas

cc:
Hon. Lisa Murkowski, U.S. Senate Committee on Energy and Natural Resources
Hon. Maria Cantwell, U.S. Senate Committee on Energy and Natural Resources
Hon. Martin Heinrich, U.S. Senate Committee on Energy and Natural Resources
Hon. Greg Walden, U.S. House Committee on Energy and Commerce
Hon. Joe Barton, U.S. House Committee on Energy and Commerce
Hon. Rick Perry, U.S. Department of Energy
Hon. Francis Brooke, Special Assistant to the President

Members:

Arkansas	Kansas	Pennsylvania
California	Maryland	Rhode Island
Colorado	Massachusetts	South Dakota
Delaware	Minnesota	Virginia
Hawaii	Montana	Washington
Illinois	New York	
Iowa	Oregon	

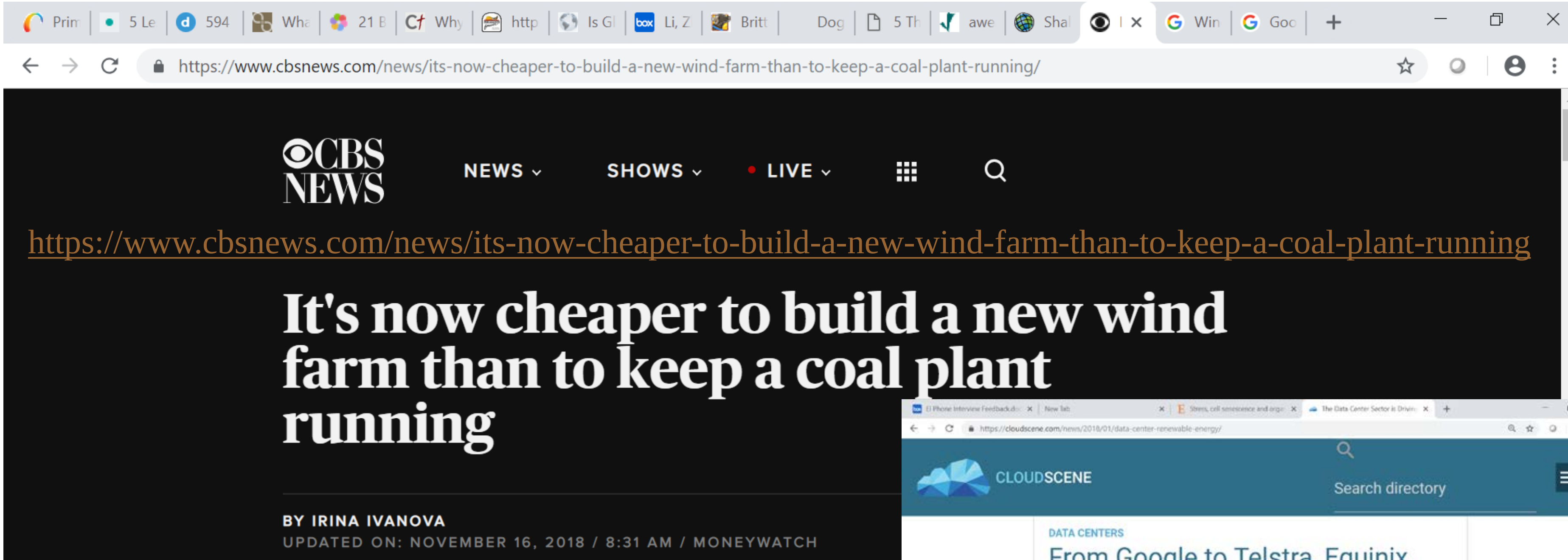
https://governorswindenergycoalition.org/coalition-members/

Path forward – Step 3

1. **<u>Step 3a</u>:** Additional studies (e.g., refine design): expansion planning, production cost, power flow, and dynamics.
2. **<u>Step 3b</u>:** Develop two oversight bodies:
   - Technical studies/design: the RTOs and utilities.
   - Regulatory issues: FERC and states.
3. **<u>Last thought:</u>** The thrust of the work presented is:

   Given a high renewables future, inter-market & cross-seam trading pays for itself in direct economic benefits plus additional significant (non-quantified) benefits in the form of
   - *Post-2038 op savings;*
   - *Reliability*
   - *Flexibility to large changes in regional gen capacity*
   - *Economic stimulus*

But is a high renewable future (> 40% by energy) attractive?



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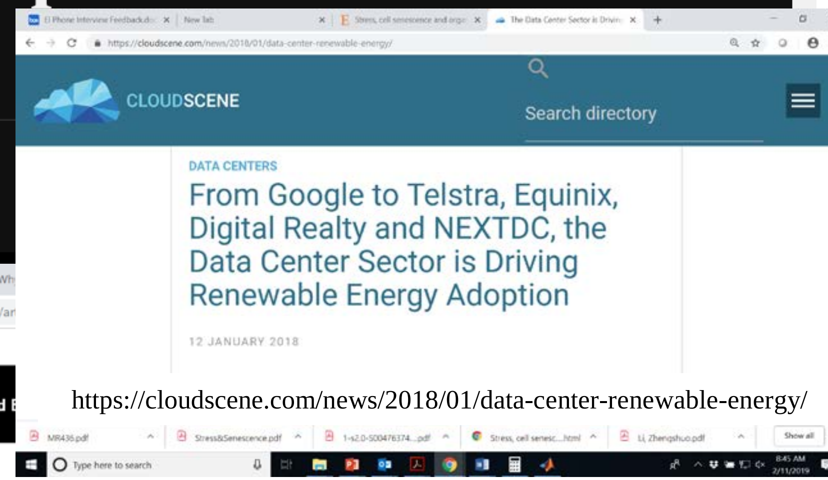
https://www.cbsnews.com/news/its-now-cheaper-to-build-a-new-wind-farm-than-to-keep-a-coal-plant-running

It's now cheaper to build a new wind farm than to keep a coal plant running

BY IRINA IVANOVA

UPDATED ON: NOVEMBER 16, 2018 / 8:31 AM / MONEYWATCH



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From Google to Telstra, Equinix, Digital Realty and NEXTDC, the Data Center Sector is Driving Renewable Energy Adoption

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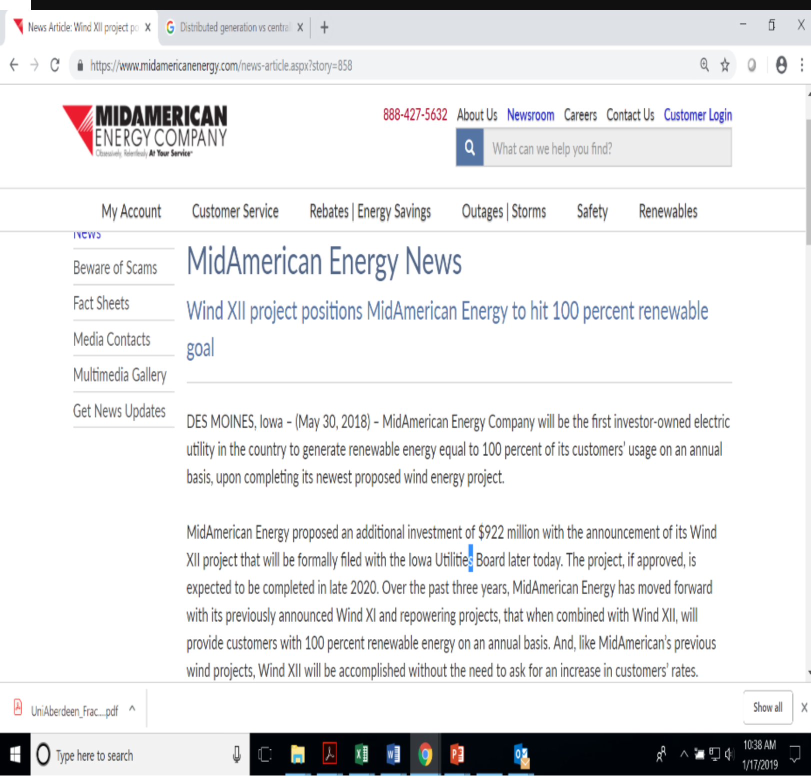

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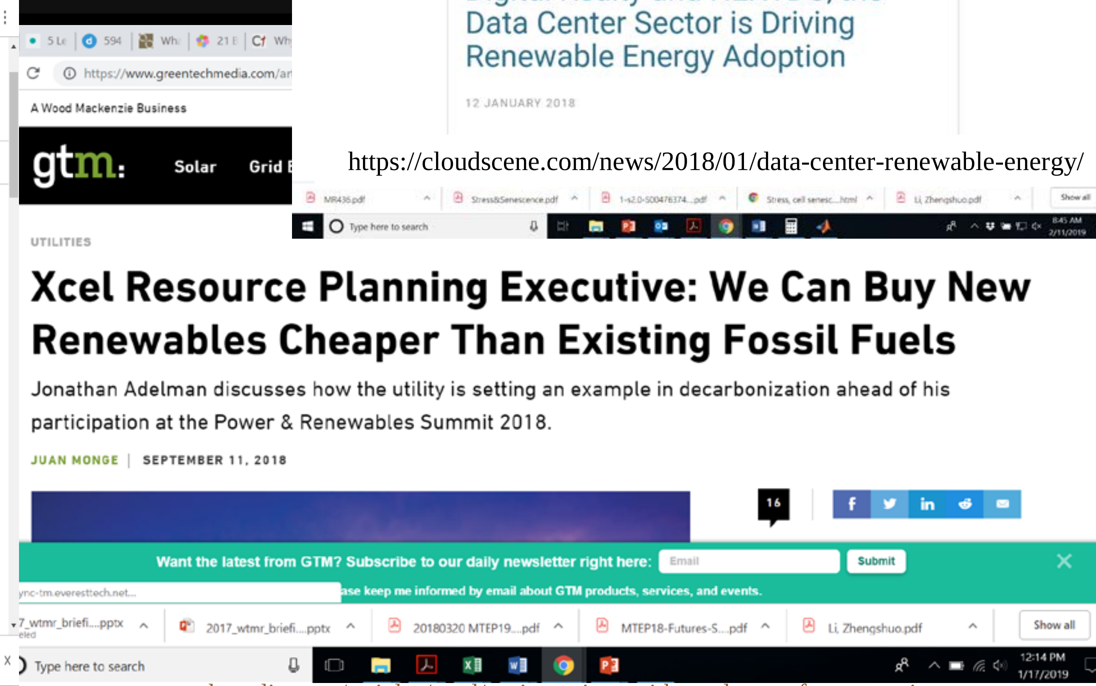
MidAmerican Energy News

Wind XII project positions MidAmerican Energy to hit 100 percent renewable goal

DES MOINES, Iowa – (May 30, 2018) – MidAmerican Energy Company will be the first investor-owned electric utility in the country to generate renewable energy equal to 100 percent of its customers' usage on an annual basis, upon completing its newest proposed wind energy project.

MidAmerican Energy proposed an additional investment of $922 million with the announcement of its Wind XII project that will be formally filed with the Iowa Utilities Board later today. The project, if approved, is expected to be completed in late 2020. Over the past three years, MidAmerican Energy has moved forward with its previously announced Wind XI and repowering projects, that when combined with Wind XII, will provide customers with 100 percent renewable energy on an annual basis. And, like MidAmerican's previous wind projects, Wind XII will be accomplished without the need to ask for an increase in customers' rates.



https://www.greentechmedia.com/ar

A Wood Mackenzie Business

gtm: Solar Grid

UTILITIES

Xcel Resource Planning Executive: We Can Buy New Renewables Cheaper Than Existing Fossil Fuels

Jonathan Adelman discusses how the utility is setting an example in decarbonization ahead of his participation at the Power & Renewables Summit 2018.

JUAN MONGE | SEPTEMBER 11, 2018

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www.greentechmedia.com/articles/read/an-interview-with-xcels-avp-for-strategic-resource-business-planning-the-re#gs.M9DtFWlZ

Questions?

James McCalley

(jdm@iastate.edu)

Transmission cost data

- Transmission investment base costs are used in conjunction with appropriate multipliers.
- EI:
  - 345 kV Single Circuit: $2,100,000/mile
  - 345 kV Double Circuit: $2,800,000/mile
  - 500 kV Single Circuit: $3,450,000/mile
  - 765kV AC single circuit: $5,550,000/mile
- WI:
  - 345 kV Single Circuit: $2,100,000
  - 345 kV Double Circuit: $2,800,000
  - 500 kV Single Circuit: $3,450,000
- 800 kV, 6000 MW DC: $3,300,000/mile
- LCC Converter: $472,000,000/terminal, VSC converter: $285,000,000/terminal
- Cost of upgrading existing B2B ties: $300,000/MW (2 converter stations).