Optimal Design of Inter-regional Transmission Grids

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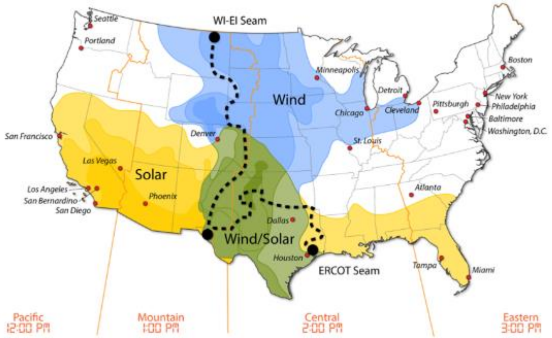
4/3/2017



Special thanks to Hussam Nosair, Ali Jahanbani and Abhinav Venkatraman for their contribution to this work.

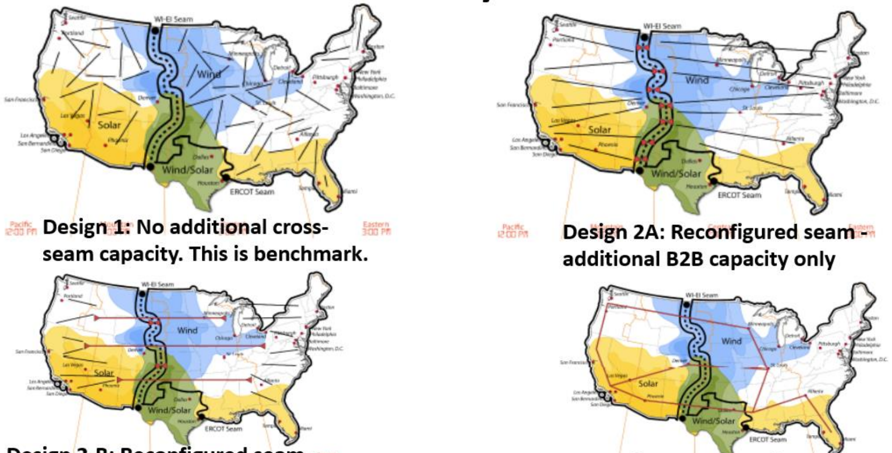
Two weeks ago…

Developing critical national infrastructure for low carbon futures: Can we/should we do it?”?

James McCalley
London Professor of
Power Systems Engineering
Iowa State University

WESEP 594, March 20, 2017

Interconnection Seams Study (DOE Grid Modernization Laboratory Consortium)



Design 1: No additional cross-seam capacity. This is benchmark.

Design 2A: Reconfigured seam - additional B2B capacity only

Design 2-B: Reconfigured seam - additional capacity via B2B/HVDC lines

Design 3: Macrogrid overlay.

Presentation Overview

1. High-capacity inter-regional transmission studies
2. The Interconnections Seams Project
3. Project features
4. The macrogrid overlay
5. Issues to building it
6. Possible paths forward
7. Compare to China
8. Conclusions

Project features

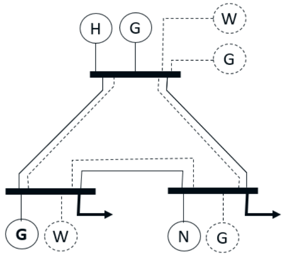
Co-optimized generation/transmission planning: identifies future generation and transmission investments to minimize total costs.

Identify investment & retirement decisions to MINIMIZE → **PRESENT WORTH**

{ G&T Investment Costs
+ Fixed O&M Costs
+ Var O&M Costs
+ Fuel Costs
+ Reserve Costs
+ Environmental Costs }

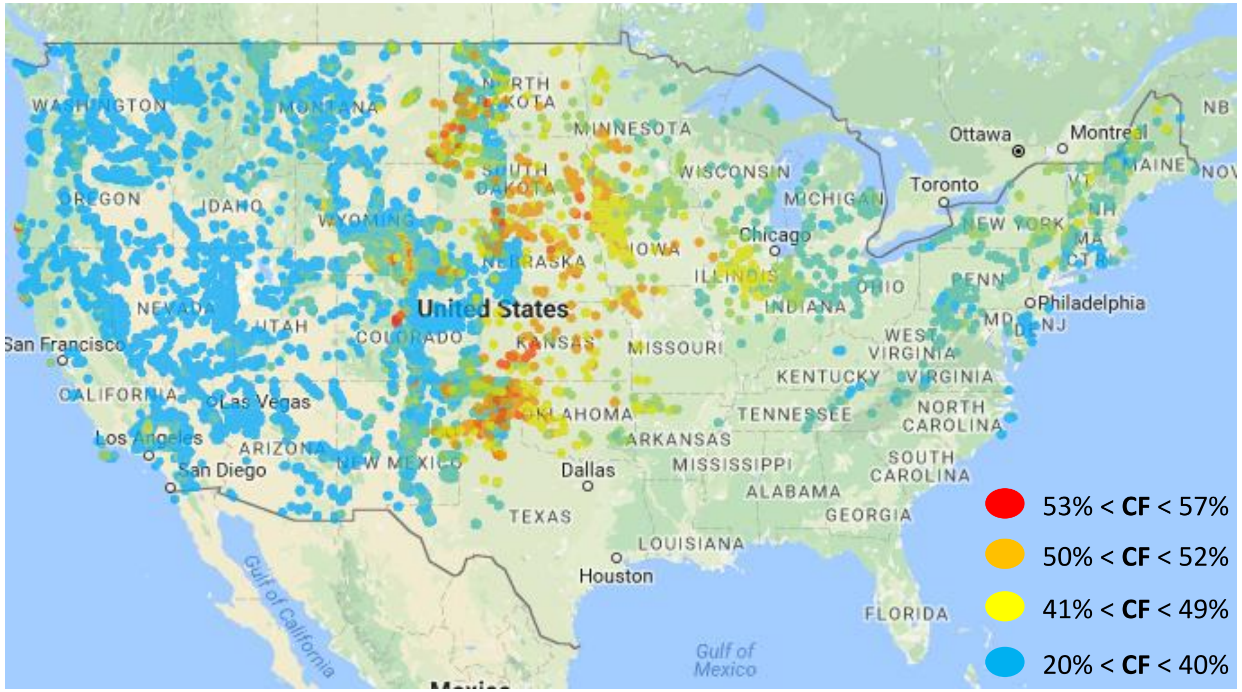
SUBJECT TO:
Investment constraints
Operational, planning, environmental constraints
Uncertainty characterization

Year 1 | **Year 2** ••• **Year N**



Shift in Wind Resources Quality?

Eastern/Western Wind Dataset [1]

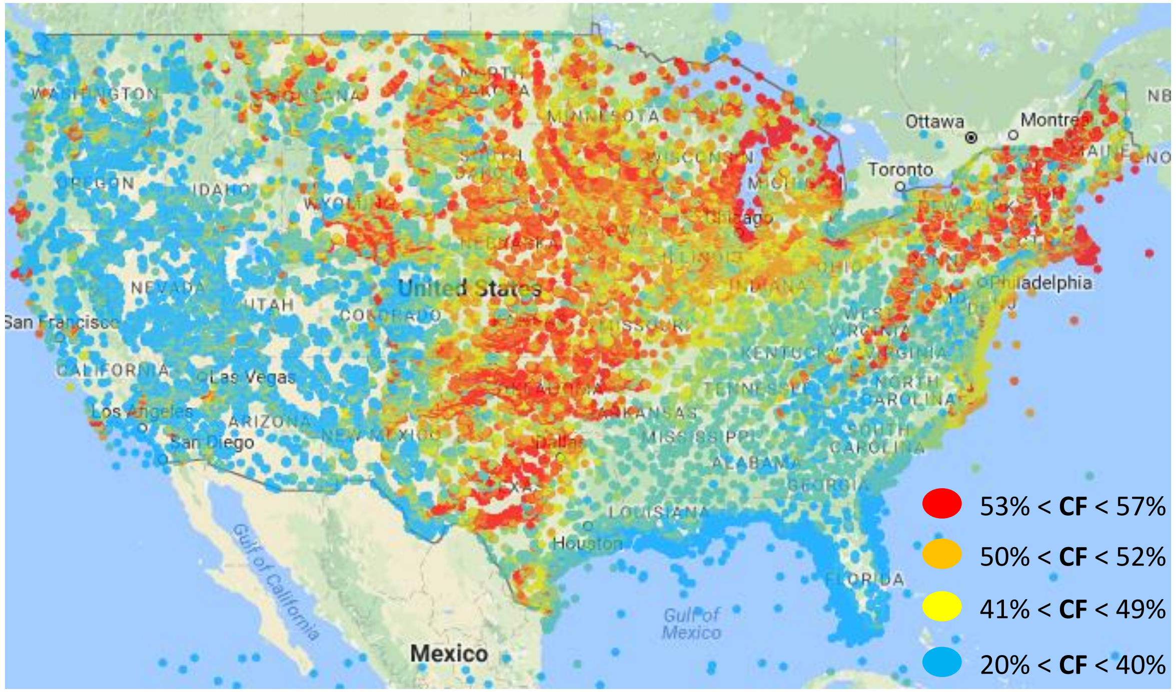


- 2004-2006
- 80m towers

* Previous CEP work using this dataset

1. Eastern Interconnection Study
2. Western Interconnection Study
3. EIPC Phase 1 & 2
4. EISPC-NARUC

Wind Toolkit Dataset [1]

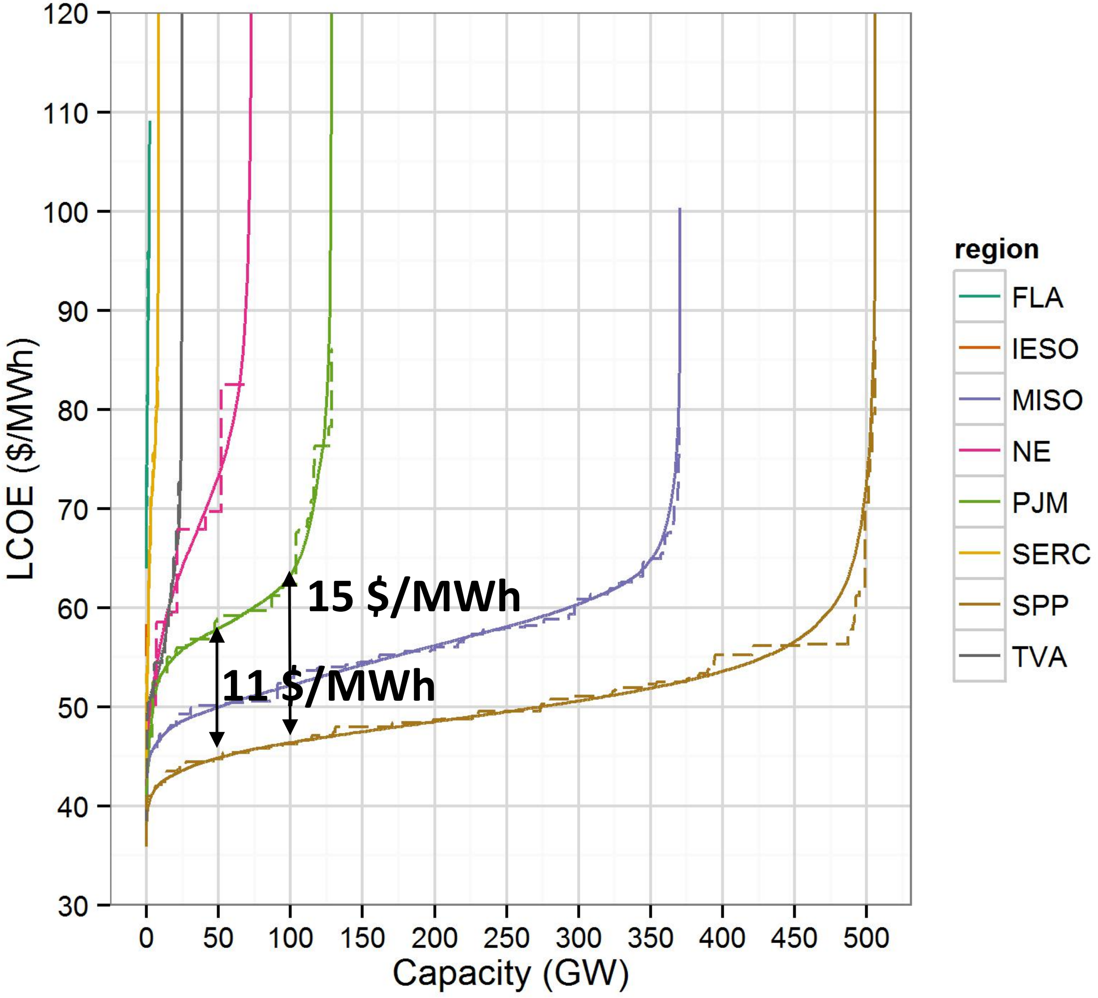


- 2007-2013
- 100m towers, 3 tower types, 3 bins

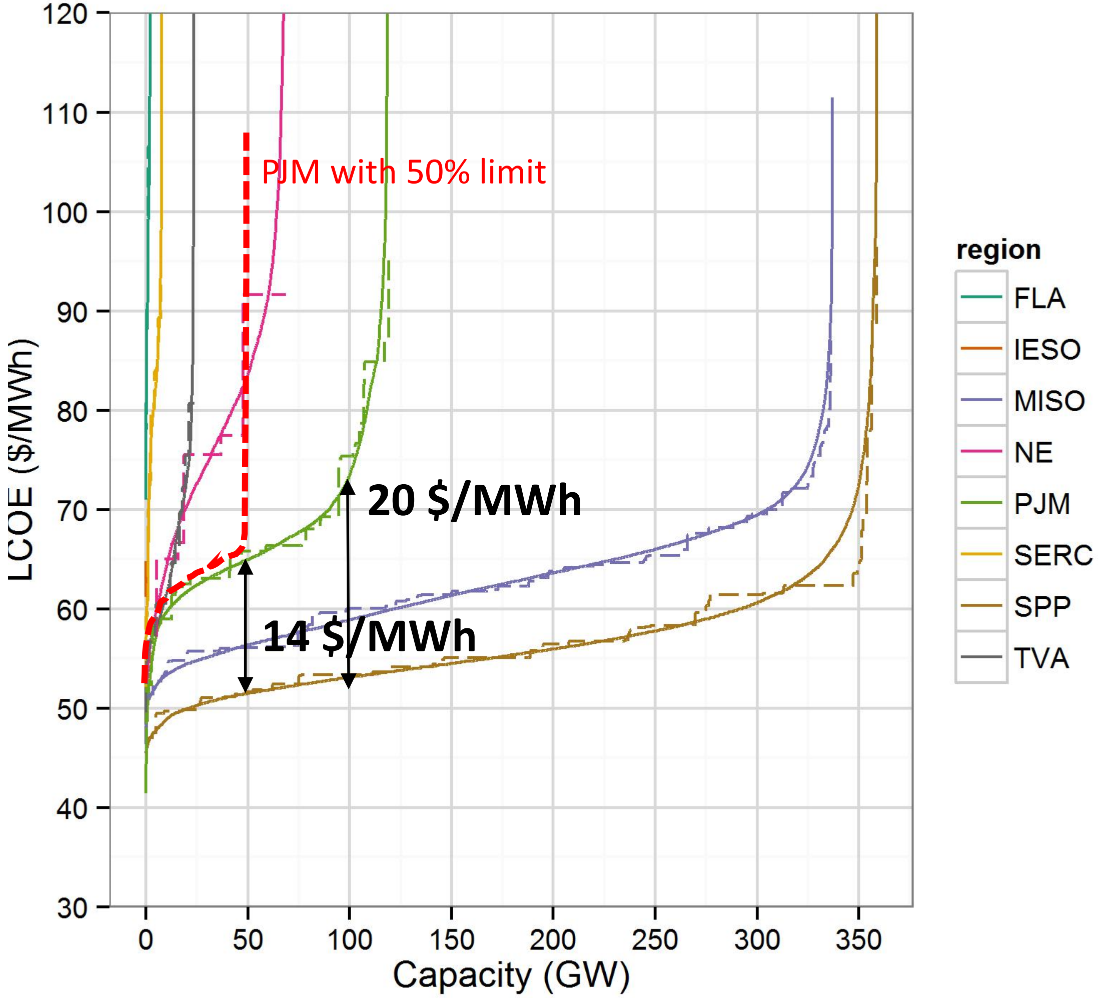
[1] http://www.nrel.gov/gis/data_wind.html

Supply curves for 100-m wind

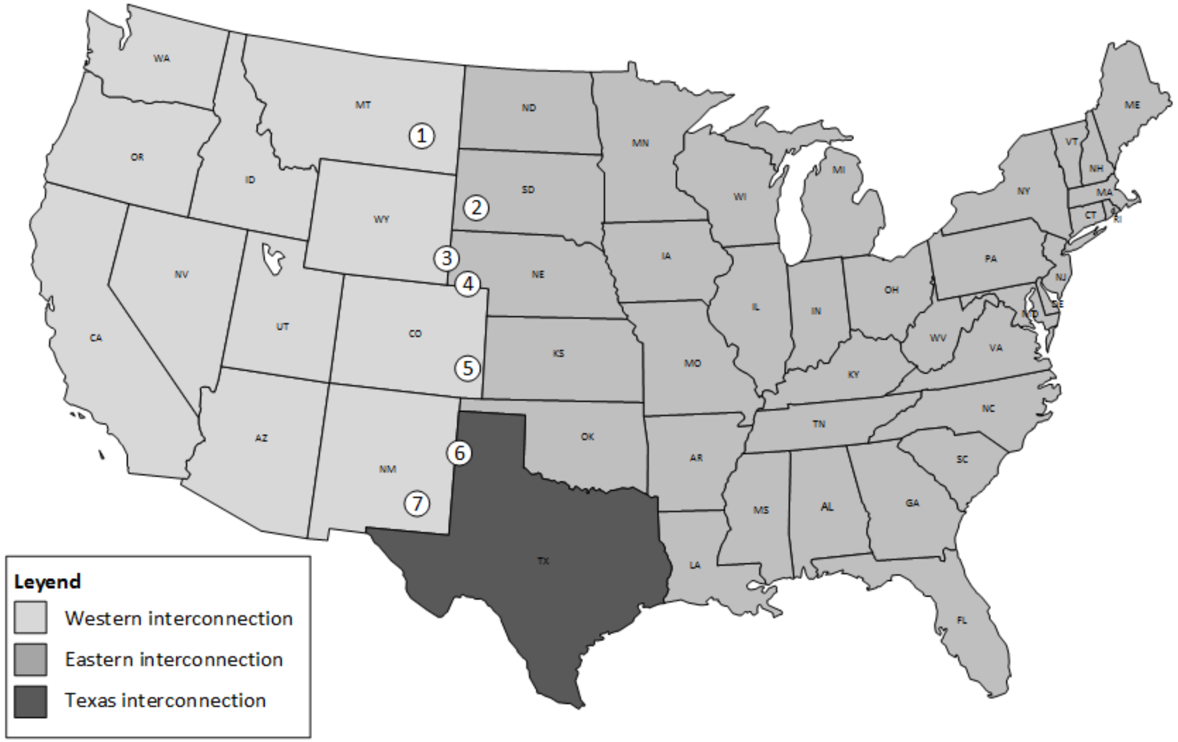
Original supply curves using the Wind Toolkit



Modified supply curves → Larger LCOE gap between PJM and Midwest (MISO and SPP)



What about transmission?



HVDC back-to-back facilities between the Eastern and Western interconnections

	Facility Name	Location	Vendor	Converter Type	Voltage	Rating	Commissioning year
1	Miles City	Miles City, MT	GE	LCC	82 kV	200 MW	1985
2	Rapid City	Rapid City, SD	ABB	CCC	13 kV	200 MW	2003
3	David A. Hamel	Stegall, NE	GE	LCC	50 kV	100 MW	1977
4	Virginia Smith	Sidney, NE	Siemens	LCC	50 kV	200 MW	1988
5	Lamar	Lamar, CO	Siemens	LCC	63.6 kV	210 MW	2005
6	Eddy County	Artesia, NM	GE	LCC	82 kV	200 MW	1983
7	Blackwater	Clovis, NM	ABB	LCC	60 kV	200 MW	1984

Moving rich wind energy from the Great Plains to the West and East coasts requires major transmission capacity between Eastern and Wester Interconnection

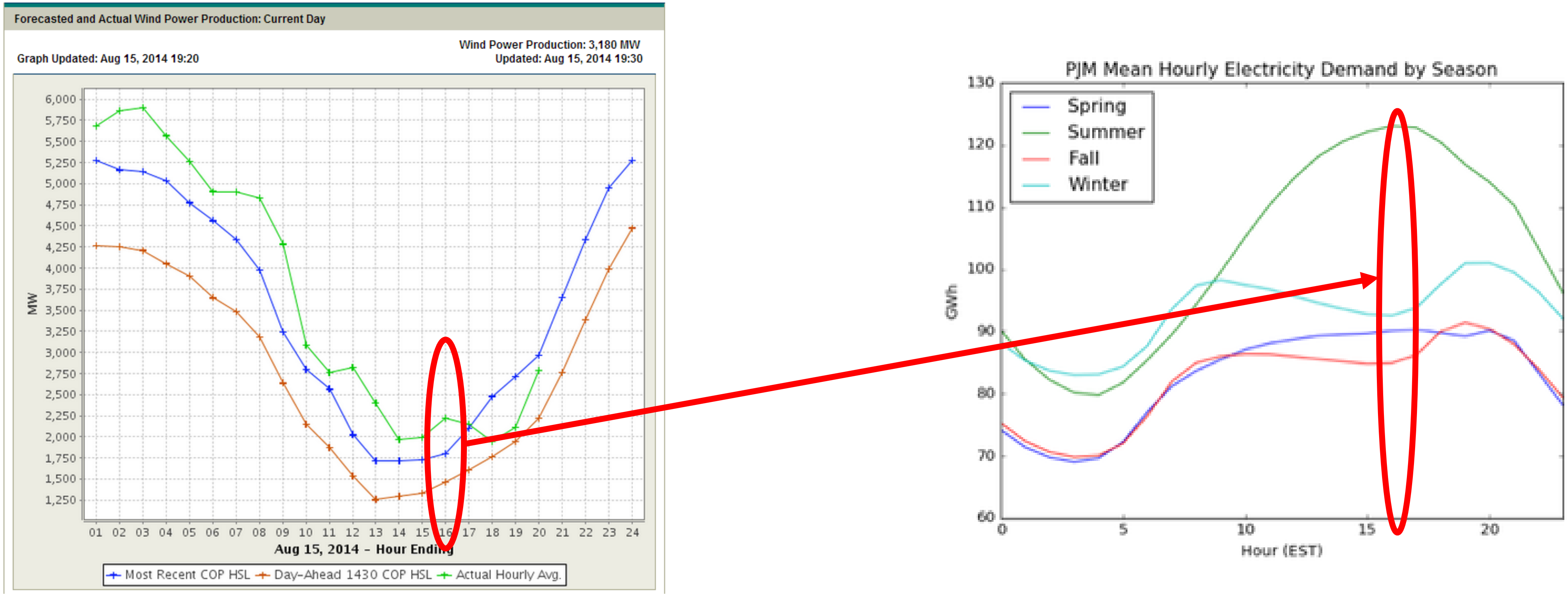
CEP Bus	State	Minimum LCOE Difference
BEPC	North Dakota	29.68009703
CBPC-NIPCO	Iowa	26.78559198
CSWS+	Oklahoma	33.14189126
EES-ARK	Arkansas	31.92660331
IA-E	Iowa	29.16653349
KCPL+	Kansas	34.77951558
LES	Nebraska	34.40449928
MDU	North Dakota	34.88530142

Seams Transmission Capacity = 1.3 GW
US Peak-load ~ 850 GW

Wind integration issues

Variability and Uncertainty of wind power

Correlation between maximum wind and maximum load is low



Hypothesis

- The benefits of a well-design inter-regional transmission grid outweigh its costs under a future with high wind and solar generation
- Value drivers
  - Geo-diversity of wind and solar resources (smoothing effect)
  - Geo-diversity of load (time-zone differences)
  - **Reserves sharing opportunities**

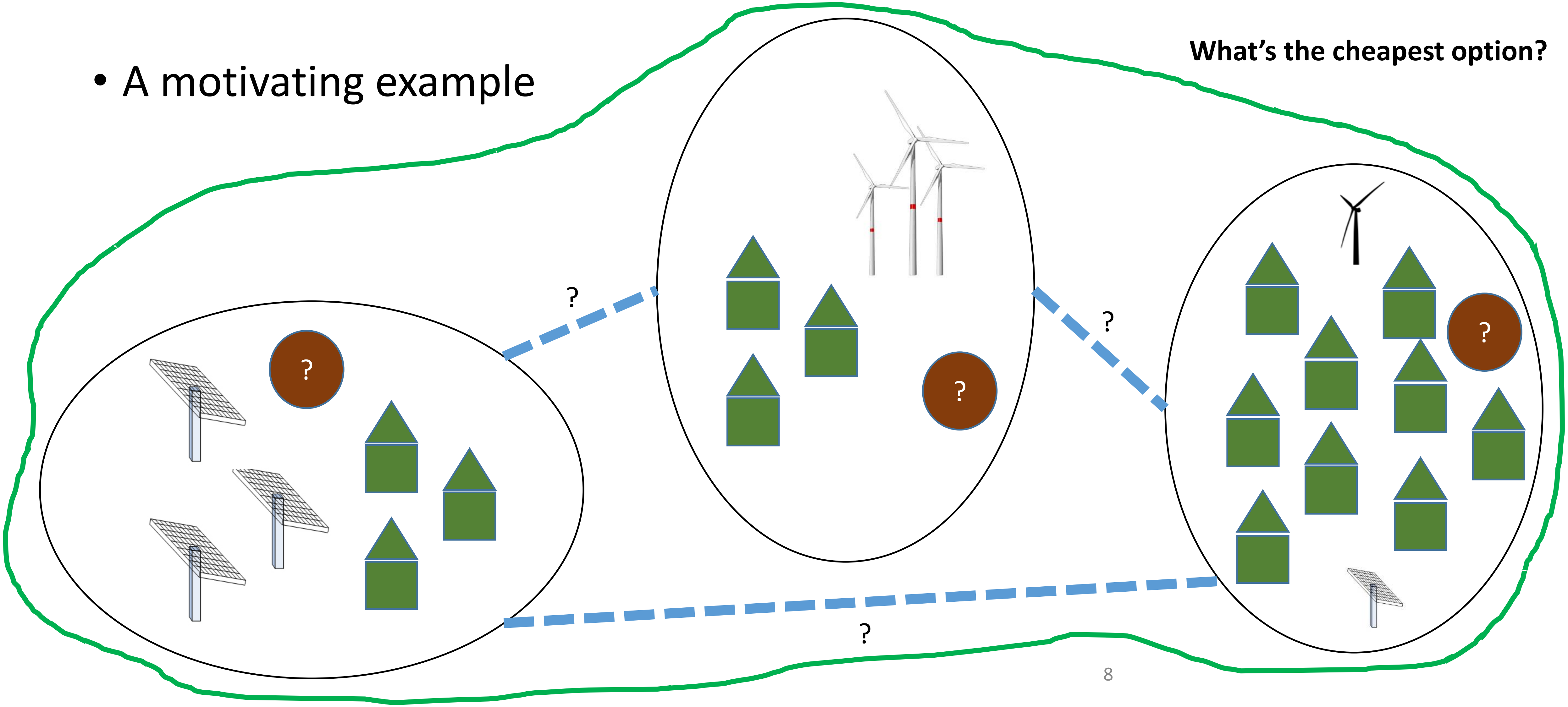
Benefit/Cost Ratio	1.25

Benefit	Total	
Load Diversity	$ 21.0 Billion	46%
Frequency Response	$ 9.8 Billion	22%
Wind Diversity	$ 2.2 Billion	5%
Other Energy Based Benefits	$ 12.2 Billion	27%
Grand Total	**$45.3 Billion**	

Concept of Reserves Sharing

- A motivating example

What's the cheapest option?

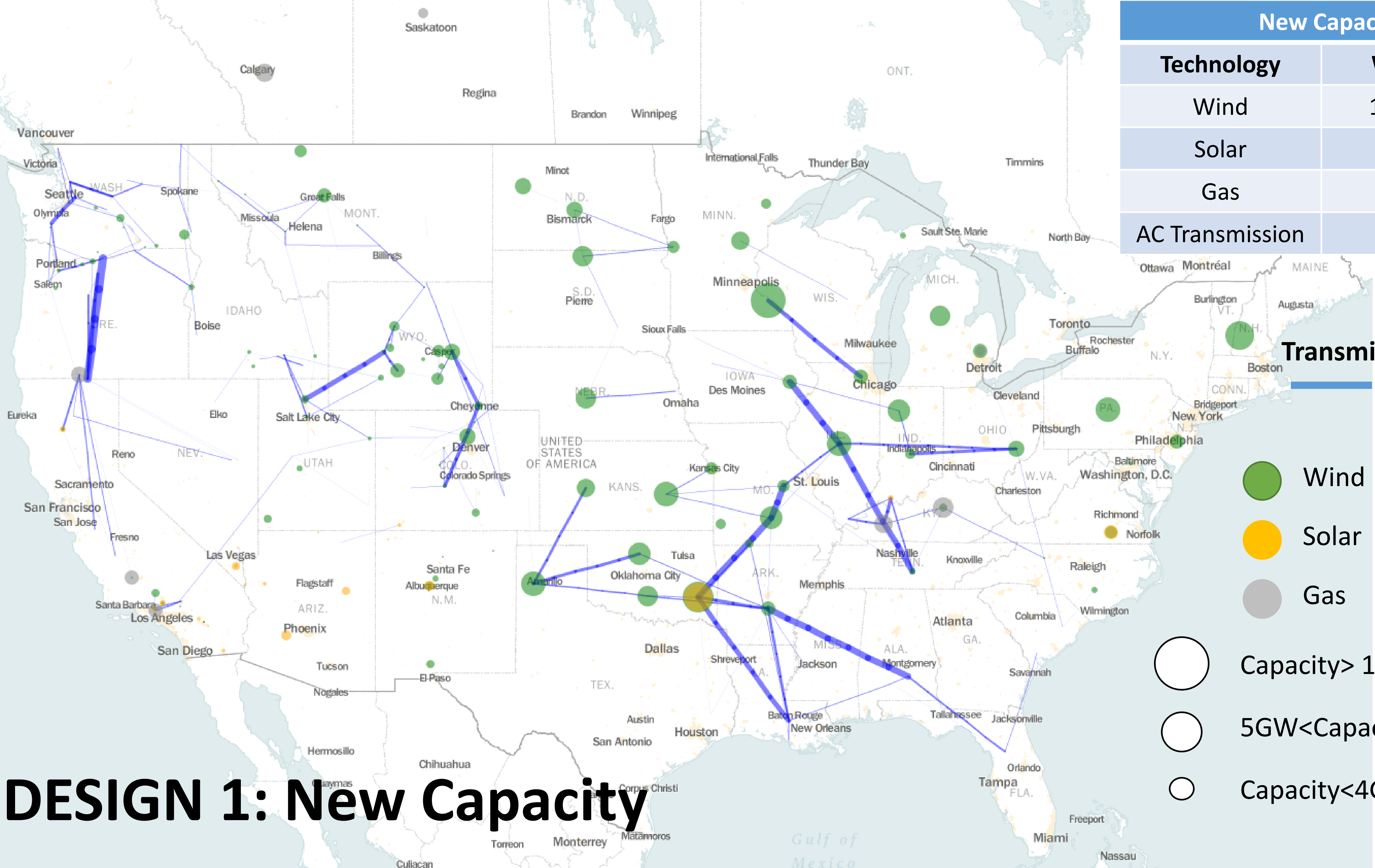


Economic Summary

	Design 1	Design 2a		Design 2b		Design 3	
Objective Function	Total	Total	Delta (Value)	Total	Delta (Value)	Total	Delta (Value)
Gen Inv. Cost(B$)	678.0	703.0	25.0	679.3	0.0	720.1	42.1
Fixed O&M Cost (B$)	465.0	451.0	-14.0	463.0	-2.0	452.7	-12.3
Variable O&M Cost (B$)	73.0	71.0	-2.0	71.8	-1.2	68.9	-4.1
Fuel Cost (B$)	528.0	509.0	-19.0	510.5	-17.5	482.1	-45.9
Carbon Cost (B$)	454.0	434.0	-20.0	436.7	-17.3	410.1	-43.9
Line Inv. Cost (B$)	43.1	49.9	6.8	49.5	6.4	50.4	7.3
Total (B$)	2,241.0	2,217.0	-24.0	2,209.5	-31.5	2,189.7	-51.3

DESIGN 1: New Capacity

New Capacity	
Technology	WI/EI (GW)
Wind	134.7/201.0
Solar	27.1/15.2
Gas	20.1/22.8
AC Transmission	78.3/81.9



Transmission Capacity

TC=6 GW

Wind

Solar

Gas

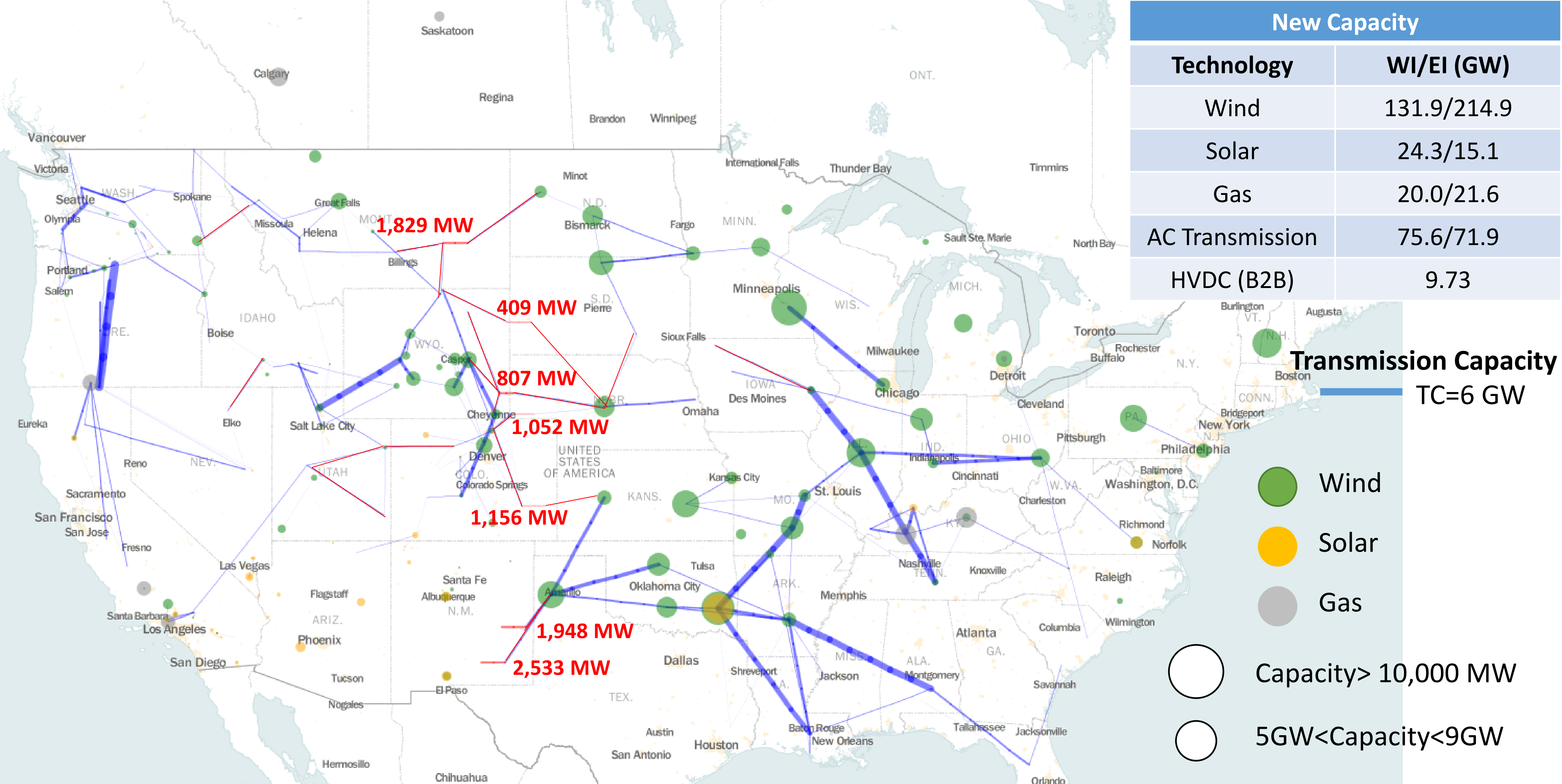
Capacity> 10,000 MW

5GW<Capacity<9GW

Capacity<4GW

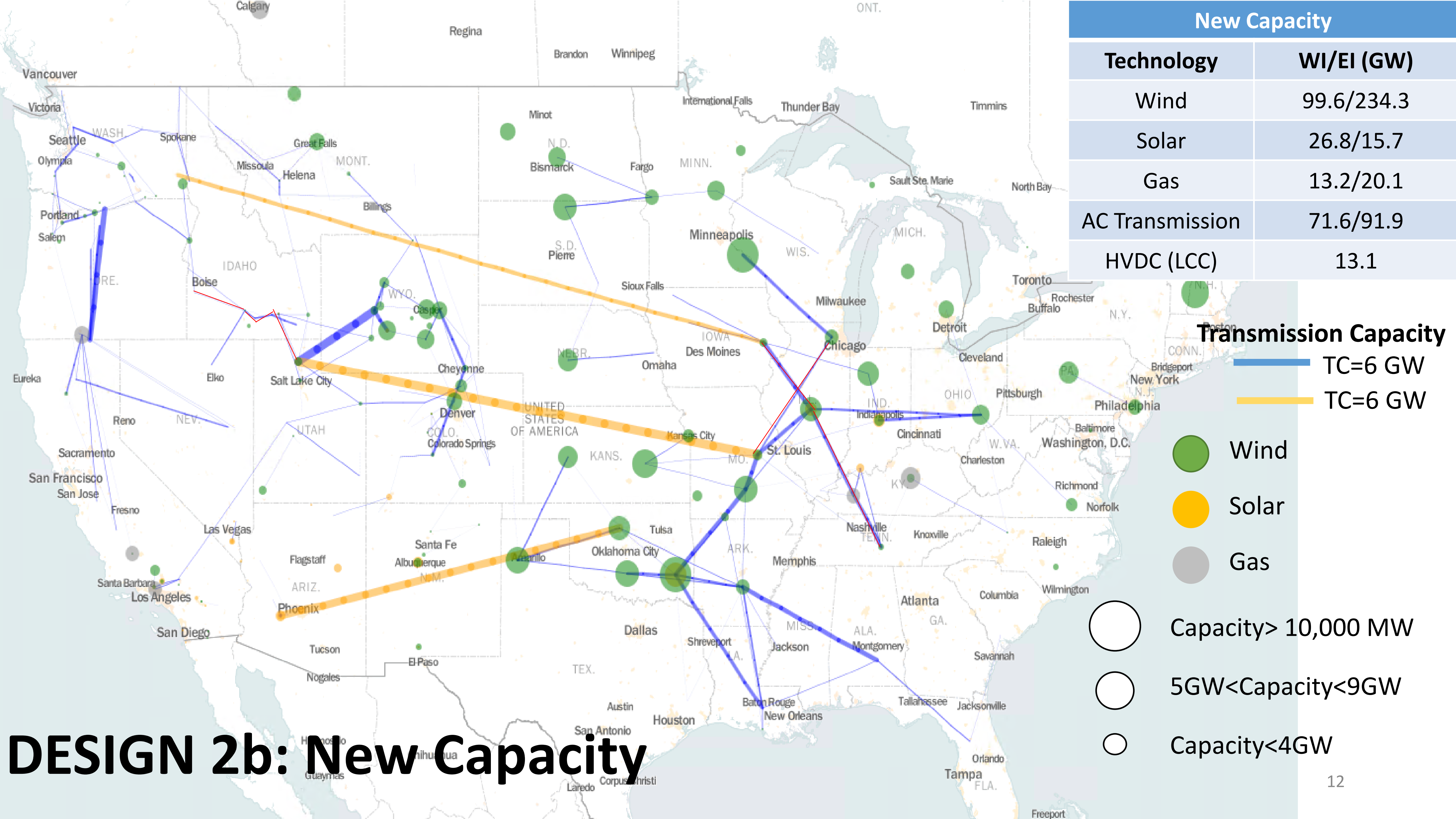
DESIGN 2a: New Capacity

New Capacity	
Technology	**WI/EI (GW)**
Wind	131.9/214.9
Solar	24.3/15.1
Gas	20.0/21.6
AC Transmission	75.6/71.9
HVDC (B2B)	9.73



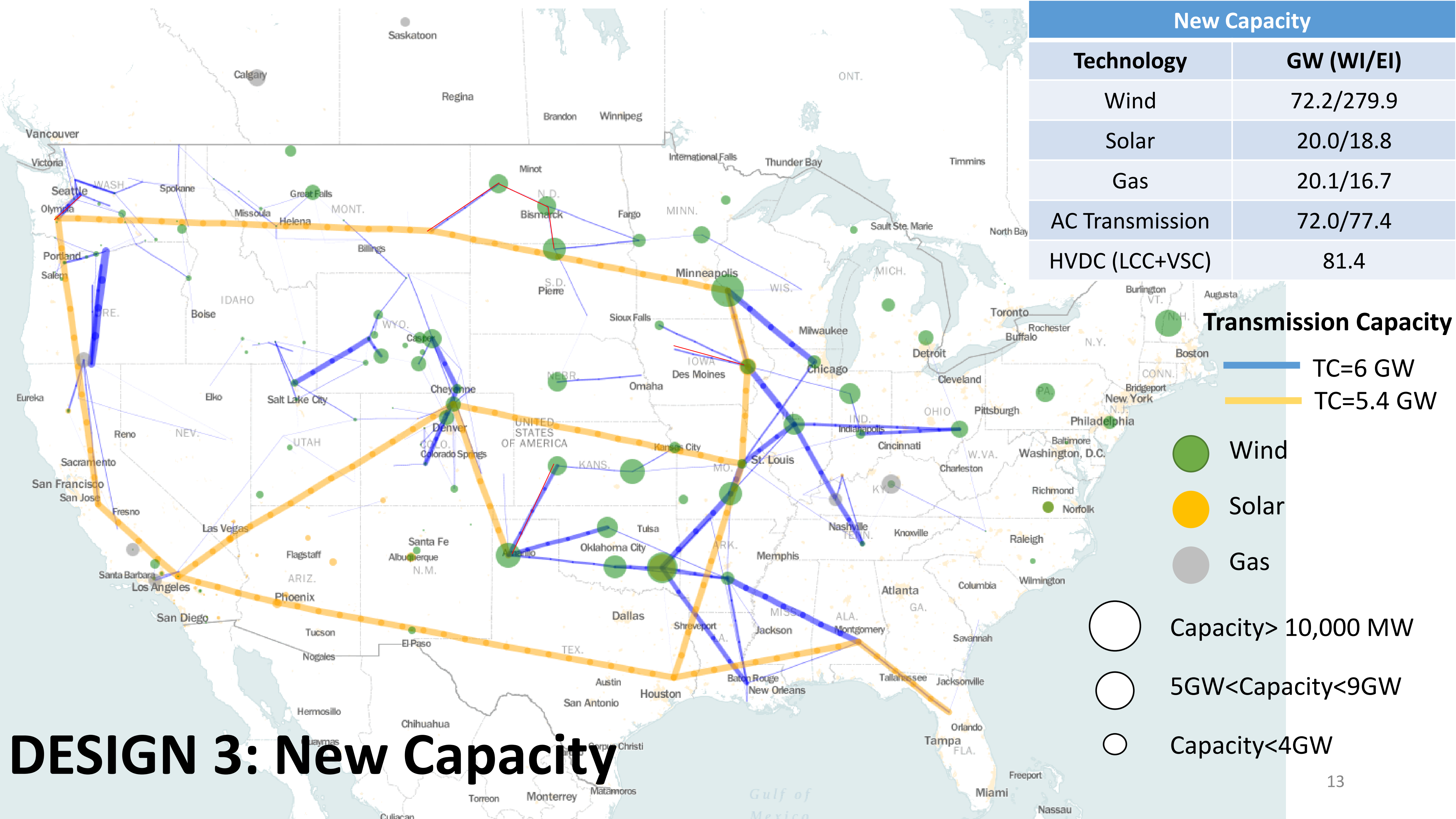
DESIGN 2b: New Capacity

New Capacity	
Technology	**WI/EI (GW)**
Wind	99.6/234.3
Solar	26.8/15.7
Gas	13.2/20.1
AC Transmission	71.6/91.9
HVDC (LCC)	13.1



DESIGN 3: New Capacity

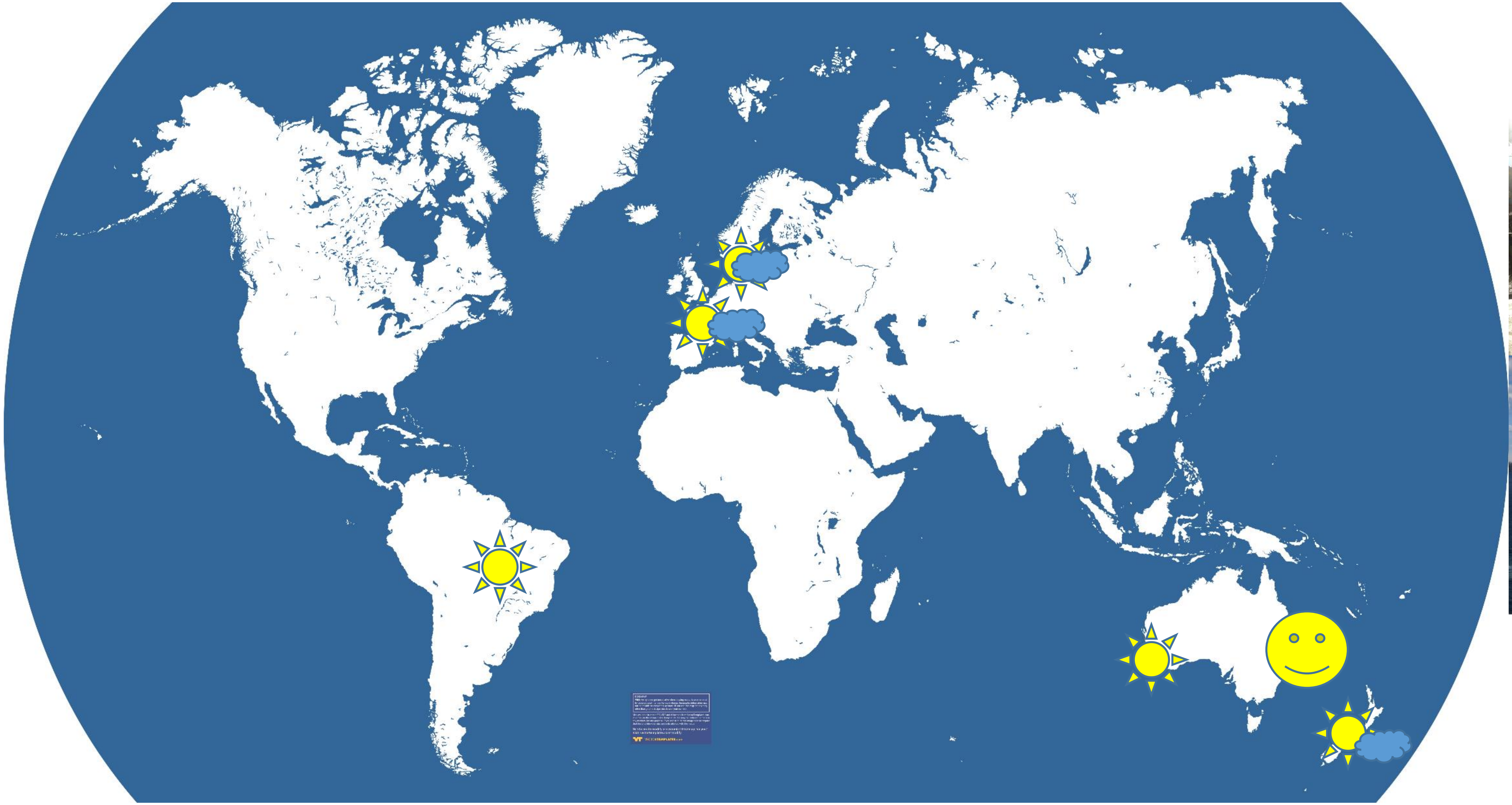
New Capacity	
Technology	**GW (WI/EI)**
Wind	72.2/279.9
Solar	20.0/18.8
Gas	20.1/16.7
AC Transmission	72.0/77.4
HVDC (LCC+VSC)	81.4



Robustness Tests & Sensitivities

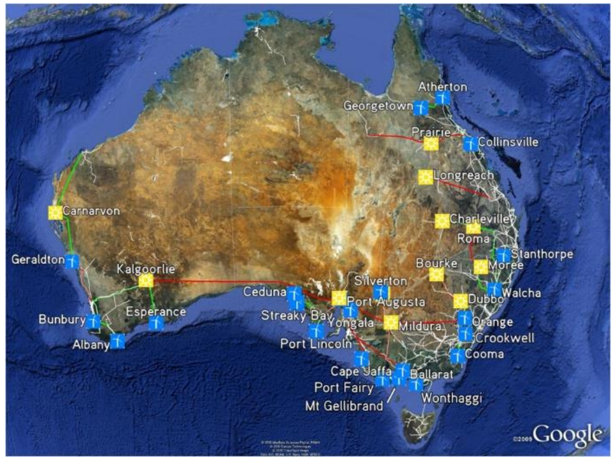
- Robustness
  - How Seams transmission investments change with high DG-PV?
  - How Seams transmission investments change with 80-m wind towers?
- Sensitivities
  - How Seams transmission investments change with different fuel prices?
  - How Seams transmission investments change with different CO_2 price?
  - How Seams transmission investments change with different gas price?

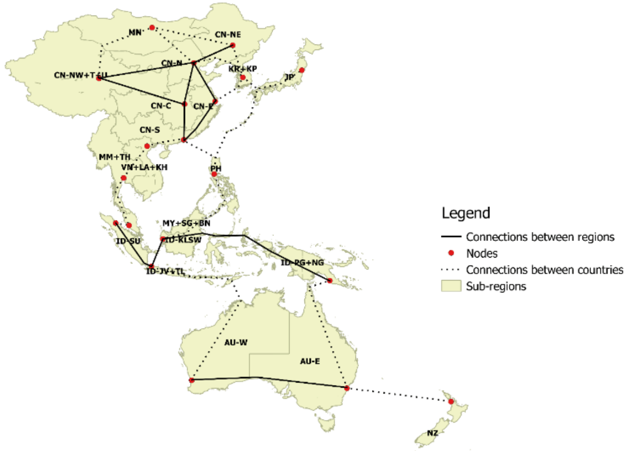
International Experience: Pre-Departure

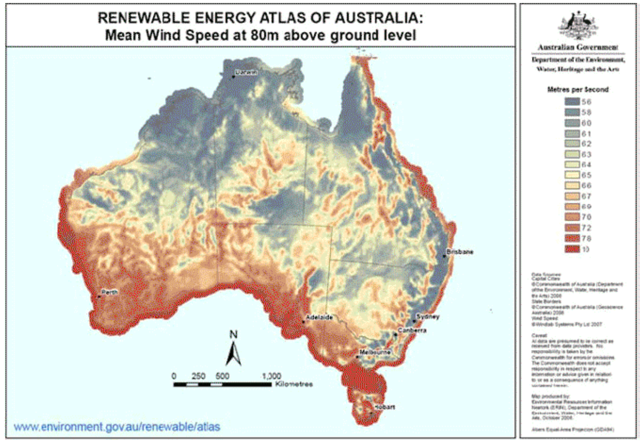


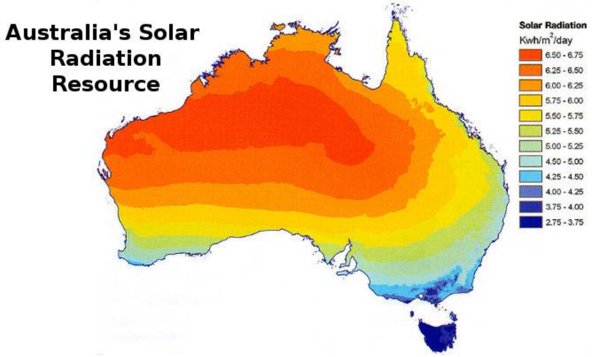
International Experience: Collaboration

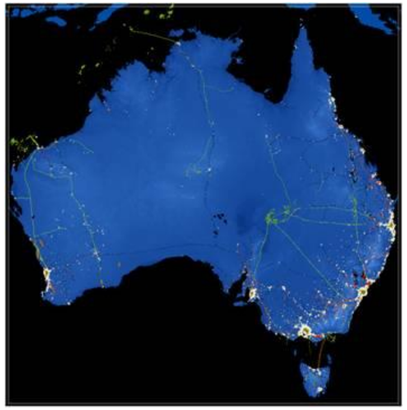
- The University of Sydney
  - Prof. Joe Dong & Dr. Ke Meng
- Energy group at USYD is also investigating about inter-regional transmission











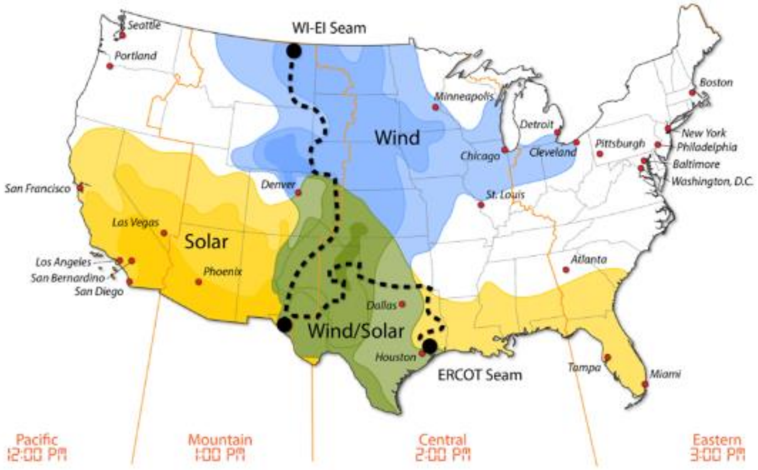
Ongoing collaboration about multi-terminal HVDC configurations

International Experience: Benefits

- A once in a life time opportunity to
  - Do research in a different environment
  - Collaborate with international peers
  - Travel and make friends

Conclusions

- Cross-seam transmission is good
  - ✓Provides economic benefits
  - ✓Allows energy movement from most economic resources to load centers
  - ✓Allows reserves to be shared across the contiguous US



Thank you!