Integrated Resource Planning for Modern Power Systems

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Chair, ESIG System Planning Working Group

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

Energy Systems Integration Group is a non-profit educational association that provides workshops, resources and education on the evolving electricity and energy systems.

ESIG supports engineers, researchers, technologists, policymakers and the public with the transformation of energy systems in a way that is economic, reliable, sustainable, thoughtful and collaborative.

www.ESIG.energy

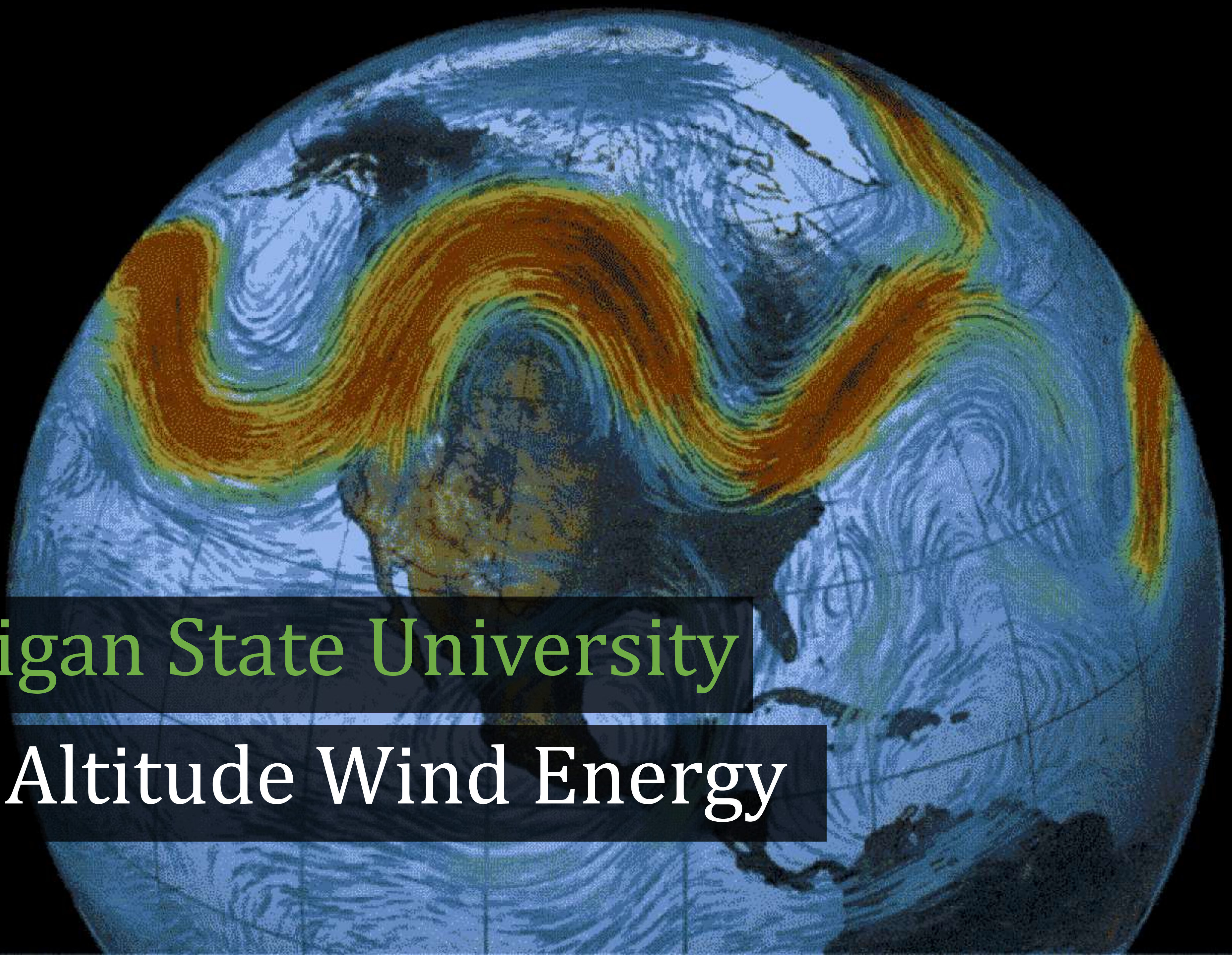
Agenda

- Part 0: Prologue
- Part I: The Math
- Part II: People and the Environment
- Part III: The Interconnections Seam Study
- Part IV: What does this mean?
- Part V: What should be done?
- Appendix: Want to learn more?

Part 0: Prologue

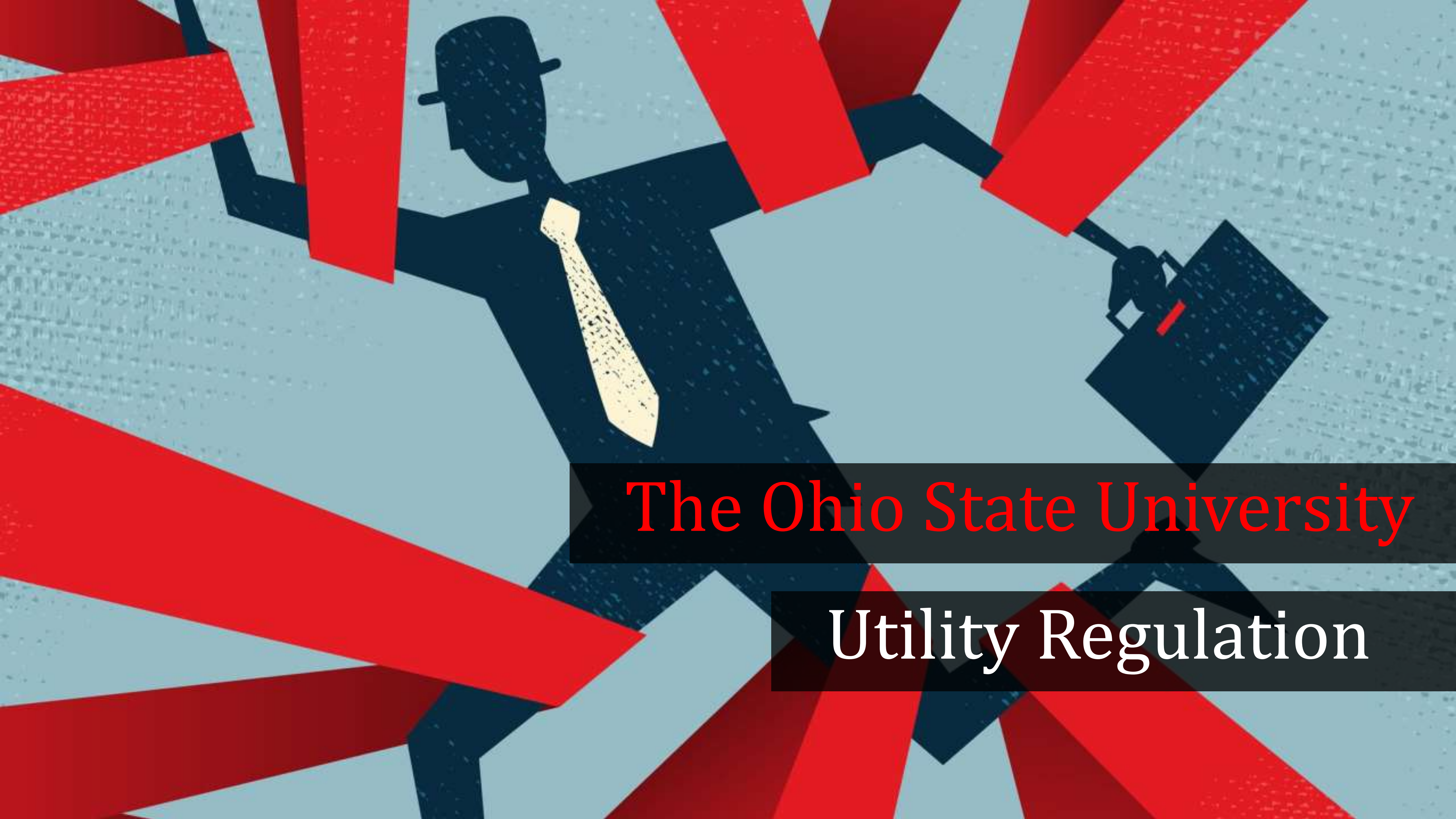
Aspiring Energy Nerd

1986 solar home replica



Michigan State University

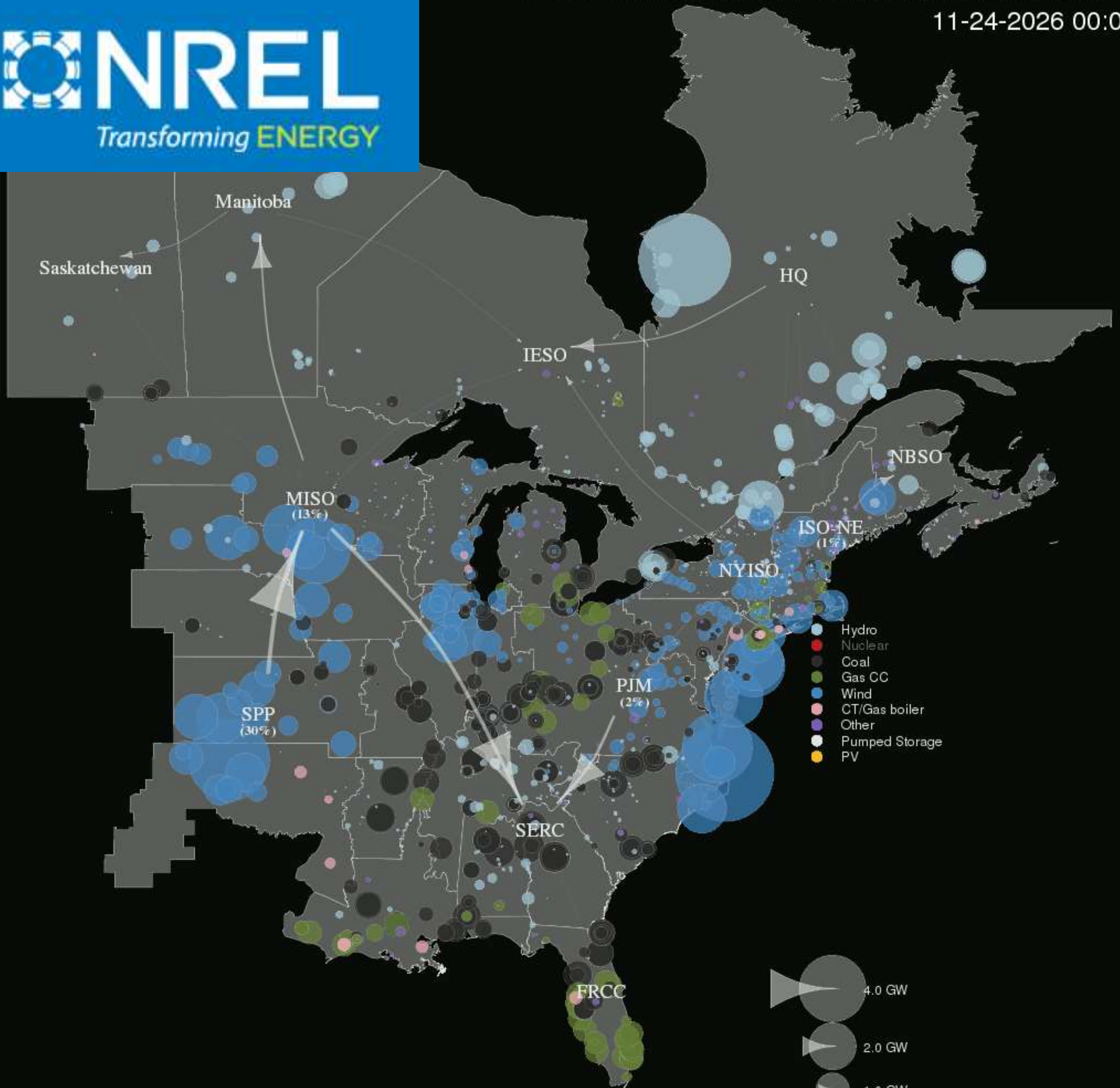
High Altitude Wind Energy


The Ohio State University
Utility Regulation

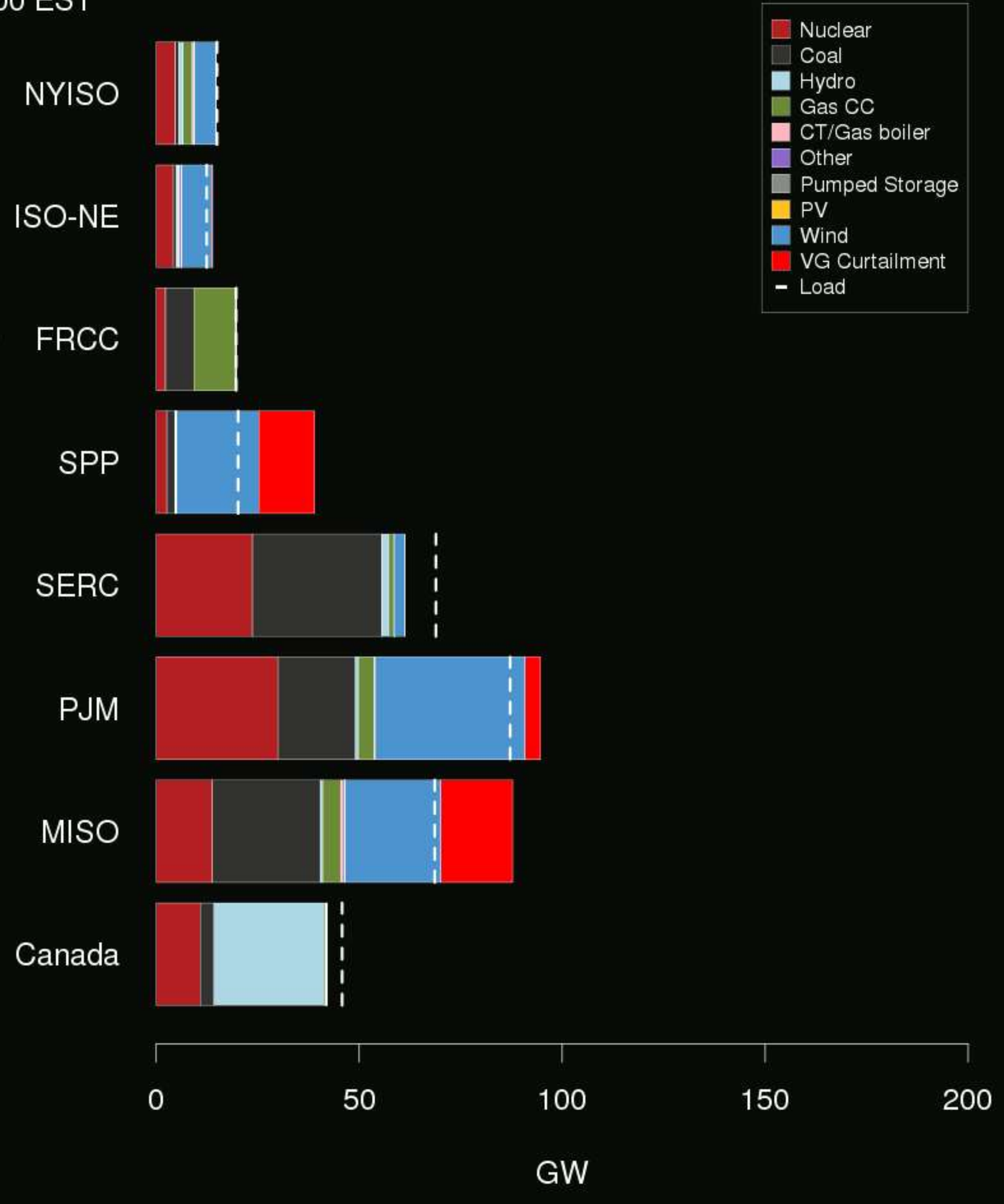

DEPARTMENT OF ENERGY
FEDERAL ENERGY REGULATORY COMMISSION

Eastern Renewable Generation Integration Study (RTx30)

11-24-2026 00:00 EST



Generation & Flow



Regional dispatch

NEXTera®
ENERGY


GREETINGS FROM
ST. PAUL
Minnesota

NEXTera®
Analytics

NextEra Analytics helps industries reach decarbonization goals using physics, data science, and software

Session Goals

- Be able to define an Integrated Resource Plan
- Identify data and tools used in an Integrated Resource Plan
- Explain why Integrated Resource Plans are imperfect
- Identify a few challenges associated with planning for renewables
- Learn about some examples of Integrated Resource Plans

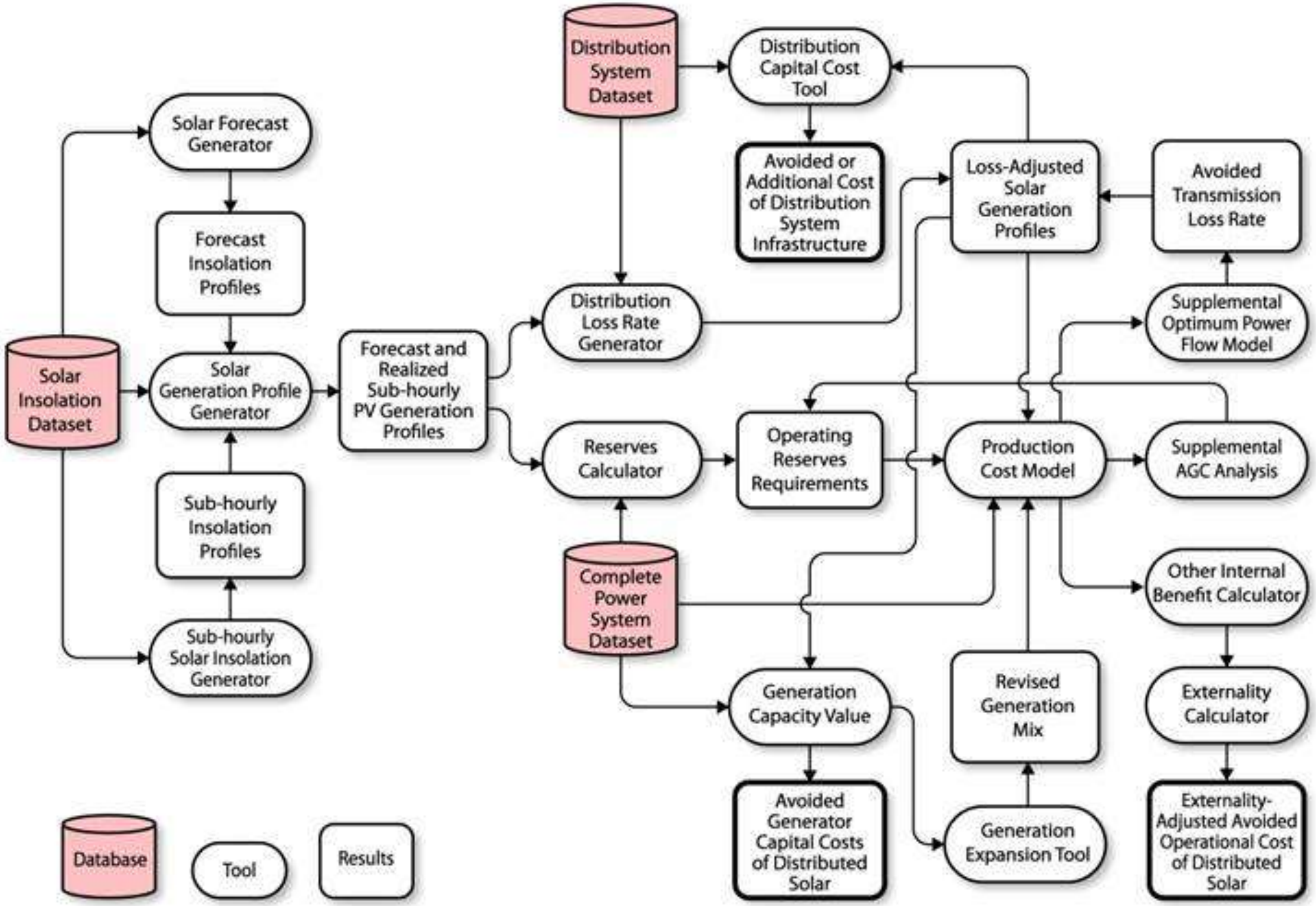
What is an

Integrated Resource Plan?

Integrated Resource Plan

- <u>Definition</u>: is an economic and engineering process that uses various tools and data to ensure reliable and least-cost electric service to customers.

Distributed Energy Resource Integrated Resource Plan



https://www.nrel.gov/docs/fy14osti/62447.pdf


ISO new england
This sounds complicated
It is

Let’s break it down

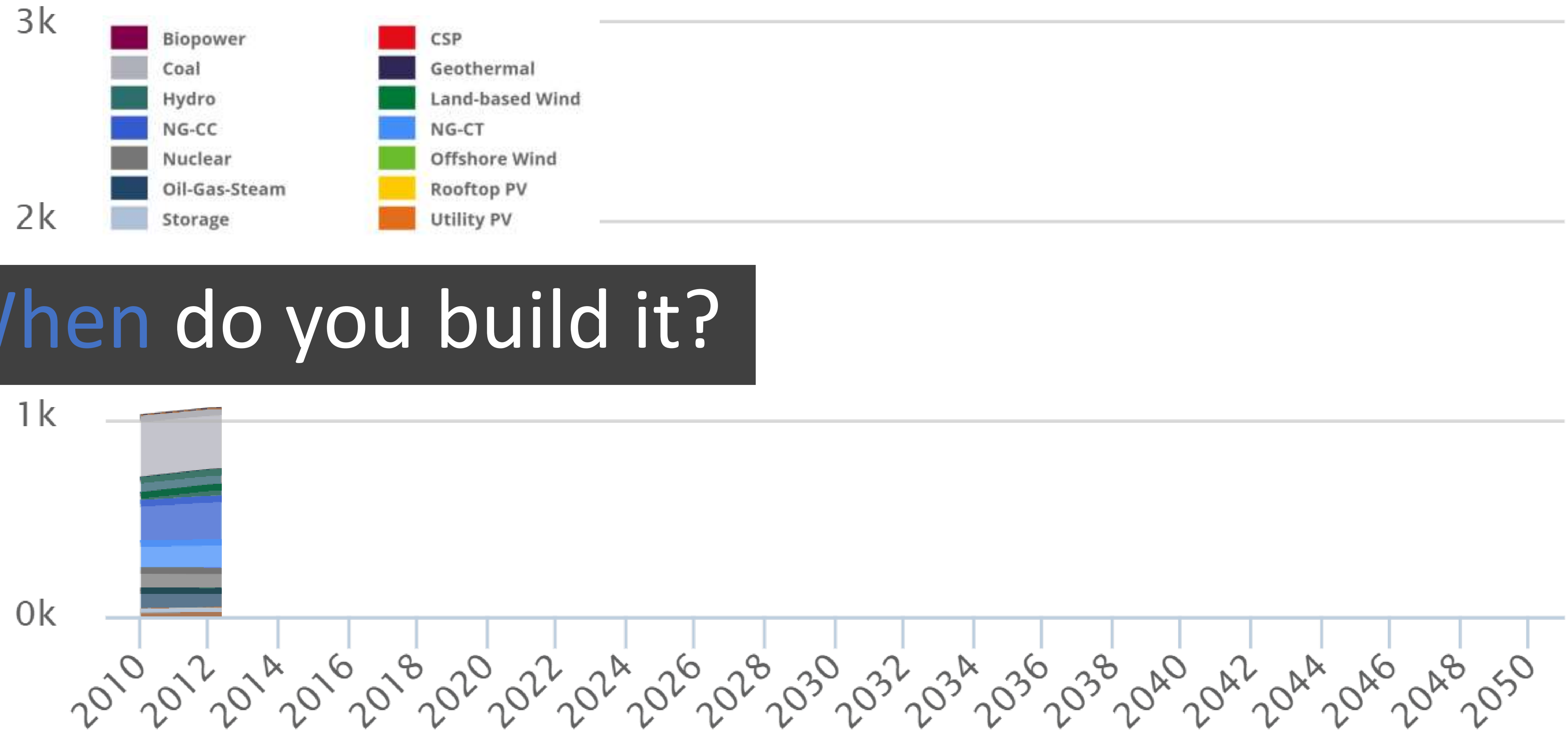
Five questions answered in an integrated resource plan

What do you build?

Image courtesy of NREL

Image courtesy of NREL

80% National RPS: Capacity

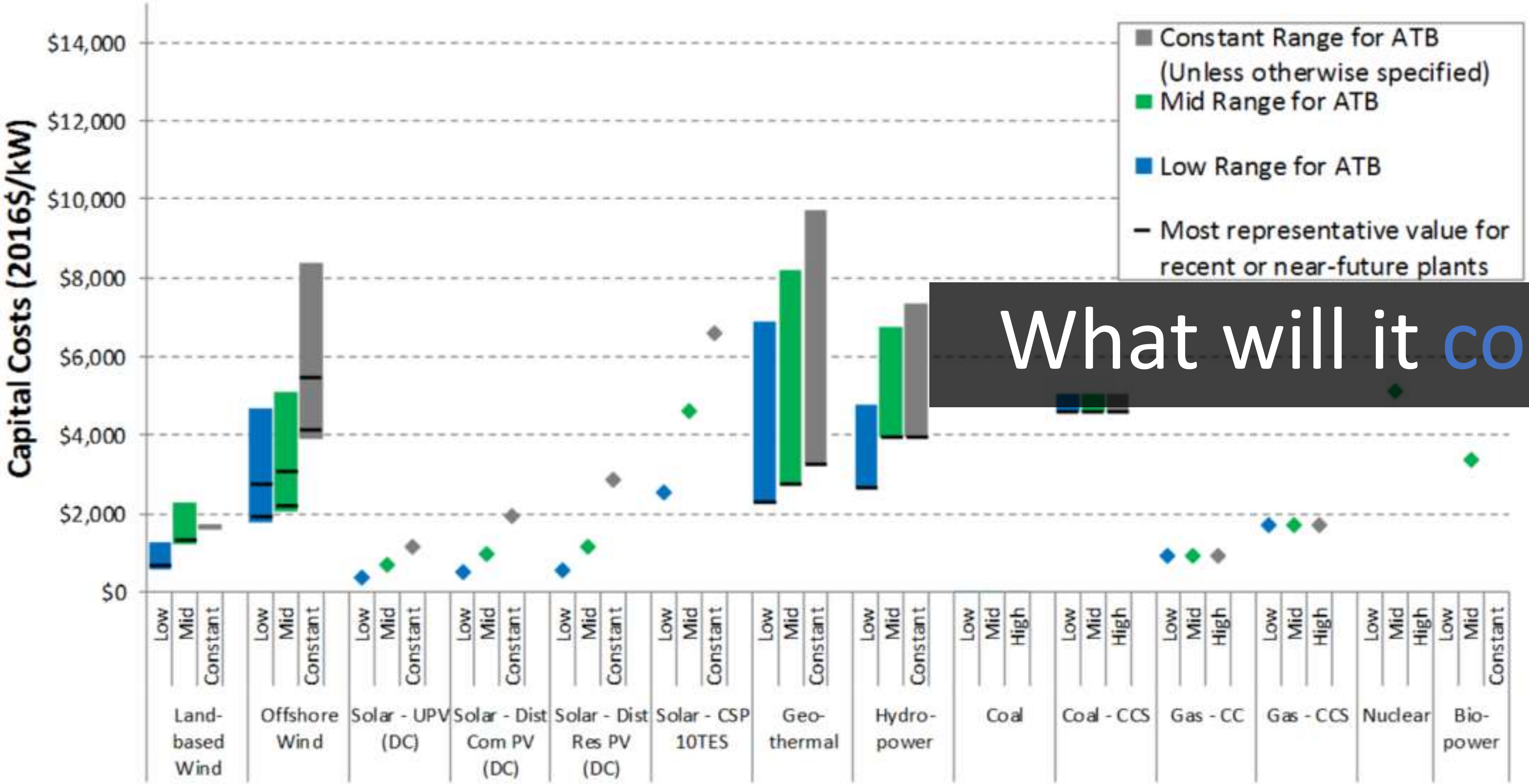


When do you build it?

https://openei.org/apps/reeds/#

2018 ATB CAPEX range by technology for 2030

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov



What will it cost?

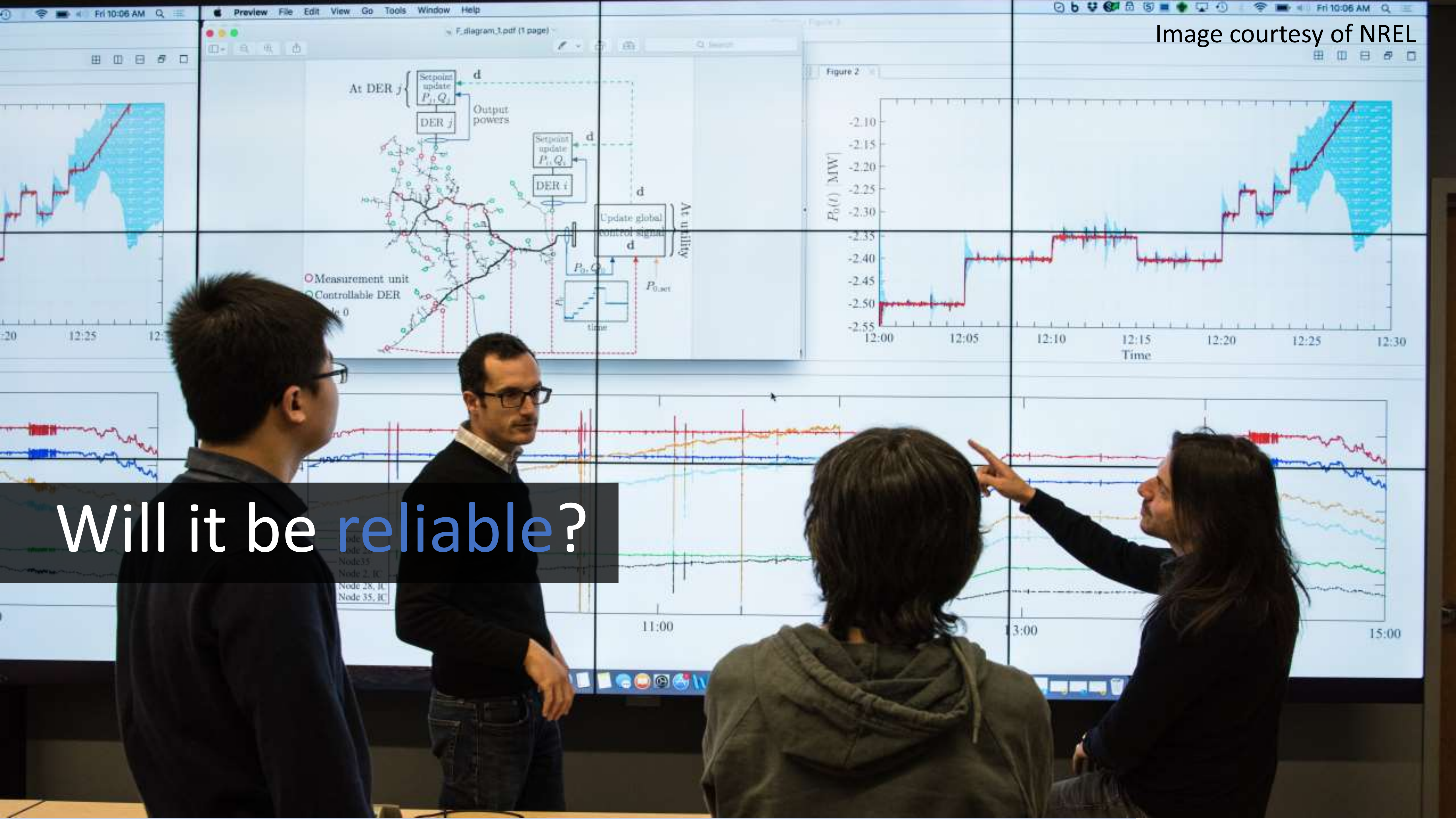


Image courtesy of NREL

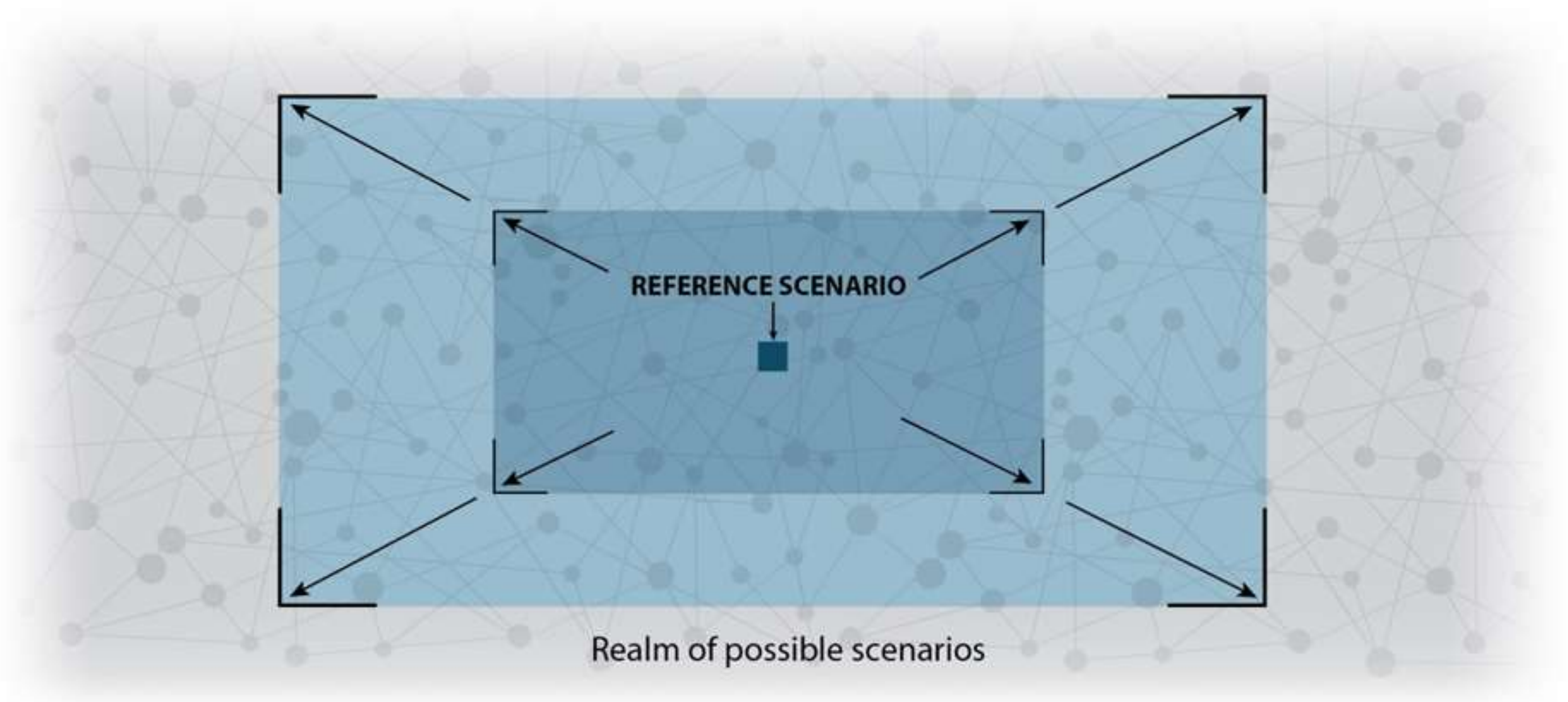
Will it be reliable?

https://www.syfy.com/syfywire/neil-degrasse-tyson-explains-what-sets-cosmos-apart-at-nycc

It is…but

It’s also an Art

We can’t study every possible future. We must make choices.



What does this mean?

- The data we use to model the power system are imperfect.
- Our methods are incapable of considering all of the conditions that could exist.
- We as regulators, engineers, scientists, artists, and consumers have different interpretations of safe, reliable, affordable, and clean.

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Part I: The Math

Why Integrated Resource Planning is an Artful Science

Cost and Reliability are determined using math

- Least-cost
  - Capital costs

$$\sum_{\substack{n \in N,\\ q \in Q}} CapacityN_{n,q} * (fcr_q * (regmult_{n,q} * capcost_q + gridconnect_q) + fomN_q)$$

  - Variable costs

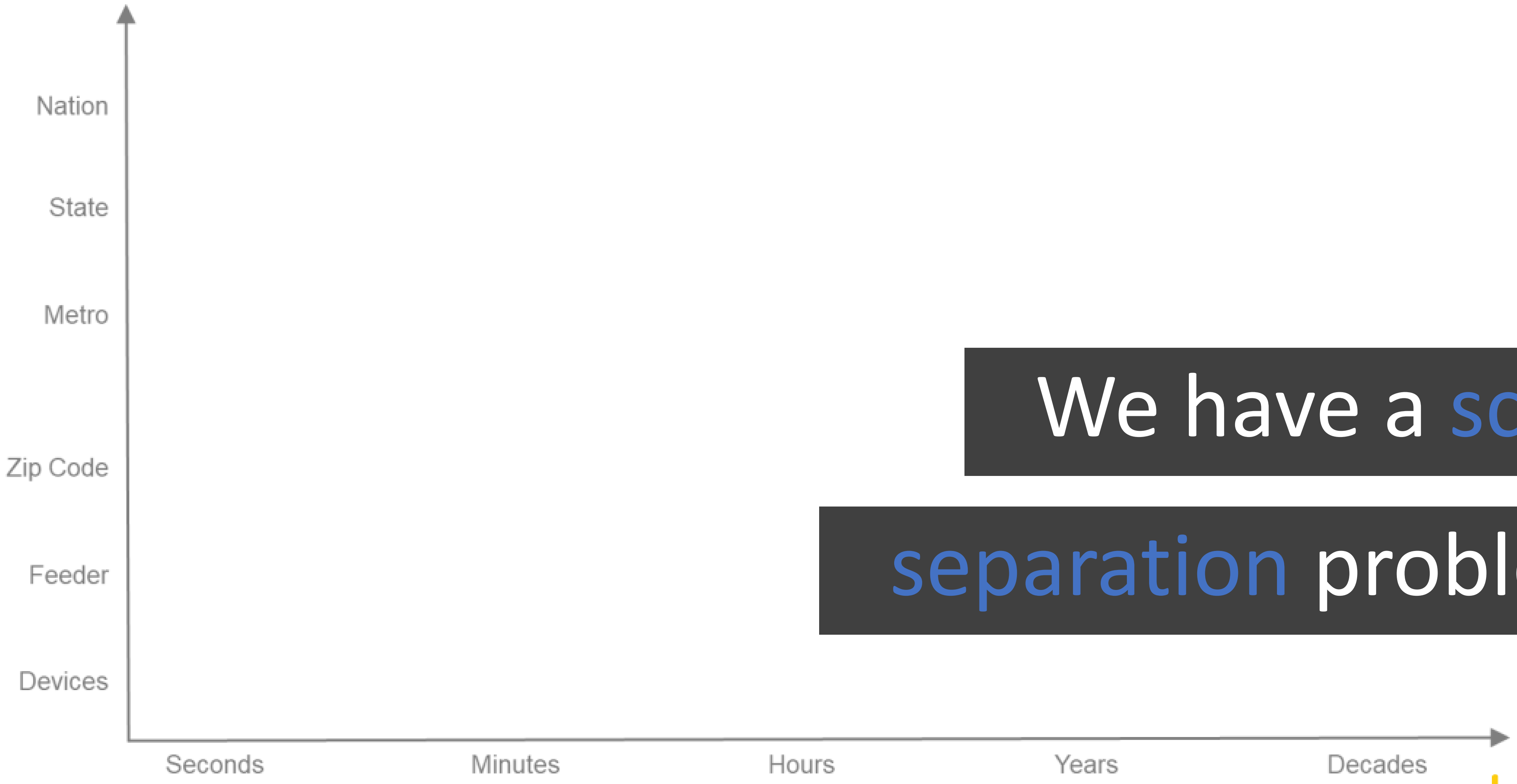
$$\text{min.} \quad \sum_t \sum_k c_k^t g_k^t + c_k^{t,su} su_k^t + c_k^{t,sd} sd_k^t$$

- Reliable
  - Resource Adequacy

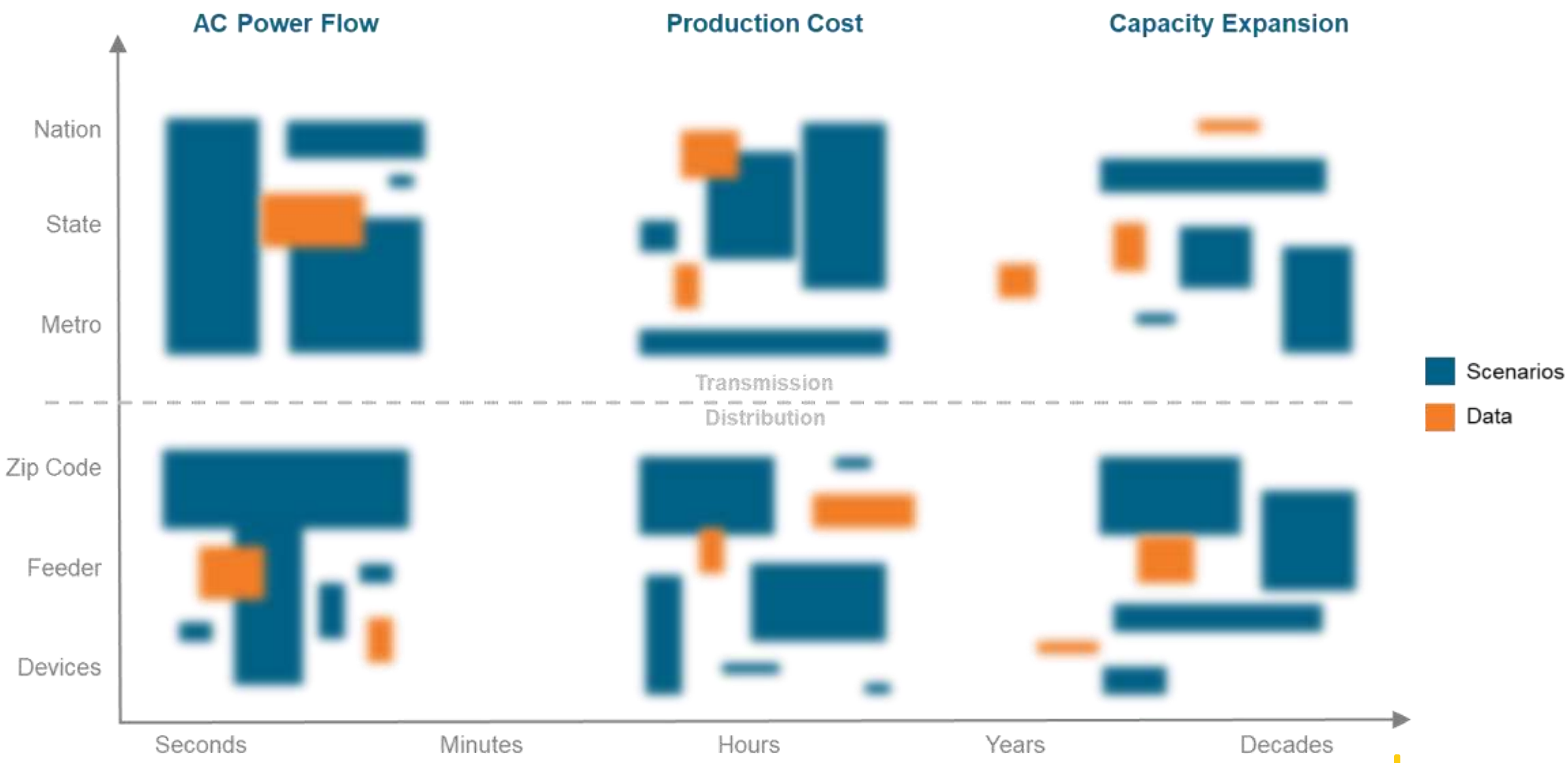
$$\text{LOLP} = \sum_j p[C_A = C_j].P[L > C_j] = \sum_j \frac{P_j.t_j}{100}$$

  - System Security

$$0 = -P_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik} \cos\theta_{ik} + B_{ik} \sin\theta_{ik})$$



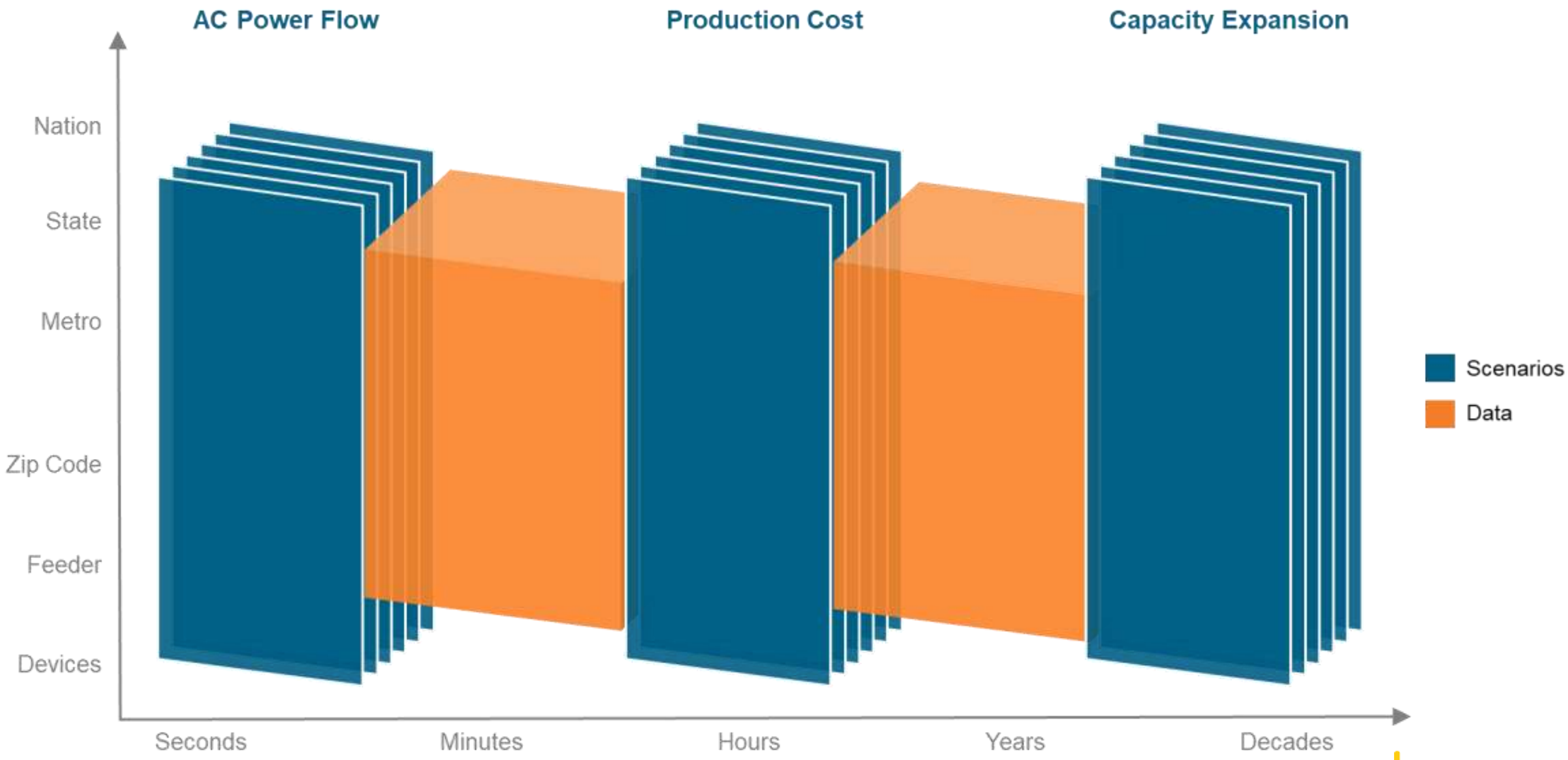
We have a scale separation problem



Energy Systems Integration Group

Charting the Future of Energy Systems Integration and Operations

ESIG

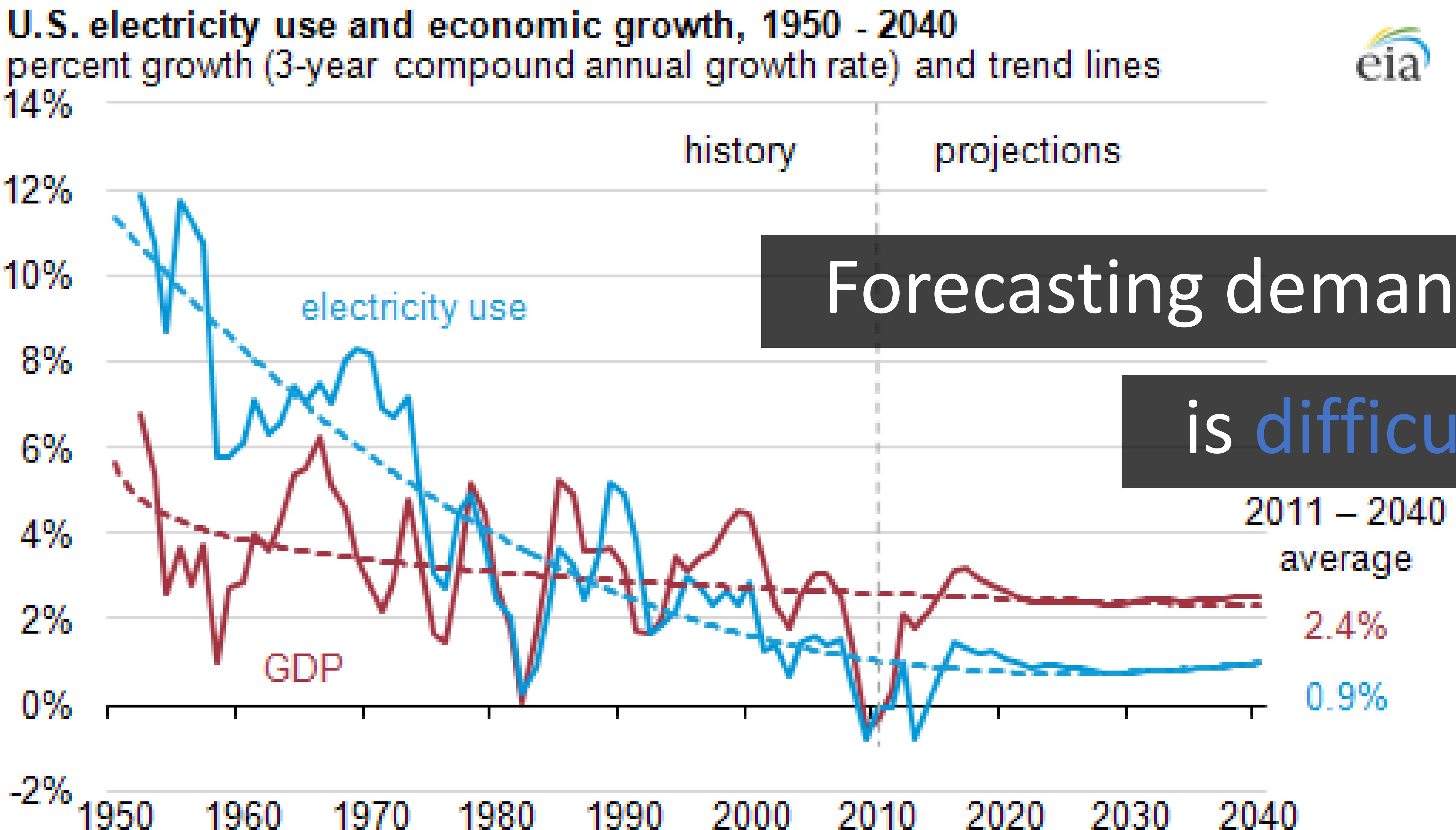

AC Power Flow
Production Cost
Capacity Expansion
Nation
State
Metro
Zip Code
Feeder
Devices
Seconds
Minutes
Hours
Years
Decades
Scenarios
Data

Major Publications from these domains

- Capacity Expansion Modeling
  - Renewable Electricity Futures Study:
    https://www.nrel.gov/analysis/re-futures.html
- Production Cost Modeling
  - Eastern Renewable Generation Integration Study:
    https://www.nrel.gov/grid/ergis.html
- AC Power Flow
  - Definition and Classification of Power System Stability
    https://ieeexplore.ieee.org/document/1318675

Part II: People & Environment

Why Integrated Resource Planning is an
Artful Science



Forecasting demand is difficult

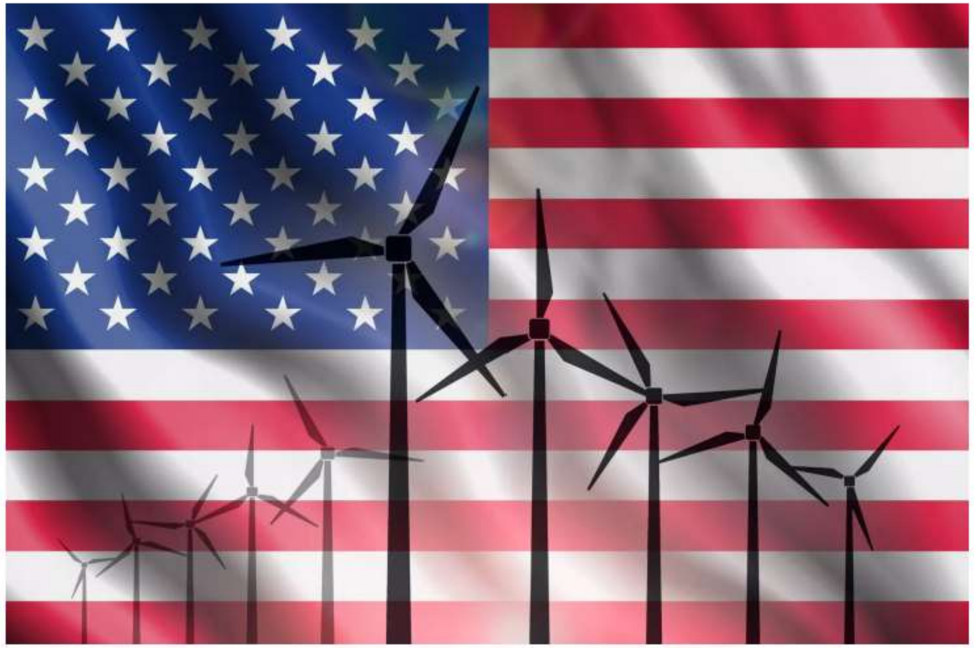
Consumer preferences constantly evolve

Vox

Utilities have a problem: the public wants 100% renewable energy, and quick

The industry is groping for ways to talk the public down.

By David Roberts | @drvox | david@vox.com | Updated Oct 11, 2018, 9:19am EDT



American as apple pie. | Shutterstock

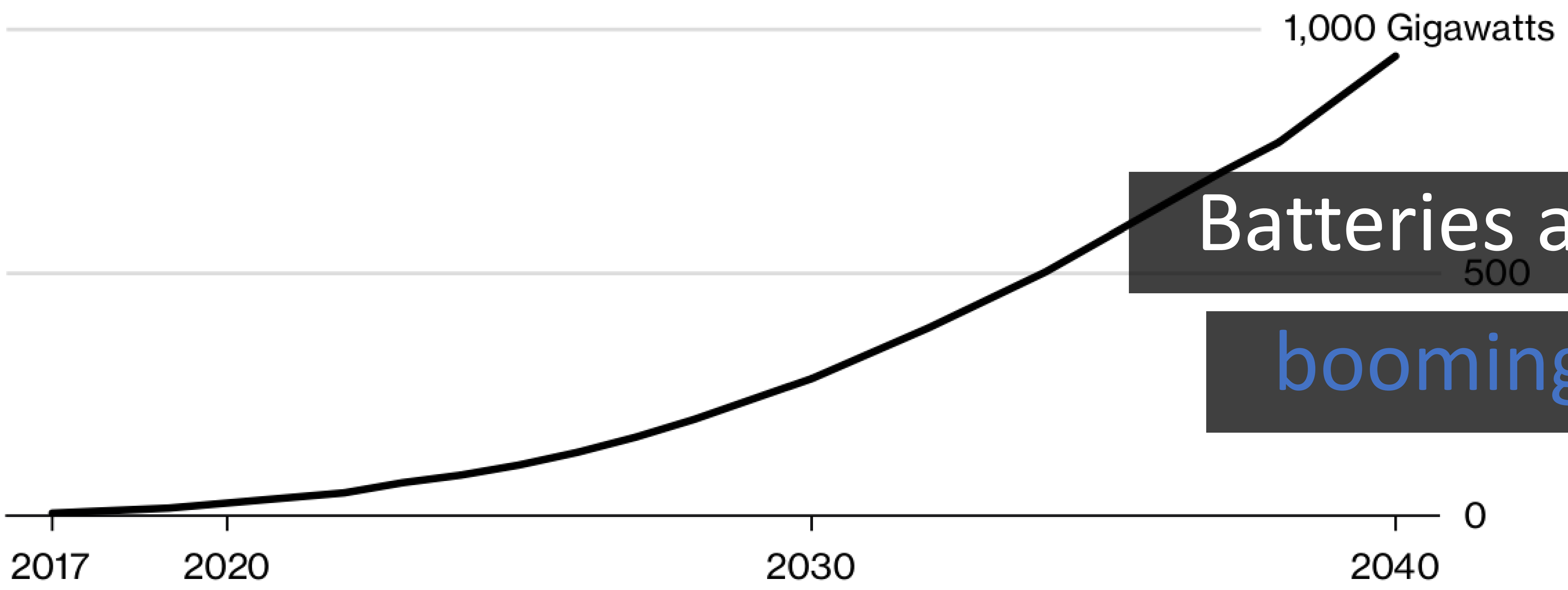
Renewable energy is hot. It has incredible momentum, not only in terms of deployment and costs but in terms of public opinion and cultural cachet. To put it simply: Everyone loves renewable energy. It's cleaner, it's high-tech, it's new jobs, it's the future.

People are adopting new technology

Homes are Smart

Battery Bonanza

Global energy storage rising to one terawatt in two decades



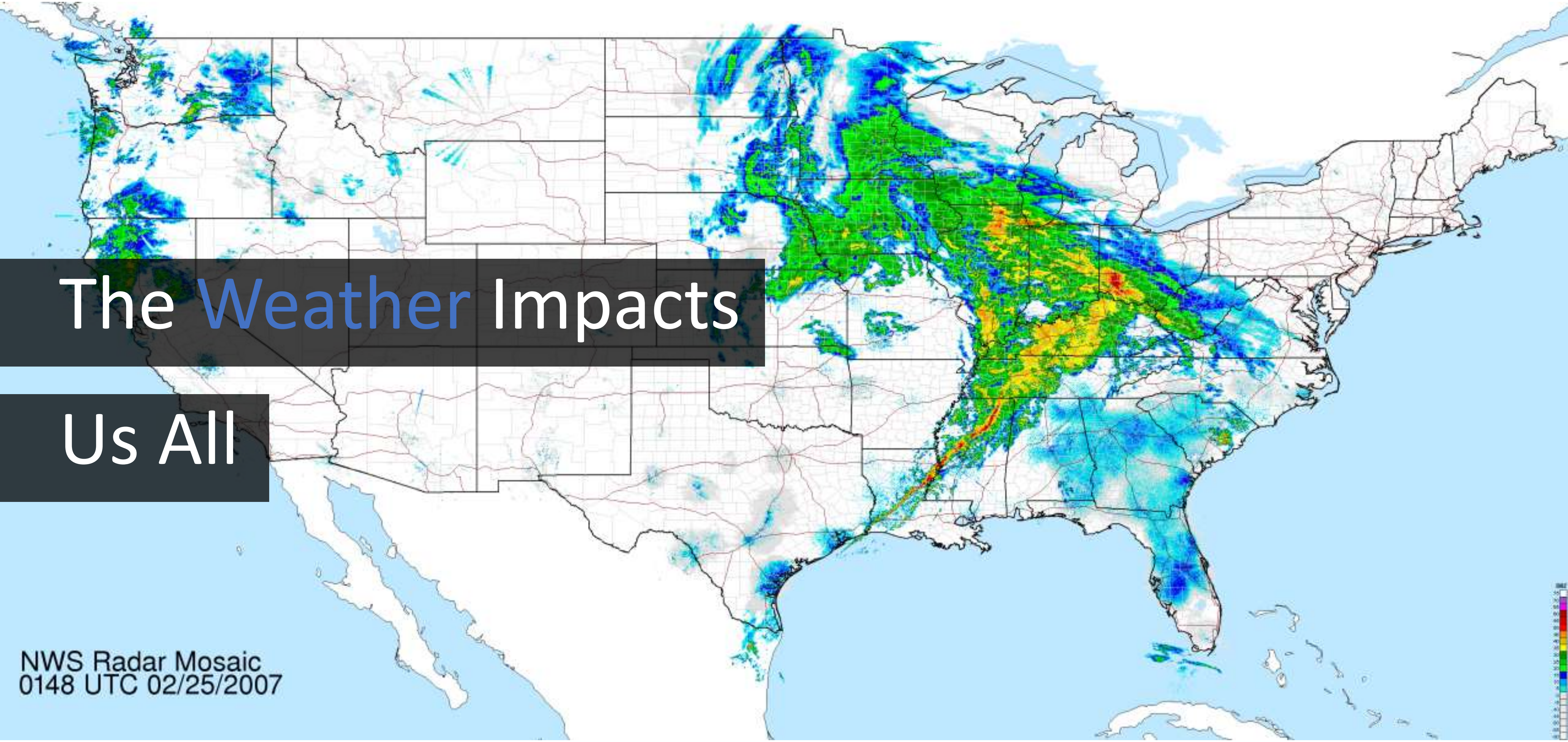
Batteries are booming

Bloomberg NEF

Bloomberg

We're going to need all of this technology

The Weather Impacts Us All



Daily patterns drive demand and supply

https://www.youtube.com/watch?v=hVymyJ9q5a0

Energy Needs and Supply Change with the Seasons

https://svs.gsfc.nasa.gov/4452

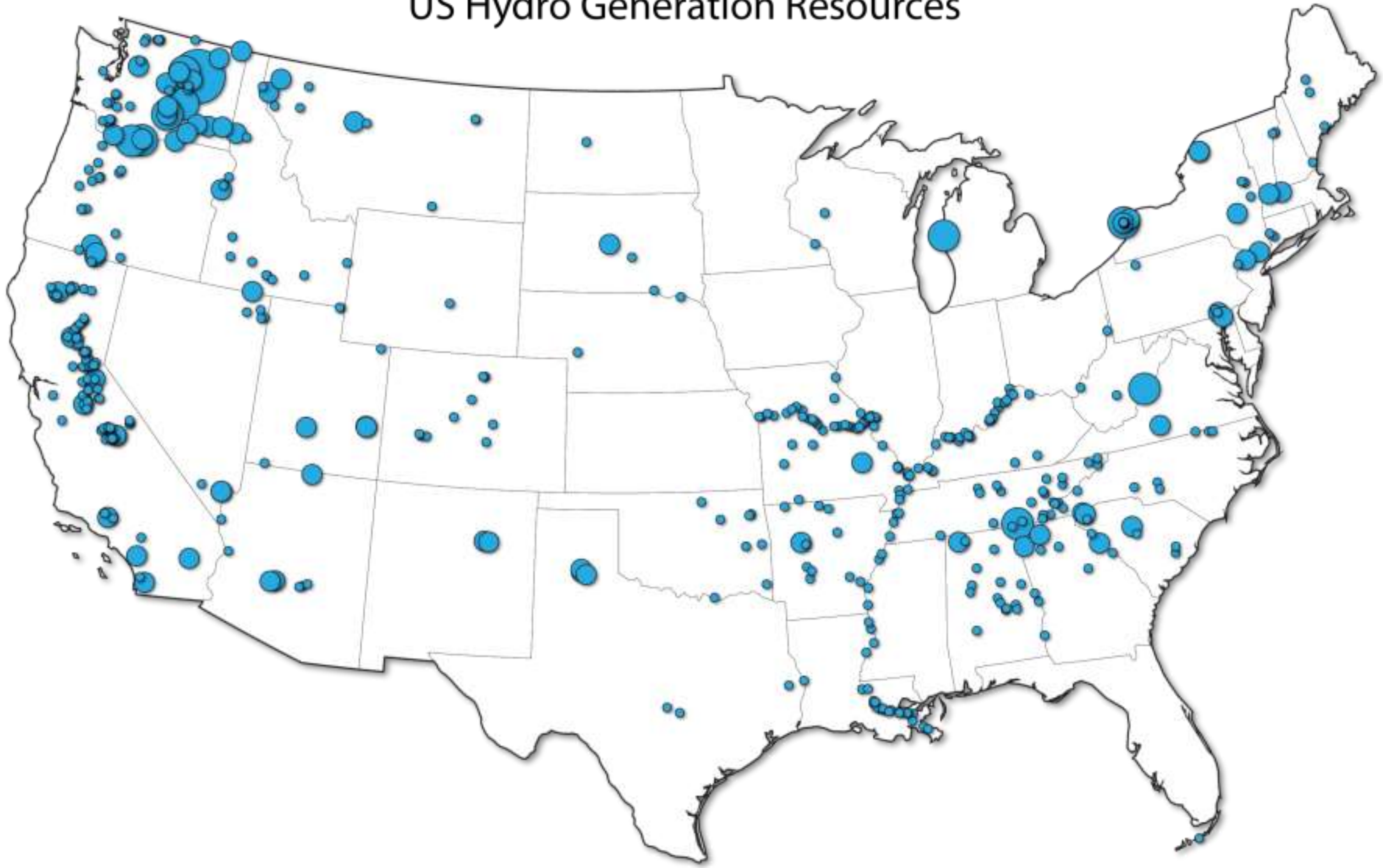
Technology can ensure

Ensure affordability

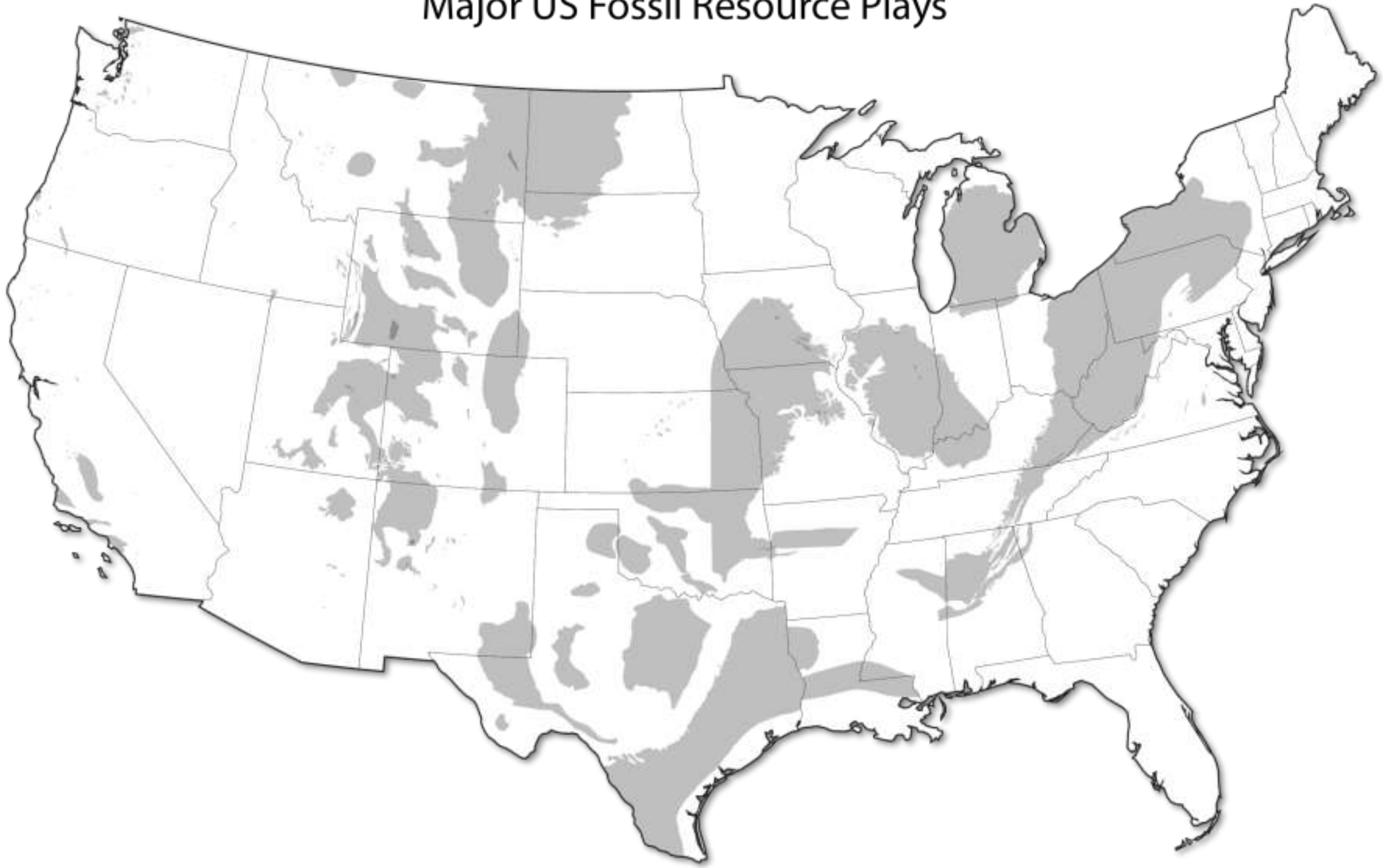
Part III: The Interconnections Seam Study

Why Integrated Resource Planning is an
Artful Science

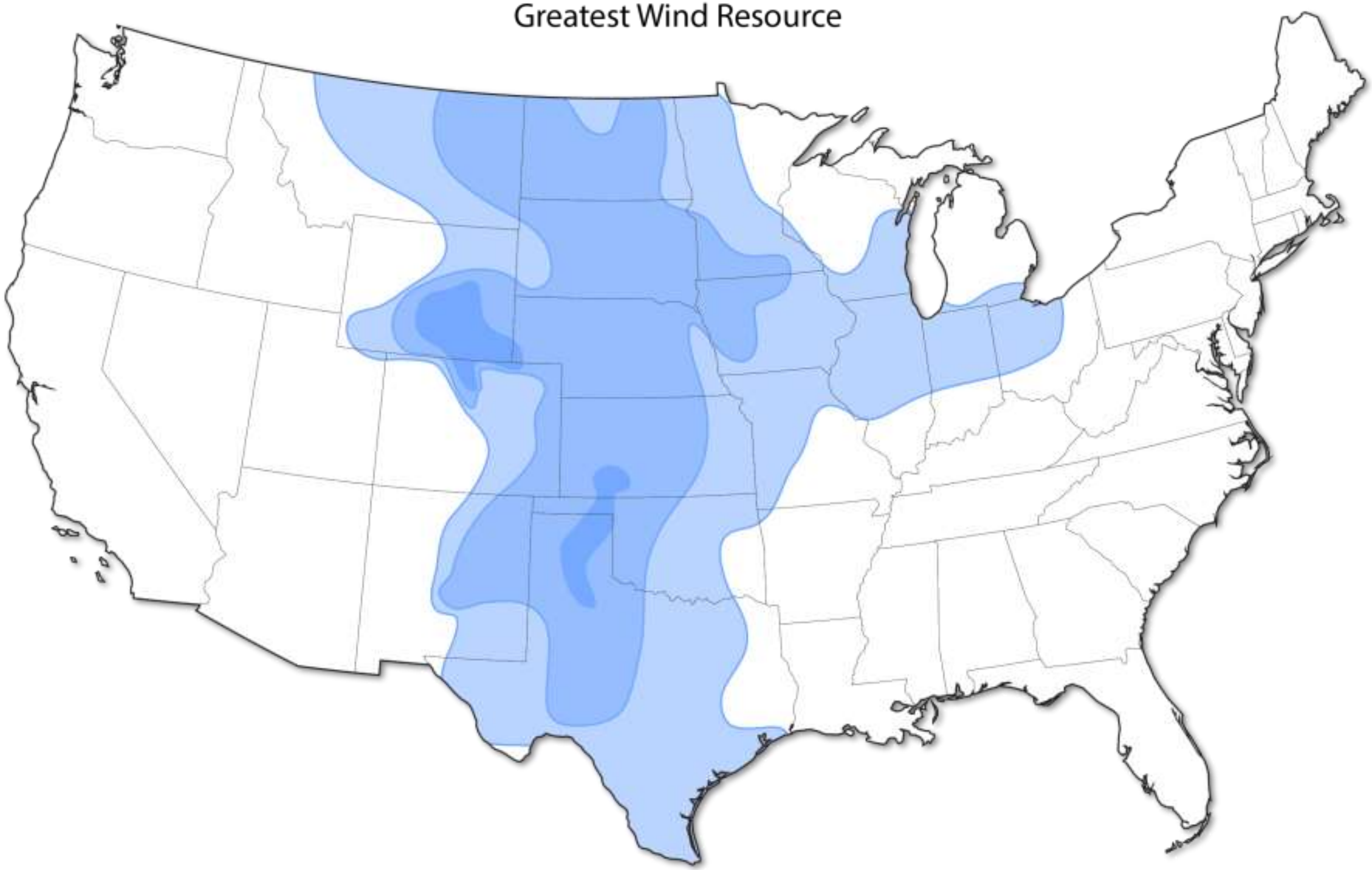
US Hydro Generation Resources



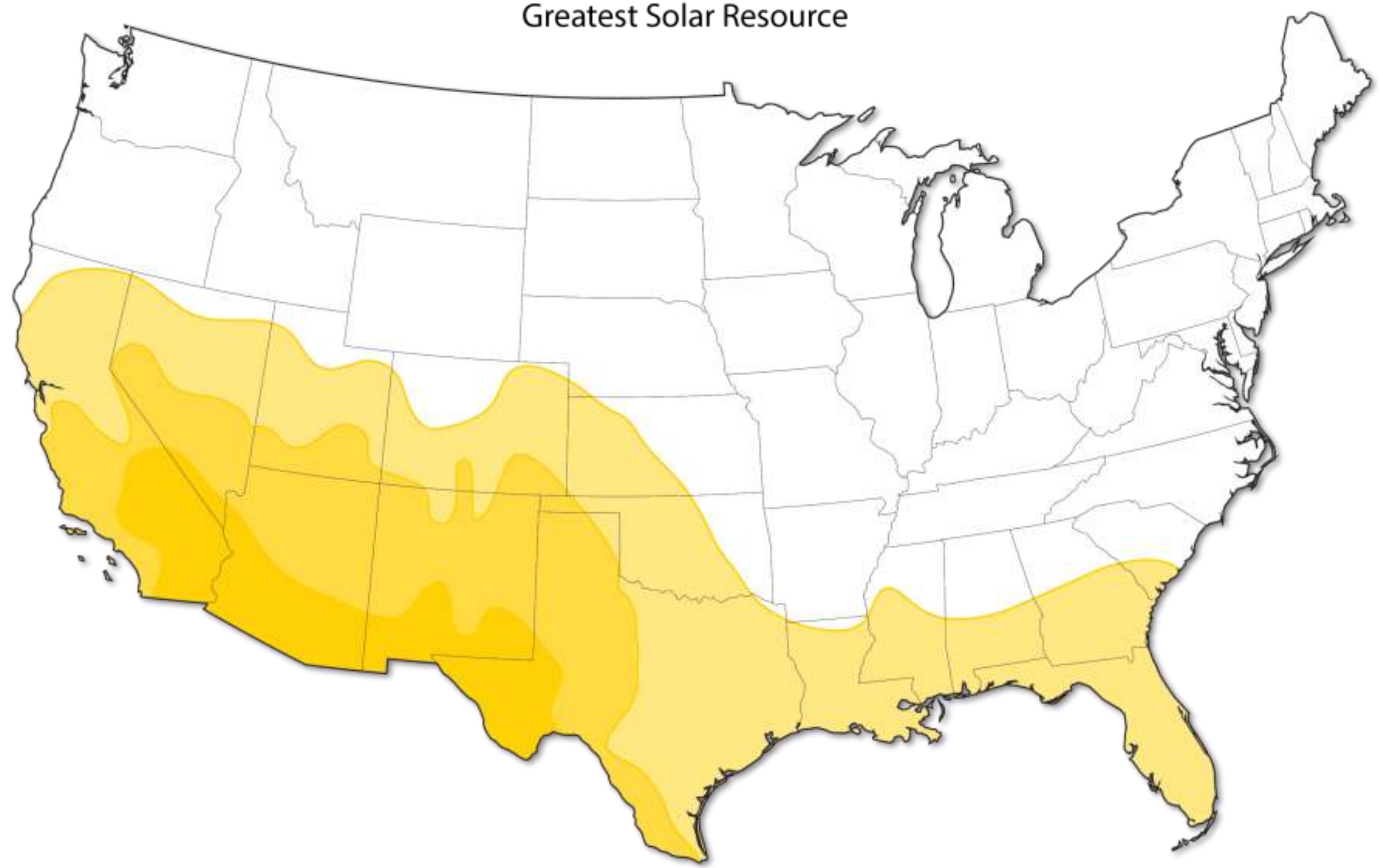
Major US Fossil Resource Plays



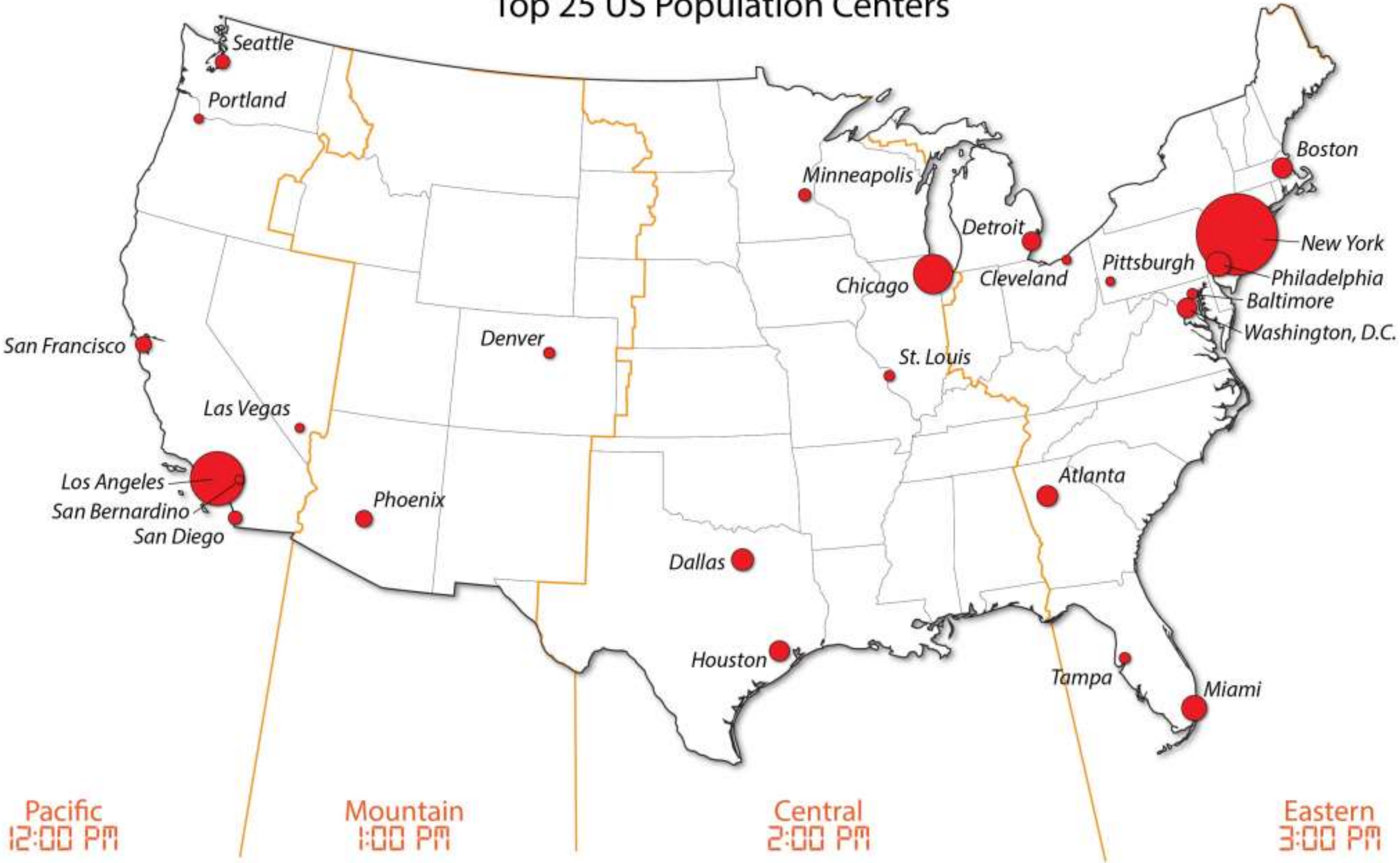
Greatest Wind Resource

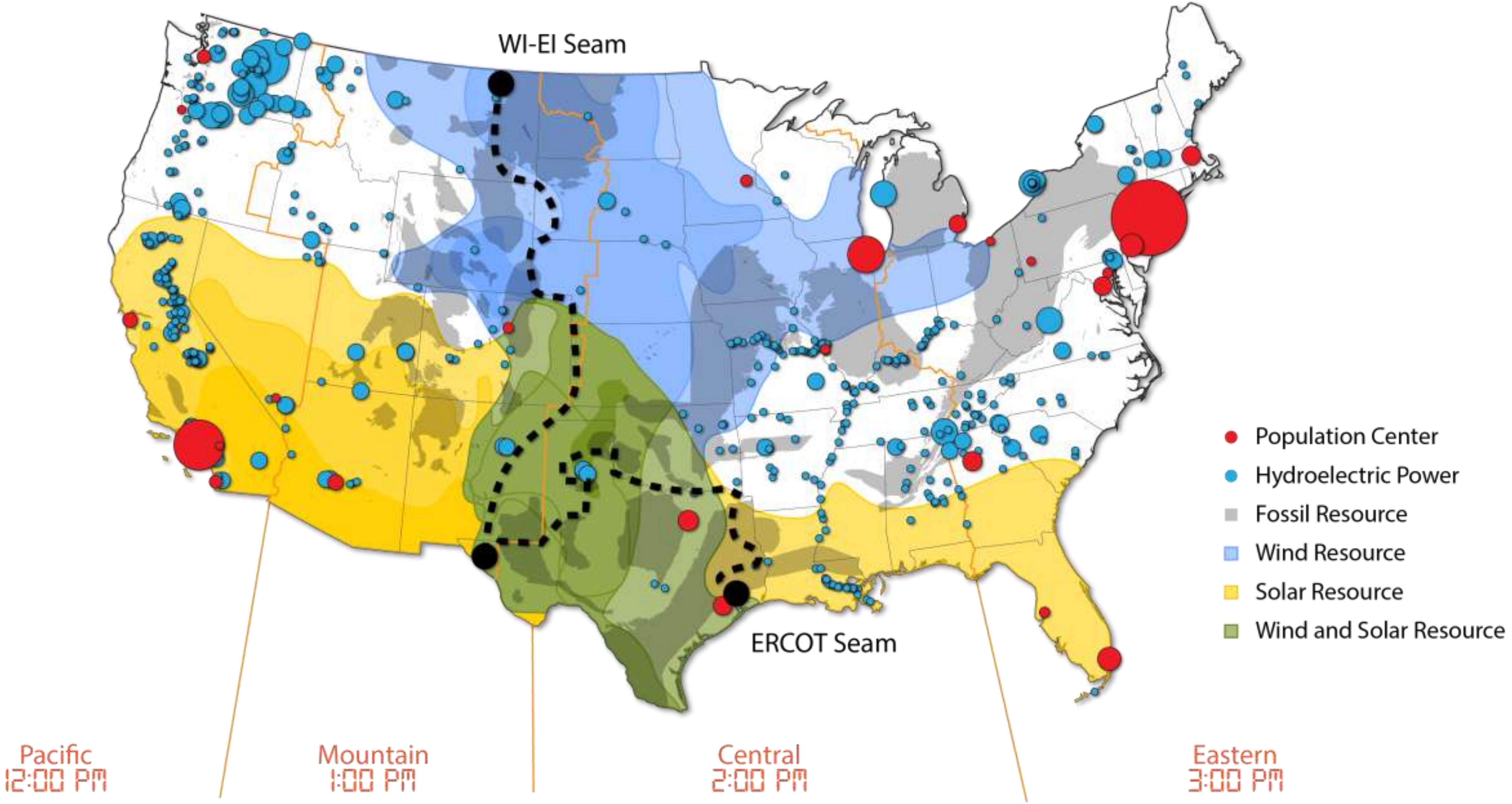


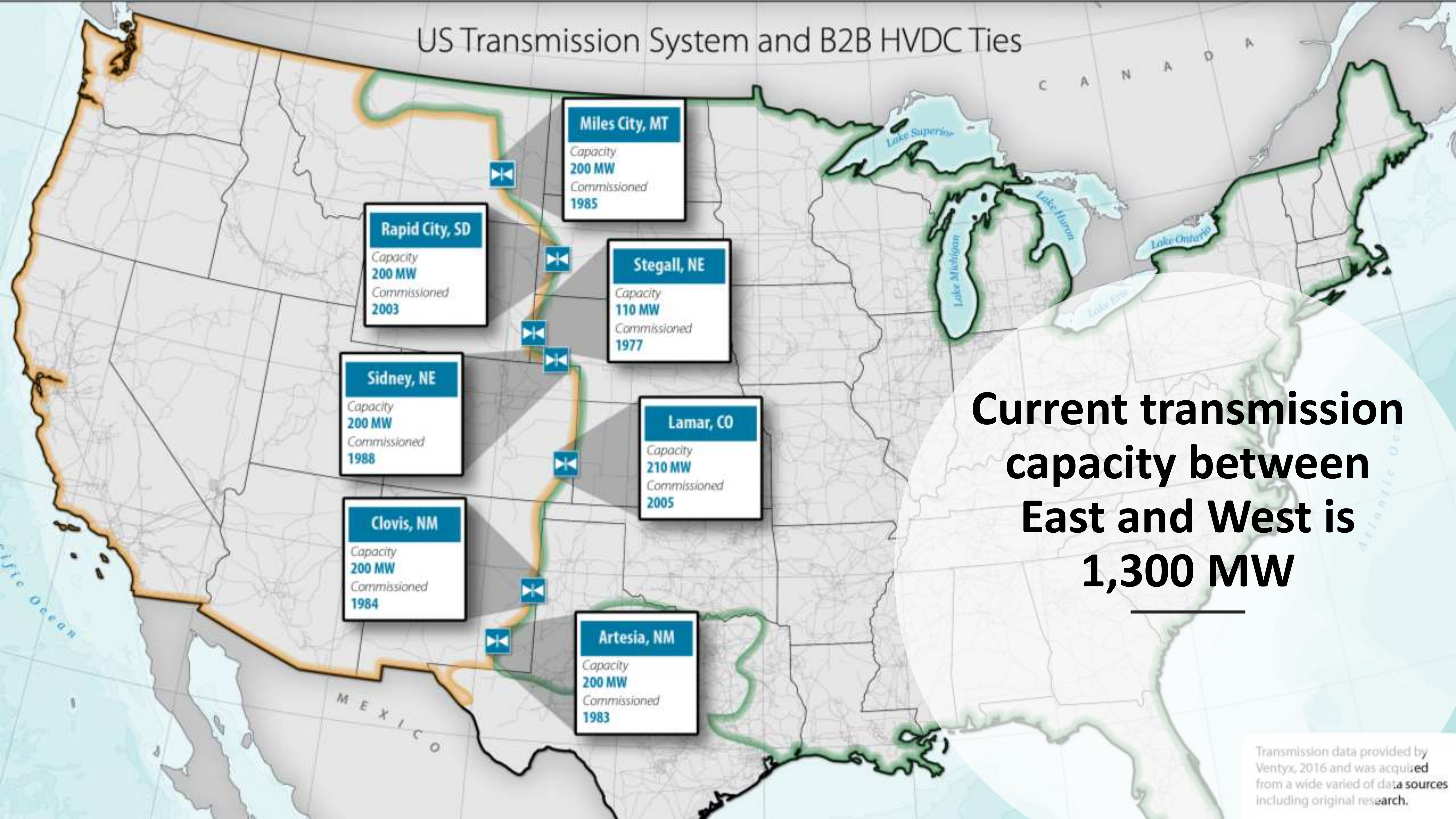
Greatest Solar Resource



Top 25 US Population Centers




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



Current transmission capacity between East and West is 1,300 MW

Continental

Power Systems

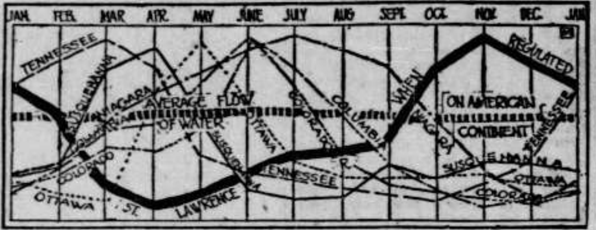
Continental Transmission Studies

Chicago Tribune	Bureau of Reclamation	Bonneville Power Administration	Western Area Power Administration	Department of Energy
1923	1952	1979	1994	2002
Tying the Seasons to Industry	Super Transmission System	Interconnection of the Eastern and Western Interconnections	East/West AC Intertie Feasibility Study	National Transmission Study

TRIBUNE OFFERS HYDRO-ELECTRIC SYSTEM FOR U. S.

Would Hitch Seasons to All Industries.

Making Rivers Work Together



This chart shows how flood waters in different water sheds occur in different months. The artist has drawn a line showing the St. Lawrence river under artificial regulation.

ONE OF THE POWER RESERVOIRS

PACIFIC STATES PLAN FIGHT ON PITTSBURGH PLUS

“This is neither prophecy, propaganda, nor rhapsody, but the assured goal of the scientific and economic forces at work.”

Chicago Tribune, 1923

COAL MAY PROVIDE POWER FOR WEST

Reclamation Bureau Pictures Super Transmission System Operated by Steam Plants

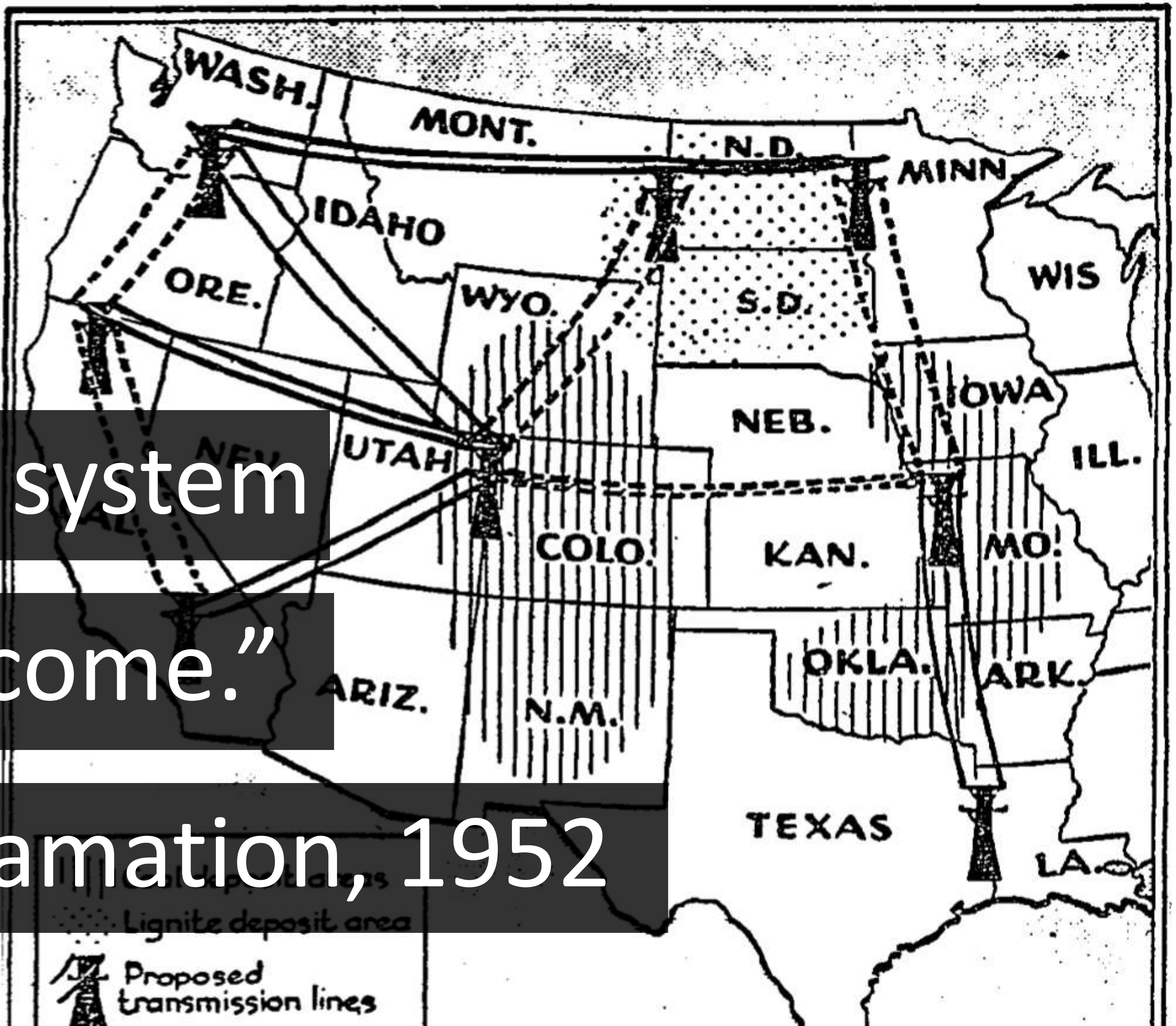
The Reclamation Bureau today pictured the West's future power needs being supplied in large part

long distance transmission system. More than half now is supplied by hydroelectric plants.

The bureau made public a study

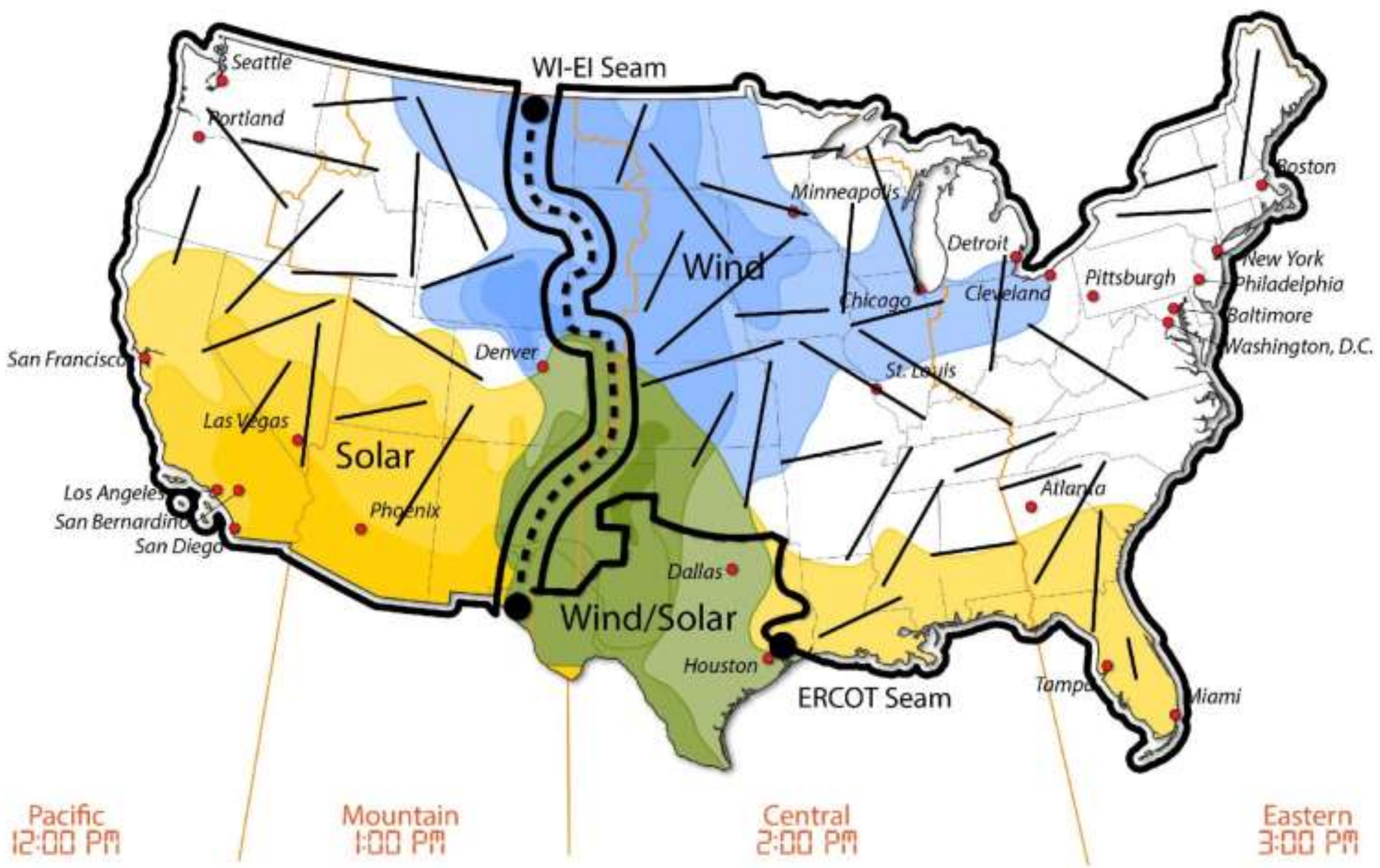
Minnesota and Louisiana to the west, and proposing long range planning to fill them.

Michael W. Straus, Reclamation



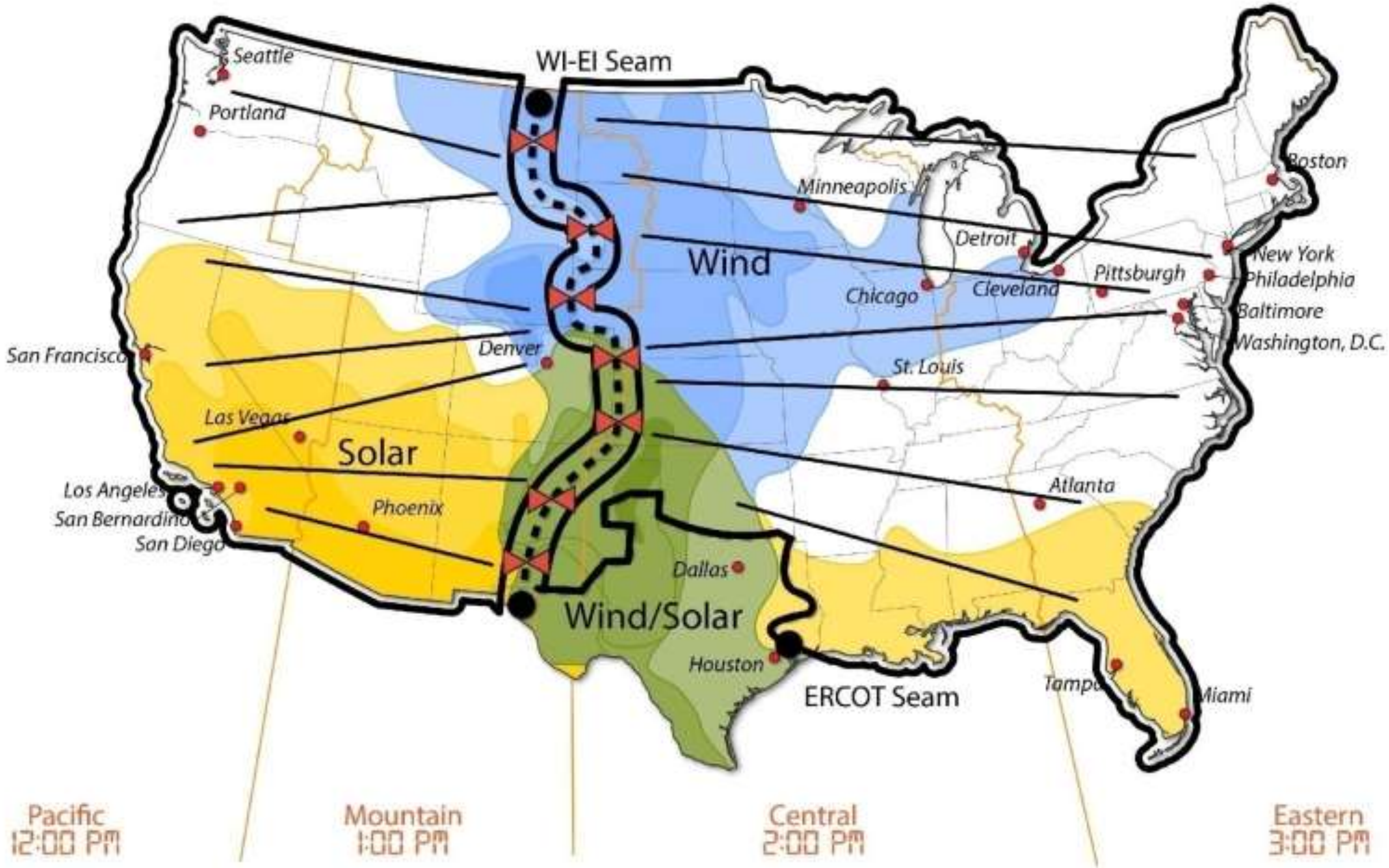
"Such a power system will *inevitably* come."

Bureau of Reclamation, 1952



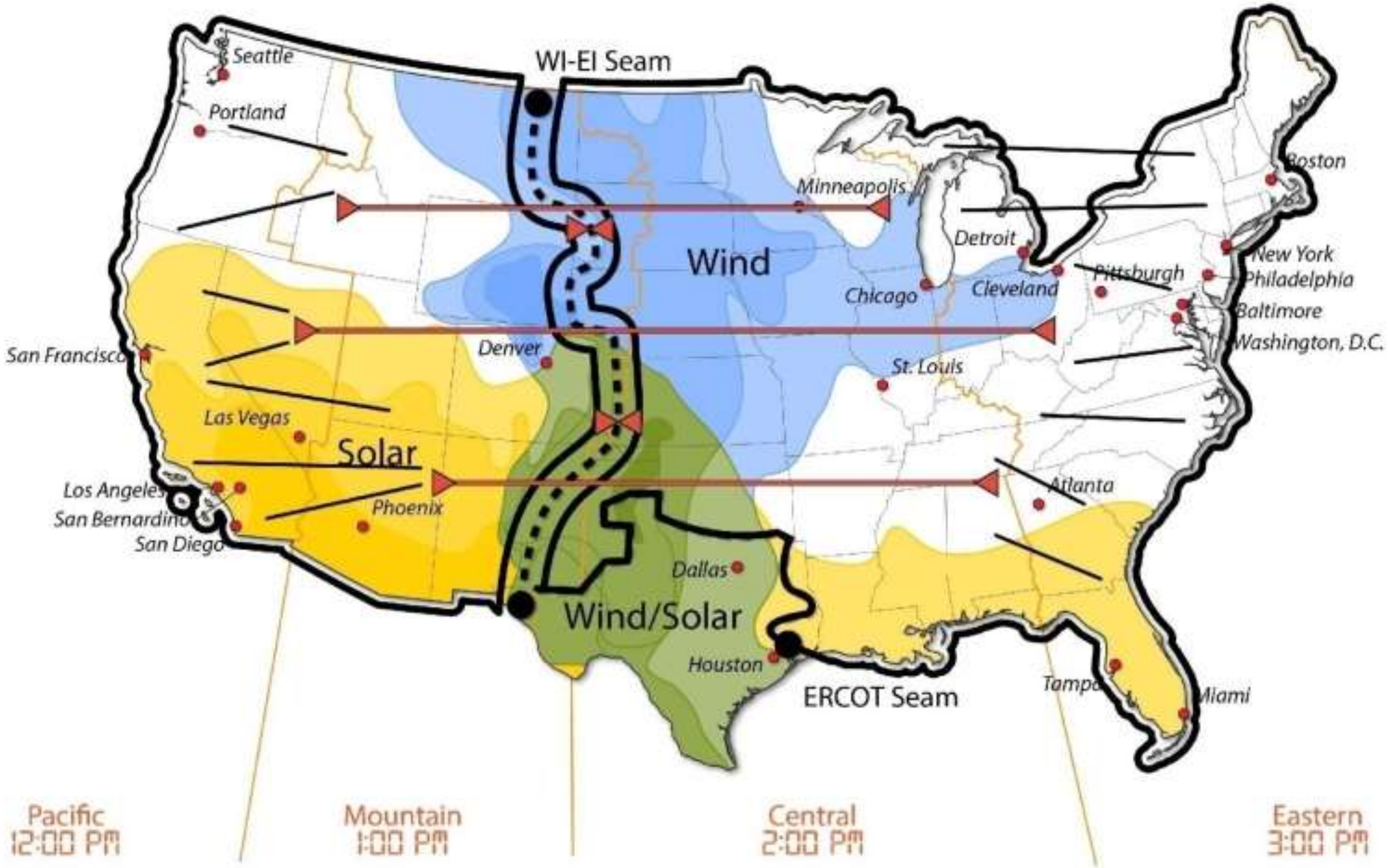
Design 1

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.



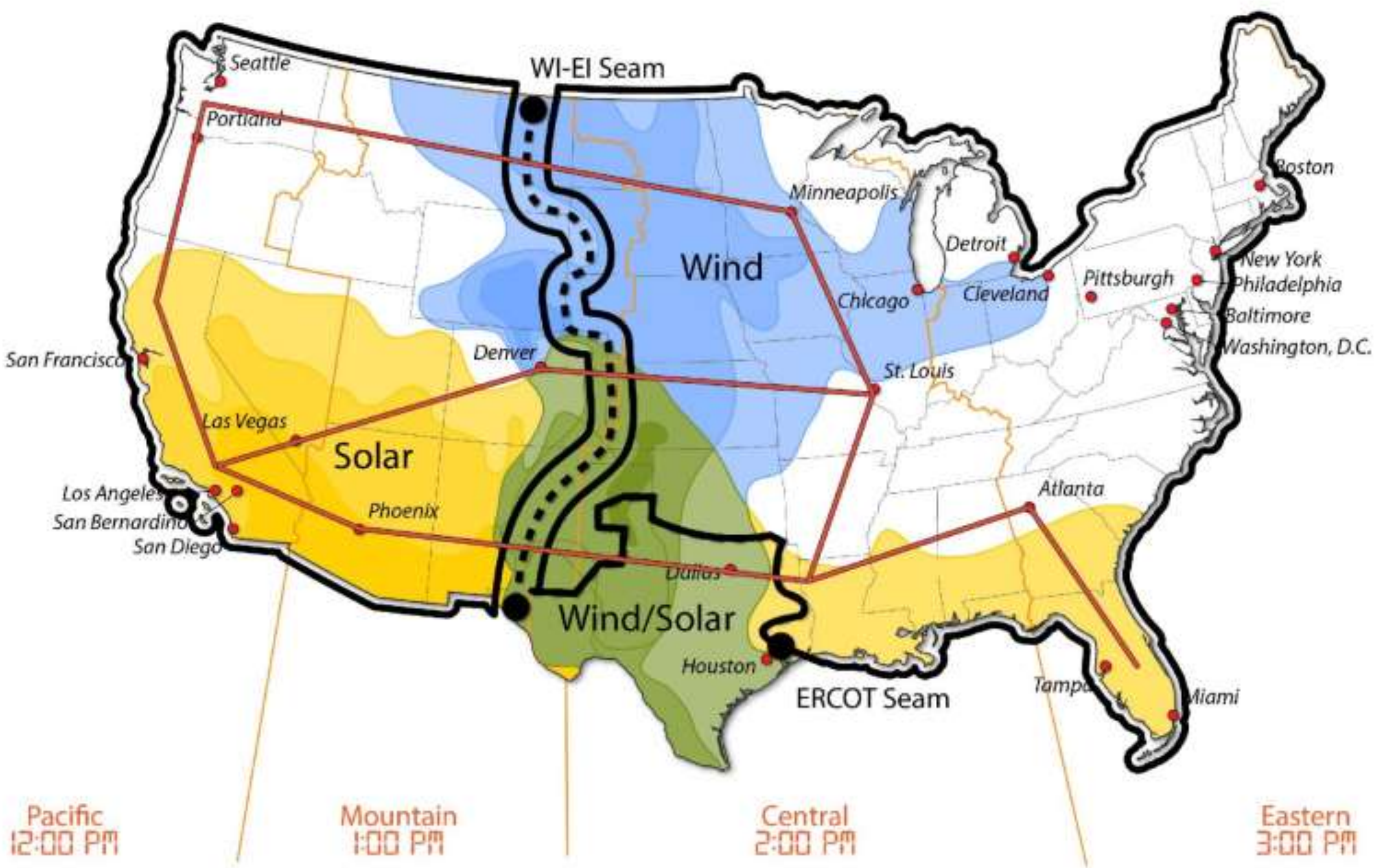
Design 2a

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



Design 2b

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

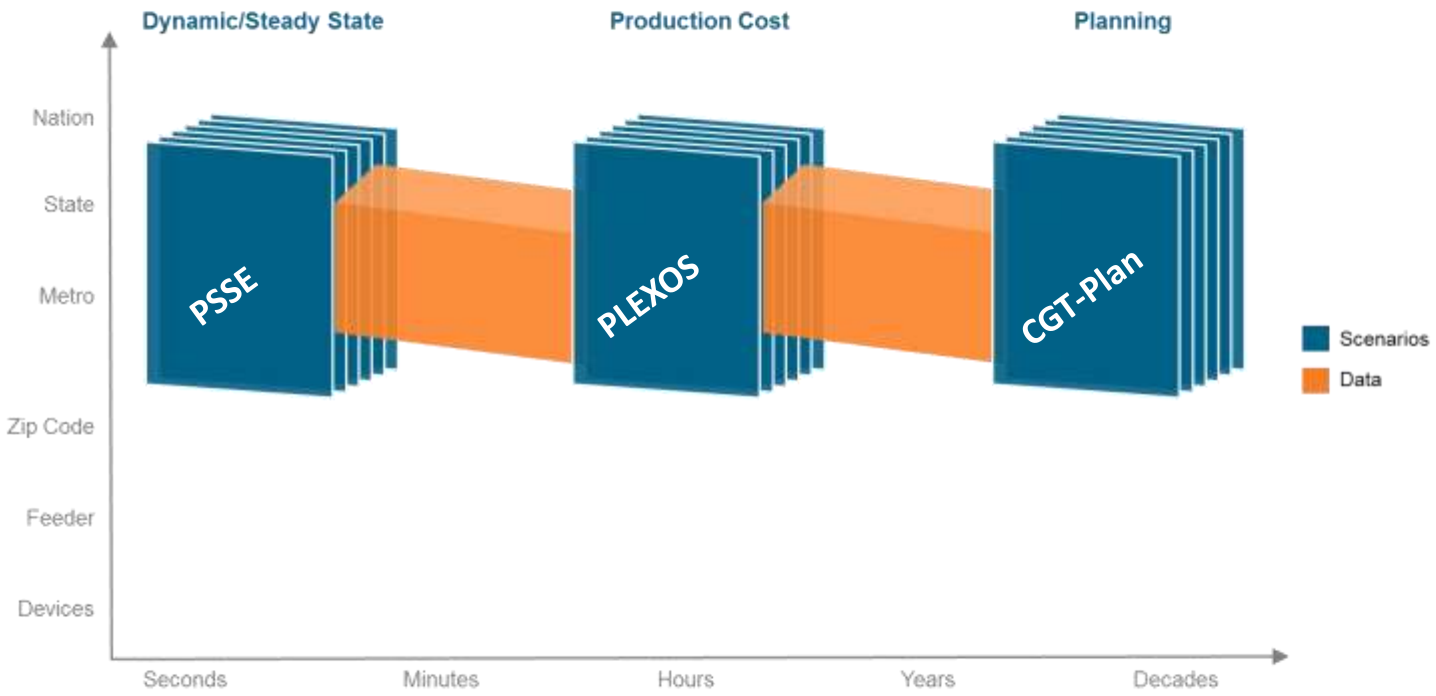


Design 3

A national scale HVDC transmission network, Macro Grid, is built and other investments in AC transmission and generation.

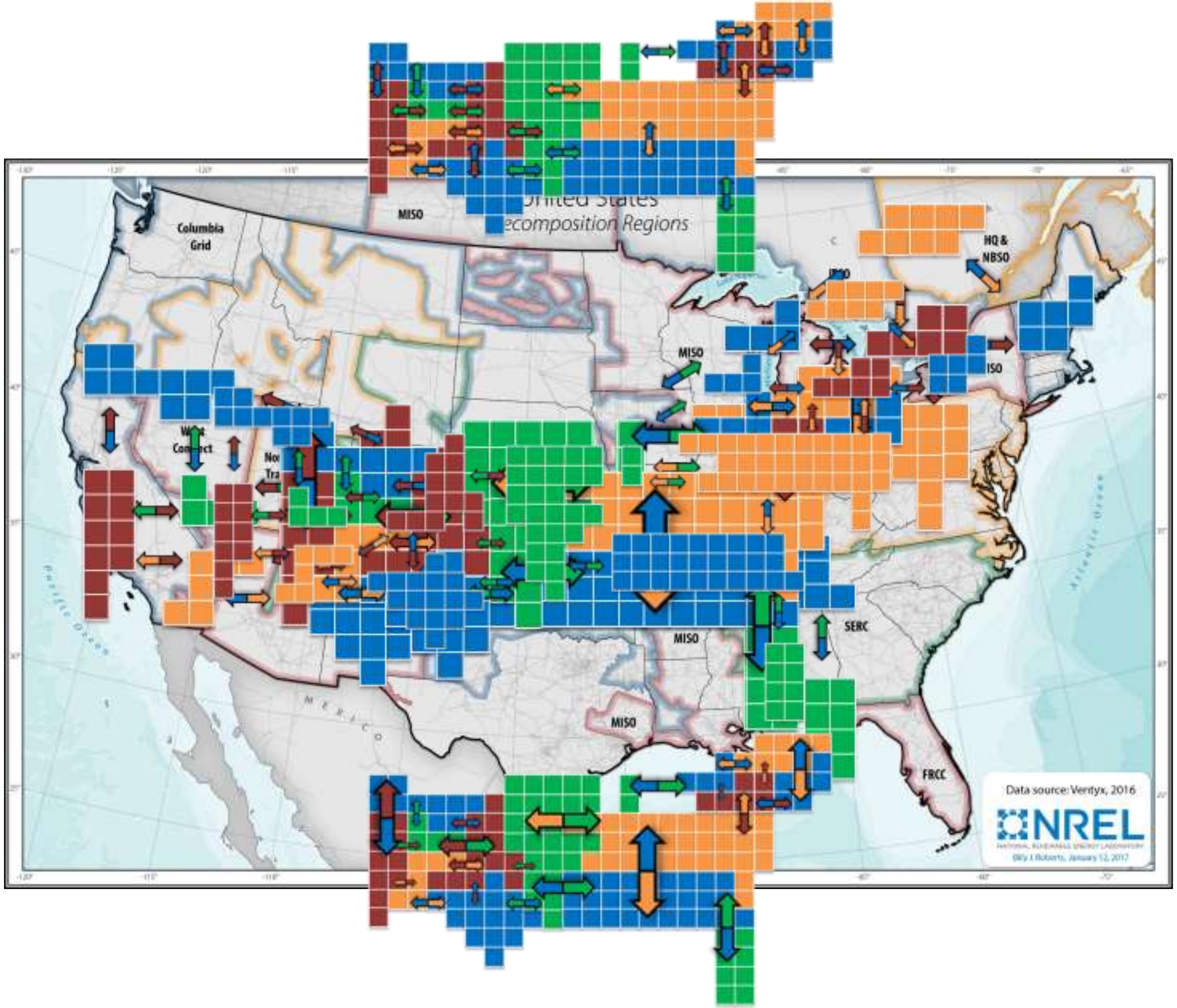
Comprehensive Economic and Reliability Analysis

- CGT-Plan
  - Iowa State University
  - Capital and operating costs 2024-2038
  - Generation and transmission system for 2038
- PLEXOS
  - NREL
  - Operating costs 2038
  - Hourly unit commitment and economic dispatch
- PSSE
  - PNNL
  - Develop a capability for future work
  - Preliminary analysis of AC power flow impacts

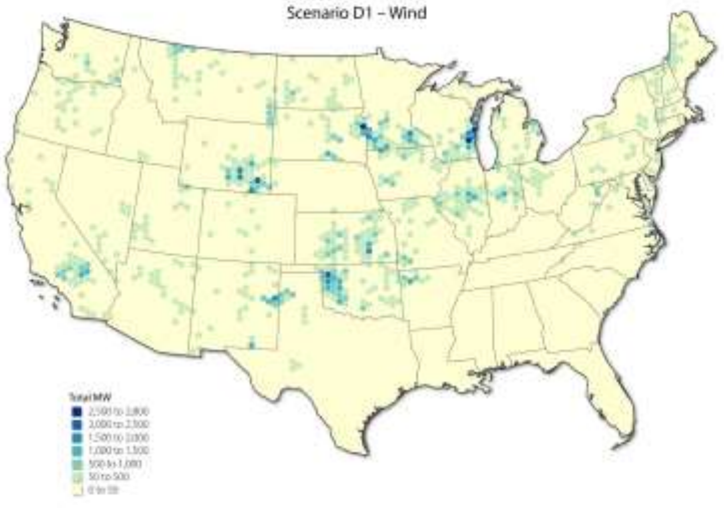


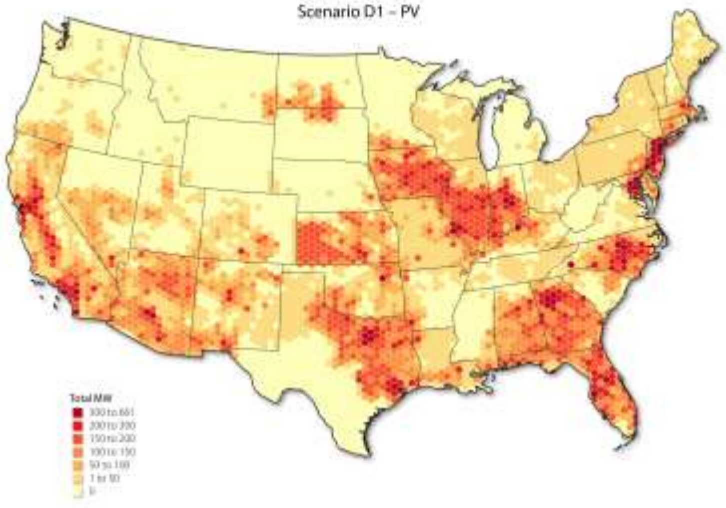
Geographic Decomposition

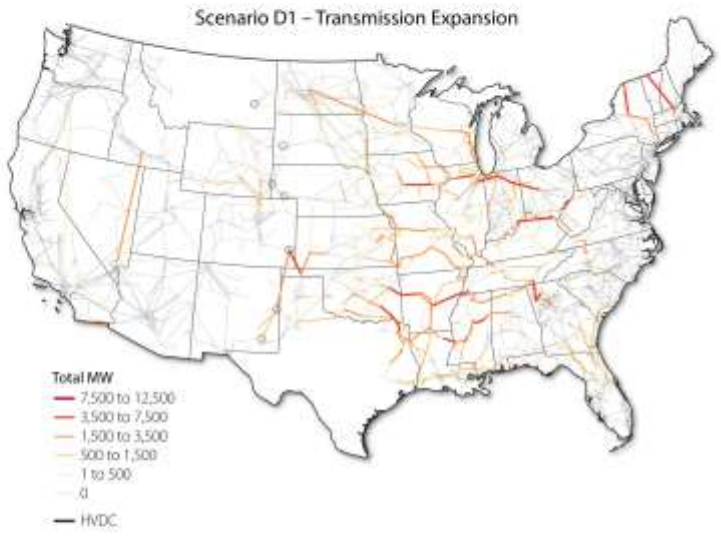
- Respects regional operating borders
- Advanced computation methods solve in days, not years
- Represents information asymmetries between operators



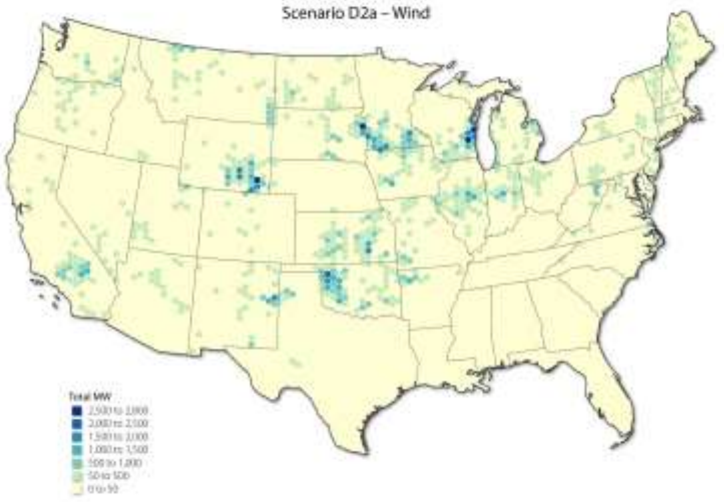

Here are
the results

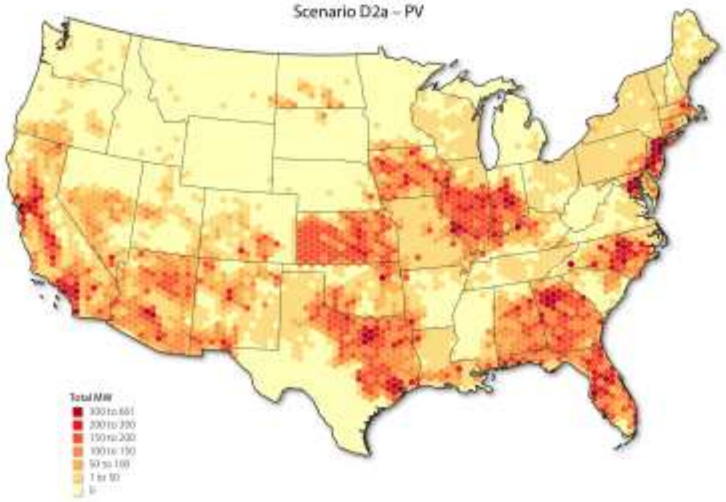


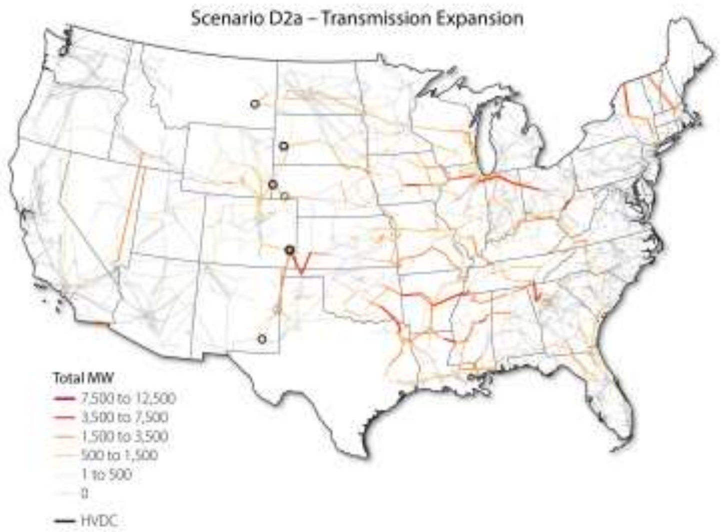




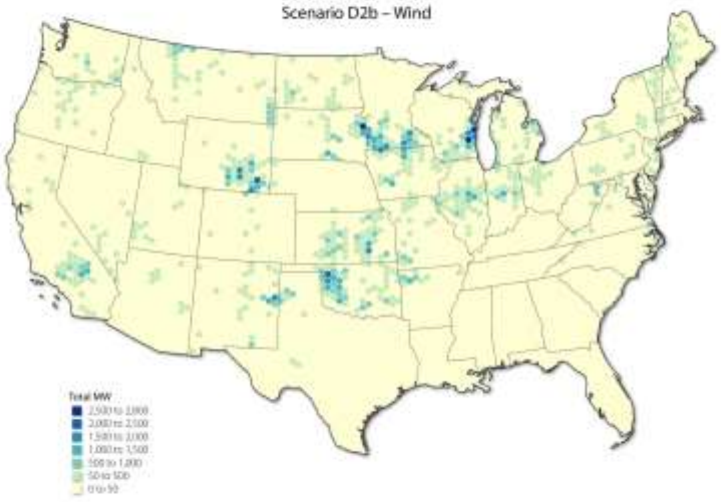
Design 1
Base Case

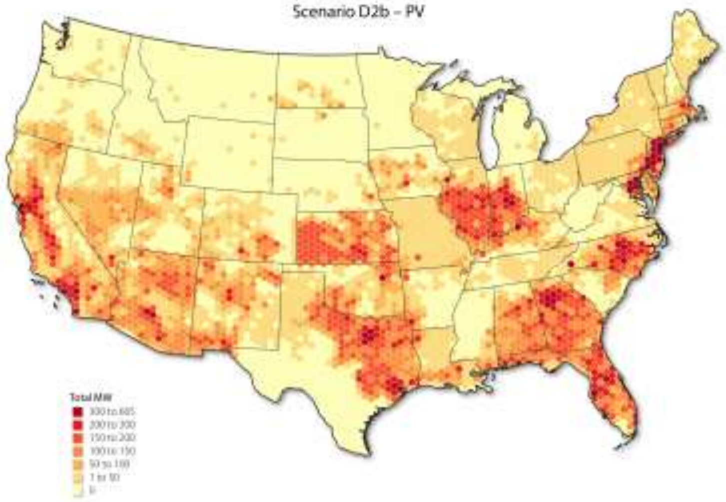


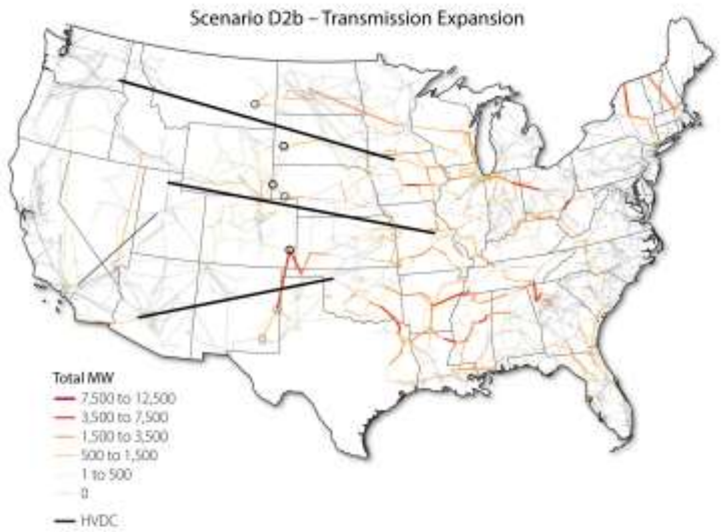




Design 2a
Base Case

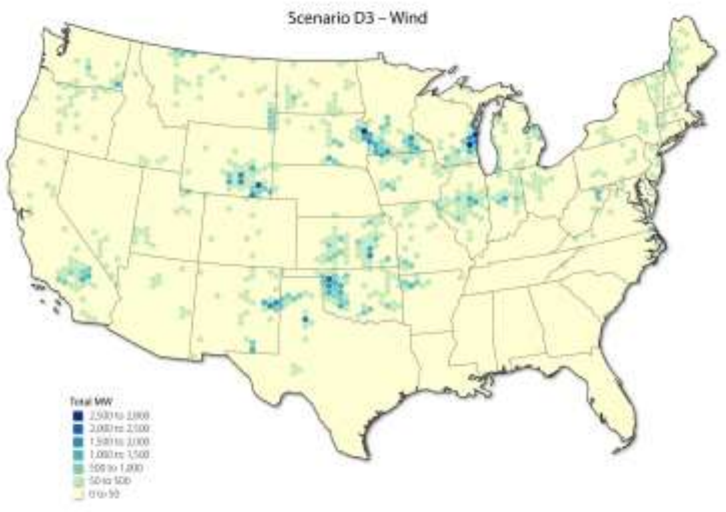


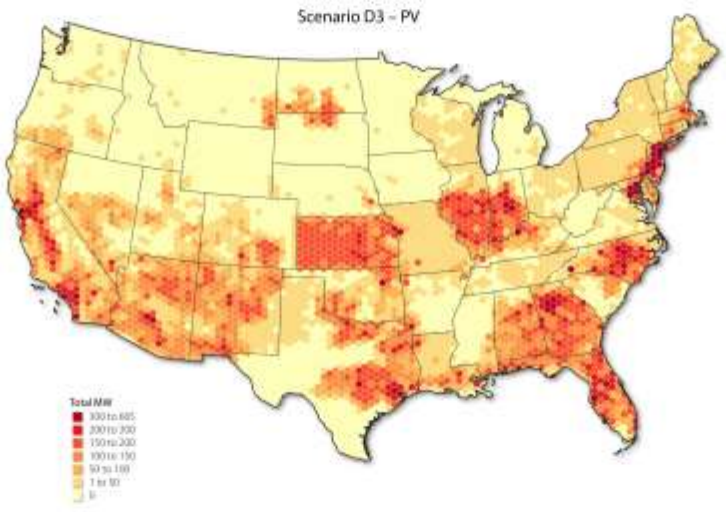


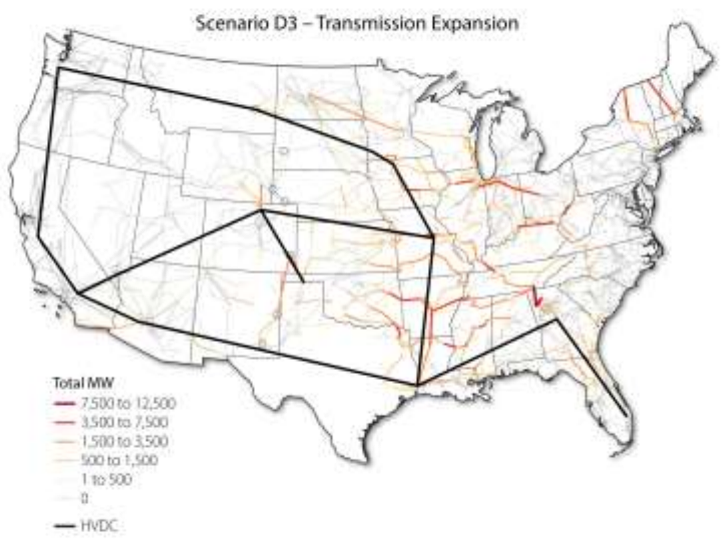


Design 2b

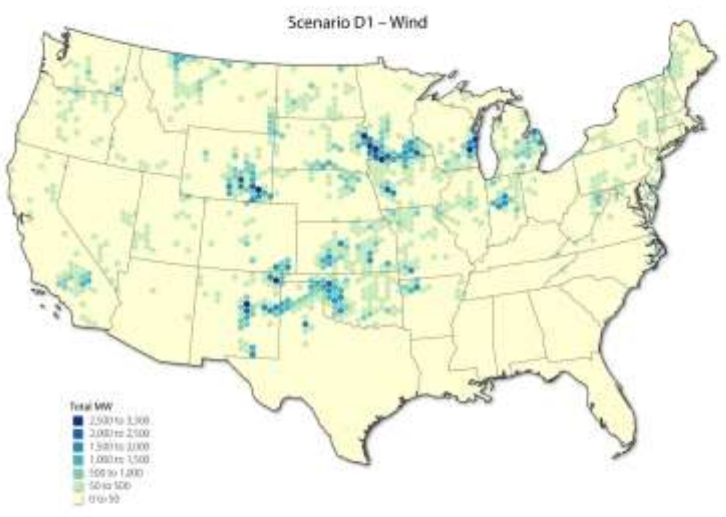
Base Case

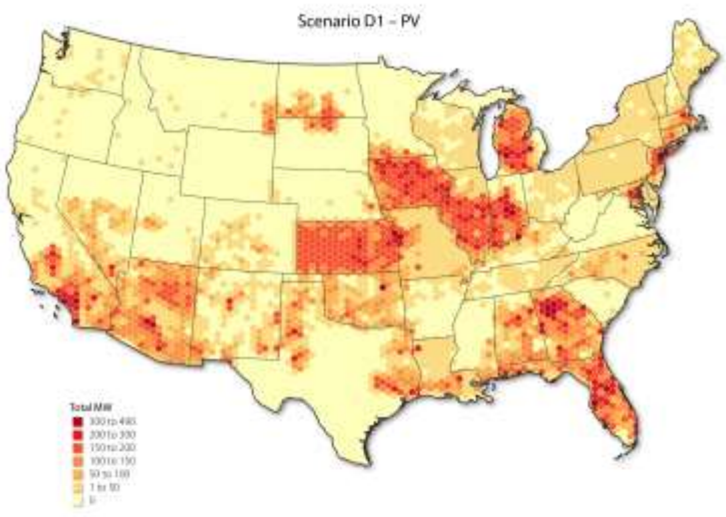


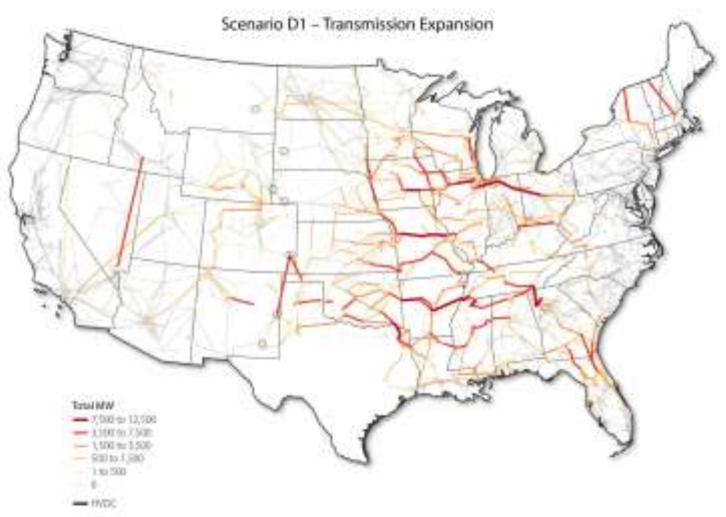




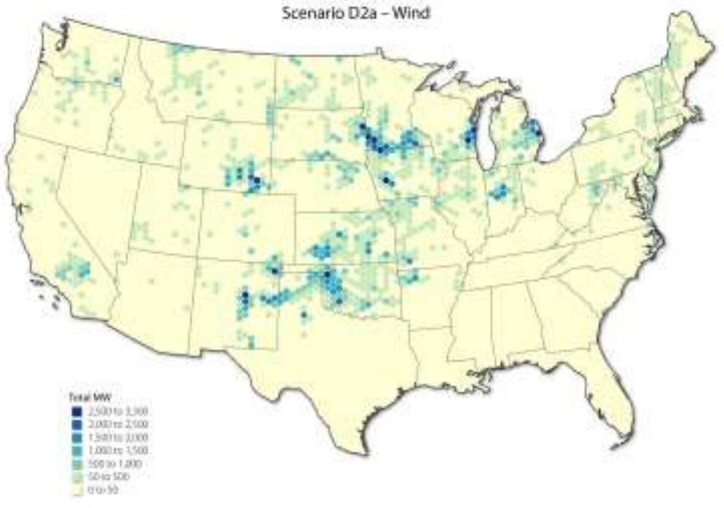
Design 3
Base Case

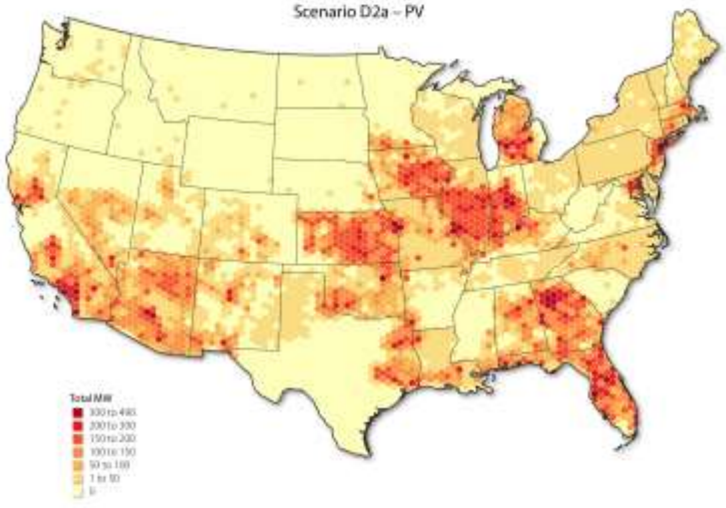




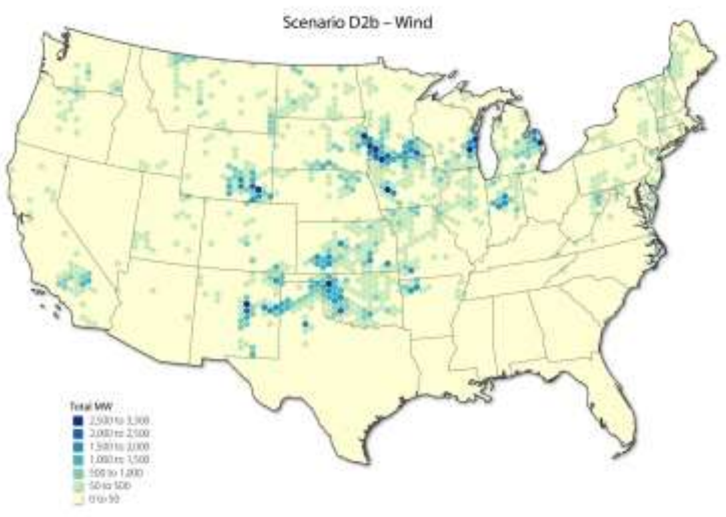


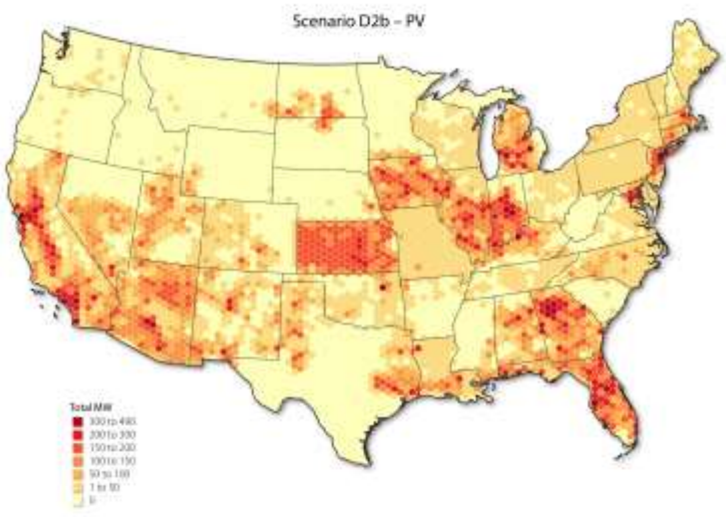
Design 1
High VG Case



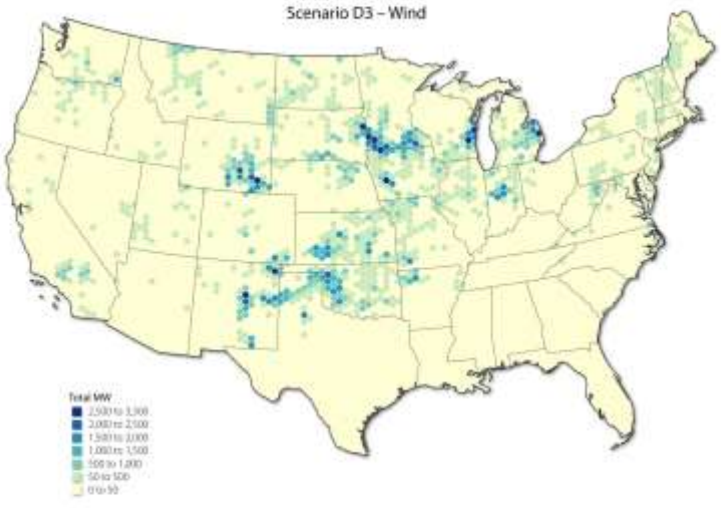


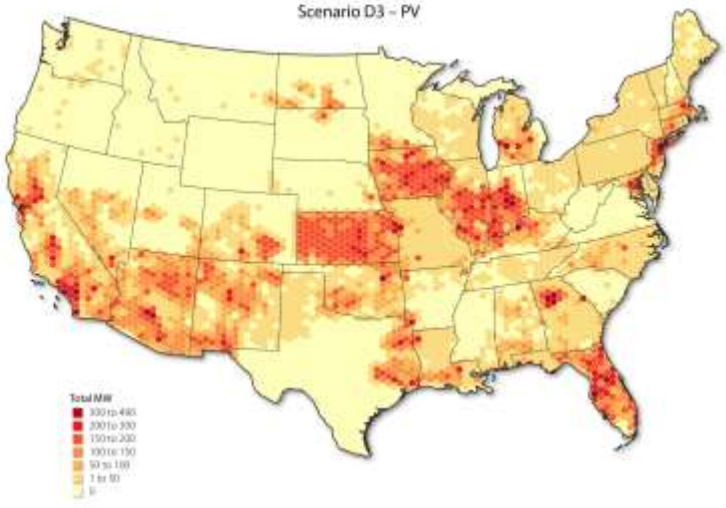
Design 2a
High VG Case

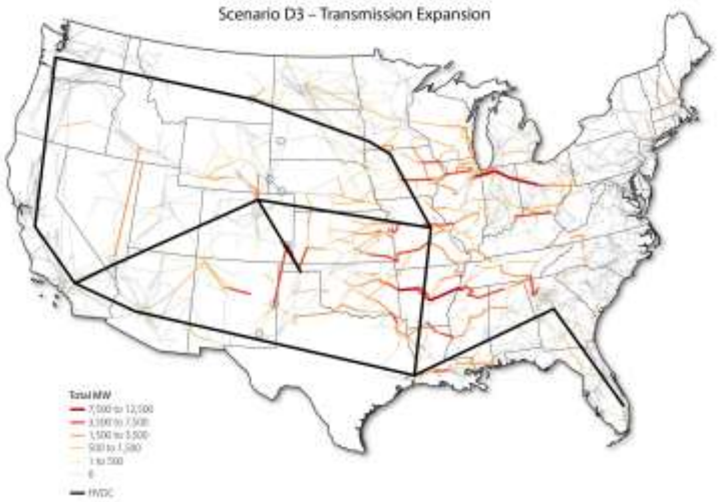




Design 2b
High VG Case





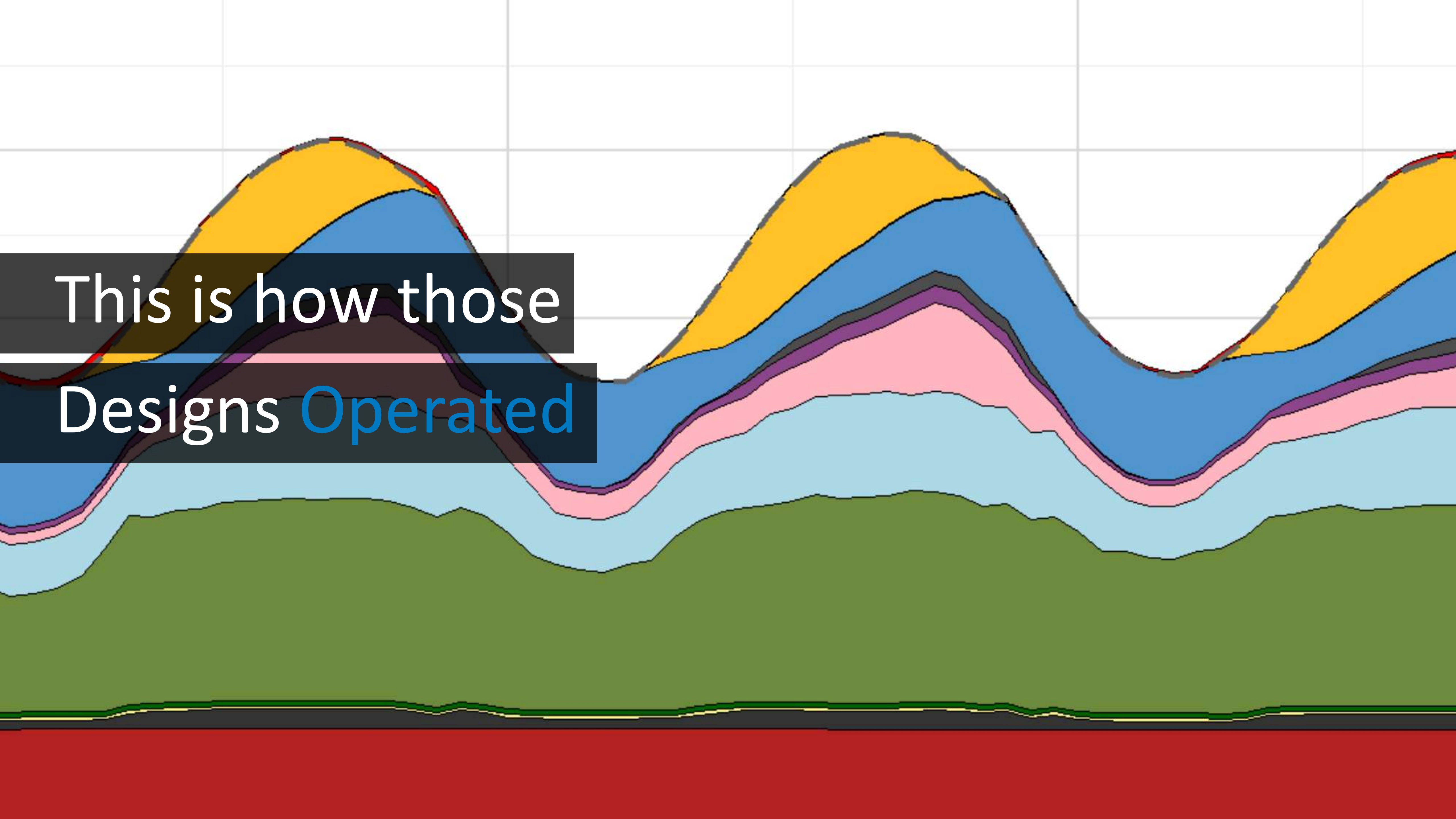


Design 3
High VG Case

Installed Capacity (GW)

	2024	Base Case				High VG Case			
		D1	D2a	D2b	D3	D1	D2a	D2b	D3
Coal	266	120	113	111	115	65	37	29	32
Hydro	198	198	198	198	198	198	198	198	198
Natural Gas	443	437	431	418	421	467	453	450	448
Nuclear	132	132	132	132	132	132	132	132	132
Solar	64	281	277	271	278	246	241	241	239
Wind	94	320	324	326	324	450	487	488	487

This is how those Designs Operated

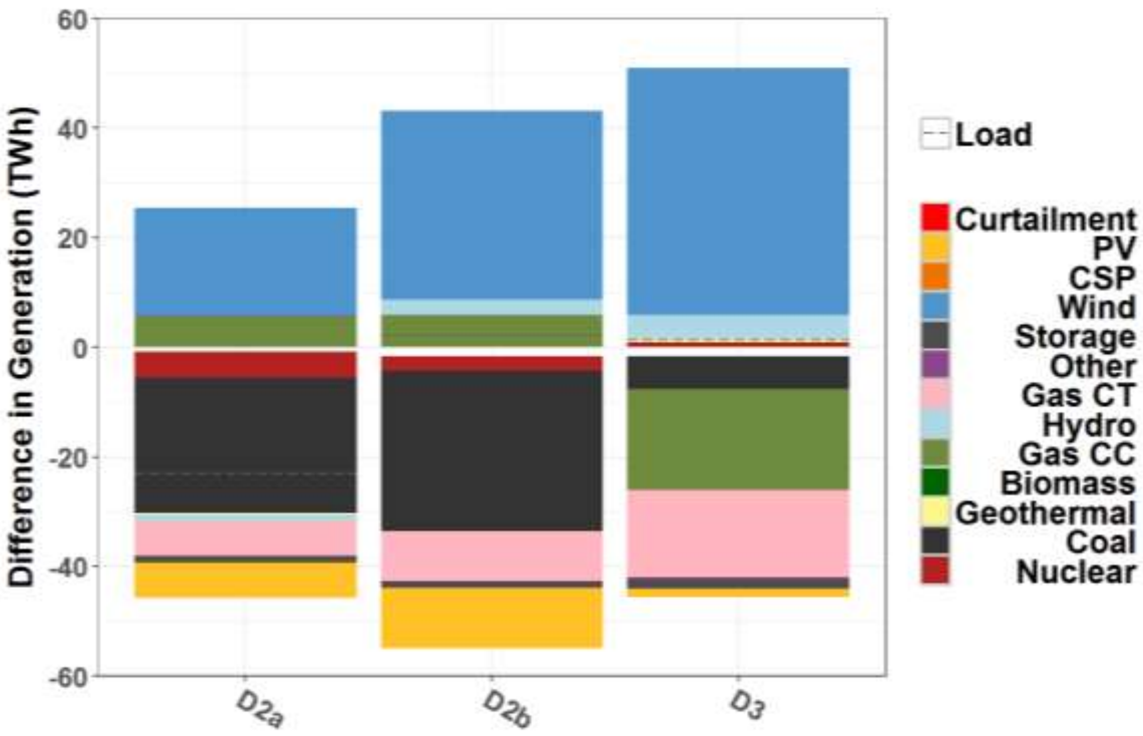


Is this decarbonization?

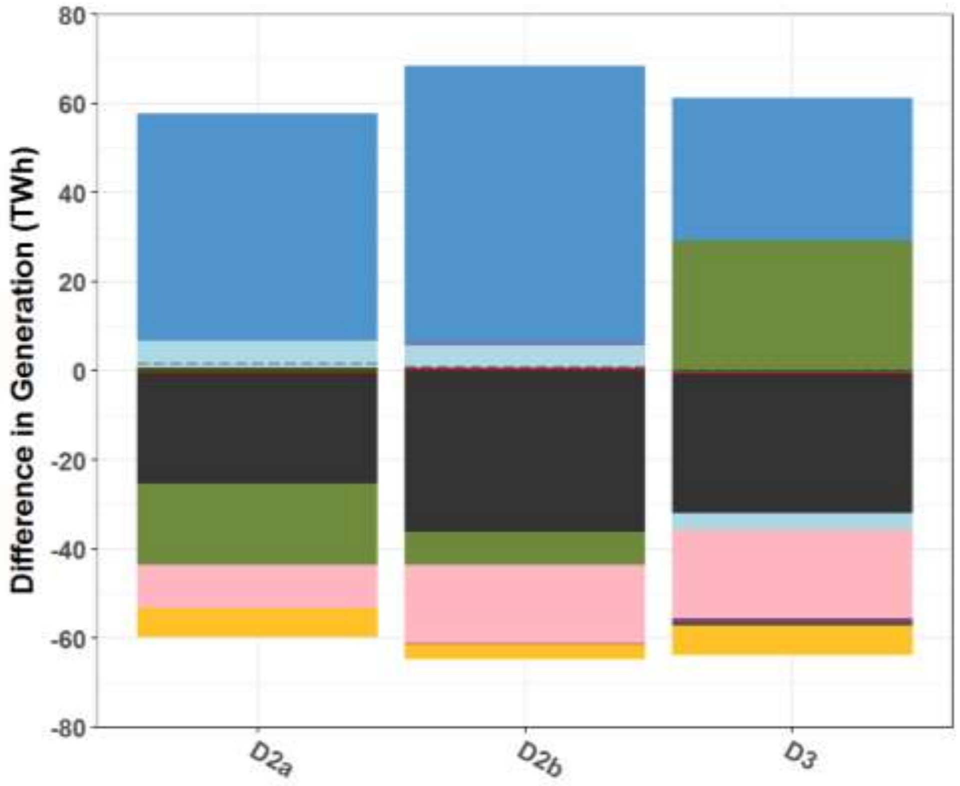
	Base Case				High VG Case			
	D1	D2a	D2b	D3	D1	D2a	D2b	D3
Fossil Fuel	36%	36%	36%	36%	26%	25%	25%	25%
Wind and Solar	28%	29%	29%	29%	38%	39%	39%	39%
CO_2 Free	63%	63%	63%	64%	73%	74%	74%	73%

Generation Difference

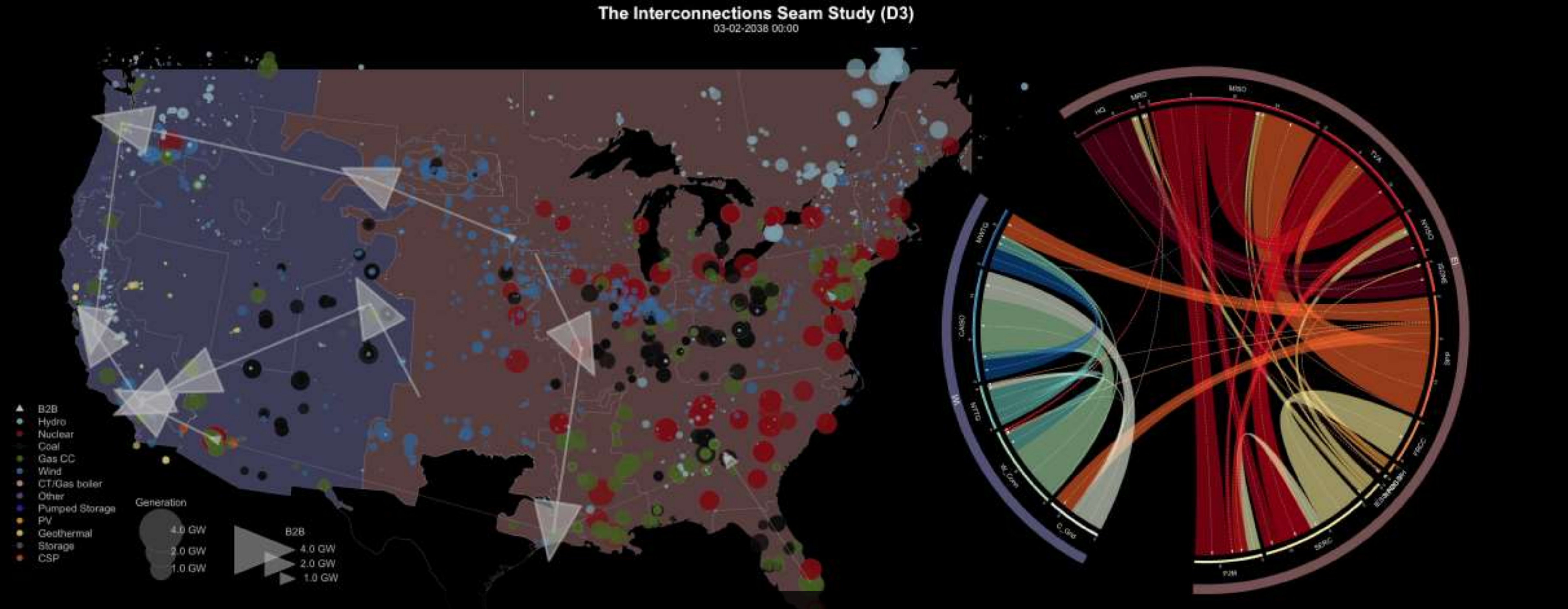
- Base Case



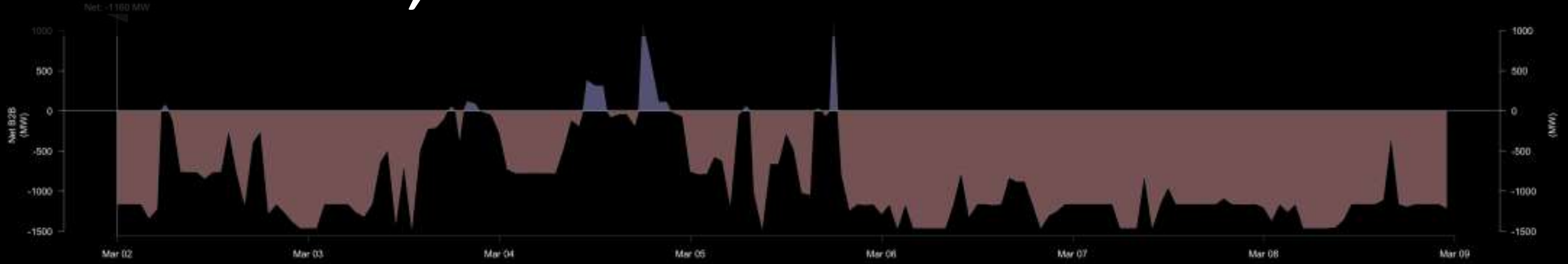
- High VG Case



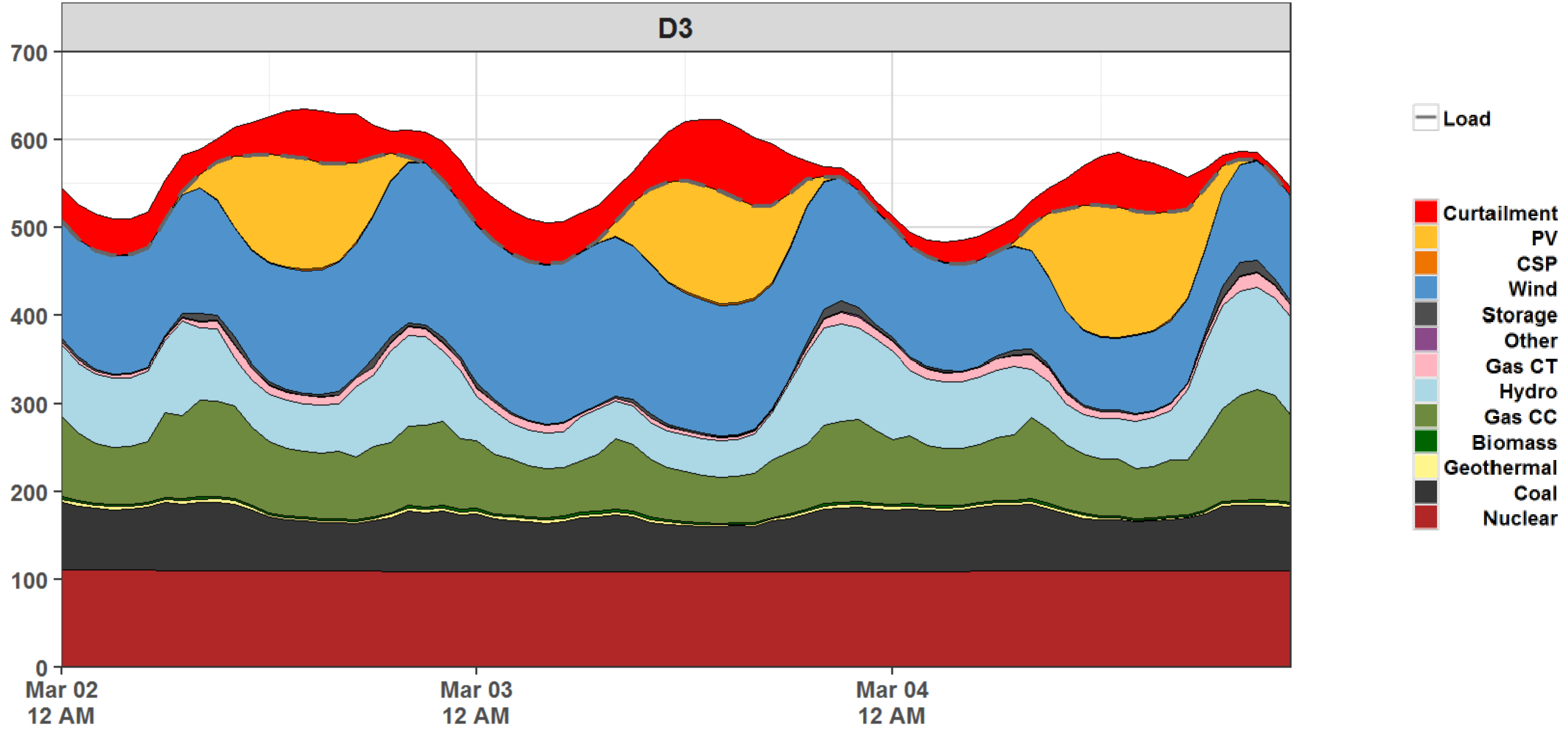
- Note smaller scale of the Base Case
- Nuclear changes under Base Case are an artifact of outage schedules.

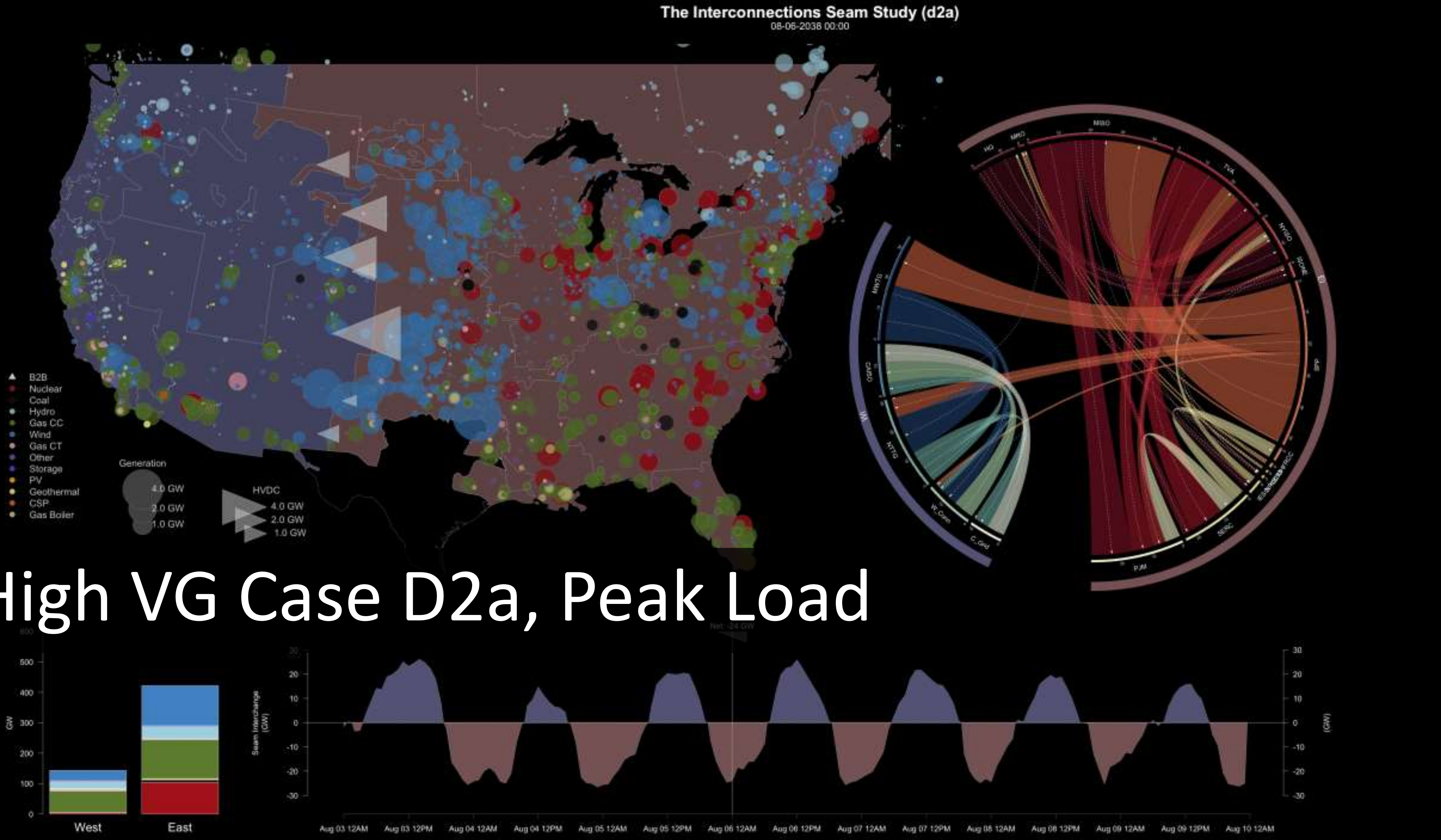


Base Case D3, Low Net Load



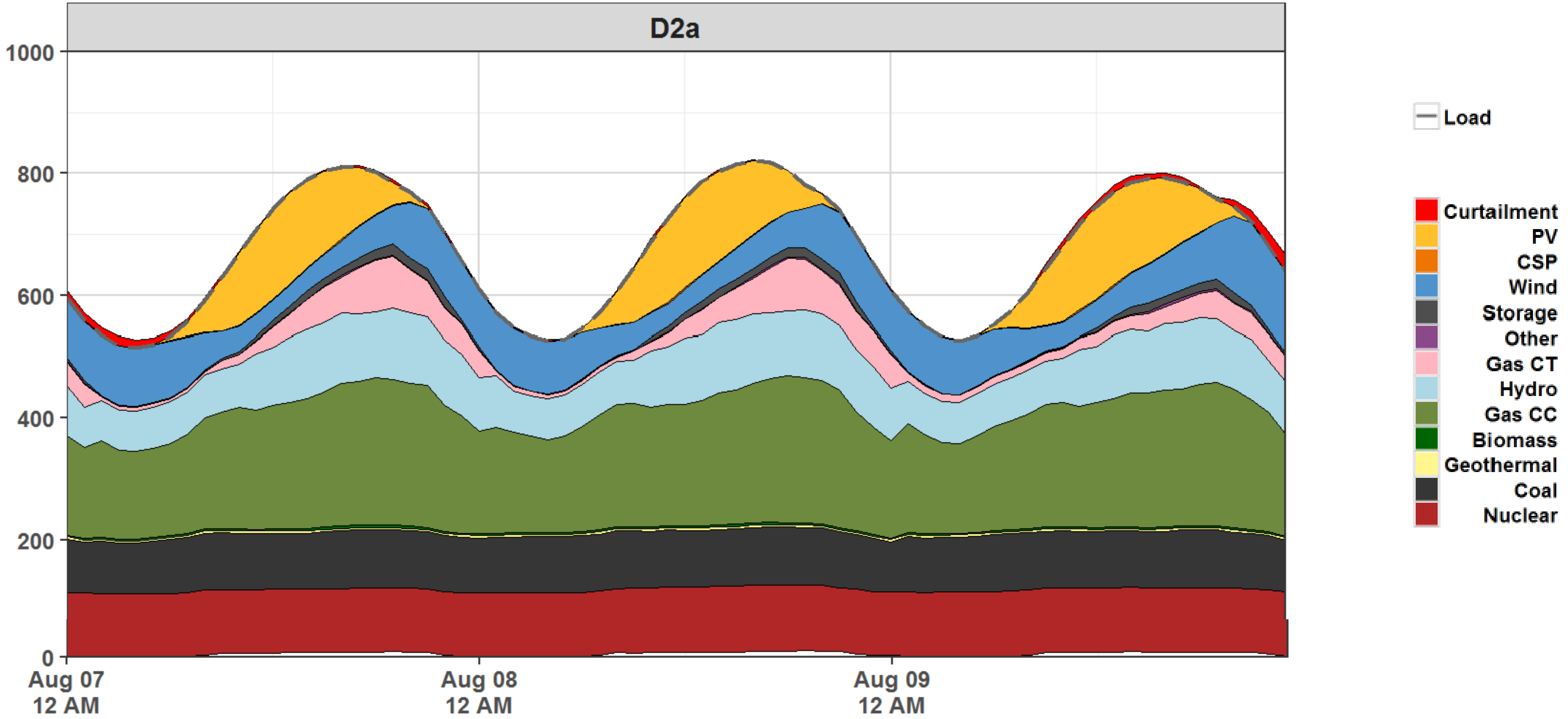
Combined EI and WI Dispatch during Low Net Load





High VG Case D2a, Peak Load

Combined EI and WI Dispatch during Peak Load



Takeaways

- Each design is Reliable from a Resource Adequacy perspective for the single year we studied.
- All load is met while respecting reserve and transmission constraints that approximate N-1.
- Increase transmission results in opportunities for expanded and more efficient capacity and energy markets.
- Increased cross seam transmission enables efficient energy sharing.

What could it cost?

What are the benefits?

Total Costs 2024-2038 (NPV $B)

BCR = $\frac{\text{Change in Total non-Transmission Costs}}{\text{Change in Transmission Investment Costs}}$

Example, D1 vs D2a Current Policy: 4.01/3.19= 1.26

	Base Case							High VG Case						
ECONOMICS, NPV $B	**D1**	**D2a**	**Delta**	**D2b**	**Delta**	**D3**	**Delta**	**D1**	**D2a**	**Delta**	**D2b**	**Delta**	**D3**	**Delta**
Line Investment Cost	23.5	26.69	3.19	31.5	8	37.7	14.2	61.21	73.89	12.68	74.88	13.67	80.1	18.89
Generation Investment Cost	493.6	494.7	1.1	492.5	-1.1	494.2	0.6	704.03	703.32	-0.71	696.99	-7.04	700.51	-3.52
Fuel Cost	855.1	852.7	-2.4	851.2	-3.9	845.6	-9.5	753.8	738.98	-14.82	737.3	-16.5	736.12	-17.68
Fixed O&M Cost	416.4	415.6	-0.8	413.7	-2.7	413.8	-2.6	455.6	450.2	-5.4	448.95	-6.65	450.23	-5.37
Variable O&M Cost	81	81.1	0.1	81.2	0.2	81.2	0.2	64.5	63.9	-0.6	64.27	-0.23	64.39	-0.11
Carbon Cost	0	0	0	0	0	0	0	171.1	164.2	-6.9	162.6	-8.5	162.5	-8.6
Regulation-Up Cost	31.6	30.97	-0.63	31.13	-0.47	30.02	-1.58	33.29	31.63	-1.66	29.96	-3.33	26.63	-6.66
Regulation-Down Cost	45.1	44.2	-0.9	44.42	-0.68	42.85	-2.26	4.76	4.52	-0.24	4.29	-0.47	3.81	-0.95
Contingency Cost	23.9	23.42	-0.48	23.54	-0.36	22.71	-1.2	24.41	23.19	-1.22	21.97	-2.44	19.52	-4.89
Total Non-transmission Cost (Orange)	1,947.00	1,943.00	-4.01	1,937.70	-9.01	1,930.00	-16.34	2,211.49	2,179.94	-31.55	2,166.33	-45.16	2,163.71	-47.78
15-yr B/C Ratio (Orange/Green)			1.26		1.13		1.15			2.48		3.3		2.52

Benefits

- All designs produce benefits that exceed costs.
- Results should be viewed directionally, not definitively.
- Comparisons are made to D1, which includes significant AC expansion, but no cross seam expansion.
- Full asset life is assumed to be 35 years, over the long run, the benefit may be significantly higher.
- Not appropriate to assume 2038 savings will stay the same until retirement, they may increase or decrease depending on the rest of the system.

	Benefit-to-Cost Ratio 2024-2038	
	Base Case	High VG Case
D1	-	-
D2a	1.26	2.48
D2b	1.13	3.3
D3	1.15	2.52

	Production Cost Savings 2038 ($B)	
	Base Case	High VG Case
D1	-	-
D2a	-0.8	-3.5
D2b	-1.1	-3.8
D3	-2.5	-1.9

Findings

- There is substantial value to increasing the transfer capability between the interconnections, status quo on the existing B2Bs is the least desirable.

- Cross seam transmission has a substantial impact on the location, size, and type of wind and solar.
  – The “best” wind (Eastern Interconnection) and “best” solar (Western Interconnection).

- Cross-seam transmission enables substantial energy & operating reserve sharing on diurnal and seasonal basis.

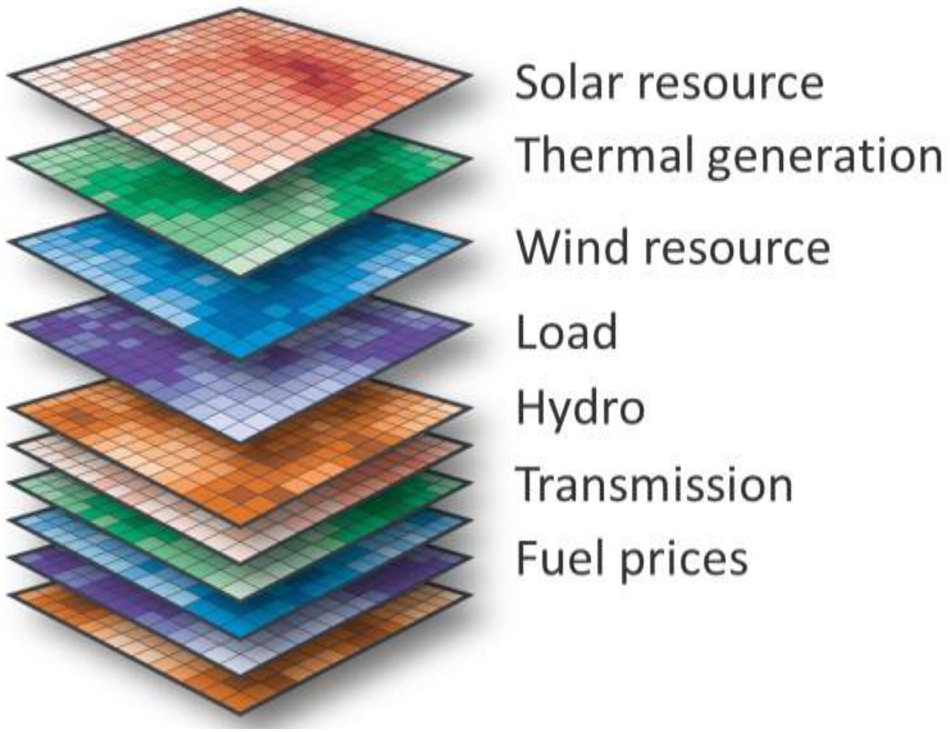
- Additional benefits (and costs) may exist, i.e. frequency response and resilience to extreme events.

Part IV: What does this mean?

Why Integrated Resource Planning is an
Artful Science

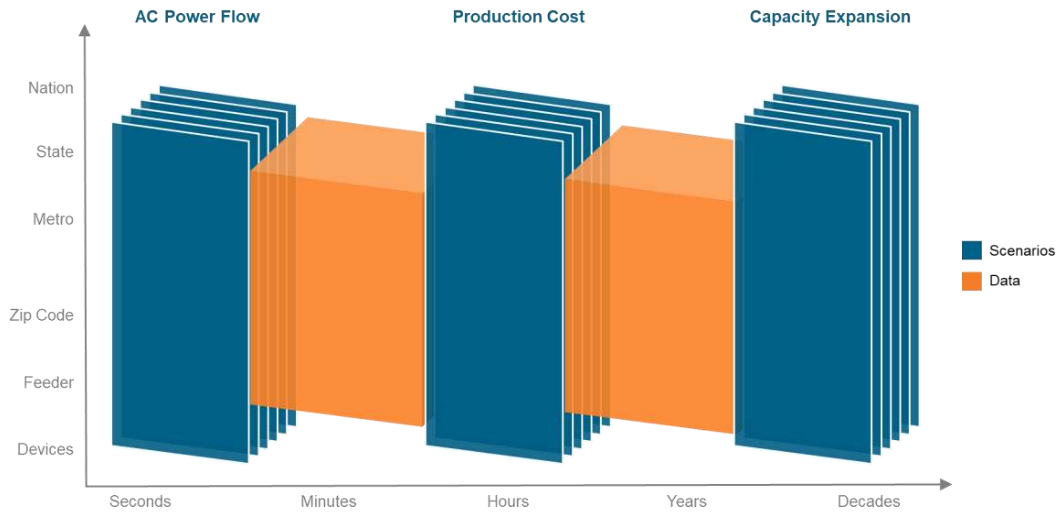
Data is critical, but it's never perfect

- Chronological data sets are needed for load and generation
- Simple averages don't work
- Data must be time synchronous
- Uncertainty space has grown
- You need to do more scenarios



There is no super model

- The various aspects of reliability and cost require different tools/approaches
- Data is the great unifier
- Model resolution matters, but don't get hung up on the nitty gritty
- All models are wrong, some are helpful



You don't *need* a Super Computer

- NREL showed us the art of the possible, and documented new algorithms to solve big problems
- At NextEra Analytics we are deploying many of these technologies on regional problems to deliver answers in minutes, not days
- Cloud computing can be used to decrease model uncertainty, control for data quality issues, and accelerate the transition to a modern grid
- Just because a tool promises Artificial Intelligence, doesn't mean it's Applied Intelligence

Five Questions to ask of an Integrated Resource Plan

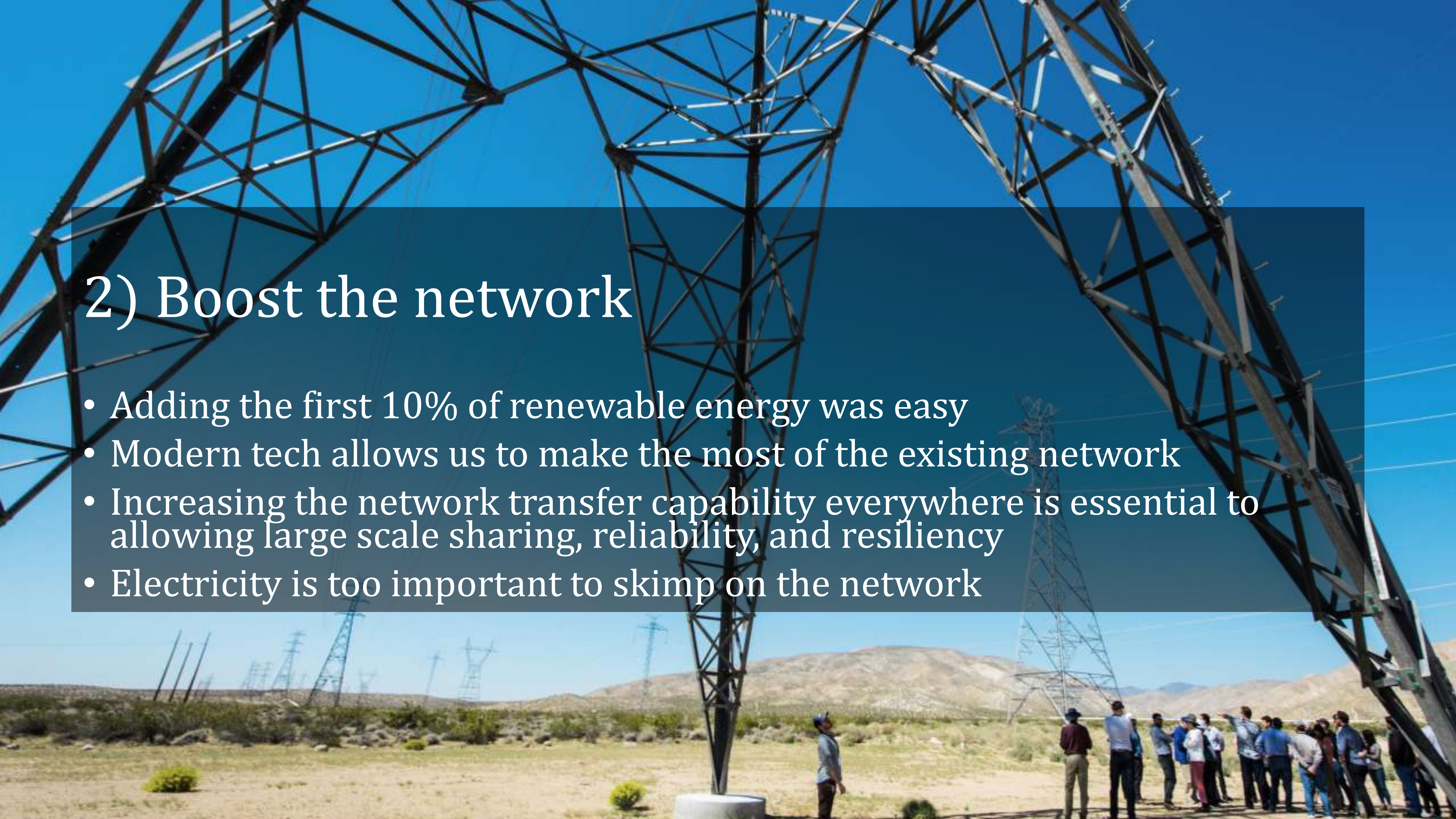
1. What simplifications were made to the transmission network and generator representations?
2. Who reviewed the work?
3. What tools did they use to evaluate cost and reliability?
4. How does the analysis account for the weather?
5. What scenarios were considered?

Part V: What should be done?

Why Integrated Resource Planning is an Artful Science

1) Build everywhere

- Diversity is critical to giving everyone a role in the future
- It helps with cost allocation
- Reduces variability at all time scales
- Our power system needs an overhaul due to age, let’s build the right new stuff
- Grid scale and distributed scale resource have complementary characteristics

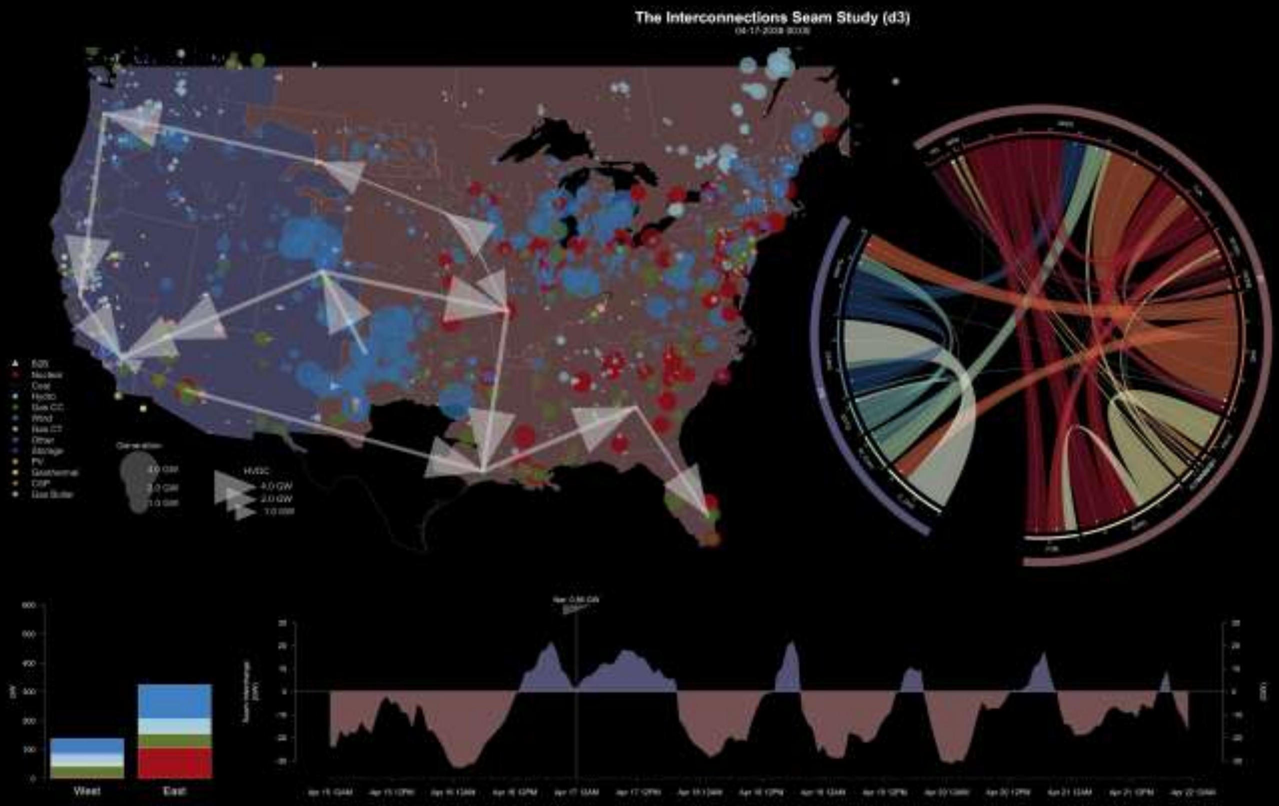


2) Boost the network

- Adding the first 10% of renewable energy was easy
- Modern tech allows us to make the most of the existing network
- Increasing the network transfer capability everywhere is essential to allowing large scale sharing, reliability, and resiliency
- Electricity is too important to skimp on the network

3) Join the interconnections

- Electricity is the only commodity without a national supply chain
- Managing the seasons and large scale distributed generation can't be done with storage alone
- Even California needs to import avocados sometimes



https://www.terrawatts.com/seams-transgridx-2018.pdf

4) Scale hybrid power plants

- Renewables are no longer simple consumers of reliability services
- With a little software and a little storage they can operate like the perfect generator
- Hybrids don’t have to be co-located; we can make thermostats, EVs, and grid scale plants work intelligently in tandem or isolation

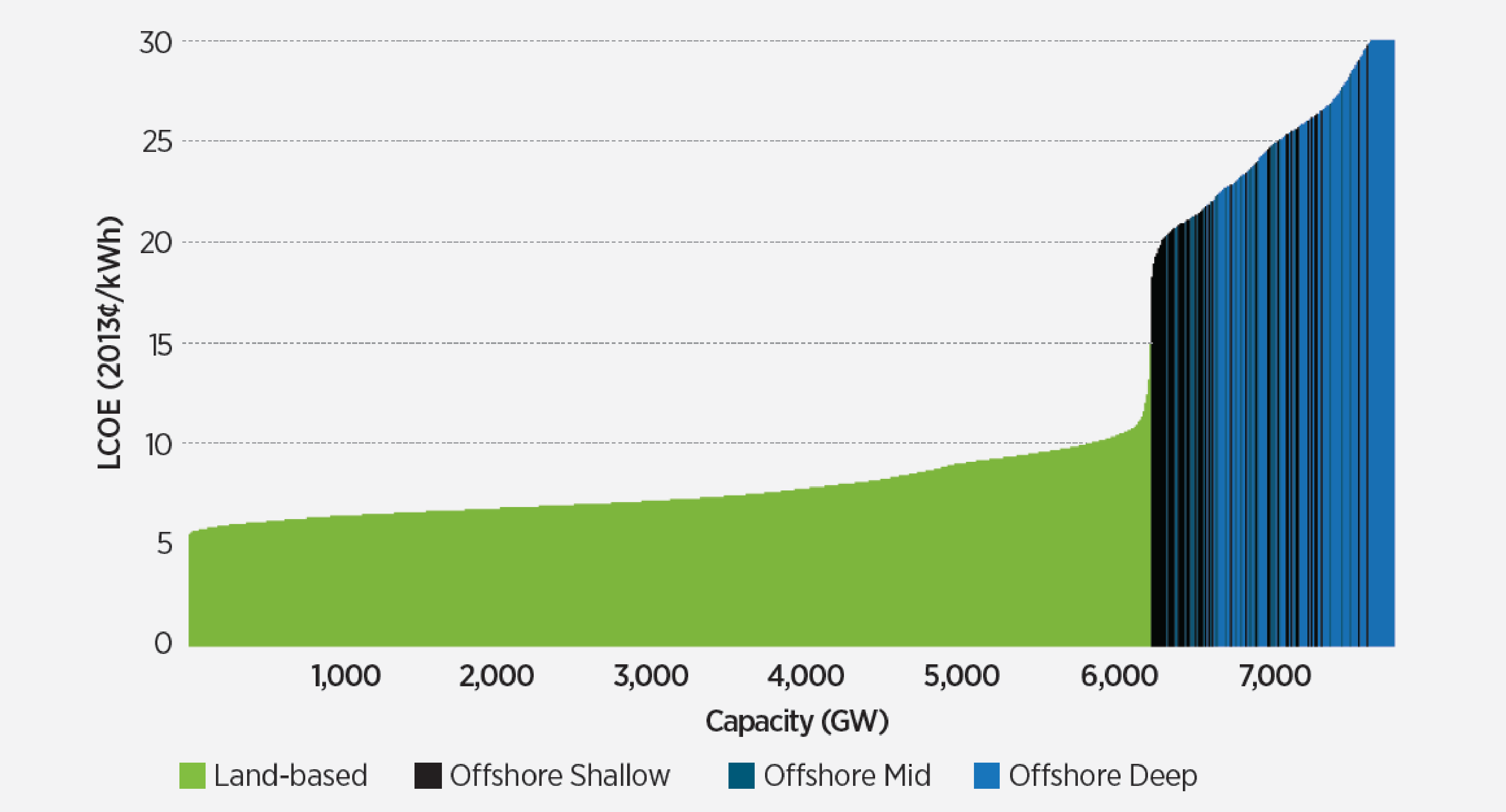
5) Share

- The economy needs to spend trillions on modernizing the electric grid, and even more if we want to decarbonize all energy
- Everyone can benefit, and we will all need to pay something
- Our differences are the key to our success; by finding complementary goals and resource profiles we can be more efficient and competitive
- Work with regulators on common sense cost allocation, i.e. Shared Use

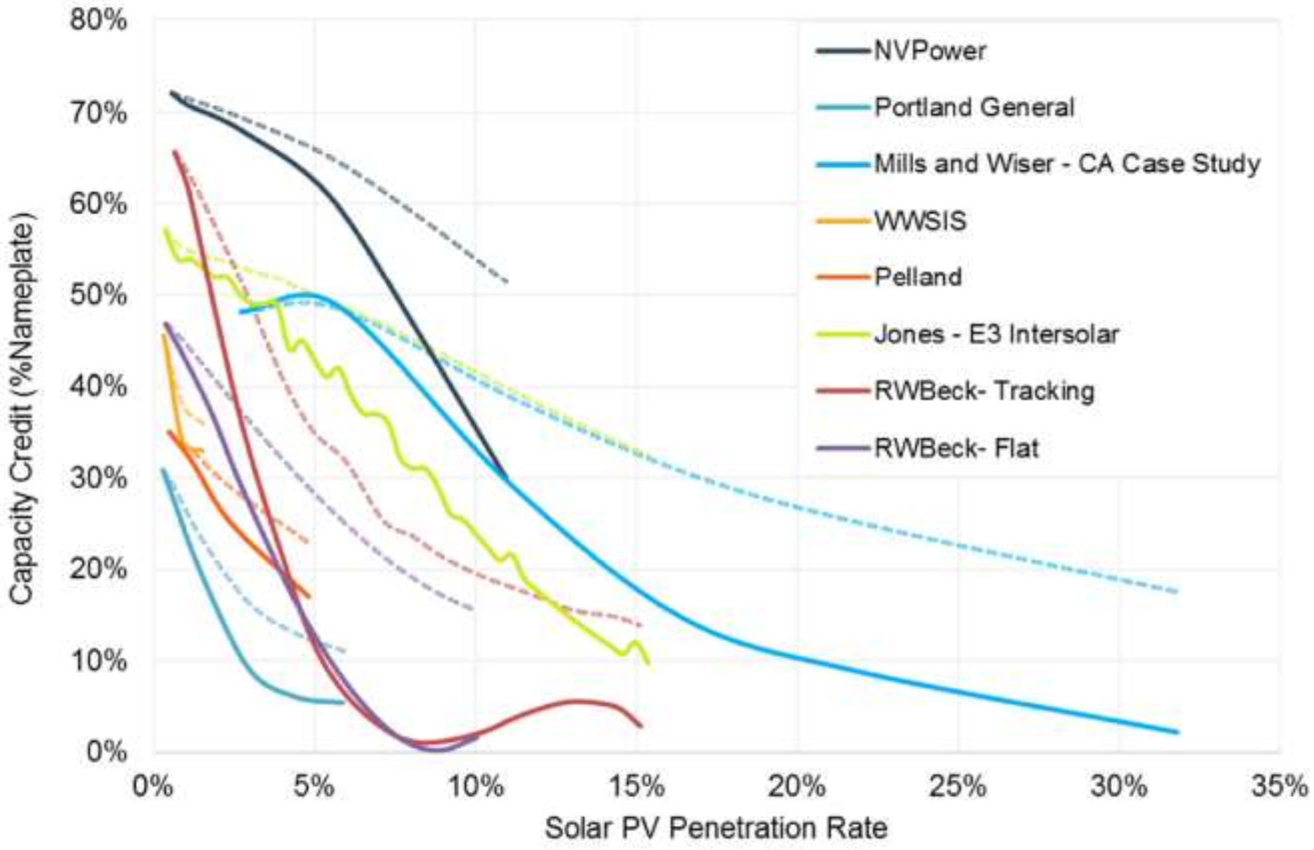
Appendix: Want to Learn More?

Renewable resources are more than sufficient in quantity

Combined land-based and offshore wind resource supply curve, based on estimated costs in 2012



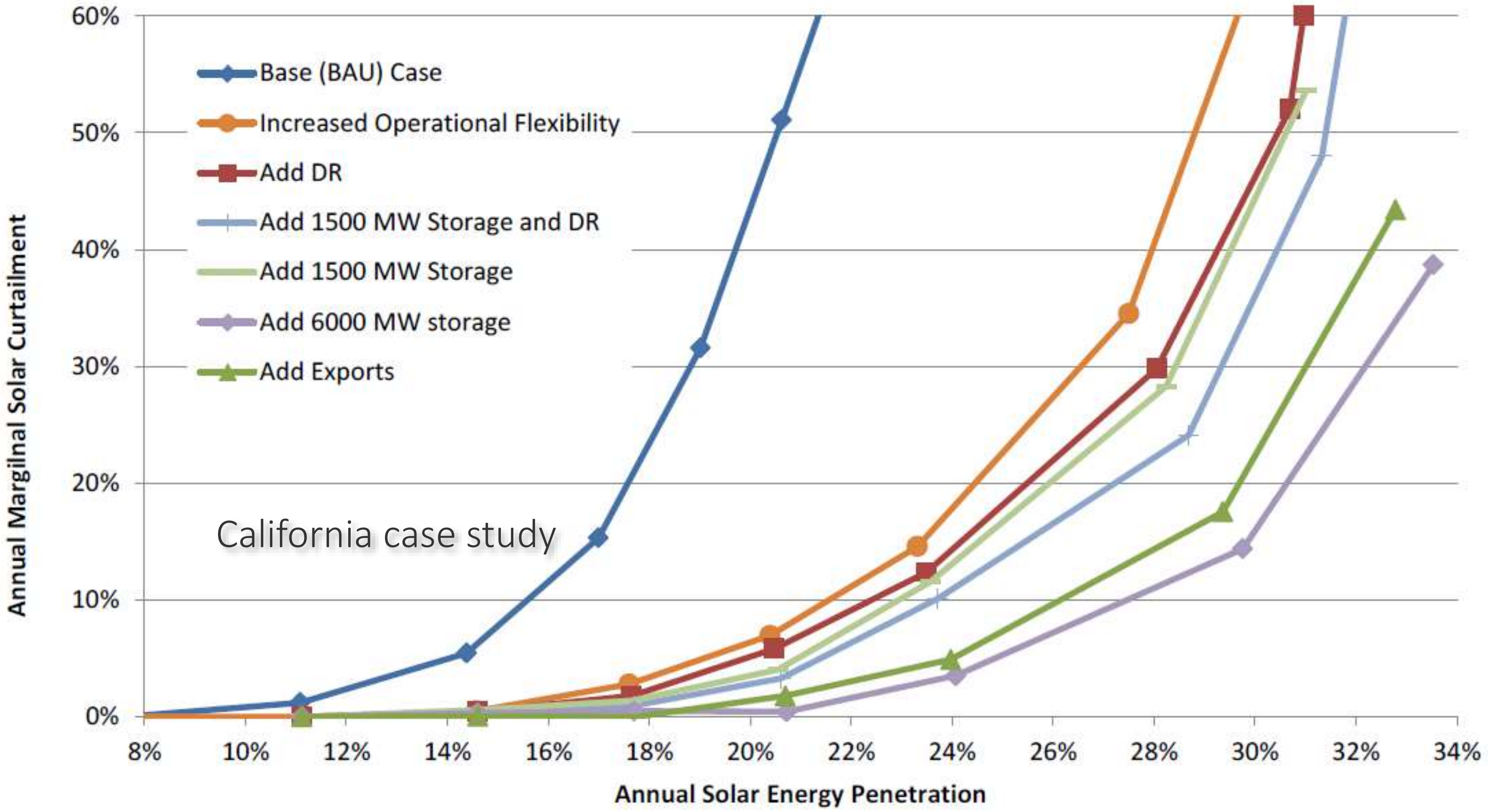
Capacity credit of VG declines rapidly with penetration



Dashed lines are average (fleet-wide) capacity credit while solid lines are marginal capacity credit.

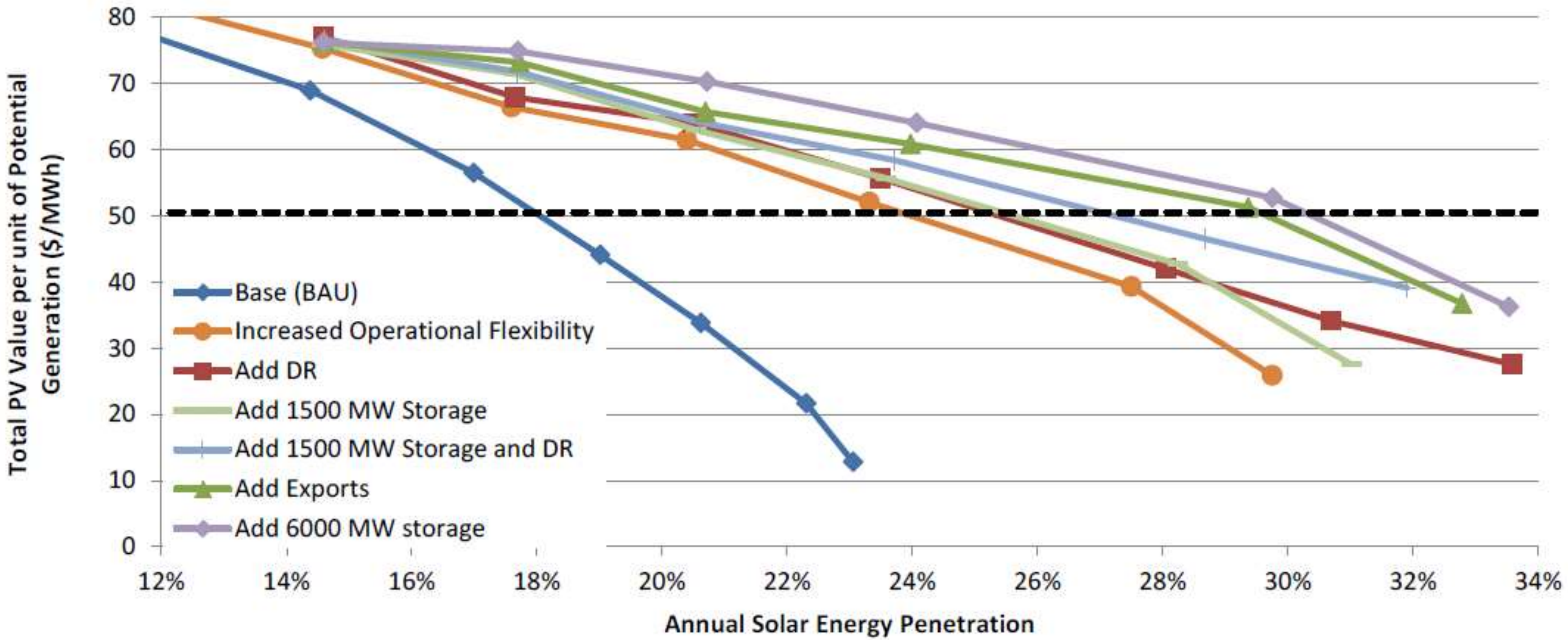
Source: Adapted from Mills and Wiser, 2012

…and curtailment increases



Source: Denholm et al., 2016

This creates an economic and technical challenges for variable generation



Source: Denholm et al., 2016

Top 10 Resource to Learn More

1. FERC Energy Market Primer: https://www.ferc.gov/market-oversight/guide/energy-primer.pdf
2. FERC Reliability Primer: https://www.ferc.gov/legal/staff-reports/2016/reliability-primer.pdf
3. Eastern Renewable Generation Integration Study: http://www.nrel.gov/docs/fy16osti/64472.pdf
4. Denholm, et al. "The Role of Energy Storage with Renewable Electricity Generation" NREL/TP-6A2-47187: http://www.nrel.gov/docs/fy10osti/47187.pdf
5. Ela et al. Operating Reserves and Variable Generation: http://www.nrel.gov/docs/fy11osti/51978.pdf
6. Denholm et al. Over-generation from Solar in California: a field guide to the duck chart: http://www.nrel.gov/docs/fy16osti/65023.pdf
7. A Wider Horizon: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5753335
8. Milligan et al. Operational Analysis and Methods for Wind Integration Studies http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=5934624
9. Wholesale Electricity Market Design Initiatives in the United States: Survey and Research Needs https://www.epri.com/#/pages/product/3002009273/?lang=en-US
10. "Expansion Planning for Electrical Generating Systems: A Guidebook", International Atomic Energy Agency, Technical Reports, 1984 http://www.energycommunity.org/documents/IAEATRS241.pdf

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