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State Of the Markets: Key Opportunities On The Path To Net-Zero GHG

Part 2:bThree Observation From The Texas Blackout That Highlights These Opportunities

February 2021

Alan Brazil

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State Of the Markets: Key Opportunities On The Path To Net-Zero GHG

Part 2: Three Observation From The Texas Blackout That Highlights Theses Opportunities

- Part 1: Framing the magnitude of a net-zero GHG emissions policy for the world and the US
  - Example of transitioning to a 100% electric vehicles
  - Example of projected costs for the US of a 100% renewable energy grid
- **Part 2: Three Observation From The Texas Blackout That Highlights These Opportunities**
  - **Observation 1: Renewable Energy Is Variable By Nature And Is Particularly Vulnerable To Extreme Events**
  - **Observation 2: Renewable Grids Need To Have Substantial Overcapacity Or Days Worth Of Storage To Replace Carbon**
  - **Observation 3: A Transmission Network Needs To Built To Link Major Wind And Solar Area To The Whole Country**
- Part 3: Key opportunities along the path to Net-Zero

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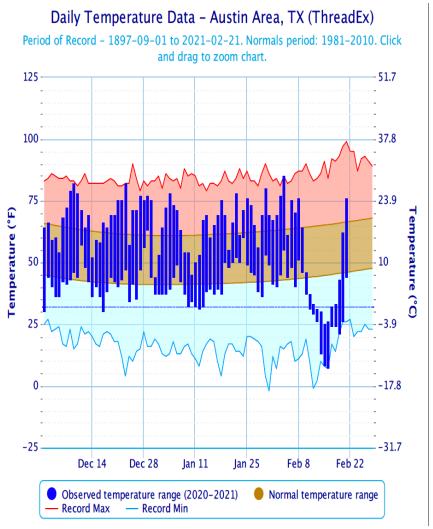
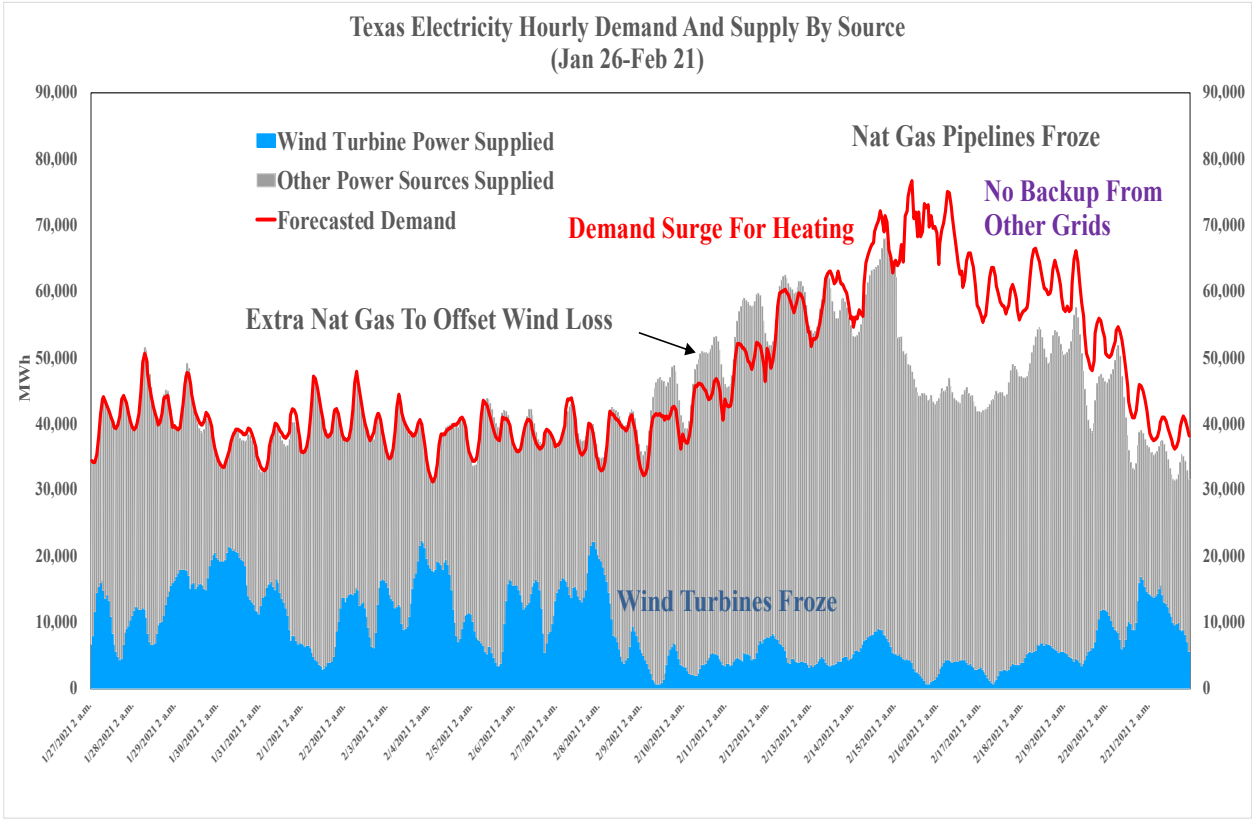
Step 1: Macro Theme

The Timeline That Led To The Breakdown In The Texas Electrical Grid

Texas Temps Fell To Record Lows[1]



Loss Of Wind Power Started The Event Then The Gas Pipelines Froze[2]



1. National Weather Service
2. EIA

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Step 2: Fundamental Economic Framework

Three Observation From Texas That Highlight The Opportunities On The Path To A Renewable Grid

The Texas Observations

- **Observation 1: Renewable Energy Is Variable By Nature And Is Particularly Vulnerable To Extreme Events**
  - Wind/solar capacity is variable and changes by time: hour, day, season, over years, and in unexpected ways
  - Texas wind turbine freeze out was driven by seemingly a black swan low temp event
- **Observation 2: Renewable Grids Need To Have Substantial Overcapacity Or Days Worth Of Storage To Replace Carbon**
  - Even with a linkage of renewable grids, a 100% renewable grid will fail sometimes 100% of the time
  - Wind/solar + battery storage is still too expensive to be a replacement of a grid with Nat Gas
  - In Texas, Nat Gas acted as battery storage after the wind turbines froze
- **Observation 3: A Transmission Network Needs To Built To Link Major Wind And Solar Area To The Whole Country**
  - The current electric grid is linked to major carbon resource areas by a countywide network of pipelines and freight-lines
  - A renewable grid needs the a network that links major solar areas and wind areas with each for back up and to replace carbon in the rest of the country
  - in Texas shows what could happened in a 100% renewable grid without backup or linkage to other areas of the country through an electrical grid
    - Texas is basically cut off from the rest of the grids in the country by design
    - The black out in Texas would have been substantially worse if not for Nat Gas, which provided the backup after the shortfall from the wind turbines

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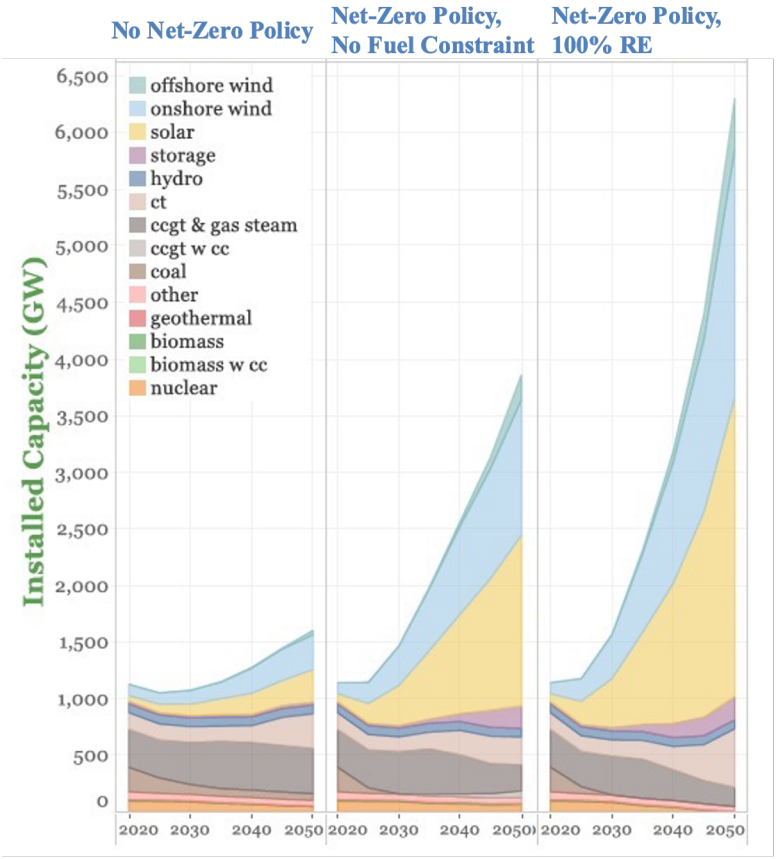
The Push For A Net-Zero Policy In The US Is Accelerating And That Means A 100% Renewable Grid

Biden's Green New Deal

Net Zero	Net-Zero 2050 Decarbonize all sectors of economy: transportation, power and consumer, industrial and commercial
Power Sector	100% pollution-free emissions by 2035 $2 trillion infrastructure for clean energy over next two years 80% electrical power generated by renewable energy by 2035 Build the next generation electric transmission and distribution network Green hydrogen that is cost competitive to carbon based fuel sources Development and deployment of large scale carbon capture systems $400 billion in additional energy research next 4 years Grid scale battery storage at 1/10th the cost of Lithium-ion battery
Transportation	Move to 100% EV transportation by 2050 Build 500,000 EV charging stations Consumer rebates/incentive to buy and produce EVs Substantially higher fuel economy standards to pushout ICE vehicles

The Growth Of Wind/Solar Power Could Be Exponetial[1]



as1. E. Larson, C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, R. Williams, S. Pacala, R. Socolow, EJ Baik, R. Birdsey, R. Duke, R. Jones, B. Haley, E. Leslie, K. Paustian, and A. Swan, Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report, Princeton University, Princeton, NJ, December 15, 2020.

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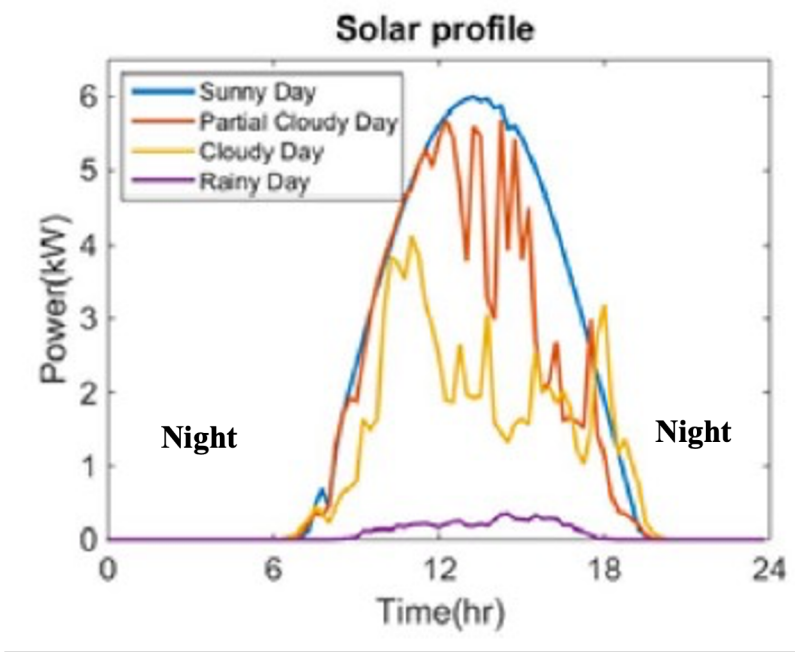
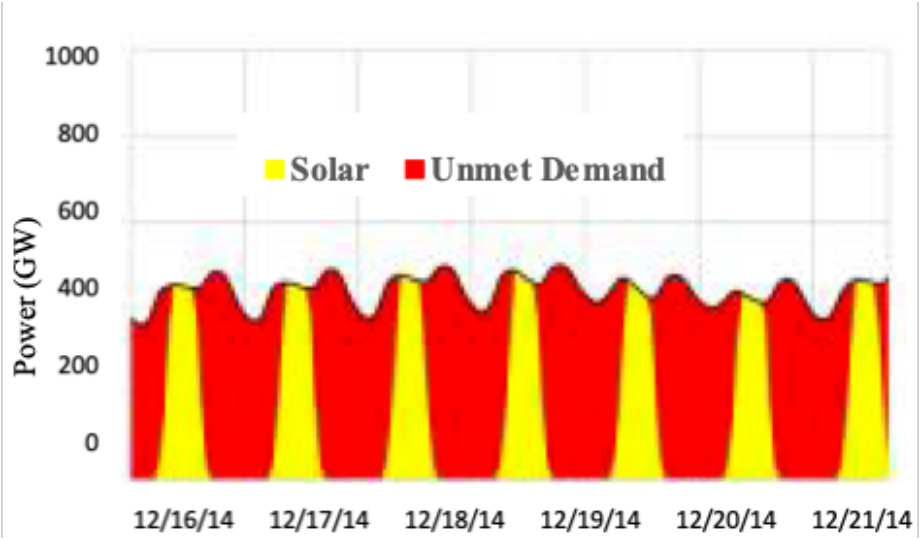
Step 2: Fundamental Economic Framework

Observation 1: Renewable Energy Is Variable By Nature And Is Vulnerable To Extreme Events

Night Is One Thing, Even During The Day Solar Power Is Variable[1]



Using Only Solar For A Renewable Grid Is 100% Unreliable[2]



1. Zhu, et.al " A Graphical Performance –Based Energy Storage capacity Sizing Method for Solar Penetration Residential Feeders", IEEE Transactions on Smart Grid, January 2016
2. Shaner, Matthew & Davis, Steven & Lewis, Nathan & Caldeira, Ken. (2018). Geophysical constraints on the reliability of solar and wind power in the United States. Energy & Environmental Science

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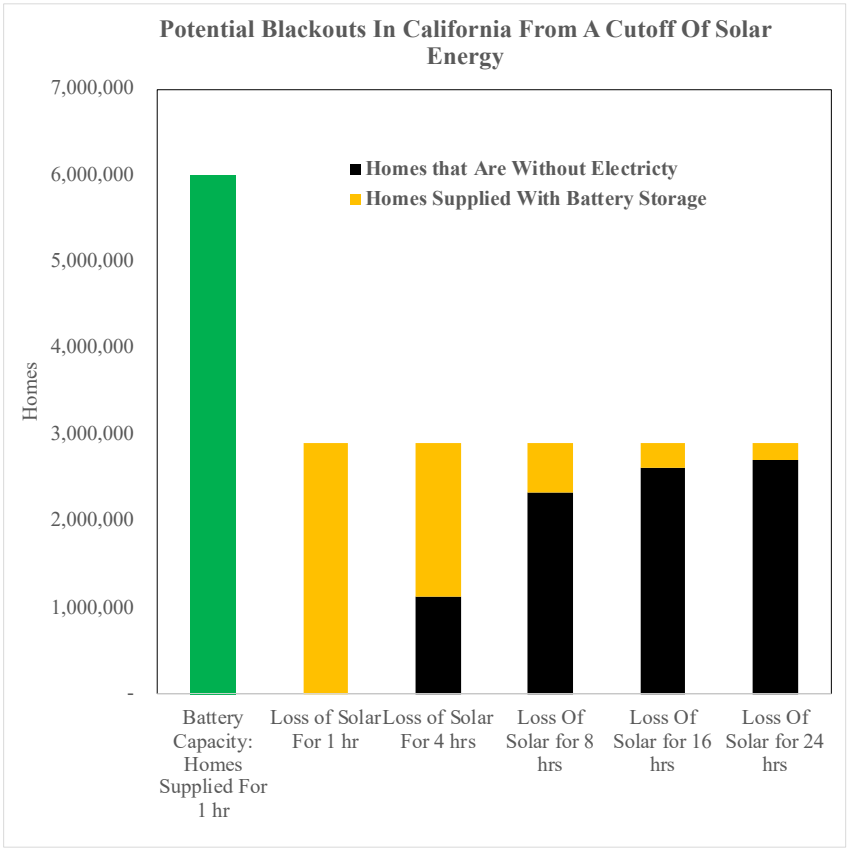
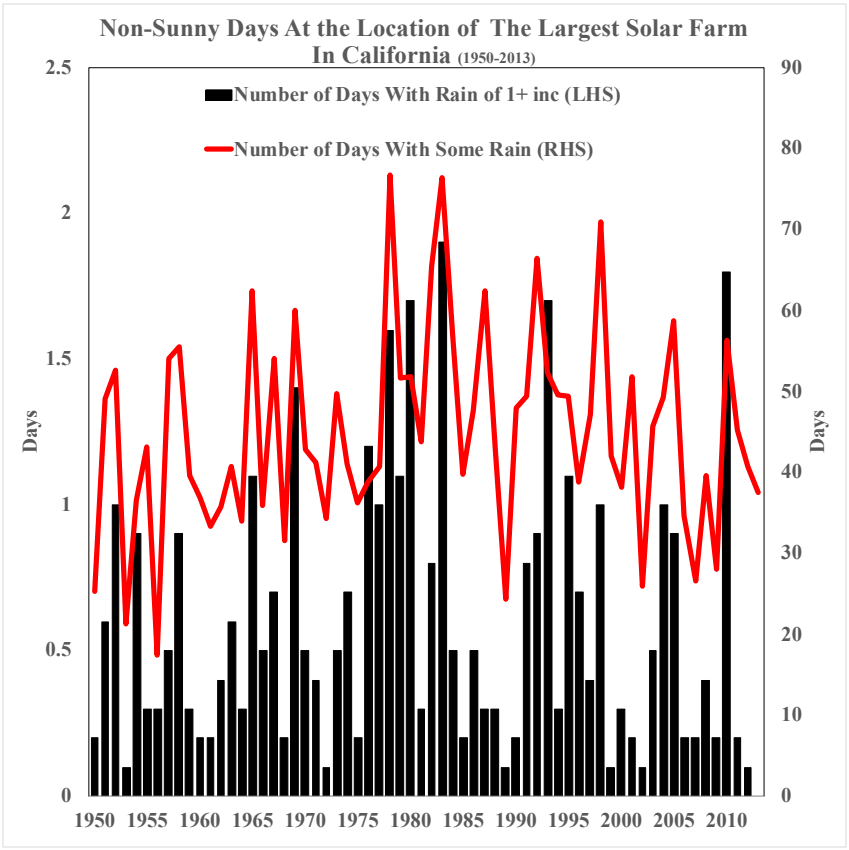
Observation 1: Texas Highlights The Risk Of A Renewable Energy--It's Variable: Is California Next?

Without Storage, California Is A Storm Away From A Texas Event[1]



For Texas It Was Wind, For California It Will Be A Solar Event[2]



1. CASIO
2. Authors calculation using 11.6 mm homes in California
3. NOAA, National Centers For Environmental Information

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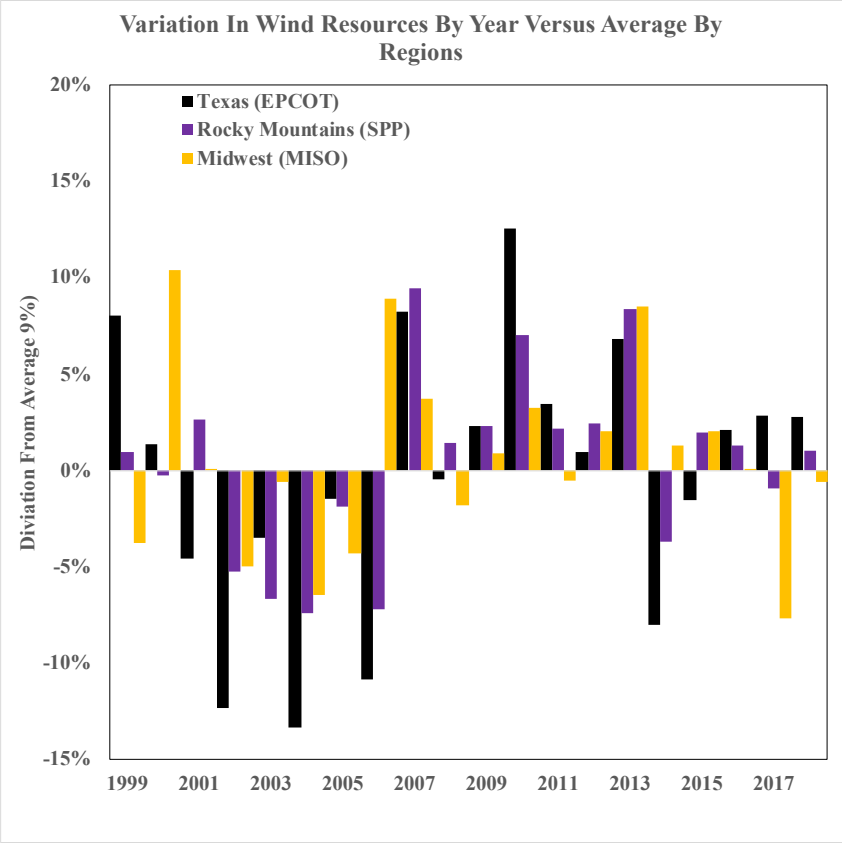
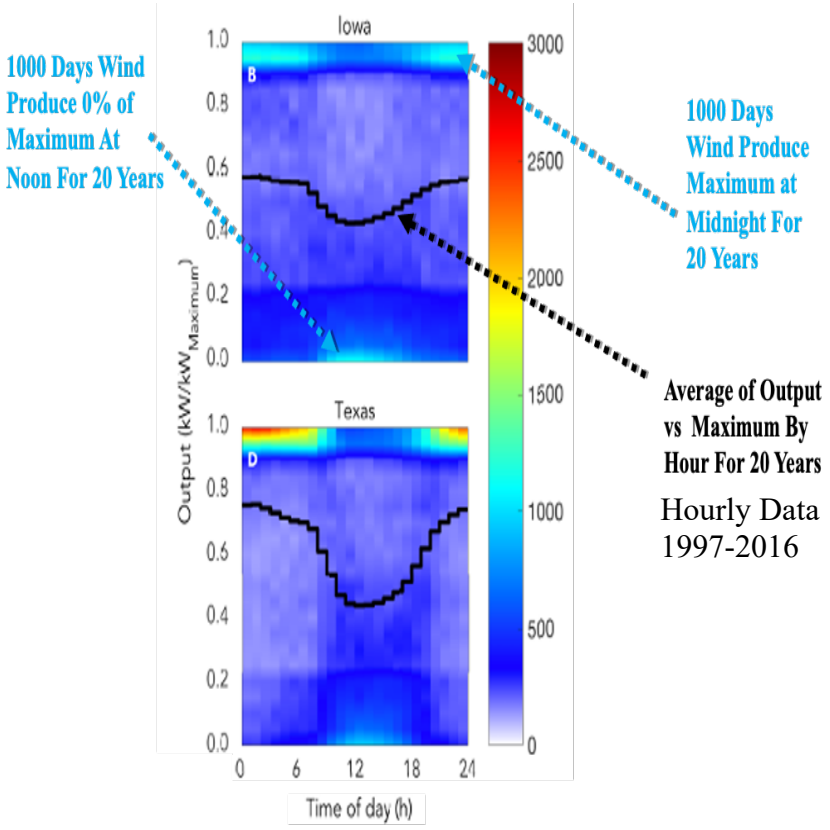
Step 2: Fundamental Economic Framework

Observation 1: Wind Energy Is Also Variable Over Hours, Days, Months And Year

Wind Energy Has Long Periods Below Average….[1]



And Substantial Variable Over Time Of Day, Month And Years[2]



1. Wiser, Et al, " Wind Energy Technology Data Update:: 2020 Edition", Berkeley Lab August 2020
2. Ziegler , et al "Storage Requirements and Costs of Shaping Renewable Energy Toward Grid Decarbonization", Joule , Vol 3, September 2018

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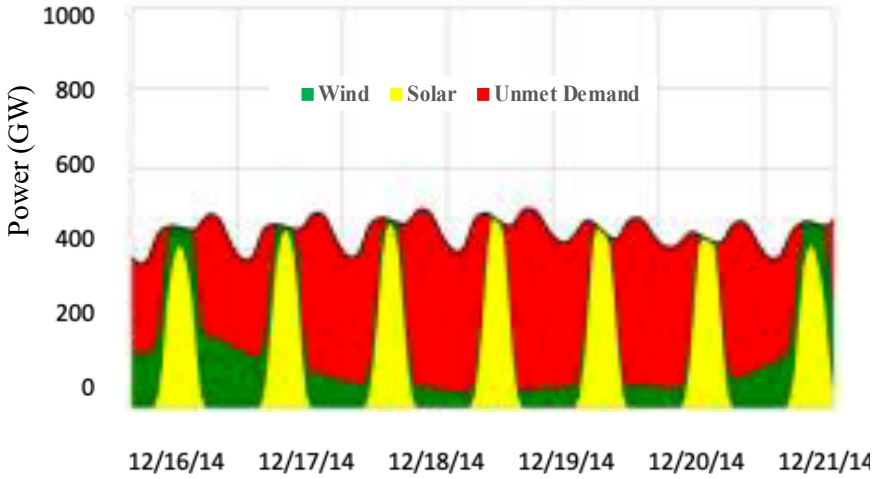
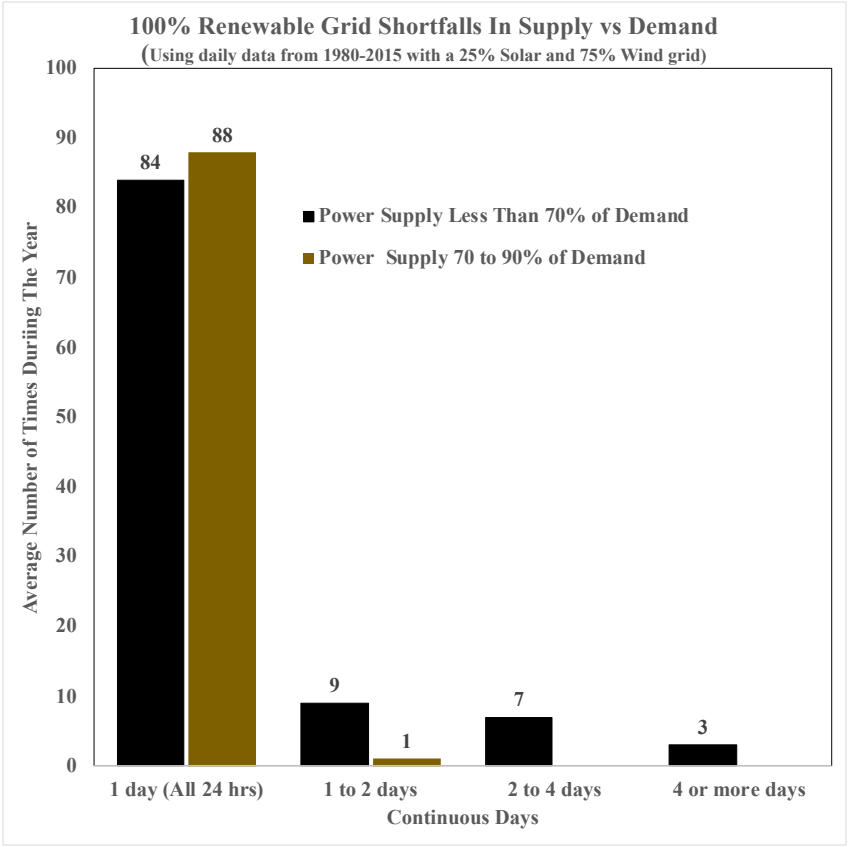
Observation 1: Combining Wind And Solar Is Still Not 100% Reliable[1]

Not Enough Wind/Solar Energy To Supply Demand In Winter

Wind/Solar Grid December That Was Optimized For Summer Demand



A 100% Renewable Grid Could Face For Days Of Blackouts



1. Shaner, Matthew & Davis, Steven & Lewis, Nathan & Caldeira, Ken. (2018). Geophysical constraints on the reliability of solar and wind power in the United States. Energy & Environmental Science

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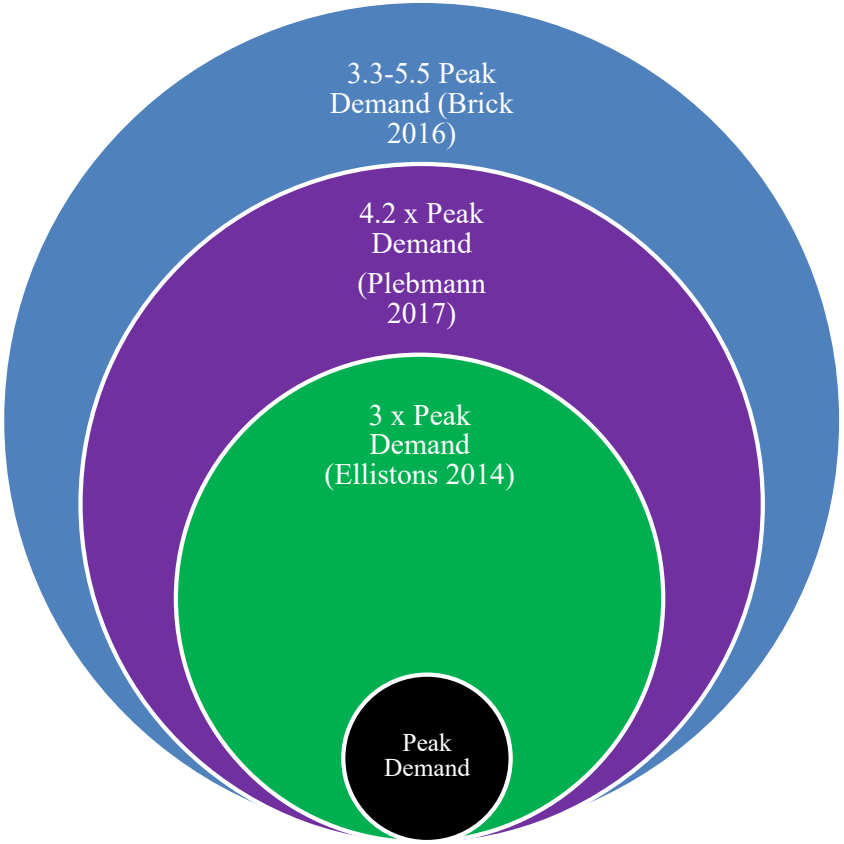
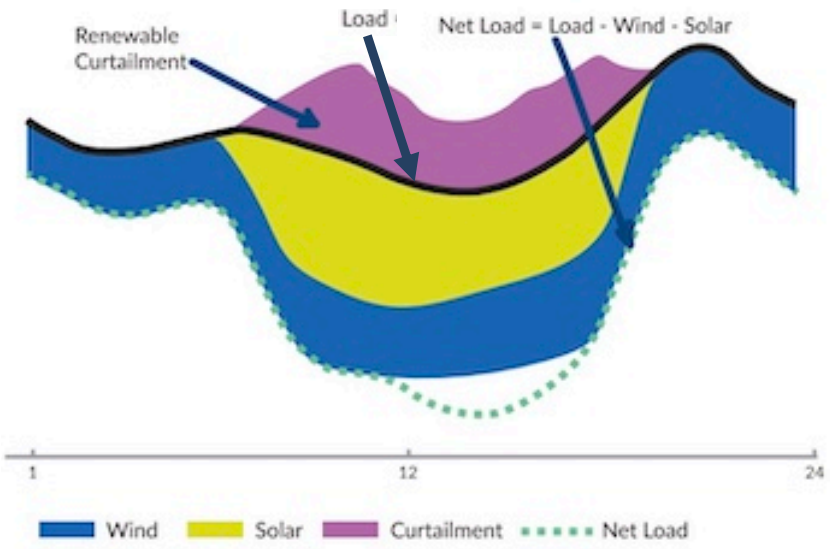
Observation 2: Renewable Grids Need Substantial Overcapacity Or Days Worth of Storage To Replace Carbon Grids

Renewable Grid Needs Over Capacity To Be 100% Reliable[1]



Example of Curtailment In California in 2019, AKA The Duck Graph[2]



1. Jenkins, J.D., & Thernstrom, S. ," Deep decarbonization of the electric power sector: Insights from recent literature. Energy Innovation Reform Project (EIRP), 2017
2. Casio

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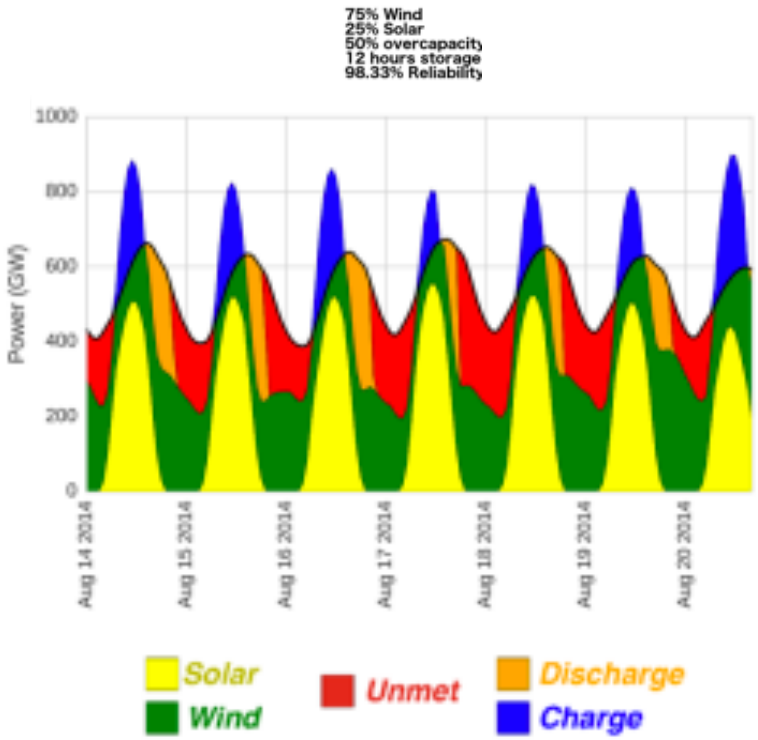
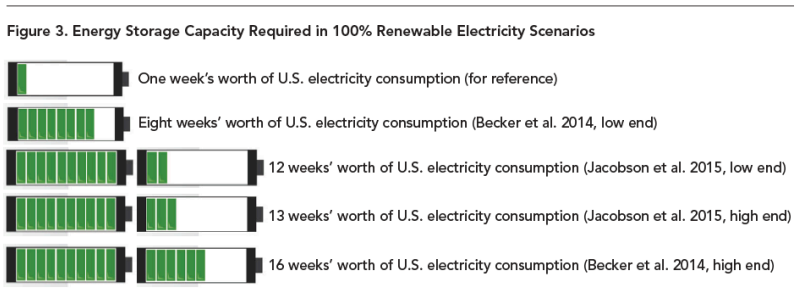
Step 2: Fundamental Economic Framework

Observation 2: Days Worth Of Battery Storage Is An Alternative To Overcapacity And Curtailments

Adding Some Battery Storage To The Grid Does Reduce Variability[1]



But Storage Measured In Days Is Needed To Make It 100% Reliable[2]



1. Shaner, Matthew & Davis, Steven & Lewis, Nathan & Caldeira, Ken. (2018). Geophysical constraints on the reliability of solar and wind power in the United States. Energy & Environmental Science1
2. Jenkins, J.D., & Thernstrom, S. ," Deep decarbonization of the electric power sector: Insights from recent literature. Energy Innovation Reform Project (EIRP), 2017

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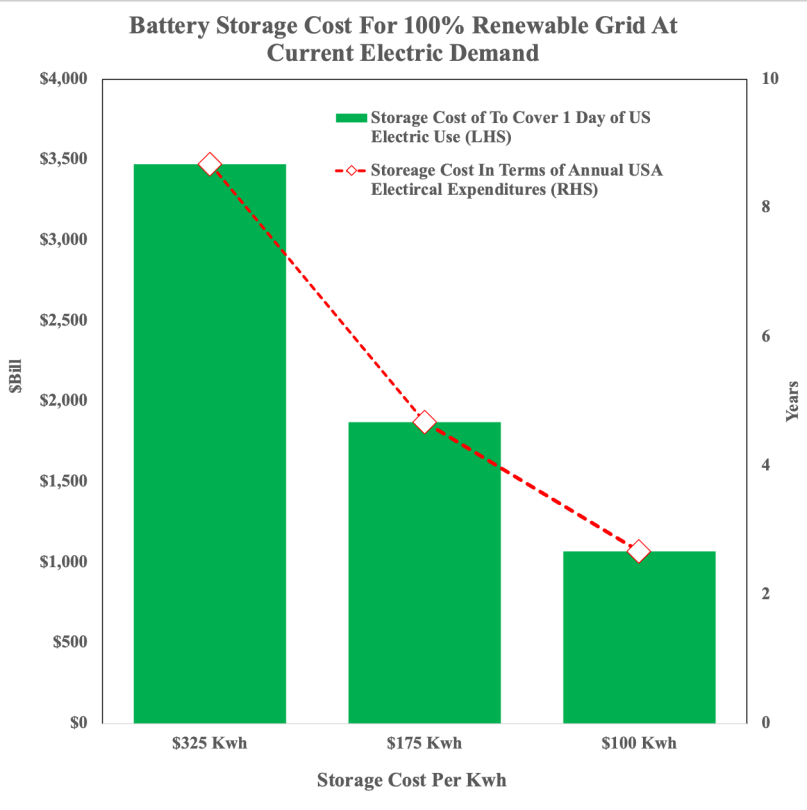
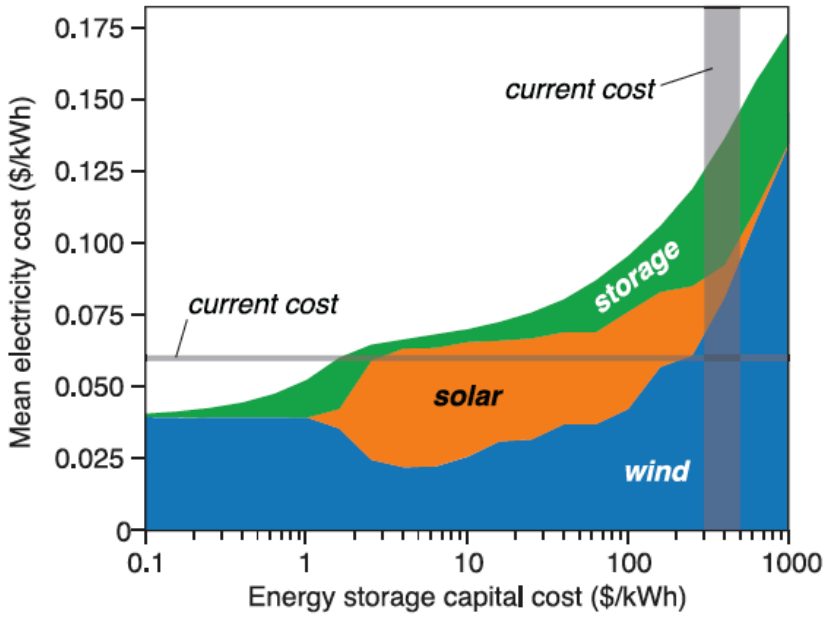
Observation 2: However Days Worth Of Battery Storage Means Multiples Of Current Electricity Costs

Even California, the Leader In Storage, Would Need More[1]



The Problem Is Battery Storage Is Very Expensive[2]



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Observation 2: Storage to Supply 10% of a Renewable Grid Would Require A Massive Buildout

Need 6000 Of The Largest Battery Storage Facility In the US[1]

40 Dedicated Telsa Gigafactory's That Is Now Being Built In Berlin[2]

1. 1500 MW, 6000 MWh, Moss Landing, Monterey, California, Vistra
2. Tesla, Berlin Giga Factory

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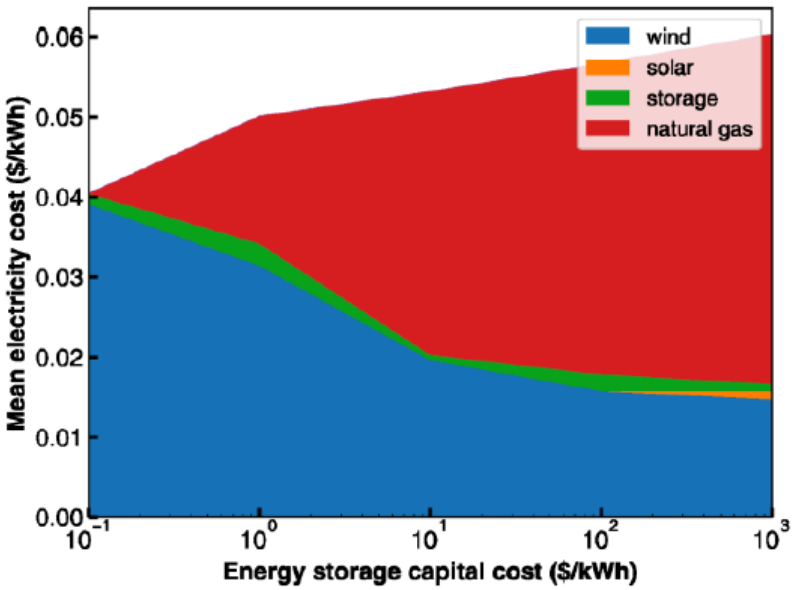
Step 2: Fundamental Economic Framework

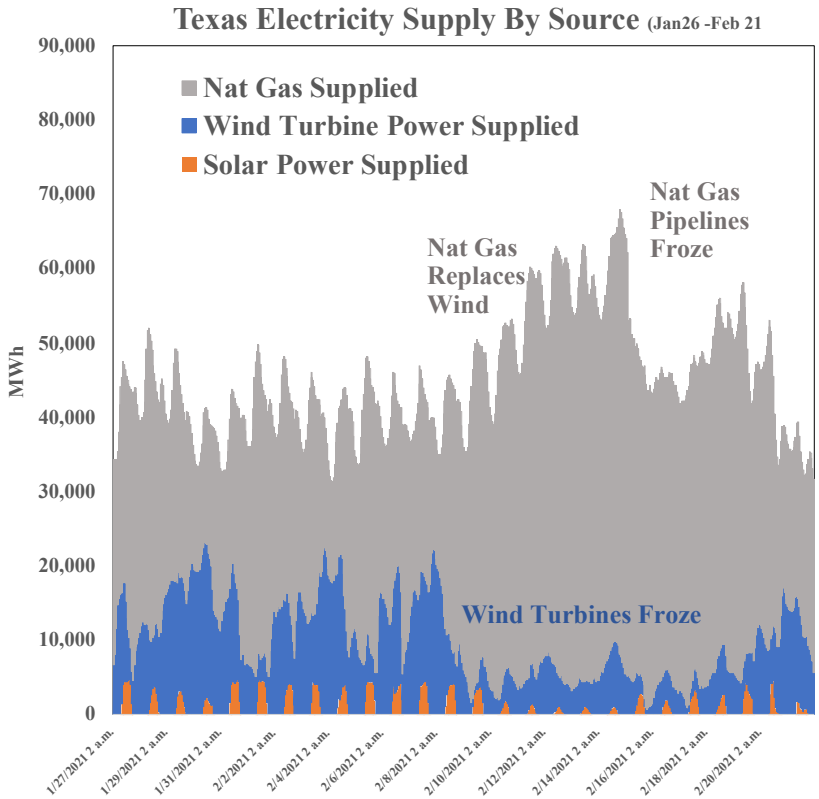
Observation 2: More Importantly, Nat Gas Substantially Cheaper As A Backup For A Renewable Grid

Nat Gas Is Much Cheaper Storage Alternative Than Batteries[1]

The Optimal Grid Mix With Nat Gas



Think About What Happen In Texas But Without Nat Gas Backup[2]



1. Tong, Et all, "Effects of Deep Reductions in Energy Storage Costs on Highly Reliable Wind and Solar Electricity Systems", iSceince, vol 23, September 2020
2. Eia

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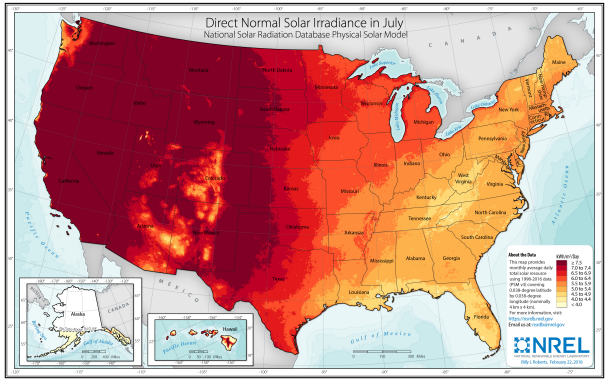
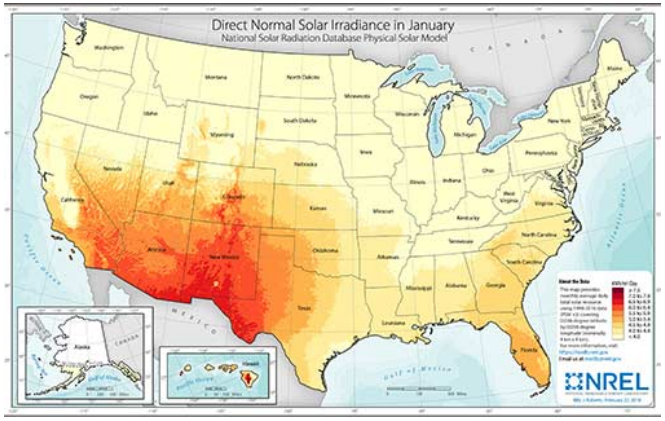
Observation 2: The Key To Replace Nat Gas Is New Storage Technology Not Cheaper Lithium Batteries[1]

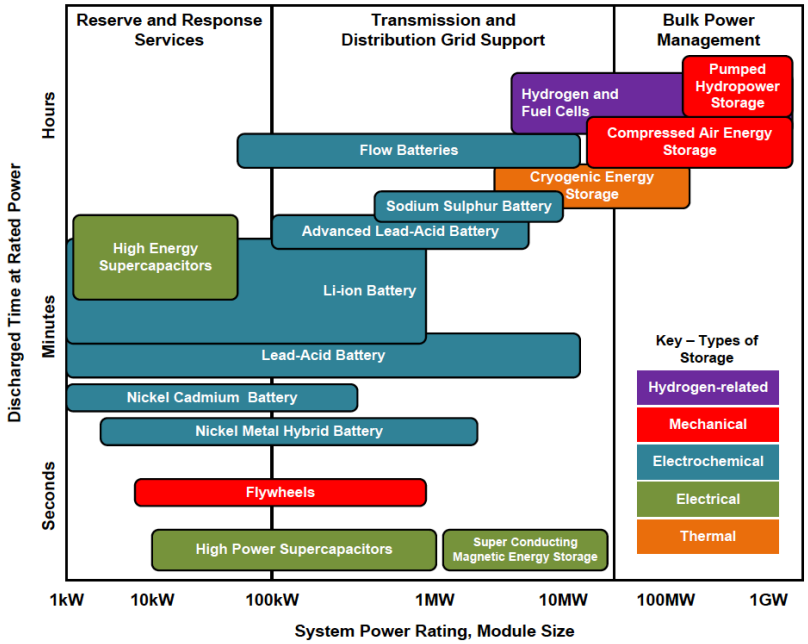
Long Duration Storage Moves Abundant Solar Energy From Summer



To Low Levels Of Solar In The Winter



Potentially Large May Technologies Are Being Developed



1. NREL

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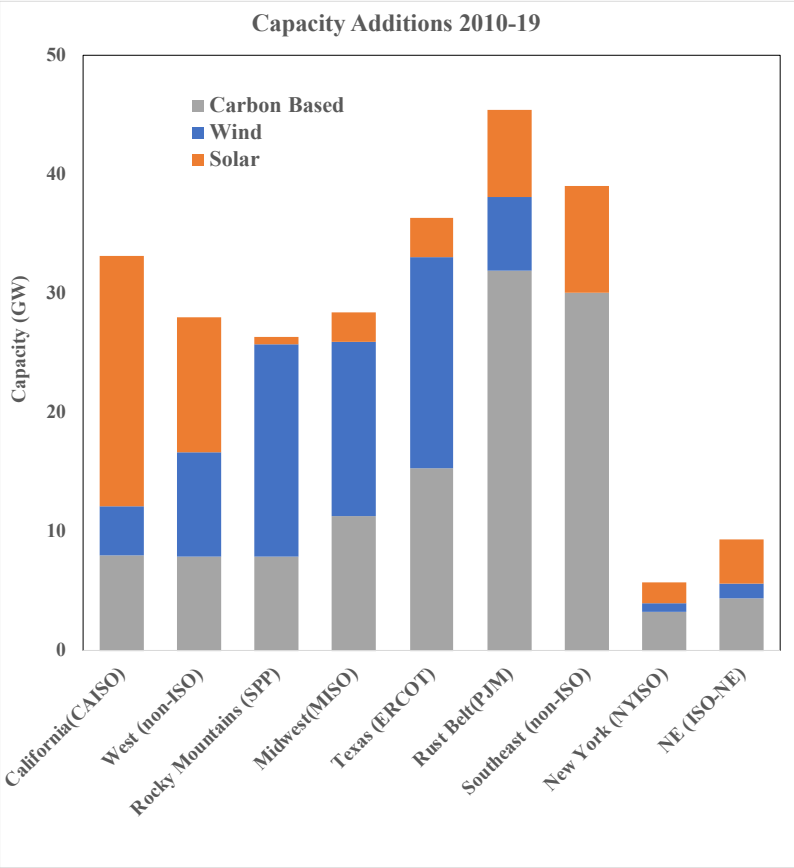
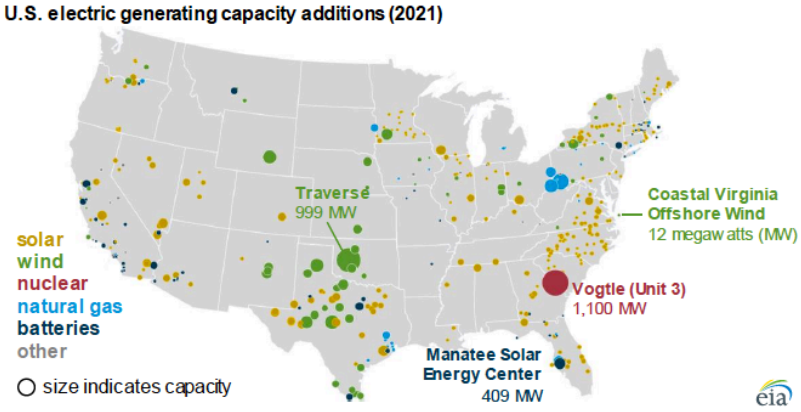
Observation 3: Capacity Additions of Wind/Solar Reflects Economic Incentives And Need For A Network[1]

Solar Added In the Southwest And Wind In the Midwest



Future Capacity Additions Largely Reflect Economics As Well



1. EIA

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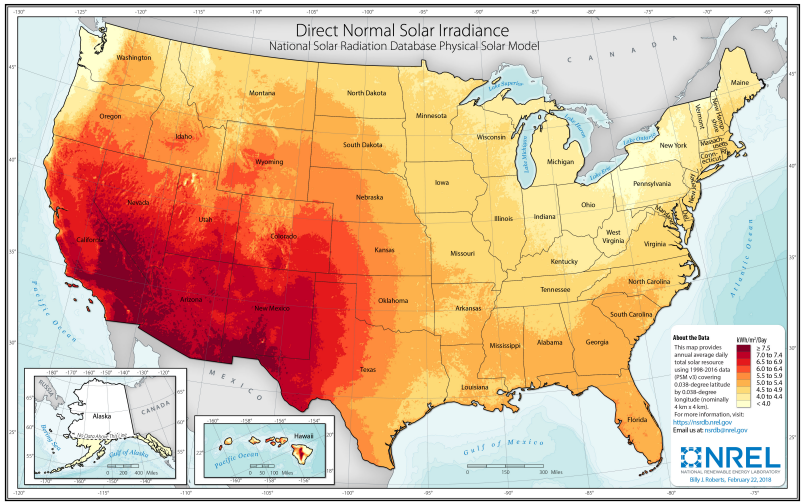
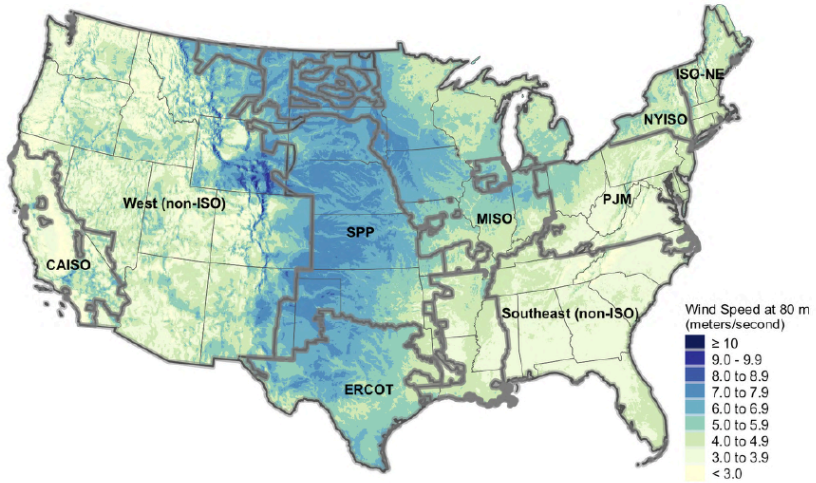
Observation 3: A Transmission Network Needs To Built To Link Major Wind And Solar Areas Throughout The Country

Solar Capacity Is Highest In the Southwest[1]



Solar East

Wind Capacity Is Highest In the Midwest[2]



Wind East & West

1. NREL
2. "Wind Energy Technology Data Update: 2020 Edition", Berkeley Lab, August 2020

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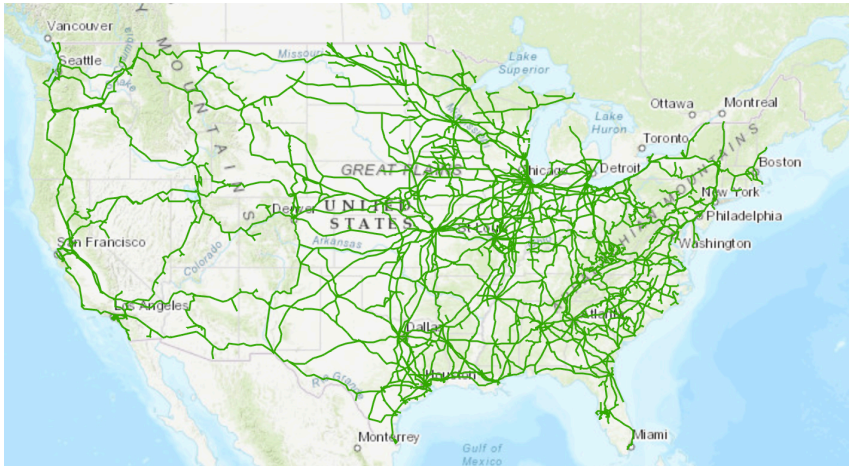
Step 2: Fundamental Economic Framework

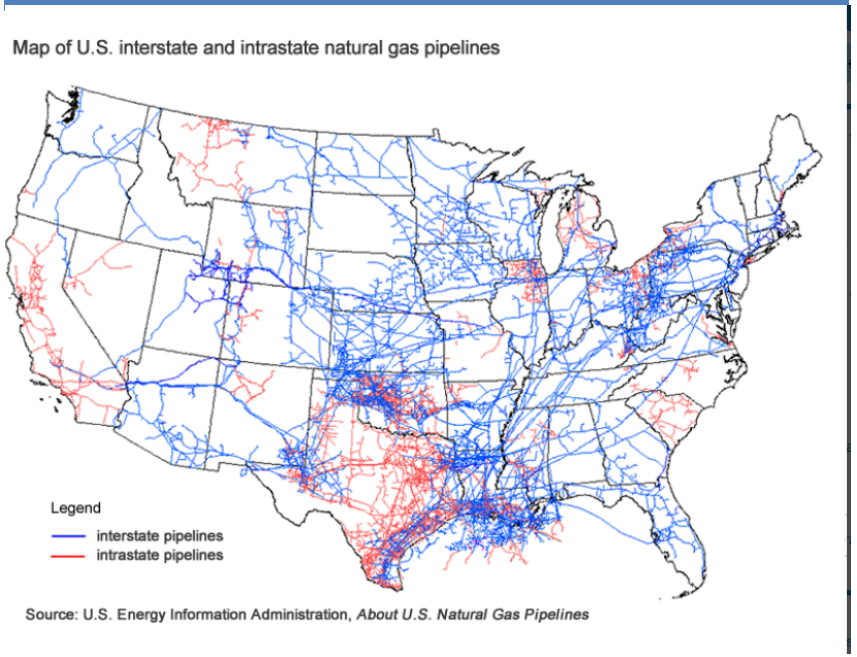
Observation 3: A Renewable Grid Needs A Network As Extensive As the Carbon Grid Has Now

Coal Gets Shipped On Railroads to Utilities Through Out The US[1]

Map Of US Freight Railroad Lines



Nat Gas Is Distributed To Utilities Country Wide Through Pipelines [2]



Source: U.S. Energy Information Administration, *About U.S. Natural Gas Pipelines*

1. DOT
2. EIA

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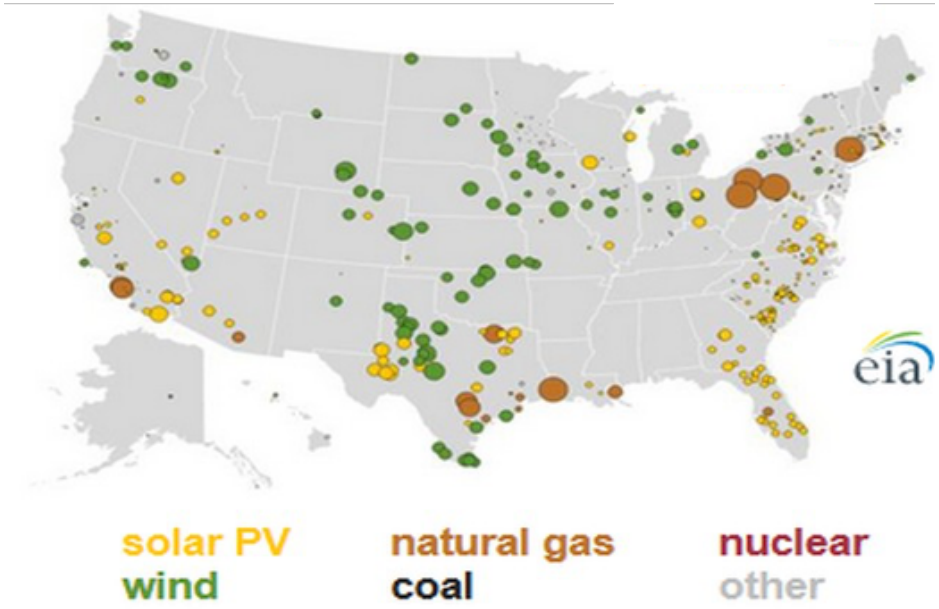
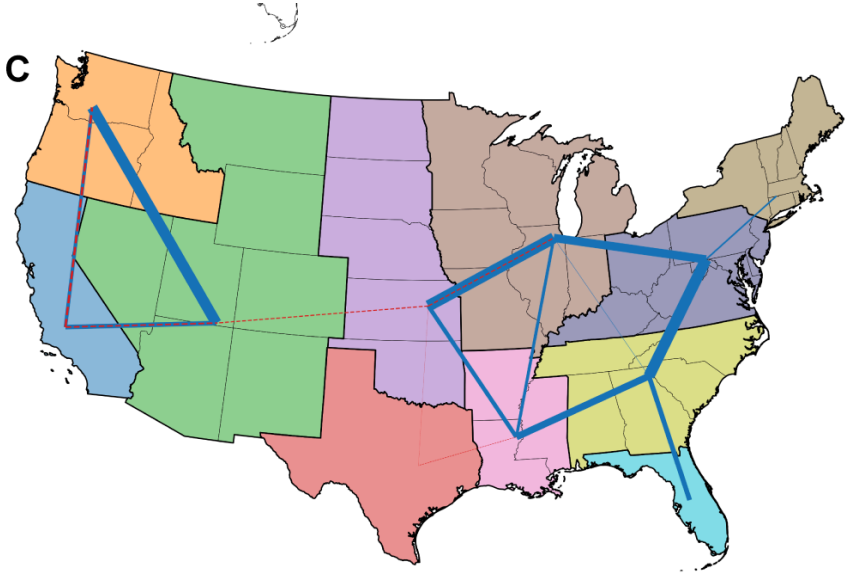
Observation 3: The Major Energy Regions Have Linkage To Each Other Or To The Rest Of The US [1]

Wind/Solar Capacity Adds Highly Regional In Nature[1]



But No Transcontinental Electrical Transmission Network Exists[2]



Texas Had No Major Electrical Transmission Links

1. EIA
2. Patrick R. Brown and Audun Botterud, "The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity System", Joule, Volume 6, January 2021

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