What does a decarbonized future look like: The Last 10%

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

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ISO-NE Board Meeting

Nov 1, 2023

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You can easily run a system with 100% renewable electricity… if you are Iceland

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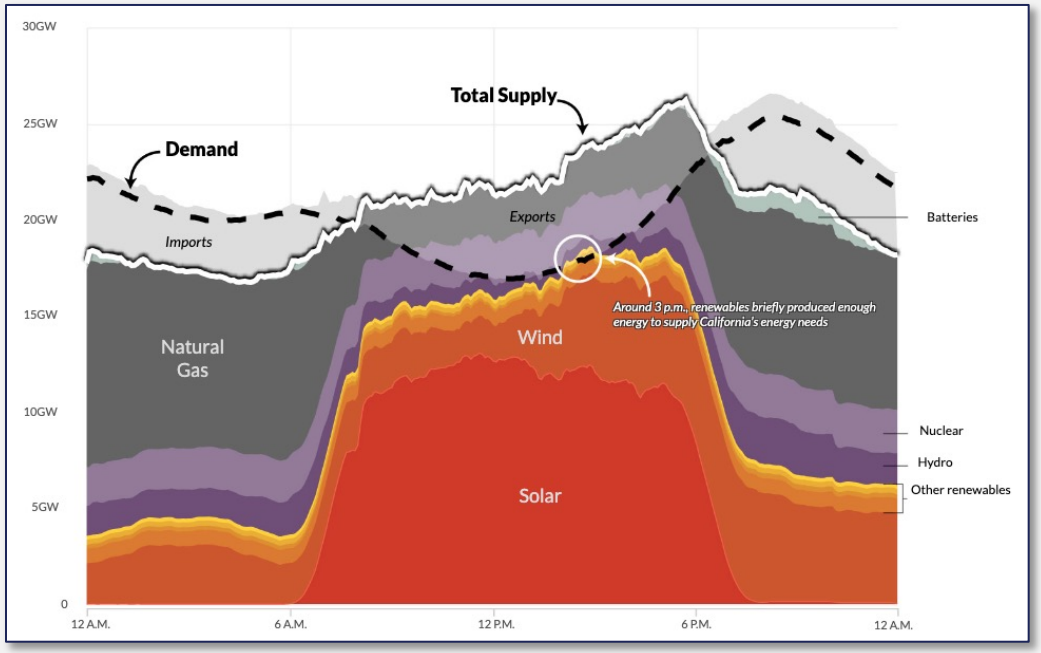
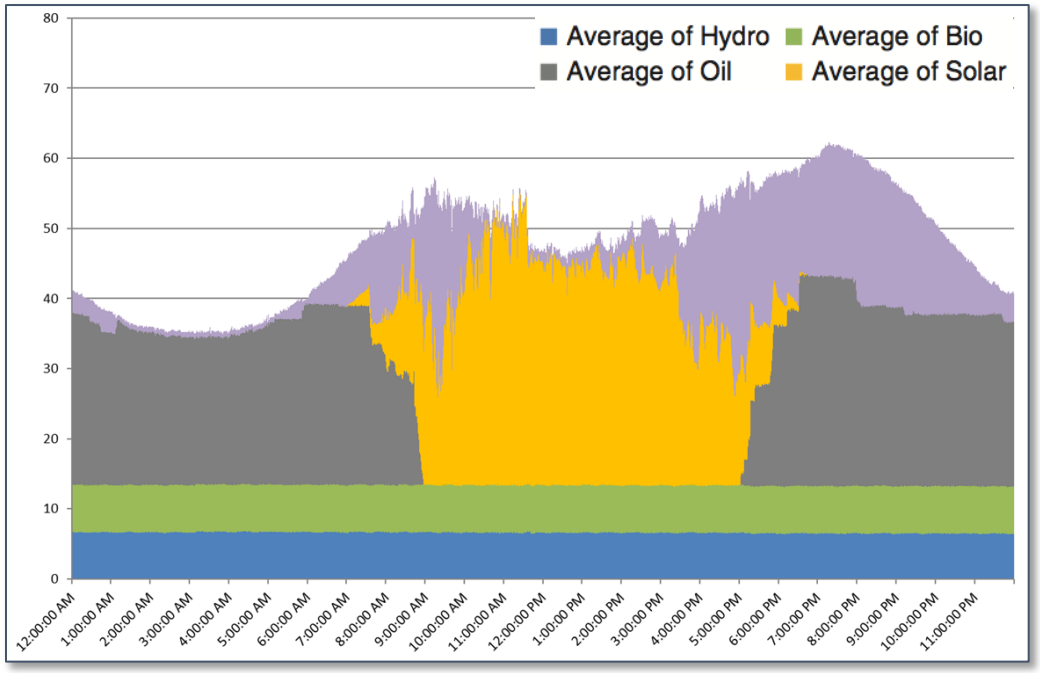
We can operate a power system with very high levels of clean energy today

CAISO met 100% of load with renewables in 2022



Kauai can operate at 100% renewables for 8 hours



L. Sommer, NPR 2022; KIUC data 2021

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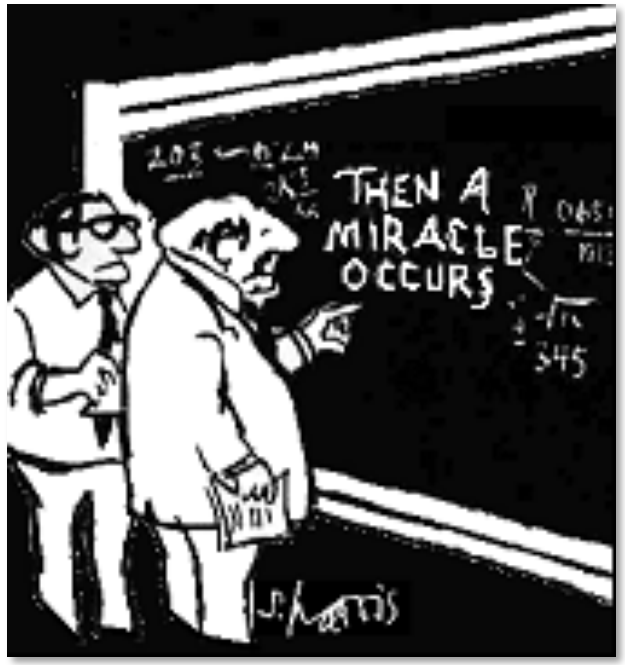
What do the studies tell us?

- If we keep doing what we're doing, can we reach 100% clean electricity?
- In the US, our current strategy appears to be – Build as much wind, solar and battery storage as you can, while retiring as much coal generation as you can. Electrify and use the flexibility from those new loads, plus the existing gas system, to help balance the system. That'll get us to 90%. At that point, we hope to have developed a cost-effective clean, firm resource that'll get us to 100%.
- Does this strategy work?
  - How fast can we retire fossil plants, given the pace of load growth and the difficulty interconnecting new resources?
  - What kind of new resource do we need to make this work? When do you need it? What's the capacity factor of that resource? How often does that resource run and for how long?
  - Should we retire gas plants? Should we build new gas plants?



Bottom line is reliable, affordable, clean energy

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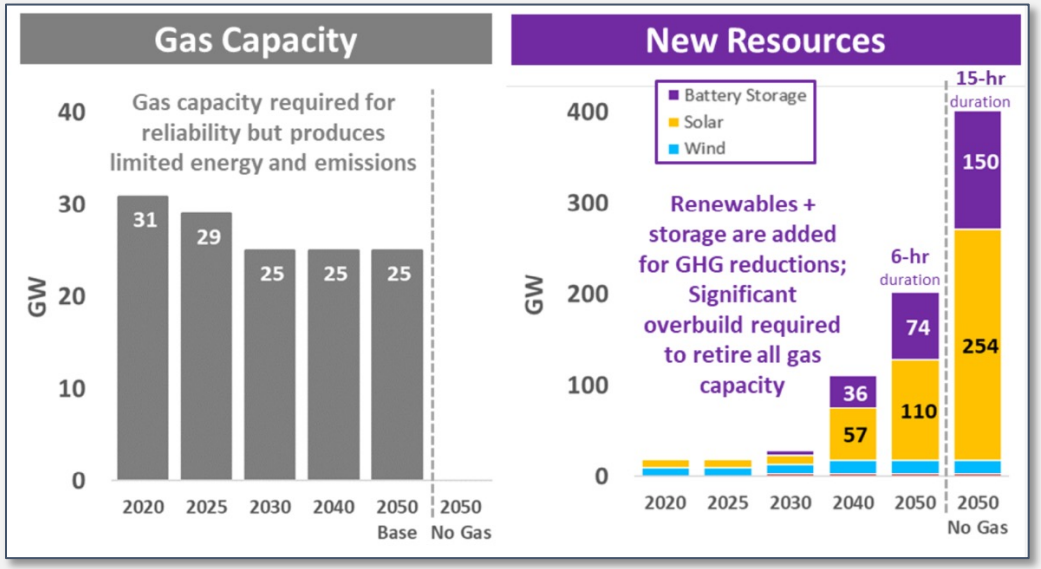
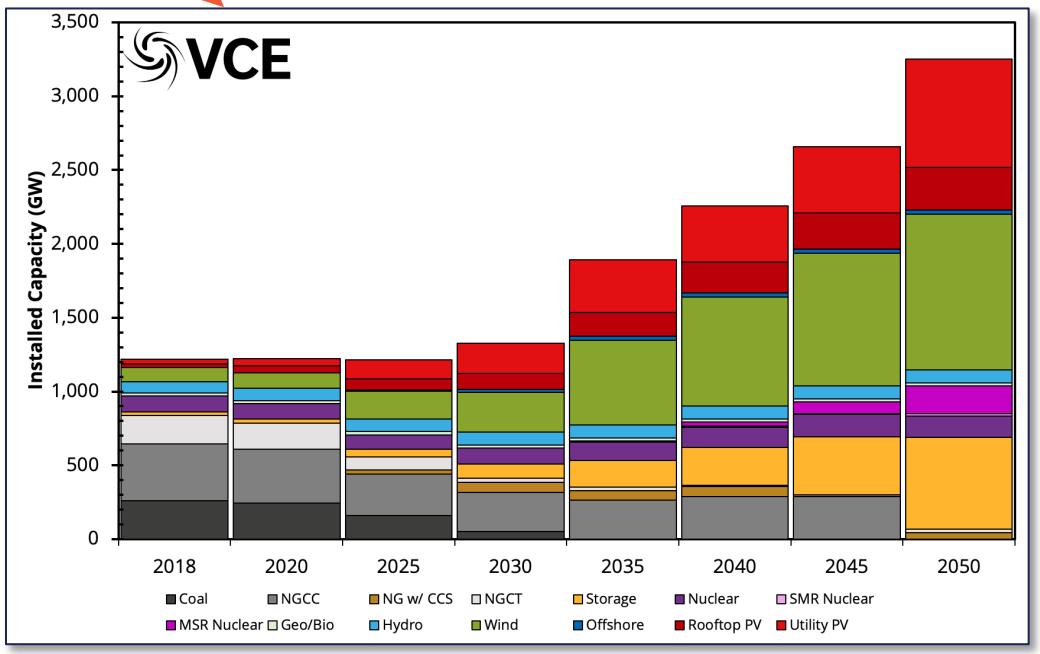
Resource portfolios show a need for some amount of clean, firm resource

Fossil fuels are transitioned to clean firm

California



US - Zero energy emissions by 2050



Lots of options, but not sure which will be most cost-effective! Hydrogen, advanced nuclear, carbon capture & sequestration, direct air capture, bioenergy, geothermal, long-duration storage

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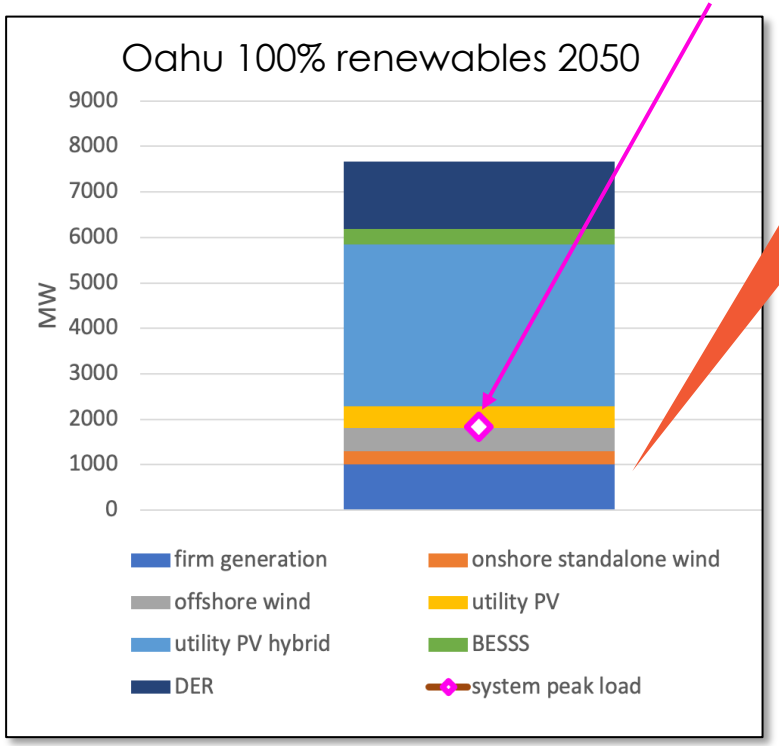
E3, Long Run Resource Adequacy under Deep Decarbonization Pathways for California, 2019; Vibrant Clean Energy, ZeroByFifty; 2021

You don't need clean, firm resources equivalent to peak demand

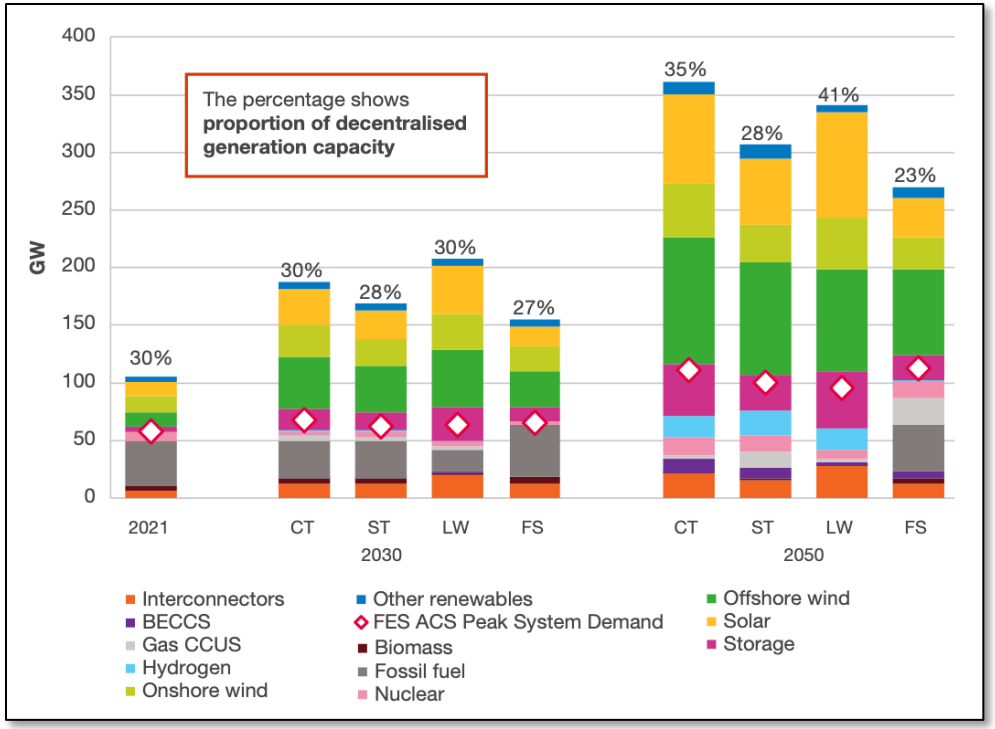
Peak demand



Need a LOT of firm but not equivalent to peak demand

Firm resources provide capacity value close to nameplate. Wind, PV & batteries provide capacity value but suffer saturation effects

UK National Grid - Net zero energy emissions by 2050



HECO IGP, 2023; UK National Grid Future Energy Scenarios, 2022

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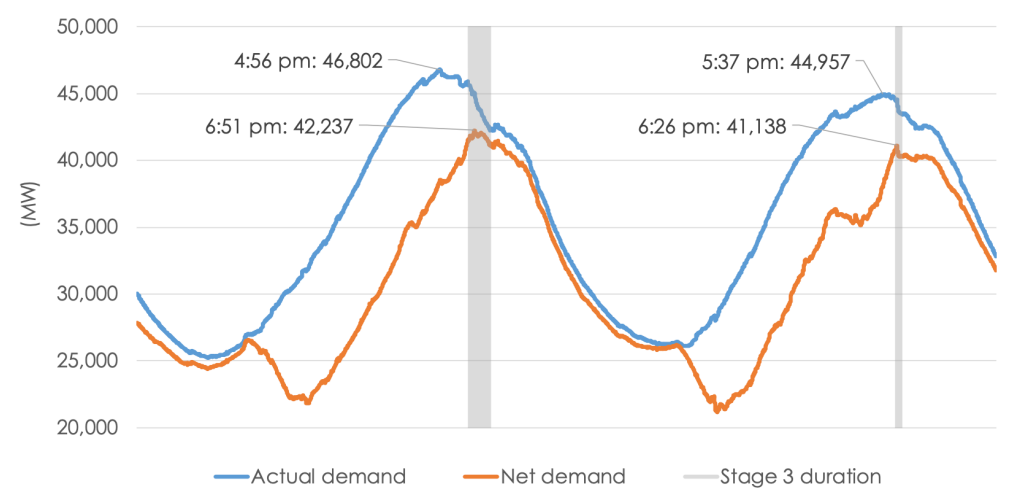
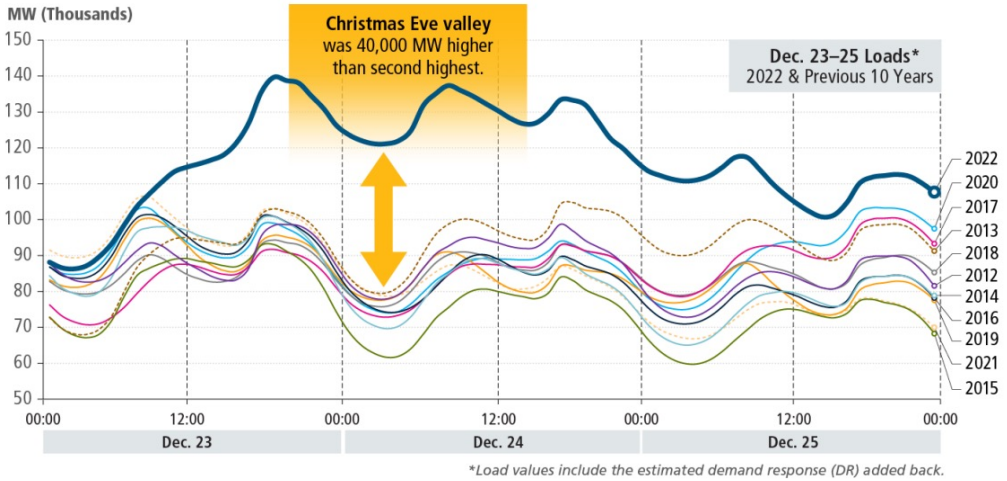
Many regions will become winter peaking. Winter risk tends to be longer duration.

CAISO summer events in 2020



PJM Dec 23-25



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CAISO, Root Cause Analysis Mid-Aug 2020 Extreme Heat Wave, 2021; PJM, Winter Storm Elliott Event Analysis and Recommendations, 2023.

What are the implications on resources? New York example

New York Targets

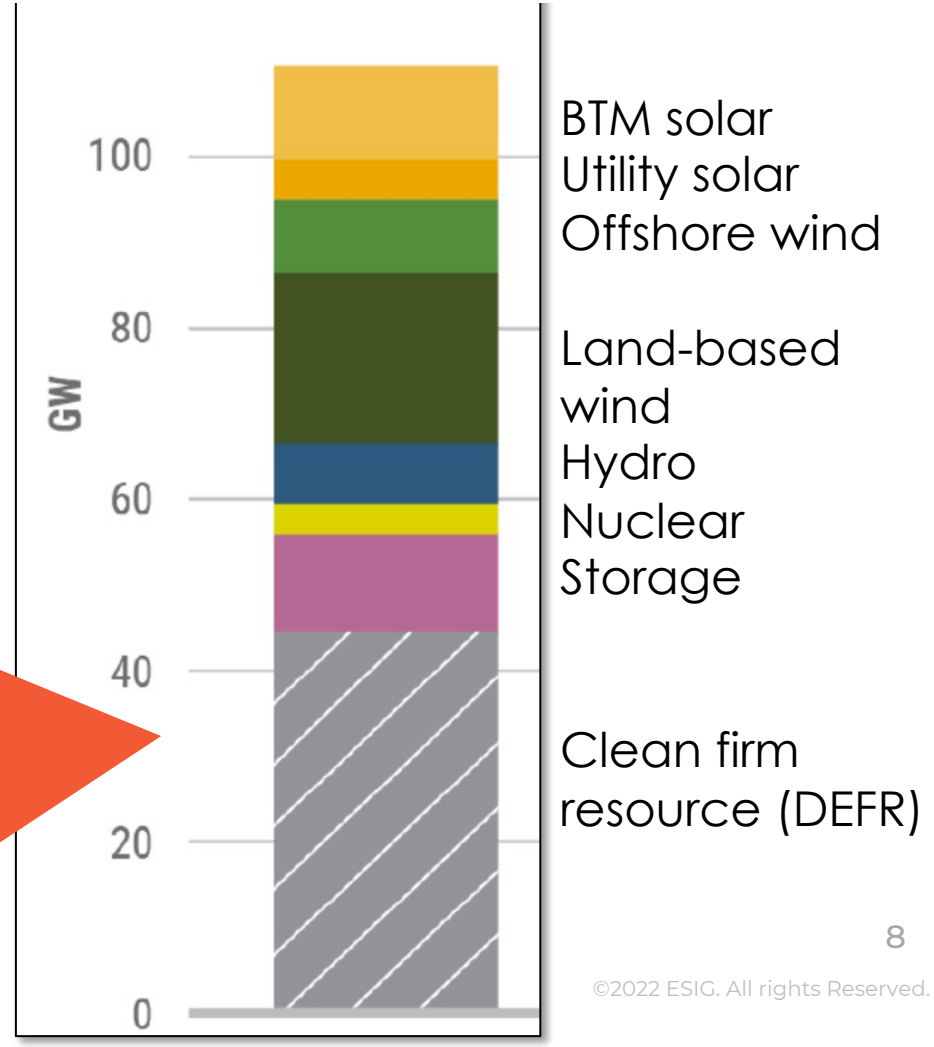
- 70% renewable energy by 2030
- 100% zero emissions by 2040

This scenario uses NYISO load forecasts

- High demand, 57 GW winter peak, 208,679 GWh energy in 2040 (compared to today which is about 30 GW, summer peak)
- Optimal fossil-fueled generator retirements

NYISO Outlook 2021-2040, 2022

New York Independent System Operator zero emissions 2040



If you can't build clean firm, then this 45 GW would be replaced by 30 GW offshore wind + 40 GW storage

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When do you need to build the clean, firm resource?

Installed Capacity (MW)	2019	2025	2030	2035	2040
Nuclear	5,400	3,346	3,364	3,364	3,364
Fossil	26,262	21,310	21,232	21,234	-
DEFR - HcLo	-	-	-	-	3,812
DEFR - McMo	-	-	-	-	-
DEFR - LcHo	-	-	420	7,053	40,938
Hydro	6,331	6,302	7,537	7,540	7,540
LBW	1,985	3,335	9,086	12,612	19,087
OSW	-	1,826	5,036	9,000	9,000
UPV	32	4,676	4,676	4,676	4,676
BTM-PV	2,116	6,834	10,055	10,828	11,198
Storage	1,405	2,910	4,410	5,793	11,450
Total	43,838	50,763	66,460	89,376	111,066

Need a little in 2030 and 2035 and a lot in 2040

Generation (GWh)	2019	2025	2030	2035	2040
Nuclear	45,429	28,338	27,444	28,338	27,092
Fossil	50,520	54,174	19,987	14,516	-
DEFR - HcLo	-	-	-	-	33,482
DEFR - McMo	-	-	-	-	-
DEFR - LcHo	-	-	-	-	523
Hydro	40,034	36,418	46,342	46,392	46,391
LBW	4,416	8,189	26,971	38,297	59,362
OSW	-	7,331	20,186	35,460	35,647
UPV	51	8,817	8,816	8,817	8,819
BTM-PV	2,761	7,483	11,068	11,983	12,454
Storage	612	4,347	7,004	10,084	21,339
Total Generation	146,262	157,088	169,810	195,879	245,109
RE Generation	47,261	68,238	113,383	140,949	162,672
ZE Generation	93,301	100,922	147,831	179,371	245,109
Load	151,386	152,336	162,122	184,836	221,828
Load+Charge	151,773	157,089	169,811	195,879	245,109
% RE [RE/Load]	31%	45%	70%	76%	73%
% ZE [ZE/(Load+Charge)]	61%	64%	87%	92%	100%

But it doesn't run until 2040

Mostly deployed in NYC and Long Island for load and reserve margin

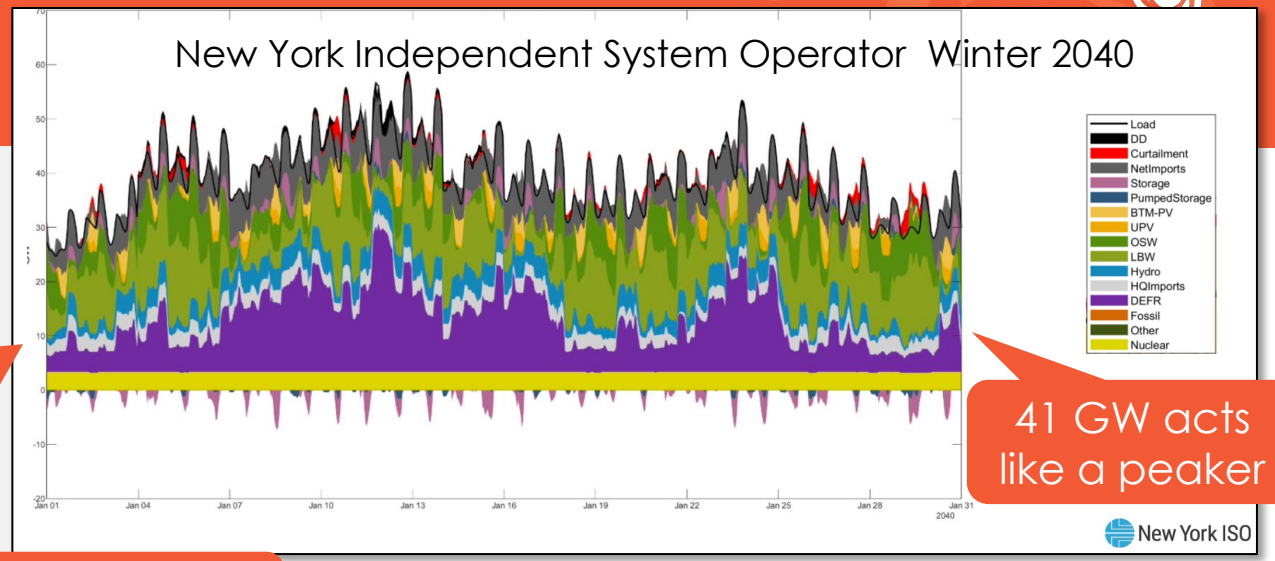
NYISO Outlook 2021-2040 Appendix F, 2022

How does this change with clean, firm resource type?

Defines 3 clean, firm resource types:

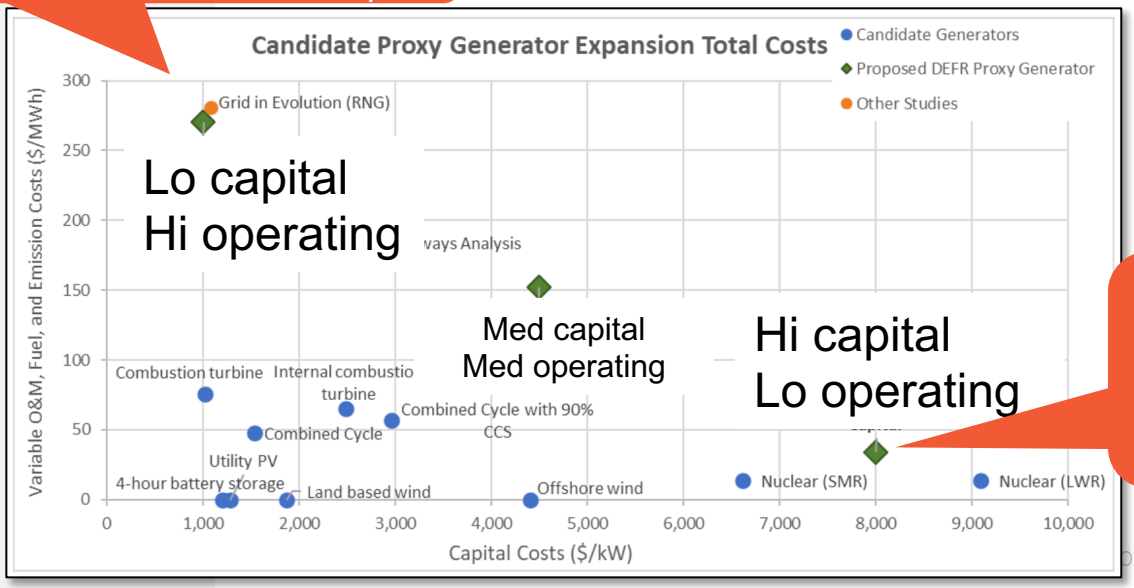
- Low capital, high operating cost: Needs a little in 2030, grows to 41 GW by 2040; hardly ever runs; rare capacity events; runtime 3-10 hours
- High capital, low operating cost: Doesn't need until 2040 and then only 4 GW; operates baseloaded in summer and winter with near 100% capacity factor; overall runtime averages ~ 50 hours
- Medium capital, medium operating cost: Does not need at all

4 GW clean, firm acts base-loaded



41 GW acts like a peaker

Builds a lot of this to sit around on standby



Builds a little of this as baseload for winter/summer

NYISO Outlook 2021-2040 Appendix F, 2022

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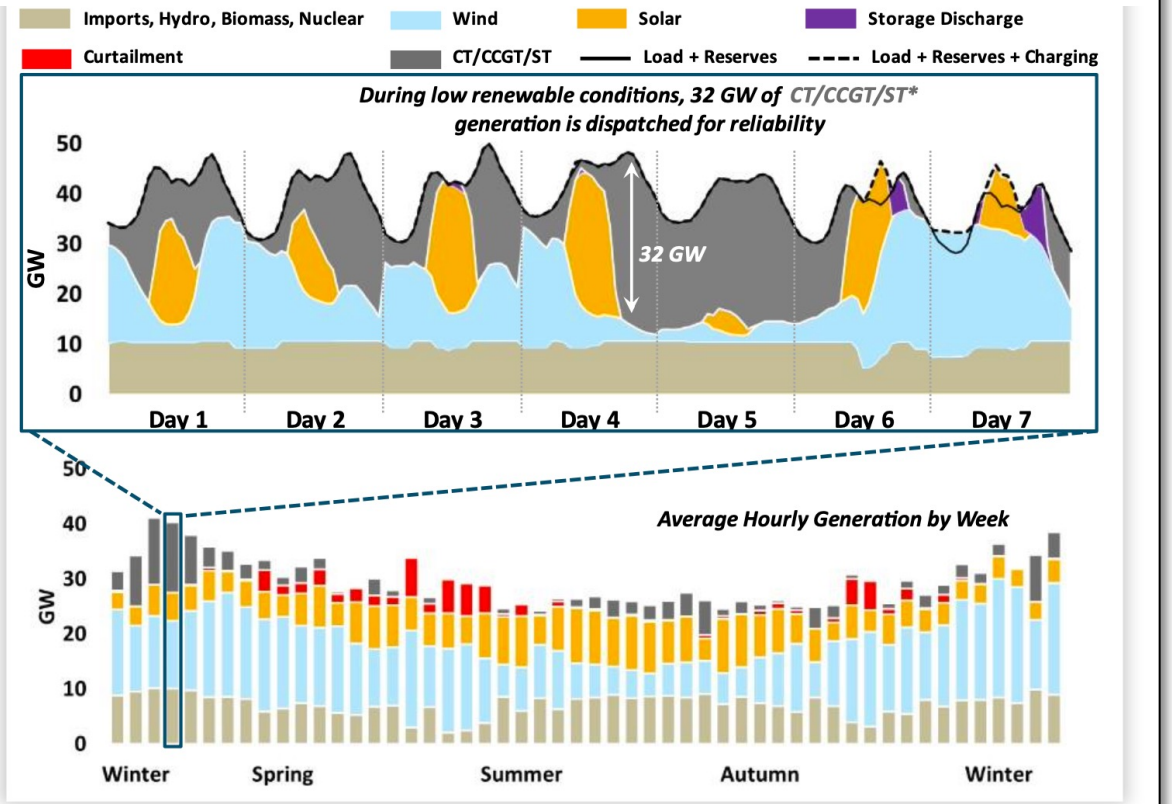
Clean, firm resource vs batteries
New England example

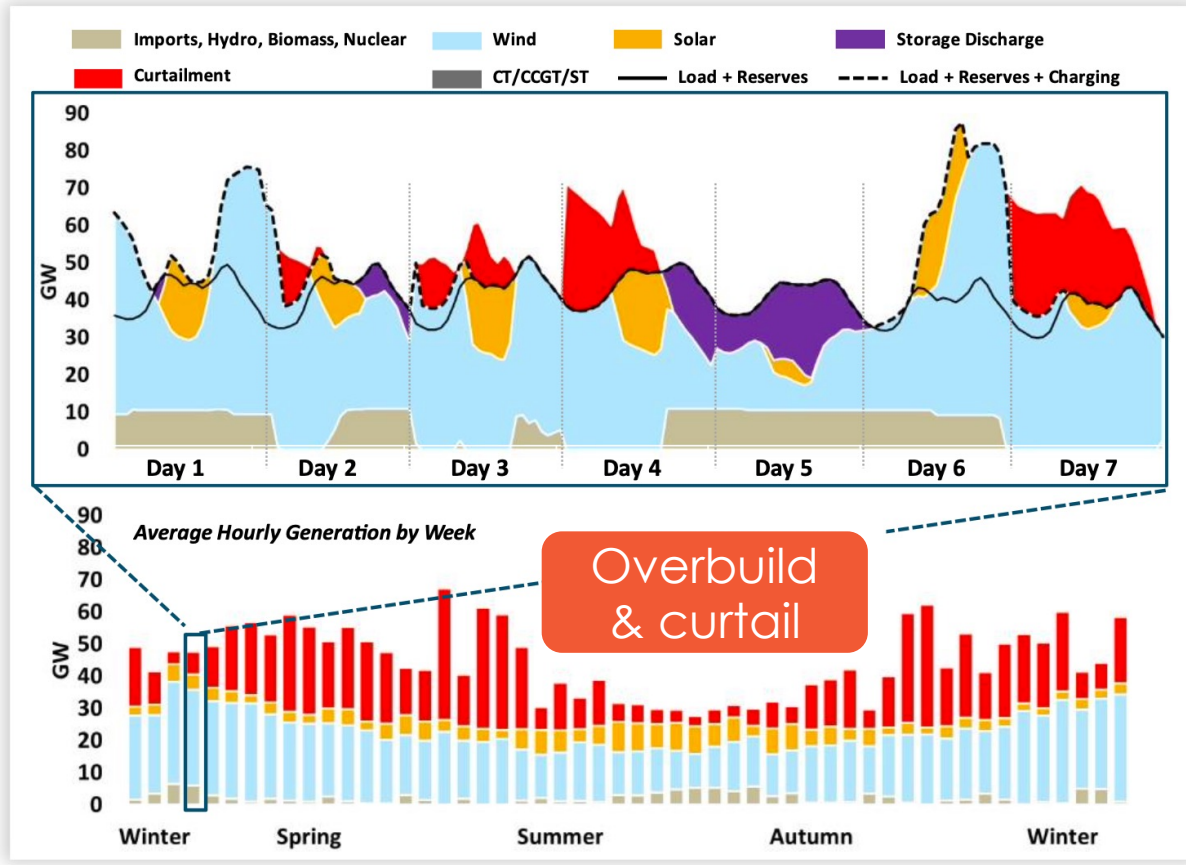
High electrification Scenario; 92% and 100% emissions reductions for 2050

Clean, firm resource



*Note: * CT/CCGT/ST could represent natural gas with or without CCS, hydrogen or other zero-carbon fuels burned in CT/CCGT, advanced nuclear or long duration storage.*

Today's batteries



E3, New England Reliability under Deep Decarbonization, 2020

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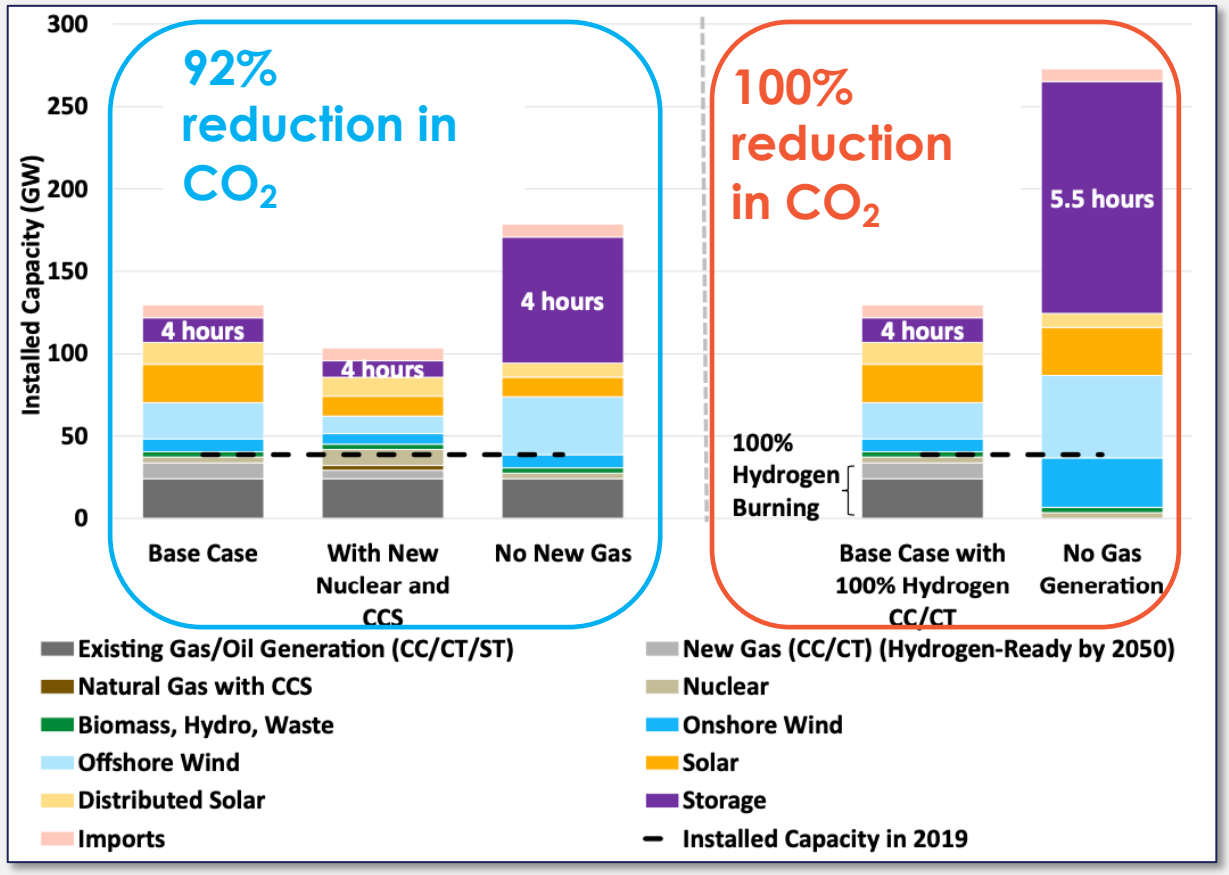
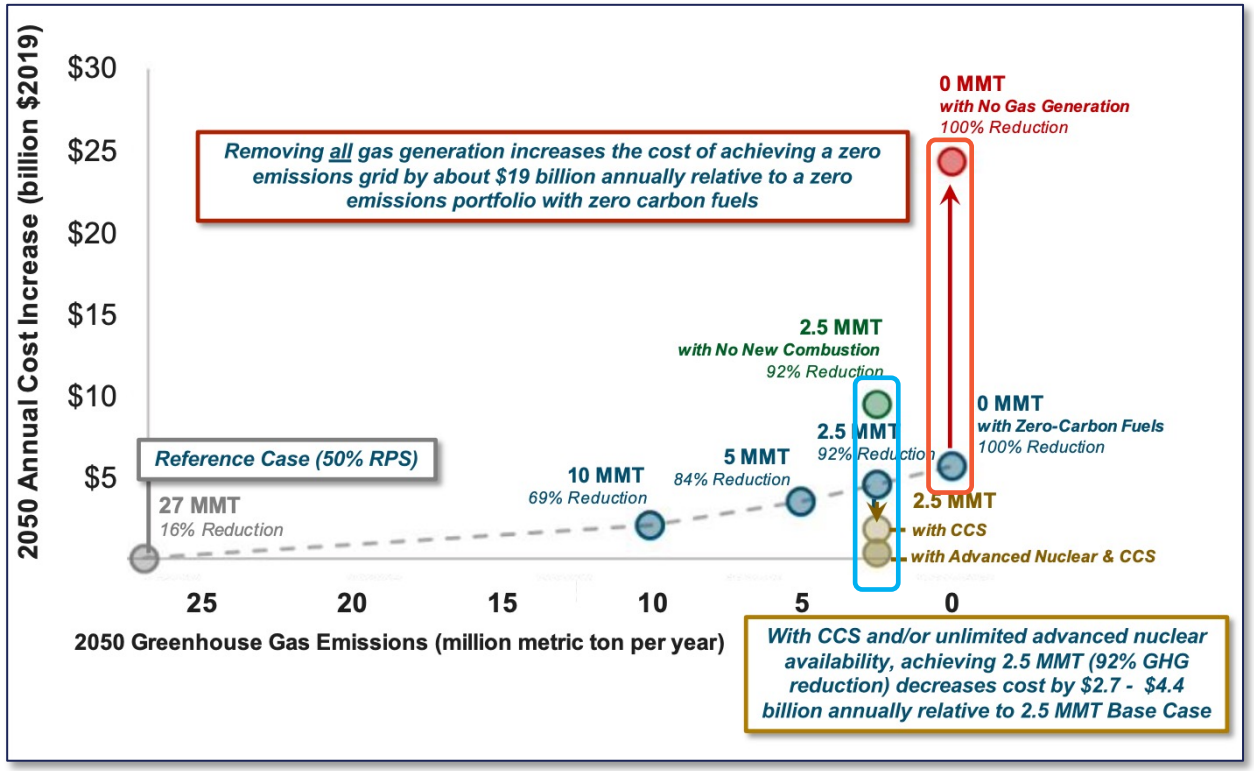
You can do it without clean, firm resources but it'll cost you



If we can't develop clean, firm resources is it worth it to go to zero emissions in the electricity sector?

E3, New England Reliability under Deep Decarbonization, 2020



What would we need to do to keep existing gas plants (and perhaps build more) but rarely run them?

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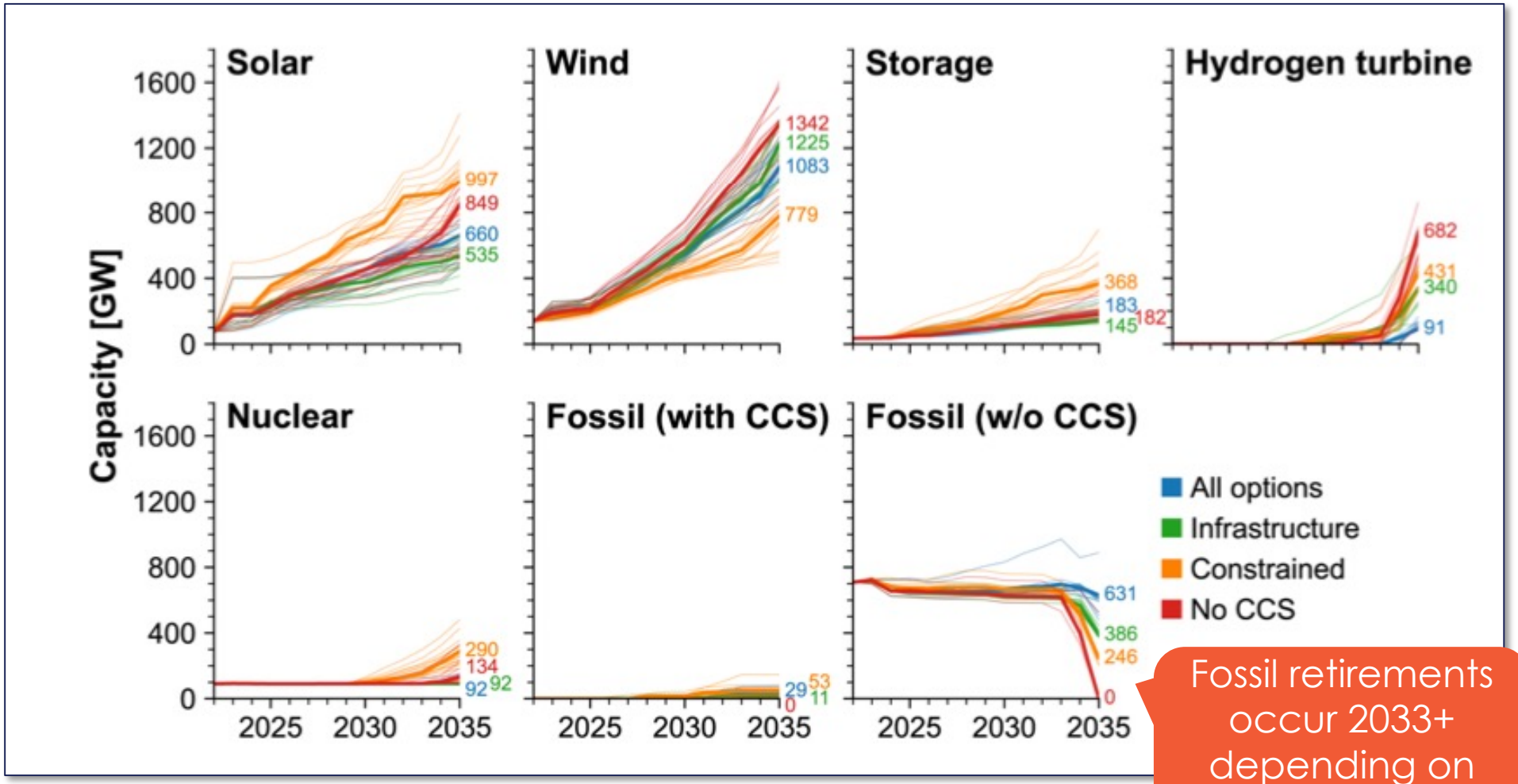
Should we be focusing on retiring fossil plants as soon as possible?



We install huge amounts of wind/solar for the next decade to provide energy to offset fossil generation. In the 2030's we focus on resources that contribute to resource adequacy to shut down (or refuel) fossil generators.

Fossil retirements occur 2033+ depending on CCS

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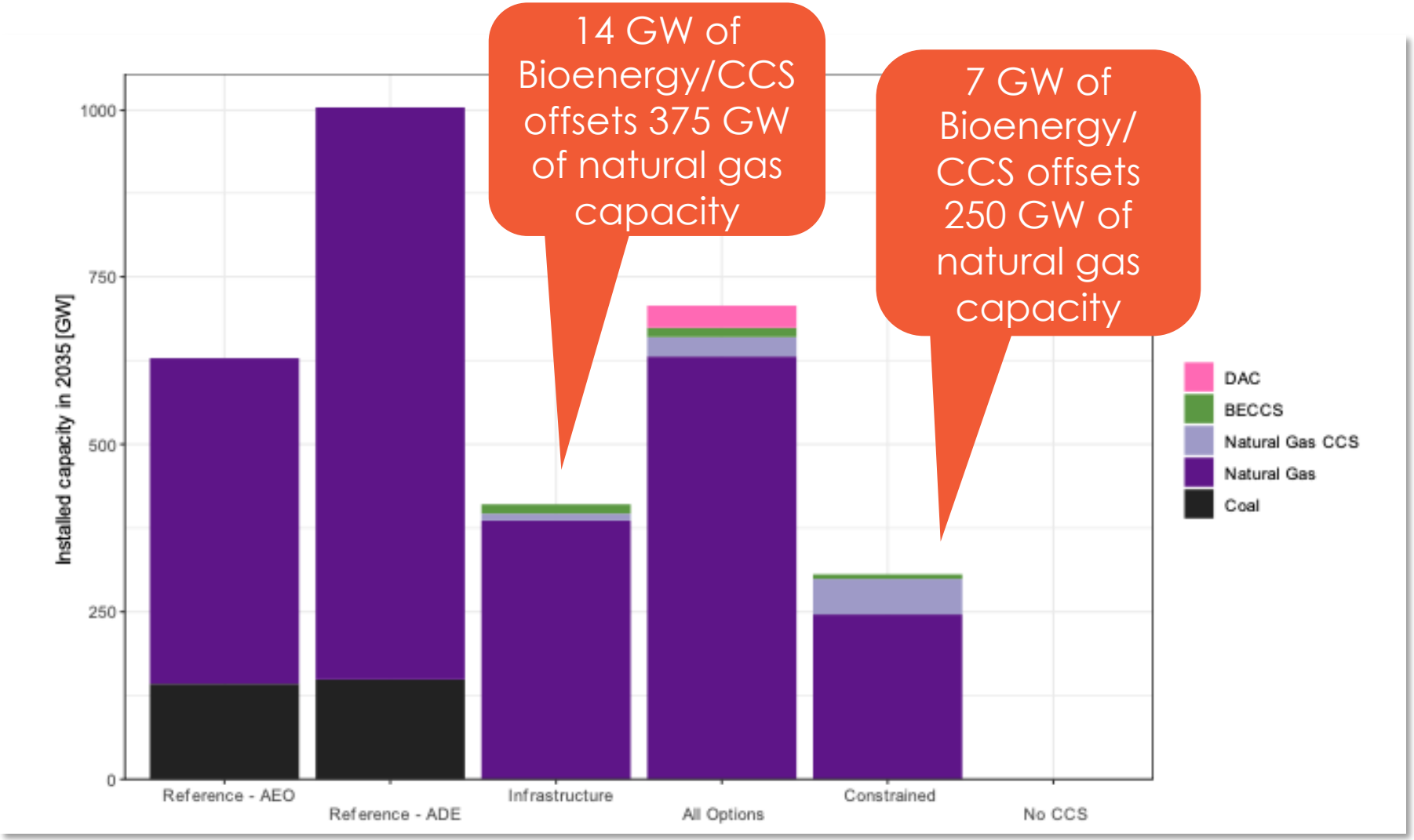
Denholm et al, "Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035", 2022

Low amounts of negative emissions resources can offset much larger gas capacity



Denholm et al, "Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035", 2022

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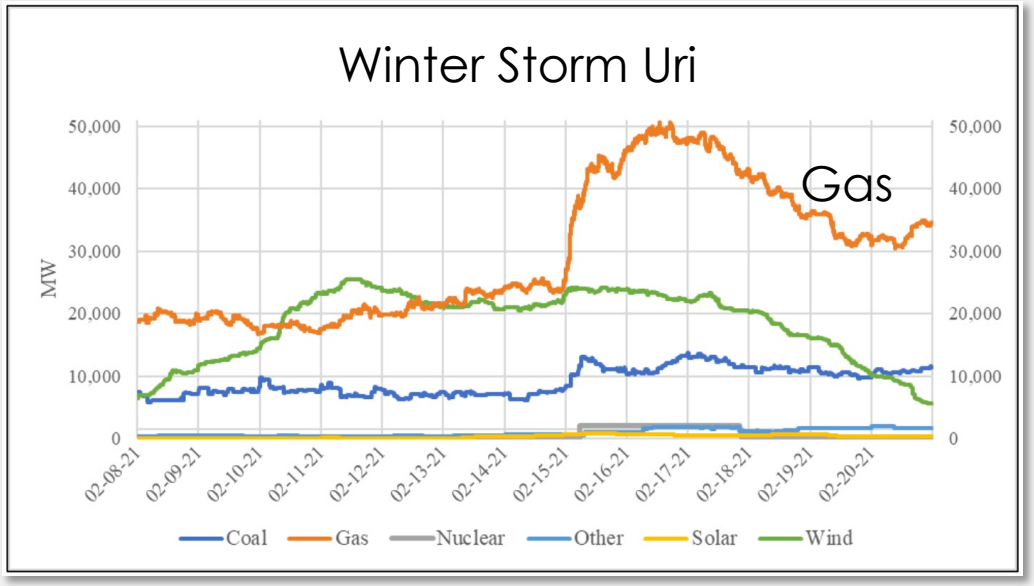
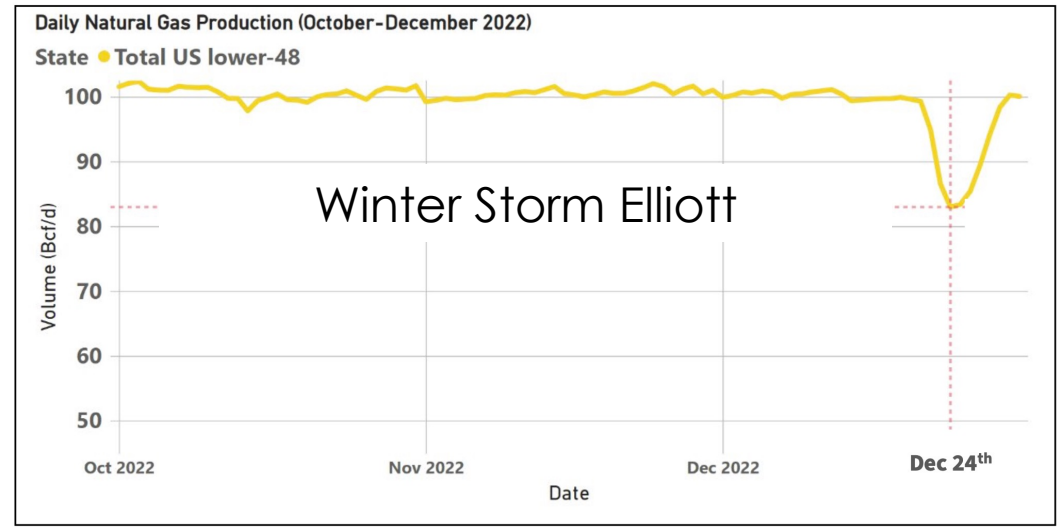
How firm are gas plants and gas supply?



The 90,500 MW of coincident unplanned outages during Elliott = 13% of US anticipated resources in the EI



(Source: S&P Global Commodity Insights)

"5th event in 11 years in which unplanned cold weather-related generation outages jeopardized bulk power system reliability"

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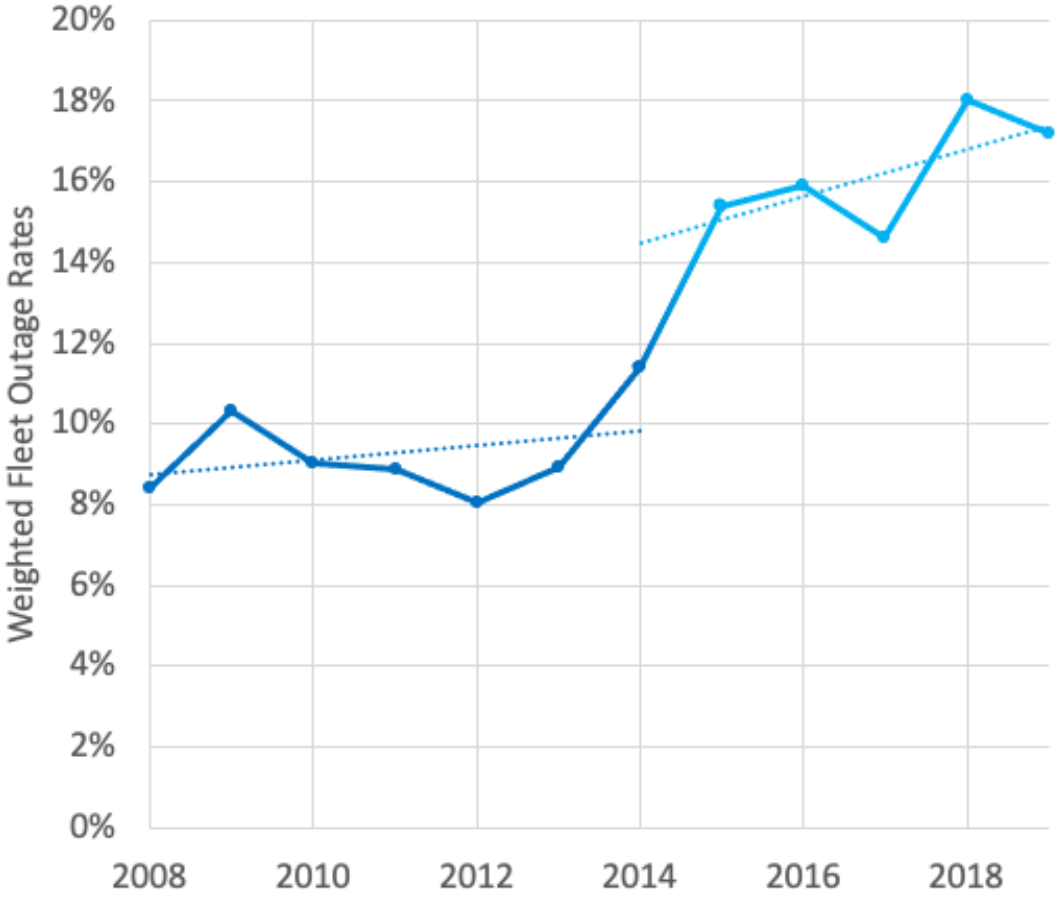
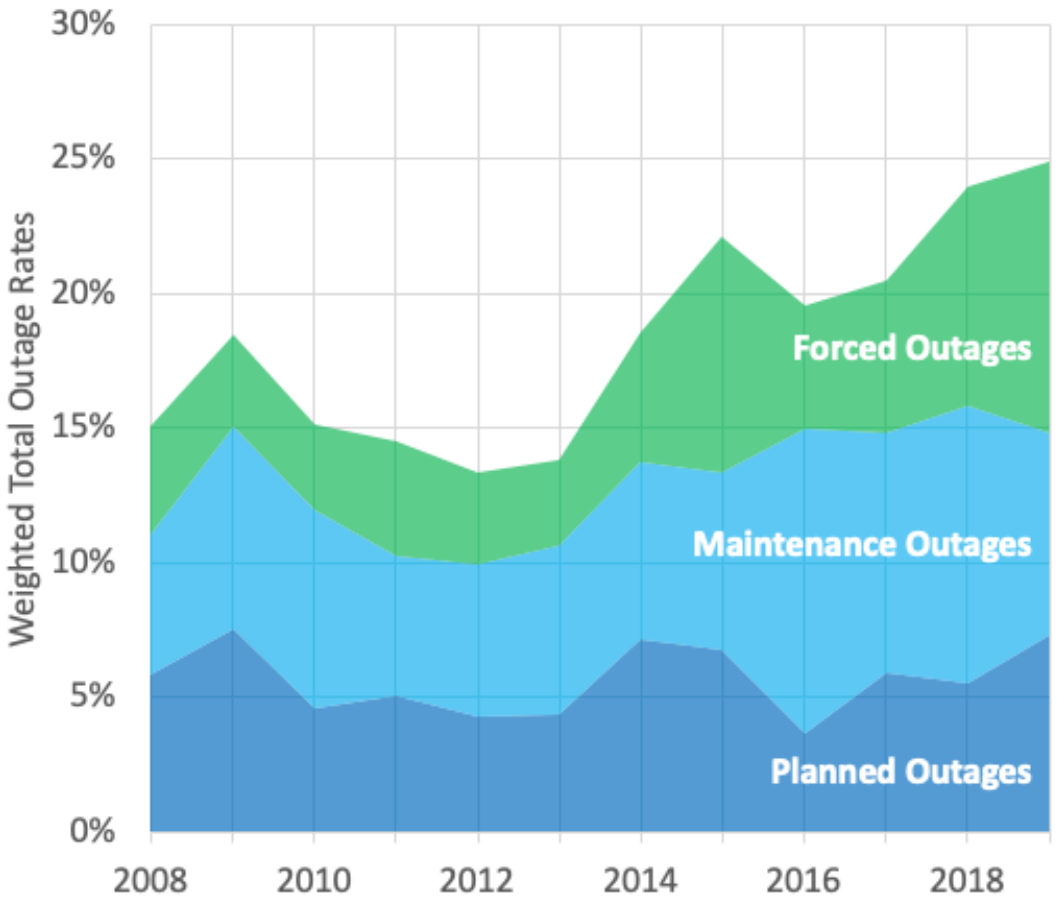
NERC/FERC Cold Weather Report Nov 2021; NERC/FERC, Dec 2022 Winter Storm Elliott Grid Operations Key Findings and Recommendations, 9/21/23

Increased age, cycling and environmental compliance can reduce thermal unit reliability





D. Stenclik, Telos Energy, Hawaii Pathways to 100%, July 2022

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Forecast errors may drive the need to dispatch 'firm' resources. Can gas respond?

Forecast errors also contributed to 2011, 2018, 2021 cold weather events

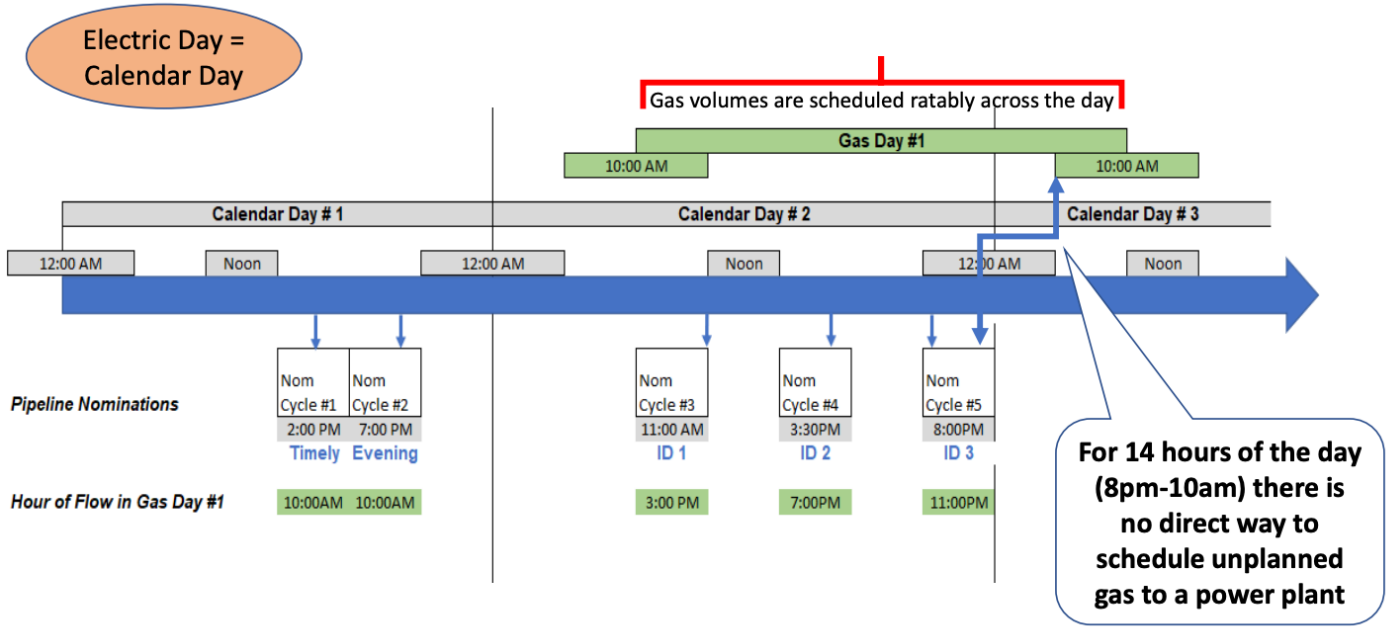
Electricity Demands Exceeded Grid Operators' Forecasts

- The majority of the BAs' short-range forecasts of peak electricity demands underestimated load on December 23 and December 24.*
- One BA's underestimation was as much as **11.6%** for their "Day-Ahead" forecast for December 23.
- Two BAs' underestimations were as much as **5.0%** for their "Day-Ahead" forecasts for the December 24.

	Peak Load Forecasts for Friday, December 23 Underestimation		Peak Load Forecasts for Saturday, December 24 Underestimation	
Forecasts Produced ->	2 Days-Ahead	Day-Ahead*	2 Days-Ahead	Day-Ahead*
Total Load Forecast Underestimation (MW) for Grid Entities' Footprints Combined	23,047	17,773	13,316	10,033
Average Percent Forecast Underestimation for Core Entity Footprints Combined	8.8%	6.8%	5.1%	3.9%

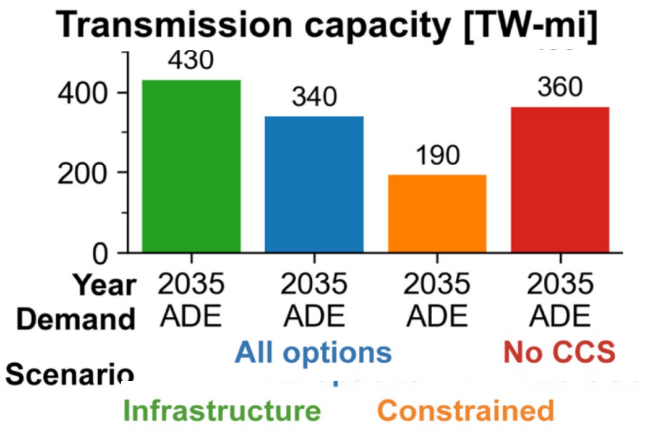
Coordination issues begin with mismatched scheduling days

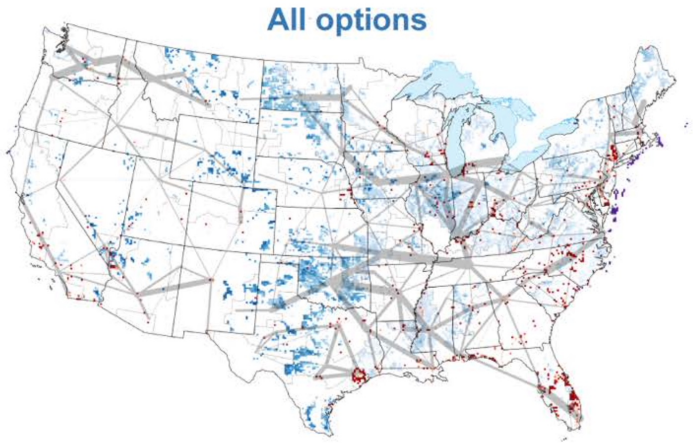
Gas Day vs. Electric Day

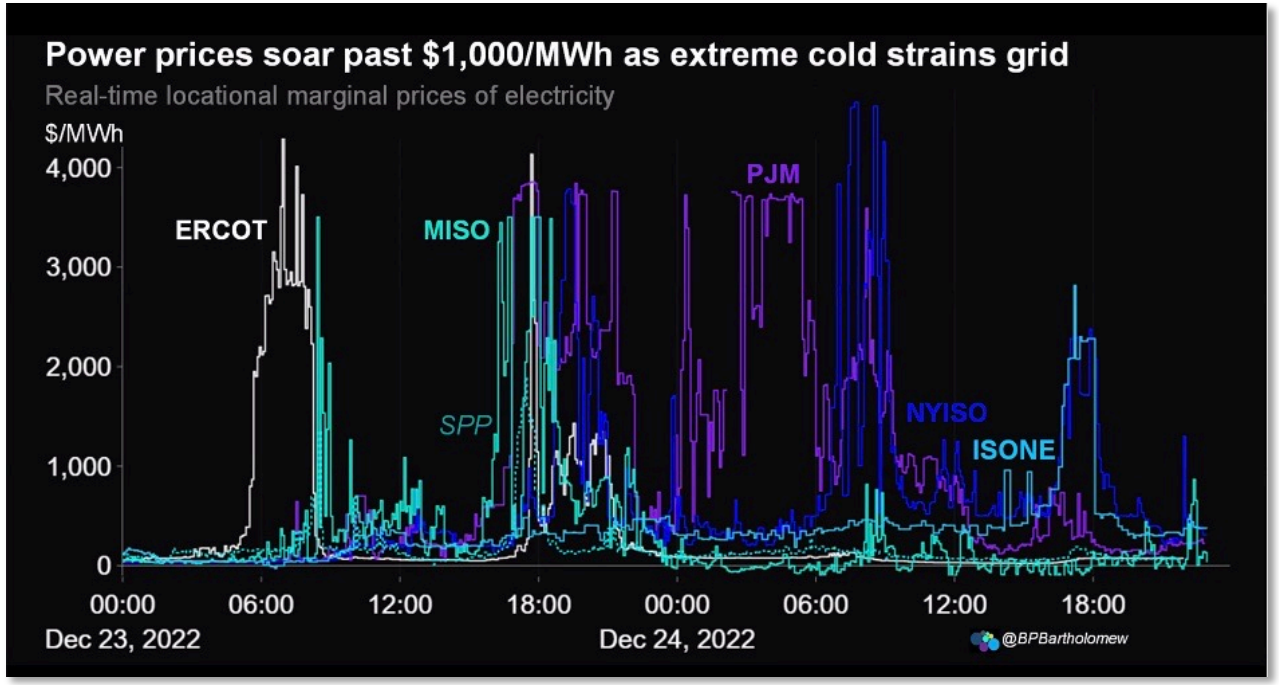


NERC/FERC, Dec 2022 Winter Storm Elliott Grid Operations Key Findings and Recommendations, 9/21/23; Dominion Energy, PJM Gas Electric Coordination Task Force, 11/5/21

Transmission is a key part of the solution







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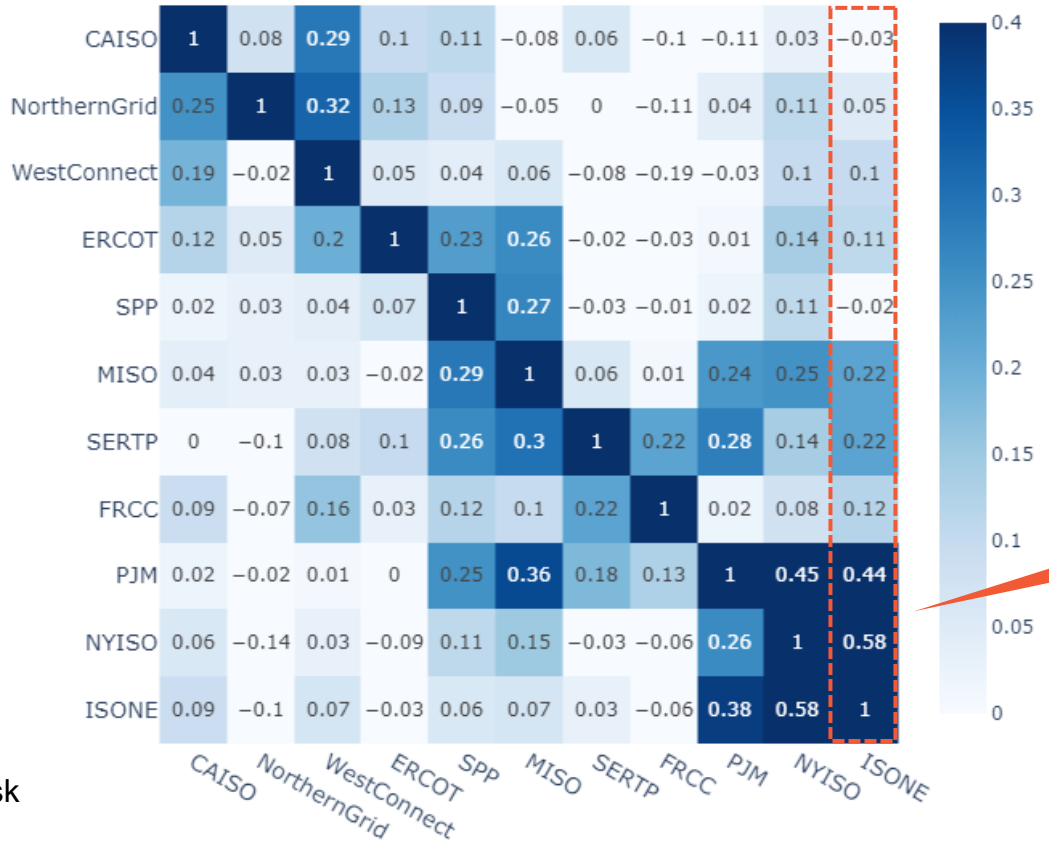
Denholm et al, "Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035", 2022

B. Bartholomew, ESIG Resilience and Transmission Task Force, Jan 2023

ISONE may need to look beyond immediate neighbors

Correlation Visualizations: Used to inform the correlation between regional periods of high stress (low margin) across many years of timeseries data and can be used to focus on low margin periods (encapsulates load, resource, and weather diversity)

Bottom 1400 Margin Hours Correlation by FERC 1000 Region (Lowest 2.2% of Margin Hours)



For transmission to provide resilience in a weather dependent system, geographic distance is key.

During ISONE's most stressful hours, NYISO is also likely to be stressed. Even PJM has a reasonable chance of being stressed.

Preliminary results from ESIG's Resilience and Transmission Task Force

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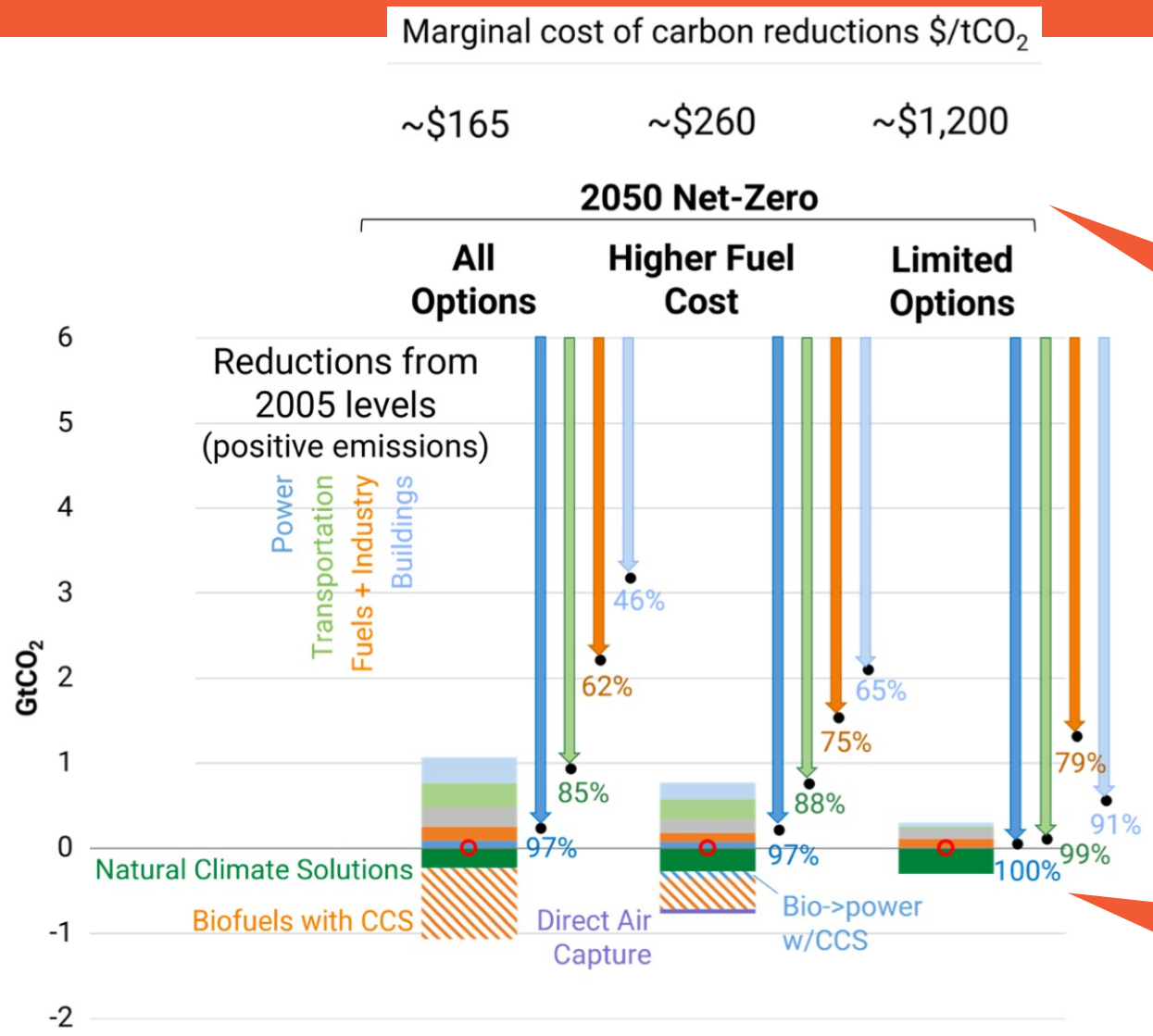
Achieving ***zero*** emissions from electricity may not be the cheapest way to reduce carbon



Limited options case: no CCS/DAC; limited bioenergy

Marginal cost of carbon is 7x higher in this case

This case has zero emissions from electricity

EPRI LCRI Net Zero 2050, Mar. 9, 2023

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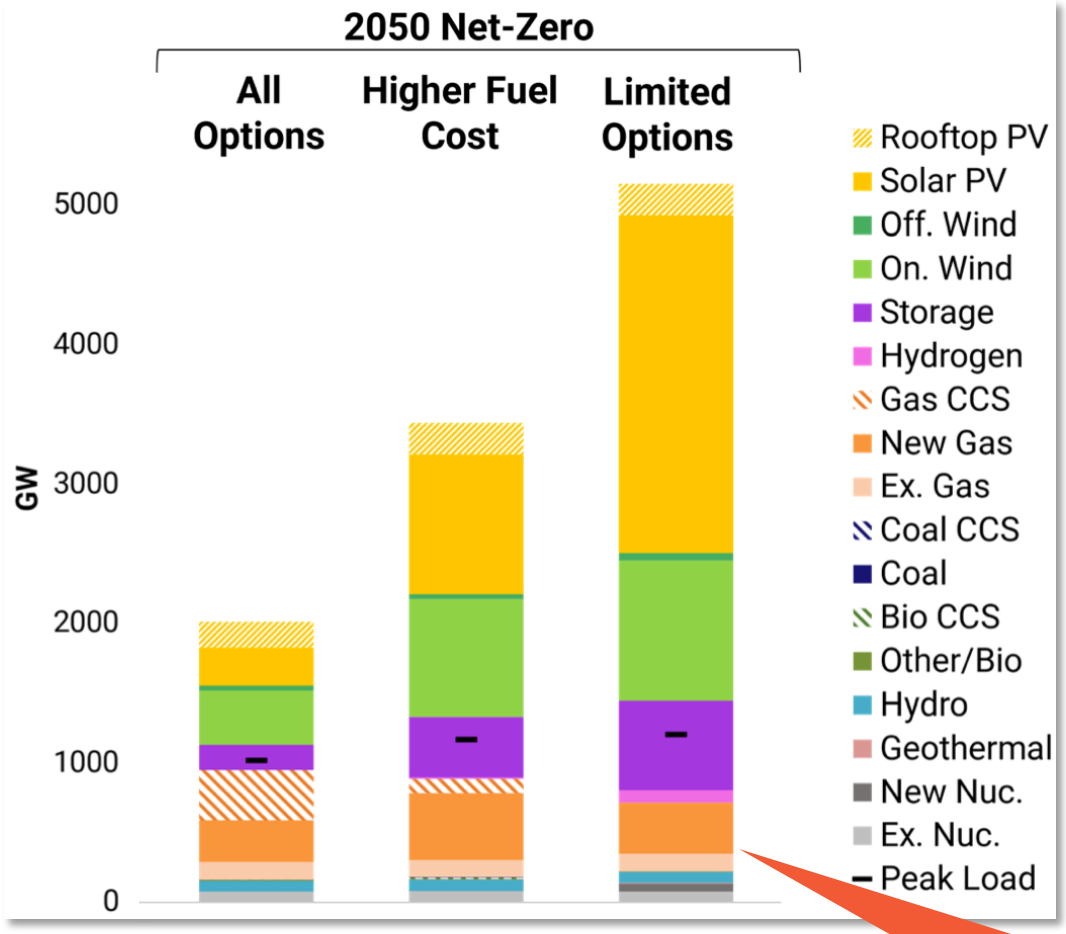
Installed capacity is 2-5x higher



This gas is mostly renewable and synthetic natural gas

EPRI LCRI Net Zero 2050, Mar. 9, 2023

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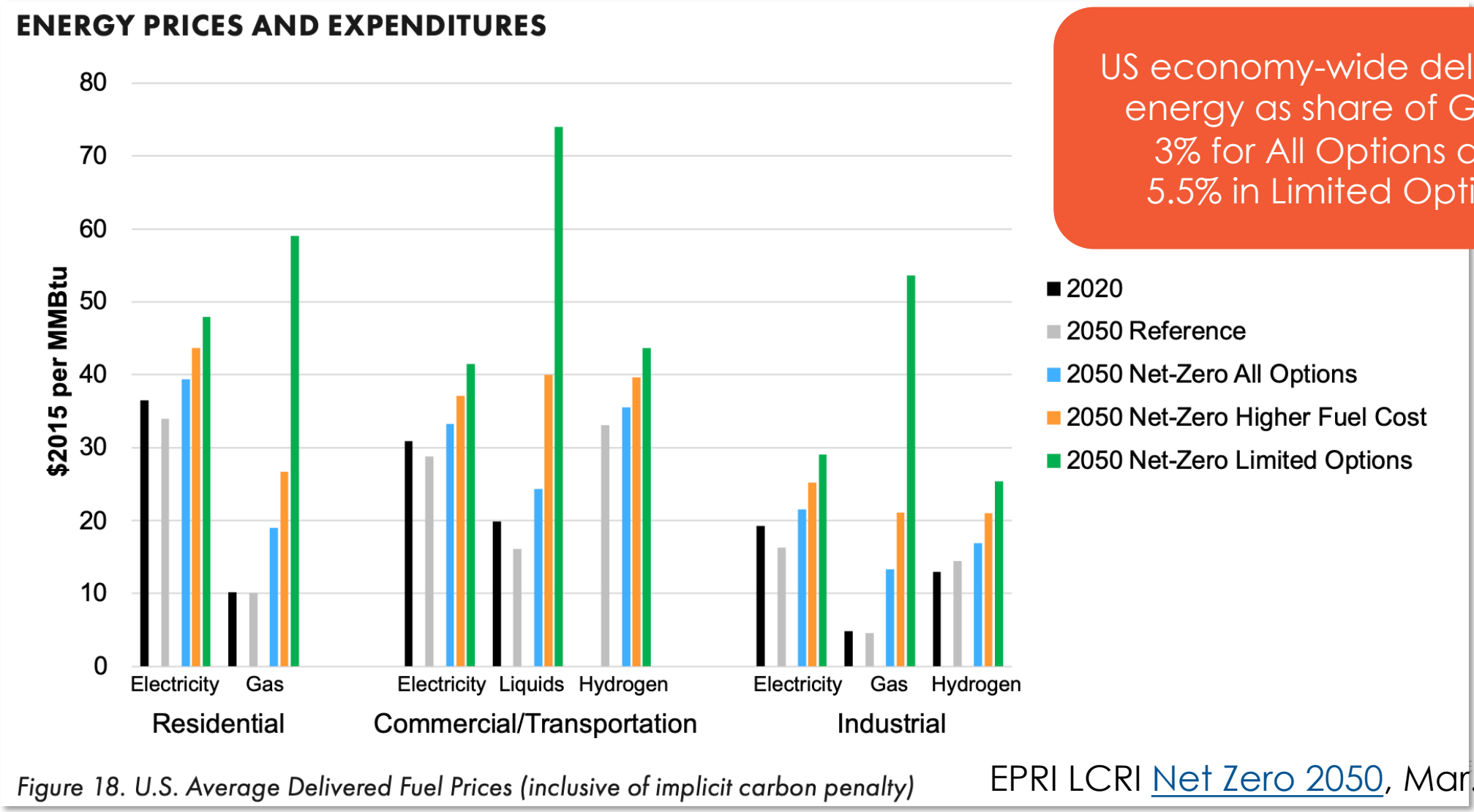
Cost of electricity, gas, liquids, hydrogen are highest when you limit your options



US economy-wide delivered energy as share of GDP is 3% for All Options and 5.5% in Limited Options

Figure 18. U.S. Average Delivered Fuel Prices (inclusive of implicit carbon penalty)

EPRI LCRI Net Zero 2050, Mar. 9, 2023

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Parting thoughts

- The more you constrain the solution, the more expensive it becomes.
- Is 100% clean electricity the right question or should we focus more broadly on decarbonizing energy?
- If you don't have a broader and longer-term perspective, you may make decisions today that reduce your options tomorrow.
- We need transmission that is bigger than weather systems.
- This clean, firm resource:
  - Needs much longer duration than a lithium-ion battery, likely multiple days.
  - Needs high availability of resources/fuel during stressful periods potentially on short notice
  - Needs to be capable of being rarely used but when it is run, it's run a lot and for days.
  - Do we need to adjust market design to keep a 'firm' resource sitting around for resource adequacy but hardly ever run it? Note potentially increased wear-and-tear due to cycling of the resource.
- If gas is used as the pathway (with ultimate transition to CCS or hydrogen) we have a lot of work to do! We need better gas/electric market coordination. We need better understanding and incorporation of correlated gas unit outages. How can we make it 'firm'? Do we need more gas storage?
- Did not focus here, but demand flexibility and distribution management are essential parts of the solution.

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THANK YOU

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