Getting to Zero

Can America Transition to a Net-Zero Emissions Energy System?

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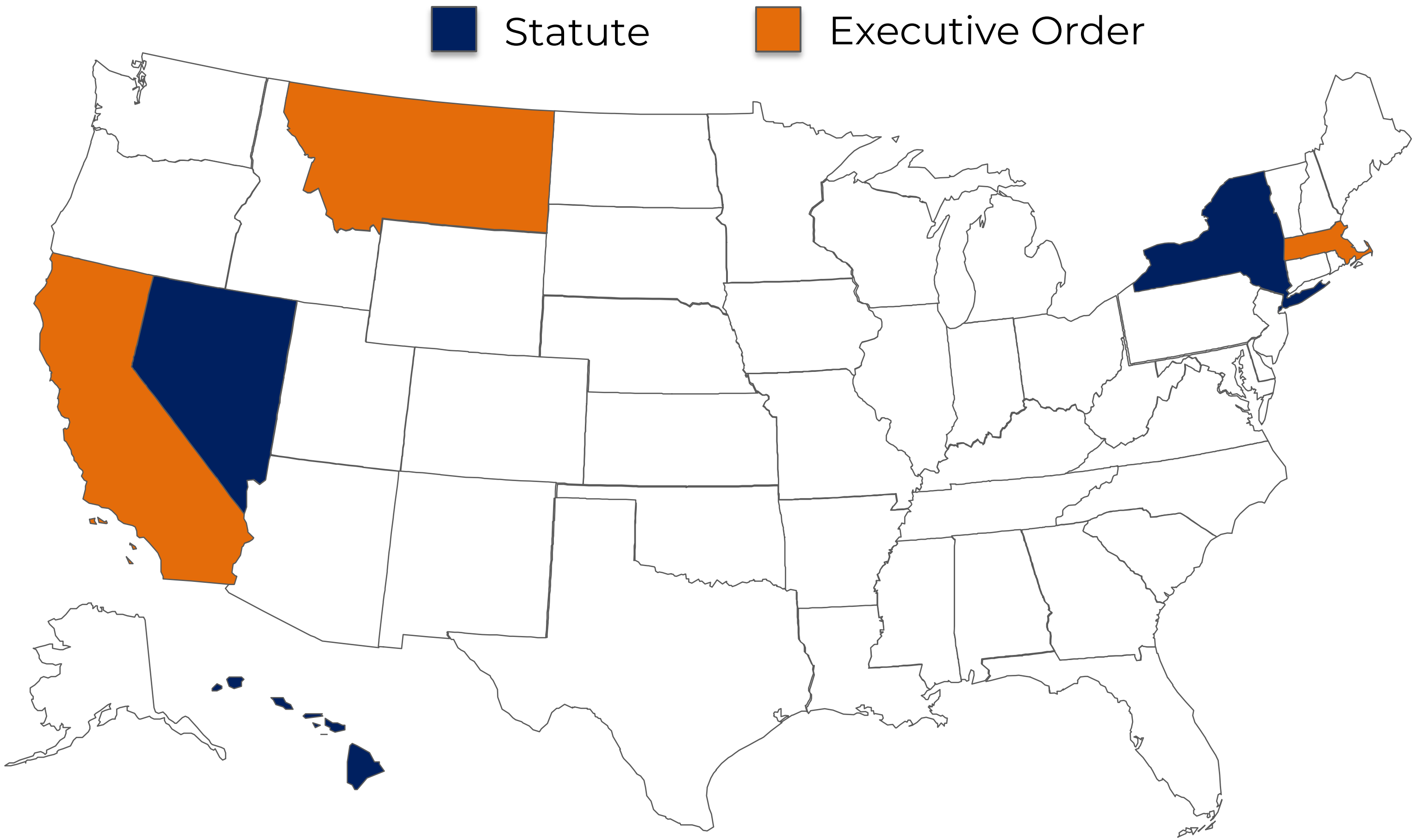
1. Why Net-Zero?

States committed to net-zero emissions



Last updated February 8, 2020. Source: http://www.usclimatealliance.org/state-climate-energy-policies

Utility DIVE

BRIEF **November 22, 2019**

Democrats move to take 100% clean energy push national with new bill

Credit: Getty

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Dive Brief:

- Democrats introduced new legislation Thursday to adopt a 100% clean energy economy goal nationwide by 2050.
- The bill, introduced by Rep. Donald McEachin, D, with more than 150 co-sponsors, would require all sectors of the economy to achieve net-zero greenhouse gas emissions by the middle of the century. Federal agencies

Roll Call

House Democrats offer plan for zero carbon emissions by 2050

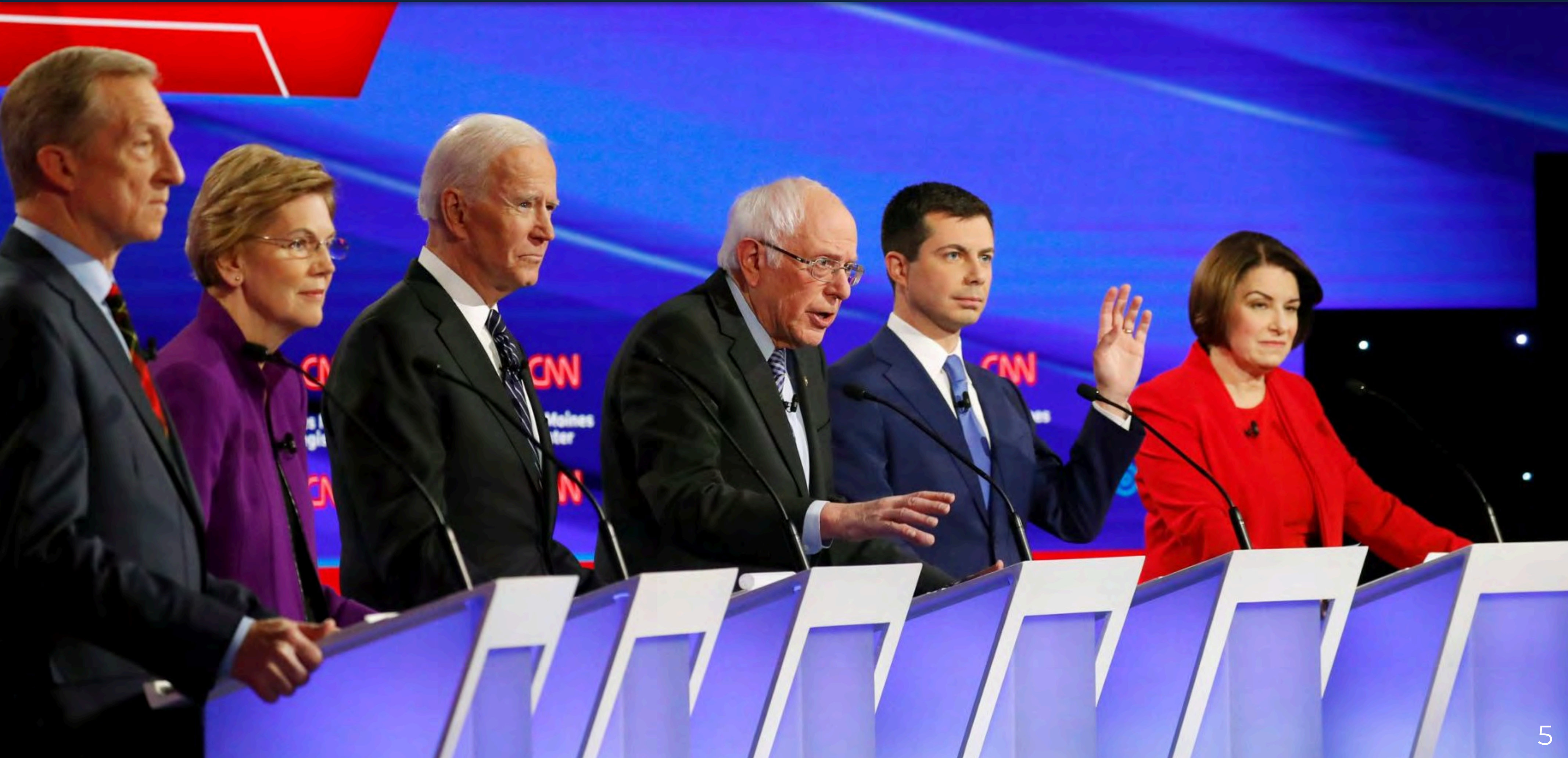
Republicans promise a plan of their own, but it's unlikely to reach zero-carbon goal

January 28, 2020

Energy and Commerce Chairman Frank Pallone Jr., D-N.J., talks with reporters after a meeting of the House Democratic Caucus. (Tom Williams/CQ Roll Call file photo)

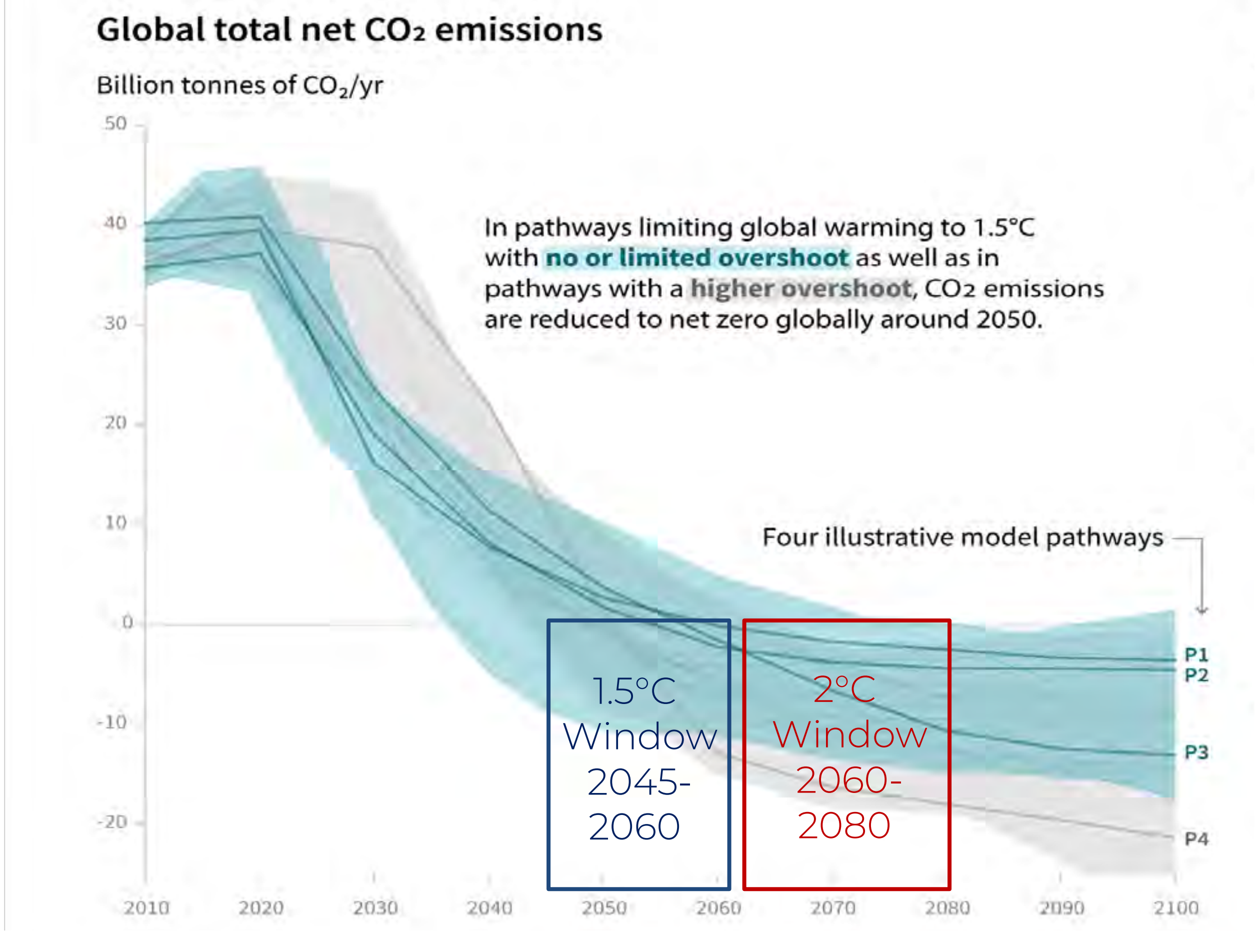
House Energy and Commerce Democratic leaders unveiled a draft climate bill aimed at decarbonizing the U.S. economy by 2050, even as House Republicans expect to release their own plan in coming weeks.

All committed to net-zero by 2050 (at the latest)



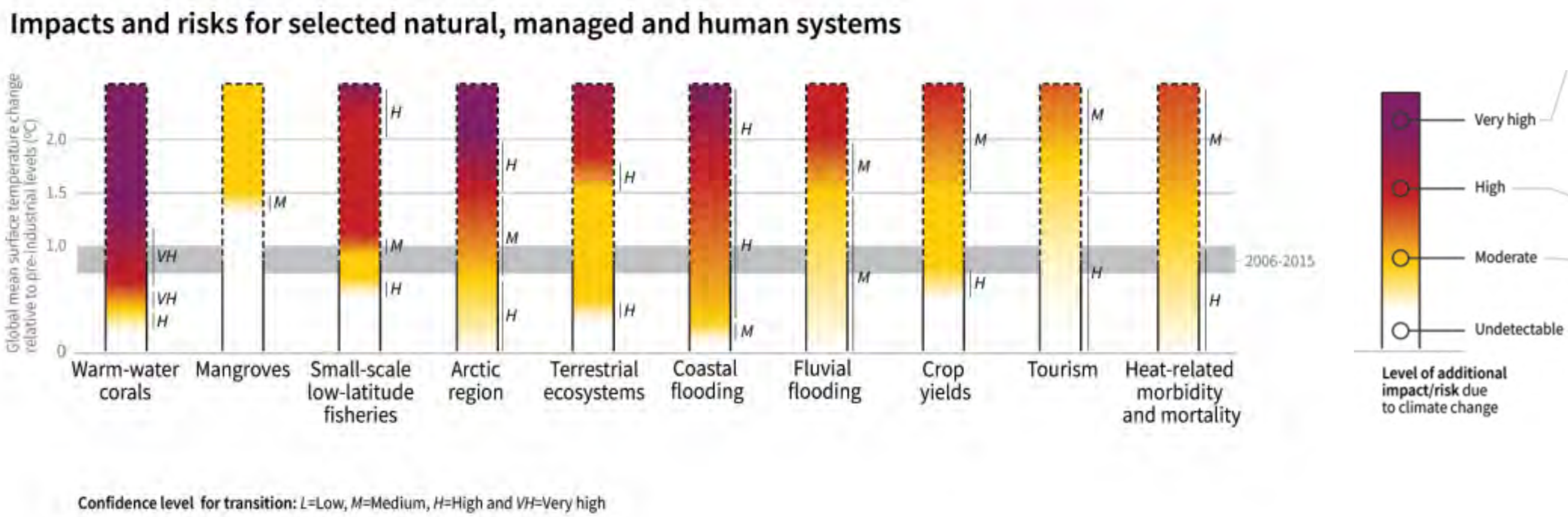
October, 2018

Getting to zero: the Decarbonization Challenge



Source: IPCC (2018) Special Report on Global Warming 1.5°C

Every tenth of a degree matters!



Source: IPCC (2018) Special Report on Global Warming 1.5°C

America should lead, not follow

2. Decarbonizing the United States

The *Net-Zero America* Study (A Sneak Peak)

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PRINCETON UNIVERSITY

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CMI

With Steve Pacala, Rob Socolow, Bob Williams, Erin Mayfield, Andrew Pascale, Chuan Zhang, Rick Duke (Gigaton Strategies), Rich Birdsey (US Forest Service, retired), Keith Paustian (Colorado State University), Emily Leslie (Energy Reflections), and Ryan Jones (Evolved Energy Research).

Funding from CMI-BP, Andlinger-ExxonMobil, Dow, Princeton University

Consultative committee: BP, ExxonMobil, Natural Resources Defense Council, Environmental Defense Fund, the Nature Conservancy, Clean Air Task Force, and others

The time to plan is now!

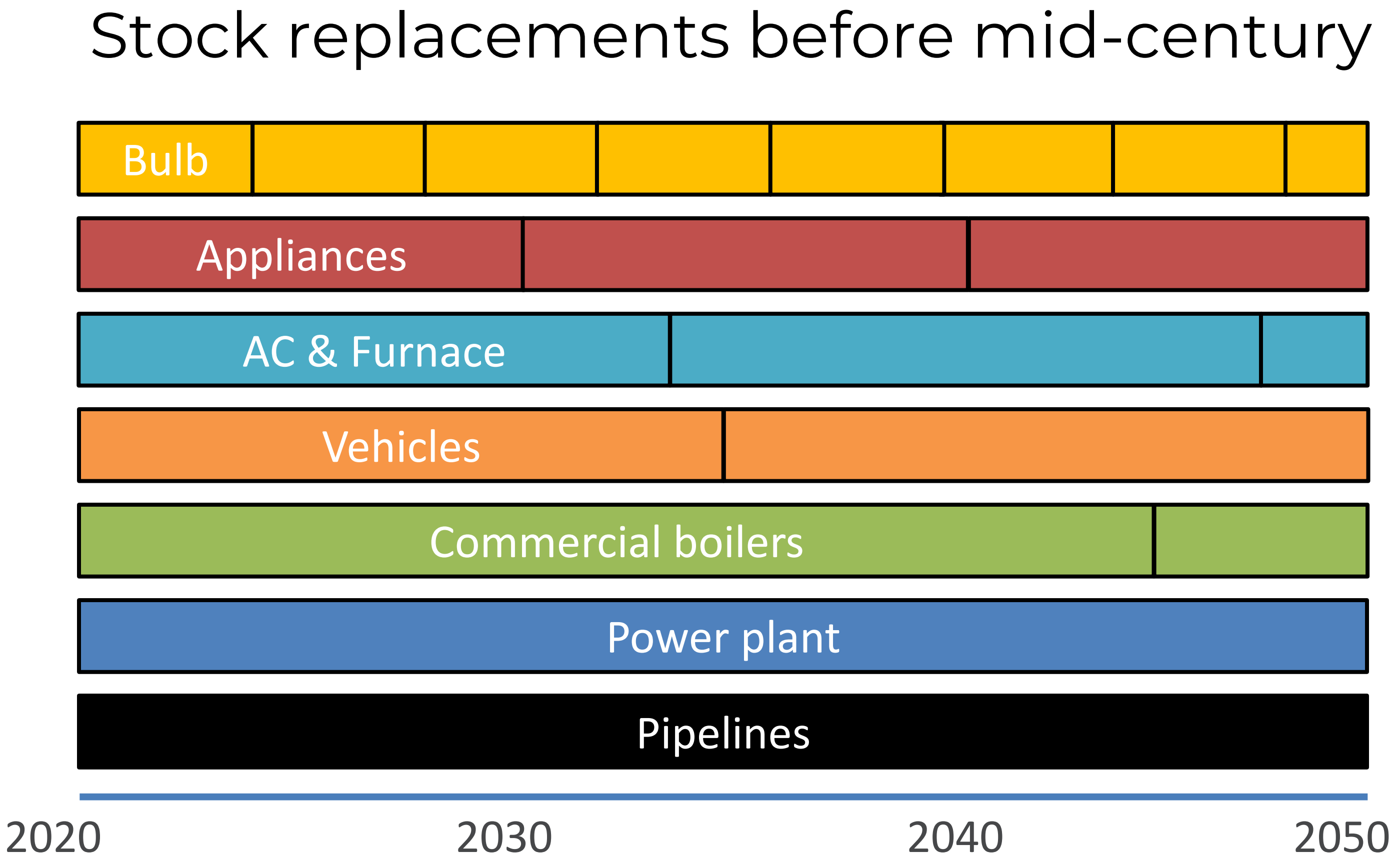
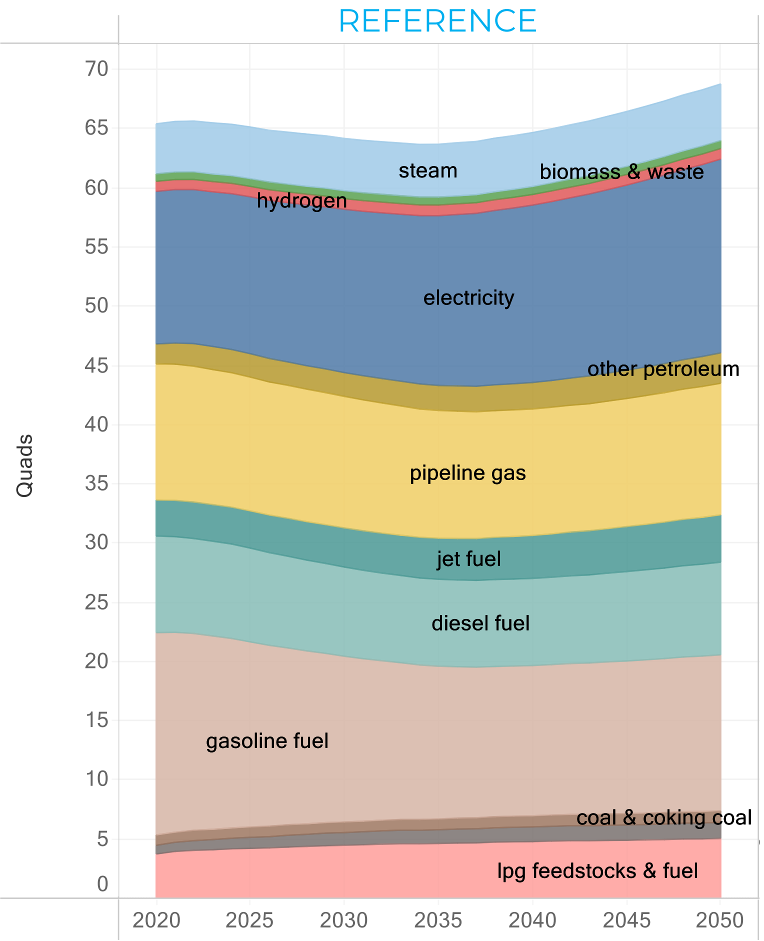
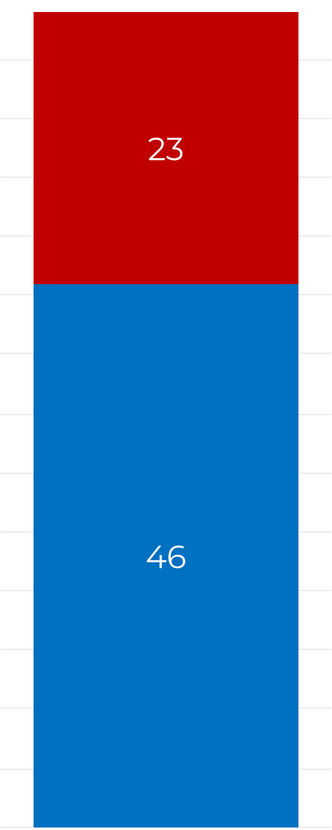


Image credit: Ryan Jones, Evolved Energy Research


DEAD
END

Sizing up the challenge





~23 quads of non-hydrocarbon final energy demands could be satisfied with **zero carbon electricity** (1/3 of total)

~46 quads demand for hydrocarbons (2/3 of total) with the following solutions:

- **Energy productivity (efficiency, mode shifting, conservation)**
- **Electrification of end-uses**
- **Drop-in zero-carbon fuels**
- **Emissions offsetting and continued fossil fuels**

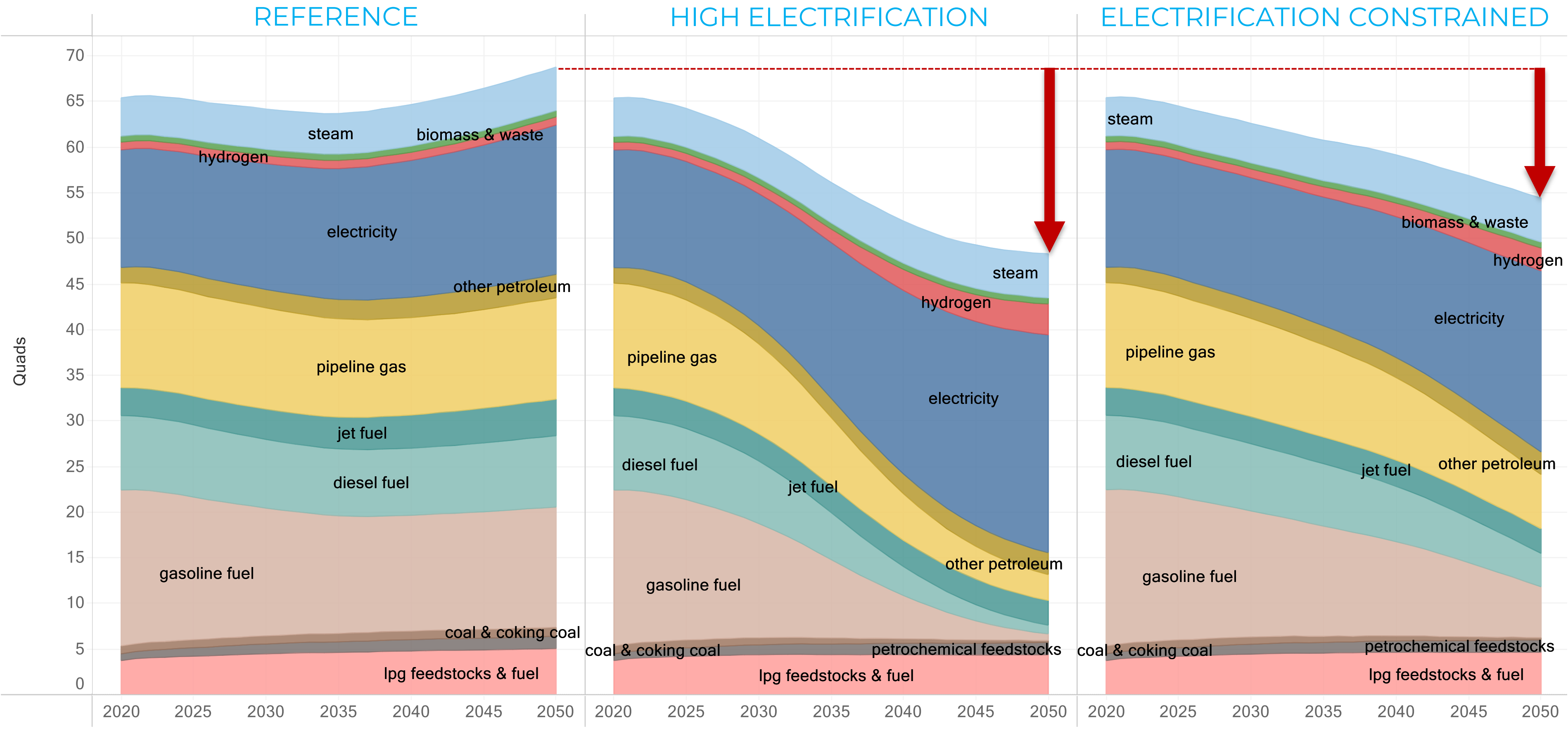
Six Pillars of Decarbonization

1. Energy productivity (efficiency)
2. Electrification
3. Clean electricity
4. Net-zero carbon fuels
5. Carbon capture and sequestration
6. Enhanced land sinks

3. Electricity: the linchpin

Energy productivity + Electrification

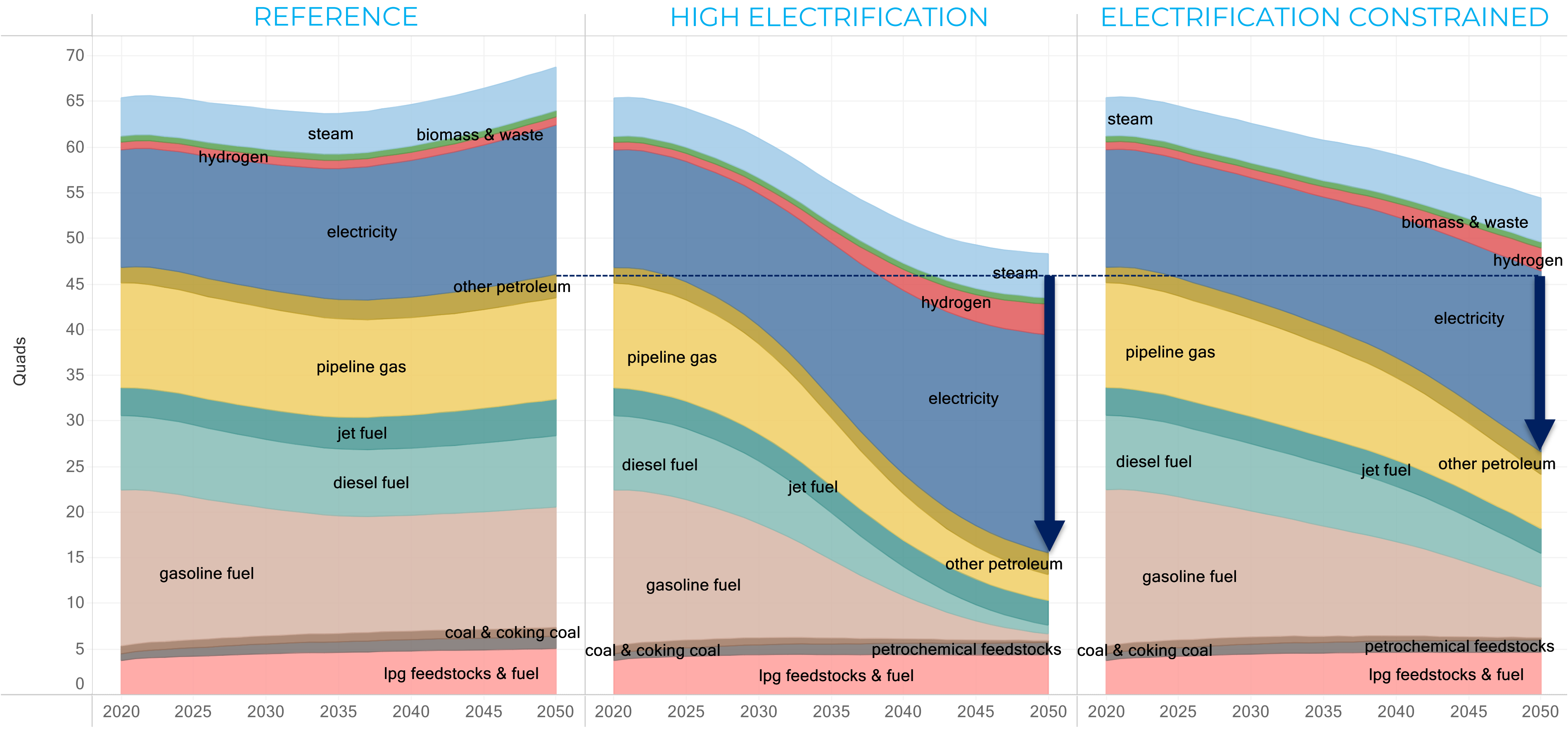
1. Final energy consumption down ~20-30% (~13-20 Quads saved)



Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

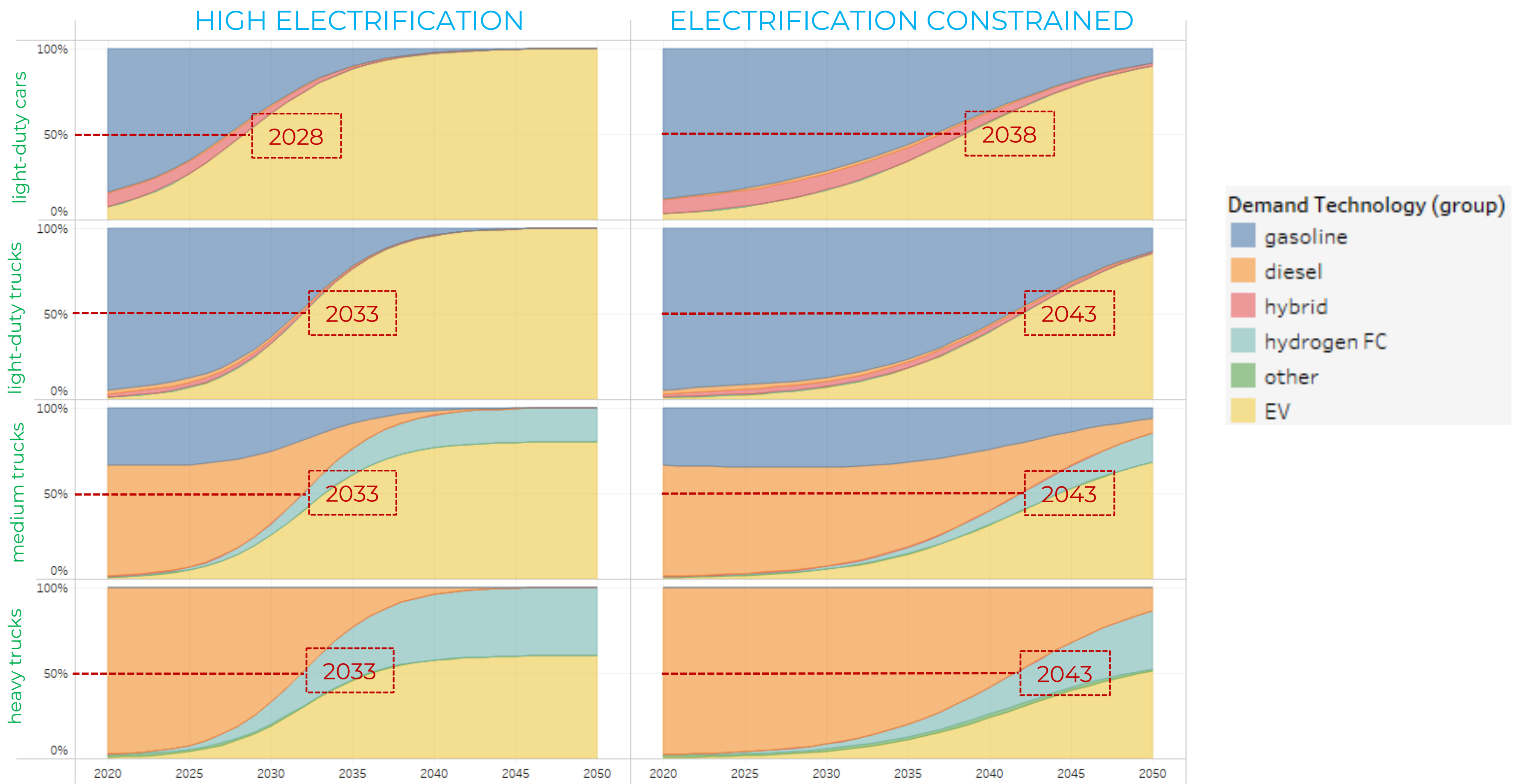
Energy productivity + Electrification

2. Hydrocarbons consumption down ~40-67% to ~15-27 Quads



Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

Electrification (new vehicle sales)



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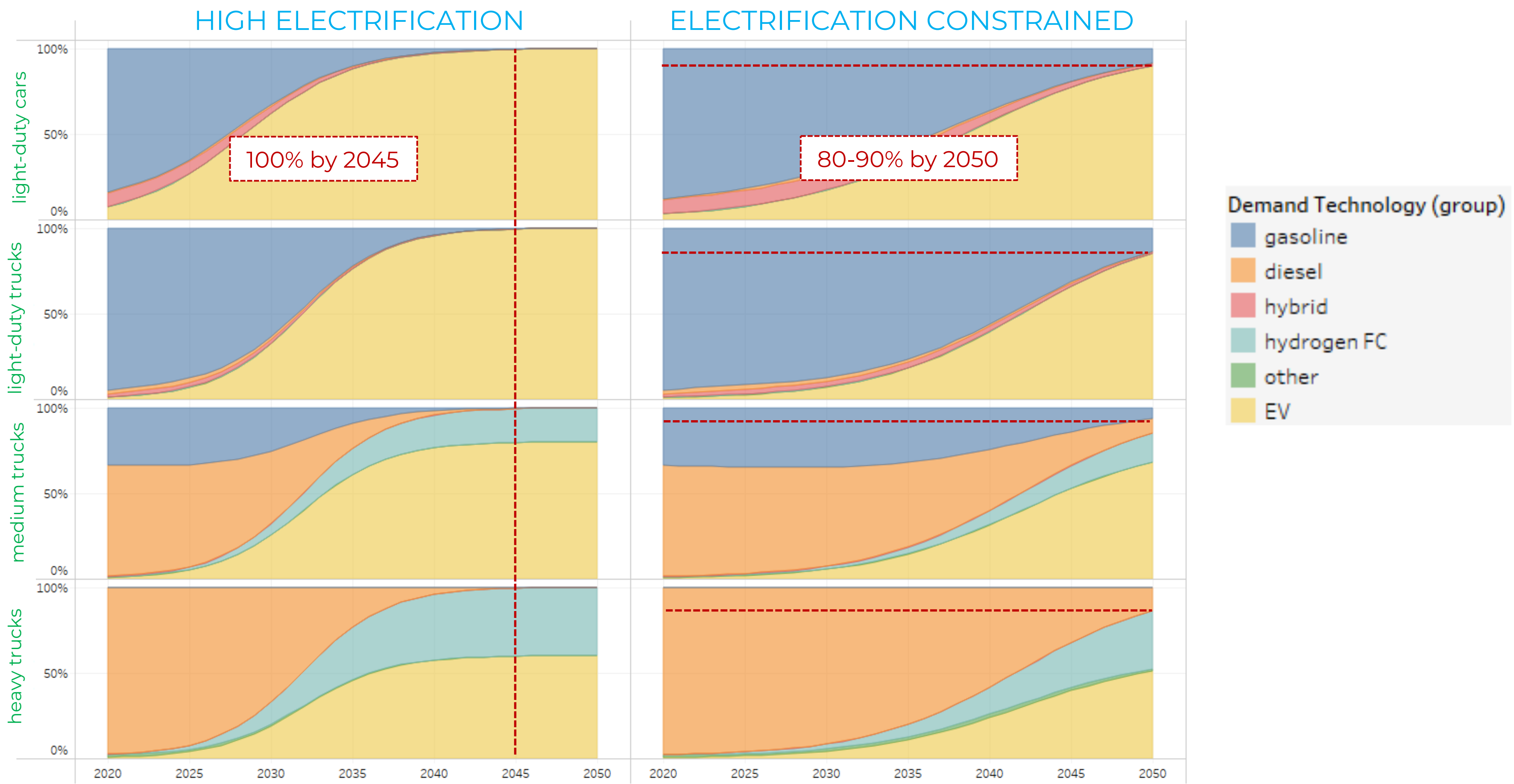
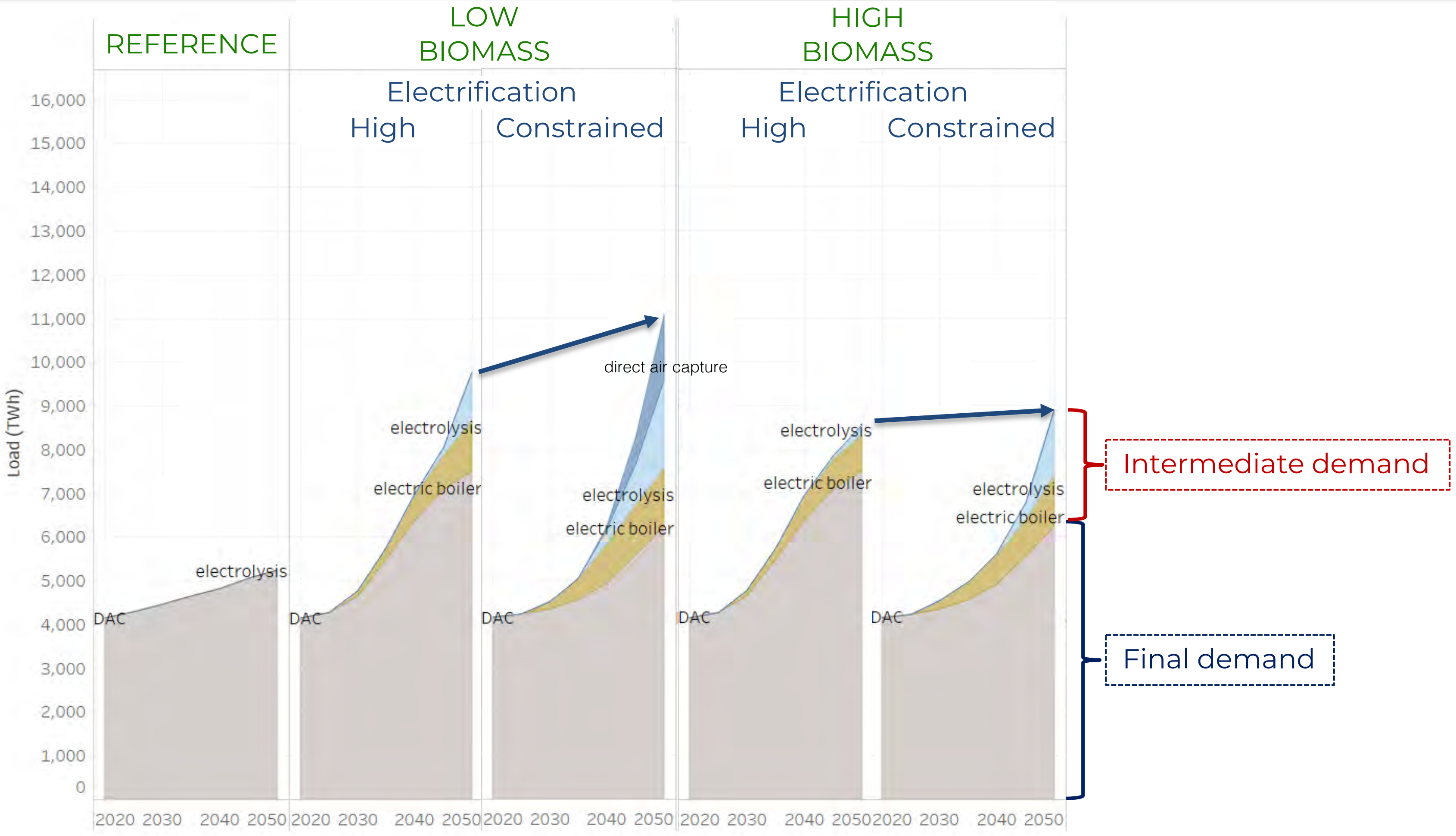
Electrification (new vehicle sales)



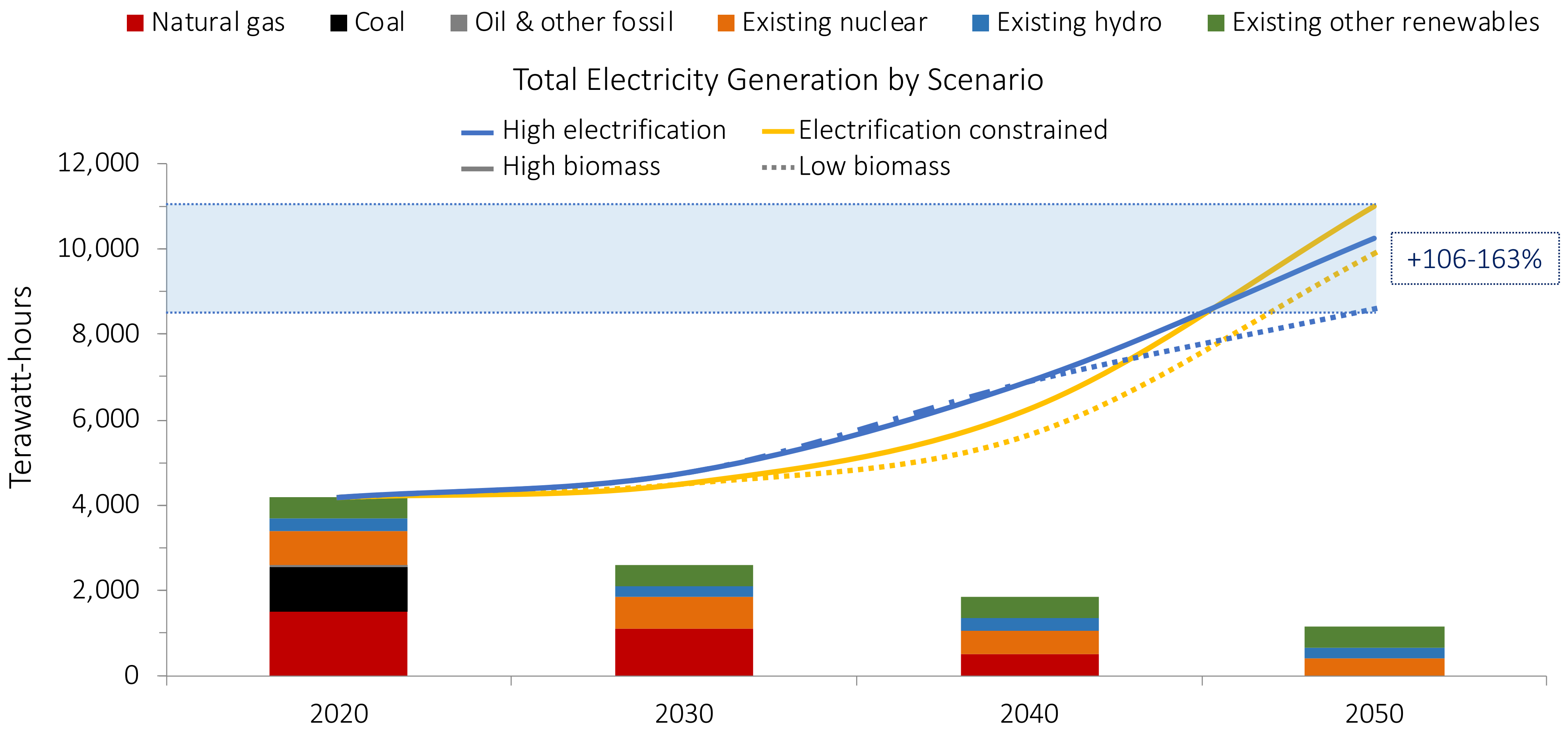
Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

The substitute for electrification: more electricity!



Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

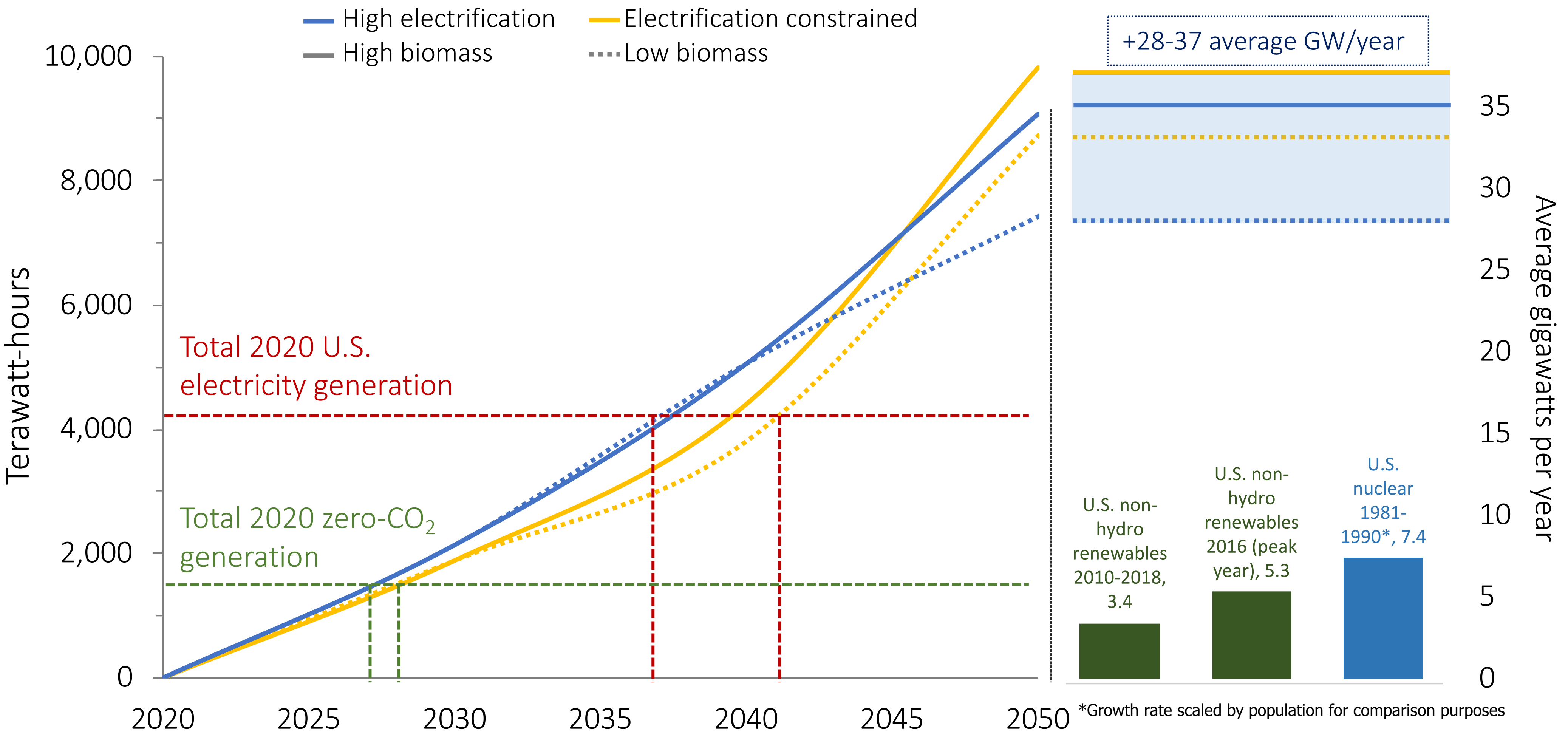
Twin challenges: zero carbon, >double demand



Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

(a) Total New Carbon-free Electricity Generation

(b) Annual Additions Rate (2020-2050)

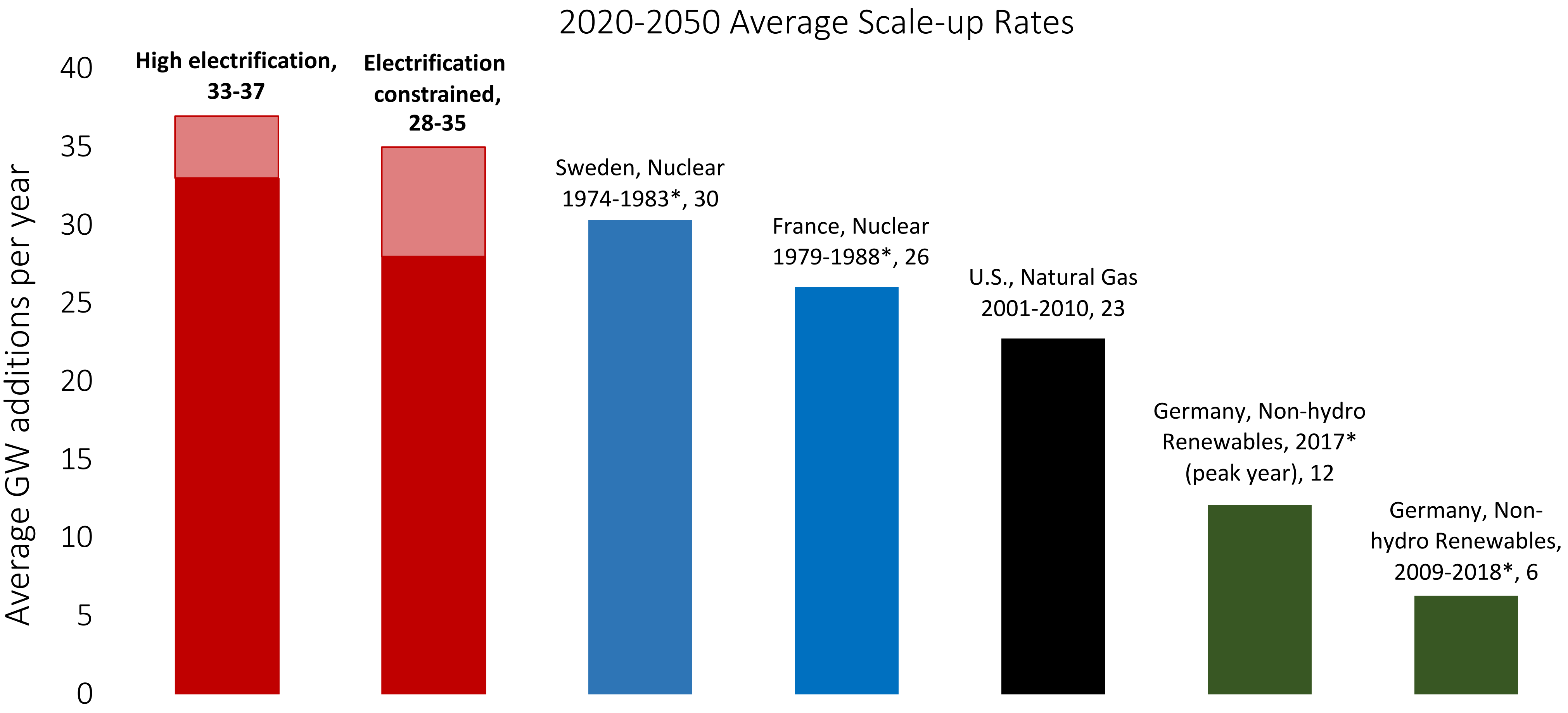


*Growth rate scaled by population for comparison purposes

(a) Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

(b) Data source: U.S. EIA for renewables growth rate. MIT *Future of Nuclear in a Carbon Constrained World* study for historic nuclear growth rate (rescaled by population for comparison)

Clean electricity growth without precedent

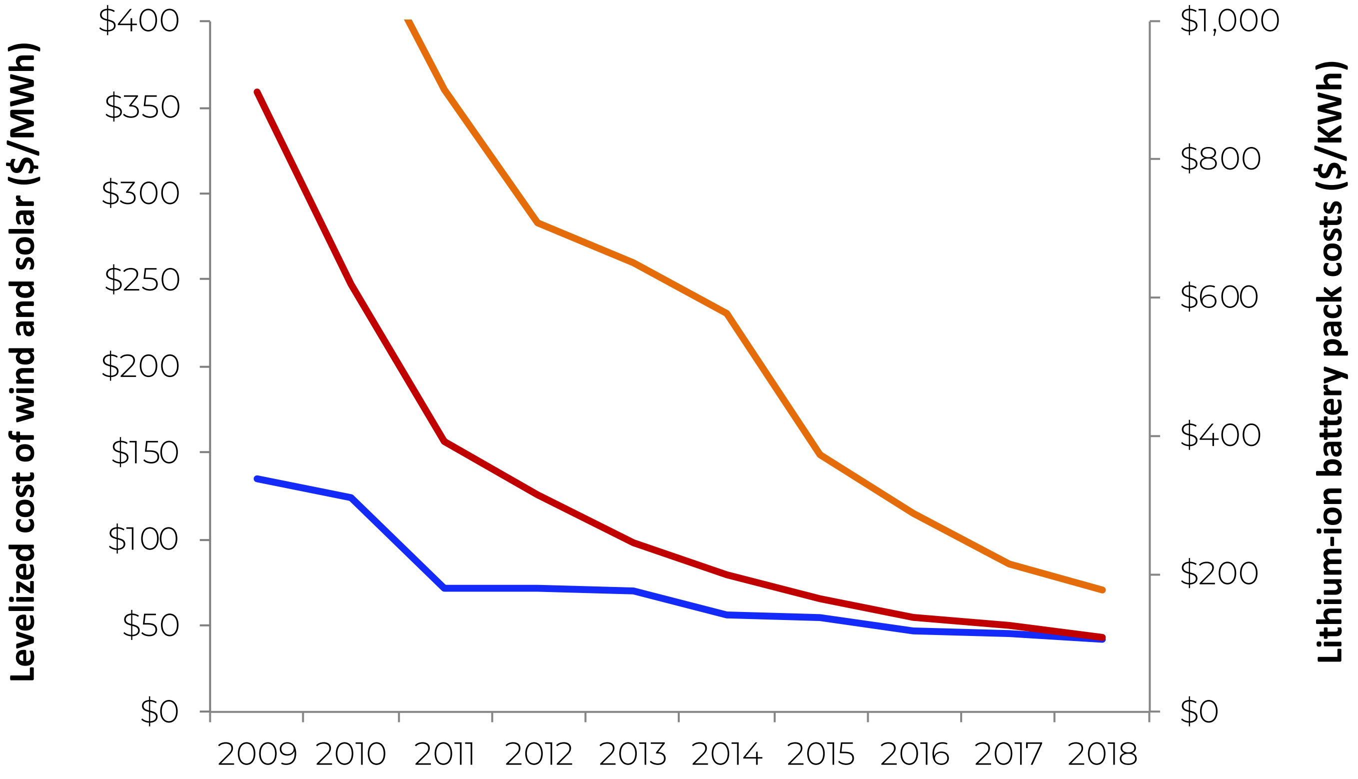


*Growth rate scaled by population for comparison purposes

Data sources: U.S. renewables from Historical per capita deployment rates from MIT 2018, The Future of Nuclear in a Carbon Constrained World, scaled to based on projected 2035 U.S. population of 364 million from U.S. Census Bureau.

4. Renewables take center stage

The good news: wind, solar, battery costs falling



Total cost declines (2009-2018)

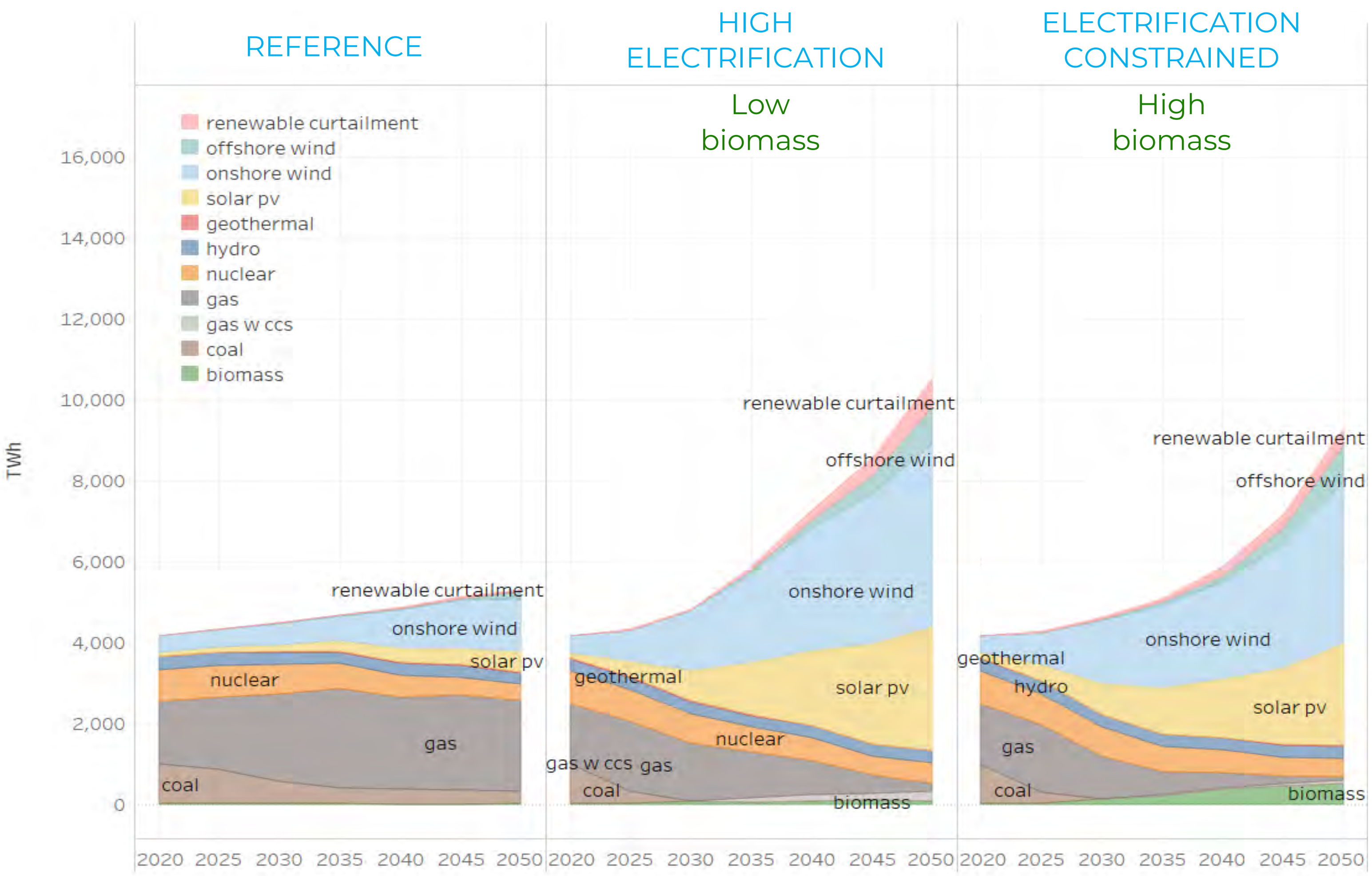
Solar $/MWh -88%

Li-ion packs $/KWh -85%

Wind $/MWh -69%

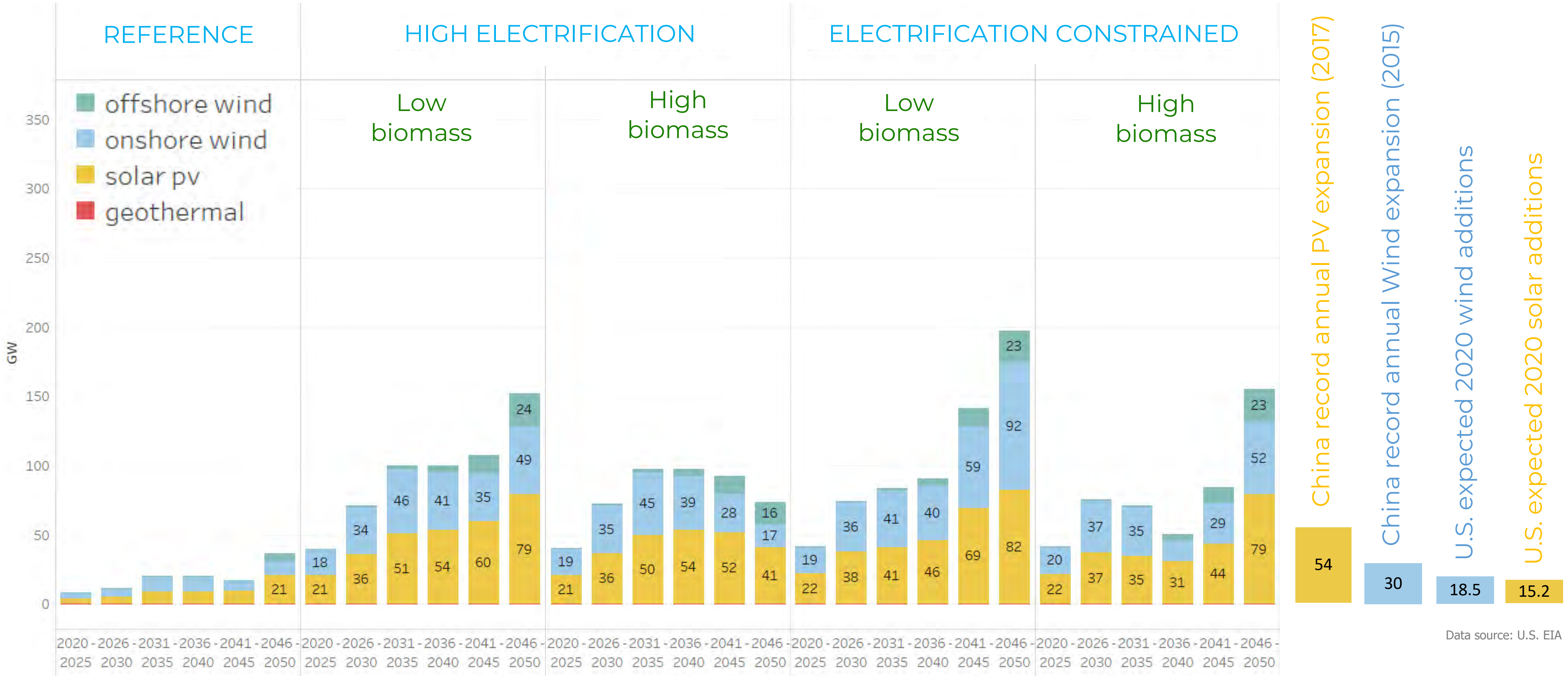
Data Sources: Wind & solar costs from Lazard (2018), Lazard's Levelized Cost of Energy Analysis – Version 12.0, https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf/. Battery pack costs from Bloomberg New Energy Finance (2018), Battery Price Survey, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

Wind and solar can become dominant



Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

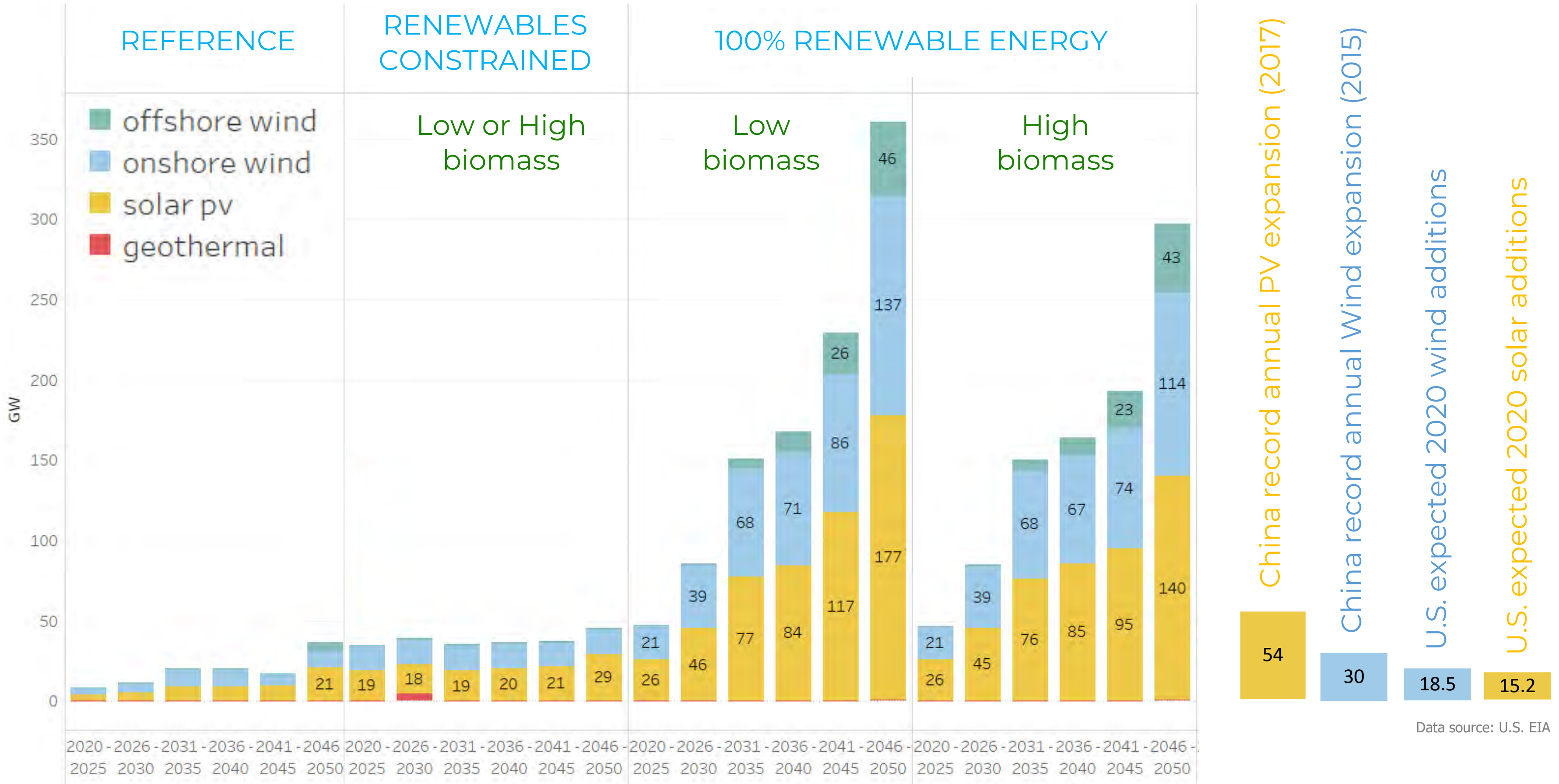
Pace of new wind and solar additions



Data source: U.S. EIA

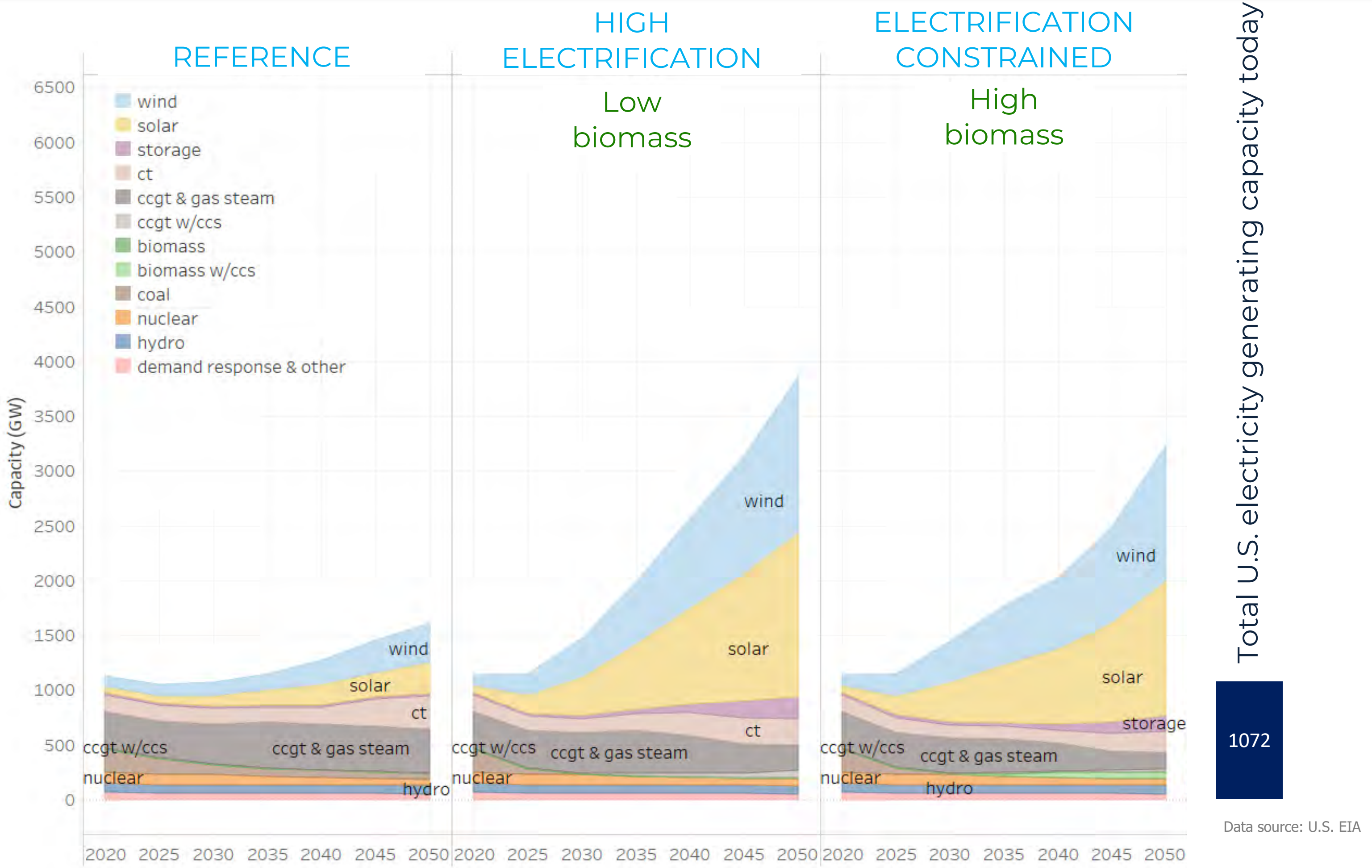
Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

Pace of new wind and solar additions



Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

Why not 100% renewables?



Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

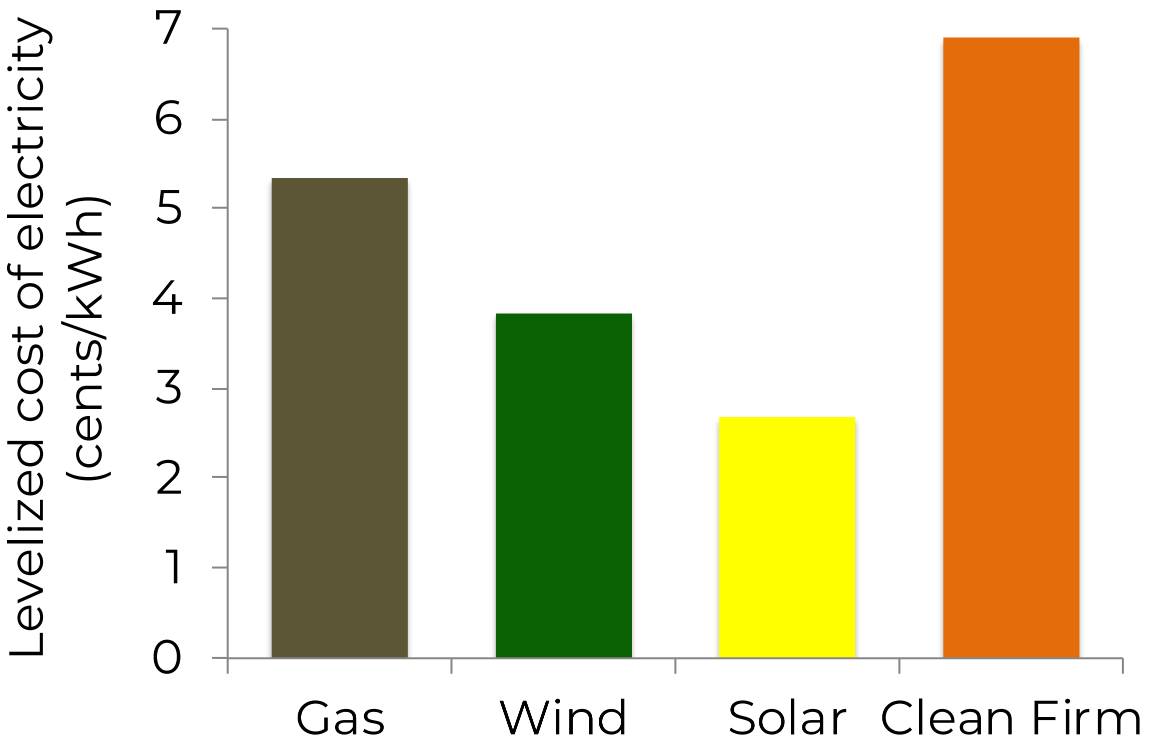
A riddle…

"It can be more expensive to add cheap solar than to add expensive geothermal."

-David Olsen, Member of CAISO Board of Governors, former President & CEO of Patagonia

https://www.utilitydive.com/news/geothermals-surprise-cheap-renewables-could-keep-states-from-achieving-cl/569807/

The answer…



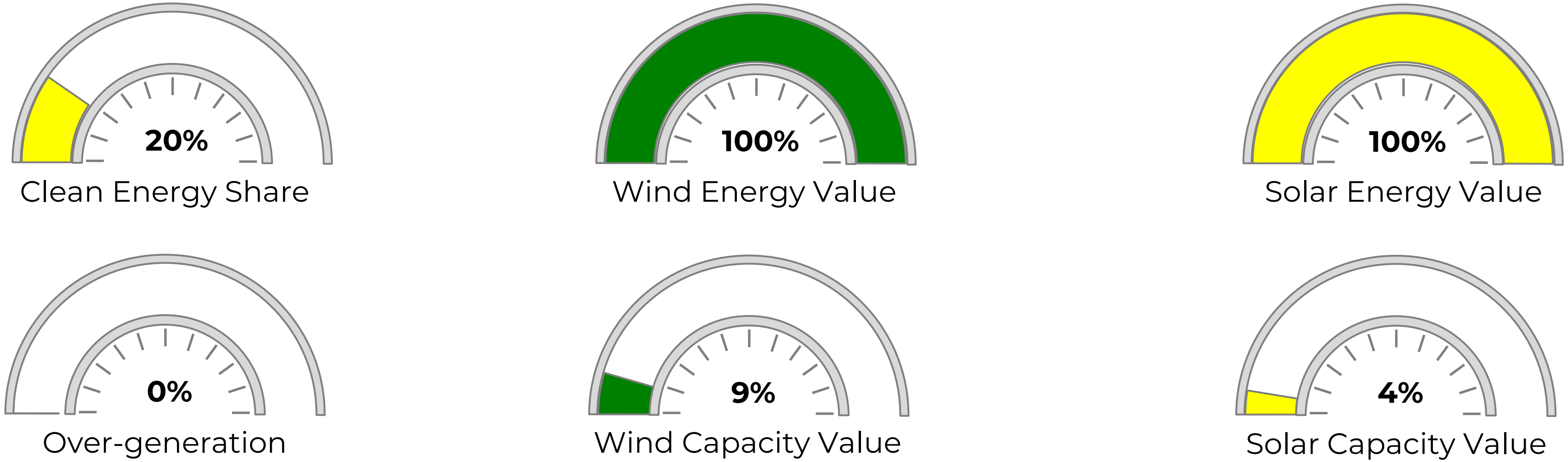
Peak demand: 34 GW

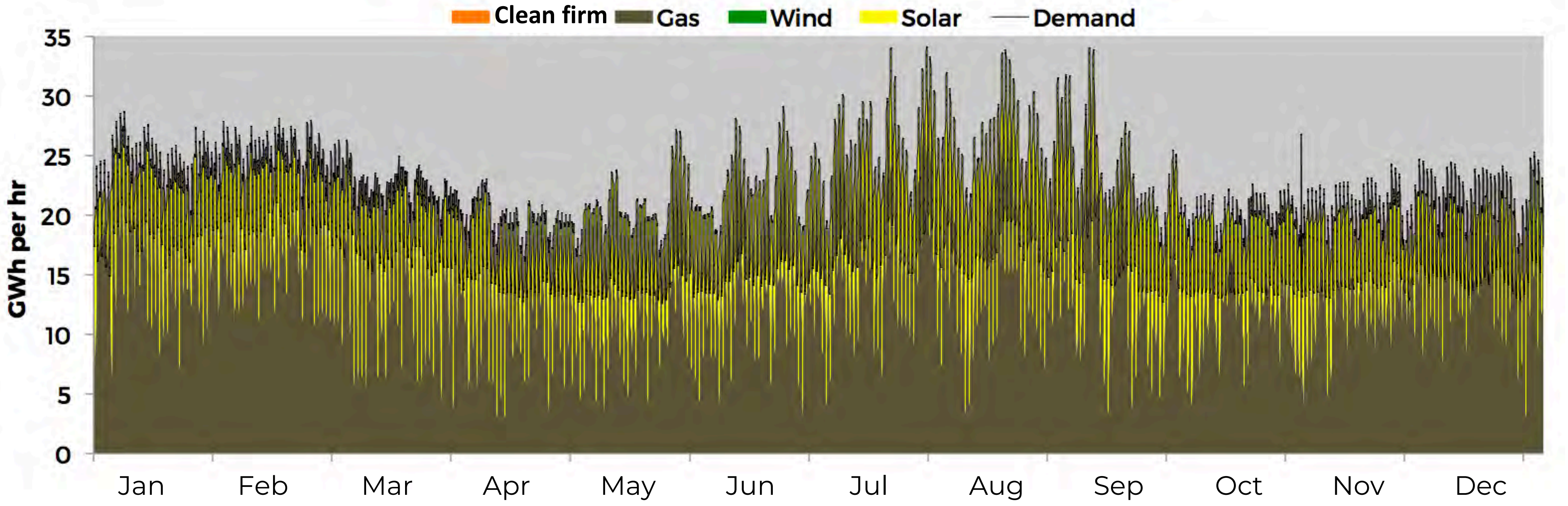
Capacity factors

Wind: 28%

Solar: 24% (ac)

No storage or flexible demands in this example


20%
Clean Energy Share
100%
Wind Energy Value
100%
Solar Energy Value
0%
Over-generation
9%
Wind Capacity Value
4%
Solar Capacity Value


Clean firm
Gas
Wind
Solar
Demand
GWh per hr
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
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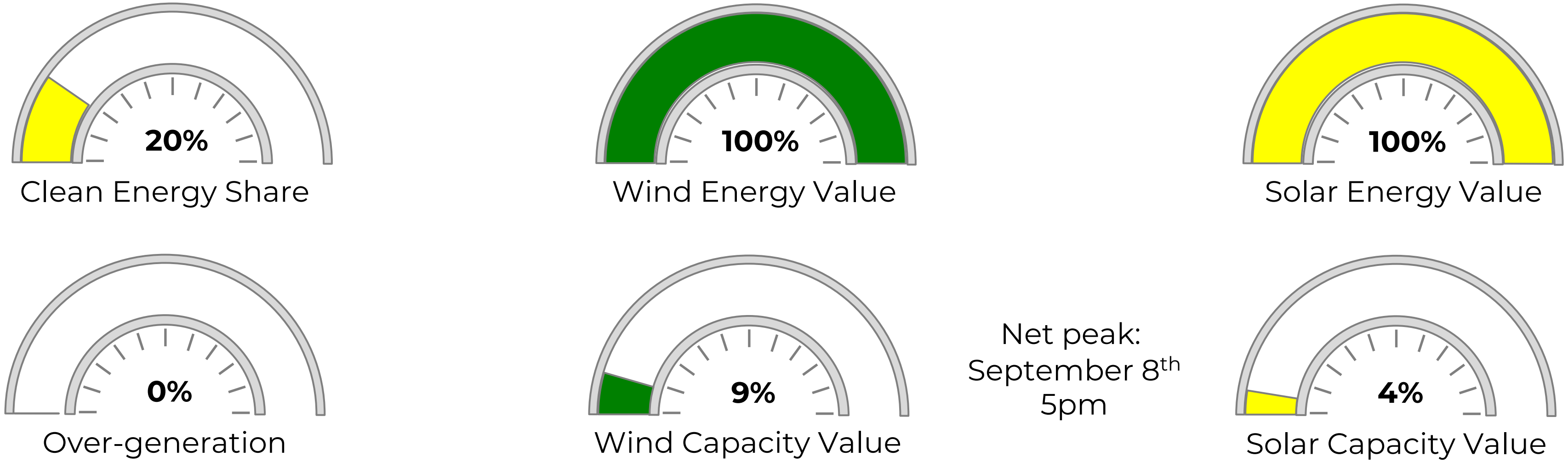
Aug
Sep
Oct
Nov
Dec


20%
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Solar Energy Value
0%
Over-generation
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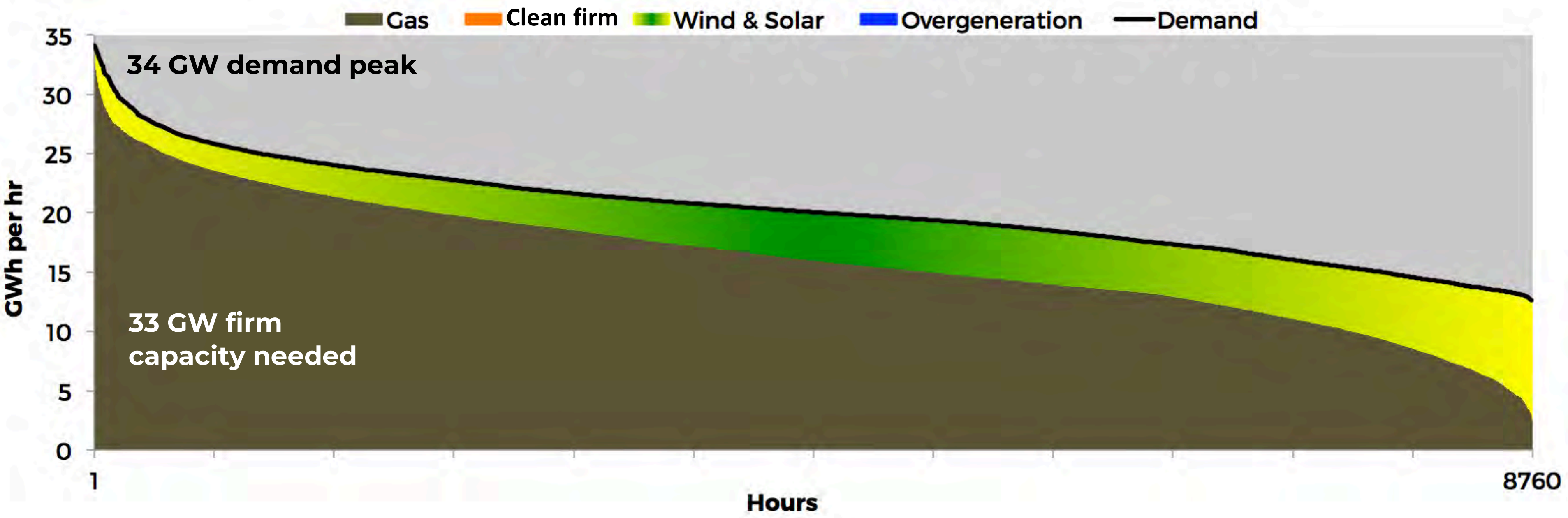
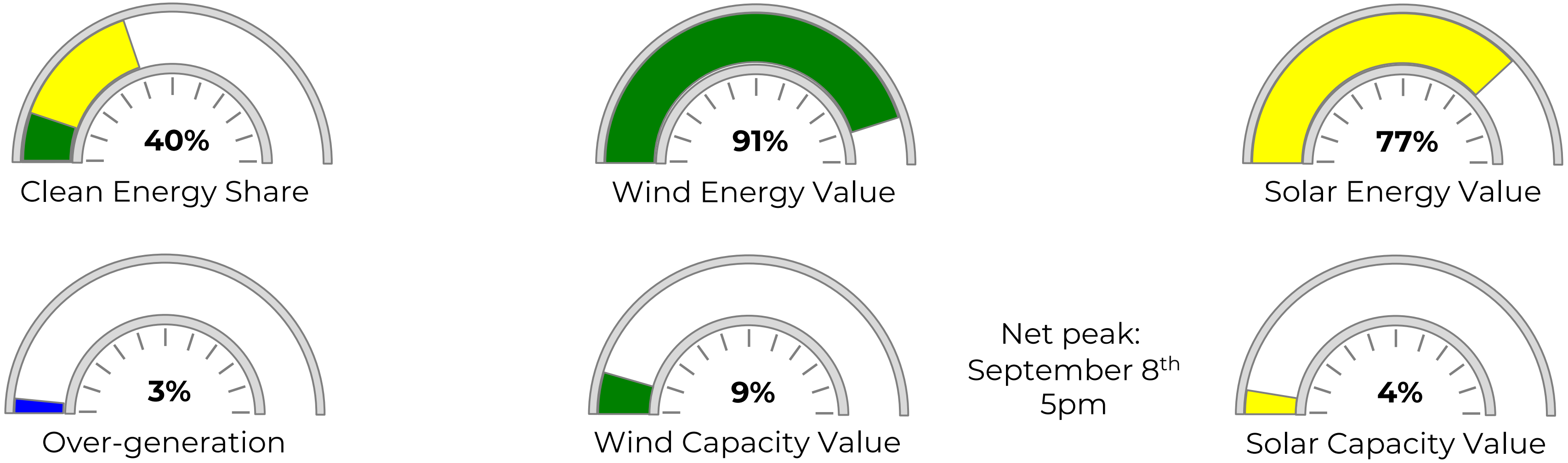
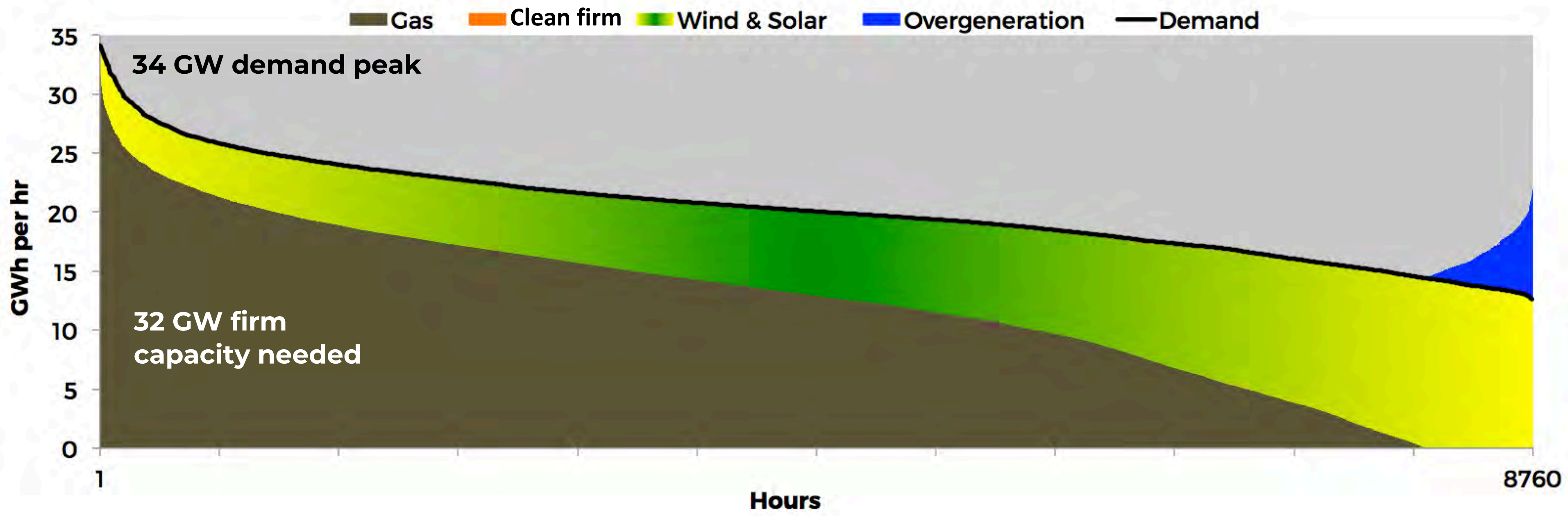
Wind Capacity Value
Net peak:
September 8th
5pm
4%
Solar Capacity Value


Gas
Clean firm
Wind & Solar
Overgeneration
Demand
34 GW demand peak
33 GW firm
capacity needed
GWh per hr
35
30
25
20
15
10
5
0
1
8760
Hours


40%
Clean Energy Share
91%
Wind Energy Value
77%
Solar Energy Value
3%
Over-generation
9%
Wind Capacity Value
Net peak:
September 8th
5pm
4%
Solar Capacity Value


Gas
Clean firm
Wind & Solar
Overgeneration
Demand
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32 GW firm
capacity needed
GWh per hr
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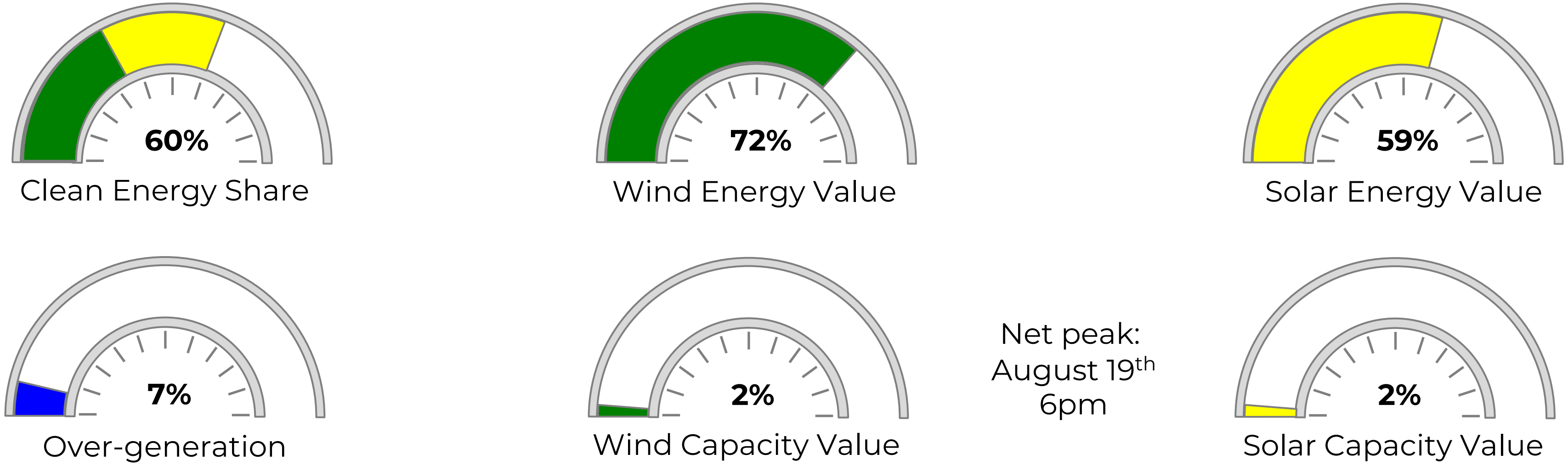
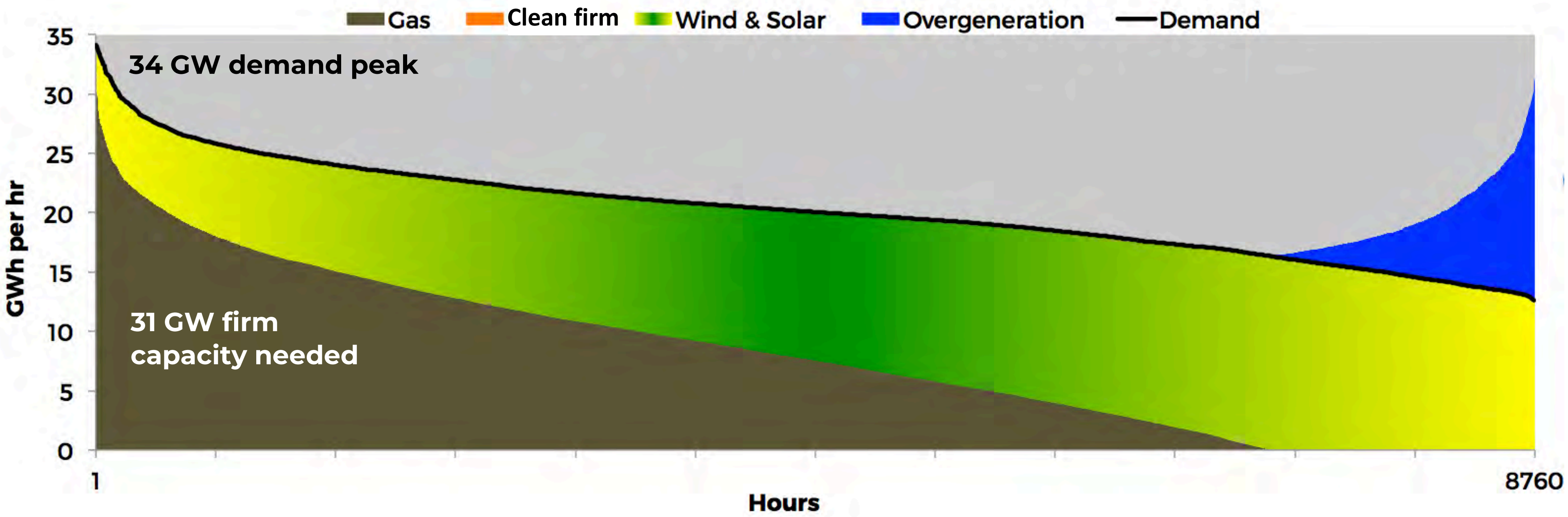
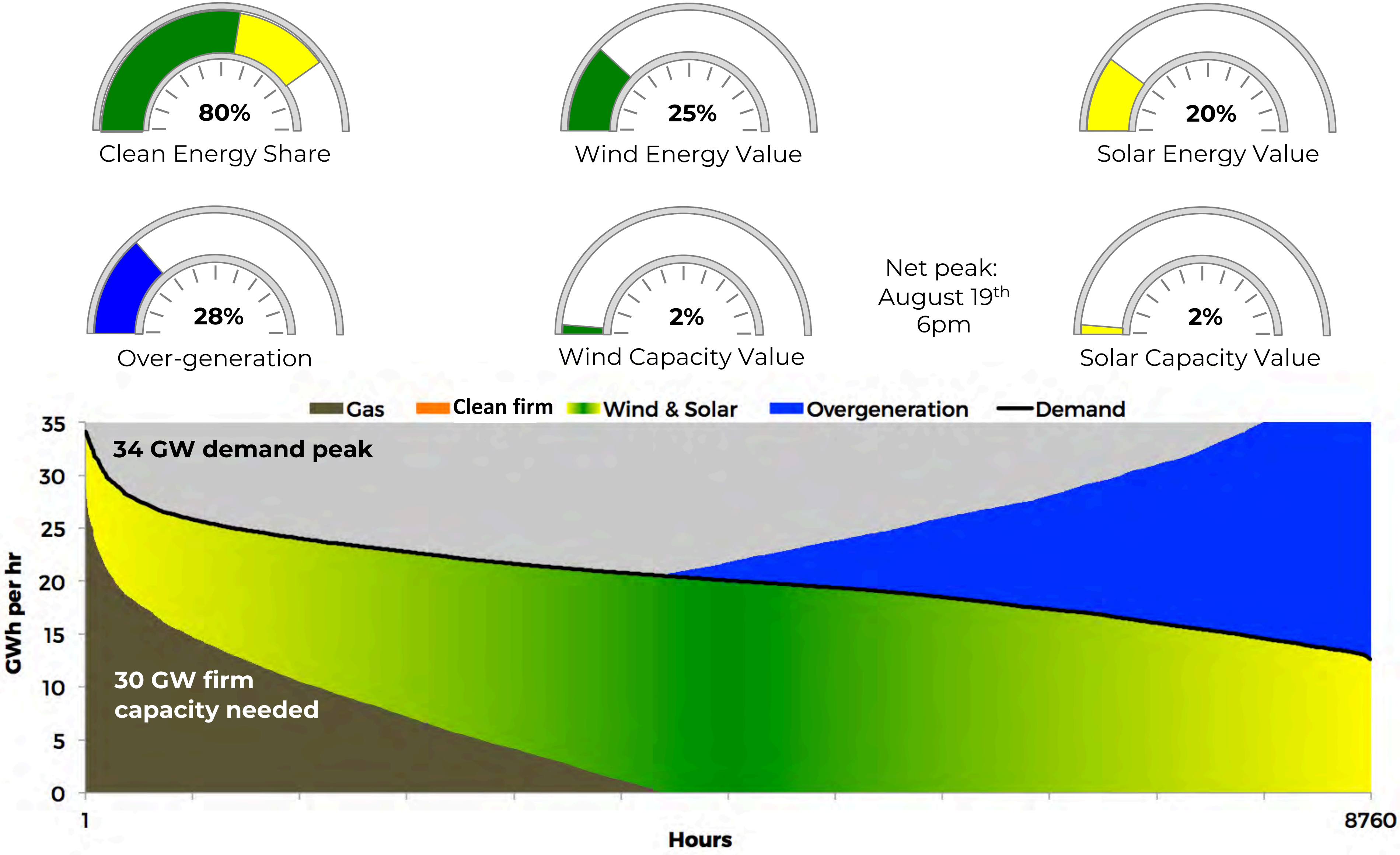
30
25
20
15
10
5
0
1
8760
Hours



Net peak:
August 19th
6pm




80%
Clean Energy Share
25%
Wind Energy Value
20%
Solar Energy Value
28%
Over-generation
2%
Wind Capacity Value
Net peak:
August 19th
6pm
2%
Solar Capacity Value
Gas
Clean firm
Wind & Solar
Overgeneration
Demand
34 GW demand peak
30 GW firm
capacity needed
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35
30
25
20
15
10
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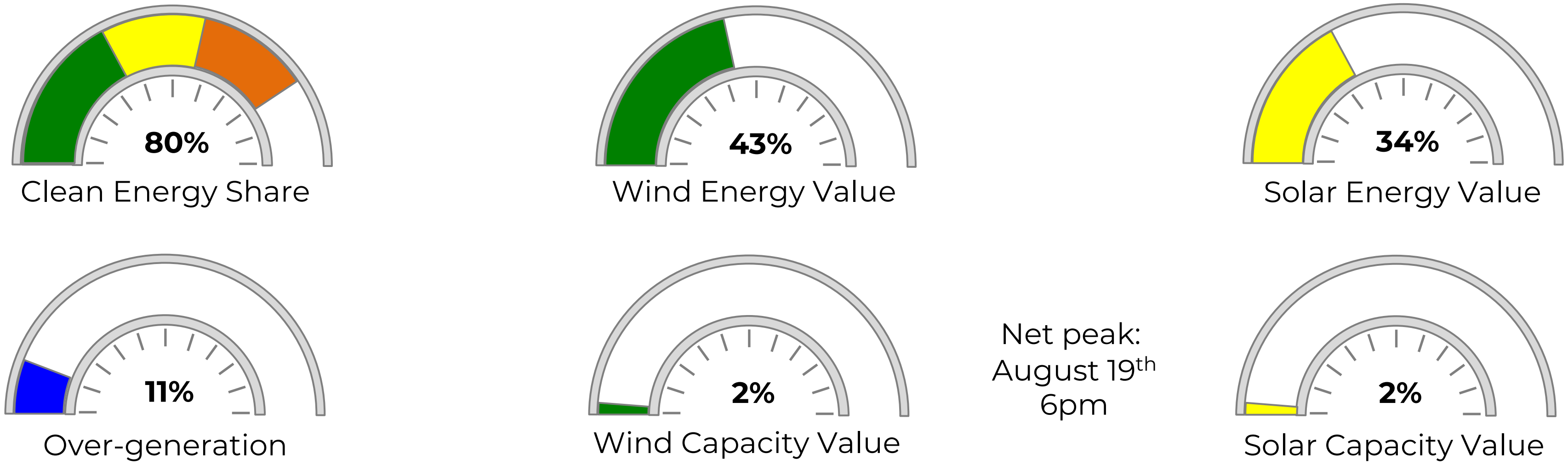
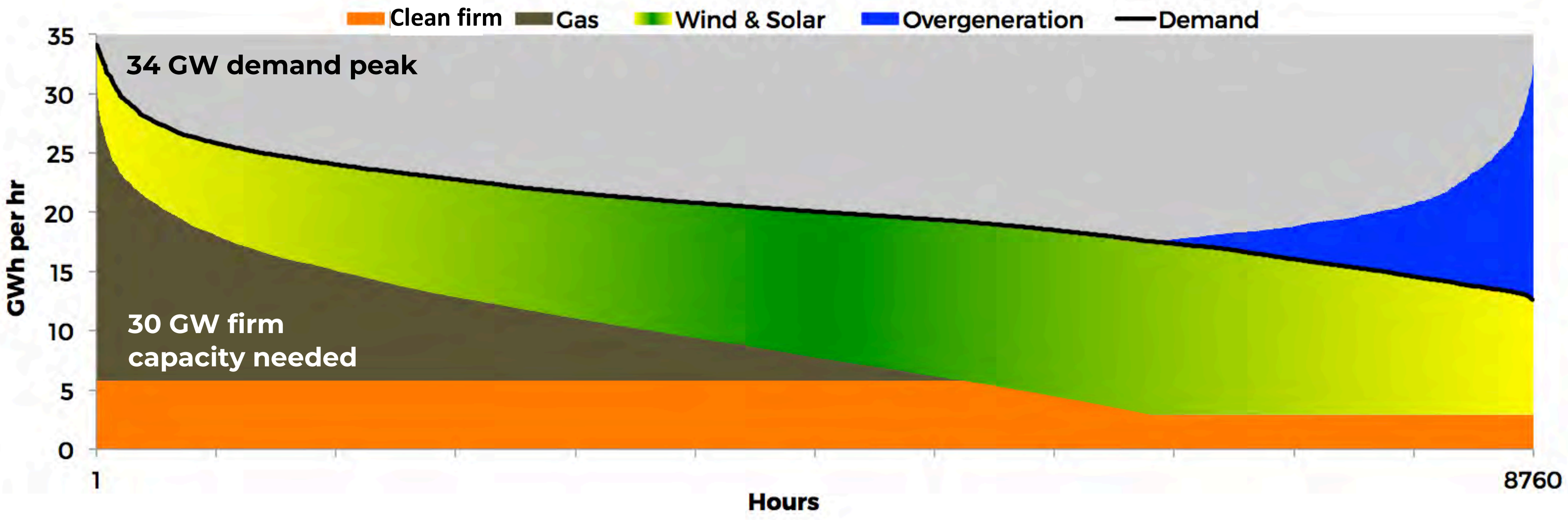
0
1
8760
Hours


80%
Clean Energy Share
43%
Wind Energy Value
34%
Solar Energy Value
11%
Over-generation
2%
Wind Capacity Value
Net peak:
August 19th
6pm
2%
Solar Capacity Value


Clean firm
Gas
Wind & Solar
Overgeneration
Demand
34 GW demand peak
30 GW firm
capacity needed
GWh per hr
35
30
25
20
15
10
5
0
1
8760
Hours

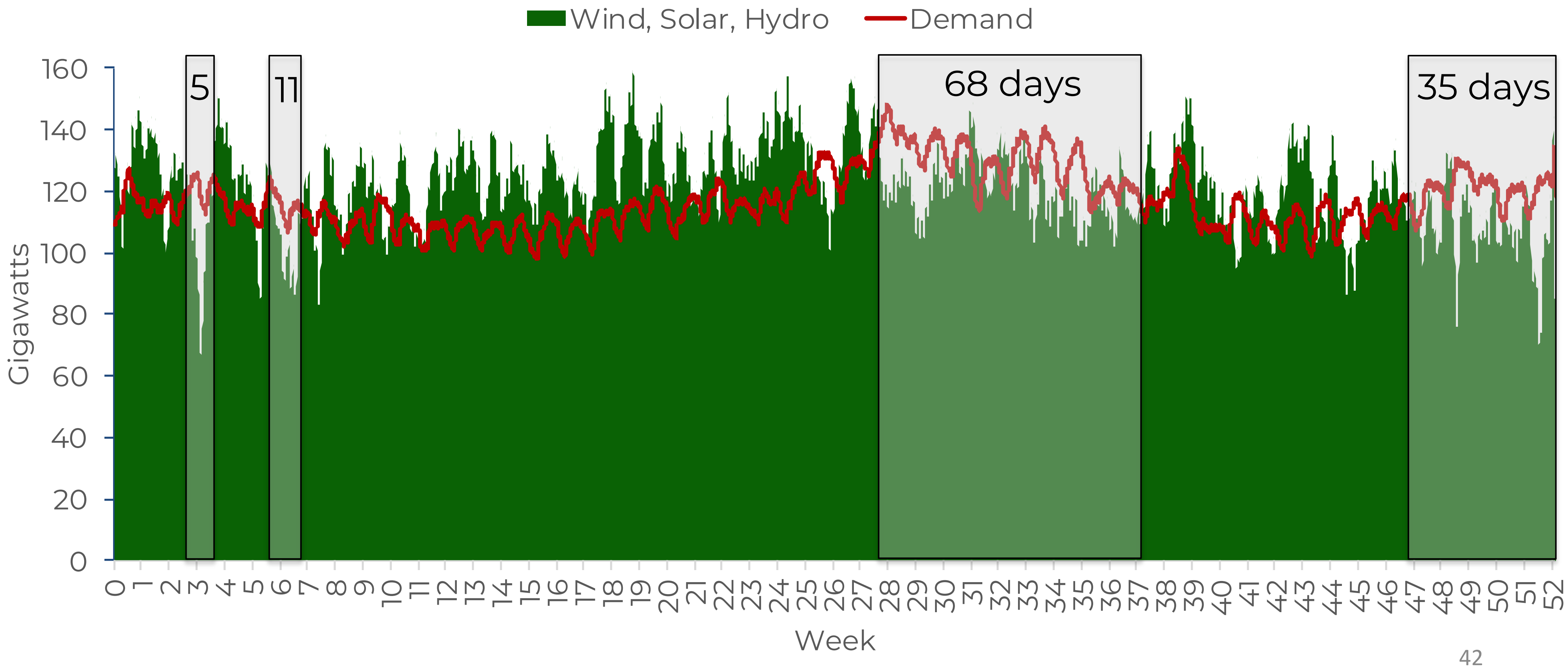
?

What about storage?

The *Dunkelflaute* ("Dark Doldrums")

Western Interconnection, Renewables + Storage Only

(24 hour rolling average power)

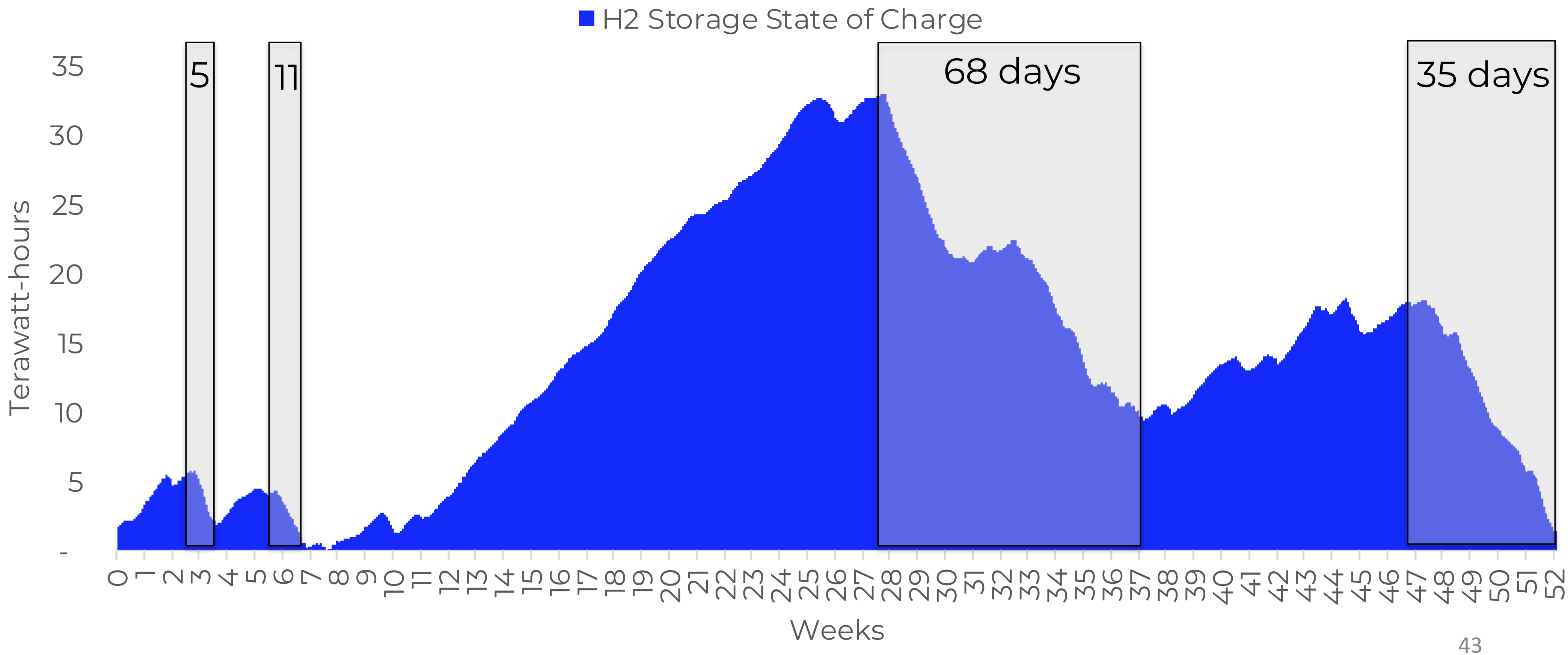


Data source: Unpublished results, Jesse D. Jenkins, GenX model, Western Interconnection.

Long Duration Storage Needed

Western Interconnection, Renewables + Storage Only

(24 hour rolling average power)



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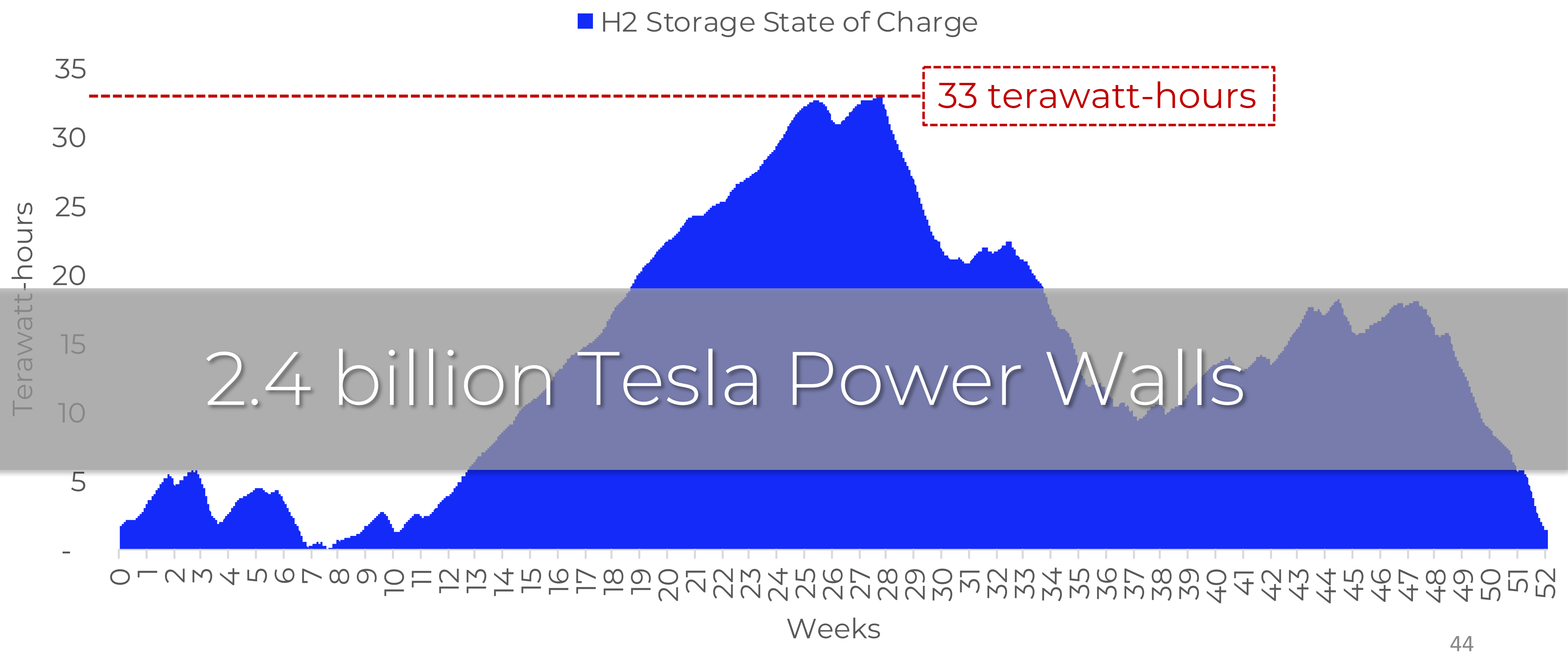

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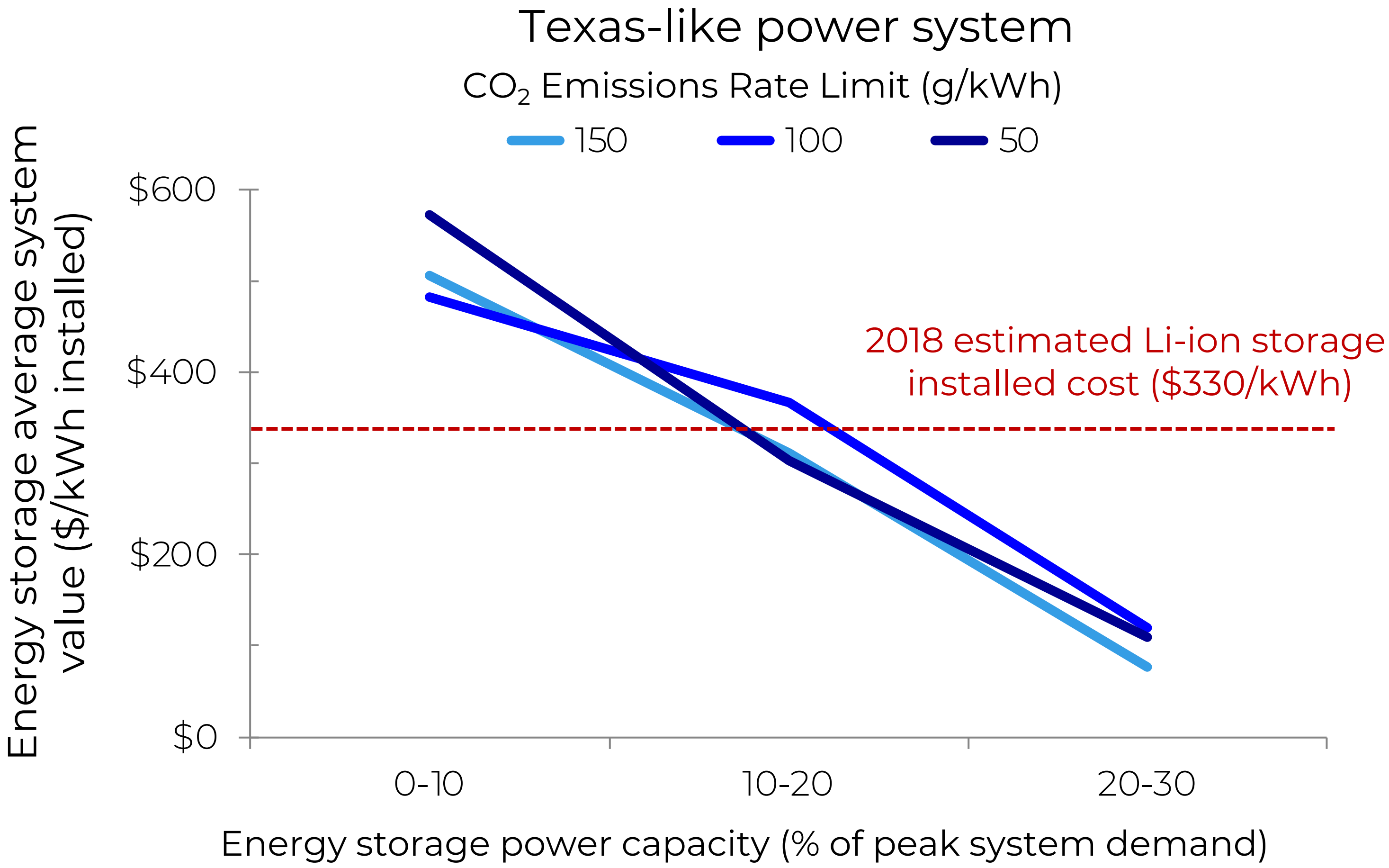
Declining Value of Storage



Graphic is author's own created with data from: de Sisternes, Jenkins & Botterud (2016), "The value of energy storage in decarbonizing the electricity sector," *Applied Energy* 175: 368-379. Assumes Li-ion storage system with 2 hours storage duration and 10 year asset life. Estimated 2018 Li-ion storage cost per kWh from Lazard (2018), Lazard's Levelized Cost of Storage Analysis – Version 4.0.

Solar, wind & batteries will be stars...

…but we need to complete the team

Solar PV

Solar thermal

Wind energy

Run-of-river hydro

Solar thermal with storage

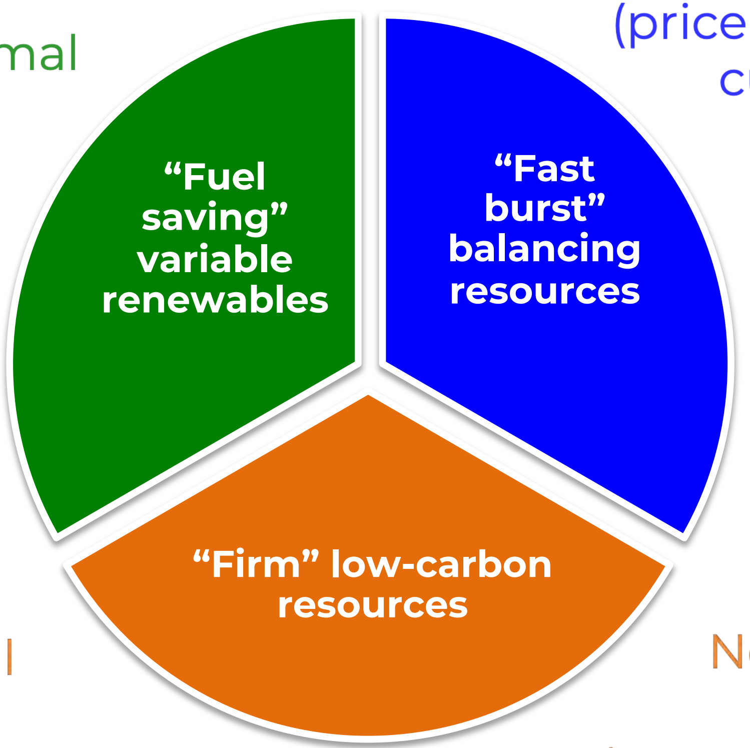
Reservoir hydro

Demand response (price responsive curtailment)

Flexible demand (rescheduling)

Battery storage

Long-duration storage



Geothermal

Net-Zero CO_2 gas

Nuclear

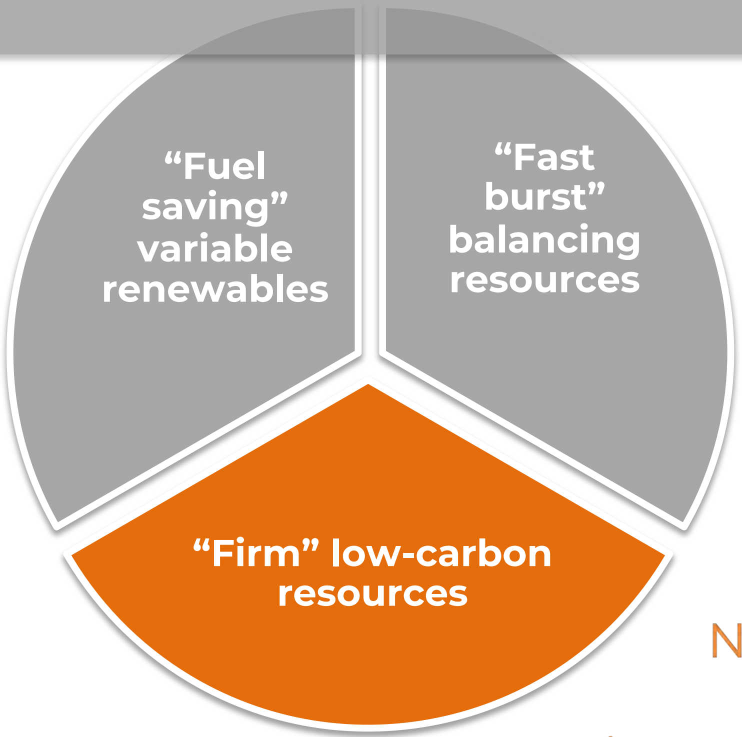
Gas or coal w/CCS

Biomass

“Flexible base”

“Firm cyclers”

5. Clean firm resources



Large reservoir hydro

Geothermal

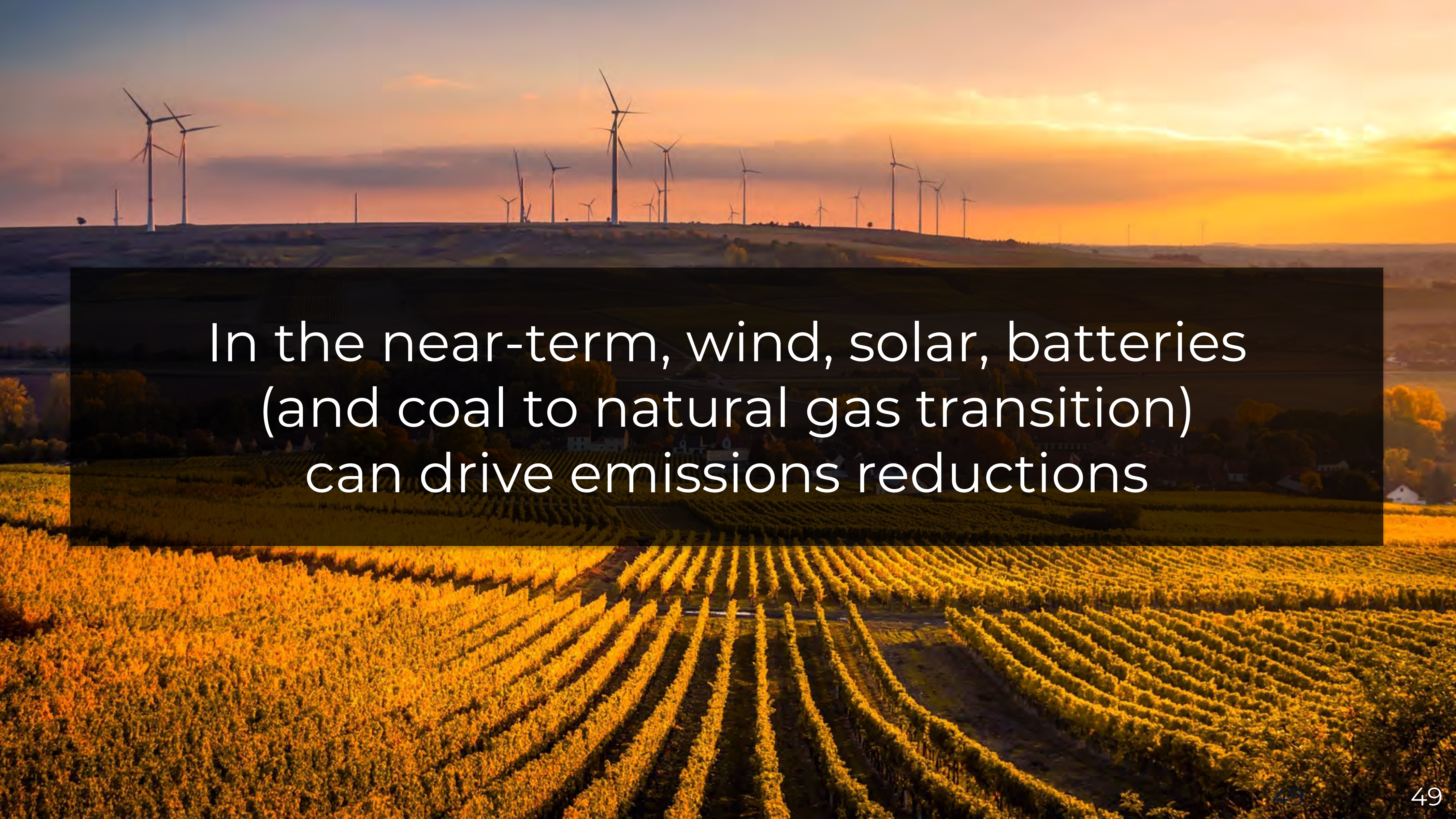
Nuclear

Gas or coal w/CCS

Biomass

Net-Zero CO_2 gas

Firm storage



In the near-term, wind, solar, batteries (and coal to natural gas transition) can drive emissions reductions

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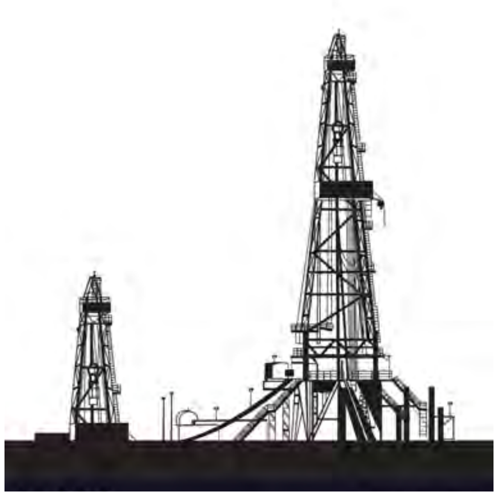
Fully decarbonizing electricity requires "clean firm" substitutes for natural gas *and* retiring nuclear units

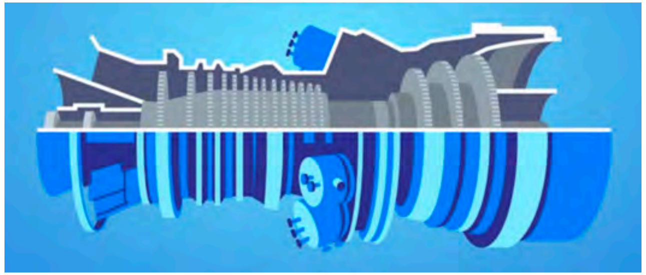
Image: International Energy Agency

Three main clean firm options

New nuclear:
Commercialization, construction cost, waste storage

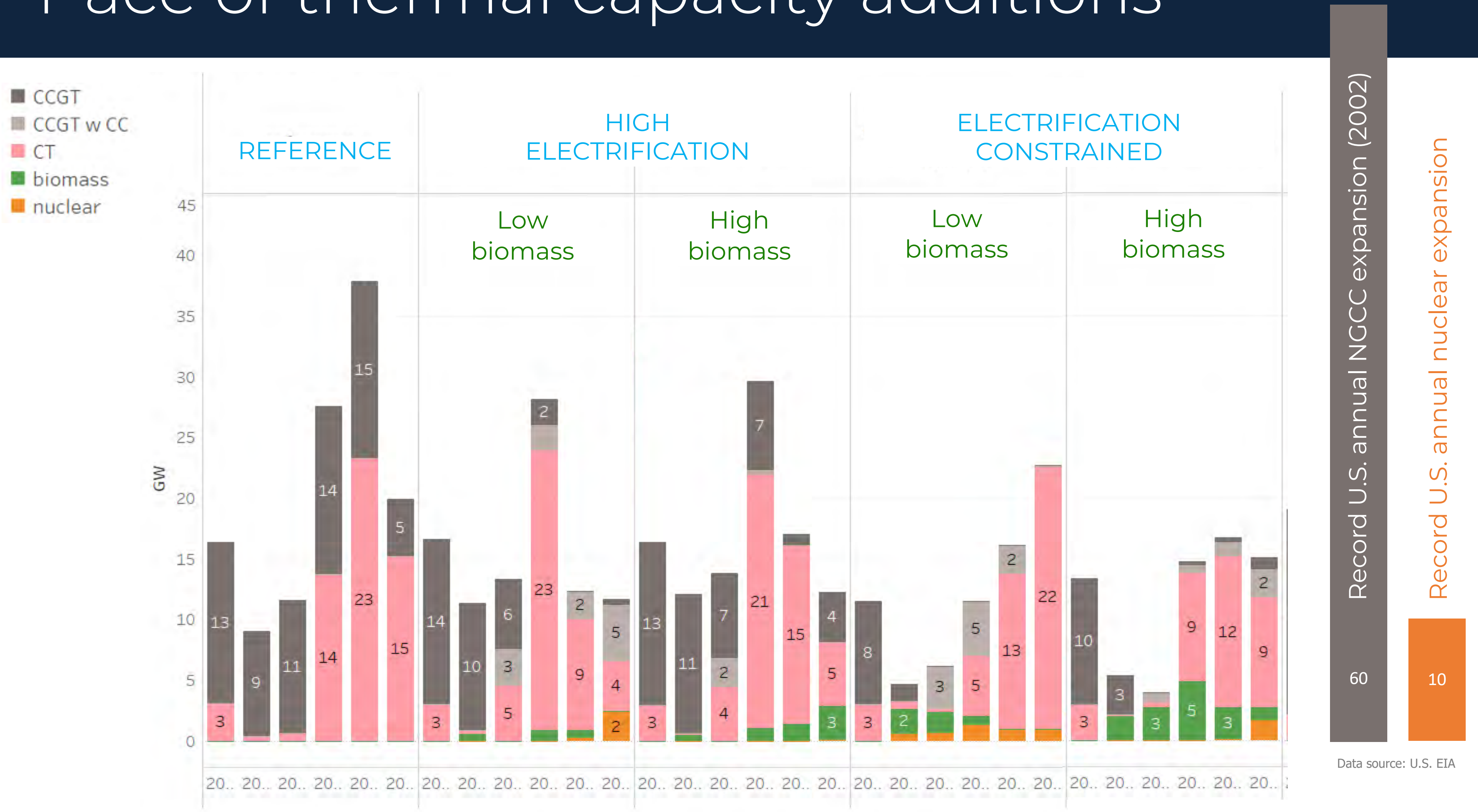


Carbon capture and sequestration:
For (1) power plants, (2) hydrogen from gas, or (3) with biomass or air capture to offset remaining natural gas burn



Hydrogen combustion:
Need combustion turbines capable of burning high hydrogen blends and produce & supply sufficient hydrogen to plants

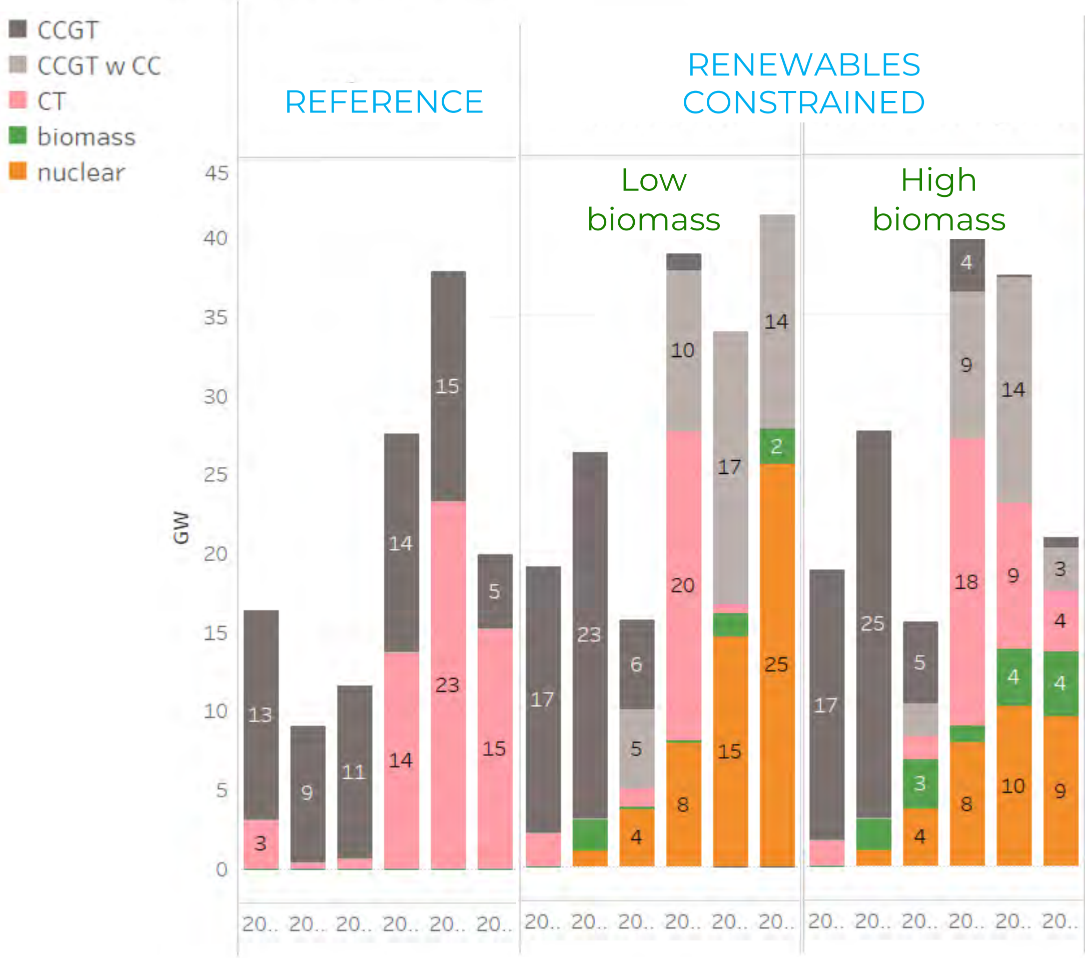
Pace of thermal capacity additions



Data source: U.S. EIA

Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

Pace of thermal capacity additions



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Data source: U.S. EIA

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The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation

Nestor A. Sepulveda [4] • Jesse D. Jenkins • Fernando J. de Sisternes • Richard K. Lester •
Show footnotes

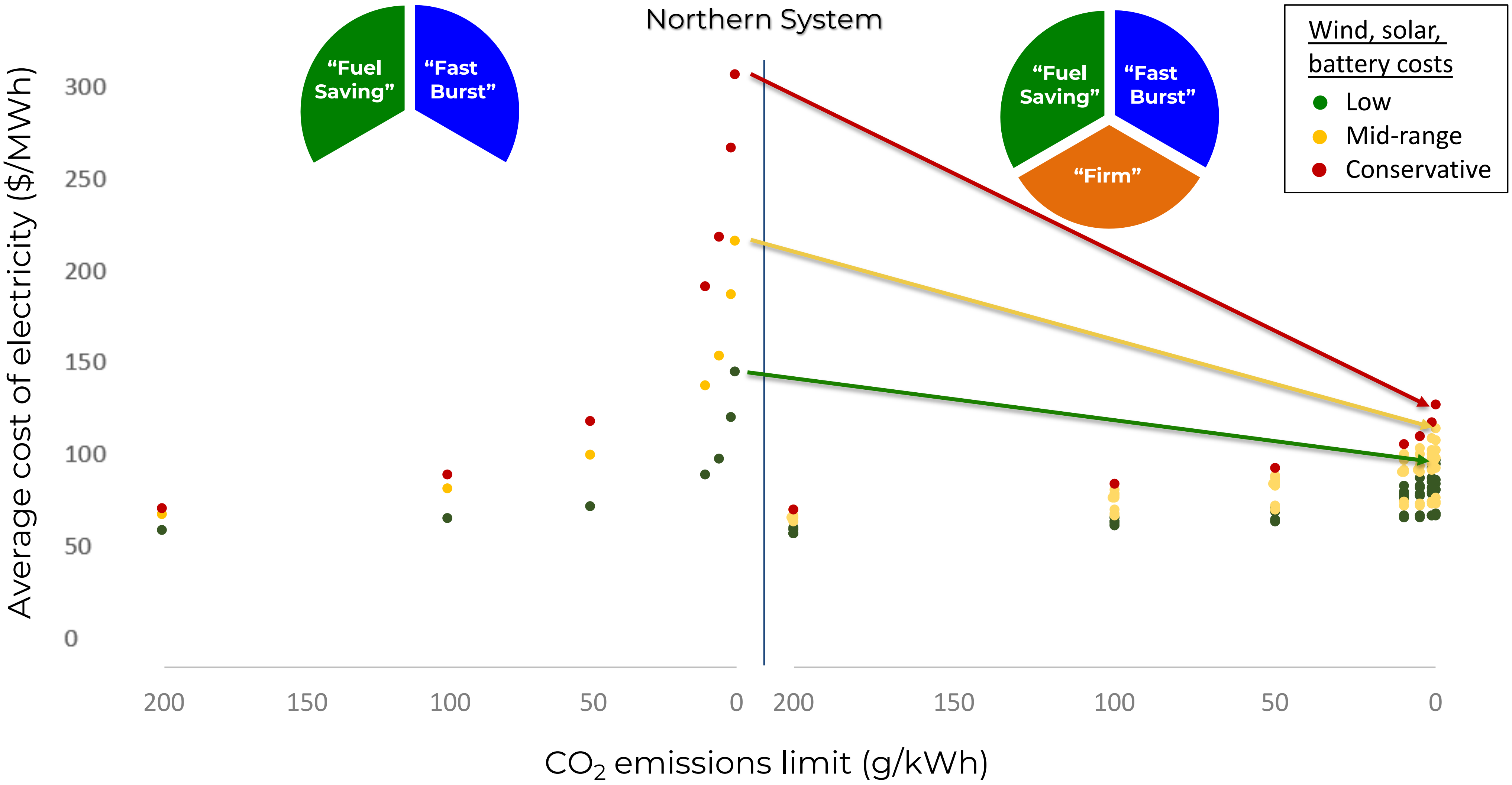
Published: September 06, 2018 • DOI: https://doi.org/10.1016/j.joule.2018.08.006

http://bit.ly/FirmLowCarbon

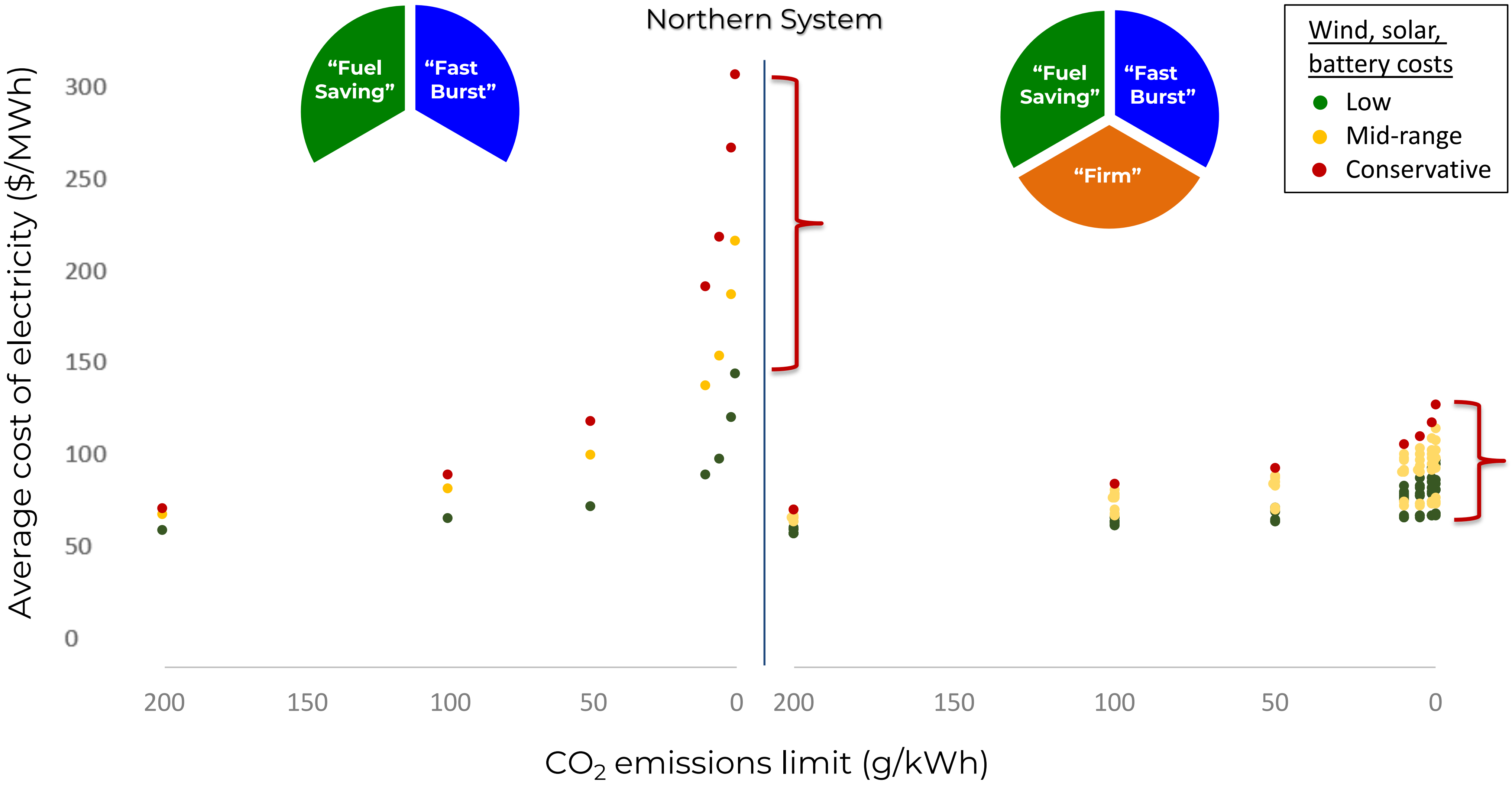
PlumX Metrics

Highlights

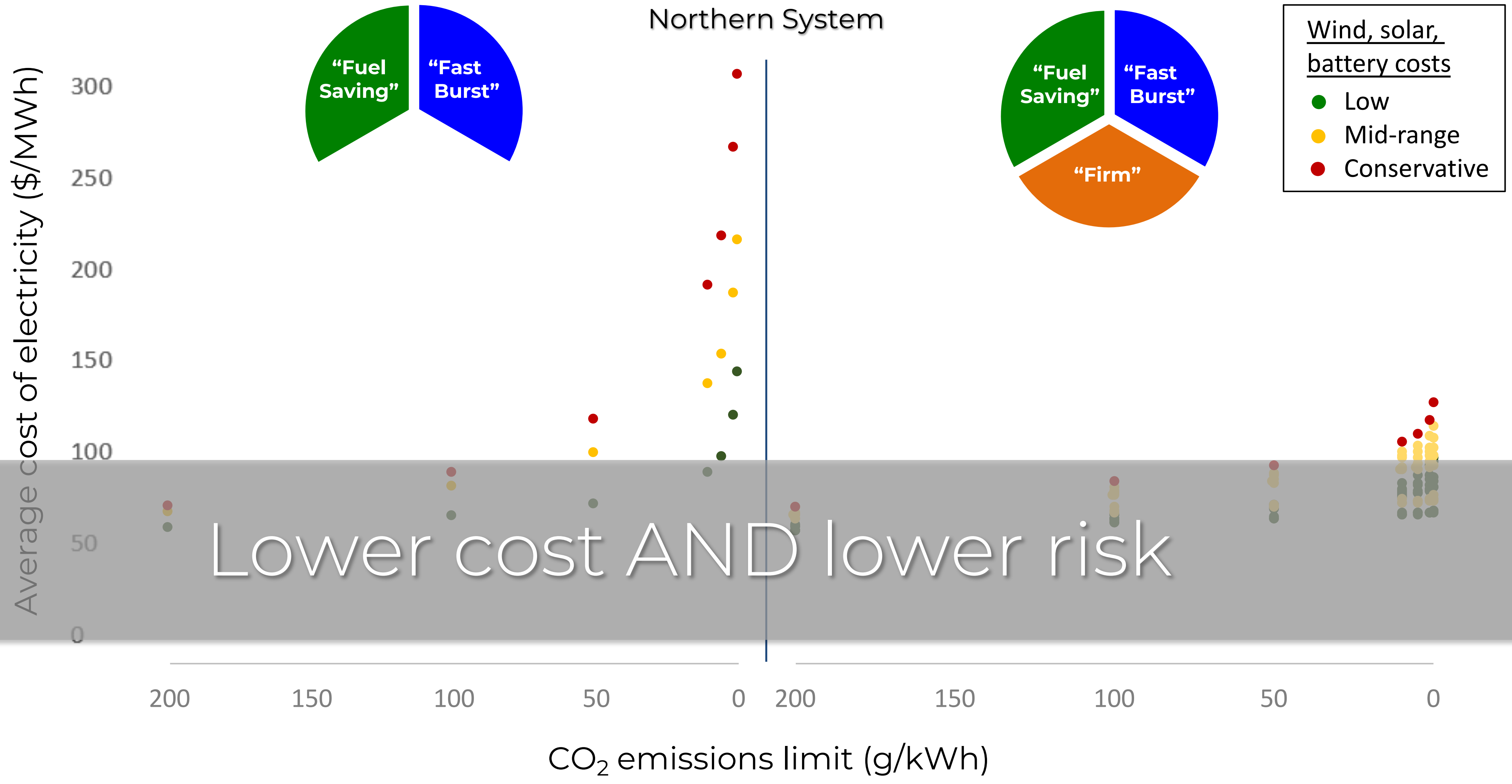
- Firm low-carbon resources consistently lower decarbonized electricity system costs
- Availability of firm low-carbon resources reduces costs 10%–62% in zero-CO_2 cases
- Without these resources, electricity costs rise rapidly as CO_2 limits near zero



Data source: Sepulveda, N., Jenkins, J.D., et al. (2018), "The role of firm low-carbon resources in deep decarbonization of electric power systems," *Joule* 2(11).



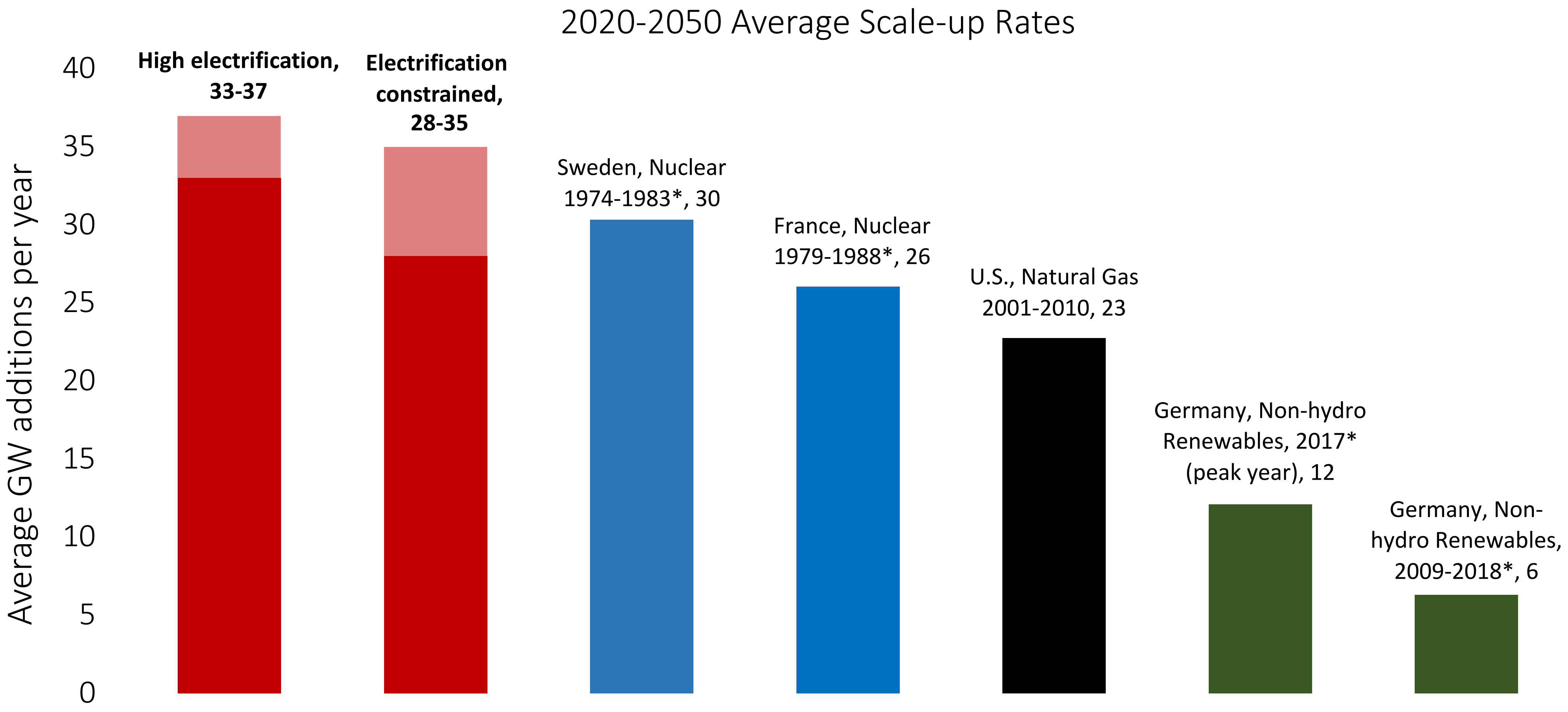
Data source: Sepulveda, N., Jenkins, J.D., et al. (2018), "The role of firm low-carbon resources in deep decarbonization of electric power systems," *Joule* 2(11).



Data source: Sepulveda, N., Jenkins, J.D., et al. (2018), "The role of firm low-carbon resources in deep decarbonization of electric power systems," *Joule* 2(11).

6. Securing social license

Enormous infrastructure build required



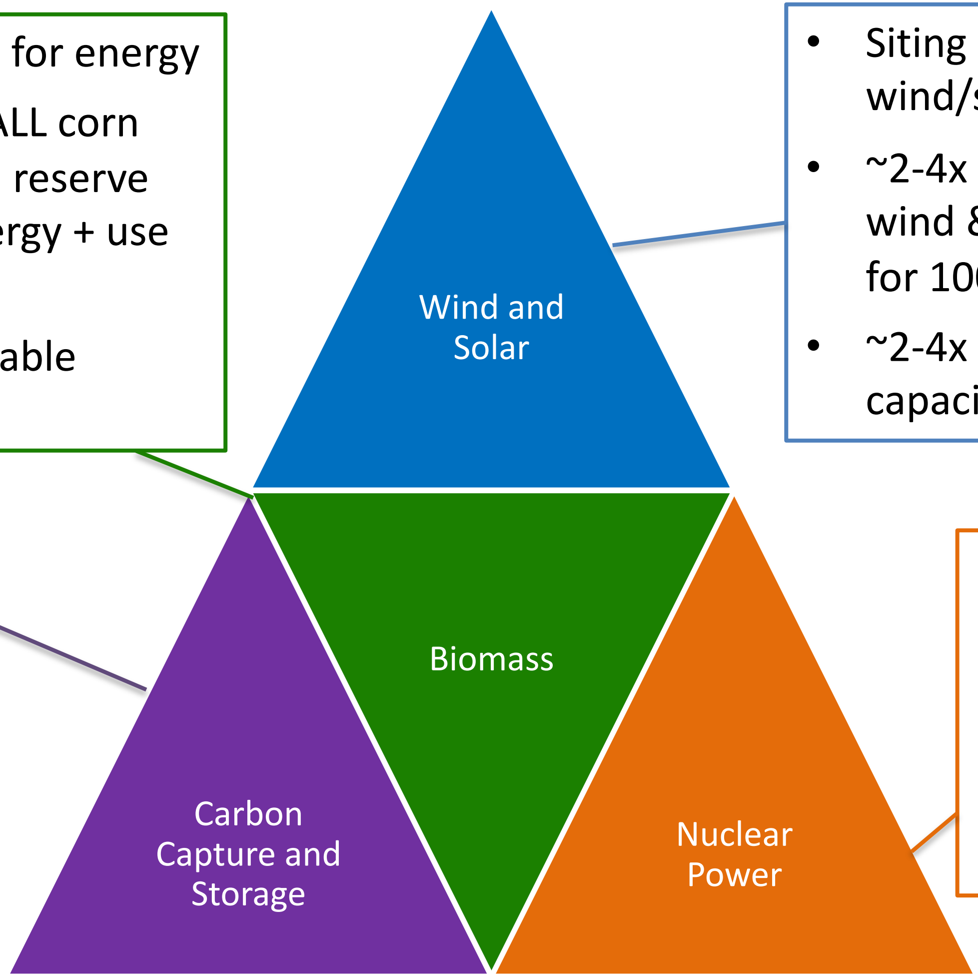
*Growth rate scaled by population for comparison purposes

Data sources: U.S. renewables from Historical per capita deployment rates from MIT 2018, The Future of Nuclear in a Carbon Constrained World, scaled to based on projected 2035 U.S. population of 364 million from U.S. Census Bureau.

Social license challenges unavoidable

- ~12-22 Quads of biomass for energy
- "Low" biomass: convert ALL corn ethanol and conservation reserve lands to high yield bioenergy + use ag/forest/muni. waste
- "High" biomass: ~all available biomass in US economy

- Siting up to ~50-200 GW of new wind/solar *annually* for decades
- ~2-4x New Jersey's land area for wind & solar siting nationwide (18x for 100% renewables cases)
- ~2-4x interstate transmission capacity



- Large new interstate CO_2 pipeline network needed
- 0.9-1.7 billion metric tons injected *annually* by 2050

- Siting up to 250 new 1,000 MW-scale reactors or 3,800 small modular reactors by 2050
- Spent fuel storage solution needed

Data source: Preliminary results, Princeton University and Evolved Energy Research, "Net Zero America Project." Net zero greenhouse gas emissions by 2050 scenarios.

The *Net-Zero America* Study

Coming soon...

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