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Getting to 100% zero-carbon power

How can we build our net-zero team of the future?

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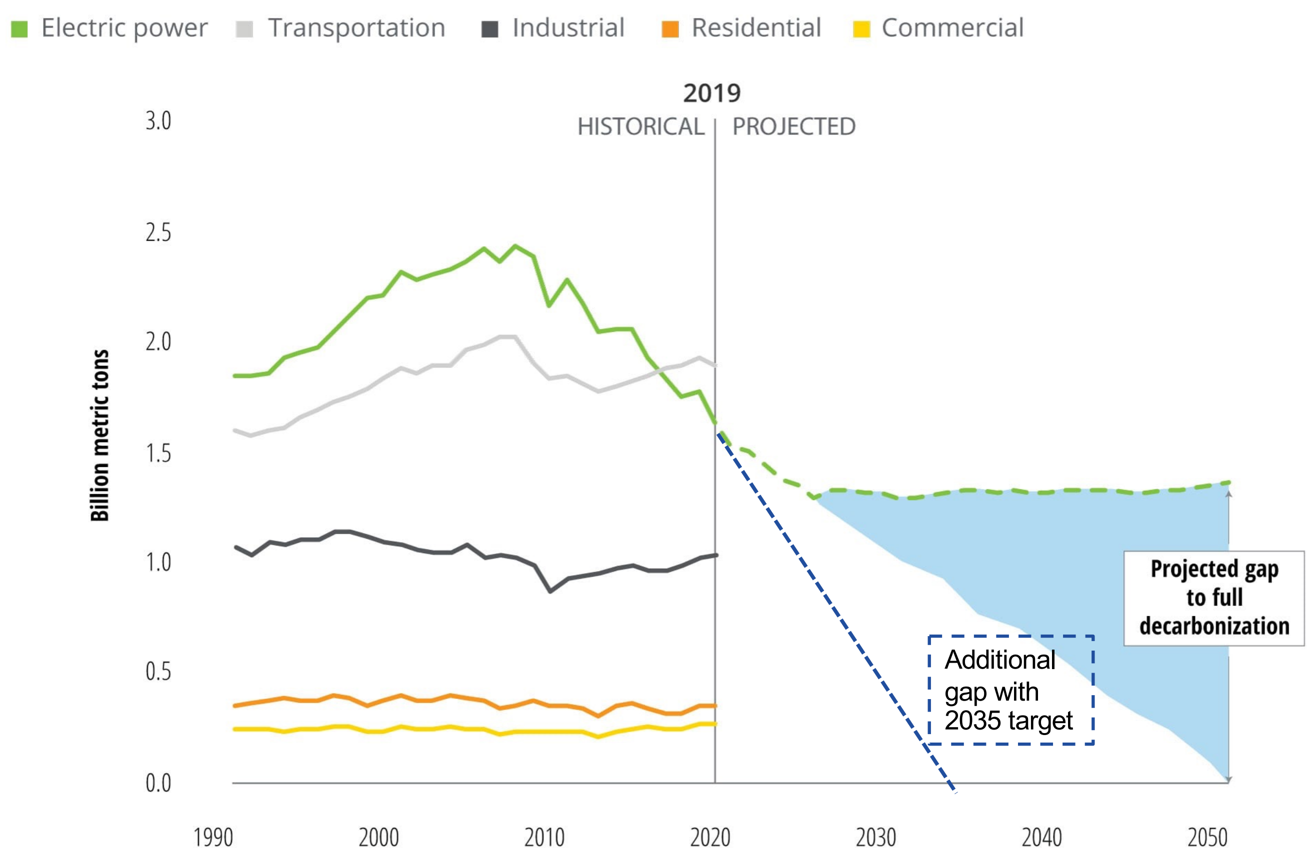
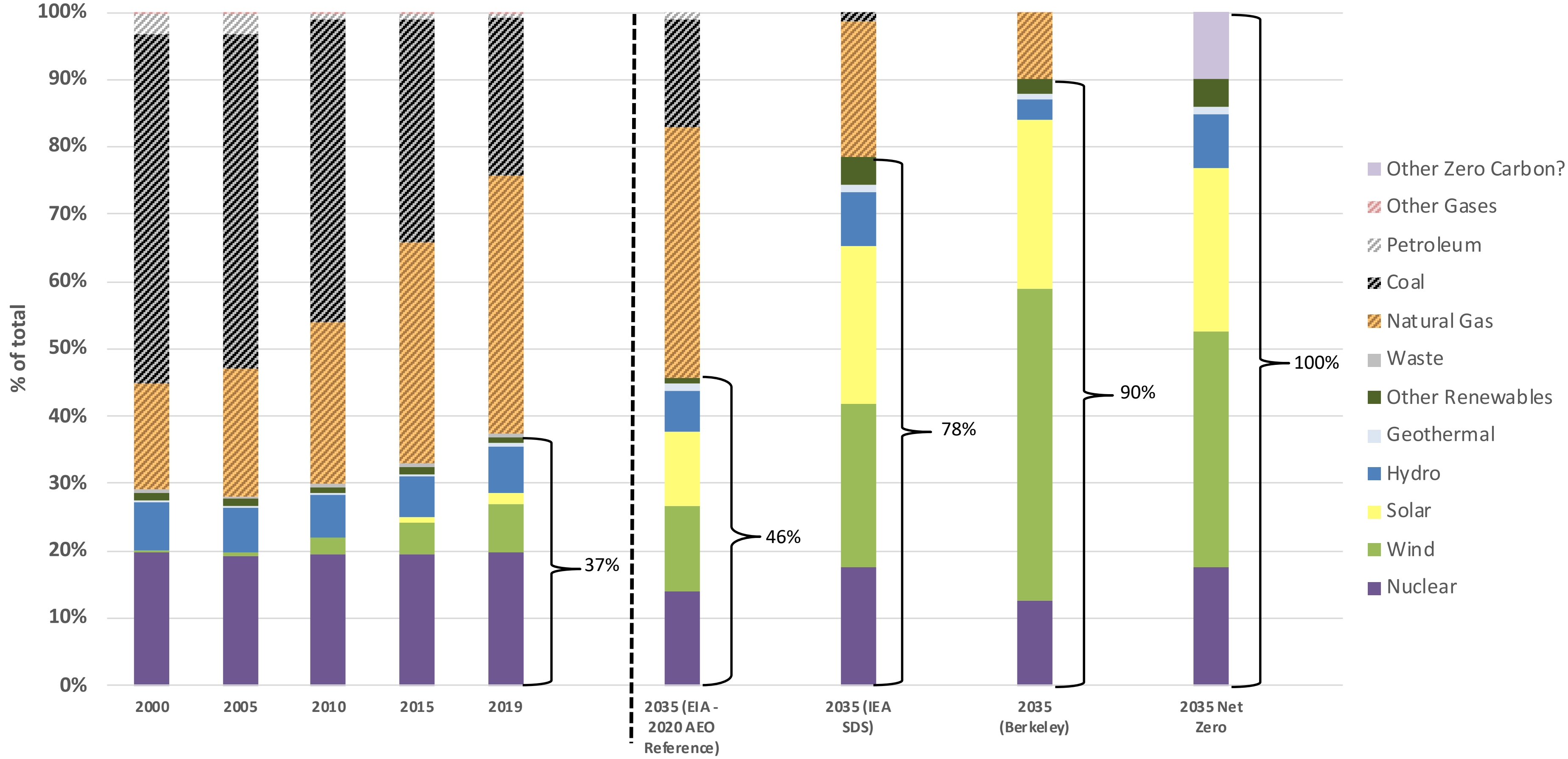
Where do we need to go to meet net-zero?

Energy-related CO_2 emissions in the USA

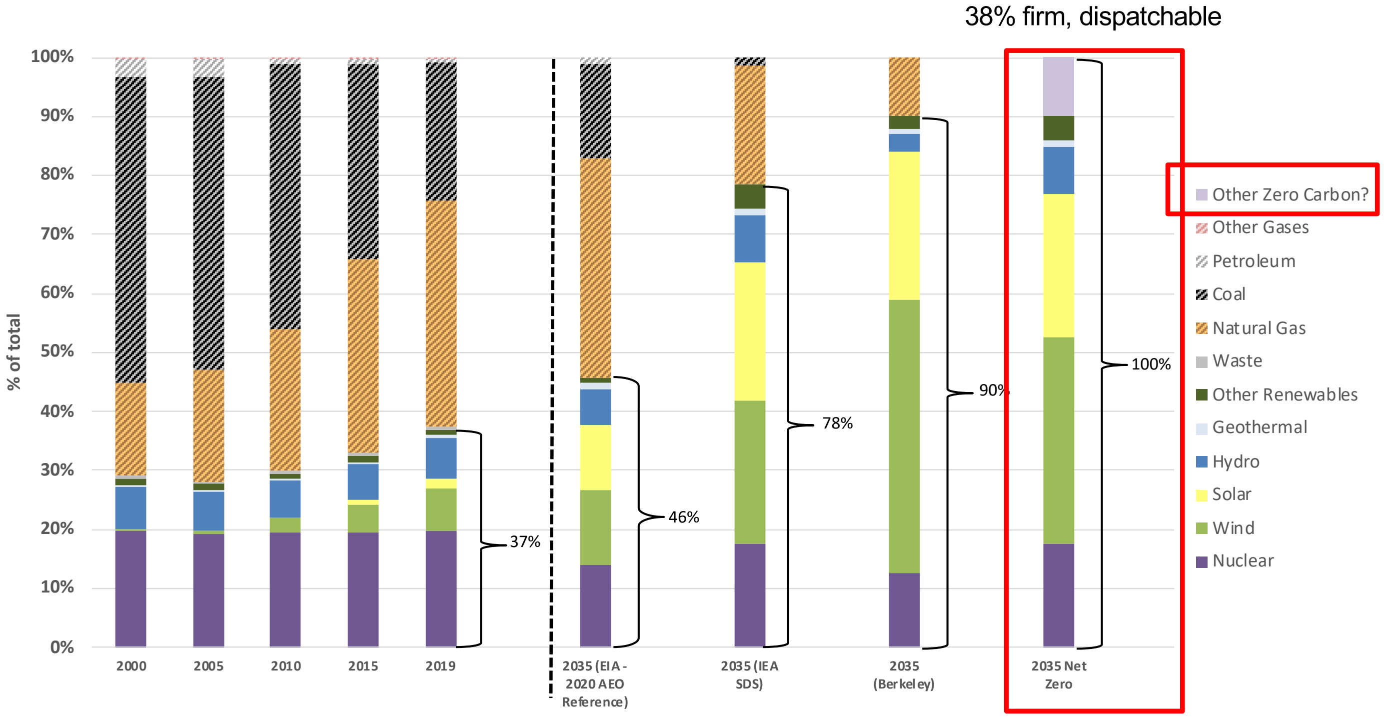


Sources: Based on EIA Annual Outlook 2020; Deloitte adaptation.

Pathways to Zero-Carbon by 2035 - Electricity Generation
Example Scenarios



Pathways to 2035 – Dealing with the gap…



Potential technology options on the horizon…

1. Advanced nuclear
2. green hydrogen + fuel cells
3. CCS retrofits on existing NGCC
4. use green hydrogen in NGCC
5. Green hydrogen derived methane in NGCC
6. Direct air capture (DAC) with other technologies
7. …

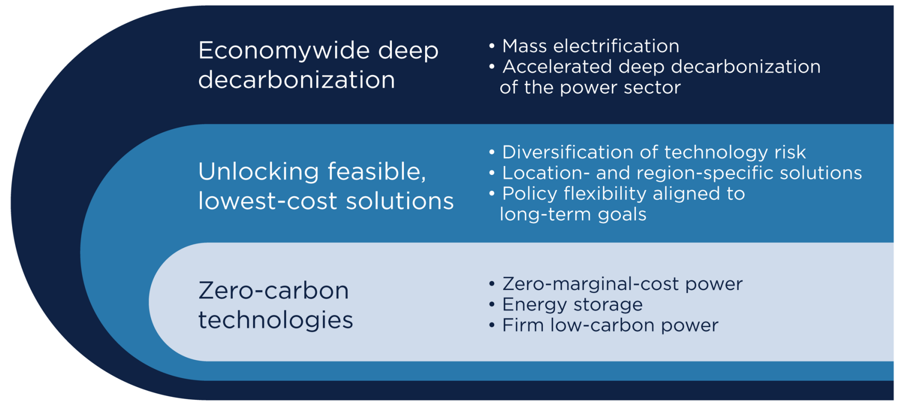
Policies, regulations + RDD&D needed to fill these gaps.

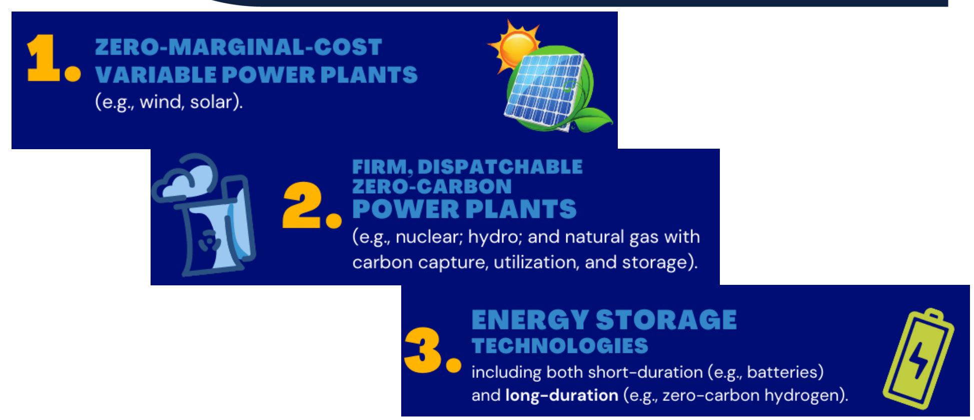
Reference: Phadke, A., Aggarwal, S. et. al. September 2020.Illustrative Pathways to achieving 100 Percent Zero Carbon Power by 2035 without Increasing Customer Costs. https://energyinnovation.org/wp-content/uploads/2020/09/Pathways-to-100-Zero-Carbon-Power-by-2035-Without-Increasing-Customer-Costs.pdf

Getting to net-zero electricity

How do we build the zero-carbon team of the future that we need?

- To get to an net-zero **economy**, we use a LOT more electricity.
- That electricity supply (i.e., our power plants) becomes zero-carbon very quickly. It leads in the energy transition.
- Scenarios and analysis show that – in order to keep our energy systems both **affordable** and **reliable** – we use a set of technologies with different characteristics in order to meet this goal.
- Variable renewables (e.g., wind and solar) play a huge role. As does energy storage (e.g., batteries). But they aren't enough if we want to keep costs low and the lights on…





Ref: Lott and Smith (2021). Energy Transition Fact Sheet: Pathways to 100% Clean Electricity
https://www.energypolicy.columbia.edu/research/article/energy-transition-fact-sheet-pathways-100-clean-electricity

How do we build the zero-carbon team of the future that we need?

Start with your strikers

(Variable) Renewables

Now add some midfielders

Energy Storage

Then add in some defenders

Firm, Dispatchable Power

And don't forget your goalie…

Carbon Removal Technologies

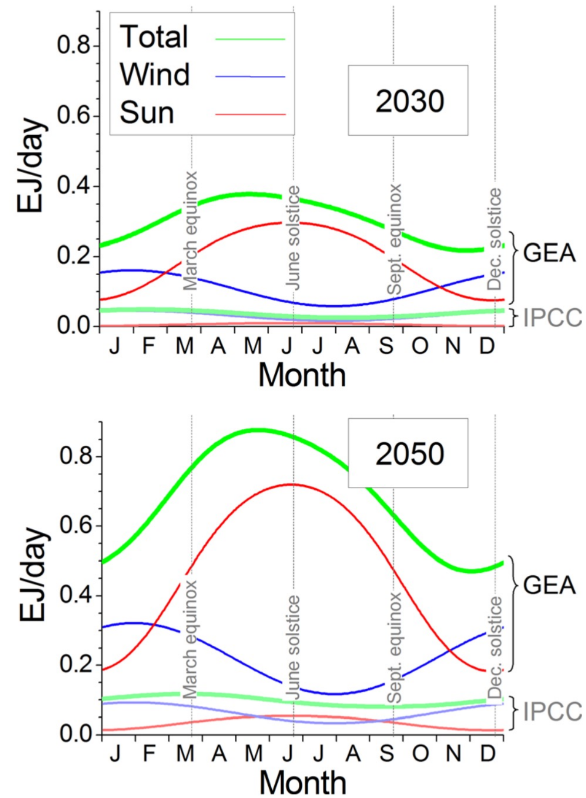
The net-zero electricity team

Each technology comes with tradeoffs, but together they make a great team

1. **Strikers: Zero-marginal-cost variable power plants (e.g., wind, solar)**
   - these technologies have no fuel costs and are frequently the cheapest source of electricity in the system. But they are not always available and so need other technologies to ensure reliability.
2. **Mid-fielders: Energy storage technologies**
   - including both short-duration (e.g., batteries) and long-duration (e.g., zero-carbon hydrogen).
3. **Defenders: Firm, dispatchable zero-carbon power plants (e.g., nuclear; hydro; and natural gas with carbon capture, utilization, and storage)**
   - These plants can provide electricity 24-7-365 in order to support the reliable supply of electricity to customers while keeping costs low.
4. **Goalie: Carbon removal technologies**
   - including direct air capture and storage.

What happens if we lose a member of the team?

Cost, impact, reliability, resilience



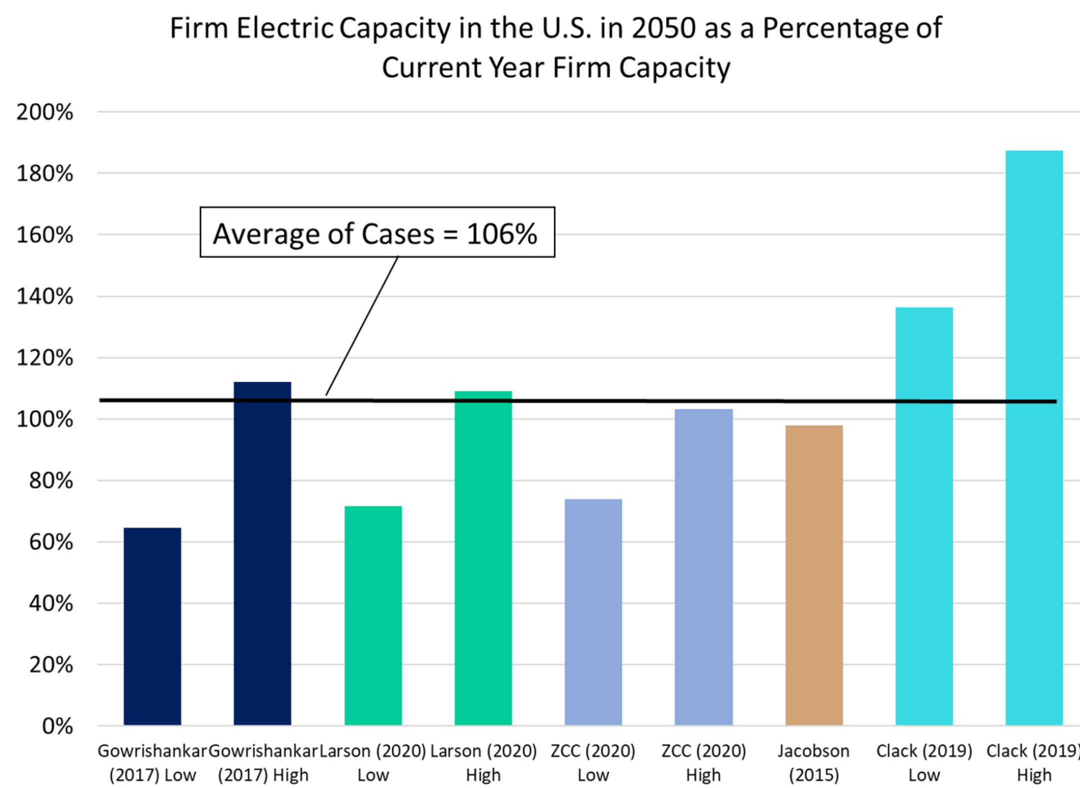
Ref: Mulder (2014 Implications of diurnal and seasonal variations in renewable energy generation for large scale energy storage. Journal of Renewable and Sustainable Energy **6**, 033105 (2014); https://doi.org/10.1063/1.4874845

"…including at least one firm low-carbon generation technology in the capacity mix **lowered the cost of zero-emissions electricity systems by 10–62%** across a range of scenarios"

~ Sepulveda, N. A., Jenkins, J. D., de Sisternes, F. J. & Lester, R. K. The role of firm low-carbon electricity resources in deep decarbonization of power generation. Joule 2, 2403–2420 (2018).

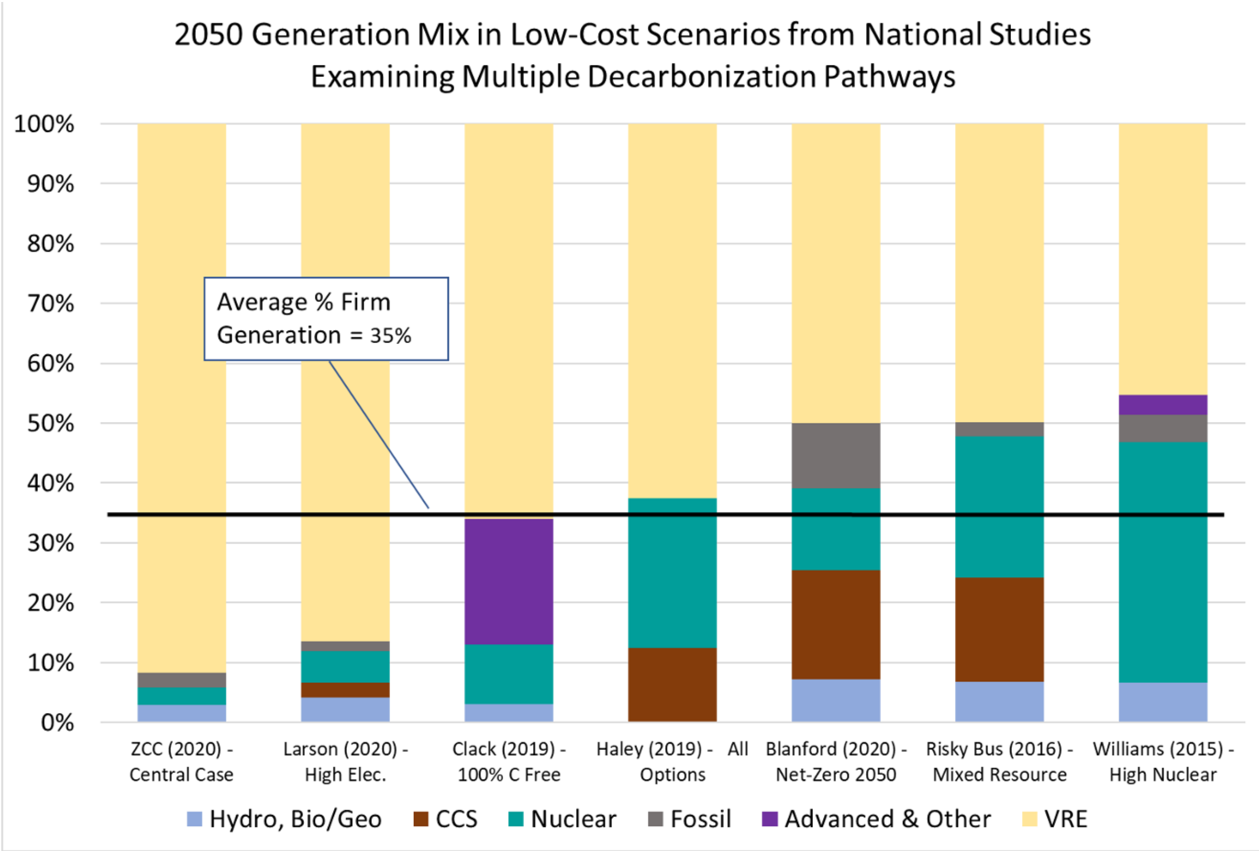
Many scenarios see a need for firm power equal to present levels

- Without firm, dispatchable power plants we see a range of concerns arise, including:
  - Rising costs: the pathway to reach net-zero quickly becomes more expensive
  - Reliability concerns: gaps between electricity supply and demand that can result in blackouts
- There are a number of technologies that can supply this firm, zero-carbon power
  - Existing technologies (e.g., nuclear, geothermal, large hydro…)
  - New technologies (e.g., advanced nuclear, fossil fuels with carbon capture and storage, hydrogen power plants…)



For nuclear, scenarios show large variations

- These scenarios show continued use of existing nuclear power plants and/or adoption of new, advanced technologies
- [How long] Will currently operating nuclear power plants stay online (early retirements and lifetime extensions)?
- Will we bring advanced nuclear technologies into the system (and what types, where)?



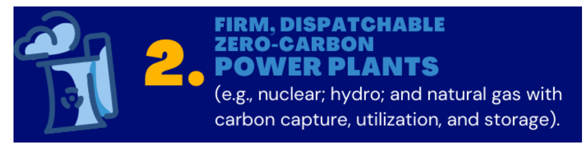
What about long-duration energy storage?

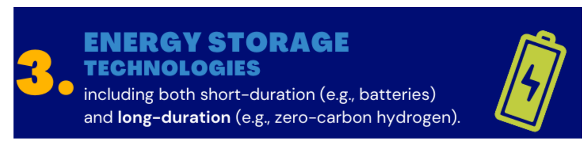
- ”Energy capacity costs must be ≤US$20/kWh to reduce electricity costs by ≥10%.”
- “With current electricity demand profiles, energy capacity costs must be ≤US$1/kWh to fully displace all modelled firm low-carbon generation technologies.”
- Geography matters: it’s more difficult (expensive) to displace firm generation in the northern parts of the USA and would require combinations of cost and performance that is “unlikely to be feasible with known LDES technologies.”
- “LDES systems with the greatest impact on electricity cost and firm generation have storage durations exceeding 100 h[ours]”

Reference: Sepulveda, Jenkins, et. al. *The design space for long-duration energy storage in decarbonized power systems*. Nature Energy. Nature Energy. 2021. https://www.nature.com/articles/s41560-021-00796-8

Key Takeaways

- Policy makers seeking paths to accelerate the transition to zero-carbon electricity can take the following concrete actions to support a rapid and affordable transition to zero-carbon power:
  - Keep existing zero-carbon technologies (e.g., nuclear power plants and hydropower facilities) operating for as long as possible.
  - Frame policies to support 100 percent **zero-carbon** power, including an array of zero-carbon technology options across the three technology pillars.
  - Support research, development, and deployment of new and improved zero-carbon technologies across the three technology pillars.
  - Support investments in the transmission and distribution grid to advance the efficient movement of zero-carbon electricity from power plants to communities.
  - Explore and establish regional collaborations





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Thank You

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