Decarbonizing Electricity: The Critical Role of Firm Low-Carbon Resources

May 15, 2020
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Webinar Speakers

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(moderator)
Decarbonizing Electricity
The Critical Role of Firm Low-Carbon Resources

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Dept. of Mechanical & Aerospace Engineering | Andlinger Center for Energy & Environment
Clean Energy States Alliance Webinar | May 15, 2020
Twin challenges: zero carbon, >double demand

(a) Total New Carbon-free Electricity Generation

(b) Annual Additions Rate (2020-2050)

Total 2020 U.S. electricity generation

Total 2020 zero-CO₂ generation


(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).

*Growth rate scaled by population for comparison purposes

Data: +35-37 average GW/year
Clean electricity growth without precedent

THE GOOD NEWS: WIND, SOLAR, BATTERY COSTS PLUMMET

A race to beat fossil fuels on cost...

“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

An Illustrative Example

Peak demand: 34 GW
Capacity factors
Wind: 28%
Solar: 24% (ac)
No storage in this example

<table>
<thead>
<tr>
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<th>Levelized cost of electricity (cents/kWh)</th>
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<tbody>
<tr>
<td>Gas</td>
<td>5</td>
</tr>
<tr>
<td>Wind</td>
<td>4</td>
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<tr>
<td>Solar</td>
<td>2</td>
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<td>Clean Firm</td>
<td>7</td>
</tr>
</tbody>
</table>
Net peak: September 8th 5pm

33 GW firm capacity needed

34 GW demand peak

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

Clean firm
Gas
Wind & Solar
Over-generation
Demand

Wind & Solar
Gas
Clean firm
Over-generation
Demand

Clean Energy Share: 20%
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Clean Energy Share: 20%
Wind Energy Value: 100%
Solar Energy Value: 100%
Wind Capacity Value: 9%
Solar Capacity Value: 4%
Over-generation: 0%
Over-generation: 3%
Clean Energy Share: 40%
Wind Energy Value: 91%
Solar Energy Value: 77%
Wind Capacity Value: 9%
Solar Capacity Value: 4%
Net peak: September 8th, 5pm
Clean firm capacity needed: 32 GW
34 GW demand peak
32 GW firm capacity needed
Clean Energy Share: 60%
Wind Energy Value: 72%
Solar Energy Value: 59%
Over-generation: 7%
Wind Capacity Value: 2%
Solar Capacity Value: 2%

Net peak: August 19th, 6pm

Clean Energy Share: 60%
Wind Energy Value: 72%
Solar Energy Value: 59%
Over-generation: 7%
Wind Capacity Value: 2%
Solar Capacity Value: 2%

34 GW demand peak
31 GW firm capacity needed
Over-generation 28%

Wind Capacity Value 2%

Solar Capacity Value 2%

Net peak: August 19th 6pm

Clean Energy Share 80%

Wind Energy Value 25%

Solar Energy Value 20%

30 GW firm capacity needed

34 GW demand peak

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

Clean Energy Share: 80%
Wind Energy Value: 43%
Solar Energy Value: 34%
Over-generation: 11%
Wind Capacity Value: 2%
Solar Capacity Value: 2%

30 GW firm capacity needed
34 GW demand peak
“Fast burst” balancing resources

“Fuel saving" variable renewables

“Firm” low-carbon resources

- Solar PV
- Solar thermal
- Wind energy
- Run-of-river hydro
- Solar thermal with storage
- Reservoir hydro
- Geothermal
- Nuclear
- Gas or coal w/CCS
- Zero carbon fuels
- Biomass
- Nuclear
- Gas or coal w/CCS
- Zero carbon fuels
- Biomass
- “Flexible base”
- Flexible demand (rescheduling)
- Battery storage
- Long-duration storage
- Demand response (price responsive curtailment)
A Race Between Declining Cost & Value
A RACE AGAINST DECLINING VALUE (SOLAR PV)

Solar PV average market value ($/MWh)

Solar PV market share (% of total annual energy)

- Germany (Hirth, 2013)
- California (Mills & Wiser, 2012)
- Texas (MIT Future of Solar Study, 2015)

2018 estimated solar PV levelized cost ($43/MWh)

Solar cost estimate for 2018 from Lazard (2018) op. cit. above.
1. Declining “fuel-saving” value (energy substitution)

2. Decreasing “capacity value” (capacity substitution)

3. Increasing “over-generation” (energy that must be stored or wasted when supply exceeds demand)

Additional factors (aka “integration costs”): Increasing flexibility, ramping and reserve requirements; thermal plant cycling costs; transmission network costs
A RACE AGAINST DECLINING VALUE (ENERGY STORAGE)

Energy storage average system value ($/kWh installed)

CO₂ Emissions Rate Limit (g/kWh)
- 150
- 100
- 50

Energy storage power capacity (% of peak system demand)

2018 estimated Li-ion storage installed cost ($330/kWh)

~64-77 percent below 2018 costs

1. “Niche” markets fill quickly for regulation & reserves

2. Increasing energy storage (longer duration) needed to maintain capacity substitution value

3. Reduced energy arbitrage (buy-sell) spread

4. Declining utilization rate
In the near-term, wind, solar, batteries (and coal to natural gas transition) can drive emissions reductions.
Fully decarbonizing electricity requires firm low-carbon substitutes for natural gas and retiring nuclear units.
The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation

Nestor A. Sepulveda • Jesse D. Jenkins • Fernando J. de Sisternes • Richard K. Lester

Published: September 08, 2018 • DOI: https://doi.org/10.1016/j.joule.2018.08.006

Highlights

- Firm low-carbon resources consistently lower decarbonized electricity system costs
- Availability of firm low-carbon resources reduces costs 10%–62% in zero-CO₂ cases
- Without these resources, electricity costs rise rapidly as CO₂ limits near zero
Average cost of electricity ($/MWh) vs. CO₂ emissions limit (g/kWh) for the Northern System.

One Possible Balanced Portfolio

- **Firm Low-carbon Resources** ("Flexible Base")
- **Fuel Saving Resources**
- **Fast Burst Resources**
Without Firm Low-Carbon Resources

Note 2x increase in y-axis scale

Fast Burst Resources

Fuel Saving Resources
Solar, wind & batteries will be stars...
...but firm resources complete the team
Carbon Capture and Storage
Zero Carbon Fuels

Image: Mitsubishi Heavy Industries
Hydropower with Large Reservoirs
Enhanced Geothermal Energy Systems
What about storage?
The *Dunkelflaute* ("Dark Doldrums")
Western Interconnection, Renewables + Storage Only
(24 hour rolling average power)

- **Wind, Solar, Hydro**
- **Demand**

- **68 days**
- **35 days**
Long Duration Storage Needed for Renewables + Storage Only Western Interconnection, 0 CO$_2$ emissions limit

(24 hour rolling average power)
Long Duration Storage Needed
Western Interconnection, Renewables + Storage Only
(24 hour rolling average power)

- H2 Storage State of Charge

33 terawatt-hours

2.4 billion Tesla Power Walls

Data source: Unpublished results, Jesse D. Jenkins, GenX model, Western Interconnection.
A very different kind of storage...

**ENERGY STORAGE**

**Long Duration Breakthrough? Form Energy’s First Project Tries Pushing Storage to 150 Hours**

Minnesota utility Great River Energy will use new storage technology from the Bill Gates-backed startup to replace coal power with dispatchable wind.

**JULIAN SPECTOR | MAY 07, 2020**

**ENERGY STORAGE**

**Utah Aims to Shatter Records With 1,000MW Energy Storage Plant**

The one-of-a-kind facility would combine compressed air storage in salt caverns with hydrogen storage, large flow batteries and solid-oxide fuel cells.

**JULIAN SPECTOR | MAY 30, 2019**
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UT Austin Energy Symposium Lecture, “Getting to Zero: What will it take to decarbonize electricity?” Watch: [https://www.youtube.com/watch?v=F3YMIzK8d0o](https://www.youtube.com/watch?v=F3YMIzK8d0o)

Thank you for attending our webinar

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Replacing New York City’s Dirty Peaker Power Plants with Renewables and Battery Storage
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