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Explained: Causes of Three Recent Major Blackouts and What Is Being Done in Response

Maintaining reliability of the bulk power system, which supplies and transmits electricity, is a critical priority for electric grid planners, operators, and regulators. Based on the standards set by power system reliability entities, the U.S. grid has been—and continues to be—very reliable. Over the past decade, the average U.S. customer has only experienced about 15 minutes of outages per year due to supply limitations of the bulk power system. Recent major blackouts were largely caused by extreme weather conditions that are increasingly impacting the ability of the power system to provide reliable electricity. This trend was reflected in the 2022 Long-Term Reliability Assessment by the North American Electricity Reliability Corporation (NERC) that stated: "Extreme temperatures and prolonged severe weather conditions are increasingly impacting the [bulk power system]."[1]

Though the power grid is designed to have an adequate supply of electricity generating capacity under weather conditions well outside average conditions, weather in recent years has exceeded the bounds of anticipated conditions—in both magnitude and duration. And extreme weather can result in unanticipated levels of electricity demand and correlated power plant outages driven by extreme temperatures.[2] How power system planners account for the changing role of wind and solar also plays an important role

[1] NERC (North American Electric Reliability Corporation). 2022 *Long-Term Reliability Assessment* (December 2022), https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2022.pdf.

[2] ESIG (Energy Systems Integration Group). Redefining Resource Adequacy for Modern Power Systems (2021), A Report of the Redefining Resource Adequacy Task Force. Reston, VA: ESIG. https://www.esig.energy/resource-adequacy-for-modern-power-systems/.

in the power grid's ability to supply enough electricity during extreme weather.

In response to recent significant outages, power system planners are focused on implementing methods to evaluate reliability during periods of net peak demand[3] and during extreme weather events. Planners have emphasized the need to evaluate the availability of power plants of all types, including renewable resources, and the ability of natural gas-fueled power plants to operate during periods of extreme cold temperatures.

The need for improved planning processes is evident when examining causes of three significant outages that occurred in 2020, 2021, and 2022.

2020 Western Heat Wave Event

On August 14, 2020, during a period of extreme heat, the California Independent System Operator (CAISO) was forced to shed up to about 2% of its firm demand, or about 1,000 megawatts (MW), for about 2.5 hours, affecting about 500,000 customers, with about 1.5 hours of outages the following day.[4] Three main factors were identified leading to a shortfall of supply:

- Extreme heat impacted not only California but surrounding regions as well, and temperatures stayed high for several days in a row, keeping demand high. Temperatures were 15°F to 30°F above normal, and many areas in the western United States broke daily heat records.[5] This caused electricity demand to increase by about 4.6% (2,000 MW) higher than the annual forecasted peak. The temperature also reduced the efficiency and availability of thermal generators such as natural gas.[6]
- The planning process did not fully account for the need to plan for the early evening hours and not just the peak demand hours. This time period was critical during the event because that is the time that solar generation is declining while demand from cooling loads is still elevated.
- Other factors led to the shortfall of supply, including how the generation and transmission system was operated, leading to underutilization of energy storage, demand response, and available resources outside of California.[7]

Cause: High demand and generator outages caused by extreme heat, planning issues, and other factors like generation and transmission operations

Response: Changes to the planning process, such as how solar can contribute to meeting peak demand, increased planning reserve margin, and additional capacity, including energy storage added

While there were several root causes, the challenge of planning for evening peaks represents an important change in systems with greater solar deployment. This challenge, including how it has now been addressed in California to prevent future issues, is discussed in more detail below.[8]

Traditional planning for reliability focuses on the contribution of resources during the hour of highest demand. When solar makes up a small fraction of total energy supply, its contribution during the summer peak can be quite high. However, as the contribution of solar increases, its ability to reduce the remaining or "net" peak drops, because it shifts the net peak from the late afternoon to the early evening, when solar generation is lower.

Figure 1 demonstrates why the evening period is important to consider in the planning process, and shows the load, supply of wind and solar, and net load10 during the event. On August 14, 2020, at the overall peak at 4:56 p.m., solar was producing more than 7,500 MW and contributing significantly to meeting demand. However, at 6:51 p.m., solar output had dropped more than 5,000 MW, and although the load had also dropped, the reduction in solar output was greater than the reduction in normal demand due to the extreme heat increasing cooling load into the night.[9]

California grid operators and planners recognized importance of the evening hours well before the 2020 event, but the process used at the time still over-estimated solar's ability to meet evening load.[10] For example, in February 2019, regulators proposed for the following year a significant reduction

[3] Net peak represents the peak demand period considering the contribution of renewable resources.

[4] CAISO. *Final Root Cause Analysis: Mid-August Extreme Heat Wave* (January 2021), http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf.

[5] WECC (Western Electricity Coordinating Council). August 2020 Heatwave Event Analysis Report (March 19, 2021), https://www.wecc.org/Reliability/August%202020%20Heatwave%20Event%20Report.pdf.

[6] CAISO. *Final Root Cause Analysis: Mid-August Extreme Heat Wave* (January 2021), http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf.

[7] Both energy storage and demand response were underutilized, possibly in part due to how the CAISO market schedules operations. Other factors include a scheduling error that resulted in a 248-MW reduction in the output of a natural gas plant. These factors are largely unrelated to deployment of wind, solar, or any other type of generation resource, and they more generally point to the continued need to assess means to ensure reliability in day-to-day operations.

[8] NERC. *2020 Summer Reliability Assessment* (June 2020), https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SRA_2020.pdf

[9] As part of the resource adequacy process, CAISO also evaluates the need for capacity to ramp (i.e., vary output) in response to the decline in solar output in the hours before sunset. CAISO. *Final Flexible Capacity Needs Assessment for 2023* (May 17, 2022), http://www.caiso.com/InitiativeDocuments/Final2023FlexibleCapacityNeedsAssessment.pdf.

[10] In 2020, solar supplied about 13% of the state's electricity demand, not including the significant contribution of behind-the-meter (largely rooftop) solar. California Energy Commission. "2020 Total System Electric Generation." https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2021-total-system-electric-generation/2020.

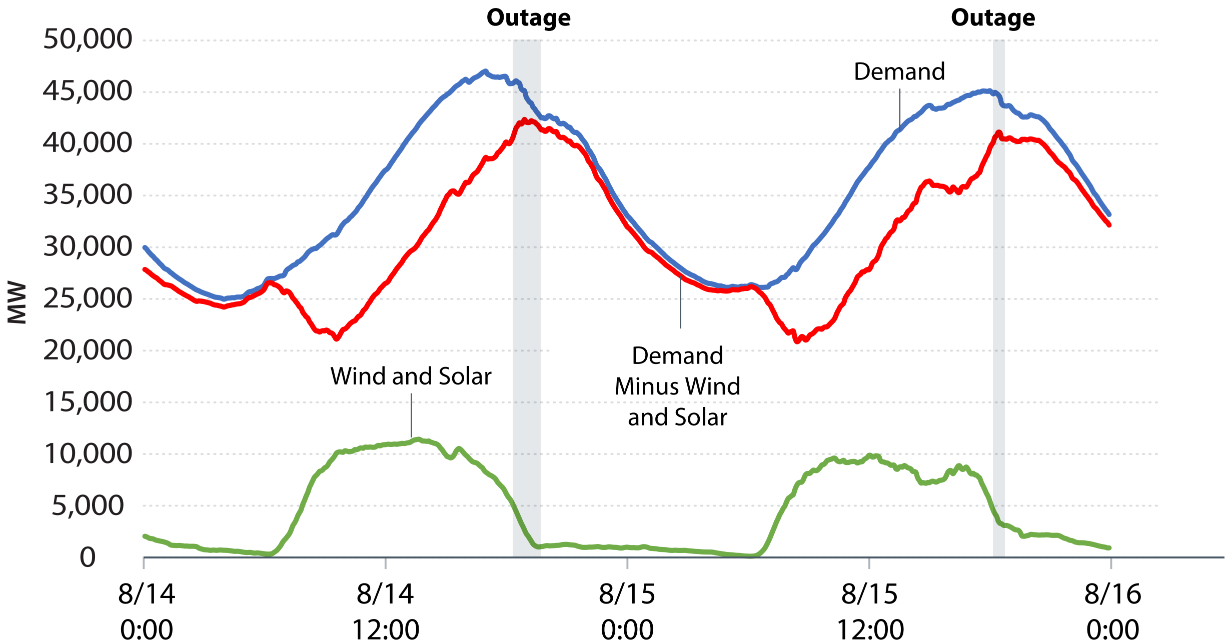

Figure 1. Actual impact of solar on net load in CAISO during the August heat event[13]

in the assumed contribution of solar to meeting peak demand. However, because of the lag in the planning process, the contribution of solar toward meeting demand was overestimated compared to what was available during the event.[11]

Since the event, California regulators have further decreased the assumed contribution of solar (without storage) to serving peak demand, and the State of California has also increased its generator reserve margin (a measure of reliability planning discussed in a fact sheet on reliability of the future grid).[12] There has been significant deployment of energy storage capacity with additions of more than 4,000 MW (significantly more than the load shed during the 2020 event) completed from 2021–2022. Overall, since 2020, available generation capacity for the 2023 summer peak season (including storage) increased by more than 11,000 MW.

2021 Cold Weather Event (Winter Storm Uri)

From February 8 through February 20, 2021, the southcentral United States experienced a cold weather event, and the largest impacts occurred in the Texas (Electric Reliability Council of Texas, or ERCOT) grid.[14] The event resulted in the largest controlled load shed in U.S. history: an estimated peak of 20 GW and total 1,016 gigawatt-hours (GWh) of load shed (compared to a peak of about 1 GW and total energy of about 4 GWh in the western heat wave event). More than 4.5 million people in Texas lost power for as long as 4 days.[15]

Two primary factors impacted the event: increased demand driven by extreme temperatures and correlated outages of generators.[16]

Cause: High demand and generator outages due to extreme cold

Response: Several actions to improve winter power plant performance, including weatherization standards and back-up fuel requirements

The NERC 2020-2021 Winter Reliability Assessment report anticipated an extreme peak demand of about 67.2 GW.[17] But the actual (estimated) peak load on February 14, 2021, was about 76.8 GW, or about 10 GW higher than the extreme peak demand forecast.[18]

[11] CPUC (California Public Utilities Commission). *Decision Adopting Local Capacity Obligations for 2020-2022, Adopting Flexible Capacity Obligations for 2020, and Refining the Resource Adequacy Program* (July 25, 2019), Rulemaking 17-09-020. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M309/K463/309463502.PDF.

[12] CPUC. *Incremental ELCC Study for Mid-Term Reliability Procurement* (August 31, 2021), https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/integrated-resource-plan-and-long-term-procurement-plan-irp-ltpp/20210831_irp_e3_astrape_incremental_elcc_study.pdf.

[13] Data are from CAISO (https://www.caiso.com/todaysoutlook/Pages/supply.html) and are supplemented by data from the event report: CAISO. *Final Root Cause Analysis: Mid-August 2020 Extreme Heat Wave* (January 2021), http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf.

[14] This event is sometimes referred to as Winter Storm Uri: FERC (Federal Energy Regulatory Commission). *The February 2021 Cold Weather Outages in Texas and the South Central United States: FERC, NERC and Regional Entity Staff Report* (November 2021), https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and.

[15] This number is the number of individuals—not customers—so, it is not directly comparable to the numbers described previously for the CAISO (2020 heat wave) event.

[16] Other factors mitigated the impact of the winter event outside Texas, including market consideration and connections to other regions.

[17] NERC. 2020–2021 *Winter Reliability Assessment*. (November 2020.) https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2020_2021.pdf

[18] The peak is estimated because of the outages. The actual recorded peak was about 69.9 GW.

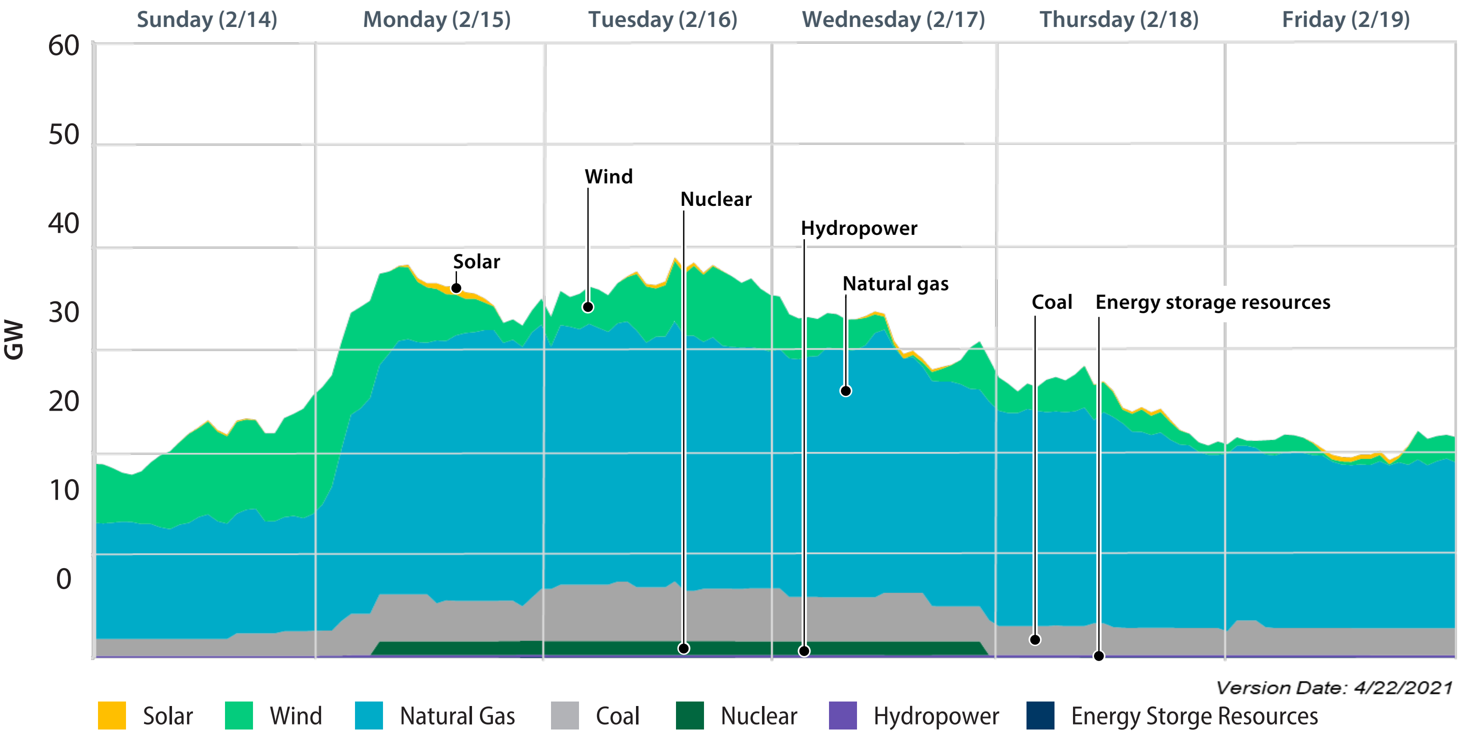

Figure 2. Net generator outages in ERCOT during the 2021 event[20]

In addition to higher than anticipated demand, there was a significant loss of generation resources due to concurrent outages of natural gas and other fossil fuel generators. The planning process traditionally assumes a limited degree of correlated outages, meaning the failure of any given generator is assumed to be largely independent of other generator failures. During extreme weather events, correlated outages are more likely, such as when pipelines and power plant equipment freezes in cold weather, resulting in outages of natural gas-fueled plants at much greater rates than the 5%-10% levels often assumed in planning.[19]

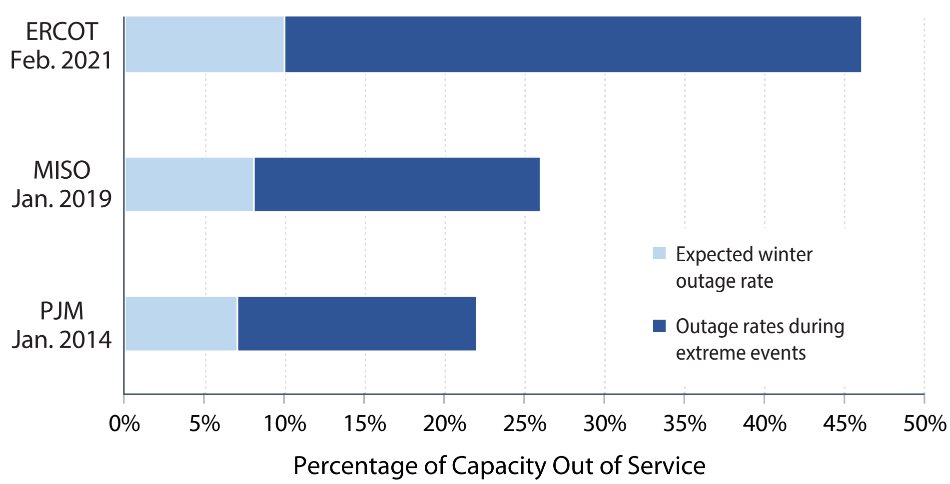

Figure 3. Correlated outages of power plants during extreme weather[21]

Figure 2 shows the outages of all generator types in ERCOT during the cold weather event. A total of 160 natural gas-fueled plants totaling more than 25 GW were unavailable or operating at reduced output. Though most of the capacity affected was fossil-fueled generation, the lack of winterization also reduced the availability of wind capacity.[22]

Figure 3 shows the overall outage rate for all generators experienced during the event, which reached over 45% across all unit types. Figure 3 also shows that this type of impact has been observed before in other regions, but to a lesser degree (ERCOT also had correlated outages in 2011 and 2014, but the severity of the 2021 event exceeded these previous events).

The 2021 event clearly points to the need to consider the impact of extreme weather-driven correlated outages and

[19] Murphy, Sinnott, Fallaw Sowell, and Jay Apt. "A Time-Dependent Model of Generator Failures and Recoveries Captures Correlated Events and Quantifies Temperature Dependence." *Applied Energy* 253 (2019): 113513. https://doi.org/10.1016/j.apenergy.2019.113513.

[20] ERCOT. *Update to April 6, 2021 Preliminary Report on Causes of Generator Outages and Derates During the February 2021 Extreme Cold Weather Event* (April 27, 2021), https://www.ercot.com/files/docs/2021/04/28/ERCOT_Winter_Storm_Generator_Outages_By_Cause_Updated_Report_4.27.21.pdf.

[21] The figure includes all technology types. Energy Systems Integration Group. 2021. *Redefining Resource Adequacy for Modern Power Systems*. A Report of the Redefining Resource Adequacy Task Force. Reston, VA. https://www.esig.energy/reports-briefs.

[22] The actual capacity of wind impacted was higher, but the net outage rate in this figure accounts for the derate of wind expected during this period.

appropriate winterization precautions. Many colder climate regions of the United States tend to experience lower plant outage rates than what occurred during the 2021 event, even during significantly colder conditions, demonstrating the ability of generation equipment to maintain capabilities during extreme cold weather.[23]

Since the event, regulators, grid operators, and system planners have taken several actions to improve winter power plant performance. These include implementing power plant weatherization standards and back-up fuel requirements.[24] These actions are "expected to reduce generator outages in extreme conditions to reduce the likelihood of energy emergencies as well as to mitigate impacts to firm load should an energy emergency occur."[25]

2022 Winter Storm Elliot

Winter Storm Elliot, which occurred from December 23 to December 25, 2022, resulted in interruptions in several parts of the Southeast and impacted about 2.1 million customers.[26,27] Total firm load shed exceeded 5,000 MW, with individual customer interruptions ranging from a few minutes to nearly 8 hours.[28]

Cause: High demand and generator outages due to extreme cold

Response: Proposals for new standards for power plant cold weather performance, and legislation at the state and federal level to establish rules for gas supply reliability

Like the 2021 cold weather event, the primary cause of customer interruptions was high demand and correlated outages of fossil-fueled (primarily natural gas) power plants. Temperatures in some regions were 25 to 30 degrees below normal low temperatures. Outages of power plants was as high as about 90,000 MW throughout the region, with about 63% of all outages occurring at natural gas-fueled plants, and 23% coal. Natural gas plant outages resulted from both a lack of fuel supply and equipment failures at the plants. In the PJM region[29] (which did not shed load) outage rates were more than three times the outages expected under extreme conditions based on NERC estimates[30] and PJM estimates about $1.8 billion in "non-performance charges" associated with these high outage rates.[31] PJM also stated, "wind and solar resources performed as the near-term forecasts projected."

In response to this event, NERC stated, "This storm underscores the increasing frequency of significant extreme weather events (the fifth major winter event in the last 11 years) and underscores the need for the electric sector to change its planning scenarios and preparations for extreme events."[32] Recommendations from the Joint Staff Inquiry include revised NERC standards for power plant cold weather performance, and legislation at the state and federal level to establish rules for gas supply reliability.[33]

Learn more about reliability of the current grid by visiting https://www.nrel.gov/fy24osti/87297. Learn about maintaining a reliable future grid with lots of wind and solar by visiting https://www.nrel.gov/docs/fy24osti/87298.

Want to learn even more? Take a deeper dive into grid reliability by visiting https://www.nrel.gov/docs/fy24osti/85880.

[23] Outside Texas, the outage rate during the winter event was much lower due to a variety of factors, including greater experience with cold temperatures. In those other regions, about 52 plants totaling 10 GW of capacity were affected, and 3,418 MW of firm load were shed on February 15 and 16, mostly in the Southwest Power Pool and Midcontinent Independent System Operator regions.

[24] NERC. 2022–2023 *Winter Reliability Assessment* (November 2022), https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2022.pdf.

[25] NERC. 2022–2023 *Winter Reliability Assessment* (November 2022), https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2022.pdf.

[26] NERC. "FERC, NERC to Open Joint Inquiry into Winter Storm Elliott." December 28, 2022. https://www.nerc.com/news/Pages/FERC,-NERC-to-Open-Joint-Inquiry-into-Winter-Storm-Elliott.aspx

[27] NREC. 2023 *State of Reliability Overview: Assessment Overview of 2022 Bulk Power System Performance*. June 2023. https://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/NERC_SOR_2023_Overview.pdf.

[28] https://www.ferc.gov/news-events/news/presentation-ferc-nerc-regional-entity-joint-inquiry-winter-storm-elliott

[29] The PJM region serves all or part of 13 states and the District of Columbia including much of the Mid-Atlantic region. "About PJM ," https://www.pjm.com/about-pjm.

[30] Outages expected under extreme conditions were about 17.6 GW according to the 2022–2023 winter assessment published shortly before the event. NERC. 2022–2023 *Winter Reliability Assessment* (November 2022), https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2022.pdf.

[31] PJM. *Winter Storm Elliott Event Analysis and Recommendation Report* (July 17, 2023), https://pjm.com/-/media/library/reports-notices/special-reports/2023/20230717-winter-storm-elliott-event-analysis-and-recommendation-report.ashx

[32] NERC. "FERC, NERC to Open Joint Inquiry into Winter Storm Elliott." December 28, 2022. https://www.nerc.com/news/Pages/FERC,-NERC-to-Open-Joint-Inquiry-into-Winter-Storm-Elliott.aspx

[33] https://www.ferc.gov/news-events/news/presentation-ferc-nerc-regional-entity-joint-inquiry-winter-storm-elliott

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