THE FEBRUARY 2021

EXTREME COLD AND ENSUING TEXAS POWER SUPPLY FAILURE

WHITE PAPER

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BACKGROUND

The historic extreme cold weather from the 14th through the 16th of February 2021 saw power shortages impact five million Texans at the peak of the event. An extreme Arctic airmass persisted over the middle of the United States and slowly spread south and east leading to the historic power shortage event and which broke over 3,000 cold temperature records and set nearly 80 all-time cold temperature records across the nation's mid-section. The state low the morning of February 13th in Minnesota was -50 which is a new record. During the event, snow fell in Mexico and on the Gulf Coast of Texas while locations in Mississippi went without power for three weeks. The forecast of this airmass moving south and east was well documented by weather models, however the extremity of the air mass in terms of record low readings was under forecast. In this paper we'll review the weather conditions that contributed to the ERCOT event, what caused renewable power plants across Texas to lose some or all of their production, and what could have been done to mitigate the event and discuss the likelihood of it happening again.

ANALYSIS OF WEATHER CONDITIONS LEADING TO THE EVENT

The extreme cold did not arrive with the speed of an Indy car, but rather trudged southward more like a slow-moving train. As early as one week before the arctic blast took foothold in Texas, the culprit was lurking in the northern plains. Figure 1 shows the afternoon surface weather map for February 6th. The surface map depicts single digit temperatures in Nebraska and Iowa with the leading edge of the cold air reaching northern Oklahoma. Temperatures remained mild in Texas for early February.

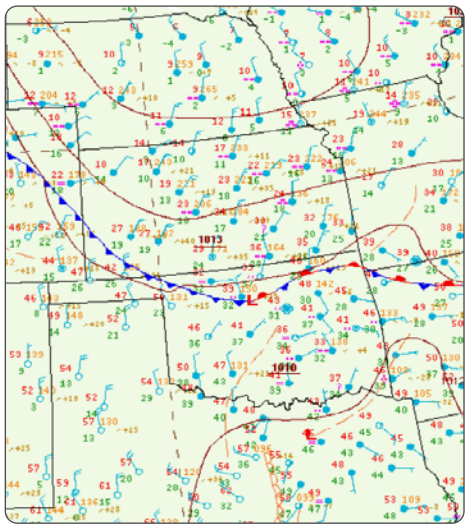

Figure 1 (WPC, 1 pm Saturday, February 6th 2021)

A short 48 hours later on Monday afternoon February 8th, figure 2 shows the cold airmass has plunged into the Texas Panhandle and freezing fog would soon commence. The icing conditions that developed will be addressed in the next section. Notice temperatures in the middle of the afternoon across Nebraska and Iowa are near zero so the airmass was not modifying in any way.

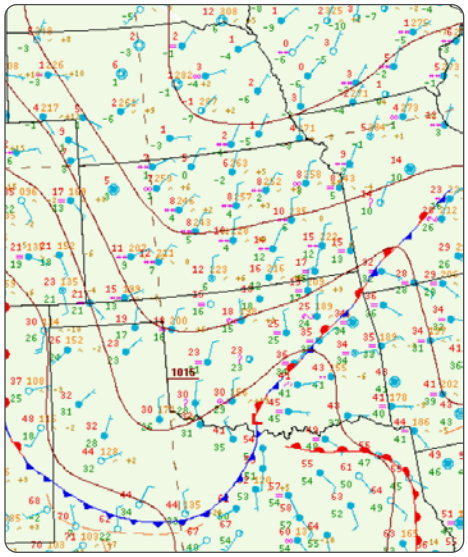

Figure 2 (WPC, 1 pm Monday, February 8th, 2021)

Fast forward another 48 hours to February 10th and you can see from figure 3 the cold air has plunged into north Texas. The area circled in blue represents a large area of freezing drizzle and freezing fog. Conditions that can quickly add up to impact a wind turbines effectiveness in capturing maximum wind.

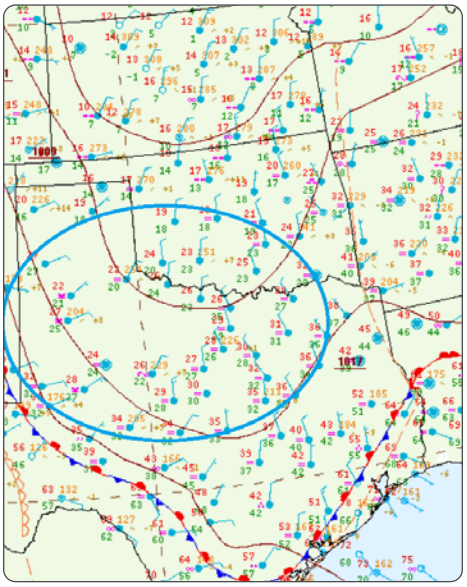

Figure 3 (WPC, 1 pm Wednesday, February 10th, 2021)

Figure 4 brings us to Friday afternoon February 12th, the doorstep of the power crisis. The area circled in blue outlines a general region of freezing fog and freezing drizzle. You can see that most of the northern half of Texas is experiencing those conditions which was a very uncommon experience.

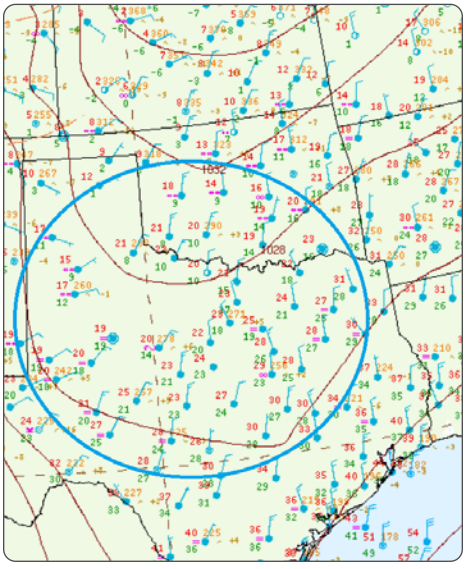

Figure 4 (WPC, 1 pm Friday, February 12, 2021)

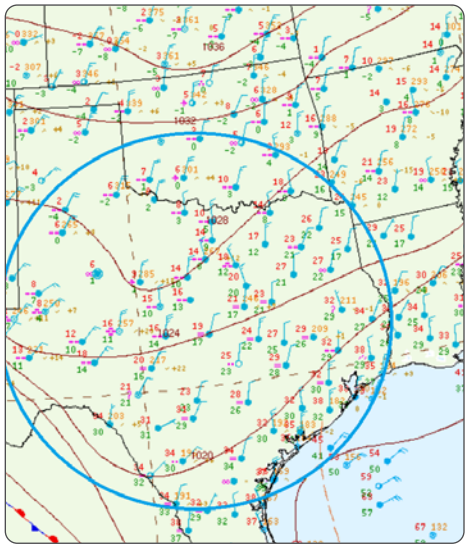

Figure 5 (WPC, 1 pm Sunday, February 14th, 2021)

Equally important, temperatures are in the 20s in large population centers in the north and the 30s and low 40s in Houston. The weekend was about to begin and the power demand was about to ramp up.

The afternoon of Valentine's Day, Sunday, shows most of Texas in the deep freeze with a frigid night coming. Figure 5 illustrates temperatures ranged from near 0 in the Panhandle to near 32 at the coast in the middle of the afternoon. Much of Texas is experiencing some form of winter precipitation from heavy snow, freezing rain to freezing fog which is shown by the area circled in blue.

Figure 6 represents 6 am Monday February 15th. Millions of Texans are without power. It is snowing on the Gulf Coast, and -10 and colder in the Panhandle, in the single digits in Dallas and near 20 in Houston. Temperatures would not climb at all during the day and the power crisis was well underway.

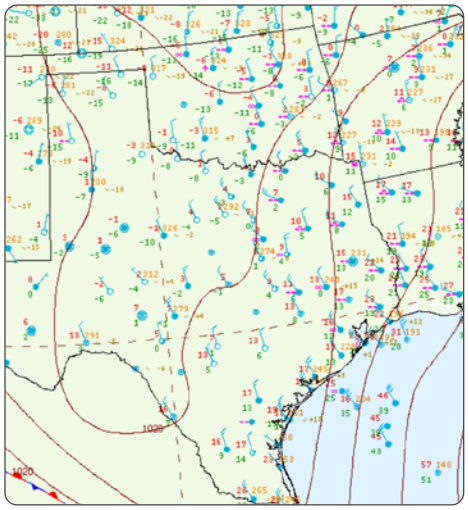

Figure 6 (WPC, 7 am Monday, February 15th, 2021)

Little improvement would be seen in the next two days with another round of snow and ice impacting Texas Wednesday, February 17th as shown in figure 7. The map depicts that you need to travel to nearly Mexico to find a temperature above 40 degrees. In summary, weather conditions would begin to gradually improve on Friday, February 19th or 10 days after the cold front entered northern Texas.

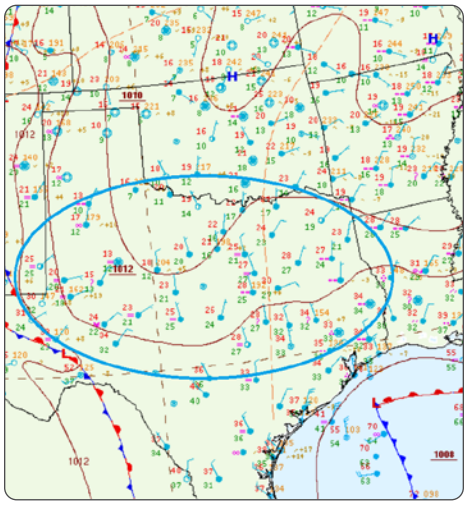

Figure 7 (WPC, 1 pm Wednesday, February 17th, 2021)

THE FEBRUARY 2021 EXTREME COLD AND ENSUING TEXAS POWER SUPPLY FAILURE
WHITE PAPER

The key takeaways in this review of the weather conditions are;

1) The extreme cold lingered in the state over 10 days.

2) A good portion of west and central Texas experienced icing and snow during the event.

3) Cloud cover was widespread during this 10 day stretch with minimal sunshine. This impacted both wind and solar production.

4) Critical weather information to the general public, such as messages by utilities to conserve power usage, may not have been as widely absorbed due to the peak of the event occurring over the weekend.

THE IMPACT TO WIND POWER PRODUCTION

In this paper we'll stay focused on the weather's impact to wind power production and primarily avoid the politics that quickly surfaced on this event. The facts of the event however do prove wind power plants did experience a considerable impact. Figure 8 shows that beginning on February 9th, power production from wind and to some degree solar was much less than normal through the historic event.

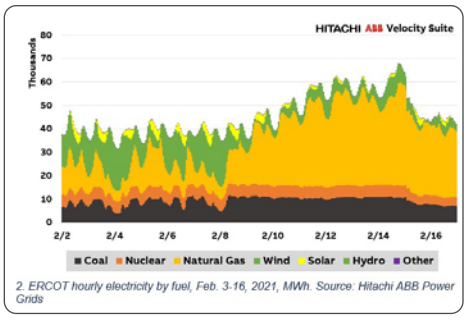

Figure 8 (Knutson, 2021)

Approximately 48% of generation was forced off at the highest point of the crisis due to extreme weather conditions. Between February 14th and the 19th there were 1,796 outages and derate incidents recorded from all sources of power generation.

THE ICING DILEMMA

It is important to establish that a wind turbine is an ice collecting machine. Turbine blades will ice over faster and accumulate more ice than any other object. This relationship of wings or blades and ice formation has always been a concern and why flights are delayed on the tarmac while the plane is being deiced. For more information on the effects of icing to turbine blades visit the Indji Systems website at **https://www.indjiwatch.com**.

Icing to wind turbines began as soon as February 8th in the Texas Panhandle. The icing was from freezing drizzle and freezing fog caused by the Arctic airmass undercutting warmer, moister air at the surface. This caused the air to rise which formed clouds, fog and eventually light precipitation in the form of super cooled water droplets which froze on turbine blades with air temperatures in the 20s. These conditions can be seen by reviewing figures 2 and 3 presented earlier. Figure 9 shows weather conditions on Tuesday afternoon the 10th with the area circled in blue indicative of freezing fog and drizzle conditions and temperatures below 32 degrees. As you can see those conditions have begun to migrate south and east from the Texas Panhandle. The situation persisted and worsened over the next two days as the icing conditions continued to migrate slowly south, deeper into Texas.

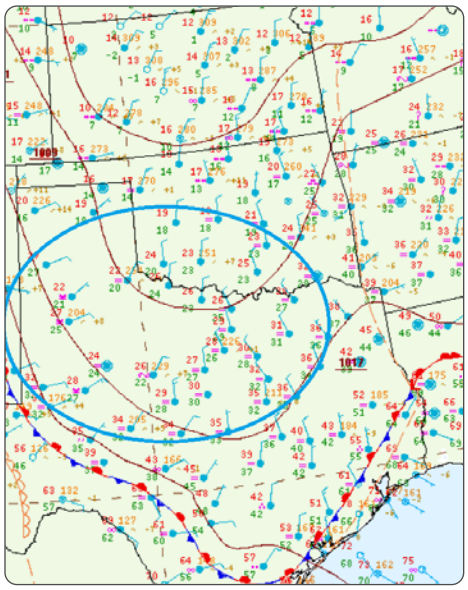

Figure 9 (WPC, 1 pm Wednesday, February 10th, 2021)

Figure 10 shows a close-up of Texas surface weather mid-day Thursday, February 11th. The region circled in blue defines a general area of freezing fog, freezing drizzle, and even areas of light to moderate freezing rain on the southern edge of this zone. The data clearly shows the picture of persistent cold with icing conditions over a good portion of Texas for many days is setting the table for what is about to happen beginning Valentine's Day weekend.

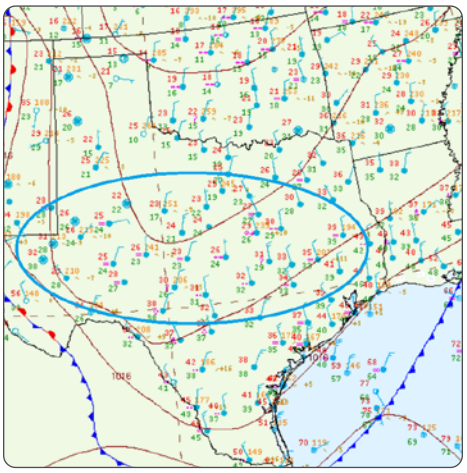

Figure 10 (WPC, 10 am Thursday, February 11th, 2021)

While turbines can still operate with low amounts of ice on the blades, they do so at a reduced capacity therefore lowering the contribution that wind turbines can make. Yet even that reduced power generation would be needed for a failing natural gas situation that would start over the weekend across the ERCOT footprint. In cases where the ice accumulation is too great the turbine can trip offline and produce no power in addition to instrumentation also being iced over. If the anemometer serving wind speed data to the turbine is iced over and not working properly the turbine will not run even if the wind is ample. To close out the impact of icing on this event, consider that turbines in the Texas Panhandle began to accumulate ice on February 8th and some turbines reported still having ice as late as February 19th.

EXTREME COLD TEMPERATURES

To set context for this section, consider that in Borger, Texas located in the Panhandle where many wind farms operate, the temperature fell below freezing on February 8th and did not rise above freezing until February 19th. In other words, the temperature was below freezing for around 260 consecutive hours. This provides perspective on why ice could have persisted on wind turbines so long. But what about energy from the sun? Even with temperatures in the low 20s solar radiation can heat blades sufficiently to melt ice.

The Borger weather station measured at least of trace of precipitation on 10 of the 12 days between February 8th and February 19th. To have precipitation you need clouds and with clouds you have an obscured sun. Therefore, solar radiation from the sun had little to no chance to overcome temperatures in the 20s and colder during this event. Turbines remained impacted by ice to some degree thereby reducing their power generation effectiveness or perhaps prohibiting it completely.

Much has been written and commented about this situation in Texas. Wind turbines in Texas, in many cases are not designed to run in very cold temperatures, especially for extended periods of time. Had the turbines been set-up with cold weather packages, many could have continued to operate. This could involve heating turbine components and lubricants. Turbines in colder climates employ cold temperature steels and special viscosity lubricants that are made to perform better in the cold. Some turbines have the ability to heat blades to prevent or remove ice accumulation. (Browne, 2021) There are many measures that can be taken to improve performance in cold climates but the state of Texas is not in that category meteorologically. Going forward will measures be taken that equip Texas turbines to better handle extreme cold and the conditions such as icing that come with it? Before leaving our discussion on the extremely cold temperatures take a good look at figure 11 showing conditions the morning of February 15th when nearly 5 million Texans had no power. Major metro areas such as Dallas/Ft. Worth were in the single digits and Houston was in the teens. In turbine country, temperatures hovered near 0 and well below that in the Pan Handle.

To put the entire situation into perspective, review the graphic shown in figure 12 from the Houston/Galveston National Weather Service. Historically, there is no one alive who has ever experienced a colder period in the state of Texas in these four locations.

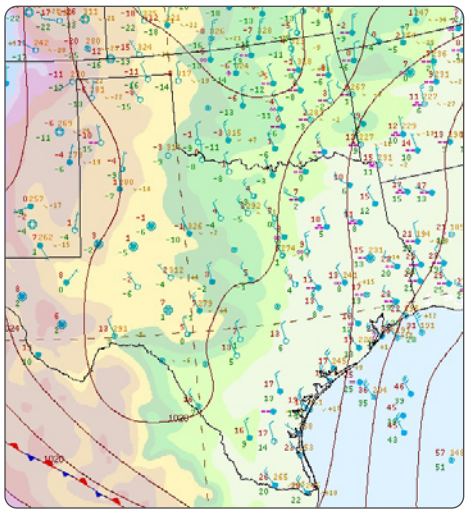

Figure 11 (WPC, 7 am Monday, February 15, 2021)

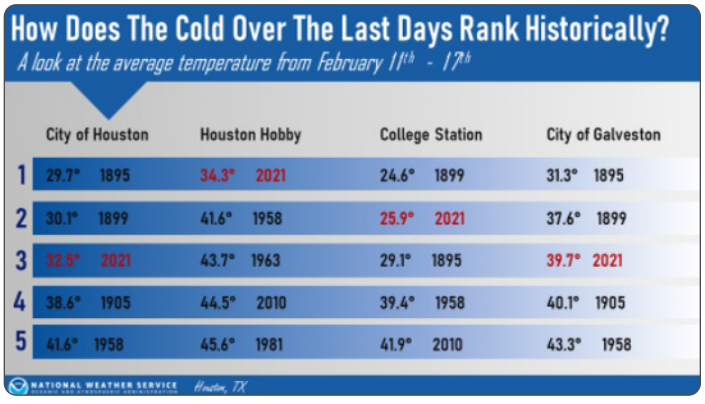

Figure 12 (US Department of Commerce, 2021)

THE FEBRUARY 2021 EXTREME COLD AND ENSUING TEXAS POWER SUPPLY FAILURE
WHITE PAPER

RECAP OF THE WEATHER IMPACT TO RENEWABLES

To summarize the weather that drove this historical event we see an unprecedented combination of conditions leading to the significant and tragic outcomes. Abnormal to extreme cold temperatures engulfed the entire state, in some cases for up to 10 consecutive days. The cold temperatures alone likely impacted turbine performance given many turbines are not designed to operate for extended periods in temperatures that in some cases dipped below zero. The arrival of the arctic airmass also triggered freezing drizzle and fog that began icing turbines in north Texas which subsequently spread into central and parts of southern Texas. Multiple atmospheric disturbances amplified the icing in south and central Texas even leading to significant snowfall. That snowfall coated solar panels reducing power output from that renewable source and significant cloud cover for over week added to the total. That same persistent cloud cover prevented solar radiation from the sun aiding in melting ice from turbine blades and thus some turbines had ice on blades for over 10 days.

It should be stated these same weather conditions caused an impact across all energy sources, coal, nuclear and natural gas. The impact to power production from natural gas plants was the biggest contributor to the energy crisis that evolved on Valentine's Day weekend.

THE INEVITABLE HUMAN IMPACT

As previously shown in figure 12, cold temperatures to this level have never been felt by living Texans. While any Southerner can brush off a day or two of very cold weather, 10 days of historic cold with little to no sunshine in many areas is intolerable. The persistent cold, blended with gray skies and various forms of winter precipitation led to an unprecedented demand for energy.

That demand could not be met and blackouts ensued. Residents shivered through days of no power or a heat source. The loss of power was persistent and prolonged to the point of the water supply being impacted due to water treatment plants that could not operate. Additionally, the loss of power and subsequent inability to heat homes caused water to freeze and pipes to burst. As of March 25th, 2021 a total 111 Texans lost their lives for reasons attributed to the historic cold weather event.

WILL THIS HAPPEN AGAIN?

Strictly speaking about the weather conditions that caused the event, the short answer is they are likely to occur again. Extreme weather events driven by a warming climate are now the norm. Record rainfall amounts, historic ice storms in the Texas Panhandle in October 2020, record setting hurricanes, melting ice caps and historic wildfires are all examples or events driven by extreme weather. The extreme cold of February 2021 in Texas was caused by an arctic airmass that was dislodged from near the North Pole and traveled nearly 4,000 miles to the Texas Coast. This was driven by warm air surging into the Arctic supplanting the cold air in the south. These events where the jet stream essentially decouples and can allow arctic air to surge south are growing in frequency thanks to the warming of the planet. A key takeaway is extreme weather events are not 1 in 100 year events anymore, the claims you hear of 1 in 100 years or 1 in 500-year events are no longer reliable benchmarks to gauge a threat of frequency of threats. Steps to plan and prepare for historic extreme weather, whatever that may be in your part of the world, should be taken now.

WHAT CAN BE DONE?

There are broader, significant measures and steps related to grid infrastructure, access to sources of back-up power outside of ERCOT and resiliency of the plants to extreme weather that can be taken, however these are long term steps involving significant capital. Much is being said about these steps in recent articles and commentary on the Texas power grid failure. On a broad sense a transition to even more renewable energy is an important step for climate reasons alone. The United States is on a strong path in this area. A growing ability to store power from renewable energy sources will become increasingly important.

However, what can be done now in the unlikely scenario where this event happens next year? This author believes there are steps that can be taken now to mitigate the impact the next time extreme cold weather and ice is knocking on the door.

It was evident that extreme cold would plunge into south Texas days before it happened. This was not a surprise weather event. Would strongly worded communication from media sources to the public urging a reduction of power consumption to prevent potential blackouts have helped? The timing of any communication is key as it is more likely to be absorbed during the week vs. the weekend when the public is more likely to avoid traditional information sources. If faced with this situation again, Texans would likely trade lowering their thermostats to 60 degrees at home and bundling up to lessen the demand for power on the grid in order to avoid a similar outcome next time.

Given the extreme cold coming and likely impacts of icing to turbines and snow on solar panels, owner operators of wind and solar farms need to be fully braced to handle this event the next time it happens. While many free and useful sources for weather information exist, are businesses that can experience million-dollar negative impacts to their operation from these events relying on professional and private sources of weather information and support which can help them prepare and mitigate the impact? These sources can target specific needs of the business as it relates to weather. For example, forecasts of freezing fog and freezing drizzle to wind turbines need to be available. Also important is the post event weather which directly effects the length of the weather event. Important elements to understand are how long the cold temperatures persist, the forecasted amount of cloud cover and for how many days. These valuable elements can be used to directly effect the market forecast of power production from a given wind plant allowing the owner to submit more accurate power production bids lessoning their market exposure and financial impact. It's a fact that some operators saw over a $100 million-dollar negative impacts from the Texas event. Factoring the impacts of extreme cold and related icing conditions to renewable energy sources could result in a more accurate picture of available power from those resources during the event. The same can obviously be said for natural gas plants. Which all ties back to gathering a more accurate picture of what COULD happen before the event unfolds which ties to communicating the situation, perhaps with a heightened tone, back to the public.

SUMMARY

As is often the case with historic events of this magnitude, a sequence of events and conditions combined to stress a system to the breaking point. Collectively all conditions needed to come together to deliver the impacts felt. The last extreme cold weather event to impact Texas and the grid occurred in 2011, although it was not to the extreme of the 2021 event. With that event only a short 10 years ago, and the trends in weather and climate, the likelihood of another extreme winter event occurring in the next decade seems realistic. Consider that in the span from October 2020 through February 2021 Texas experienced two record setting events involving ice and abnormally cold weather. Short term and long-term actions can be taken to mitigate these impacts. In the short term, Texas utilities, renewable energy plants, and other fossil fuel plants can take action now by ensuring sources of weather information are targeted to their operations and focus on vulnerable areas in their business impacted by icing and extreme cold. The information should be uniformly shared across operations allowing for consistent and collaborative decisions on needed actions. Equally, information should flow to the public on the potential severity of similar future events in sufficient time to engage the consumer on steps that could lessen the impact of demand. Action can be taken now to help when the next extreme event comes along while more longer-term measures involving grid resiliency that can be explored and funded by all entities involved.

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