

Extreme Weather and Engineering



Chief Meteorologist Sunny Wescott

Environmental Extremes Increasing

As heat trapping effects persist, like rising water vapor and others, Earth's temperature rises in response. This increases evaporation from both water and land areas. Warmer air holds more moisture, its concentration of water vapor increases, feeding the cycle.

- USGS [research](#) in 2015 showed that there has been an increase in the flow between the various stages of the water cycle over most the U.S. in the past seven decades.
- The rates of ocean evaporation, terrestrial [evapotranspiration](#), and precipitation have been increasing. In other words, water has been moving more quickly and intensely through the various stages.

More rain and flooding: With more evaporation, there is more water in the air so storms can produce more intense rainfall events in some areas. This can cause flooding – a risk to the environment and human health.

More extreme drought: Warmer temperatures cause more evaporation, turning water into vapor in the air, and causing drought in some areas of the world. Places prone to drought are expected to become even drier over the next century. This is bad news for farmers who can expect fewer crops in these conditions.

Stronger hurricanes: Warmer ocean surface waters can intensify hurricanes and tropical storms, leading to more hazardous conditions as these storms make landfall. Scientists continue to research how climate change affects the number of these storms, but we know that the storms will be powerful and destructive in the future.

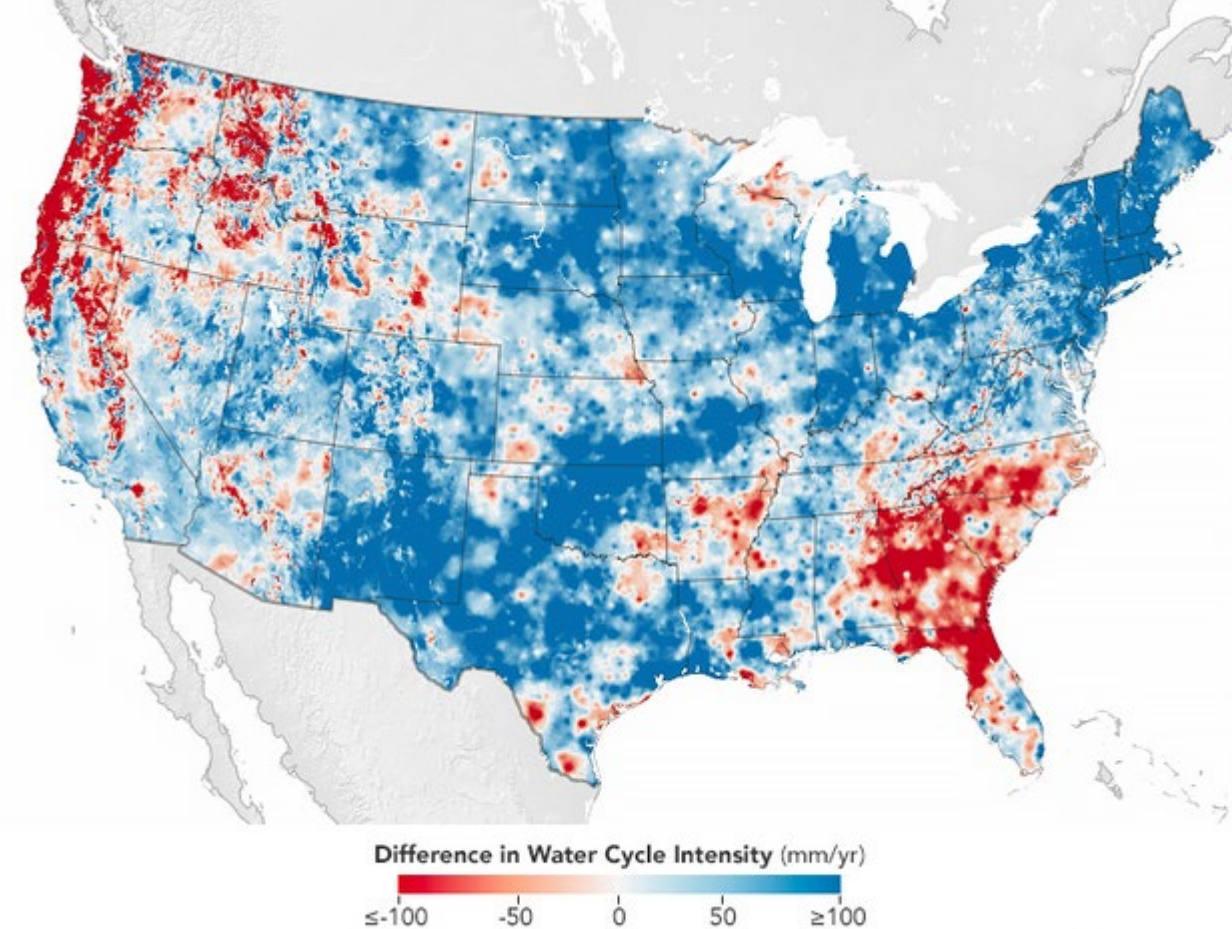
Heat waves: It is likely that heat waves have become more common in more areas of the world.

A new **Tel Aviv University (TAU)** study has found a significant statistical correlation between thunderstorms occurring around the world and the formation of wispy cirrus clouds that might increase global warming.

- The researchers say that although it is known that cirrus clouds can contribute to global warming,

Tropical study: Tropical upper-troposphere clouds are expected to rise under global warming, contributing a positive radiative feedback.

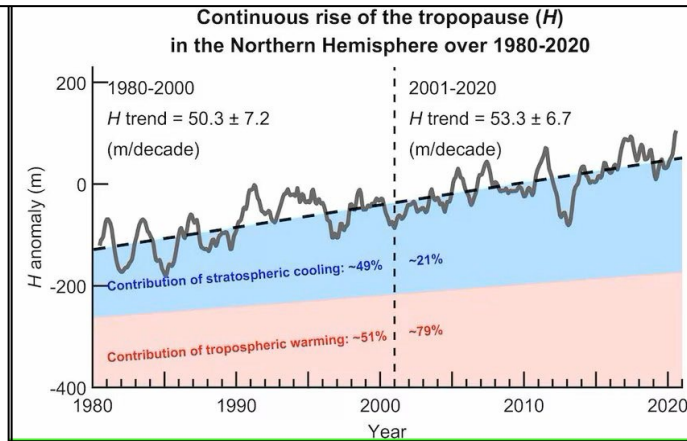
- Theory has long predicted that the highest-altitude tropical clouds would rise as Earth warms, a feedback that amplifies warming.



January 1, 1945 - December 31, 2014



The [University Corporation for Atmospheric Research](#) found that the tropopause has increased in height at a steady pace since 1980, with [Science | AAAS](#) estimating an increase of 50-60 meters per decade, [Science | AAAS](#) and [Canadian Meteorological and Oceanographic Society](#) estimate an increase of around 200-250 meters between 1980 and 2020



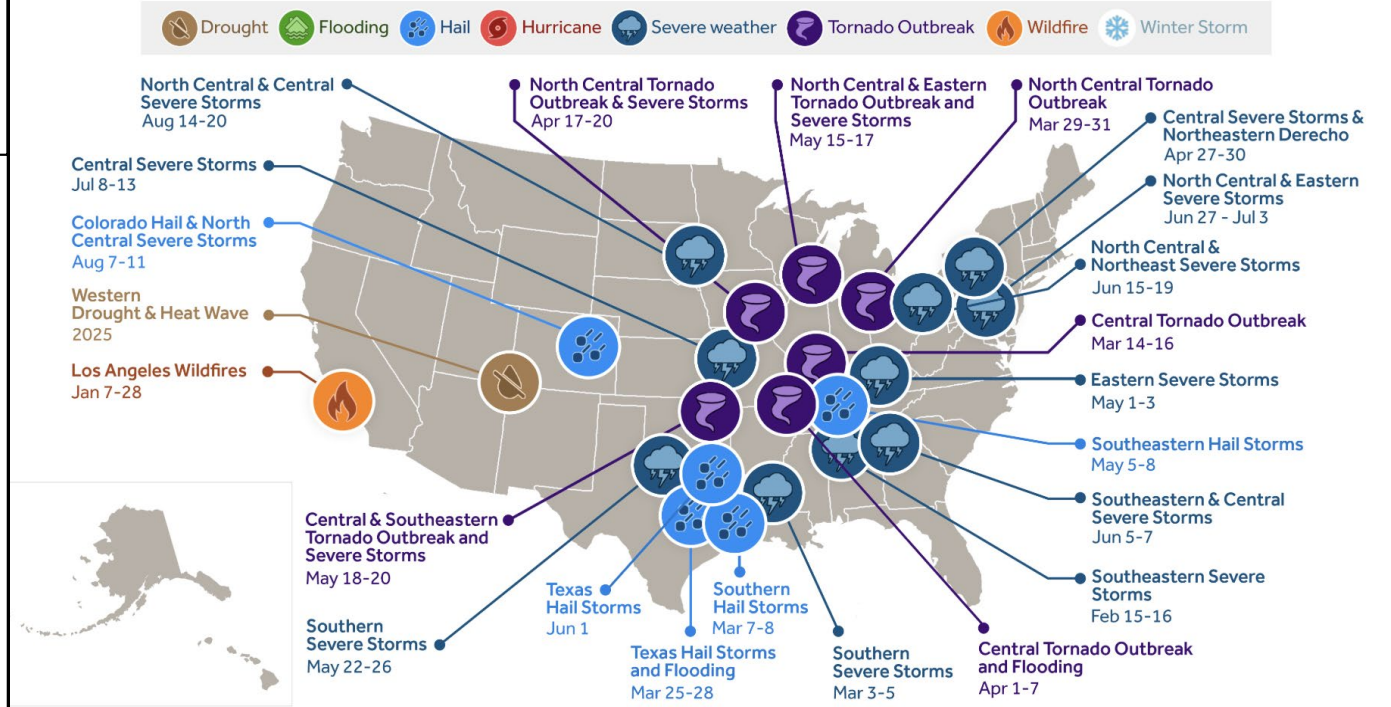
Climate Central: 2025 Billion Dollar Disasters

A new analysis finds that the US in 2025 major catastrophes took 276 lives and caused \$115 billion in damages.

- The US reported 23-billion-dollar weather and climate disasters in 2025.
- Only 2023 and 2024 recorded more of these events, and 2025 was the 15th consecutive year with an above-average number.
 - The Los Angeles fires accounted for more than half of the losses from the 23 total events in 2025.
- Of the 23 events, 21 were related to tornadoes, hail, or high wind events. Reviewing severe storms, 2025 was the second most costly year for billion-dollar disasters, after 2023.

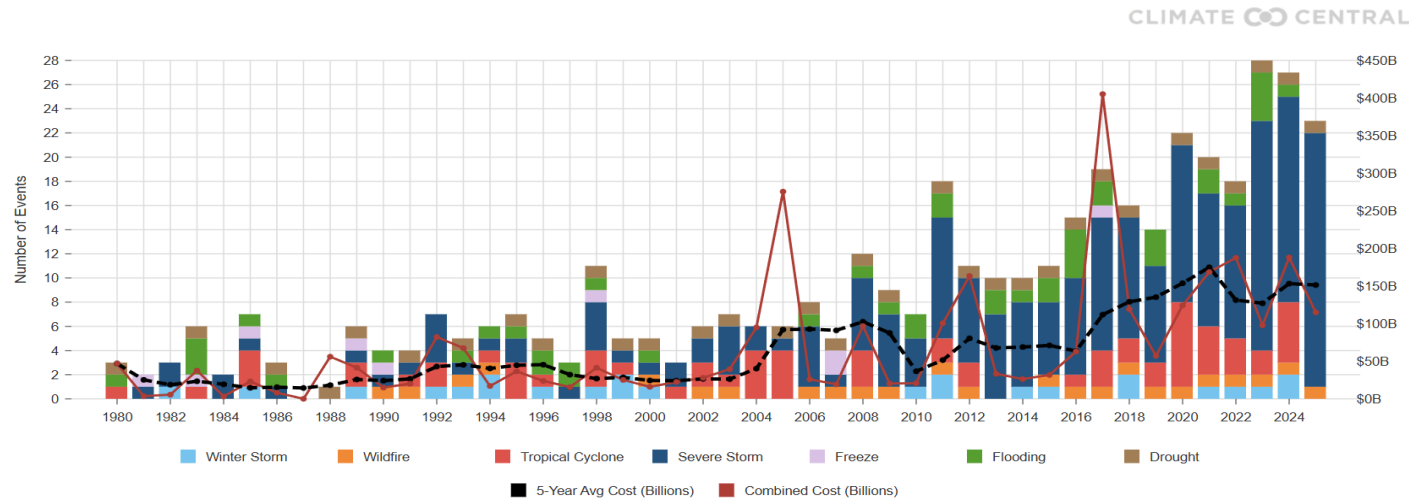
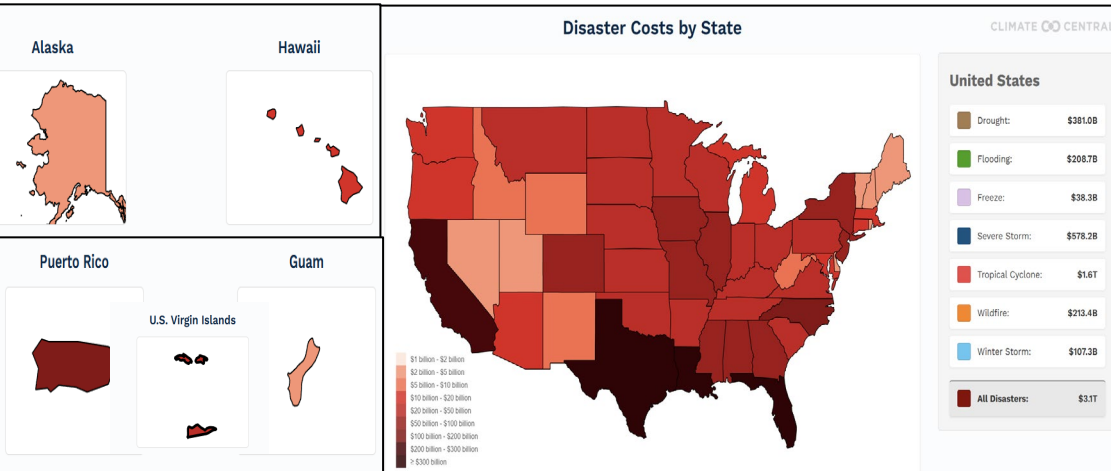
From 1980 to 2025 the U.S. has sustained 426 billion-dollar disasters totaling +\$3.1 trillion.

U.S. 2025 Billion-Dollar Weather & Climate Disasters



This map shows the approximate location for each of the 23 separate billion-dollar weather and climate disasters that impacted the United States from January-December of 2025.

CLIMATE CENTRAL



The history of billion-dollar disasters in the United States each year from 1980 to 2025, showing event type (colors), frequency (left-hand vertical axis), and cost (right-hand vertical axis) adjusted for inflation to 2025 dollars.

Weather Impacts

Extreme Weather as an engineering systems problem: One material's movement becomes another material's stress. One material's corrosion product can damage adjacent materials. One failed seal can expose multiple systems. Engineering must evaluate assemblies, not isolated parts.

- Materials do not fail in isolation. Joints, seals, adhesives, fasteners, and enclosures often govern failure. The design life of material is changing faster than expected as assets face repeated multi-hazard exposures.

Many composites offer strength and weight advantages, but lifespan can collapse when heat, UV, moisture, and cyclic loads combine.

- Matrix cracking, fiber matrix debonding, delamination, and moisture uptake can compound.
- Damage may be hidden while stiffness, insulation, or impact tolerance declines.

Where do these damages show up?

- Utility poles and crossarms
- Cable insulation and connectors
- Rooftop equipment
- Solar and storage systems
- Building envelopes
- Bridges and transportation assets
- Water and wastewater infrastructure
- Telecom shelters and towers

Interface	Weather issue	Failure mode
metal to polymer	expansion mismatch	cracking, loosening
coating to substrate	UV, moisture, heat	peeling, blistering
adhesive bondline	heat, water, contamination	debonding
seal and enclosure	pressure, aging, smoke	leakage, ingress
composite to fastener	cyclic load, impact	delamination, pull through

Hazard	Primary stressors	Typical engineering effect
Storms	pressure, debris, water ingress	impact, fatigue, seal failure
Lightning	current, heat, surge	burn, puncture, electronics loss
Hail	repeated impact	cracking, denting, coating loss
Damaging winds	uplift, vibration	loosening, fatigue, instability
Tornadoes	extreme pressure and debris	catastrophic structural failure
Flooding	immersion, contamination, scour	corrosion, shorting, undermining
Wildfire	radiant heat, flame, smoke	charring, embrittlement, loss of function
Extreme temperatures	thermal cycling, expansion	creep, cracking, delamination

Recommendations to Resiliency: Changing the pattern of operations requires evaluating the entire system: which weather events typically cause which impacts where? Which aspect of the weather event produced the damage? Was it the site damaged, or the interdependent infrastructure. Shift from time-based maintenance to condition based inspection. Update replacement cycles for weather accelerated aging. Track exposure history by asset and material class. Inspect after near miss events, not just obvious failures.

Lightning Impacts

In the Central Plains, lightning has directly damaged distribution lines, power poles, transformers, and substation-connected equipment, causing outages ranging from localized service interruptions to broader feeder-level disruption.

- [Beatrice, Nebraska — July 20, 2020](#): A lightning strike burned down a primary line and tripped a substation breaker, cutting power to about 670 customers.
- [Near Palmyra, Nebraska — June 21, 2019](#): A lightning strike hit a power pole, dropped a conductor, and caused an outage across the western half of Nebraska City Utilities' system, including Palmyra, Douglas, and Bennett.

Conductive paths matter as much as strike resistance.

- Bonding, grounding, shielding, and surge protection must work as a system.
- Composite structures need deliberate current pathways because they do not behave like steel.
- Hidden damage can remain after a strike: resin degradation, puncture, connector damage.

Each lightning strike causes a surge which stresses the internal metal-oxide blocks in an arrester.

- Big or repeated strikes can degrade performance over time and in some cases a positive lightning strike can destroy one outright.

Lightning can delay operations, degrade insulation and electronics, damage poles, substations, arresters, and transformers, and in severe cases destroy critical energy infrastructure by forcing outages, accelerating hidden material aging, and triggering cascading failures across interconnected systems.

Power poles

- Wood: surface charring, steam cracking from moisture flash, hardware loosening.
- Steel: coating burn-through, local heating, corrosion starts at damaged spots.
- Composite: resin burn, delamination, hidden structural loss.
- Concrete: spalling, rebar heating, cracking near grounding paths.

Transistors and power electronics

- Lightning creates surge overvoltage and fast current spikes.
- Semiconductors fail by junction punch-through, gate oxide damage, overheating.
- Damage may be immediate or latent, shortening life after a near miss.

Lightning arresters

- They are sacrificial protection, so repeated surges age them.
- Varistor blocks degrade, moisture ingress increases risk, thermal runaway can follow.
- End-of-life often shows as leakage current rise or catastrophic rupture.

Substations

- Main risks: insulation flashover, bus damage, relay mis-operation, control system upset.
- Connectors, bushings, grounding grids, and instrument transformers are common weak points.
- The issue is system coordination, not just one strike point.

Transformers

- Surges stress winding insulation, bushings, tap changers, and cooling controls.
- Even when the unit survives, insulation aging can accelerate.
- Result: reduced remaining life, not just visible failure.

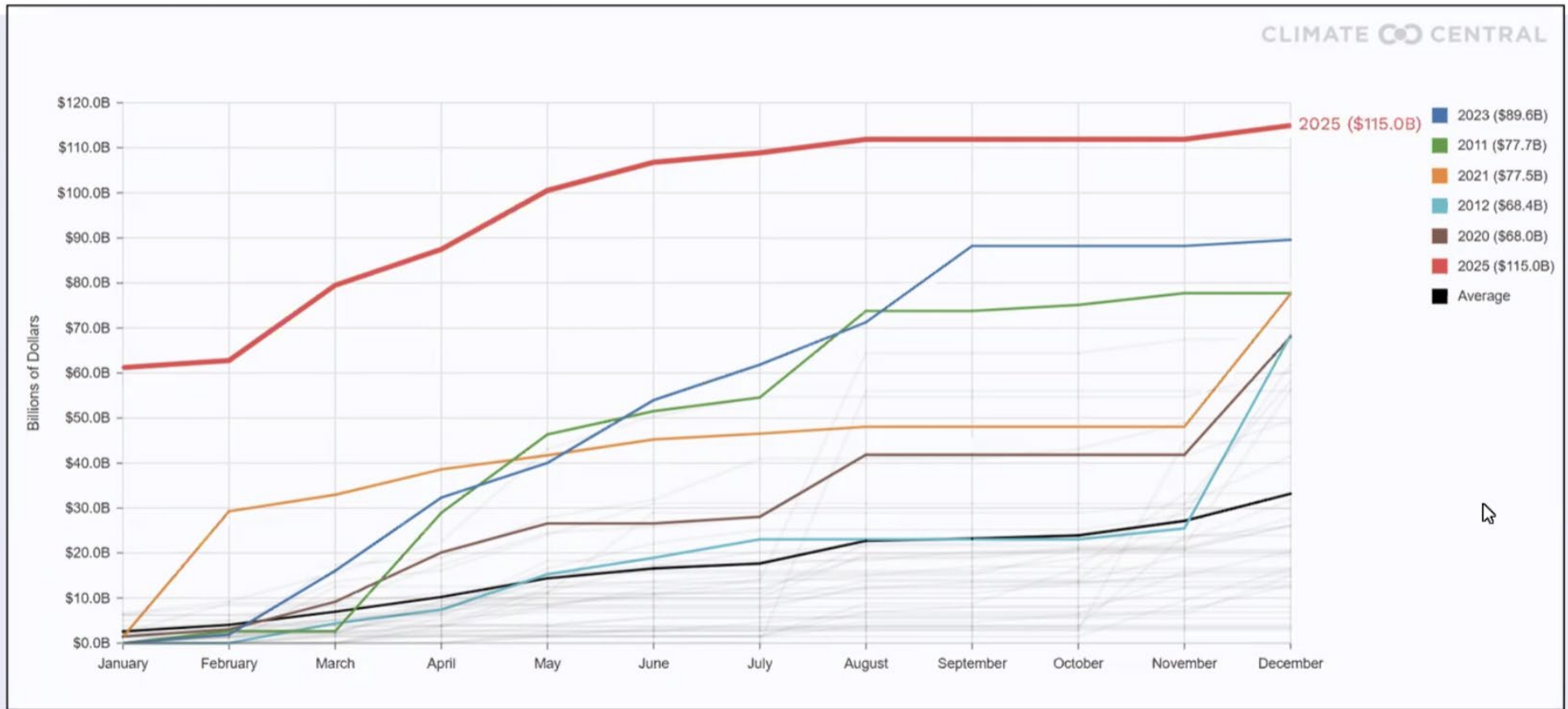
Power plants

- Impacts include trips, sensor faults, control system damage, switchyard disturbances, and fire risk.
- Tall stacks, cooling systems, exposed cable runs, and auxiliary systems are frequent pathways.

Staff

- Risks include step potential, touch potential, arc blast, burns, hearing damage, and secondary trauma.
- Outdoor crews, substation workers, and line teams are highest exposure groups.

1980-2025 United States Billion-Dollar Disaster Annual Cost (without tropical cyclones)



- The top 3 most costly years w/o tropical cyclones: **2025** (\$115.0 billion); **2023** (\$89.6 billion); **2011** (\$77.7 billion)

Worsening Hail Impacts

Hail can damage energy infrastructure by cracking insulators, bushings, control house windows, solar panels, sensor housings, lights, and exposed coatings, while also denting metal surfaces and weakening weather seals on substation equipment.

- Even when hail does not cause immediate failure, it can create small fractures and water entry points that later lead to corrosion, insulation problems, misreads, or flashover risk.

Hail usually does less direct damage to conductors than wind or ice, but it can still harm power lines by striking and weakening insulators, spacers, dampers, covers, and connectors attached to the line.

- Large hail can also damage nearby poles, crossarms, and hardware, and if it cracks protective components or creates moisture entry points, it can increase later fault and outage risk.

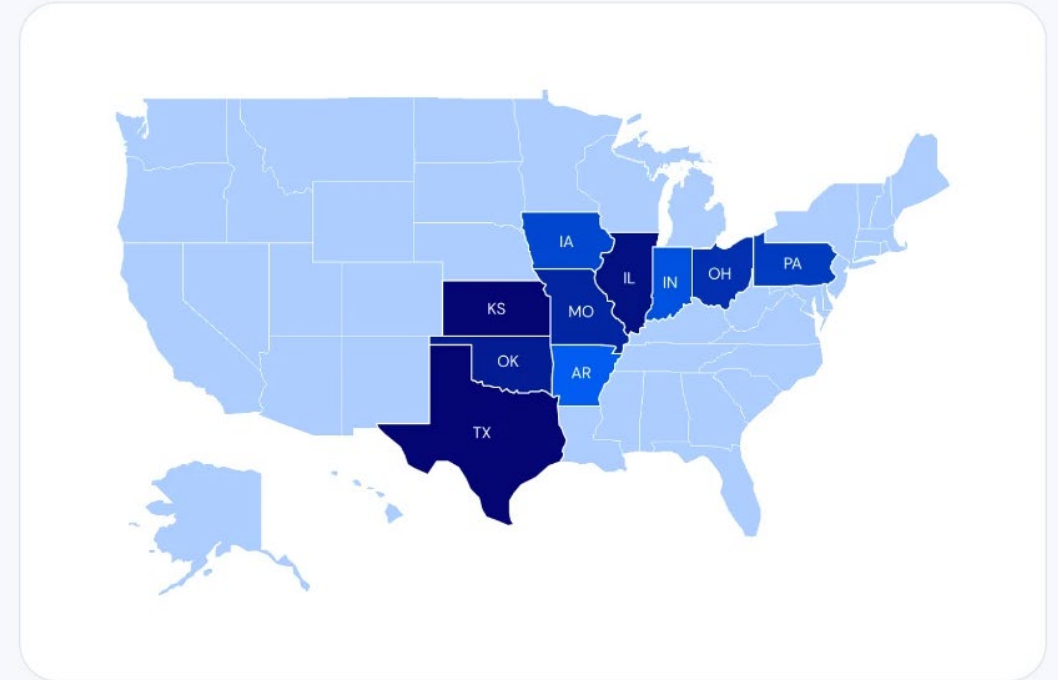
Hail Alley is the informal name for the part of the central U.S. that gets some of the country's most frequent and damaging hailstorms, generally centered on eastern Colorado, Wyoming, western Nebraska, and western Kansas where dry air from the Rockies and Southwest collides with warm, moist Gulf air and strong spring-to-summer thunderstorm dynamics, creating ideal conditions for large hail.

- Nebraska is one of the highest hail-risk states in the US and across the US hail causes annual economic losses exceeding \$1 billion nationally.

Hail is a repeat impact problem, not just a surface damage problem.

- Brittle materials crack.
- Coatings lose integrity.
- Laminates can suffer subsurface delamination.
- Performance loss may appear later through moisture ingress.

States with the Most Hail in 2024



Number of Hail Incidents by State

1	Texas	529	6	Ohio	115
2	Kansas	250	7	Pennsylvania	113
3	Illinois	225	8	Iowa	112
4	Oklahoma	201	9	Indiana	76
5	Missouri	160	10	Arkansas	75

Wind Impacts: Increases in Gusts and Prevailing

Wind fuels power outages primarily by damaging electrical infrastructure, with high winds (40–50+ mph) snapping tree branches, toppling trees onto lines, and causing utility poles to fail. These events break power lines, trigger short circuits, and damage equipment like transformers, forcing safety systems to cut power to prevent further damage

- Wind loads exploit edges, corners, fasteners, and fatigue sensitive connections.
- Tornadoes add debris impact and rapid pressure change.
- Failure often cascades from envelope breach to internal damage.
- Design should prioritize load path continuity and sacrificial protection.

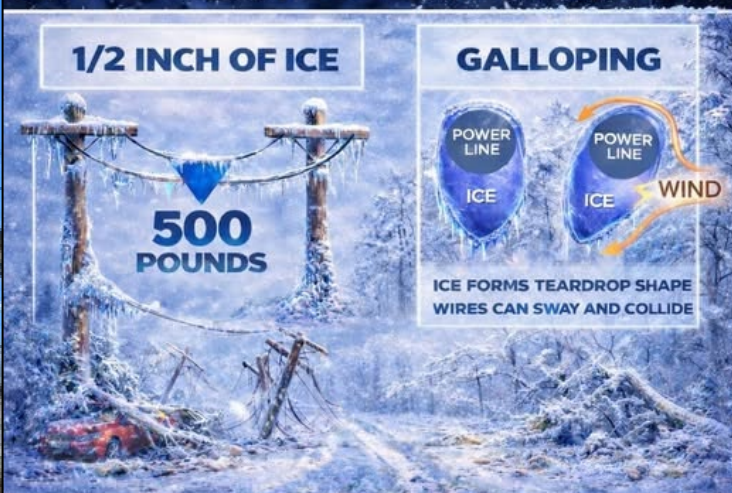
While not the wind itself, combined freezing conditions can cause wind turbines to freeze (if not properly winterized), reducing energy production, although major outages in these cases are usually due to thermal power source failures, not just wind. Wind turbines are designed to automatically shut down at extremely high speeds to prevent mechanical damage, which can temporarily reduce power supply in heavily reliant areas

2021 Windstorm Damage

CO

- 248 wires down (6.2 miles)
- 101 wood distribution poles
- 5 wood transmission poles
- 33 overhead transformers
- 182 cross arms

Ice & Power Grid Impacts



.25" OR LESS	.25"-.50"	.50" OR MORE
▶ Minor Power Outages	▶ Numerous Power Outages	▶ Widespread Power Outages

WHAT ARE STRAIGHT-LINE WINDS?

60-130
MPH



Straight-line winds can be sustained at over 60 mph and gust up to 130 mph.

TYPES OF STRAIGHT-LINE WINDS

- DOWNBURST.** A strong ground-level wind caused by (usually) cold air rushing downward and spreading out in all directions away from the point of impact with the ground.
- MICROBURST.** A strong downburst that is highly concentrated.
- GUST FRONT.** The leading edge of a storm system, where rain-cooled air hits warmer air outside the storm front.

- Minor mistakes in installation or damage from regular aging can become severe damage in straight-line winds.
- Blowing debris and falling trees can cause more damage than the wind itself.



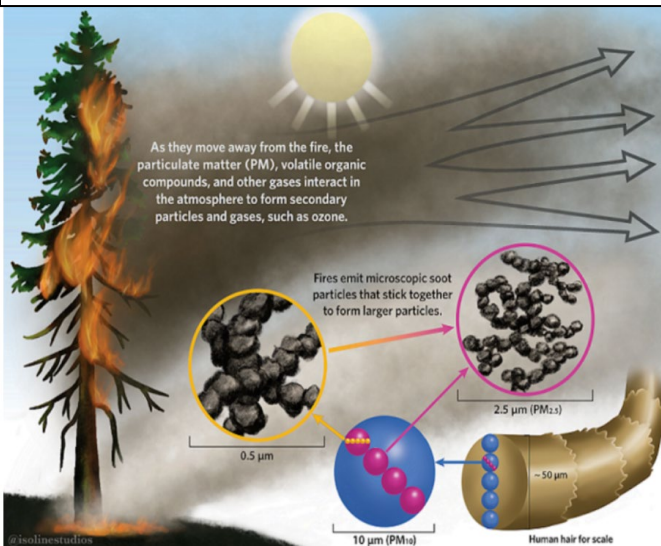
People who live in trailers or other housing without a foundation are the most at risk.

Wildfire Impacts/Dependency

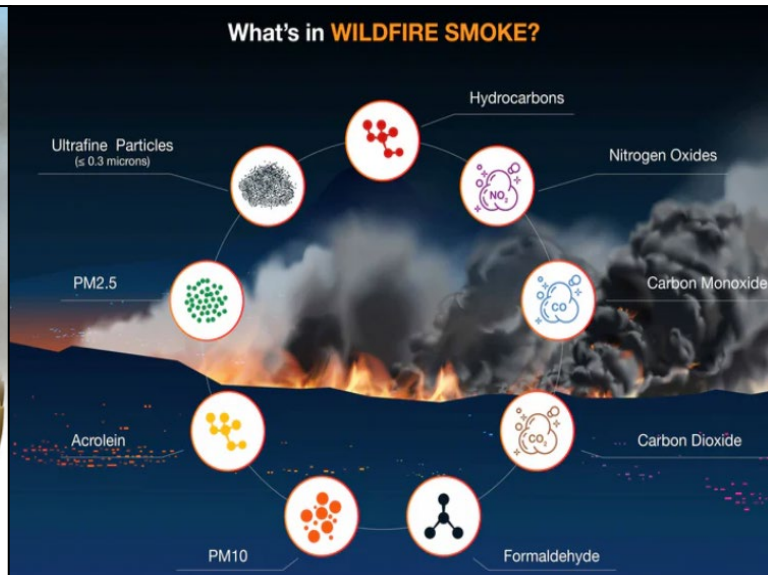
Wildfire smoke can quickly load and clog air filters in energy systems, reducing airflow, lowering cooling efficiency, increasing pressure drop, and forcing fans, turbines, generators, HVAC, and enclosure systems to work harder or overheat.

It can also leave conductive or semi-conductive ash and fine particulates on insulators, bushings, connectors, and other energized surfaces, which raises contamination risk and can increase tracking, arcing, or flashover potential, especially when the smoke residue mixes with moisture.

- Wildfire exposure includes flame, radiant heat, smoke, ash, and corrosive residues.
- Polymers soften, char, or off gas.
- Elastomers lose sealing performance.
- Smoke and particulates impair cooling, sensing, and electrical reliability.
- Post fire inspection must include hidden thermal damage.

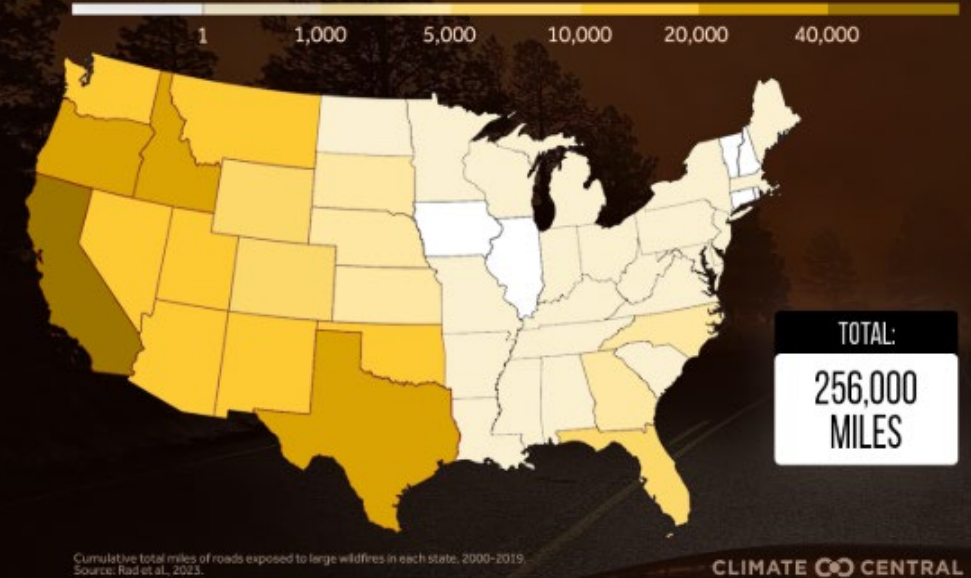


Smoke has particles much smaller than the width of a hair and gases that react in sunlight. (en Burgess/IsolineStudios/BC Centre for Disease Control)



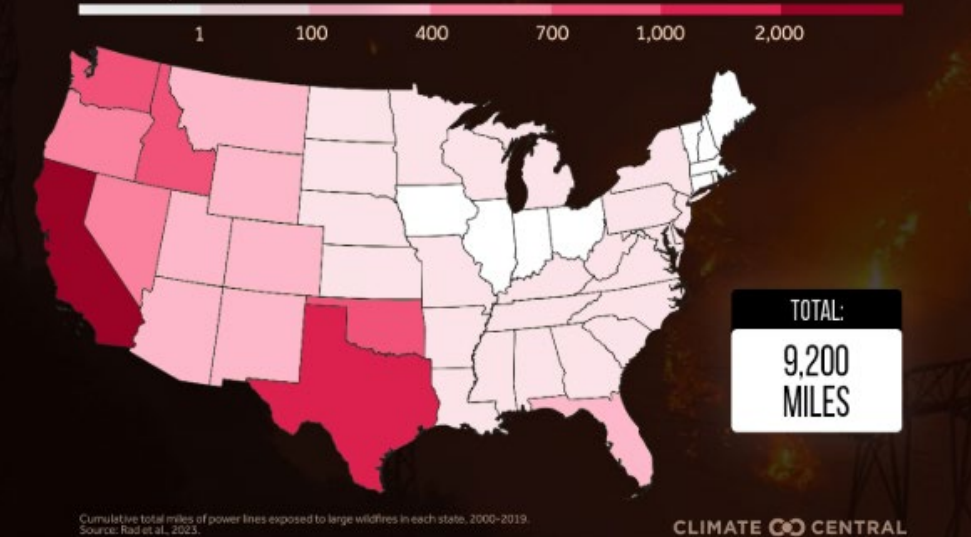
ROADS EXPOSED TO WILDFIRE

Miles exposed, 2000-2019



POWER LINES EXPOSED TO WILDFIRE

Miles exposed, 2000-2019



As fires burn wider areas and into higher elevations topography shifts from tree-creep, soil composition changes, soot deposits, debris flows, burn scars, vegetation/foilage decay, early blooms, flooding post-burn, less wildfire activity, and increased pollution from wildfire smoke, the cycle of heightened wildfire activity will worsen each year.

- Damaged soil from heat transfer result in less fire-resistant plant retention and more scraggly brush growing back between fire weather active periods.

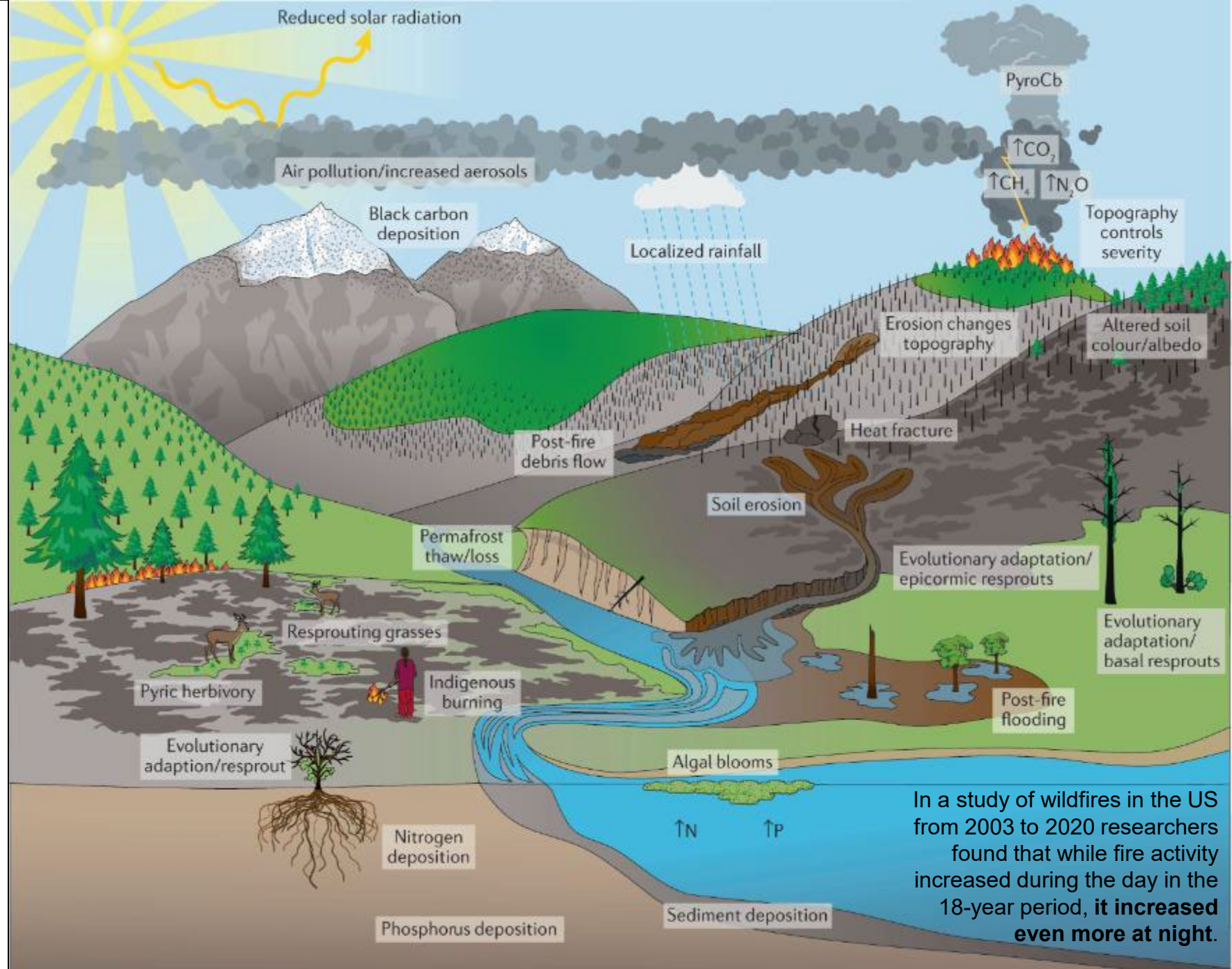
Large wildfires in the right atmospheric conditions can create Pyro-cumulus clouds which can amplify fire growth as they develop severe storm cell traits by causing erratic surface wind gusts, lightning ignitions, downbursts, and even tornadic activity.

Fires are getting larger and harder to extinguish.

The threats from fewer fires burning more acres can impact the immediate area of the fire by removing the groves/forests and amplifying wind threats and drying while reducing the water retention and force breakup capabilities naturally present historically.

- Without mature trees to hold soils back and slow runoff from storms, sedimentation rates are expected to increase across the rivers and reservoirs system.
- As bodies of water report greater rates of sedimentation there can be an increase in algal blooms or a decrease in retention capacity, causing water safety and ecology concerns.

Deposits of ash/soot into high elevations can provide a dark albedo, feeding snow algae and reducing the stability of snowpacks – yielding avalanche threats.



In a study of wildfires in the US from 2003 to 2020 researchers found that while fire activity increased during the day in the 18-year period, **it increased even more at night.**

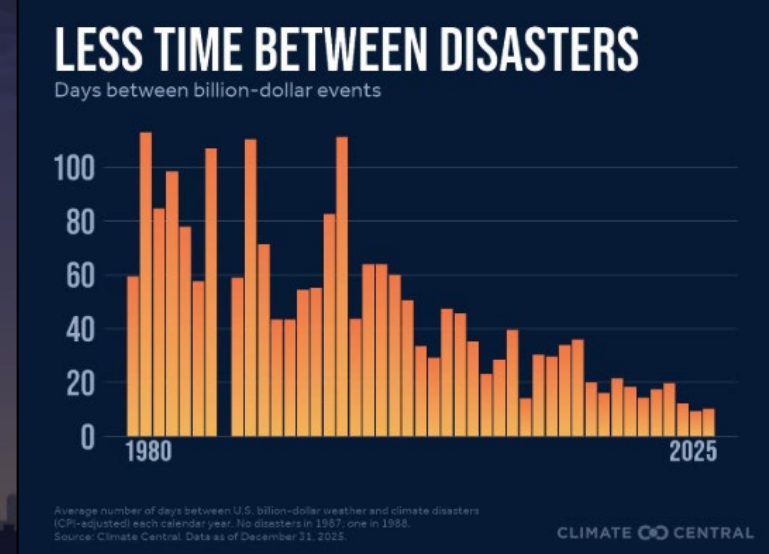
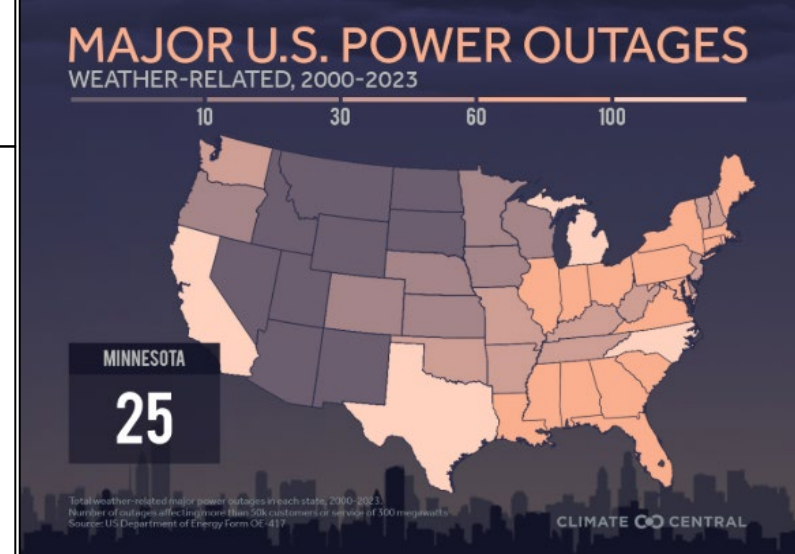
Flood Impacts

Flood water disrupts energy sector operations by inundating substations, underground equipment, control rooms, fuel systems, and access roads, which can force shutdowns, damage insulation and electronics, contaminate critical components, and delay restoration.

It also weakens foundations, corrodes equipment, blocks crews from reaching assets, interrupts fuel and supply logistics, and increases both immediate outage risk and longer-term reliability problems after the water recedes.

- Flooding changes chemistry, not just moisture level.
- Mud, salt, sewage, hydrocarbons, and debris accelerate degradation.
- Adhesives, insulation, electronics, bearings, and foundations all respond differently.
- Drying an asset does not restore its original life.

Back-to-back flood events damage energy sector engineered materials more because the first flood often leaves behind moisture, contamination, corrosion, sediment, and hidden weakening, and the second flood hits before equipment, insulation, coatings, seals, foundations, and structural materials have fully dried, cleaned, or recovered. That repeated wetting, contamination, and stress accelerates corrosion, insulation breakdown, coating failure, connector degradation, concrete and soil instability, and overall asset fatigue, raising both failure risk and restoration costs.



FLOOD AFTER FIRE



Did you know that wildfires dramatically alter the terrain and increase the risk of floods?

To learn more about **Increased Flood Risks After Fires**, please visit the FEMA website.



Temperature Impacts

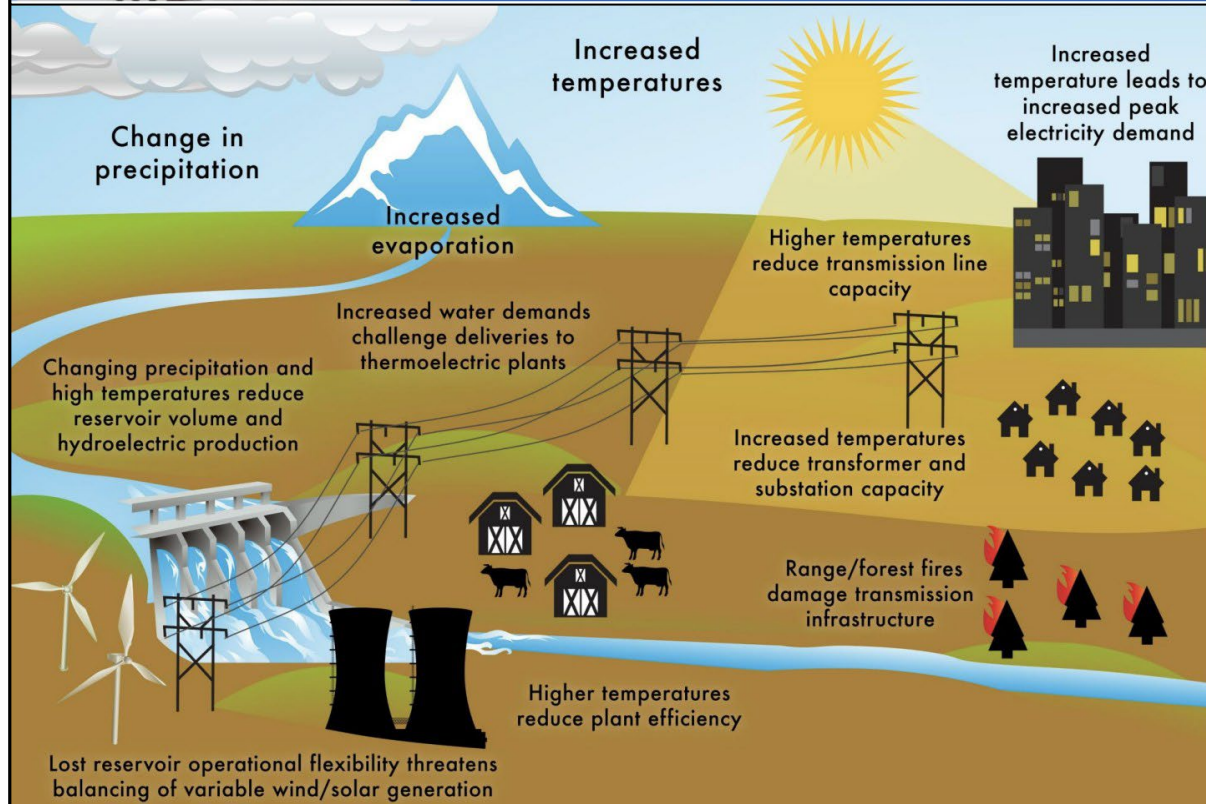
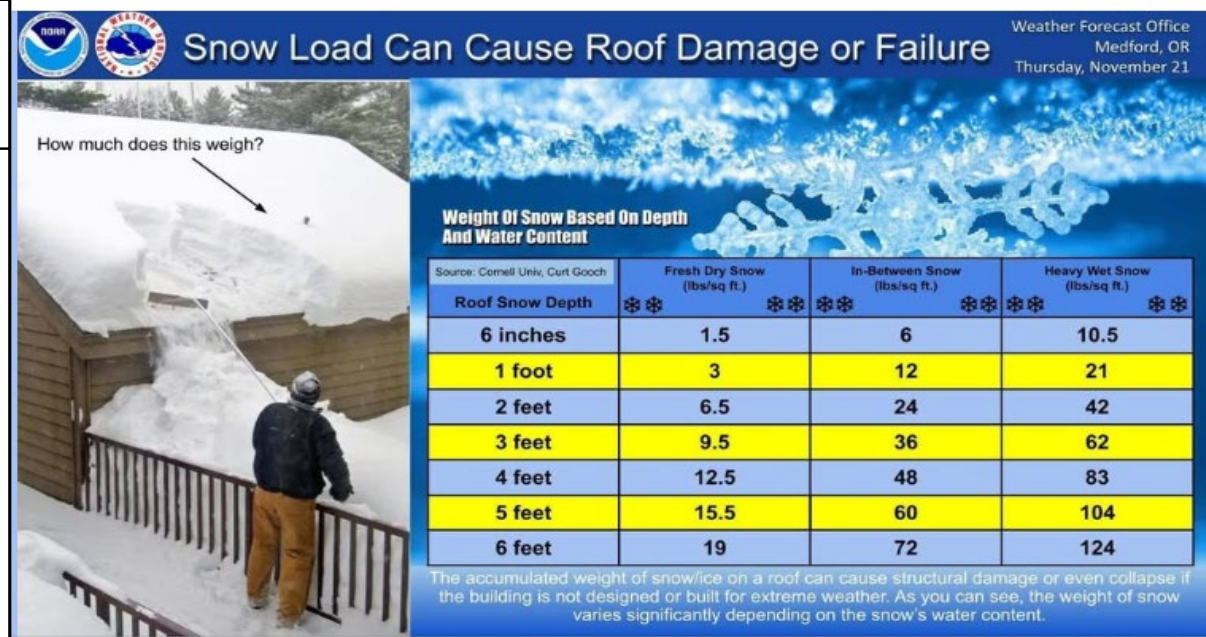
Extreme cold stresses grid equipment in different but compounding ways:

- **Power lines:** low temperatures reduce flexibility, increase brittleness, and, when combined with ice and wind, add mechanical loading that can damage conductors, connectors, poles, and nearby vegetation interfaces.
- **Resistors:** can drift from their intended values as temperature changes, while frost, moisture intrusion, and material cracking can degrade exposed assemblies and affect protection performance.
- **Transformers:** face thicker insulating oil, harder mechanical operation, and greater risk of cracked seals, leaking bushings, and insulation problems, especially when heavy load returns after prolonged cold.

In practice, extreme cold is not just a performance issue; it increases mechanical strain, insulation vulnerability, and restoration difficulty across the system.

- March 2025 blizzard: OPPD called it the most destructive weather event in its history. The blizzard caused tens of thousands of outages, with major damage to poles and equipment, especially in rural areas.
- December 2006 ice storm: NPPD documented that 37 transmission circuits were out of service because of physical damage from heavy ice loads. That is a clear example of winter storm damage to transmission infrastructure.
- January 2002 winter storm: A National Weather Service performance review covering Nebraska noted that storm damage was mainly due to power outages during a major ice, sleet, and snow event.

Operators should focus on high and low temperatures, the size and speed of the temperature swing, and time during high demands along with wind speed, humidity, dew point, freezing rain or snow amounts, and forecast confidence.



Concrete: In high heat environments over 80°F, concrete should not be poured, or it will not set effectively. This can increase setting time from 2-3 days up to 7 days in hot weather.

- Thermal cracking is found particularly in thick slabs, or mass concrete, where the temperature differential between different areas of the concrete is too high. (Examples: airport aprons, bridge headsticks, and highways where repaving needs have been increasing).

Epoxy: Most heat-resistant epoxies need to be cured at temperatures at or beyond the temperature it will need to endure. If temperatures exceed these maximum service temperatures, the material could start to distort. At a temperature of 135°F or higher, epoxy may begin to exhibit heat damage.

- Epoxy faces the same concerns of needing a few days to cure but in persistent high heat/humidity levels it could take up to two weeks.
 - If Epoxy cures in too high of a temperature it can become too solid, resulting in less give during temperature swings and may crack.

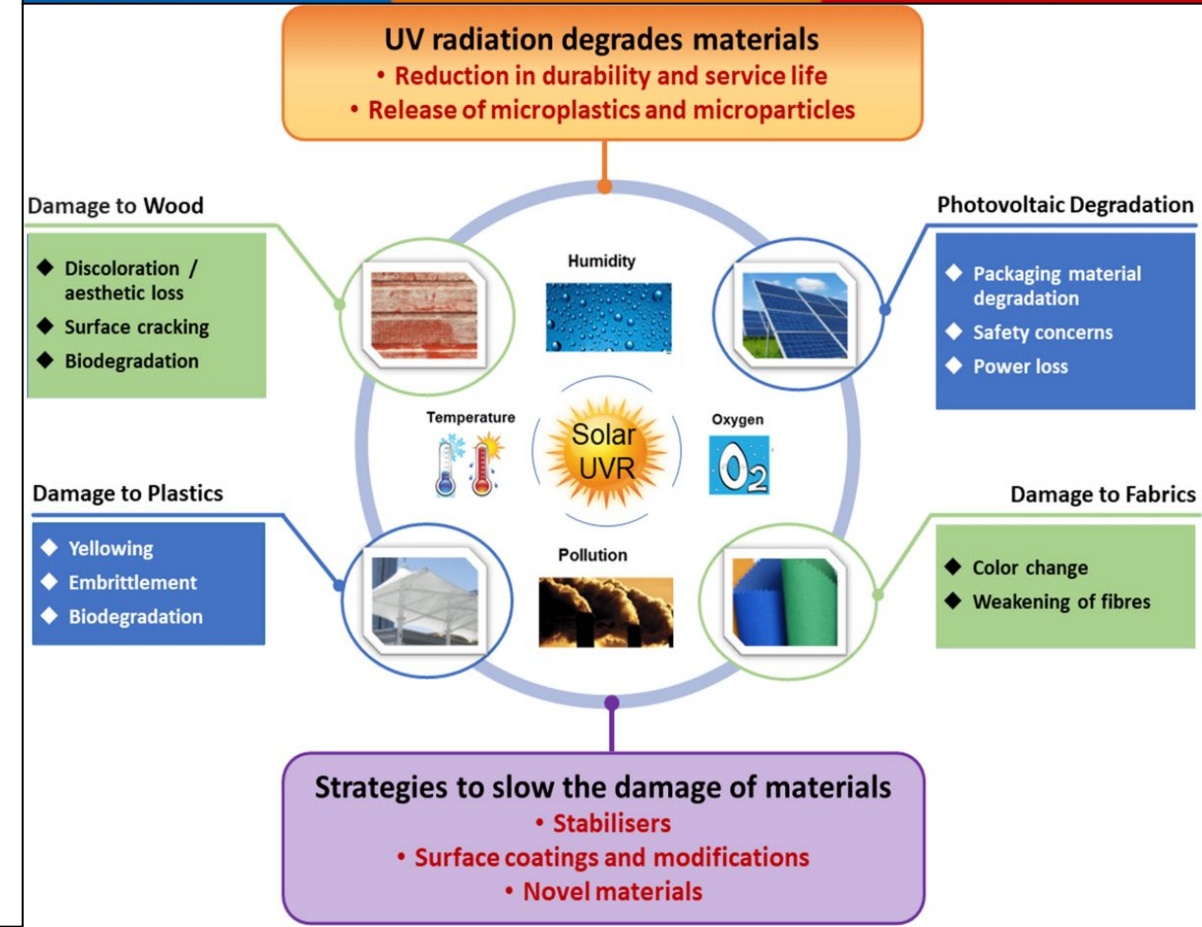
Metals: Extreme heat causes various metals to expand in addition to impacting the structure, electrical resistance, and magnetism. When metal heats, the bonds begin to break.

- Bridges in New York, Sacramento, and London have faced thermal expansion or cracking— 95°F in New York, 103°F in Sacramento, and 65°F in London.

Powerlines: Extreme heat can sag powerlines causing transmission lines to lose up to 5.8% of their capacity to carry electricity. Wind turbines can be 25% less efficient in high temperatures.

- The combined effects of extreme heat cost the US over \$162 billion in 2024 – equivalent to nearly 1% of the U.S. GDP.

Despite 2025's below-average total area burned, fires burned more intensely, leading to a 10% increase in emissions compared to the 20-year average. Smoke can pose a serious hazard near power lines because it is conductive and can cause electricity to arc.



Radiative Heat Threats: Cities + Canals

In the 1980s, concurrent heat waves only occurred for 20-30 days each summer. **Recent warming has driven a sixfold increase in the frequency of simultaneous heat waves over the last 40 years.** The study also found that concurrent **heat waves covered about 46% more space and reached maximum intensities that were 17% higher than 40 years ago.**

Concrete is a great material for absorbing and storing heat from the sun, meaning it can warm to higher temperatures than most other materials and releases that heat more slowly as direct heating stops. On a hot summer day, concrete that's in the shade can easily average 70°F, however, concrete that's in direct sunlight can reach 135°F. Due to the higher temperature, these mixtures are at risk of expansion-triggered water incursion, weakening the structural integrity of various sites and foundations.

- Grass rarely exceeds 80°F, wood peaks around 90°F, composite decking about 100°F, but concrete can reach a hotter temperature and hold onto that heat longer. In cities, the developed areas of cityscapes may have cooler temperatures due to additions of vegetation and shading, creating significant heat disparities.

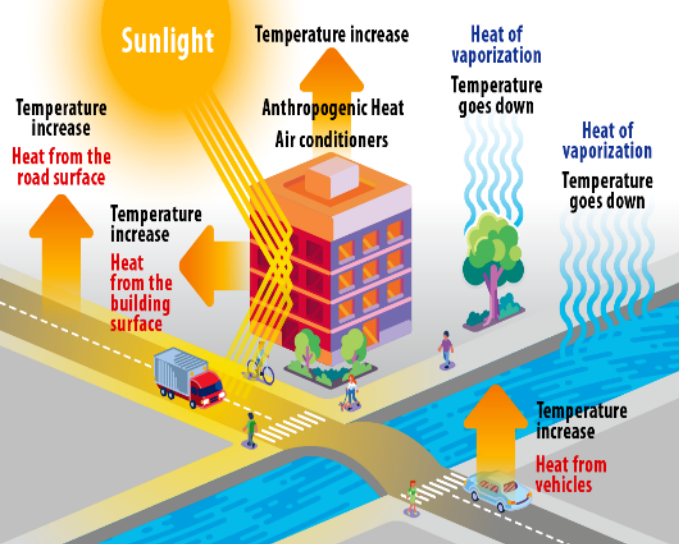
City Landscapes: Park benches in direct sunlight during summer months can easily reach temperatures of 125°F when ambient air is around 82-83°F. Metal benches can reach 136°F with coated benches still exceeding 108°F. Marble benches comparable can range up to 105°F while limestone can reach 116°F in sunlight. Shade drops the temperature by 16-18°F. Water fountains can reach 95°F, bus stop signs/posts can reach 105°F, bicycles can range to 104°F for seats, 102°F for handles, and crosswalk buttons near 98°F.

Without cooling centers staying open overnight, at-risk populations are purged back into an abnormally warm city where pollution concentrations remain high due to lingering heat.

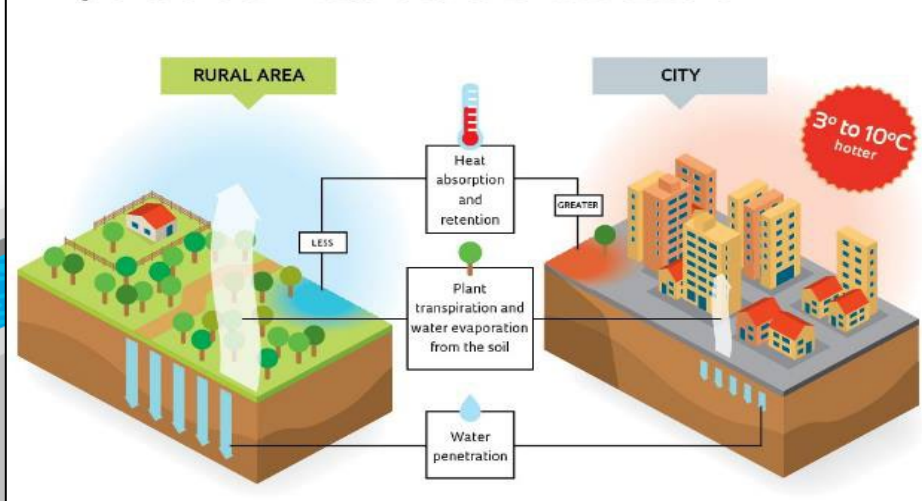
- The more densely packed a metro car is or a bus is, the greater the ambient temperature will become making it more difficult to cool down between stops.

When asphalt heats it becomes more malleable, making it soft and able to compress under weight and become disformed. High heat also rapidly ages the material, making infrastructure on or near it weaker.

At the current rate of heating, the expansion buffer will not stop the material from buckling more often. This will yield more potholes and lower income communities may not be able to repair at the heightened damage rate.



Why the urban heat island effect occurs



SURFACE TEMPERATURES			
	3/4/22 10:30am	6/21/22 10:30am	3:30pm
AIR TEMPERATURE	52°	84°	104°
1. Concrete (sidewalk)	■ 58°- 61.5°	▲ 110°	◆ 142°
2. Asphalt (street)	■ 62°- 64°	▲ 125°	◆ 155°
3. Plants	■ 65°	▲ 89°- 91°	◆ 105- 115°
4. Turf (grass)	■ 69°- 71°	▲ 93.5°	◆ 99.5°
5. Bare Dirt	■ 78°	▲ 119°	◆ 159°
6. Mulch	■ 81°	▲ 120°	◆ 154°
6a. Soil under mulch		▲ 96°	◆ 110°
7. Gravel (stones)	■ 82° large ■ 90° small	▲ 122° lg. ▲ 129° sm.	◆ 140° ◆ 149°
8. Artificial Turf	■ 90.5°- 93°	▲ 143.5°	◆ 165°

Extreme Temperatures and EV Fleet Risk

When temperature drop significantly, electric vehicle (EV) charging can become impaired at public stations. When extreme heat causes public safety power shut offs (PSPS) public vehicle charging can also be hindered.

- Electric cars can also face decreased ranges from the wear and tear major temperature fluctuations can have on their battery storage capabilities. Some charging stations may not report when they are shut down due to power loss from storms or temperatures.

Extreme Cold: Full EVs, which run exclusively on battery packs, typically [lose 30-41% of their range](#) when outdoor temperatures drop to 20F and the heat's cranked on (AAA/Recurrent).

- Recurrent measured the range loss [for a number of EVs](#) and found extremes such as the range for the Kia Kona EV drops 34% in freezing weather, while the loss for a Tesla Model S was 28%.

Extreme Heat: EVs can lose up to 20% of their range in 95 degrees or hotter. Some companies provide rentals during blackouts.

- Some of the highest levels of EV adoption are in hot places. California, Florida, Texas, Arizona and Georgia are home to 56% of the nation's battery-powered cars, according to the Department of Energy.
 - As EVs are nearly 50% heavier than a standard gas-powered vehicle, wear and tear rates on parking lots and garages may be shifted towards charging station users with garage fire risks rising from heat.

Strategic planning at Cox Automotive Inc., said 4 out of 5 EV shoppers consider battery longevity when buying

- When temperatures climb, the ions in a car battery speed up. Once that happens, they often have trouble attaching to the anode or cathode. The pressure and speed can also create small cracks, which slow chemical reactions and make for less usable battery life.
- EVs with heat pumps lose an average 20% of their range in extreme weather, compared with up to 40% in those without heat pumps

[Consumer Reports' testing](#) of four popular EV models — the Hyundai Ioniq 5, the Volkswagen ID-4, the Ford Mustang Mach-E and the Tesla Model Y — also found significant battery depletion in cold weather.

Battery range dropped 25% from spring to winter and 30% from summer to winter, with the researchers looking at temperatures near zero Fahrenheit for the coldest conditions and around 80 degrees in the summer.



MERCEDES EV

EXPLOSION

In South Korea leaves **21 injured**
and **140 cars damaged**



Hydroelectric Dams Impacts

A [study](#) published in the journal *Earth's Future* found that hydro availability and summer air temperatures are likely the biggest determinants in Western electricity prices.

In 2021, a historic drought that affected much of the western US led to reduced water supply and, as a result, lower hydropower generation in the Pacific Northwest and California.

- Electricity generation at California's hydropower plants was 48% below the 10-year average (2011–2020). The Lake Oroville Dam was shut down for the first time since 1967 due to low water levels and Lake Shasta's dam was generating about 30% less power than usual.
- St. Cloud hydroelectric dam shut down in August 2021 when Mississippi River flows fell below 700 cubic feet per second for first time since 1988 when it was last shut down due to low flows.

The hydropower shortfall from January 2021 to July 2022 caused WAPA to [spend \\$78m of a \\$146m buffer fund](#) as it had to buy alternative power for its customers in times of shortages. Customers faced a 40% price increase.

- Navajo Tribal Utility Authority reported its operating costs rose by \$4.5m in 2022 due to drought.

In 2022, The Hoover Dam was down 25% while the Glen Canyon output reduced about 35%.

- In the Pacific Northwest hydropower generation was 14% below the 10-year average with the Grand Coulee dam at 12% below the 10-year average.

The six mainstem hydroelectric power plants for the Missouri River System generated 832 million kWh of electricity in September 2022, compared with typical 902 million kWh September generation.

- The power plants generated 7.4 billion kWh of electricity by the end of 2022, compared to the annual long-term average of 9.4 billion kWh. The region saw 2x the drought coverage of normal.

At current reservoir sedimentation rates, the existing global reservoir storage capacity could be nearly halved by 2100. Sedimentation rates vary widely according to the river basin's geologic and physical condition. Causing some dams to age faster than others due to sedimentation alone.

- The estimated loss of storage capacity in reservoirs in the US due to sedimentation ranges to a loss of \$100 million. The annual cost for promoting the removal sediments is about \$6 billion. Semi-arid locations are more susceptible for reservoir problems as they have higher capacities.

In 2025: According to ISO-New England records, average daily hydropower generation went from more than 23,000 megawatt hours in June to about half that in August.

A [2022 study published in 'Water'](#) assesses the risks of floods and water scarcity to hydropower projects and how those risks may shift due to climate change with regions highlighted for risk of water scarcity by 2050.

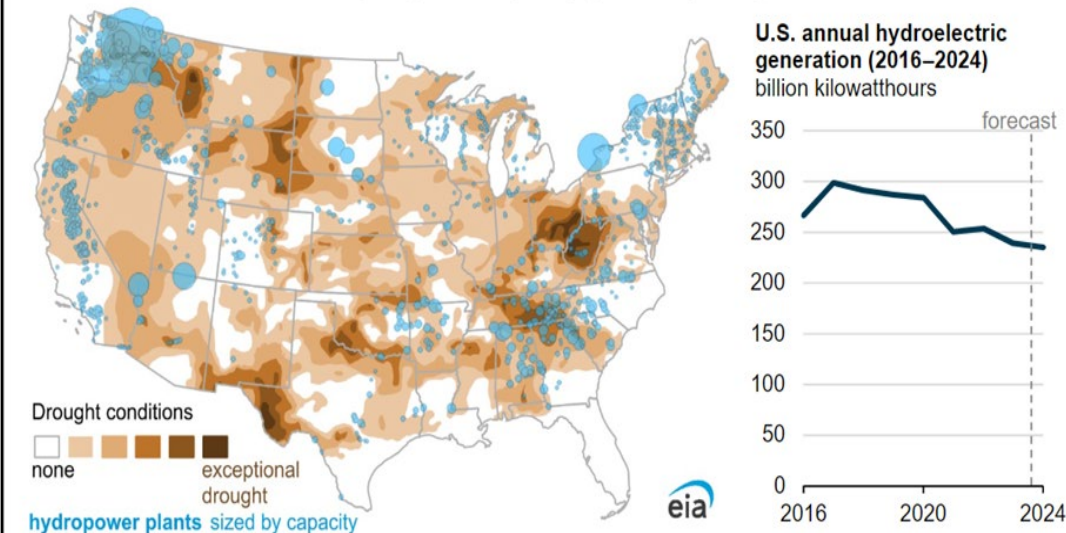
- **By 2050, 61% of all global hydropower dams will be in basins with very high or extreme risk for droughts, floods or both. By 2050, 1 in 5 existing hydropower dams will be in high flood risk areas because of climate change, up from 1 in 25 today.**
- Only 2% of planned dams are in basins that currently have the highest level of flood risk, but by 2050, nearly 40% of this same group of dams will be in basins with the highest flood risk.

Water flow in the Colorado river could drop 30% by 2050 and 55% by 2100 due to greenhouse gas emissions. ~1.9 million acre-feet (13% of the water from the reservoirs across the entire river) evaporates each year.

In 2022, drought forced factories in the hydropower-reliant province of Sichuan, China to close temporarily due to a lack of electricity.

In 2025, multiple African nations like Zambia and Zimbabwe reported their reservoir levels fell with immediate hydroelectric losses and resulting power cuts triggering a boom in solar panel purchases.

U.S. drought conditions and hydropower capacity (as of Sep 2024)



Data source: U.S. Energy Information Administration, *Short-Term Energy Outlook* and *Electric Power Annual*; U.S. Drought Monitor

Gravity Waves, Sprites, Elves – Unseen Threats

Gravity Waves are ripples in the air that spread out like those from a dropped stone, visible as concentric rings in satellite imagery and airglow layers high above the Earth.

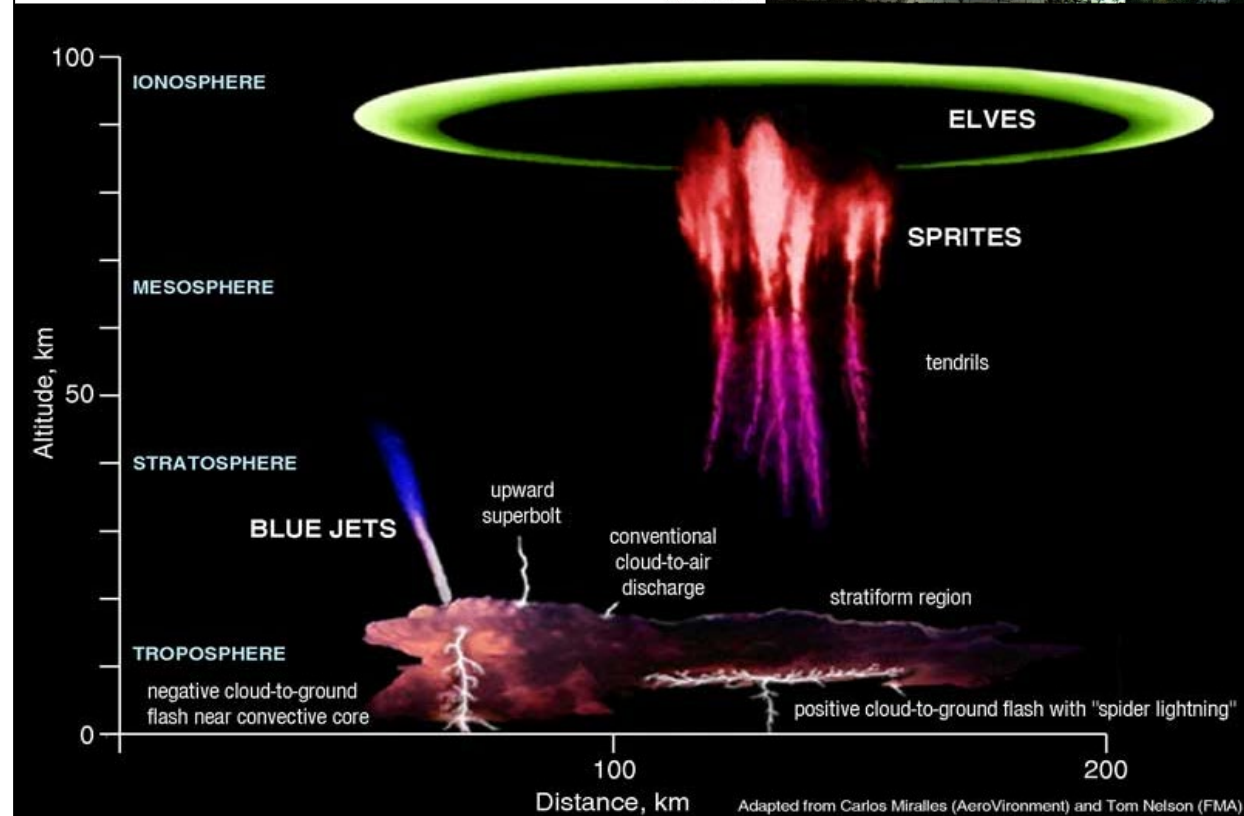
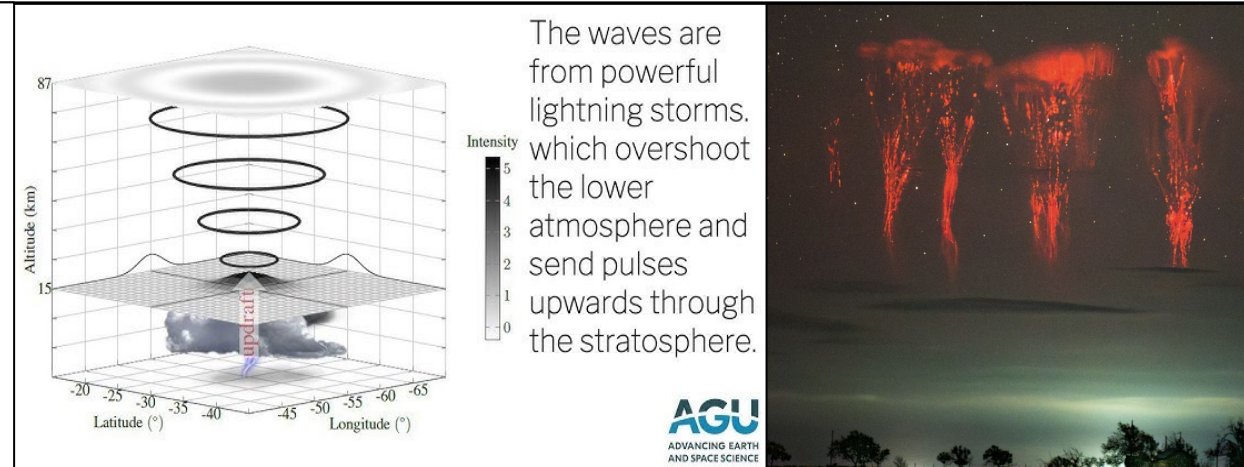
- These waves are caused by the strong updrafts punching into the stable air of the tropopause, and their intensity correlates with lightning activity, serving as an indicator of strong convective weather and even triggering new storms elsewhere.
 - The dynamic region where these waves dissipate energy can disrupt space-based communications and navigation signals, including GPS
 - Gravity waves can produce significant clear-air turbulence, even at high altitudes (up to 50,000 feet). This turbulence poses a physical hazard to aviation, including drones, potentially affecting their stability, control, and safety.

Sprites are large-scale electrical discharges appearing as brief, reddish flashes typically 30-60 miles above large thunderstorms stretching up to 50 miles vertically and 30 miles wide.

- These Gravity Waves can produce significant clear-air turbulence, even at high altitudes (up to 50,000 feet). This turbulence poses a physical hazard to aviation, including drones, potentially affecting their stability, control, and safety.

Elves, aka (Emission of Light and Very Low Frequency perturbations due to Electromagnetic Pulse Sources), are halos of light in the upper atmosphere up to 300 miles wide caused by powerful electromagnetic pulses from intense thunderstorms below exciting nitrogen molecules in the ionosphere. (TLEs)

- TLEs can disrupt communication systems on the ground and pose a threat to aircraft and spacecraft.



Tropical Impacts

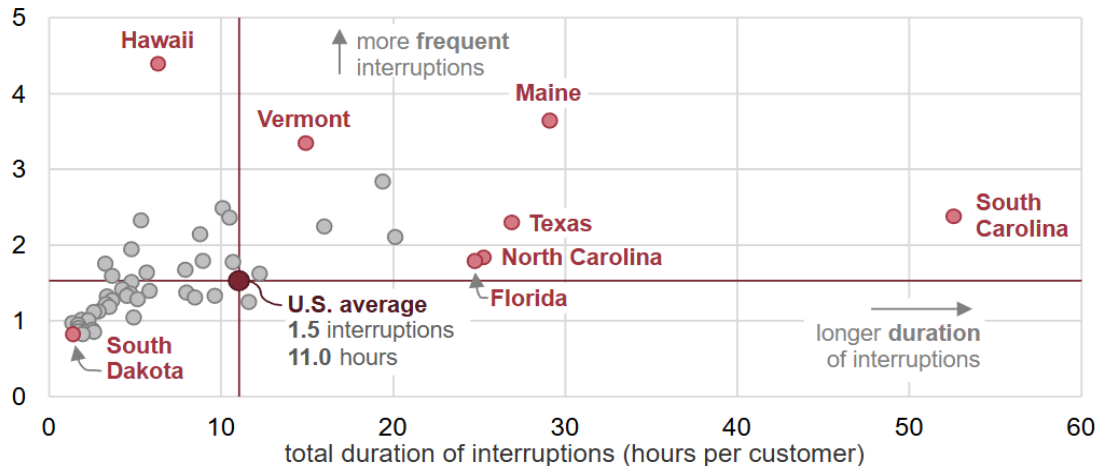
In 2024, Hurricanes Beryl, Helene, and Milton accounted for 80% of U.S. hours without electricity that year.

U.S. electricity customers experienced an average of 11 hours of electricity interruptions in 2024, or nearly twice as many as the annual average experienced in the decade before.

- States with the most time without power dealt with major weather events in 2024.
- In July, Hurricane Beryl left 2.6 million customers without power in Texas.
- In September, Hurricane Helene left 5.9 million customers without power across 10 states; at least 1.2 million of those customers were in South Carolina.

Customers in South Carolina experienced longer service interruptions than in any other state, at nearly 53 hours in 2024.

Average annual total electric power interruptions by state (2024)
number of interruptions per customer



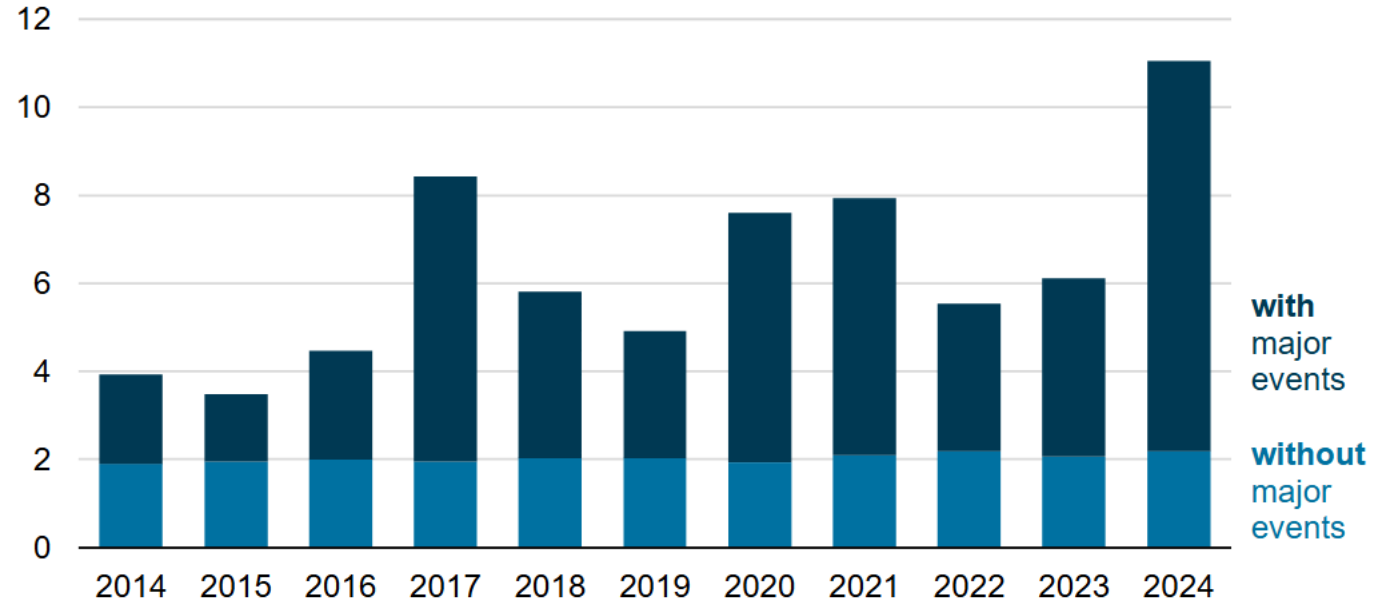
Data source: U.S. Energy Information Administration, *Electric Power Annual 2024*
Data values: Distribution System Reliability, SAIDI and SAIFI values of U.S. distribution system by state

DECEMBER 1, 2025

Hurricanes in 2024 led to the most hours without power in the United States in 10 years

U.S. electric power interruptions (2014–2024)

number of hours per customer



Data source: U.S. Energy Information Administration, *Electric Power Annual 2024*
Data values: Distribution System Reliability, Reliability metrics of U.S. distribution system

Customers in states like Arizona, South Dakota, North Dakota, and Massachusetts experienced, on average, less than two hours of service interruptions in 2024.

- Some states experienced outages more frequently than the U.S. average (1.5 instances) in 2024. For example, Hawaii electricity customers experienced 4.4 electricity interruptions in 2024, the most of all states.
- States such as South Dakota, Maryland, Illinois, and Massachusetts experienced, on average, less than one power interruption last year.

Tropical remnants can travel into areas like Kansas, Nebraska, Kansas, Missouri and Iowa often fueling severe weather outbreaks during the later part of Summer.

Tropical Cyclones Strengthening: Wind/Water

Basing emergency response operations off solely a 'category' will not prepare regions properly for floods or mudslides

Globally, average sea level has risen over half a foot since 1900 and is expected to rise [1 to 2.5 feet during this century](#). [Coastal regions](#) will experience the worst of these effects.

Sea level rise increases the risk of coastal flooding and has intensified the impact of several recent storms.

- A [study of Hurricane Katrina](#) estimated that higher sea levels led to flood elevations 15-60 percent higher than climate conditions in 1900.
- A [study of Hurricane Sandy](#) estimated that sea levels at the time increased the likely of flooding by three times and that additional rising will make severe flooding four times more likely in the future.

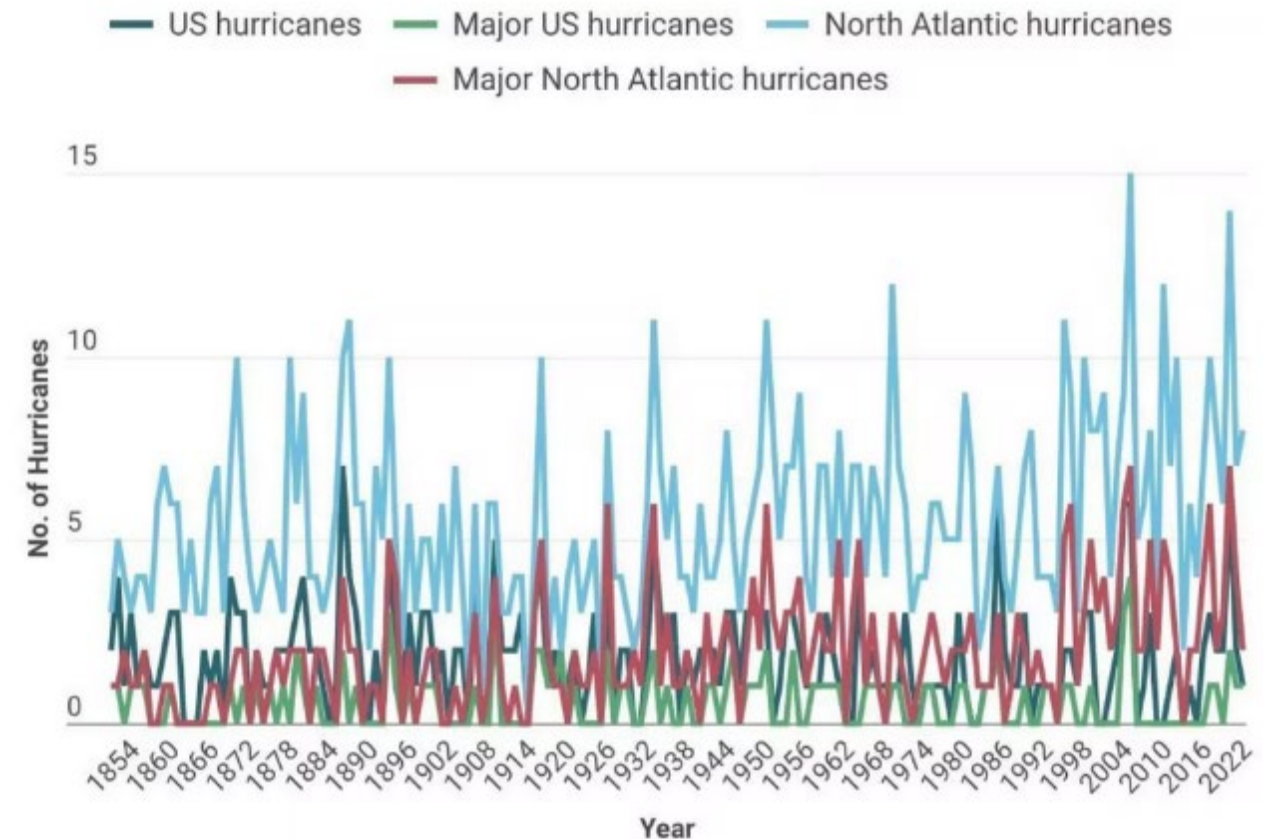
Research reported by [Studholme et al](#) in the January 2022 issue of Nature Geoscience suggests northward forming tropical cyclones are consistent with oceanic heating-induced poleward migration of tropical cyclones.

- By 2080, we are likely to see significant tropical cyclone formation and intensification between 30°N – 40°N to include New York, Boston, Beijing, Tokyo, etc.

A recent study from China on tropical cyclone landfall producing abnormally heavy rainfall rates, the strongest rains occur when tropical cyclones reach super typhoon (cat 4-5) strength and then weaken to tropical storms after making landfall, meaning cyclones dropping strength before landfall present a larger issue in more flood damage and underestimated event cost/impact.

Number of North Atlantic and US hurricanes

The Saffir-Simpson scale consider major hurricanes those of category 3, 4 or 5 while it classifies storms based on the intensity of sustained winds.



Source: Hurricane Database (HURDAT), National Oceanic and Atmospheric Administration

Tropical Cyclone Changes

Over the recent 2013–2022-decade, rainfall flooding accounted for 57% of all U.S. deaths from tropical cyclones, according to a 2023 report from the NHC.

- From 1980 to 2023, 177 landfalling Atlantic tropical cyclones rapidly intensified.
 - In the North Atlantic, the number of storms that quickly intensified from Category 1 (or weaker) into a major hurricane has more than doubled in 2001-2020 compared to 1971-1990.
 - Most (72%) of the 67 total billion-dollar tropical cyclones in the U.S. since 1980 rapidly intensified.
- Since 1979, warming has increased the global likelihood of a tropical cyclone developing into a major hurricane (+Category 3) by ~8% per decade.
- Warm ocean waters that fueled Hurricane Beryl are up to 400 times more likely.
- The Atlantic hurricane season is expected to be about a month longer by 2100.

Research shows Atlantic hurricanes are experiencing a reduction of roughly 17% in forward motion speeds than in previous decades, which translates into an increase of about 25% in rainfall.

- Extreme rainfall rates (focusing on *hurricane strength only*) saw increases for 3-hourly rainfall rates of 11% and 3-day total accumulated rainfall by 8%.

A recent assessment indicated an increase of global tropical cyclone rainfall rates at 7% per degree of warming with an observational finding of a 1.3% global increase in tropical cyclone rainfall rates per year since the early 1900s.

- A study on the 2020 North Atlantic hurricane season found that hourly hurricane rainfall totals were around 10% higher compared to hurricanes recorded in the pre-industrial (1850s) era.

2025 hurricane season is not forecast to produce a record number of cyclones but could produce more significant damage to US infrastructure via rain and surge.

CLIMATE CHANGE AMPLIFIES HURRICANE IMPACTS

- STORM SURGE**
Sea level rise has elevated and dramatically extended the storm surge driven by hurricanes.
- EXTREME RAINFALL**
Warmer air holds more moisture, feeding more precipitation into all storms.
- POTENTIAL WIND SPEED**
As climate change warms sea surfaces, the heat available to power hurricanes has increased.

STRONGER WINDS
The intensity of tropical cyclones is expected to increase, leading to a higher proportion of severe tropical cyclones (and a decreased frequency overall). Cyclones may also intensify faster.

MORE RAINFALL
Warmer ocean temperatures and a warmer atmosphere mean that the rainfall associated with tropical cyclones will likely increase. Flooding is often the most destructive aspect of tropical cyclones.

INCREASED COASTAL EROSION & FLOODING
Rising sea levels mean that the storm surges that accompany tropical cyclones are even more damaging.

LENGTHENED SEASON, INCREASED RANGE
Climate change is likely to extend the cyclone season, and extend the range of cyclones southwards, where housing is not built to withstand cyclones.

CLIMATE COUNCIL.ORG.AU | crowd-funded science information

TROPICAL CYCLONES:
Rapid Intensification

Wind speed increases at least **35 mph** in 24 hours

79% of major tropical cyclones rapidly intensify

Projected to **happen more** in a warming world

STRONGER, FASTER
Atlantic tropical cyclones intensifying at least 35 mph in 24 hours

Year	Number of Storms
1980	5
1981	3
1982	2
1983	1
1984	3
1985	2
1986	1
1987	2
1988	1
1989	2
1990	1
1991	2
1992	1
1993	2
1994	1
1995	2
1996	1
1997	2
1998	1
1999	2
2000	1
2001	2
2002	1
2003	2
2004	1
2005	2
2006	1
2007	2
2008	1
2009	2
2010	1
2011	2
2012	1
2013	2
2014	1
2015	2
2016	1
2017	2
2018	1
2019	2
2020	1
2021	2
2022	1
2023	2

CLIMATE CENTRAL

Hurricane Milton
10/07/2024

At point of peak intensification climate change made ocean warmth at least 100x more likely increasing maximum wind speed

+23 MPH

CLIMATE CENTRAL

Transmission Impacts from Extreme WX

Shifting the scale of the grid system to being more impervious to weather events requires an expansion of the grid in a localized approach.

- Interconnecting hubs to improve resiliency across multiple states and regions, ideally creating a national system of transmission.
- As storms get larger in size and intensity, the grid will need resiliency to feed through the backside of the storm, being able to locally respond from unimpacted areas in transmission needs.
- Ensuring a diversified portfolio of energy generation within renewables will prevent any one storm from reducing production in full and will disperse supporting energy infrastructure efficiently.

As supercells propagate across larger regions, worsening intensities outside of built norms, matching innovation progress and failure will cost more than past decades.

- A study by Texas A&M and Potsdam Institute showed that **storm-proofing as little as 1% of the power lines in an electricity grid could slash the chance of hurricane-induced blackouts by between fivefold and 20-fold in a study done using the Texas electricity grid.**

As drought continues to prematurely decay vegetation across the nation, wildfire threats will rise, and the number of downed trees will increase.

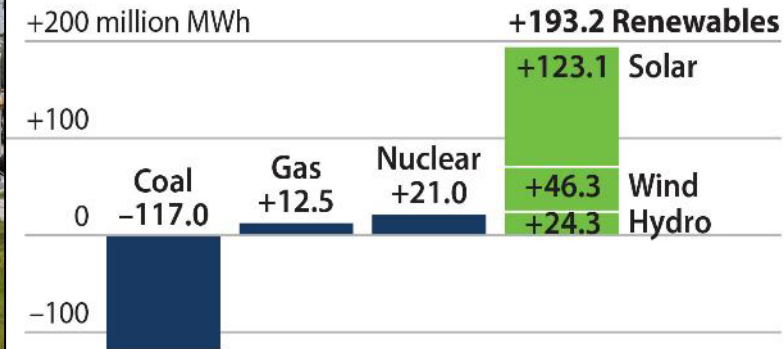
- The climate crisis is driving more extreme weather which means more heat-stressed power lines, fallen trees, flooding, and more AC usage.

Combined, the stress on the aging infrastructure and weakening of vegetation results in more damage from each storm causing more frequent and often longer lasting outages more likely as concrete weakens, powerlines sag, and branches fall more frequently.



Power Changes: EIA's Outlook to 2025

Change in generation from 2023 to 2025 for each fuel

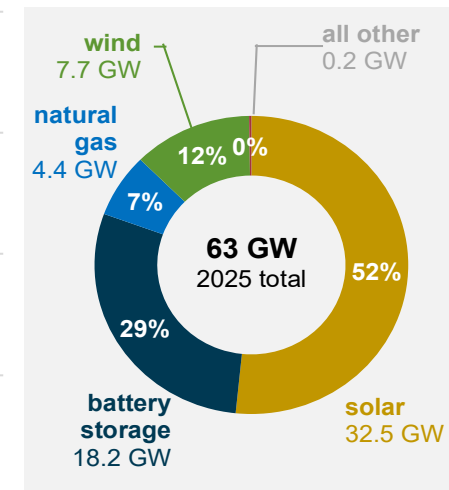
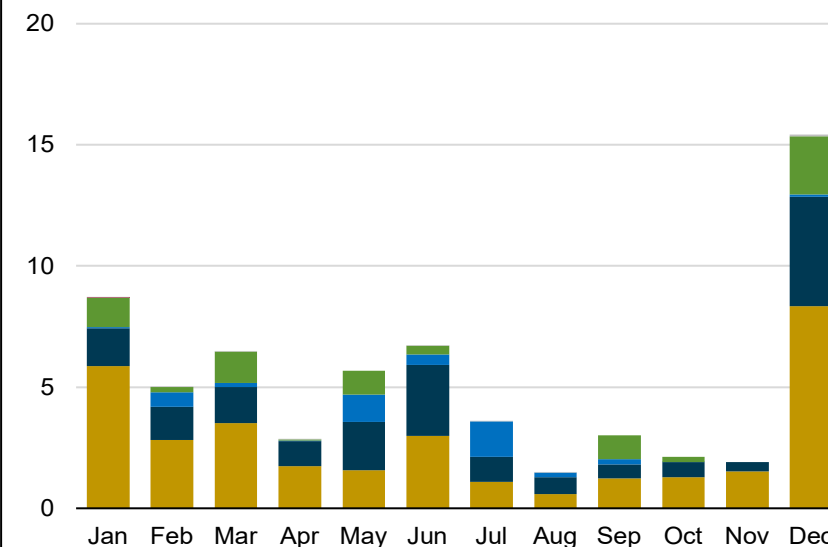


Source: EIA Short-Term Energy Outlook, Jan. 2024

IEEFA

The two largest natural gas plants expected to come online in 2025 are the 840-MW Intermountain Power Project in Utah and the 678.7-MW Magnolia Power in Louisiana. Two large offshore wind plants are expected to come online this year: the 800-megawatt (MW) Vineyard Wind 1 in Massachusetts and the 715-MW Revolution Wind in Rhode Island. Indiana, Arizona, Michigan, Florida, and New York each to account for more than 1 GW of added solar capacity in 2025 and collectively account for 7.8 GW of planned solar capacity additions.

U.S. planned utility-scale electric-generating capacity additions (2025)



Engineer/Staff Impacts

If the wet bulb temperature exceeds the human body's skin temperature of around 95°F sweating can no longer cool the body, which can result in death by overheating; causing more downtime for outside workers will be necessary to reduce mortality rates.

- At this temperature, even young, healthy people *die* in about six hours.
- **Air conditioning removes humidity from the air and is the best solution when wet-bulb temperatures get too high.**
- Fans can help sweat evaporate more efficiently but are less effective. People can die of heat stress at wet-bulb temperatures lower than 95°F.

“If there's enough moisture in the air, it's thermodynamically impossible to prevent the body from overheating, even if there is an endless supply of water available, shade, and light clothing.”

A sustained wet-bulb temperature **exceeding 87°F** is likely to be fatal even to fit and healthy people, unclothed in the shade next to a fan; at this temperature human bodies switch from shedding heat to the environment, to gaining heat from it.

- At an internal temperature of **109.4°F** serious brain damage, continuous convulsions, shock, and death are possible results for humans. Cardio-respiratory collapse will likely occur.

During a heat stroke the body temperature increases to over 104°F. The acute overheating causes a brain edema, that evokes symptoms such as cramps, clouding of consciousness, headache, and sickness. In the worst cases heat stroke ends with lasting brain damages or with death.

Within 50 years, states like Arkansas, Missouri, and Iowa will likely hit the critical wet-bulb temperature limit (NASA).

The CDC states some medications can interfere with your body's ability to regulate temperature, making it harder to cool down and increase sun sensitivity to the skin, like:

- Heart medications (ex. water pills, Lasix, Microzide)
- Antidepressants (ex. Lexapro, Prozac, Zoloft)
- Antipsychotics (ex. Risperdal, Zyprexa)
- Central nervous system stimulants (ex. Adderall, Ritalin)
- Anticholinergics (ex. Cogentin, Detrol)
- Antihistamines (ex. Benadryl)
- Decongestants (ex. Sudafed, Afrin, Mucinex, and Zicam)
- Dopaminergics (ex. Sinemet)

The heat can also damage or degrade some medical devices such as insulin, inhalers, hearing aids, and EpiPens so make sure those are properly stored. Some drugs and substances that can act as diuretics, which rid the body of extra fluid and salt, include:

Antibiotics	Antidepressants	Corticosteroids
Alcohol	Antihistamines	Laxatives
Anticholinergic drugs	Beta-blockers	Lithium

LOW-INCOME FAMILIES ARE DISPROPORTIONATELY AFFECTED BY HIGH HOME ENERGY COSTS.

16.3%

OF A LOW-INCOME FAMILIES' GROSS ANNUAL INCOME IS SPENT ON HOME ENERGY COSTS

3.5%

OF OTHER HOUSEHOLDS' ANNUAL INCOME IS SPENT ON HOME ENERGY COSTS COMPARATIVELY

Heat Affects Health in Many Ways

Warmer temperatures increase the risk for a diverse range of health risks. For example:



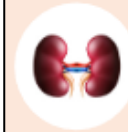
An increased risk of **hospitalization for heart disease.**



Heat exhaustion, which can lead to **heat stroke** if not treated, can cause critical illness, brain injury, and even death.



Worsening **asthma** and **chronic obstructive pulmonary disease (COPD)** as heat increases the production of ground-level ozone.



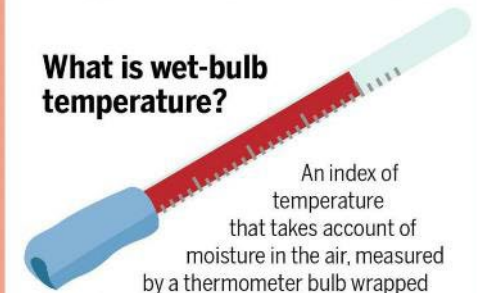
Dehydration, which can lead to **kidney injury** and blood pressure problems. Some kidney damage can become irreversible with repeated or untreated injury.



Violence, crime, and suicide may increase with temperature, adding to the rates of depression and anxiety already associated with climate change.

Wet-bulb temperature is a superior index of heat as perceived by the human body

What is wet-bulb temperature?



An index of temperature that takes account of moisture in the air, measured by a thermometer bulb wrapped in a wet cloth.

Wet-bulb temperature of 35 C is the survivability limit for humans



CORE TEMPERATURE: 37 C | SKIN TEMPERATURE: 35 C

Above 35 C, the body cannot cool itself through sweat

Extreme Weather and Unrest: Response Risk

AED Equipment: Typically, the temperature range for normal AED operations is 32-122° F, since extreme temperatures can impact normal functions by draining the battery or altering the gel found in pads.

- High temperatures can negatively impact an AED's functionality and lifespan. Extreme heat can cause the internal circuitry to malfunction, potentially leading to device failure during a critical moment.
- Additionally, high temperatures can shorten the lifespan of the AED's battery and affect the gel on the electrode pads.

Emergency Vehicles: extreme heat or high humidity can impact safe temperatures of seatbelt buckles, steering wheels, laptop systems, windshield mounted radar, rifle racks, camera systems, leather accessories, radio console, prisoner cages, in-vehicle fire extinguishers, road flares, etc.

- High temperatures can impact the accuracy and performance of police car radar (speed guns).
- Higher temperatures are linked to increased rates of tire blowouts, diminished battery ranges, radiator cracks, and in smart vehicles may result in touchscreen lifting and loss of access to critical applications due to extremes.
- Over prolonged exposure, fire extinguishers can explode due to excessive heat and pressure buildup.
- Road flares degrade in high temperatures or humidity and should not be left in temperatures >120F for long.

Wounds: High moisture levels can make it harder for these chronic wounds to heal, increasing the risk of infection and complications. Dehydration can worsen ulcers and can reduce the ability to properly judge the level of discomfort.

- Whether you're recovering from a minor scrape, a surgical incision, or a more significant injury, the amount of moisture in the air can determine how quickly and effectively your body repairs itself.
- Too much humidity can increase the risk of infection, while too little can slow the healing process, causing unnecessary pain and discomfort.

Social Impact - Asthma: People may notice their asthma symptoms get worse on humid days when there is a lot of moisture in the air. This is especially true when exercising in humid conditions.

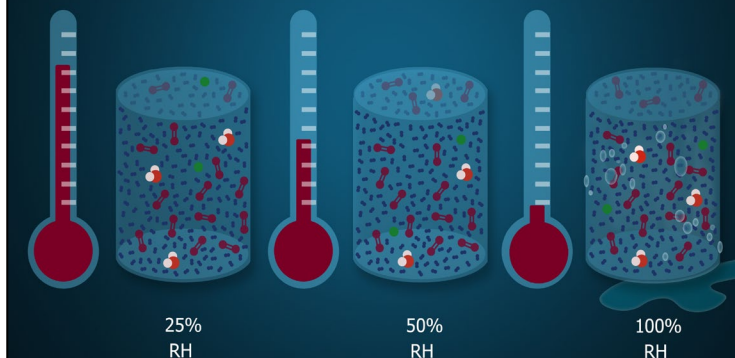
- Humidity can increase the levels of other substances in the air that irritate the bronchial tubes, such as pollen and pollution.
- After experiencing hot, humid air (49°C and 75–80% humidity) for 4 minutes, people with asthma had a 112% increase in airway resistance as opposed to the healthy group that only had a 22% increase in airway resistance.

Social Impact - Thunderstorm Induced Asthma: During the first 20-30 min of a thunderstorm, patients suffering from pollen allergies may inhale a high concentration of the allergenic material that is dispersed into the atmosphere, which in turn can induce asthmatic reactions, often severe.



THE EFFECTS TEMPERATURE HAS ON RELATIVE HUMIDITY

Relative Humidity (RH) refers to the amount of water vapour in the air in relation to how much water vapour the air can hold. Cool air cannot hold as much water vapour as warm air. 25% RH means that the air is holding just 25% of the vapour it is capable of before it is saturated. When the temperature has been reduced to the dew point the RH is 100%, meaning the air is fully saturated and the moisture will begin to condense to liquid phase.



Weather and Weapons

Guns: *humidity and heat impact manufacturing, firing, and successful shots.*

- Higher humidity causes less dense air and a faster bullet trajectory, delivering a high impact on the target when you don't account for it.
- Lower humidity results in thicker air, slowing down your bullet's trajectory and delivering low impact on target when you don't account for it.
- As temperature increases, the muzzle velocity increases as the air density reduces, causing less bullet drag. This action flattens the bullet path, resulting in high hits if there's no compensation.
- A temperature increase of 5°C can displace a bullet by as much as 8 inches between shots. Complete seasonal temperature changes, on the other hand, can result in far more drastic effects.
- Humidity has a significant influence on the preservation of ammunition and its components - ammunition bunkers must be kept dry and their relative humidity low.

Handcuffs: *metal handcuffs exposed to direct sunlight can cause thermal burns.*

- Most police handcuffs are made of stainless steel or similar metals that conduct heat well. Some agencies use polymer or coated handcuffs to reduce this risk.
- Arresting on hot asphalt/concrete may result in additional injury and liability risks.

Tasers: *humidity and heat can increase impact and degrade batteries.*

- High humidity or wet areas can damage sensitive electronics and batteries in stun guns and Tasers.
- Environmental conditions, such as humidity, can potentially change the chemical composition of the primer used to ignite the firing sequence in Taser cartridges, decreasing energetic output over time.
- Higher humidity means more moisture in the air, which can increase the electrical conductivity of both the air and skin.

Tear Gas: In a heatwave, you're likely to sweat more, which means more moisture for the tear gas to interact with, potentially increasing the discomfort and pain.

- Heat can help the tear gas spread more easily, increasing the risk of exposure.
- High temperatures can degrade the active chemical compounds in tear gas (e.g., CS gas), potentially reducing its effectiveness over time.

Humidity and Sirens: High humidity affects sound propagation by altering how sound waves travel through the air, specifically impacting higher frequencies. Increased humidity can lead to a decrease in sound absorption, allowing higher frequencies to travel further than they would in drier air. High humidity can reduce warning lights visibility.

Service Dogs and Emergency response dogs face amplified risks in heatwaves as the temperature and humidity are often higher closer to the ground. Areas with thinner fur, like the nose, ears, belly, and around the eyes, are susceptible to sunburn.

An increase in ticks, mosquitoes, and fleas are also noted during high heat and humidity days, bringing threats of disease.

HOT ASPHALT AWARENESS

Press the back of your hand firmly against the asphalt for 7 seconds to verify it will be comfortable for your dog.

K9 Heatwave Risks



Air Temp.	Asphalt Temp.
77°F	~125°F
86°F	~135°F
87°F	~143°F

Other factors could make a worst scenerio, such as direct sunlight, no wind, very low humdy, and high radiant energy.

At 125°F, skin destruction can occur in 60 seconds.

An egg can fry in 5 minutes at 131°F

PROTECT YOURSELF FROM HEAT & SUN



Drink plenty of **water** and avoid alcohol. Beverages with electrolytes can also help protect against heat stress.



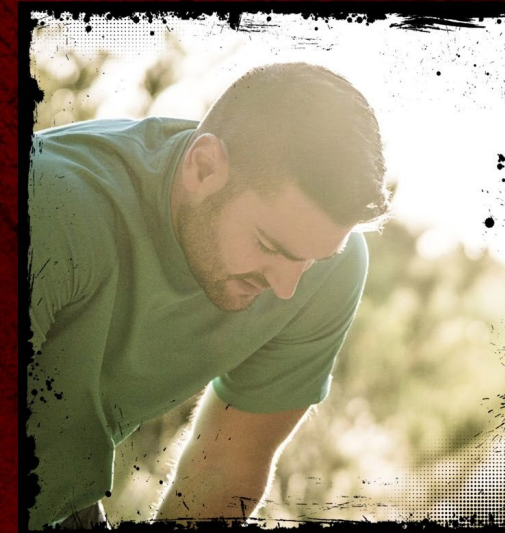
Apply **sunscreen** (SPF 30 or higher) every two hours.



Wear lightweight, loose-fitting, and **light-colored clothing**.



Take regular breaks in the **shade**.



weather.gov



Avoid leaving your pepper spray or gel in a place where the temperature will drop below 32°F or above 120°F. Excessive heat or cold could cause the can to burst.

Weather and Unrest Response

Clear weather, high-pressure days, often encourage higher turnout for events both in attendance and in protest settings due to the logistics and reduction of risk, whereas rainy days often add hazards in umbrella heights and slips/falls and reduced visibility.

- During warmer days, various groups face increased risk of heat exhaustion, heat stroke, dehydration, irritability, and aggression which can be even greater if certain medications are involved such as antipsychotics, beta-blockers, and stimulants.

Pepper Spray: extreme temperatures, sunlight, and moisture accelerate degradation.

- High humidity can affect pepper spray in two main ways: by impacting its effectiveness and by affecting its storage.
- While high humidity doesn't directly degrade the active ingredient (OC) in pepper spray, it can cause the canister to corrode or malfunction, and it can affect how the spray disperses and how it is cleaned up.
 - ❖ **Pressure Build-up:** High temperatures can cause the propellant inside the pepper spray canister to expand, increasing internal pressure. This can lead to leaks or cause the canister to burst if the temperature is excessively high.
 - ❖ **Effectiveness:** Heat can potentially degrade the active ingredients (capsaicin and related compounds) over time, reducing the spray's potency and effectiveness in self-defense or crowd control.
 - ❖ **Dispersion:** In very hot weather, the spray may disperse more quickly or evaporate faster once deployed, potentially reducing its range and duration of effect.
 - ❖ **Storage Risks:** Storing pepper spray in hot environments (like inside a car on a sunny day) can increase the risk of malfunction or accidental discharge.

Security Rotations: staff rotations, break schedules, and gear choices may change

- Severe heat, cold, or storms can reduce staff availability or performance, leading to gaps in security coverage.
- Extreme weather affects radios, surveillance cameras, lighting, and entry sensors.
- Weather can heighten tensions, heat increases irritability, storms drive urgency, potentially escalating conflict and can impact response times for first responders.

EXTREME HEAT PREPARATION

AND SAFETY TIPS FOR BUSINESSES

FAST FACTS



Follow the 20% rule:

Limit employees' work in extreme heat to 20% of their shift on their first day. Gradually increase their heat exposure by a maximum of 20% each subsequent day until they acclimate to working in high temperatures.

When working in extreme heat nearly 3 out of 4 fatalities happen during the first week of work.

In extreme heat, employees should stay hydrated with cool water and drink at least 1 cup every 20 minutes.

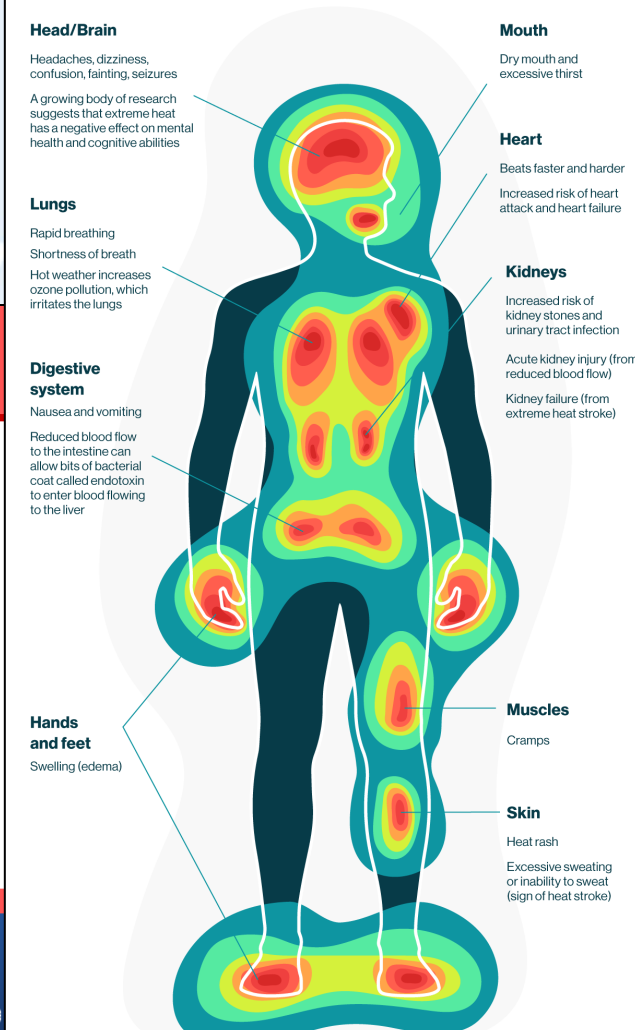
HEAT EXHAUSTION	HEAT STROKE
 FAINT OR DIZZY	 THROBING HEADACHE
 EXCESSIVE SWEATING	 NO SWEATING
 PALE, COLD, CLAMMY SKIN	 RED HOT SKIN
 RAPID WEAK PULSE	 RAPID STRONG PULSE
 MUSCLE CRAMPS, FATIGUE	 MAY LOSE CONSCIOUSNESS
MOVE TO COOLER PLACE, DRINK WATER IF CONSCIOUS, TAKE A COOL SHOWER OR USE COLD COMPRESSES	CALL 9-1-1



How heat affects the body

Your body cools itself by sweating and by increasing blood flow to the skin. In extreme or prolonged heat, this can cause dehydration, electrolyte imbalances, organ damage and even death. People with existing health conditions are at higher risk.

See how heat affects different organs of the body.



SwissRE: Extreme Heat and Insurance

Potential insurance impacts

Extreme heat poses a growing threat to the insurance industry, with property, specialty and L&H business most exposed. It increases the risk of electrical outages and wildfire risk, and can damage and cause disruption to transport, water and energy infrastructure, thus driving up property and specialty claims.

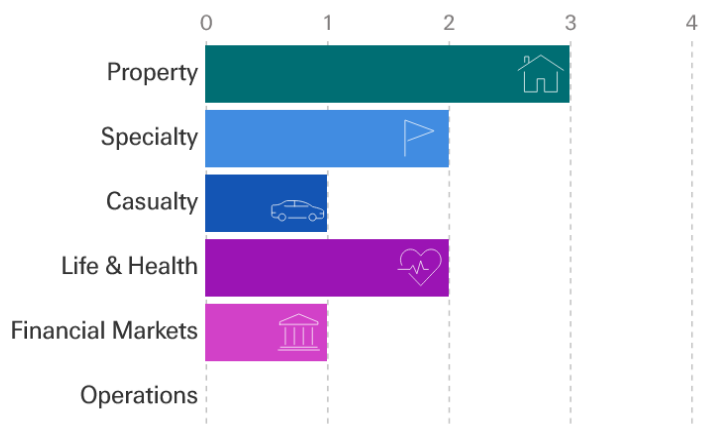
- During June 2023-April 2024, there were 76 heat waves in 90 countries impacting over 6 billion people (about 78% of the global population) with at least 31 days of extreme heat.
 - Since 1991, such conditions have become twice as likely to occur.

According to the World Economic Forum (WEF), conditions of extreme heat will likely cause damage to corporate fixed assets, driving annual losses of USD 404-448 billion across all listed companies by 2035.

- As of 2020, around 71% of the world's working population was exposed to excessive heat.
 - Hot weather has impacted ambulance call-out response times and led to cancellations of surgeries and overheating in surgical theatres.
- Global insured losses due to wildfires have risen in the last decades, reaching \$74 billion during 2014-2023.

Impact rating

0=no impact; 4=high impact



Source: Swiss Re Institute

Impacts of extreme heat by sector

Energy

- Extreme heat increases demand for electricity demand, stressing the power grid and increasing the risk of blackouts and power shortages.
- It affects thermoelectric power generation by impacting water availability and temperature, both critical for cooling operations.
- Power transmission becomes inefficient in high temperatures, reducing the capacity of generators, transformers and transmission lines.
- Solar panels and wind turbines also experience reduced efficiency.

Transportation

- High heat can cause road ruts, buckling and pavement cracking, leading to damage to rail tracks, bridges, and power cables for railways and streetcars.
- Train rails and bridges are vulnerable to heat-induced deformation.

Construction

- Extreme heat can damage building materials, accelerate rust, and cause steel and iron beams to expand, leading to structural vulnerabilities.

Telecommunications

- High risk due to sensitivity of data centers and network infrastructure to extreme heat, more so where there are limitations to access to water.
- Fixed asset losses projected at USD 518-563 million/year by 2035.
- Extreme heat can cause terrestrial cable materials to expand and contract, leading to sagging, equipment malfunction, and insulation degradation.
- Strain on data center cooling systems, potentially leading to overheating or equipment failure.

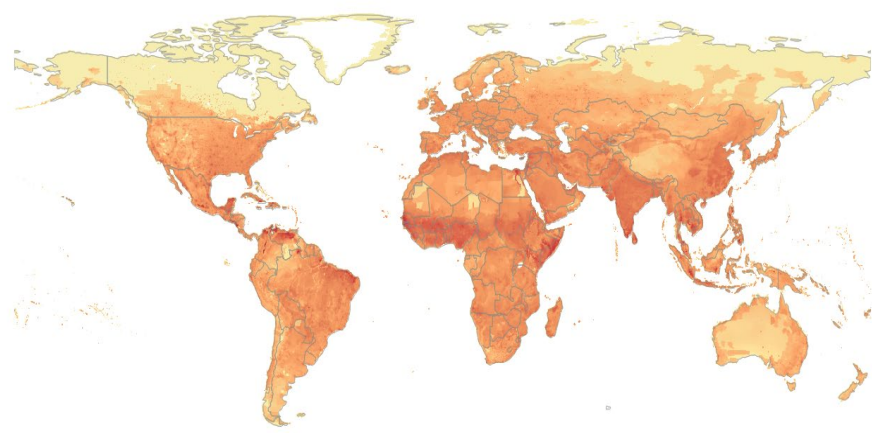
Batteries

- Prolonged exposure to temperatures above 30°C can cause pre-mature degradation of lithium-ion batteries.
- Battery degradation can reduce electric vehicle range by 20%. Elevated risk of thermal runaway, which can potentially lead to battery fire or explosion.

Agriculture

- Extreme heat and drought cause economic losses in forest productivity and also crop and livestock farming.

Regions of extreme heat risk by 2040*



Lower risk Higher risk

*Note: as a function of a) population in 2040 (as a proxy for people and assets exposed; this would exclude agricultural assets and nature) and b) change in number of days per year above 35°C between 2005 and 2040 for "intermediate" climate change scenario SSP2-4.5. Source: Gao J. GeoTIFF_SSP2_total_2010-2050.zip, Global 1-km Downscaled Population Grids, SSP-Consistent Projections and Base Year, v1.01 (2000-2100), Harvard Dataverse, vol 1, 2020; CMIP6 climate projections, 2021 and ERA5 hourly data on single levels from 1940 to present, 2023, Copernicus Data Store, Climate Change Service; Swiss Re

2026 Power and Utilities Industry Outlook

According to Energy Central, the 2025 record-breaking heatwaves in June pushed European electricity demand to winter-level peaks, forced shutdowns at nuclear and hydro plants, and exposed new pressure points across the grid.

According to Deloitte analysis, peak demand is projected to grow by approximately 26% by 2035, testing today's grid limits.

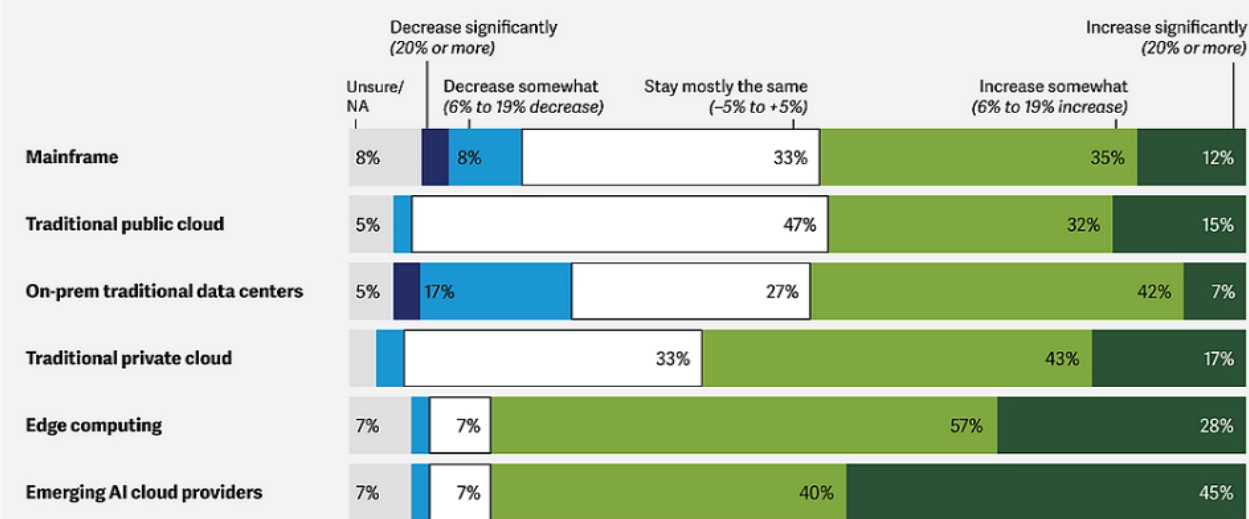
- Data center demand alone could reach 176 gigawatts by 2035, a fivefold jump from 2024.
- Industrial electrification could add 25 GW of demand by 2030, on top of growth in household and commercial consumption.

In 2026, the challenge for utilities will be quickly delivering uninterrupted or "firm" capacity to stressed parts of the grid.

- The US DOE projects about 104 GW of coal and natural gas retirements by 2030, offset by 209 GW of new capacity.
- The emphasis will then shift to storage duration and diversity, with long-duration energy storage (LDES) advancing from pilots to procurement. At least two states now have LDES requirements totaling more than 2.75 GW.

Figure 2
Power company executives expect AI workloads to grow on all computing platforms

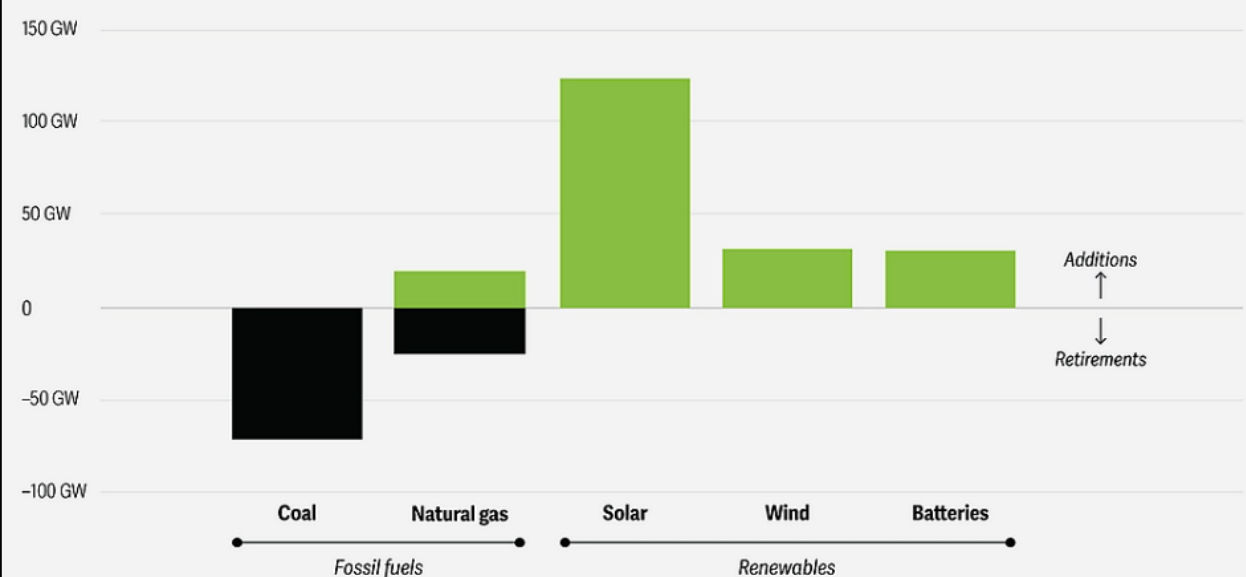
Question: To what extent do you expect computing workloads across each of these platforms to change in the next 12 months?



By 2027, it's expected that ~40% of utility control rooms will use AI

Note: n = 60.
 Source: Deloitte's 2025 AI Infrastructure Survey responses from power company leaders.

Figure 1
By 2030, 104 GW of firm retirements offset by 209 GW of new, mostly non-firm capacity



Source: US Department of Energy, "Resource adequacy report: Evaluating the reliability and security of the United States electric grid," July 7, 2025.

AI Water Use Updates

Behind every AI query are [two streams of water use](#):

1. [On-site cooling](#) of servers that generate enormous amounts of heat. This often uses evaporative cooling towers – giant misters that spray water over hot pipes or open basins. The evaporation carries away heat, but that water is removed from the local water supply, such as a river, a reservoir or an aquifer. Other cooling systems may use [less water but more electricity](#).
2. Power plants generating the [electricity to power the data center](#). Coal, gas and nuclear plants use large volumes of water for [steam cycles and cooling](#).
 - a) A data center in cool, humid Ireland can often rely on outside air or chillers and run for months with [minimal water use](#). By contrast, a data center in Arizona in July may depend heavily on [evaporative cooling](#).

AI water use difference: Some models may use far more resources than others. For example, one study found that certain models can [consume over 70 times more energy and water](#) than ultra-efficient ones.

- Independent analyses estimate that a medium-length GPT-5 response, which is about 150 to 200 words of output, or roughly 200 to 300 tokens, uses [about 19.3 watt-hours](#). A response of similar length from GPT-4o uses [about 1.75 watt-hours](#).
- [Independent researchers](#) and [industry reports](#) suggest that a reasonable range today is about 1.3 to 2.0 milliliters per watt-hour.
 - For a medium-length query to GPT-5, that calculation should use the figures of 19.3 watt-hours and 2 milliliters per watt-hour. $19.3 \times 2 = 39$ milliliters of water per response.
 - For a medium-length query to GPT-4o, the calculation is 1.75 watt-hours x 2 milliliters per watt-hour = 3.5 milliliters of water per response.
- Assuming the data centers are more efficient, and use 1.3 milliliters per watt-hour, the numbers drop: about 25 milliliters for GPT-5 and 2.3 milliliters for GPT-4o.

A recent Google technical report said a median text prompt to its Gemini system uses just 0.24 watt-hours of electricity and [about 0.26 milliliters of water](#) – roughly the volume of five drops. However, the report does not say how long that prompt is, so it can't be compared directly with GPT water usage.

One AI query may not use much water, but it adds up

Everyday water uses consume a lot more than any single prompt to an artificial intelligence system. But lots of people entering lots of prompts can consume a lot of water.

Water use	Amount of water consumed	Number of GPT-5 medium-length queries	Number of GPT-4o medium-length queries	Number of Google Gemini median prompts
Water bottle	0.5 liters	13	143	1,900
Toilet flush	6 liters	154	1,714	23,000
Shower for 10 minutes	90 liters	2,308	25,714	346,000
Watering 100-square-foot (10-square-meter) lawn for 10 minutes	100 liters	2,564	28,571	385,000
Evaporation from backyard pool 350 square feet in area (32 square meters) on a hot day	100-160 liters	2,564-4,103	28,571-45,714	385,000-615,000

One liter is 0.26 gallons. A medium-length prompt for GPT-5 and GP-4o is about 150 to 200 words. Google does not disclose the median length of its Gemini prompts.

Table: The Conversation, CC-BY-ND • Source: Data from [Jegham et al., Google](#) • [Get the data](#) • [Embed](#) • [Download image](#) • Created with [Datawrapper](#)

OpenAI reports about [2.5 billion prompts per day](#). That figure includes queries to its GPT-4o, GPT-4 Turbo, GPT-3.5 and GPT-5 systems, with no public breakdown of how many queries are issued to each particular model.

- All Google Gemini median prompts: about 650,000 liters per day.
- All GPT 4o medium prompts: about 8.8 million liters per day.
- All GPT 5 medium prompts: about 97.5 million liters per day.

Americans use about 34 billion liters per day watering residential lawns and gardens. One liter is about one-quarter of a gallon.

Energy supply: [wind turbines and solar panels use almost no water](#) once built, aside from occasional cleaning.

Repurposing Coal Mines

The Lewis Ridge Pumped Storage Project by Rye Development in Kentucky will create about 1,500 construction jobs to build what officials described as a first-of-its-kind coal-to-pumped storage hydropower facility.

- Once built, the facility will create 30 operations jobs and generate enough energy to power nearly 67,000 homes.

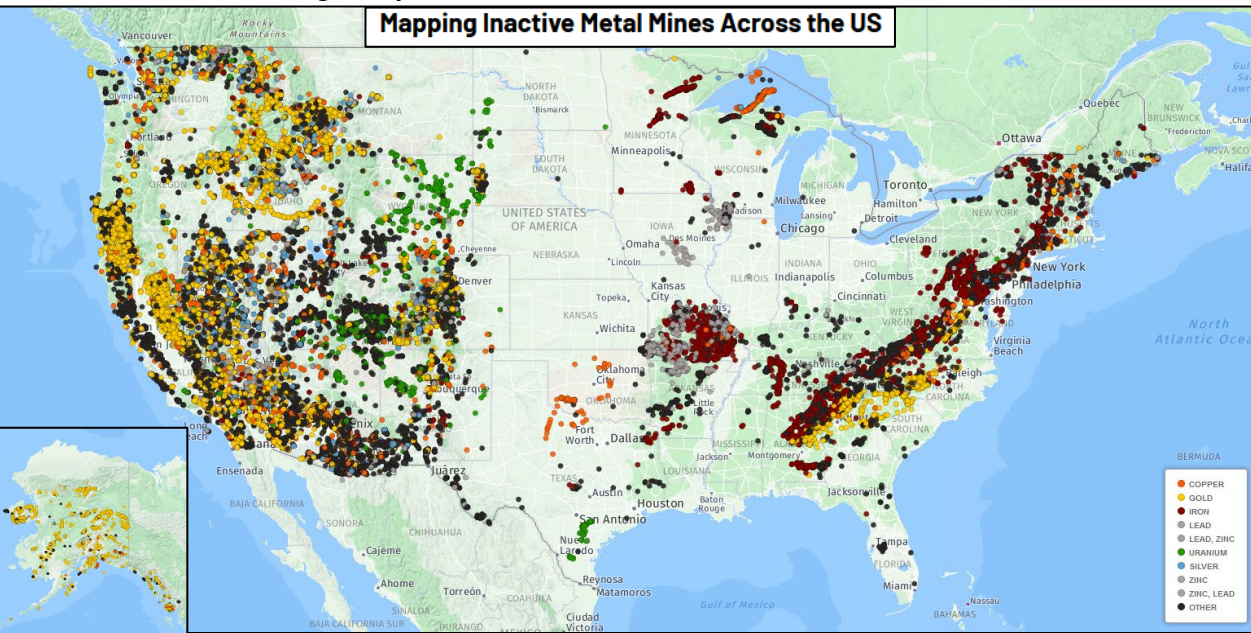
A project in Clearfield County, Pennsylvania, to repurpose nearly 2,700 acres (1,090 hectares) of former coal mining land to create a utility-scale solar facility.

- In November, it announced that it had a 20-year contract to supply power to New York's grid once completed in 2026.

A project in Nicholas County, West Virginia, to repurpose two former coal mines with a utility-scale solar system that would power about 39,000 homes.

- The two inactive mine sites provide land and access to existing energy infrastructure that will transmit the solar energy the project generates to the grid.

According to the National Renewable Energy Laboratory, the U.S. needs to add up to 10,000 miles a year of high voltage transmission to hit the administration's target of renewable-dominant grid by 2035.



Tidal Power

Tidal energy is a form of power produced by the natural rise and fall of tides caused by the gravitational interaction between Earth, the sun, and the moon.

- The US does not have any commercially operating tidal energy power plants.
 - Producing tidal energy economically requires a tidal range of at least 10 feet.

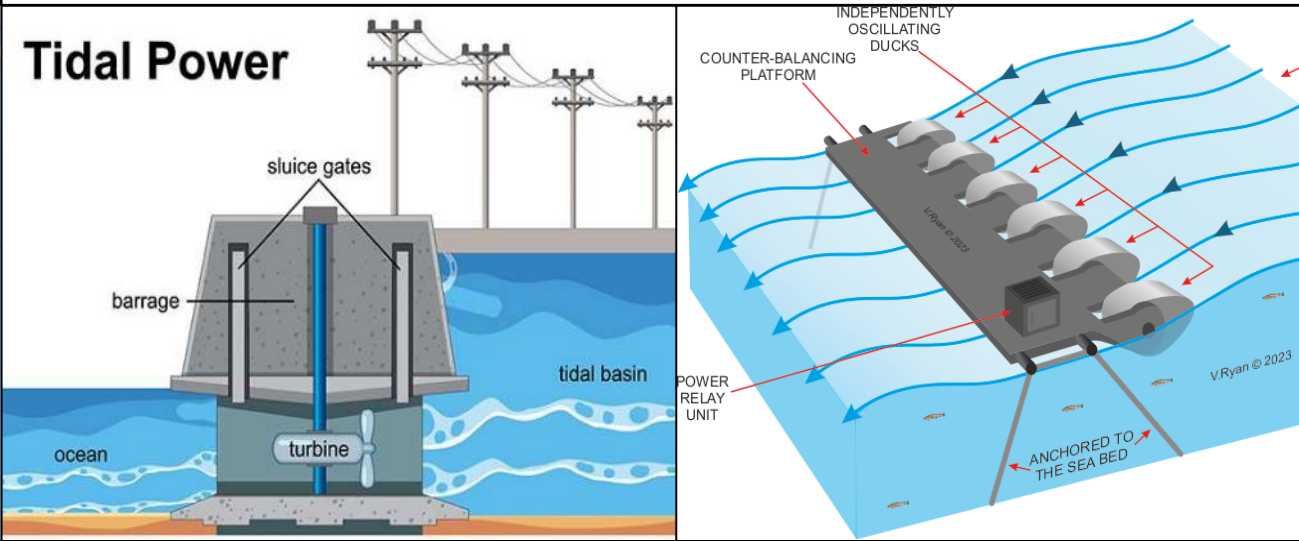
There are two methods of harnessing tidal power: One method resembles a hydroelectric dam, called tidal barrages, and another relies on underwater turbines that have blades that rotate as water flows by, powering a generator in the process.

- Tidal power can reduce wave intensity to shorelines where critical energy transmission infrastructure for cities and major supply chain hubs are at threat from sea level rise.
- Because water is roughly 830 times denser than air, tidal or ocean currents can generate more energy per unit area than winds.

In 2021, the Department of Energy [announced](#) a \$27 million investment in research and development around tidal and wave energy technology.

- Tidal power has one advantage over other [renewable energy](#) resources like wind and solar: predictability.

The oldest and second-largest operating tidal power plant is in La Rance, France



Pumped Storage Hydro

The first known use cases of PSH were found in Italy and Switzerland in the 1890s, and PSH was first used in the United States in 1930.

PHES uses water reservoirs as a way of storing energy. Excess energy, either from the grid or a renewable energy source such as a wind or solar farm, can be used during low demand periods to pump water from a lower dam to a higher one, essentially converting the upper reservoir into a giant battery.

In Australia, a former gold mine in north Queensland was funded to convert into a PHES system and is set to feed into the National Electricity Market this year.

- The Borumba pumped hydro plant is set to be completed by 2030 and will be able to store two gigawatts of power at all times — enough to provide power for 2 million homes.
- Stage one of the Pioneer-Burdekin pumped hydro project, announced on Wednesday, is estimated to be completed in 2032, with the final stage operational by 2035.

Evaporation from reservoirs is a natural process, but pumped hydro systems are typically designed with relatively smaller reservoirs, often at higher elevations, which can reduce evaporation rates compared to large, low-lying lakes.

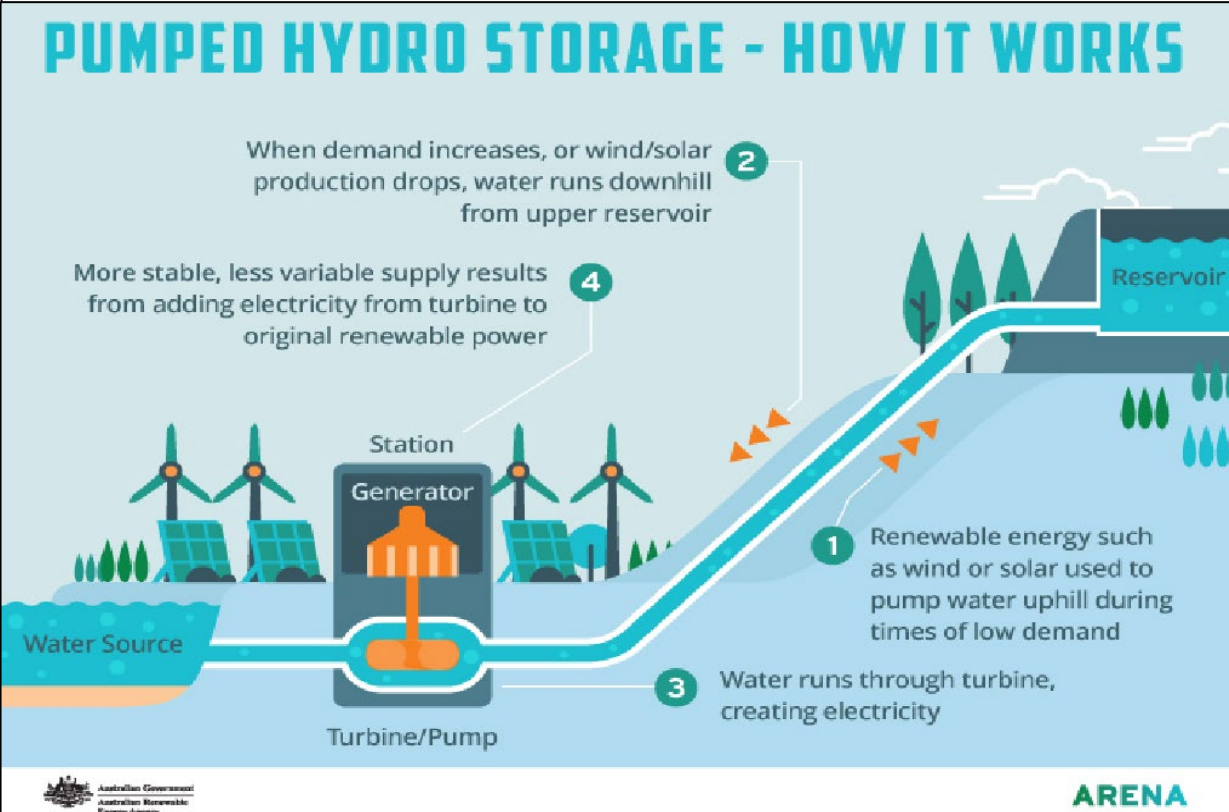
- The Bingham Canyon Mine in Utah is widely considered the largest mine in the world and could be explored for pumped hydro storage.
- America currently has 43 PSH plants and has the potential to add enough new PSH plants to more than double its current PSH capacity.

According to the [International Hydropower Association's \(IHA\) 2024 World Hydropower Outlook](#), global PSH capacity grew by 6.5 GW in 2023, reaching 179 GW.

Projections by the International Renewable Energy Agency (IRENA) to meet a global net-zero scenario by 2050 indicate that over 420 GW of PSH will be required, which means about 10 GW/year of new installed capacity or an annual installed capacity growth rate of approximately 3.3%.

- For the United States to meet its corresponding share of the global net zero goals, it would require an average of about 1000 MW of new PSH installed yearly.
- In the United States, 67 new PSH projects are planned across 21 states, representing over 50 GW of new storage capacity.

Pumped storage meets increased transmission system demands for reliability and system reserves. It shifts, stores, and reuses energy generated until there is the corresponding demand for system reserves and variable energy integration. This shifting performed at a grid-scale can also avoid transmission congestion periods



The Cortes-La Muela Hydro Complex in Spain has a capacity of more than 1,800MW in generation and 1,293MW in pumping

Advanced Compressed Air Energy Storage (A-CAES) system

A-CAES, or Adiabatic Compressed Air Energy Storage, is a system that stores energy mechanically, using compressed air, and thermally, utilizing heat exchangers.

- It works by compressing air with surplus electricity, removing heat to store it separately, and then expanding the cool air through a turbine to generate electricity when needed.

When comparing A-CAES to pumped hydro storage, both systems make use of gravity and water. In the case of pumped hydro, gravity pulls the water down through electricity generating turbines. With A-CAES, a tall, vertical column of water generates enormous pressure on the air tanks at its bottom.

A-CAES also captures and stores heat created when the air is first compressed. The system uses that heat energy to supercharge the released air's energy content just before it hits the generator turbines.

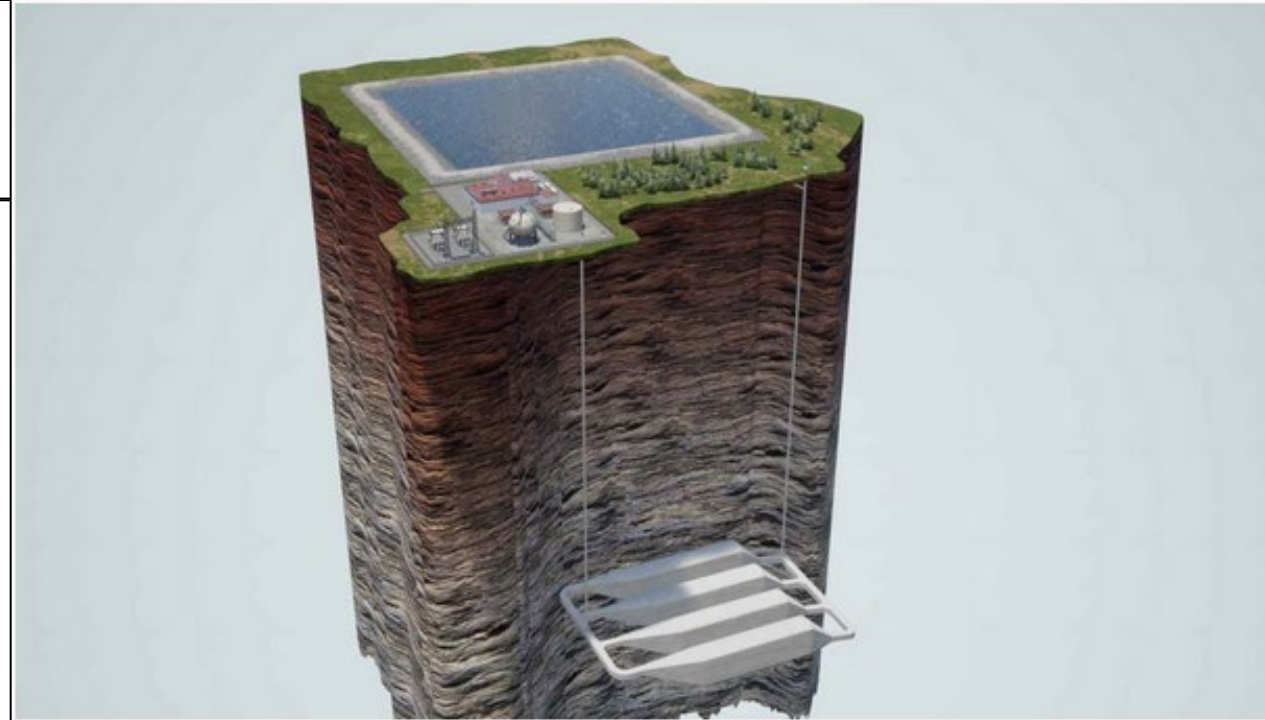
- Canadian company [Hydrostor](#) is leading the development to construct the 200 MW/ 1450 MWh facility at Perilya's Potosi Mine.

Combining advanced compressed air energy storage ([A-CAES](#)) with pumped hydro offers a promising solution for large-scale energy storage, particularly for integrating intermittent renewable sources like wind and solar.

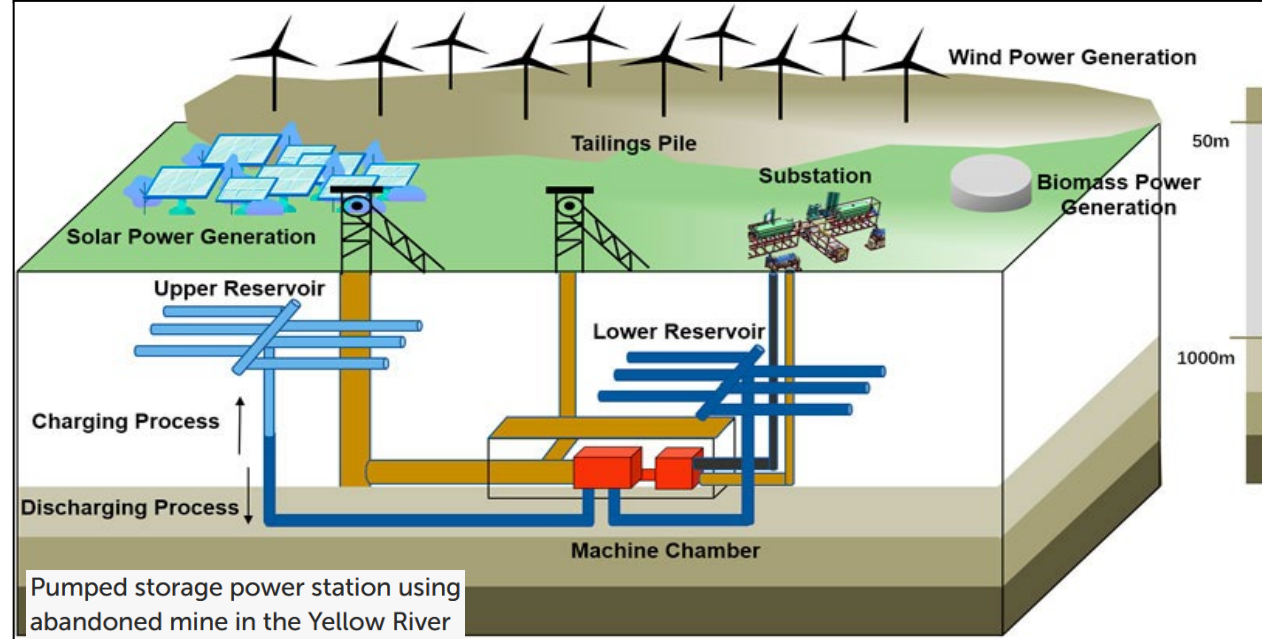
- This hybrid system, often called [PHCA](#) (Pumped Hydro Combined with Compressed Air), leverages the advantages of both technologies to address limitations in energy storage, especially in arid regions.

The Kentucky closed loop hydro facility in the abandoned coal mine is slated to come online in 2031 and will not connect to a natural body of water.

- Sandia National Lab and Stanford University analyzed underground pumped hydro storage to be about 1.1-1.3x more costly than PSH.



Air is compressed at the surface and pumped underground for high-pressure storage in purpose-built caverns. (Image courtesy of Hydrostor)



Changes in the Solar Industry: Panels vs Windows

White Solar: monocrystalline solar cells are more efficient than polycrystalline panels, and all-black panels are overall only 0.5% less efficient. **The only major difference between all-black panels and panels with a white back sheet is the aesthetic**

- Why were solar panels black to begin with? From the natural colors that silicon becomes during the manufacturing process.

The first white solar panel was developed in 2009 by a Swiss company called CSEM. The company was able to develop a white solar panel by using a plastic layer that acts as a special filter that scatters light from the entire visible spectrum while absorbing just infrared light.

- This is the wavelength most silicon solar panels use to transform into electricity. This layer works with any crystalline silicon cell and can also be applied to any existing panel whether it's flat or curved.

White panels operate at a lower temperature than traditional black solar panels, extending their lifespan and reducing local heat-sinks.

- The additional costs saved by reducing the need for cooling in buildings employing solar can be added to the overall benefits of white panels.

In 2021, Bisol won the Intersolar Award for its white solar panels. The Intersolar Award is one of the most prestigious awards in the solar industry.

Others in the industry: [MIT's solar window](#) and MSU's solar edging for windows.

- According to researchers at MSU, there are an estimated 5 billion to 7 billion square meters of glass surface in the US. Their technology can provide 40% of all the power needed in the US by generating power from those surfaces.
- The highest offering of efficiency is still at 12% to 15%. The MSU window is estimated at a 10% efficiency, a figure that is less than traditional solar panels.



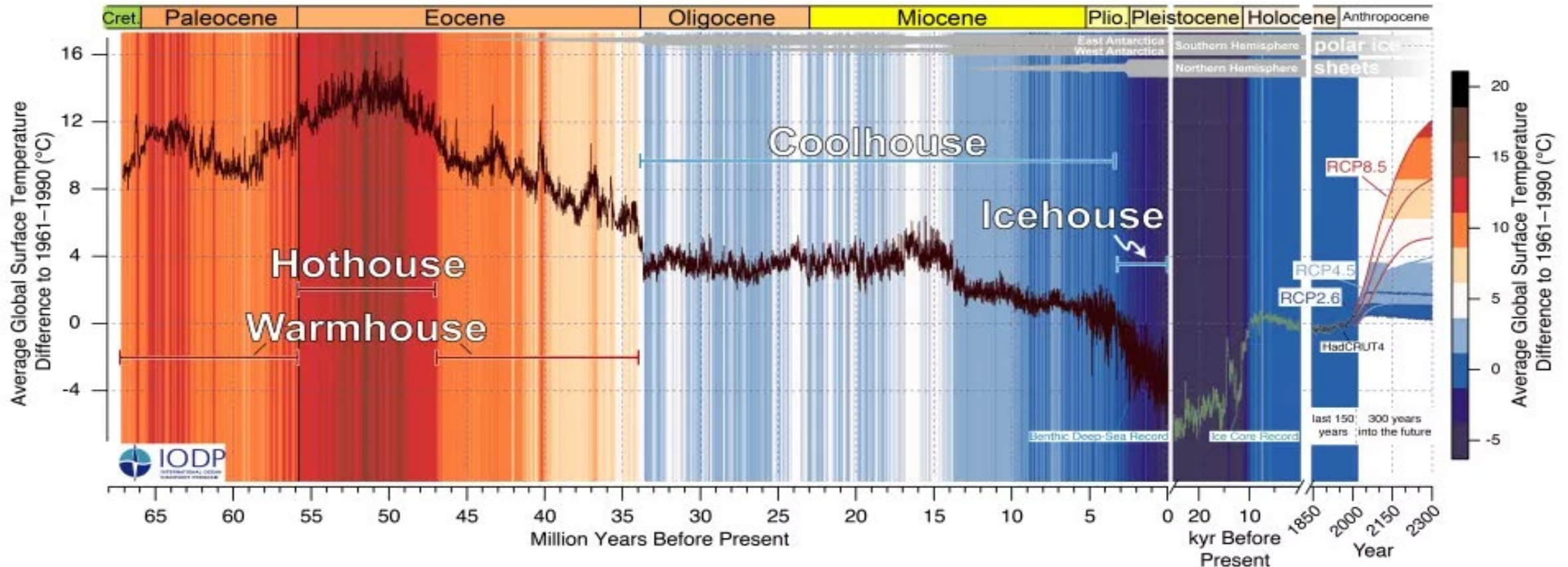
Based on the technology from MSU, a student in the Philippines created a solar window, made of a special kind of glass, that absorbs high energy particles and re-emits them as visible light working to prevent fruit decay.

Defined Threat: Condensed Period to Adjust

The change in heating is not just that it is baseline creeping upwards, it is that we built to norms from a window of time in stable conditions that we will not be returning to during the next few lifetimes. This means infrastructure was simply not built to withstand.

- The weather hazards defined in previously slides will amplify rapidly in coming decades as the temperature continues to rise.
- Acclimation periods will reduce rapidly as temperatures vary outside of human capacity and materials will face comparable strain.

When comparing the historic warming period, it is critical to annotate which materials shift from rapid heating and may push against or pull away from partnered materials or stress the binding type for future concerns of structural stability.



CONTACT

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Extreme Weather Expert

Emergency Response and Operations Support

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• Email: Sunny@unlimitedweather.com

HELPFUL STARTS

• NOAA Repository:

<https://www.ncei.noaa.gov/cdo-web/>

• Frontal Boundaries:

<https://aviationweather.gov/gfa/#progchart>

• Infographics:

<https://www.climatecentral.org/>

• World Meteorological Organization:

<https://wmo.int/topics/extreme-weather>

Number of Severe Power Outages Per Year

State	2018	2019	2020	2021	2022	2023	2024
Alabama	2	0	4	0	0	2	0
Alaska*	0	0	0	1	2	3	2
Arizona	0	0	0	0	0	0	0
Arkansas	1	1	2	1	1	6	2
California	0	3	0	0	0	1	1
Colorado*	0	1	0	0	0	0	1
Connecticut	3	1	2	0	1	1	0
Delaware	1	0	1	0	0	0	1
District of Columbia	1	0	0	0	0	0	0
Florida	2	0	1	0	2	1	3
Georgia	1	0	1	0	0	2	3
Hawaii	0	0	0	0	2	1	0
Idaho*	0	0	2	1	0	0	0
Illinois	0	0	1	0	0	1	1
Indiana	1	0	1	0	1	1	2
Iowa	0	0	2	1	0	0	0
Kansas*	0	0	0	1	0	1	1
Kentucky	2	0	1	3	1	3	3
Louisiana	0	3	8	6	1	2	3
Maine	5	2	7	1	5	5	7
Maryland	1	0	0	0	1	1	0
Massachusetts	3	1	2	1	0	1	0
Michigan	3	3	3	10	2	4	3
Minnesota	0	0	0	0	1	0	1
Mississippi	0	2	6	3	0	3	4
Missouri	0	1	0	1	0	4	2
Montana***	0	0	0	1	0	0	1
Nebraska*	0	0	0	2	0	0	2
Nevada	0	0	0	0	0	0	0
New Hampshire	3	2	2	1	2	2	3
New Jersey	2	1	2	0	0	0	0
New Mexico*	0	0	0	0	0	0	2
New York	4	0	1	0	0	0	0
North Carolina	4	1	2	1	2	0	3
North Dakota**	0	1	1	0	3	1	0
Ohio	0	0	0	0	1	3	2
Oklahoma	0	1	3	0	0	2	1
Oregon	0	1	1	3	2	0	2
Pennsylvania	2	1	2	0	0	1	2
Rhode Island	2	2	2	3	0	1	0
South Carolina	1	1	2	0	1	0	2
South Dakota**	0	1	1	0	1	0	0
Tennessee	0	0	1	1	3	3	1
Texas	0	1	1	2	0	3	5
Utah	0	0	1	0	0	0	0
Vermont	3	1	0	0	3	4	4
Virginia	3	0	1	2	2	0	2
Washington	1	2	1	2	1	0	1
West Virginia	4	3	2	4	7	4	5
Wisconsin	0	2	0	3	1	1	2
Wyoming**	0	0	1	0	0	0	0

US Total 55 39 71 55 49 68 80

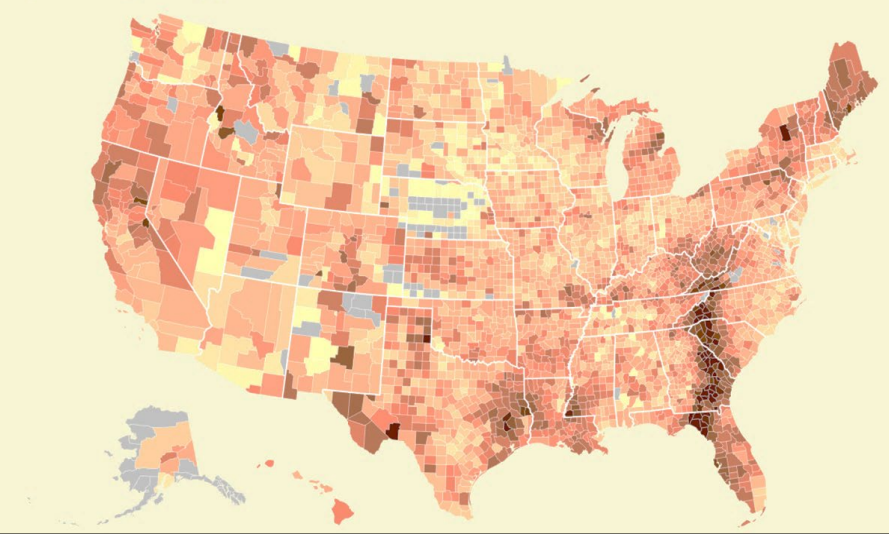
* = 2018 data is incomplete

** = 2018 and 2019 data is incomplete

*** = 2018, 2019 and 2020 data is incomplete

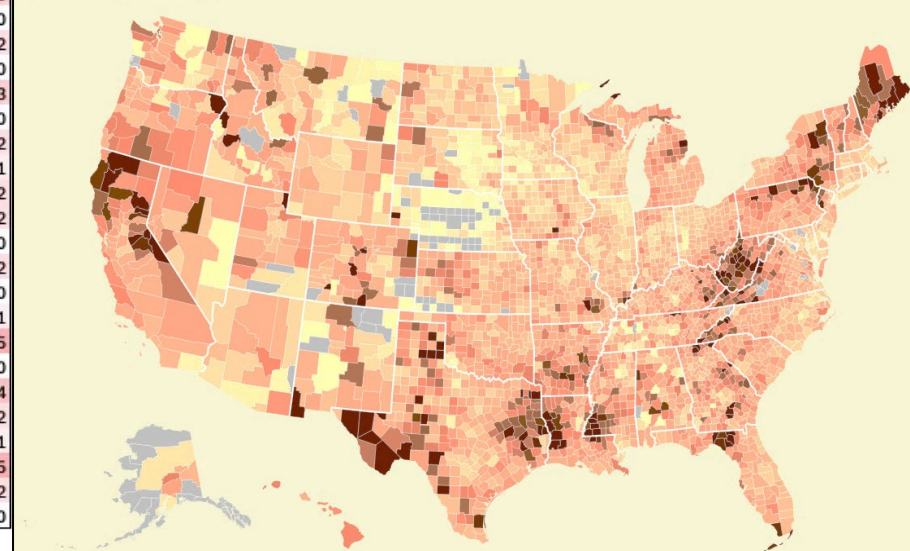
Power Outages in the US in 2024

Power outage minutes per customer, by county



US Power Outages in 2024 Minus Outliers

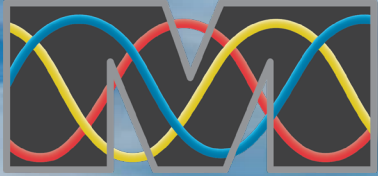
Power outage minutes per customer, with the 3 worst weeks for each county removed.



Map: Brian Potter • Source: Poweroutage.us

Outage minutes per customer in 2024 were more than 50% higher than in 2023.





MIDWEST
RELIABILITY
ORGANIZATION

May 12, 2026

Dianlong Wang, MRO
Pam Sordet, MRO

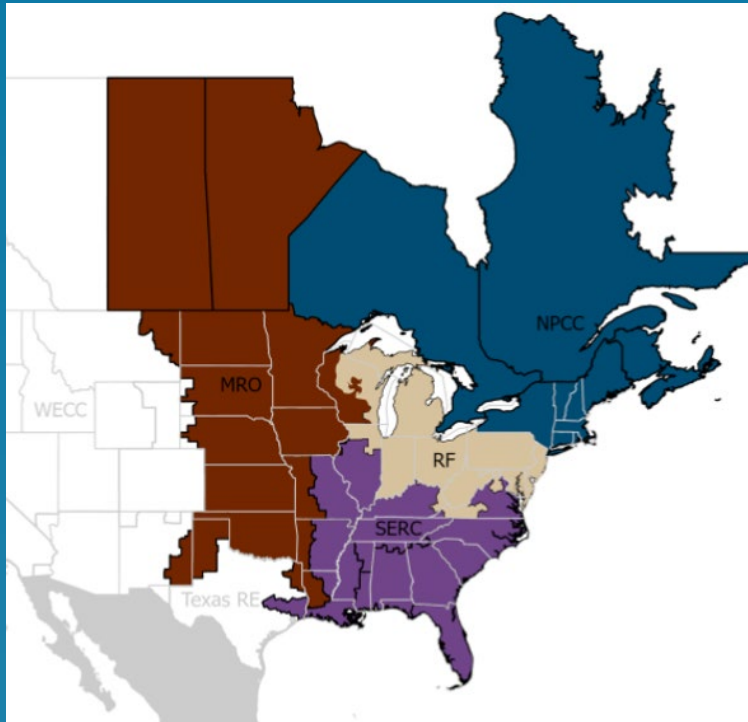
MRO Reliability Assessments

What Are Reliability Assessments

- **Studies of the grid's ability to meet anticipated electricity demand.**
- **Used to inform industry leaders, planners, operators, and other key decision makers.**
- **Areas studied include:**
 - Electricity supply and demand
 - Transmission system adequacy
 - Key issues and trends that could affect bulk power system reliability



MRO Reliability Assessments



MRO Reliability assessments are conducted pursuant to:

- MRO Delegation Agreement with NERC
- NERC Rules of Procedure (RoP) Sections 802 – 805
- Eastern Interconnection Reliability Assessment Group (ERAG) Agreement



Types of Reliability Assessments



- **Long-Term Reliability Assessments (LTRA)**
 - Ten-year, forward-looking view of long-term reliability risks
- **Seasonal Reliability Assessments**
 - Winter
 - Summer
- **Special Assessments**
 - Conducted as needed based on emerging risk(s) at a regional, interregional, or interconnection-wide level.



Long-Term Reliability Assessment Overview



 CONNECTION

 CURIOSITY

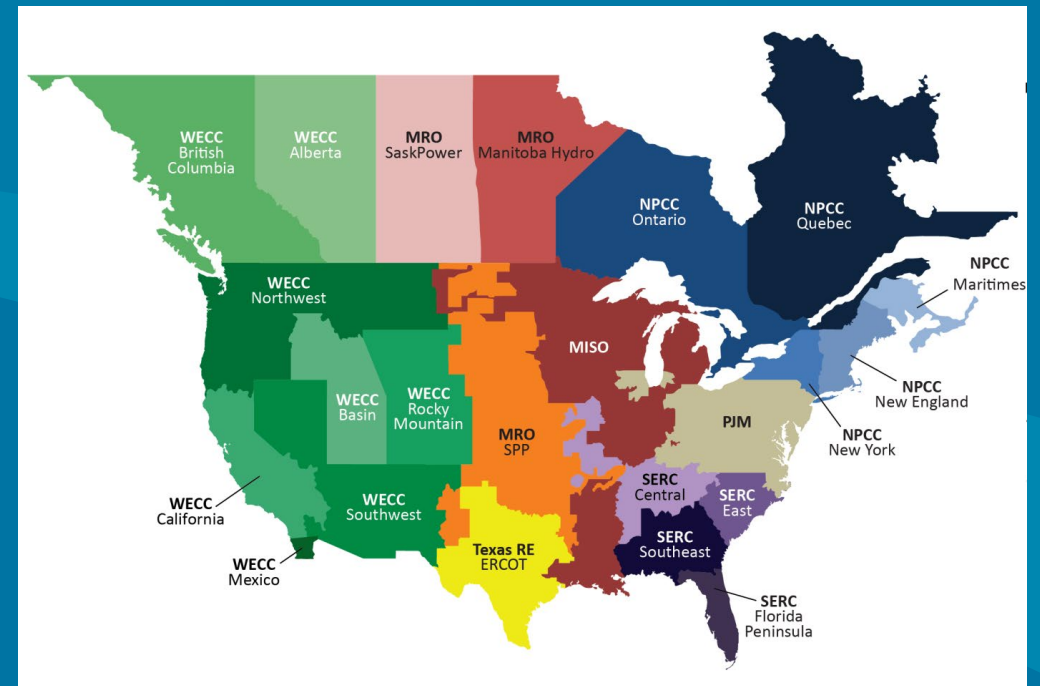
 COMMITMENT

 COMPETENCY

Overview

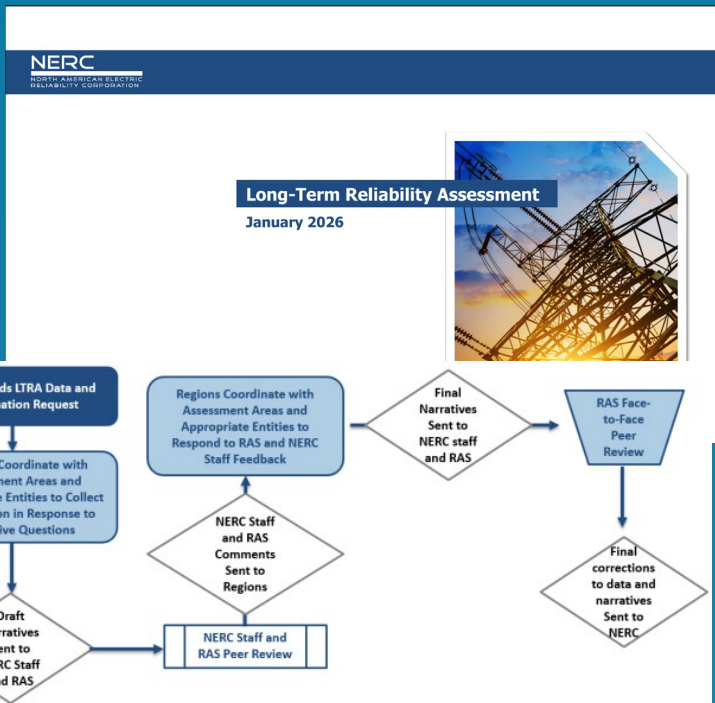
The Long-term Reliability Assessment (LTRA) is developed based on information NERC collect from Planning Coordinators/ISO/RTOs to independently evaluate the long-term reliability while identifying trends, emerging issues, and potential risks during the upcoming 10-year assessment period. MRO collects data from Manitoba Hydro, MISO, SaskPower and SPP

- Assessments are not predictions of what will happen; they are based on information supplied in July each year about known system changes with updates incorporated prior to publication in January
- NERC's reliability assessments are developed to inform industry, policymakers, and regulators
- Capacity and energy risk assessment for the first 5-year of the assessment period



LTRA Development Process

- **Data Request:** A data request letter and workbook are sent to Regional Entities to collect input on an assessment area basis.
- **Peer Review:** A comprehensive review process involving RAS members, Regional Staff and NERC staff to ensure data accuracy.
- **Reliability Review:** Aggregated data from all assessment areas is analyzed to identify trends, emerging issues, and potential risks.
- **Approval & Publication:** RSTC reviews the assessment, followed by the NERC Board of Trustees accepting and endorsing the findings.

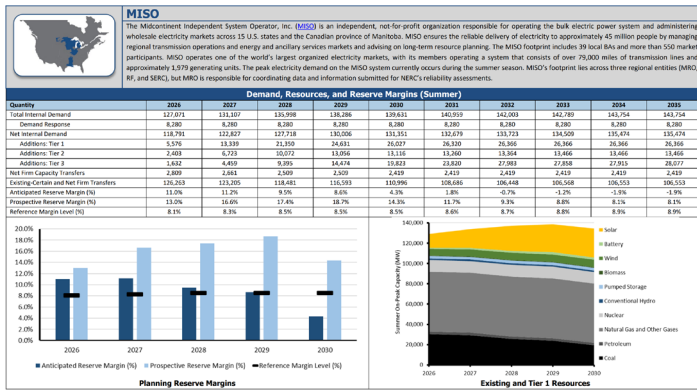
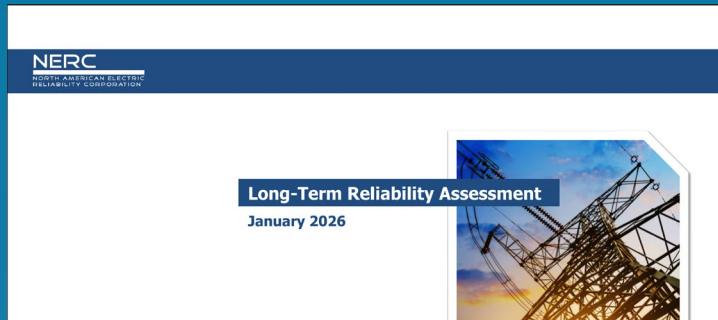


LTRA Data Collection

Data collected for the LTRA focuses on projecting electricity supply and demand over a 10-year horizon.

Key data components include:

- **Generation Resources:** Existing and planned generation capacities.
- **Demand Projections:** Projected electricity consumption.
- **Generation Retirements:** Information on planned or potential generator retirements.
- **Transmission Adequacy:** Data on transmission system performance and Planned Transmission Projects.

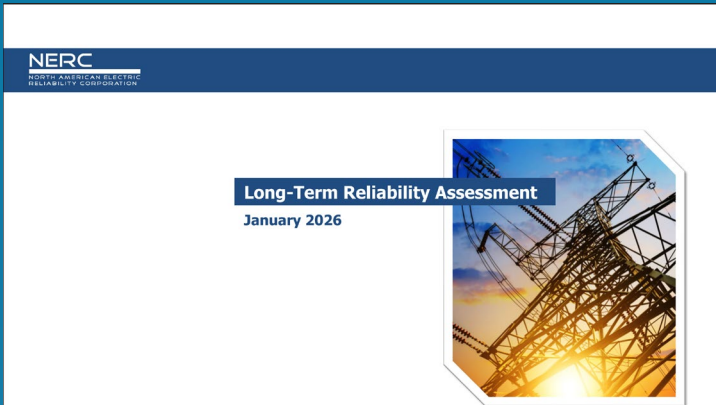


LTRA Key Data Assumptions

- **Load Forecasting:** Projections use 50/50 forecasts.
- **Generation Resources:** Assessments include existing, firm, and planned generation in the process (Tier 1).
- **Performance:** Generating and transmission equipment are assumed to perform at historical availability levels.
- **Retirements:** Planned retirements are taken into account based on current projections.
- **Demand Response (DR):** Controllable and dispatchable DR programs are considered, with only the available capacity.
- **Weather:** Peak demand calculations assume average, normal weather conditions.



LTRA Key Calculation Methods



Planning Reserve Margin Calculations

Planning Reserve Margins is the primary metric used to measure resource adequacy, defined as the difference in resources (Anticipated or Prospective) and Net Internal Demand, divided by Net Internal Demand, shown as a percentile.

$$\text{Anticipated Reserve Margin} = \frac{(\text{Anticipated Resources} - \text{Net Internal Demand})}{\text{Net Internal Demand}} \times 100\%$$

$$\text{Prospective Reserve Margin} = \frac{(\text{Prospective Resources} - \text{Net Internal Demand})}{\text{Net Internal Demand}} \times 100\%$$

- **Reserve Margin (RM):** Calculated as (Anticipated Resources - Demand) / Demand.
- **Anticipated Resources:** Includes existing capacity, firm planned additions, and net adjustments (retirements, derates), minus expected maintenance or forced outages at peak.
- **Reference Margin Level (Target Reserve Margin):** Set by regional planners to ensure reliability; areas are highlighted for risk if projected margins fall below this level.
- **Probabilistic Risk Metrics:** Used to evaluate risk, including Loss of Load Hours (LOLH) and Expected Unserved Energy (EUE).

Capacity and Energy Risk Assessment

LTRA Risk Assessment Consists of Two Parts

- Part I
 - Capacity Risk Assessment
 - Deterministic based analysis performed by NERC
 - Calculates Planning Reserve Margins to measure resource adequacy using the information from the LTRA data collection
 - Compares to Planning Coordinator's RML provided in the LTRA
 - Use MS Office Excel Workbook
- Part II
 - Energy Risk Assessment
 - Probabilistic based analysis (ProbA) performed by Planning Coordinators/ISO/RTO
 - Calculates Expected Unserved Energy (EUE) and Loss of Load Hours (LOLH) using probabilistic analysis tools with the information from the LTRA data collection plus other assumptions (historical weather years, EFOR, LFUs, etc.)
 - Takes 6-months to complete (April – September)



Capacity and Energy Risk Criteria

- **Normal Risk** if resource adequacy targets are met, and there is a low likelihood of electricity supply shortfall even when demand is above forecasts or resource performance is abnormally low (e.g., above-normal forced outages or low VER performance)
- **Elevated Risk** when it meets the established resource adequacy targets and baseline criteria specified above but does not meet more stringent thresholds of EUE and LOLH that provide for reliability in more extreme weather conditions
- **High Risk** when established resource adequacy targets or requirements are not met or when probabilistic assessment (ProbA) energy analyses find that planned resources produce shortfalls resulting in EUE or LOLH

Normal Risk

- LOLH < 0.1 hours per year in ProbA
AND
- NEUE is < 2 PPM in ProbA
AND
- Reserve margins meet established targets

Elevated Risk

- $0.1 \leq \text{LOLH} \leq 2.4$ hours per year in ProbA,
OR
- $2 \text{ PPM} \leq \text{NEUE} \leq 20$ PPM in ProbA,
AND
- Reserve margins meet established targets

High Risk

- LOLH > 2.4 hours per year in ProbA
OR
- NEUE > 20 PPM in ProbA
OR
- Reserve margins do not meet established targets



LTRA Enhancements are needed

- **Surging Demand:** Demand forecasts have surged driven by AI data centers and other industrial growth.
- **Rapid Generation Shift:** Growing reliance on weather-dependent resources (solar/wind) and accelerating retirements of dispatchable fossil plants are creating severe reliability gaps.
- **Infrastructure Delays:** Significant delays in building new transmission and interconnection queues are hindering the ability of new resources to meet rising demand.
- **Improved Accuracy:** NERC is incorporating probabilistic studies and, where appropriate, accounting for regulatory actions that can prevent unit retirements, addressing concerns that previous assessments were too pessimistic.



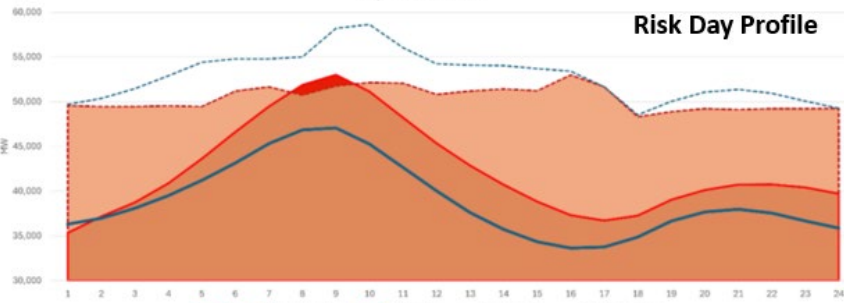
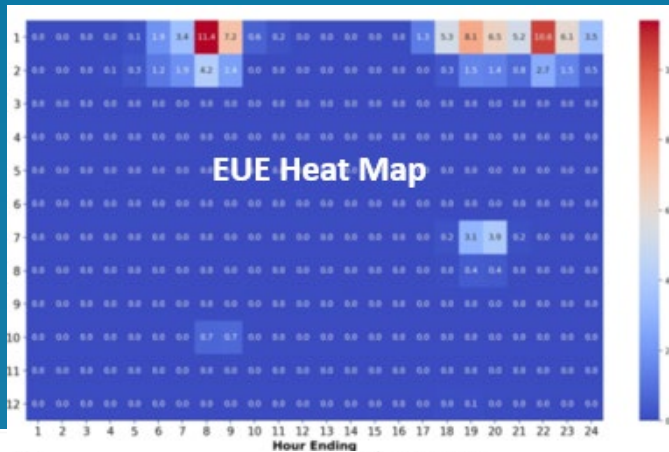
ERO Energy Assessment Pilot

Demonstrated capabilities for an interconnection-wide study:

- Resource adequacy metrics (LOLE, LOLH, EUE) by assessment area and select planning topologies
- Transmission adequacy assessment
- Charts and visualizations of energy risks

Developed the process for enhancing the LTRA:

- Process guidance for the ERO and assessment groups
- Planned and scoped for 2026 LTRA
- Lessons learned for interconnection-wide energy assessments
- Study results were not intended to be part of the 2025 LTRA

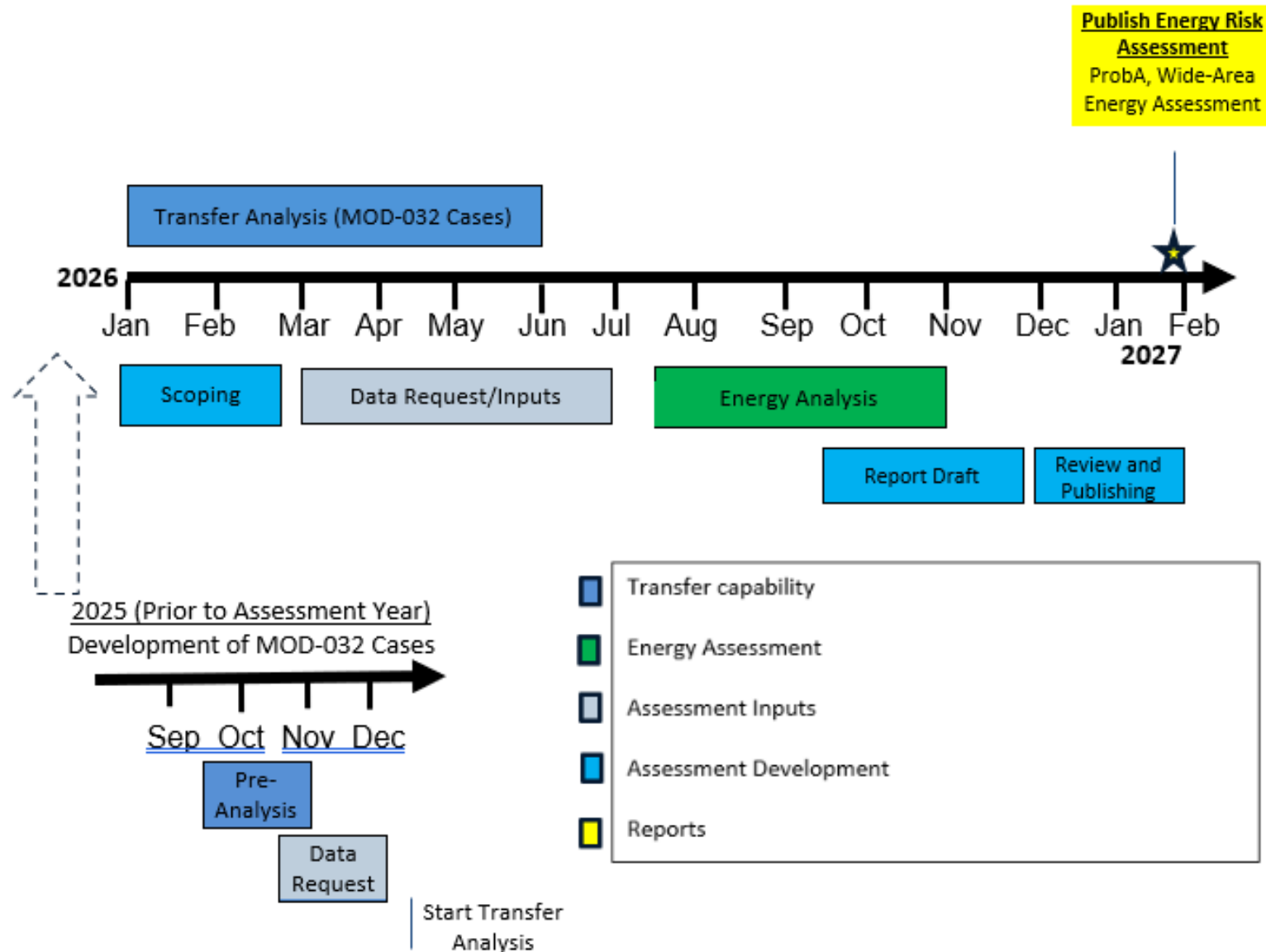


Lessons Learned

- Modeling differences between transfer analysis and energy analysis
- Challenges mapping outage information from GADS to generators in the model and LTRA data
- Model building hampered by incomplete location information in the LTRA data inputs
- Expanding the types of units in the model would help match LTRA data
- How did REs in each interconnection perform and coordinate model-building
- Outputs: A chosen transmission adequacy metric (constrained transfers in EUE events) was difficult to obtain from outputs
- Process: Project team coordination meetings were invaluable



2026 Energy Assessment Timeline






Seasonal Assessment Overview



 CONNECTION

 CURIOSITY

 COMMITMENT

 COMPETENCY

Seasonal Assessments

ASSESSMENT BACKGROUND

- NERC began performing reliability assessments in 1967
- NERC and the REs evaluate BPS operating reliability on a seasonal basis
- They identify resource adequacy concerns, assess operational readiness, and report findings in annual summer and winter assessment reports



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Seasonal Assessments

WHAT THE ASSESSMENTS COVER

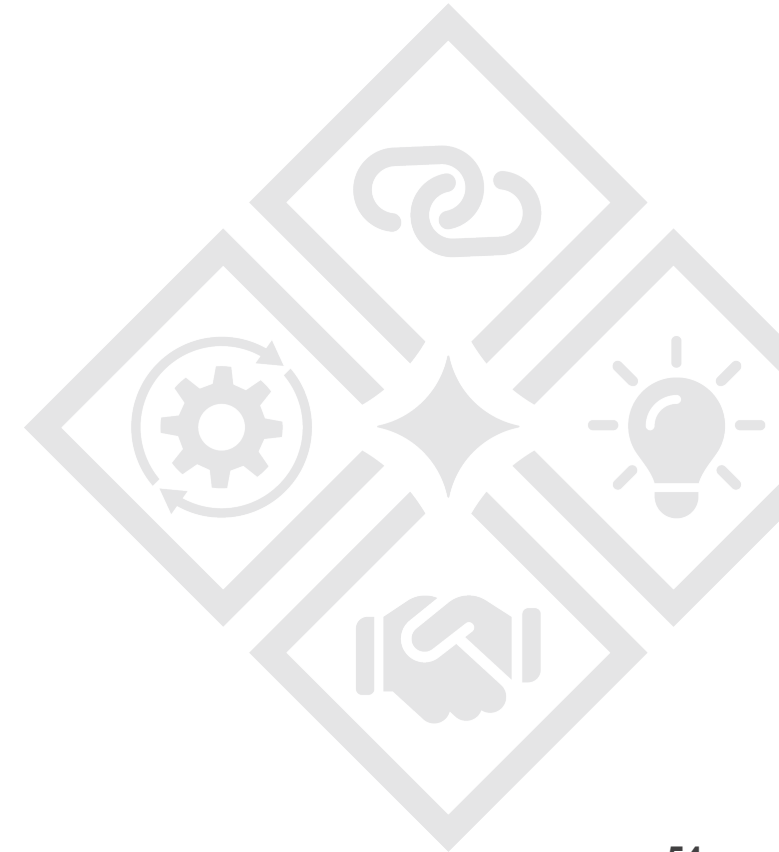
Seasonal assessments examine a wide range of activities that reinforce each area's ability to respond to conditions during the upcoming season.

Facility changes

Fuel supply

Operating procedures

Studies and analysis



Seasonal Assessments

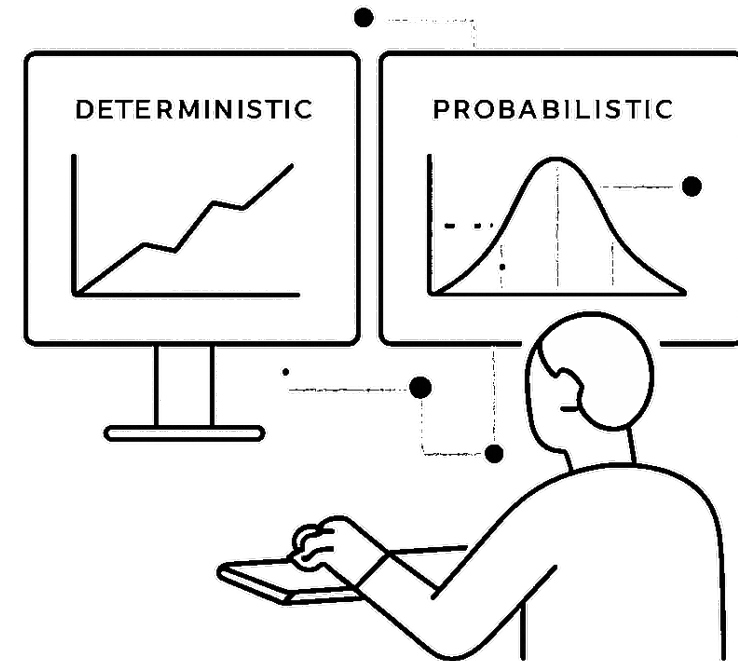
ASSESSMENT METHODOLOGY

Deterministic approach

NERC applies a deterministic framework to evaluate how potential variables may affect resource availability during summer or winter peak demand for each assessment area

Probabilistic risk layer

Seasonal assessments also incorporate probability-based risk analysis - evaluating the range of resource adequacy outcomes through sensitivity analyses based on historical data and expected changes



Seasonal Assessments

DATA COLLECTION & COORDINATION

The REs coordinate with each assessment area to review studies, outage schedules, and resource availability impacts.

Narrative guide

Data forms

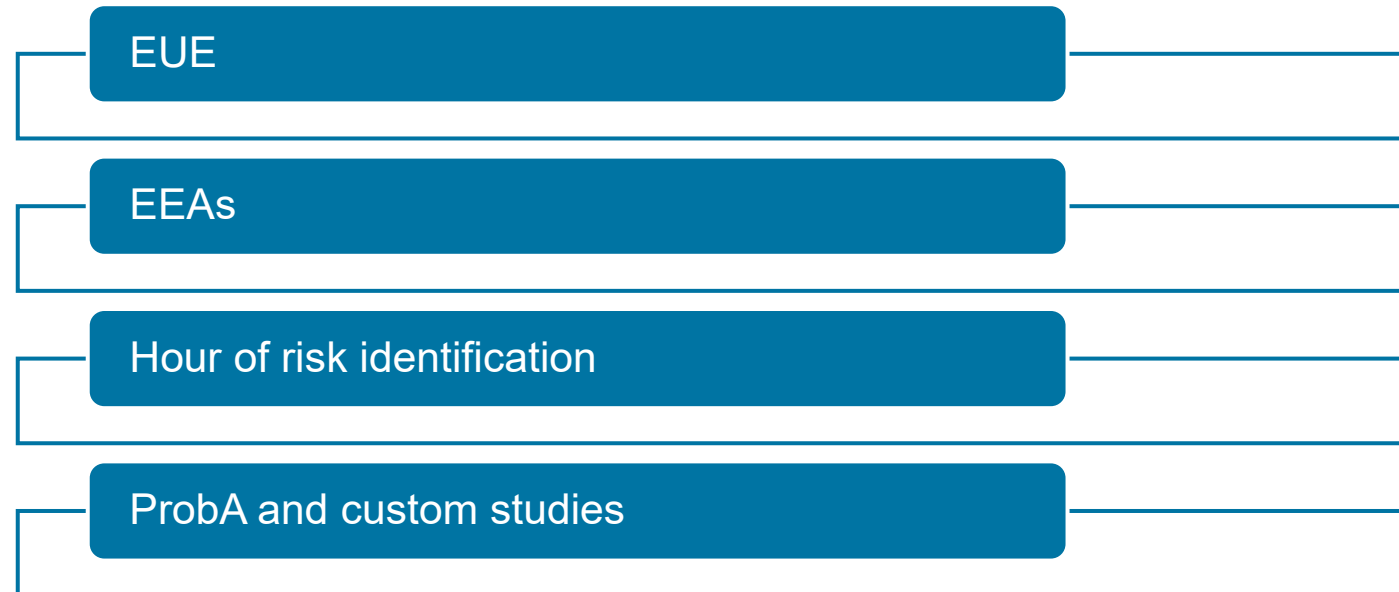
Data instructions



Seasonal Assessments

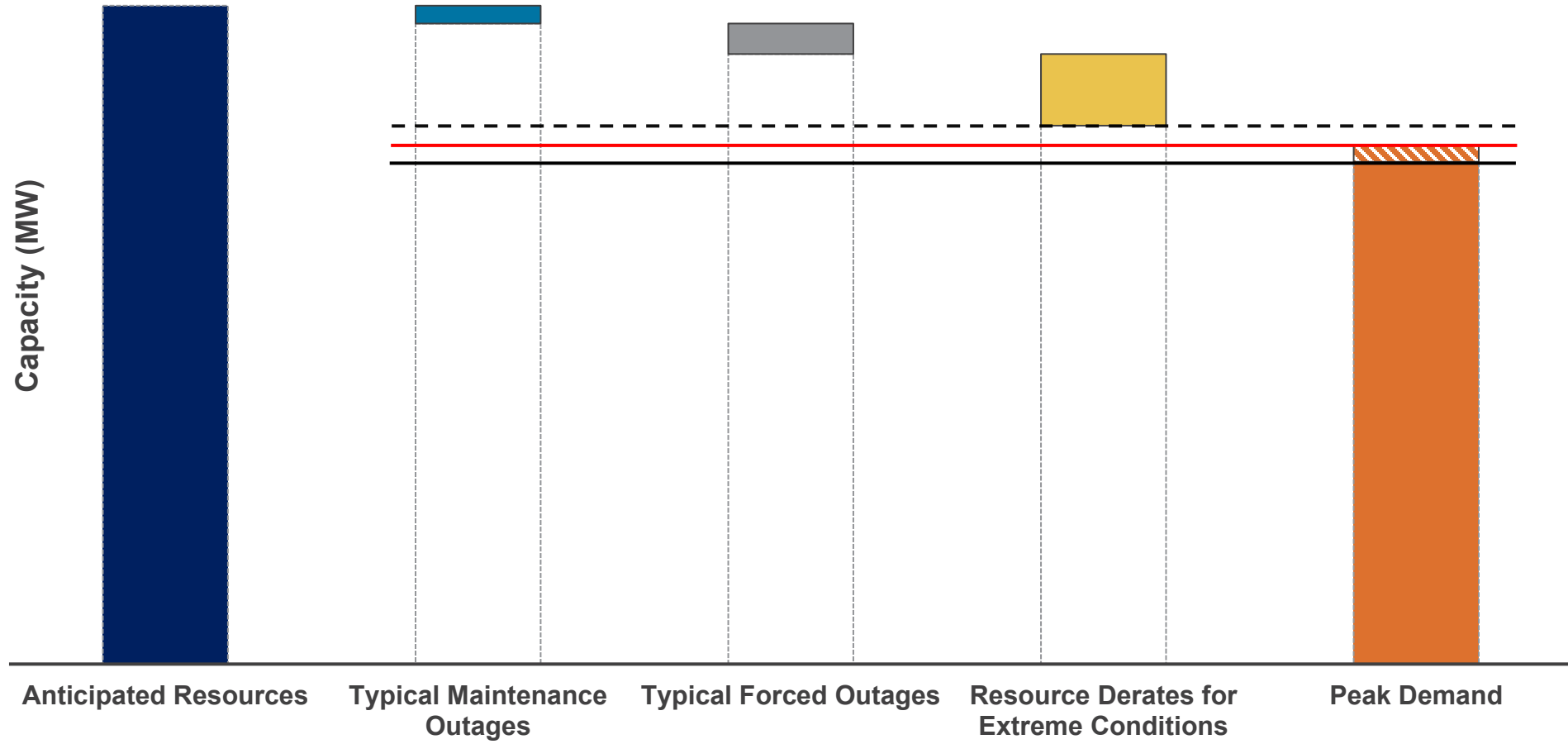
PROBABILISTIC RISK ASSESSMENT

Probabilistic risk assessment evaluates energy shortfall risk across **all hours** of the assessment season.



Seasonal Assessments

OPERATIONAL RISK ANALYSIS



Seasonal Assessments

SEASONAL RESOURCE ADEQUACY & ENERGY RISK

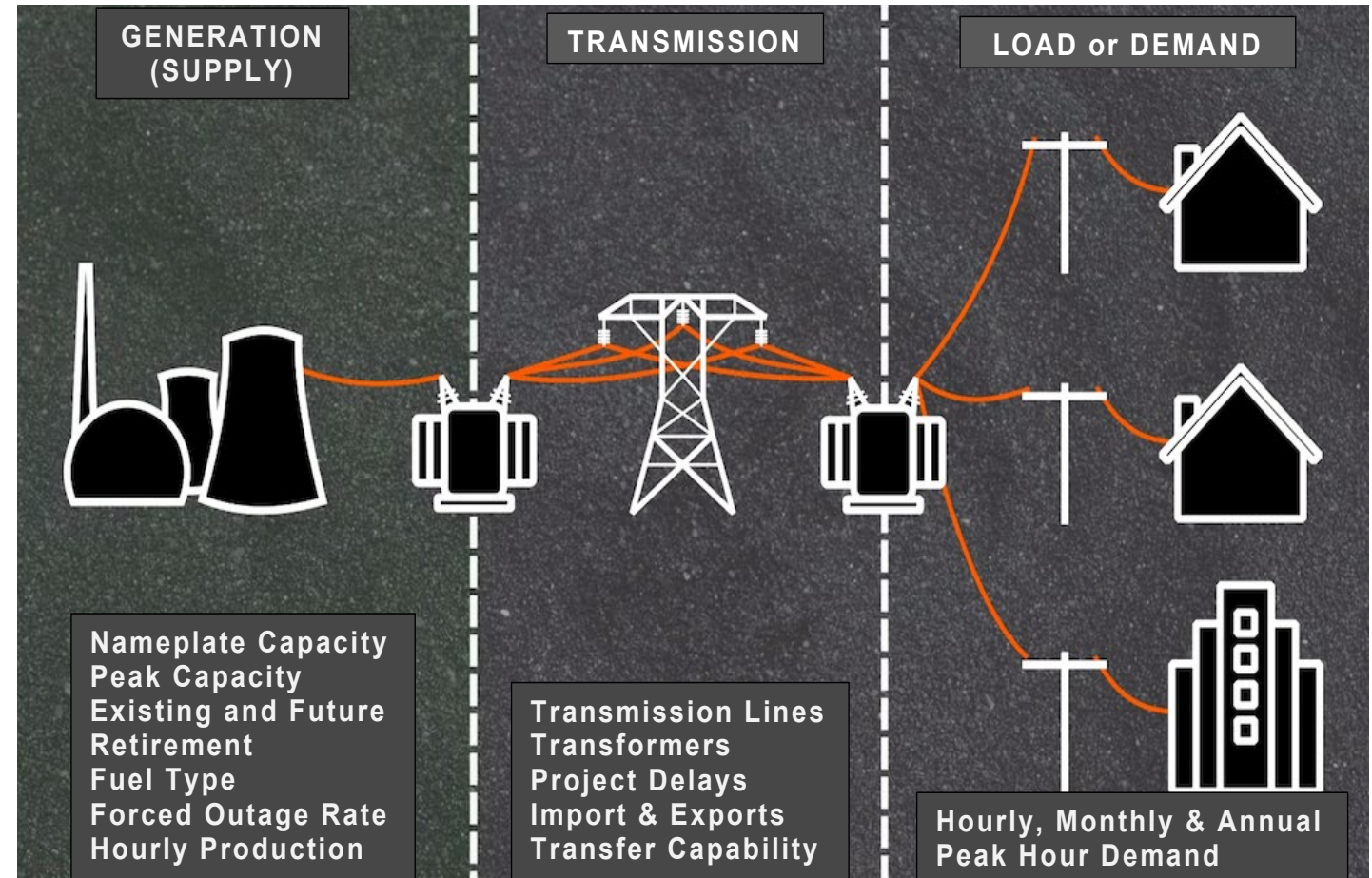
- Several different system scenarios are analyzed
- Seasonal risk factors

SUPPLY > DEMAND = Low Risk

SUPPLY = DEMAND = Elevated Risk (NERC)

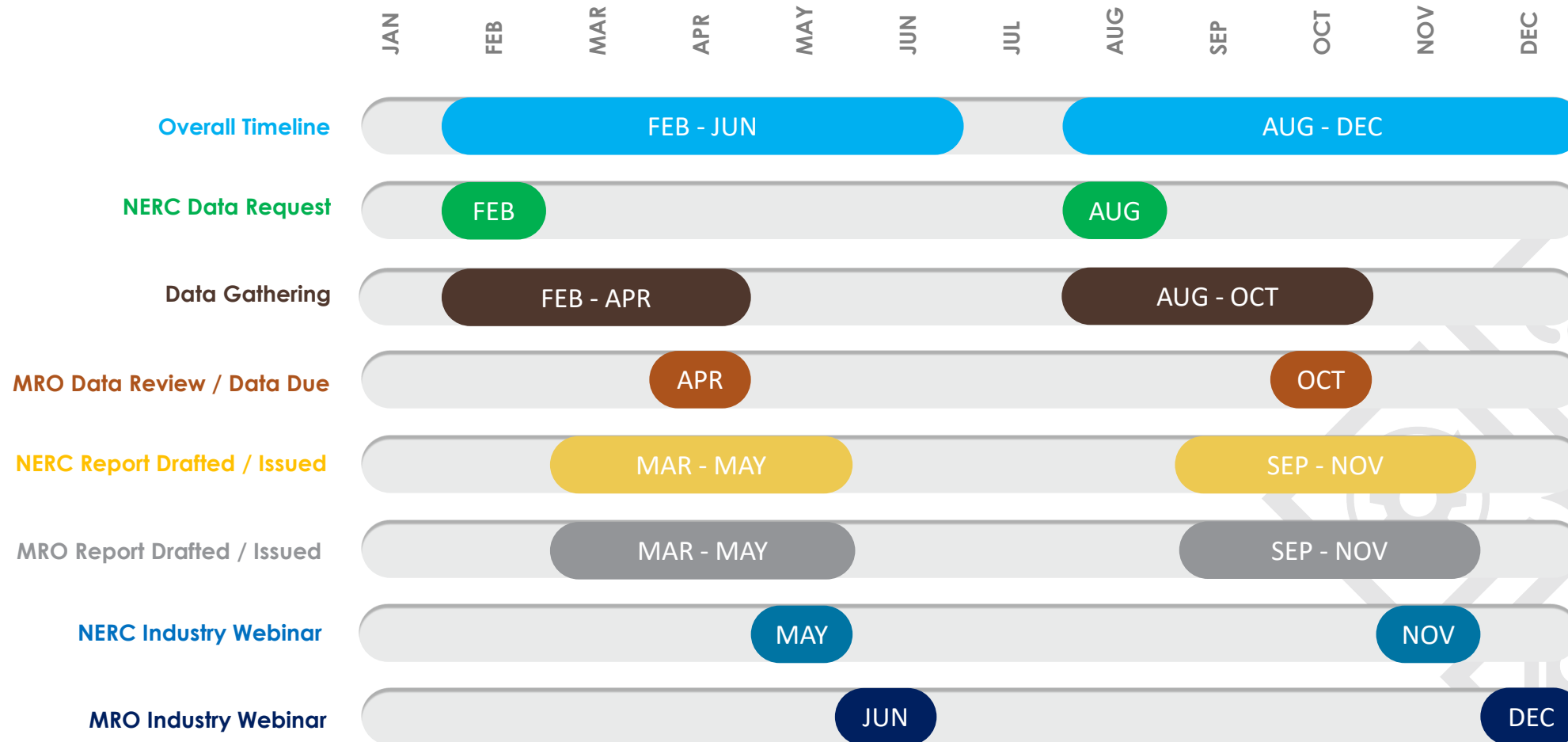
SUPPLY = DEMAND = Medium Risk (MRO)

SUPPLY < DEMAND = High Risk



Seasonal Assessment

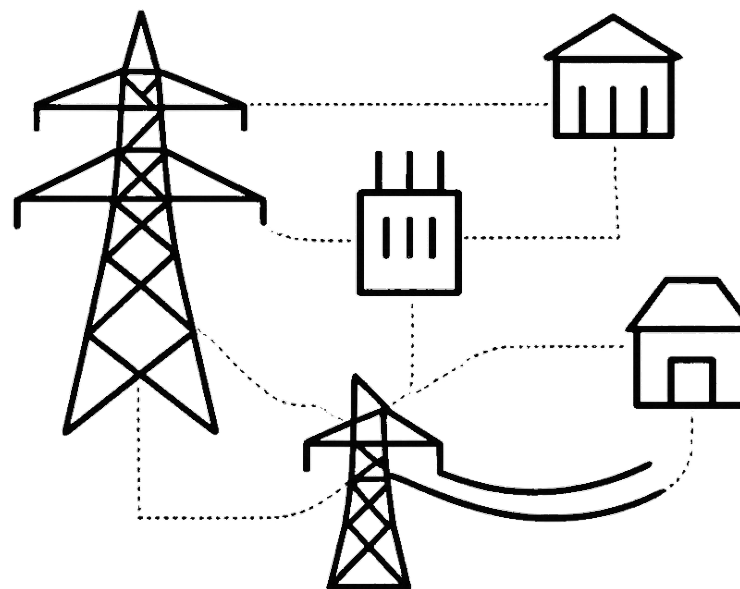
Timeline



MRO Seasonal Assessments

ADDITIONAL ANALYSIS

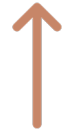
- MRO staff reviews MH, MISO, SPC, and SPP data prior to NERC's data request due date
- MRO staff incorporates the following data in each seasonal assessment:
 - GADS
 - TADS
 - MIDAS
 - EEAs / event analysis
 - Other pertinent / special information
- In addition to internal reviews, the MRO RAC reviews the assessment



Recent Trends



BES transmission events for 2025 were at an all-time low



Generation forced outage rates are increasing



Failed AC equipment continues to be leading contributor of transmission line outages



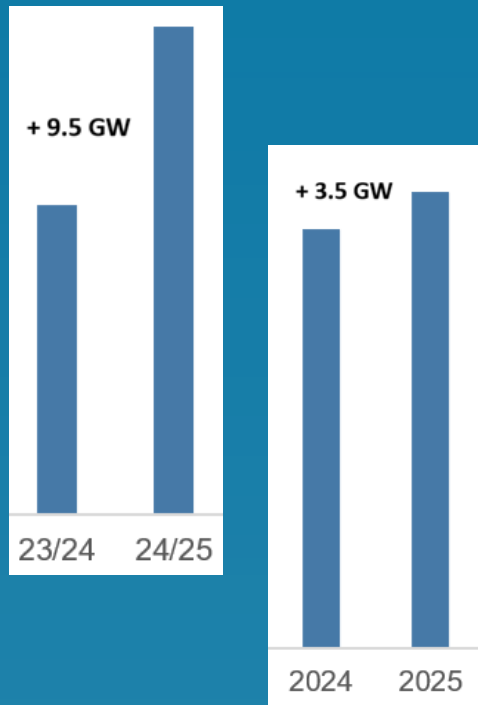
Reportable transmission outages are trending downward



Regional misoperations have seen a significant reduction



Recent Key Findings



SURGING LOAD GROWTH

- 9.5 GW from winter 23/24 to 24/25
- 3.5 GW from summer 2024 to 2025

RESOURCE CAPACITY

- Resource additions have not been keeping pace
- Resources being added are less effective and can leave operators with fewer dispatchable options when needed

SUFFICIENT RESOURCES

- All assessment areas were identified as low-risk for winter 25/26
- MRO expects sufficient resources again this summer



NERC Seasonal Assessments

OUTPUTS AND TAKEAWAYS

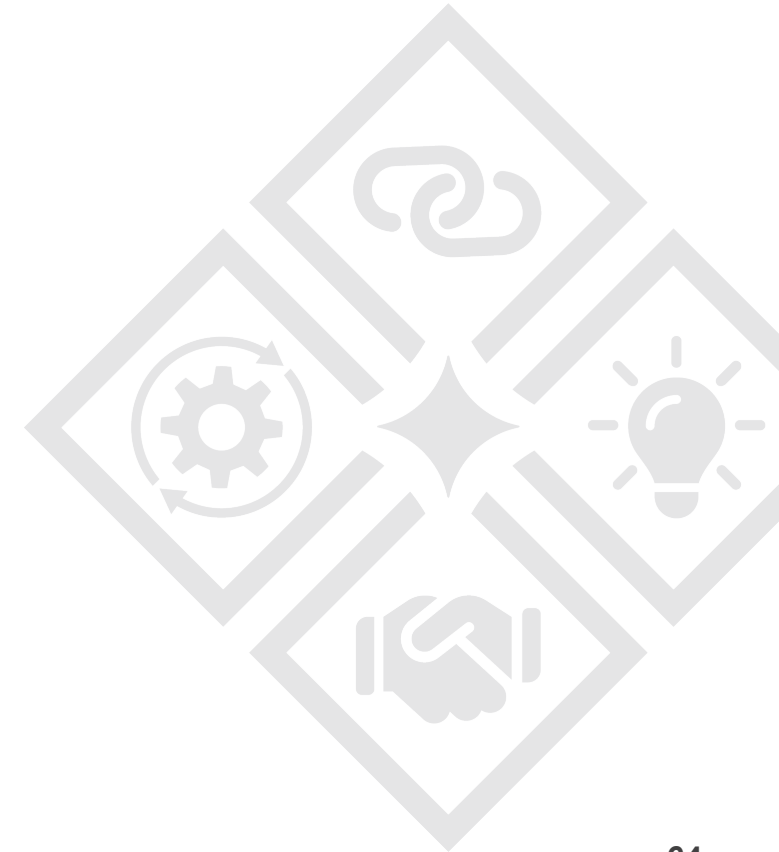
Coordinate, coordinate, coordinate

Deterministic and probabilistic

Real-world performance data

EEA likelihood

Findings published



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Pam Sordet

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NERC Reliability Assessments

<https://www.nerc.com/our-work/assessments>

MRO Reliability Assessments

<https://www.mro.net/program-areas/reliability-analysis/assessments/>

Contact Information & Links



Questions



SunZia Wind and Transmission Project

Vajira Pathirana

Pattern Energy

AVP, Project Engineering

May 12, 2026

2026 MRO Reliability, Security and CMEP Summit



Pattern Energy

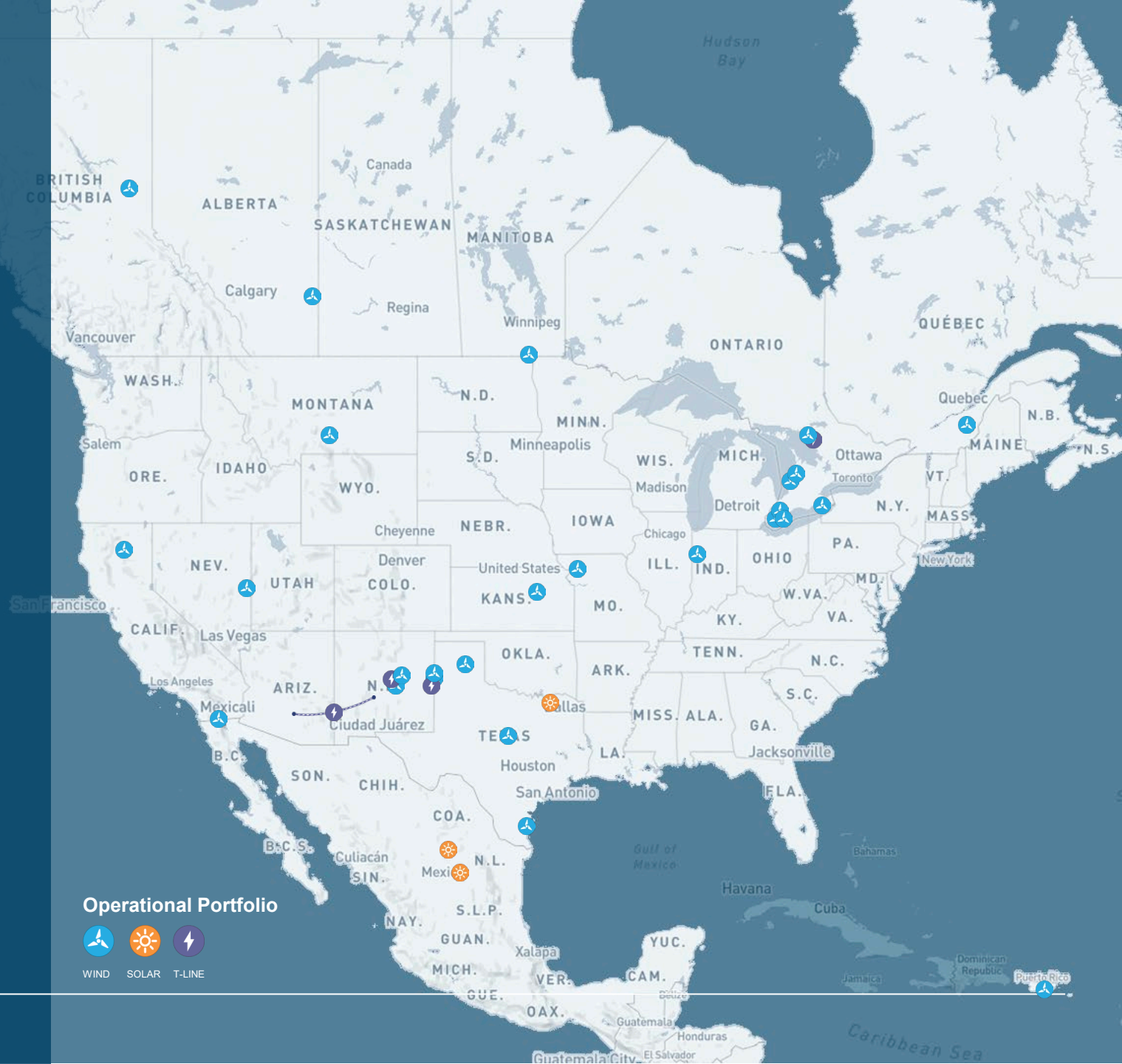
Pattern is a fully integrated renewable energy developer and one of the world's leading renewable energy generation, transmission, and energy storage companies, with operating footprints in the United States, Canada, and Mexico.

Pattern's business includes an operational portfolio of 40 utility-scale renewable energy facilities with a ~12 GW operating capacity; a 37 GW development portfolio, which includes solar, storage, wind, and transmission projects; and a commercial and industrial business focused on solar development and construction.

\$57B capital raised with **\$100M+** community benefits annually.

Pattern is majority owned by the **Canada Pension Plan Investment Board**

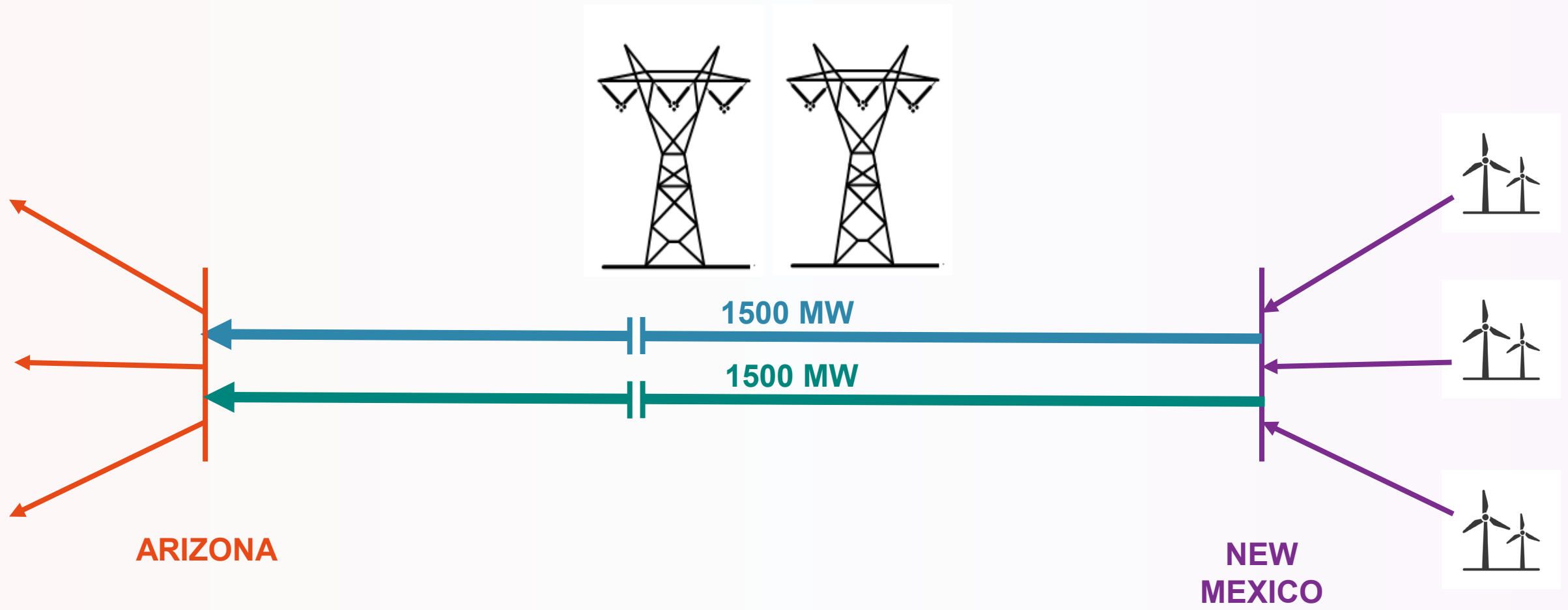
Primary offices in Houston, San Francisco, San Diego, Toronto, Chicago and Denver



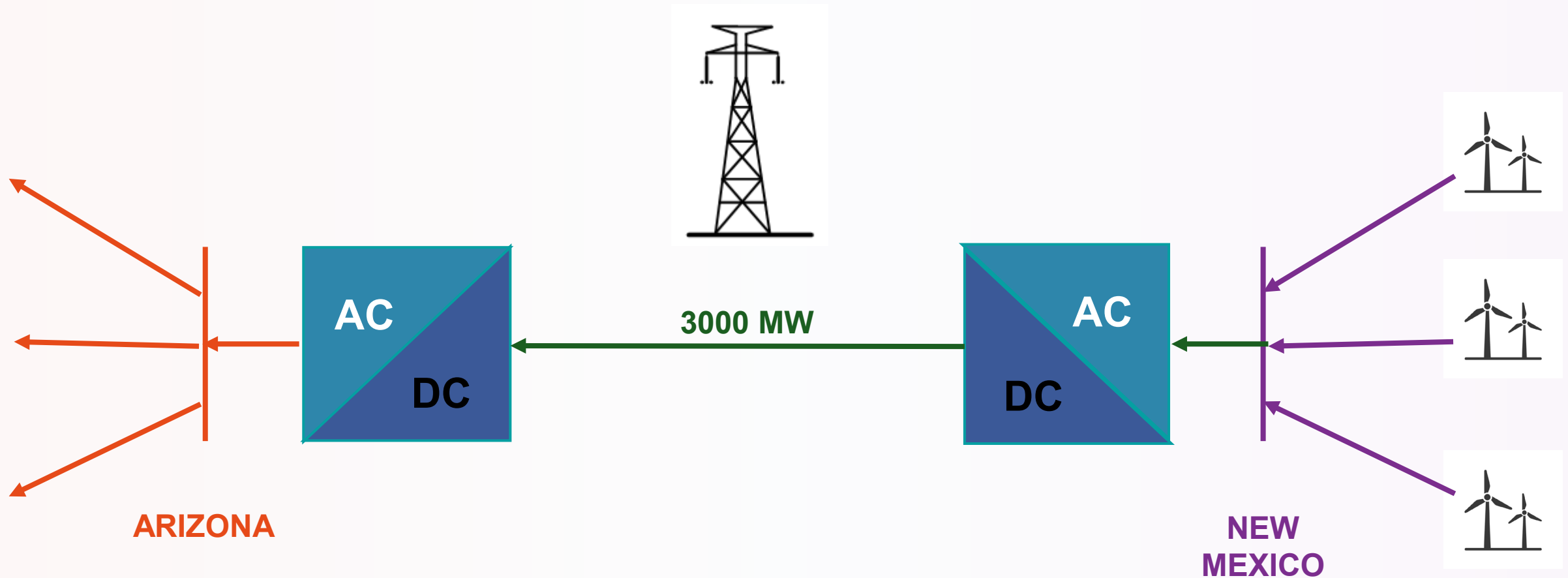
SunZia – Meeting Demand for Green Energy



SunZia – Transmission Options - AC

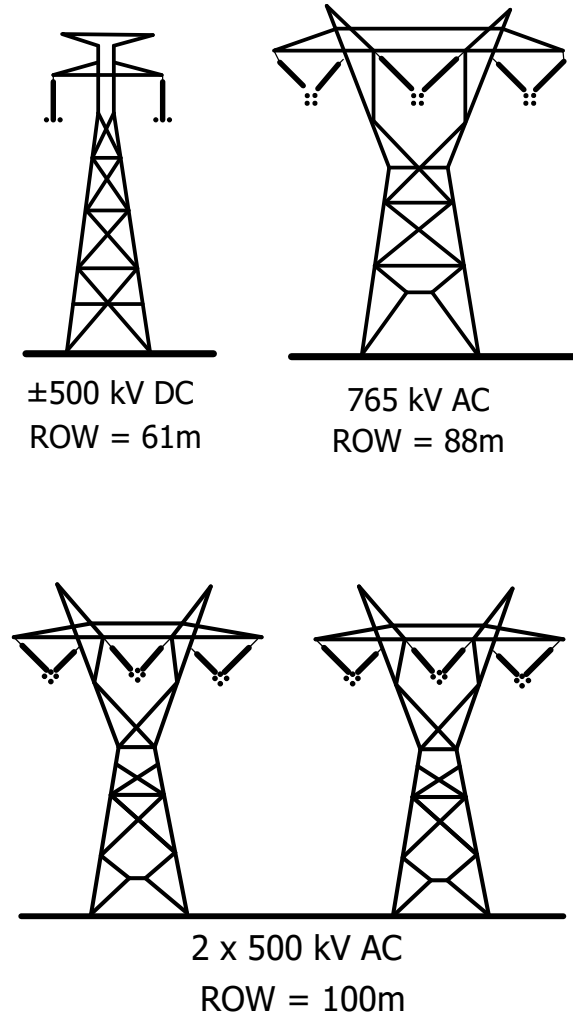
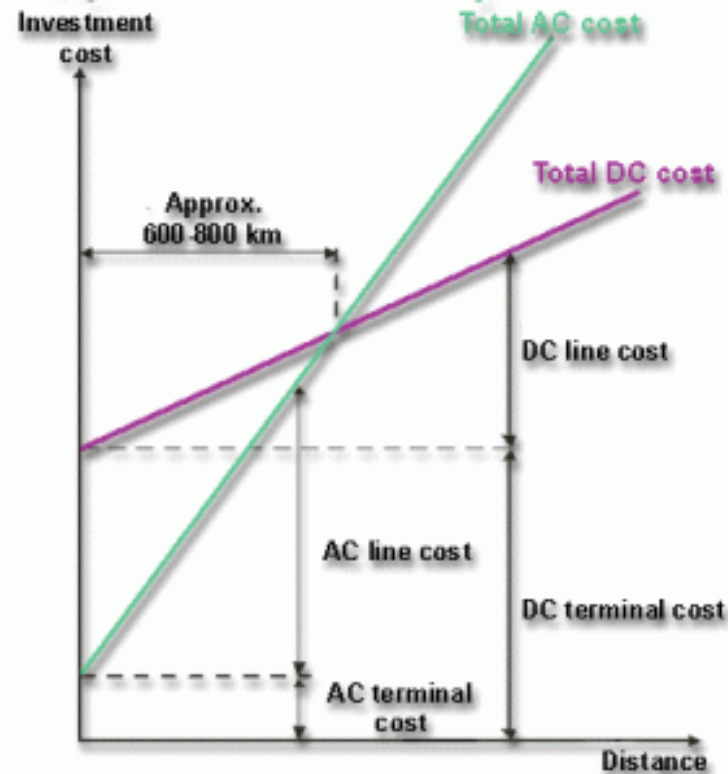


SunZia – Transmission Options - DC



Why HVDC for SunZia?

- Long distance transmission
- Lower overall cost at this distance
- Connecting islanded wind generation
- Right of way
- Bulk energy transport
- Reliability
- Availability



SunZia – Project Timeline

Initial
Discussions

2006

FERC Approval
– 50% Capacity

2011

ROW Progress
AZ/NM Permits

2019

Full Pattern
Ownership

2022

ROW Application
EIA

2008

ROW – BLM
AZ Permit

2016

LNTTP

2021

FNTP and
Start of
Construction

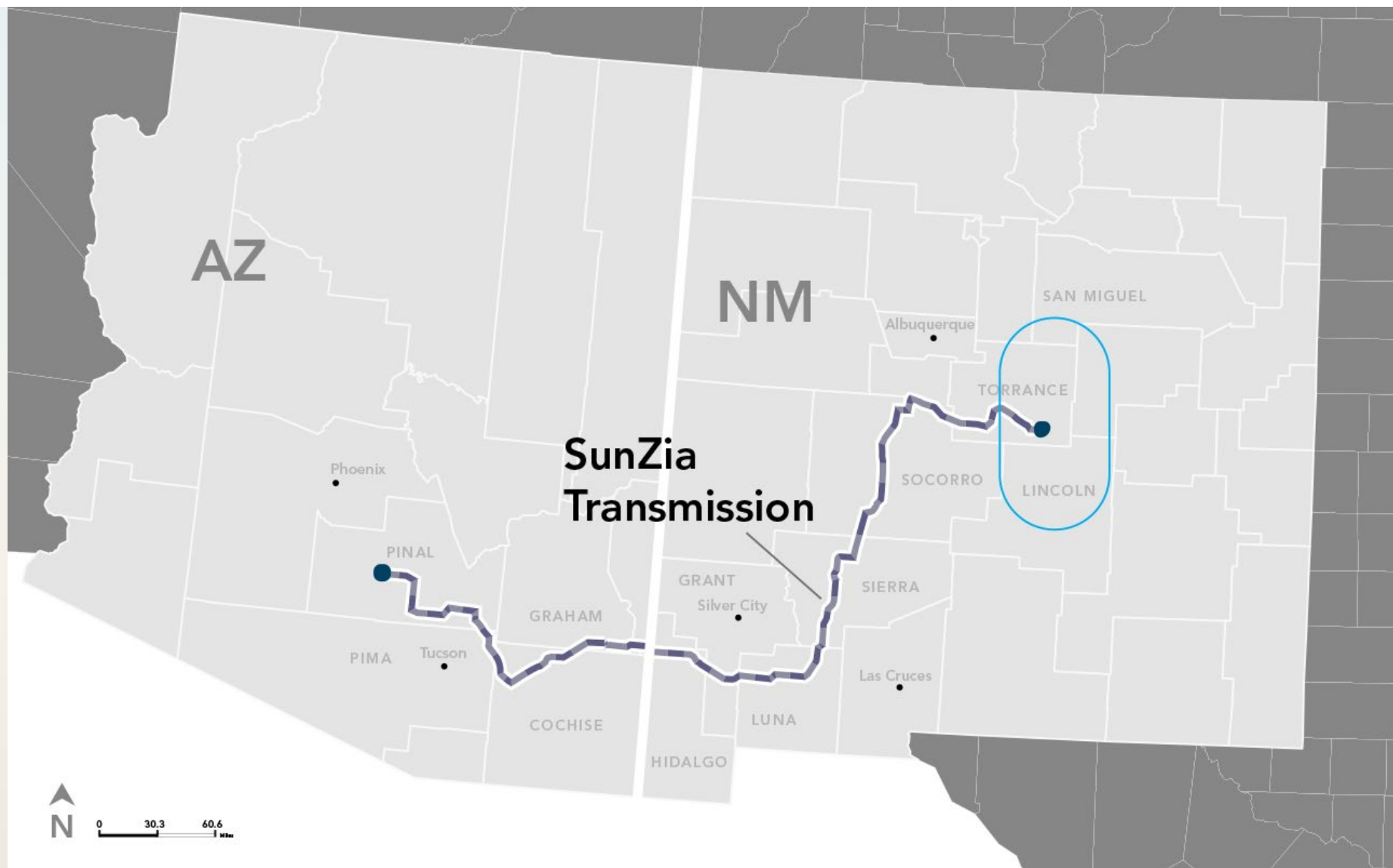
2023

Project
In Service

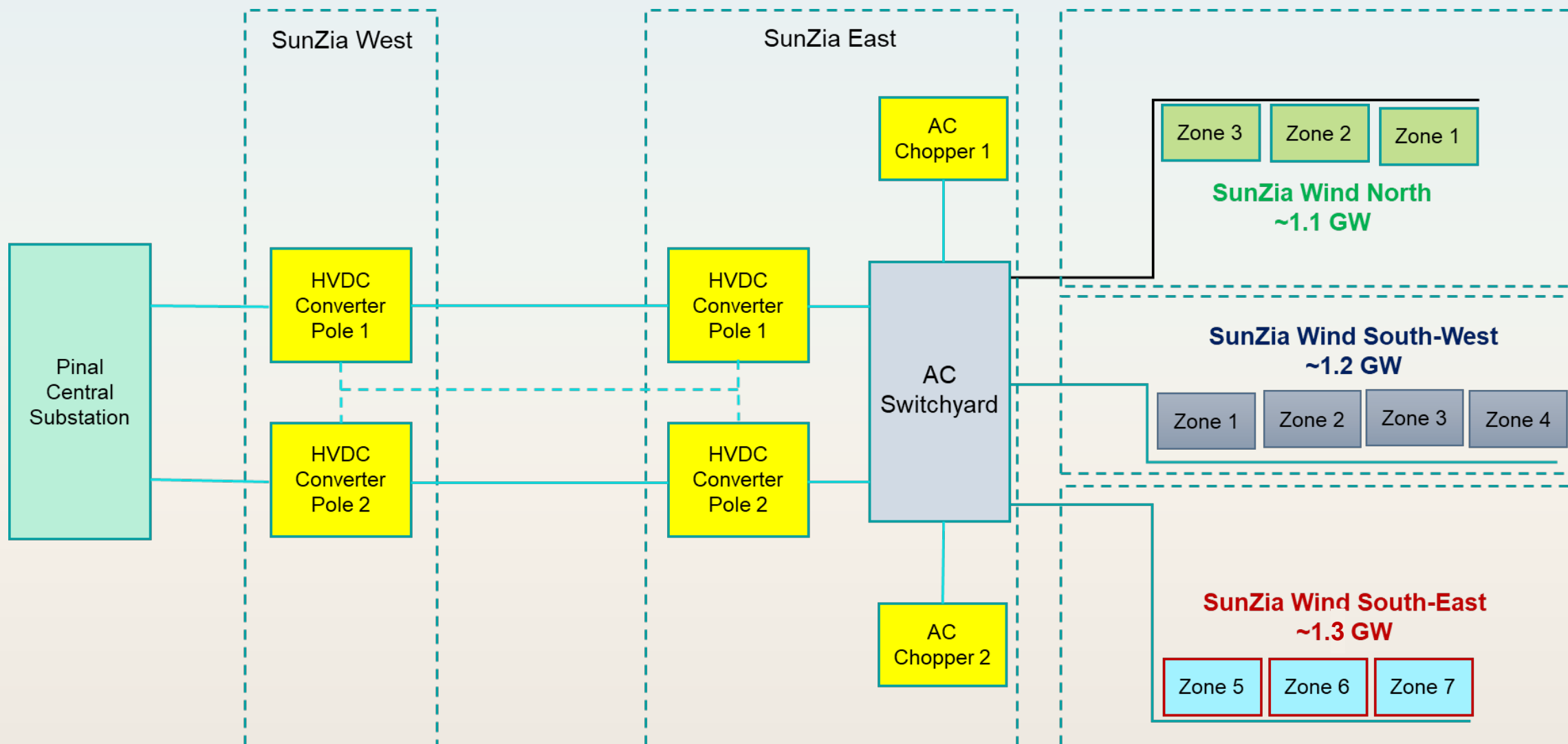
2026

SunZia Project - Making it Happen!

The largest
Clean Energy
Infrastructure
Project in North
American history
- USD\$11B
Investment



SunZia Project Overall System



SunZia HVDC Main Features

- **First onshore VSC HVDC system connected to an islanded renewable system**
 - Grid forming converters at NM end
 - Converters provide voltage and frequency to wind farm connections
- **Highest VSC HVDC power capacity: 3,000 MW at NM end**
- **Highest VSC HVDC voltage: ± 525 kV**
- **Configuration: Bipole**
- **Transmission distance: ~ 552 miles (~ 880 km)**
- **PCC voltage**
 - Sending End (NM) : 345 kV
 - Receiving End (AZ) : 500 kV
- **First bipole overhead VSC HVDC line with fault restart capability of an islanded system**
 - Need for AC choppers
- **First AC chopper installation**

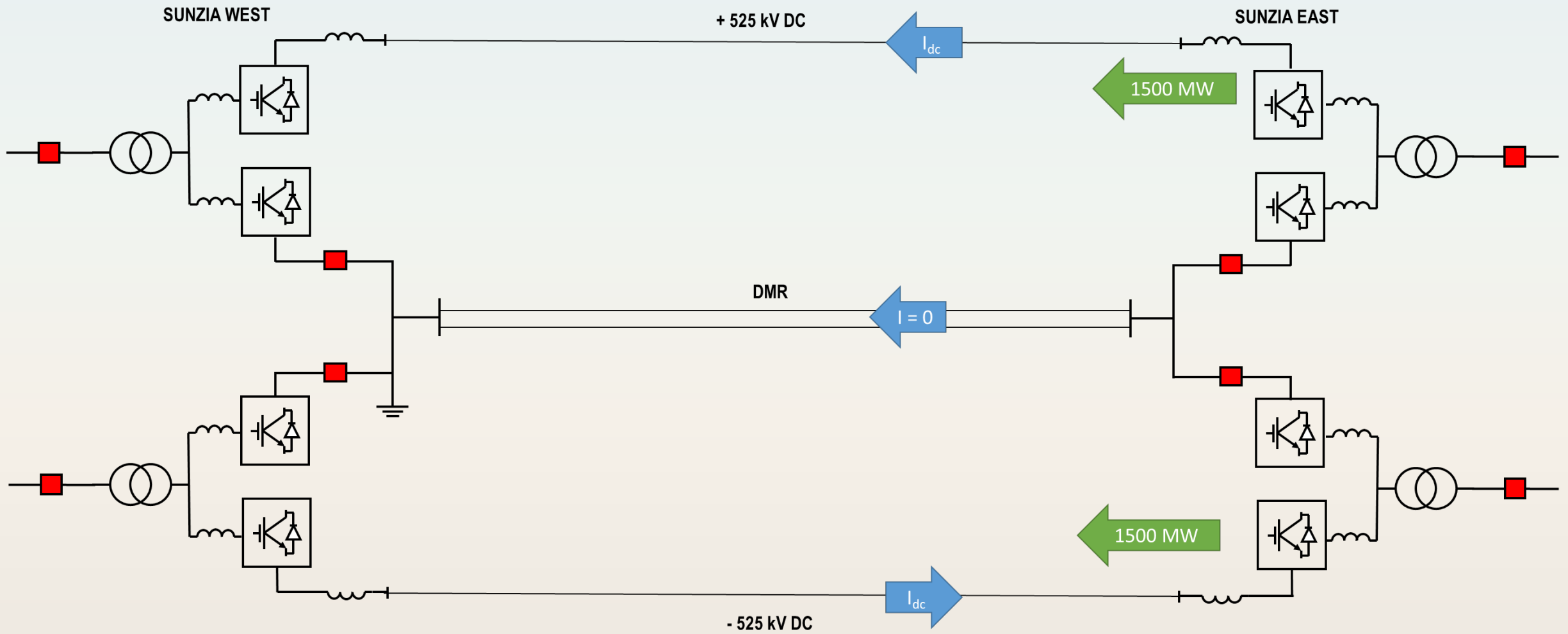


SunZia Wind Main Features

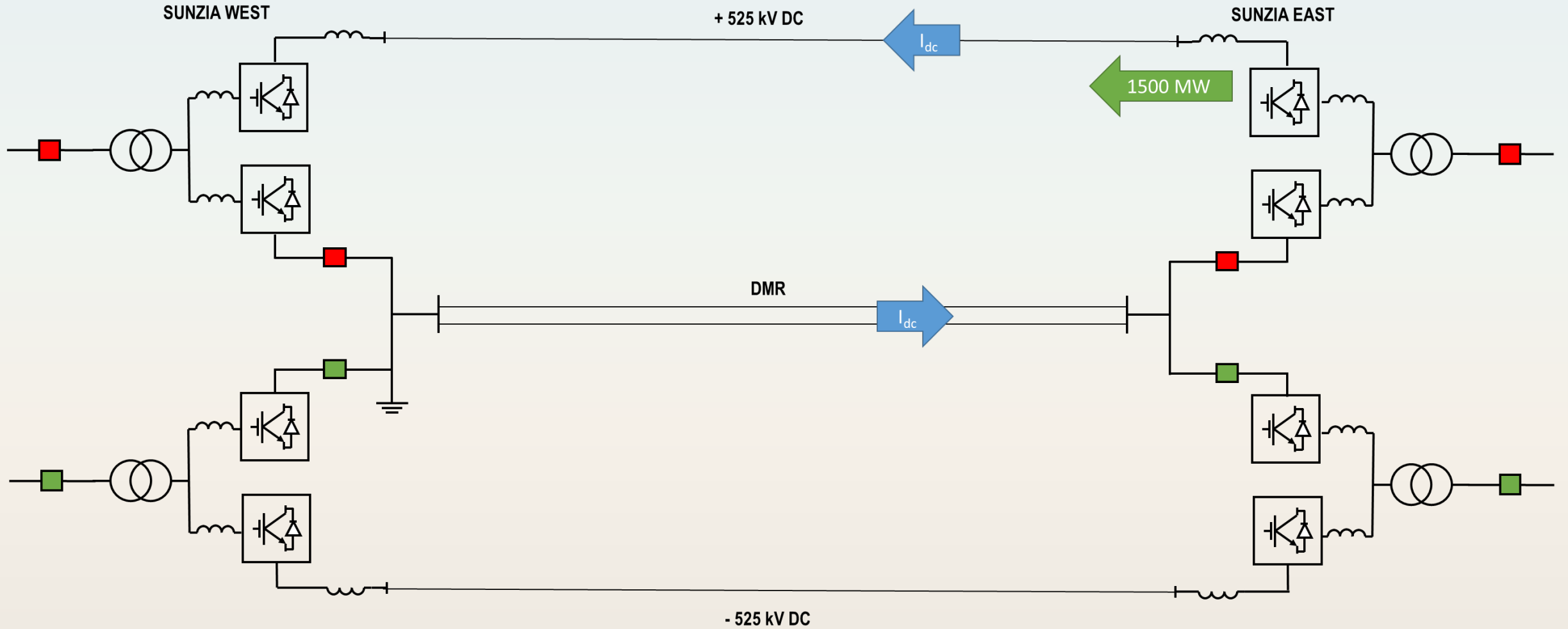
- Isolated wind farms connected to the HVDC station
- Over 3,650 MW wind generation capacity
- Ten wind substations
- Three main wind clusters
 - South-West
 - Four wind substations
 - 330 x GEV Sierra 3.8–154 WTGs
 - 1254 MW total capacity
 - South-East
 - Three wind substations
 - 344 x GEV Sierra 3.8–154 WTGs
 - 1307 MW total capacity
 - North
 - Three wind substations
 - 242 x Vestas V163 4.5 MW WTGs
 - 1089 MW total capacity



Bipolar Operation

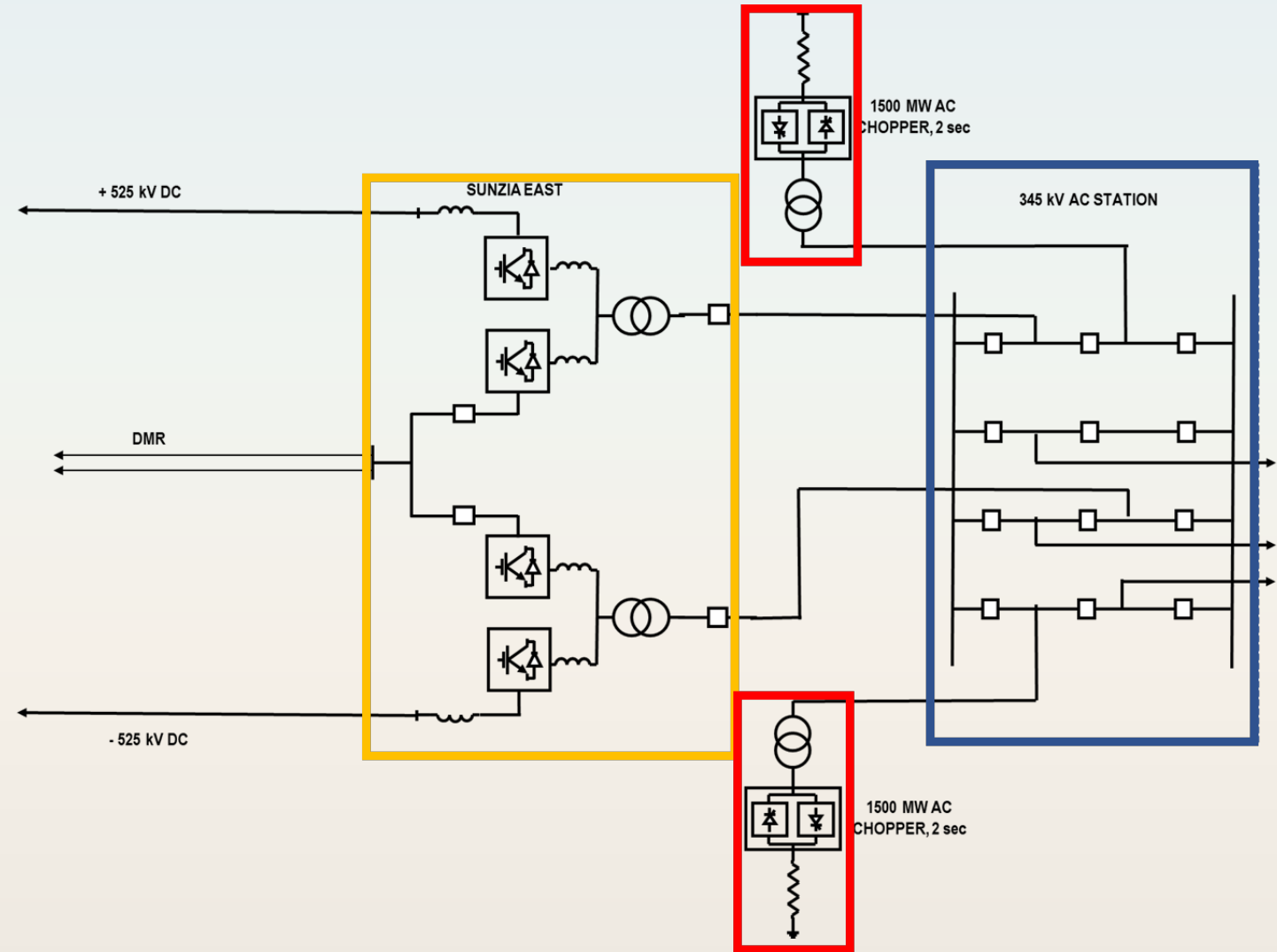


Monopolar Operation



AC Choppers

- Installed at sending end
- Two AC Choppers
- 1,500 MW each
- 2 sec. energy rating
- Thyristor based due to speed of response
- Activated when faults are detected
 - AC faults at receiving end
 - DC line faults
 - Converter faults



SunZia Project Construction



551 MILES
OF DC LINE ON LATTICE AND
MONOPOLE STRUCTURES



~15,000
CACTI RELOCATED FOR
ENVIRONMENTAL PURPOSES



~2,500+
TOTAL WORKFORCE



~1,900 MILES
OF UNDERGROUND CABLE



~450,000 T
(~900,000,000 LBS)
TOTAL TONS OF STEEL



~5,700 MILES
OF OVERHEAD CONDUCTOR



~530,000 CY
TOTAL CY OF CONCRETE



Construction of DC Transmission Line

- **552 miles of towers and conductors**
- **Two multi-conductor pole conductors**
- **Two DMR conductors**
- **Two OPGW**
- **Three Regen sites**
- **Helicopter access only at certain places**
- **Helicopter installations**
- **River crossings**
- **Construction in Sevilleta Wildlife Refuge**



Construction of Wind Farms

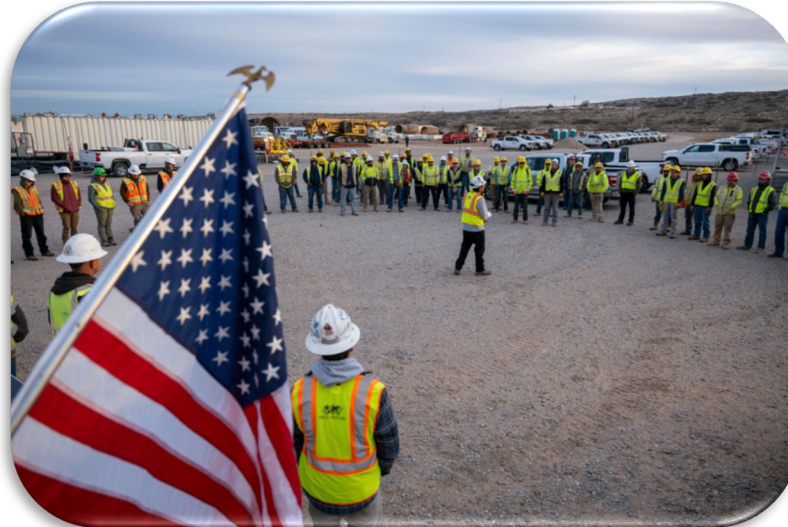
SunZia South

- 674 X GE3.8 - 154 on 98m HH
- 70.2 mi of 345kV gentie
- 445 mi of underground collection
- 530 mi of access roads
- 324K CY of concrete
- 43.2m lbs of reinforcing steel
- 74 mi of overhead collection



SunZia North

- 242 X V163 - 4.5MW on 104m HH
- 69.9 mi of 345kV gentie
- 187 mi of underground collection
- 281 mi of access roads
- 161K CY of concrete
- 19.8m lbs of reinforcing steel
- 47 mi of overhead collection



Construction of HVDC Converter Stations

- Two converter stations: NM and AZ
- 75 feet tall valve hall buildings
- Multiple additional buildings
- Seven 550 MVA transformers at each site
- Other large main circuit equipment
- Over 150 panels
- Cooling circuits
- Redundant auxiliary systems

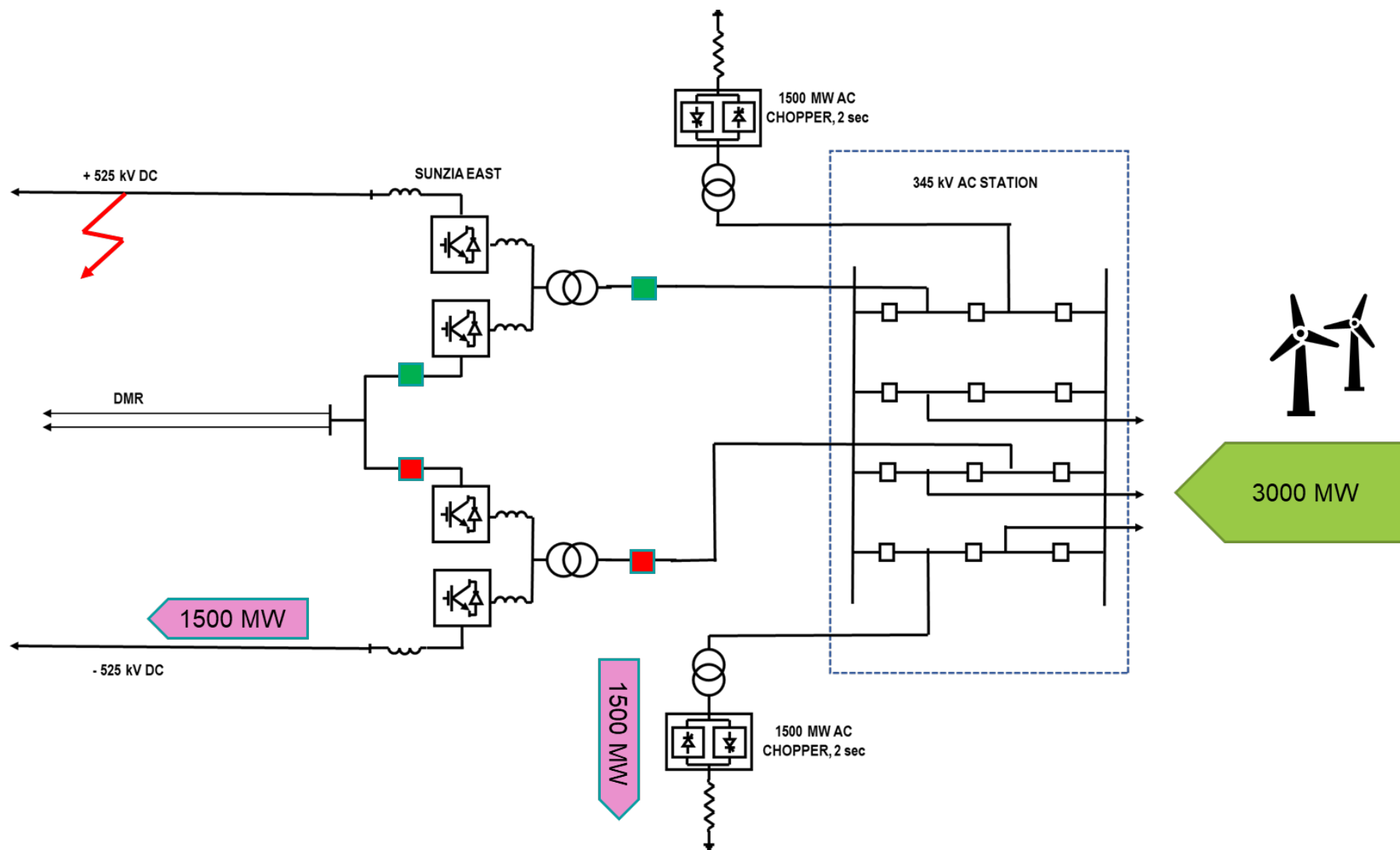


Current Status

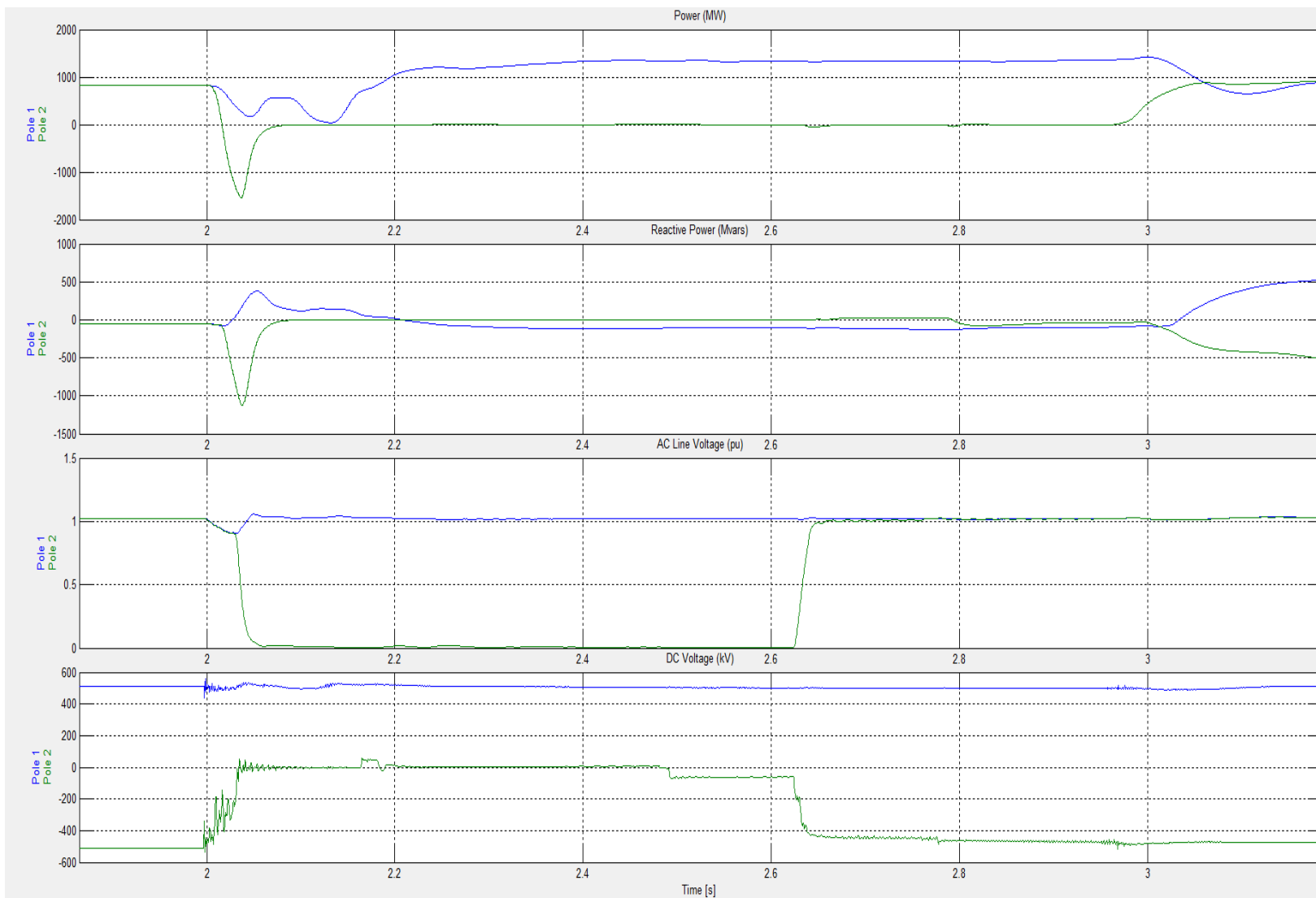
- **Converter station commissioning completed**
- **345 kV AC switchyard energization completed**
- **All wind substations energized**
- **System testing completed**
- **Over 90% of wind turbines commissioned**
- **DC line fault recovery sequence tested using staged line faults**



Temporary DC Line Fault



Staged DC Line Fault Test (1700 MW)





Pattern

Thank you!!

Questions??





Organizational Alignment for Outage Coordination Processes

— • •

Minimizing Risk to Reliability
in a More Complex Grid

Collin Hayward | Managing Director
1898 & Co., a Part of Burns & McDonnell





Collin Hayward, PMP
Managing Director - 1898 & Co.
Collin.Hayward@1898andco.com
[in/collinhayward/](#)

EXPERIENCE

16
Years

EDUCATION

BS, Electrical
Engineering

CERTIFICATIONS

Project Management
Professional

HIGHLIGHTS

Maine Power Reliability Project (\$1.4B)

Central Maine Power | Maine
Outage Planner

- 450+ miles of new 345-kV and 115-kV transmission line facilities
- 11 major 345-kV substations
- More than 40 ancillary substation upgrades

Bergen Linden Corridor Program (\$1.2B)

PSEG | New Jersey

Outage Planning Manager

- 20 miles of existing 138-kV rebuilt to 345-kV
- 20.5 miles of new 345-kV XLPE
- 6.2 miles of existing 138-kV HPFF rebuilt to 345-kV
- Six major 345-kV substation upgrades from 138-kV AIS to 345-kV GIS
- Five ancillary substation upgrades

Major Projects Program (\$1.8B)

Duke Energy | Florida

Outage & Operations Planning

- Portfolio of multiyear \$50M+ projects
- 1,500+ planned outages analyzed
- 50+ Outage Sequence Plans (OSPs)

Outage Coordination is Becoming More Complex



PEOPLE

Planning,
Operations, and
Projects



PROCESS

Shared
Timelines, Data,
Decisions Points



TECHNOLOGY

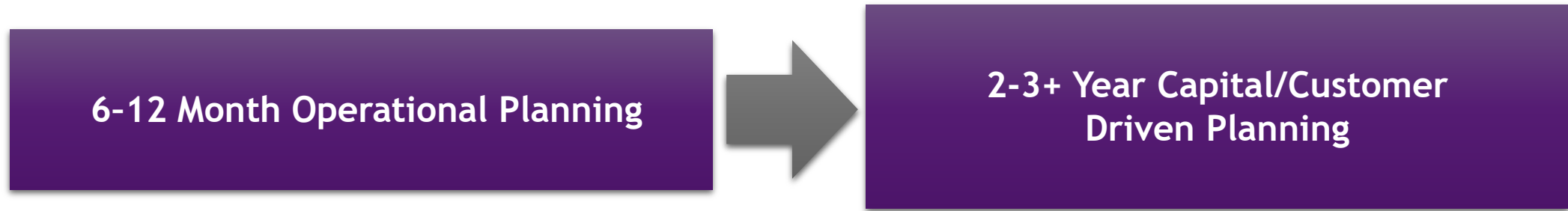
Same consistent
data and
assumptions

As outage complexity increases, alignment becomes the limiting factor

The Shift



Outage Planning Has Fundamentally Changed



DRIVEN BY

- Large Capital Programs (Resource demands)
- Speed to Energize (Large Load)
- Renewable Integration & Transfer Constraints
- ISO/RTO Coordination Complexity
- System Constraints

The Real Challenge

Outage Coordination Breaks Down Without Alignment

- More stakeholders than ever:
 - Operations
 - Transmission/Generation Planning
 - Capital Portfolio Drivers
 - Construction / Resources
 - Procurement
 - Real Estate / Permitting / Customer Influence
- More interdependencies
 - Regional Constraints
 - Increased Urgency
 - Reliability
- Escalating complexities = Higher Costs = Higher consequences of RISK



Where Alignment Breaks



Five Critical Alignment Gaps



1

Data & System

Same Truth



2

Timeline

Same Timing



3

Functional

Same Assumptions



4

Visibility

Same Priorities



5

Role & Resource

Same Ownership



Gap 1: Data & System Misalignment

Teams Are Not Operating from the Same Source of Truth

- No system-of-record scheduling platform
- Planning in:
 - Scheduling software(s) - various
 - Spreadsheets
 - Disconnected tools
- No integrated outage view across departments

Different data leads to different decisions and misaligned outages



Gap 2: Timeline Misalignment

Teams Are Not Aligned on When Decisions Happen

- Rarely enforced planning timelines
 - Submittals / Information Sharing
 - Just in Time
 - Late outage submissions
 - Regional Coordination
- No milestone-based governance (T-minus)
- No Risk evaluation

If decisions aren't made at the same time, they won't hold.



Gap 3: Functional Misalignment

Teams Are Not Aligned on How the System Is Analyzed

- Operations vs Planning vs Projects:
 - Different models
 - Different approaches
 - Different assumptions
- Heavy reliance on manual coordination

Misaligned models create rework, delay, and risk.



Gap 4: Visibility Misalignment

Teams and Leaders Are Not Aligned on What Matters

- Minimal executive-level outage visibility
- No forward-looking constraint view
 - By group/department
 - By organizational seniority
- Limited dashboards / GIS integration

If leadership can't see it, they can't act or manage it.



Gap 5: Role & Resource Misalignment

Ownership Is Not Aligned to the Work

- One or two planners supporting entire portfolio
- No embedded outage planners in capital programs
- Skill gaps
 - Planners (PSSE, TARA, transfer analysis)
 - Knowledge transfer - know your system

Critical work without ownership creates systemic risk.

Why This Matters



Misalignment Creates Real Risk



Reliability
Risk



Capital Delivery
Risk

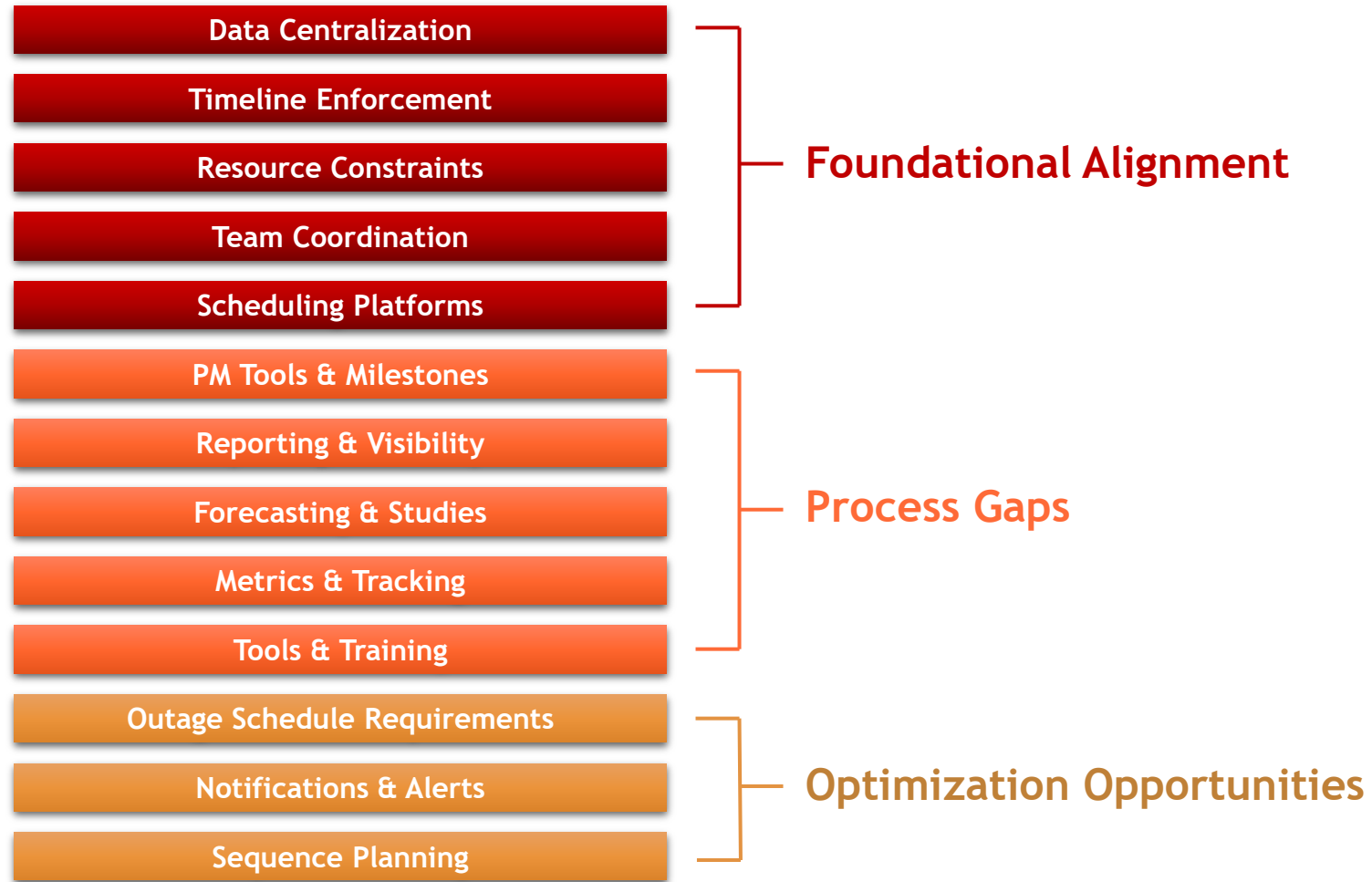


Regulatory
Exposure



Increased
Customer Impact

Where the Risk is Concentrated



What Good Alignment Looks Like

Alignment Across Five Dimensions



Aligned Systems

- Single system of record
- Integrated planning + execution tools



Aligned Timelines

- T-minus milestone framework
- Defined decision gates



Aligned Functions

- Shared models and assumptions
- Formal coordination cadence



Aligned Visibility

- Tiered reporting:
 - Ops -> Detailed
 - Leadership -> Dashboard
 - Exec -> Risk Review



Aligned Organization

- Dedicated outage planning function
- Embedded planners in major programs

T-Minus Framework



Alignment Through Time Discipline

T-36 Months	Concept + Feasibility
T-18 Months	Coordination + Alignment
T-6 Months	Submission + Readiness
T-0	Execution
Post	Review + Metrics

This works because the organization aligns around it.



Final Takeaway



- The grid has evolved
- Outage complexity has increased
- But organizational alignment has not kept pace

Tools, Process are great, but they must be matched with organizational alignment.

Thank You!



Want to Chat and Learn More?

Reach out to me via email or connect with me on LinkedIn!

Collin Hayward, PMP

collin.hayward@1898andco.com
in/collinhayward/



Collin Hayward, PMP · 1st

Managing Director - 1898 & Co. | Strategy, Planning, Utility
Consulting & More

1898  CO[®]

PART OF BURNS  MCDONNELL