HVDC and the Need for a North American Macro Grid

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Overview

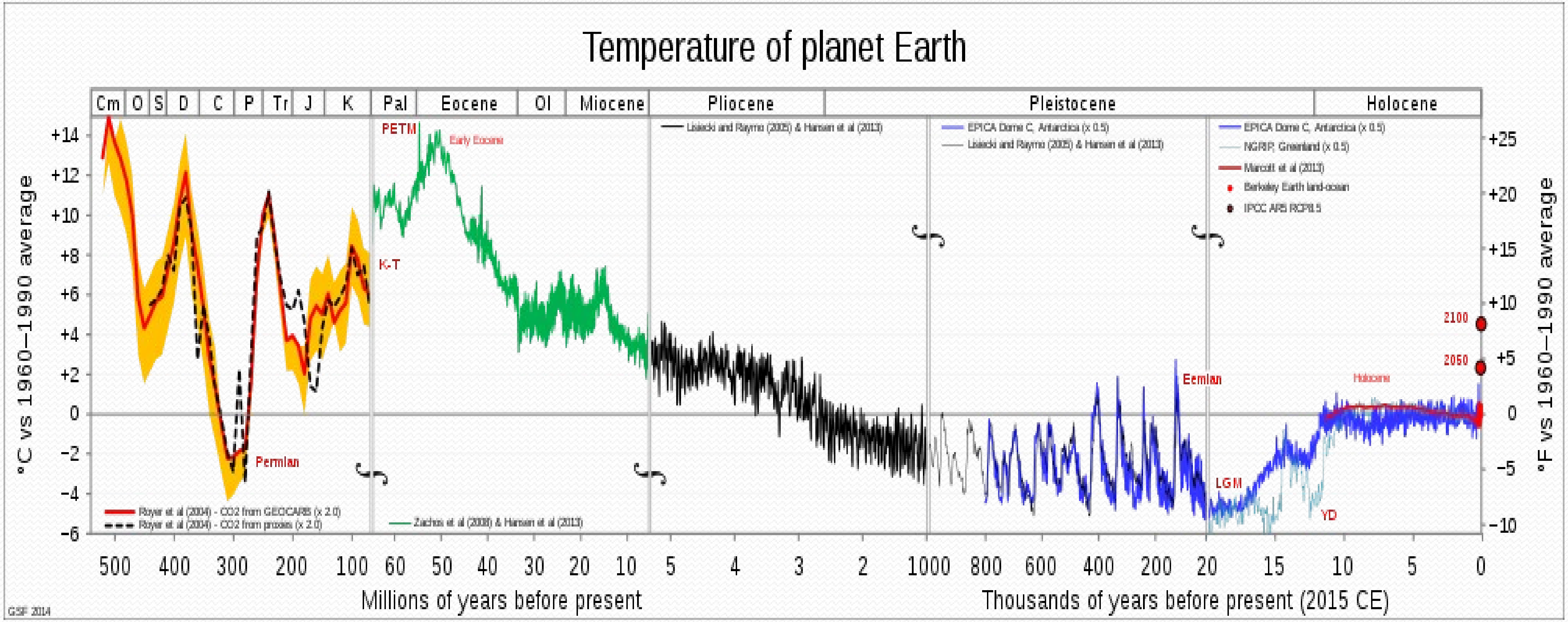
- Global warming. How serious is this?
- What are we doing about it?
- Our power system.
- How extreme events affect our system planning.
- The need for interregional links and a North American Macro Grid.
- Why HVDC?
- Need for grid resiliency.
- The shift to buried transmission.
- Closing remarks.

Global Warming and the Need for Decarbonization

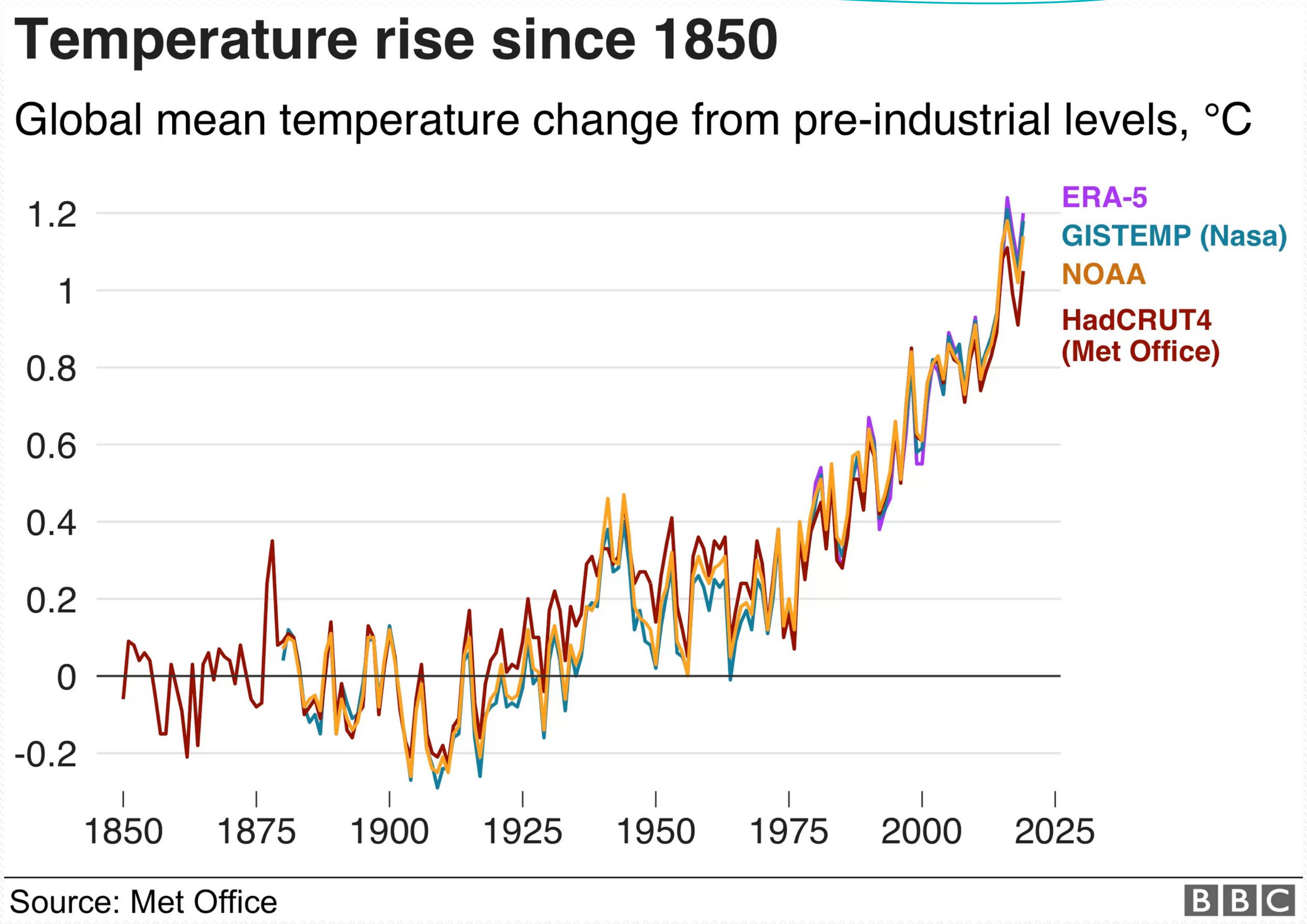
Situation Assessment

- Man-made green-house gas emissions are causing a global temperature increase with resulting consequences of extreme weather events.

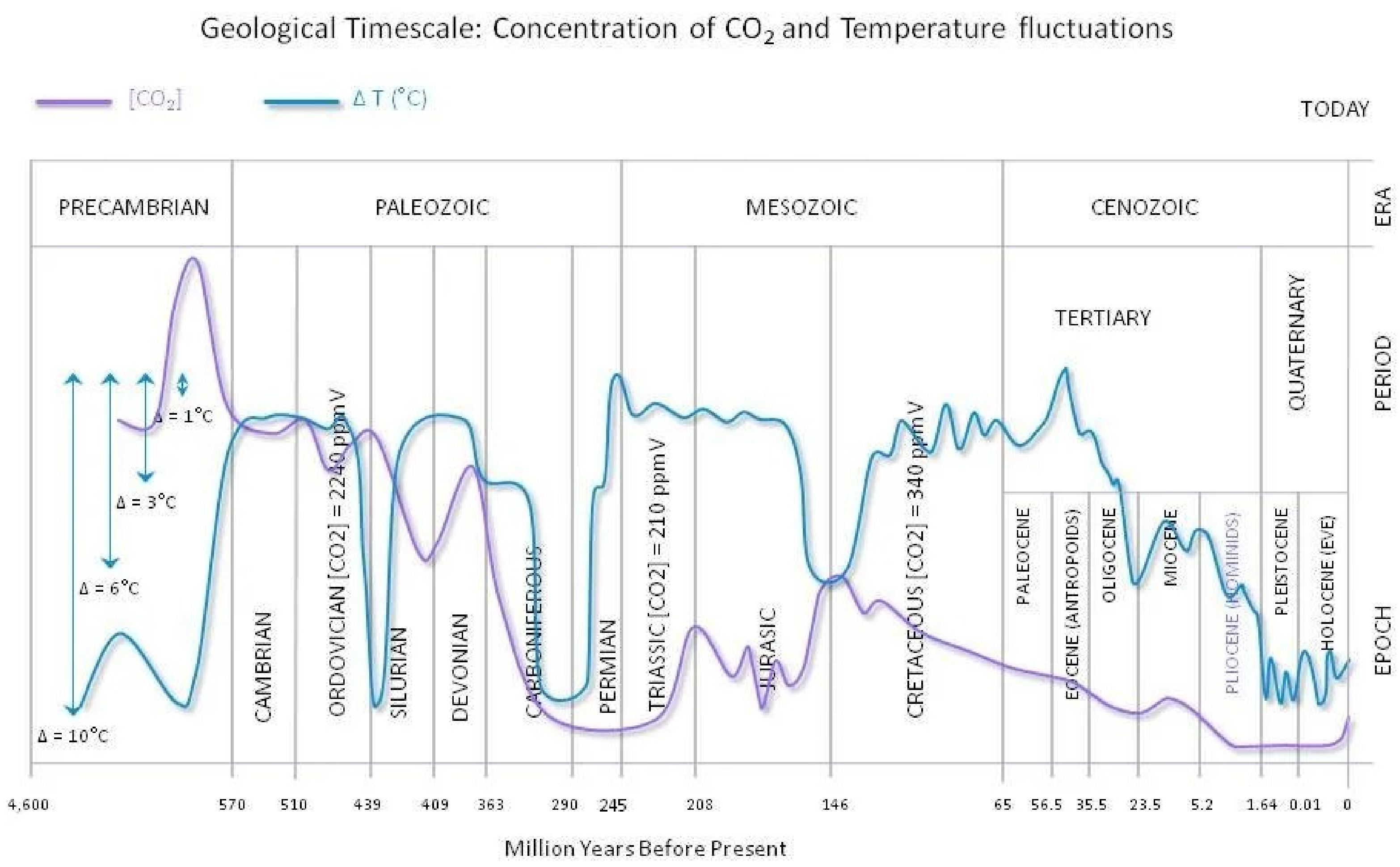
- We have long known that the world has warmed by more than 1 degree Celsius since 1900; however, the pace of warming has accelerated in recent decades.



Temperature of planet Earth
Cm
O
S
D
C
P
Tr
J
K
Pal
Eocene
Ol
Miocene
Pliocene
Pleistocene
Holocene
PETM
Early Eocene
K-T
Permian
Eemian
LGM
YD
Holocene
2100
2050
Royer et al (2004) - CO2 from GEOCARB (x 2.0)
Royer et al (2004) - CO2 from proxies (x 2.0)
Zachos et al (2008) & Hansen et al (2013)
Lisiecki and Raymo (2005) & Hansen et al (2013)
EPICA Dome C, Antarctica (x 0.5)
Lisiecki and Raymo (2005) & Hansen et al (2013)
EPICA Dome C, Antarctica (x 0.5)
NGRIP, Greenland (x 0.5)
Marcott et al (2013)
Berkeley Earth land-ocean
IPCC AR5 RCP8.5
°C vs 1960–1990 average
°F vs 1960–1990 average
+14
+12
+10
+8
+6
+4
+2
0
−2
−4
−6
+25
+20
+15
+10
+5
0
−5
−10
500
400
300
200
100
60
50
40
30
20
10
5
4
3
2
1000
800
600
400
200
20
15
10
5
0
Millions of years before present
Thousands of years before present (2015 CE)
GSF 2014



Temperature rise since 1850
Global mean temperature change from pre-industrial levels, °C
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
1850
1875
1900
1925
1950
1975
2000
2025
ERA-5
GISTEMP (Nasa)
NOAA
HadCRUT4
(Met Office)
Source: Met Office
BBC



1- *Analysis of the Temperature Oscillations in Geological Eras* by Dr. C. R. Scotese © *2002*. 2- Ruddiman, W. F. 2001. *Earth's Climate: past and future*. W. H. Freeman & Sons. New York, NY. 3- Mark Pagani *et all*. *Marked Decline in Atmospheric Carbon Dioxide Concentrations During the Paleocene*. Science; Vol. 309, No. 5734; pp. 600-603. 22 July 2005. *Conclusion and Interpretation* by Nasif Nahle ©2005, 2007. *Corrected on 07 July 2008 (CO2: Ordovician Period).*


AND YOU ARE...?
MISINFORMATION
WAR
FAMINE
PESTILENCE
DEATH

Paris Agreement
United Nations Framework Convention on Climate Change

Agreements:

- Substantially reduce global greenhouse gas emissions to limit the global temperature increase in this century to two degrees Celsius above pre-industrial levels, while pursuing efforts to limit the increase even further to 1.5 degrees;
- Review countries' commitments every five years;
- Provide financing to developing countries to mitigate climate change, strengthen resilience and enhance abilities to adapt to climate impacts.

Commitments:

- The United States and Canada have both committed to moving to net-zero emissions by 2050.
- Committed to bring their Power grids to net-zero emissions by 2035.

How are we doing so far?

U.S. Carbon Emissions Grew in 2022: Emissions ticked up 1.3 percent last year, even as renewables surpassed coal.

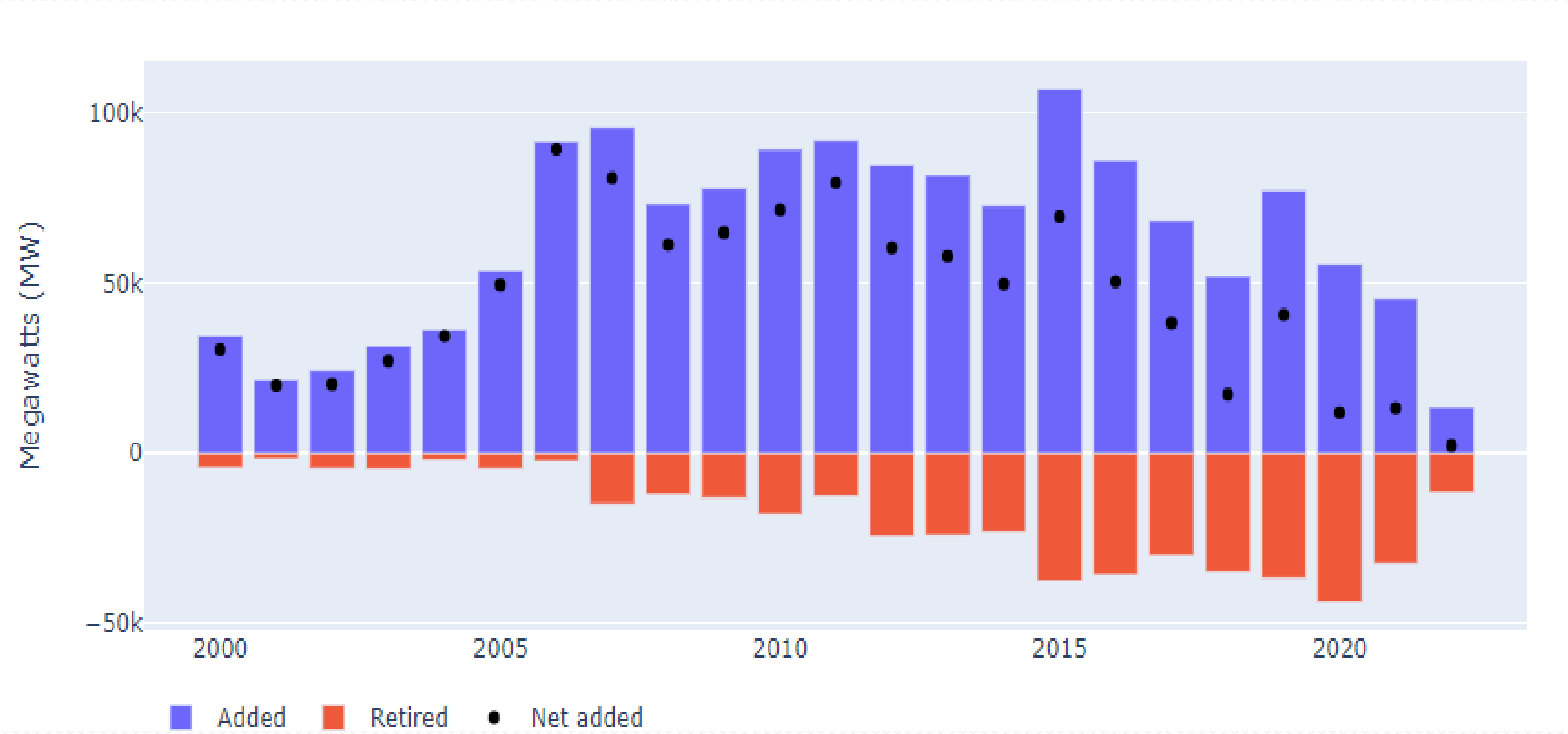
We have not been able to reduce global coal power operating capacity, a main driver of green house gas emissions (see next slide).

Electricity's share of final global energy consumption will only be about 30% compared to 50% which would be required for the Net Zero emissions by 2050.

The inability to add new capacity to the grid in a timely and predictable manner imperils reliability and net-zero decarbonization goals. (ClearPath's Dec. 9th ACORE presentation "All Queued up and Nowhere to Go").

We have to make the power grid more efficient!

Global Coal Power Capacity Added or Retired



Source: Global Energy Monitor

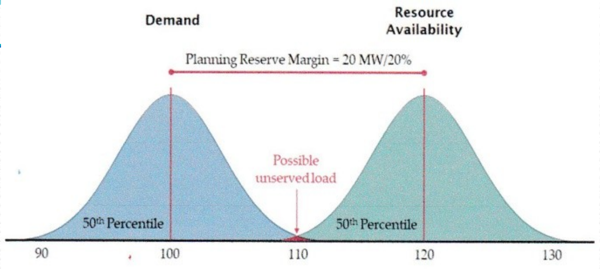


Figure 9: Example Demand and Resource Curves with 20% PRM

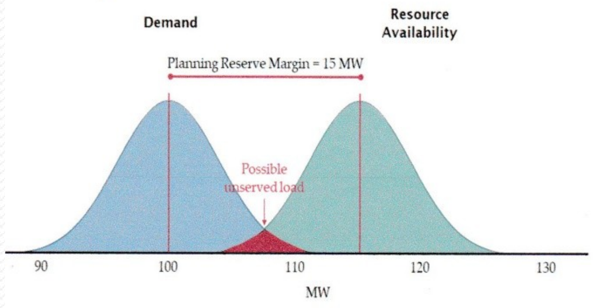


Figure 10: Example Demand and Resource Curves with 15% PRM

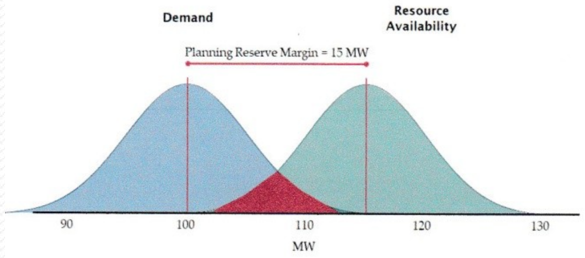


Figure 11: Expanded Demand and Resource Curves with Large Overlap

System Planning is Changing

1. **Deterministic system**: Peak demand is forecasted for some future date. Required dependable generation resources are established with a suitable reserve margin. Traditionally, a 20% reserve margin would be expected to still produce a shortfall of resource capacity <u>one day every ten years</u>.

2. Probabilistic system: Demand and available resources are depicted as probability curves which have been defined historically at times when variable energy resources (wind/solar) were small compared to traditional resources (coal, hydro, nuclear). Possible unserved load is determined by the area where the two curves intersect. (Source: WECC WARA report).

2. With time the shape of the demand curve is being influenced by the increasing amount of extreme weather events. The variability is shown by a widening of the curve.
3. Similarly, the shape of the resource curve is being influenced by the increasing amount of variable energy resources (VER) widening the resource curve. This means that for the same resource margin we now have greater possible unserved load.
4. Consequently, system planners should use a larger reserve margin and/or ensure that long-distance transmission links will exist to connect to regions where the weather effect or the reduction in VER are not happening at the same time.

The European Network of Transmission System Operators (ENTSO-E)

The EU and European countries today have a clear common objective for a fully carbon-neutral economy, by 2050 at the latest. This Vision is structured around four main ‘building blocks’, that are the key components necessary to build a power system fit for a carbon neutral Europe:

- Energy System Flexibility – facilitating the development of adequate flexibility resources to handle the increased complexity of the system and to balance what will become a weather-dependent system;
- Operation of future grids – preparing and organising the operation of a carbon-neutral energy system that will be very different from today;
- Energy infrastructure and investments – accelerating the development and financing of the future system;
- Market Design – identifying principles and possible solutions for a new market design fit for a carbon neutral economy.

Source: ENTSO-E “A Power System for a Carbon Neutral Europe” (October ’22)

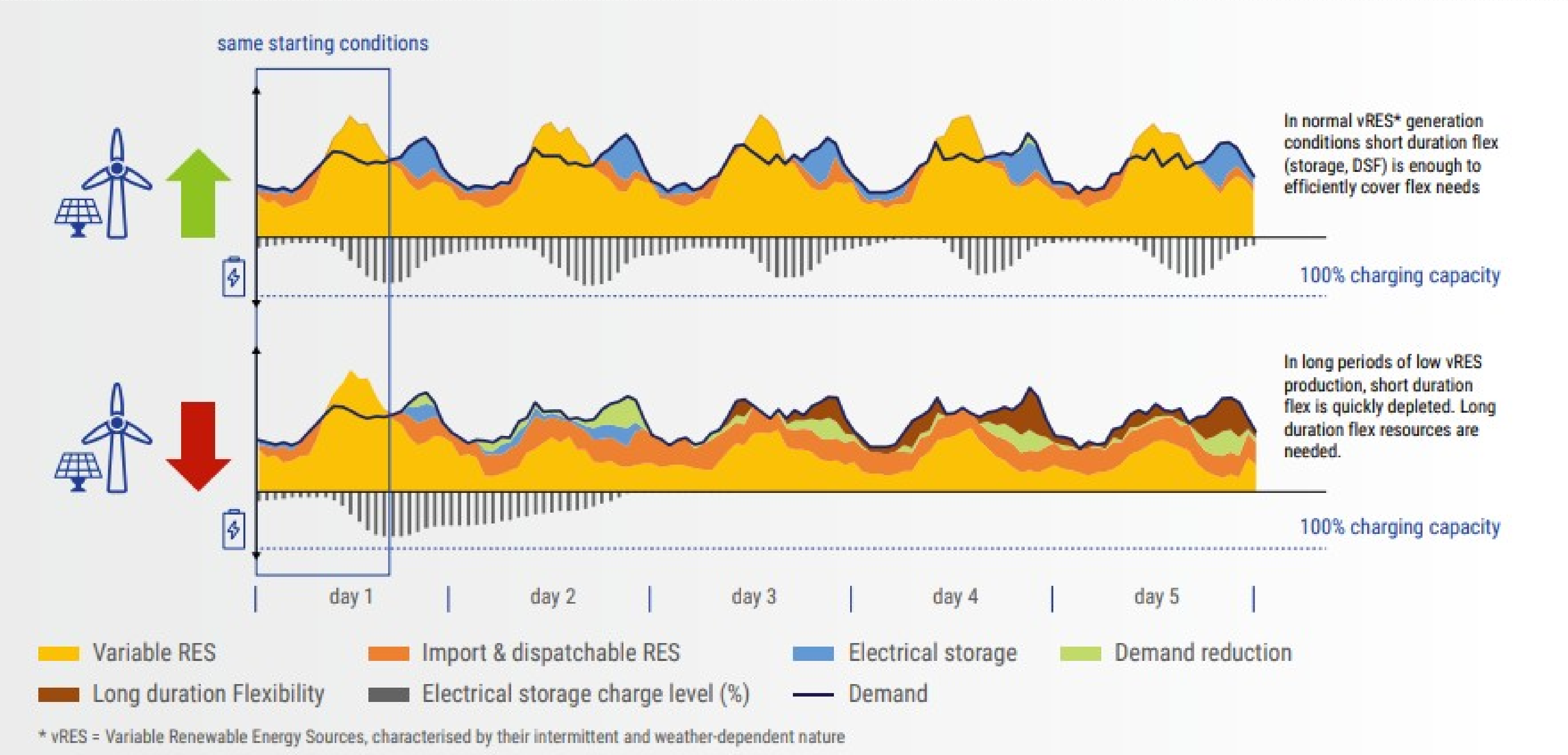
The Need for Flexibility

- A fully carbon neutral power system will become highly weather dependant
- To manage the resulting complexity a significant amount of flexibility will be required
- This will include flexible generation, active demand, storage, sector integration (natural gas/hydrogen) and flexible interregional grid use
- From a system point of view, flexibility needs can be structured under two main types, each requiring different flexibility resources:

› short duration flexibilities (from milliseconds up to a few hours, to balance the system within the day and ensure system stability),

› long duration flexibilities (up to several weeks, to compensate for long periods with shortage of wind, solar and hydro generation).

Use of Short-duration and Long-duration Resources in Different Grid Conditions



The Benefits of Interregional HVDC Transmission

U.S. Federal-State Task Force on Electric Transmission:

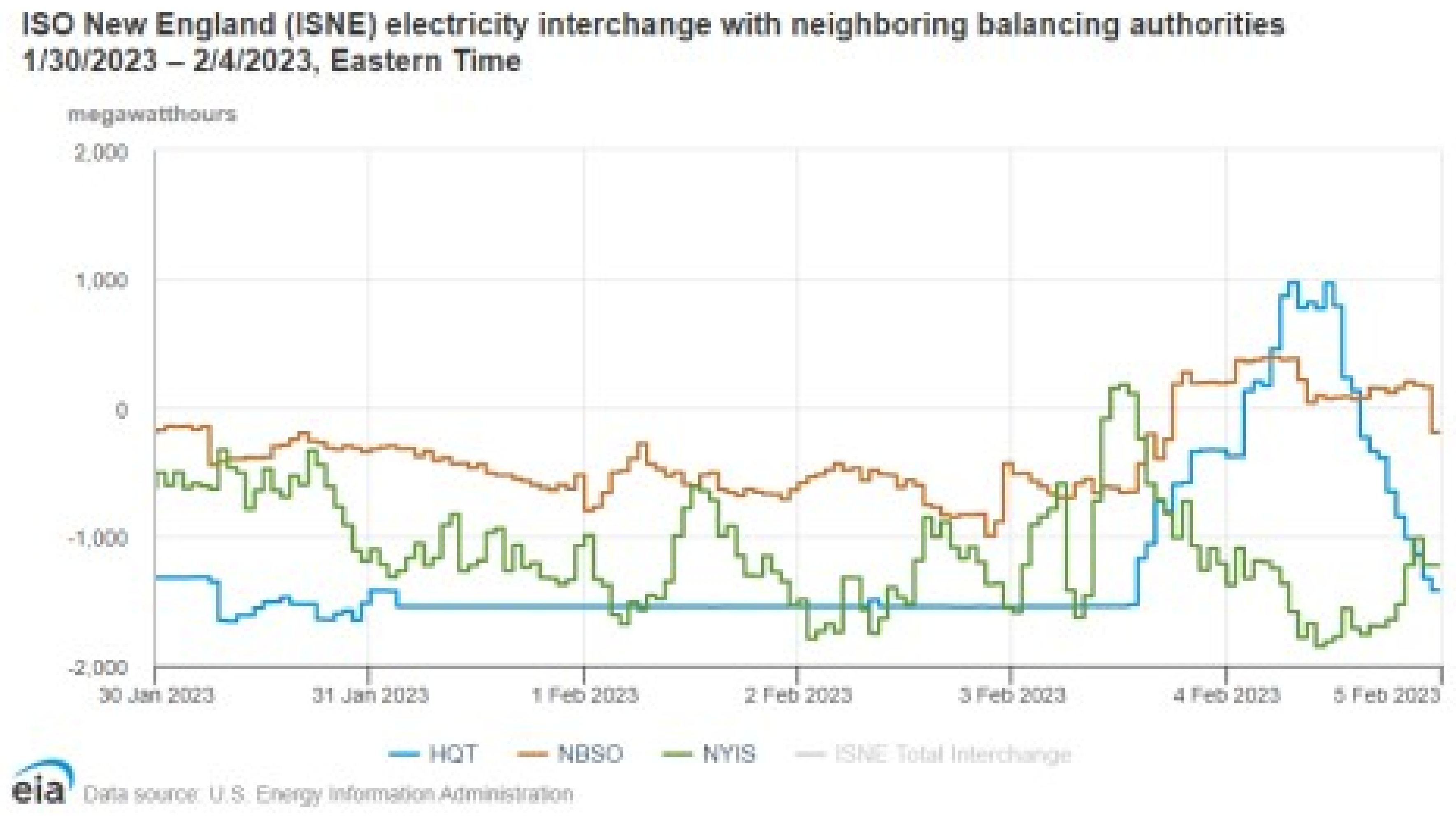
- Expanding import and export capabilities among the regions will produce **immense** economic reliability and public policy benefits

- The ability to access low-cost renewable generation by means of long-distance, high-capacity transmission will provide substantial benefits (lower rates). An MIT study found that the economic benefit of more interregional transmission is even greater than storage.

- Need for reliability and resiliency

- Will allow peak demand fuel-based capacity to be replaced by lower cost renewable energy

Example of Inter-regional Benefits



The Case for a North American Macro Grid

- U.S. seeks a more reliable national power grid – FERC leading discussions
- U.S targeting a ‘pollution-free’ power grid by 2035
- Variable energy resources (VERs) to predominate in new Regional Transmission Operators (RTOs) and Independent System Operators(ISOs) capacity additions.
- Over 35 electric transmission interconnections exist between the Canadian and US power systems. Ad hoc integration will continue expanding.
- Ample hydro and hydrogen resources North in Canada and solar South in the U.S., point to a North American Macro Grid with advantages over independent national grids in Canada & U.S. The advantages of hydro generating sites (flexibility, reliability, energy storage, longevity) are not sufficiently recognized in cross regional planning studies.

Why HVDC?

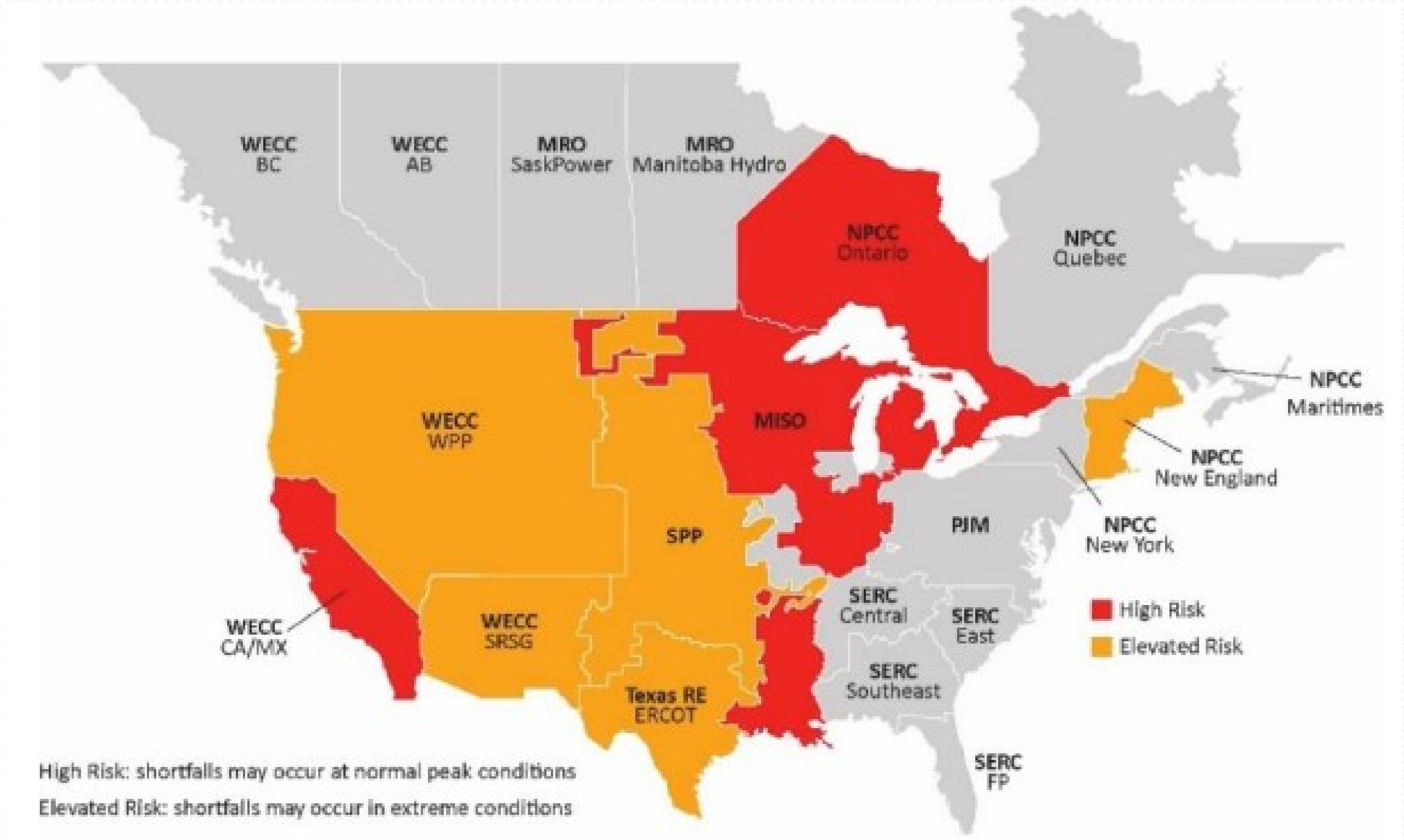
- An HVDC line costs less than an HVAC line (2 poles versus 3 phases)
- However the convertor station is more expensive than the corresponding ac substation
- With longer lines HVDC will become less expensive than AC, at around 500/600 miles. But that is not taking into account HVDC's lower line losses and the additional cost savings.
- Lower losses
  - Resistive losses (skin effect)
  - Lower corona losses
  - No reactive losses
  - No radiation losses (low noise interference)
- On long lines no need for intermediate reactive compensation stations as required for AC

Why HVDC?

But besides economics there are many other reasons to favor HVDC:

- HVDC allows asynchronous connections between regions preventing blackouts spreading from one region to the next (ex. North-East blackout from 2003)
- The HVDC's convertor station's solid-state electronics offers full control over the power flow in the link allowing it to dampen grid power swings and thus help with grid stability. In addition to active power, the systems can also independently control reactive power. This allows them to respond flexibly to fluctuations in generation and consumption in the grid.
- Narrower right-of-way, smaller towers (environmental acceptance)
- HVDC line can be designed to offer earth/sea return (electrodes)
- HVDC transmission lines can be buried (underground or in the sea)

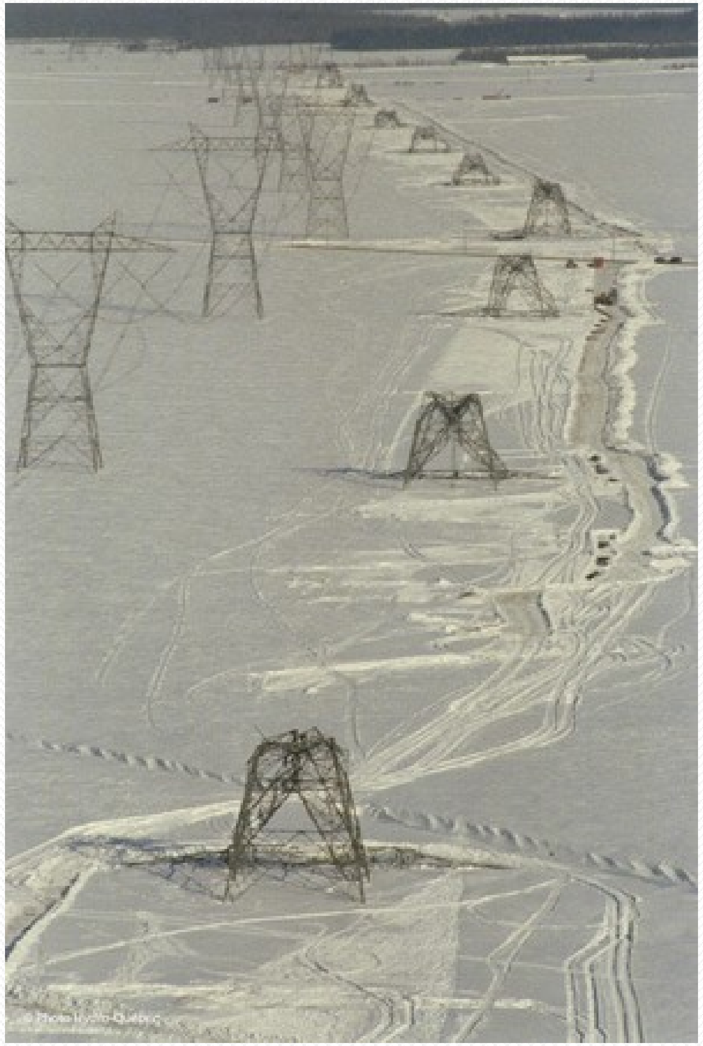
NERC – Long Term Reliability Assessment – December 2022



The Need for Reliability of Interregional Links

- Interregional links will be high capacity (several GW)
- Security of supply will be significantly improved by such interregional links.
- But the risk of a simultaneous regional and interregional breakdown should be avoided at all costs (ice storms, wildfires, hurricanes, floods, physical attacks)
- Reliability and resiliency of these links is thus of paramount importance.
- Following Winter Storm Elliott FERC and NERC launched a joint investigation. They found that there is a need for the electric sector to change their planning scenarios and preparations for **extreme weather events**.
- Past events are not a good indication for the future. Reliability planning should be scenario based not probabilistic based. What is the most worrisome scenario?
- The economic and social cost of electricity system interruptions can be extremely high!

Ice Storms



Loss of a 1,700 MVA capacity 735 kV line during the Great Ice Storm of 1998. Conductor coated with 110 mm (4.3 in) of ice, well above the line's design load. Since then Hydro Quebec has increased max. ice loads on conductors and installed dead-end anti-cascade towers every 10 towers (decreasing the cost differential with buried lines).

With global temperature rising, such extremes can be expected to reoccur and even to be exceeded.

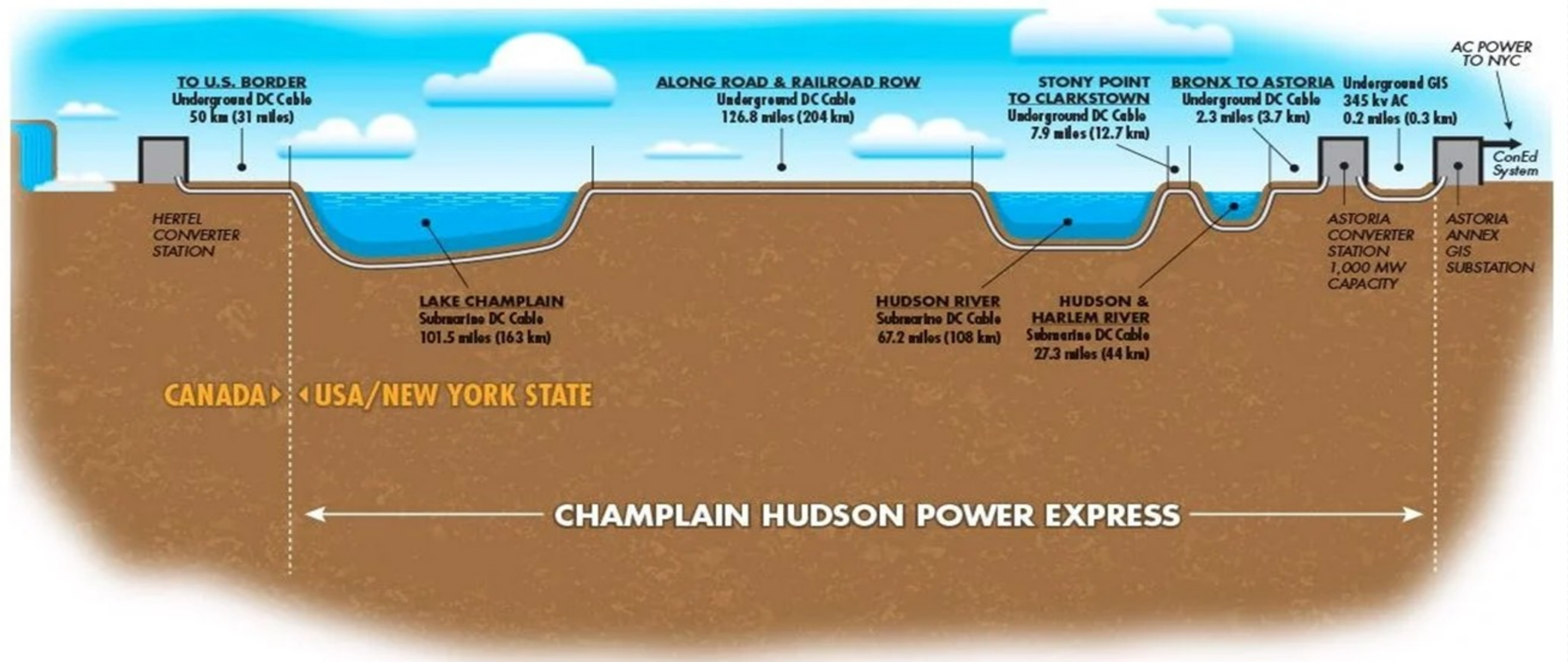
Wildfires

- What can one say about these recurring wildfires in California, seemingly getting worse by the year.
- The cost of power interruptions to customers, to the economy and to society at large are huge.
- Some California utilities have already announced plans to bury thousands of miles of overhead lines.
- To support interregional high-capacity links in their goal to increase grid reliability, and to guard them against wildfire peril, burying should be considered.
- The increase in cost should be small comparatively speaking.

The Shift to Buried HVDC Transmission

Advantages of burying HVDC transmission:

- Simpler siting, routing and permitting resulting in years study time saved
- Lower cost right of way acquisition
- Less 'visual pollution', effect on property values, less concern on potential health impacts
- More resilient transmission (ice storms, wildfires, hurricanes, extreme temperature sags, electro-magnetic pulses)



Burying HVDC is the future of interregional connections, This is truly a paradigm shift!

Improve Global Transmission

- Increase electricity from 20% today to 50% of global energy mix by 2050. This will require a much-improved global grid planning in contrast with today's regional (silo) planning.
- Improve electricity transmission between low-cost renewable energy locations (sources) and high demand areas (sinks) nation-wide
- Identifying and updating DOE's National Interest Electric Transmission Corridors (NIETCs) through national transmission studies
- Interregional power transmission links provide solutions (Being championed by both the U.S. "FERC" and Europe "ENTSO-E")

The German Example

The need is to link wind resources in the North with solar resources in the South:
Solution: provide 8,000 MW of linking capacity

Suedlink:
500 miles of 525 kV cables, 2000 MW (NKT)
360 miles of 525 kV cables, 2000 MW (Prysmian)

SuedOstLink:
310 miles of 525 kV cables, 2000 MW (NKT)
340 miles of 525 kV cables, 2000 MW (Prysmian)

Nordlink connects Norway to Germany with a 320 miles 500 kV cables, 1400 MW

All future HVDC transmission in Germany will be buried.

Other Examples of Buried HVDC Links

- Piedmont-Savoie Italy to France +/-320kV, 120 mi., 2 circuits, 1200 MW. (in service)
- Norway to UK Sealink, +/-500kV, 450 mi., 1400 MW (in service)
- The Celtic Interconnection, Ireland to France, +/-320kV, 357 mi., 700 MW (under construction)
- The Quebec to NYC Champlain-Hudson Power Express, +/-400kV, 339 mi., 1250 MW (under construction)
- SOOGreen HVDC link (Iowa to Illinois), linking the MISO and PJM energy markets, +/-525kV, 350 mi., 2100 MW (under construction)

Use of Existing Right-of-Way

(Source: SOOGreen HVDC Link)

The SOO Green HVDC Link, under construction, will be installed within Canadian Pacific Railway's right-of-way.

This innovative partnership vests SOO Green with the necessary right-of-way for nearly all of its 350-mile route.

Saved years in permitting

No visual impairment

Room to expand (other side)

Buried versus Overhead Costs

- Buried lines are 10 times more expensive than overhead lines? True for ac distribution lines, but not for HVDC lines.

- German Suedlink **2020 costs** for a 500 kV, 2 GW buried line:
  - NKT was awarded a contract worth more than €1bn ($1.1bn) for the design, supply, and installation of high-tension underground cables for one of the 2GW lines of the SuedLink over a route length of 750km in June 2020. (2.36 M$/mi).
  - Prysmian Group won a contract worth more than €800m ($900m) to design, supply, and install the other 2GW line of the SuedLink over a route length of 700km. (2.07 M$/mi).

- MISO Line Estimation Cost Guide (2021) gives the cost for a 500 kV HVDC overhead line as between 2.2 and 3 M$/mi.

- SOOGreen project estimated cost 2.5 B$ less 2 convertor stations 2x400M$ (MISO Guide) leaves 1.7B$ for the cost of the line or 4.85 M$/mi or about double the cost of the overhead line.

- Need for a robust cost/benefits analysis in selecting buried vs. overhead

Closing Remarks

- We are on a highway to climate hell with our foot on the accelerator (per Antonio Gutierrez, U.N. Secretary General, COP 27 Conference)

- Electric power generation conversion from fossil fuels to renewable energy will require interregional transmission links for grid reliability and resilience, and will minimize generation capacity additions, resulting in lower tariffs.

- A macro grid linking low-cost renewable generation **sources** to high demand load **sinks** could be studied and planned implementing DOE's National Interest Electric Transmission Corridors.

- These high-capacity HVDC interregional links need to be very reliable and resilient and should preferably be buried to avoid destruction by an extreme weather event or put out of service by terrorist or enemy action. Burying will also build social acceptance and faster implementation.

- Time is of the essence. 2035 is only 12 years away. Time saved in planning links, and the added reliability, may favor switching HVDC lines from overhead to buried links.