JUNE 23, 2025

The University of Texas at Austin
Webber Energy Group
LBJ School of Public Affairs | Cockrell School of Engineering

GLOBAL ENERGY TRENDS AND TRANSITIONS

ERCOT

DR. MICHAEL E. WEBBER
The University of Texas at Austin

Energy Is Changing

6 Demographic Trends
3 Technology Trends
1 Grand Challenge

Three Technology Trends

- Decarbonization: using less energy and mass, and generating less waste, for goods and services

- Digitalization: the rise of data and information for energy systems

- Decentralization: the movement from large energy systems far away to smaller systems nearby

One Grand Challenge

Increase energy access for the 1+ billion who need it

AND

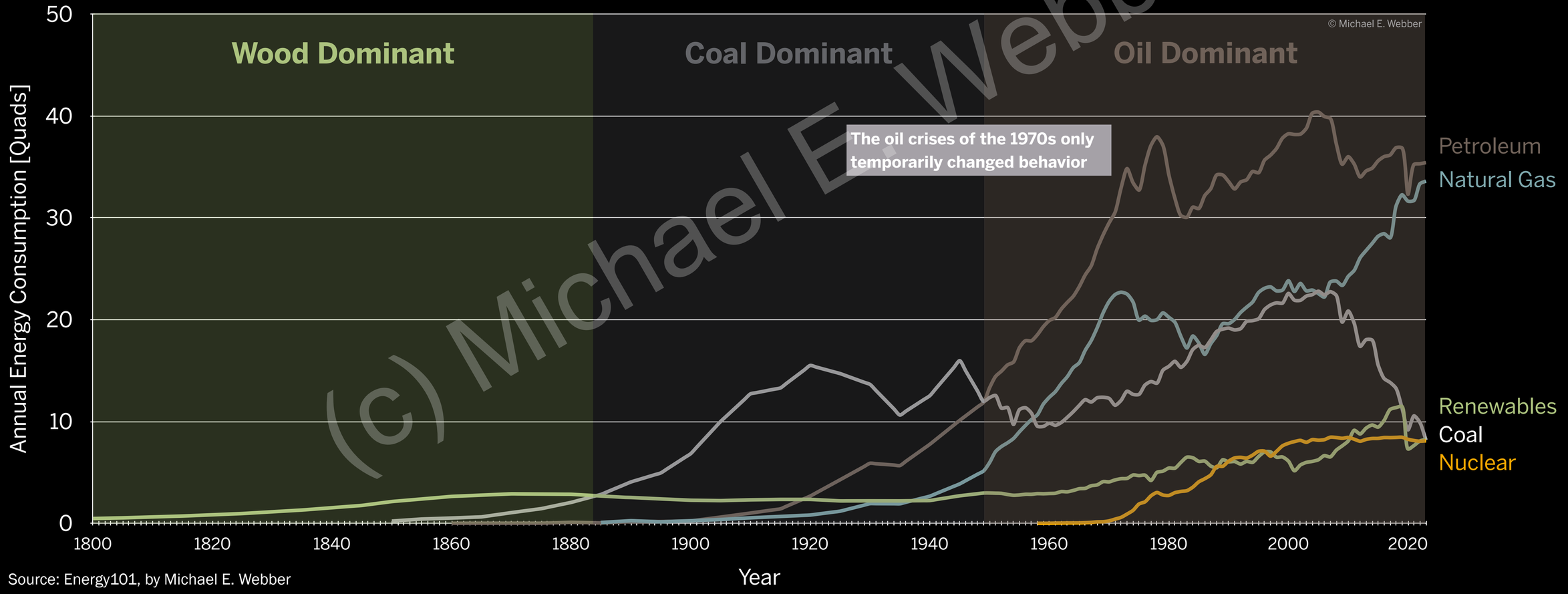
Decrease energy impacts for the 7+ billion who have it

Fuel Transitions Have Happened

The U.S. Fuel Mix Has Changed With Time

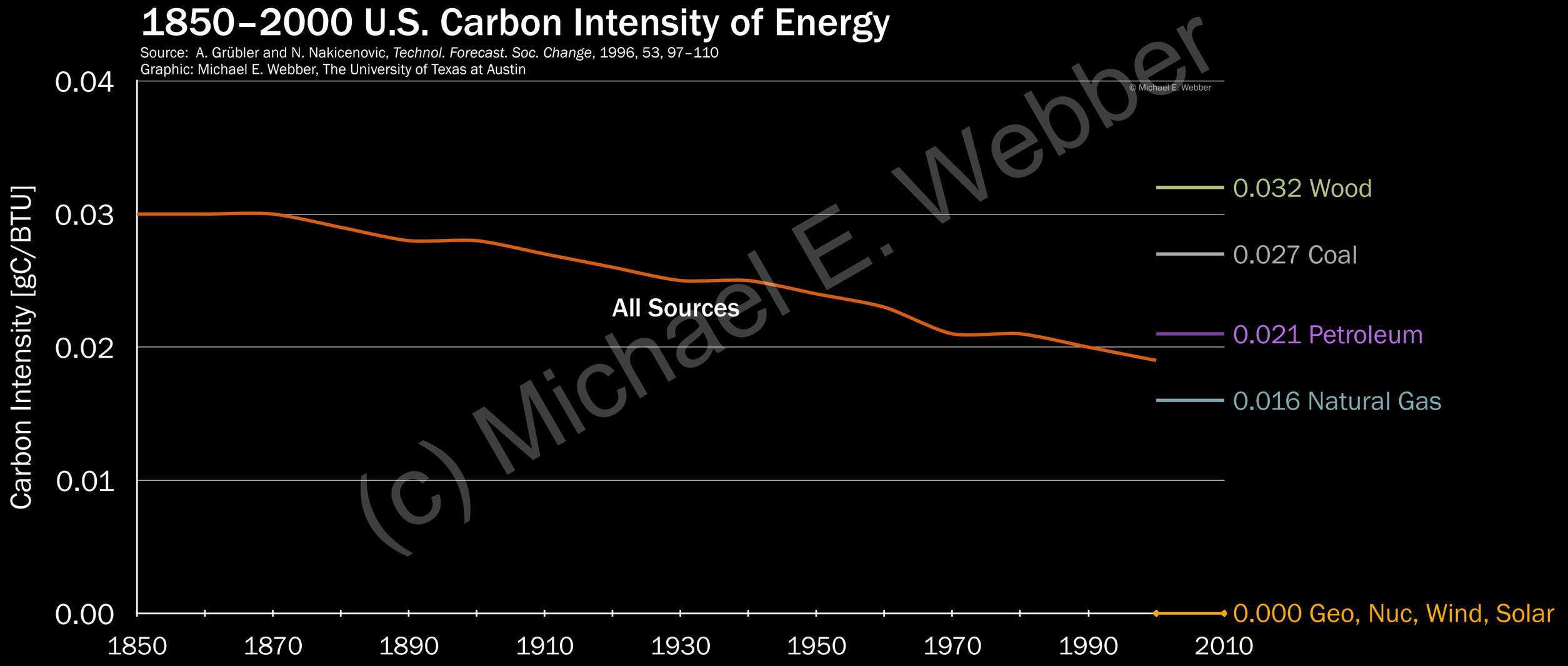
1800–2023 U.S. Energy Consumption by Source

Source: U.S. Energy Information Administration / *August 2024 Monthly Energy Review* (1.3)
Graphic: Michael Webber, The University of Texas at Austin

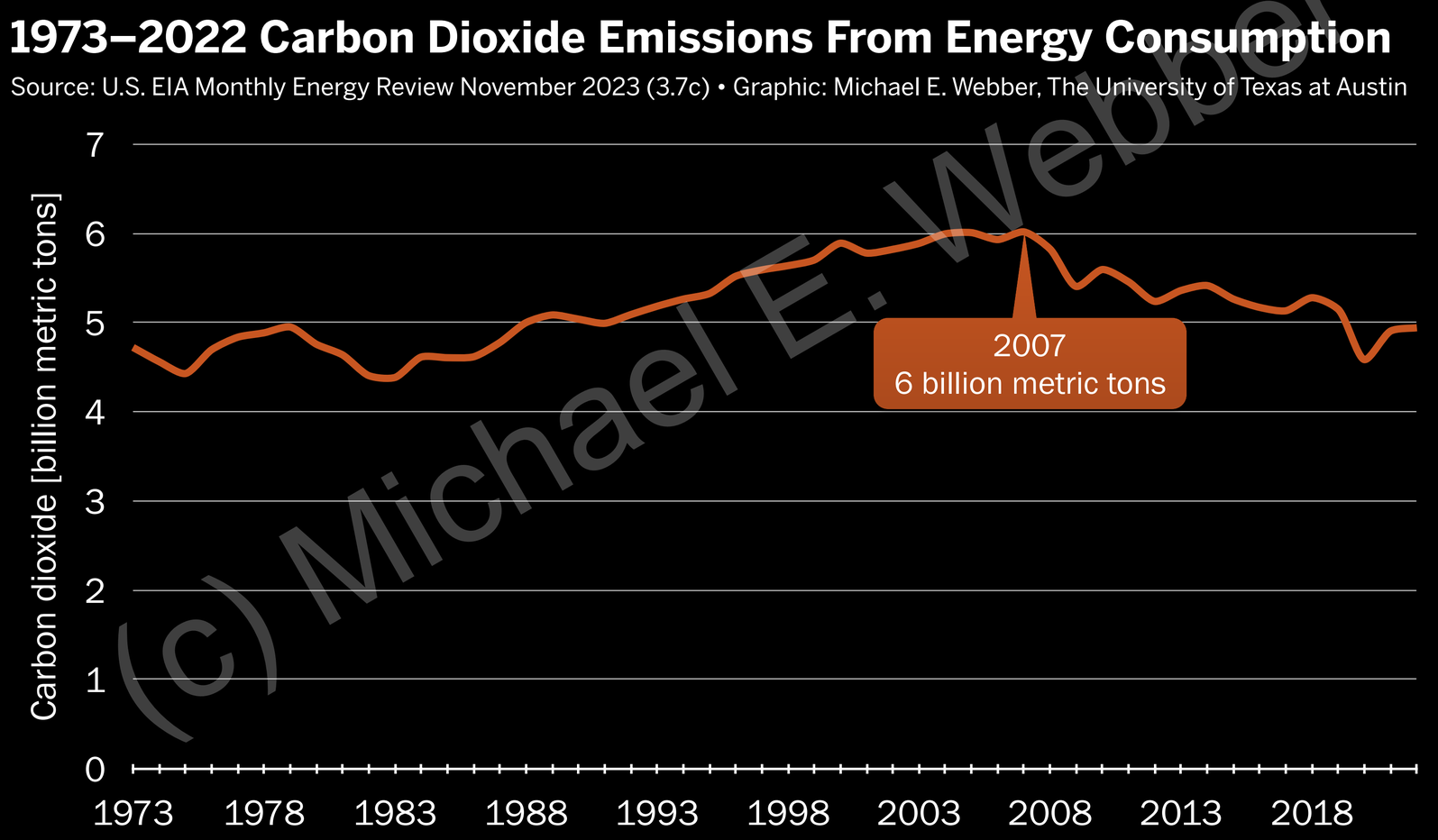


Source: Energy101, by Michael E. Webber

Energy Decarbonizes Over Time



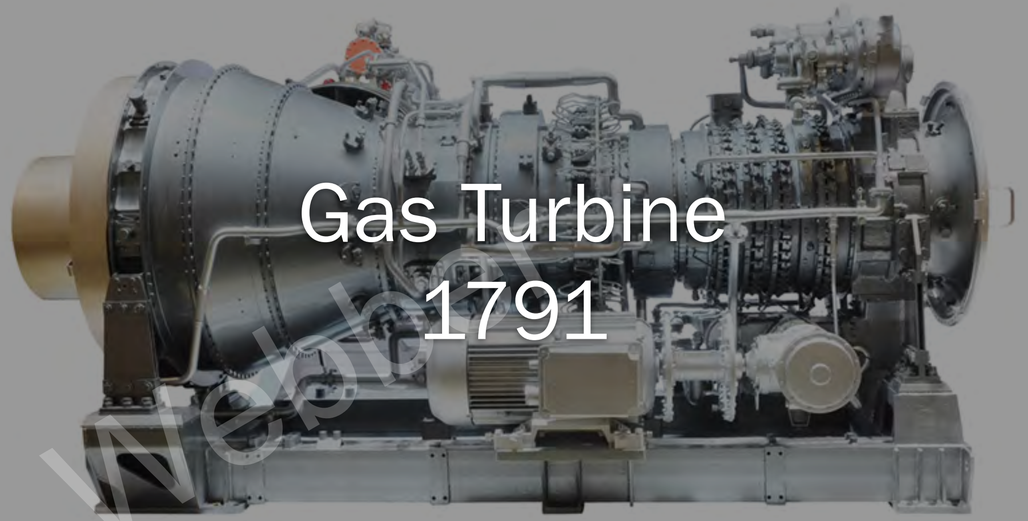
Economies Can Decarbonize Over Time



Energy Can Change Slowly

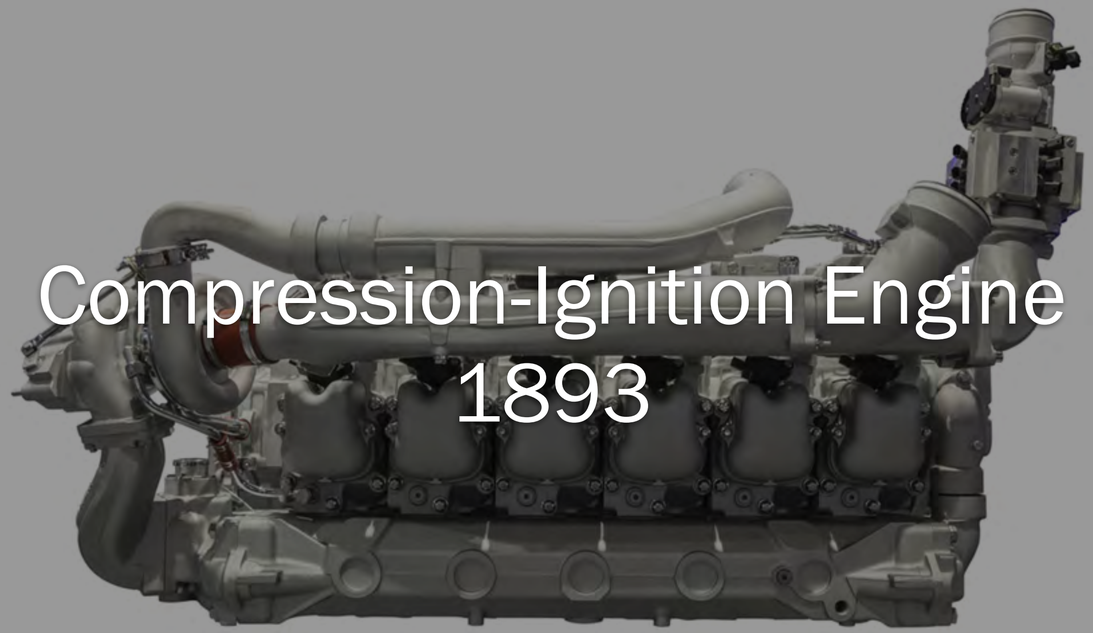
Four Technologies Are Responsible for >60% of U.S. Energy Conversion

Steam Turbine
1884



Gas Turbine
1791

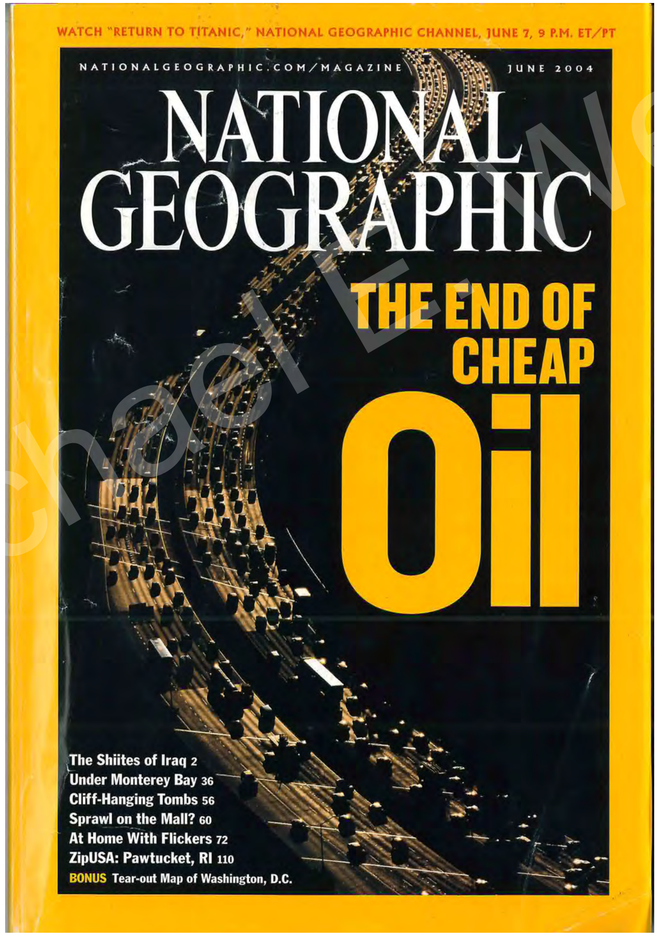
Spark-Ignition Engine
1876

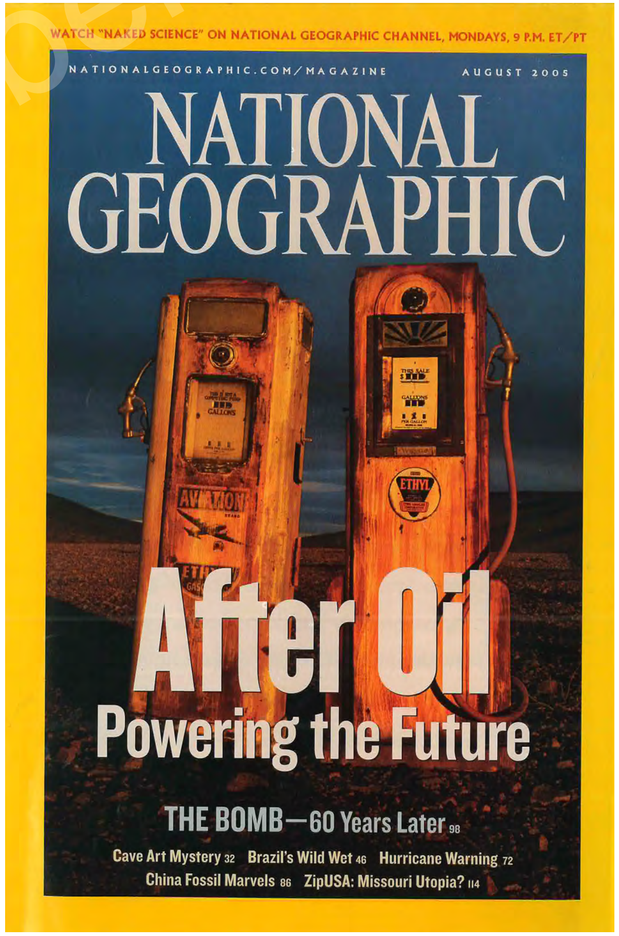


Compression-Ignition Engine
1893

Energy Can Change Quickly

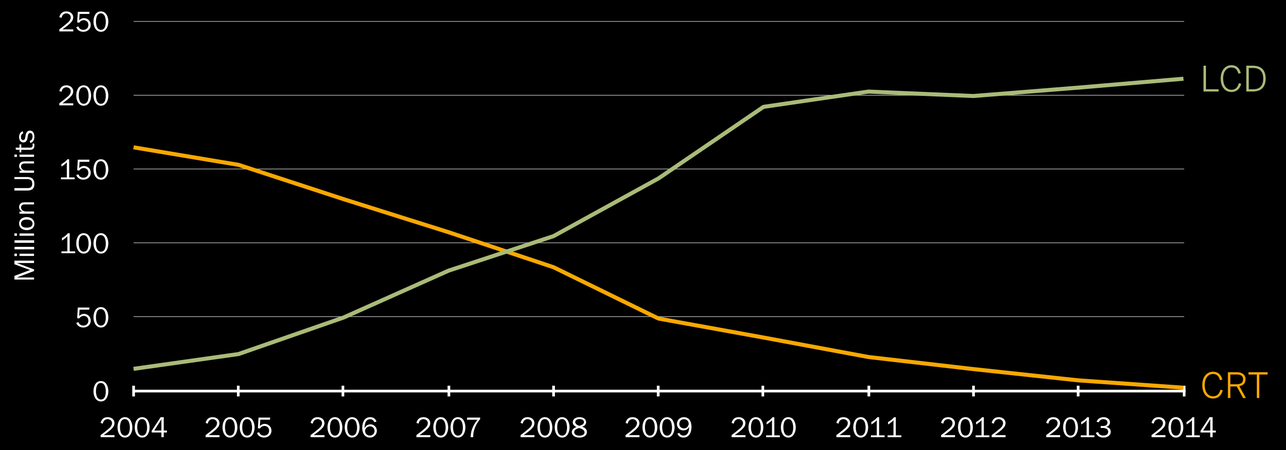
For the First Decade of the 21st Century, Headlines Declared the End of Oil





A few years later, the Headlines were Very Different

Technology Substitutions Can Be Swift



The Mismatch in Pace Is More Challenging Than People Expect

"Generally speaking, fuel substitutions for long-lived assets—steel mills, cement kilns, power plants—move more slowly than technology substitutions for short-lived assets."

—Michael E. Webber, *Mechanical Engineering*, Dec 2023

The rate of change for how we consume energy for transportation will change faster than the rate of change for how we consume energy to generate that electricity

ICE to EV: 2-3 decades

Coal to NG/RE: 3-5 decades

Prior Fuel & Technology Transitions Offer Some Important Lessons

- We move towards cleaner options
- We move towards higher-performing options
- We move towards cheaper options
- Yesterday's solutions might be tomorrow's problems
- There aren't that many new ideas
- Fuel transitions take a long time, so we better get started
- Technology transitions can be quick, so we better get ready

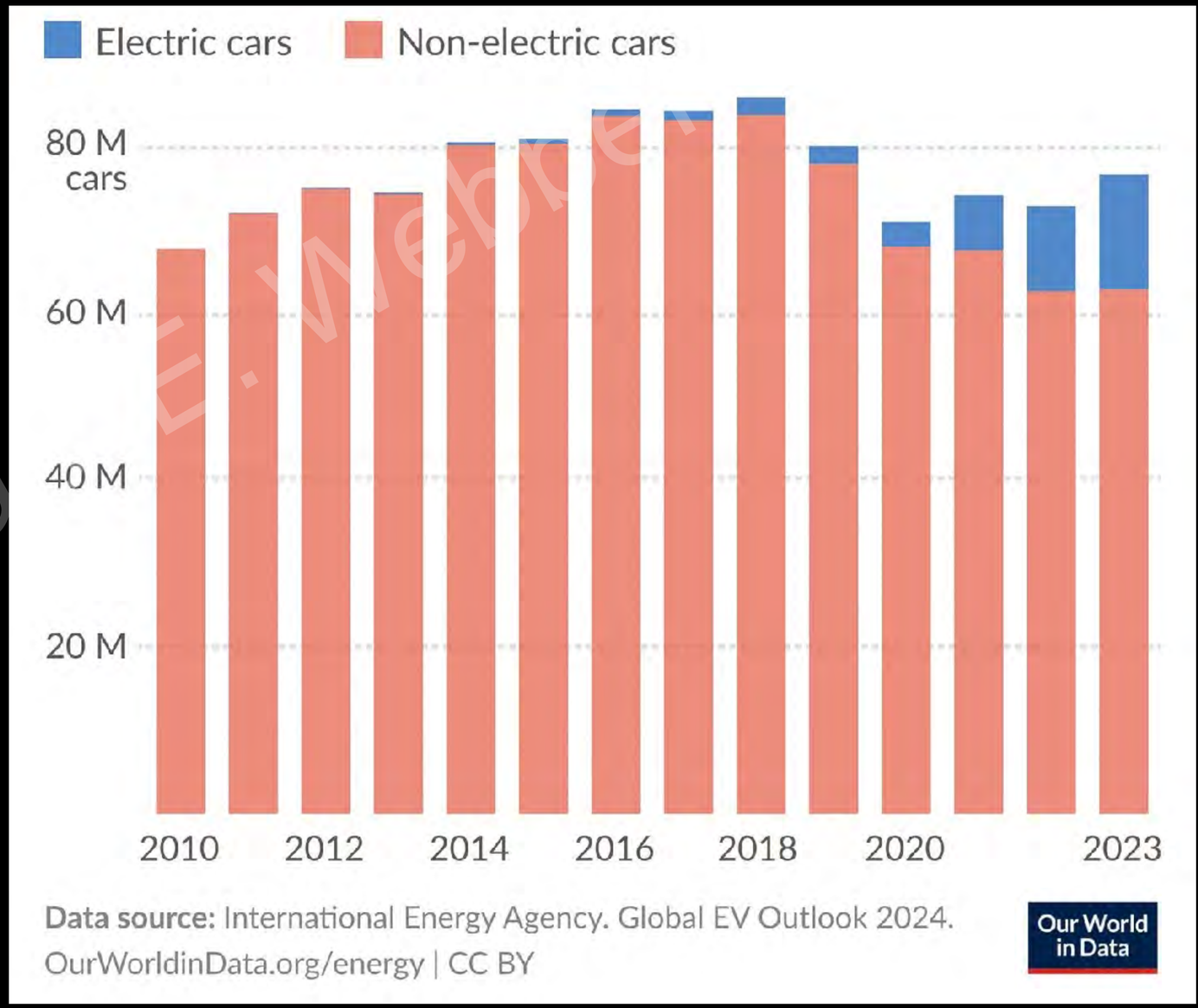
Energy is going through a global transition.

Expand Energy Access and Decarbonize While Operating In A Warmer World

We Are 5-15 Years Into a 30-40 Year Transition

Global Sales of Combustion Engine Cars Peaked in 2018

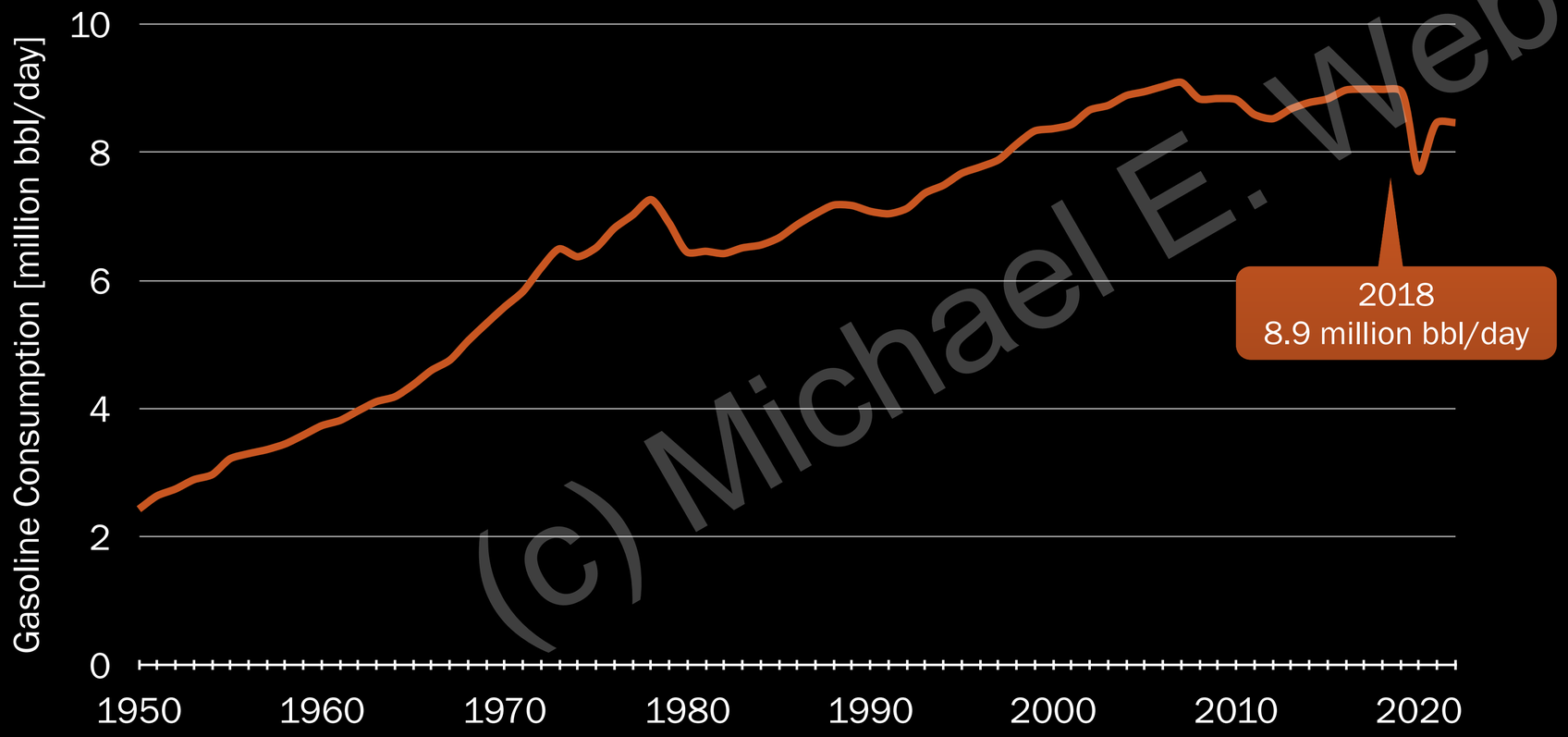
- Combustion engine cars are losing market share to electric vehicles
- That trend combined with…
  - –Work-from-home policies
  - –Virtual working tools
  - –Urban revitalization
  - –Micro e-mobility…
- …should lead to peak gasoline consumption



Peak Gasoline in the USA (2018) and China (2023)

1950–2022 Gasoline Consumed by the Transportation Sector

Source: U.S. EIA Monthly Energy Review November 2023 (3.7c) • Graphic: Michael E. Webber, The University of Texas at Austin



Newsletter | Hyperdrive

Bloomberg

China Reaches Peak Gasoline in Milestone for Electric Vehicles

Sinopec, the country's top oil refiner, brought its forecast forward by two years in a development that didn't get its due.

A Sinopec gas station in Shanghai. *Photographer: Raul Ariano/Bloomberg*

By Colin McKerracher

August 29, 2023 at 6:00 AM CDT

Chinese Diesel Consumption Might Drop Because of Electric Trucks

- Electric trucks have more competition than electric light-duty vehicles
- Alternative fuels:
  - Biodiesel
  - Hydrogen
  - Ammonia

China's Electric Truck Sales Are About To Take Off: CATL

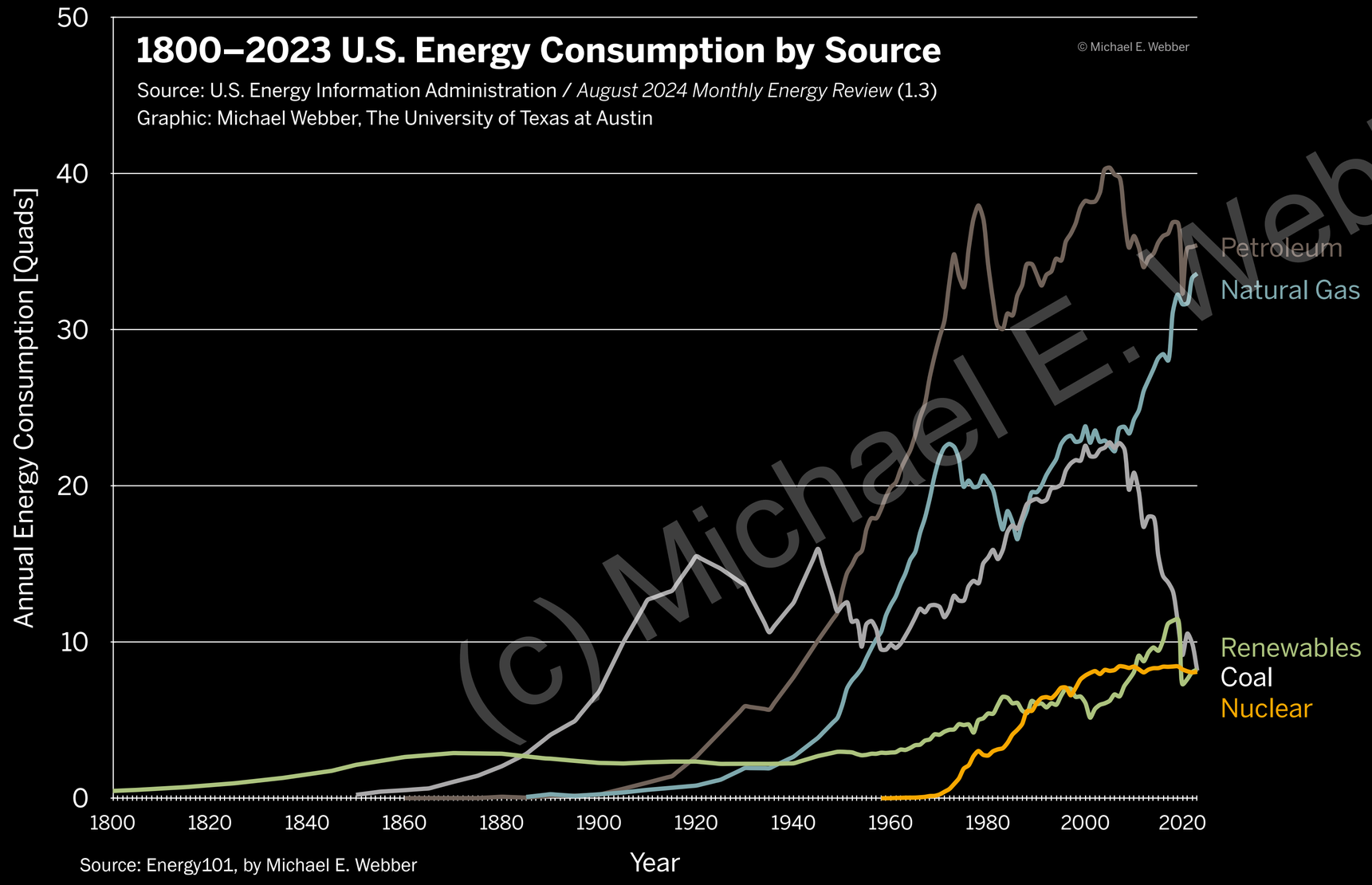
The battery giant says that up to 50% of all semi trucks sold in China will be electric in three years' time.

Andrei Nedelea, May 20, 2025

Photo by: CATL

https://insideevs.com/news/760077/catl-surge-electric-trucks-china/

Peak Coal in the USA (2006) and China (2025)



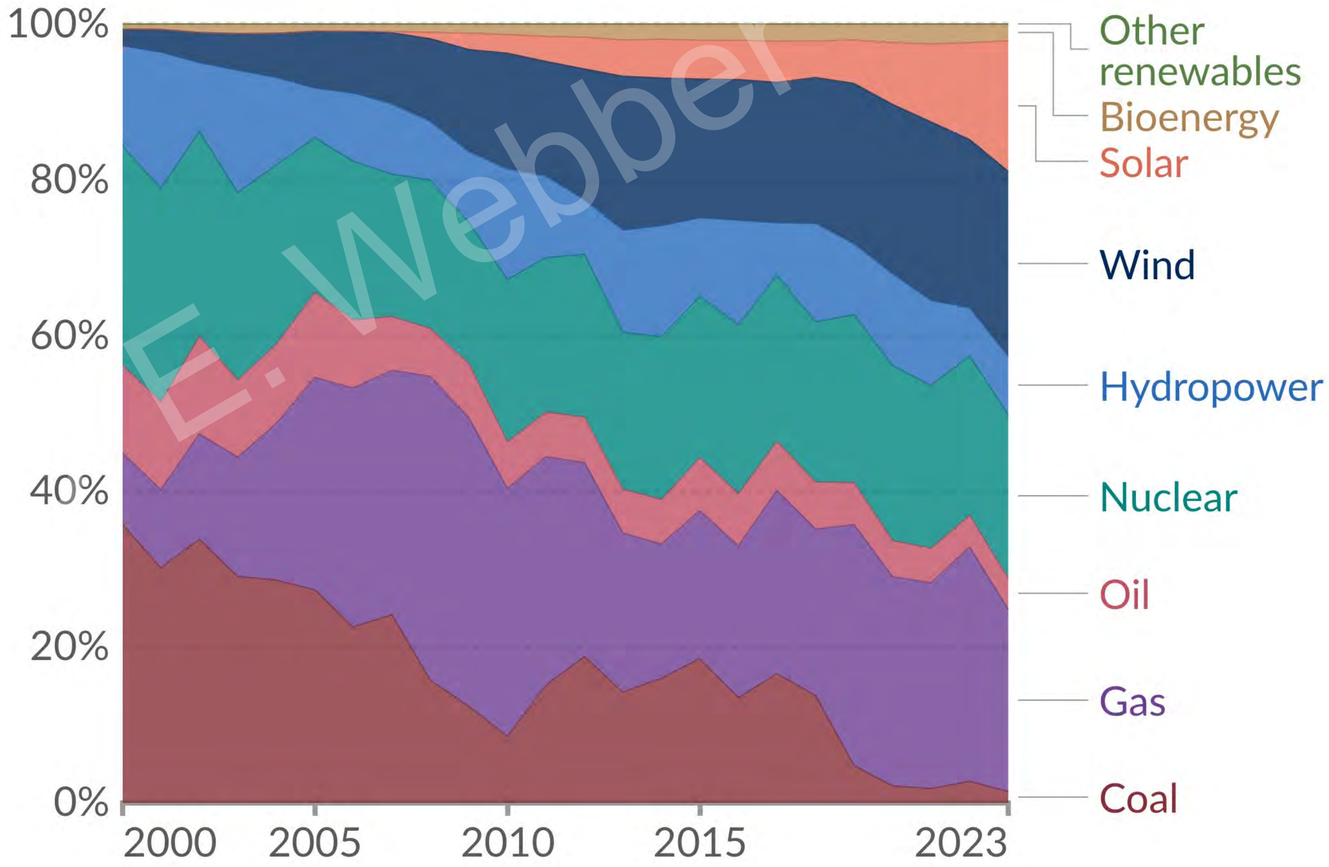
Spain's Coal Use for Power Dropped

2000: 36%
2023: 2%

Electricity production by source, Spain

Measured in terawatt-hours.

Our World in Data



Data source: Ember (2024); Energy Institute - Statistical Review of World Energy (2024)

Note: "Other renewables" include waste, geothermal, wave, and tidal.

OurWorldinData.org/energy | CC BY

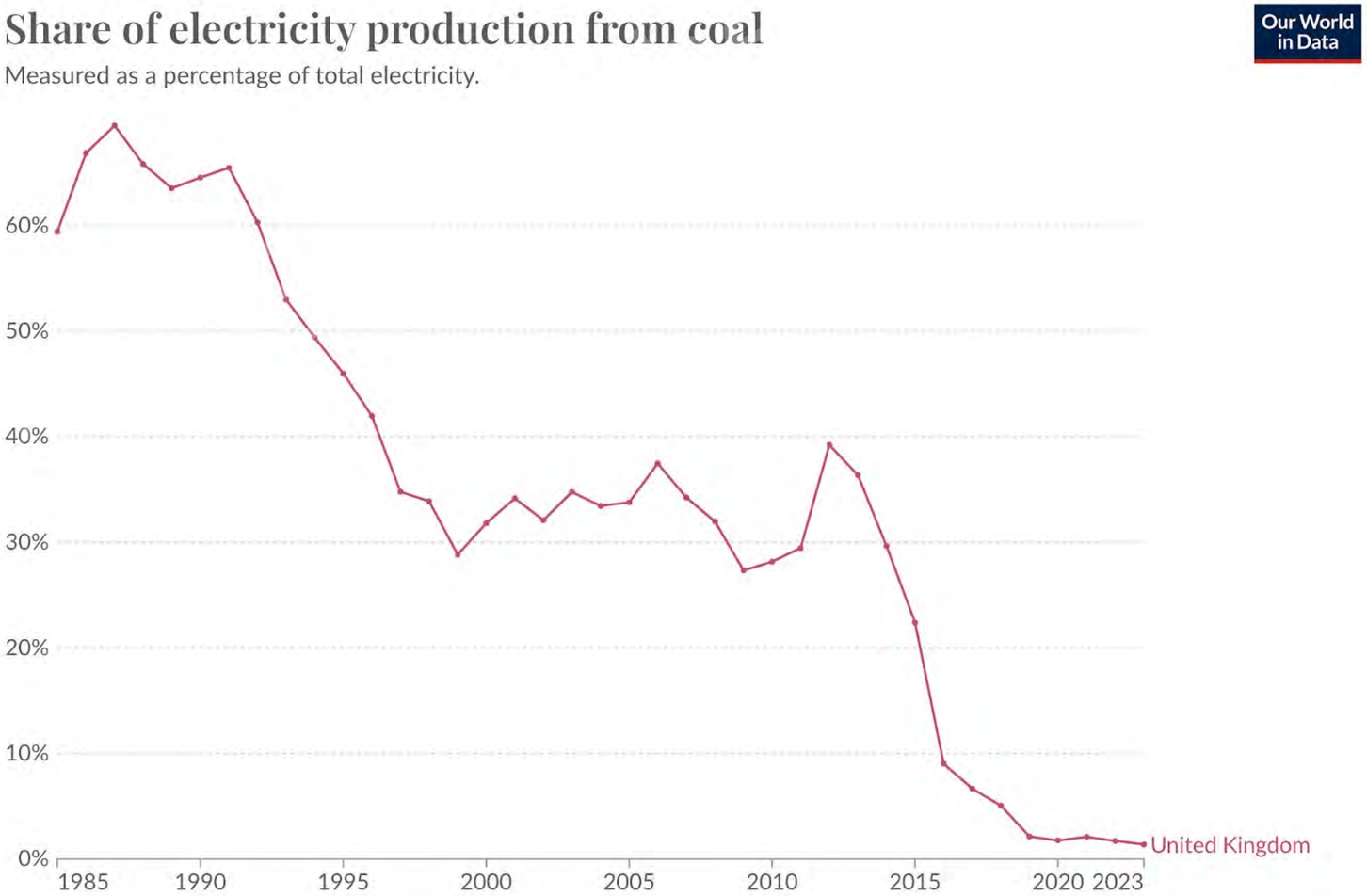
In September 2024, the UK Closed Its Last Coal Plant

'End of an era': UK closes last coal-fired power station

Stuart Stone

30 September 2024 • 7 min read

Image: Ratcliffe-on-Soar power station - Credit: iStock

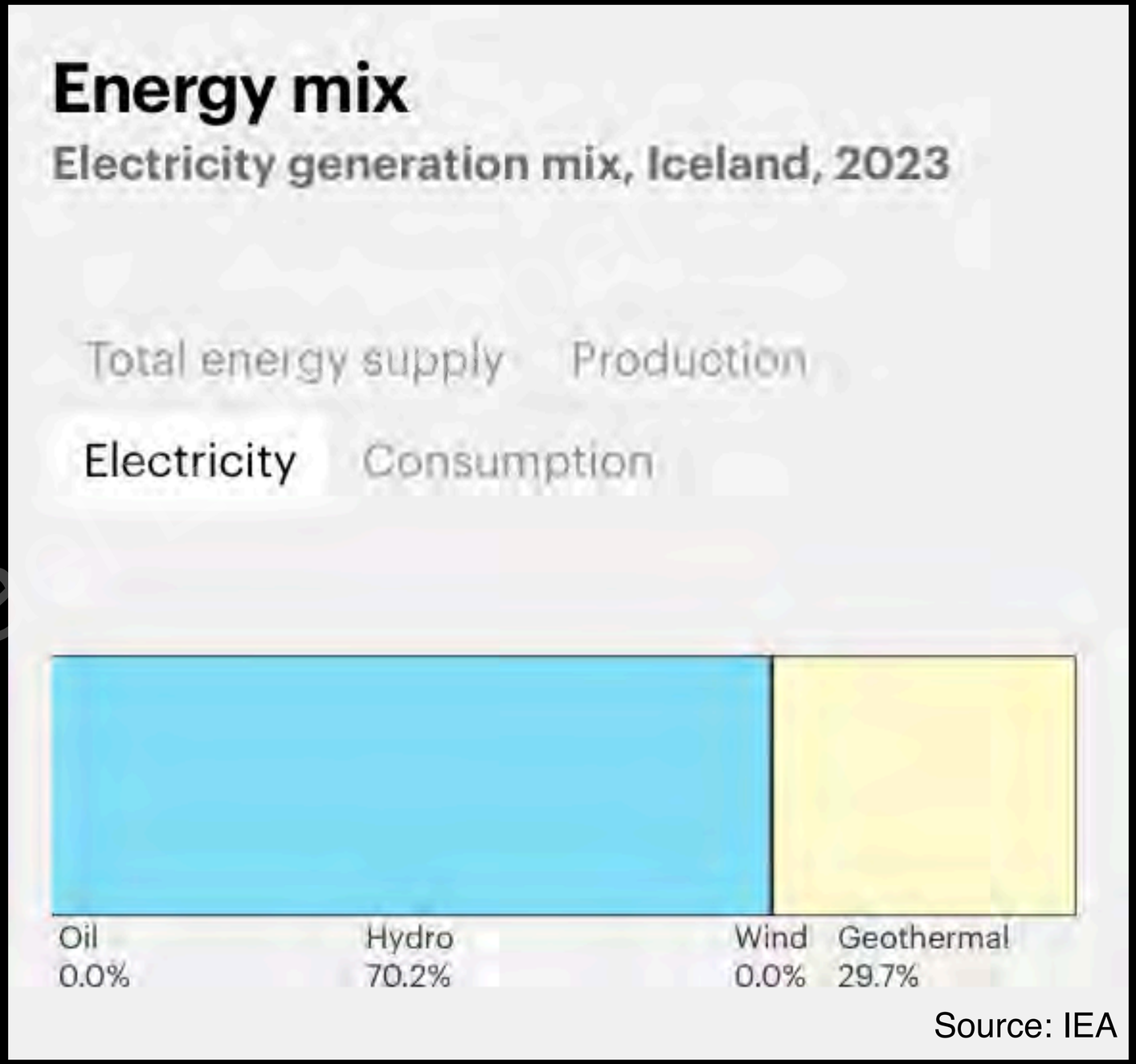


Electricity Trends

(Mostly) Decarbonized Grids Already Exist in Some Places

Iceland:
Hydro, Geothermal

- No natural gas consumption
- Oil, gasoline, diesel, coal, must be imported
- Geothermal heating is also extensive



Norway:
Hydro, Wind

- Large oil & gas producer
- Strict climate policies

The Washington Post
Democracy Dies in Darkness

Subscribe Sign

CLIMATE SOLUTIONS

This country is now the world's first to have more EVs than gas-powered cars

It leads the world in EV adoption, thanks in part to government incentives funded by oil and gas sales.

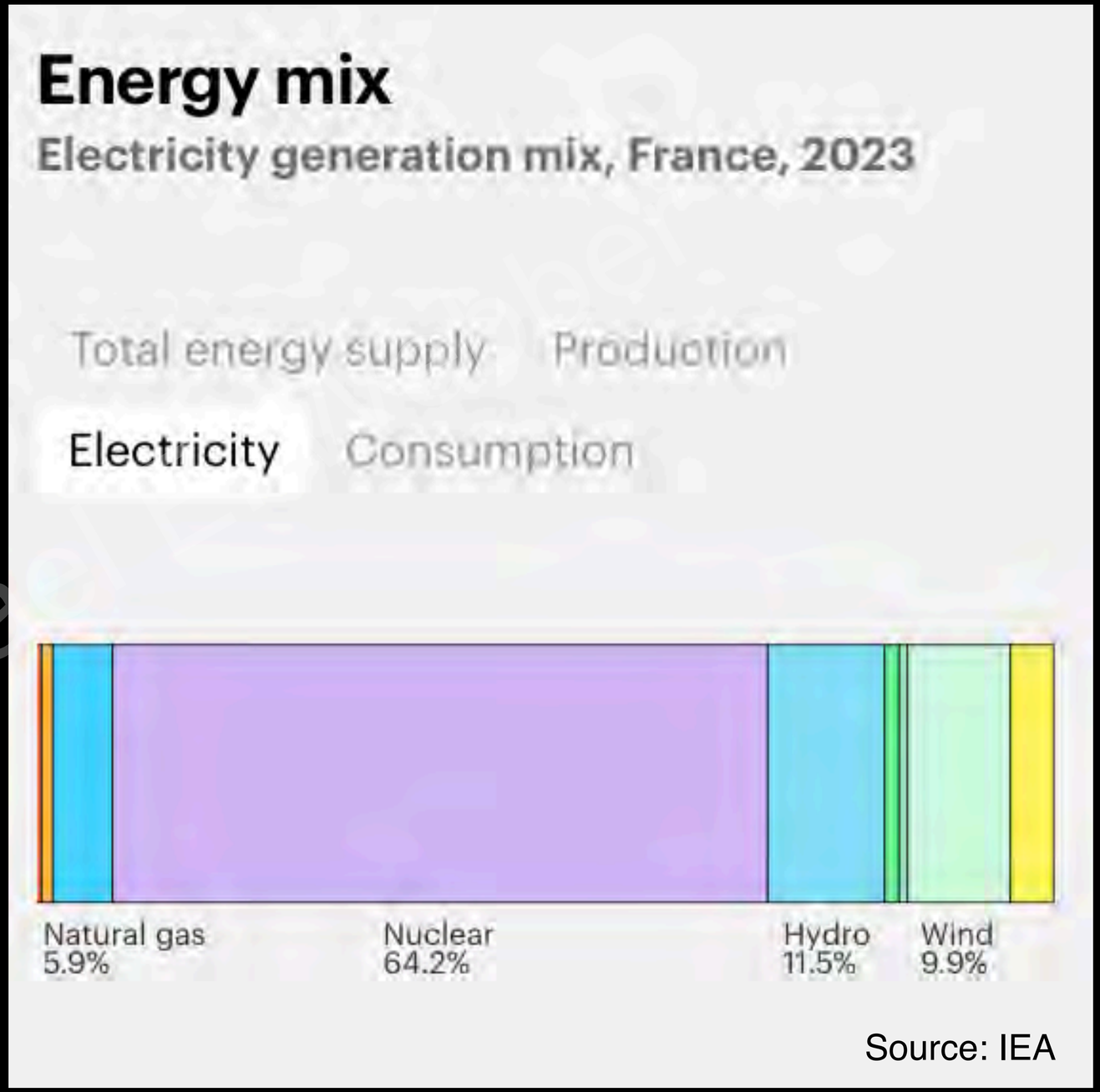
By Nicolás Rivero

Updated September 17, 2024 at 2:10 p.m. EDT | Published September 17, 2024 at 1:42 p.m. EDT

Source: IEA

France:
Hydro, Nuclear, Wind

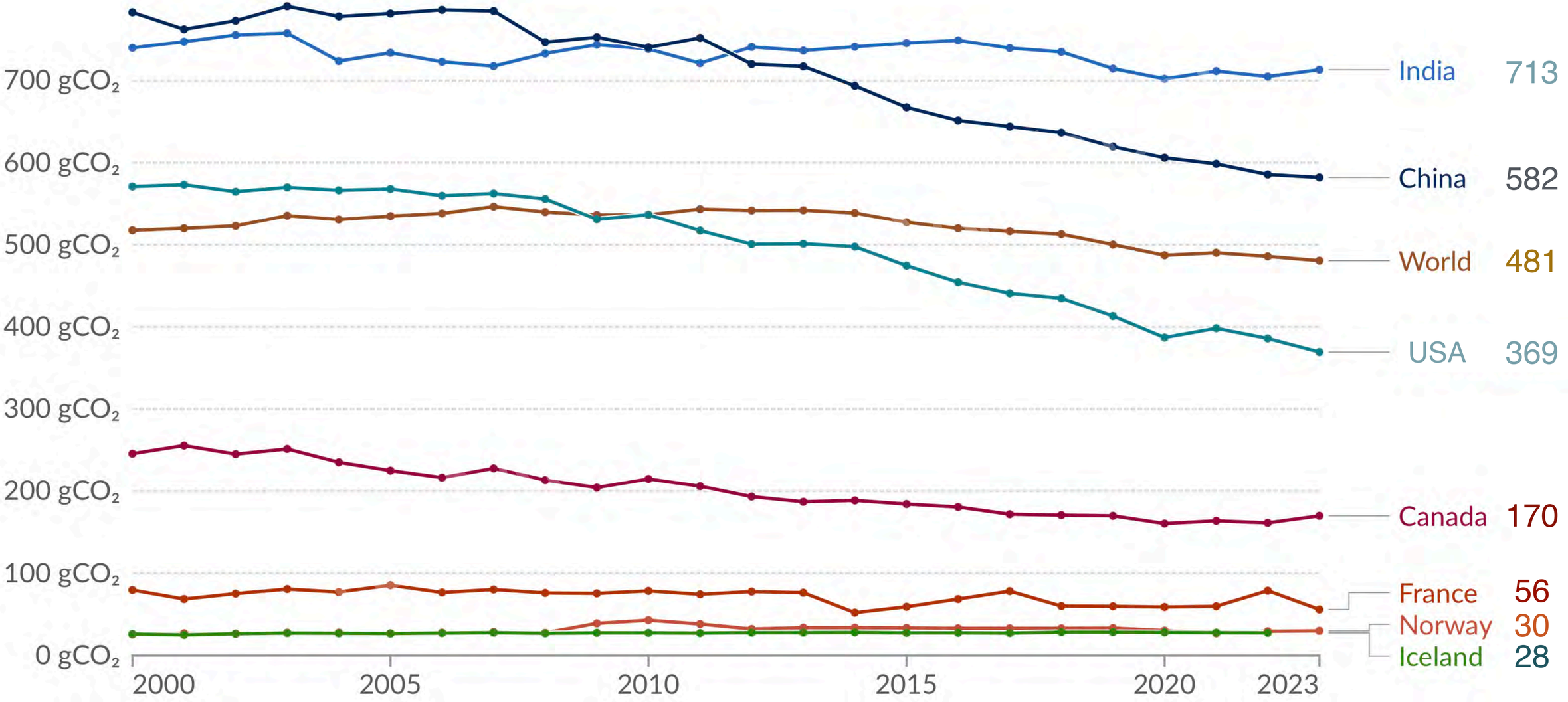
- Importer of oil & gas
- Small reserves of coal



Carbon intensity of electricity generation, 2000 to 2023

Carbon intensity is measured in grams of carbon dioxide-equivalents emitted per kilowatt-hour of electricity generated.

Our World in Data



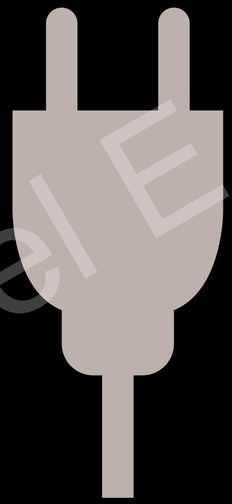
Data source: Ember (2024); Energy Institute - Statistical Review of World Energy (2024) – Learn more about this data

OurWorldinData.org/energy | CC BY

Load growth is on the way up for a few reasons

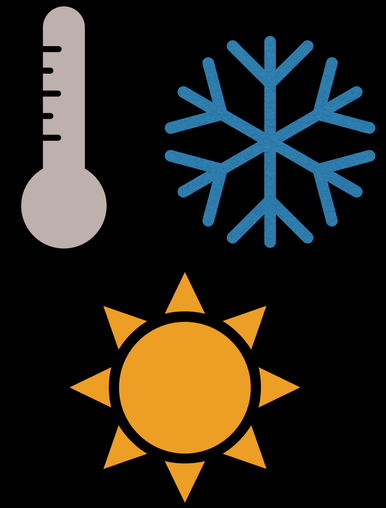
Population & Economic Growth

Electrification



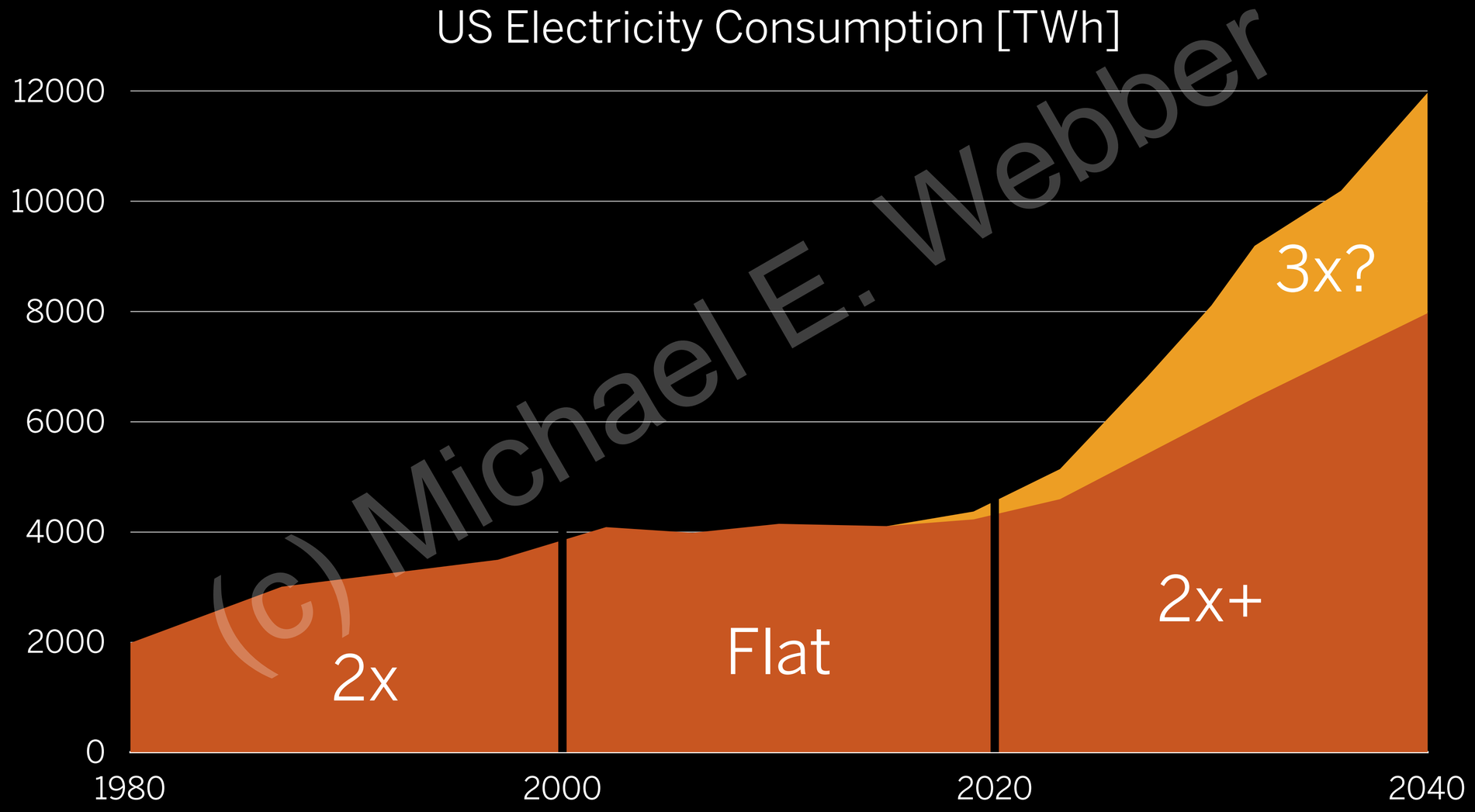
- Transportation
- Industrial Loads
- Home Heating
- Home Cooking

Climate Change

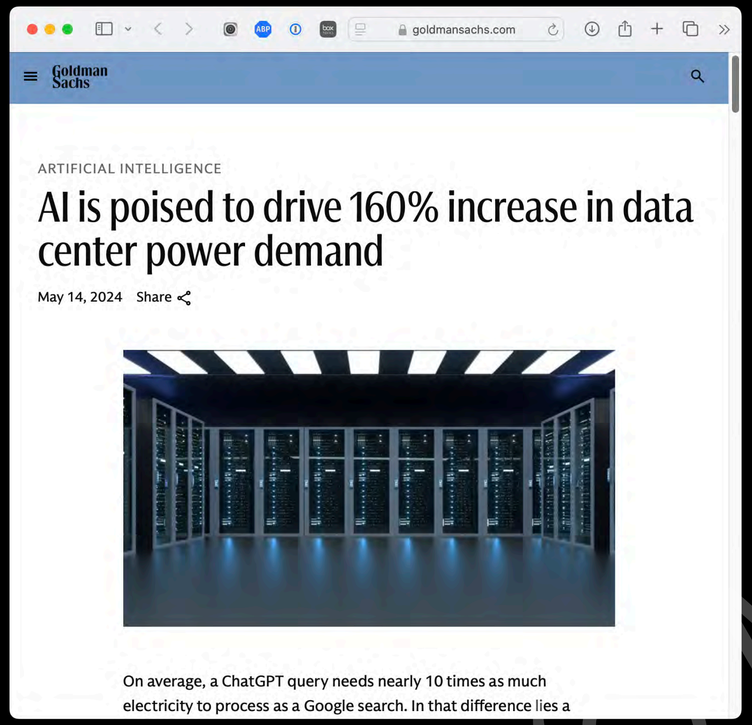


- Heat Domes
- Polar Vortices
- Warmer Summers

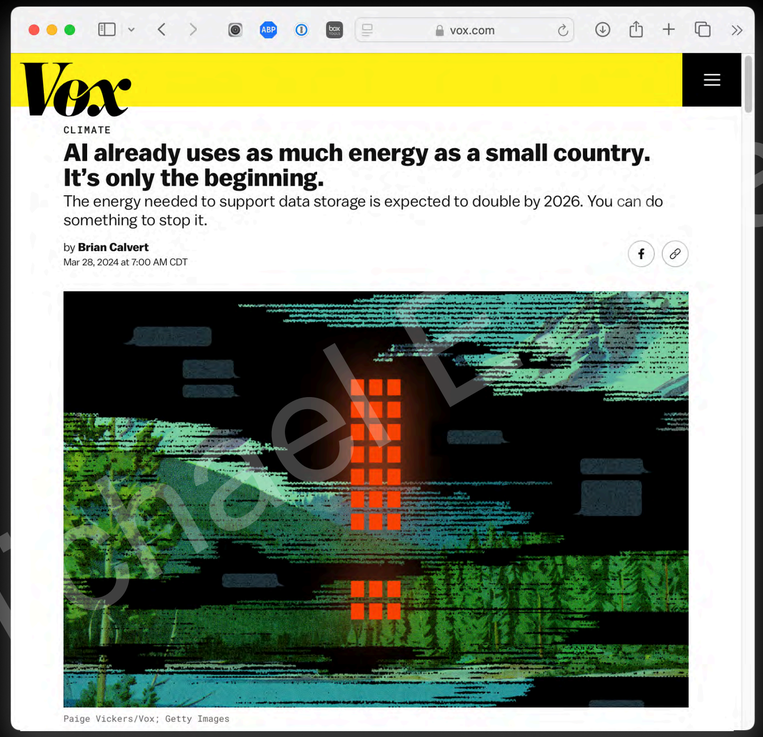
We Have Entered An Era of Unprecedented Growth in Electricity Demand



AI is Power Hungry



https://www.goldmansachs.com/insights/articles/AI-poised-to-drive-160-increase-in-power-demand



https://www.vox.com/climate/2024/3/28/24111721/climate-ai-tech-energy-demand-rising

https://www.nytimes.com/2024/07/11/climate/artificial-intelligence-energy-usage.html

Q: Is AI Part of the Problem or Part of the Solution?

A: Yes

Is AI Too Power-Hungry for Our Own Good?

Projections suggest artificial intelligence platforms may need gigawatts of electricity. But AI could offset that by unlocking new means for saving energy or producing clean power.

Written by ***Michael E. Webber***

July 2024

ASME
SETTING THE STANDARD

The American Society of Mechanical Engineers

AI Is Part of the Problem and Part of the Solution

- Problem:
  - Exacerbates strain on the grid
  - Small demand overall, but ~100% of marginal demand in some locations
- Solution: a lot of AI use cases are related to energy
  - Geological exploration to find minerals or heat,
  - Fusion reactor design,
  - Accelerated discovery of advanced battery materials,
  - Oil and gas well network optimization,
  - Extending the deployed life of critical assets like transformers through predictive maintenance and real-time determination of system health as opposed to fail-in-place or replace-when-it's-working-fine patterns used today

Market Evolution Isn't Homogenous, Linear or Smooth

- Rather than steady change, markets evolve with punctuated equilibria (e.g. phases of stability interrupted by rapid change)
  - Dam buildout 1930s-1950s in response to Great Depression & WWII
  - Coal & nuclear build out 1970s-1980s after oil crises and banned gas
  - The dash for gas in the 2000s after gas ban lifted + Clean Air Act II
- A mix of solutions will emerge
  - It won't be just one fuel or technology
  - It won't be just generation

We Need More Options to Ensure Resource Adequacy

- Clean firm sources are critical
  - Nuclear: 2030+
  - Geothermal: 2030+
  - Gas (w/ or w/o CCUS): 2030+
  - sCO_2: 2030+
  - Hydrogen or Ammonia
  - Wind/Solar/Storage
- Flexibility is critical
  - Smart load management
  - Microgrids
  - Storage
    - Battery prices drop with time
    - Battery performance improves with time
    - New long duration chemistries emerging
- Transmission expansion is critical

More Market Tools Would Be Helpful

- Demand response
- Rotational inertia

Source: @RussellGold

We Are Moving Into a Transmission-Scarce Environment

New Demand: < 2 years

New Supply: 2-5 years

New Transmission: 6-20 years

Grid edge solutions will become more important

Behind the Meter Solutions Can Be Large ...

https://www.washingtonpost.com/business/2024/09/20/microsoft-three-mile-island-nuclear-constellation/

Electric Power Systems Research 234 (2024) 110521

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Valuing distributed energy resources for non-wires alternatives

Nicholas D. Laws *, Michael E. Webber, Dongmei Chen

Walker Department of Mechanical Engineering, The University of Texas at Austin, TX, USA

Behind the Meter Solutions Can Be Large ...

...or Small

Inside Climate News Donate

Batteries and Rooftop Solar Can Lead to Huge Savings for the Entire Grid. A New Study Shows How—and How Much

Reducing demand for electricity has broad benefits, including less need to add new wires and grid equipment.

By Dan Gearino
June 27, 2024

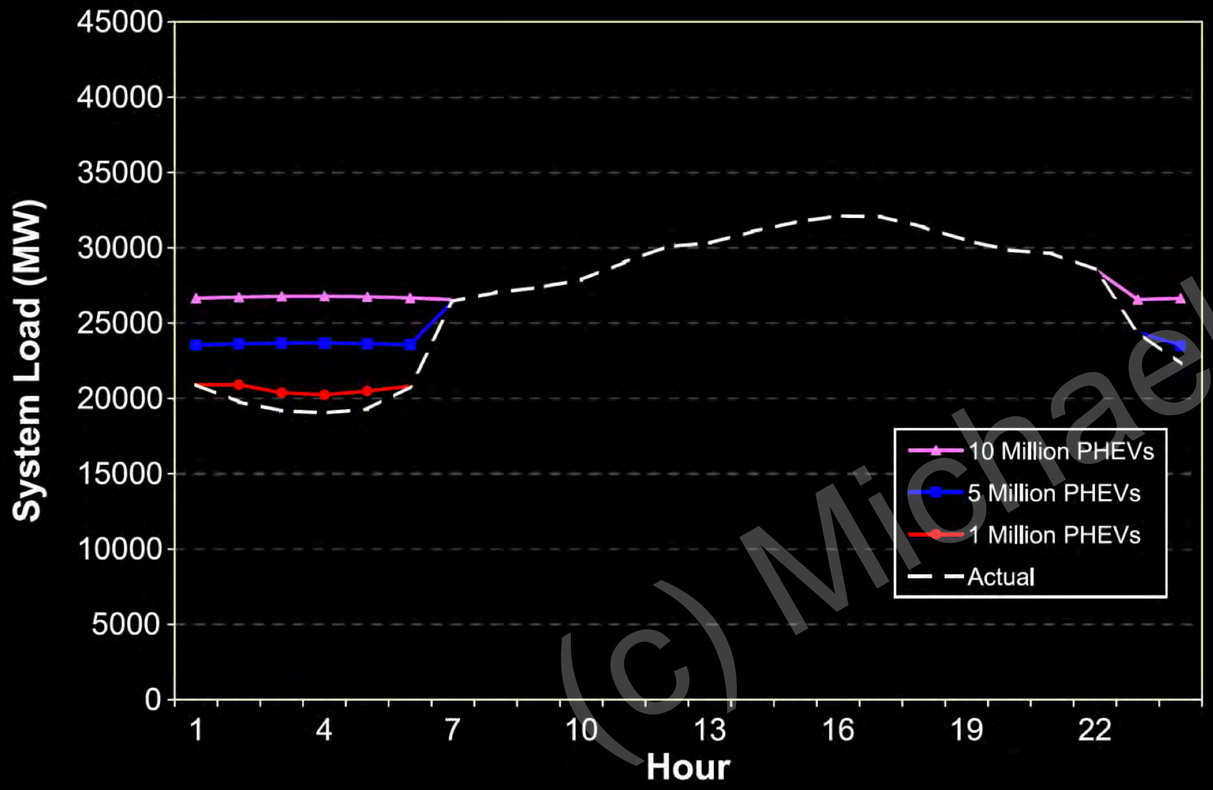
The growth of customer-owned solar and batteries can help to reduce wear and tear on the grid and save ratepayers money.

How much money? A new paper from University of Texas at Austin researchers shows savings of about 40 percent.

Smart Management of Loads at the Grid Edge Will Be Critical

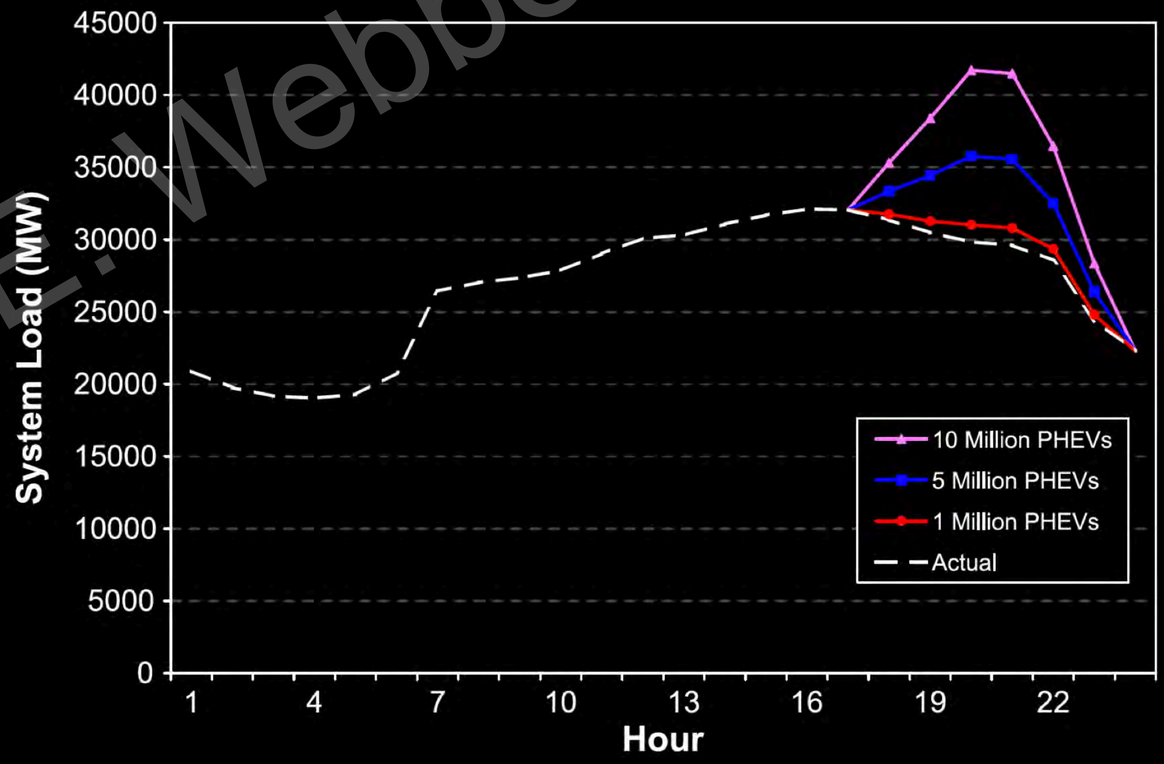
Whether EVs break or save the grid depends on what time of day you charge them (known risk since 2008)

Charging off-peak saves money for everyone



(a) Optimal Charging

Charging on-peak strains the grid for everyone



(b) Evening Charging

Source: "An innovation and policy agenda for commercially competitive plug-in hybrid electric vehicles"
Lemoine, Kammen, Farrell, *Environmental Research Letters*, 2008

Are People Across a Wide Geographic Area Really Capable of Synchronous Behavior?

- Yes, especially for weather…
  - Power demand for heating spikes during cold snaps
  - Power demand for cooling spikes during heat waves
- But would they do so for non-weather related activities?
  - Yes

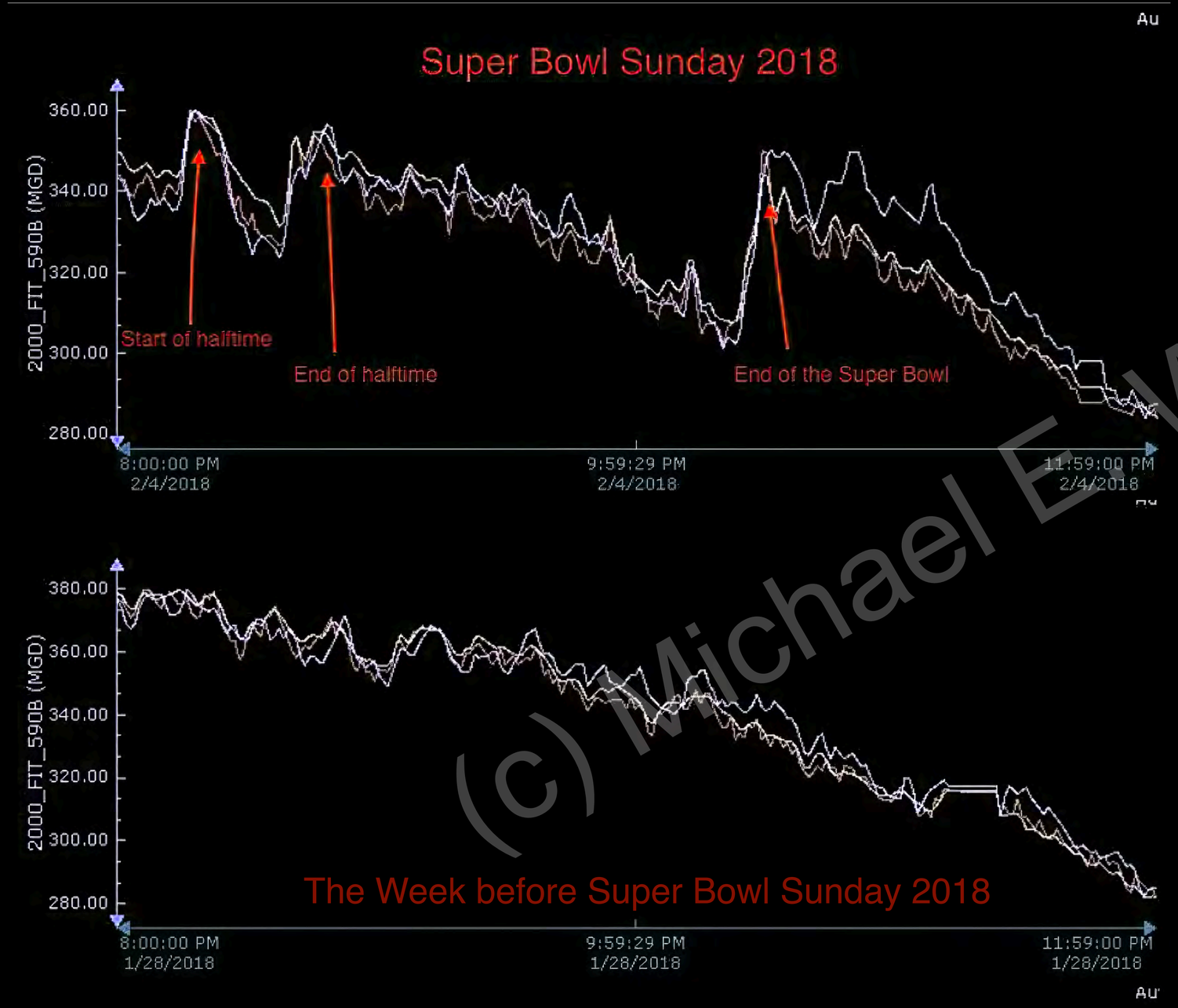
English Tea-Drinking Habits Strain The Grid

GEEK-CETERA (HTTP://WWW.GEEK.COM/CATEGORY/GEEK-CETERA/)

Tea time in Britain causes predictable, massive surge in electricity demand

BY MARK RABY
01.07.2013 - 5:27PM EST

- After a popular soap opera ends, 1.75 million tea kettles are turned on almost simultaneously
- Power surge: 3 GW for 3-5 mins
- Standby power ready from grid in UK and France



Super Bowl Flush

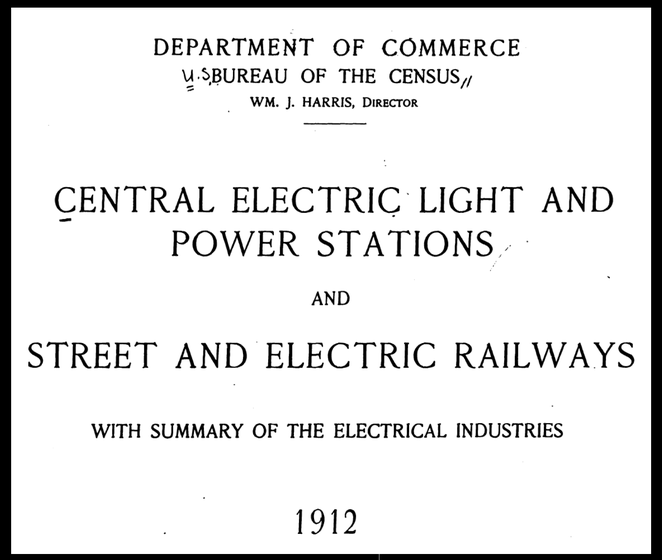
- Millions of toilets in New York City are flushed nearly simultaneously
- Creates a wave of wastewater
- Causes a spike in demand from the water reservoir

Traffic Jams: Daily Rush Hour and Holidays

2017 Thanksgiving traffic, Los Angeles, CA

https://www.latimes.com/local/lanow/la-me-thanksgiving-traffic-20171122-htmlstory.html

Let’s Manage Vehicle Charging to Improve Load Factors…



DEPARTMENT OF COMMERCE
U.S. BUREAU OF THE CENSUS
WM. J. HARRIS, DIRECTOR

CENTRAL ELECTRIC LIGHT AND POWER STATIONS

AND

STREET AND ELECTRIC RAILWAYS

WITH SUMMARY OF THE ELECTRICAL INDUSTRIES

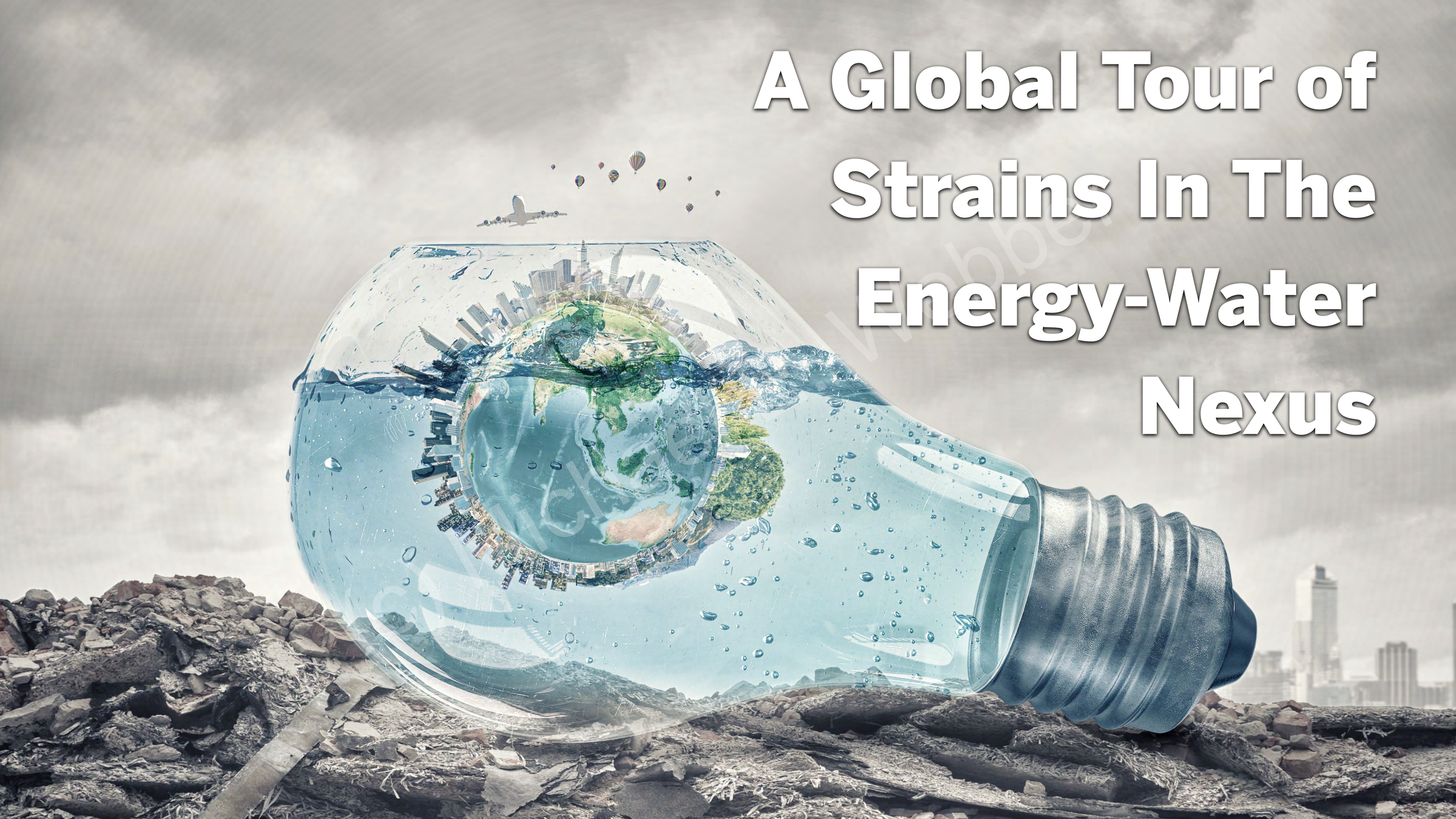
1912

...just as was proposed in the 1912 U.S. Census

At the meeting of the Illinois Electrical Association in 1912 it was stated by Mr. George Jones that if half the horses in use in Chicago were replaced by electric vehicles, the central station load created would amount to 94,000,000 kilowatt hours per annum As such vehicles are usually charged late at night, when the ordinary demand for current is small, no additional investment in central station apparatus would be necessary, and this "off peak" business would improve the general load factor about 13 per cent.

Expanding And Decarbonizing the Grid In A Warming World Can Strain the System

A Global Tour of Strains In The Energy-Water Nexus



Grid Resilience: Flooding

Andrea Booher/FEMA Photo

Mississippi River, Mo., July 1993 -- An aerial view of floodwaters showing the extent of the damage wreaked by the disaster. A total of 534 counties in nine states were declared for federal disaster aid. As a result of the floods, 168,340 people registered for federal assistance. Photo by Andrea Booher/FEMA Photo Photo by Andrea Booher - Jul 08, 1993 - Location: Mississippi River, MO

Grid Resilience: Flooding

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Mississippi River, Mo., July 1993 -- An aerial view of floodwaters showing the extent of the damage wreaked by the disaster. A total of 534 counties in nine states were declared for federal disaster aid. As a result of the floods, 168,340 people registered for federal assistance. Photo by Andrea Booher/FEMA Photo Photo by Andrea Booher - Jul 08, 1993 - Location: Mississippi River, MO

Floods Threaten the Power Sector

Nebraska Nuclear Power Plant along the Missouri River

Source: Reuters, June 24, 2011

Floods Threaten the Fuels Sector

- Hurricane Harvey shut in 4.4M bpd of refining (25% of national capacity)
- Crude production mostly unaffected
- Oil prices stayed flat, gasoline prices increased

Droughts Threaten the Power Sector

"Will Drought Cause The Next Blackout?"

Source: New York Times, July 24, 2012

MAXWELL HOLYOKE-HIRSCH

Will Drought Cause The Next Blackout?

By Michael E. Webber

they can be significant locally.

All told, we withdraw more water for the energy sector than for agriculture.

million more people in the United States over the next four decades who will need energy and water to survive and prosper. Economic growth compounds that trend, as per-capita energy and water consumption tend to increase with affluence. Climate-change models also suggest that droughts and heat waves may be more frequent and severe.

Thankfully, there are some solutions.

The government can collect, maintain and make available accurate, updated and comprehensive water data, possibly through the United States Geological Survey and the E.I.A. The E.I.A. maintains an extensive database of accurate, up-to-date and comprehensive information on energy production, consumption, trade and price. Unfortunately, there is no equivalent set of data for water. Consequently, industry, investors, analysts, policy makers and planners lack the information they need to make informed decisions about power plant siting or cooling technologies.

The government should also invest in water-related research and development (spending has been pitifully low for dec-

> Lack of rain threatens not only farmers, but power production.

ades) to seek better air-cooling systems for power plants, waterless techniques for hydraulic fracturing, and biofuels that do not require freshwater irrigation.

We should encourage the use of reclaimed water for irrigation, industry and the cooling of equipment at industrial operations like smelters and petrochemical complexes. These steps typically spare a significant amount of energy and cost. The use of dry and hybrid wet-dry cooling towers that require less water should be encouraged at power plants, since not all of them need wet cooling all the time. As power plants upgrade their cooling methods to ones that are less water-intensive, these operations can save significant volumes of water.

Most important, conservation should be encouraged, since water conservation results in energy conservation, and vice versa.

New carbon emissions standards can also help save water. A plan proposed by the Obama administration (requiring new power plants to emit no more than 1,000 pounds of carbon dioxide per megawatt hour generated) would encourage utilities to choose less carbon- and water-intensive fuels. Conventional coal plants,

Drought Triggered India's 2012 Blackout: 620 Million People In The Dark

The New York Times

2nd Day of Power Failures Cripples Wide Swath of India

Adnan Abidi/Reuters

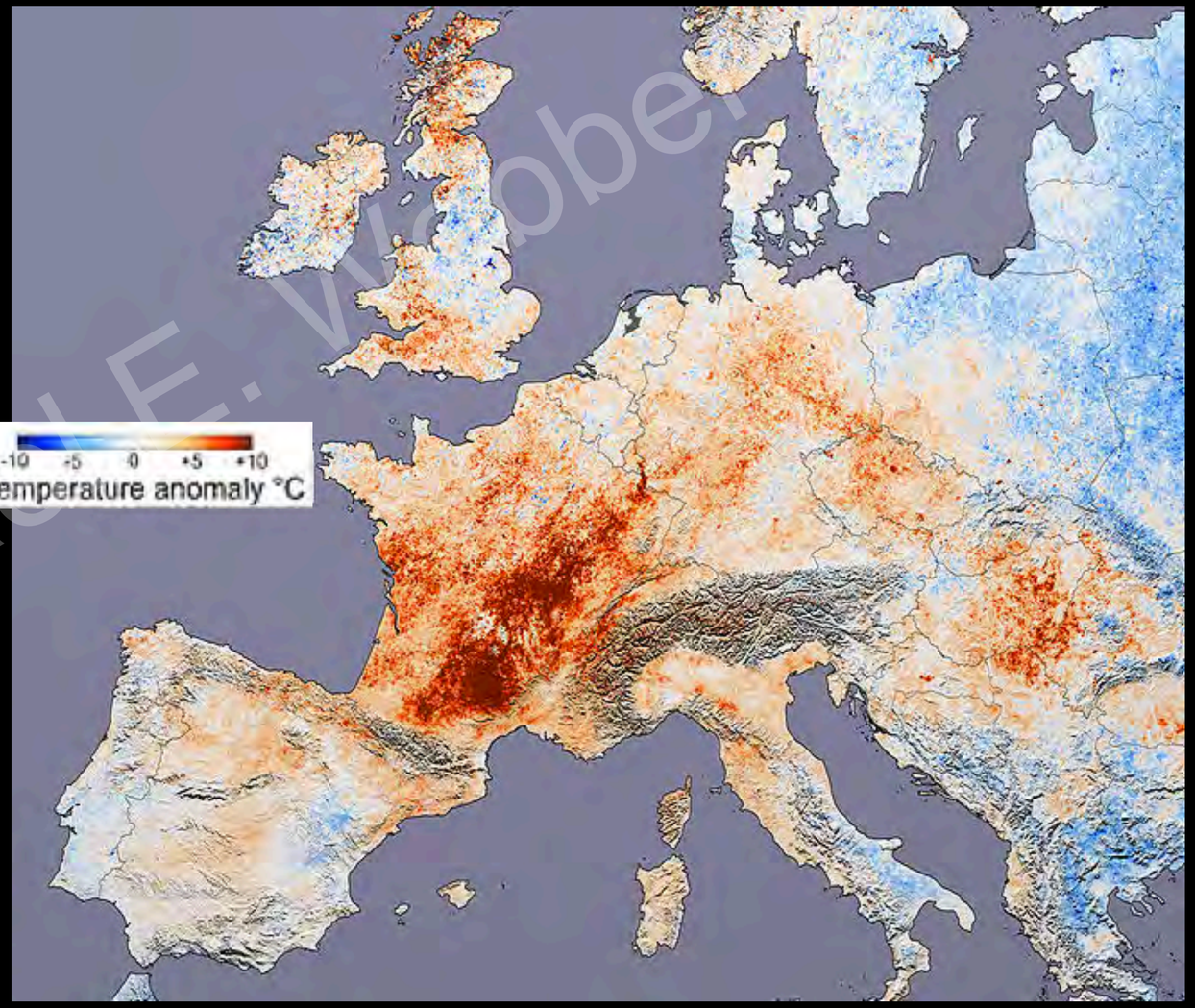
Passengers waited Tuesday for train service to be restored in New Delhi. More Photos »

By JIM YARDLEY and GARDINER HARRIS
Published: July 31, 2012 | 429 Comments

Hot Water Threatens the Power Sector

- Snapshot of the record heat wave in 2003

- Nuclear power plants dialed back because high inlet water temps meant less cooling was available without violating thermal pollution limits for the return water



NASA (2003)

Hot Water Threatens the Power Sector

EUROPE ECONOMY

Europe's evaporating rivers wreak havoc for food and energy production ahead of winter

PUBLISHED THU, SEP 1 2022•1:17 AM EDT

Sam Meredith
@SMEREDITH19

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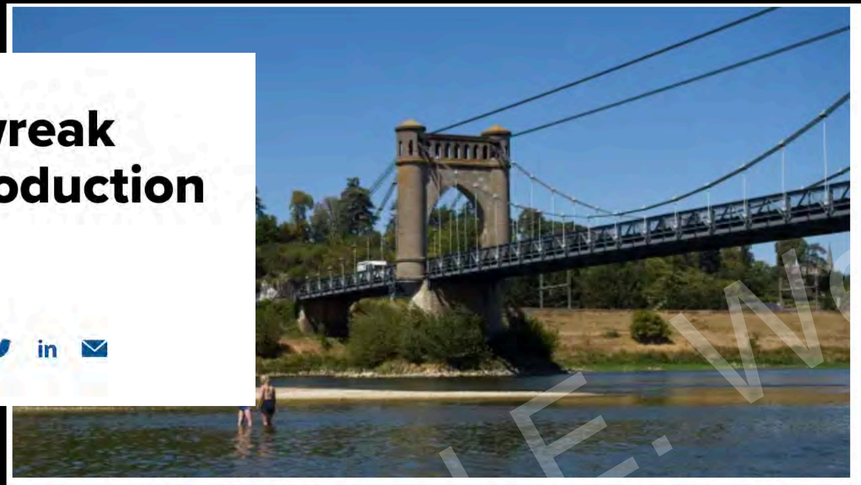
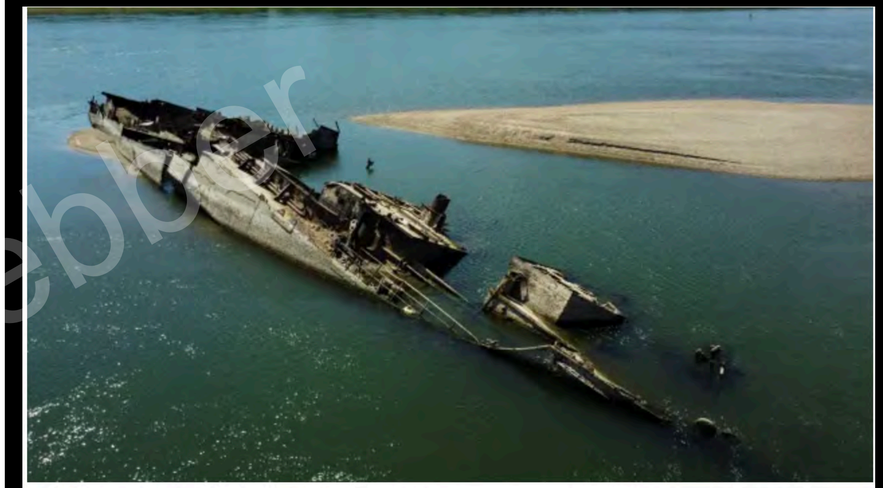
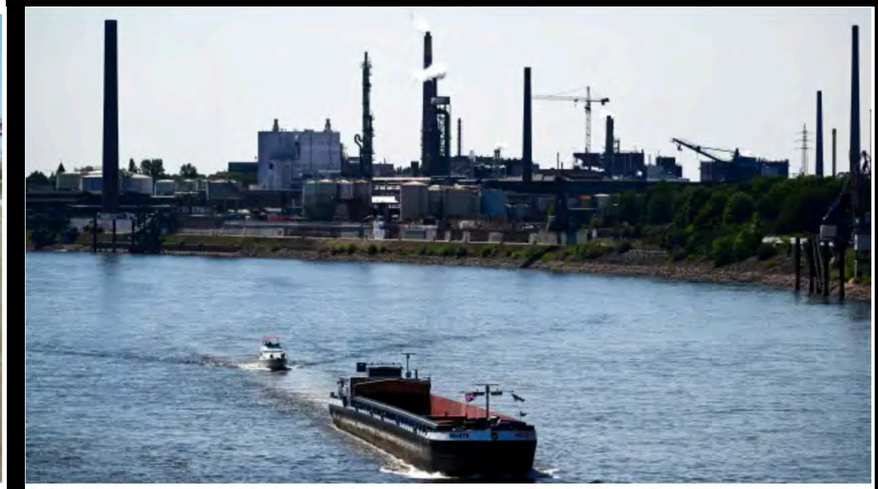


France's Loire River is at its lowest level as Europe experiences what is thought to be its worst drought in at least 500 years.
Guillaume Souvant | Afp | Getty Images

In Italy's Po valley, home to about 30% of the countrys agriculture production, torrid heat and exceptionally dry conditions have hurt corn and sunflower production.
Bloomberg | Bloomberg | Getty Images



Wreckage of a World War Two German warship is seen in the Danube in Prahovo, Serbia August 18, 2022.
Fedja Grulovic | Reuters



An unloaded inland barge moves along the Rhine River at low water level in Duisburg, western Germany, on Aug. 9, 2022.
Ina Fassbender | Afp | Getty Images

Frozen Water Threatens the Power Sector

February 6, 2011

dallasnews

Freeze knocked out coal plants and natural gas supplies, leading to blackouts

THE MINING Journal

25,000 tons of coal shipped by truck

Ice breakers challenged

April 1, 2014

JOHN PEPIN - Journal Staff Writer (jpepin@miningjournal.net) , The Mining Journal

MARQUETTE - U.S. Coast Guard icebreakers challenged by Lake Superior ice as thick as six feet in some places are not expected to make it into Marquette Harbor for several days, delaying the local opening of the shipping season.

The ice cutter William H. Lathan navigates through thick ice in the Niagara River. The cutter works constantly in cold weather to keep the water intakes for the Niagara Falls hydro-electric plants free of damaging ice.
Picture: REUTERS

Ice threatened to damage the hydroelectric facilities at Niagara Falls, January 2014

Grid Resilience: Wind

Toa Baja, Puerto Rico - Unstable power lines endangers residents and vehicles in the community. Many areas like Toaville in Toa Baja are still surrounded by debris that is still being removed by military personnel, municipal personnel and residents
Photo by Eliud Echevarria - Nov 01, 2017

Grid Resilience: Hurricanes

“The path from Helene can be seen from space with all of the power outages the day after it ripped through the Southeast,” the National Weather Service Greenville-Spartanburg, South Carolina posted on X.

Michael E. Webber, Ph.D.

Sid Richardson Chair in Public Affairs
John J. McKetta Centennial Energy Chair in Engineering
The University of Texas at Austin

webber@mail.utexas.edu
www.webberenergygroup.com

The University of Texas at Austin
Webber Energy Group
LBJ School of Public Affairs | Cockrell School of Engineering