UTSA | Electrical & Computer Engineering

EE 1322: Intro to Electrical & Computer Engineering

Module 8: Intro to Power Systems Analysis—And Climate Change

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Module 8 outline

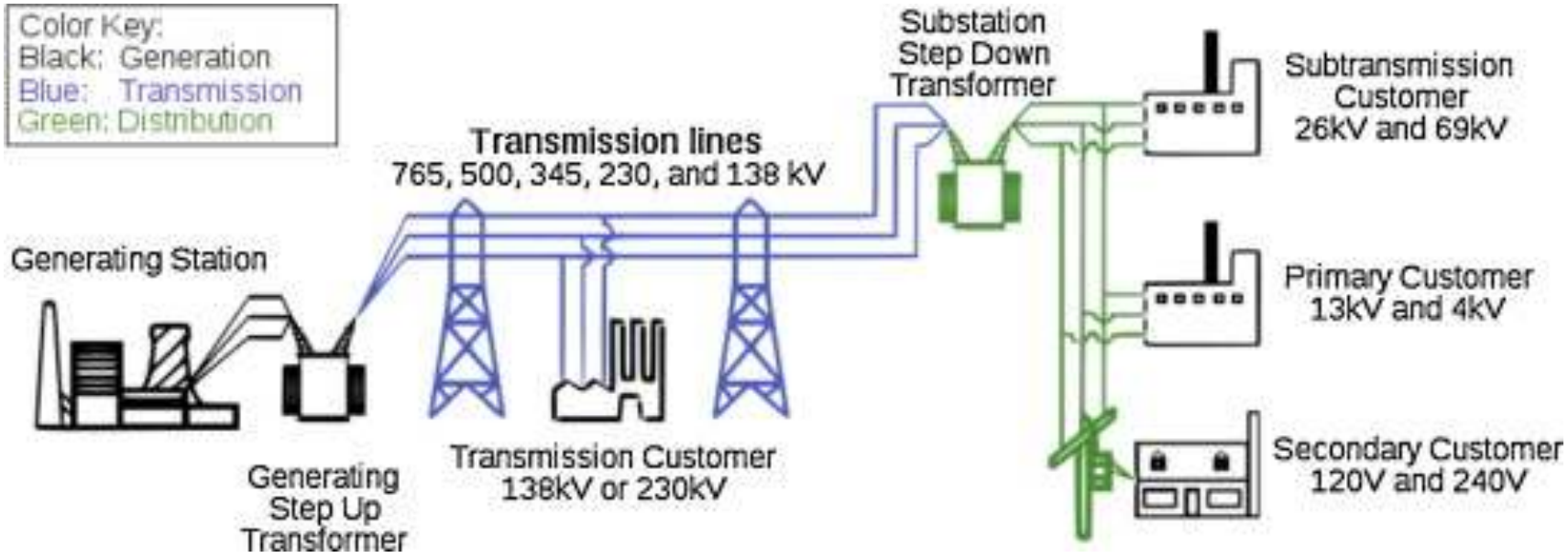
1. What are power systems? Traditional energy systems
2. Smart grids and the duck curve
3. Climate change

Part 1:

Traditional Power/Energy Systems

What is Power Systems Analysis?

Power Systems Analysis is the study of generation, transmission and distribution of electric power to various loads.



Electrical Grid: "Most significant engineering achievement of 20th century" [NAE Report, 2010] http://www.greatachievements.org/

Sources of Electricity

Sources of electricity are divided into two categories

- **Nonrenewable:** Cannot be easily replenished
  1. Coal
  2. Natural Gas
  3. Petroleum (oil)
  4. Nuclear (uranium)

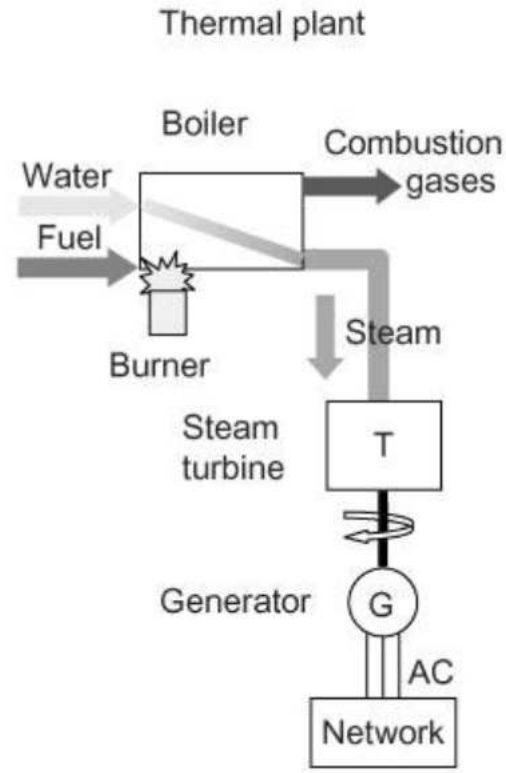
  Fossil fuels: Formed over millions of years

- **Renewable:** Can be easily replenished
  1. Wind
  2. Solar
  3. Hydropower
  4. Biomass
  5. Geothermal

Thermal Plants

Coal, natural gas, and oil are used in thermal plants following pretty much the same operating principle:

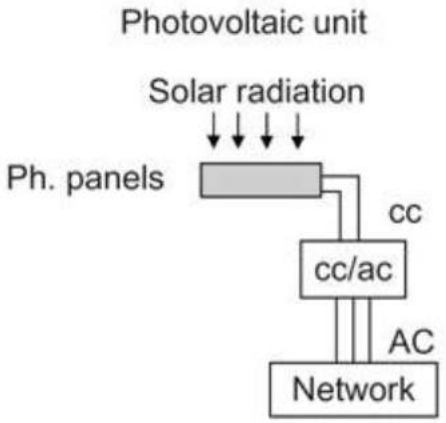
1. Fuel burned in a boiler produces high-pressure steam
2. Steam rotates the shaft of a steam turbine
3. The mechanical energy of the shaft is converted to electric energy by a generator

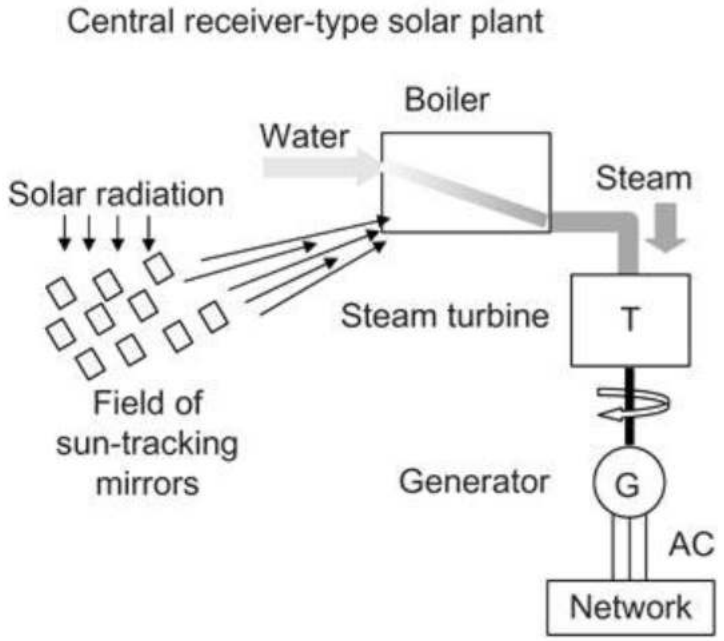


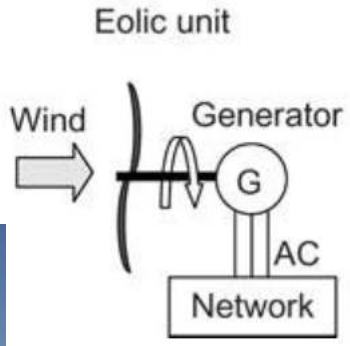
- **Gas turbine plants:** Natural gas can be burned to produce hot combustion gases that pass through a gas turbine (similarly to jet engines)
- **Nuclear power plants:** Heat from nuclear reaction is used to generate steam, which, similarly to thermal plants, is passed through a steam turbine

Wind and Solar

Photovoltaic solar generator: Solar radiation is absorbed by panels which convert solar energy into direct current





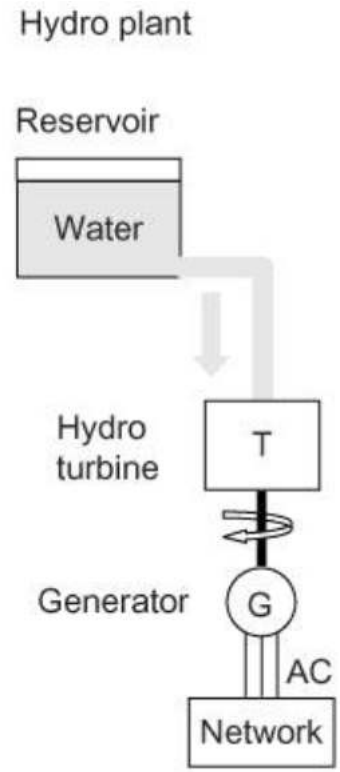


Brazos wind farm in Texas

Concentrated solar plant: Mirrors or lenses are used to concentrate the sunlight and produce heat, which is then typically used as in thermal plants

Hydropower

- Conventional hydroelectric plant: Water flow due to difference in elevation moves a hydraulic turbine
- Run-of-the-river hydroelectric plant: no storage
- Pumped storage: Plants that can pump water back to an elevated reservoir when electric power is cheap, and release it to the turbine later
- Tidal and wave power plants not widely employed

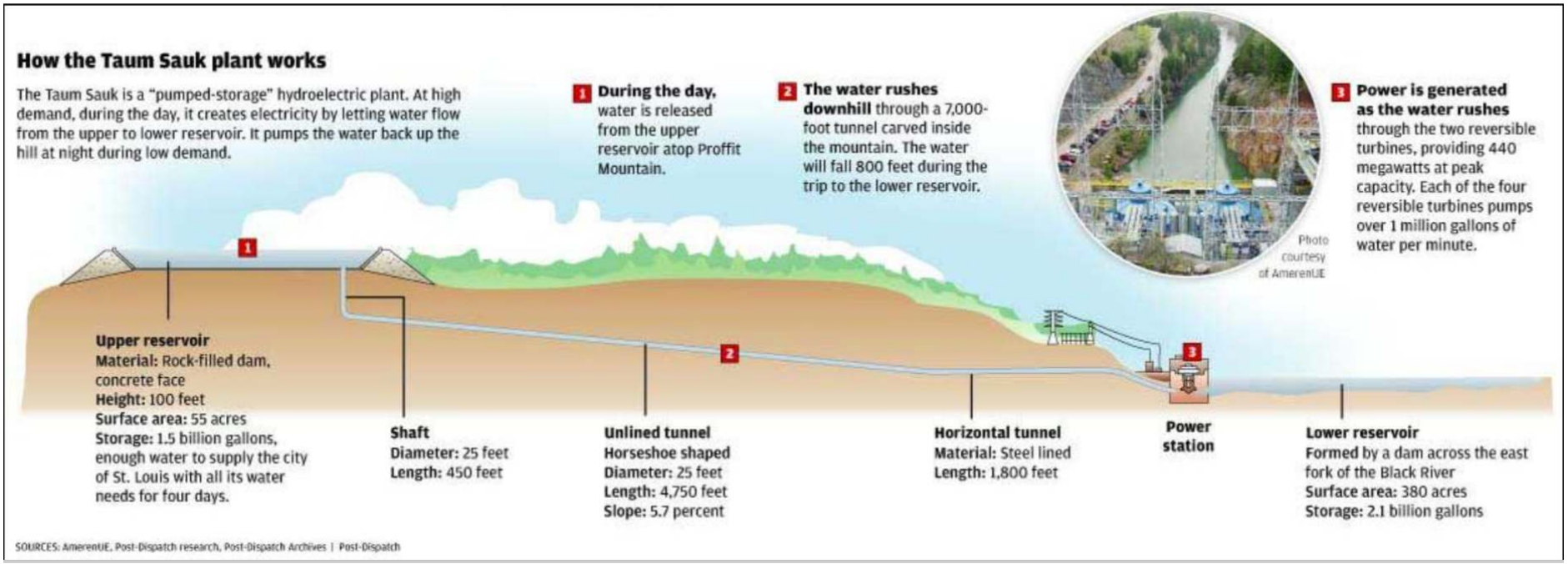


Hoover Dam
Source: https://en.wikipedia.org/wiki/Hoover_Dam

Taum Sauk Pumped Storage Plant in Missouri

Sources:
https://en.wikipedia.org/wiki/Pumped-storage_hydroelectricity

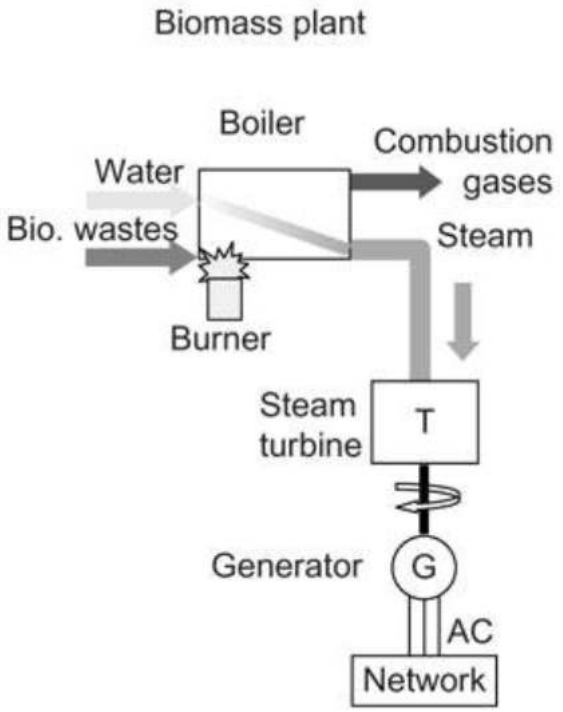
https://www.ferc.gov/industries/hydropower/safety/projects/taum-sauk/proj-desc.asp



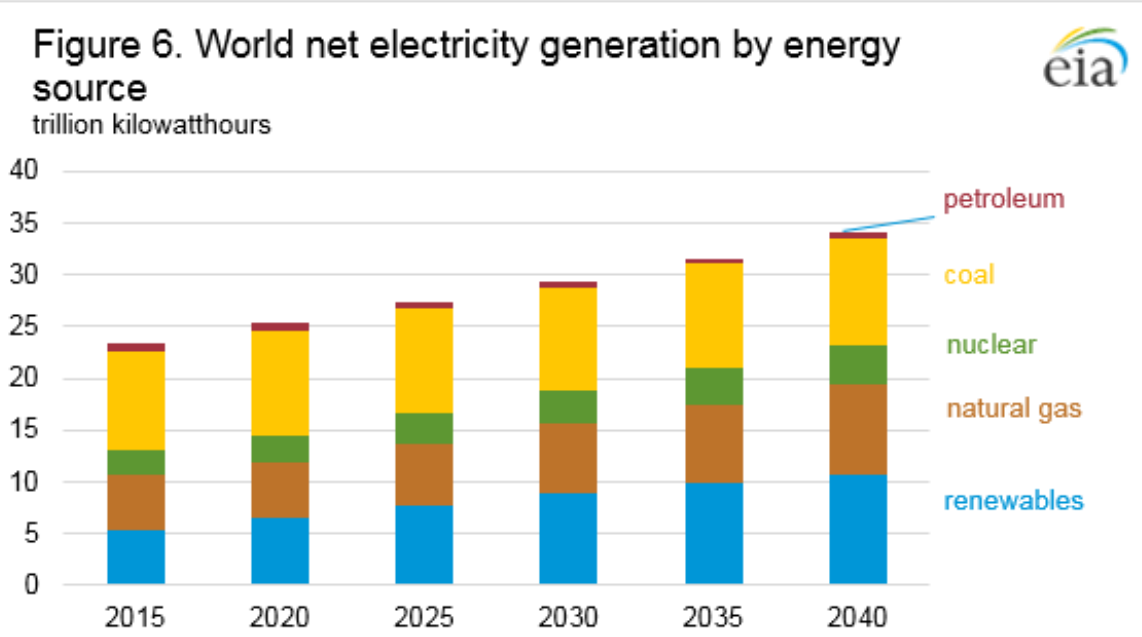
Biomass

- Biomass: Wood remains, plants, plant-based materials, animal matter

- Biomass is typically burned to produce steam, which is used for electricity generation as in conventional thermal plants
- Other technologies available
- Conventional thermal plants can be retro-fitted to burn a mixture of fossil fuel and biomass

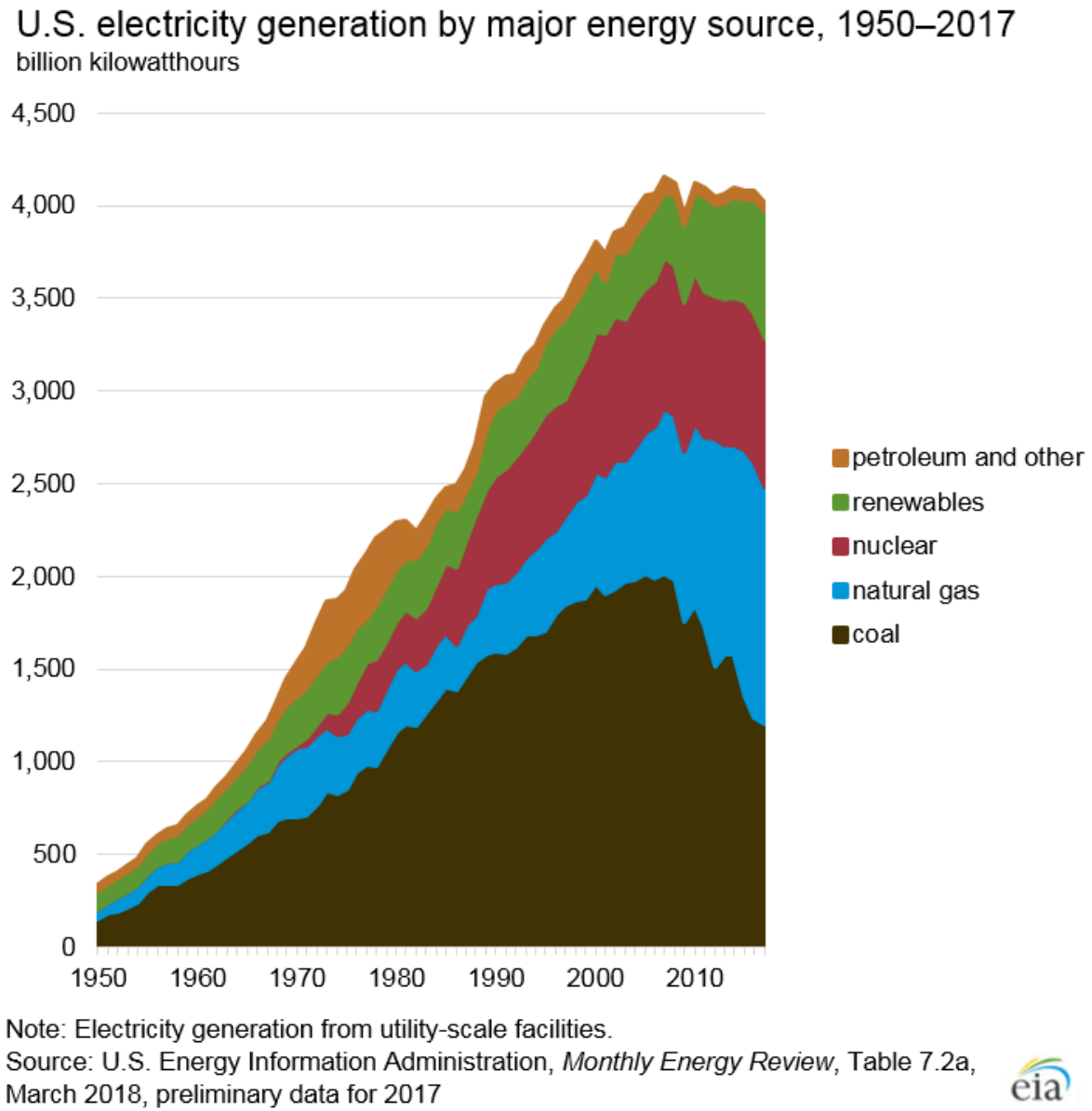


World Net Electricity Generation



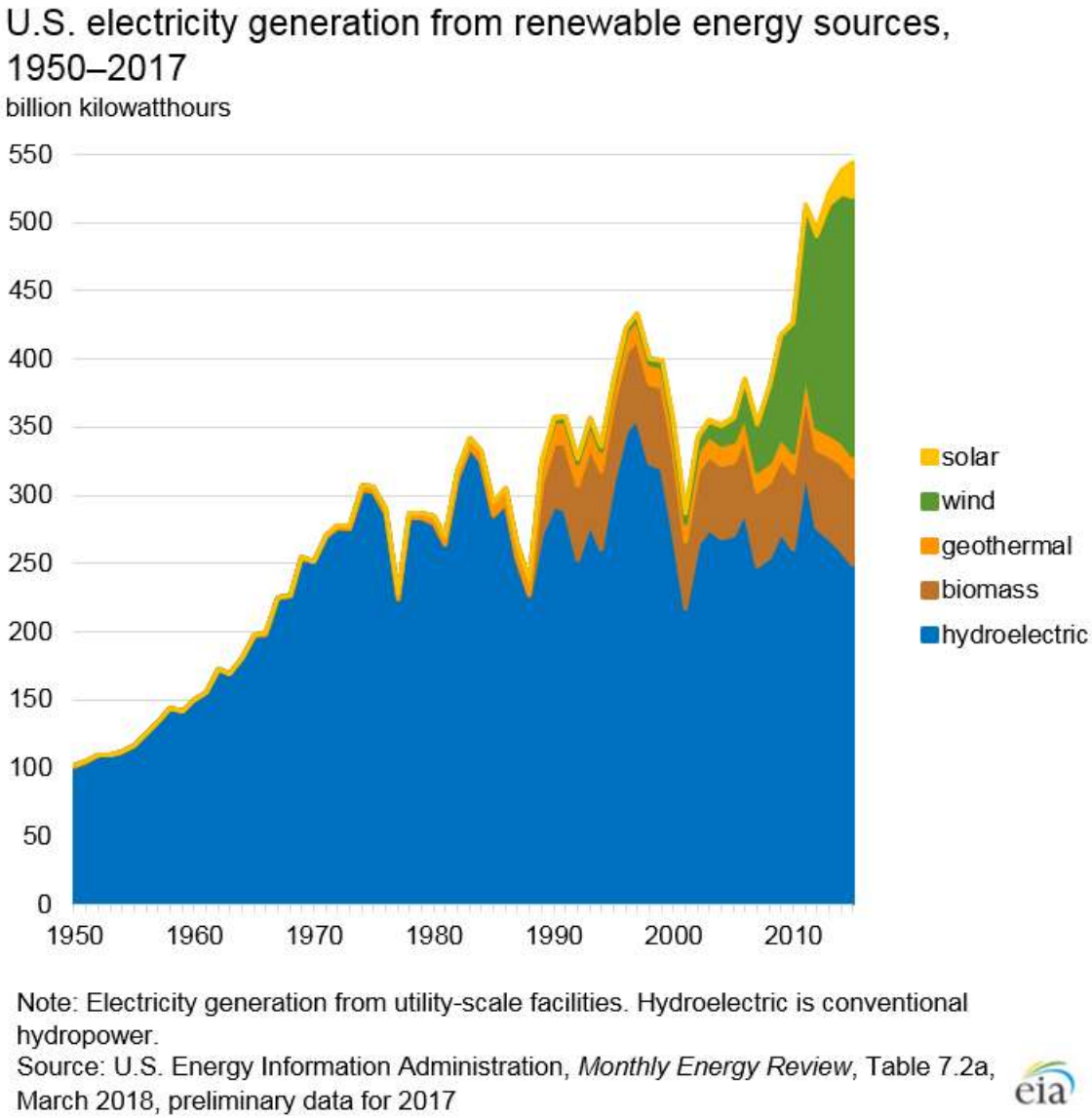
Source: Energy Information Administration, International Energy Outlook 2017
https://www.eia.gov/outlooks/ieo/exec_summ.php

- Increased generation from all fuel sources
- Renewable generation is fastest-growing source, expected to surpass coal-fired generation by 2040 on a worldwide basis
- Fossil fuels account for majority of energy generation



Note: Electricity generation from utility-scale facilities.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 7.2a, March 2018, preliminary data for 2017

https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states



Note: Electricity generation from utility-scale facilities. Hydroelectric is conventional hydropower.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 7.2a, March 2018, preliminary data for 2017

https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states

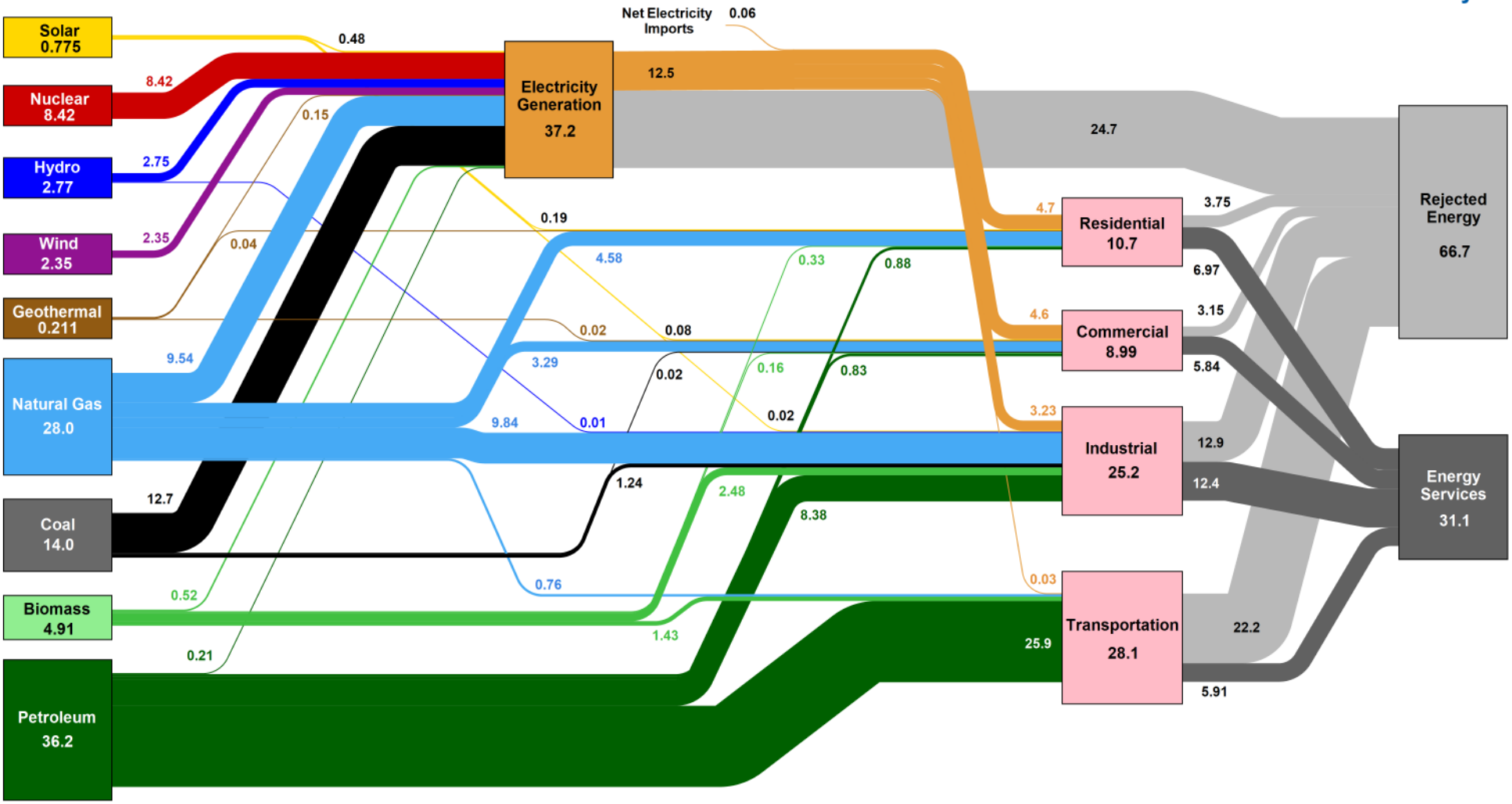
Energy Content of Fuel

- The energy content of fuel is traditionally measured in British Thermal Units (Btu)
- 1 BTU = 0.000293071 kWh
- 1 kWh = 3,412 Btu
- 1 barrel (42 gallons) of U.S. produced crude oil = 5,722,000 Btu
- 1 cubic foot of natural gas = 1,037 Btu
- It is estimated that to produce 1 kWh of electricity, a fossil fuel plant consumes on average fuel with energy content of 9,232 Btu
  - this quantity is called heat rate of the plant
- Average efficiency = 3,412/9,232 or approximately 36.9%

Sources---Units: https://www.eia.gov/energyexplained/index.php?page=about_energy_units
Heat Rate: https://www.eia.gov/totalenergy/data/browser/index.php?tbl=TA6#/?f=A&start=1991
Efficiency: https://www.eia.gov/tools/faqs/faq.php?id=107&t=3

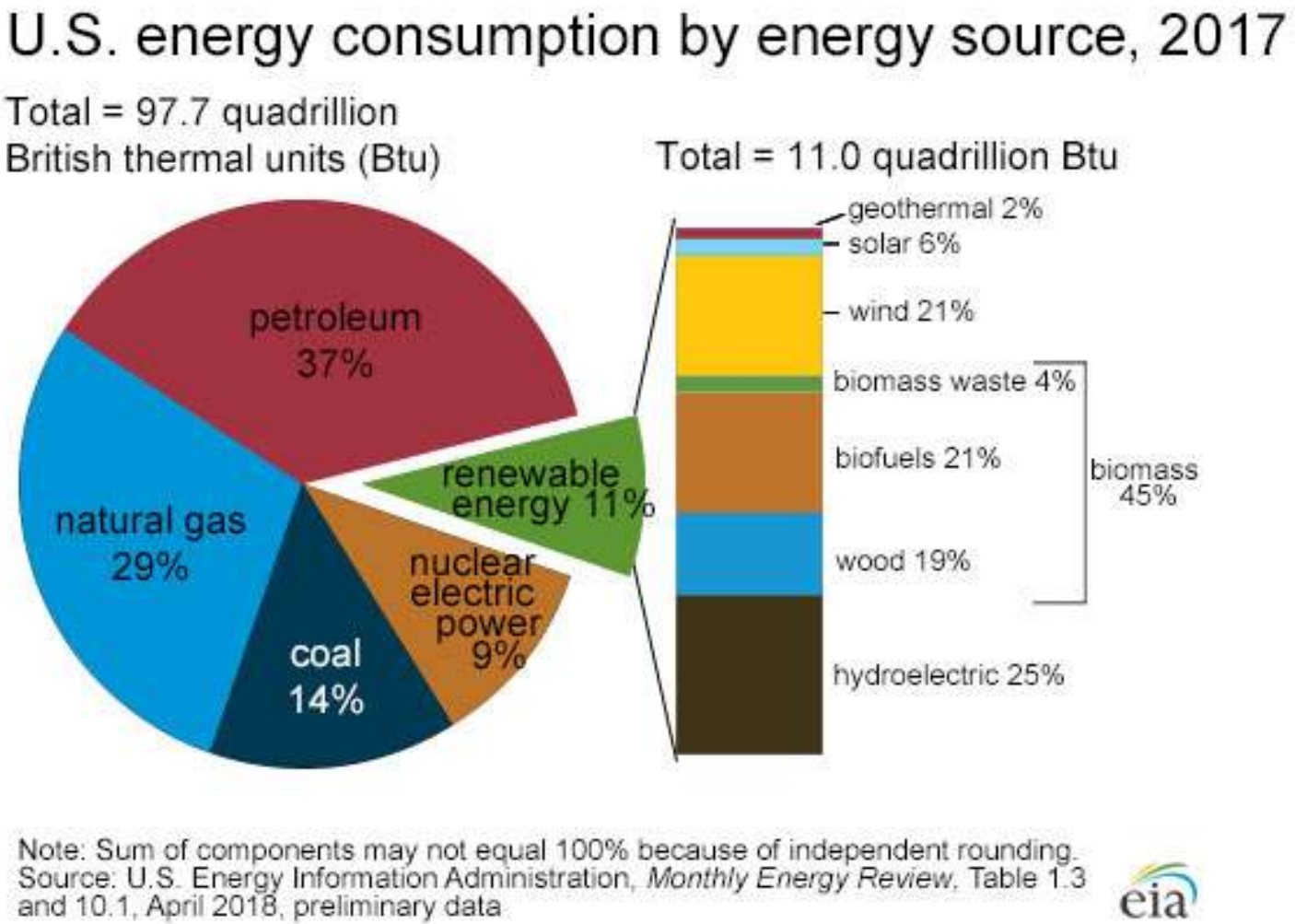
Estimated U.S. Energy Consumption in 2017: 97.7 Quads

Lawrence Livermore National Laboratory



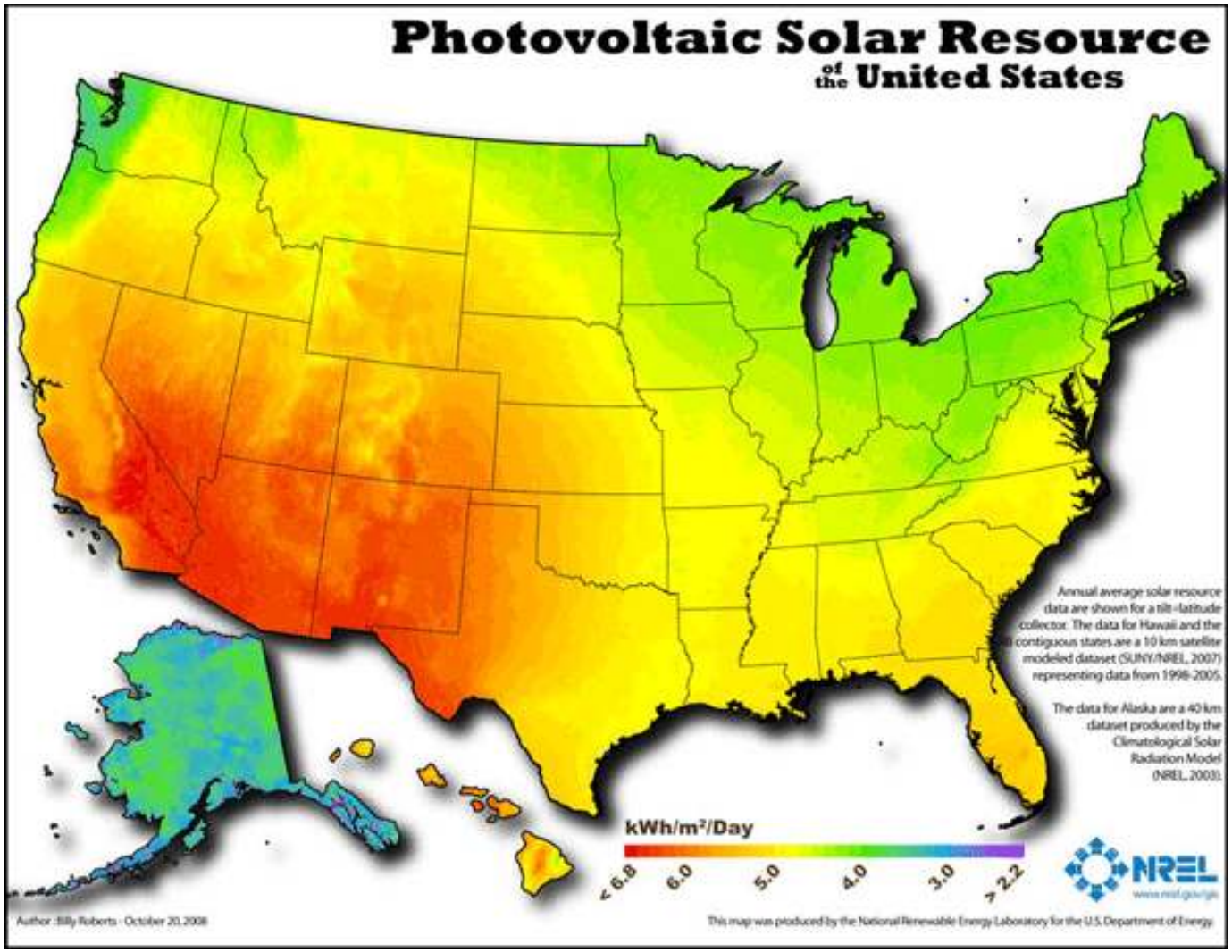
1 Quad is 1 Quadrillion (10^{15}) Btu

US Primary Energy Consumption



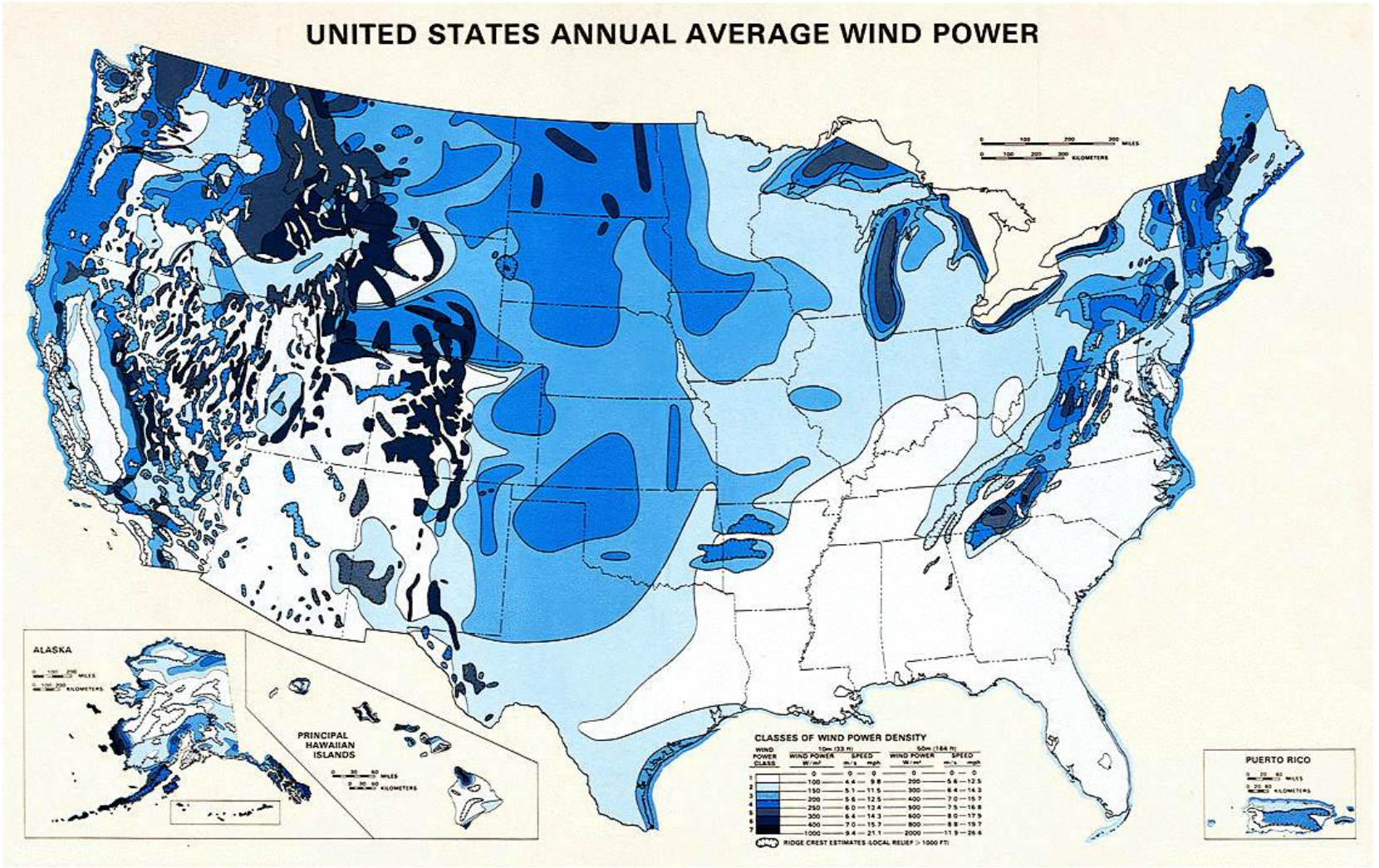
Source: Energy Information Administration (EIA), https://www.eia.gov/energyexplained/?page=us_energy_home

U.S. Solar Energy Resource Map



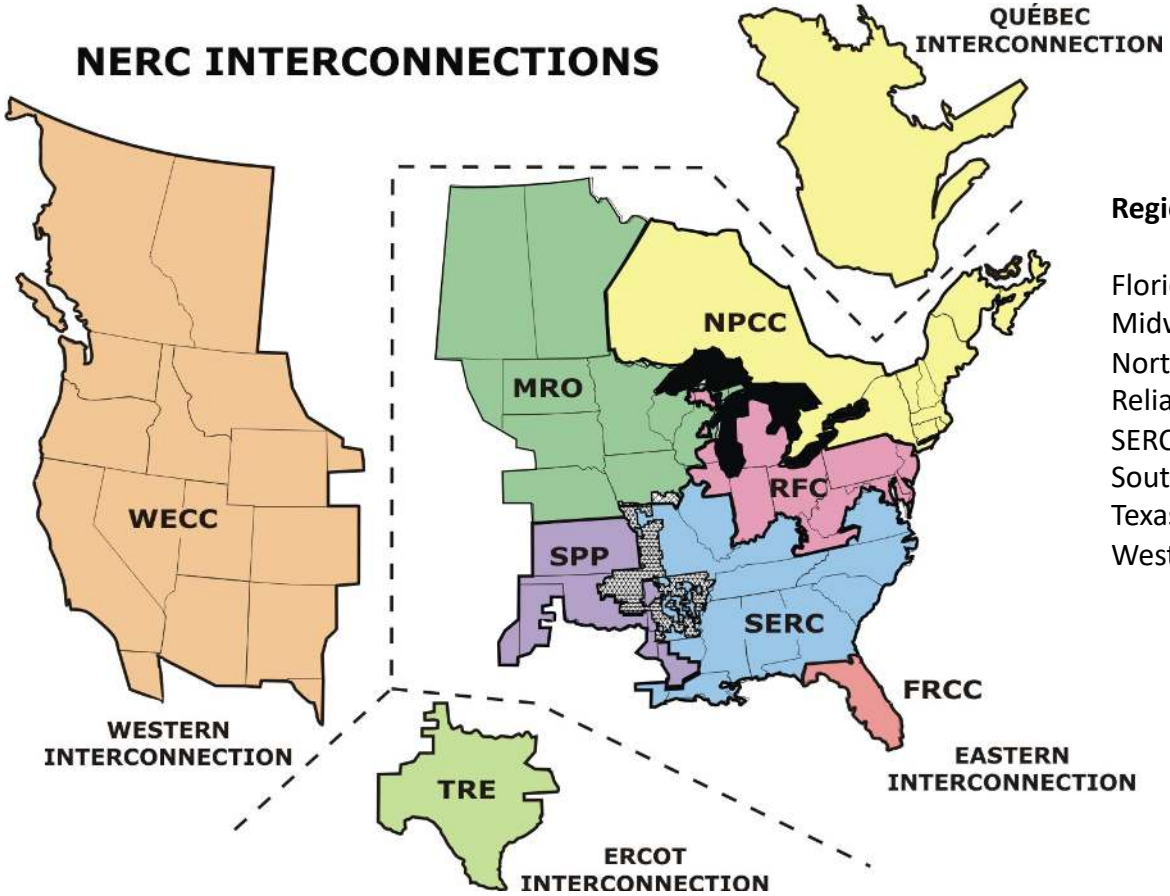
Source: National Renewable Energy Laboratory

U.S. Wind Energy Resource Map



Source: National Renewable Energy Laboratory

North America's Interconnected Grids



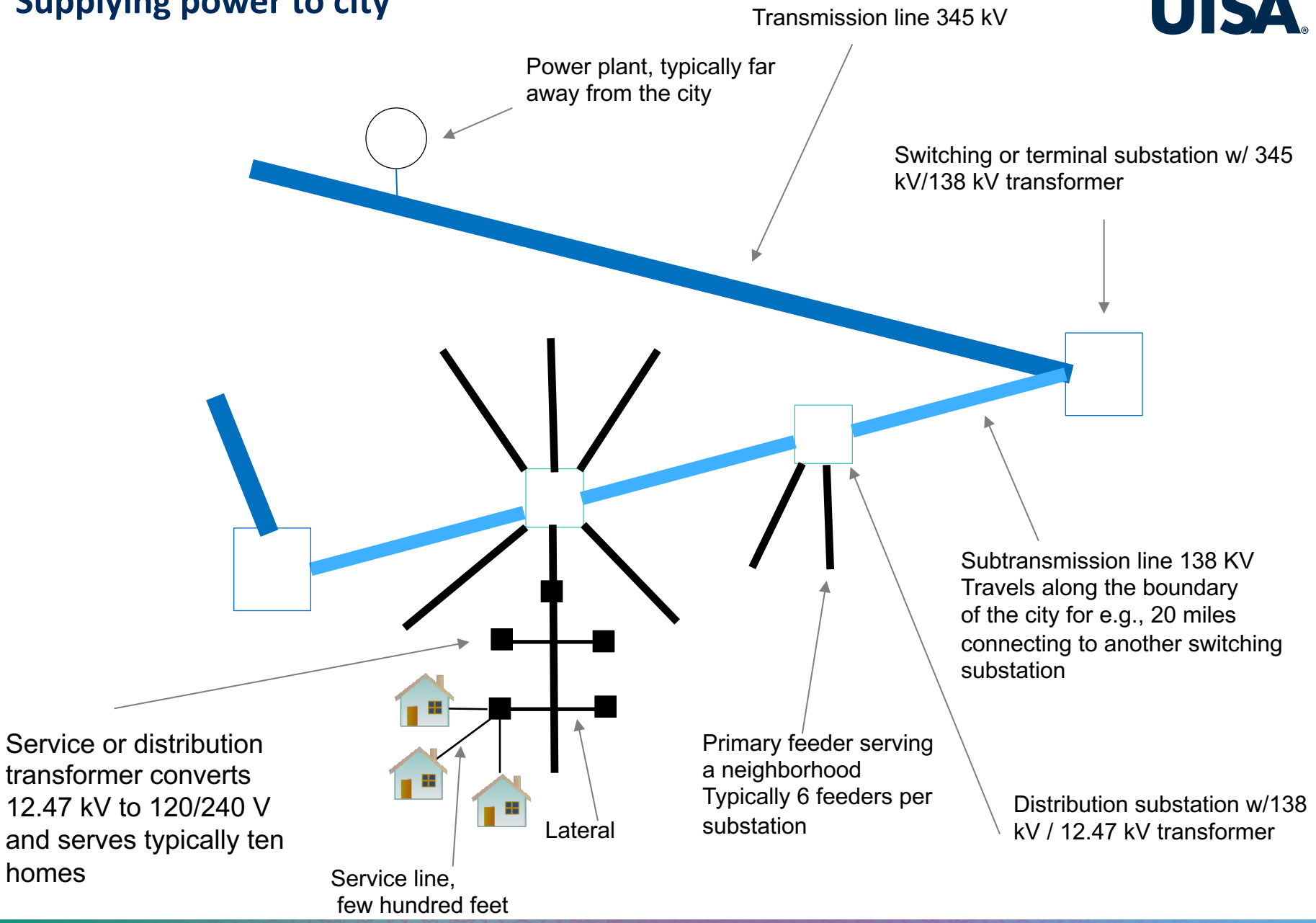
Regional Entities

Florida Reliability Coordinating Council (FRCC)
Midwest Reliability Organization (MRO)
Northeast Power Coordinating Council (NPCC)
Reliability*First* Corporation (RFC)
SERC Reliability Corporation (SERC)
Southwest Power Pool, RE (SPP)
Texas Regional Entity (TRE)
Western Electricity Coordinating Council (WECC)

Source: NERC

NERC: North American Electric Reliability Corporation

Supplying power to city



Power system operator objectives

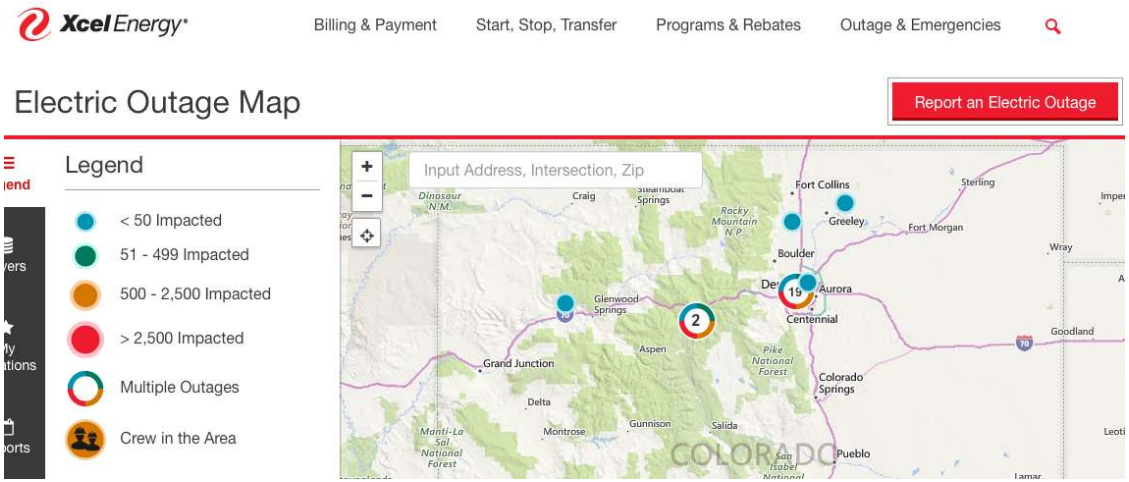
- Three-four different operators
- Market structure
- High-level objective
- Mostly regulated markets

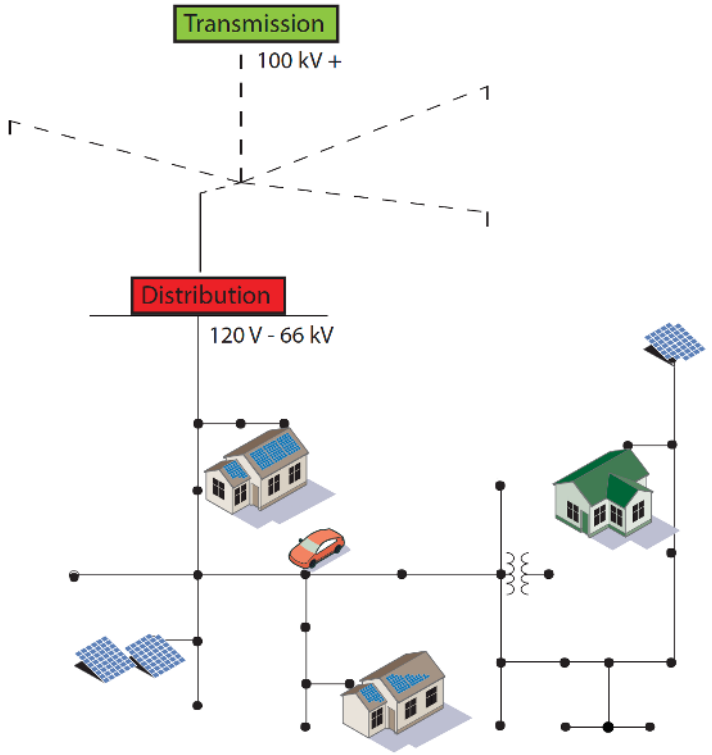
Part 2:

Smart Grids

What is a “smart grid”?

- More communication / sensors
- More distributed energy resources (DERs)
- Cleaner energy
- More modular systems
- Responds to climate disasters

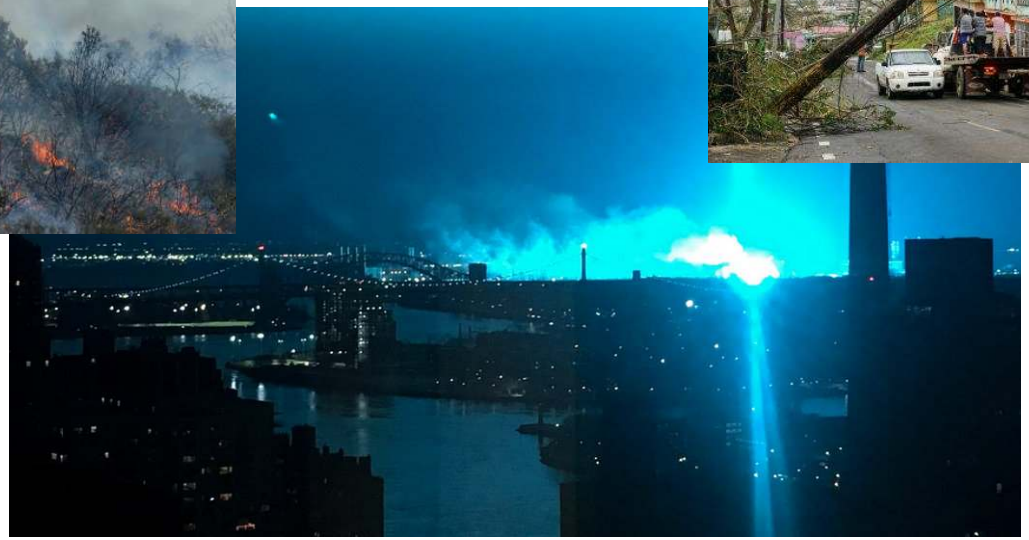




Many grid threats

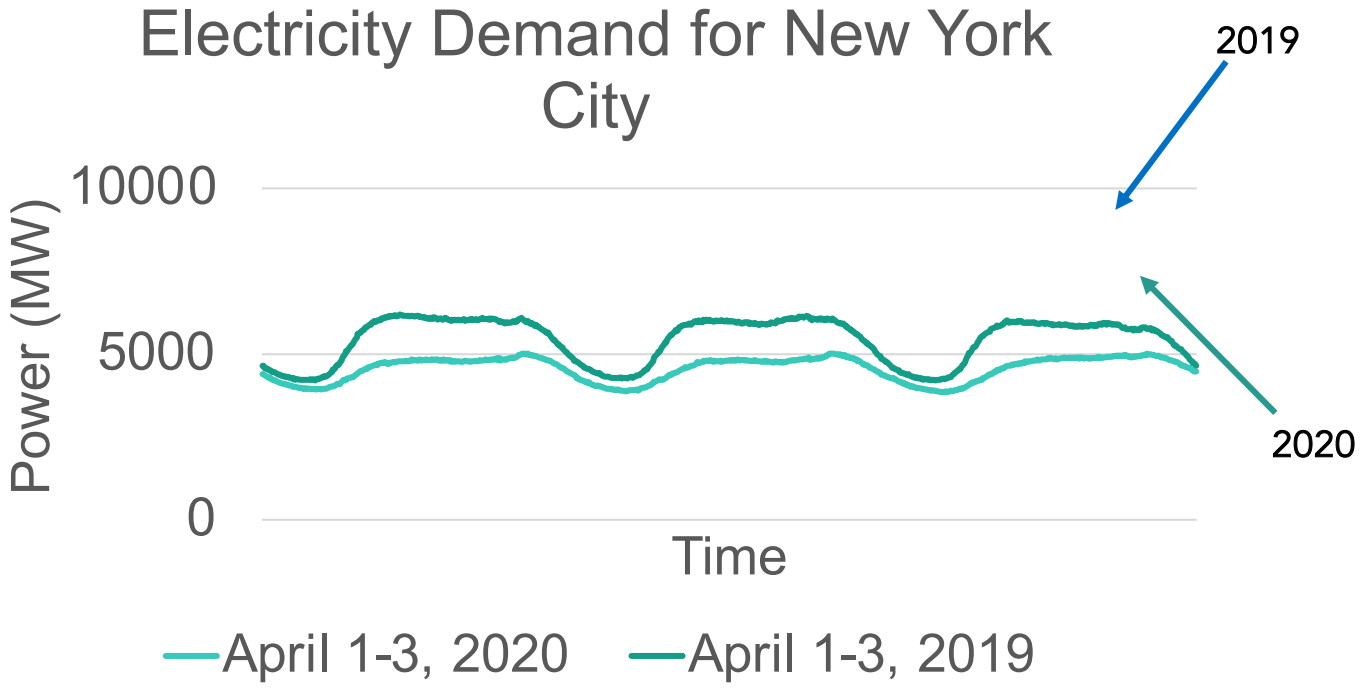
Wildfires, CA 2018-2020

Hurricane Maria, Puerto Rico 2017



NY substation arc fault 2018

How about the pandemic and stay-at-home orders?

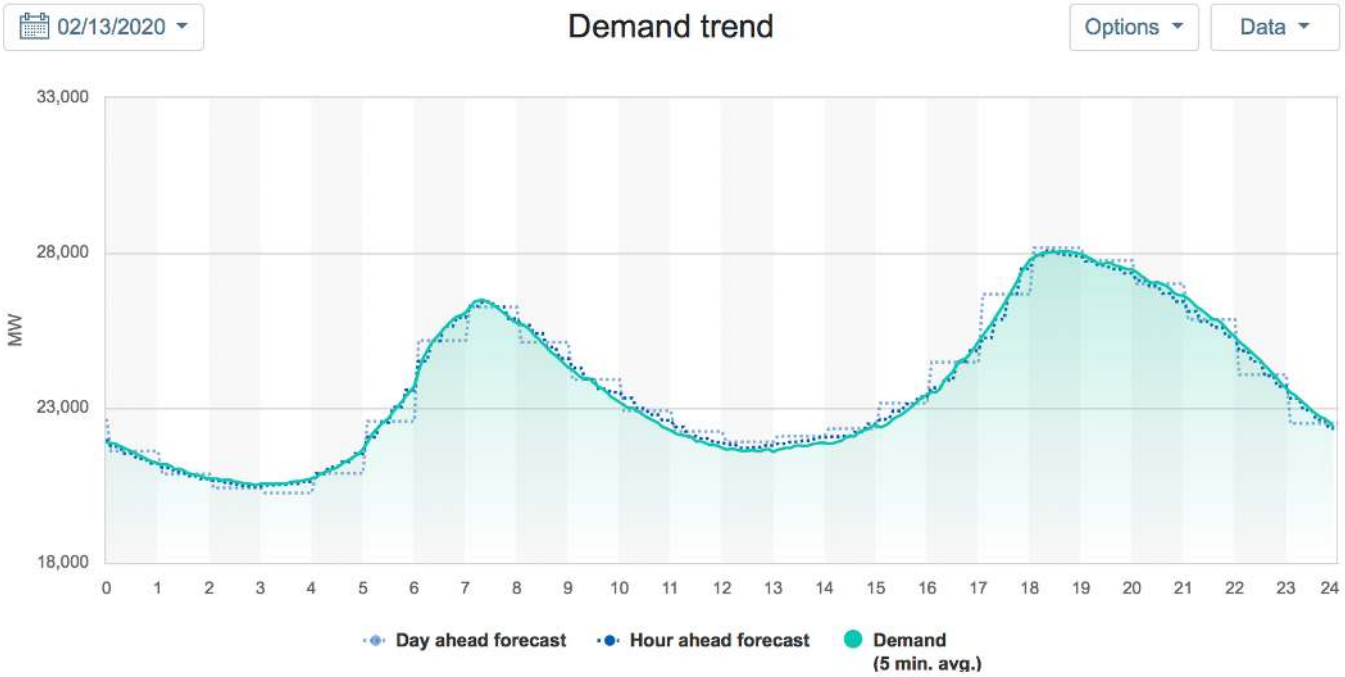


Drop of 20% / 1000 MW

1000 MW ≈ All the solar Installed in Colorado

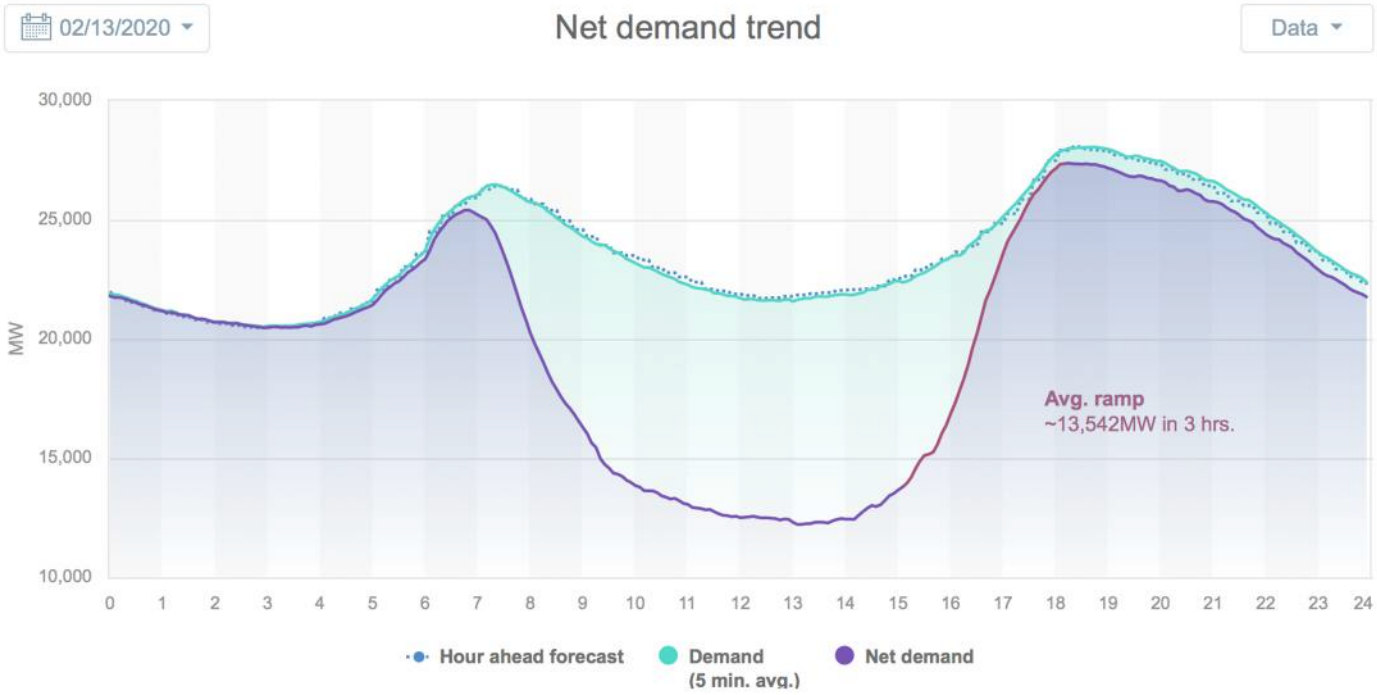
Data from NYISO's data portal (https://www.nyiso.com/energy-market-operational-data)

Typical Renewable Problems: Duck Curve



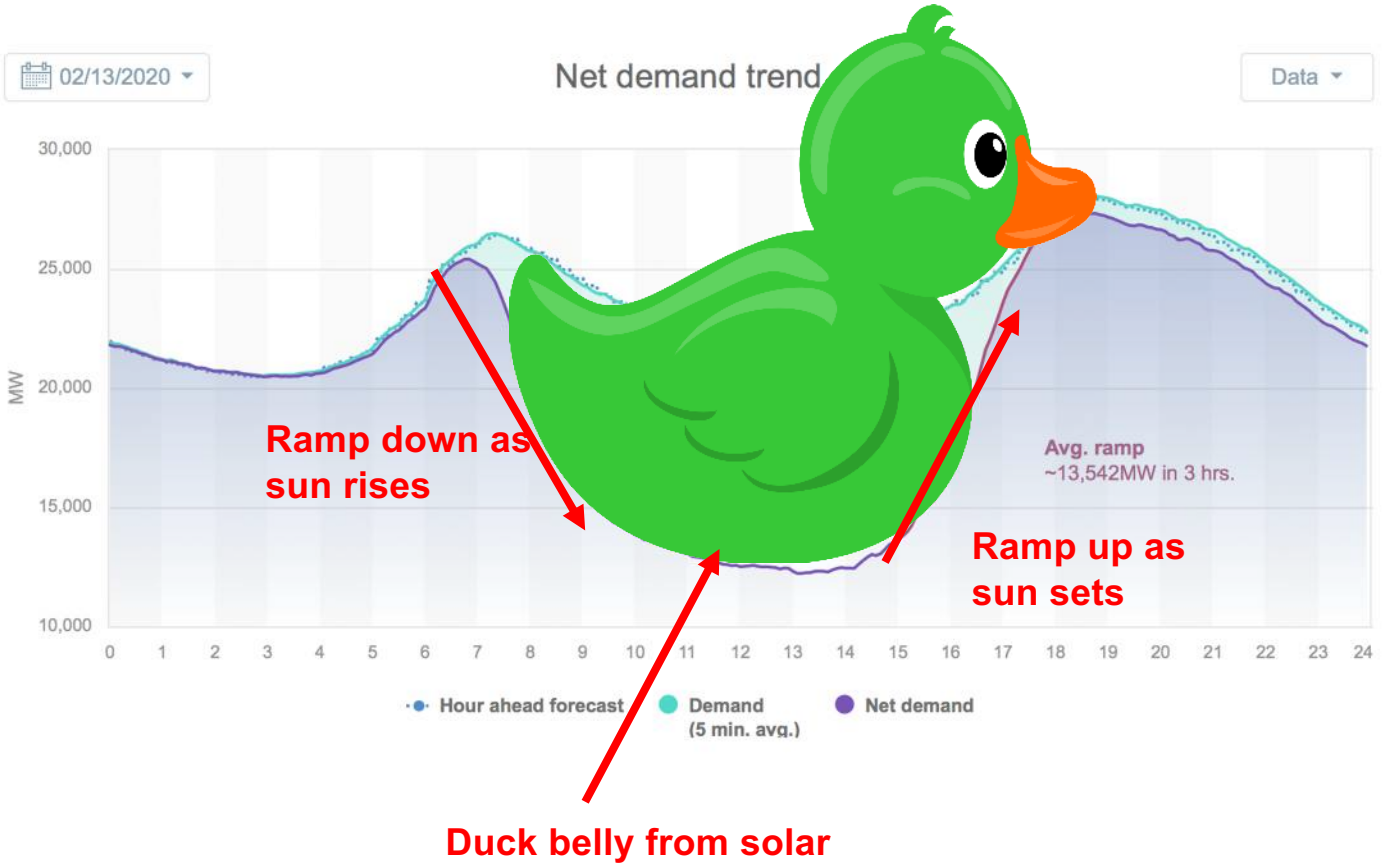
Source: California Independent System Operator (CAISO)

Subtract Solar and Wind = “Net Demand”

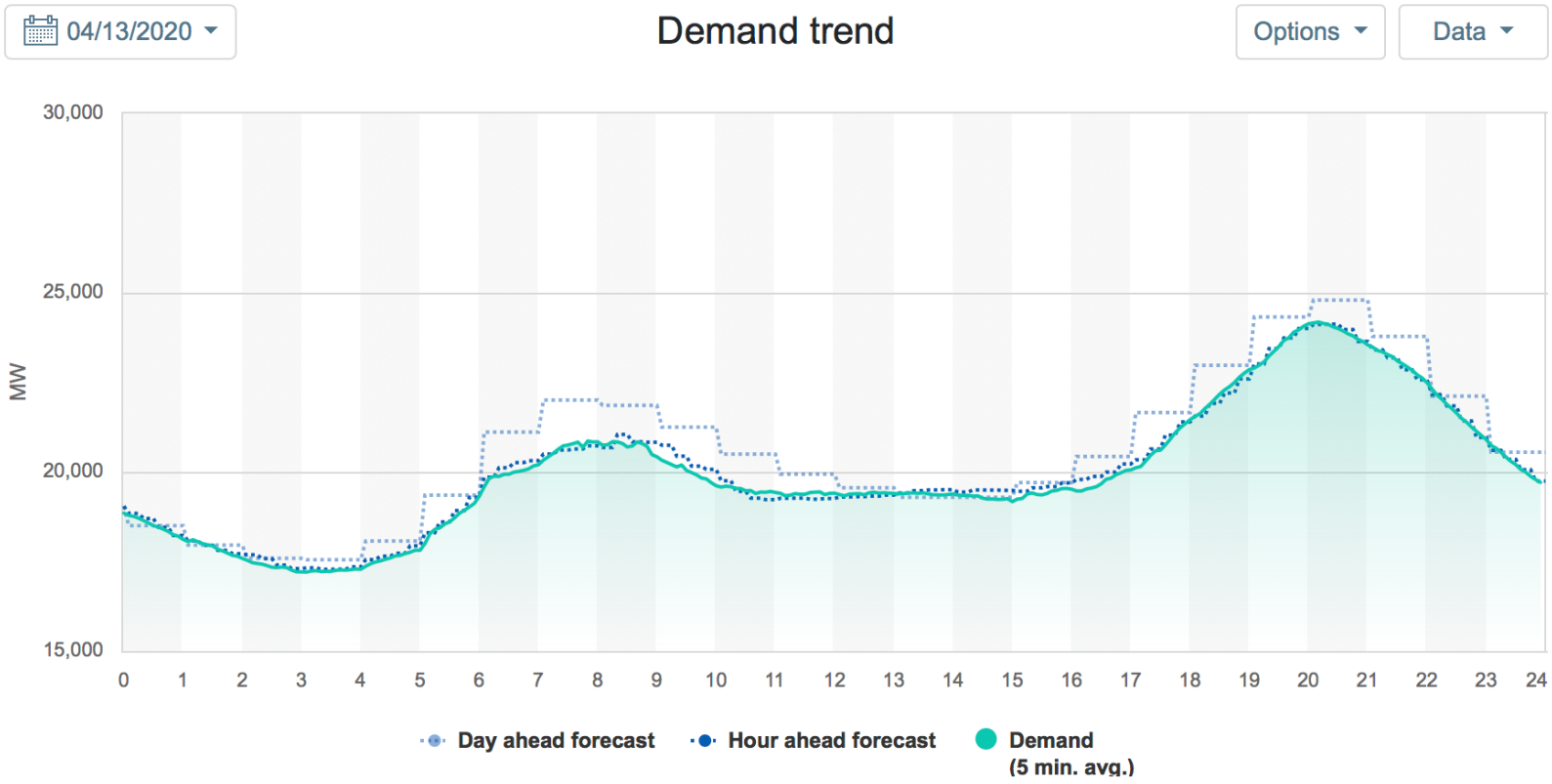


Source: California Independent System Operator (CAISO)

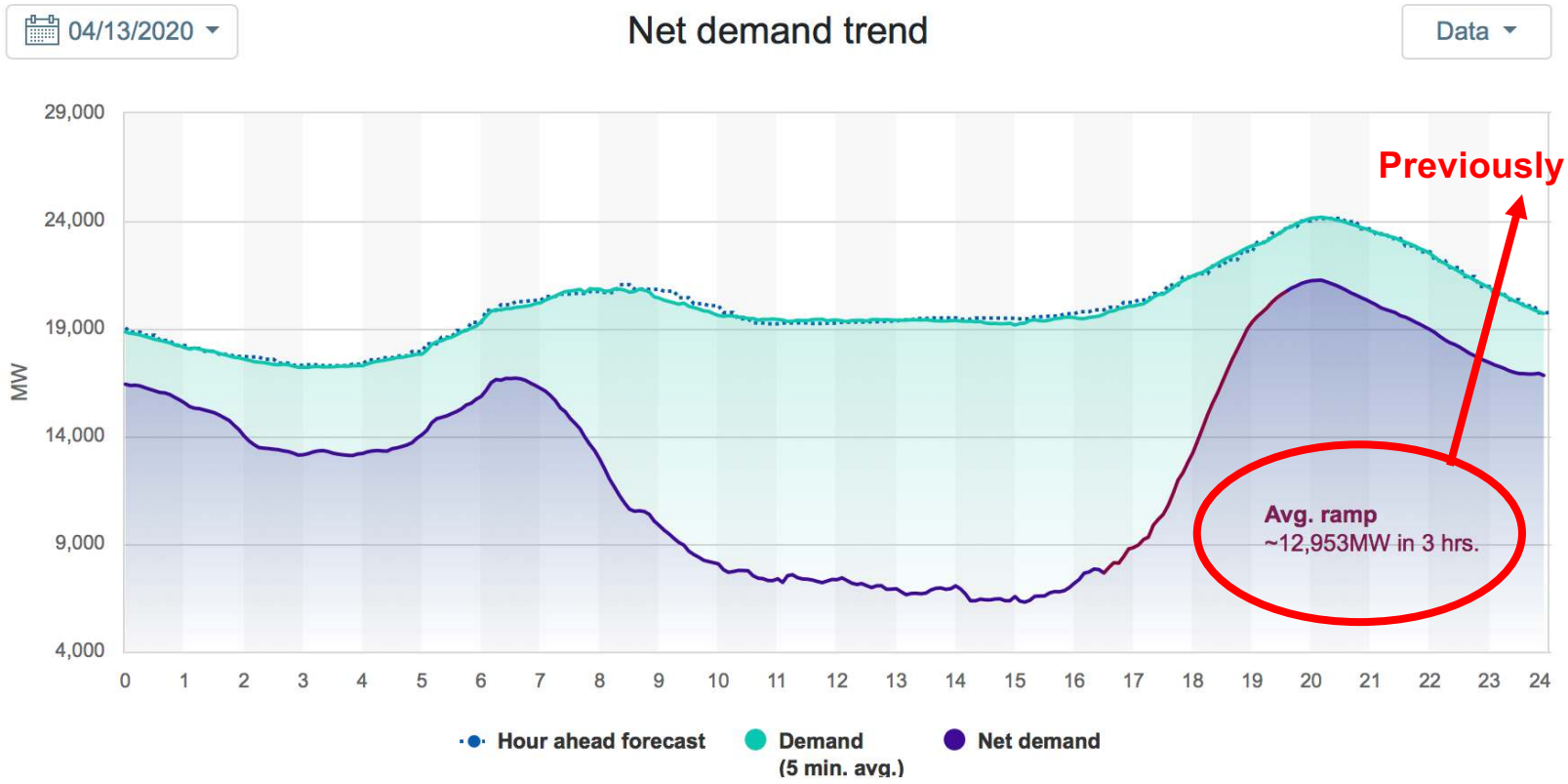
Duck curve: Sharp ramps



Duck Curve under COVID-19 : April 13

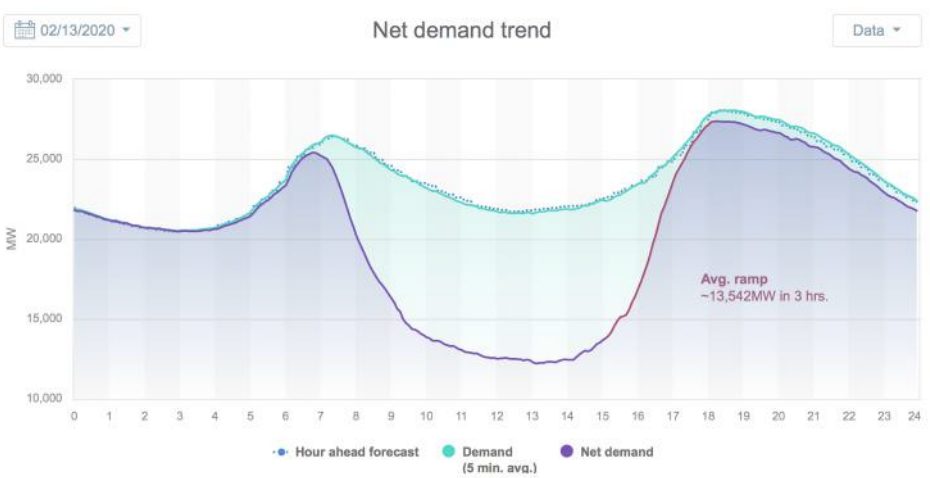


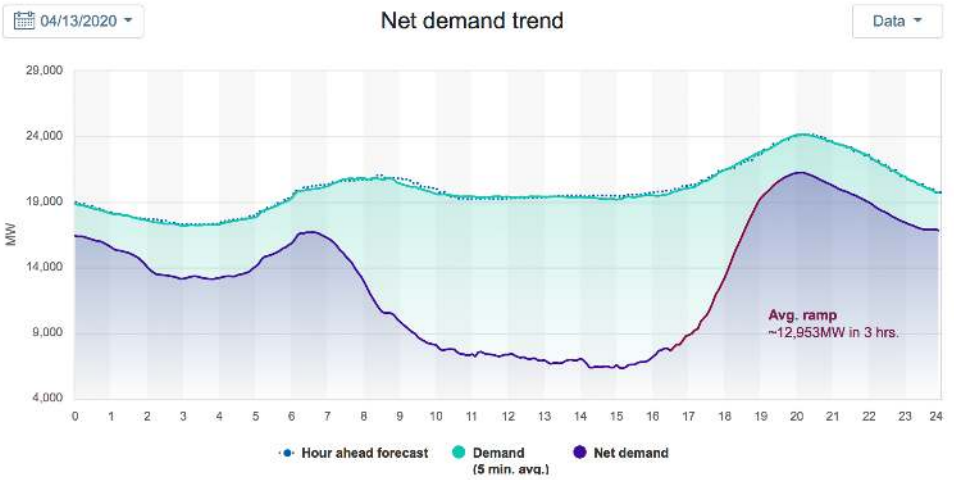
Duck Curve under COVID-19 : April 13



Duck Belly = Less Saggy

But not by as much as you'd expect due to overall demand decrease





Before stay-at-home

After stay-at-home

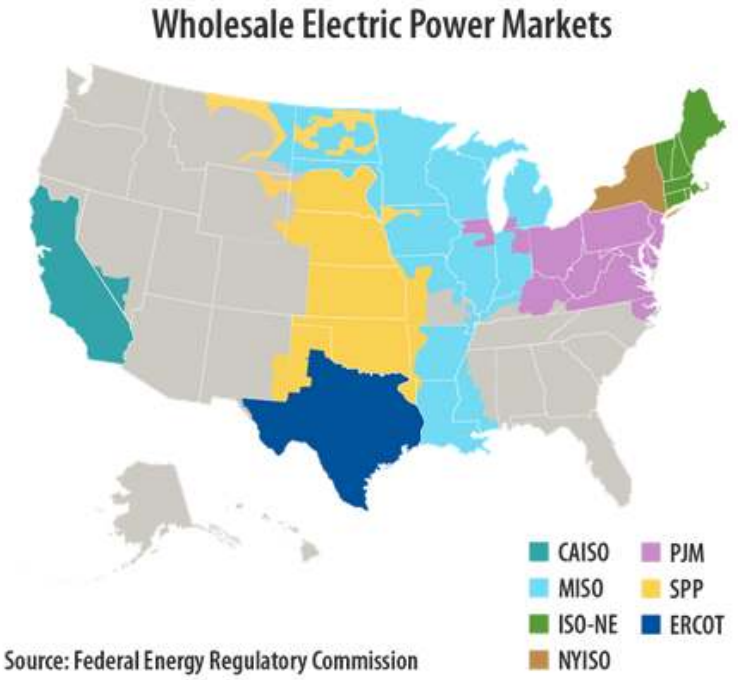
What is this doing to Electricity Markets?

Typically, rare events (natural disasters, heat waves, blackouts) have negative impacts on prices

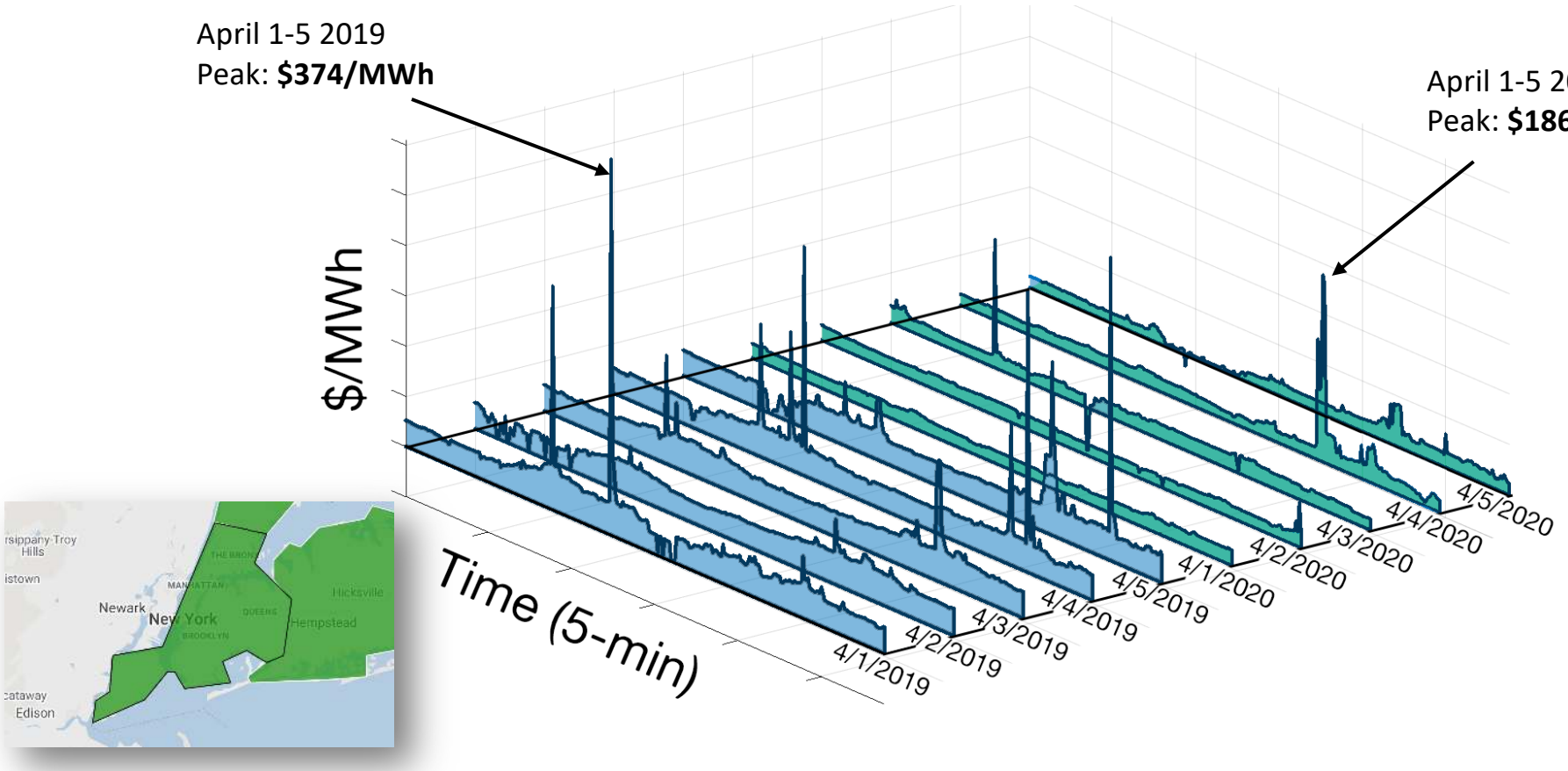
But under COVID-19, prices are actually decreasing due to decreased demand

Resulting in market participants (generating companies) making less money

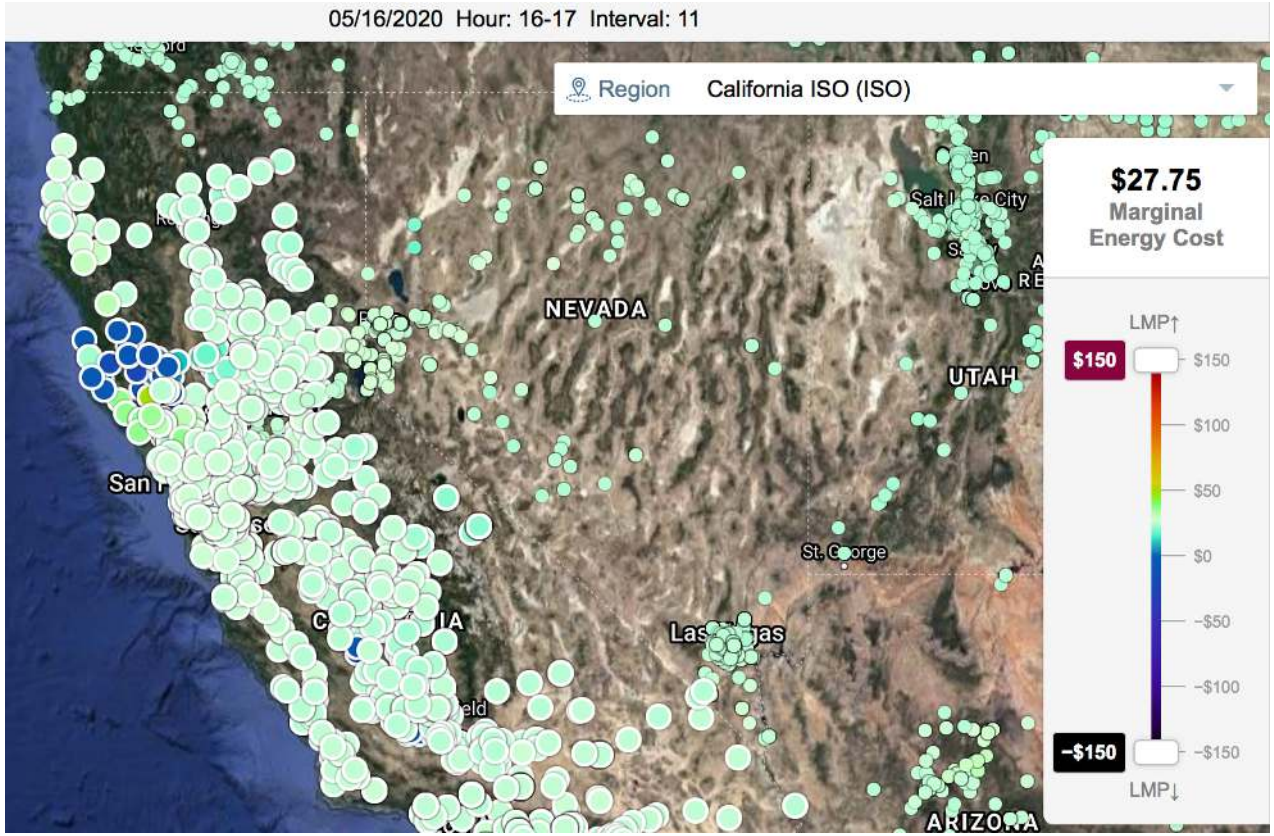
(Note: this would also result in generators in non-competitive areas to lose revenue).



NYC Locational Marginal Price: April 2019 vs 2020



Electricity Prices are going negative in many areas!!!



Supply is exceeding demand

Might be more expensive to curtail renewables or shut off power plants than to pay people to use more power

Smart grids summary

- Remember the objective of power system operators
- Smart grids are the future but there's major challenges
  - More renewable energy => more uncertainty
  - More communication networks => more cyber-security events
  - Increased population => more stress on the system
  - …

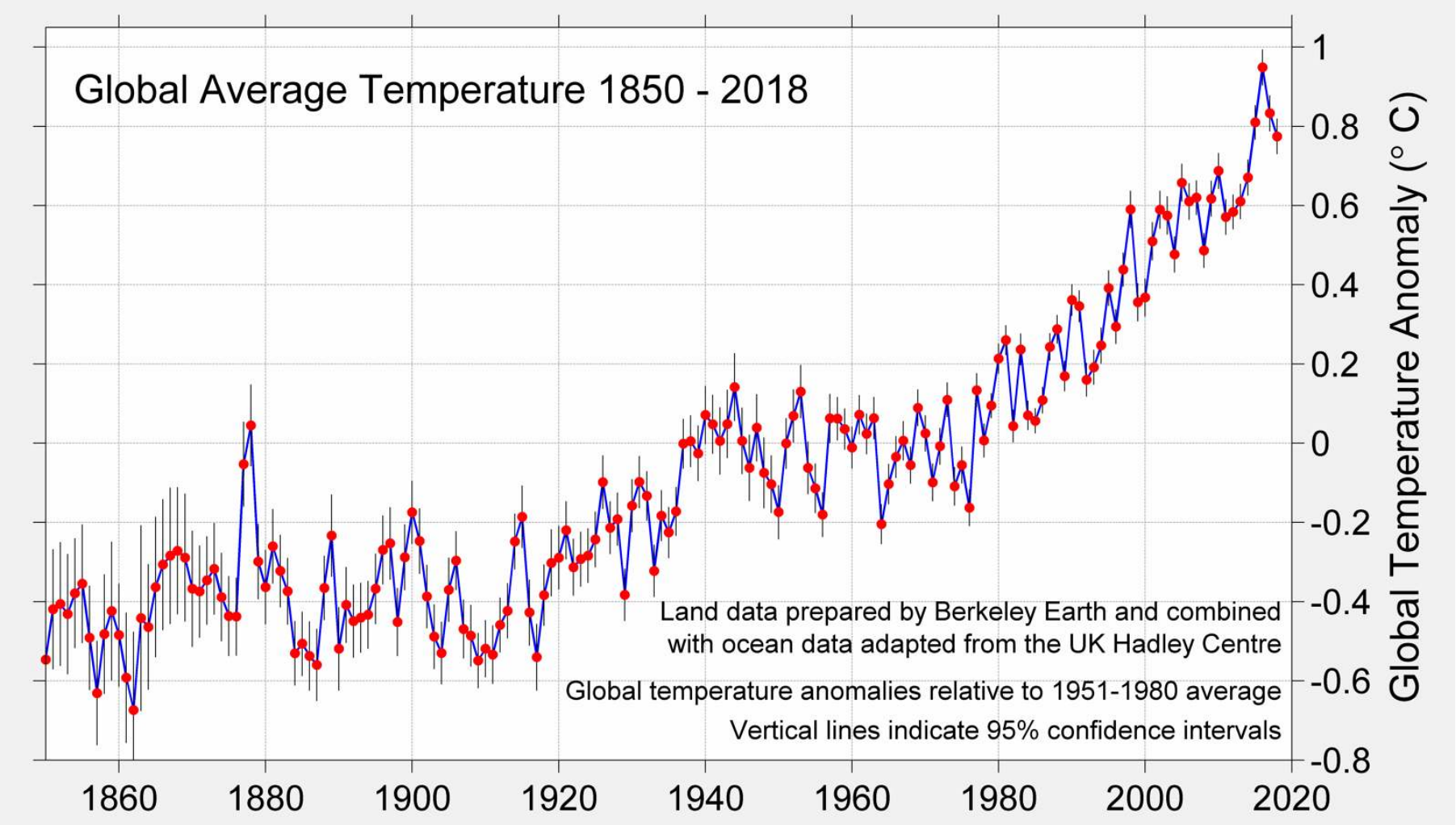
Part 3:

Climate Change

Overview

- Introduction to Climate Change
  - Causes of Global Climate Change
- Effects of Climate Change
  - Melting Ice and Rising Sea Level
  - Changes in Precipitation Patterns
  - Effects on Organisms
  - Effects on Human Health
  - Effects on Agriculture
- Dealing with Global Climate Change

Climate Change—Mean Annual Global Temperature 1960-2005



Climate Change Terminology

- Greenhouse Gas
  - Gas that absorbs infrared radiation
  - Ex: Carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and tropospheric ozone
- Positive Feedback
  - Change in some condition triggers a response that intensifies the changed condition
- Infrared Radiation
  - Radiation that has a wavelength that is longer than that of visible light, but shorter than that of radio waves
- Greenhouse Effect
  - Increase of heat in a system where energy enters (often as light), is absorbed as heat, and released sometime later

Climate Change

- Evidence for Climate Change
  - 11 of the 12 years between 1995 and 2006 were among the twelve warmest years since the mid-1800s
  - Phenological spring in N. hemisphere now comes 6 days earlier
  - Trend continues to 2020
- Warming is not due to natural causes
  - Human produced greenhouse gases are most plausible explanation

Causes

- Greenhouse gas concentrations increasing

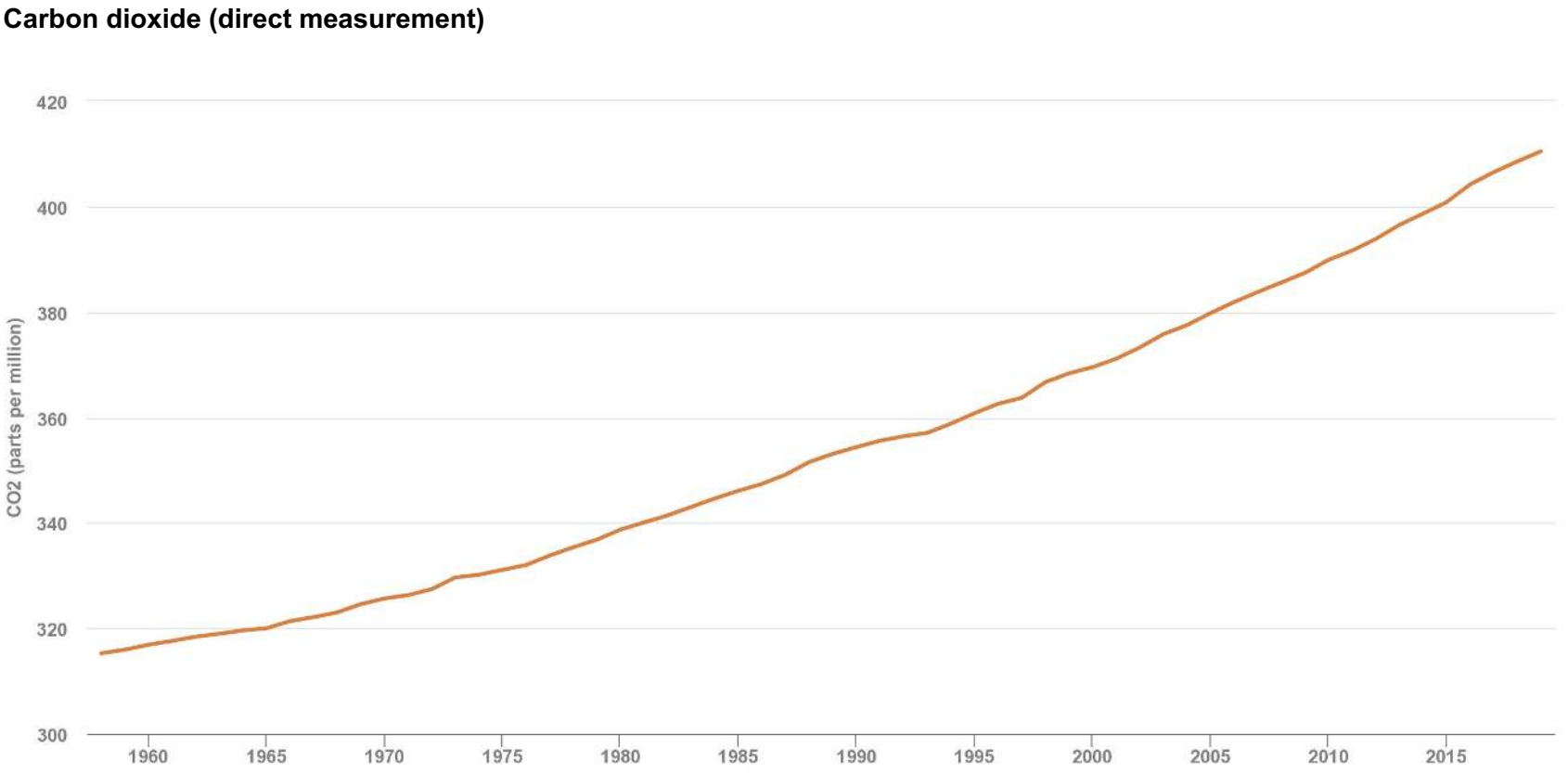
Gas	Estimated Preindustrial Concentration[1]	2006 Concentration[5]
Carbon dioxide	288 ppm[2]	382 ppm
Methane	848 ppb[3]	1,783 ppb
Nitrous oxide	285 ppb	320 ppb
Chlorofluorocarbon-12	0 ppt[4]	535 ppt
Chlorofluorocarbon-11	0 ppt	249 ppt

[1] The preindustrial value is for the 17th and 18th centuries. There have been significant variations, as, for example, over the course of the ice ages.
[2] ppm = parts per million.
[3] ppb = parts per billion.
[4] ppt = parts per trillion.
[5] 2006 annual average.
Source: Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory.

Causes

- Increased concentration of CO_2
  - Burning fossil fuels in cars, industry and homes, deforestation, burning of forests

Global CO_2 emissions have risen steadily in recent decades. Between 2008 and 2017, fossil fuel CO_2 emissions increased at a rate of 1.5 percent per year. As of early 2019, CO_2 emissions had reached 410 parts per million (ppm).



Melting Ice and Rising Sea Levels

1957

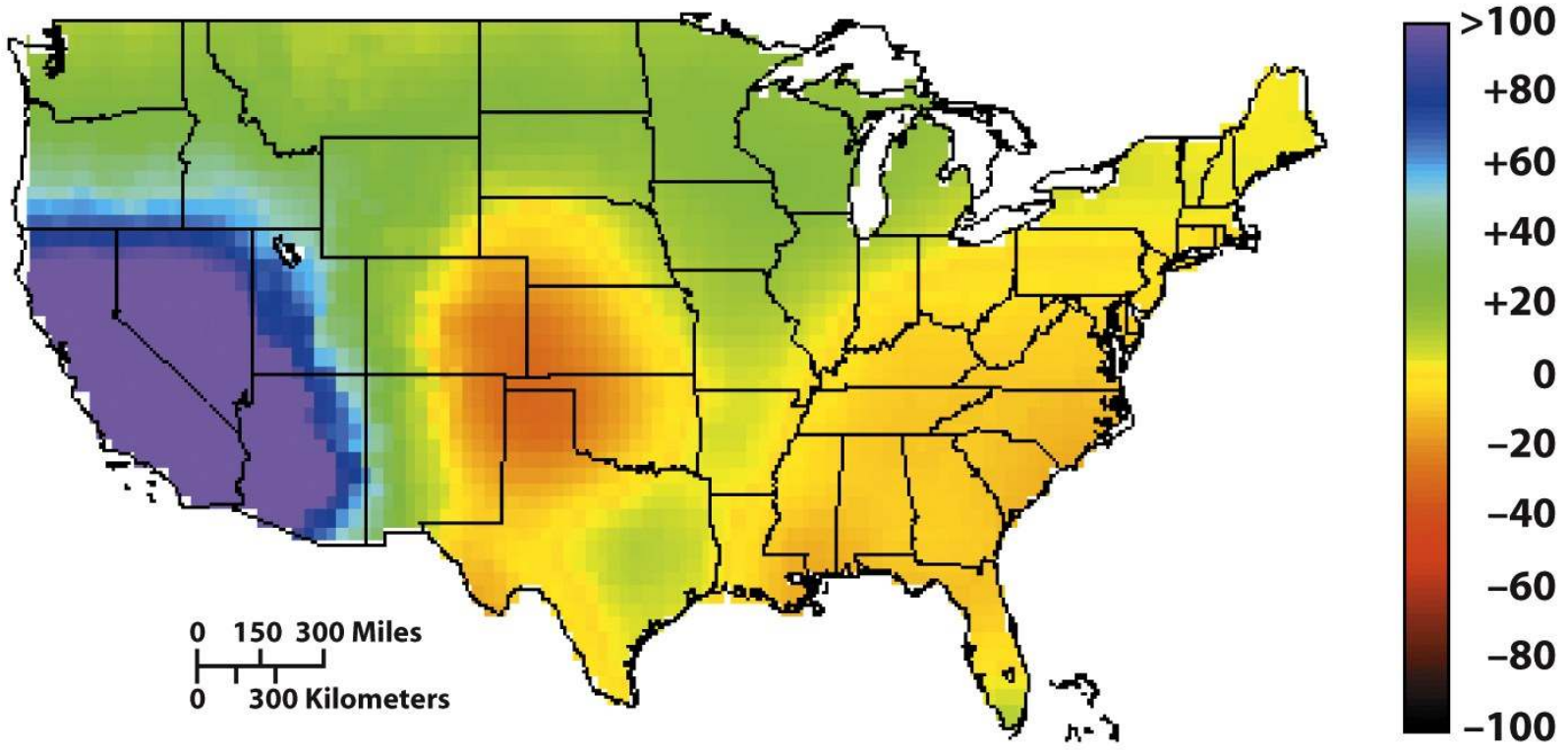
1998

Case-In-Point Impacts in Fragile Areas

- Eskimo Inuit live traditional life dictated by freezing climate
- Climate change is altering their existence
  - Wildlife are smaller or displaced
  - Reduced snow cover and shorter river ice seasons
  - Thawing of permafrost (right)

Effects of Global Climate Change- Changing Precipitation Patterns

- Some areas will get more water, some areas will have greater droughts
  - Ex: Hurricanes will likely get stronger



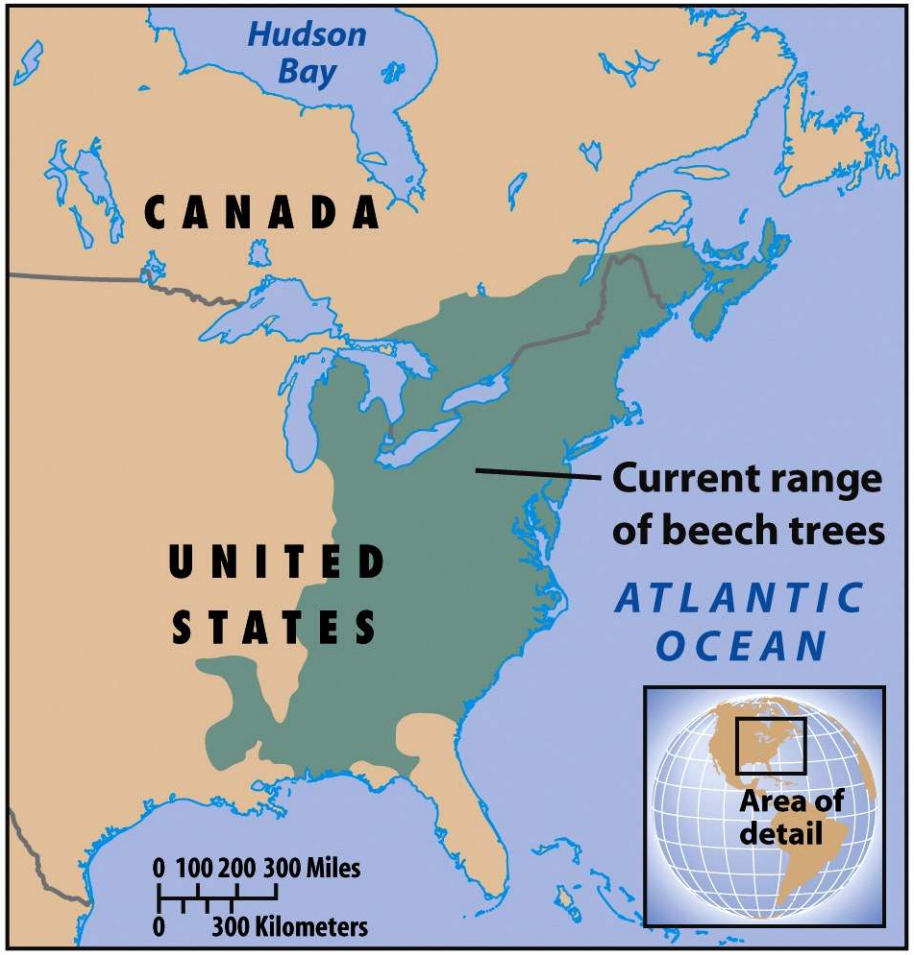
Effects on Organisms

- Zooplankton in parts of California Current have decreased by 80% since 1951
  - Effecting entire food chain
- Decline in krill around Antarctica
  - Caused decrease in penguin populations
- Species have shifted their geographic range
- Migrating birds are returning to summer homes earlier
  - Food is not available at this time

Effects on Organisms – Coral Reefs

- Coral reefs can be bleached (right) due to increase in water temperature
  - Affects coral symbiotes and makes them more susceptible to diseases to which they would otherwise be immune

Effect on Organisms – Vegetation Beech Tree Range



Effects on Human Health

- Increased number of heat-related illnesses and deaths

Disease	Vector	Present Distribution	Likelihood of Distribution Changes with Climate Warming
Malaria	Mosquito	Tropics, subtropics	Highly likely
Dengue fever	Mosquito	Tropics, subtropics	Very likely
Schistosomiasis	Water snails	Tropics, subtropics	Very likely
Yellow fever	Mosquito	Tropical South America and Africa	Very likely
Onchocerciasis	Blackfly	Africa, Latin America	Very likely
Lymphatic filariasis	Mosquito	Tropics, subtropics	Likely
Leishmaniasis	Phlebotomine sandfly	Asia, southern Europe, Africa, Americas	Likely
American trypanosomiasis	Triatomine bug	Central and South America	Likely
African trypanosomiasis	Tsetse fly	Tropical Africa	Likely
Dracunculiasis	Copepod	Central and West Africa	Unknown

Source: From Table 4.21 in *Health and Environment in Sustainable Development: Five Years After the Summit*, World Health Organization (1997), and based on an unpublished assessment prepared by A.J. McMichael et al.

Reduction of Carbon Emissions

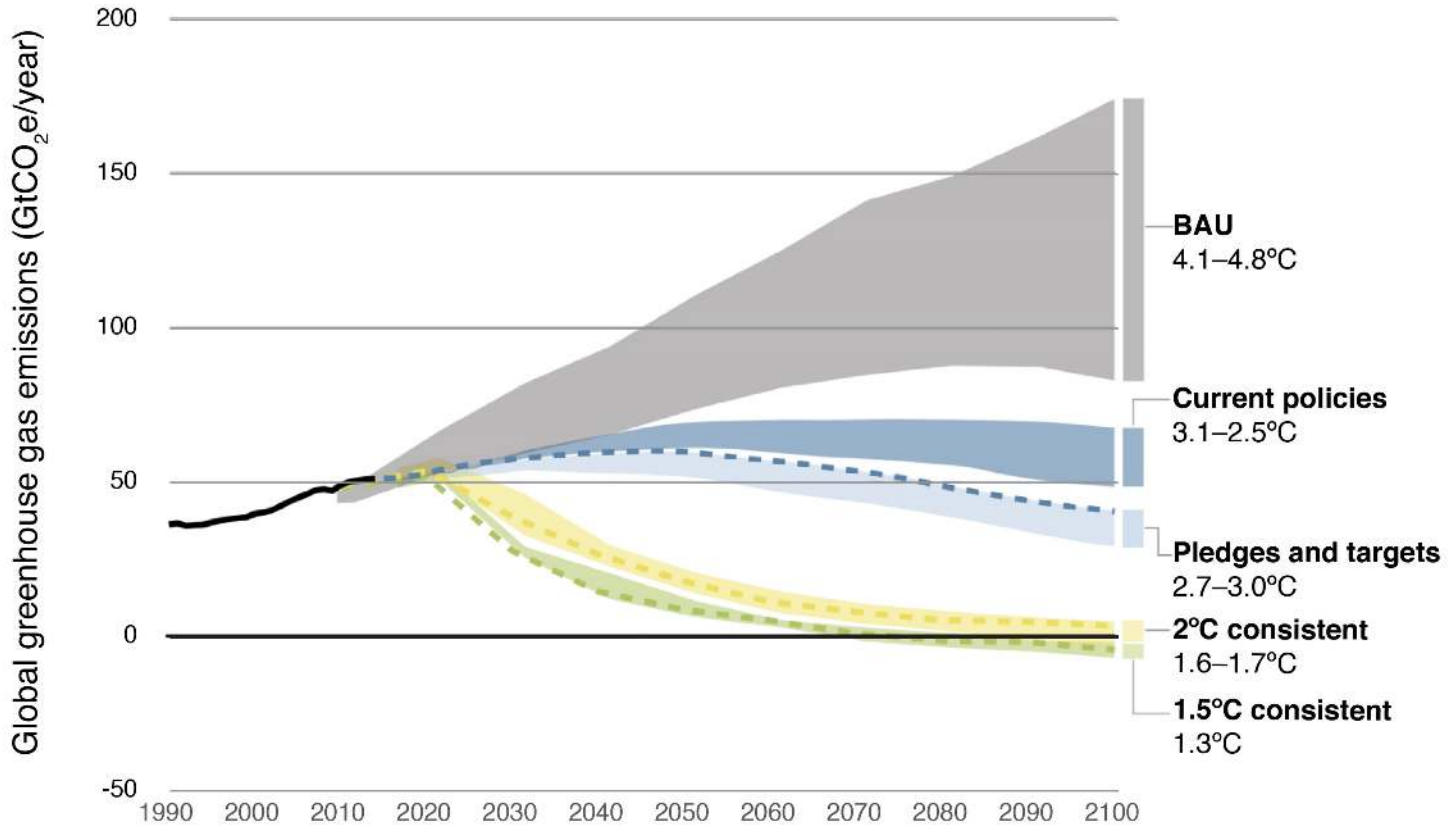
- Burn less fossil fuel: Turn down your thermostat
- Plant Trees for shade and CO_2 uptake
- Insulate your house
- Replace old appliances
- Use compact fluorescence light bulbs
- Use renewable energy

Current vs. Other Climate Policies

Current policies are expected to lead to warming of 3.3 degrees Celsius by 2100; under business-as-usual, warming is projected to reach over 4 degrees Celsius by 2100.

At current rates of warming, it is projected that the world will reach the 1.5-degree threshold between 2030 and 2052.

Greenhouse gas emissions: warming projected by 2100

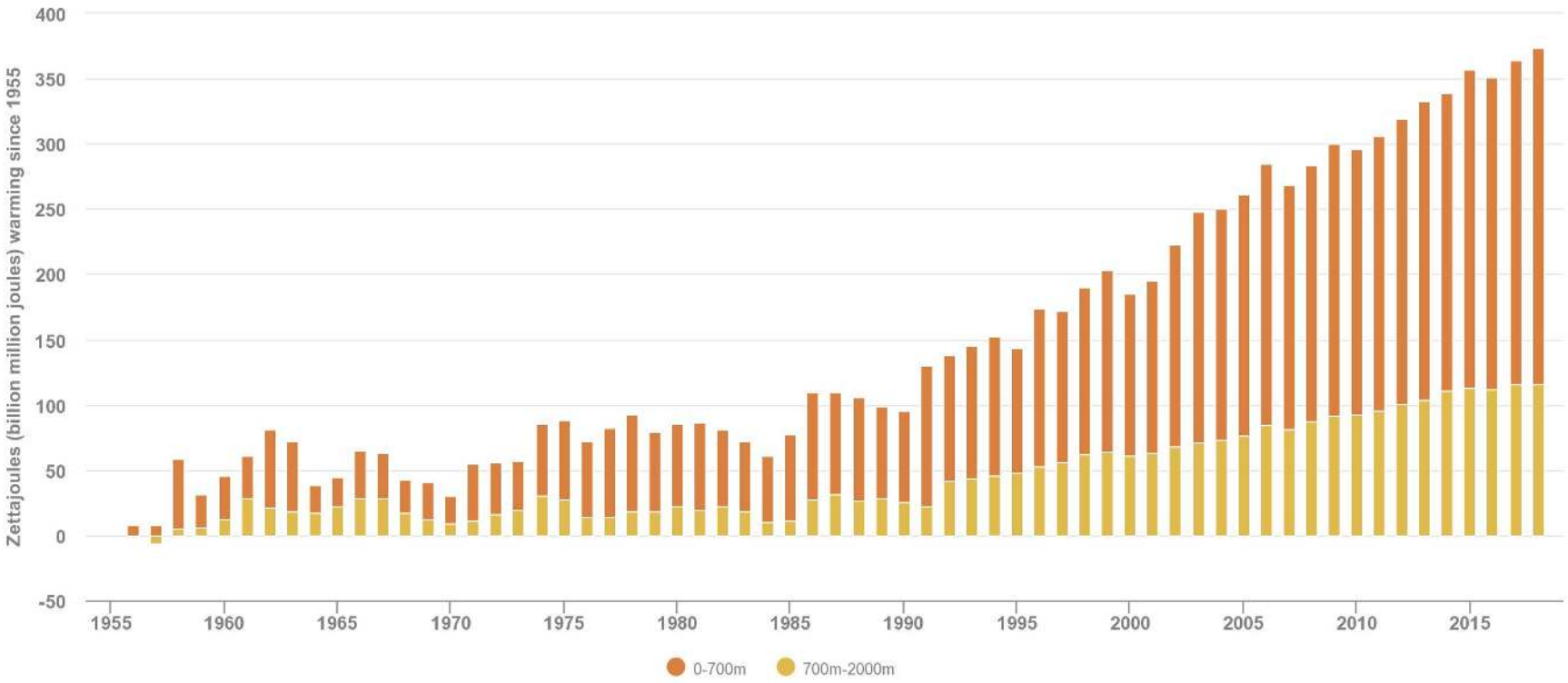


Ocean Heating

The year 2018 set a new record of ocean heating. The past five years (2014 to 2018) have ranked as the five warmest years for ocean heat content, confirming a trend that ocean warming has been accelerating since the 1990s.

New research suggests that the rate of ocean warming is much faster than previously predicted. A series of analyses indicate that the ocean is absorbing excess heat 40 percent faster than the IPCC estimated in its Fifth Assessment Report in 2013

Global ocean heat content



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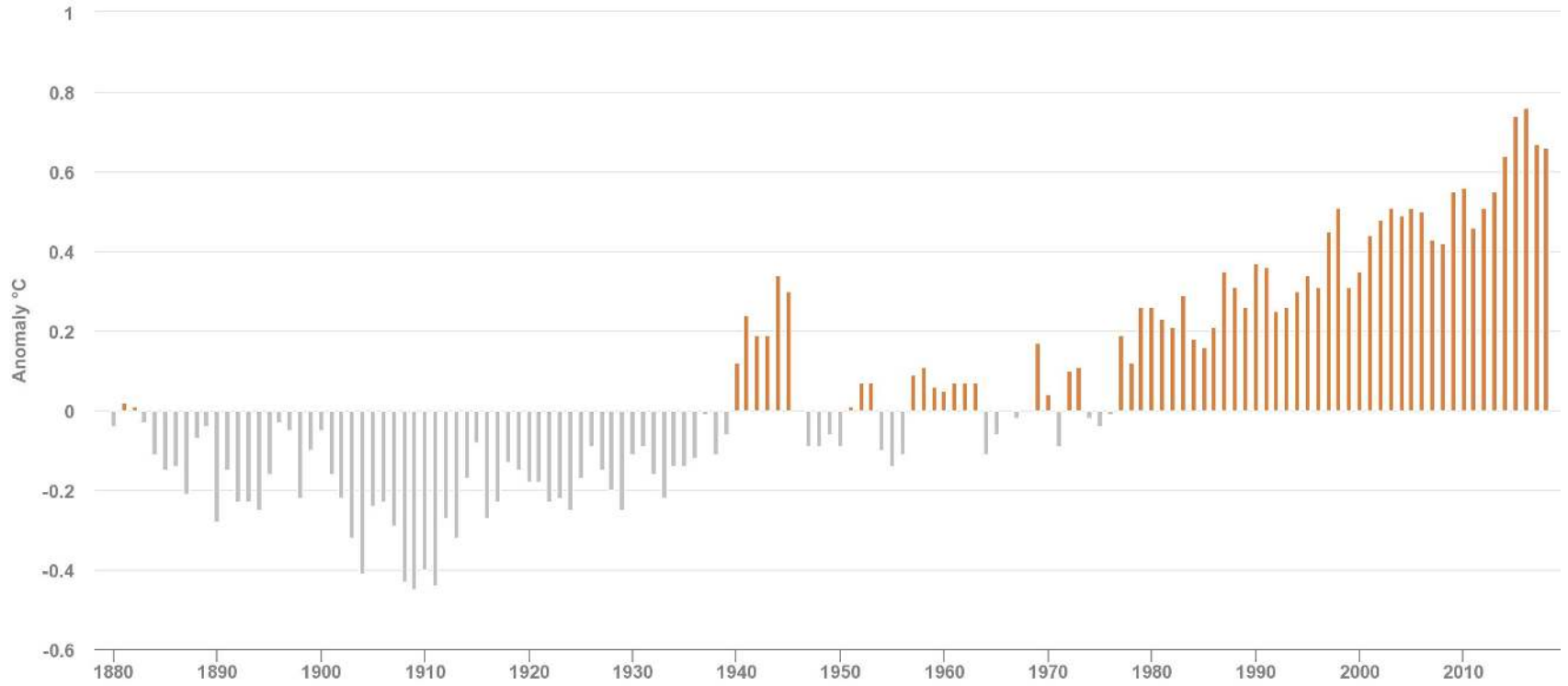
Global Ocean Temperatures

The average global sea surface temperature—the temperature from the upper few meters of the ocean—has risen about 0.12 degrees Celsius per decade over the past 50 years, with a higher rate of warming in recent years.

These higher temperatures are contributing to: mass bleaching of coral reefs, die offs of other ecosystems with low thermal sensitivity (such as kelp and intertidal communities), shifts in fisheries stocks due to temperature, a reduction in algae productivity, and more frequent and intense extreme weather events.

Global ocean temperature anomaly

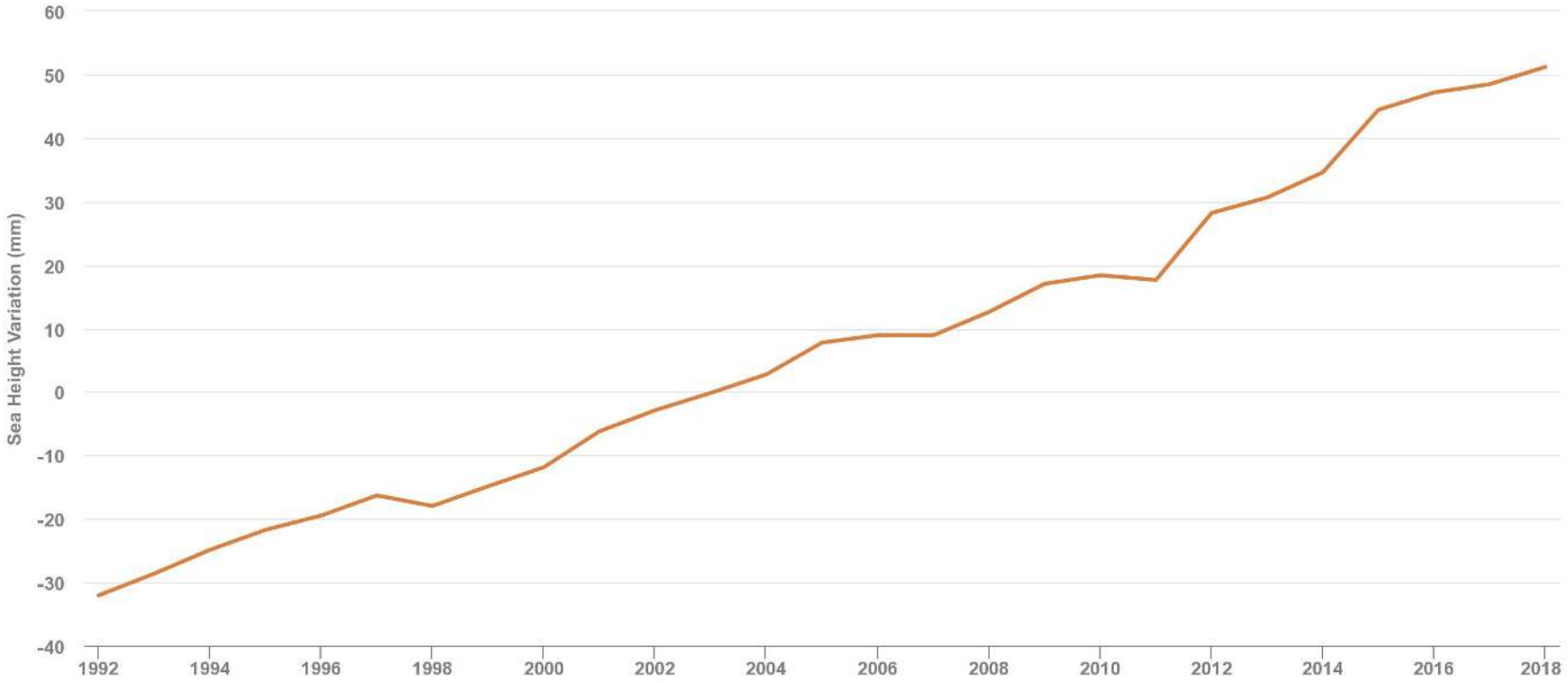


Sea Level Change

The rate of global sea-level rise nearly doubled from 1.7 mm annually throughout most of the 20th century to 3.1 mm (0.12 inch) per year since 1993.

About one-third of the rise in global sea level has been caused by the thermal expansion of water. The increase in ocean heat in 2018 led to a 29.5 millimeter (1.2 inches) global mean sea-level rise above the 1981–2010 average. Sea-level rise is further exacerbated by melting of ice sheets in the polar regions.

Global sea level change (satellite observations)

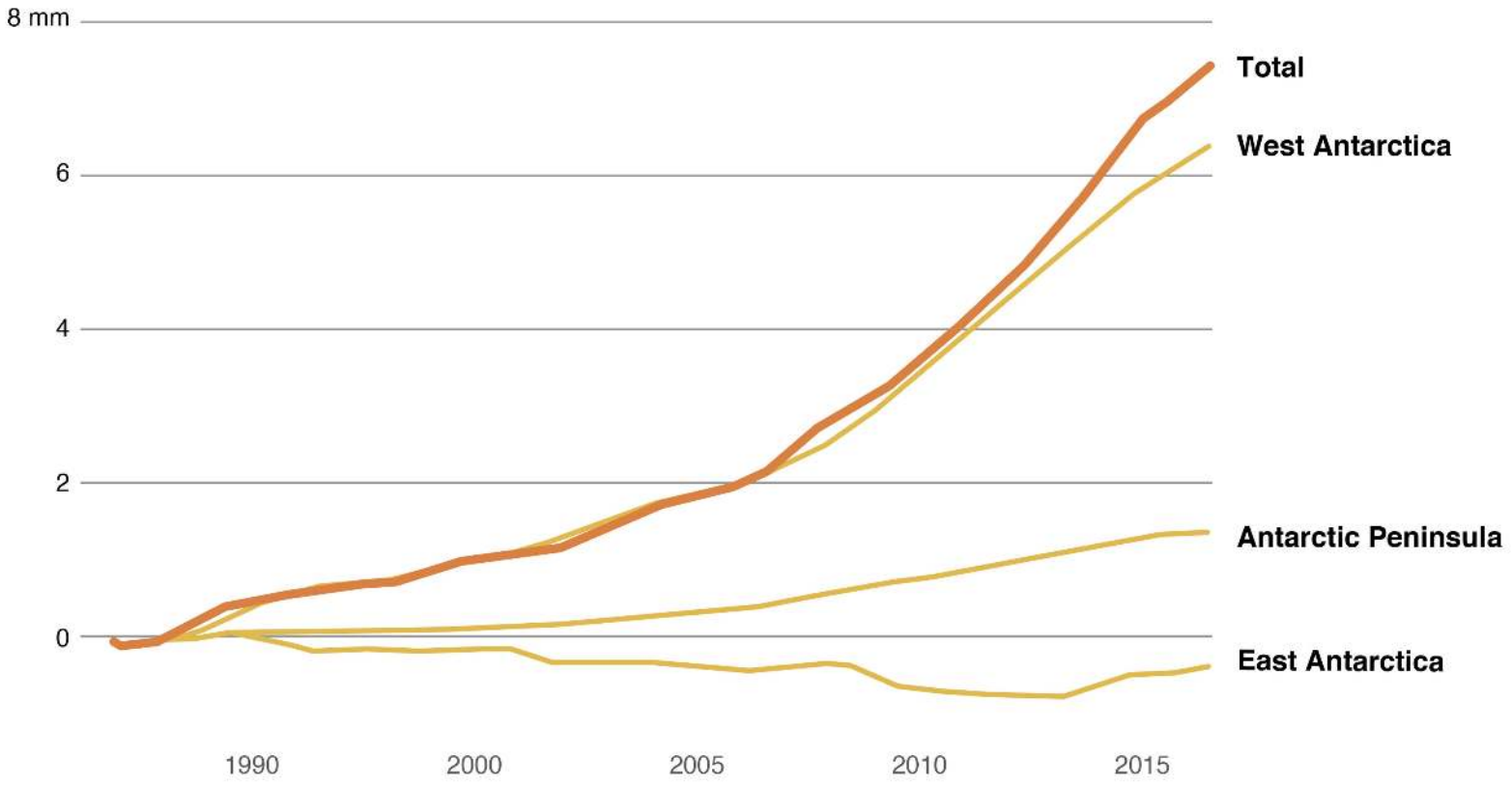


Antarctica Ice Loss

Since 2012, the amount of annual ice loss in Antarctica has tripled, increasing the global sea level by 3 millimeters (0.12 inch).

By 2100, global sea level could rise 65 centimeters (21 inches) if the rate of sea-level rise continues to accelerate at the observed rate; ice melt from Antarctica could account for nearly 25 percent of this rise.

Antarctic ice sheet contribution to global sea level

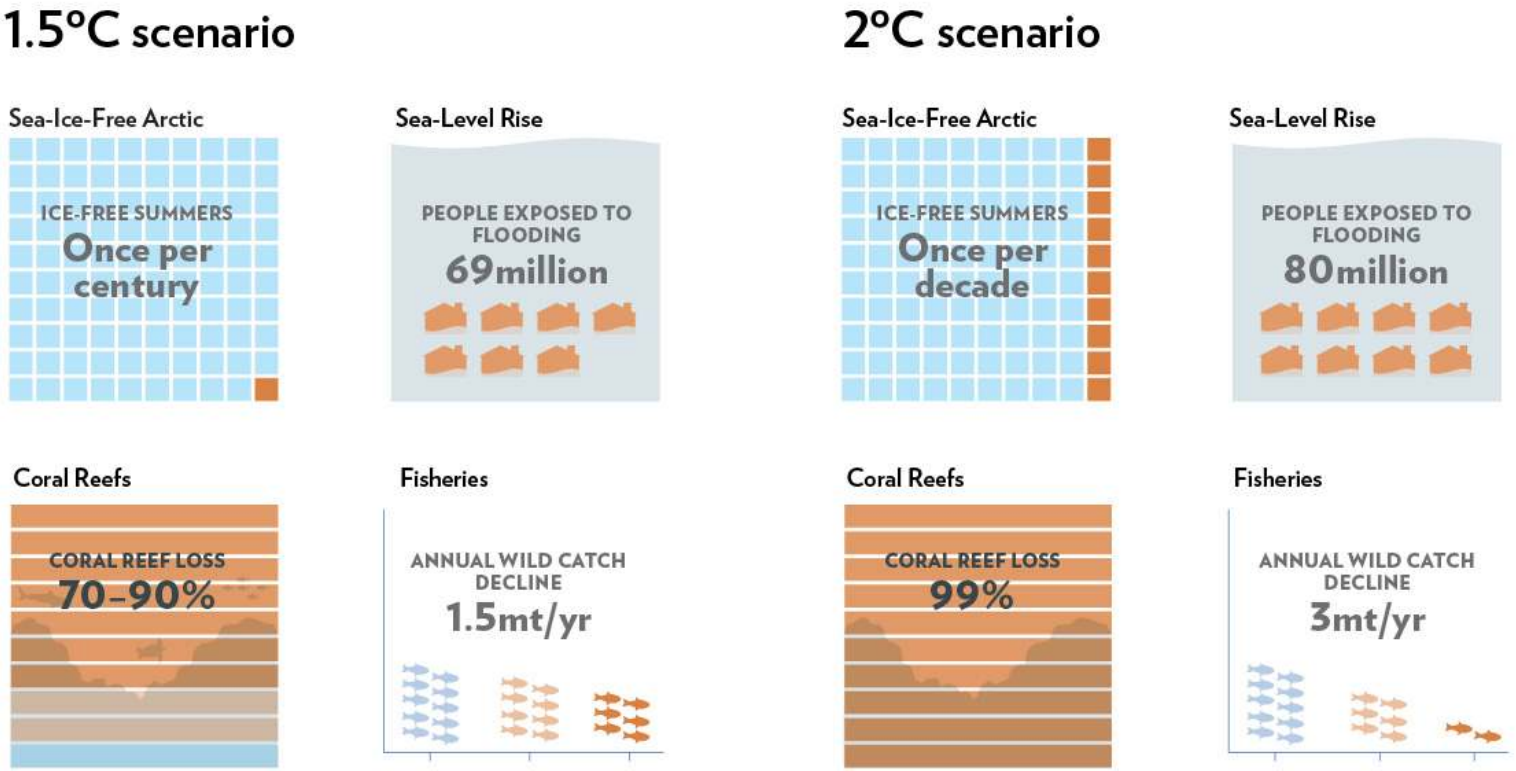


Consequences of Climate Change

A recent IPCC report examined the consequences of a future with warming of 1.5 or 2 degrees Celsius. While both scenarios would heavily impact the ocean, a half degree of warming will lead to vastly different futures for natural and human communities.

By 2100, Arctic summers could be ice-free once a decade in a world with 2 degrees of warming, or once a century under 1.5 degrees of warming. Nearly all of coral reefs could be irreversibly destroyed under 2 degrees of warming, or 10 to 30 percent may persist if warming is limited to 1.5 degrees Celsius.

Impacts associated with 1.5 and 2-degrees Celsius temperature increase

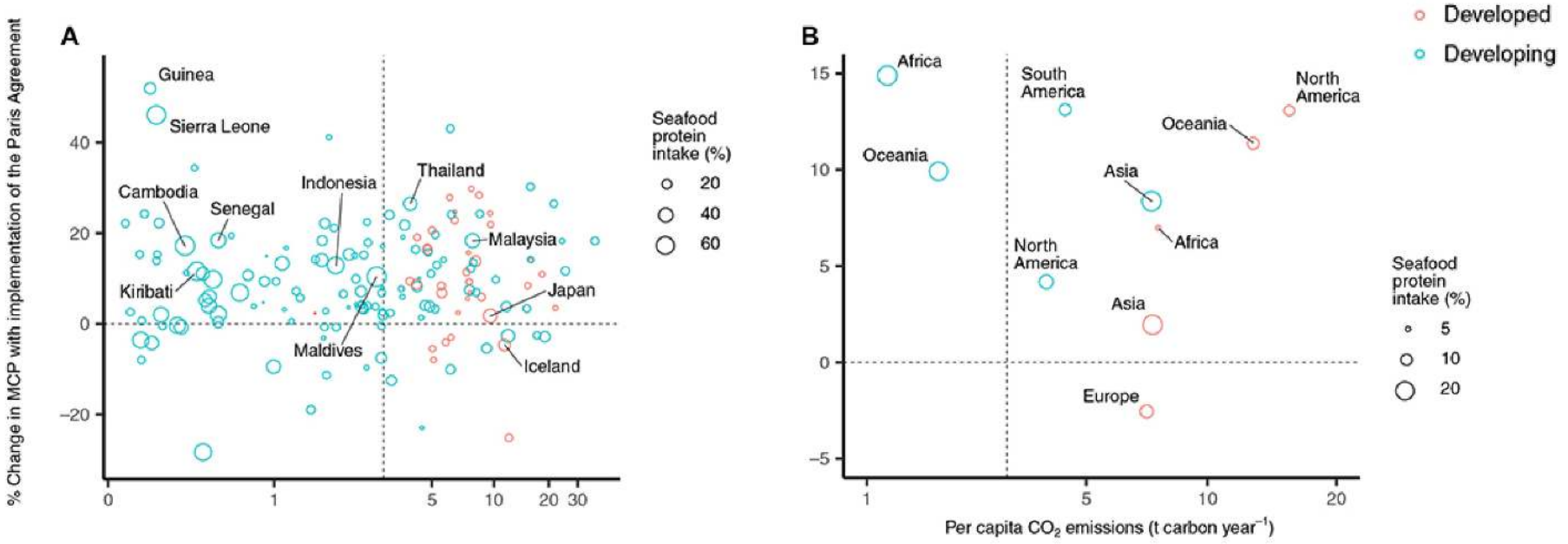


Paris Agreement

New research suggests that as compared to a high-emissions scenario of 3.5 degrees Celsius, achieving the Paris Agreement would result in significant benefits for ocean productivity, economies, and human communities.

Limiting warming to 1.5°C could increase global fishers' revenues by USD 13.1 billion annually (due to higher fish biomass and ocean productivity), raise seafood workers' income by USD 10.6 billion, and reduce household seafood expenditures by USD 18.3 billion.

Projected gains in Maximum Catch Potential under Paris Agreement targets, by country and continent



Action

- Is everything terrible?
- Are we doomed?
- What can you do?
- Why is this important?
- Climate justice…what is that?
- Politics and voting

UTSA | Electrical & Computer Engineering

EE 1322: Intro to Electrical & Computer Engineering

Module 8: Intro to Power Systems Analysis—And Climate Change

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