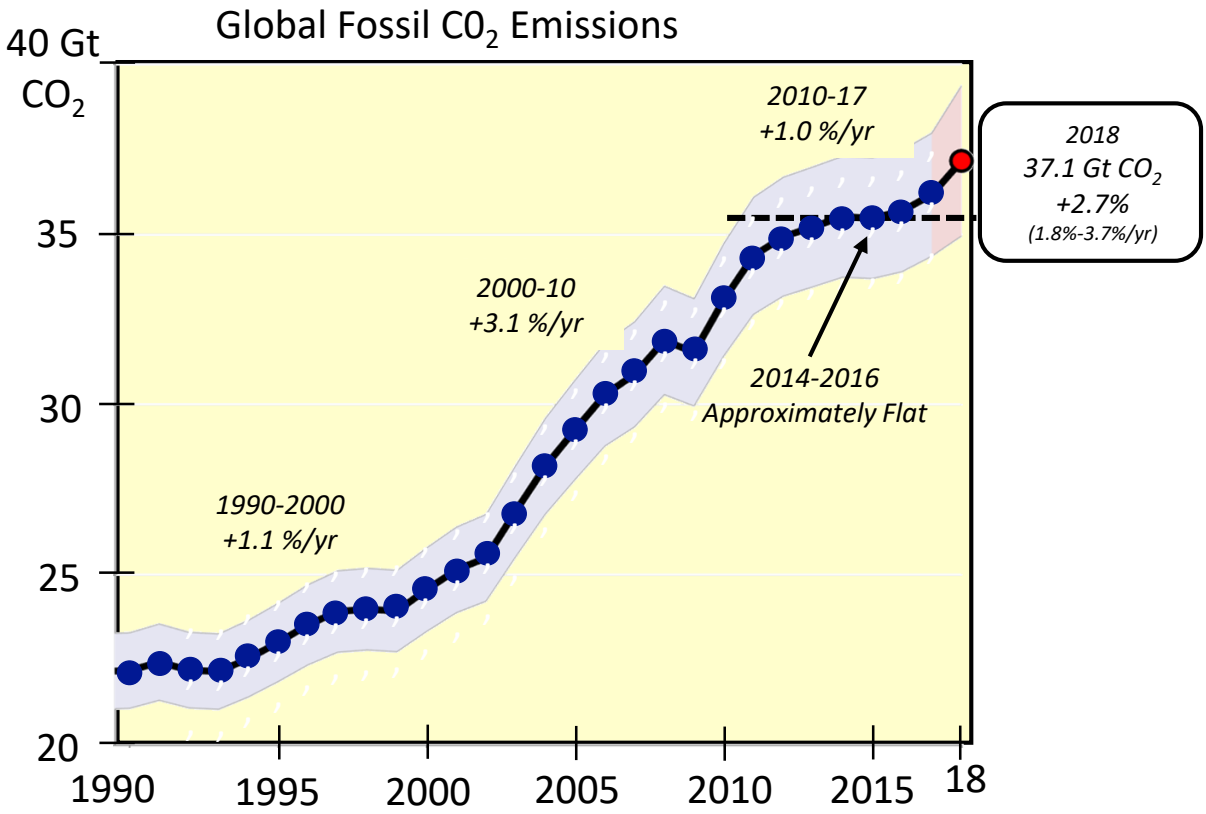
Joint Center for Energy Storage Research

Deep Decarbonization



George Crabtree

Director, Joint Center for Energy Storage Research (JCESR)

Argonne National Laboratory

University of Illinois at Chicago

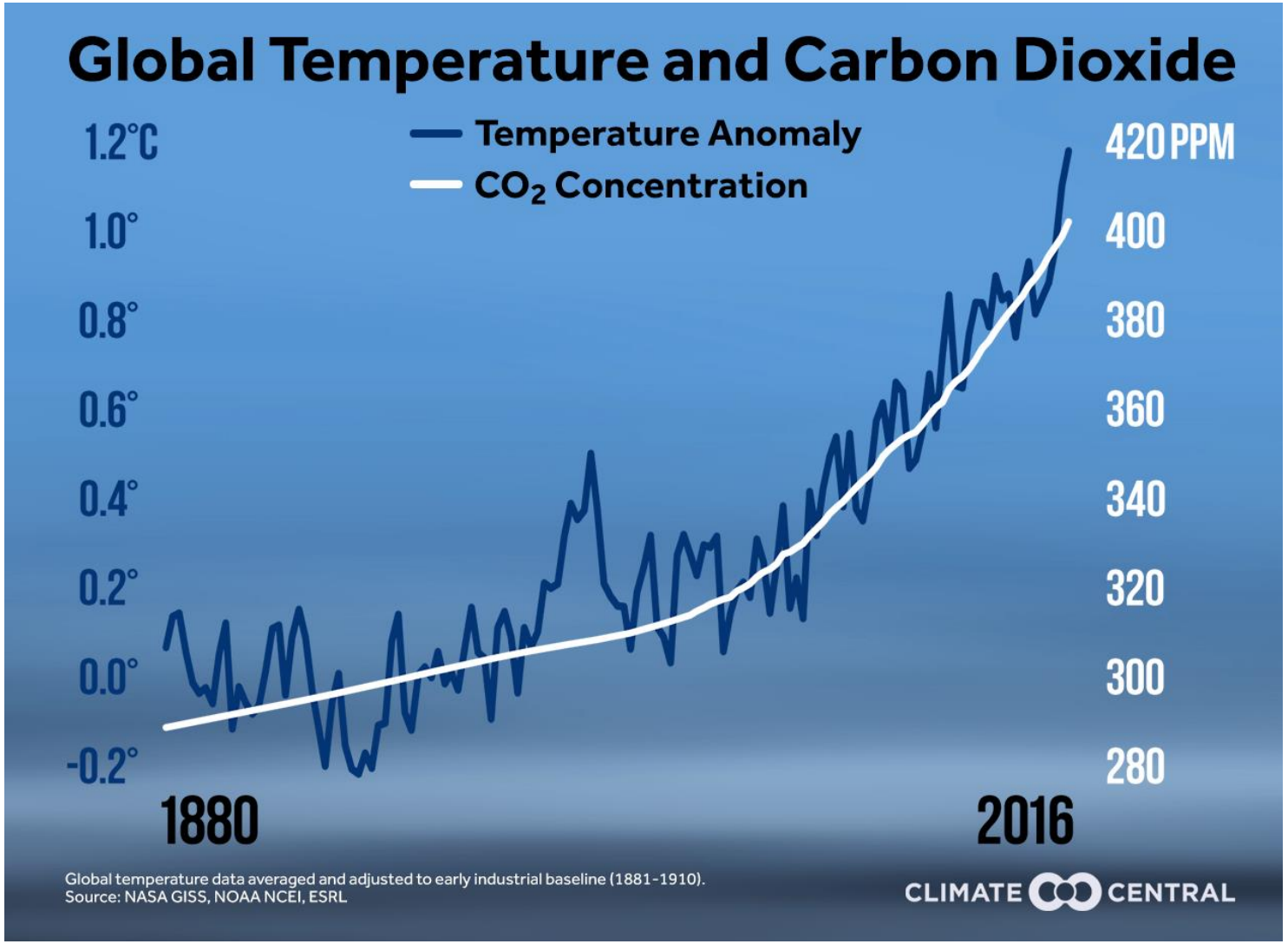
350 Chicago

DePaul University

November 11, 2019

U.S. DEPARTMENT OF ENERGY

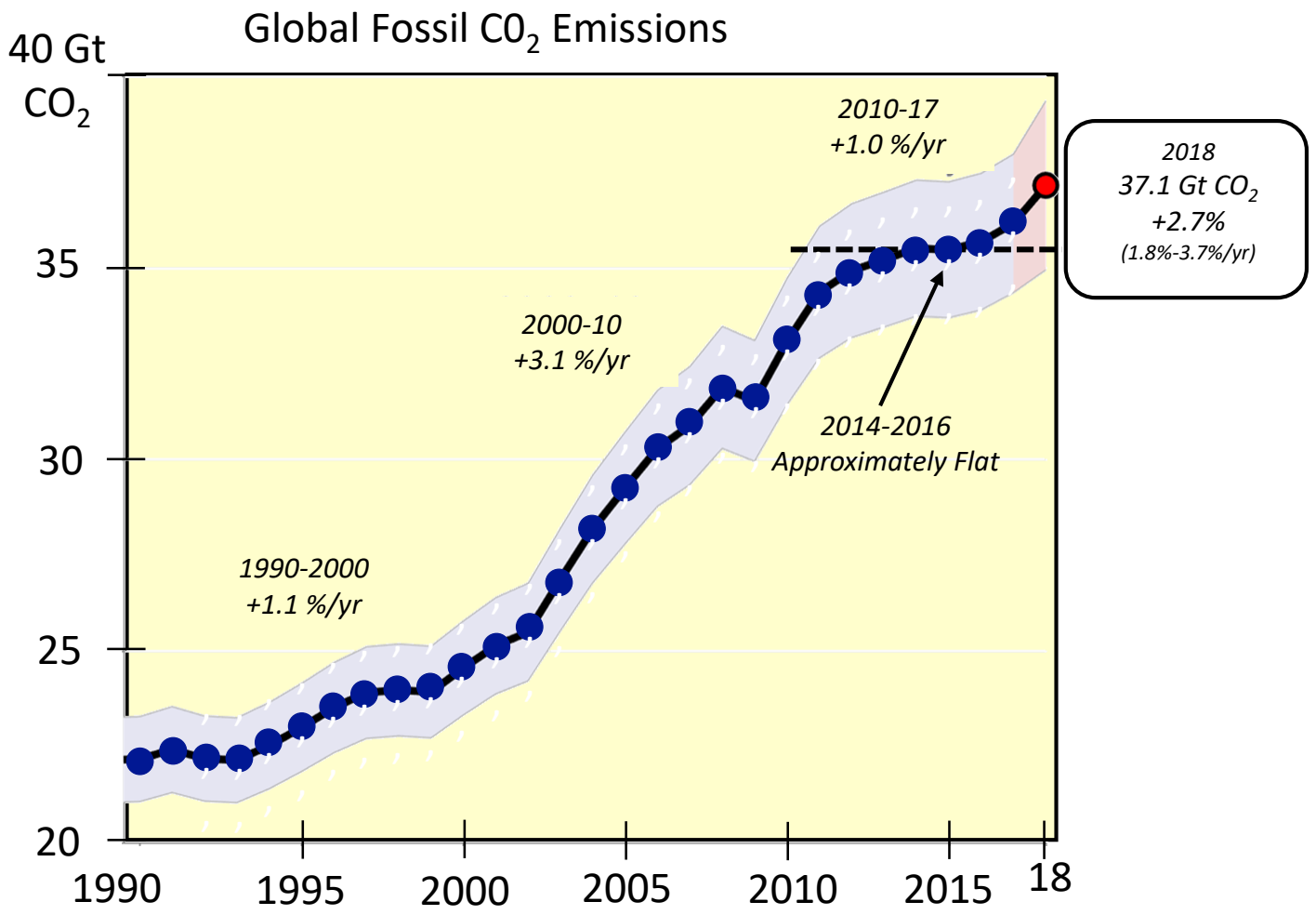
CO_2 Concentration in the Atmosphere Correlates with Global Temperature Rise



http://www.climatecentral.org/gallery/graphics/co2-and-rising-global-temperatures

Svante Arrhenius
1859-1927
1896 CO_2 causes global warming
"cutting edge 19th century science"

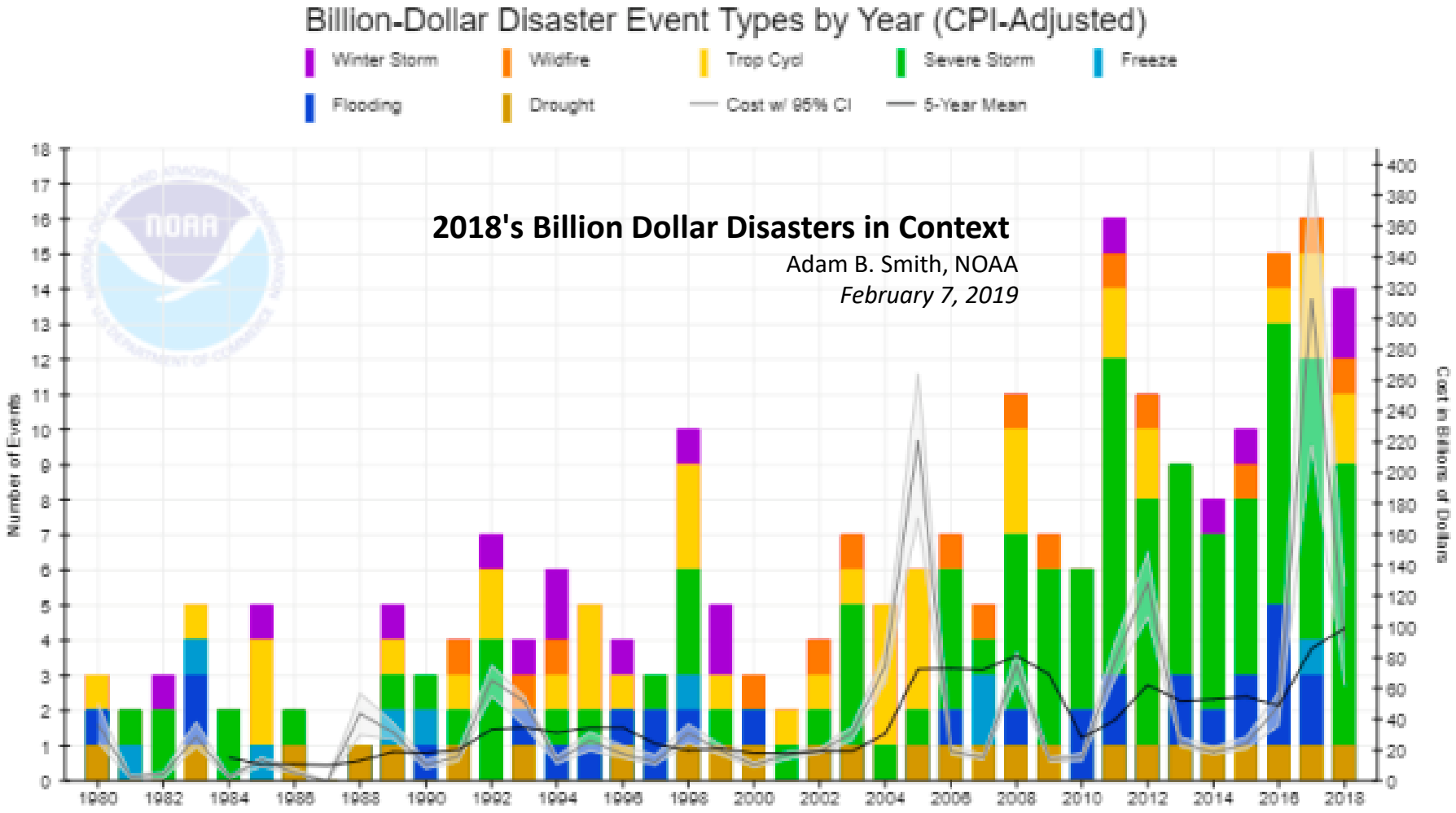
Global Carbon Emissions Seemed to be Peaking . . . But Are Now Rising



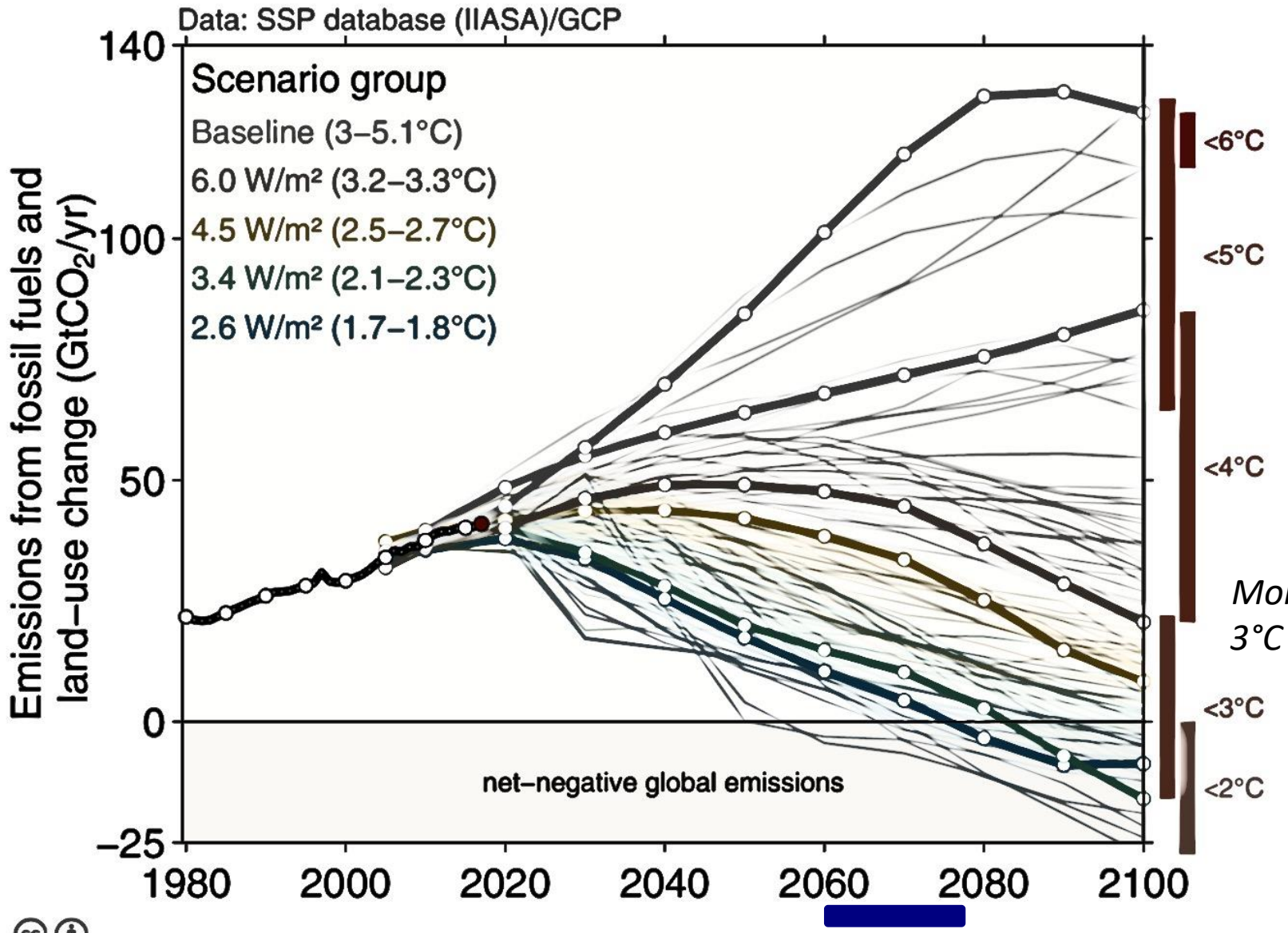
Global Carbon Budget December 5, 2018

http://www.globalcarbonproject.org/carbonbudget/18/presentation.htm /

Extreme Weather



We Are Not on a Path to < 2°C Global Temperature Rise



< 2°C temperature rise requires

full decarbonization by 2060-2080

and negative emissions thereafter

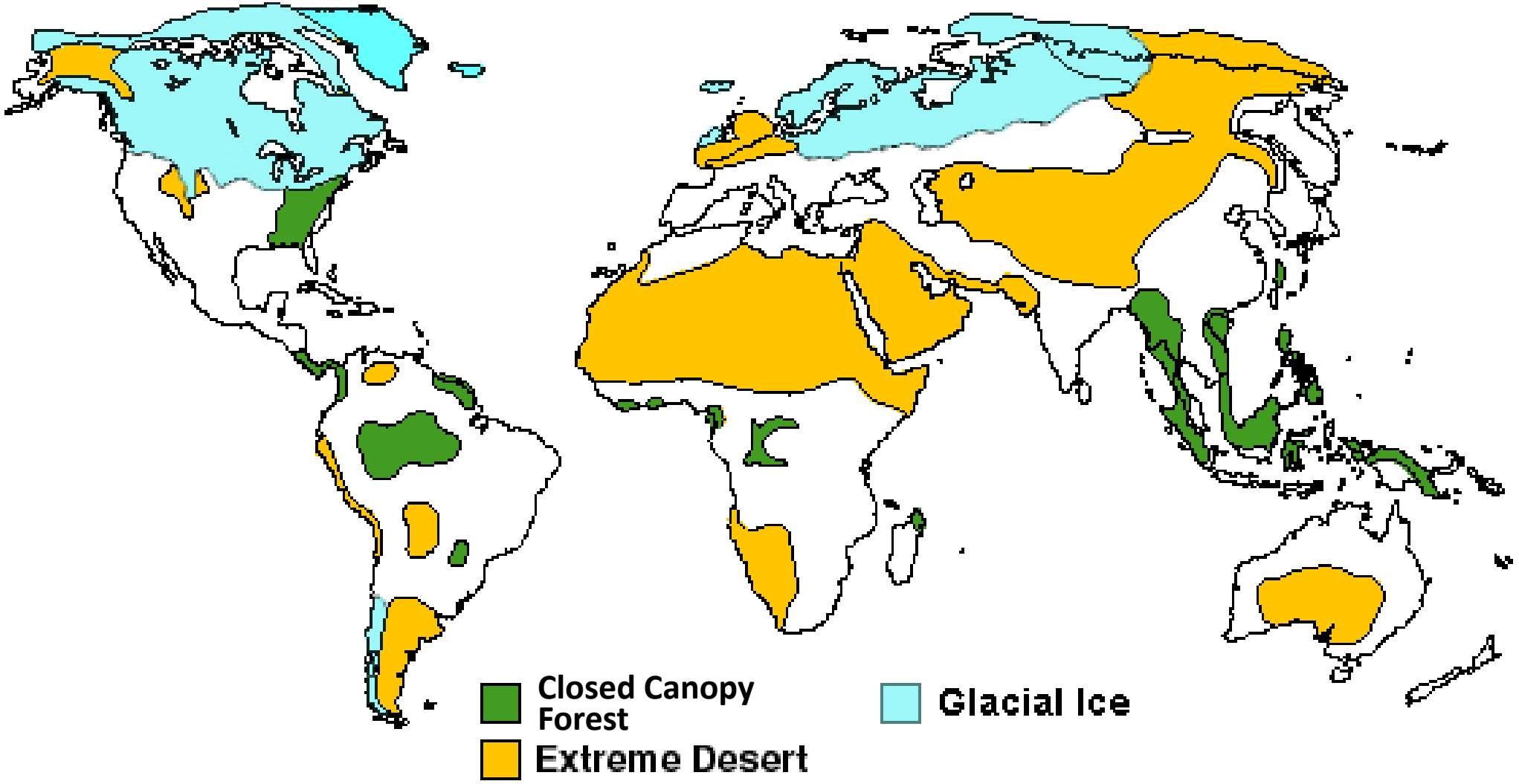
More Like
3°C or 4°C

Global Carbon Project

Global Carbon Budget Nov 13, 2017
http://www.globalcarbonproject.org/carbonbudget/

How Big is 2°C?

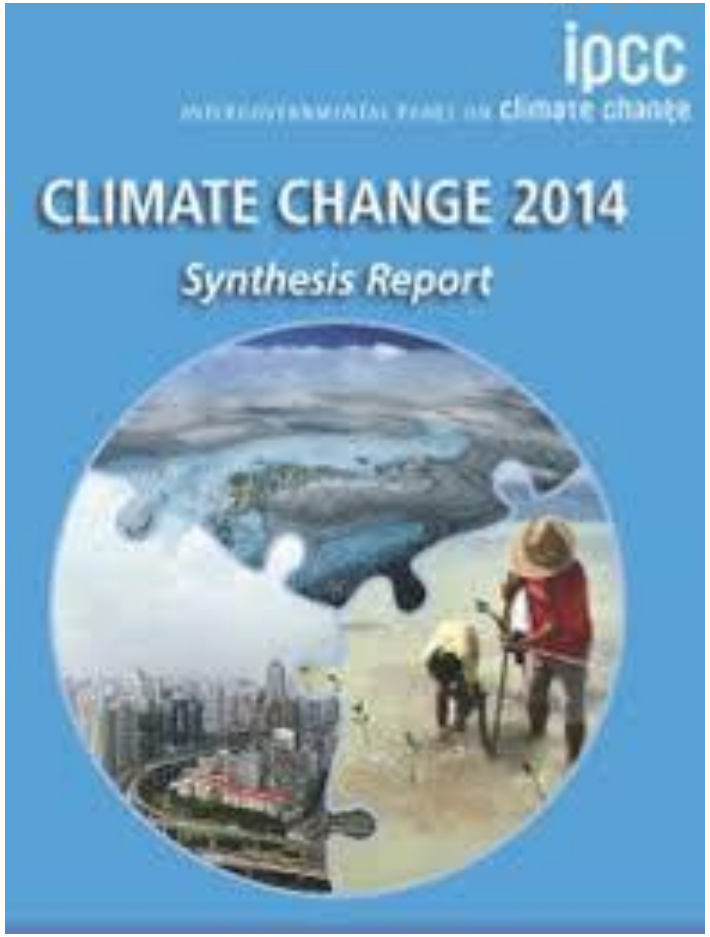
The last ice age was 4.5°C colder
Sea level rise 120 m



Earth 18 000 years ago

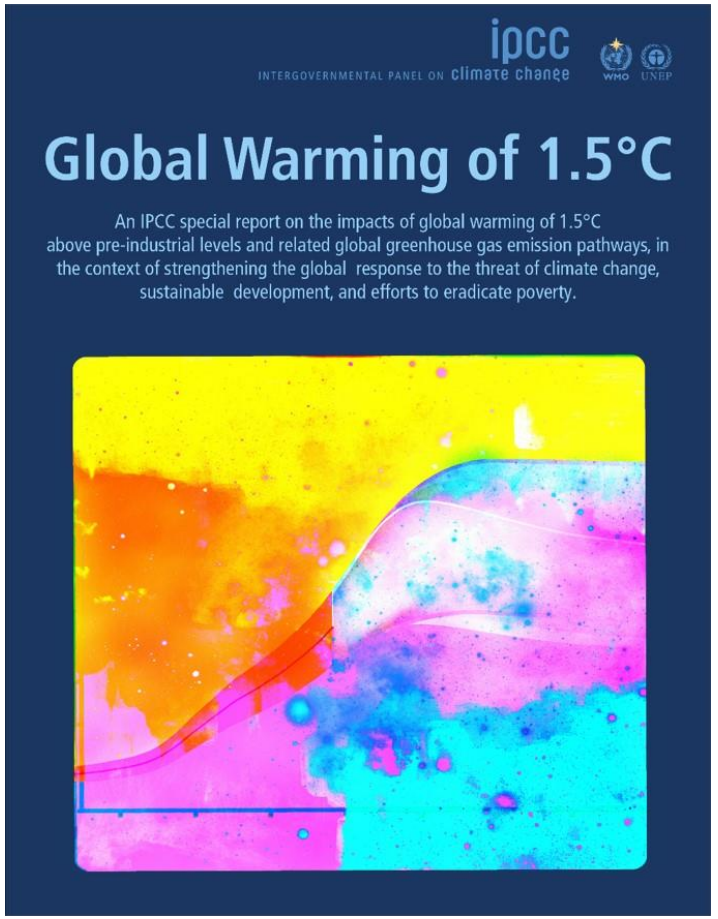
http://www.lakepowell.net/sciencecenter/paleoclimate.htm

Recent Climate Change Reports

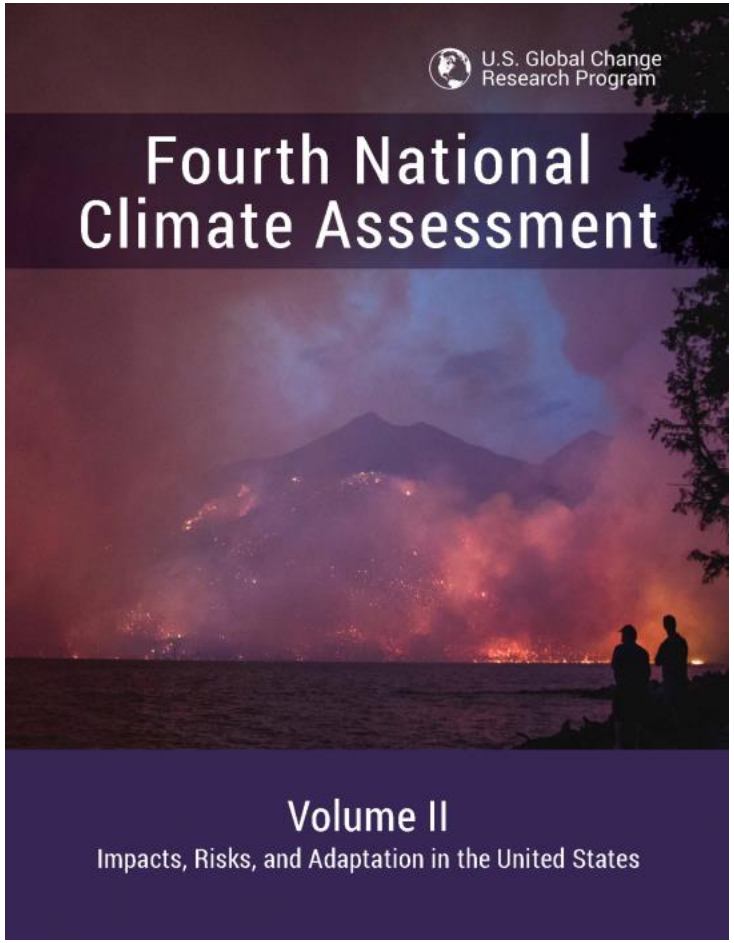


21st Conference of Parties
Paris, November 2015

Must decarbonize by 2050



IPCC SR15.
October 2018
Limit warming to 1.5°C
Above pre-industrial levels



US Global Change Research Program
Congressionally mandated
November 2018
Climate changing faster than expected

Possible "Tipping Points"

Collapse of major ice sheets in Greenland and Antarctica: reflecting white ice replaced by absorbing dark water triggers runaway warming, loss of ice, dramatic changes in sea level and ocean circulation.

Disruption of thermohaline circulation:

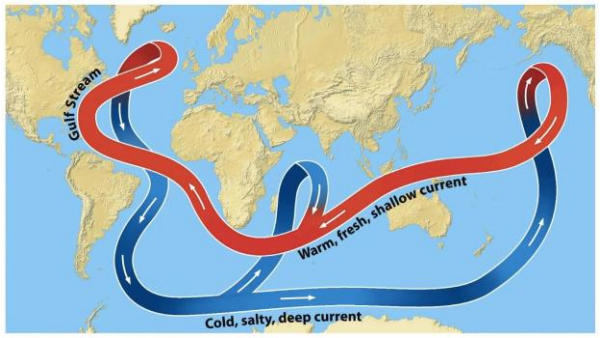
- Transfer of heat from equator to poles interrupted
- Transfer of CO_2 from shallow to deep ocean interrupted

Onset of new climate regime

Sudden release of methane from arctic permafrost or undersea methane clathrates: Runaway increase in rate of warming

Ocean uptake of carbon: acidification of the oceans could kill photosynthesizing plankton, that remove CO_2 from the air. Shells of marine organisms might begin to dissolve, releasing carbon back into the environment.

Larsen C ice shelf cracked on July 12, 2017 spawning 2.200 mi^2 iceberg weighing more than a triliion tons, size of Delaware,10% of Larsen C ice

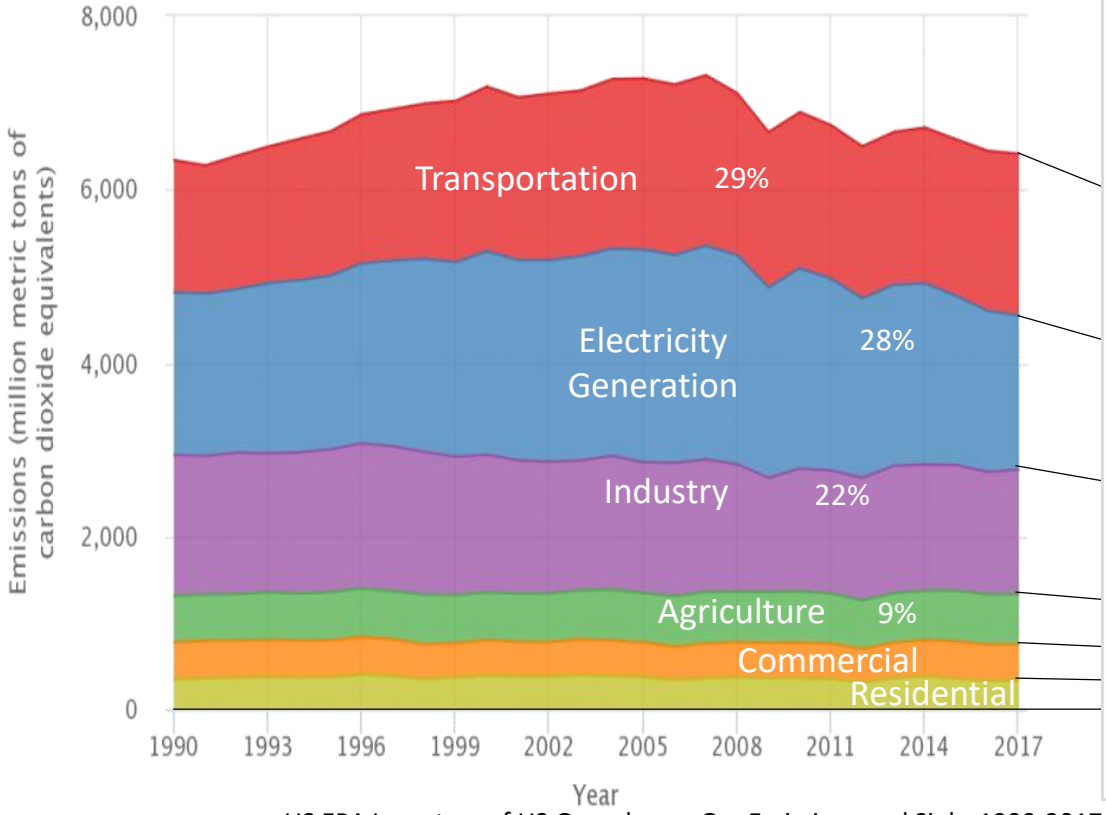


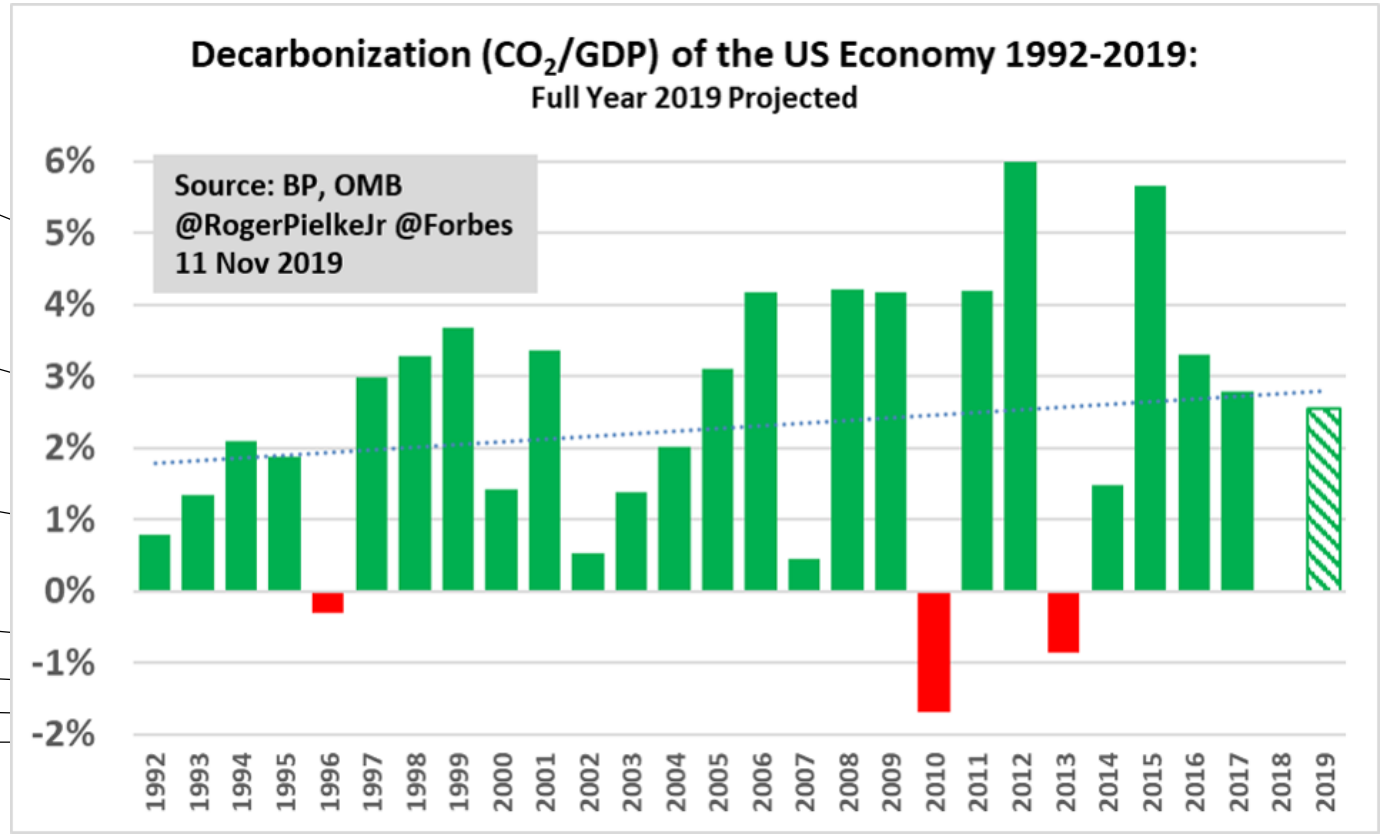
Thermohaline current, carries heat from equator to poles, carbon dioxide from shallow to deep ocean, sets regional climate, 1000 year cycle

https://scied.ucar.edu/longcontent/predictions-future-global-climate

How Fast are We Decarbonizing?

US Greenhouse Gas Emissions by Sector, 1990-2017





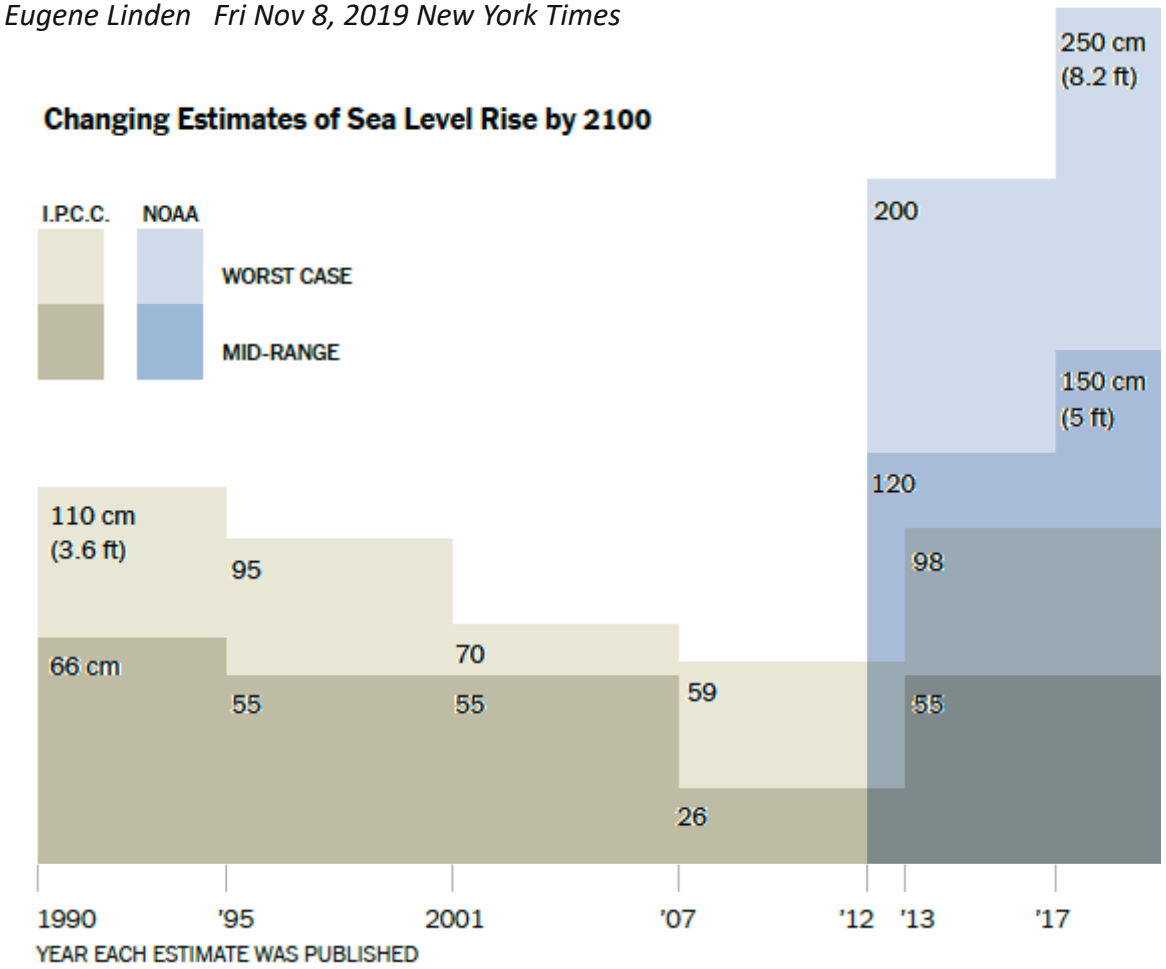
US EPA Inventory of US Greenhouse Gas Emissions and Sinks 1990-2017
https://cfpub.epa.gov/ghgdata/inventoryexplorer/#allsectors/allgas/econsect/all

Climate Change is Accelerating

How Scientists Got Climate Change So Wrong

Few thought it would arrive so quickly. Now we're facing consequences once viewed as fringe scenarios.

Eugene Linden Fri Nov 8, 2019 New York Times



Note: The I.P.C.C.'s 2007 estimate of future sea level rise did not include satellite data on the contribution of melt water from Greenland and Antarctica because of disagreements among scientists.

Source: E. Linden, How Scientists Got Climate Change So Wrong, NYT Nov 8, 2019

Scientists triple their estimates of the number of people threatened by rising seas

150 million could live below the high tide line by 2050, new research finds.

Washington Post Oct 29, 2019

https://www.washingtonpost.com/climate-environment/2019/10/29/scientists-triple-their-estimates-number-people-threatened-by-rising-seas/

Public Awareness of Climate Change

24% ... believe that **half of climate scientists, or fewer,** think human-caused global warming is happening.

36% ... believe that between **51 and 90 percent of scientists** think global warming is happening.

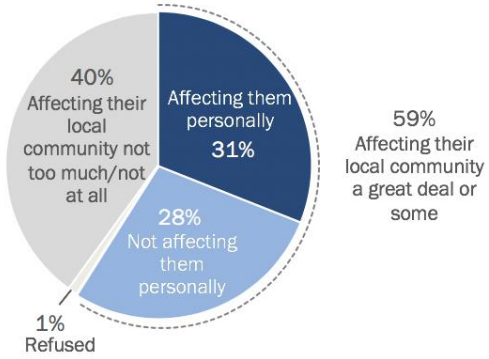
17% **... correctly understand that almost all climate scientists think global warming is happening.**

21% Don't know

Source: Yale Program on Climate Change Communication survey conducted in April; figures do not add up to 100 percent because of rounding

A majority of U.S. adults say climate change affects their local area; 31% say it affects them personally

% of U.S. adults who say the effects of global climate change are ...

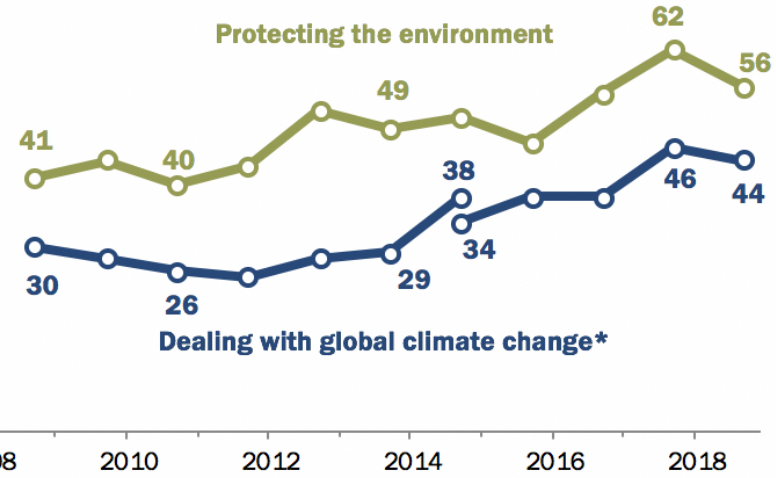


Source: Survey conducted March 27-April 9, 2018.
"Majorities See Government Efforts to Protect the Environment as Insufficient"

PEW RESEARCH CENTER

Increased support for prioritizing policies on the environment, climate change since 2011

% U.S. adults who say ____ should be a top priority for the president and Congress



*In 2014 and earlier, respondents were asked about dealing with "global warming." In 2015 half the sample was asked about either "global warming" or "global climate change"; 34% called "global climate change" a top priority while 38% said this about "global warming."

Source: Survey of U.S. adults conducted Jan. 9-14, 2019
"Public's 2019 Priorities: Economy, Health Care, Education and Security All Near Top of List"

PEW RESEARCH CENTER

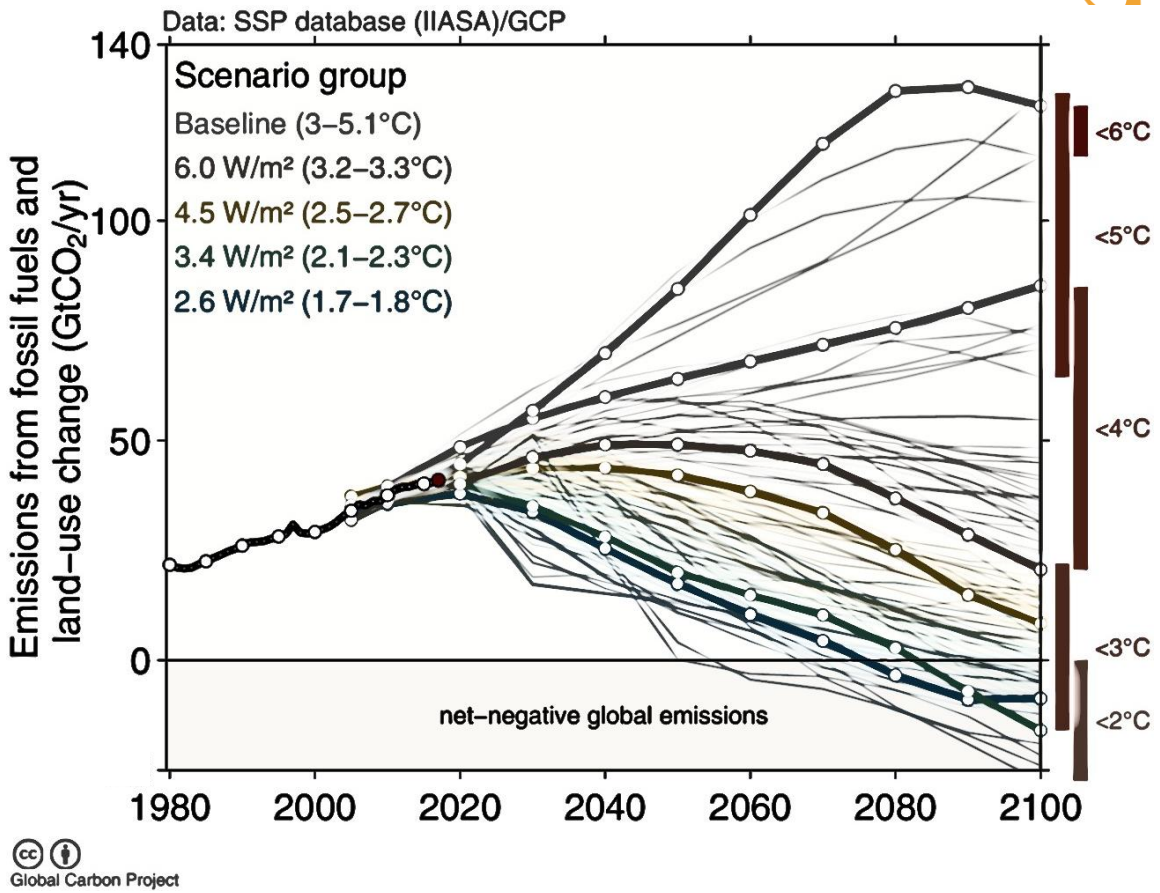
Can We Achieve 100% Decarbonization by 2050?

After Paris 2015:

Focus on 100% reduction after 2050, and negative emissions after 2080

40 year life of natural gas turbines is a negative legacy compared to renewables

Electric vehicles transforming transportation became thinkable



Conversation shifted from the first 50% to the last 50%

How to decarbonize long haul air, trucking and sea transportation?

What about space and water heating, industrial processes that use combustion of fossil fuel for heat

Do we have the technology, or do we need new technology?

Electric Vehicle Challenges

- Greater range
  > 400 miles not 250 miles
- Faster charging
  minutes not hours
- Lower purchase price
  $20K not $50K
- Longer battery lifetime
  16 years not 8 years
- Greater safety
  greater danger from EV battery fires
- Recycling
  to meet EV demand for resources
- Less temperature sensitivity
  lose 40% of range in Minneapolis winter

Argonne Energy Plaza

Nissan Leaf Battery Pack

Electric Vehicle Battery Fire

All of These Challenges are Battery

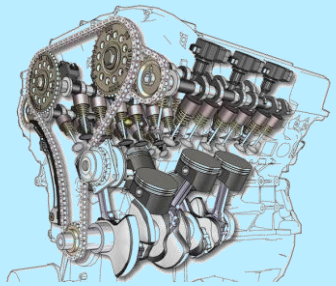
Electric Vehicles - High or Low Cost?

JCESR

Electric Vehicles

Fewer Moving Parts

Engine + Transmission



Hundreds

Electric Motor

One

Lower Maintenance Cost

Higher Efficiency

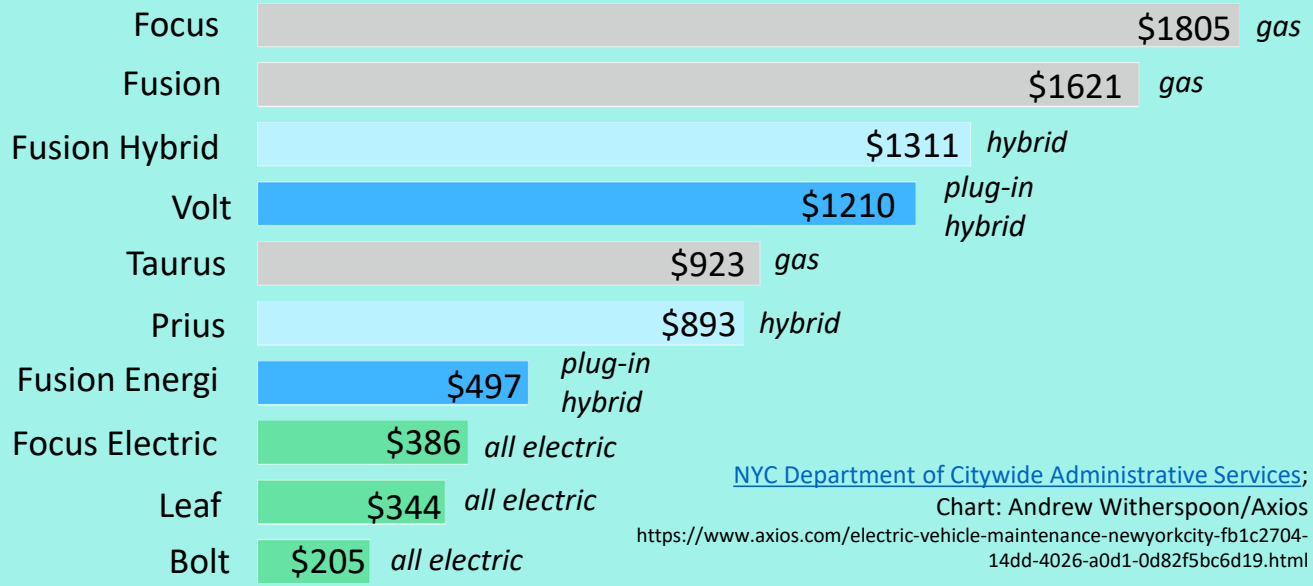
25% >90%

Lower Fuel Cost

Gasoline / mile	Electricity / mile
$0.08 -$0.12	$0.04 -$0.06

EVs are the economic choice for high mileage vehicles

Average maintenance cost for NYC municipal vehicles in 2018



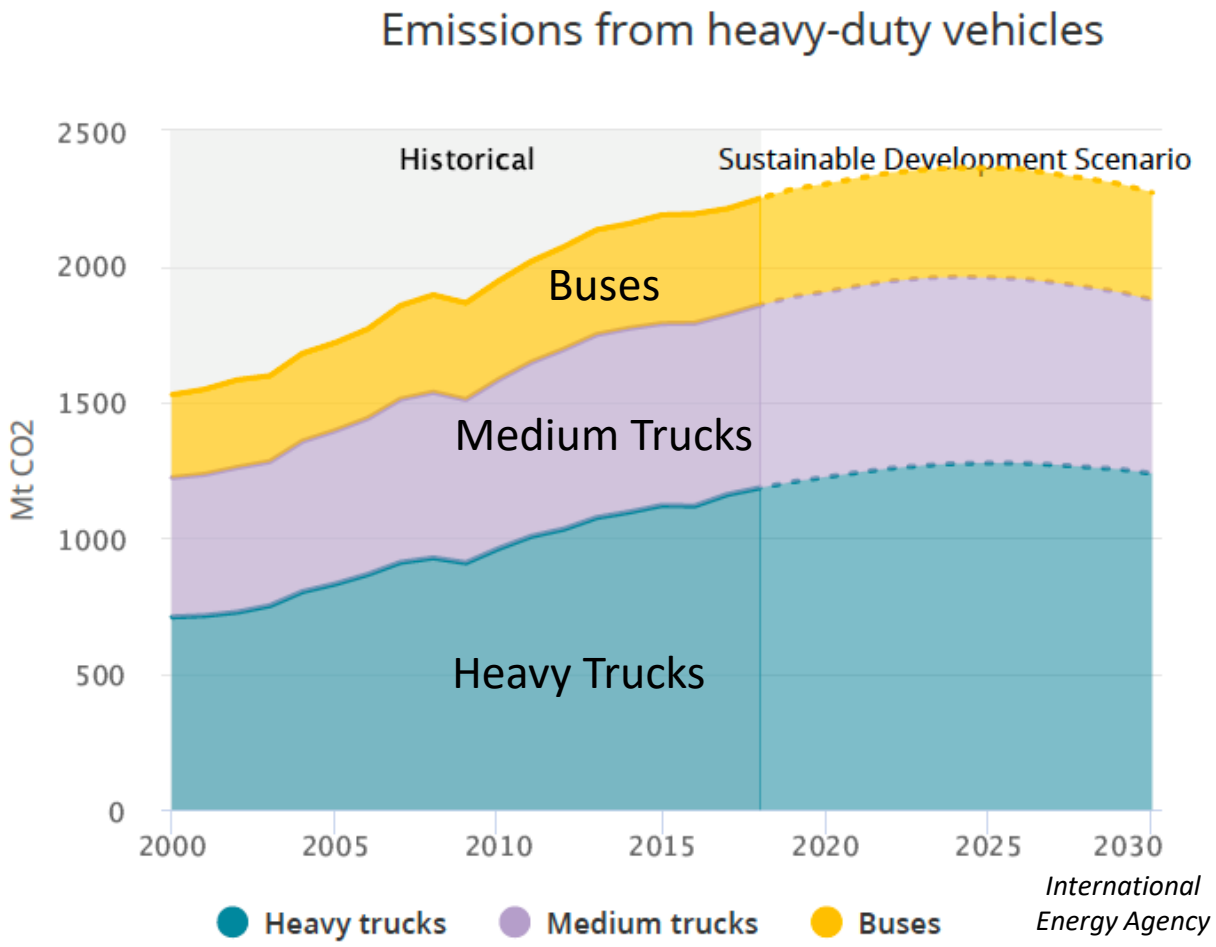
NYC Department of Citywide Administrative Services;
Chart: Andrew Witherspoon/Axios
https://www.axios.com/electric-vehicle-maintenance-newyorkcity-fb1c2704-14dd-4026-a0d1-0d82f5bc6d19.html

Electric Vehicle Battery Cost: Barrier to Entry, Benefit for High Mileage and Fleet Use

Fleet vehicles switch to electric – high impact on sales and grid

Amazon will order 100,000 electric delivery vans from EV startup Rivian, delivery 2021-2024
https://www.theverge.com/2019/9/19/20873947/amazon-electric-delivery-van-rivian-jeff-bezos-order

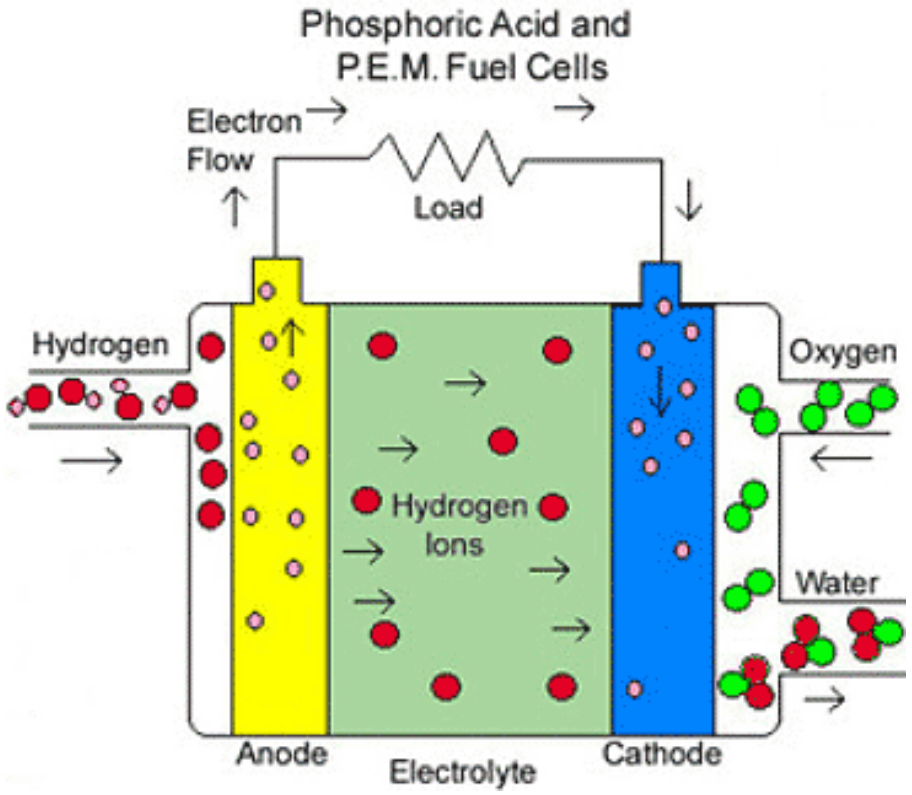
Beyond EVs – Electric Buses and Long Haul Trucks



International Energy Agency

Cost of battery packs for trucks
$500/kWh (2013) → $200/kWh (2019)
Electric trucks are heavier than diesel trucks
Energy density of lithium ion batteries << diesel fuel
→ Recharging en route → delays

Hydrogen Fuel Cell Trucks



Hydrogen fuel cell

Hydrogen + oxygen → electricity, water and heat

Long range, fast refueling
50-60% efficiency
No emissions
Still need to lower cost

Two Routes to All-Electric Flight

Scale up prototype all-electric air taxis

Boeing's first autonomous air taxi flight ends in fewer than 60 seconds. Jan 19, 2019
https://www.cnn.com/2019/01/23/tech/boeing-flying-car/index.html

Expected deployment 2020-2025

Eviation Aircraft "Alice" https://www.eviation.co/alice/
9 passengers, 650 mile range, 275 mph, 10 000-30 000 ft,
Li-ion 900kWh, propellers on tail and wingtips, $4M
Planes bought by Cape Air, Barnstable MA,
for short hop coastal flights

Electrify existing full size plane

Hybrid-electric aircraft

Airbus E Fan X
The future is electric
https://www.airbus.com/newsroom/news/en/2018/07/the-future-is-electric.html

Paris Air Show
Le Bourget, Paris, June 17-23, 2019

Decarbonizing the Electricity Grid

Mega-trends shaping the grid

Decarbonization

Energy storage

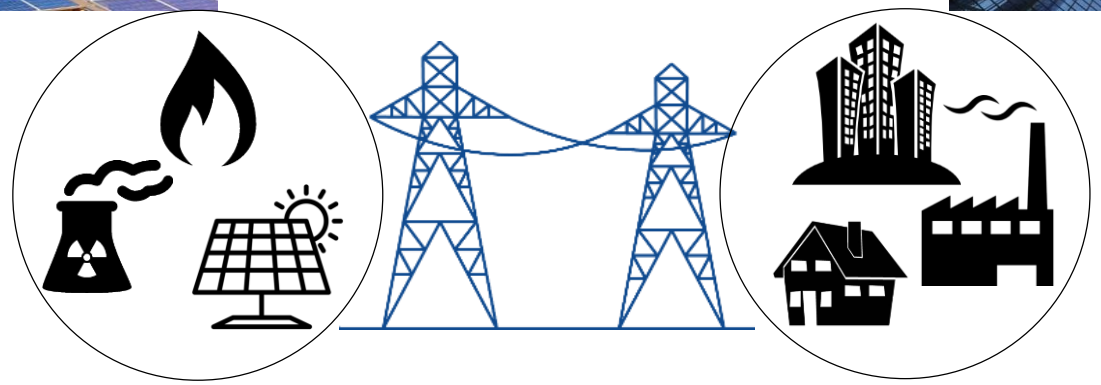
Renewable wind and solar

Electric cars, buses and trucks

Distributed energy resources

Smart energy management

Two way flow



Storage is central to all the mega-trends

Critical Outcomes

Decarbonization – 100% by 2050?

Reliability

US	EU
214 outage minutes/year	~50 outage minutes/year

Resilience How fast to restore power? Time or cost metric?

Cyber-security A hack-proof grid

Cost

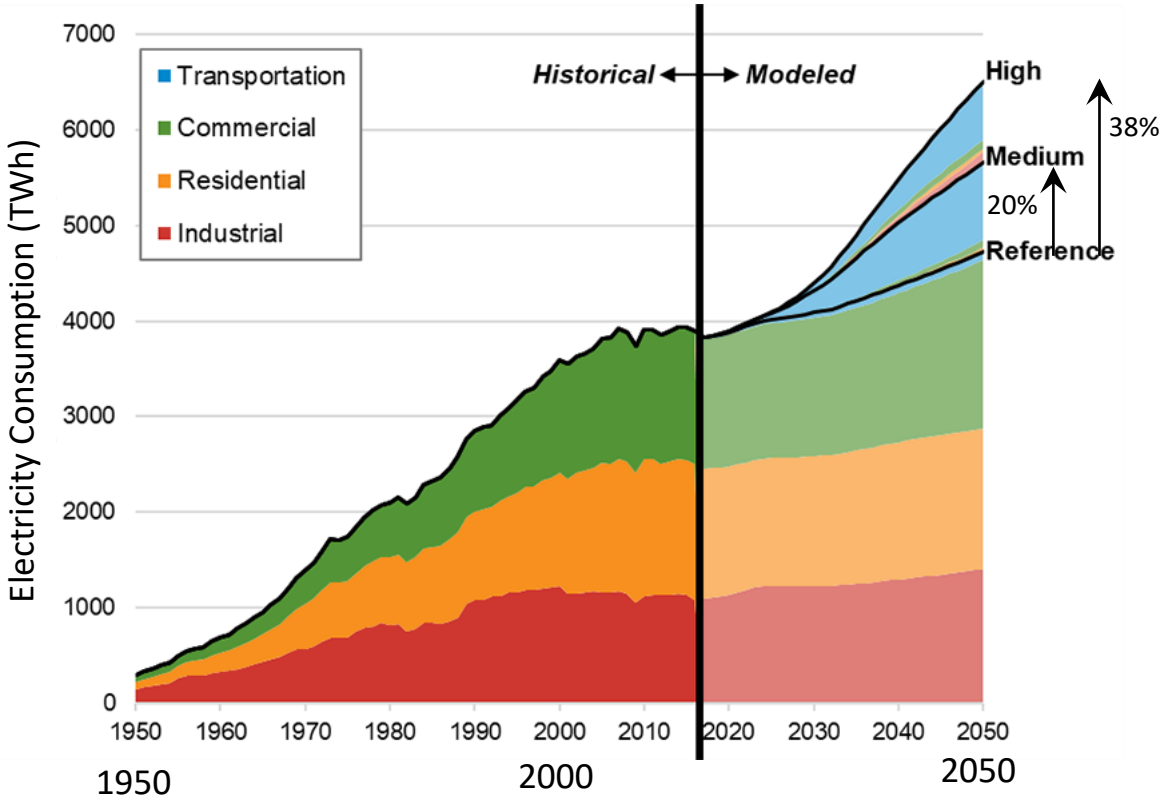
US	EU
12.7 c/kWh	26.6 c/kWh

Can we achieve critical outcomes with present technology?

Yes	**No**
Policy, regulation, and business plan innovation	Where are the gaps? → R&D funding priorities

Charging Electric Vehicles

EVs could increase electricity demand by 20% - 38% in 2050



Source: NREL, https://www.utilitydive.com/news/evs-could-drive-38-rise-in-us-electricity-demand-doe-lab-finds/527358/

First significant increase in demand since 2000

Integrates transportation and the electricity grid into a single universal energy system

Frees transportation from dependence on foreign oil

Path to decarbonize transportation along with electricity grid

How to meet additional demand?

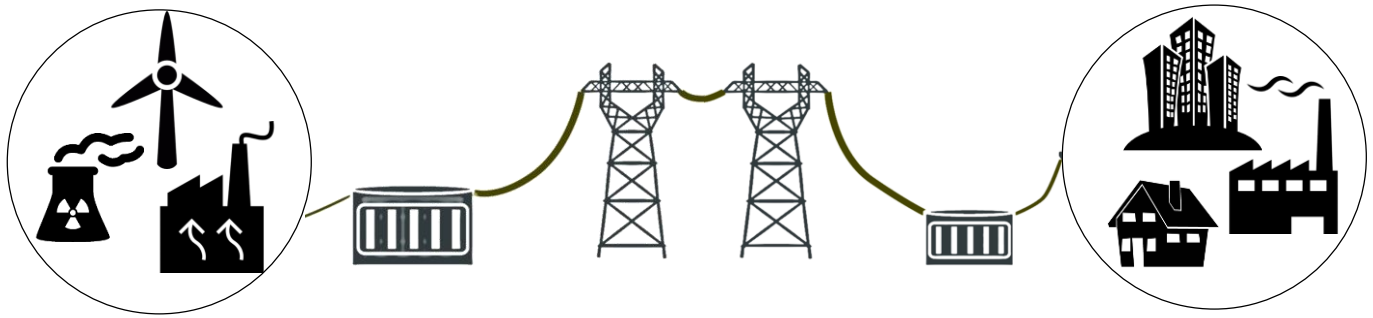
- *Charge off peak to avoid building new generation capacity*

Off-peak capacity is typically idle gas peaker plants

→ *Significantly greater carbon emissions than renewable charging*

Solution: Charge EVs only with renewable electricity
Replace gas peaker plants with storage

Decarbonizing the Grid: Wind, Solar, Storage, Transmission



Renewable+Storage falling faster than either alone

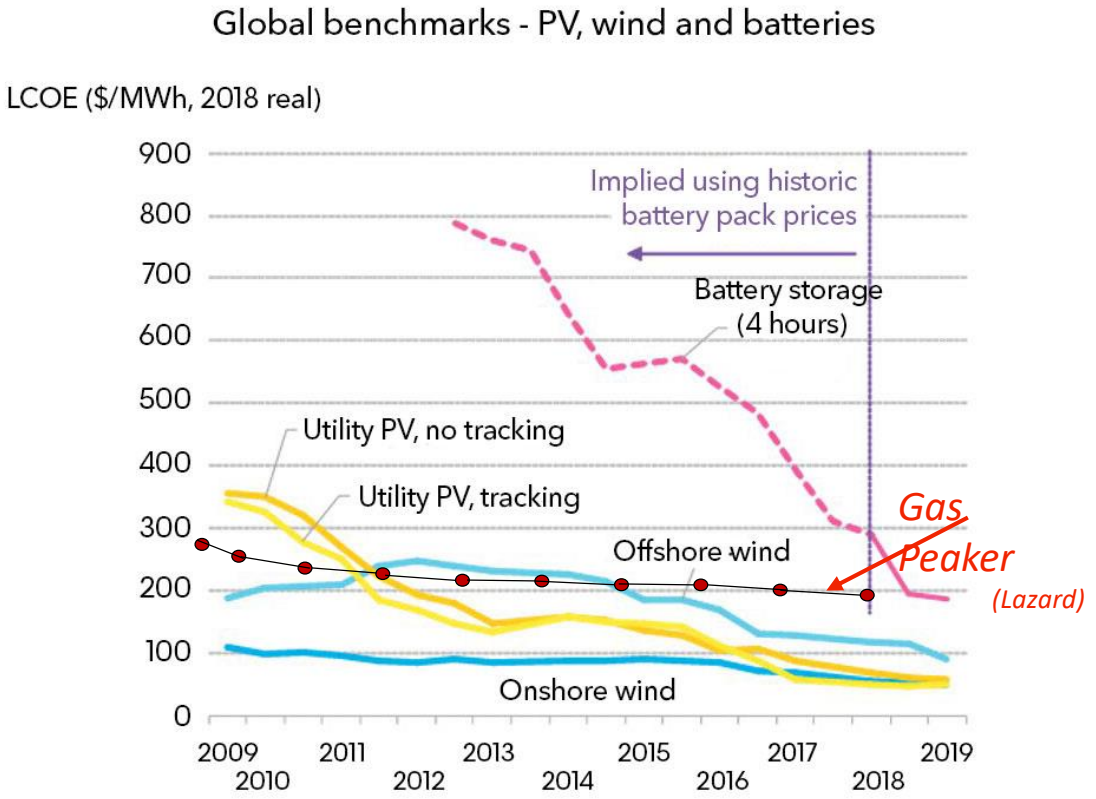
No fuel cost: Floor depends only on technology cost

Storage alone competitive with gas peaker plants

Solar+Storage < $0.03/kWh=$30/MWh
in NV and AZ: the economic choice

> $0.02/kWh in Los Angeles (7-1-19)

"+Storage" moving beyond first adopters



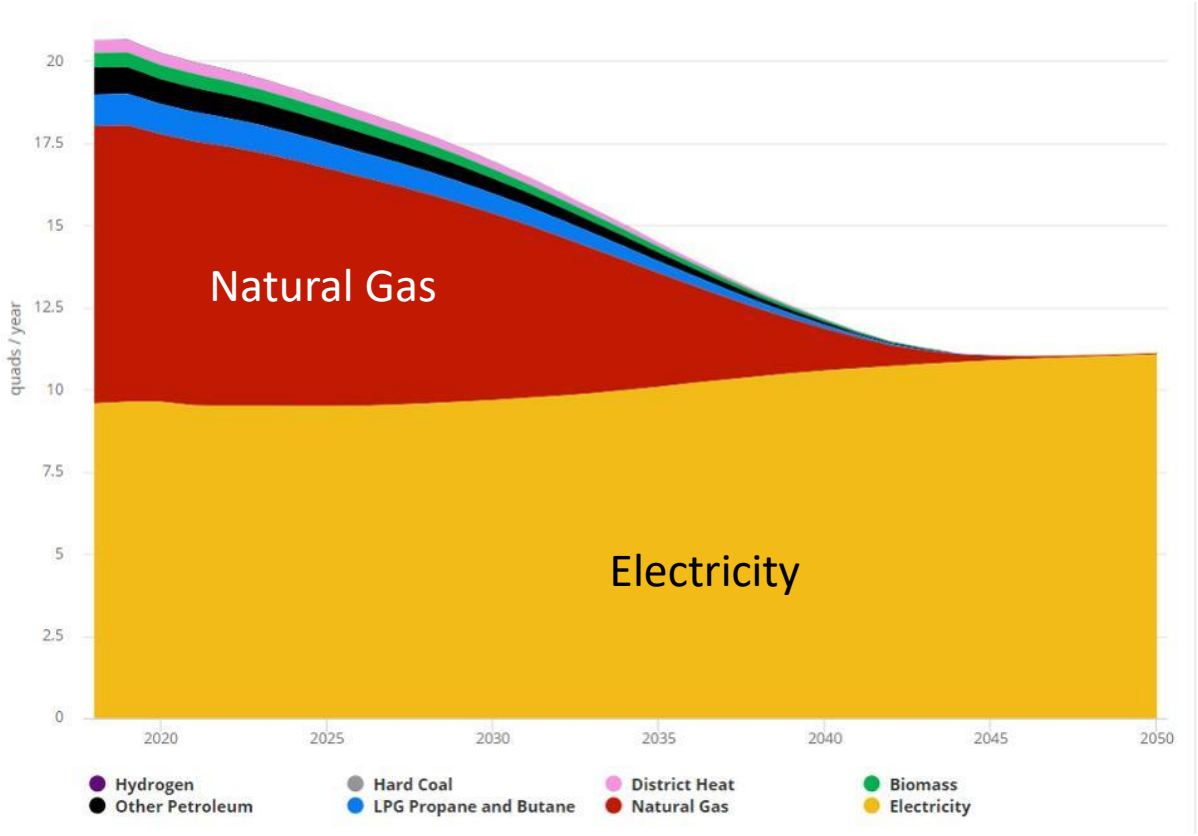
Source: BloombergNEF. Note: The global benmark is a country weighed-average using the latest annual capacity additions. The storage LCOE is reflective of a utility-scale Li-ion battery storage system running at a daily cycle and includes charging costs assumed to be 60% of whole sale base power price in each country.

Electric Heating of Commercial and Residential Buildings

Technology exists

Policy incentives needed

Berkeley, California: ban on natural gas pipes in many new buildings starting January 1, 2020



Decarbonizing Industry

Industry uses fossil fuels in two ways

Feedstocks for plastics and other high value products

Combustion for high process temperatures for steel production

Electricity cannot produce the high temperatures needed for industry – requires combustion

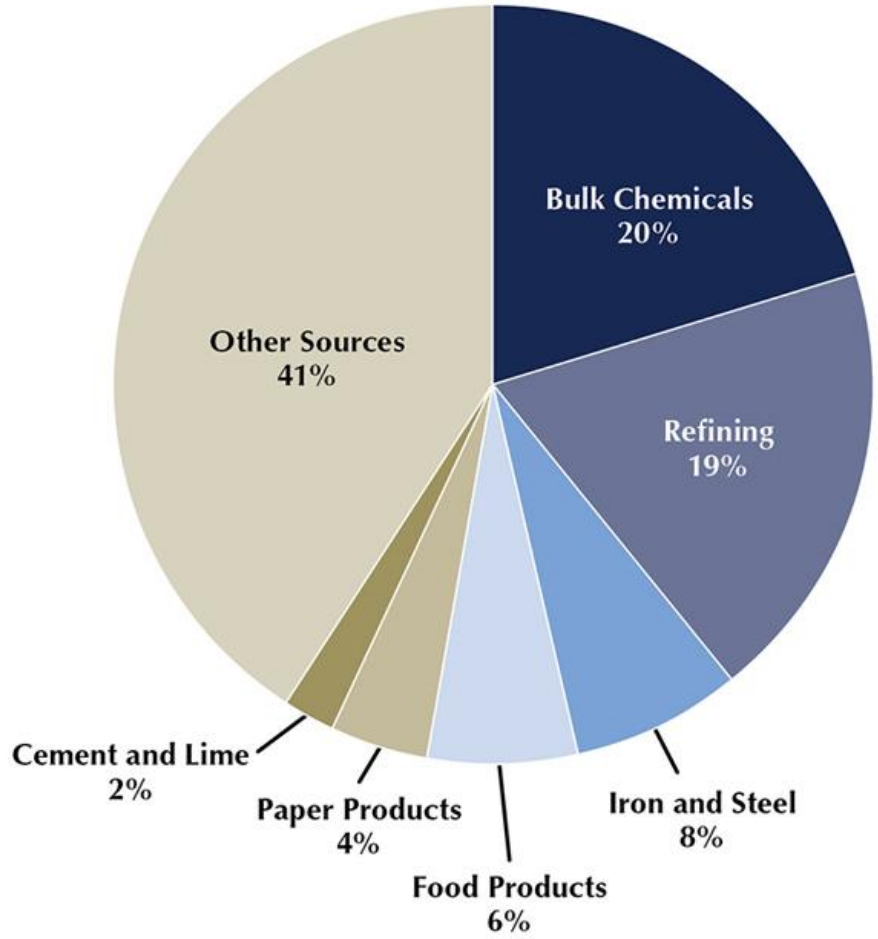
Hydrogen as a combustion fuel ?

76% comes from reforming natural gas
22% from coal gasification
2% from electrolysis

Electricity costs more than natural gas per unit energy, and less energy is required to convert natural gas to hydrogen than to electrolyze water

→ R&D to decrease cost of producing hydrogen by electrolysis

FIGURE 1: Energy-Related CO_2 Emissions from Industry (2016)



Source: U.S. Energy Information Administration, Annual Energy Outlook 2018 (Washington, DC: U.S. Department of Energy, 2018), Table 19 Energy-Related Carbon Dioxide Emissions by End Use, https://www.eia.gov/outlooks/aeo.

Perspective

Deep decarbonization of the global economy is needed to avoid the worst consequences of climate change

Some technology exists: renewable electricity, electric cars, hydrogen fuel cells, hydrogen combustion

Policy is needed to promote deployment of existing technology

R&D is needed to promote new technology for energy storage and electrolysis of water to hydrogen

We are not yet on track to achieve deep decarbonization of the economy by 2050.