Climate Change – A Hot Topic Session 4

Mitigation and Adaptation to Climate Change

Be willing to change because the climate won’t stay the same.

Roy Campbell and Don Fournier

February 5, 2024

Overview Week 4

Mitigation

- The Transportation Sector
  - Automobiles
  - Trucks
  - Aviation
  - Rail System
  - Ships
- The Built Environment
  - Industry
  - Commercial & Residential
- Agriculture
- Land Use and Forestry

Adaptation

- Definition
- Disaster risks, response and preparedness
- Vulnerabilities, Exposure, Capacity
- Case Studies of Extremes

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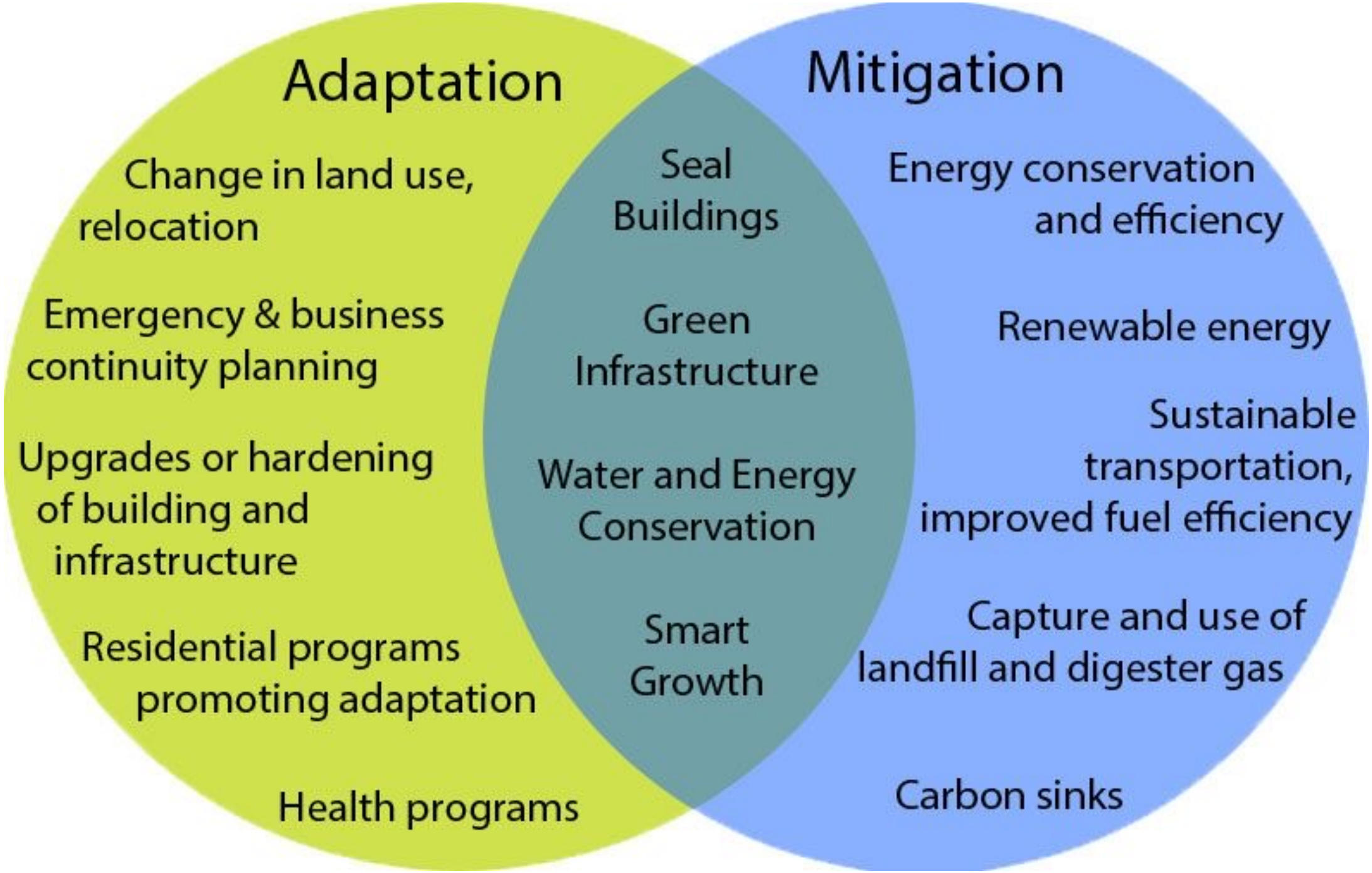
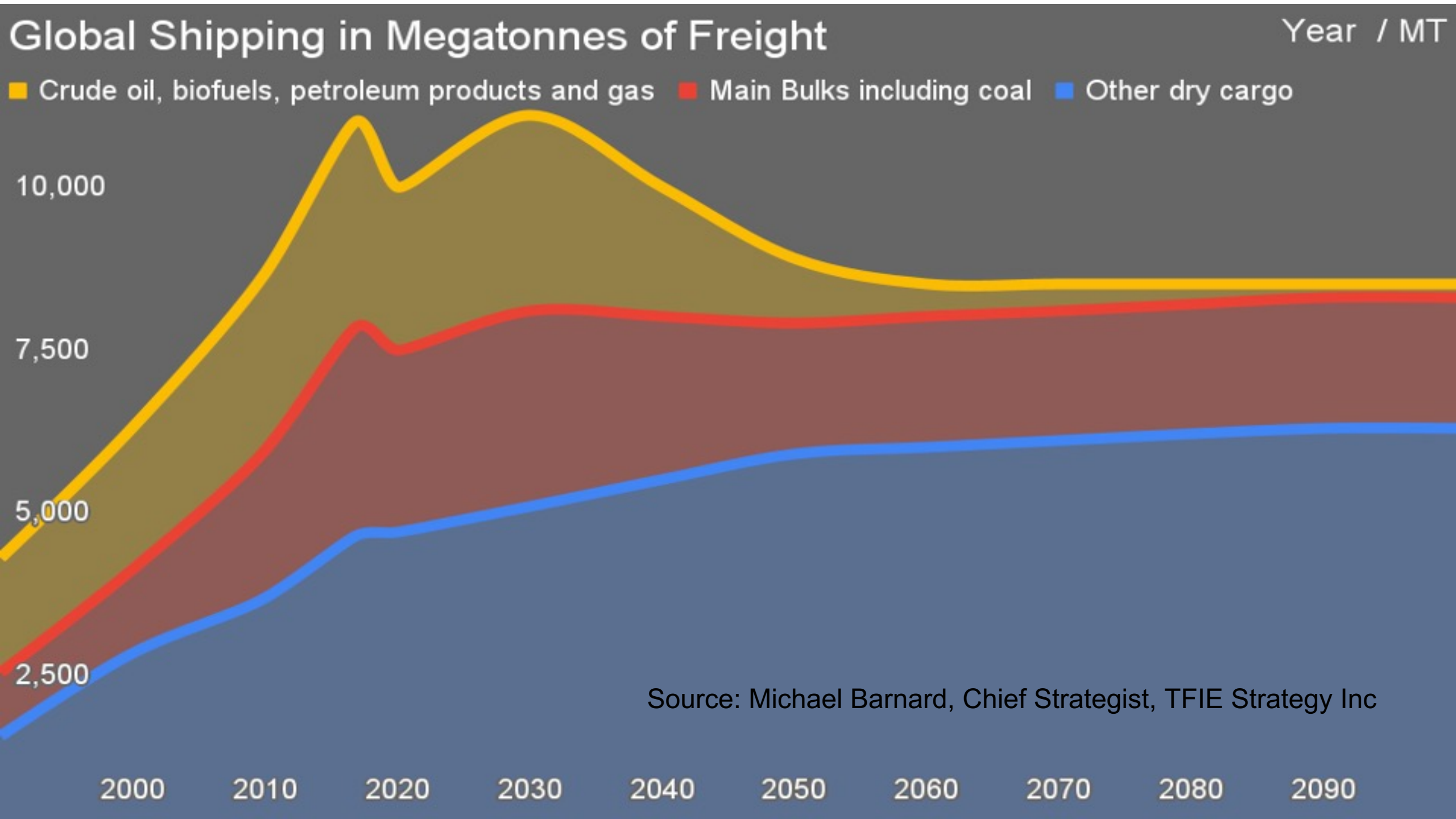

Adaptation
Change in land use, relocation
Emergency & business continuity planning
Upgrades or hardening of building and infrastructure
Residential programs promoting adaptation
Health programs
Seal Buildings
Green Infrastructure
Water and Energy Conservation
Smart Growth
Mitigation
Energy conservation and efficiency
Renewable energy
Sustainable transportation, improved fuel efficiency
Capture and use of landfill and digester gas
Carbon sinks

The Transportation Sector creates 29% total US greenhouse emissions 2021

Road Transportation	Truck Transportation	Marine and Rail Transport	Aviation
45.1%	29.4%	12.4%	11.6%
Buses	Freight	Ships	
Cars		Boats	
		Rail	

World Wide Freight Moved 2023

Type of freight transport	Amount of freight moved (billions of tonne-kilometers)	CO_2 emissions (millions of tonnes)
Air	303	155
Rail	10,842	170
Road (mainly trucking and urban deliveries)	26,807	2,230
Sea and inland waterways	101,486	657


Global Shipping in Megatonnes of Freight
Year / MT
Crude oil, biofuels, petroleum products and gas
Main Bulks including coal
Other dry cargo
10,000
7,500
5,000
2,500
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Source: Michael Barnard, Chief Strategist, TFIE Strategy Inc

Marine Digital

MODEL OF THE "GREEN" SHIP

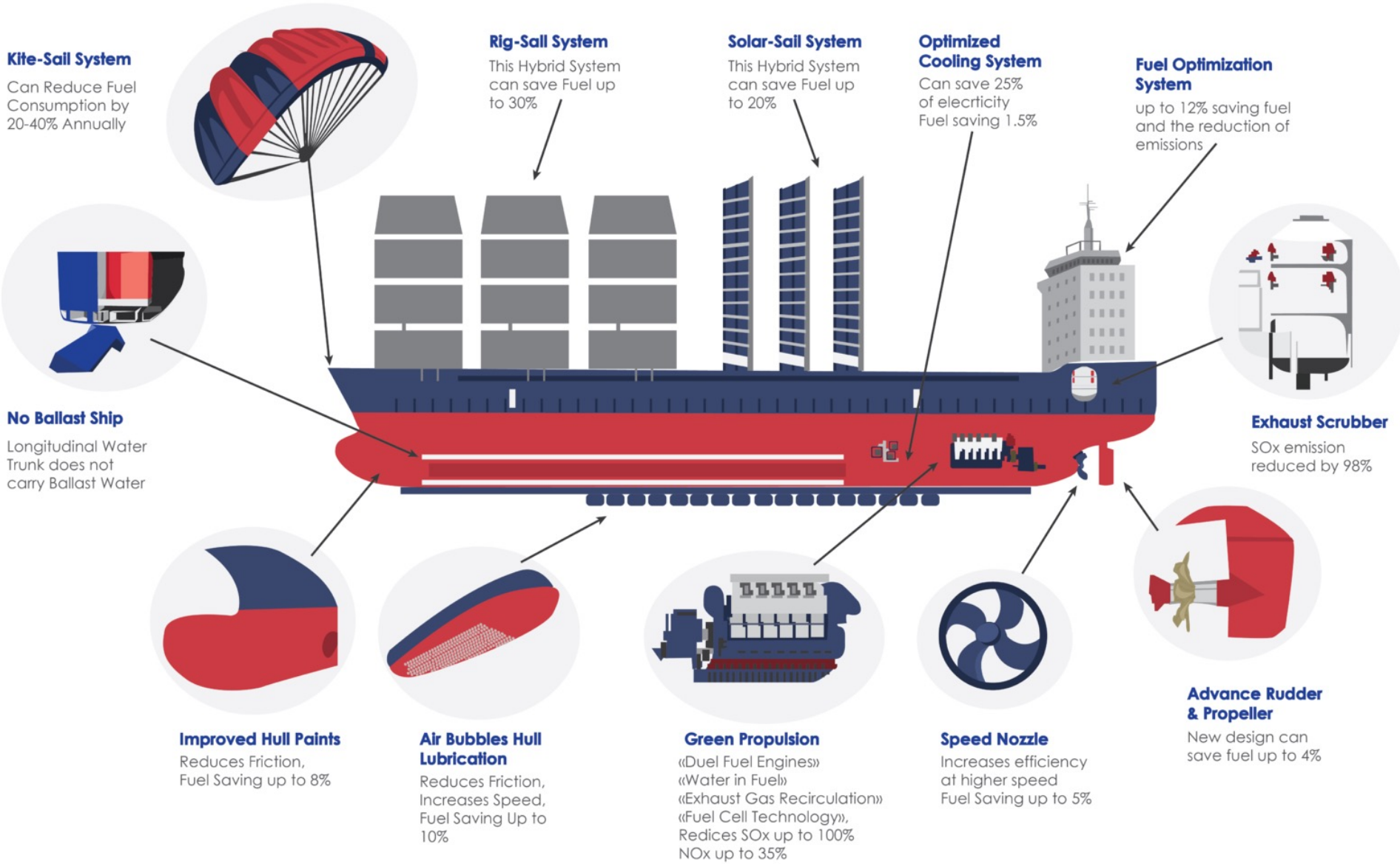
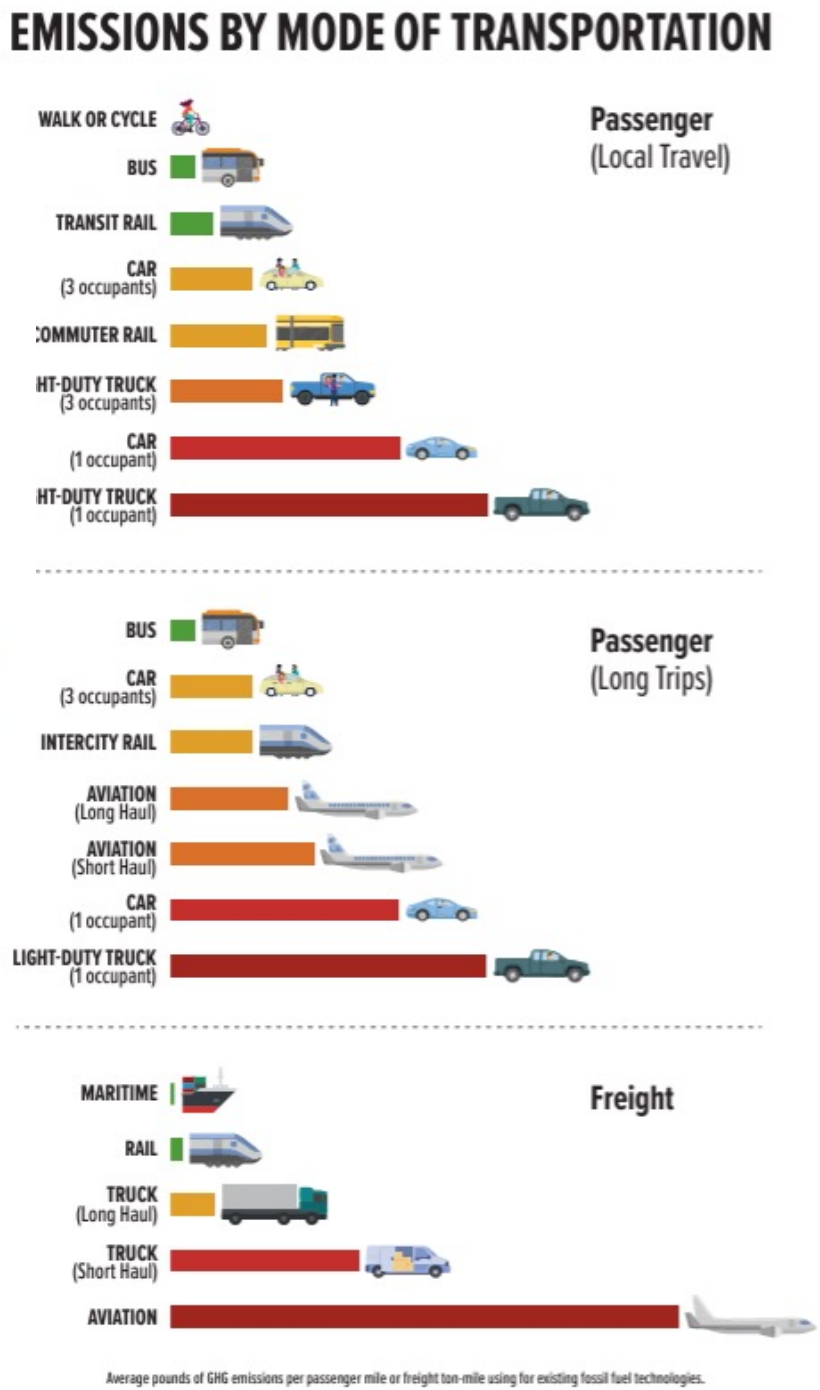
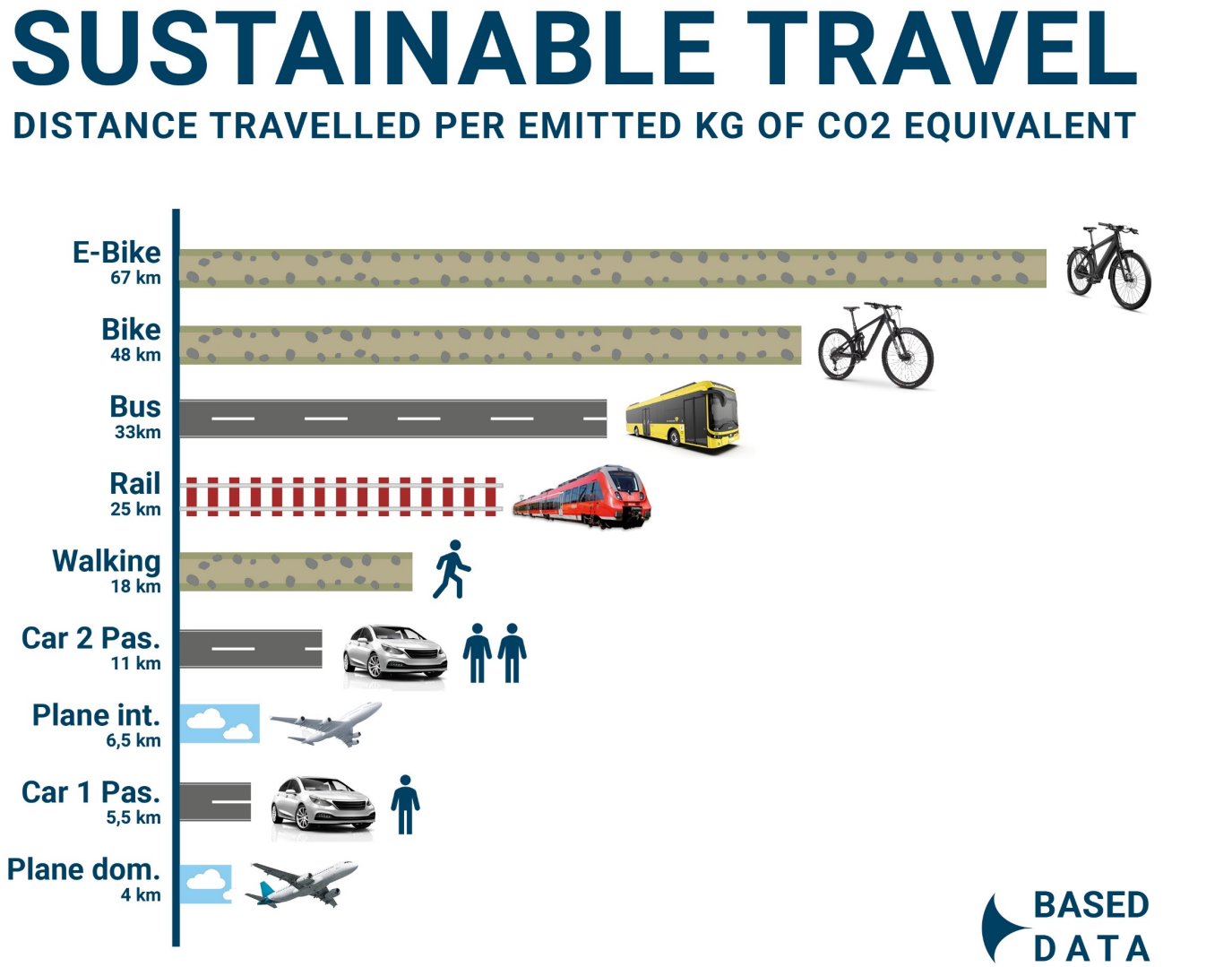


Figure 6. Different modes of transportation have different carbon intensities per passenger mile or per ton mile, and a system that prioritizes low-carbon-intensity options has fewer emissions overall. Note: emissions vary significantly based occupancy, fuel type, and other factors, so the scale in this figure is meant to be illustrative and represent the current fuel mix. For example, transit rail is fully electrified, while most other modes rely on fossil fuels. Illustrative data informed by GREET modeling REF and EPA data REF.



https:ourworldindata.org
https://www.bikeradar.com/features/long-reads/cycling-environmental-impact

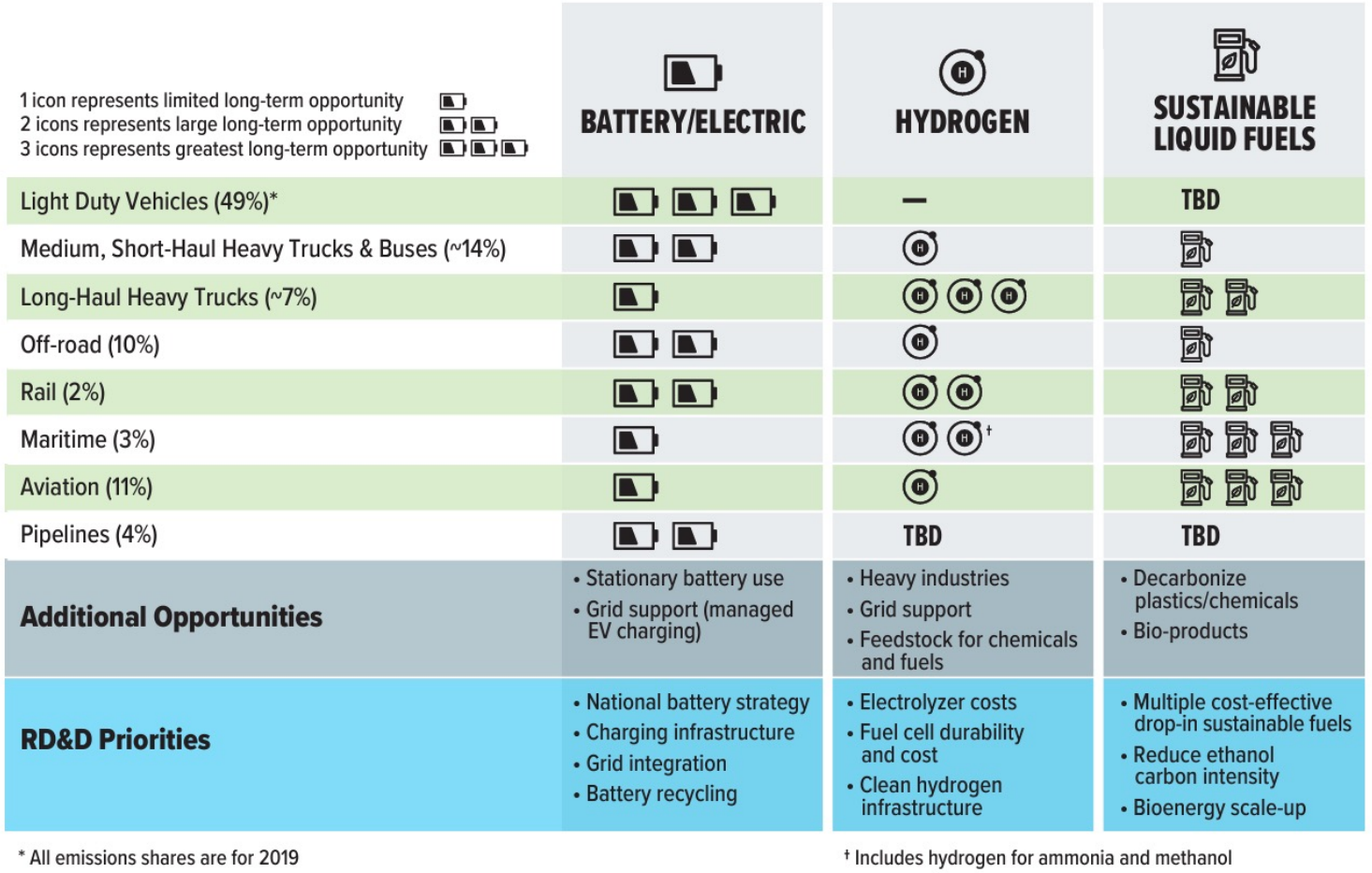
- Cycling has a carbon footprint of about 21g of CO_2 per kilometer.
- About three-quarters of cycling's greenhouse gas emissions occur when producing the extra food required to "fuel" cycling, while the rest comes from manufacturing the bicycle.
- Electric bikes have an even lower carbon footprint than conventional bikes because fewer calories are burned per kilometer, despite the emissions from battery manufacturing and electricity use.



THE U.S. NATIONAL BLUEPRINT FOR TRANSPORTATION DECARBONIZATION (energy.gov) circa 2021

Net 0 or 80-100% reduction in transportation emissions by 2050,

Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA).



1 icon represents limited long-term opportunity 2 icons represents large long-term opportunity 3 icons represents greatest long-term opportunity	BATTERY/ELECTRIC	HYDROGEN	SUSTAINABLE LIQUID FUELS
Light Duty Vehicles (49%)*		–	TBD
Medium, Short-Haul Heavy Trucks & Buses (~14%)			
Long-Haul Heavy Trucks (~7%)			
Off-road (10%)			
Rail (2%)			
Maritime (3%)		†	
Aviation (11%)			
Pipelines (4%)		TBD	TBD
Additional Opportunities	• Stationary battery use • Grid support (managed EV charging)	• Heavy industries • Grid support • Feedstock for chemicals and fuels	• Decarbonize plastics/chemicals • Bio-products
RD&D Priorities	• National battery strategy • Charging infrastructure • Grid integration • Battery recycling	• Electrolyzer costs • Fuel cell durability and cost • Clean hydrogen infrastructure	• Multiple cost-effective drop-in sustainable fuels • Reduce ethanol carbon intensity • Bioenergy scale-up

* All emissions shares are for 2019

† Includes hydrogen for ammonia and methanol

Figure B. Summary of vehicle improvement strategies and technology solutions for different travel modes that are needed to reach a net-zero economy in 2050 (more details provided in Section 5).

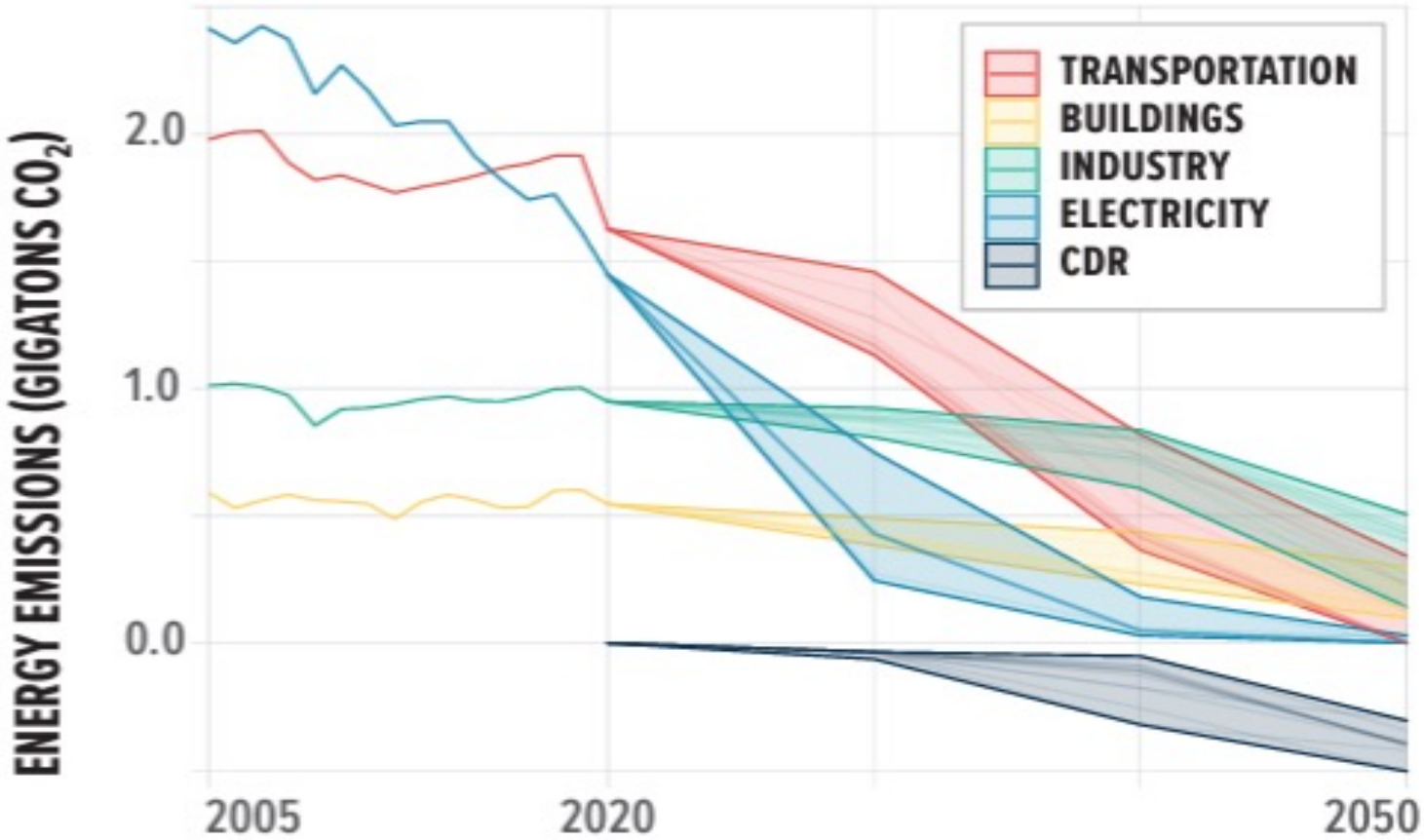


Figure 1. The path to economy-wide decarbonization entails electricity emissions and emissions from transportation, buildings, and industry falling dramatically in all scenarios, with the greatest reductions coming from electricity, followed by transportation, and growth in non-land sink carbon dioxide removals (Source: LTS).

Transportation Mode	Share of Current Transportation Emissions	Federal GHG Emissions Reduction Goals
 Light-Duty Vehicles	49%	• Achieve 50% of new vehicle sales being zero-emission by 2030 supporting a pathway for full adoption, and ensure that new internal combustion engine vehicles are as efficient as possible • Deploy 500,000 EV chargers by 2030 REF • Ensure 100% federal fleet procurement be zero-emission by 2027 REF
 Medium and Heavy-Duty Trucks and Buses	21%	• Aim to have 30% of new vehicle sales be zero-emission by 2030 and 100% by 2040 REF • Ensure 100% federal fleet procurement is zero-emission by 2035 REF
 Off-road	10%	• Work to establish specific targets • Focus resources to develop technology pathways and set efficiency and zero-emissions vehicle and equipment targets
 Rail	2%	• Work to establish specific targets • Focus resources to develop technology pathways and set efficiency and zero-emissions vehicle targets • Encourage greater use for passenger and freight travel to reduce emissions from road vehicles

 **Maritime**	**3%**	• Continue to support the Zero-Emission Shipping Mission (ZESM) goals to ensure that 5% of the global deep-sea fleet are capable of using zero-emission fuels by 2030, at least 200 of these ships primarily use these fuels across the main deep sea shipping route, and 10 large trade ports covering at least three continents can supply zero-emission fuels by 2030 REF • Support the U.S. domestic maritime sector by performing more RD&D into sustainable fuels and technologies and incentivize U.S. commercial vessel operators to move towards lower GHG emissions • Work with countries in the International Maritime Organization to adopt a goal of achieving zero emissions from international shipping by 2050 REF
 **Aviation**	**11%**	• Reduce aviation emissions by 20% by 2030 when compared to a business-as-usual scenario • Achieve net-zero GHG emissions from the U.S. aviation sector by 2050 • Catalyze the production of at least three billion gallons of SAF per year by 2030 and ~35 billion gallons by 2050, enough to supply the entire sector REF

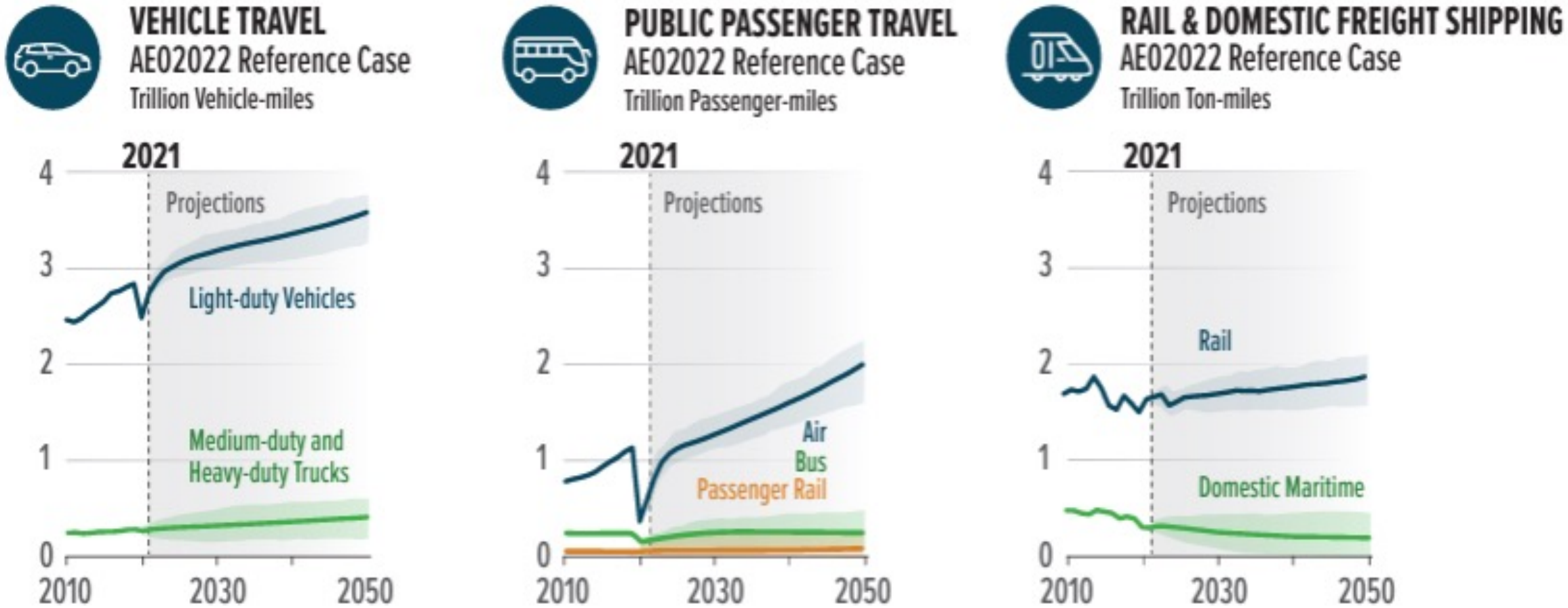


Figure 3. Passenger and freight demand projections from AEO 2022 with additional illustrative uncertainty bounds.

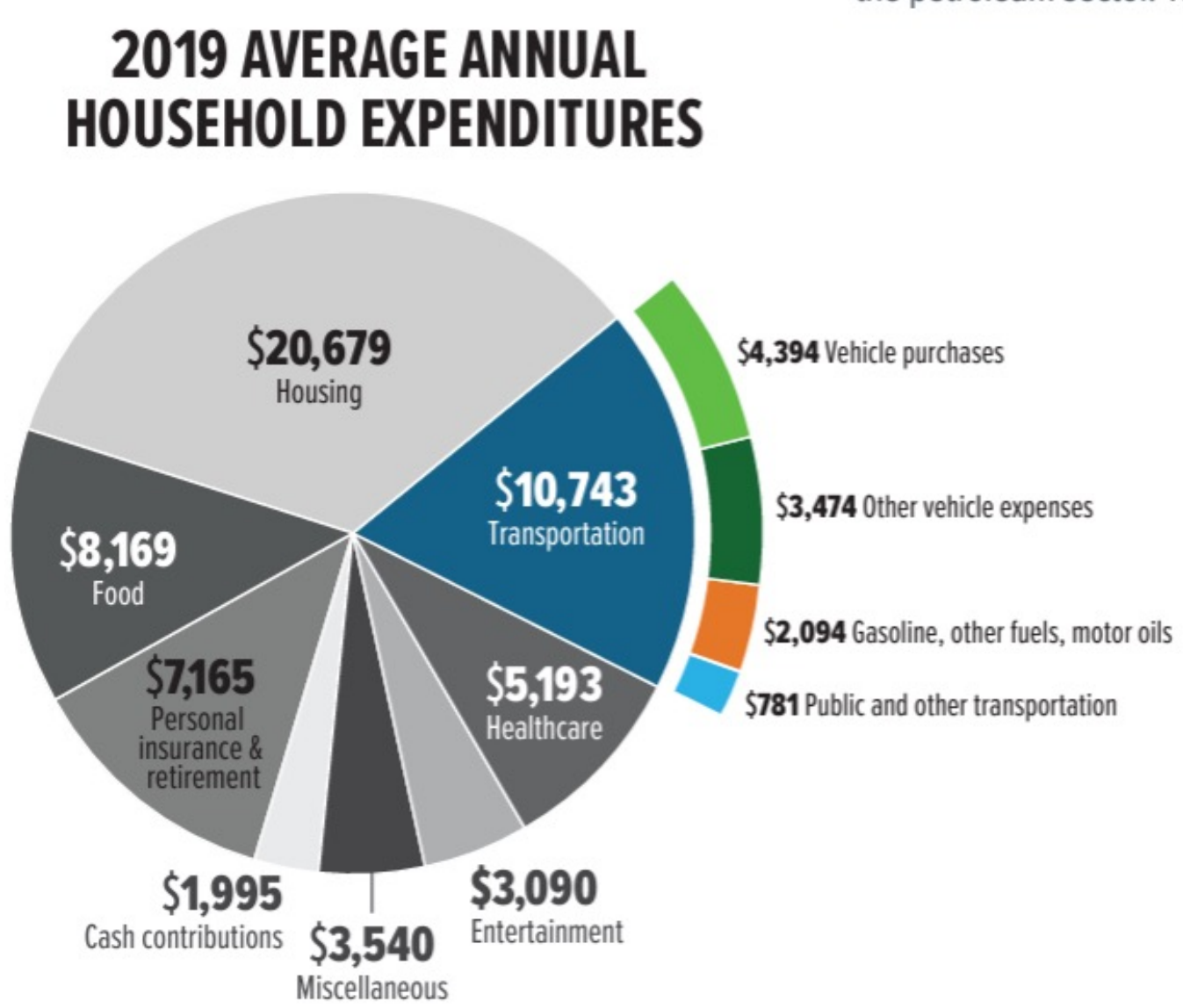


Figure 4. Consumers expenditures highlight the burden of transportation, the second-largest expenditure after housing, at over $10,000 per year on average. Data source: Bureau of Labor Statistics [REF]. This Blueprint uses 2019 as a baseline since impacts due to COVID-19 complicate the use of later data.

2021 Data

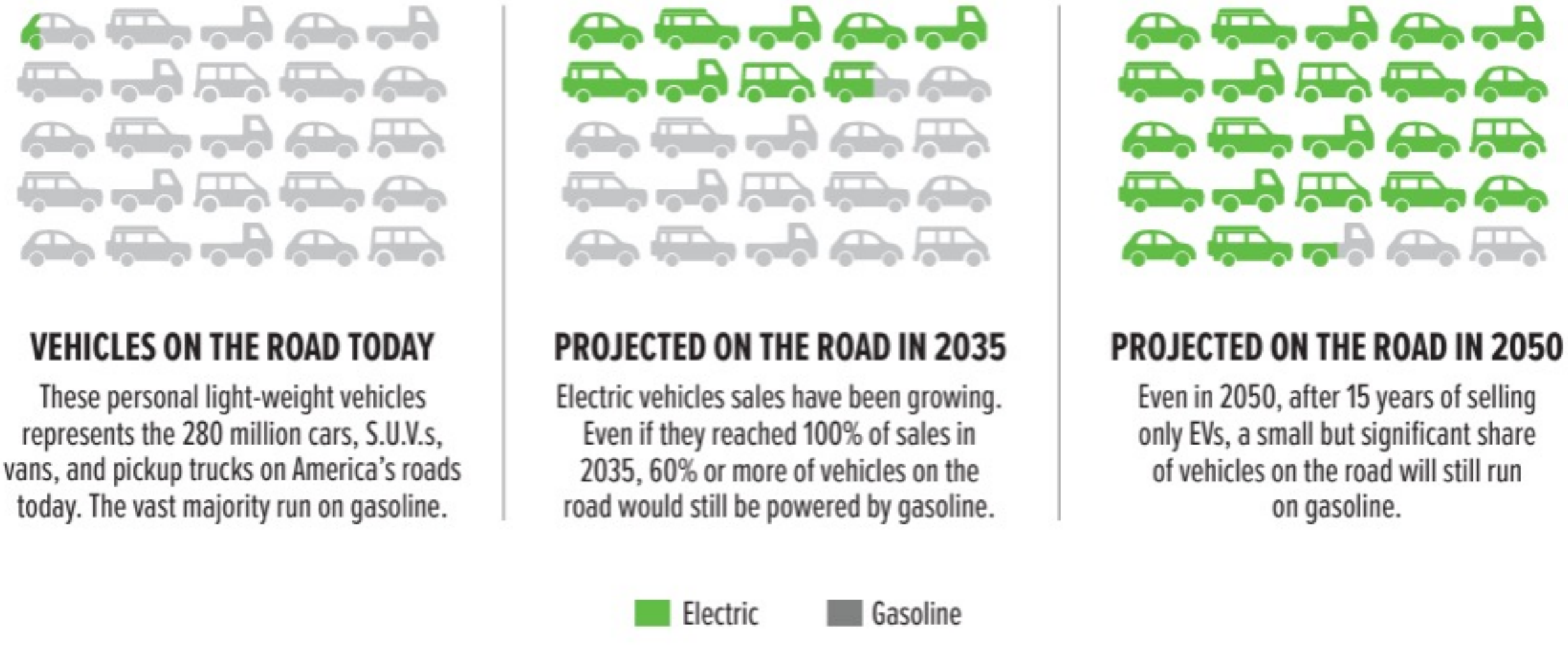
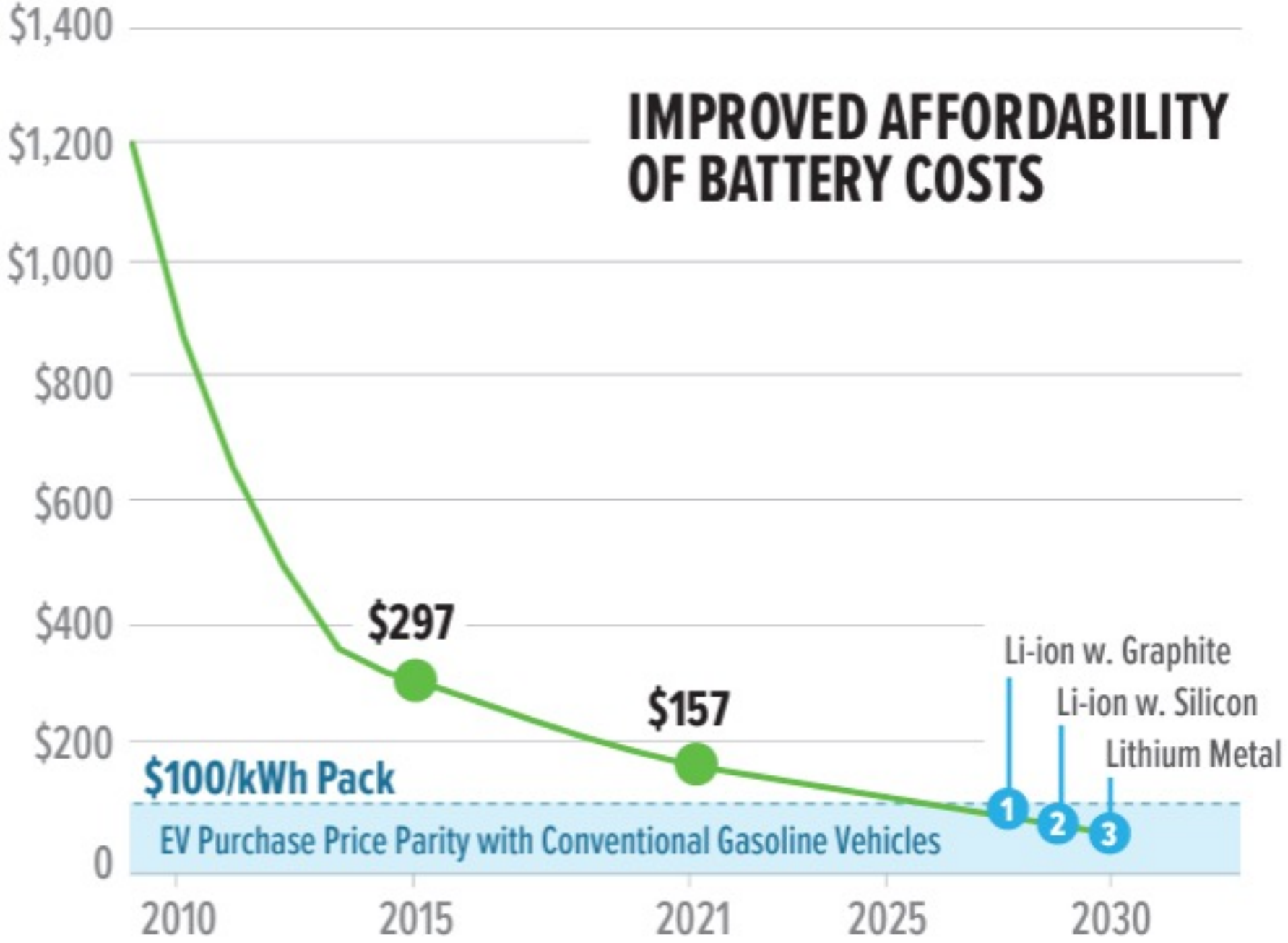


Figure 8. Illustrative example of fleet turnover evolution in a scenario achieving 100% light-duty EV sales in 2035 based on modeling framework documented in Muratori et al.


IMPROVED AFFORDABILITY OF BATTERY COSTS
$1,400
$1,200
$1,000
$800
$600
$400
$200
0
$297
$157
$100/kWh Pack
EV Purchase Price Parity with Conventional Gasoline Vehicles
Li-ion w. Graphite
Li-ion w. Silicon
Lithium Metal
1
2
3
2010
2015
2021
2025
2030

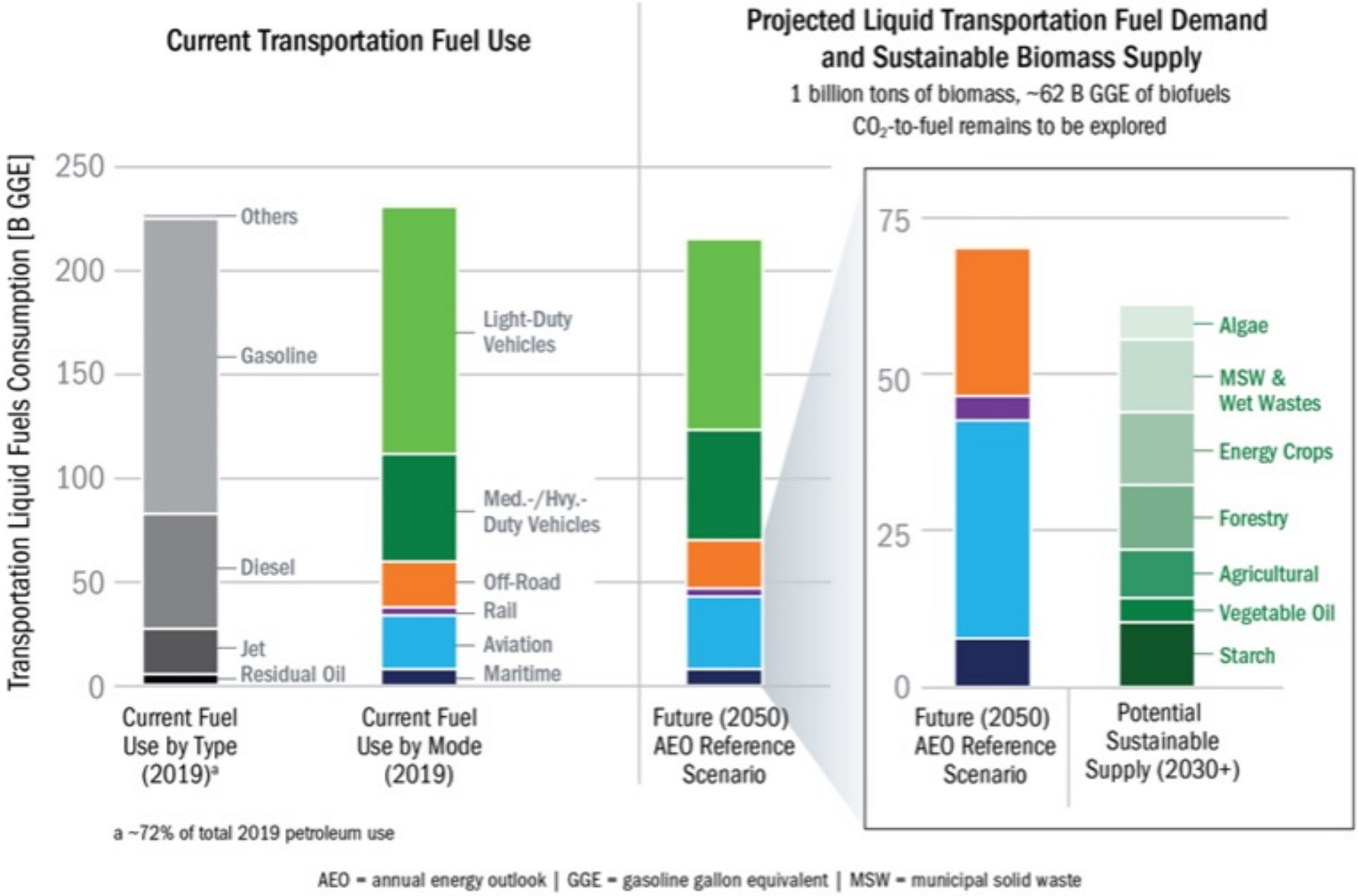
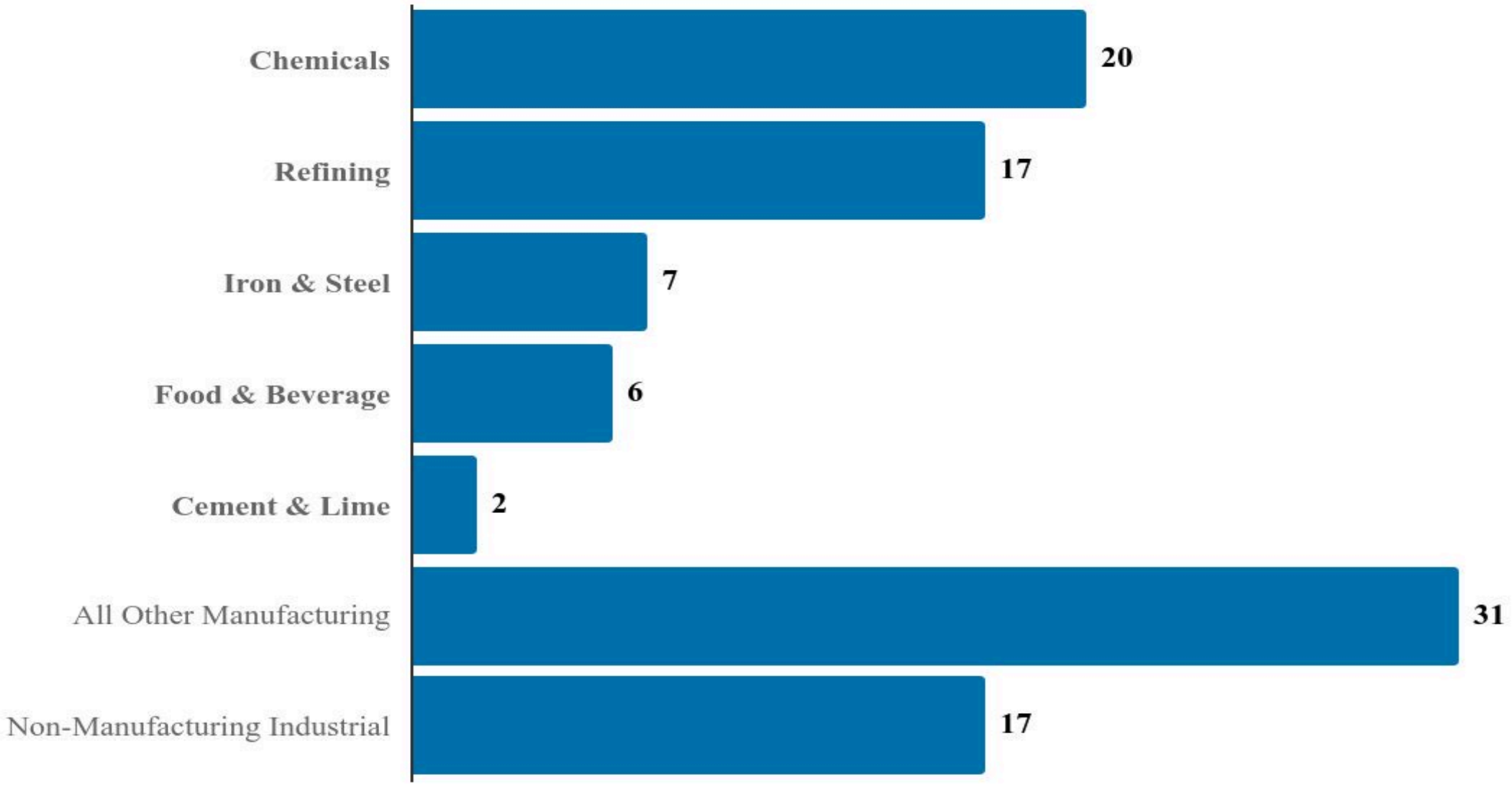


Figure 9. Current and projected liquid transportation fuel demand and sustainable biofuel supply. Note that the AEO reference case represents a business-as-usual perspective with limited changes from the current systems and does not reflect the transformative changes this Blueprint envisions. Data sources: EIA AEO Ref case REF and DOE BETO assessments REF.

Remediation – The Built Environment
Industrial Sector - 35% of Emissions

- Energy efficiency is a foundational, crosscutting decarbonization strategy and is the most cost-effective option for greenhouse gas emission reductions in the near term.
- Leveraging advancements in low-carbon electricity from both grid and onsite renewable generation sources will be critical to decarbonization efforts.
- Substituting low-and no-carbon fuel and feedstocks reduces combustion associated emissions for industrial processes.
- Carbon capture, utilization, and storage refers to the multicomponent strategy of capturing generated CO_2 from a point source and utilizing the captured CO_2 to make value added products or storing it long-term to avoid release.

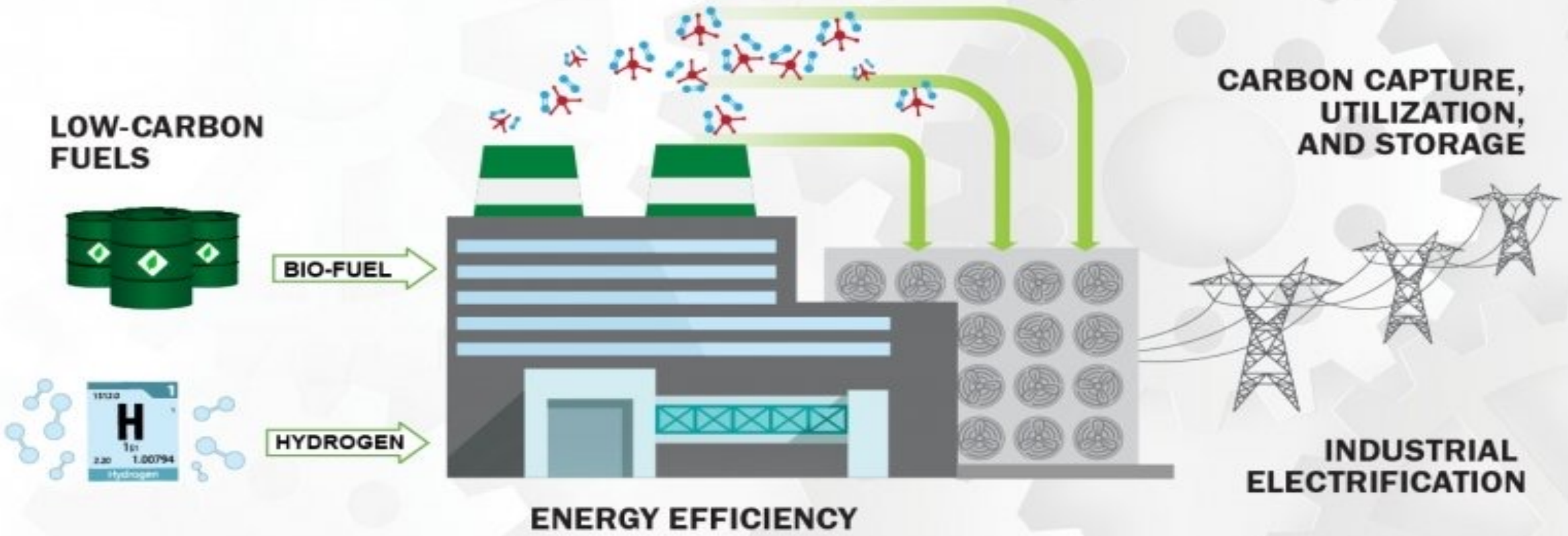
Percent of Industrial MMT CO2



Non-Manufacturing Industrial includes agriculture, mining and construction.

Remediation – The Built Environment

Industry



Remediation – The Built Environment

Commercial & Residential Buildings – 34% Emissions

- Building decarbonization encompasses a building's life cycle, including building design, construction, operation, occupancy, and end of life.
- Building construction, energy use, methane, and refrigerants are the primary sources of GHG emissions.
- Building life-cycle assessment involves consideration of operational and embodied emissions.
- Some state and local government have adopted policies that address building specific operational fuel types and related emissions in the United States.

Remediation – The Built Environment

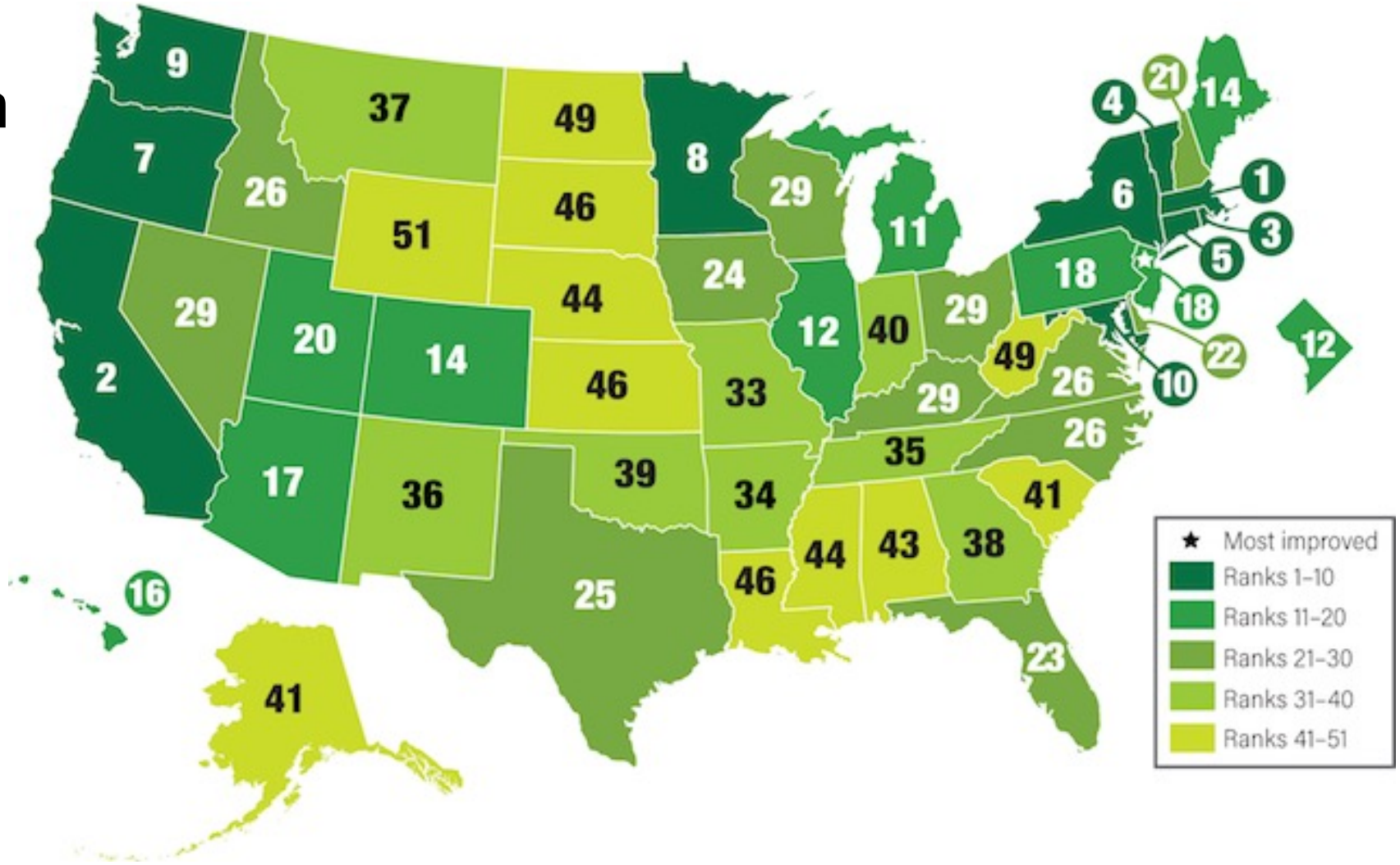
Commercial & Residential Buildings -- 37% of Emissions

- The primary means for reducing GHG emissions are the following:
  - Efficiency measures and building electrification
  - Decarbonized electrical grid -- Ameren 67% fossil-fired.
  - Operations and maintenance.
  - Refrigerants: Low-GWP, minimizing volume, and improving management.
  - Renewable energy sources (on and off site) and energy storage.
  - Building-grid integration and real-time carbon signals.
  - Embodied carbon.

Remediation – The Built Environment

Commercial & Residential Buildings

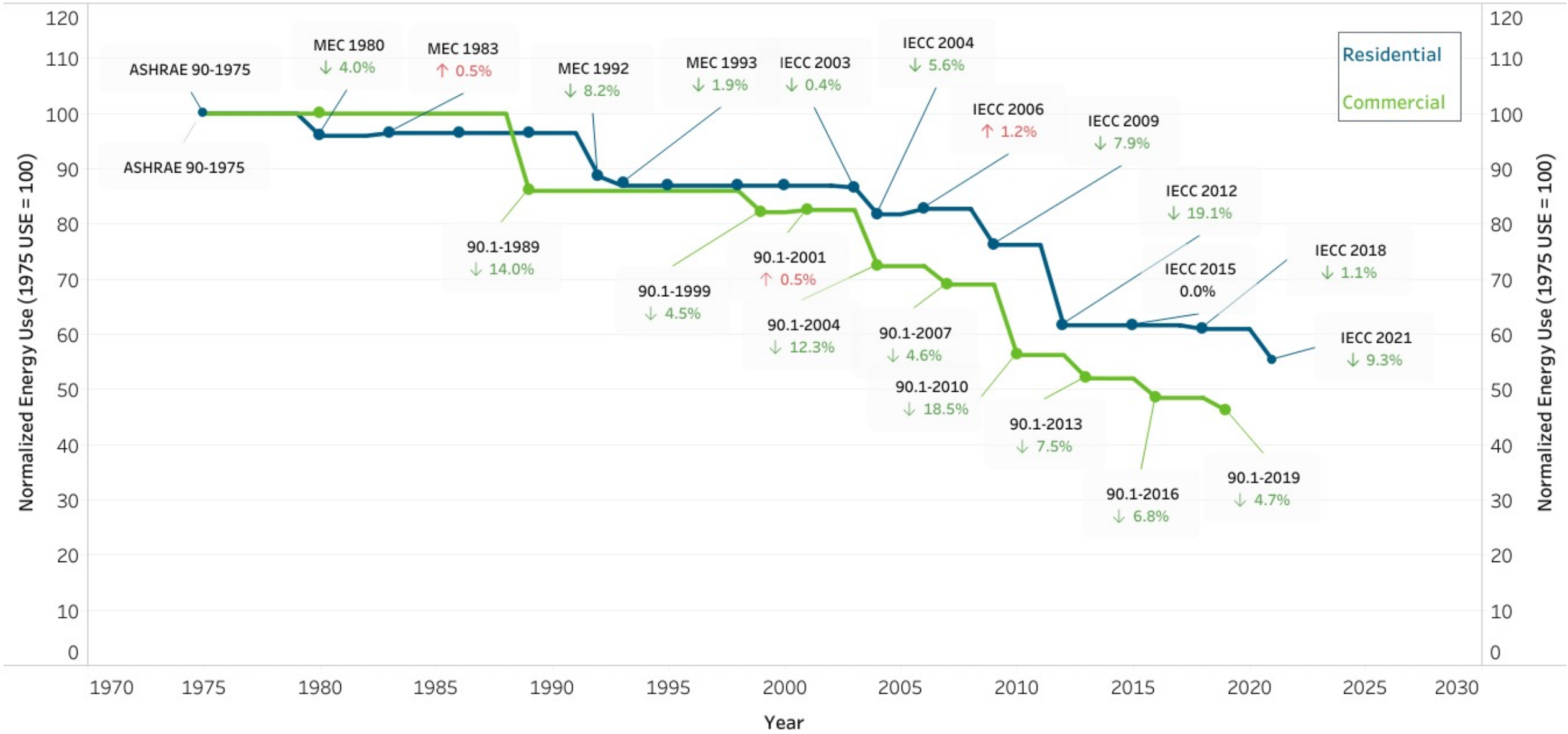
- Building Codes have had a great impact on building energy performance over the past 45 years.
- States that accepted energy money during the Great Recession had to agree to keep their building codes current.

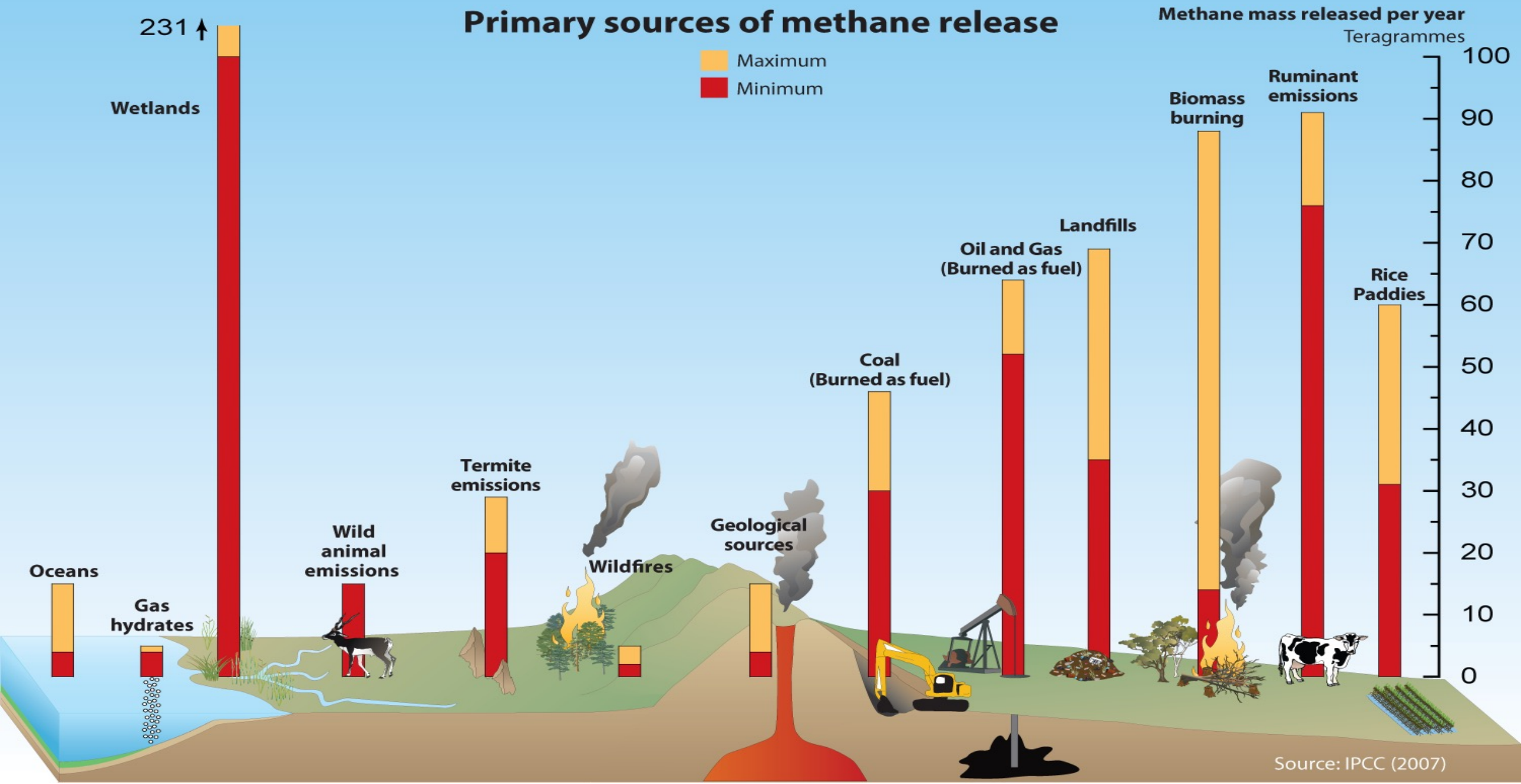


U.S. DEPARTMENT OF ENERGY

Estimated Improvement in Residential & Commercial Energy Codes
(1975 - 2021)

Pacific Northwest NATIONAL LABORATORY




Primary sources of methane release
Maximum
Minimum
Methane mass released per year
Teragrammes
231
Wetlands
Oceans
Gas hydrates
Wild animal emissions
Termite emissions
Wildfires
Geological sources
Coal (Burned as fuel)
Oil and Gas (Burned as fuel)
Landfills
Biomass burning
Ruminant emissions
Rice Paddies
100
90
80
70
60
50
40
30
20
10
0
Source: IPCC (2007)

Remediation – Agriculture, Land Use, & Forestry

Reducing Agricultural Emissions – 11% of Emissions

- Agriculture is a complicated: climate goals versus biodiversity, nutritional needs, food security, and profits.
- By 2030, U.S. farms and ranches can cut agricultural emissions by 23
- Cut nitrous oxide emissions by optimizing fertilizer use.
- Reduce on-farm emissions by shifting from traditional fossil-fuel equipment and machinery—such as tractors, harvesters, and dryers—to their zero-emission counterparts.

Remediation – Agriculture, Land Use, & Forestry

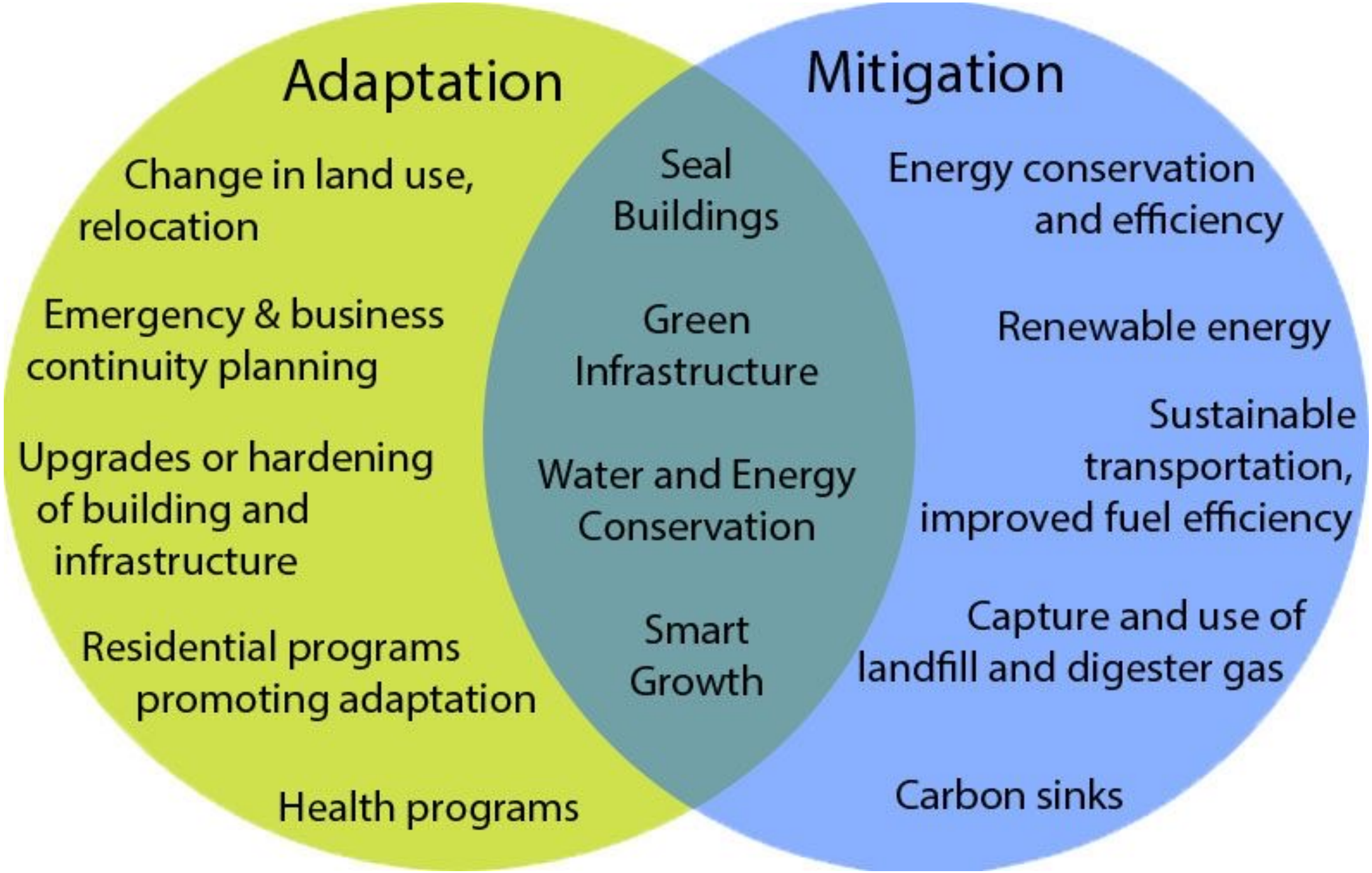
Reducing Agricultural Emissions – 11% of Emissions

- Genetic selection and breeding programs focused on ruminant animals' enteric fermentation. About 20 percent of a ruminant's methane emissions rate stems from genetics alone.
- Use anaerobic digesters for dairy cow and hog manure. Biogas can be used to generate electricity for the farm or sold back to the grid (electricity).
- Combine deep placement of nitrogen with low- and no-tillage practices — such as shallow plowing, fewer tillage passes, chisel coulter drilling, and zone tillage — to reduce fuel usage and denitrification.
- Use cover crops to absorb carbon and improve production.

Remediation – Agriculture, Land Use, & Forestry

Land Use & Forestry – 6% of Emissions

- Plants, forests, and soil absorb carbon dioxide, making management of forests and land paramount to achieving climate goals. Deforestation is rapidly reducing the planet's potential to absorb carbon dioxide and mitigate its warming effects.
- Keeping all existing forests, wetlands and grasslands intact rather than clearing them for new cropland or urban development.
- Increase carbon storage in forests by natural reforesting and afforesting land, improve management of existing forests, and adopt agroforestry practices that integrate trees and shrubs into crop- and pastureland.
- U.S. forests can boost carbon storage by 43% by 2030.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Capture and use of landfill and digester gas
Carbon sinks

Adapting to Climate Change

Adaptation -- Strategies

- **Climate change adaptation** is the process of adjusting to the **effects** of climate change.
- These can be both current or expected impacts.[1]
- Adaptation aims to moderate or avoid harm for people.
- It also aims to exploit opportunities.
- Humans may also intervene to help adjustment for natural systems.

https://en.wikipedia.org/wiki/Climate_change_adaptation

Adapting to Climate Change

Adaptation -- Classification

Help manage impacts and risks to people and nature.

Adaptation actions can be classified in four ways:

1. Infrastructural and technological;
2. Institutional;
3. Behavioral and cultural; and
4. Nature-based options.

Adapting to Climate Change

Adaptation -- Definition

- "In human systems, as the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities."[7]
- "In natural systems, adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate this."[7]

- IPCC, 2022: Summary for Policymakers pp. 3–33,

Adapting to Climate Change

Adaptation -- Disaster Risks, Response, and Preparedness

- Climate change contributes to disaster risk. So experts sometimes see climate change adaptation as one of many processes within disaster risk reduction. In turn, disaster risk reduction is part of the broader consideration of sustainable development. Climate change adaptation and disaster risk reduction have similar goals (to reduce potential impacts of hazards and increase the resilience of people at risk). They use similar concepts and are informed by similar sources and studies.

Adapting to Climate Change

Adaptive Capacity

Adaptive capacity in the context of climate change covers human, natural, or managed systems. It looks at how they respond to both climate variability and extremes.

- Economic resources: Wealthier nations are better able to bear the costs of adaptation to climate change than poorer ones.
- Technology: Lack of technology can impede adaptation.
- Information and skills: Information and trained personnel are necessary to assess and implement successful adaptation options.
- Social infrastructure:
  - Institutions: Nations with well-developed social institutions are likely to have greater adaptive capacity than those with less effective institutions. These are typically developing nations and economies in transition.
  - Equity: Some believe that adaptive capacity is greater where there are government institutions and arrangements in place that allow equitable access to resources

Example North America Risks from Climate Change Requiring Adaptation (IPCC)

- Climate-sensitive mental health outcomes, human mortality and morbidity due to increasing average temperature, weather and climate extremes, and compound climate hazards
- Risk of degradation of marine, coastal and terrestrial ecosystems, including loss of biodiversity, function, and protective services
- Risk to freshwater resources with consequences for ecosystems, reduced surface water availability for irrigated agriculture, other human uses, and degraded water quality
- Risk to food and nutritional security through changes in agriculture, livestock, hunting, fisheries, and aquaculture productivity and access
- Risks to well-being, livelihoods and economic activities from cascading and compounding climate hazards, including risks to coastal cities, settlements and infrastructure from sea level rise

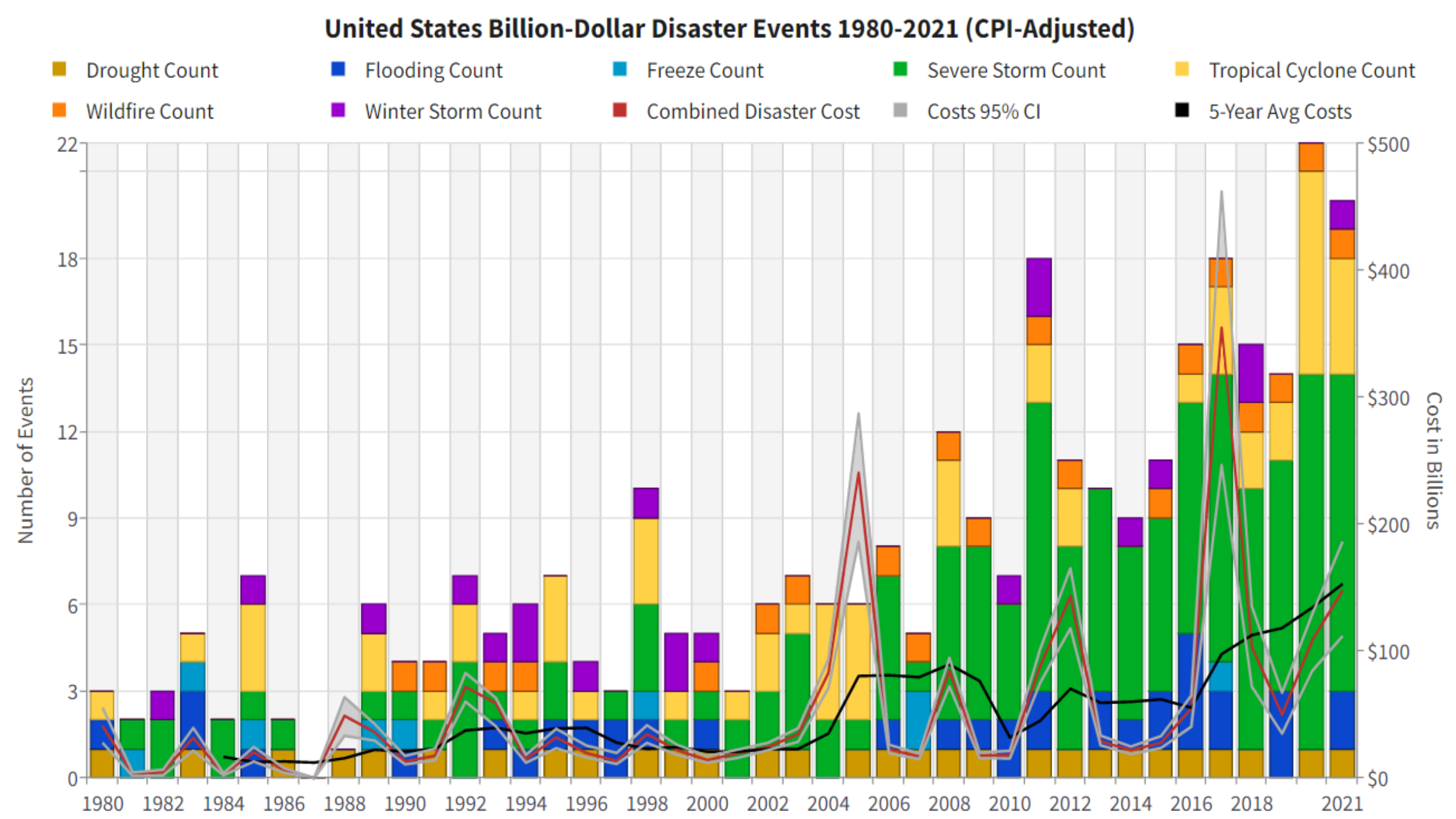
Adapting to Climate Change

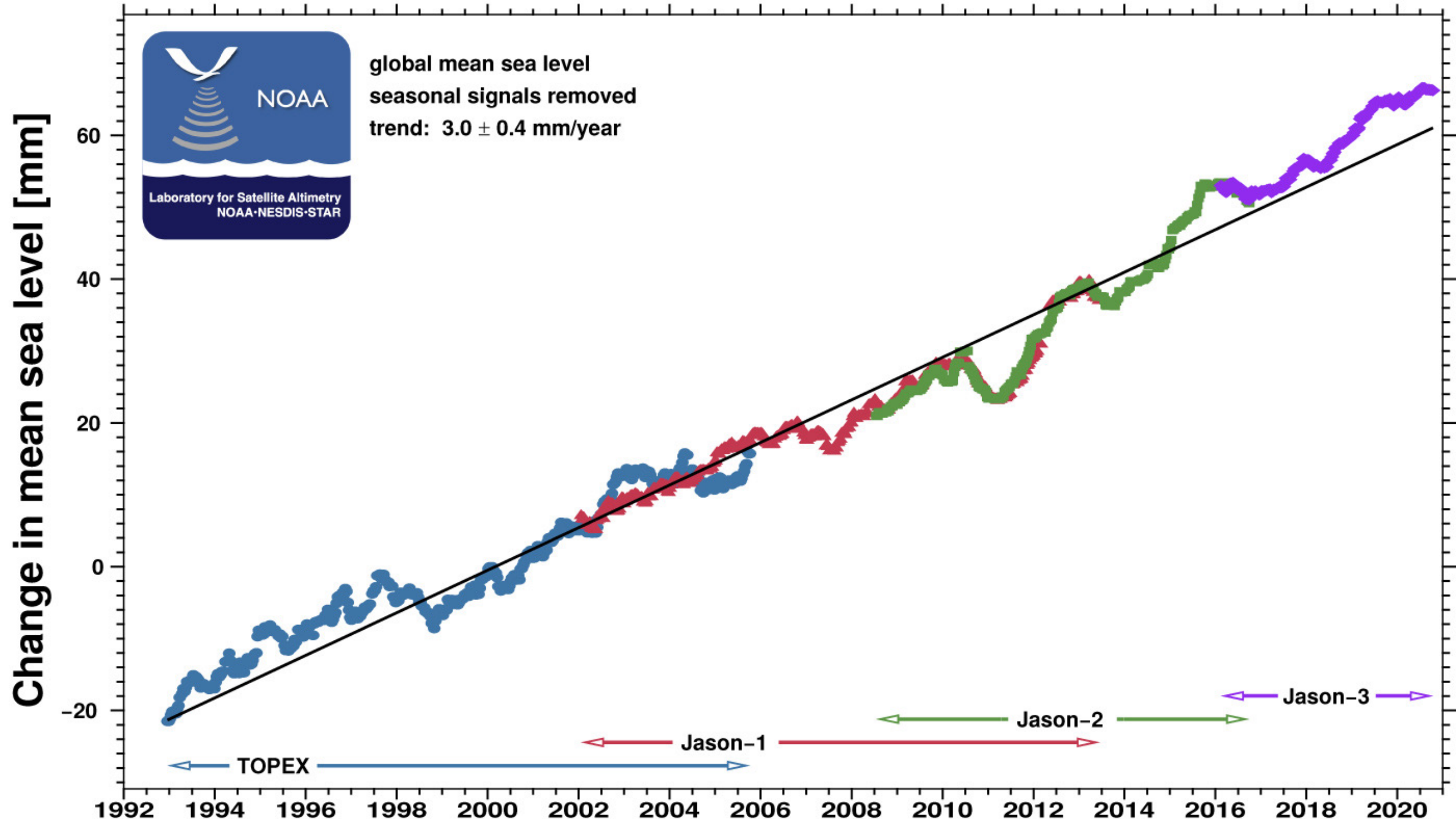
Air
- Indoor Air Quality
- Outdoor Air Quality
- Temperature
- Precipitation
- Wind
- Wildfires

Water
- Drought
- Saltwater Intrusion
- Sea Level Rise
- Flooding
- General Utility Preparedness
- Stormwater Runoff
- Erosion and Sedimentation
- Algal Blooms

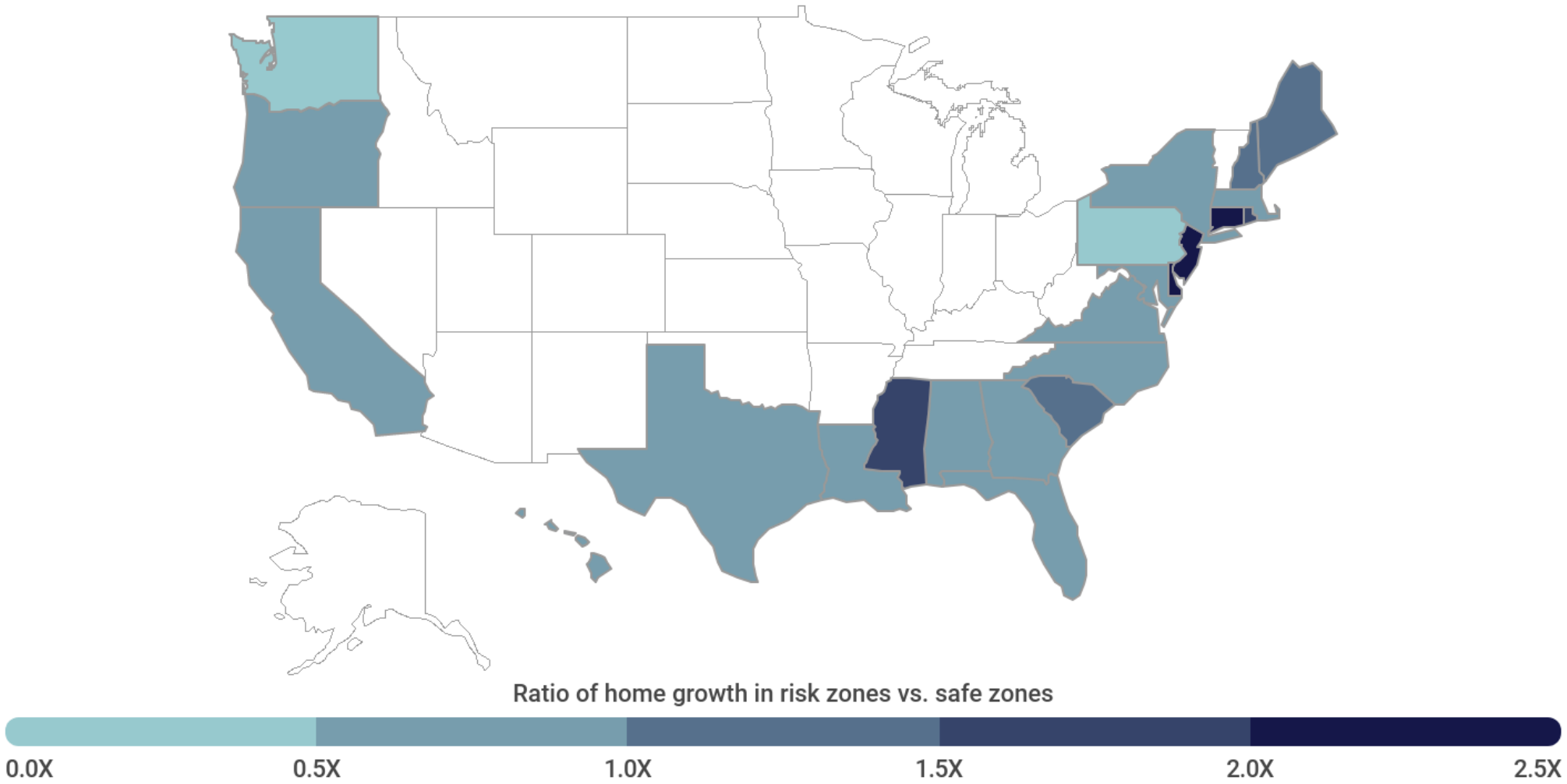
Waste
- Waste Facility Protection adaptation strategies
- Waste Management

Public Health
- Viruses
- Air, Water and Insect born diseases
- Heat stroke
- Dehydration
- Hypothermia


United States Billion-Dollar Disaster Events 1980-2021 (CPI-Adjusted)
Drought Count
Flooding Count
Freeze Count
Severe Storm Count
Tropical Cyclone Count
Wildfire Count
Winter Storm Count
Combined Disaster Cost
Costs 95% CI
5-Year Avg Costs
Number of Events
Cost in Billions
0
3
6
9
12
15
18
22
$0
$100
$200
$300
$400
$500
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2021

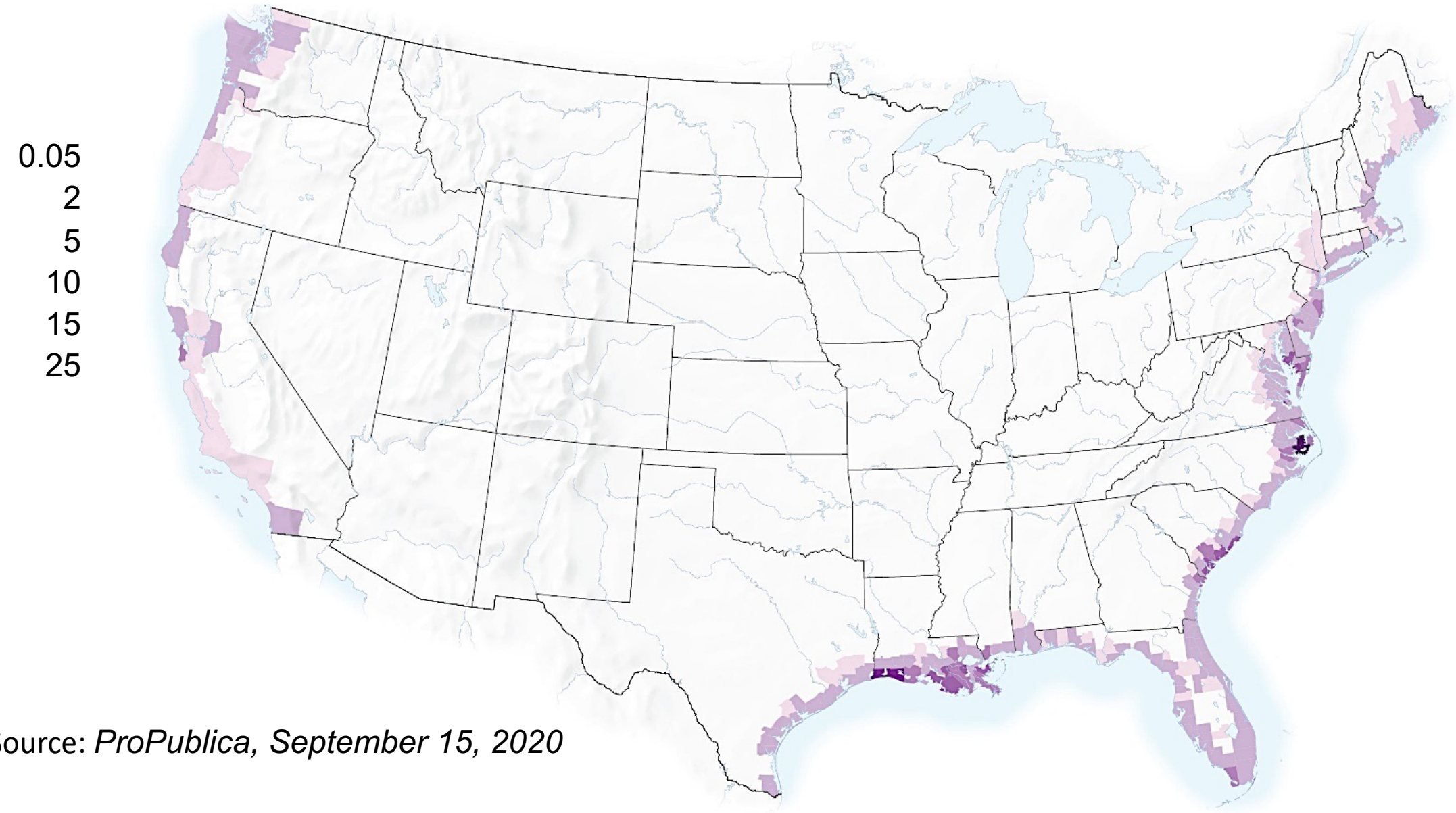

NOAA
Laboratory for Satellite Altimetry
NOAA·NESDIS·STAR
global mean sea level
seasonal signals removed
trend: 3.0 ± 0.4 mm/year
Change in mean sea level [mm]
60
40
20
0
−20
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
TOPEX
Jason−1
Jason−2
Jason−3

Certain Mid-Atlantic states are developing high-risk flood zones more than 2X faster than safer areas



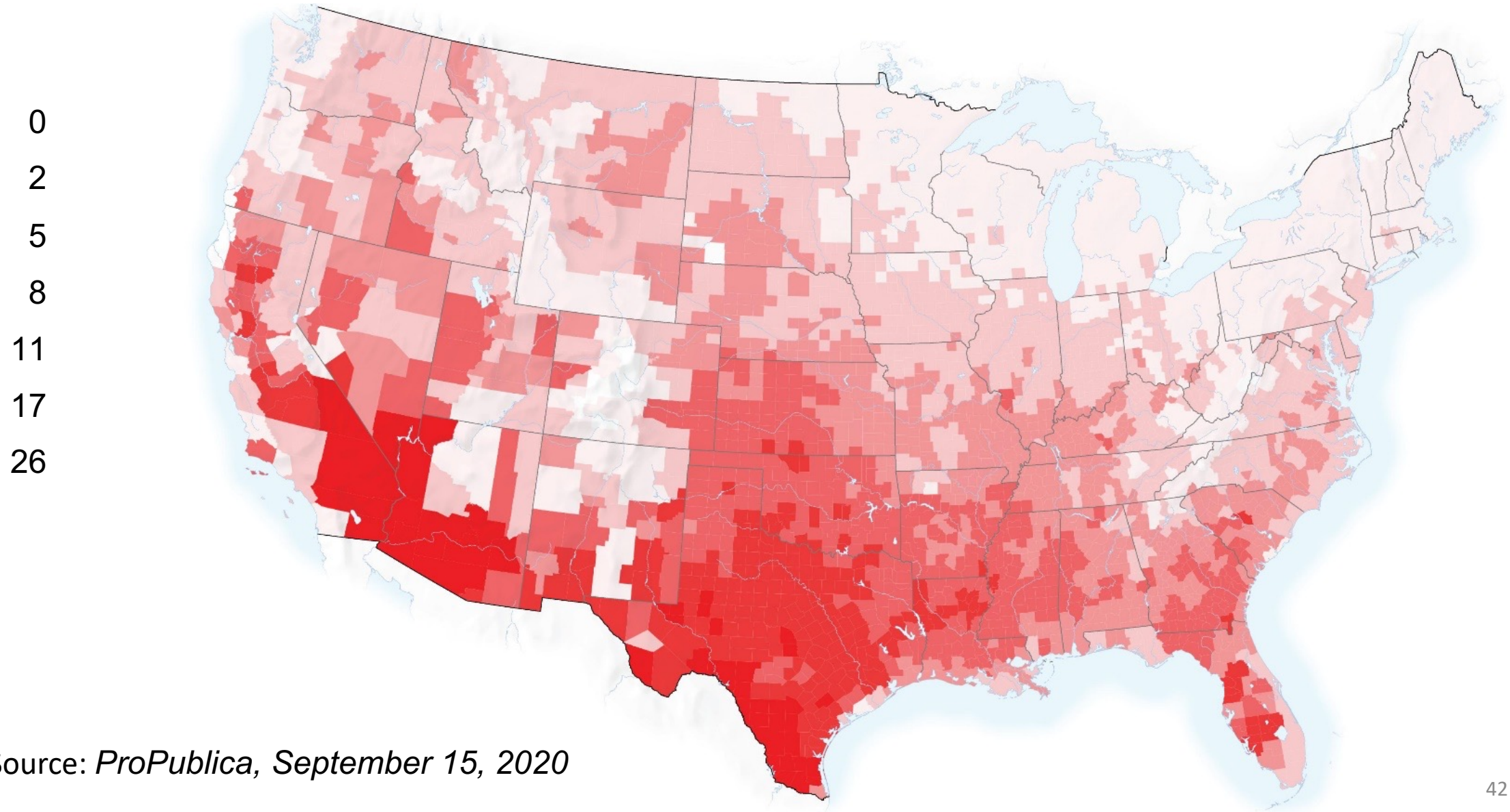
Source: Climate Central and Zillow

Sea Level Rise: 2040-2060 Percentage of property below high tide



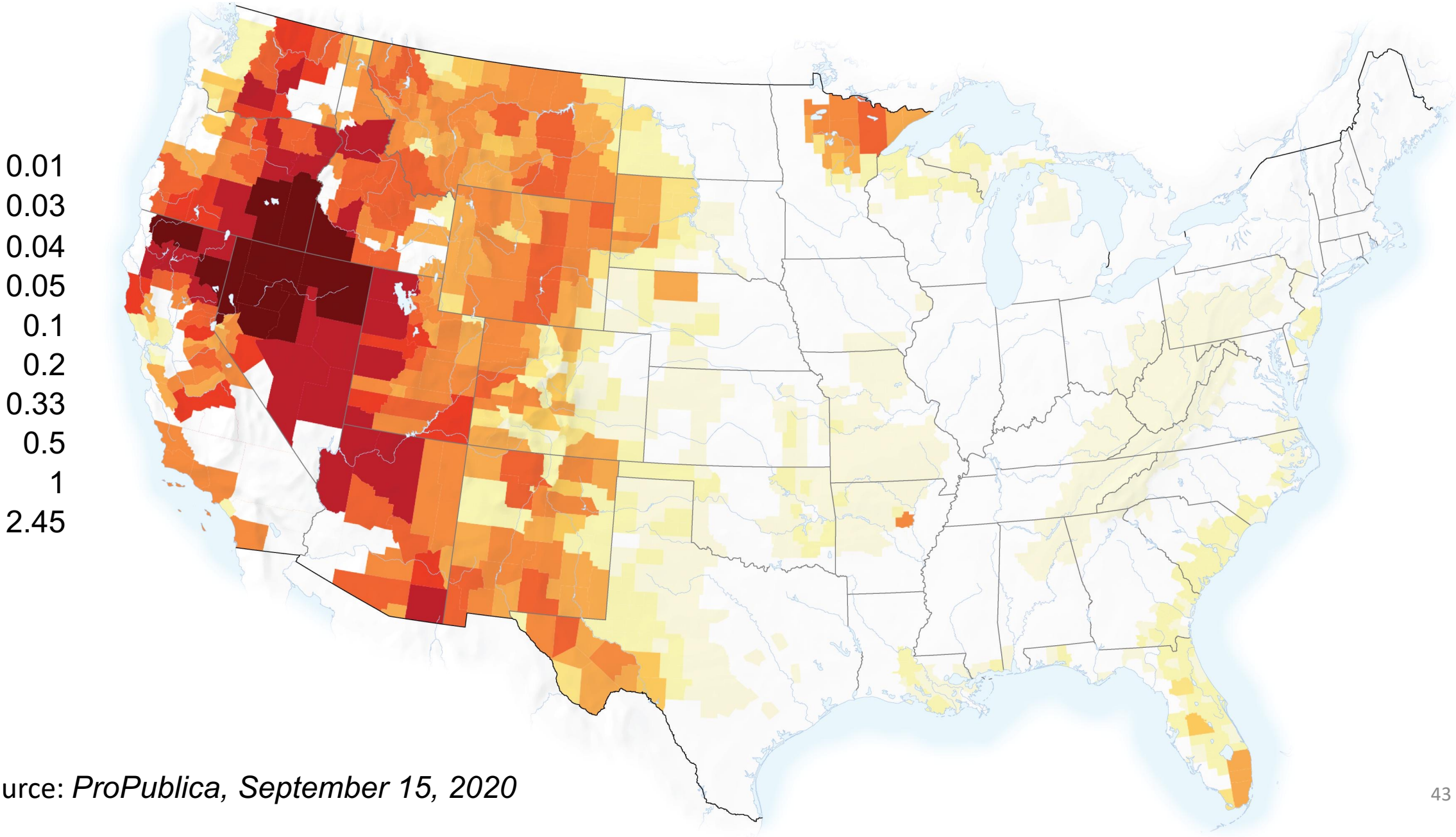
Source: *ProPublica, September 15, 2020*

2040-2060 Weeks per year above 95 degrees F



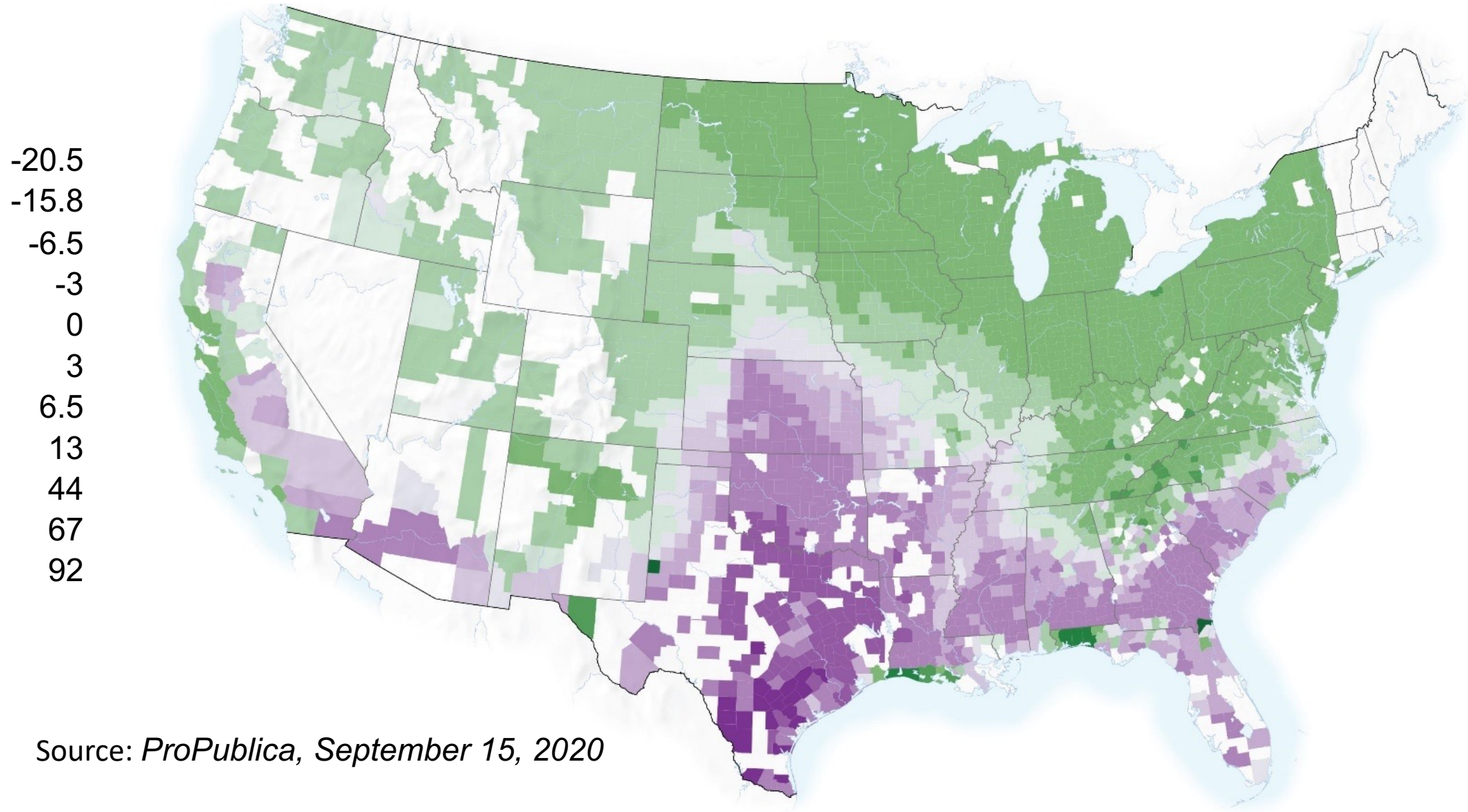
Source: *ProPublica, September 15, 2020*

Large Wildfires: 2040-2071 Average number of very large fires per year



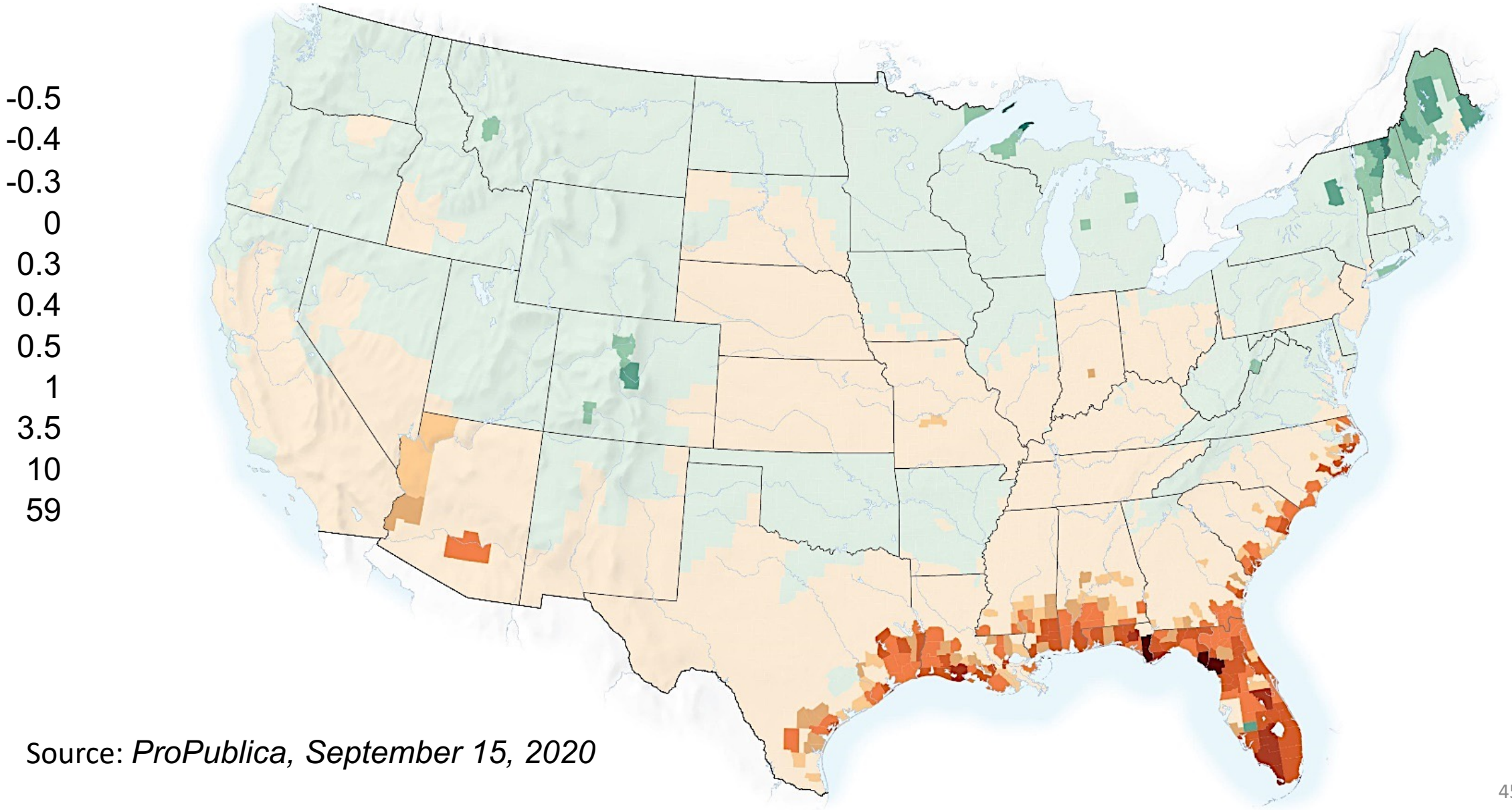
Source: *ProPublica, September 15, 2020*

Farm Crop Yields: 2040-2060 Percent decline in yields



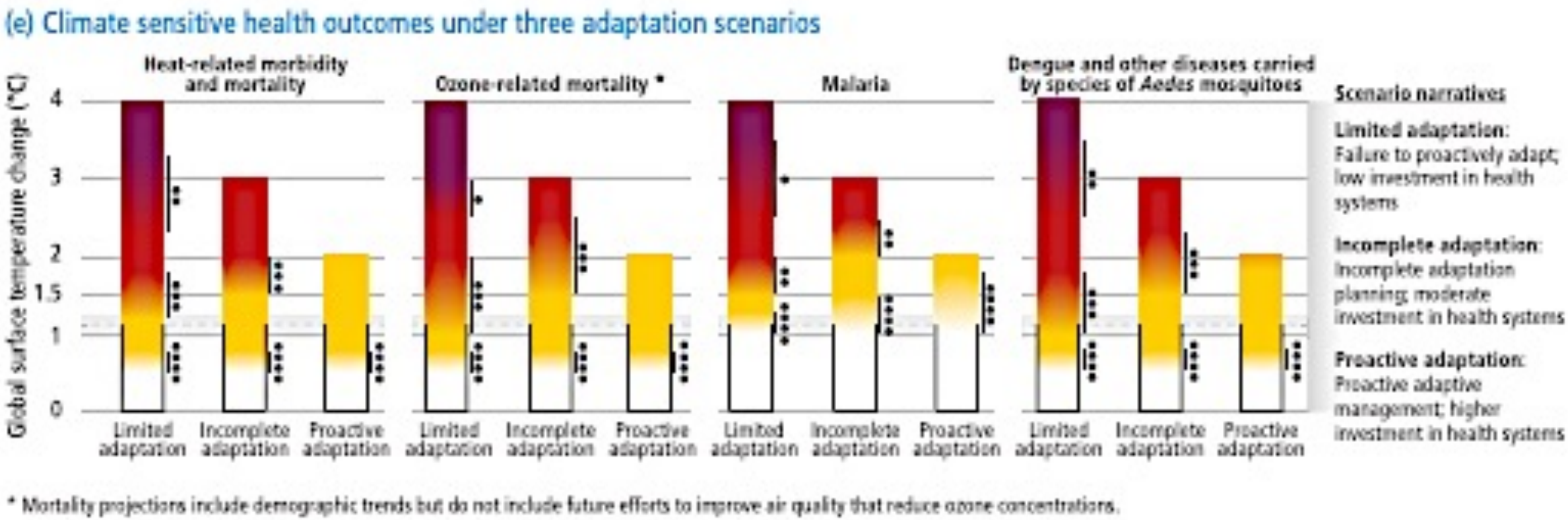
Source: *ProPublica, September 15, 2020*

Economic Damages From Climate: 2040-2060 Climate damage as a percent of GDP



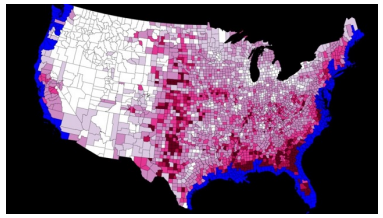
Source: *ProPublica, September 15, 2020*

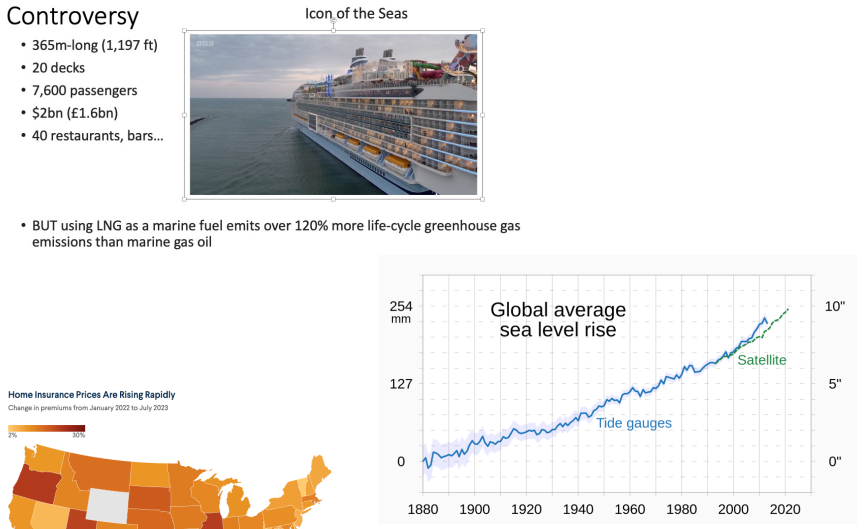
Health


(e) Climate sensitive health outcomes under three adaptation scenarios
Heat-related morbidity and mortality
Ozone-related mortality *
Malaria
Dengue and other diseases carried by species of Aedes mosquitoes
Global surface temperature change (°C)
4
3
2
1.5
1
0
Limited adaptation
Incomplete adaptation
Proactive adaptation
Scenario narratives
Limited adaptation: Failure to proactively adapt; low investment in health systems
Incomplete adaptation: Incomplete adaptation planning; moderate investment in health systems
Proactive adaptation: Proactive adaptive management; higher investment in health systems
* Mortality projections include demographic trends but do not include future efforts to improve air quality that reduce ozone concentrations.

Next Week – Politics versus Science

- Politics, Science and Controversy
  - Methane
  - Sea Level Rise
  - Home Insurance





  - Oil and Fossil Fuels - Follow the money!
  - Storage – Not near me!
  - Power Grid – Not where I can see it!

Introduction: https://en.wikipedia.org/wiki/List_of_climate_change_controversies