Climate Change – A Hot Topic Session 3

Mitigation of Climate Change

Electrify Everything, Everywhere, All at Once

Roy Campbell and Don Fournier

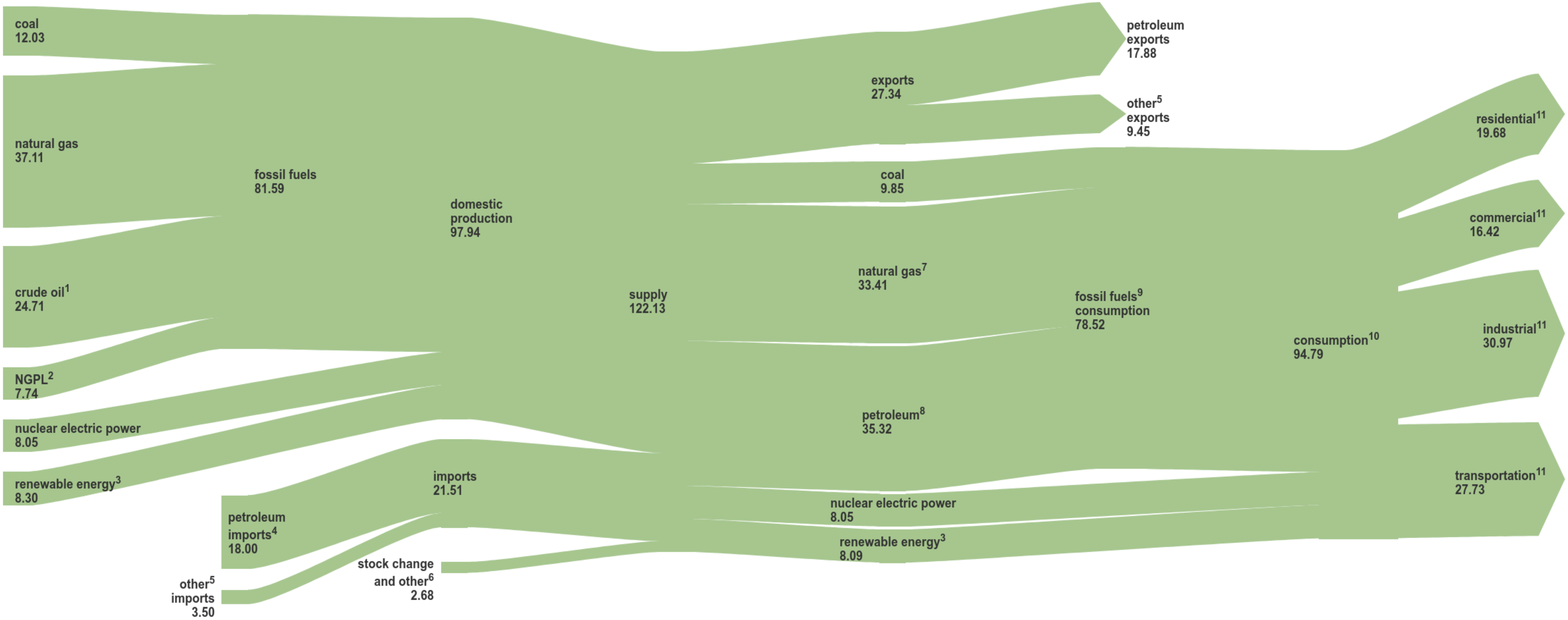
January 29, 2024

Remediation -- Getting off Carbon

- Electricity Production
  - Nuclear Power
  - Renewables (Solar, Wind, Energy Storage, & Geothermal)
- The Transportation Sector
  - Automobiles
  - Trucks
  - Aviation
  - Rail System
  - Ships
- The Built Environment
  - Industry
  - Commercial & Residential
- Agriculture
- Land Use and Forestry

U.S. energy flow, 2022

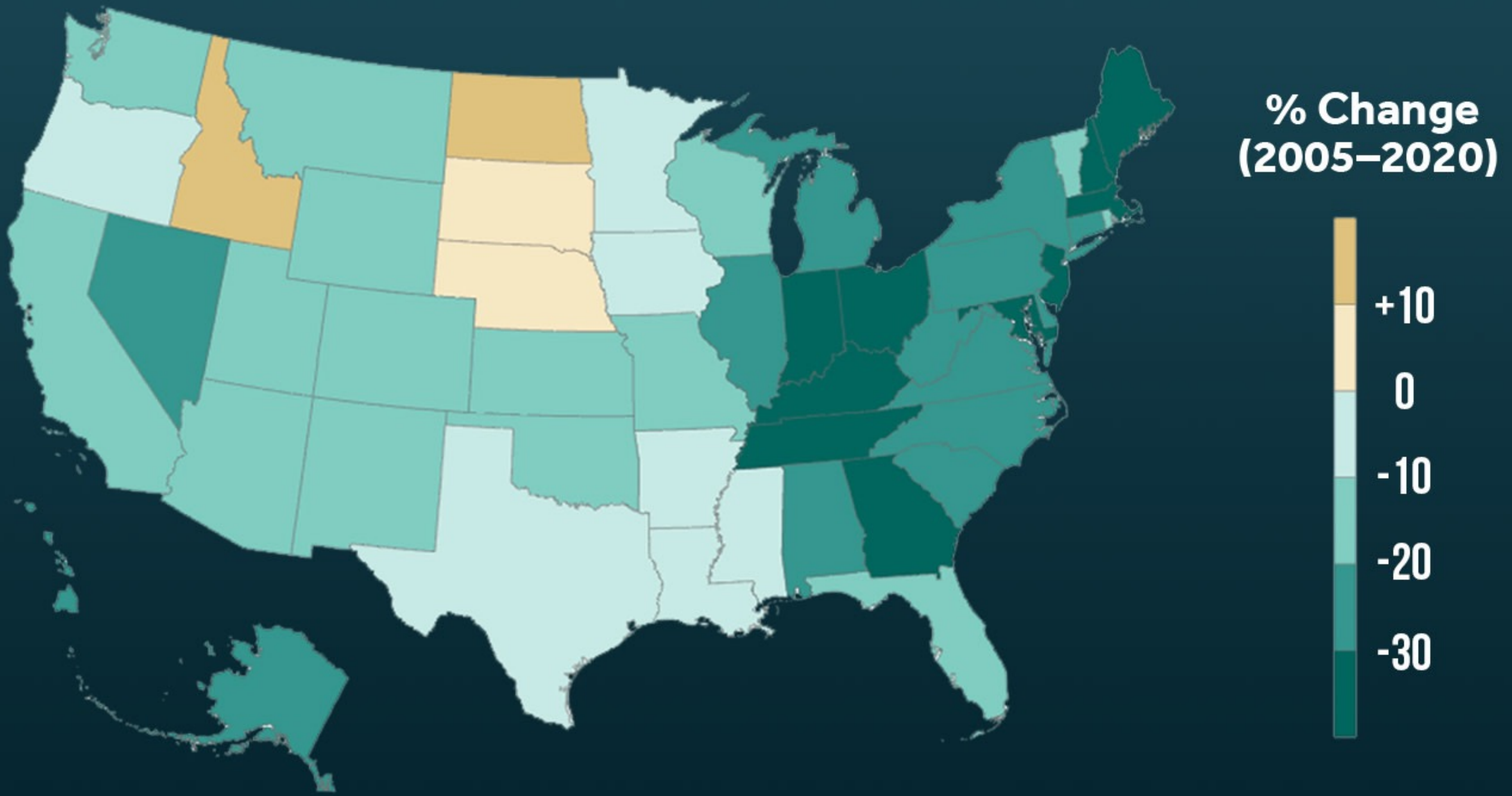
quadrillion Btu



[1] Includes lease condensate. | [2] Natural gas plant liquids. | [3] Conventional hydroelectric power, biomass, geothermal, solar, and wind. | [4] Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve. | [5] Natural gas, coal, coal coke, biomass, and electricity. | [6] Adjustments, losses, and unaccounted for. | [7] Natural gas only; excludes supplemental gaseous fuels. | [8] Petroleum products supplied. | [9] Includes -0.06 quadrillion Btu of coal coke net imports. | [10] Includes 0.14 quadrillion Btu of electricity net imports. | [11] Total energy consumption, which is the sum of primary energy consumption, electricity sales to ultimate customers, and electrical system energy losses. Losses are allocated to the end-use sectors in proportion to each sector's share of total electricity sales. See Note 1, "Electrical System Energy Losses," at the end of U.S. Energy Information Administration (EIA), *Monthly Energy Review* (September 2023), Section 2. See Note 2, "Other Energy Losses," at the end of U.S. Energy Information Administration (EIA), *Monthly Energy Review* (September 2023), Section 2. | Notes: • Data are preliminary. • Values are derived from source data prior to rounding for publication. • Totals may not equal sum of components due to independent rounding.

Sources: EIA, *Monthly Energy Review* (September 2023), Tables 1.1, 1.2, 1.3, 1.4a, 1.4b, 1.4c, 2.1a, and 2.1b

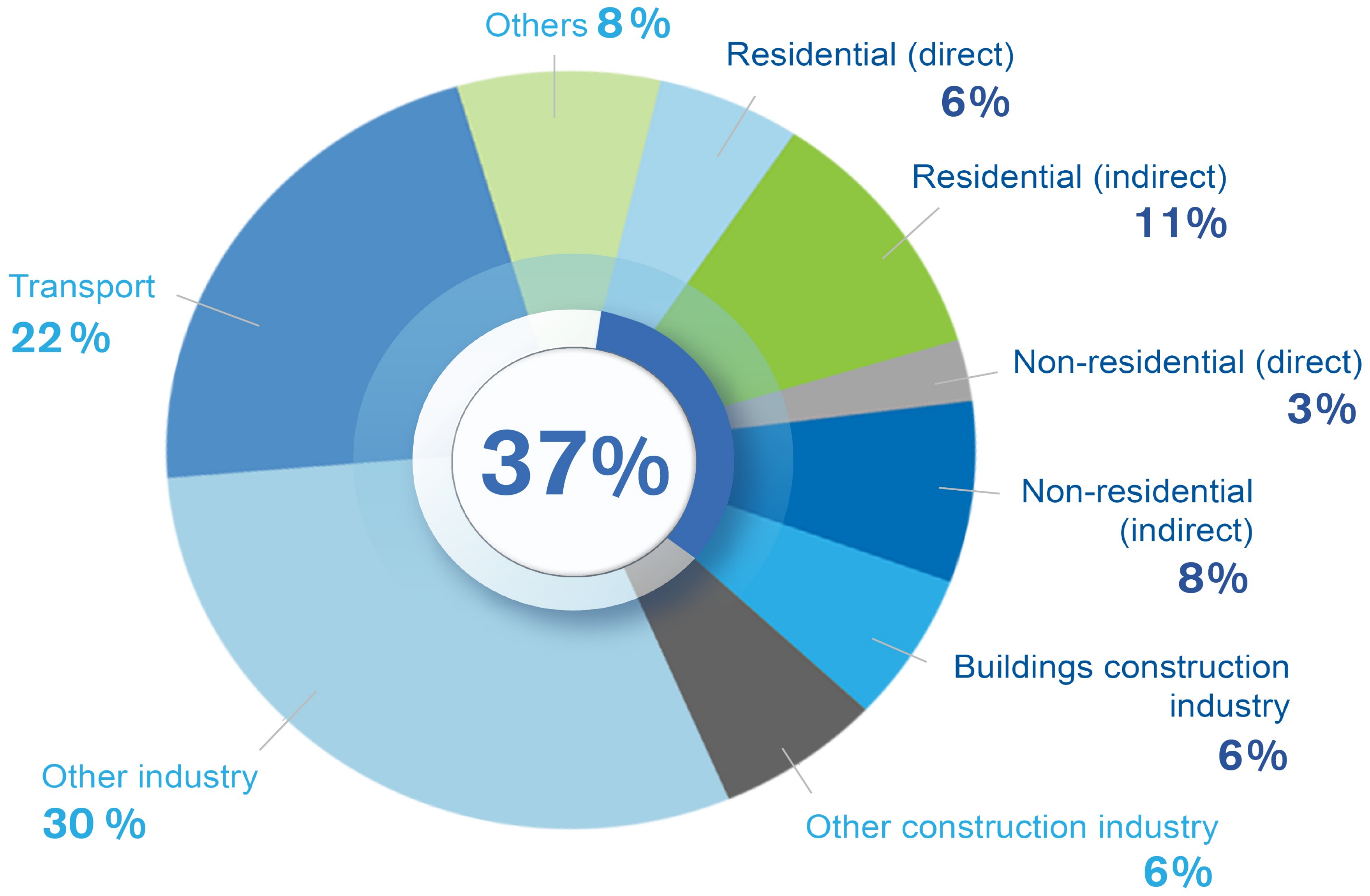
CHANGE IN HEAT-TRAPPING EMISSIONS



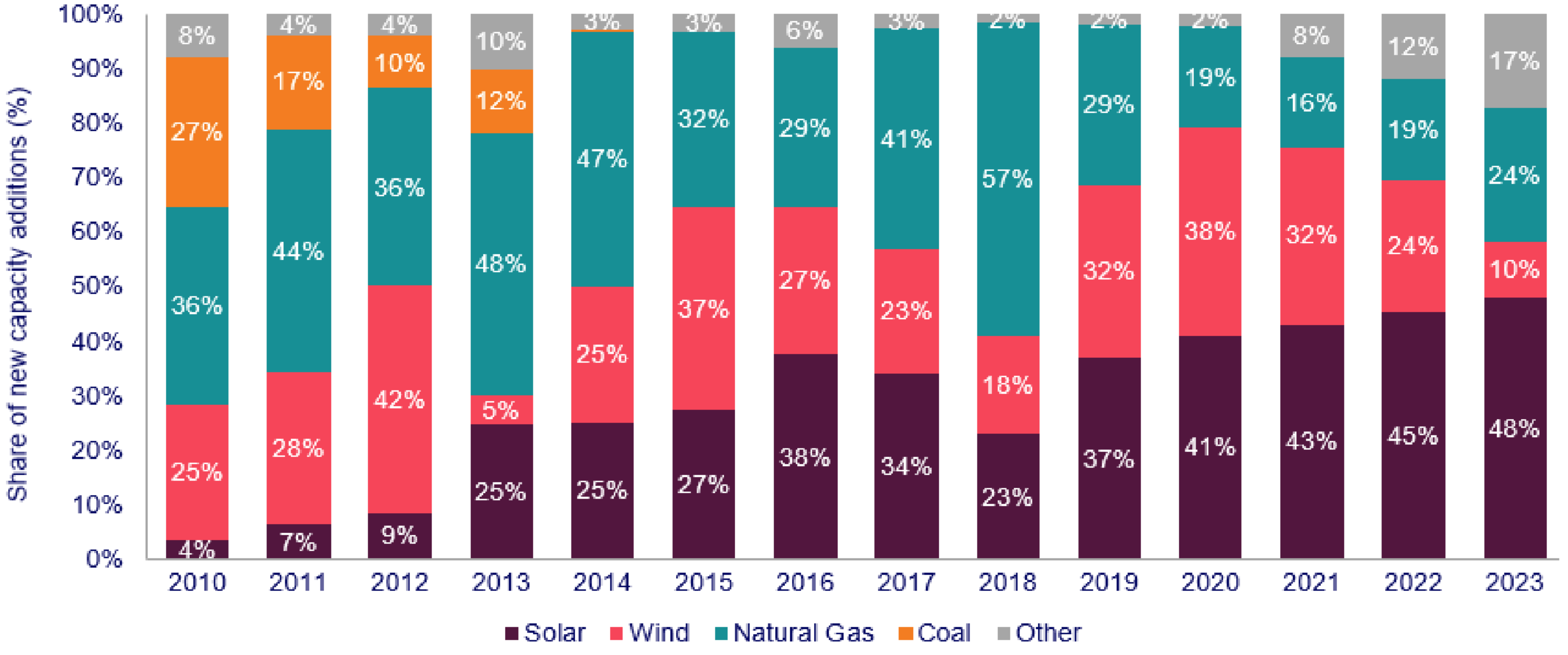
Percent change in total greenhouse gas emissions in each state (2005–2020).
Source: EPA (2021)

CLIMATE CENTRAL

Sector Energy-related CO_2 Emissions 2021



New U.S. electricity-generation capacity additions, 2010 – Q1-Q3 2023



Reducing Carbon in our Electrical System

Nuclear Power

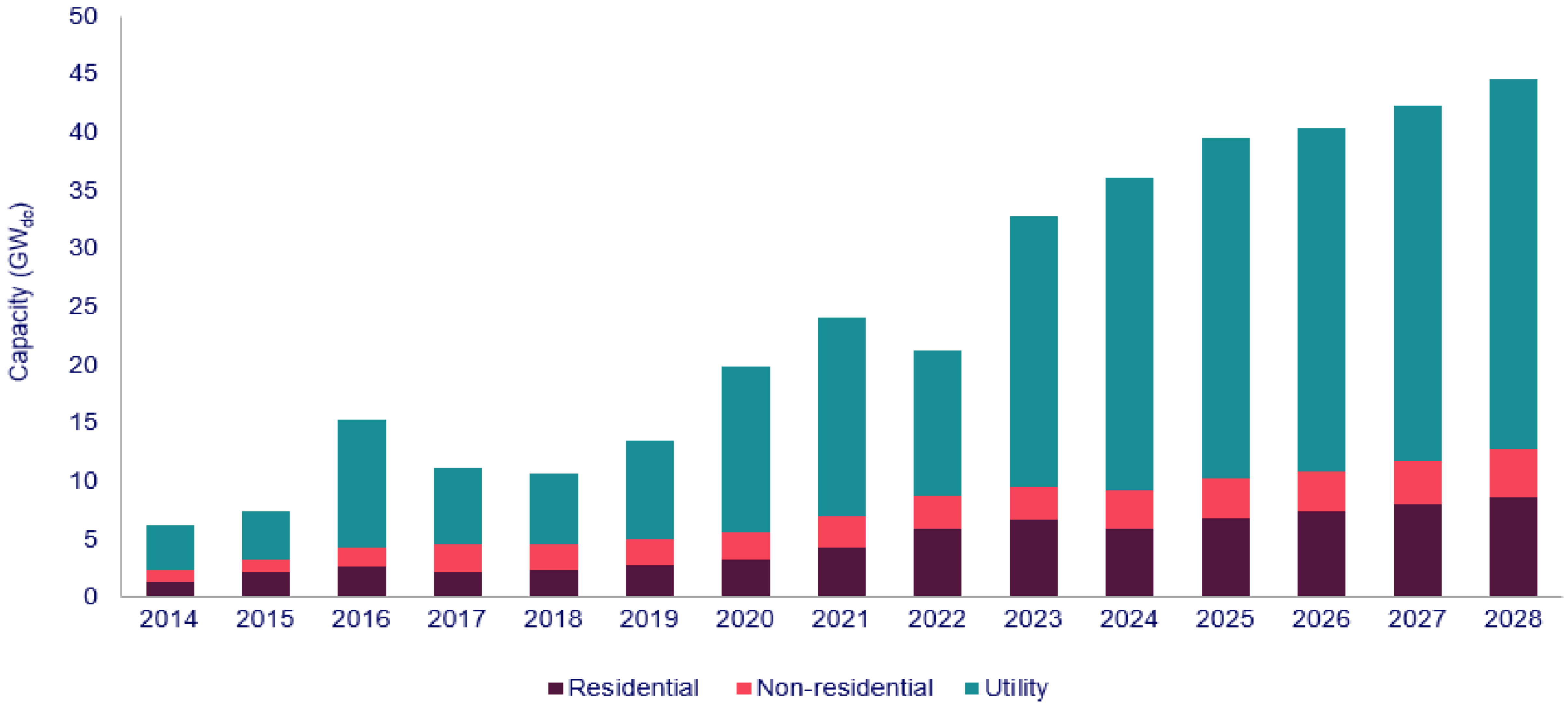
- Nuclear power plants have generated about 20% of U.S. electricity since 1990. New large plant are uneconomical.
- The new fad is small/micro rectors (3 MW to 300MW).
- Plan is for modular design/factory fabrication and easy set up, none are currently licensed or constructed, most demos have been cancelled due to rising costs.
- Best bets for the future are the GE BWRX-300 with target cost of $2,250/kW or the Westinghouse AP300 PWR with a target cost of $3,333/kW.

Reducing Carbon in our Electrical System

Renewables - Solar

- Large installations are the lowest cost Solar at about $890-$1,000/kW.
- Average Capacity Factor is about 24.3%.
- Many new solar farms are also built with battery capacity of 2 to 4 hours based on regulations of the system operator.
- Residential solar is more expensive at about $2,500-$5,000/kW and has a payback of around 15 years, sometimes less, depending on incentives.

U.S. solar PV installations and forecasts by segment, 2014-2028



SEIA Solar Energy Industries Association®

Wood Mackenzie

Source: SEIA/Wood Mackenzie Solar Market Insight Report Q4 2023

Reducing Carbon in our Electrical System

Renewables Wind

- As of January 2023, the total installed wind power nameplate generating capacity in the United States was 141,300 megawatts (MW) from over 70,000 turbines.
- 19 states had over 1,000 MW of installed capacity with five states (Texas, Iowa, Oklahoma, Kansas, and California), generating over half of all wind energy in the nation. Illinois is fifth with over 7,383MW.
- In 2022, 434.8 terawatt-hours were generated by wind power, or 10.25% of electricity in the United States.
- In 2019, wind power surpassed hydroelectric power as the largest renewable energy source in the U.S.
- The state generating the highest percentage of energy from wind power is Iowa at over 57% of total energy production. Illinois is 11% wind.

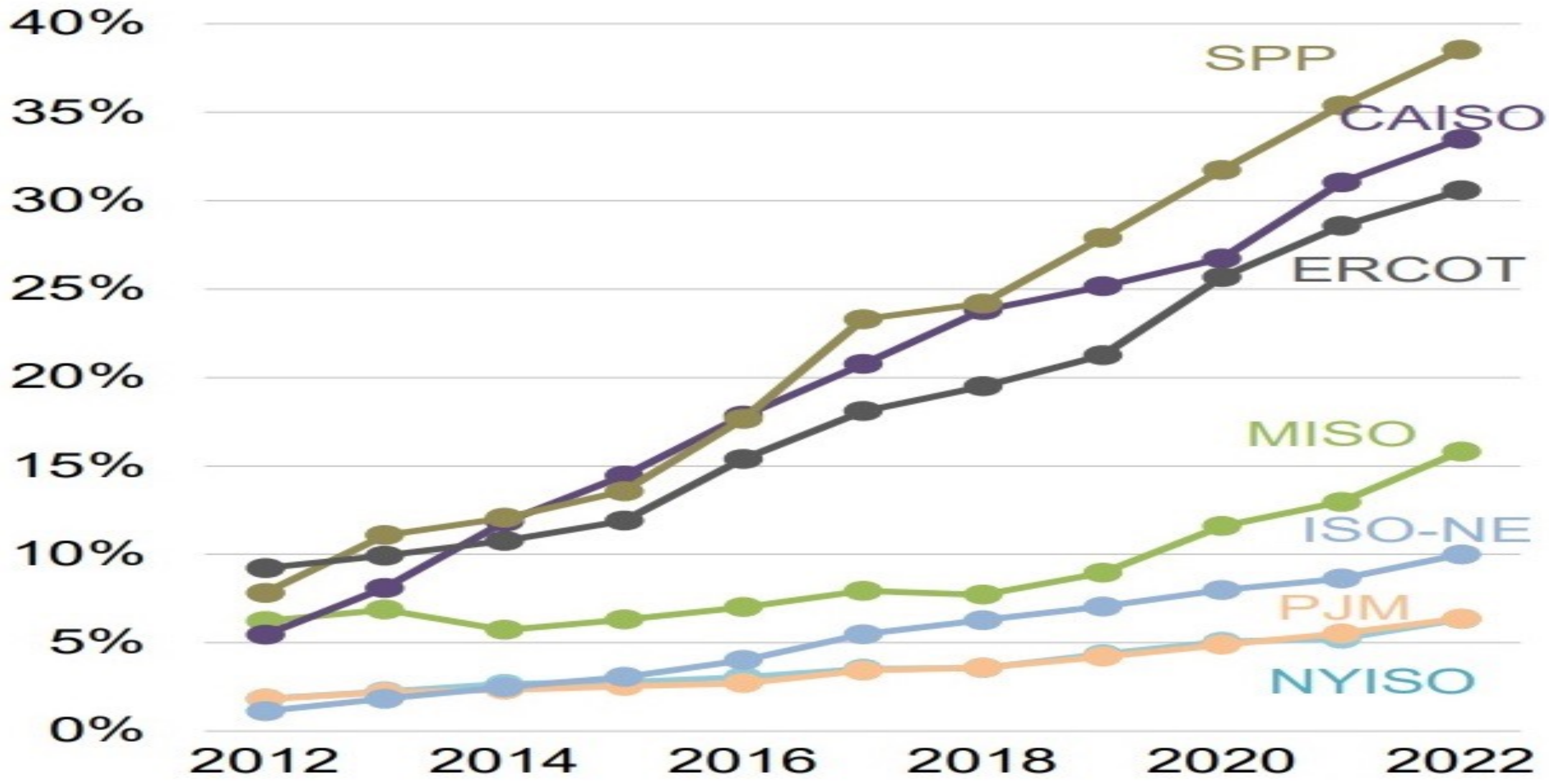

Wind Resource of the United States
Annual Average Wind Speed at 100 Meters above Surface Level
NREL

Reducing Carbon in our Electrical System

Renewables Wind

- Modern onshore wind farms often have capacity factors greater than 40% for new turbines at about 3MW in size
- Onshore wind is the cheapest source of electricity.
- In 2021, the average cost to install land-based wind was $1,500/kw with a levelized cost of electricity of $0.032/kWh.
- Offshore wind costs more with a current levelized cost of $0.114/kWh and a capital costs of about $6,500/kW.
- GE Power makes 6-14MW turbines with capacity factor of 63%.

Market Share of Solar and Wind By US Power Pool



Source: USDOE

Reducing Carbon in our Electrical System

Renewables Energy Storage

- Stand alone storage and hybrid solar and wind are now being built.
- A battery storage power station uses a group of batteries to store electrical energy.
- They are used to stabilize grids, as battery storage can transition from standby to full power in under a second to deal with grid contingencies.
- Arbitrage is also a driver of stand alone projects.
- Current capacity is about 16,000MW (approx. 80GWh).

LFP Cells – 140Wh/kg, 750kWh DC blocks
NMC Cells – 255Wh/kg, 1.3MWh DC blocs

Rendering of a project using the company's 750kWh LFP DC Blocks. Image: KORE Power.

Reducing Carbon in our Electrical System

Renewables Enhanced Geothermal

- Enhanced Geothermal System (EGS) is a man-made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation.
- Expected electric costs for EGS is $0.02-$0.039/kWh.
- Estimated potential is about 90-100GWe.
- Hot, dry crystalline basement rocks are found almost everywhere sufficiently far beneath the surface.
- EGS plants are suitable for load-following operations as the electricity is consistent and dispatchable.

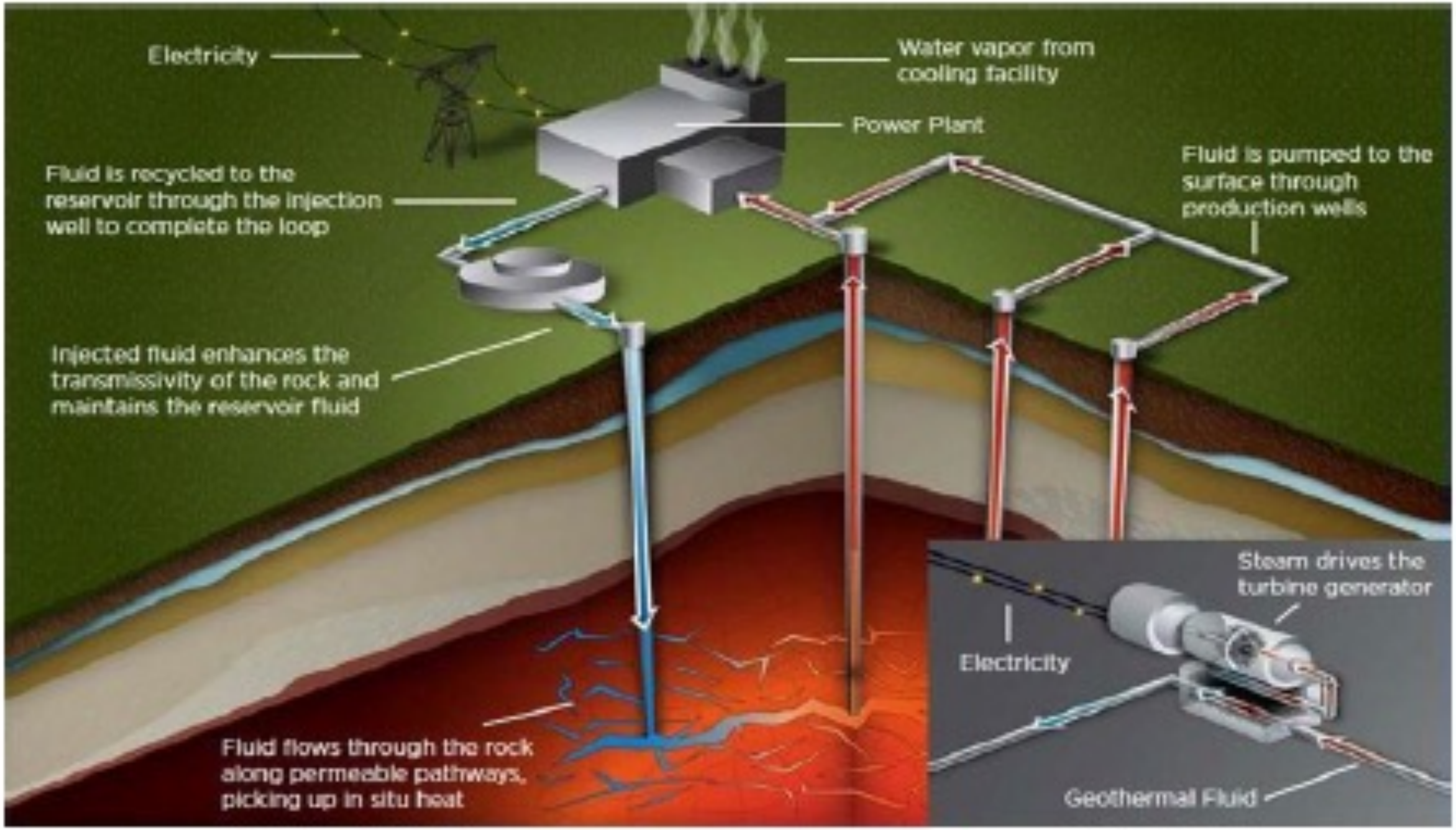
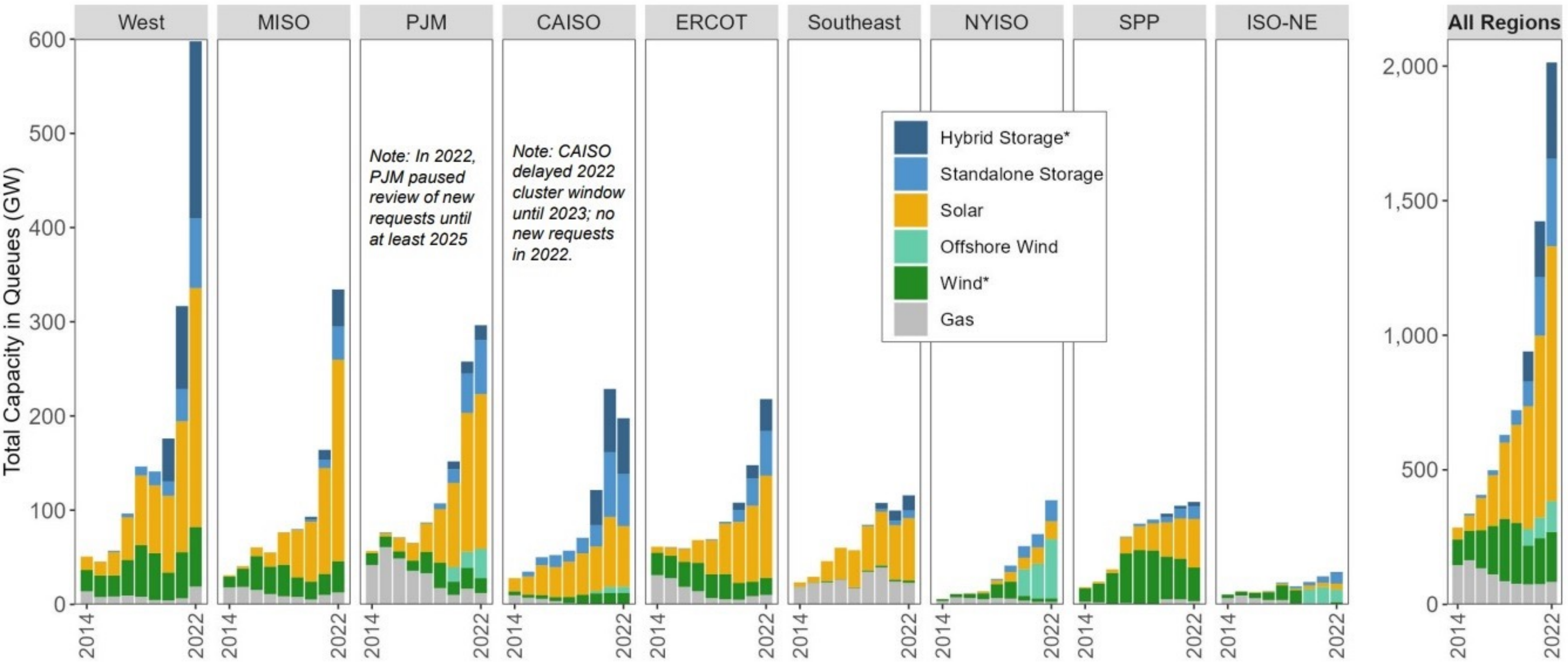


Figure 4: Power generation in deep geothermal systems.

Power Capacity in US Grid Connection Queues



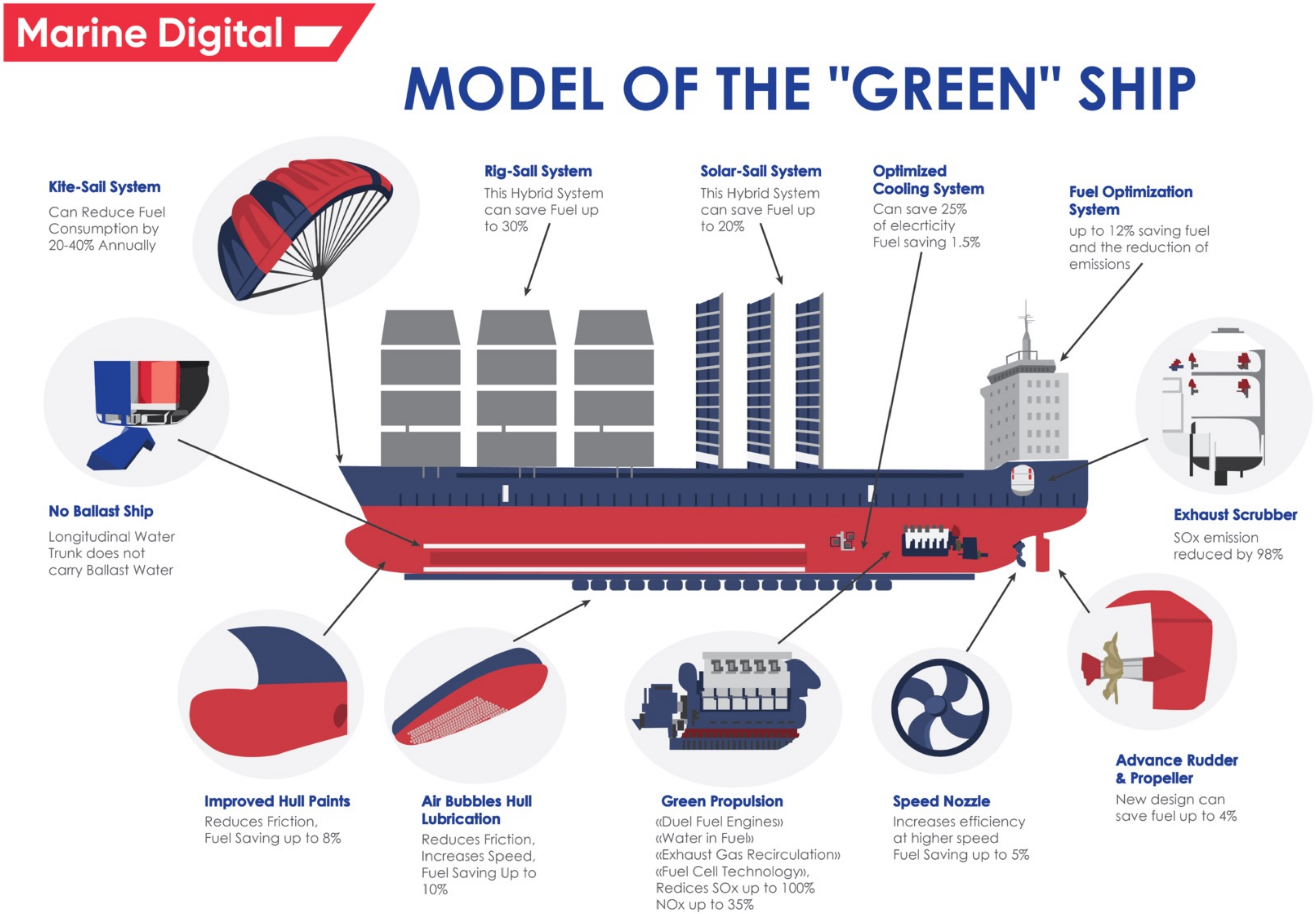
Source: Berkeley Lab, 2023

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	

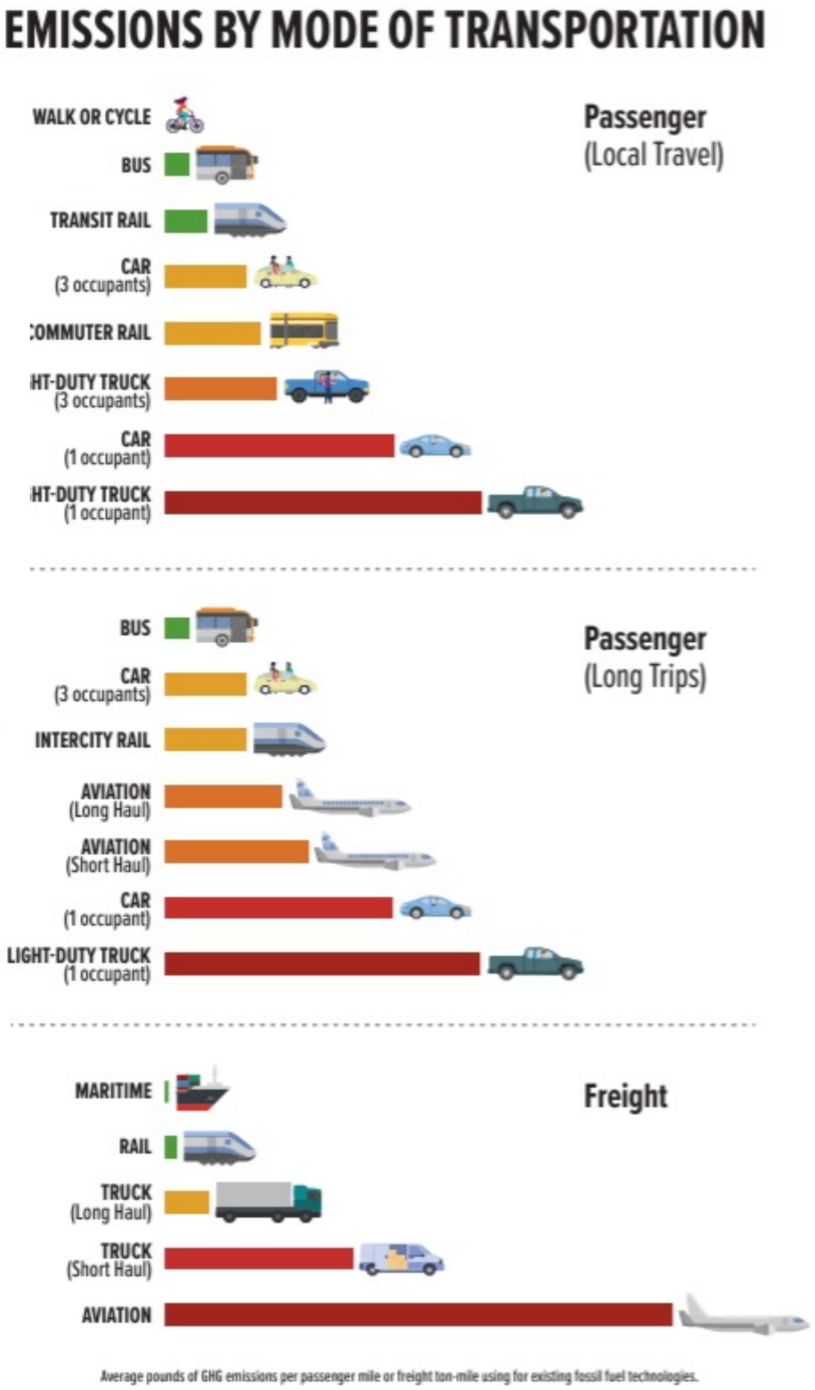
World Wide Freight Moved 2023

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



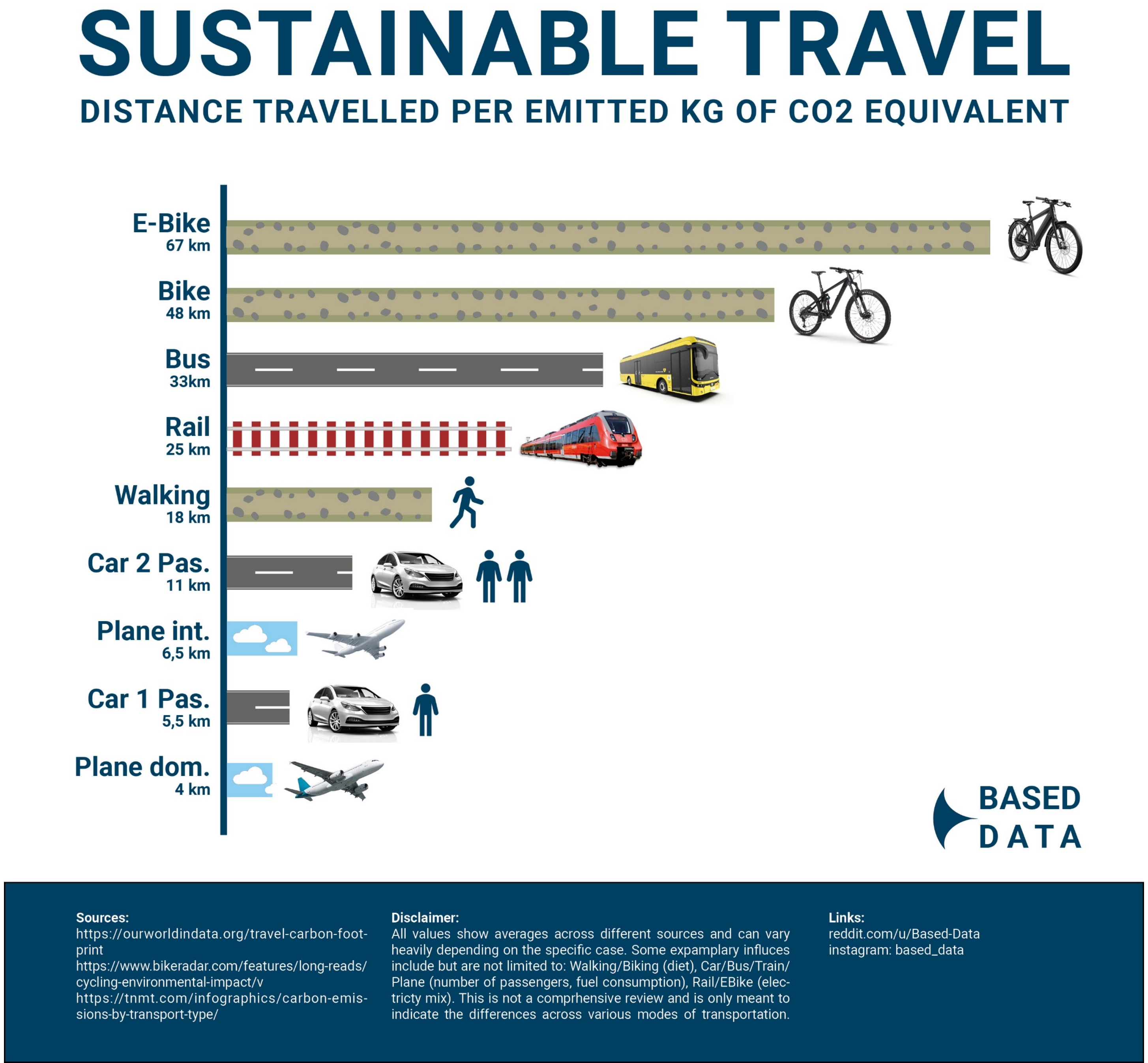
Marine Digital
MODEL OF THE "GREEN" SHIP
Kite-Sail System
Can Reduce Fuel Consumption by 20-40% Annually
Rig-Sail System
This Hybrid System can save Fuel up to 30%
Solar-Sail System
This Hybrid System can save Fuel up to 20%
Optimized Cooling System
Can save 25% of elecrticity Fuel saving 1.5%
Fuel Optimization System
up to 12% saving fuel and the reduction of emissions
No Ballast Ship
Longitudinal Water Trunk does not carry Ballast Water
Exhaust Scrubber
SOx emission reduced by 98%
Advance Rudder & Propeller
New design can save fuel up to 4%
Improved Hull Paints
Reduces Friction, Fuel Saving up to 8%
Air Bubbles Hull Lubrication
Reduces Friction, Increases Speed, Fuel Saving Up to 10%
Green Propulsion
«Duel Fuel Engines»
«Water in Fuel»
«Exhaust Gas Recirculation»
«Fuel Cell Technology»,
Redices SOx up to 100%
NOx up to 35%
Speed Nozzle
Increases efficiency at higher speed
Fuel Saving up to 5%

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).

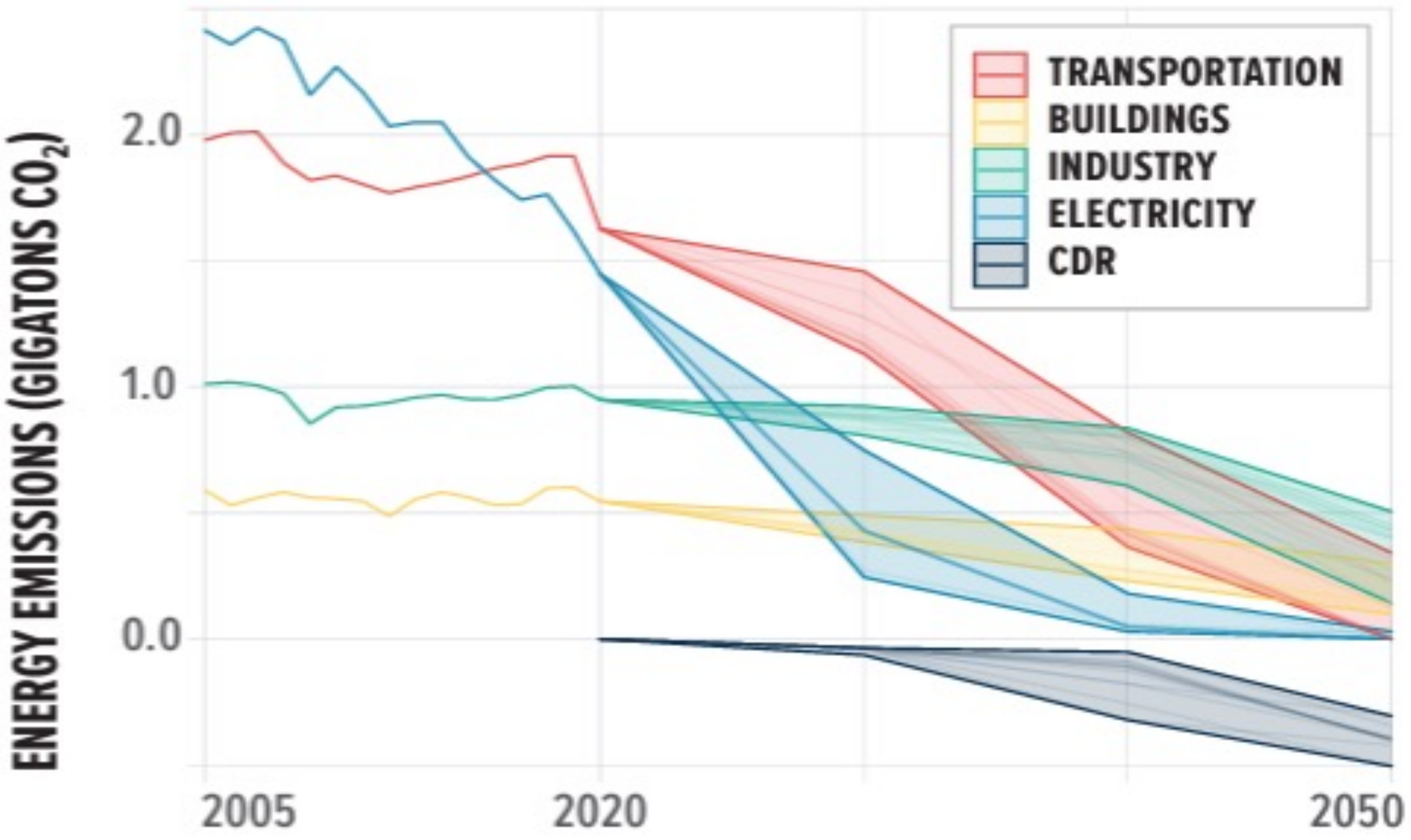


Figure 1. The path to economy-wide decarbonization entails electricity emissions and emissions from transportation, buildings, and industry falling dramatically in all scenarios, with the greatest reductions coming from electricity, followed by transportation, and growth in non-land sink carbon dioxide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

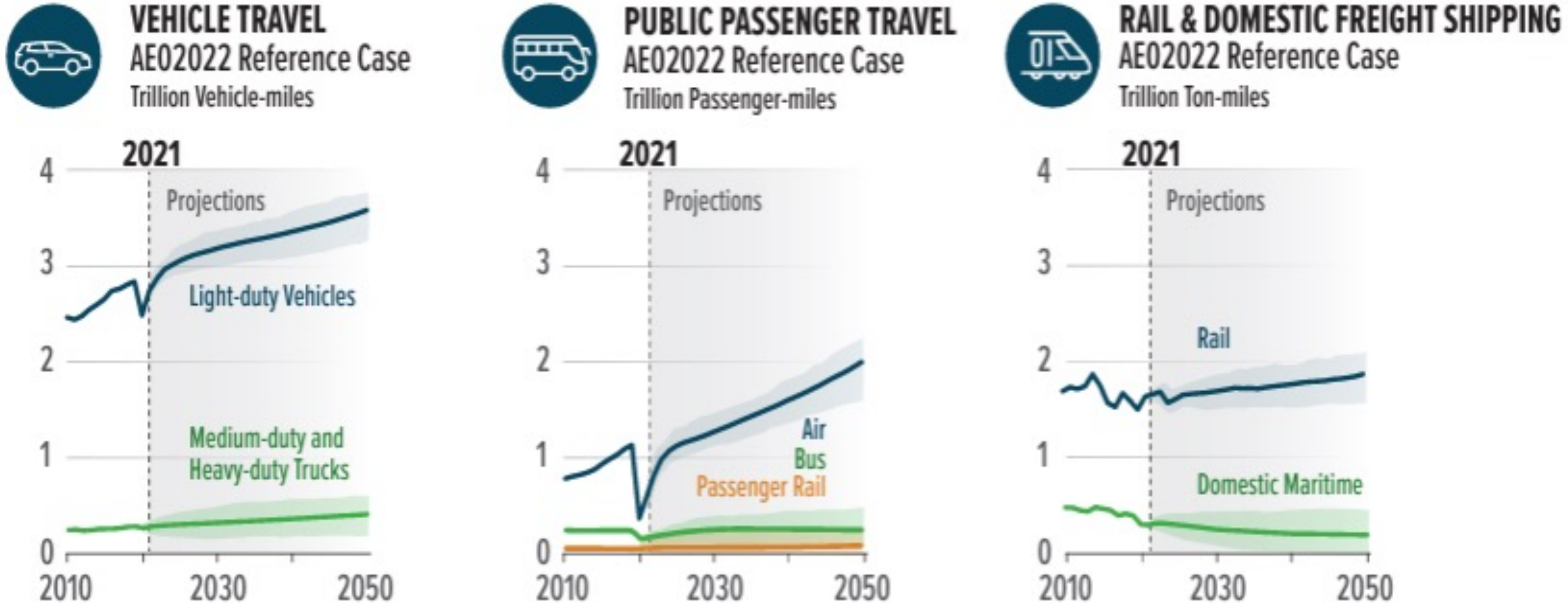


Figure 3. Passenger and freight demand projections from AEO 2022 with additional illustrative uncertainty bounds.

2019 AVERAGE ANNUAL HOUSEHOLD EXPENDITURES

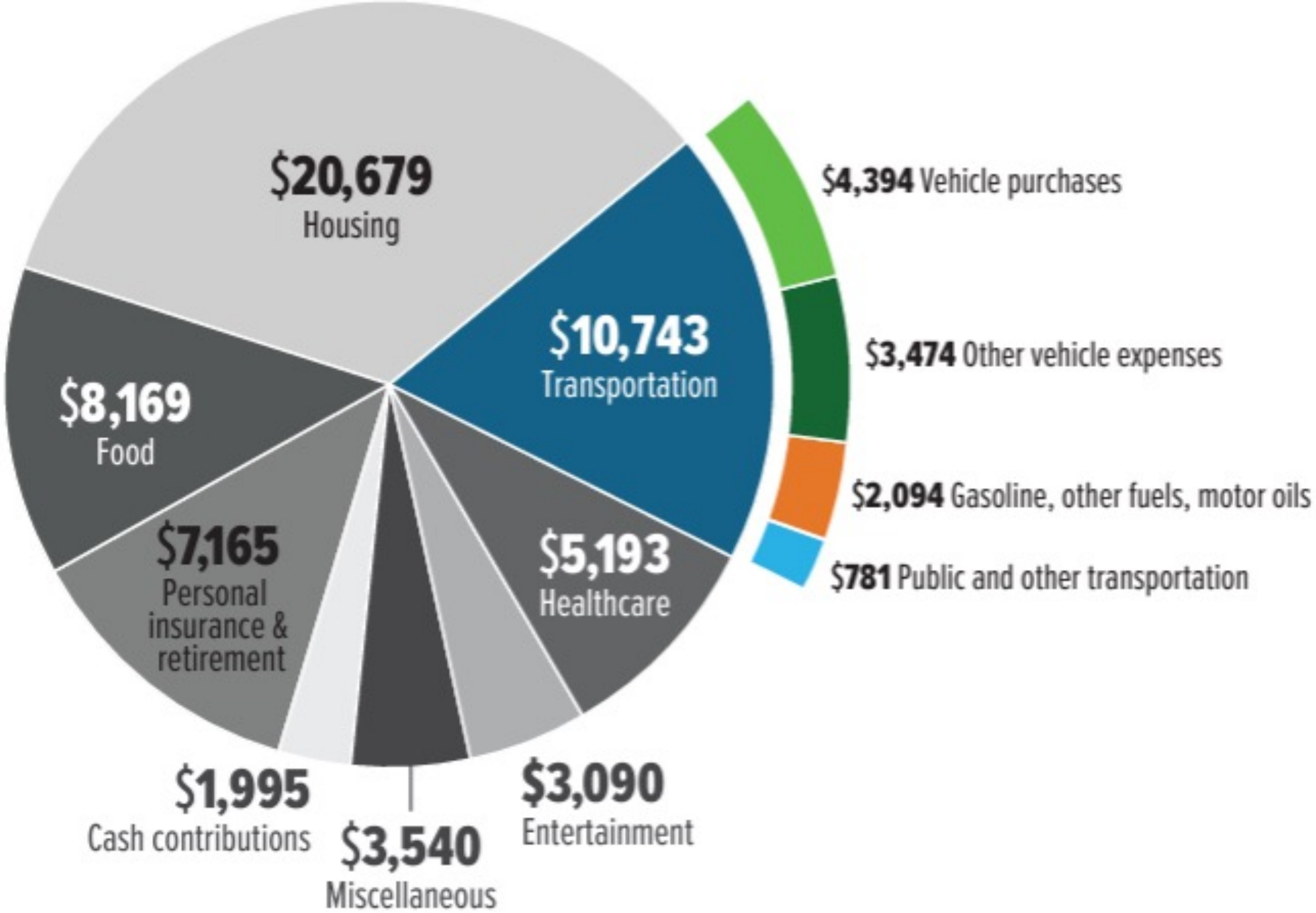


Figure 4. Consumers expenditures highlight the burden of transportation, the second-largest expenditure after housing, at over $10,000 per year on average. Data source: Bureau of Labor Statistics [REF]. This Blueprint uses 2019 as a baseline since impacts due to COVID-19 complicate the use of later data.

2021 Data

VEHICLES ON THE ROAD TODAY

These personal light-weight vehicles represents the 280 million cars, S.U.V.s, vans, and pickup trucks on America's roads today. The vast majority run on gasoline.

PROJECTED ON THE ROAD IN 2035

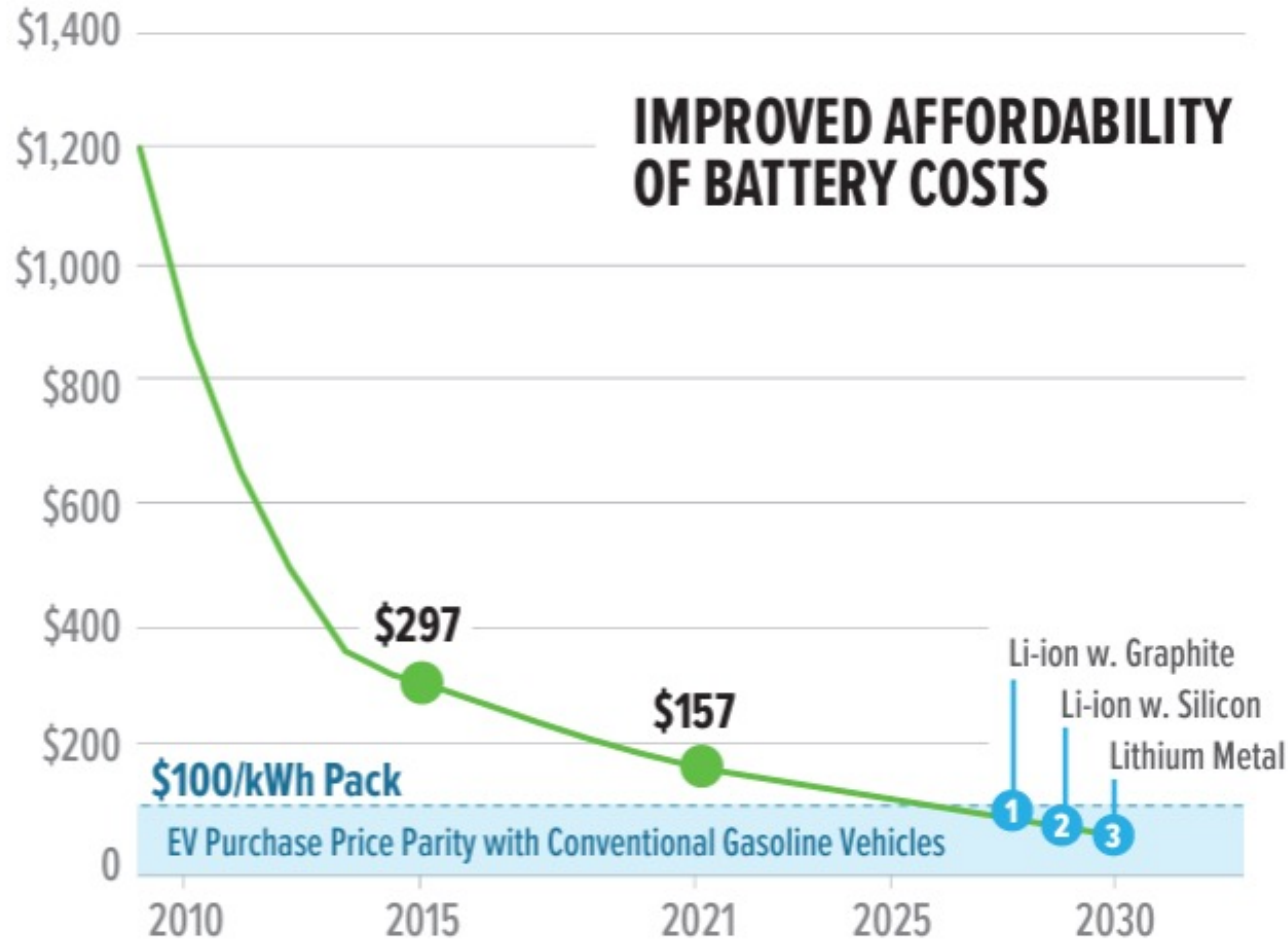
Electric vehicles sales have been growing. Even if they reached 100% of sales in 2035, 60% or more of vehicles on the road would still be powered by gasoline.

PROJECTED ON THE ROAD IN 2050

Even in 2050, after 15 years of selling only EVs, a small but significant share of vehicles on the road will still run on gasoline.

Electric Gasoline

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.


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

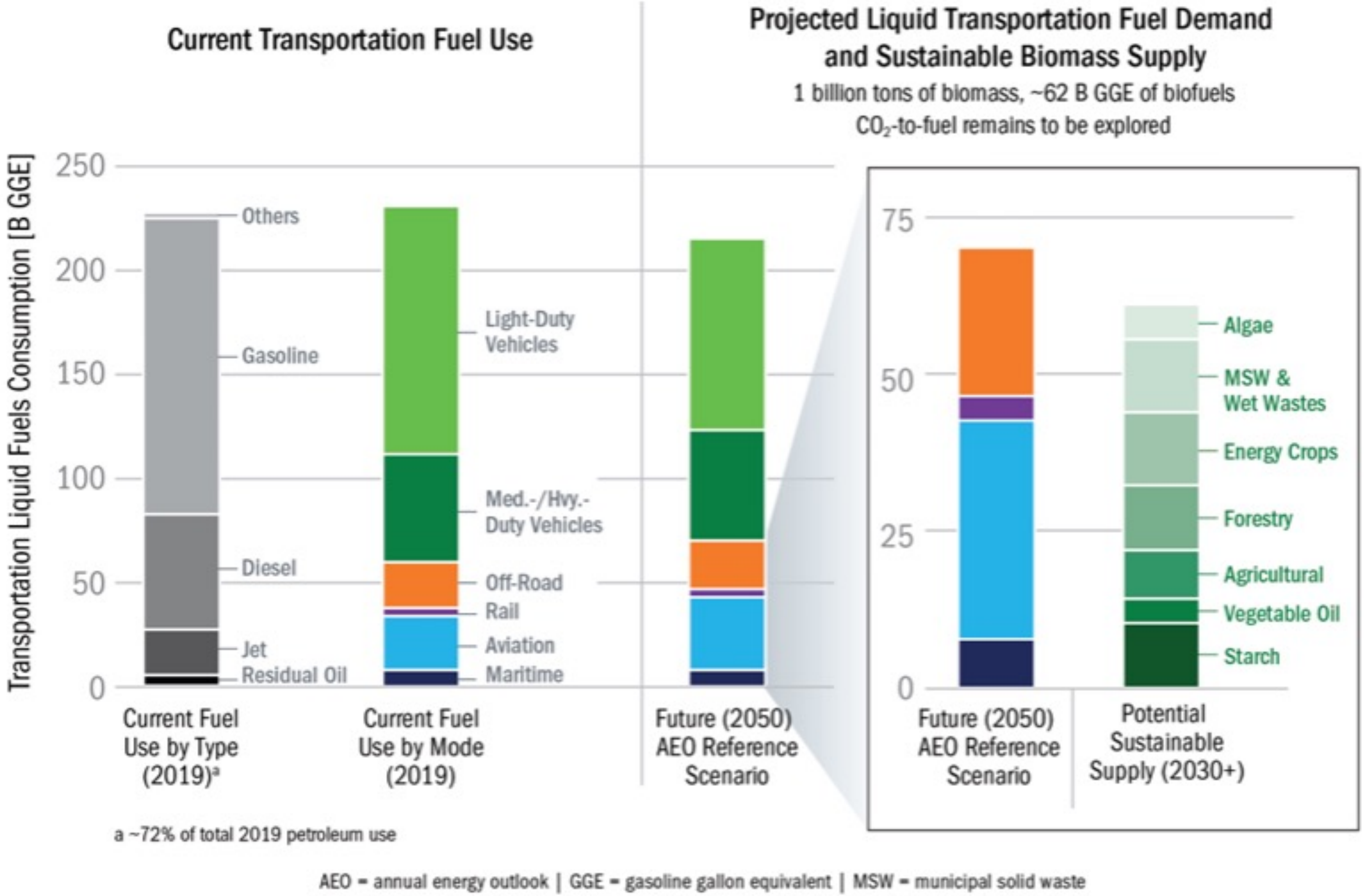
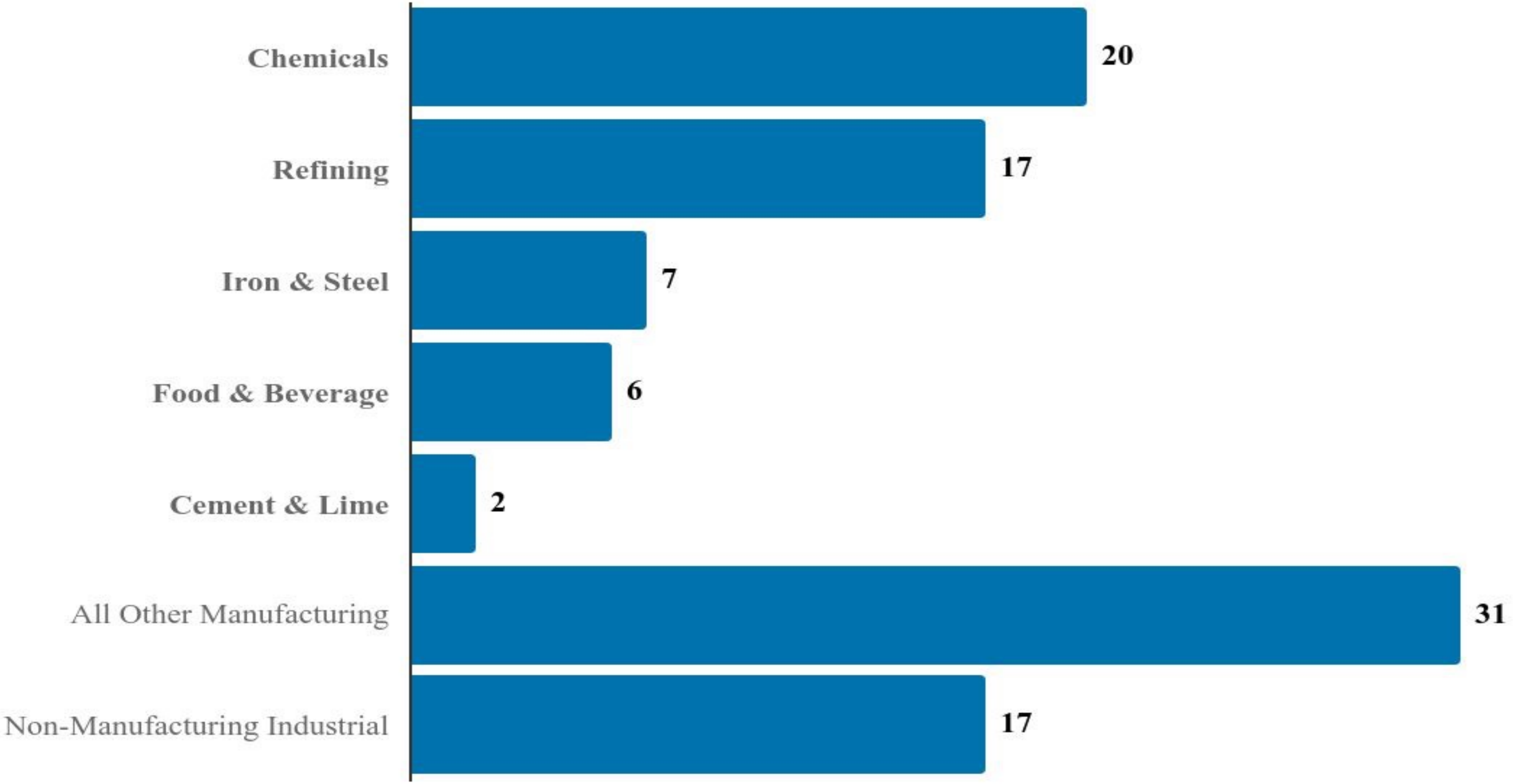


Figure 9. Current and projected liquid transportation fuel demand and sustainable biofuel supply. Note that the AEO reference case represents a business-as-usual perspective with limited changes from the current systems and does not reflect the transformative changes this Blueprint envisions. Data sources: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

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

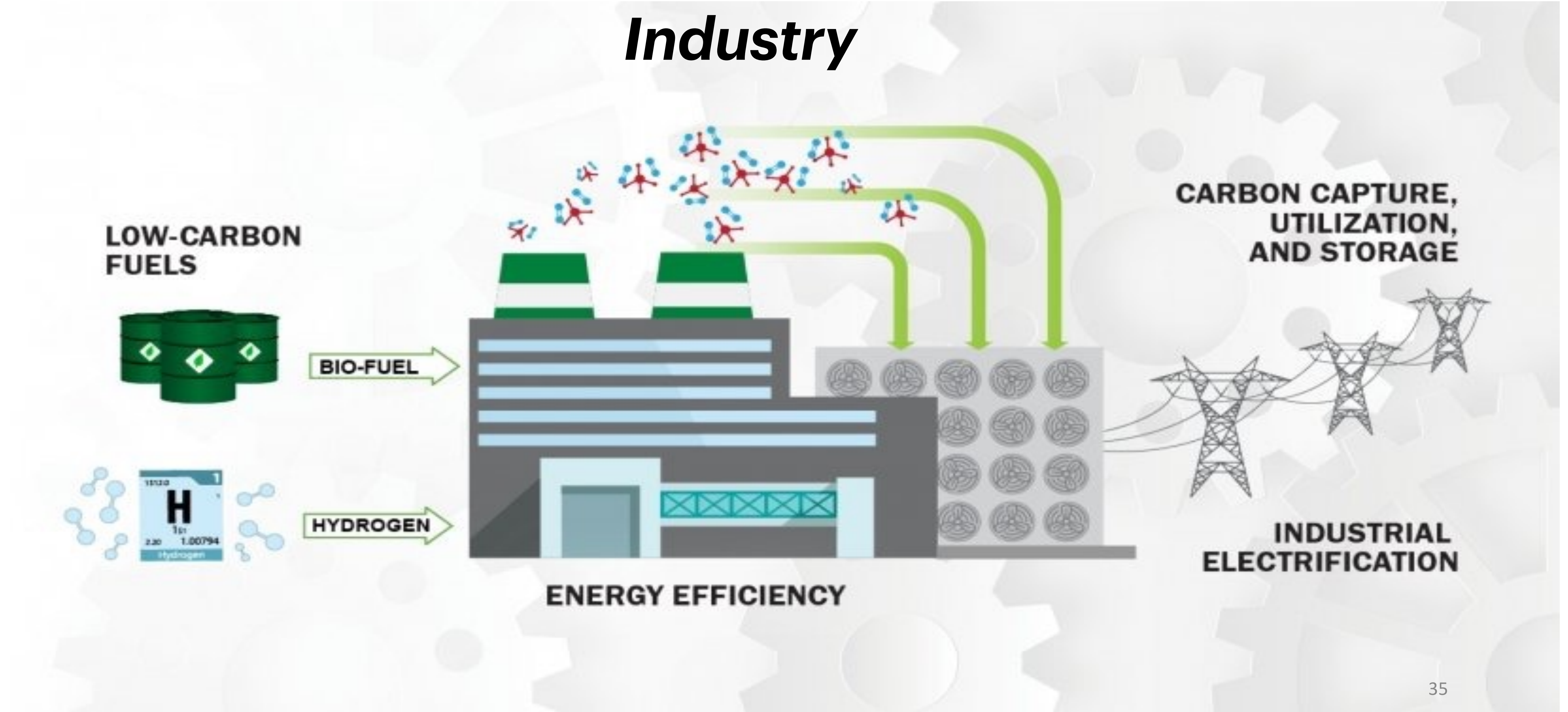
- Energy efficiency is a foundational, crosscutting decarbonization strategy and is the most cost-effective option for greenhouse gas emission reductions in the near term.
- Leveraging advancements in low-carbon electricity from both grid and onsite renewable generation sources will be critical to decarbonization 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



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

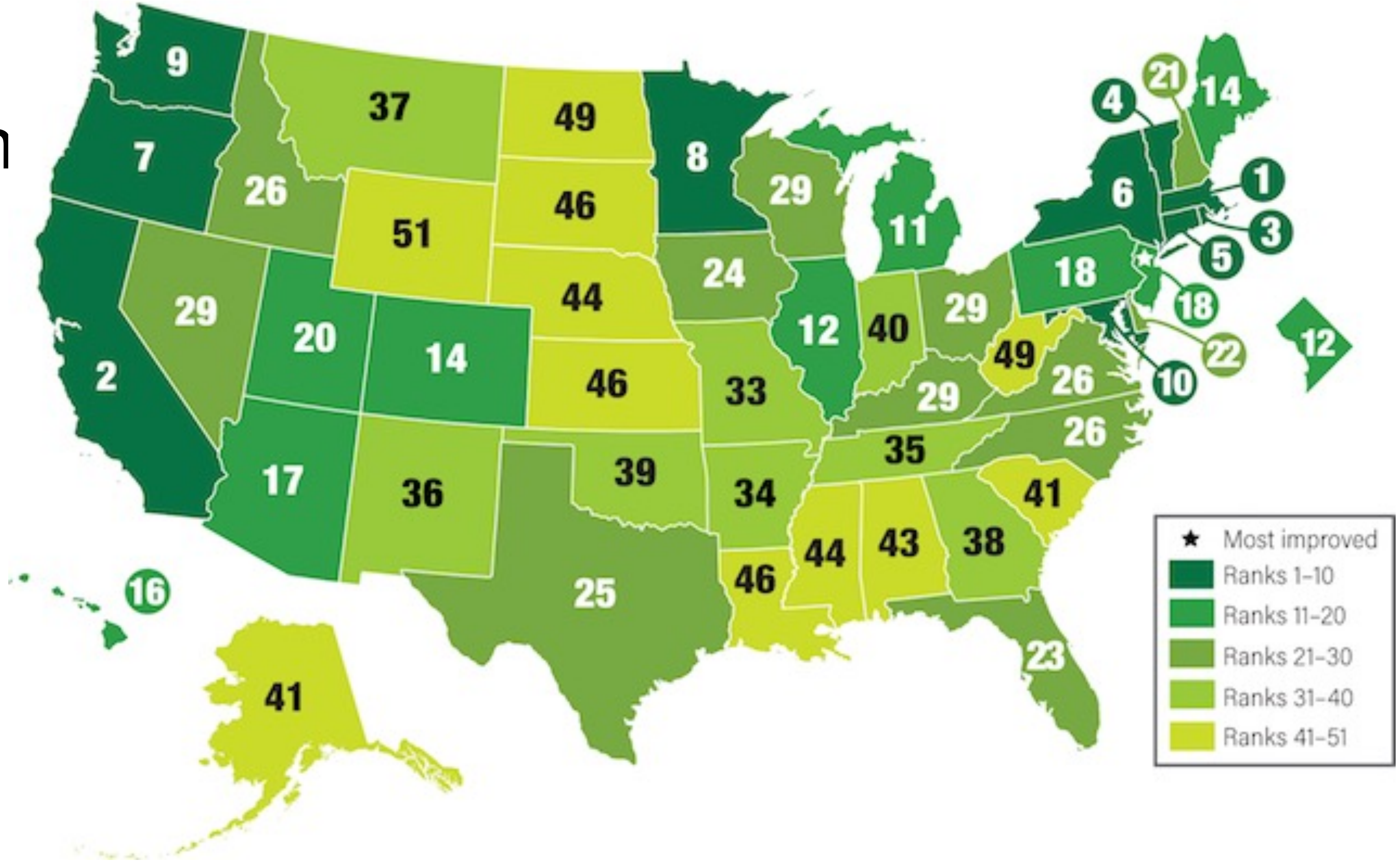
Commercial & Residential Buildings

- The primary means for reducing building GHG emissions are the following:
  - Efficiency measures and building electrification
  - 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.
  - Decarbonized electrical grid -- Ameren 67% fossil-fired.

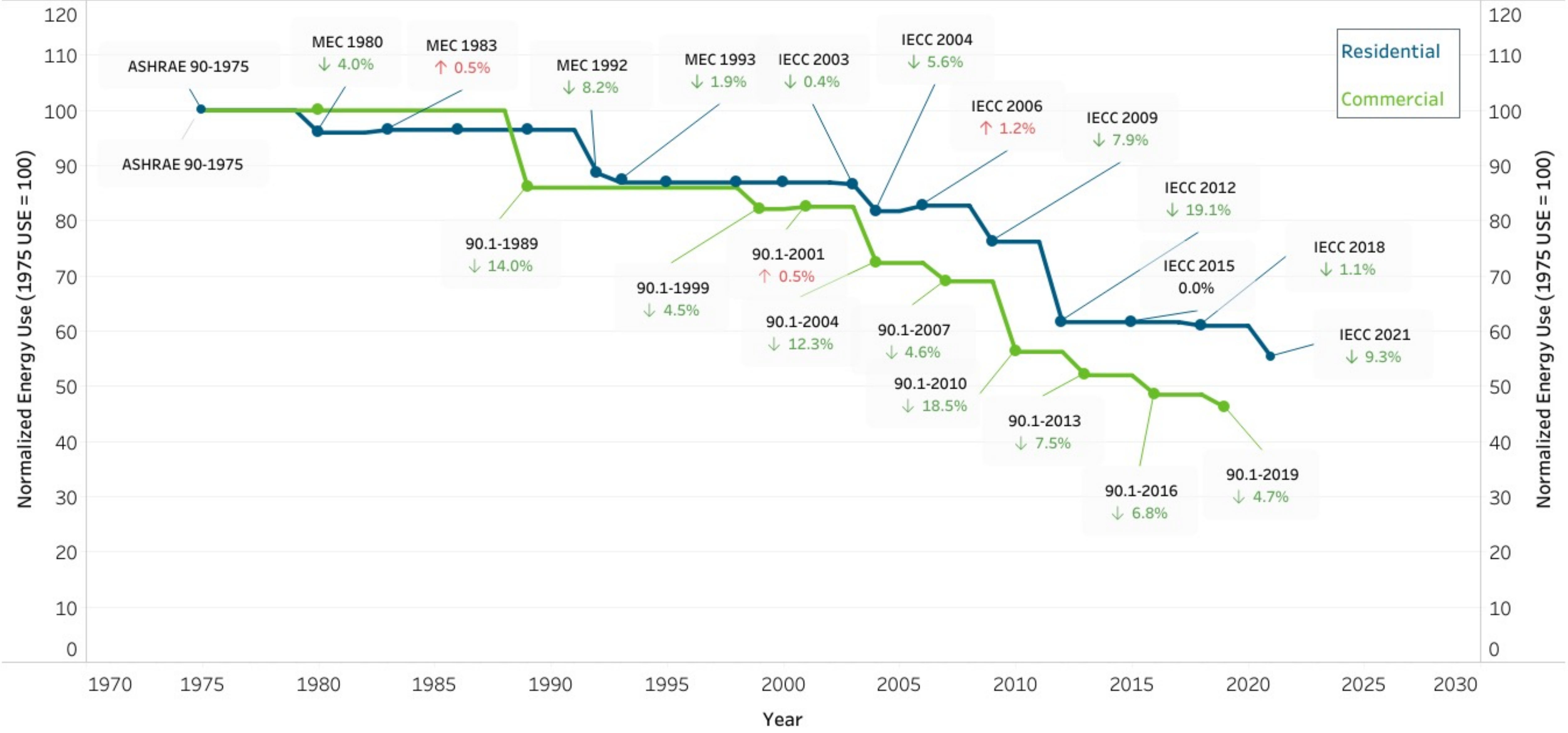
Remediation – The Built Environment

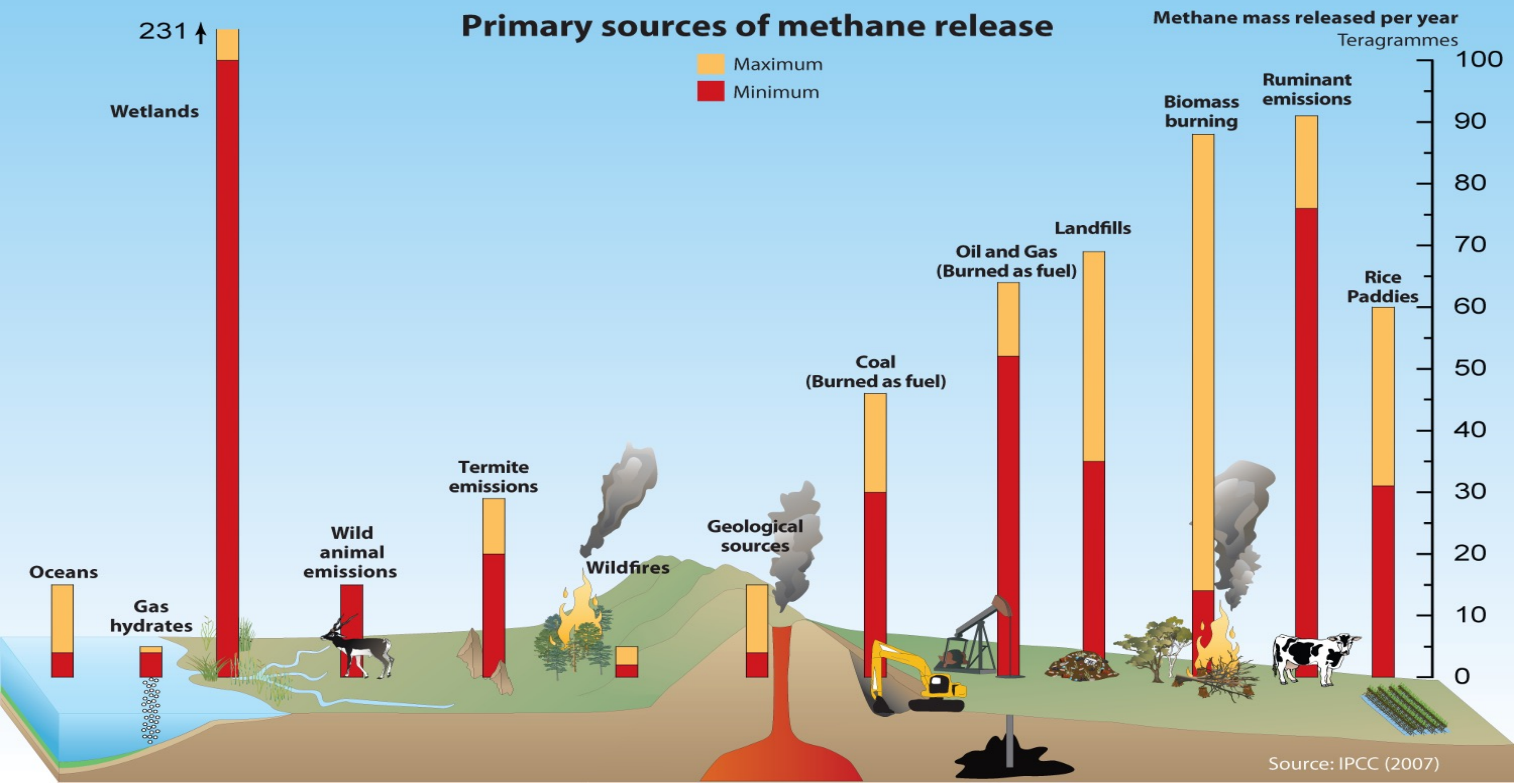
Commercial & Residential Buildings

- 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.



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




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

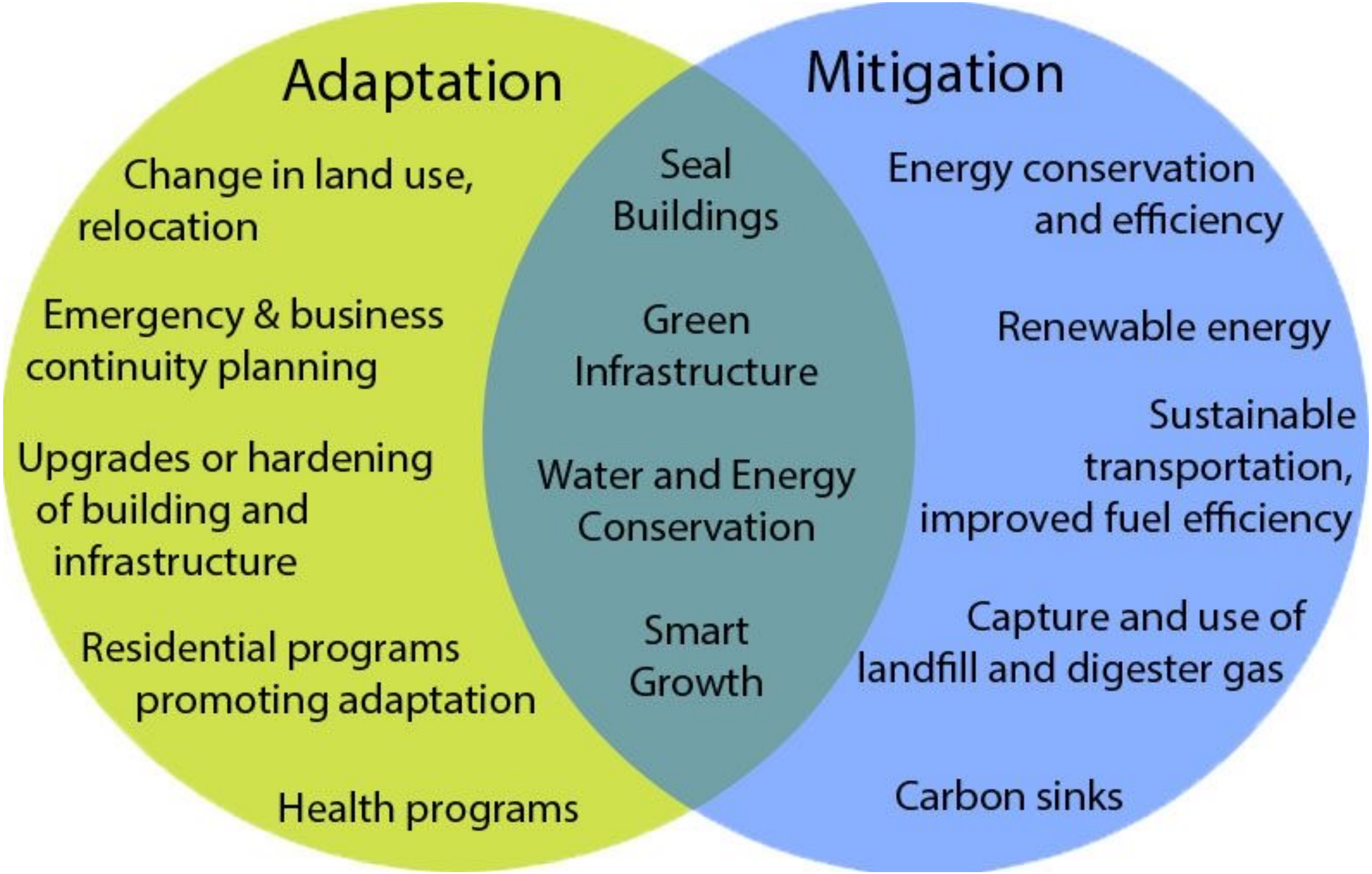
Reducing Agricultural Emissions – 11% of Emissions

- 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 on 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.
- U.S. forests can boost carbon storage by 43% by 2030.
- Keeping all existing forests, wetlands and grasslands intact rather than clearing them for new cropland or urban development.
- Increase carbon storage in forests by reforesting and afforesting land, improve management of existing forests, and adopt agroforestry practices that integrate trees and shrubs into crop- and pastureland.


Adaptation
Mitigation
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
Energy conservation and efficiency
Renewable energy
Sustainable transportation, improved fuel efficiency
Capture and use of landfill and digester gas
Carbon sinks