

# The Clean Energy Path to Zero Carbon in the U.S.

## Summer Solstice Virtual Kickoff

### June 18, 2020

Chuck Kutscher, Jeff Logan, Tim Coburn, Bob McGrath  
University of Colorado  
Renewable and Sustainable Energy Institute

# Extreme Weather Events: The New Abnormal



# Extreme Events

## Drought



Syria, 2005-2010

## Wildfires



Mendocino Fire, 2018

## Flooding



Seawater Flooding of Miami

## Hurricanes



Puerto Rico, September 2017

## Beetle Kill



Rocky Mountain Nat'l Park

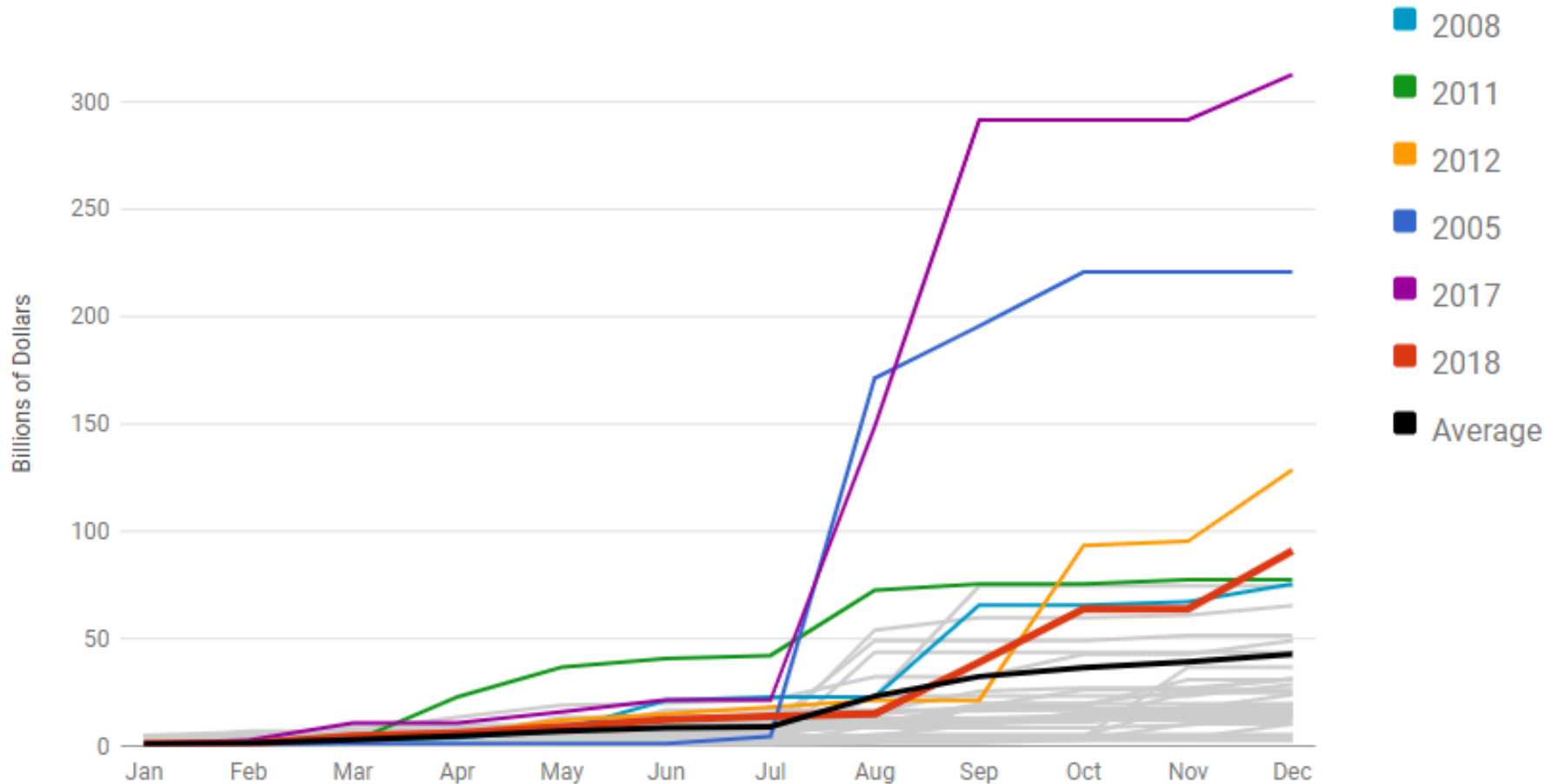
## Coral Bleaching



Great Barrier Reef, March 2016

at 1°C temperature rise!

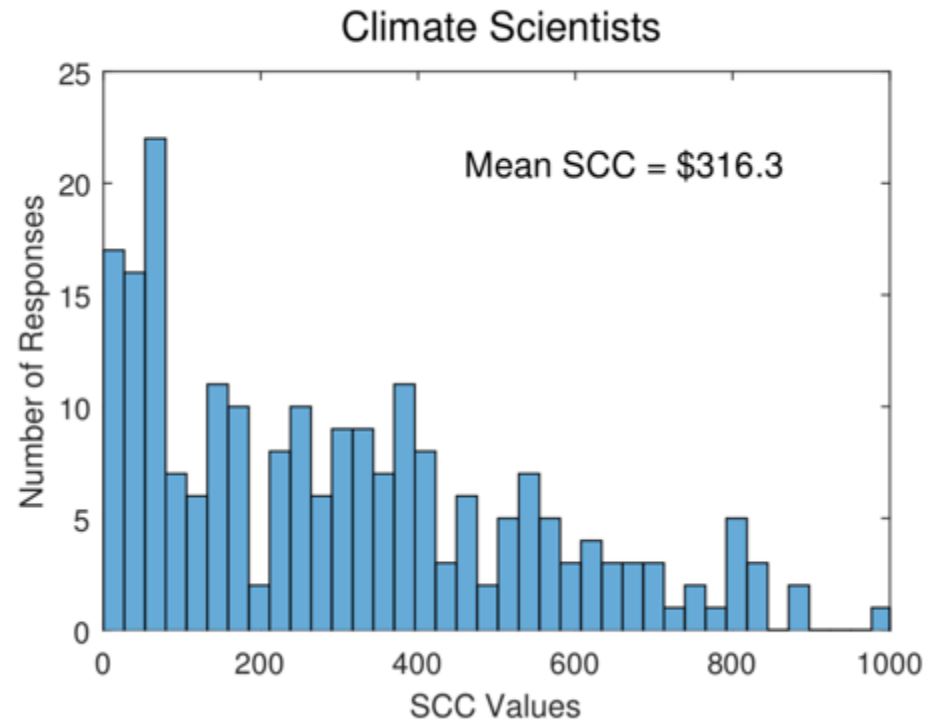
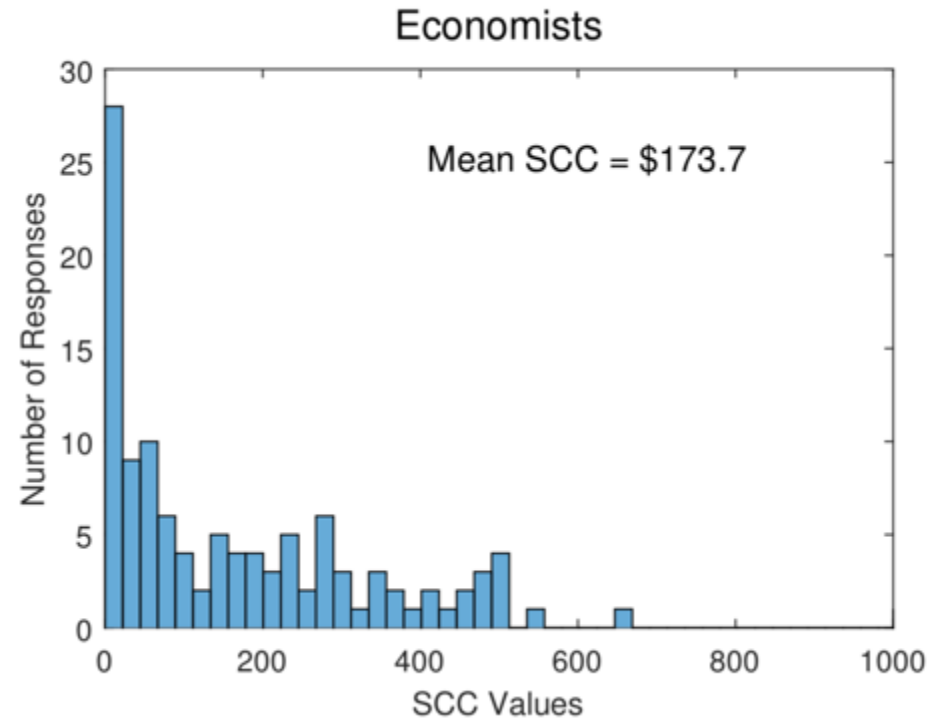
# Costs of US Billion-Dollar Disaster Events 1980-2018



Source: NOAA



# True Social Cost of Carbon (\$/tonne CO<sub>2</sub>)



The Social Cost of Carbon Revisited, R.S. Pindyck, National Bureau of Economic Research, 2016

# IEA Floats 'Green Recovery' Plan To Boost Economies, Cut Emissions

Marlowe HOOD June 18, 2020

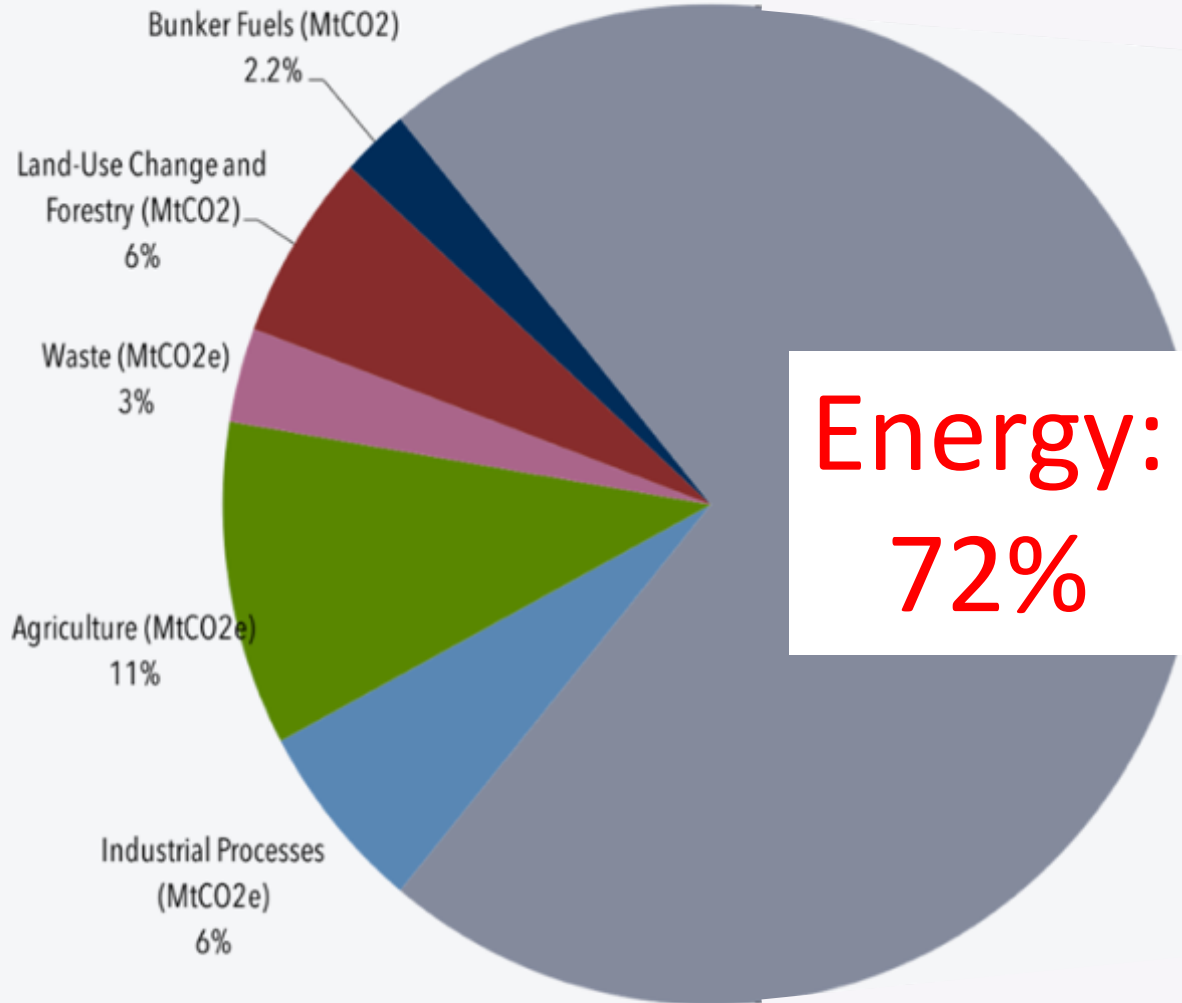


World leaders have a "once-in-a-lifetime opportunity" to reboot their economies and tackle global warming at the same time, the IEA has said

SIMON MAINA



# Global Manmade GHG Emissions



The #1 Goal:  
Reduce all carbon emissions  
to zero as rapidly as possible





# Steps Needed

- Maximize energy efficiency
- Electrify everything we can; use renewable fuels where we can't
- Provide electricity reliably with wind, solar, storage
- Draw down atmospheric CO<sub>2</sub>

# Outline

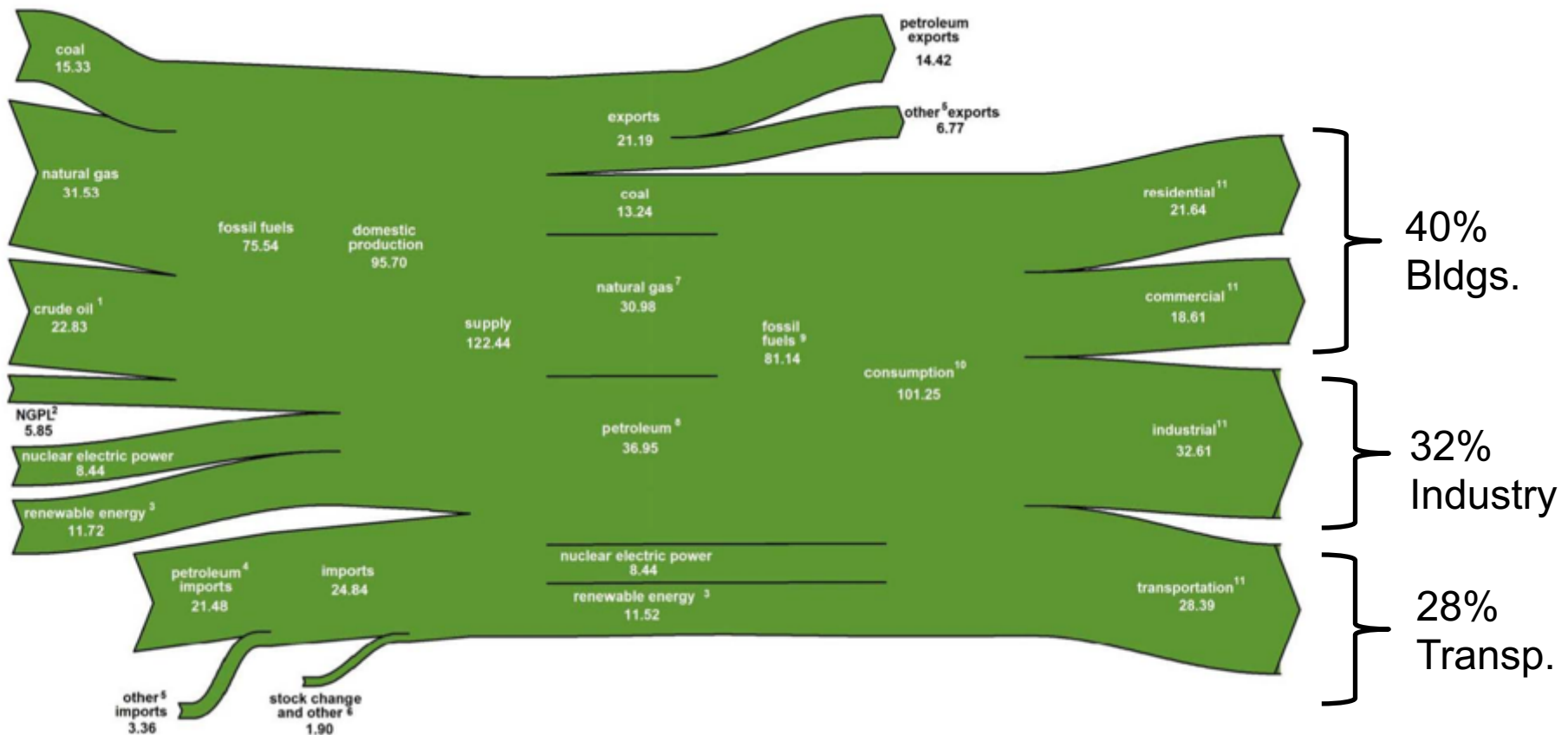
Develop Recommendations by Sector:

- 1. Buildings
  - 2. Transportation
  - 3. Industry
  - 4. Electric Power
  - 5. Negative Emissions
- } End use sectors



# U.S. Primary Energy Flow by End Use

## EIA, 2018



# 1. Buildings



# Net Zero Energy Buildings



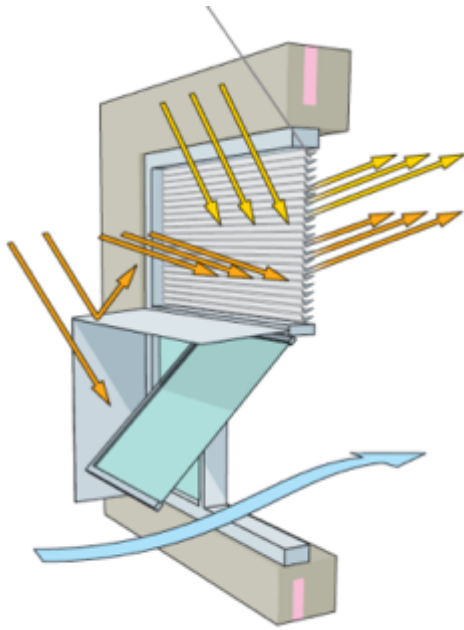
NREL Research Support Facility

# Performance-Based Acquisition

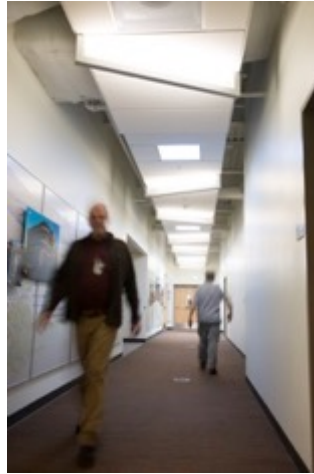
**25 kBtu/SF-yr**

**\$259/SF**





LightLouvers



Solar Tubes



Internal Mass/Night Purge



SolarWall® Vent Preheat



Radiant Ceilings



# NREL PV Systems Powering RSF



1,156 kW

857 kW

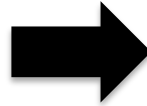
524 kW



# Scaling Up to Zero Carbon Districts

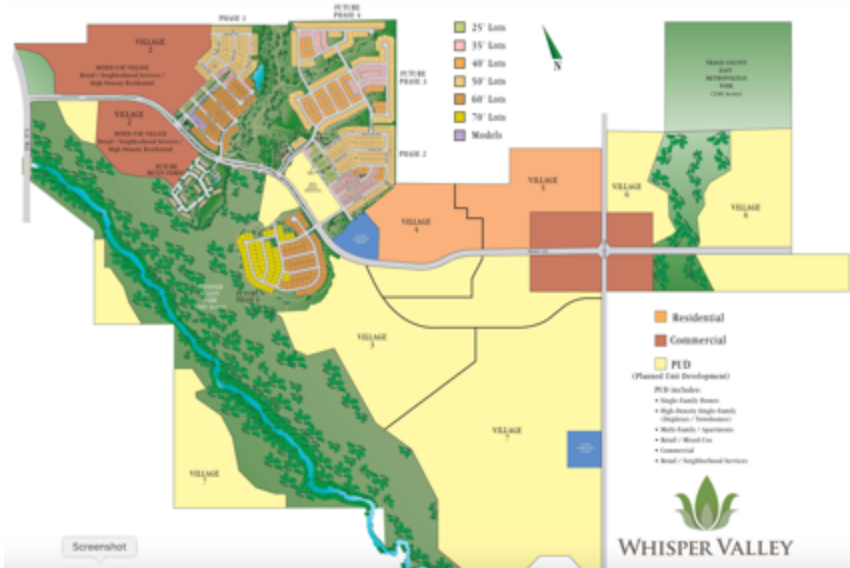


Net Zero Energy Buildings



All-Electric Zero Carbon Districts

# Whisper Valley Community



# Denver National Western Center



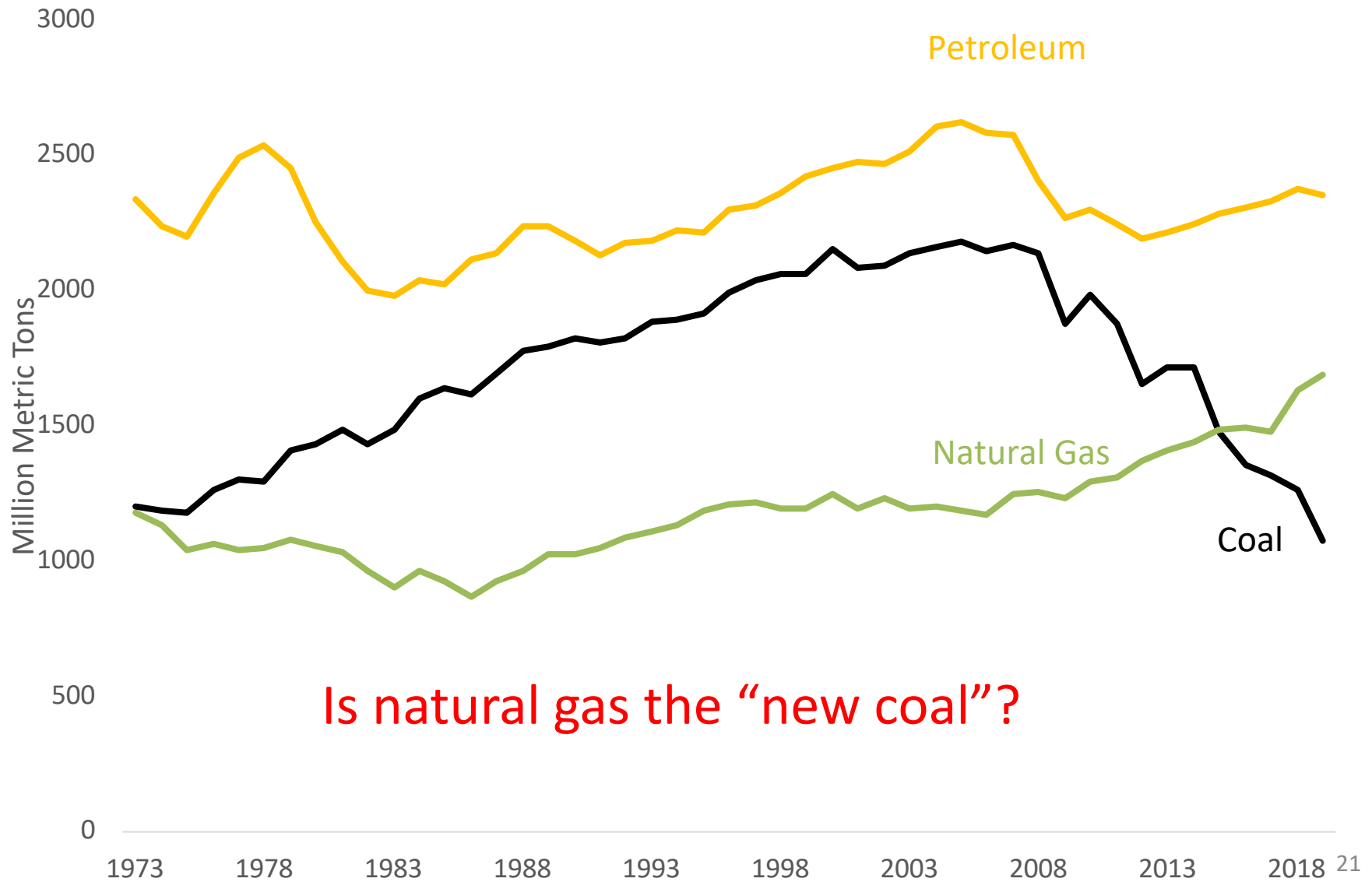
- Redevelop 130 acres
- Zero energy district
- Building EE, RE generation, wastewater heat capture





# Building Electrification

# U.S. Economy-wide Carbon Dioxide Emissions by Fuel



# Natural Gas Rush Drives a Global Rise in Fossil Fuel Emissions

Often talked about as a 'bridge fuel' to renewable energy, natural gas and LNG are instead boosting fossil fuel use, a new study shows.



BY NICHOLAS KUSNETZ

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DEC 3, 2019



# Berkeley first city in California to ban natural gas in new buildings



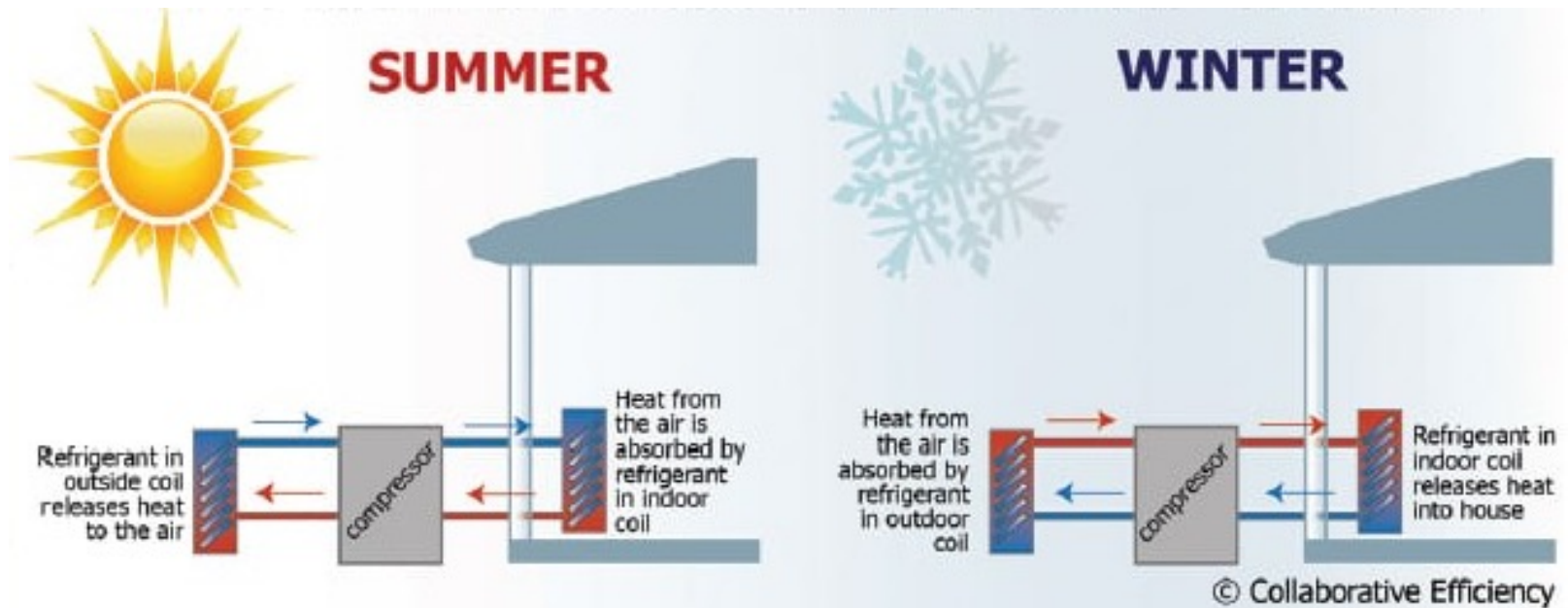
Berkeley is leading the way again with a new law to ban natural gas infrastructure in new construction. Photo: Emilie Raguso

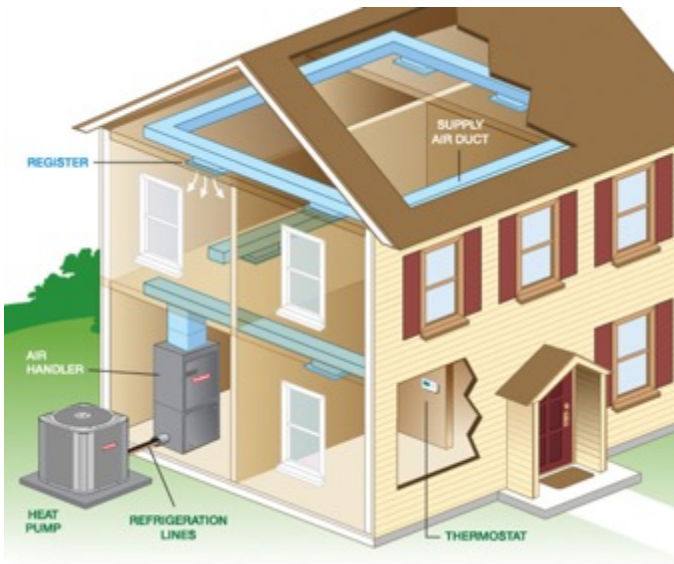


# Electrification Myth-Busting: Heat Pumps Are Ready for Cold Climates Today

When paired with better building standards and rooftop solar, the electrification of homes pencils out economically even in regions with the harshest winters.

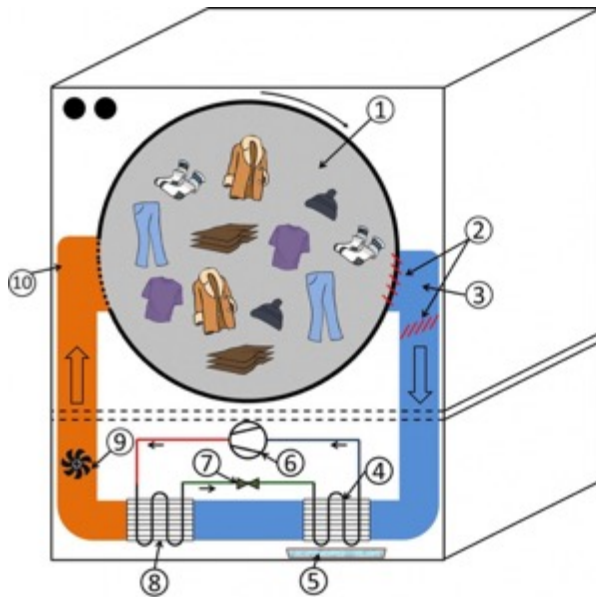
JUSTIN GERDES | APRIL 15, 2019





## INDUCTION COOKING—HERE'S WHY YOU SHOULD MAKE THE SWITCH

Induction cooking is superior to gas and electric in many ways. And it's finally trending in the U.S.

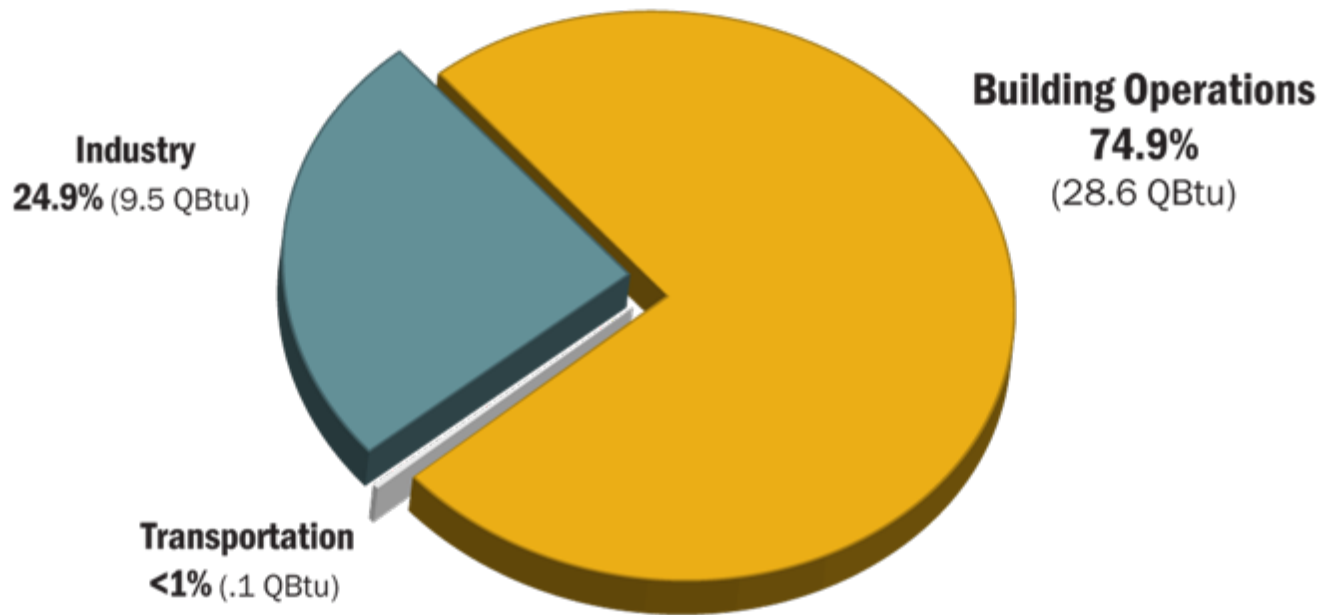


1. Drum
2. Filter
3. Warm Humid Air
4. Evaporator
5. Condensate
6. Compressor
7. Expansion Device
8. Condenser
9. Blower
10. Hot Dry Air



## Heat Pumps and Induction Stovetops

# Buildings are–by far–the biggest consumer of electricity



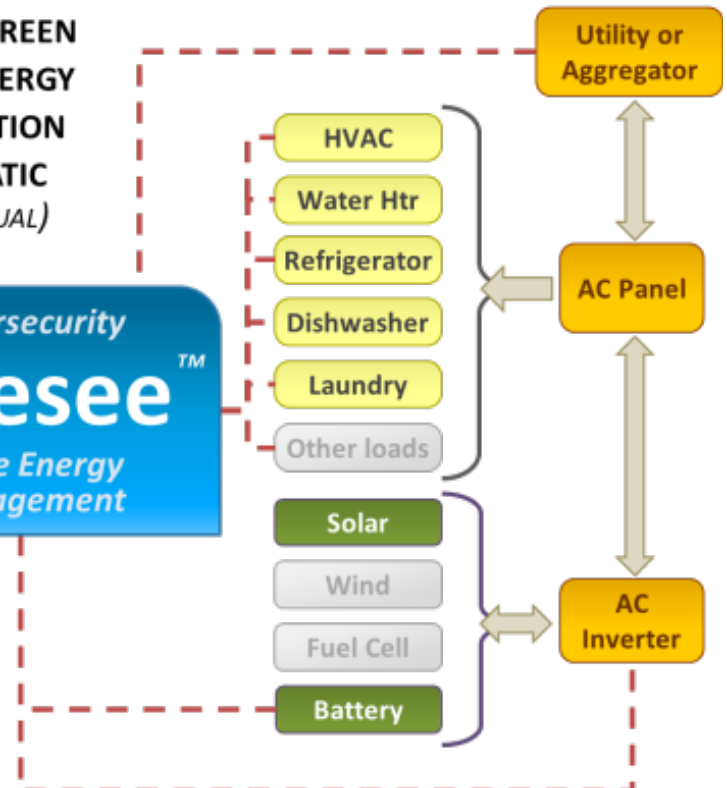
## U.S. Electricity Consumption by Sector

Source: ©2013 2030, Inc. / Architecture 2030. All Rights Reserved.  
Data Source: U.S. Energy Information Administration (2012).

# Home Energy Management System



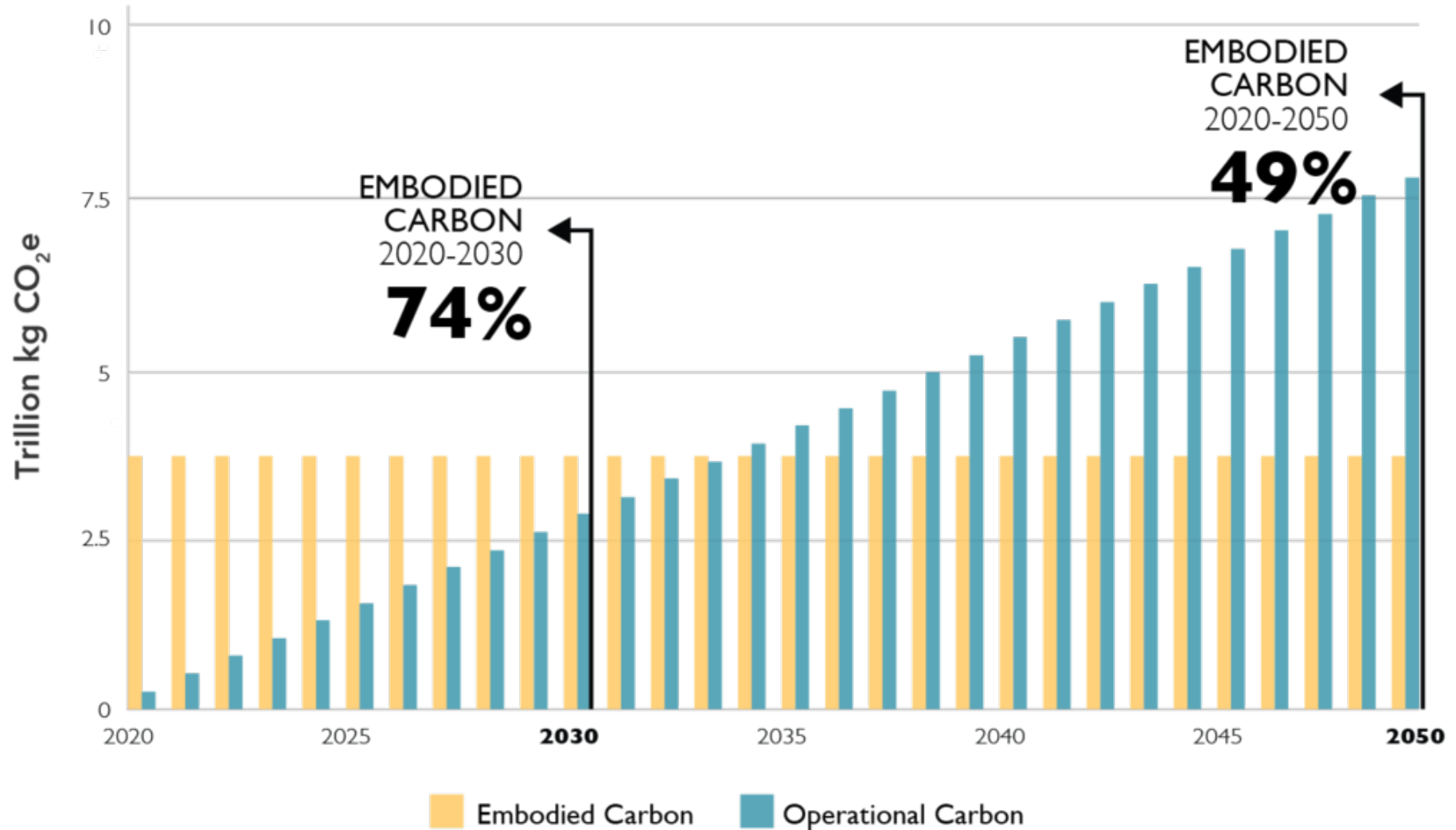
## SMART/GREEN HOME ENERGY AUTOMATION SCHEMATIC (CONCEPTUAL)





# Importance of Embodied Emissions

# Construction vs. Operating Emissions



# Buildings Measures

## Efficiency

- Annual benchmark of commercial buildings
- All new buildings net zero by 2030; performance-based acquisition
- Expand Energy Star for all appliances

## Electrification

- All new buildings all electric beginning in 2022
- Target propane- and oil-heated homes and replacement equipment for existing buildings
- All new homes equipped with 240-V EV charging beginning 2022
- R&D to develop low-GWP refrigerants

## Demand Response

- All new homes with WiFi-enabled electric appliances and an EPA-compliant Smart Home Energy Management System beg. 2023

## Building Materials

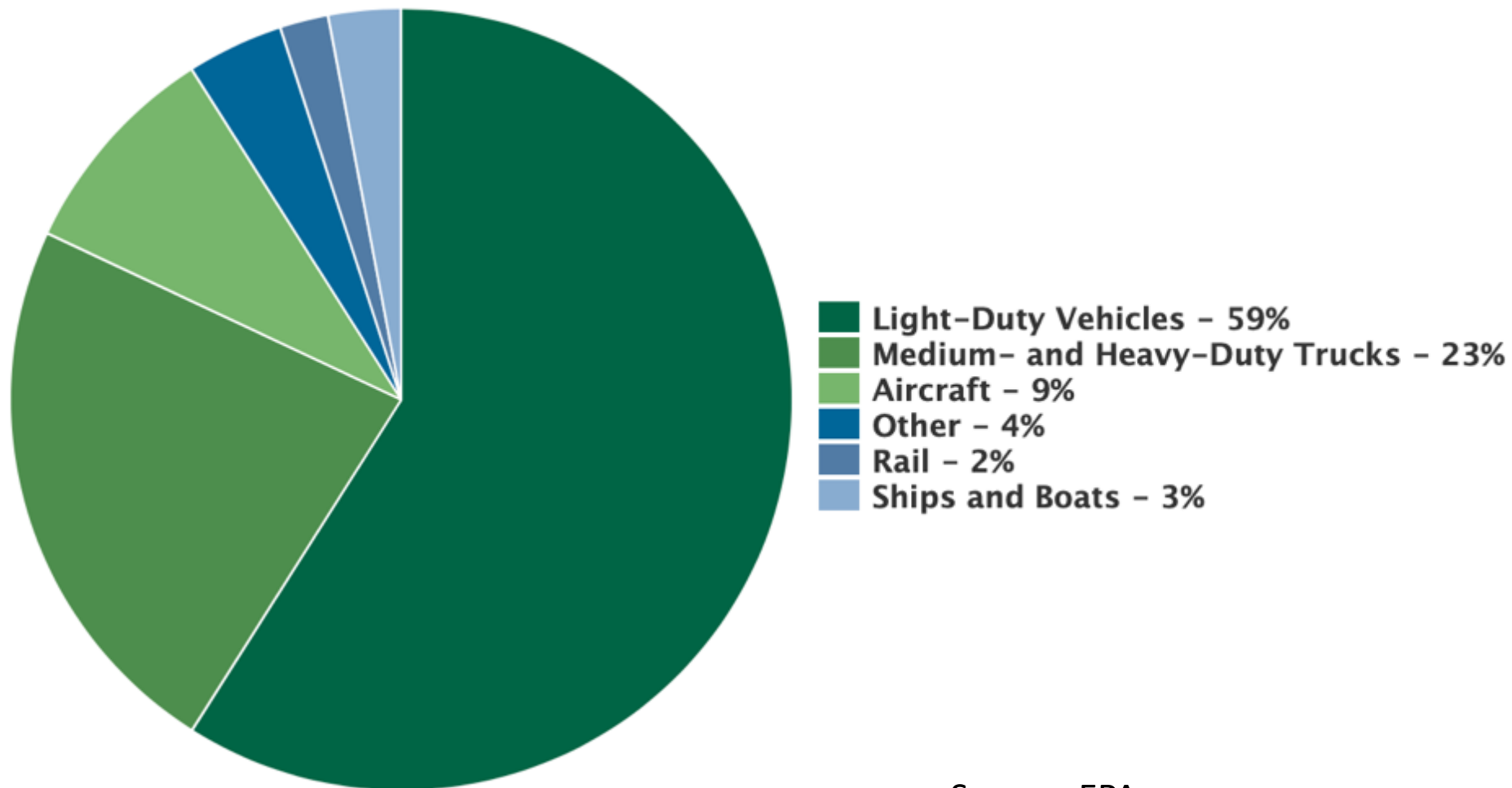
- All new buildings reduce embodied carbon compared to 2020:
  - 45% by 2025
  - 65% by 2030

## 2. Transportation



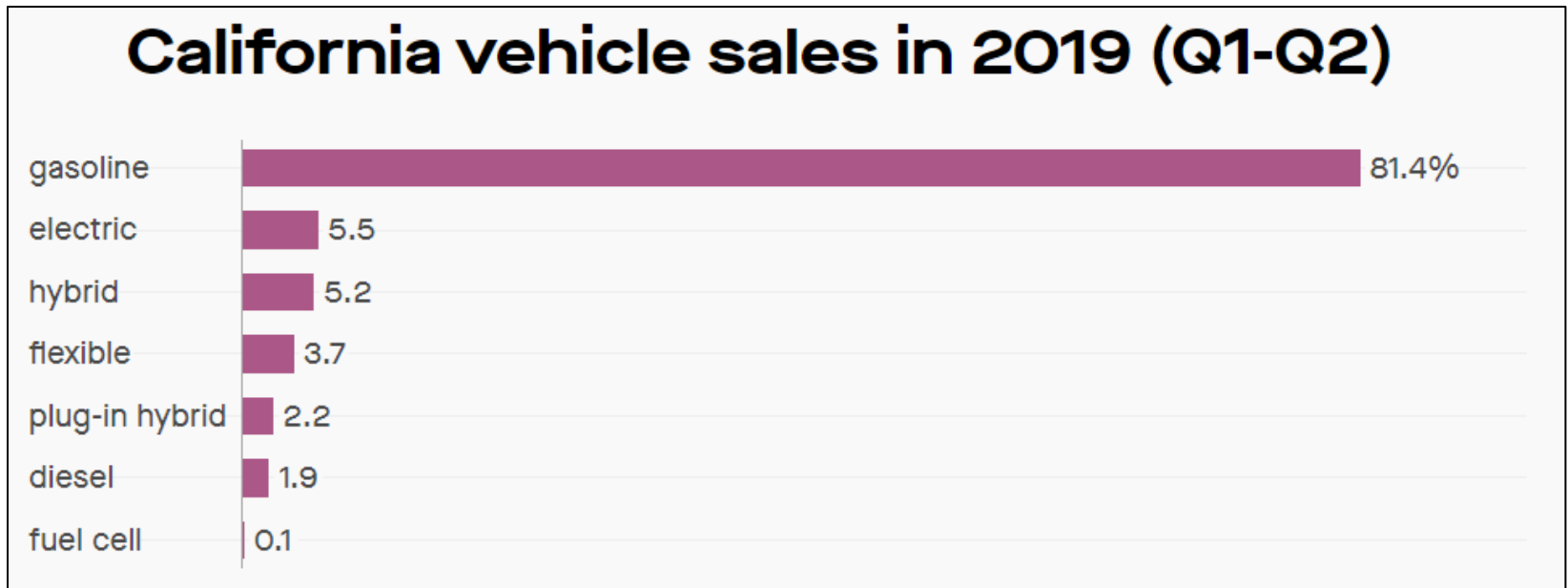
# U.S. Transportation GHG Emissions

## 2017



Source: EPA

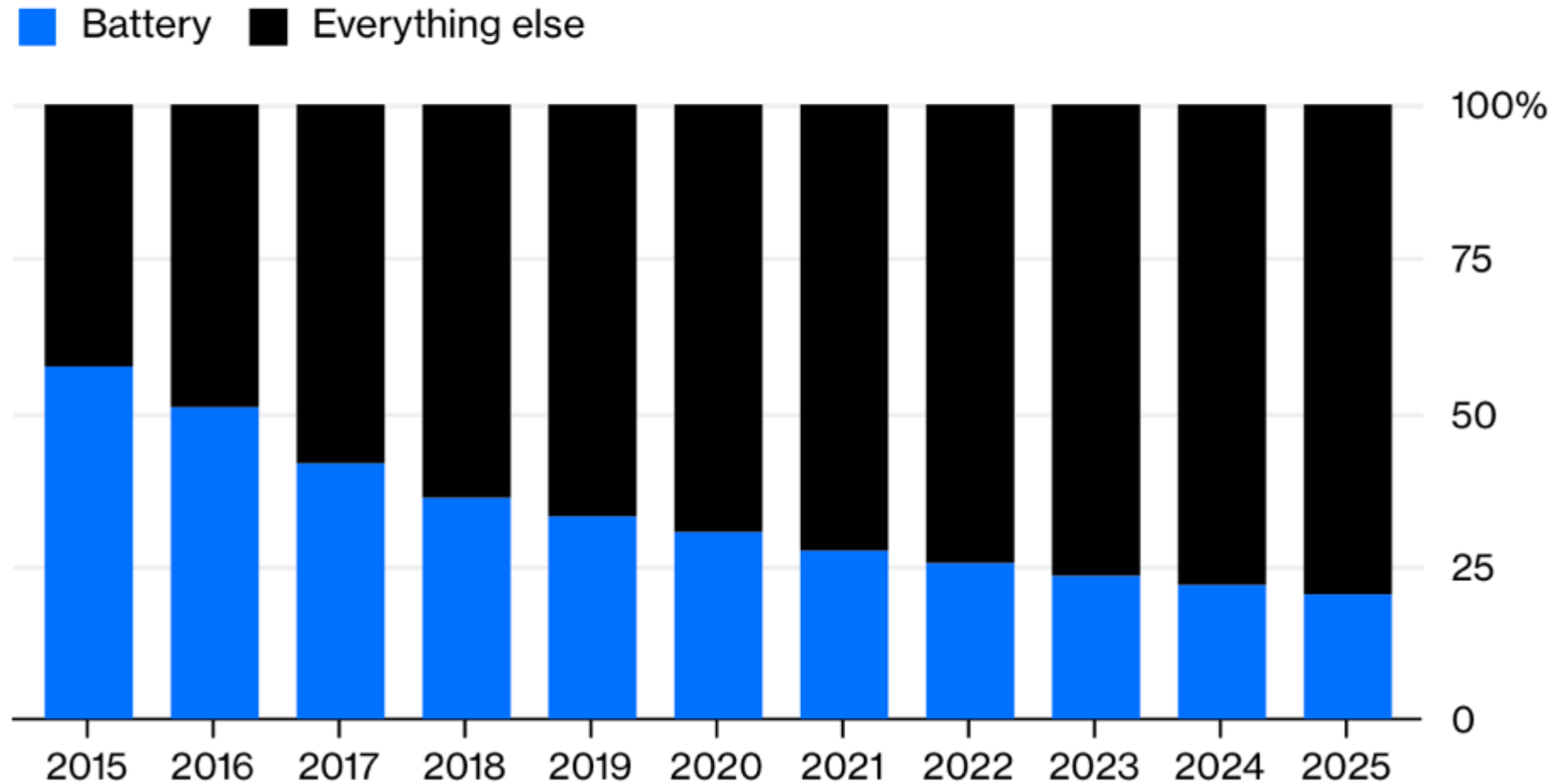
# EV Sales are Up, but Still Have A Long Way to Go



<https://qz.com/1709036/electric-cars-are-cutting-into-combustion-engine-sales>

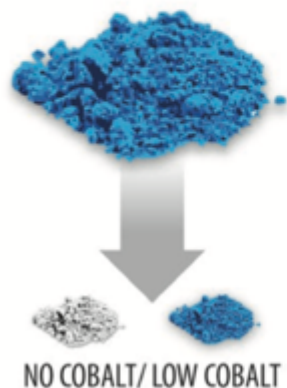
# The Incredible Shrinking Car Battery

EV battery cost for U.S. medium-size car as a percentage of retail price

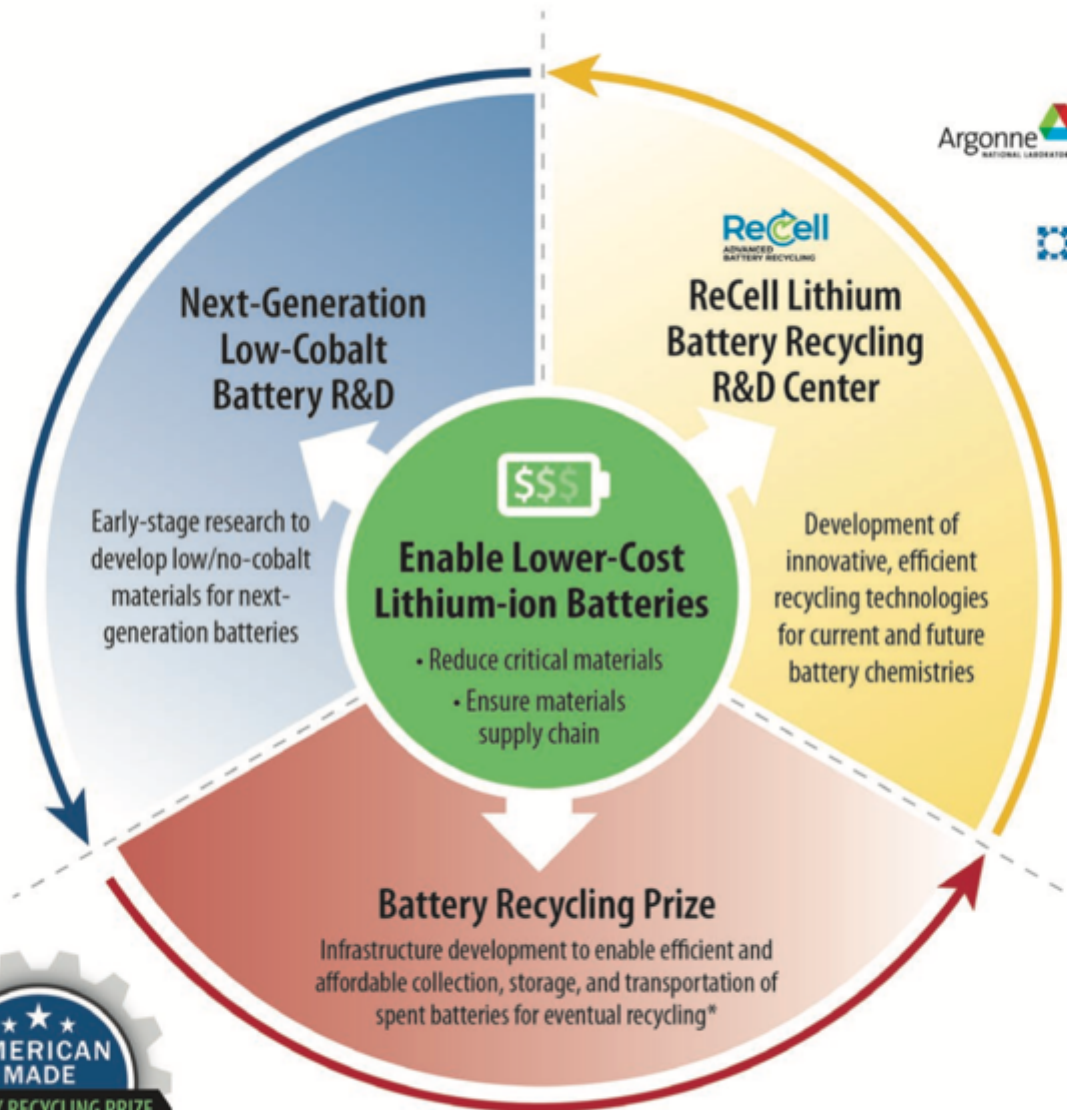


Source: BloombergNEF

# Critical Materials Research Plan for Batteries



U.S. DEPARTMENT OF ENERGY



Argonne  
NATIONAL LABORATORY

NREL  
Transforming ENERGY

OAK RIDGE  
National Laboratory

Michigan  
Technological  
University

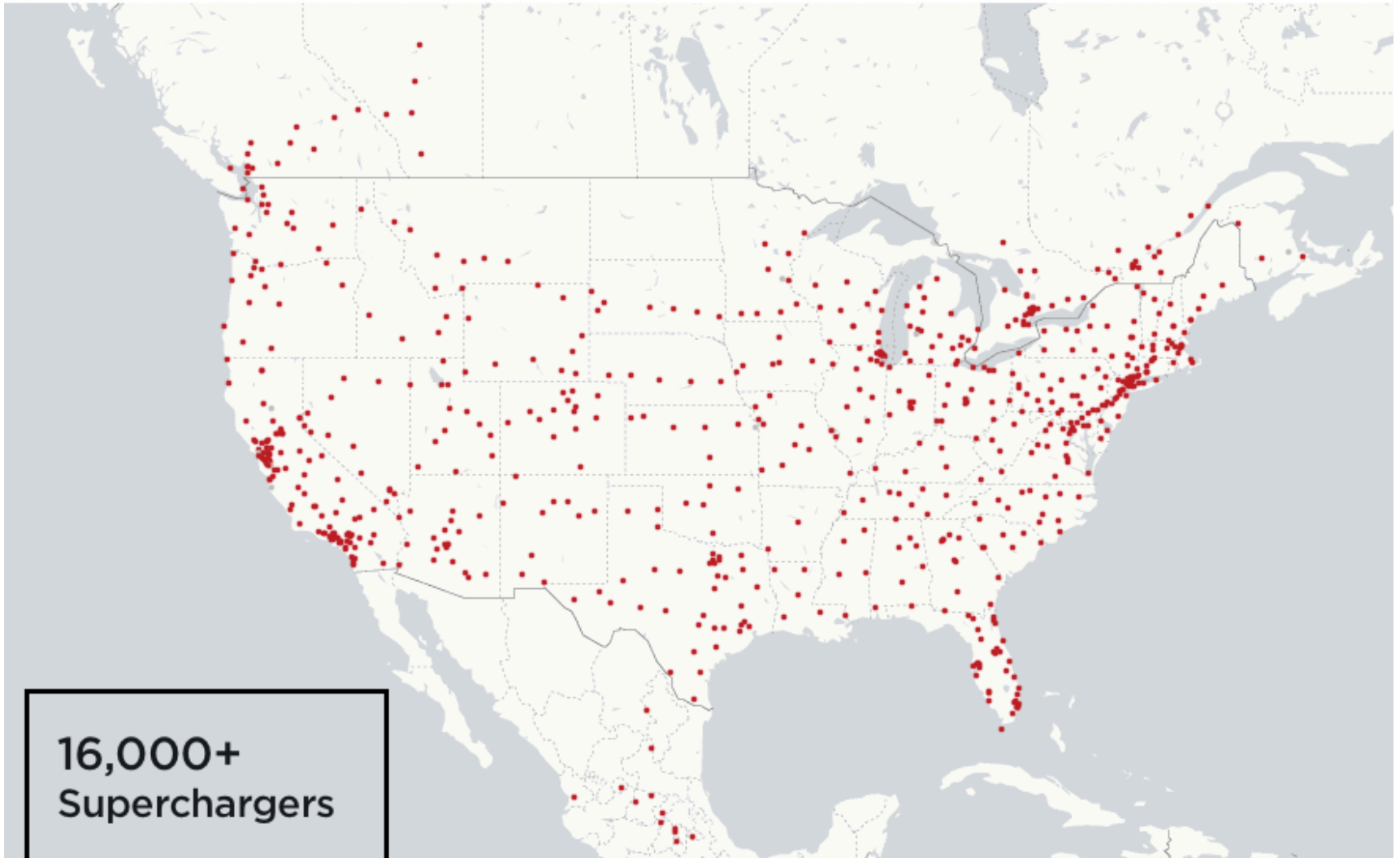
UC San Diego

WPI

\* Funded by the U.S. Department of Energy Vehicle Technologies Office, within the Office of EERE, in collaboration with the Advanced Manufacturing Office, and administered by the National Renewable Energy Laboratory

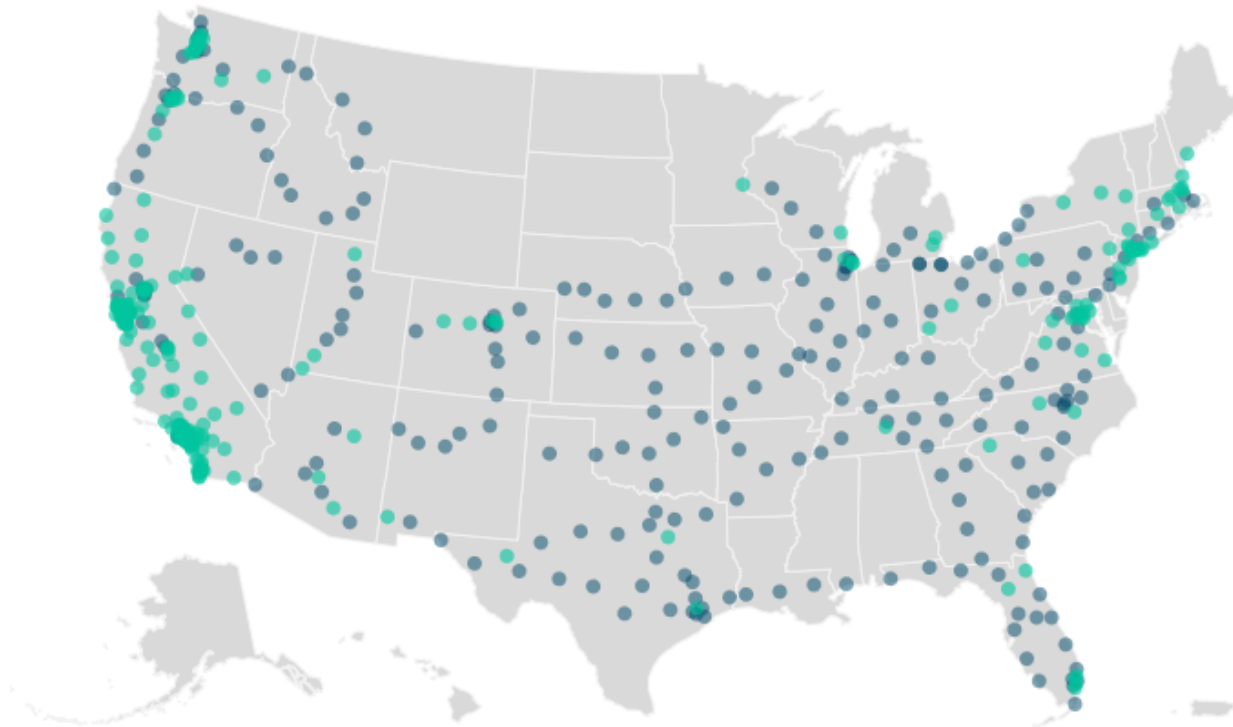


# Tesla Charging Network



# High-Speed Charging Station Networks are Growing

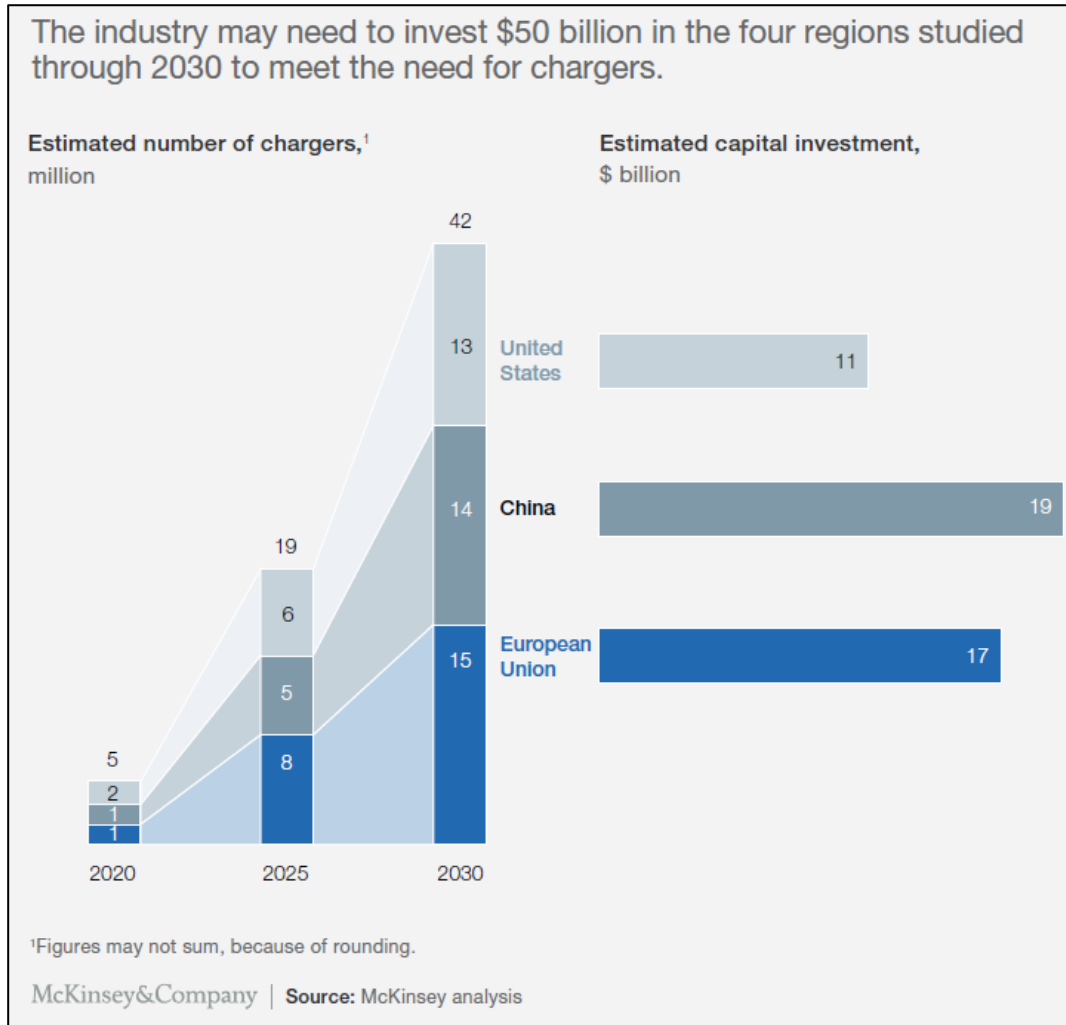
Electrify America is expanding its network of high-speed charging stations for electric vehicles at a rapid rate. As of July 17, the company had **251 stations installed in the US** with plans to add **235 more before the end of the year**.



Source: Electrify America  
Graphic: Curt Merrill, CNN

[www.cnn.com/2019/08/01/cars/future-of-electric-car-charging/index.html](http://www.cnn.com/2019/08/01/cars/future-of-electric-car-charging/index.html)

# Projected Charging Investment Needs



[www.mckinsey.com/~media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Charging%20ahead%20Electric-vehicle%20infrastructure%20demand/Charging-ahead-electric-vehicle-infrastructure-demand-final.ashx](https://www.mckinsey.com/~media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Charging%20ahead%20Electric-vehicle%20infrastructure%20demand/Charging-ahead-electric-vehicle-infrastructure-demand-final.ashx)

# Driveways, Garages Are the EV Fueling Stations of the Future

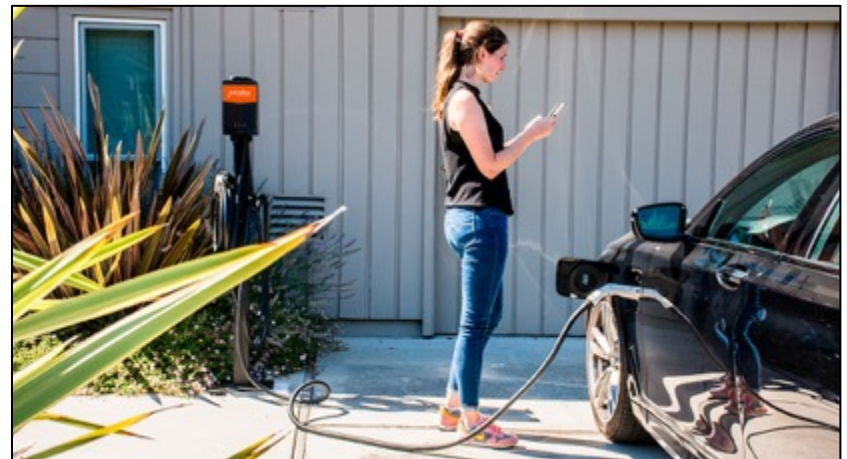
## Qualcomm's Wireless Charging Technology



[www.landmarkdividend.com/ev-charging-stations](http://www.landmarkdividend.com/ev-charging-stations)



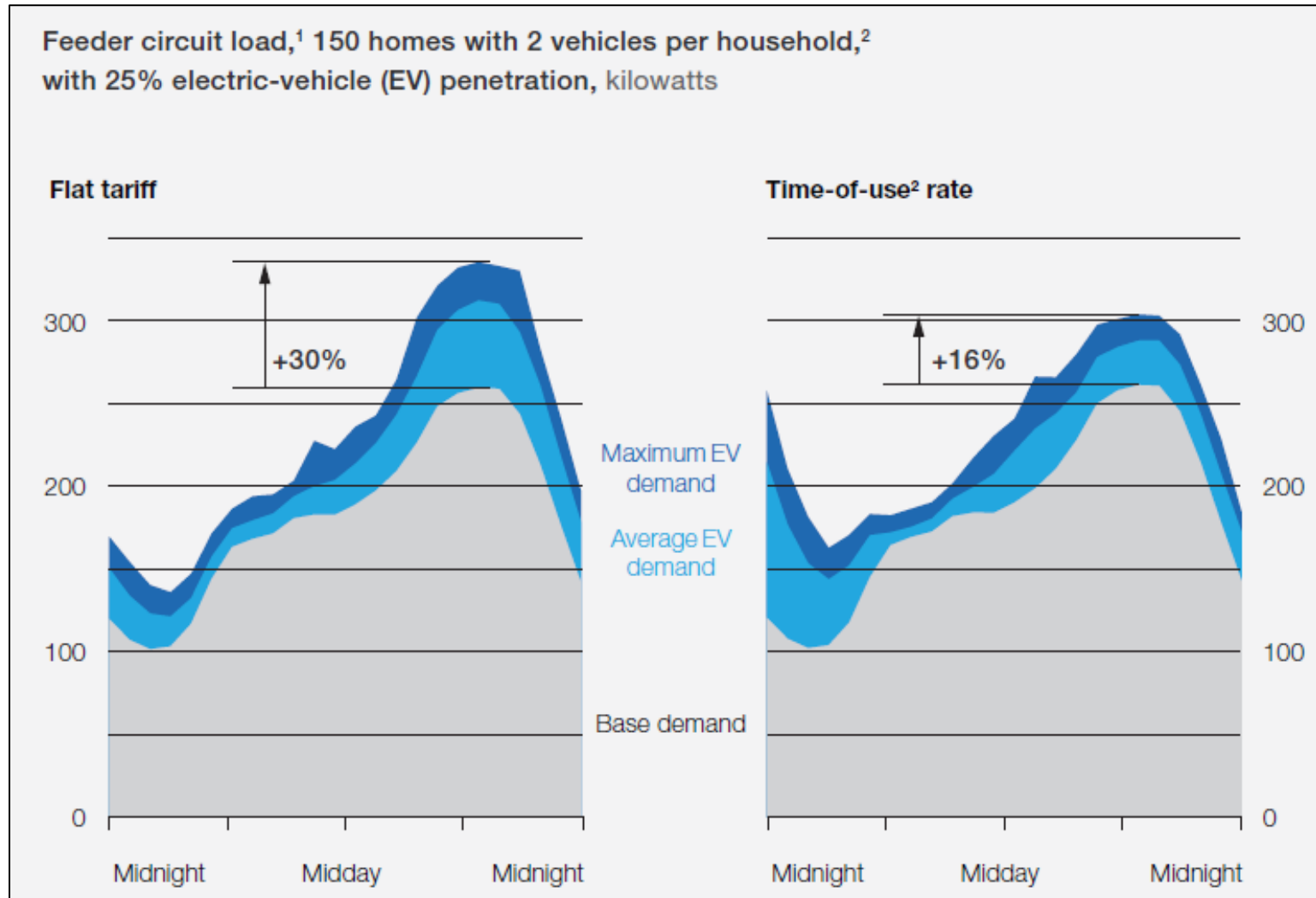
<https://insideevs.com/news/343589/where-will-ev-charging-stations-of-the-future-be-located>



<https://evcharging.enelx.com/news/blog/551-electric-car-charging-at-home>

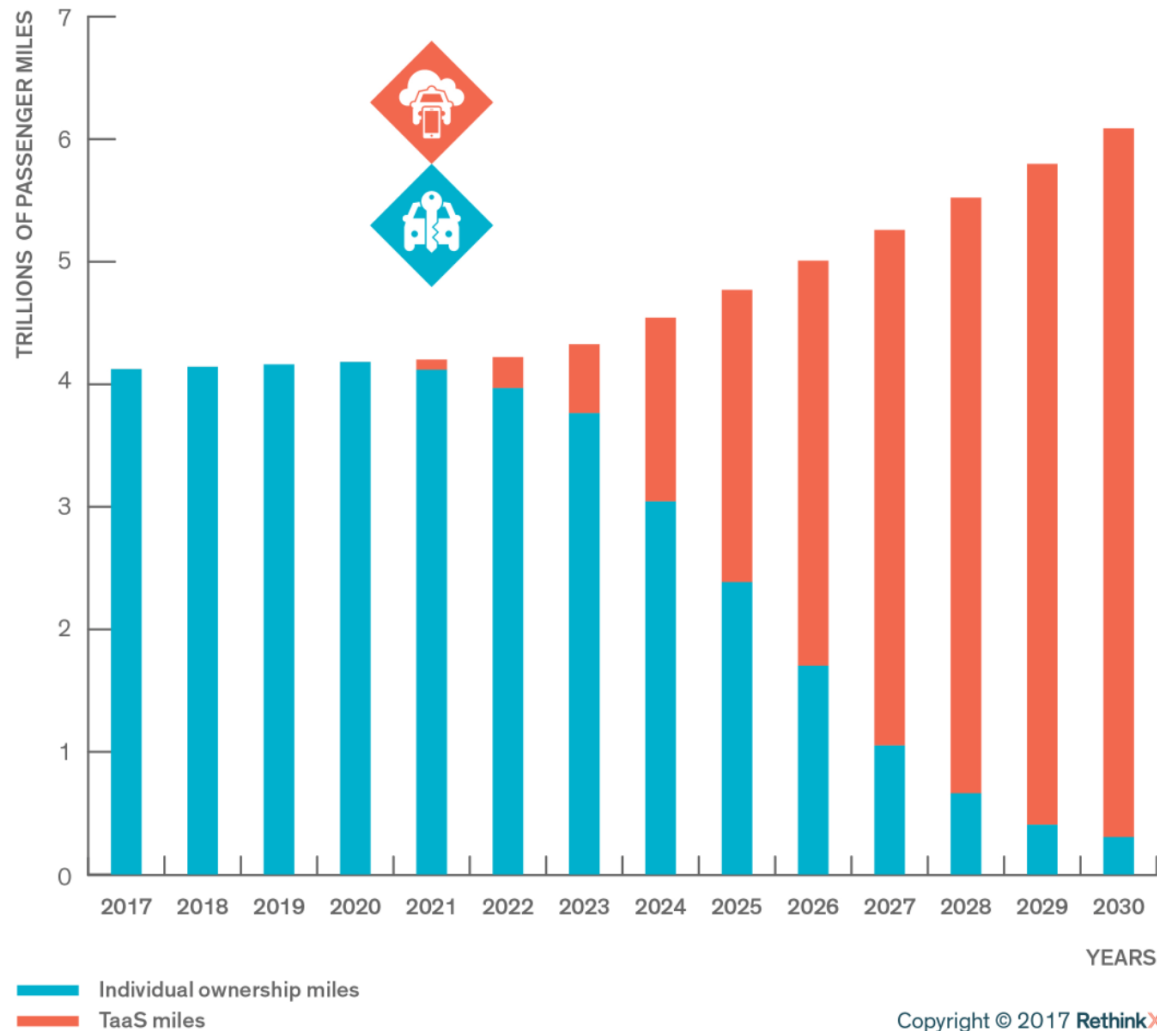


# Time-of-Use Rates Could Halve Peak Loads



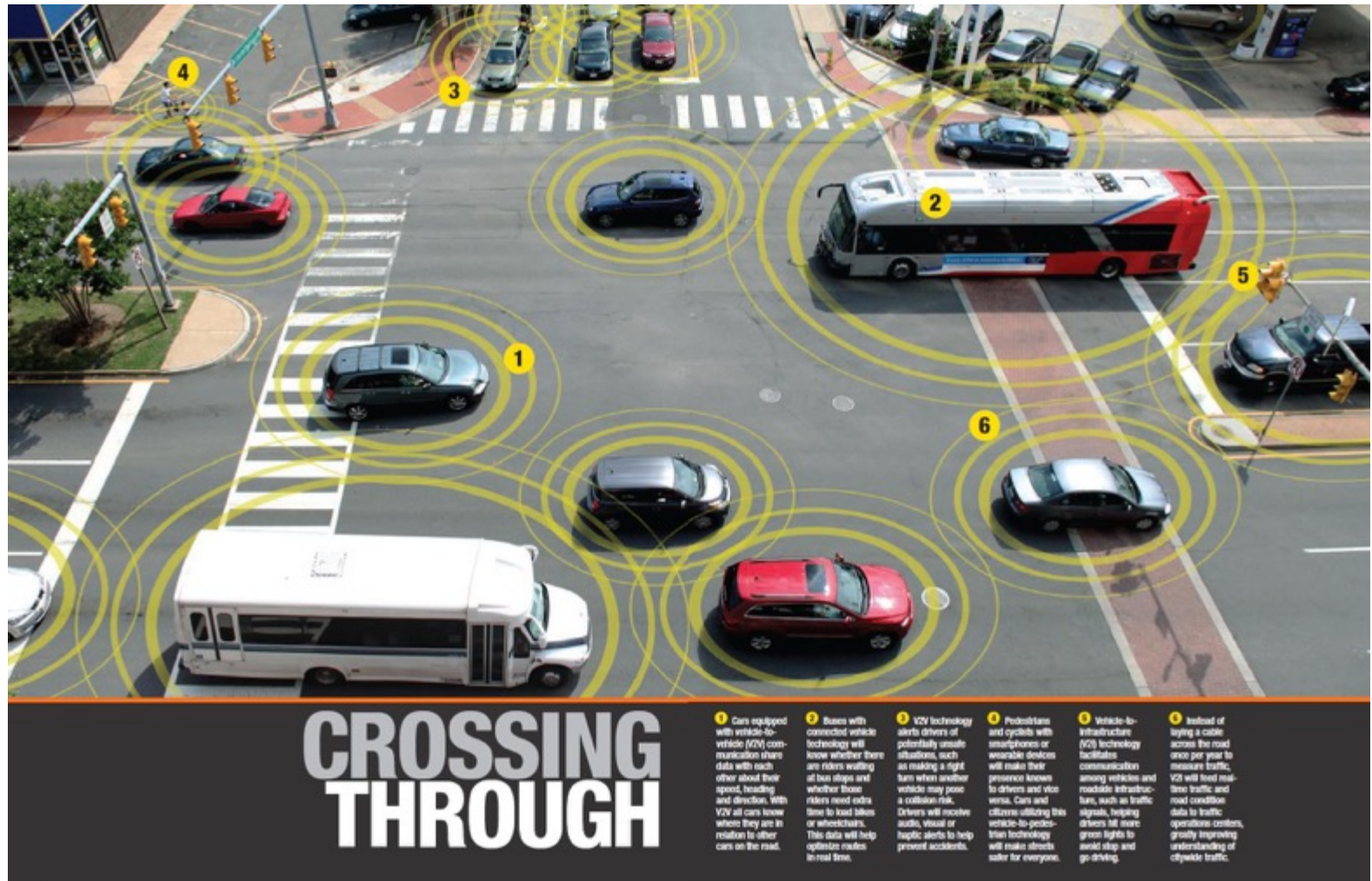
<https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-potential-impact-of-electric-vehicles-on-global-energy-systems#>

# Transportation as a Service



# The Transportation System of the Future

V2V: Completely Connected by Information and Communications Technology, Data, and Analytics



# A Rapid Transition



1900



1913

5<sup>th</sup> Avenue, New York City

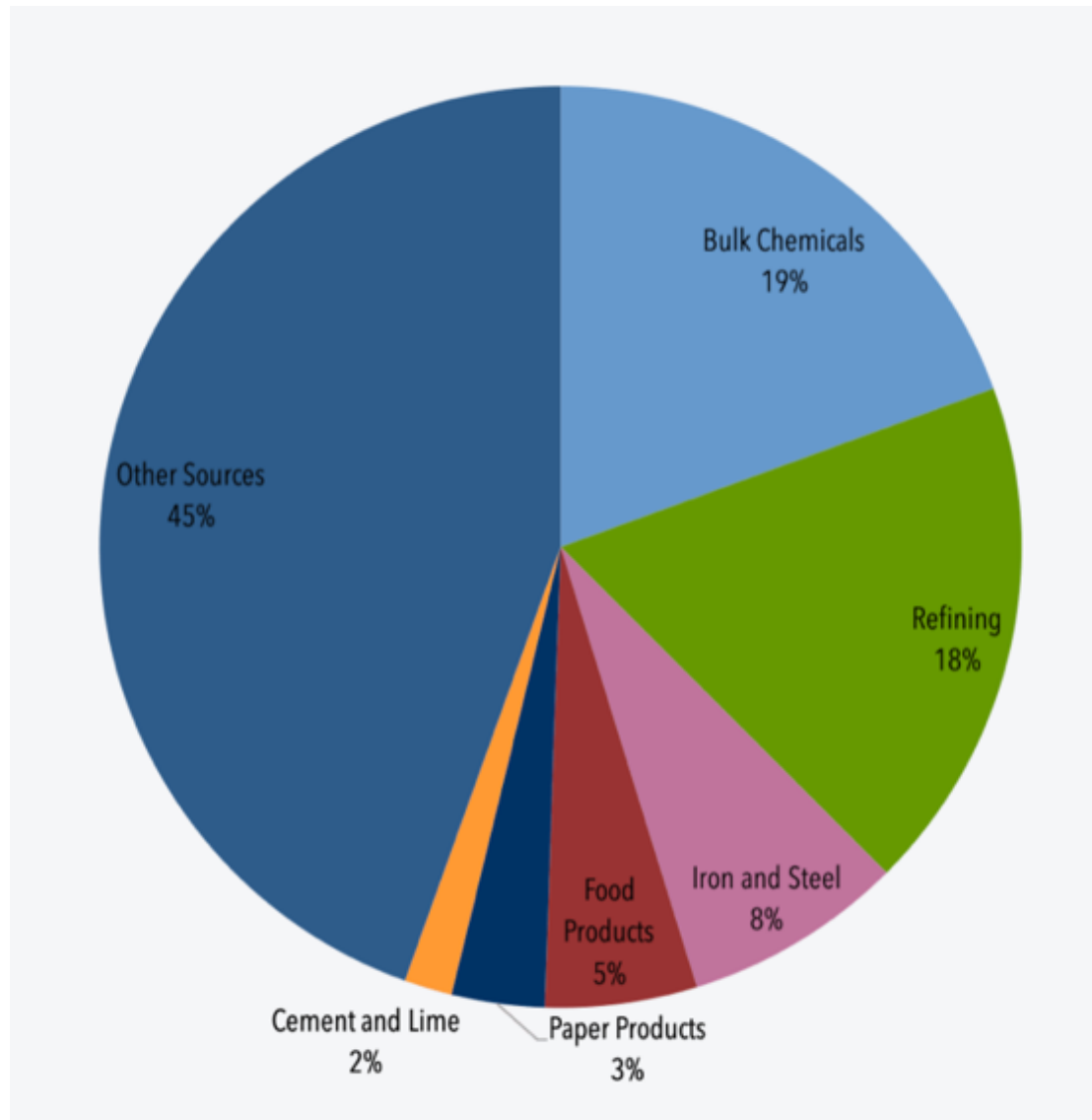


# Transportation Measures

- All new light duty vehicles sold by 2030 must be electric
- Extend and expand federal tax credit for EVs (not hybrids)
- Allow EVs (not hybrids) HOV lane access
- Federal R&D to reduce battery cost and materials needs (e.g., cobalt content)
- Federal buy-back program for conventional and hybrid vehicles
- State and city programs to install EV charging stations in multi-family buildings
- Government incentives for companies to provide close-in EV parking spaces with charging
- Utility pricing programs to utilize EV batteries to avoid RE curtailment
- R&D to improve Li-ion batteries and develop new battery types
- Development of V2G technology; requirement for EV batteries to provide home power
- Expand high-speed and light rail

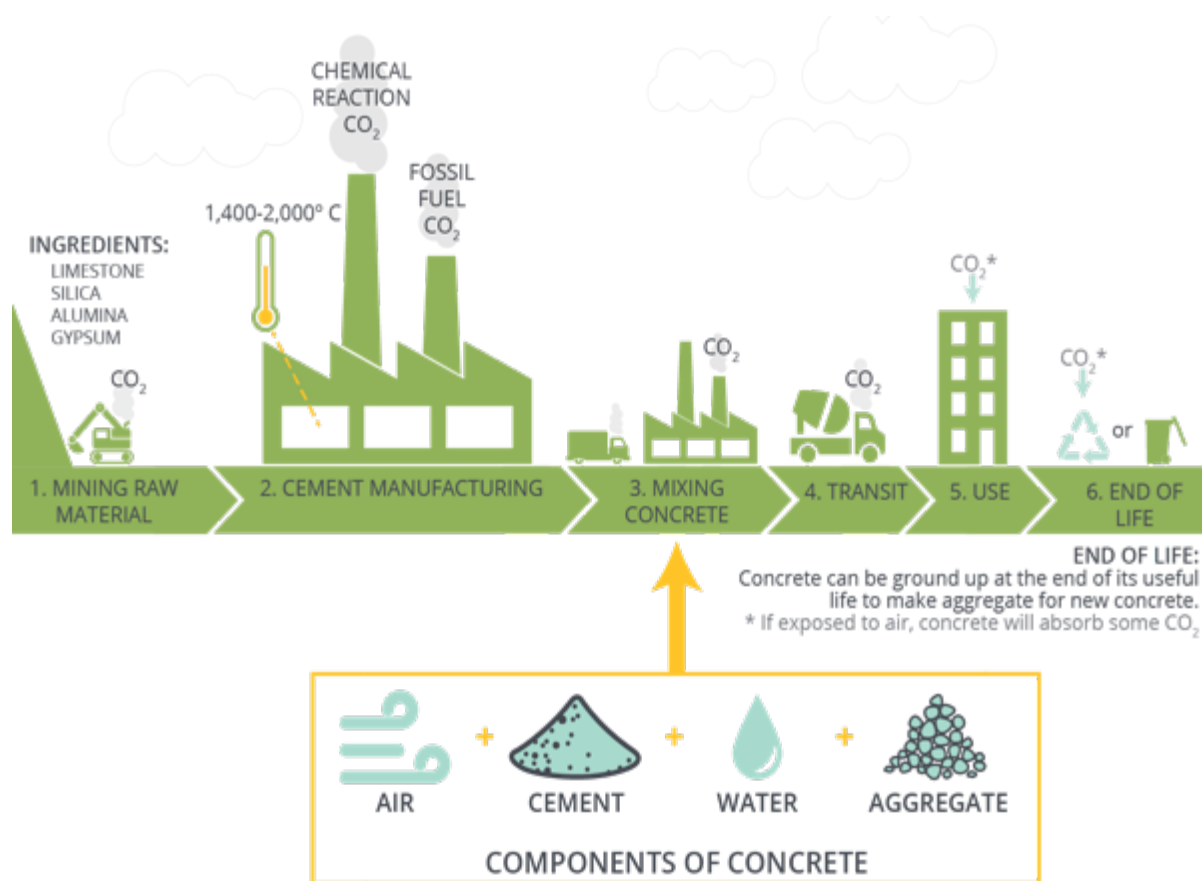
# 3. Industry

# U.S. Energy-Related Industrial CO2 Emissions



*EIA Annual Energy Outlook, 2020*

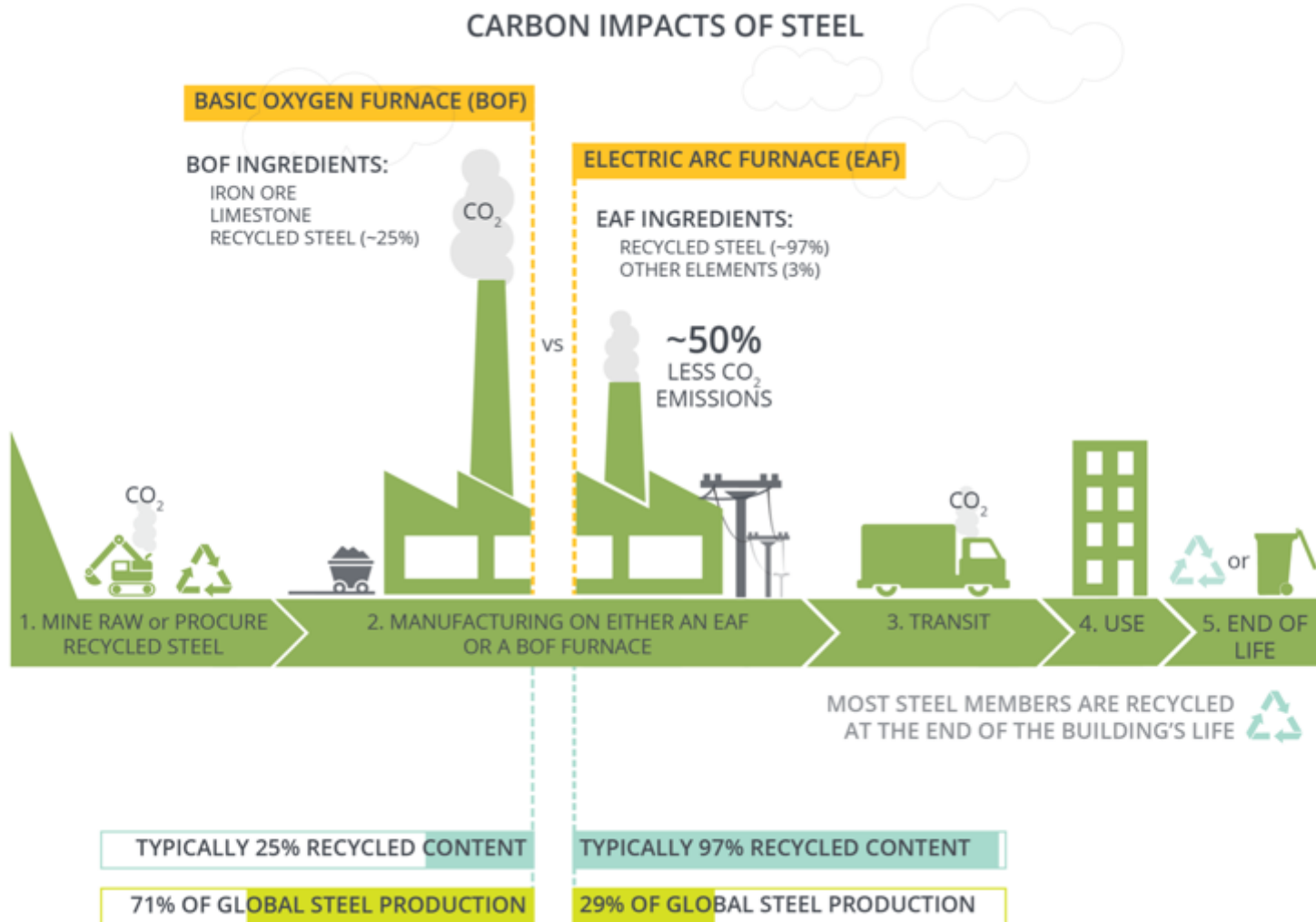
# Concrete Manufacture



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# Steel Manufacture



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# Industrial Electrification Opportunities

## Industrial Subsector

## Electric Technology

Food, chemicals

Electric boiler, resistance heater, heat pumps

Glass and glass products

Electric resistance melt furnace

Primary metals, transportation equipment

Induction furnace

Plastics, rubber

Resistance heating, infrared processing

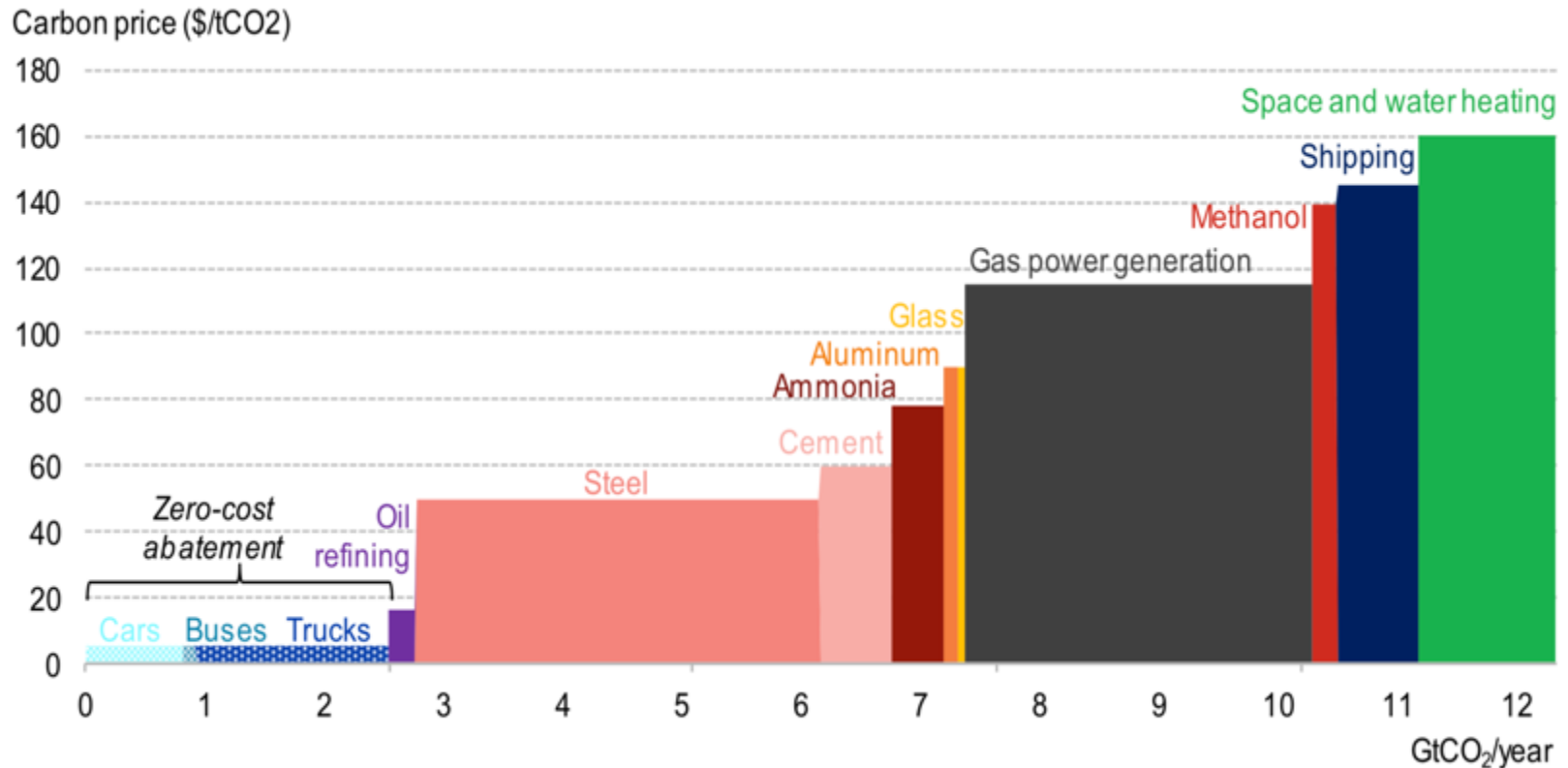
Wood products

UV curing

Other

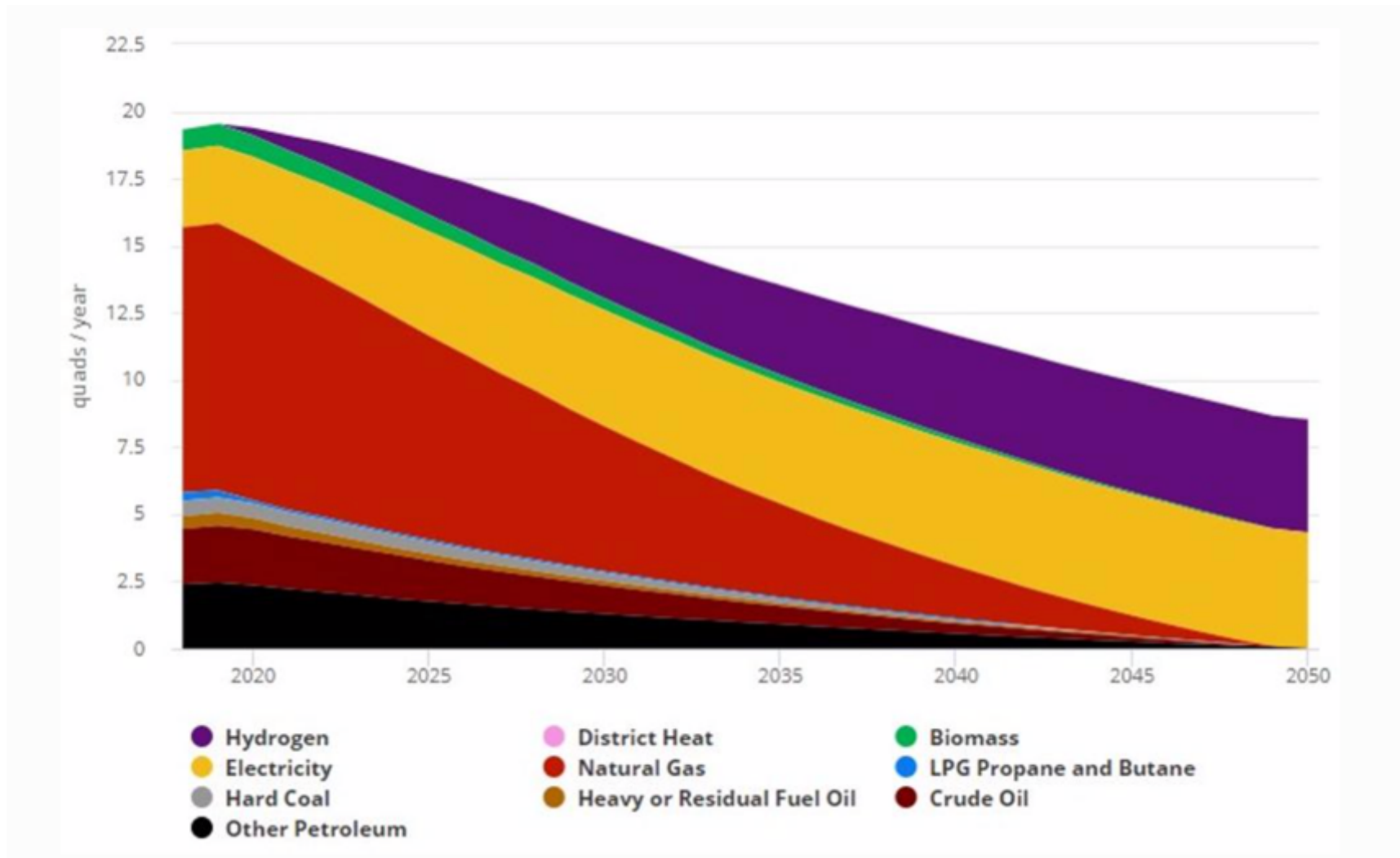
Resistance heating

# Cost of Replacing Fossil Fuel with Hydrogen



Source: Bloomberg BNEF

# Industry Fuel Transition Scenario

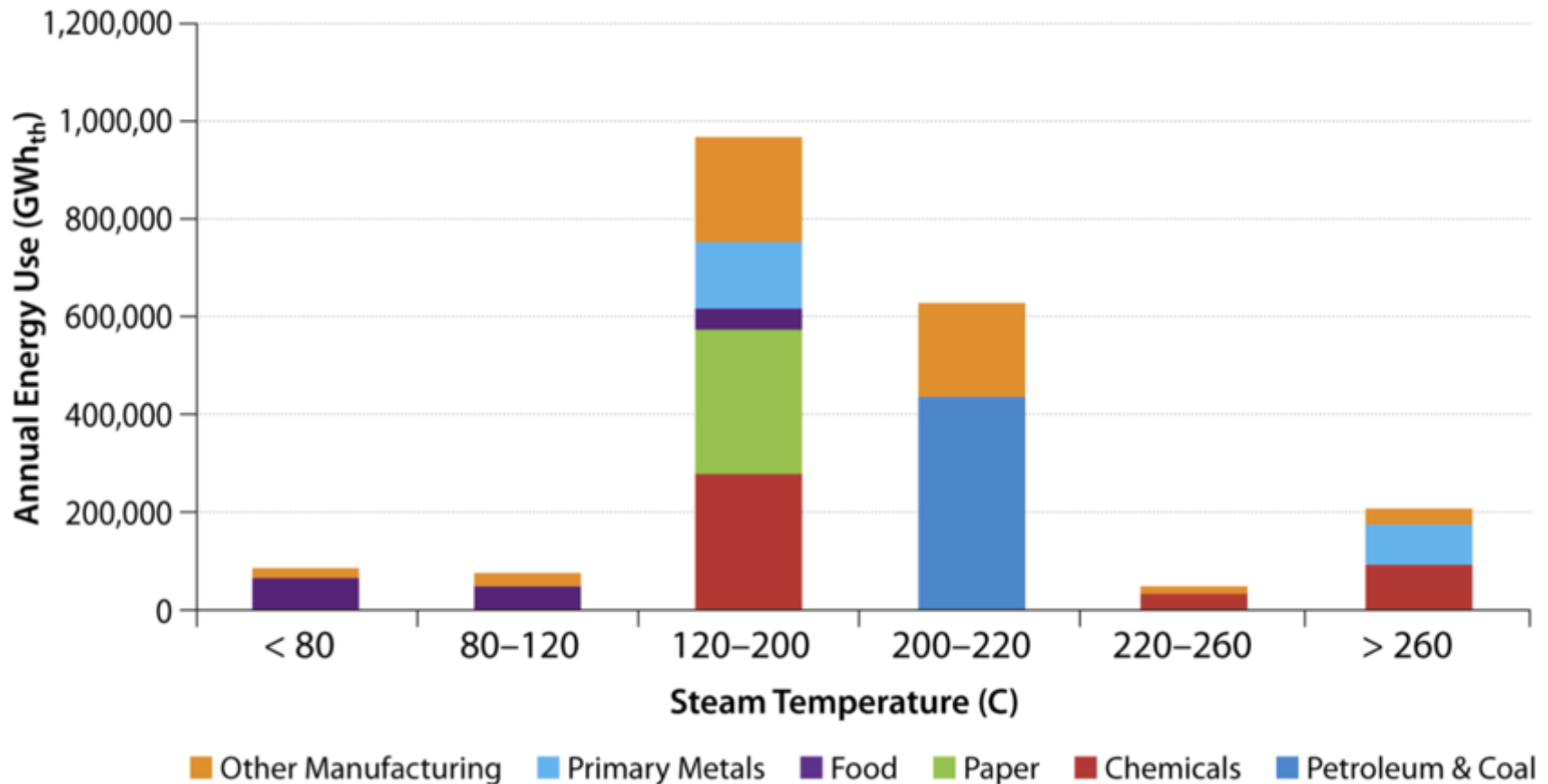


Source: Energy Innovation

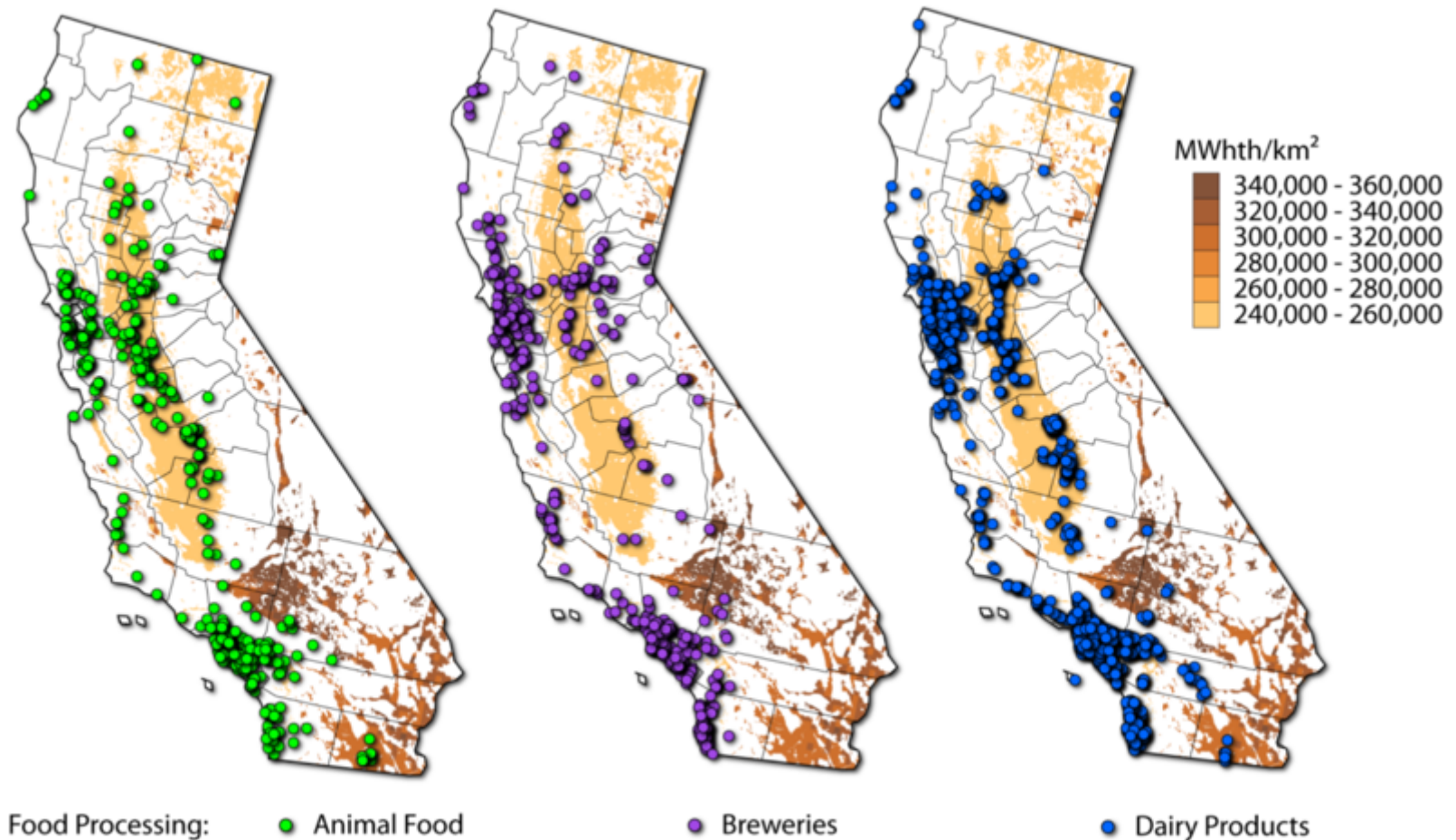


# Solar Industrial Process Heat

# Most Industrial Steam at Right Temperature for Solar Thermal



# California Central Valley Ideal Combination of Industry/Solar Radiation



# Frito-Lay Solar IPH Plant Modesto, CA



# Industry Measures

## Efficiency

- Emissions mandate to incentivize waste minimization, recycling, and process system improvements
- More aggressive federal government efficiency standards for key components such as motors and compressors.

## Electrification

- A federal R&D effort in collaboration with industry to identify opportunities for electrification of processes and develop and test the equipment to convert from fuels to electrical energy supply.

## Hydrogen

- A federal R&D effort aimed at reducing the cost of renewable hydrogen production and hydrogen storage.
- Extend hydrogen piping network

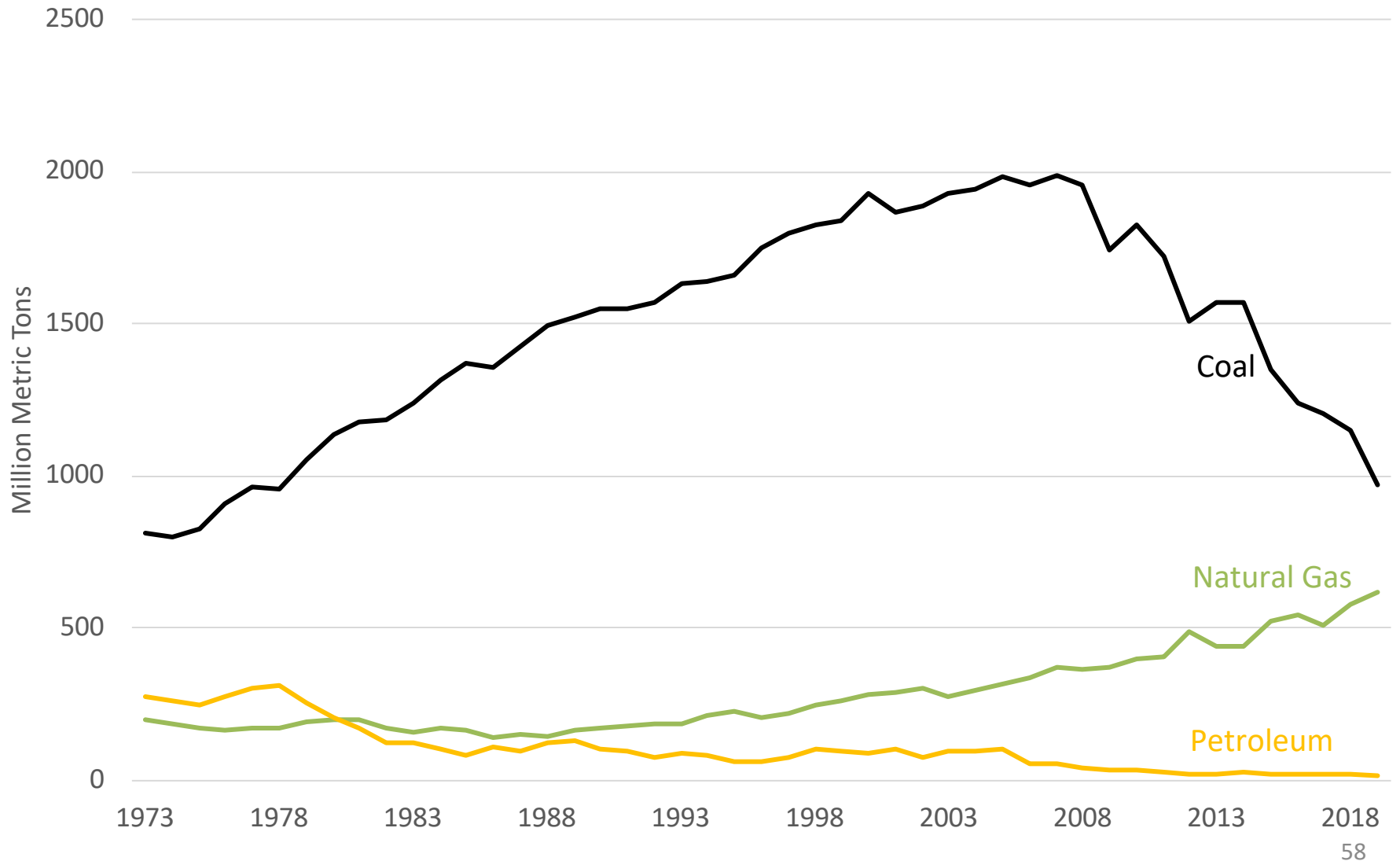
## Solar Thermal

- The State of California should evaluate solar IPH opportunity in Central Valley.



# 4. Electric Power

# U.S. Power Sector Burner-tip Carbon Dioxide Emissions by Fuel



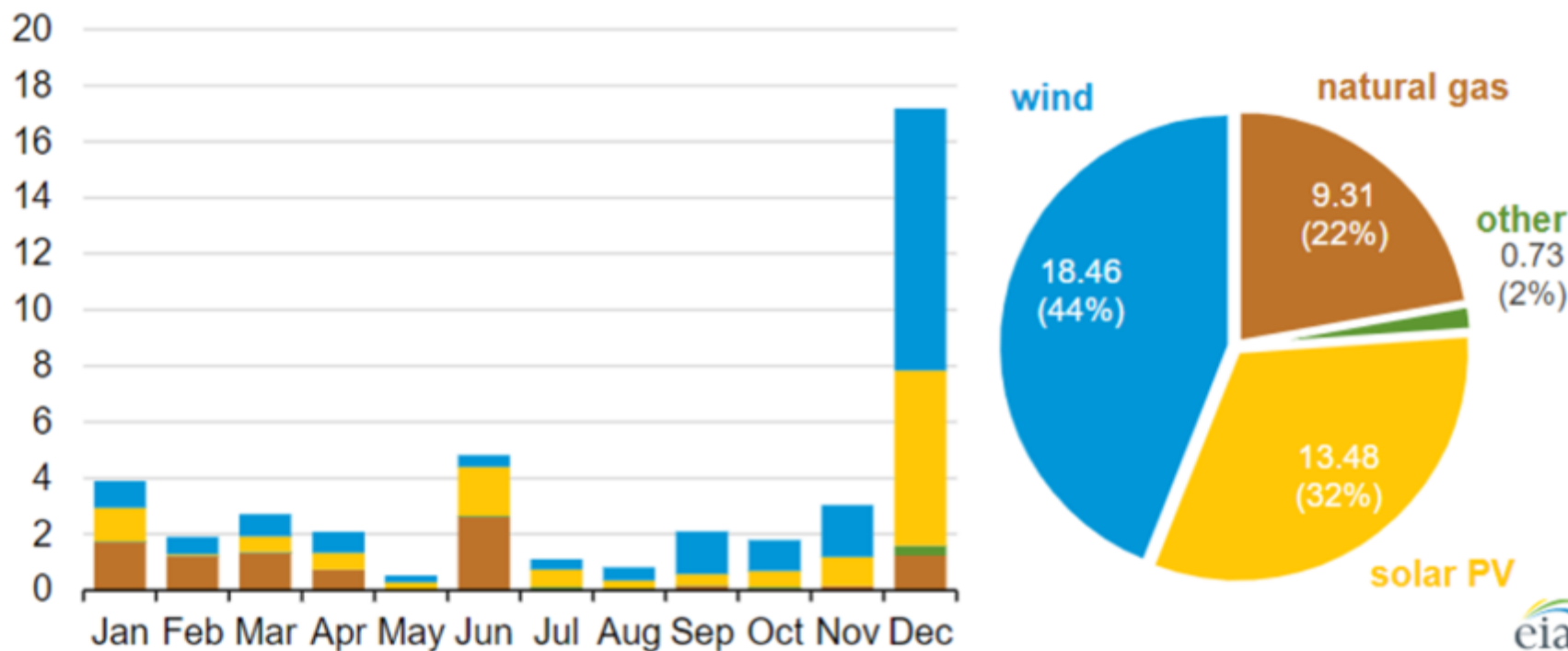


Wind Farms



Solar Photovoltaics

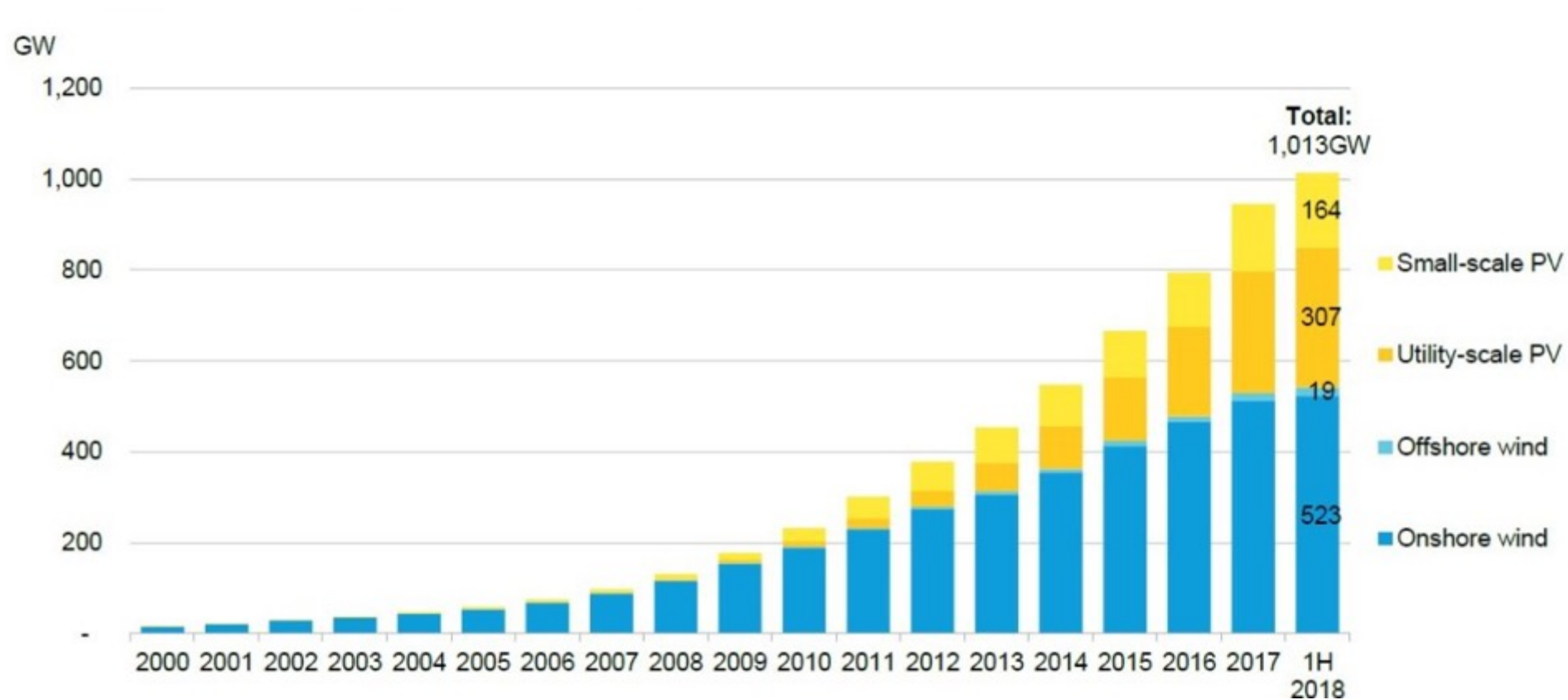
# 2020 Planned U.S. Capacity Additions (GW)



Source: U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory*

Planned US electric generating capacity additions 2020 U.S. ENERGY INFORMATION ADMINISTRATION

# Global Growth of Renewable Electricity

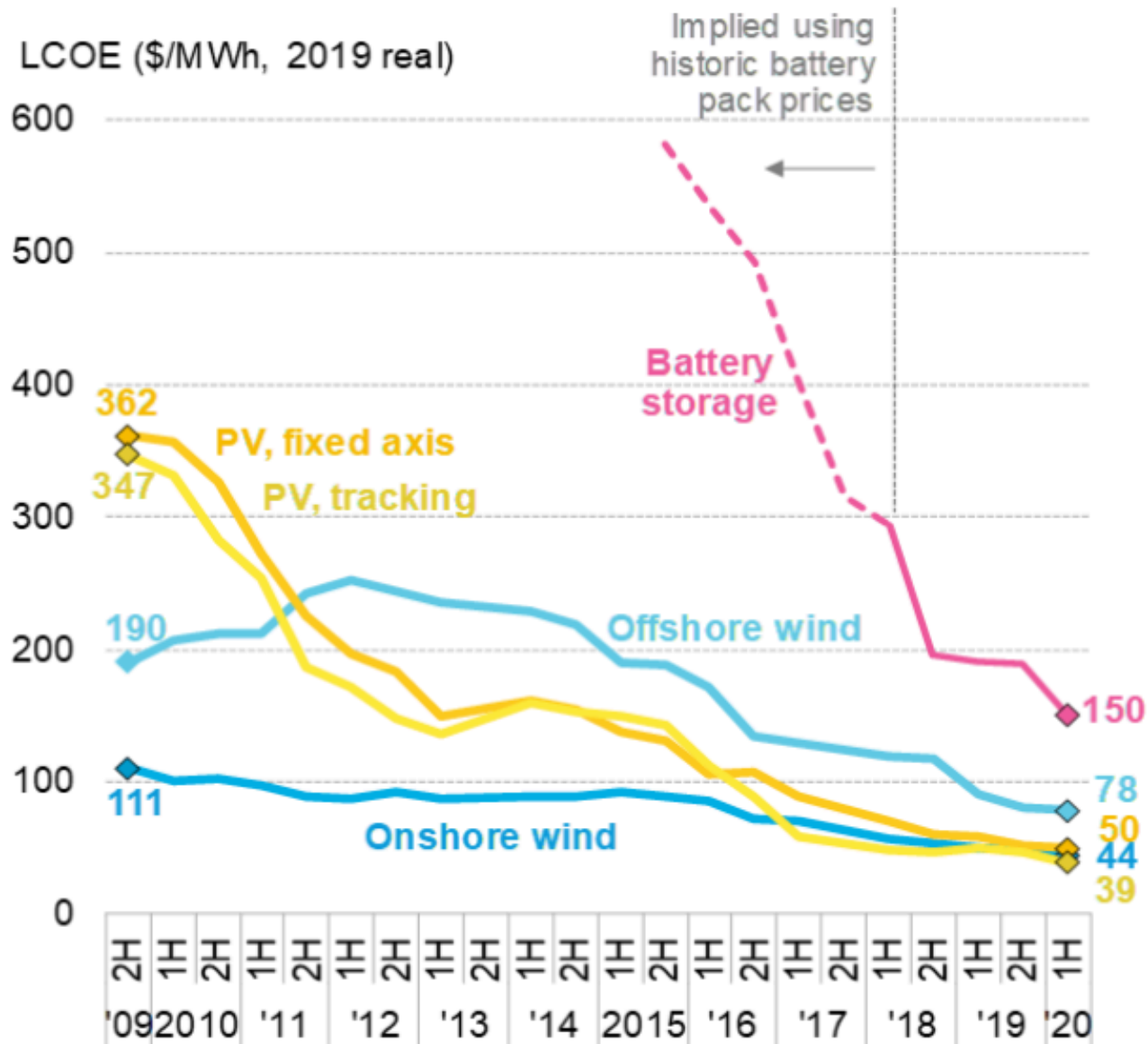


Source: Bloomberg NEF

Recent Xcel bids in CO for wind and solar with battery storage: 2-4 cents/kWh

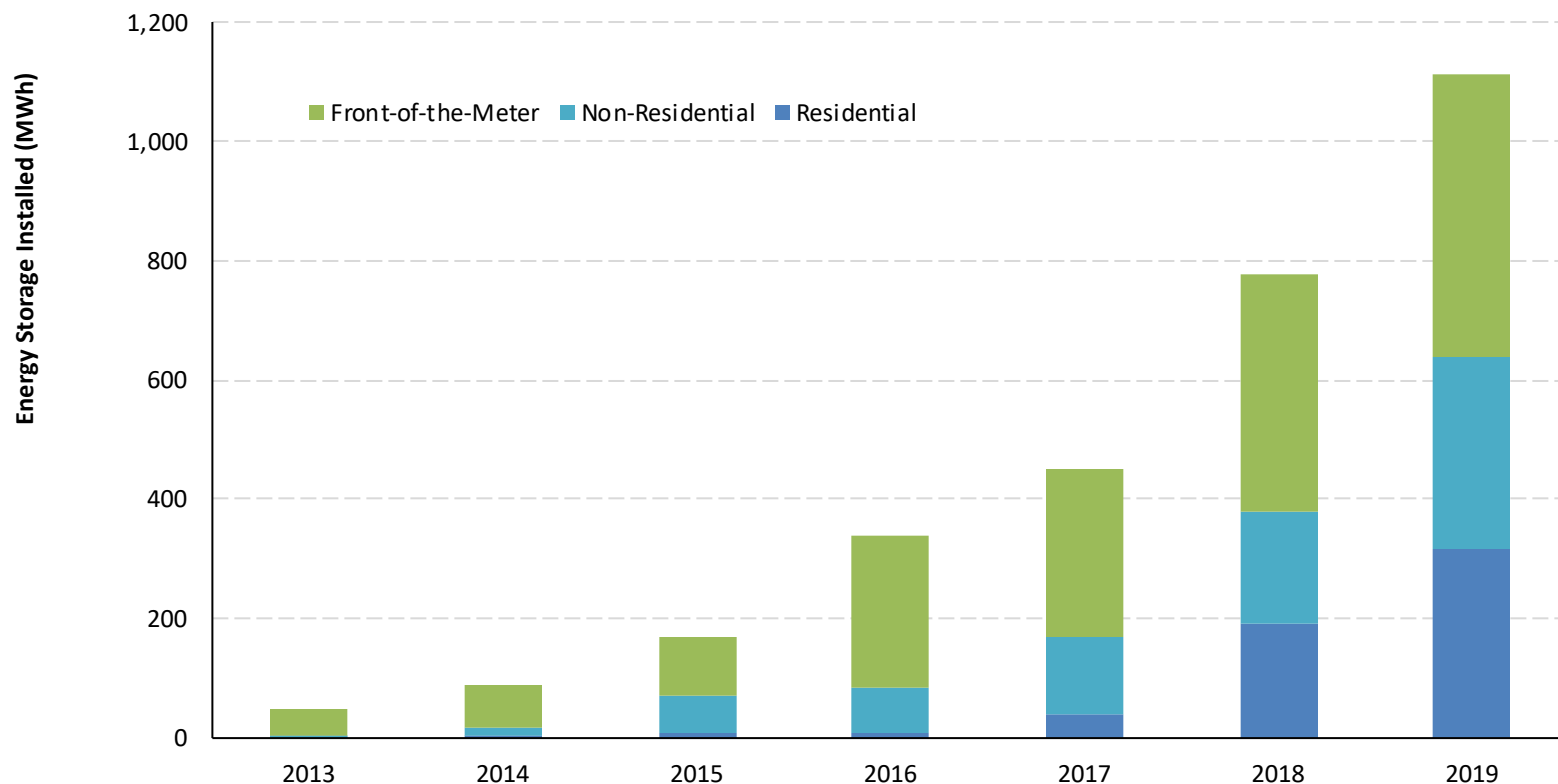


# Wind, Solar, Battery Costs



# Booming U.S. Energy Storage Market

U.S. Energy Storage Installations by Market Segment



# The Challenge: Integration of Variable RE

# Operational flexibility is required to help meet “residual load”

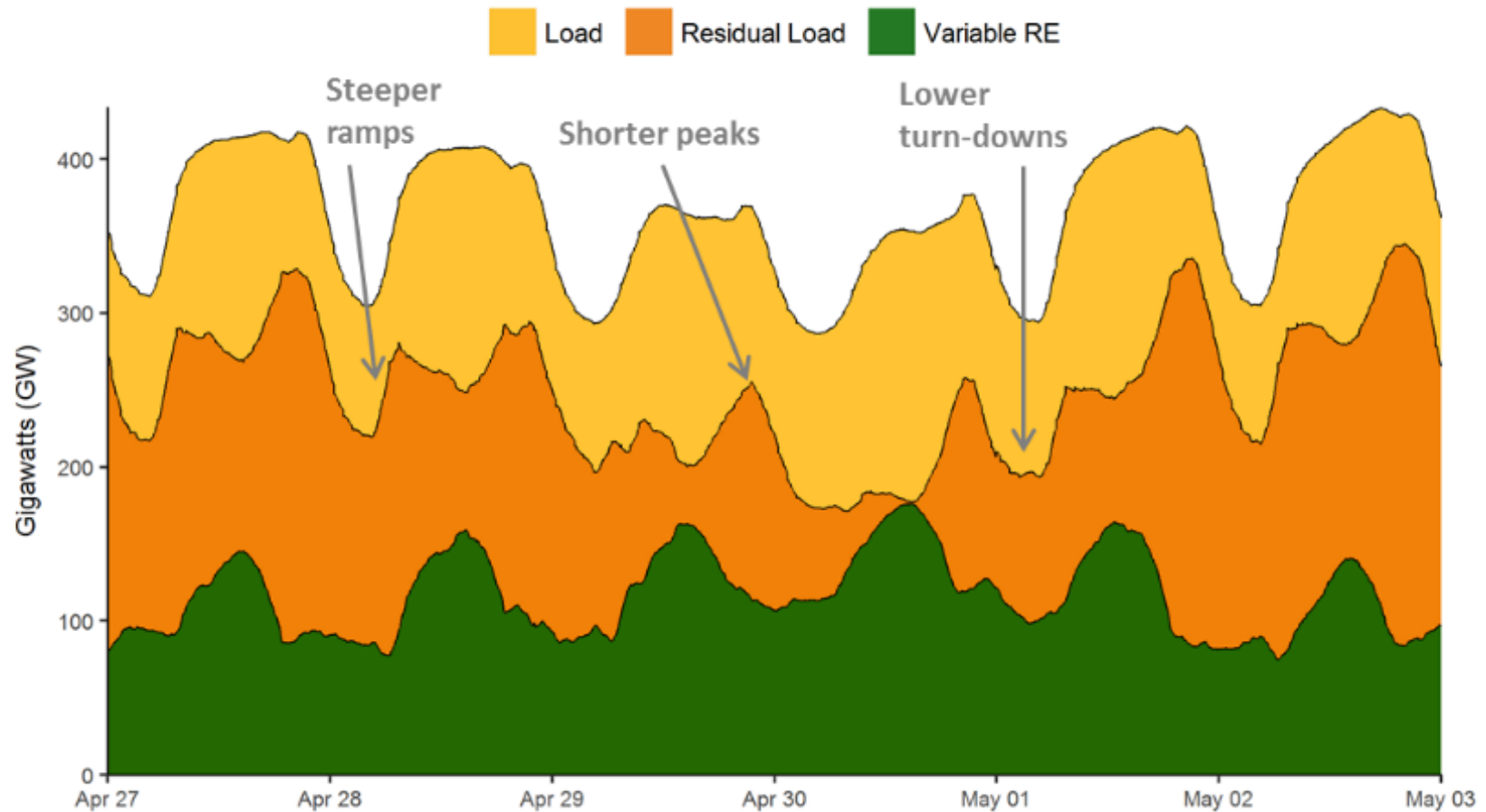
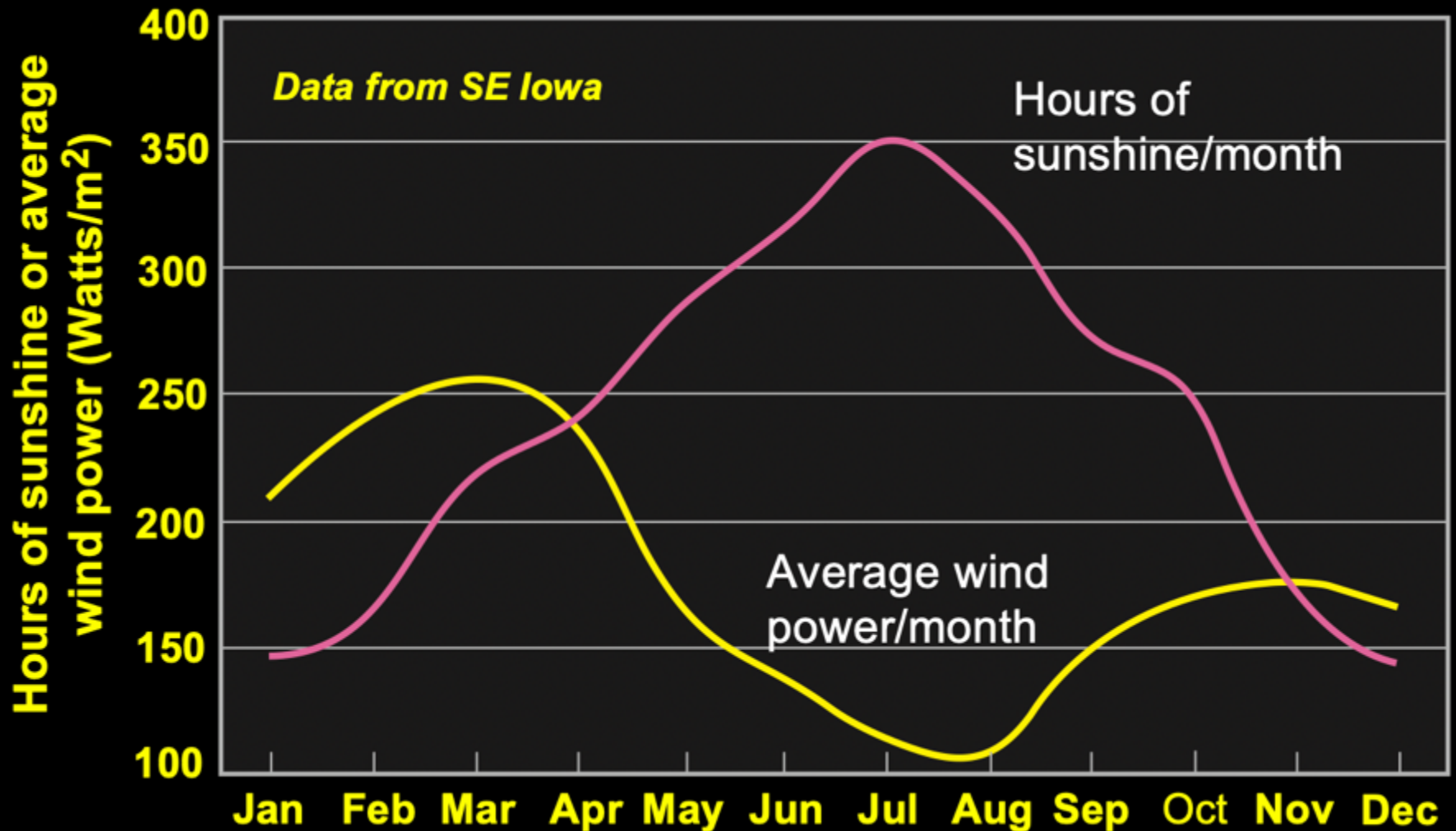


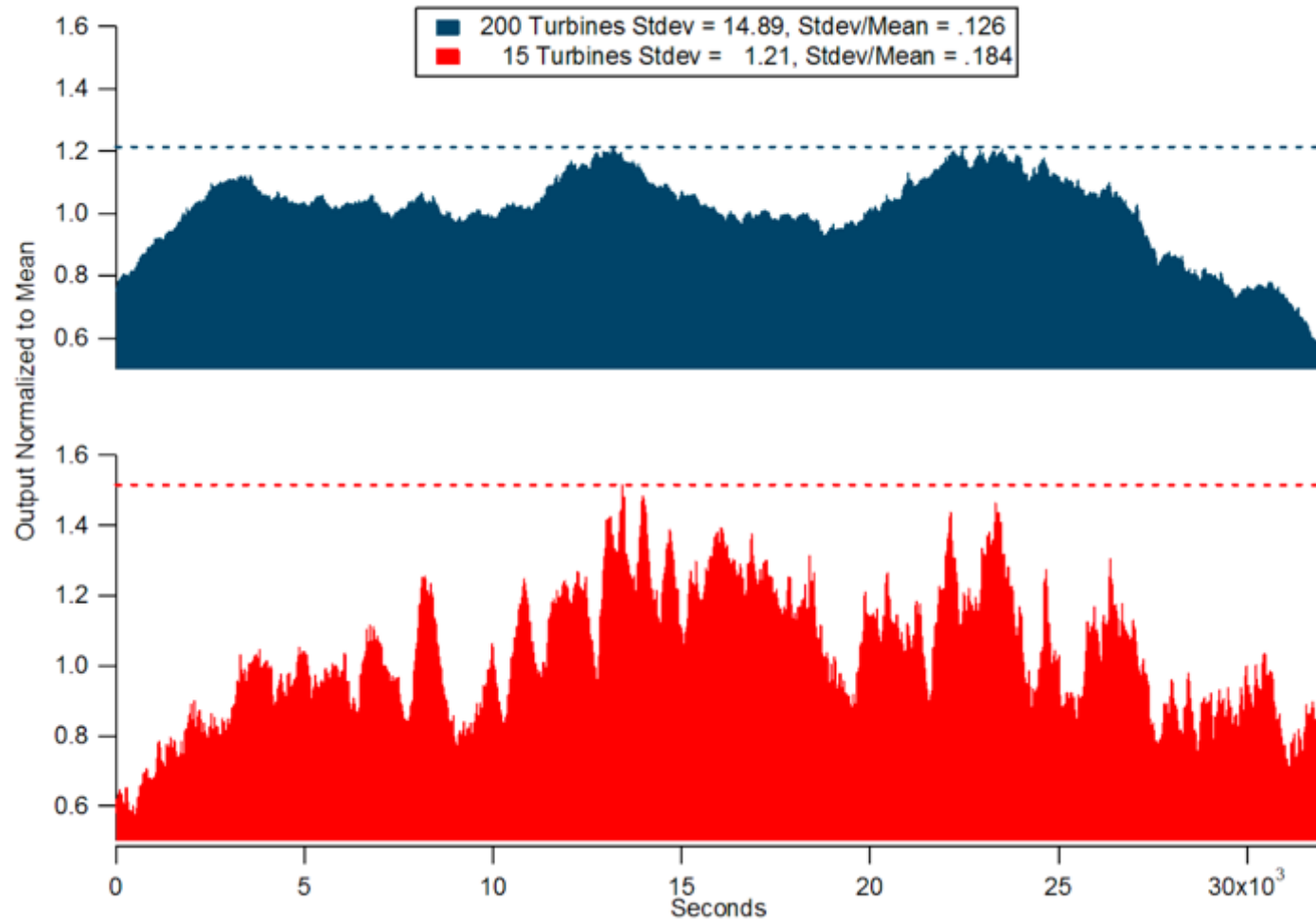
Figure source: NREL Report No. FS-6A20-63039

# Solar and Wind Are Complementary



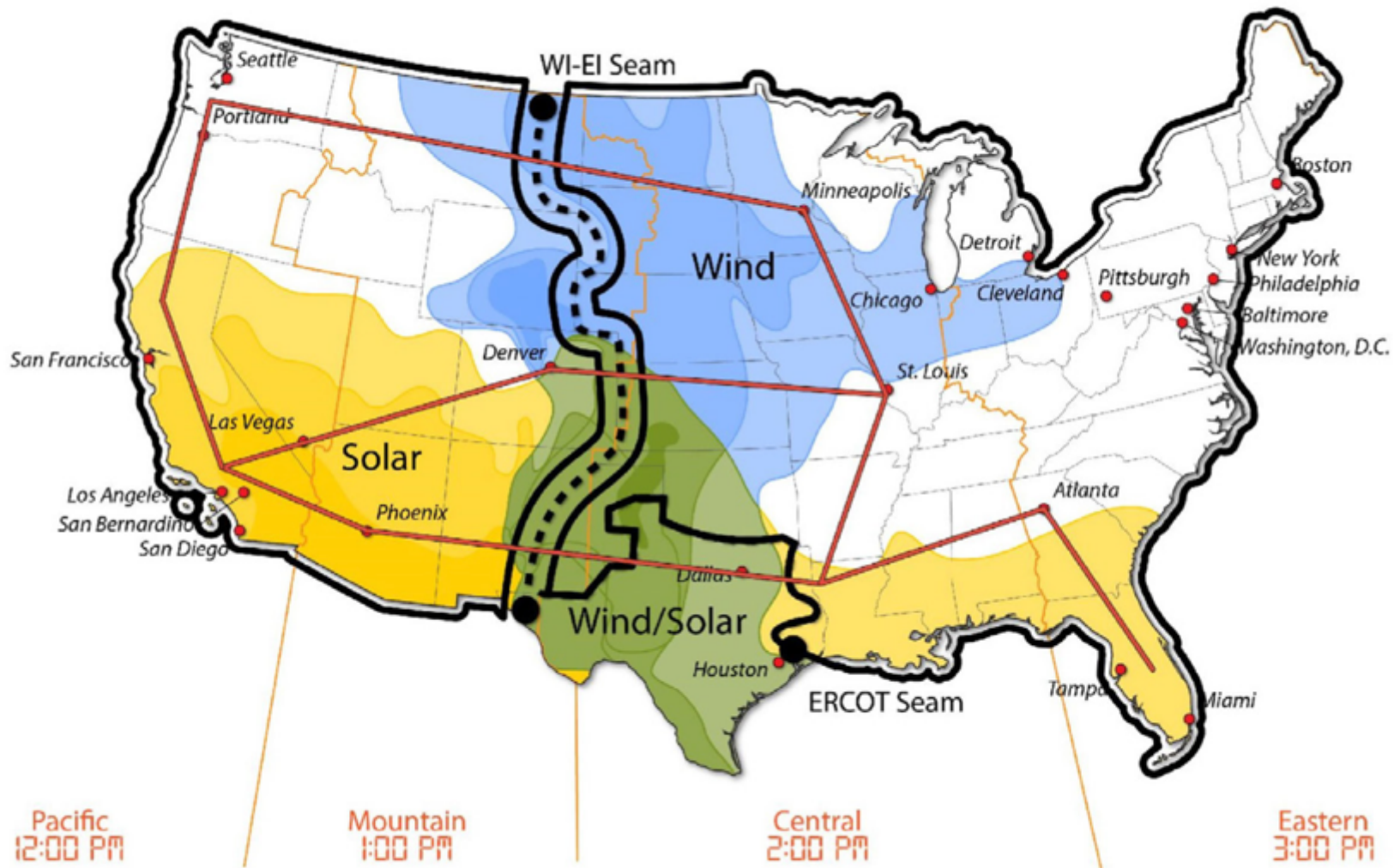


# Importance of Spatial Diversity: Wind

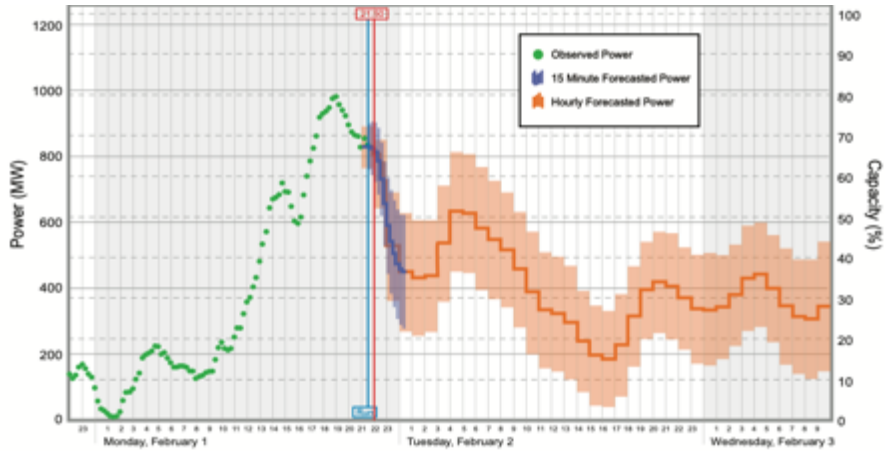


Source: Milligan, M. and B. Kirby, *Market Characteristics for Efficient Integration of Variable Generation in the Western Interconnection*, NREL/TP-550-48192, August 2010, <sup>67</sup>

# High Voltage DC Transmission Network



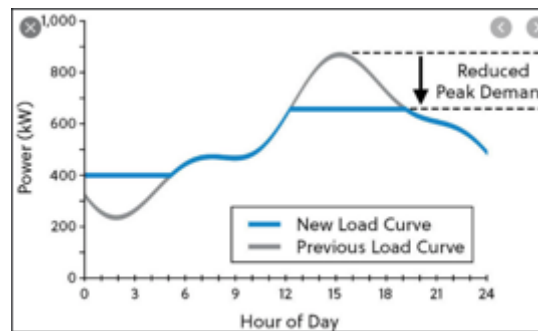
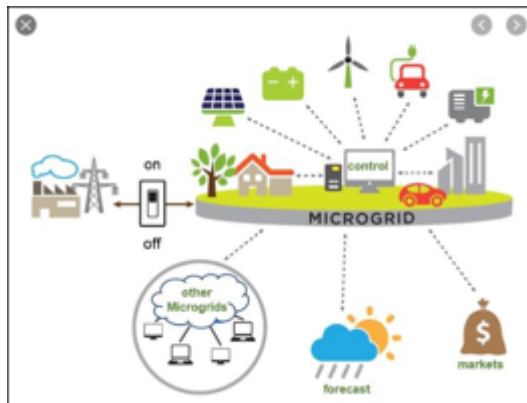
# Enabling Variable Renewable Energy



Advanced Wind/Solar Forecasting



Integrated Energy Storage



Demand Response



V1G and V2G EV Charging

Microgrids and Transactive Energy

# Rate Schedules that Support Clean Energy

## WEEKDAYS



## WEEKENDS



Source: CAISO

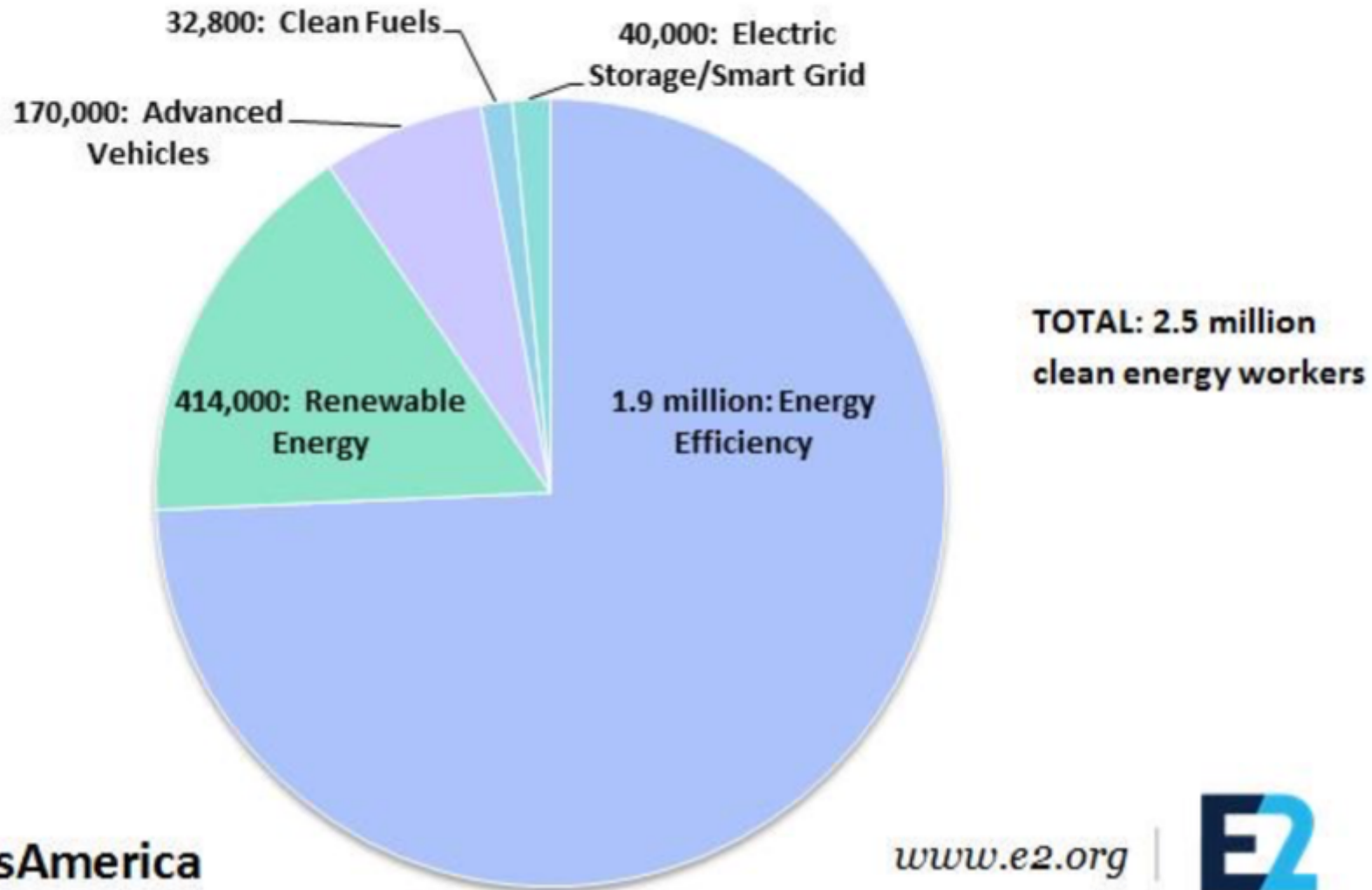
# Electric Power Measures

- Enact Clean Electricity Standard
  - Carbon free power: 55% by 2025, 75% by 2030, 90% by 2035 in line with recent UC-Berkeley study
  - Require that a carbon price and appropriate discount rate be used in planning all new generation
- Keep existing nuclear plants operating until they can be fully replaced by new low-cost RE + storage
- Fund green stimulus in EE, RE, EVs, and grid modernization
- Establish roadmap to dramatically reduce natural gas generation
- Fund zero-carbon RD&D priorities for electricity, including advanced storage



# Job Impacts of Clean Energy Transition

# Clean Energy Workers in America: Sector Breakdown



# Jobs in the Energy Transition

Direct and Indirect Jobs Created per \$10 million in spending

## Renewable technologies

(wind, solar, bioenergy,  
geothermal, hydro)



75 jobs

## Energy efficiency

(industrial energy efficiency,  
smart grid, mass transit)



77 jobs

## Fossil fuel

(oil and gas, coal)



27 jobs

Note: Does not include induced jobs.

# The Two Fastest-Growing U.S. Jobs



1. Solar PV installer  
Median salary: \$39,000

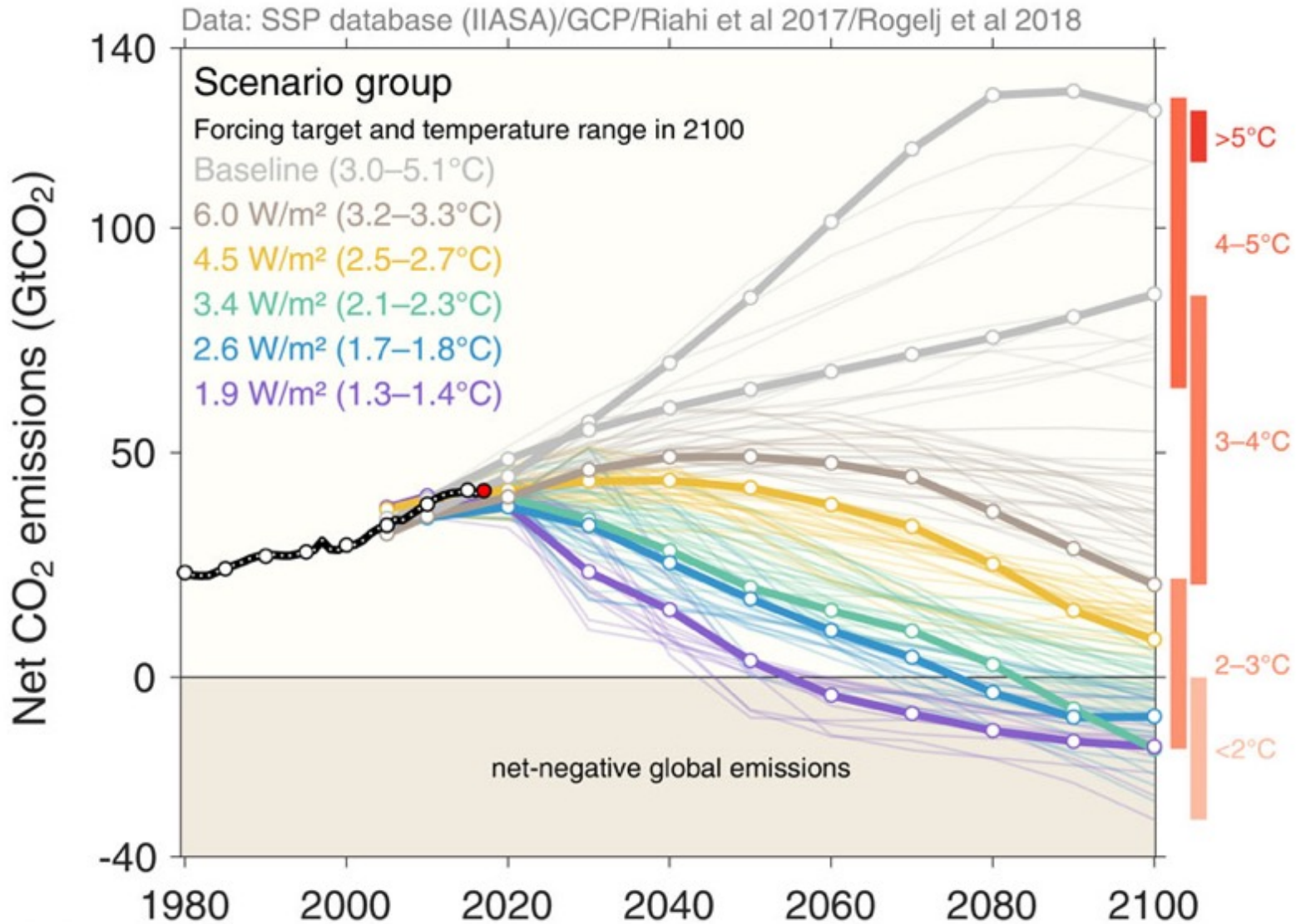


2. Wind turbine technician  
Median salary: \$54,000

Source: U.S. Bureau of Labor Statistics

## 5. Negative Emissions

# Negative Emissions Are Needed

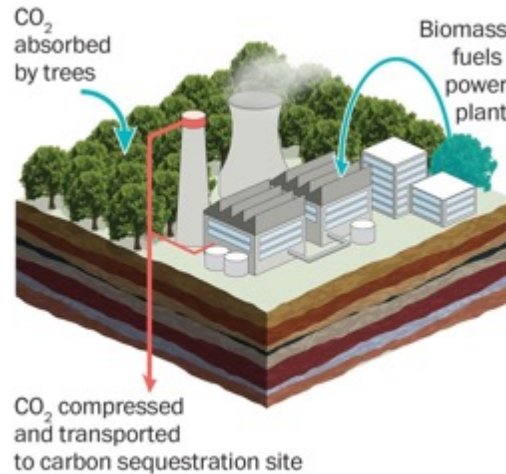




# Negative Emissions Technologies



Forest and soil stewardship



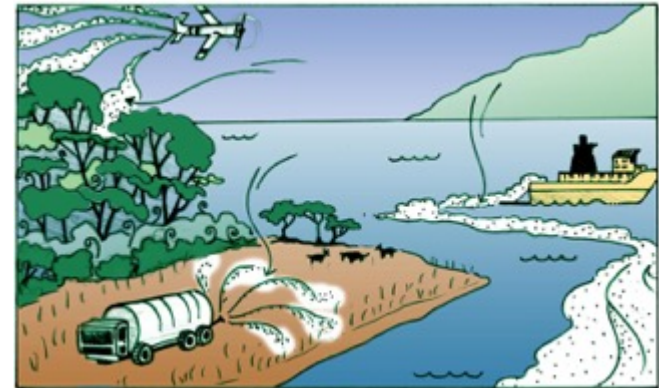
BECCS



Direct air capture

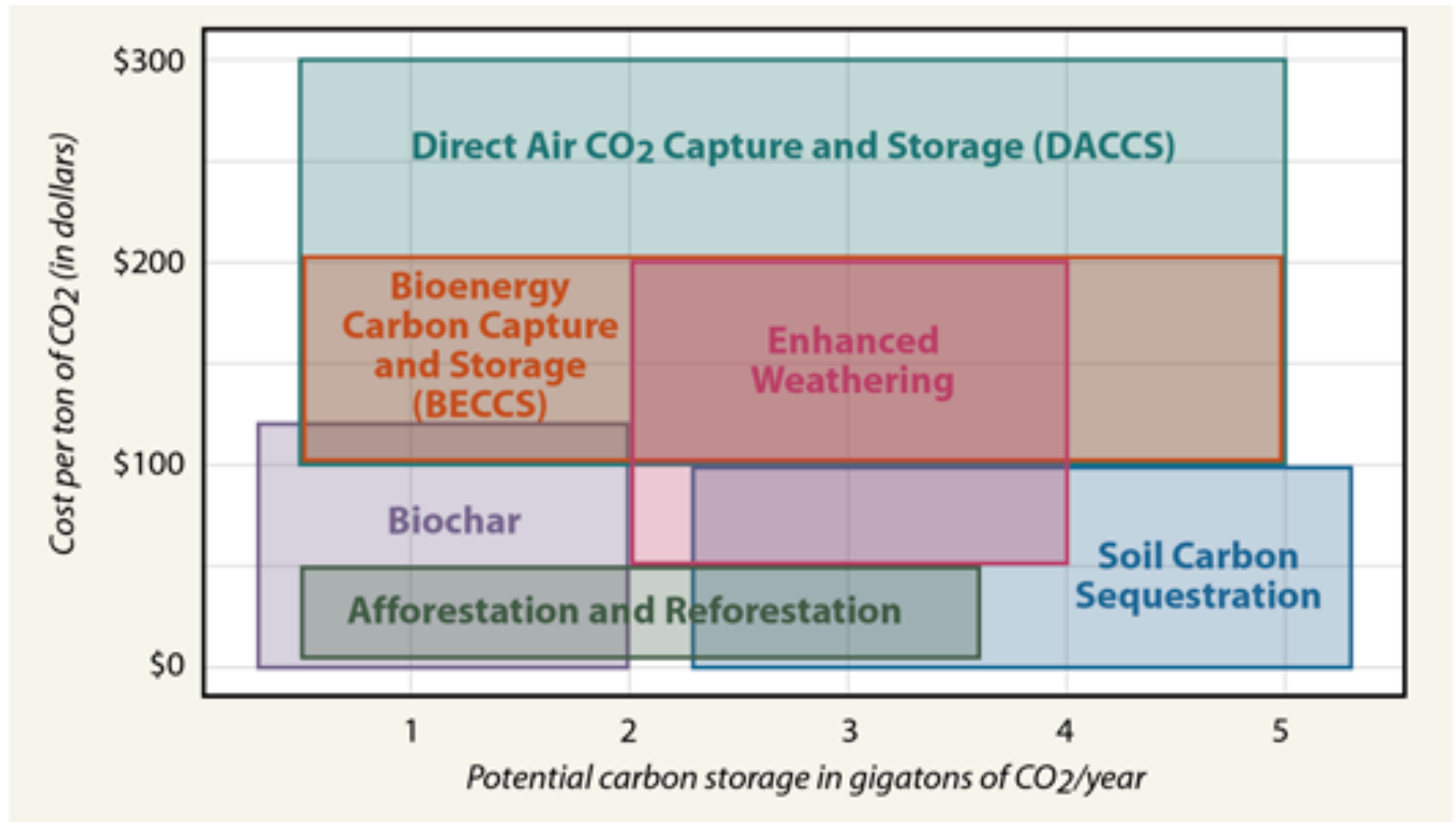


Biochar



Enhanced weathering

# Comparison of Different Negative Emissions Technologies



SOURCE: IPCC

InsideClimate News

# Negative Emissions Measures

- Reduce deforestation by finding palm oil substitutes and incentivizing biggest offenders
- Evaluate tree planting potential as function of location
- Develop & test best techniques for regenerative agriculture and improve productivity of perennial crops
- Conduct total systems analysis of net carbon reduction potential of BECCS as function of location
- Perform R&D to determine the long-term impact of biochar in different soil types and conduct market analysis
- Conduct field testing to determine the effectiveness and environmental impacts of different enhance weathering approaches
- Perform R&D on DACCS to reduce capital and operating costs; include ocean capture and innovative approaches

# Broader Measures

- Establish a 2050 economy-wide net zero carbon goal with intermediate goals every 5 yrs to ensure progress
- Phase out fossil fuel subsidies by 2025
- Continue to pursue carbon tax; develop a means to account for cost of carbon especially in the industrial sector
- Provide free EE and RE training for post-COVID workforce
- Establish a National Climate Bank to channel funds to regional green banks.



Chuck Kutscher, Ph.D., P.E.  
Fellow & Sr. Research Associate, RASEI, CU-Boulder  
[chuck.kutscher@gmail.com](mailto:chuck.kutscher@gmail.com)  
Twitter: @ChuckKutscher