

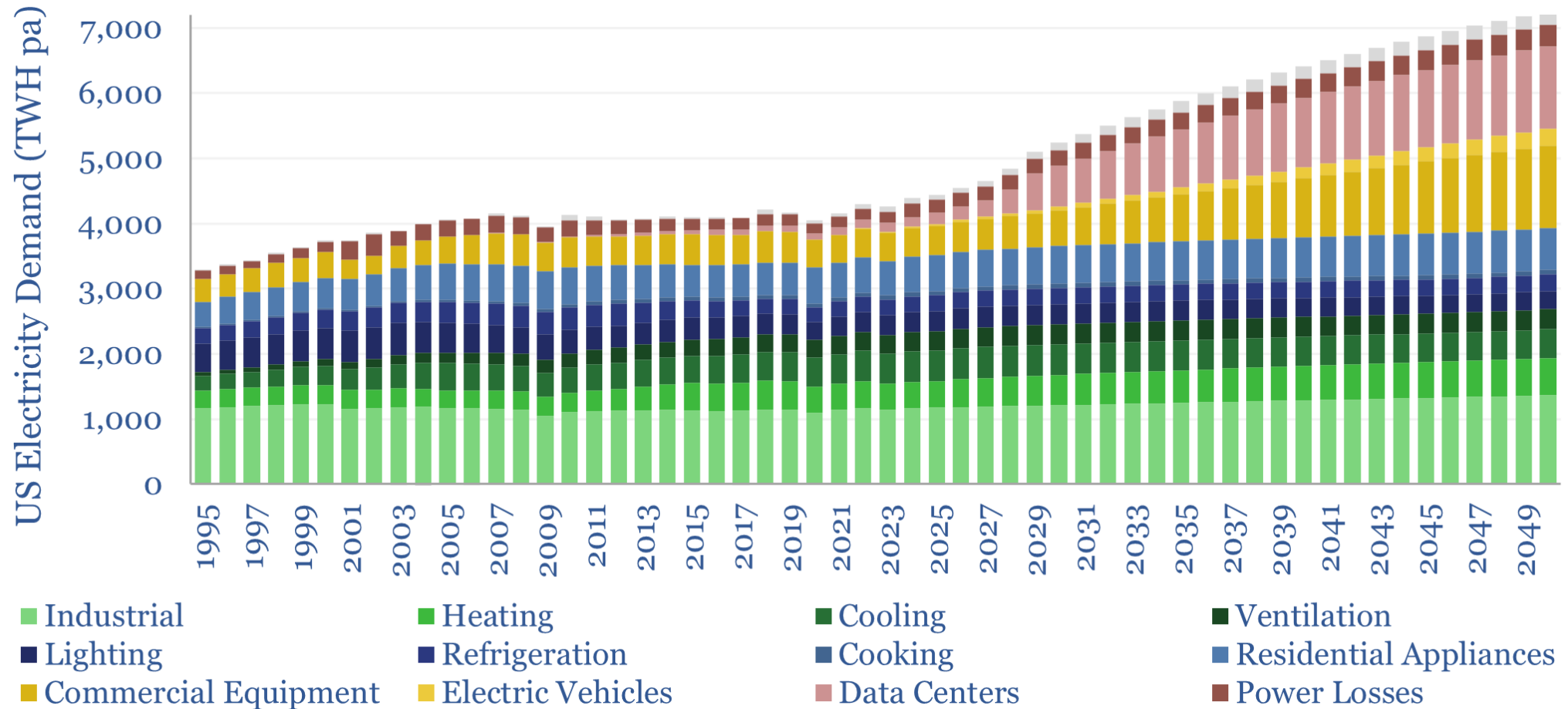
# Environmental and Economic Impacts of Large Load Interconnection

Dr. Will McNeil

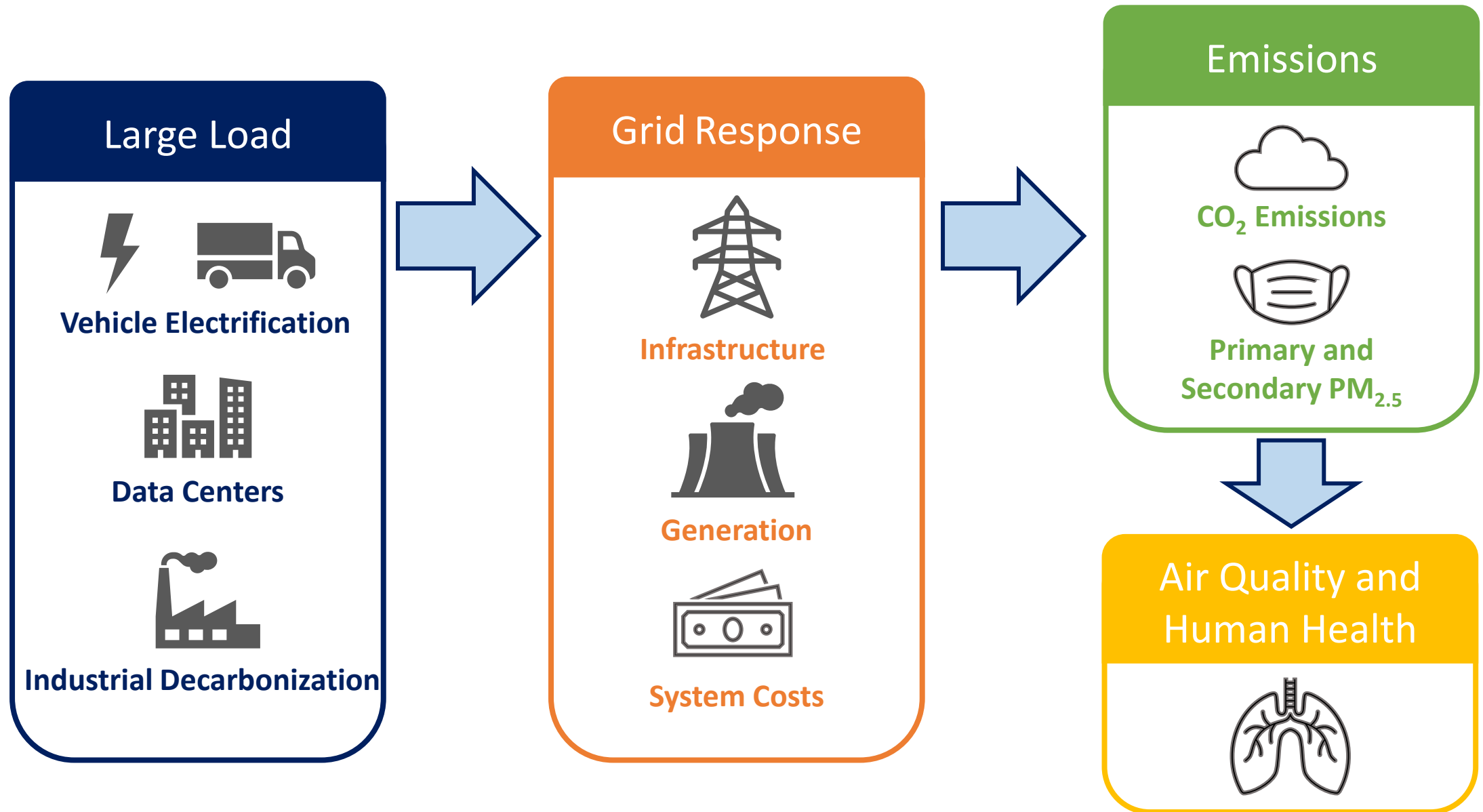
Stanford Energy Postdoctoral Fellow



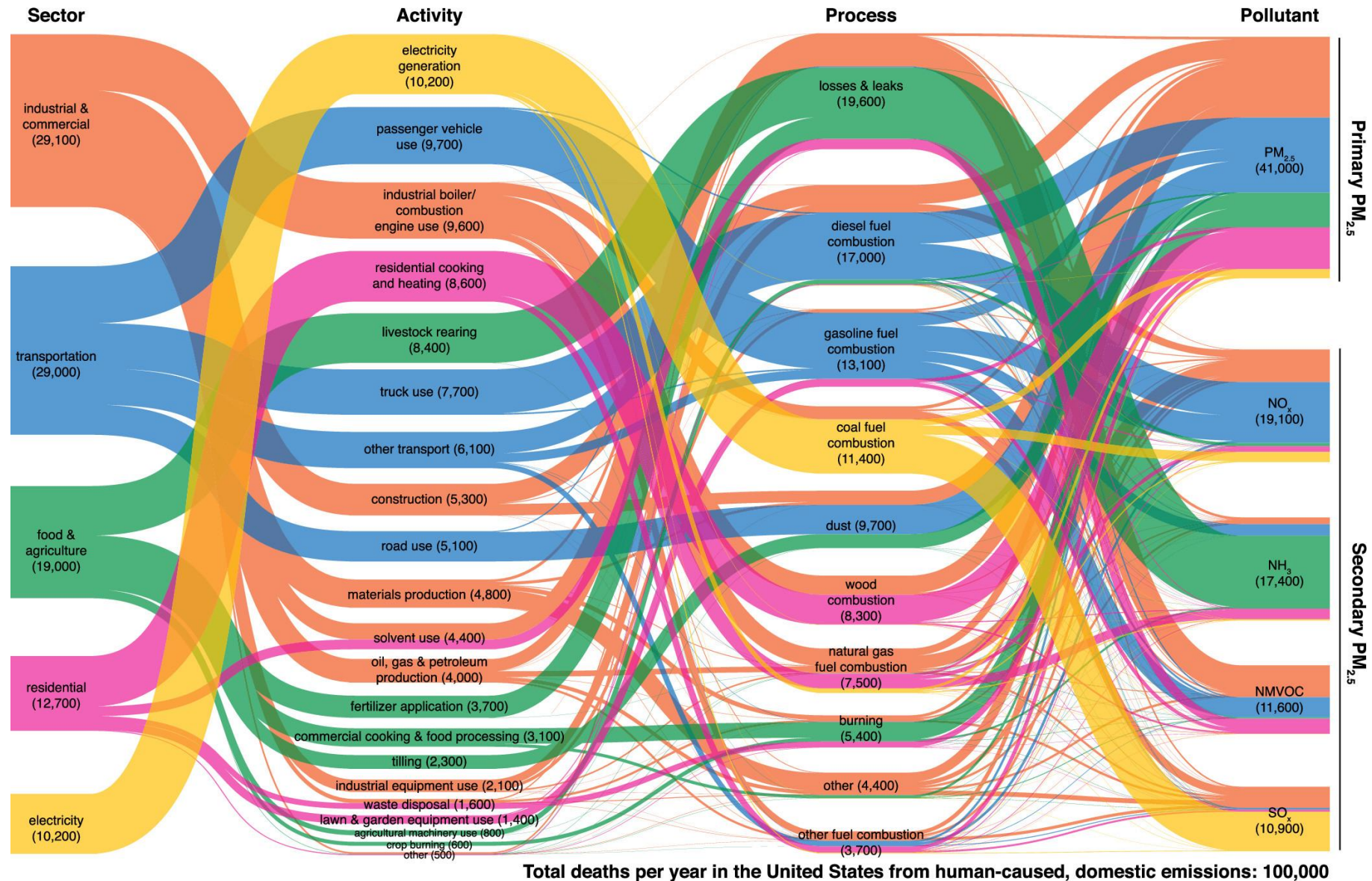
# Electricity demand is growing again after years of stagnation



# Large load interconnection has cascading impacts

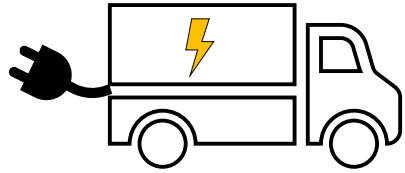


# Annual air pollution-related premature mortality in the U.S.



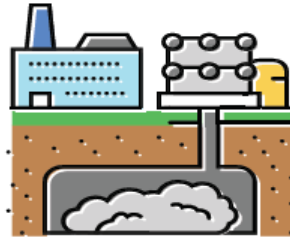
# Three case studies of large load interconnection

## Heavy-Duty Truck Electrification



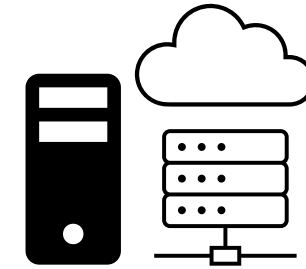
- **Air quality / human health impacts**
  - Diesel vs. electric trucks
- **GHG emissions**
- **Environmental justice**
- **Infrastructure**
  - Battery-electric vs. fuel cell trucks

## Post-Combustion CCS Retrofits



- **Parasitic load**
- **Air Quality tradeoffs**
  - Pretreatment
  - Solvent degradation
- **Human health impacts**
- **Maximum potential**

## Data Centers

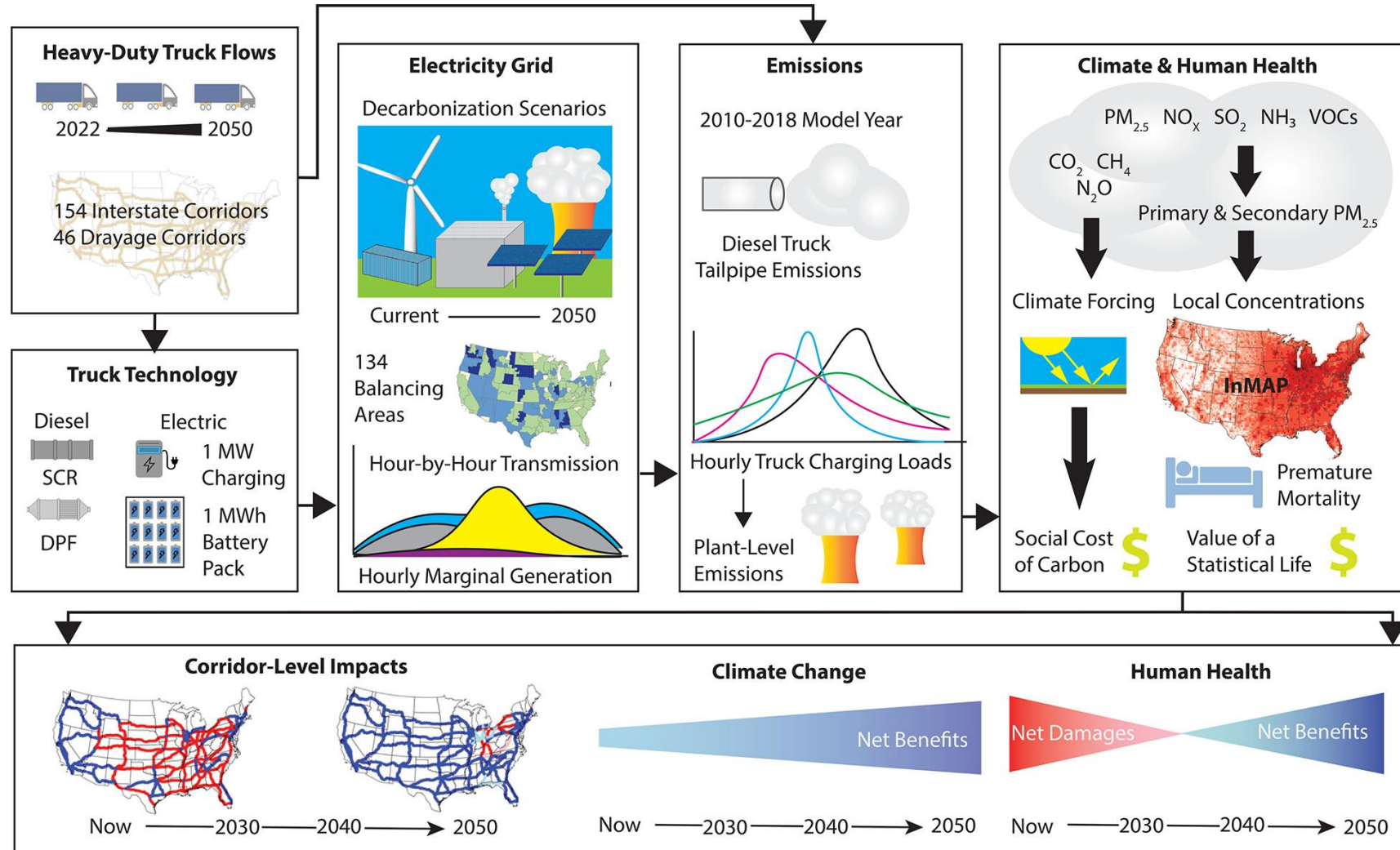


- **Behind-the-Meter vs. Grid Supply**
  - Geographic variation
  - Energy cost
  - Emissions
- **Systemwide impacts of cumulative load**

# Part 1: Heavy-Duty Truck Electrification



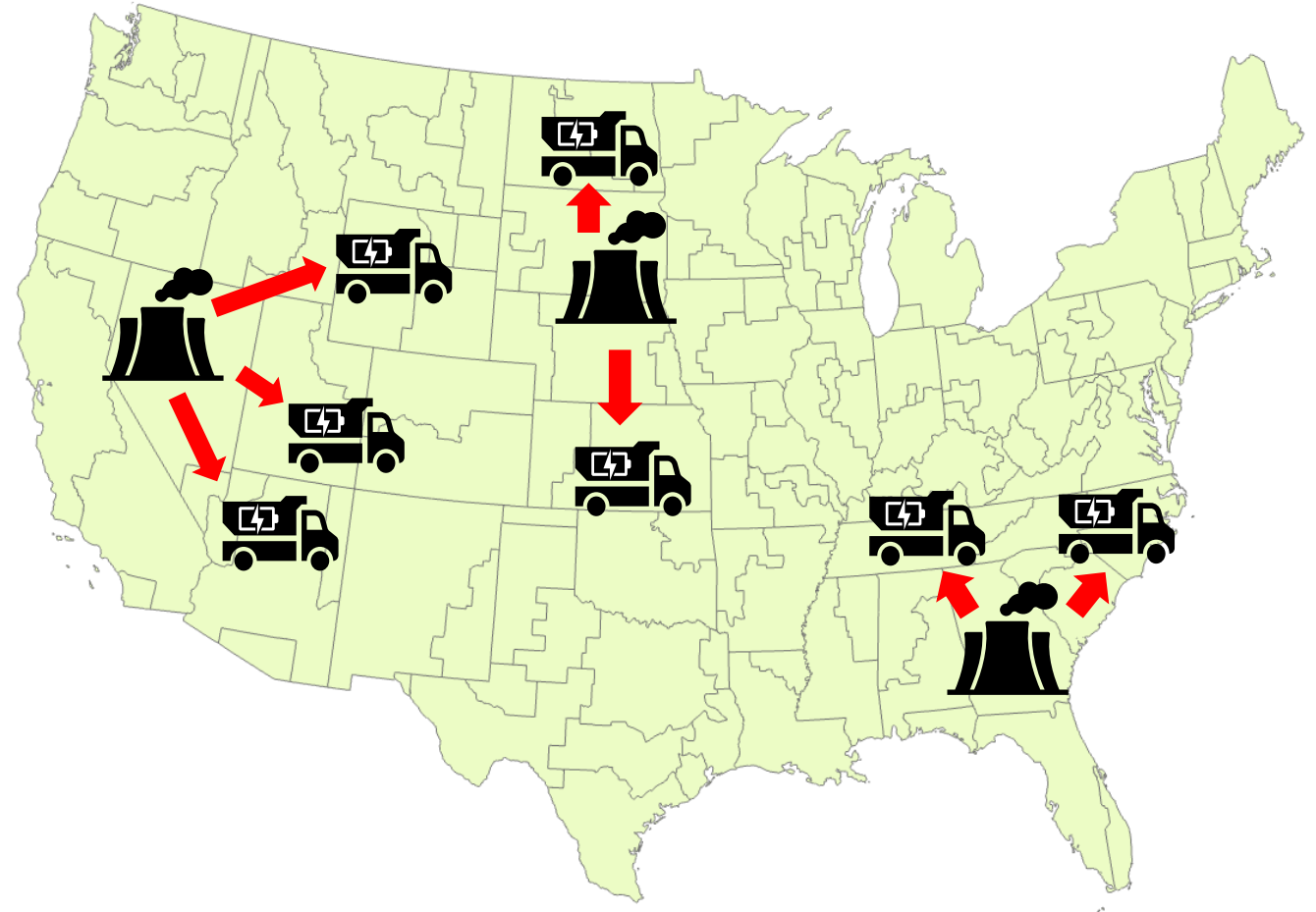
# Framework for estimating health and climate impacts of truck electrification



# Marginal Grid Emissions

## McGrid Model

- Predicts power flow at an hourly resolution
- Assigns marginal load to specific power plants
- Able to run multiple grid decarbonization scenarios through 2050
- Outputs include plant-level air pollutant and greenhouse gas emissions from load increases



# Truck electrification results in health benefits by 2040

Scenario:  
Low Renewable  
Energy Cost

Current

2030


2040

2050


Before the  
Inflation  
Reduction  
Act



Premature Mortality Impacts of Electric Trucks Relative to Diesel

 New Net Cost

 Remains Net Benefit

 Remains Net Cost

 New Net Benefit

(McNeil, Tong, Harley,  
Auffhammer, Scown;  
*ES&T*; 2024)

# Inflation Reduction Act accelerates truck electrification benefits

Scenario:  
Low Renewable  
Energy Cost

Current

2030

2040

2050


Before the  
Inflation  
Reduction  
Act



After the  
Inflation  
Reduction  
Act



Premature Mortality Impacts of Electric Trucks Relative to Diesel

 New Net Cost

 Remains Net Benefit

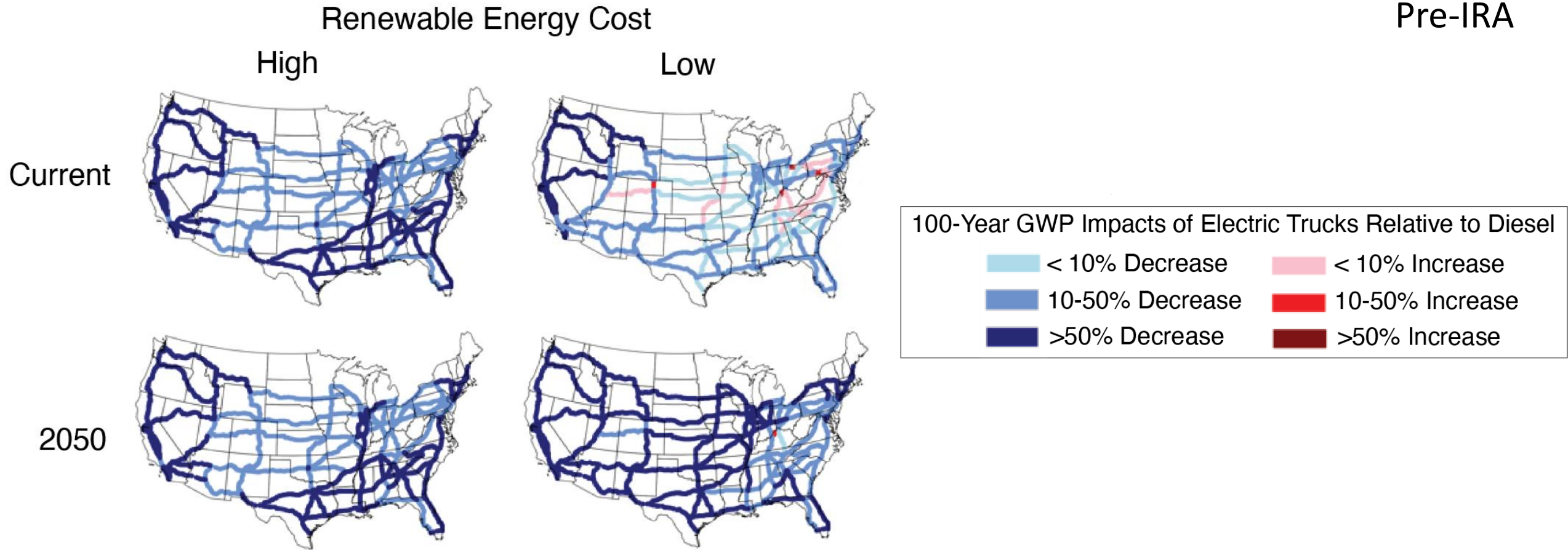
 Remains Net Cost

 New Net Benefit

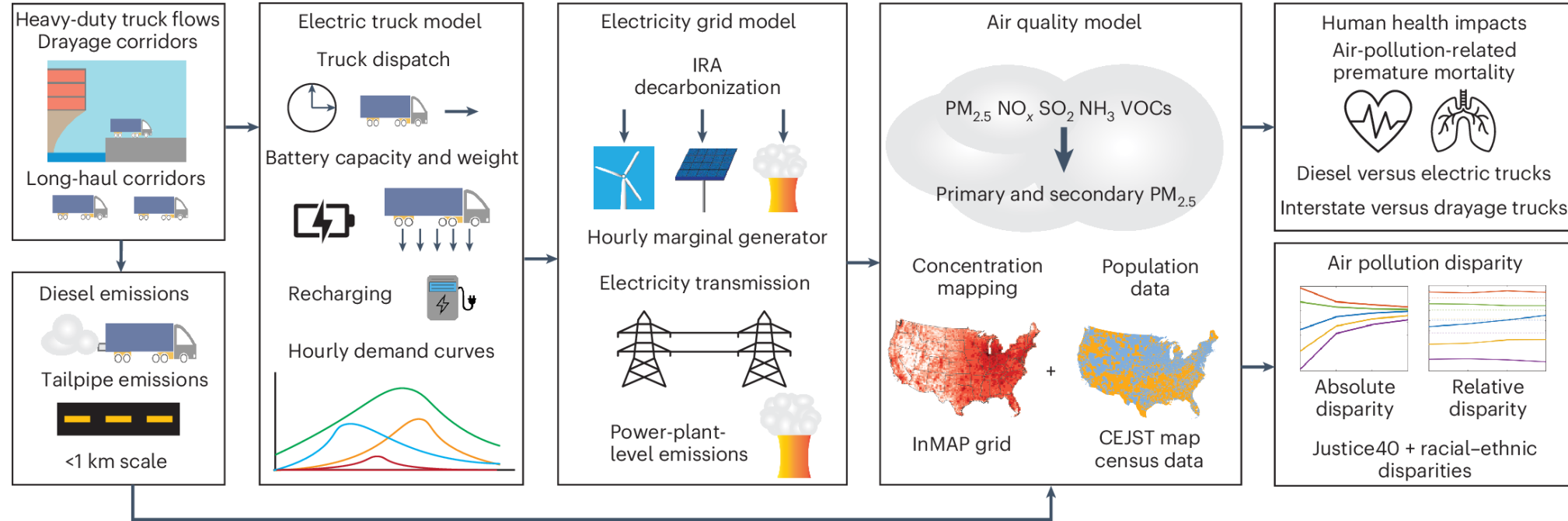
(McNeil, Tong, Harley,  
Auffhammer, Scown;  
*ES&T*; 2024)

# Widespread GHG emission benefits from truck electrification

Scenario:  
Pre-IRA



# Framework for estimating health, climate, and equity impacts of truck electrification



Justice40 Initiative: 40% of the benefits of Federal investments (e.g., clean energy, clean transit) should go to disadvantaged communities

# Electrification benefits health, but few corridors meet equity goals




Current

2030

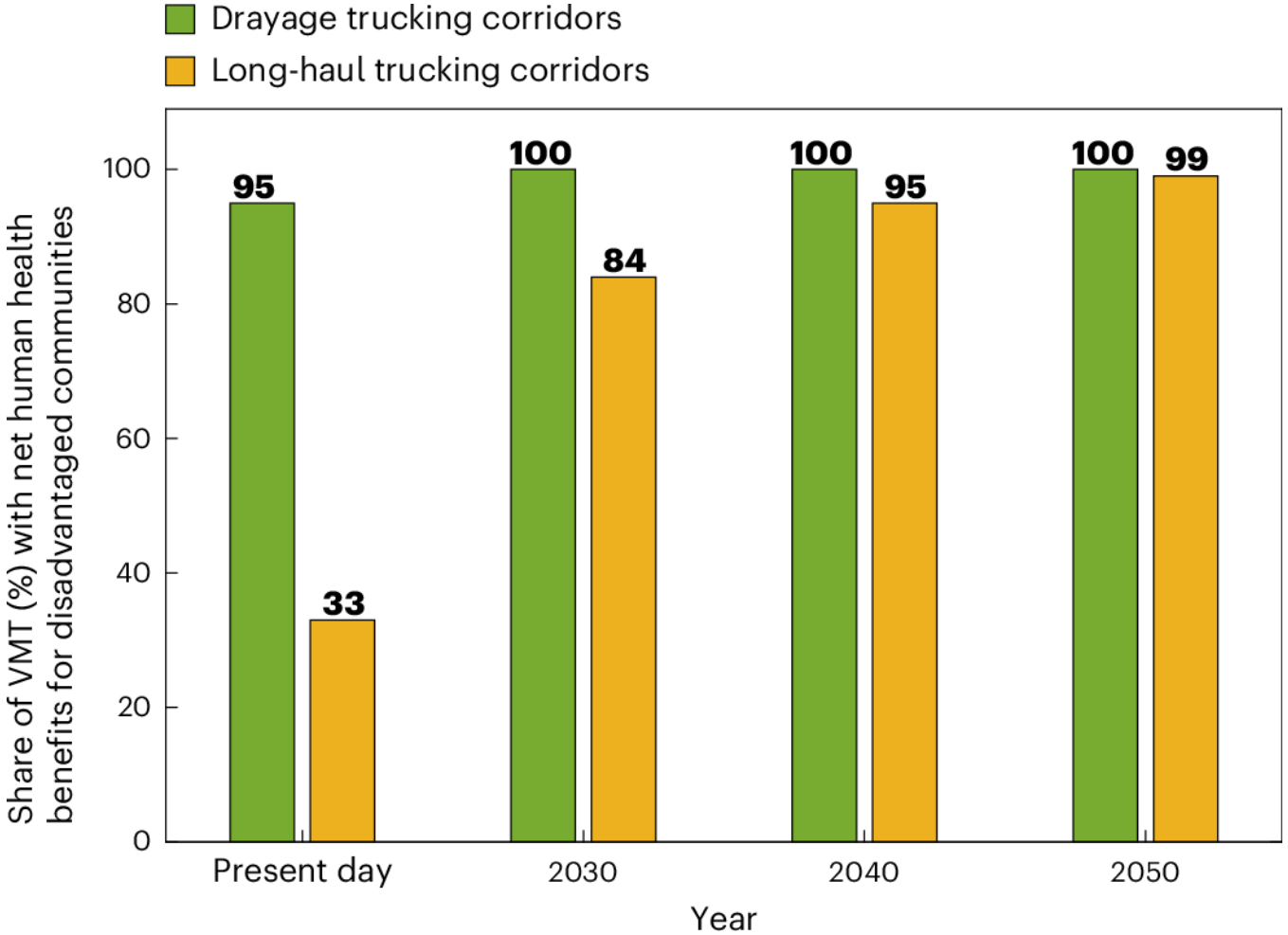
2040

2050



-  Truck Electrification Increases Mortality in Disadvantaged Communities
-  Truck Electrification Reduces Mortality in Disadvantaged Communities
-  Truck Electrification Reduces Mortality in Disadvantaged Communities + Meets Justice40 Goals

# Electrifying drayage (short-haul, intermodal) freight trucks results in relatively greater near-term health and equity benefits



(McNeil, Porzio, Tong, Harley, Auffhammer, Scown; *Nature Sustainability*; 2025)

# Battery versus hydrogen trucks

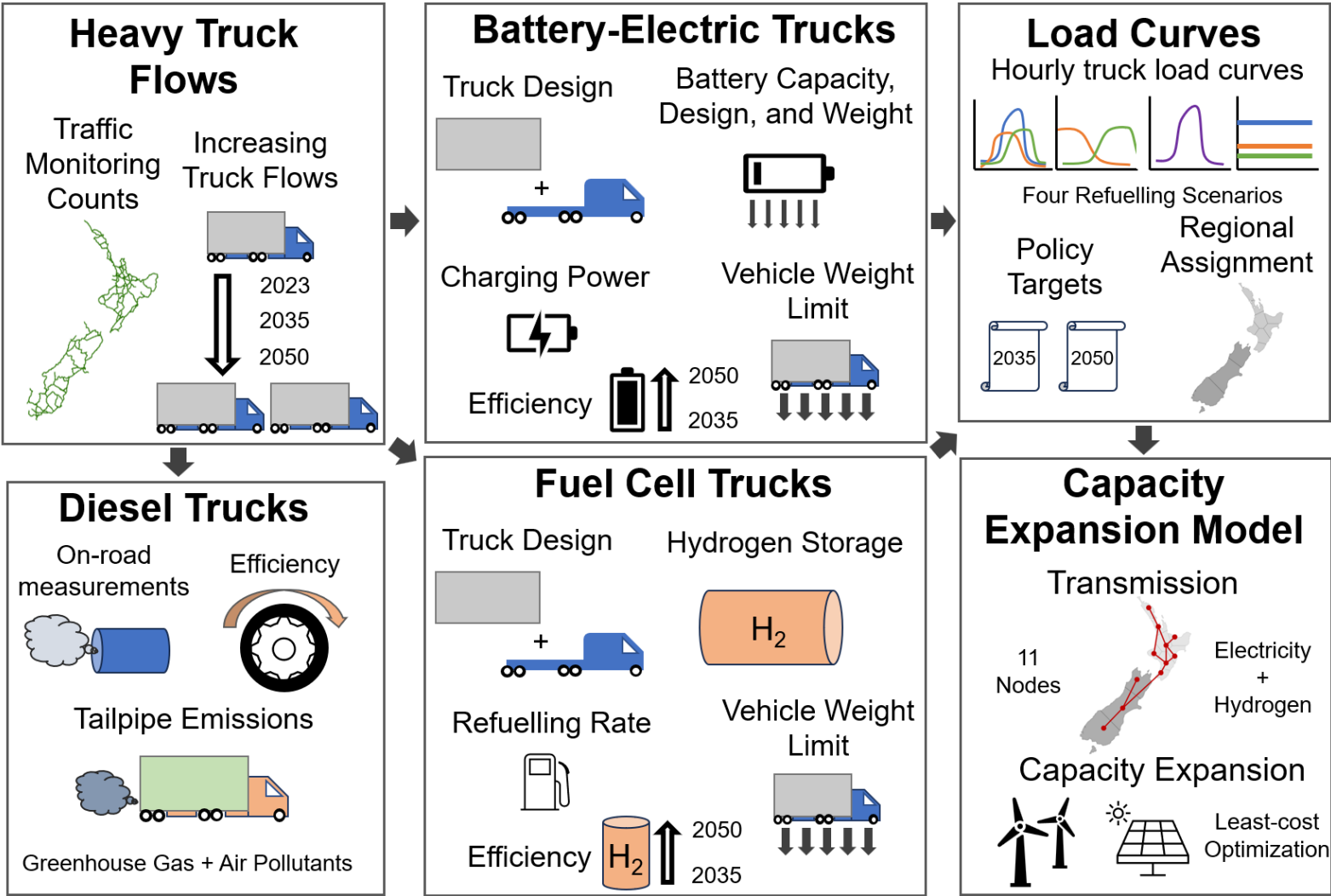
## Battery-electric truck



## Hydrogen fuel cell truck



# Energy demand and grid infrastructure requirements of battery vs. hydrogen trucks in New Zealand



(McNeil, Canessa, Scown, Haas, Peer; *Transport Policy*; 2026)

# Freight in New Zealand

- Trucking is responsible for 93% of freight by tonnage
- Trucking emissions
  - 6% of vehicle kilometers travelled
  - 25% of on-road CO<sub>2</sub> emissions
- No air pollution control technology
- Average age of truck fleet = 18 years
- Transport responsible for:
  - 2,200 air pollution-related premature deaths annually (7.5% of all mortality)
  - Diesel vehicles responsible for 82% of damages



# Truck electrification in New Zealand

- New Zealand freight emissions reduction targets:
  - 35% by 2035
  - Net-zero by 2050
- How to decarbonize heavy trucks
  - Battery-electric trucks
  - Hydrogen fuel cell trucks
- Longest freight route in NZ
  - Nelson to Dunedin (750 km)
  - Auckland to Wellington (650 km)
  - Current battery-electric truck range (~800 km)



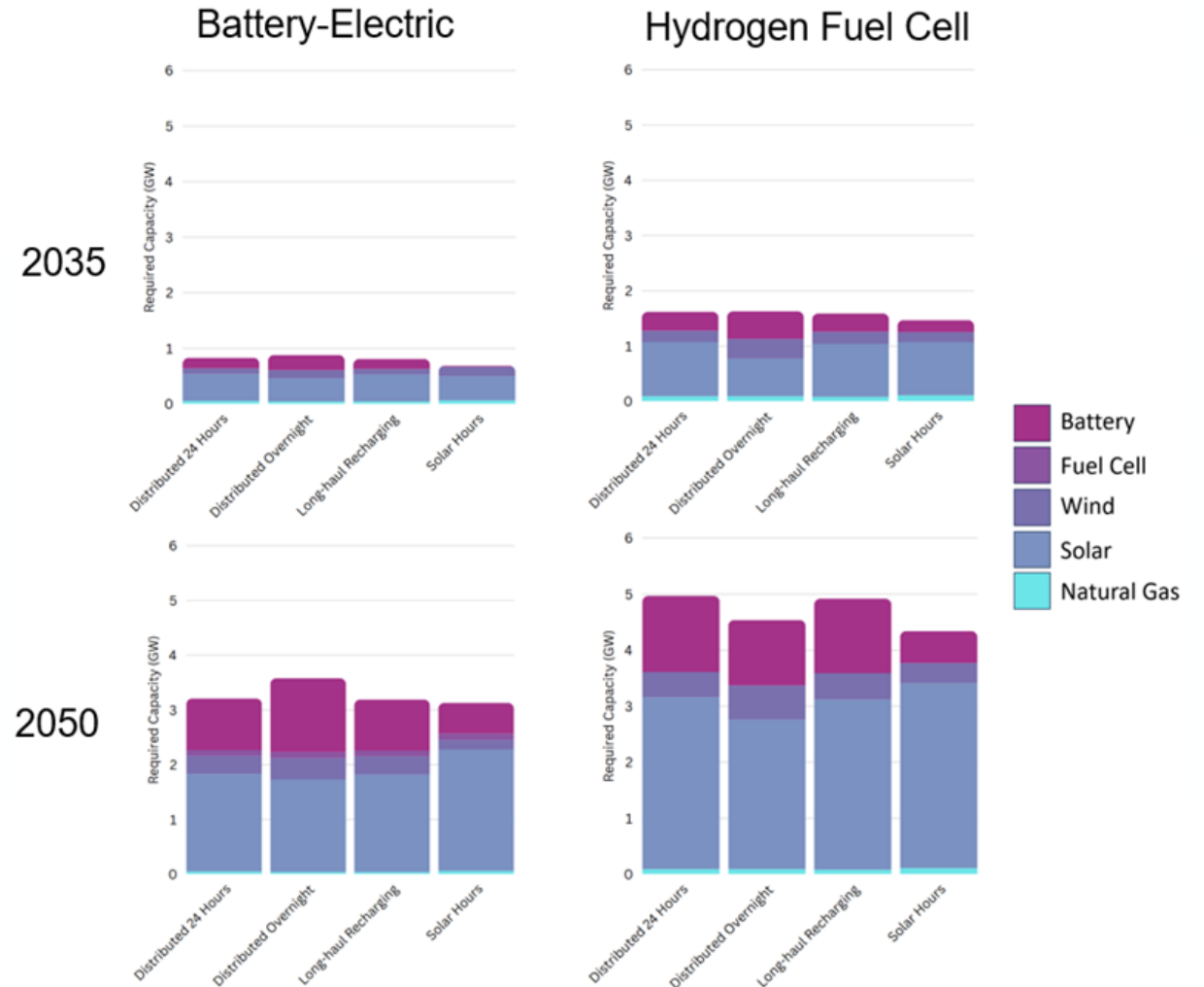
# Truck electrification requires significant energy and grid upgrades

## Generation (Current: 43 TWh)

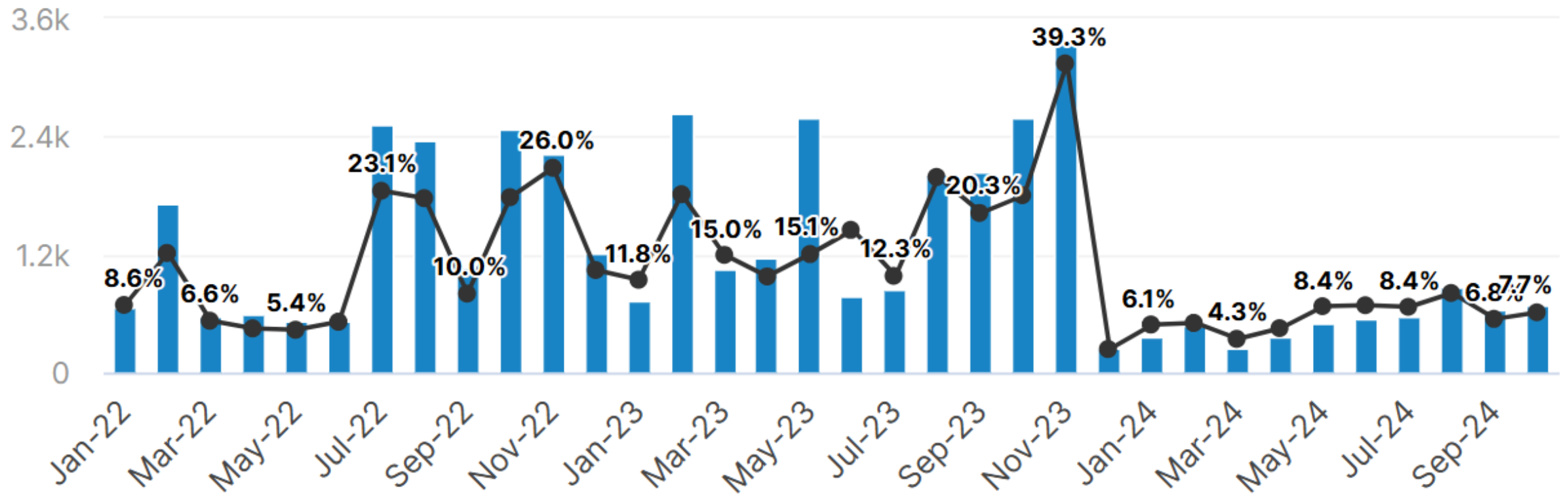
- Battery-electric trucks: 3 TWh (7% of current generation)
- Fuel cell trucks: 6 TWh (14% of current generation)

## Capacity (Current: 10 GW)

- Battery-electric trucks: ~3 GW (mostly solar)
- Fuel cell trucks: ~4-5 GW



# Electric vehicle market share in New Zealand

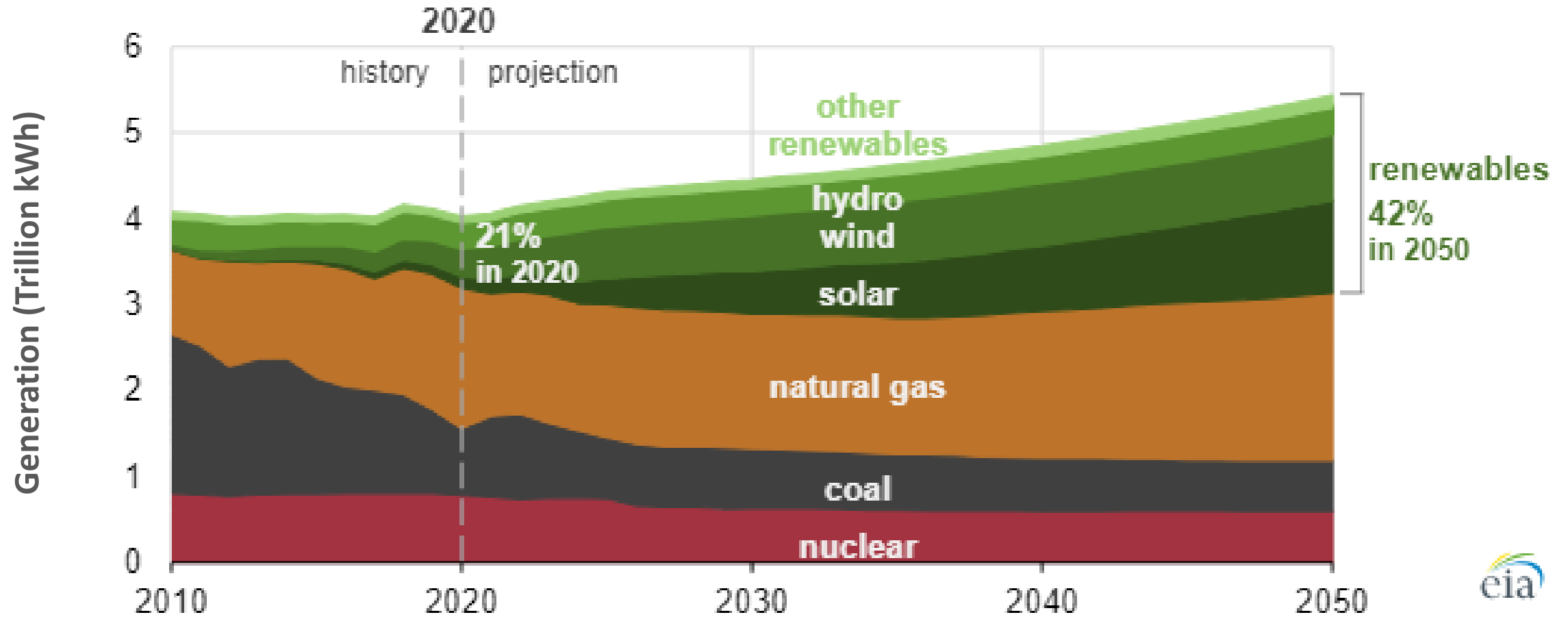


Source: Ministry of Transport / evdb.nz

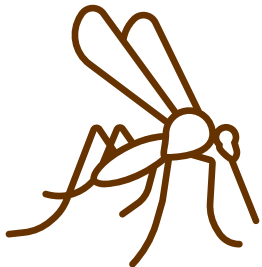
# Part 2: Human Health Effects of Post-Combustion Carbon Capture and Storage



# 60% of U.S. electricity still comes from fossil fuels



# Competing processes

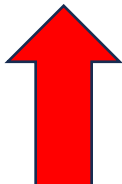


**Parasitic Load**

**Energy**



**Emissions**



**Solvent  
Degradation**

**NH<sub>3</sub> Emissions**

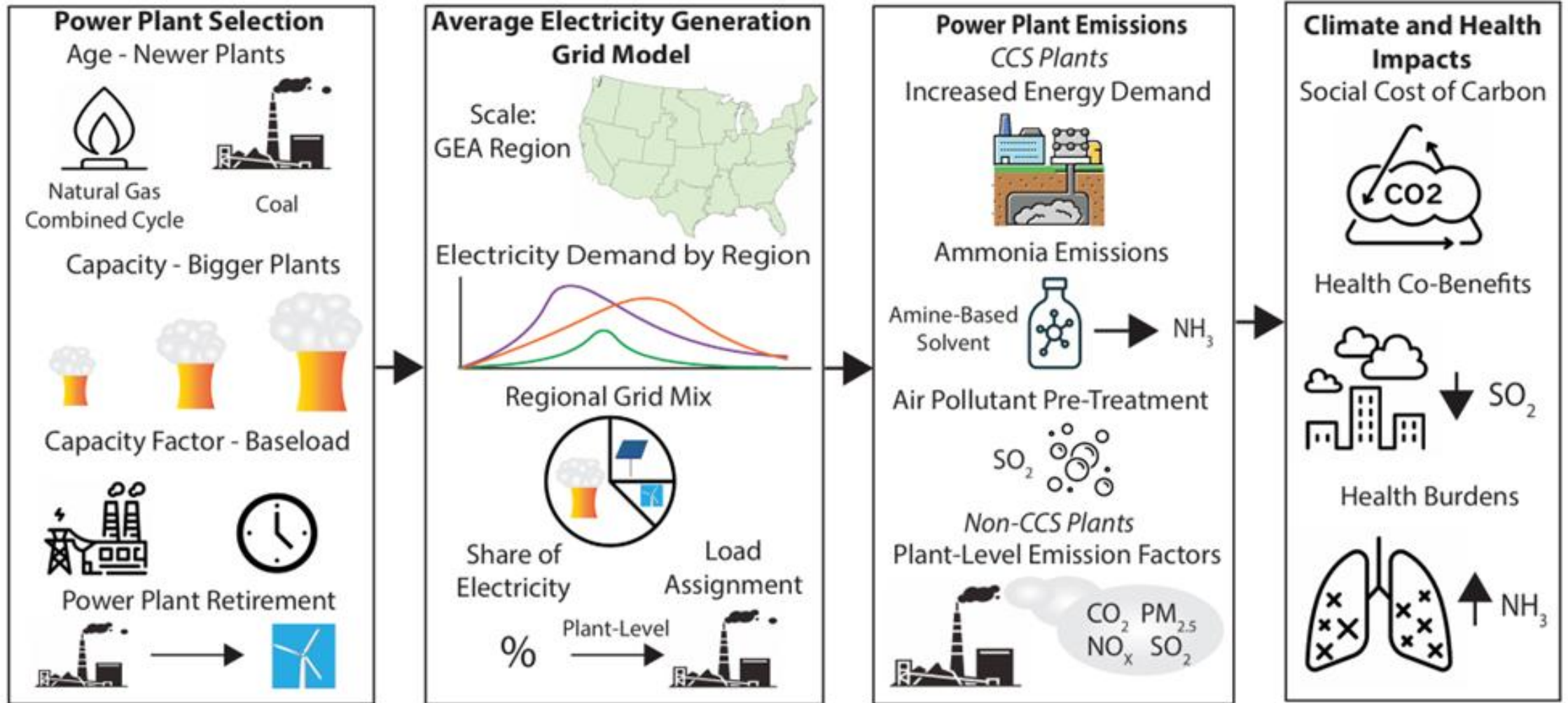


**Impurity  
Pre-treatment**

**SO<sub>2</sub> Emissions**



# Methods



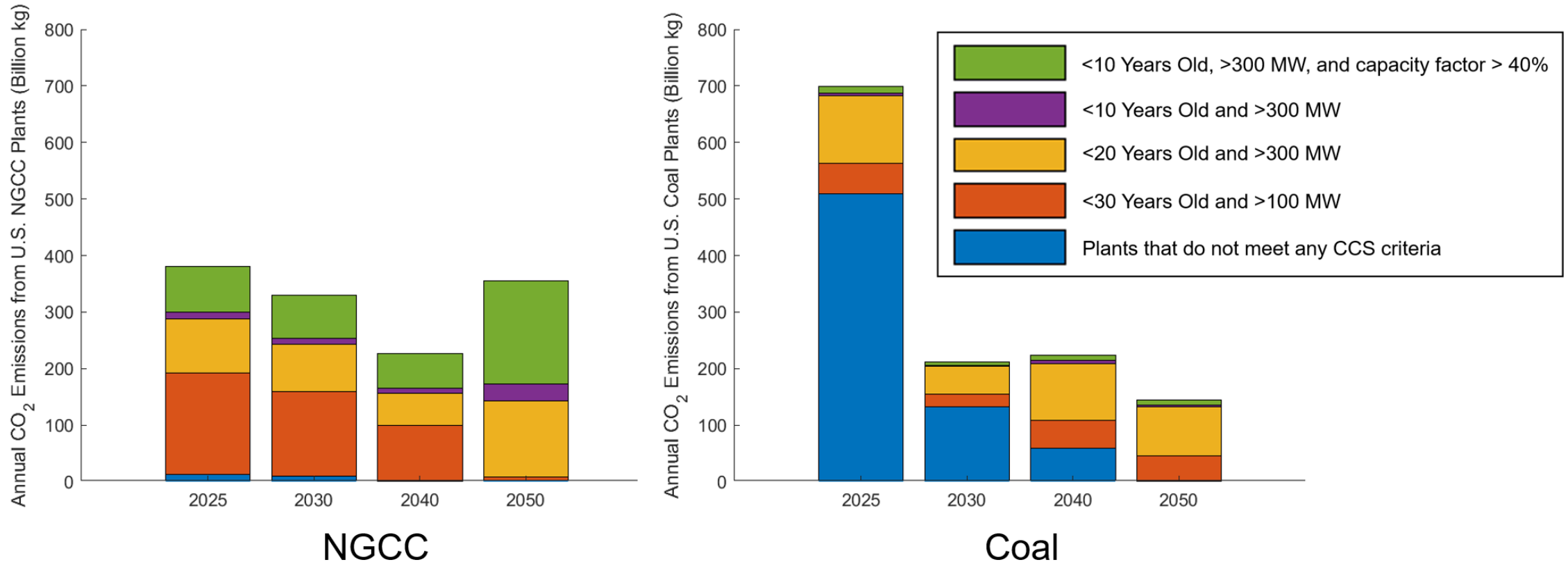
# Applicable Power Plants for CCS Retrofit

Increasingly  
Strict



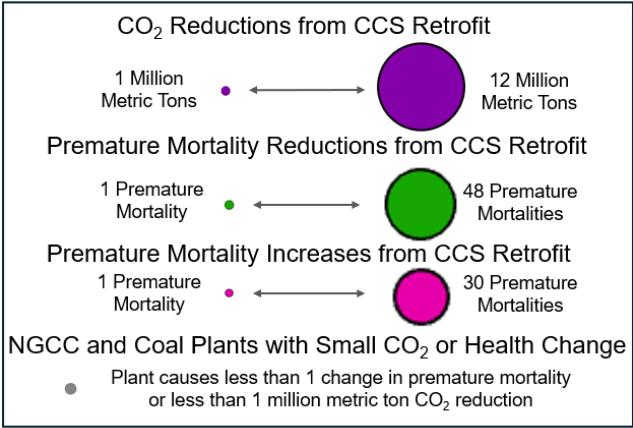
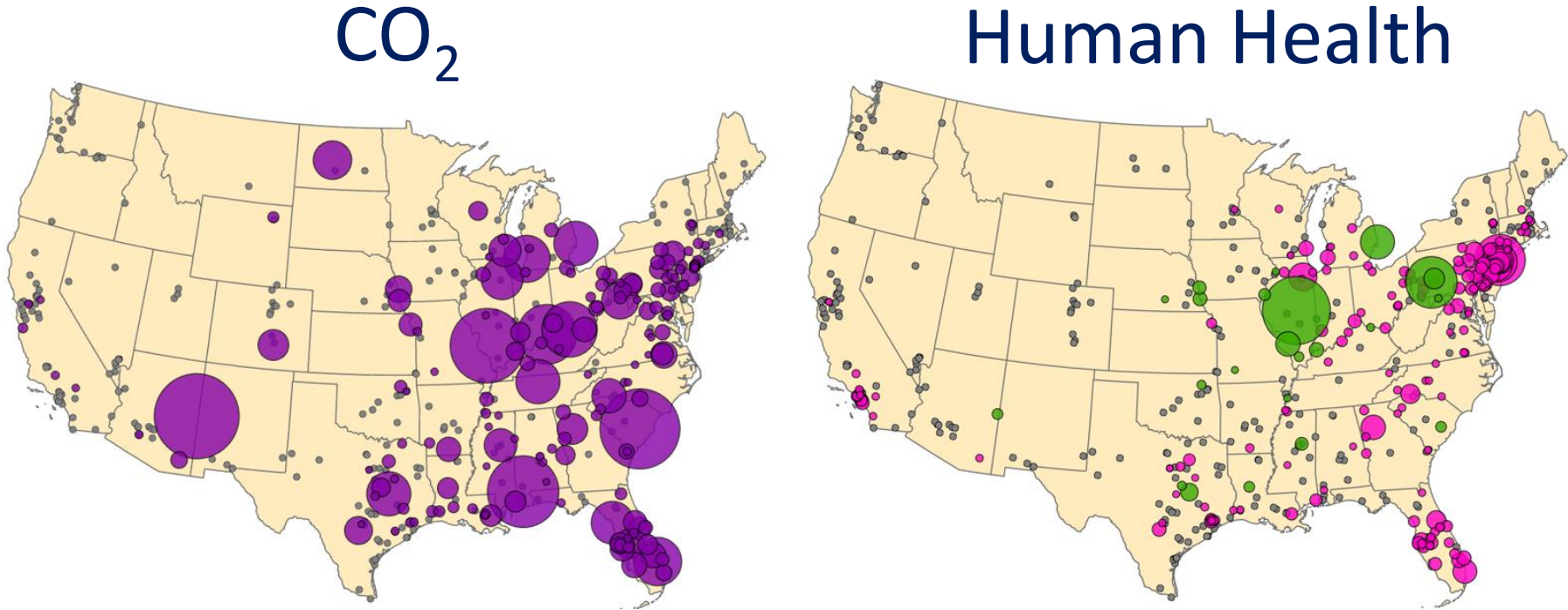
1. <30 years and >100 MW
2. <20 years and >300 MW
3. <10 years and >300 MW
4. <10 years and >300 MW and >40%  
Capacity Factor

# NGCC has fewer emissions than coal but higher addressable emissions through CCS



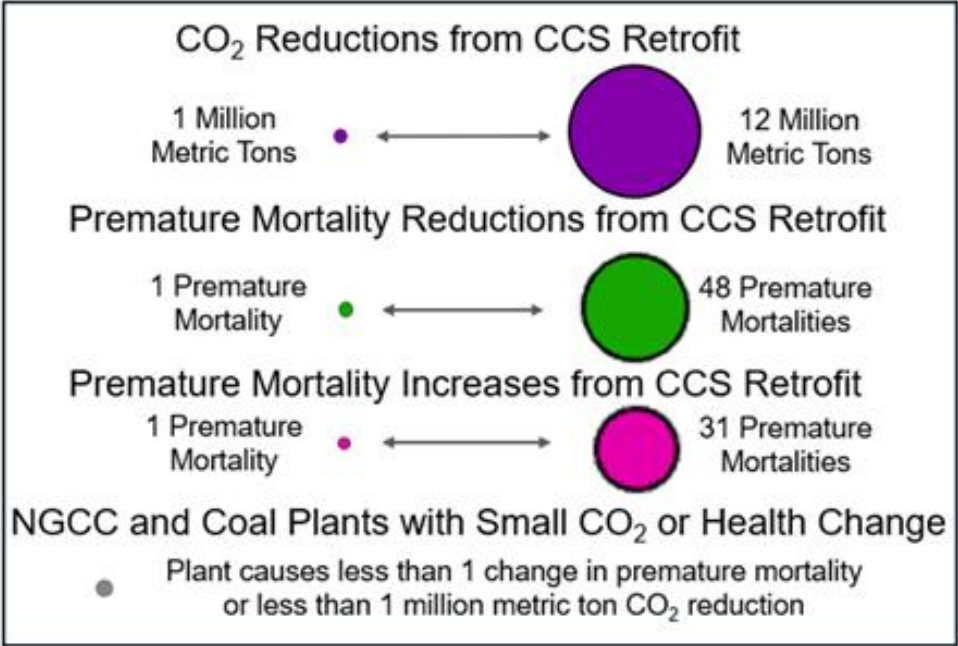
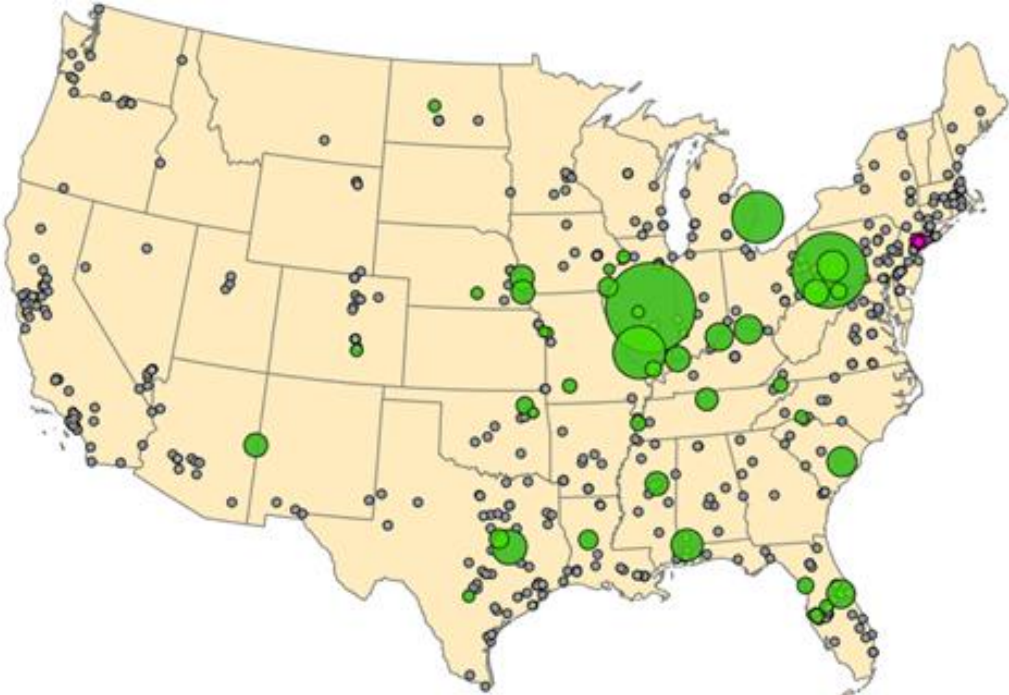
97% of CO<sub>2</sub> emissions are potentially addressable through CCS from NGCC plants compared to 27% from coal plants

# CCS can cause health co-benefits or co-burdens



(McNeil, Harley, Preble, Scown; *Under Review*; 2026)

# Controlling ammonia emissions results in net benefits

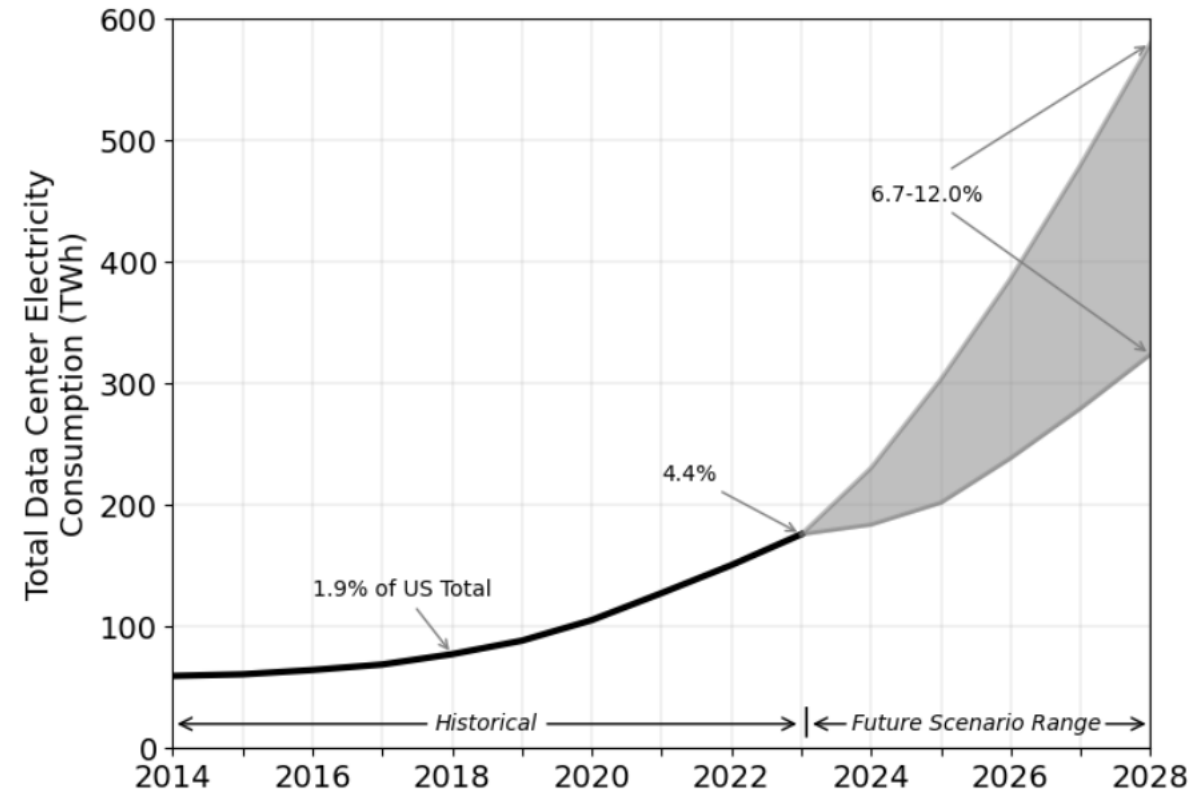


# Part 3: Location-Specific Strategies for Powering Data Centers



# Motivation

- Data centers are the fastest growing source of electricity demand in the U.S.
- Data centers are projected to account for ~half of all demand growth through 2030
- Around half of data center capacity is located at just five regional clusters in the U.S.
- One hyperscale data center can draw power on the order of tens to hundreds of megawatts
- Data centers run 24/7 with very high uptime requirements
- Securing grid interconnection can take ~3 to 7+ years in constrained regions
  - Some data center developers are pursuing co-sited/behind-the-meter generation and storage to supply part or all of their load and reduce dependence on near-term grid interconnection capacity



LBNL (2024)

# Research questions

Overall question: How do data center siting decisions shape costs, emissions, and grid outcomes for operators and the broader power system?

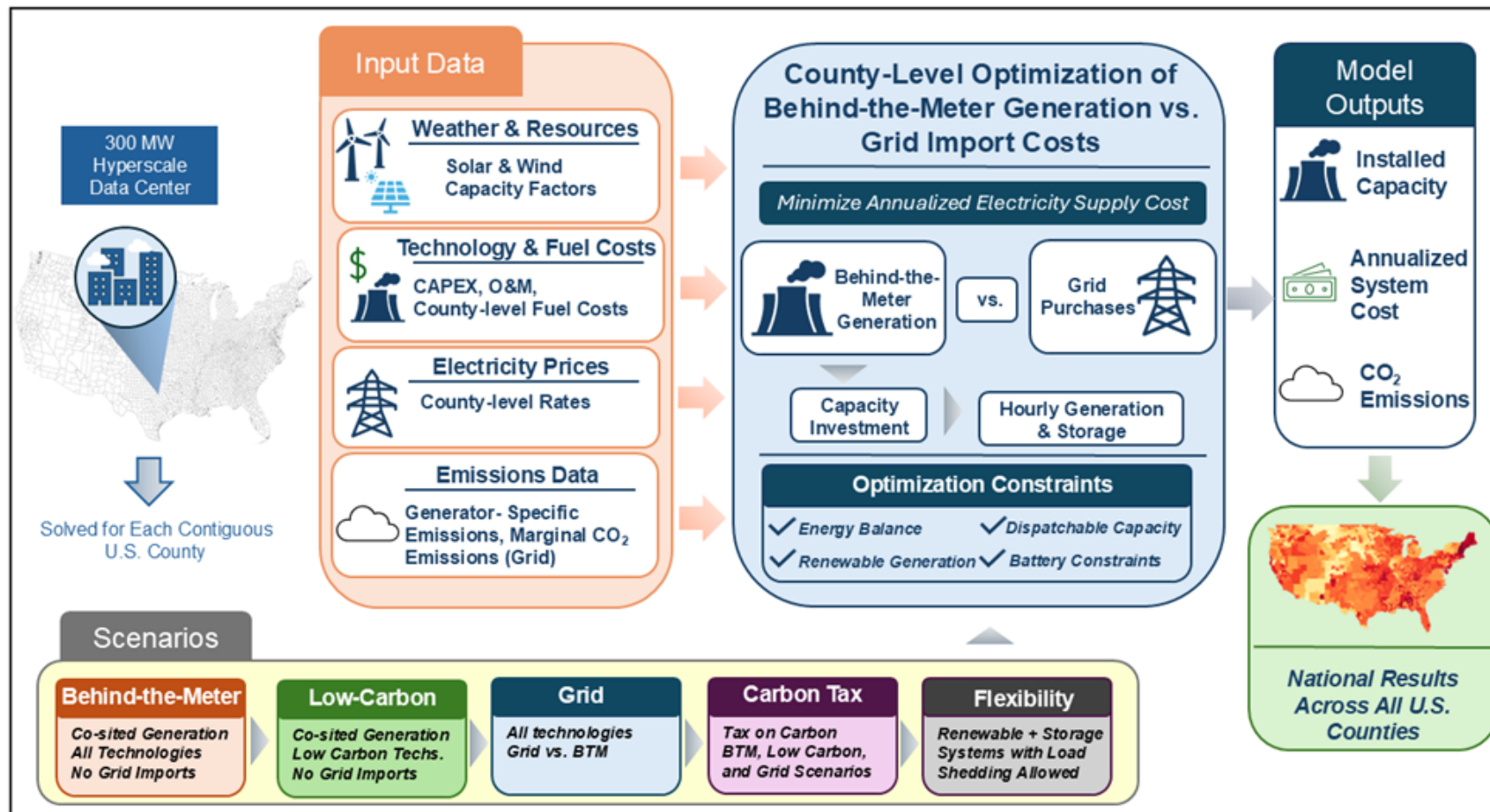
Part 1: Facility / operator perspective (technoeconomic co-siting model)

1. How do location-specific renewable resources, electricity prices, and carbon intensity change the optimal way to power a single data center?
2. What is the optimal behind-the-meter portfolio (solar, wind, battery) by location, and how much can it reduce grid consumption and emissions?

Part 2: System perspective (grid-wide impacts through 2035)

1. Under plausible growth scenarios, where and how much new data center load will materialize, and what are the resulting regional grid impacts?
2. How does cumulative data center growth affect generation build-out/dispatch, wholesale prices, and emissions across the U.S. through 2035?

# Objective: Determine optimal electricity supply portfolios for hyperscale data centers (~300 MW) across all contiguous US counties

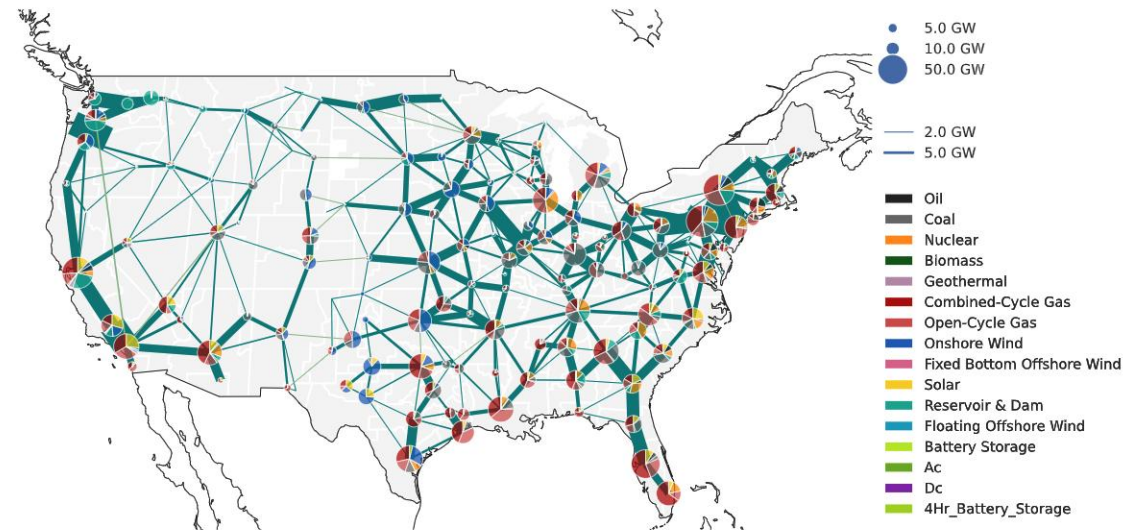


# Ongoing Work (Results Withheld)

- Key high-level insights
  - Strong geographic variation in optimal strategies driven by energy prices and resource availability
  - Firm dispatchable generation (e.g., thermal or nuclear) often emerges as cost-competitive for meeting constant, 24/7 demand
  - Grid vs. on-site supply decisions are highly location-dependent based on regional prices
  - Fully renewable systems with storage require substantial overbuild to meet reliability needs, leading to high costs in inflexible scenarios
  - Limited operational flexibility can significantly reduce costs of renewable-based systems
- Implications
  - Tradeoff between cost, emissions, and reliability
  - Results are sensitive to key modeling assumptions and system design choices

# Current/Future Work

- Determine likely load from data centers (2025-2035)
  - Proposed data center sites  $\neq$  actual realized demand. Developers often file multiple interconnection requests across different ISOs/utilities for the same project to secure the first available queue position
- Quantify system-level grid impacts
  - PyPSA-USA: open-source capacity expansion model
    - Compares future electricity system plans showing what mix of power plants and transmission could meet demand at lowest cost under different policy and technology assumptions
  - Add likely data center load, determine impacts on system-wide electricity costs, capacity, and emissions



## PyPSA-USA Network

# Acknowledgements



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UC Berkeley



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LBNL

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ENERGY**

# Summary

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- Regional electricity grid mixes dictate whether truck electrification will increase or decrease air pollution-related human health burdens
- Clean energy investments (such as IRA investments) can accelerate the benefits of truck electrification by a decade
- CCS can contribute to decarbonization goals but can have health co-benefits or co-burdens
- When emissions are not constrained, natural gas is most often the least-cost option for powering data centers
- Modest flexibility lowers price of fully renewable systems for powering data centers