



Energy+Environmental Economics

Achieving Carbon Neutrality in California: Draft Report

Public Workshop

8/19/2020

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- + Study purpose and background**
- + Scenarios**
- + Key findings**
- + Next steps**

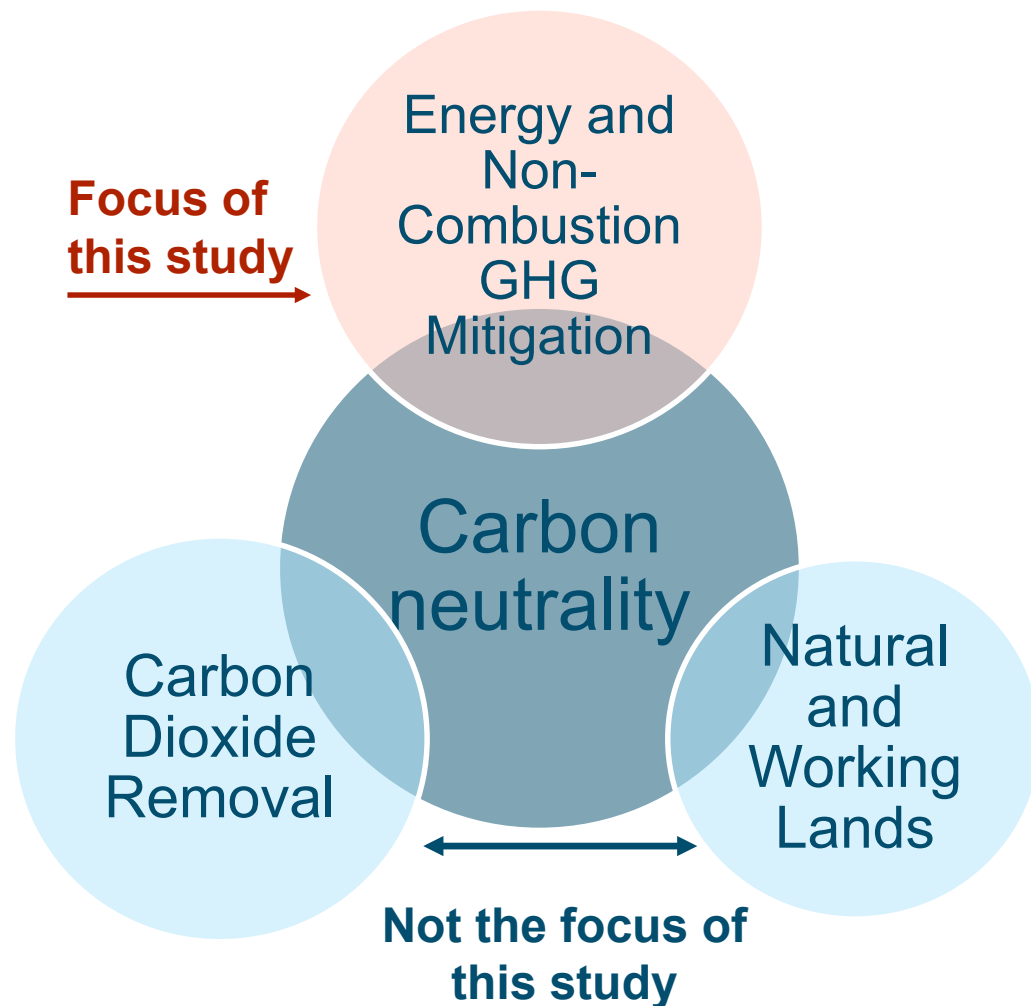
- + Appendix**
 - sector-by-sector assumptions & results



Study purpose and background

+ Executive Order B-55-18: **carbon neutrality by 2045**

+ This study examines potential **energy system and technology transformations** to achieve carbon neutrality





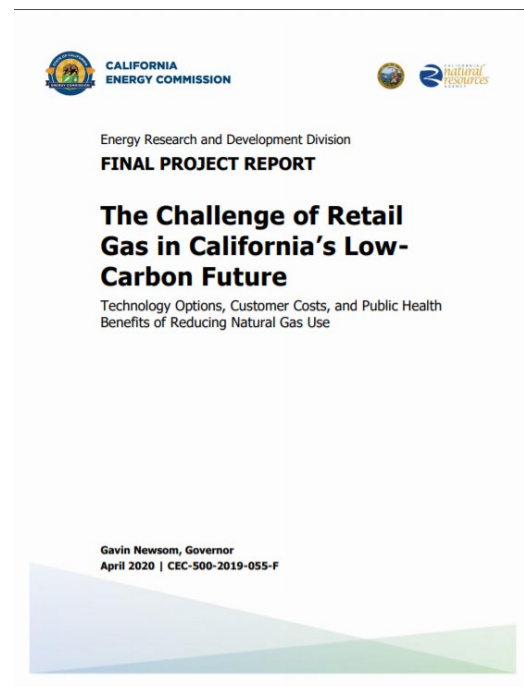
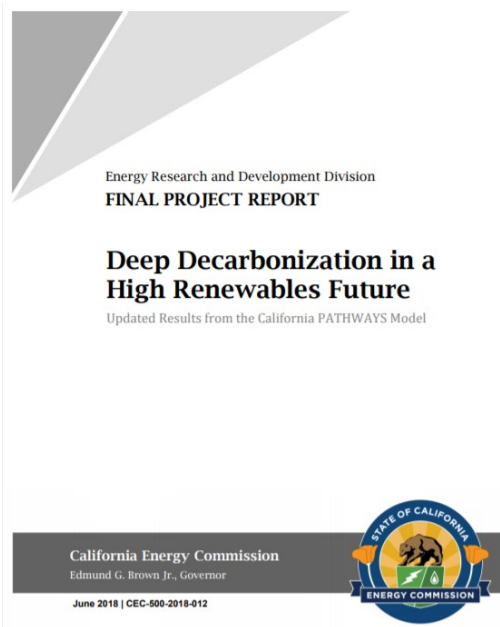
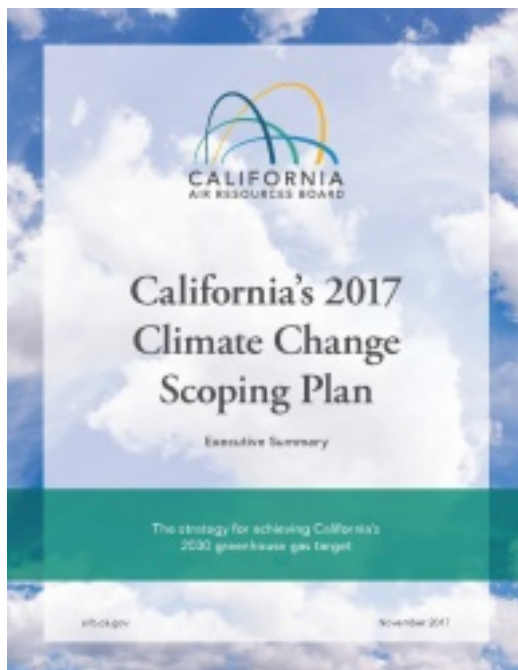
Key questions

1. What are the available energy and non-combustion GHG mitigation strategies to help achieve carbon neutrality by 2045?
2. How should California consider the tradeoffs between achieving additional energy-sector greenhouse gas reductions, versus relying on carbon dioxide removal?
3. How do different mitigation strategies compare on the basis of fuel combustion (implying air quality and health impacts), climate change mitigation risk, and technology adoption and implementation risk?
4. What are least regrets strategies that are likely to be indispensable in working towards carbon neutrality?



Project Context

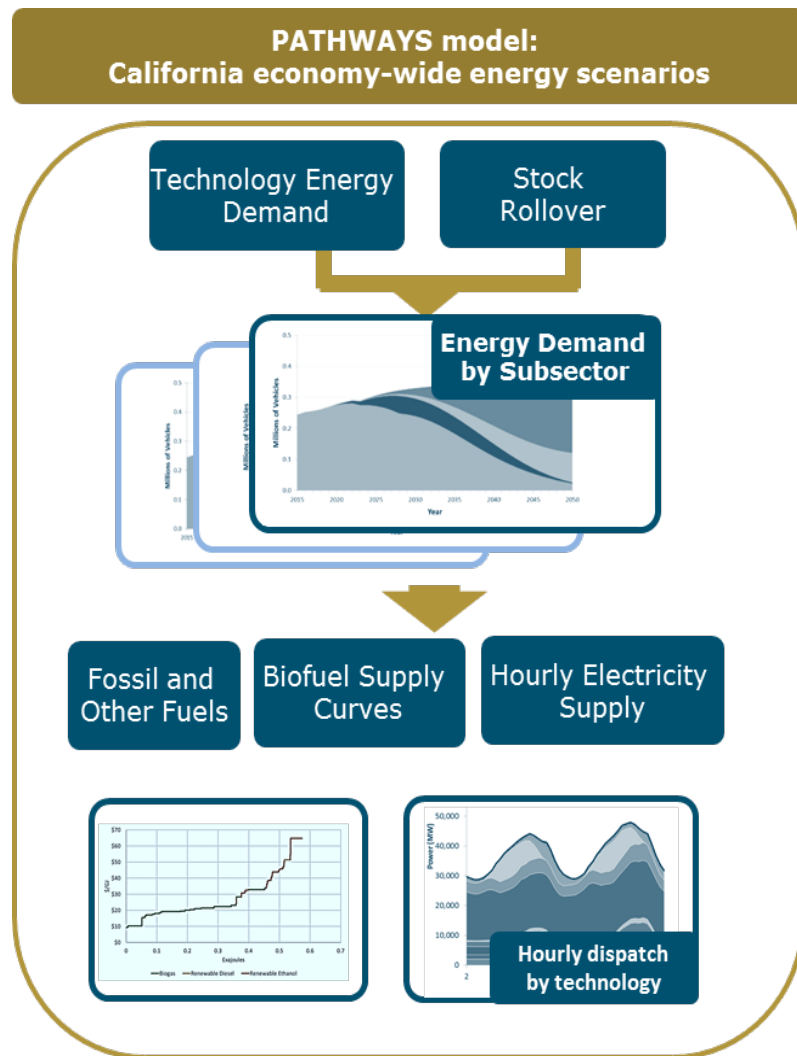
+ Carbon neutrality study builds on a literature review of deep decarbonization studies in the U.S. and Europe, and prior E3 research into decarbonization strategies in California, using the PATHWAYS model





About the PATHWAYS model

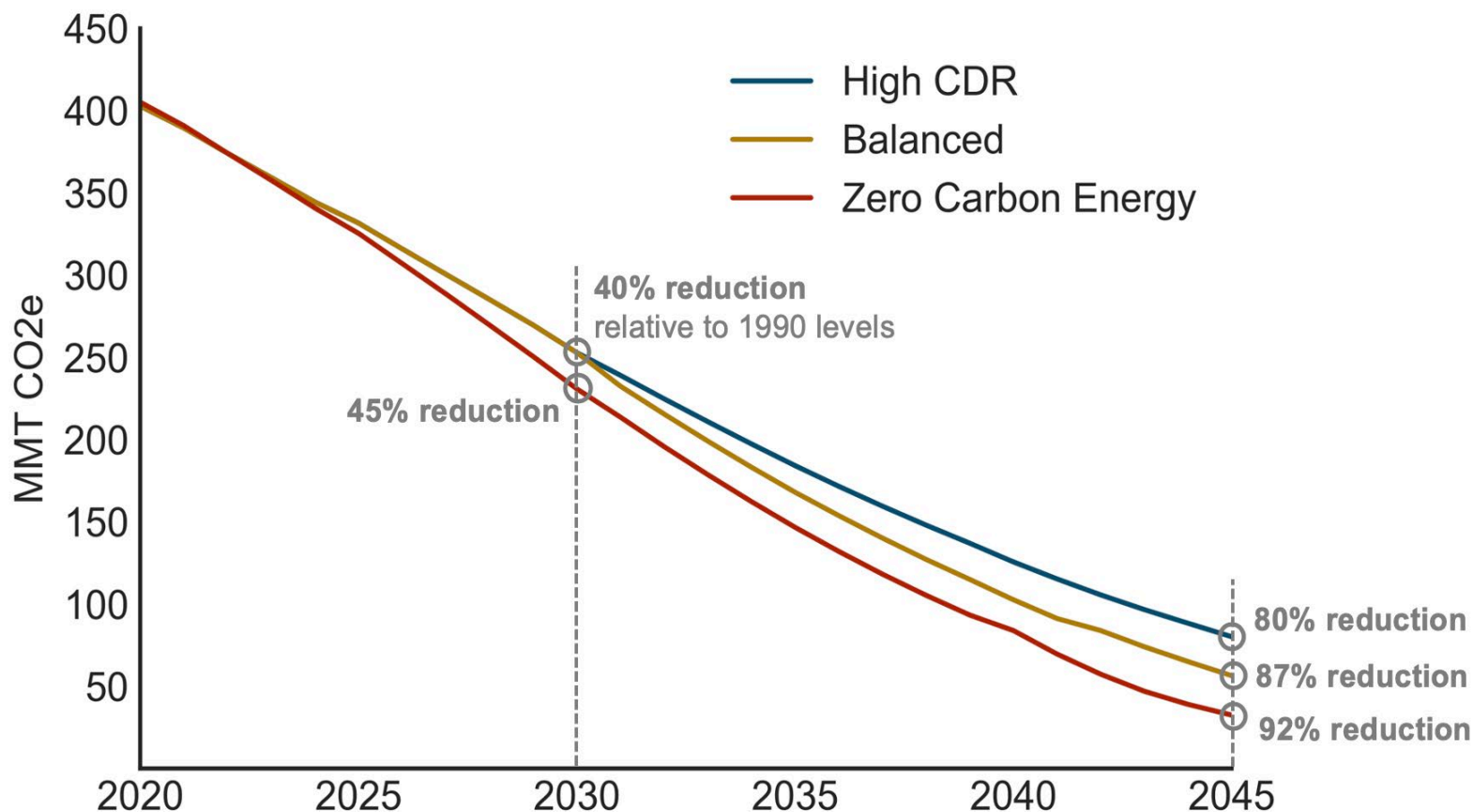
- + Covers California, economy-wide energy consumption and non-energy GHG emissions based on the CARB AB 32 Annual GHG Inventory
- + Stock-roll over treatment of building equipment and vehicles in transportation provides realistic timeframes for technology adoption
- + Biofuels, hydrogen, synthetic fuels, electricity sector representations reflect potential abatement opportunities from energy supply options





Three Scenarios

+ Scenarios examine **80% to 92% reductions in direct emissions** (energy and non-combustion GHGs) by 2045, using a “high electrification” scenario as the starting point for each





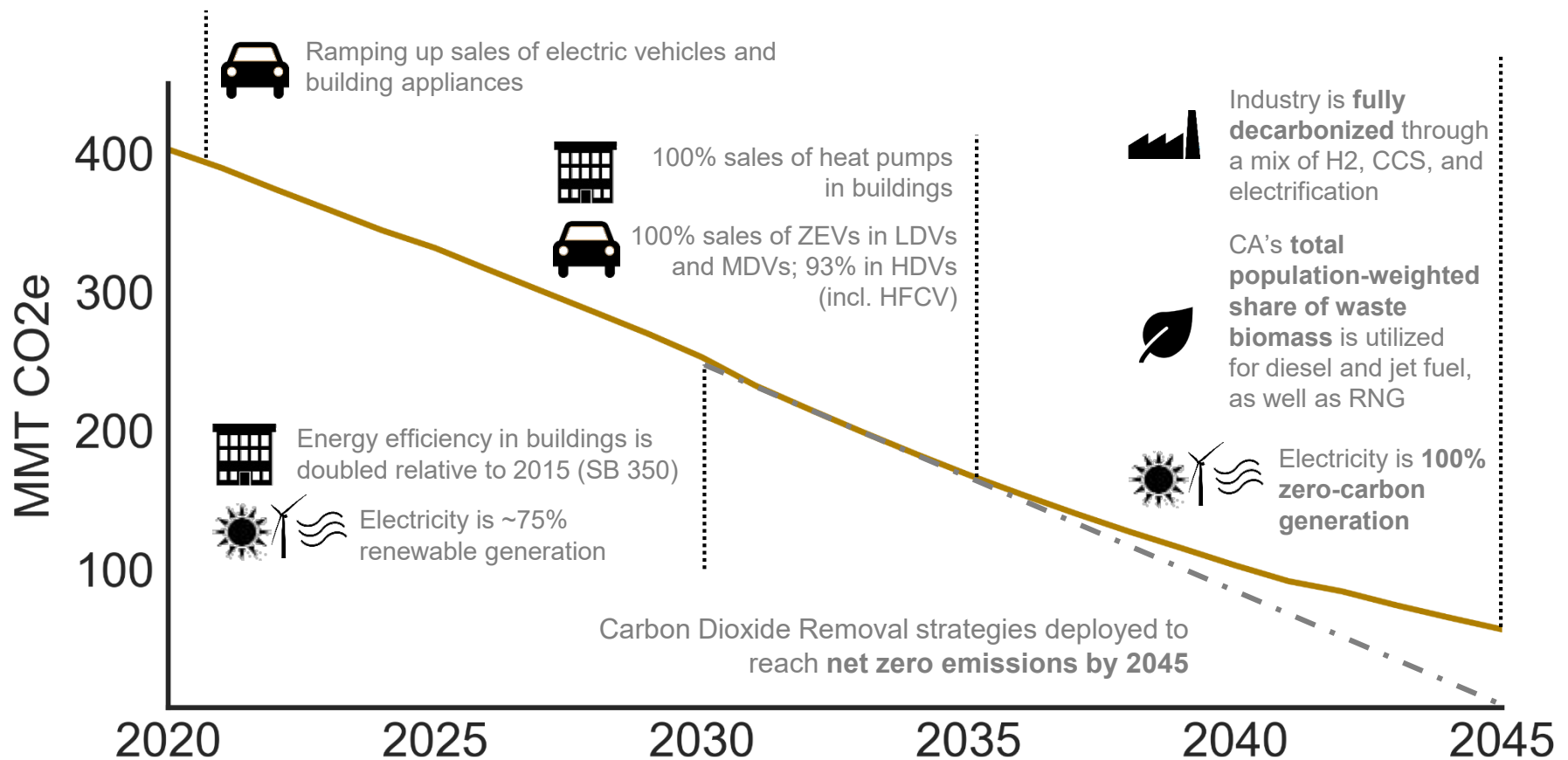
Scenario Descriptions

- + **“High Carbon Dioxide Removal (CDR)” scenario:** broad range of deep decarbonization strategies, similar to E3’s prior “high electrification” scenario, including energy efficiency, electrification, low-carbon fuels, zero-carbon electricity, and reductions in non-energy GHG emissions. **Highest reliance on CDR of all three scenarios.**
- + **“Zero-Carbon Energy” scenario:** similar set of decarbonization strategies as the High CDR scenario but electrification is deployed **earlier** and **more completely**. Emerging emission reduction technologies, including synthetic natural gas in the gas pipeline, electric aviation, and fuel-cell trains in off-road transportation **eliminate all fossil fuel emissions by 2045.**
- + **“Balanced” scenario:** less reliance on CDR compared to the High CDR scenario; slower electrification and less reliance on emerging emission reductions technologies included in the Zero-Carbon Energy scenario, i.e. less electric aviation and hydrogen fuel-cell trains. **Intermediate direct GHG reductions between other two scenarios.**



Balanced Scenario: Key Assumptions

+ The “Balanced” scenario includes widespread efficiency and electrification paired with zero-carbon electricity, as well as zero-carbon fuels for hard-to-decarbonize sectors





Scenario Details

Sector

High CDR

Balanced

Zero Carbon Energy

Low-Carbon Fuels

All scenarios utilize CA's full population-weighted share of US waste biomass to produce liquid and gaseous biofuels, plus 5% electrolytic H2 blend in pipeline

No additional H2

Widespread use of H2 in industry and HDV trucks

Widespread use of H2 in industry and HDV trucks

Buildings

All scenarios achieve SB 350 doubling of additional achievable energy efficiency by 2030 (Scoping Plan interpretation): 46 TWh of electric EE in 2030 relative to 2015; 67 TWh in 2045

100% sales of all-electric appliances in buildings **by 2040**

100% sales of all-electric appliances in buildings **by 2035**

100% sales of all-electric appliances in buildings **by 2030**, with **gas distribution grid retirement in 2045**

Transportation

100% LDV ZEV sales by 2035;
100% MDV ZEV sales by 2040;
45% HDV ZEV sales by 2035

100% LDV ZEV sales by 2035;
100% MDV ZEV sales by 2035;
93% HDV ZEV sales by 2035

100% LDV ZEV sales by 2030;
100% MDV ZEV sales by 2030;
100% HDV ZEV sales by 2030

Industry and Agriculture

High industry EE;
Minimal industry decarbonization;
90% reduction in O&G emissions

High industry EE;
High industry decarbonization (H2+CCS+electrification);
90% reduction in O&G emissions

High industry EE;
High industry decarbonization (H2+CCS+electrification);
100% reduction in O&G emissions

Electricity

95% zero carbon electricity

100% zero carbon electricity (~5% firm dispatchable generation provided by zero carbon fuels)

100% zero carbon electricity (~5% firm dispatchable generation provided by zero carbon fuels)

High GWP and Non-Combustion

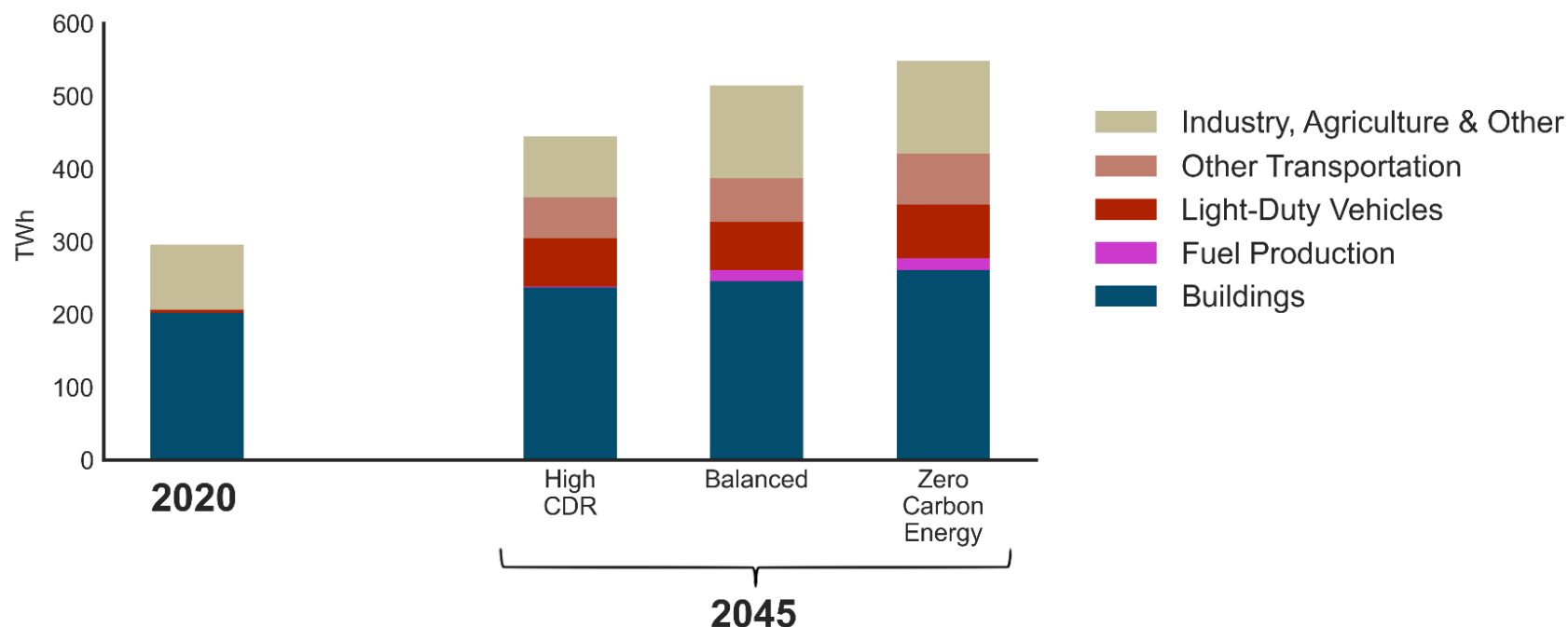
~50% reduction in high GWP and non-energy emissions relative to 2020 (~33 MMT remaining in 2045)



Electric Loads: Scenario Comparison

- + **Electric loads increase** by 50-90% relative to today by 2045
- + **Loads for direct air capture** (up to ~50-100 TWh) and **hydrogen production to serve industry** (~90 TWh in Balanced and ZCE scenarios) are assumed to be provided by off-grid renewables, and are **not included in this graphic**

Electric loads by category: today, and in 2045 across scenarios

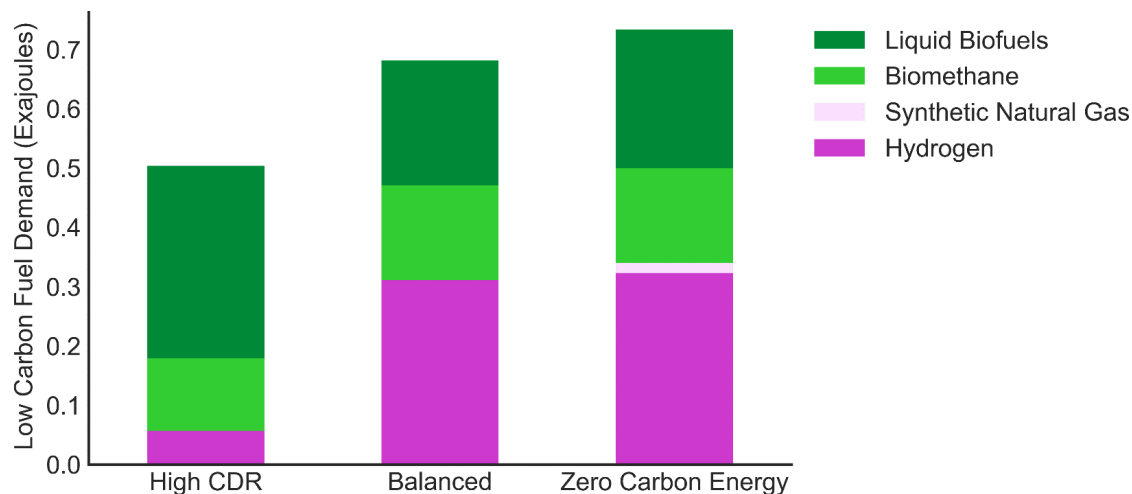




Low-Carbon Fuels: Scenario Comparison

- + All scenarios assume similar **total quantity of waste & residues biomass for biofuels**, based on CA's population-weighted share of waste biomass
- + All scenarios include hydrogen, **Balanced and Zero Carbon Energy scenarios assume widespread use of hydrogen** in HDV trucks & industry

Low Carbon Fuel Demand by Scenario in 2045

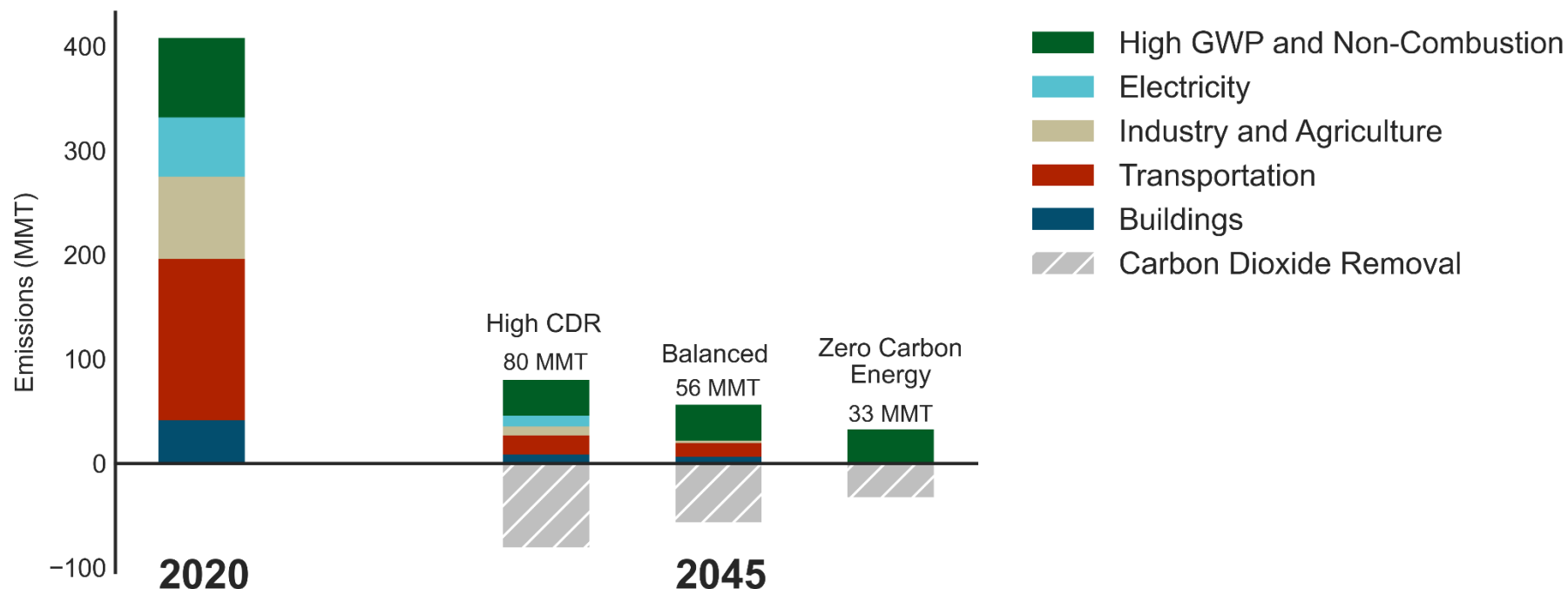




GHG Emissions: Scenario Comparison

- + Largest source of remaining GHG emissions in all scenarios is from high global warming potential gases (GWP), e.g. fluorinated refrigerant gases and non-combustion emissions, e.g. fugitive methane from agriculture

AB 32 emissions: today, and in 2045 across the three scenarios

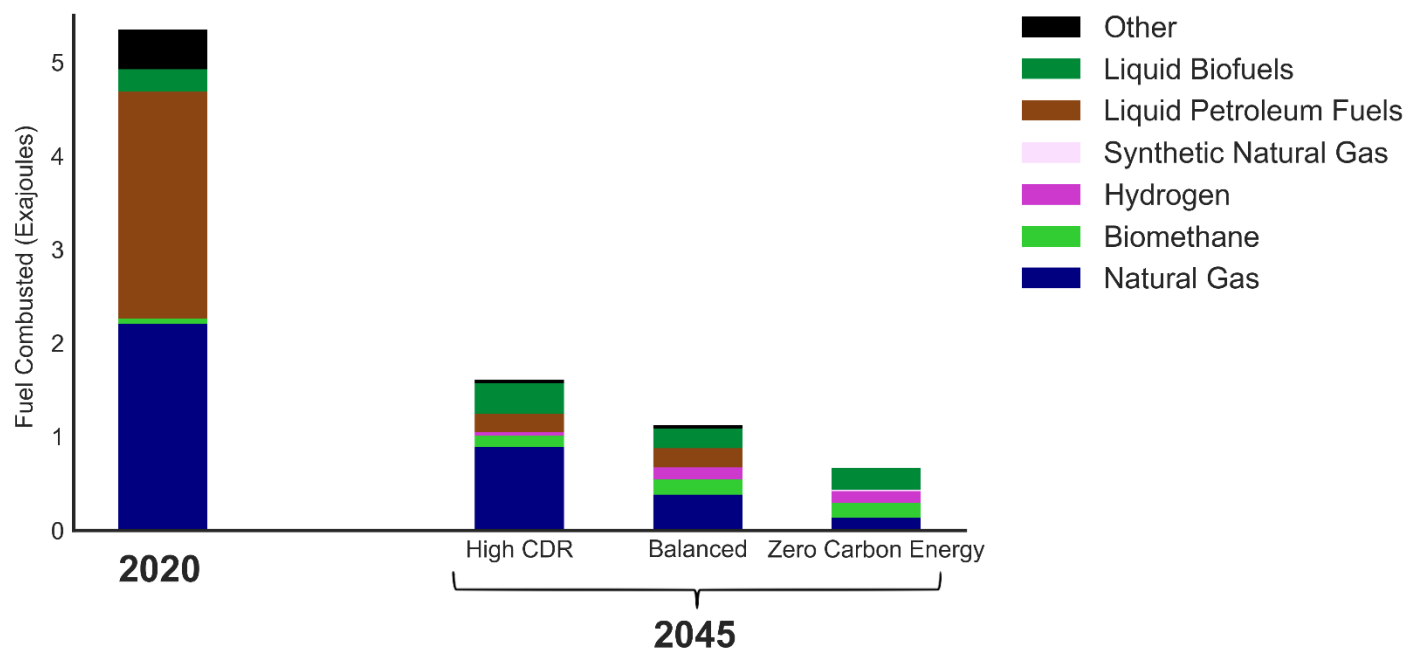




Scenario comparison: air quality and human health

- + All scenarios include a significant reduction in fuel combustion relative to today, implying potential **co-benefits for air quality and human health** could be significant
- + This study does not perform a detailed air quality analysis, but rather uses total statewide fuel combustion as a proxy for **potential human health impacts**
 - High CDR scenario has the highest relative risk for air quality and human health (although air quality would be significantly improved relative to today), while Zero Carbon Energy is the lowest risk. Fossil fuels in the Zero Carbon Energy scenario are associated with Carbon Capture and Sequestration.

Total statewide fuel combustion: today, and in 2045 across scenarios





Scenario comparison: technology adoption and implementation risk

- + All scenarios involve risk trade-offs in the categories of **technology adoption risk** and **implementation risk**
 - Technology adoption risk includes the risk that consumers will be able to feasibly transition to buying electric technologies by a certain timeline
 - Implementation risk includes the risk that certain technologies will be commercialized and cost-effective by 2045, such as hydrogen and biofuel production
- + The balanced scenario represents the **lowest risk scenario** in both of these categories, by minimizing reliance on non-commercialized technologies such as CDR, while also minimizing the technology adoption risk of rapidly transitioning to all-electric technologies



Higher implementation risk

Higher technology adoption risk



Scenario risk framework

+ “Balanced” scenario falls between the other two scenarios across key risk categories

	High CDR Scenario	Balanced Scenario	Zero Carbon Energy Scenario
Fuel combustion (implying potential health impacts)			
Climate change mitigation risk			
Technology adoption and implementation risk			

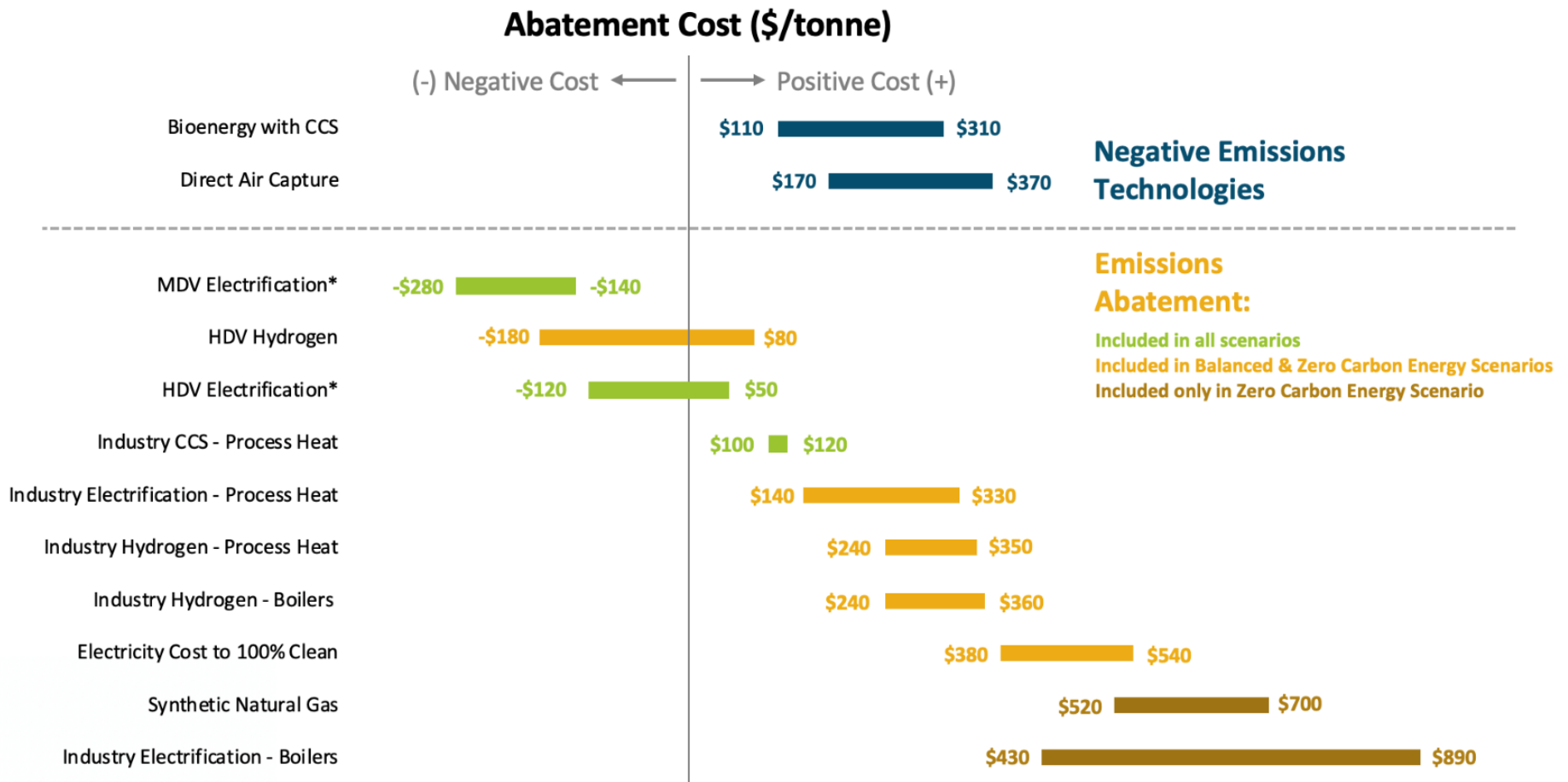
Key:

-  Highest
-  Mid
-  Lowest



Cost comparison: GHG mitigation options

+ Cost difference between scenarios is uncertain



*Included in lower penetrations in the High CDR scenario than in other scenarios.



Key findings

- + **Least-regrets strategies** for getting to carbon neutral include:
 - **Energy efficiency** in buildings, industry, and agriculture
 - **Widespread transportation and building electrification**
 - **Zero-carbon electricity**
 - Investment in **zero-carbon fuel** options for hard-to-decarbonize sectors where electrification is not practical
 - Pursuing **reductions in non-combustion emissions**
 - Investment and research into **carbon dioxide removal (CDR) technologies**



Next steps

- + **Receive comments on draft report & finalize report for consideration by CARB**
- + **Areas for further study include:**
 - **Maximizing co-benefits** for heavily burdened communities with respect to environmental justice issues and equity;
 - **The impact of large infrastructure development** associated with renewable energy development, hydrogen production, and/or DAC with CCS on land use compared to the use of natural and working lands as a carbon sink;
 - **A better understanding of the adoption challenges** that vehicle and building electrification strategies might face as well as the practical infrastructure rollout needed, e.g. distribution and transmission upgrades to match growth in electric loads
 - **Strategies to incentivize the development of advanced mitigation strategies**, in particular low carbon fuel production, CCS, and NETs and to bring down their costs



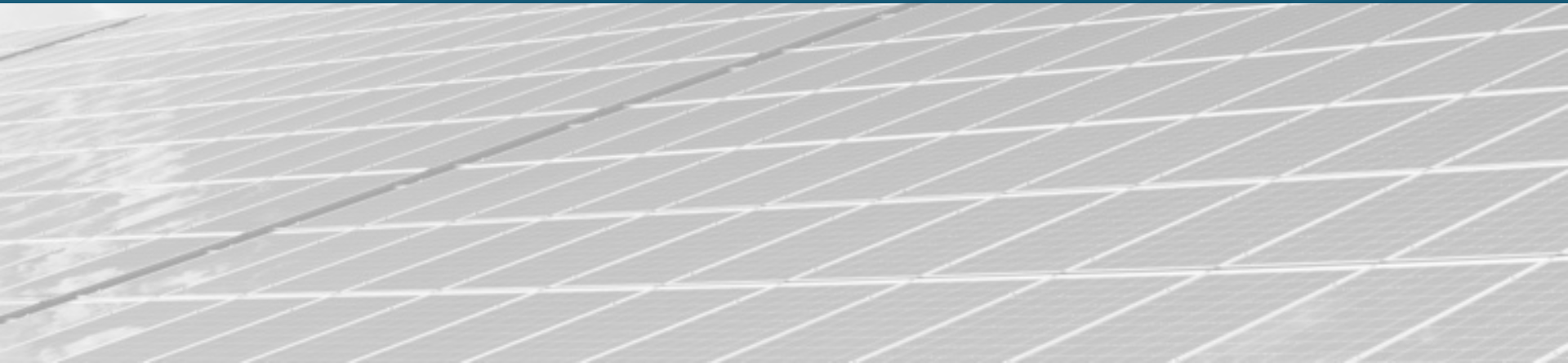
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Questions/Discussion



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Appendix: Additional Slides

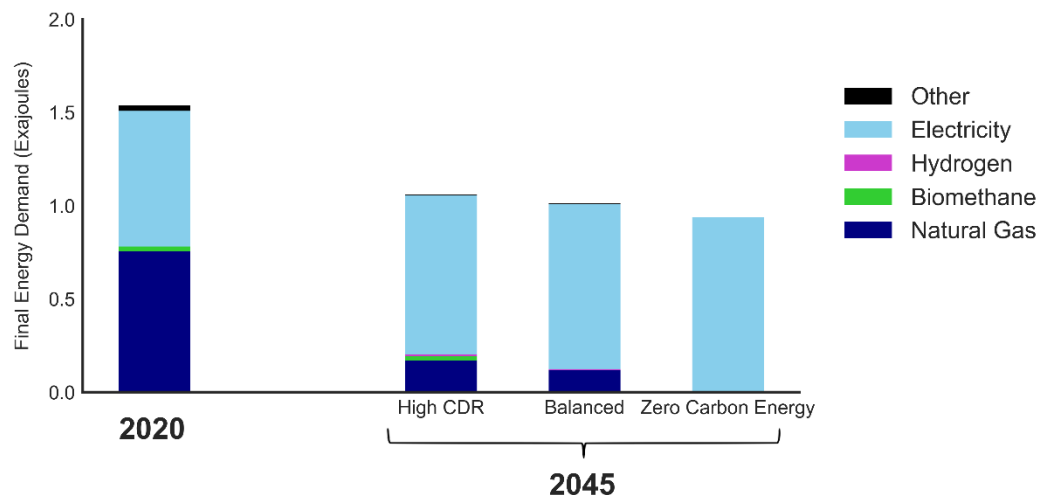




Buildings

- + All scenarios employ high levels of efficiency and a transition to 100% all-electric buildings, with the date of 100% electric appliance sales varying by scenario
- + Significant reduction in final energy demand occurs mainly due to the 3-4x efficiency gain from heat pumps

Final energy demand in buildings: today, and in 2045 across scenarios

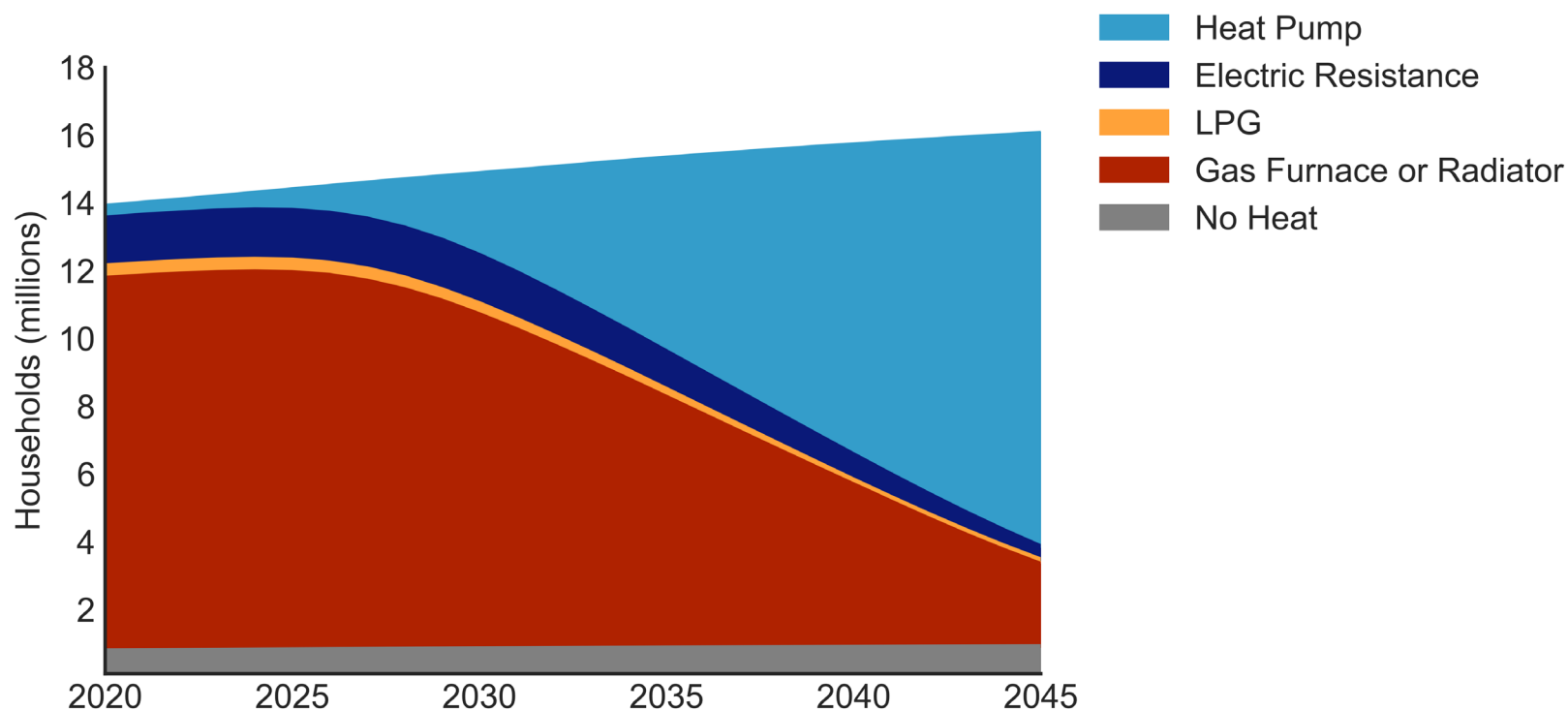


High CDR	Balanced	Zero Carbon Energy
100% sales of all-electric appliances by 2040	100% sales of all-electric appliances by 2035	100% sales of all-electric appliances by 2030; with gas distribution grid retirement in 2045



Residential Space Heating: Balanced Scenario

Residential Space Heating Stocks: Balanced scenario, 2020 - 2045

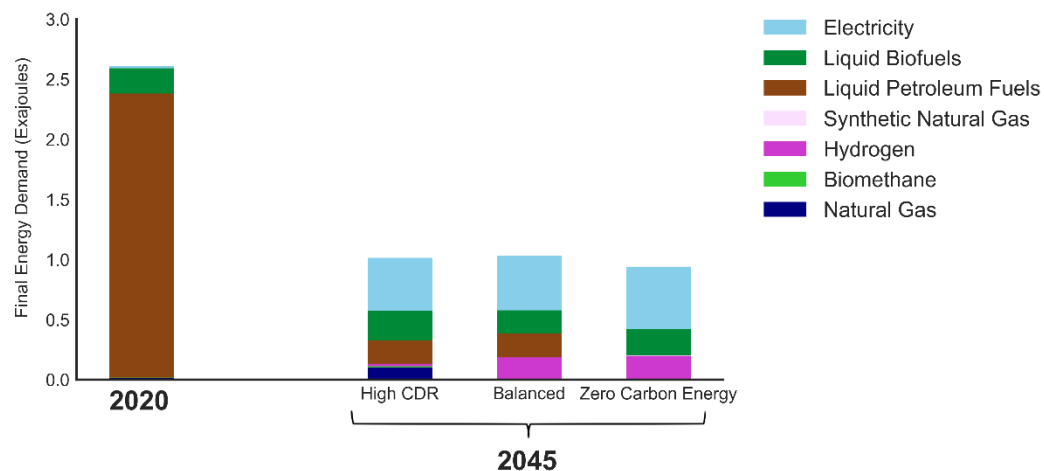




Transportation

- + All scenarios employ significant VMT reductions and a widespread transition to zero-emission vehicles, with the level of ambition varying by scenario
- + Significant reduction in final energy demand occurs mainly due to the 2-3x efficiency gain from electric drivetrains

Final energy demand in transportation: today, and in 2045 across scenarios

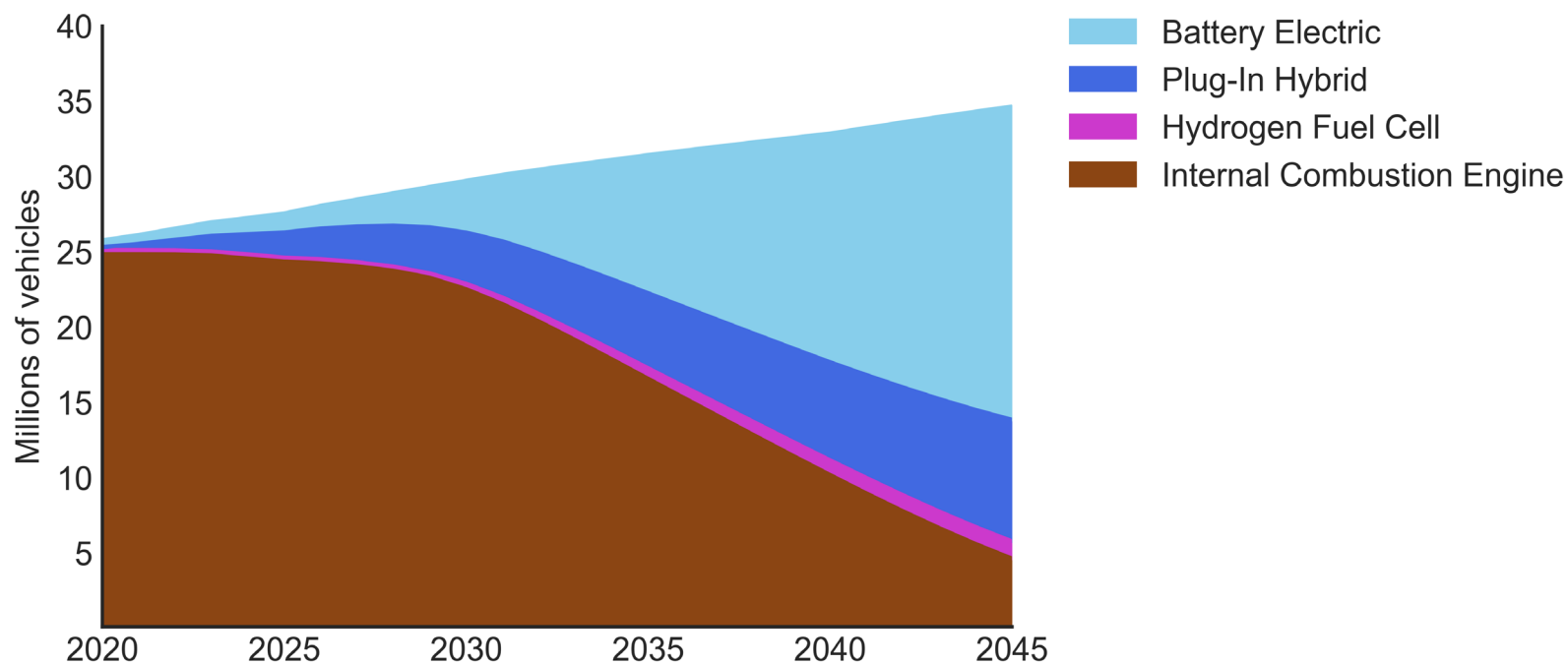


High CDR	Balanced	Zero Carbon Energy
100% LDV ZEV sales by 2035; 100% MDV ZEV sales by 2040; 45% HDV ZEV sales by 2035	100% LDV ZEV sales by 2035; 100% MDV ZEV sales by 2035; 93% HDV ZEV sales by 2035 (50/50 H2/BEV)	100% LDV ZEV sales by 2030; 100% MDV ZEV sales by 2030; 100% HDV ZEV sales by 2030 (50/50 H2/BEV)



Light Duty Vehicles: Balanced Scenario

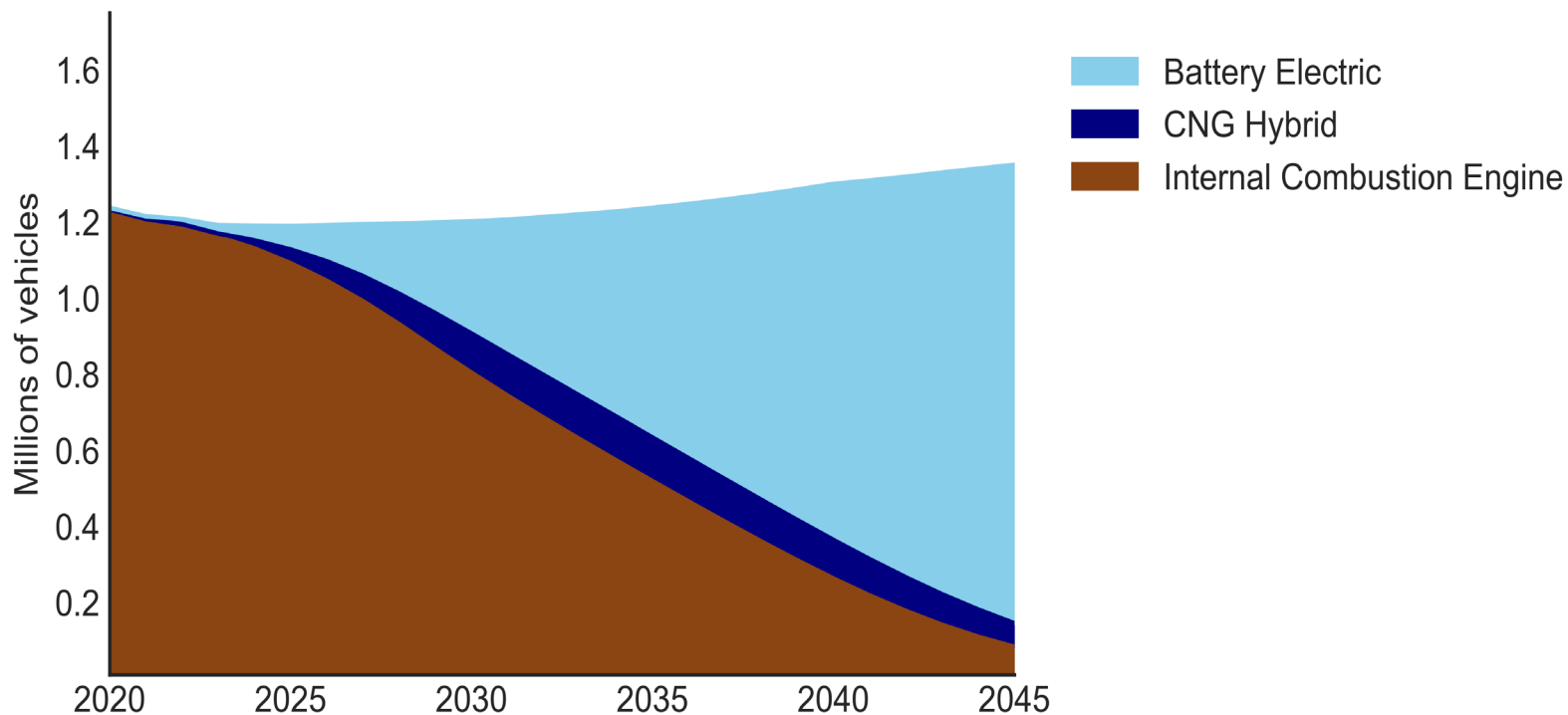
Light Duty Vehicle Stocks (Millions): Balanced scenario, 2020 - 2045





Medium Duty Vehicles: Balanced Scenario

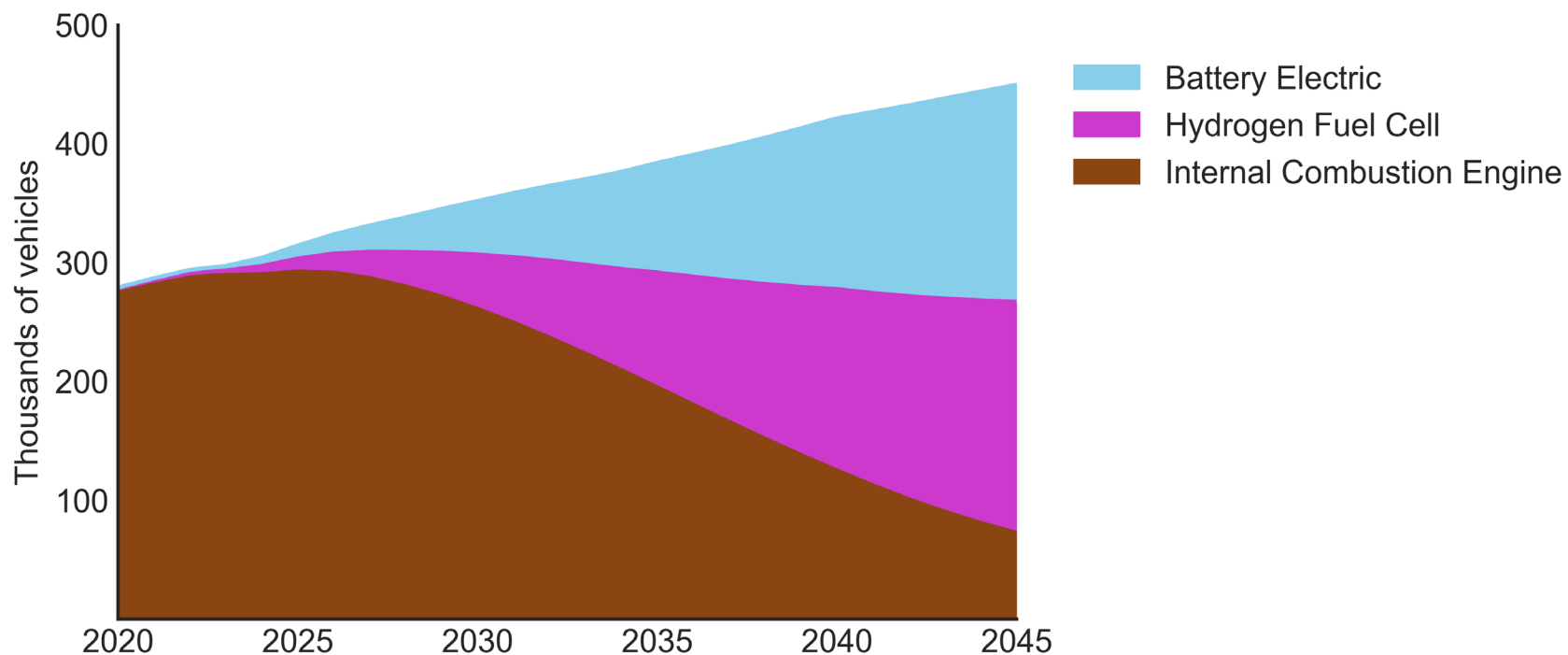
Medium Duty Vehicle Stocks (Millions): Balanced scenario, 2020 - 2045





Heavy Duty Vehicles: Balanced Scenario

Heavy Duty Vehicle Stocks (Thousands): Balanced scenario, 2020 - 2045





Industry and Agriculture

- + All scenarios include **high levels of EE** in industry and a **near to complete phase-out** of oil & gas extraction and petroleum refining
- + **High CDR scenario assumes minimal industry decarbonization**, while the other two scenarios assume **full industry decarbonization** via a variety of strategies:
 - **Electrification** for low temperature heat
 - **Hydrogen** for medium temperature heat, including all boilers
 - **Natural gas with CCS** for high temperature heat and non-combustion CO2 emissions, such as cement production (these applications only are included in High CDR scenario)

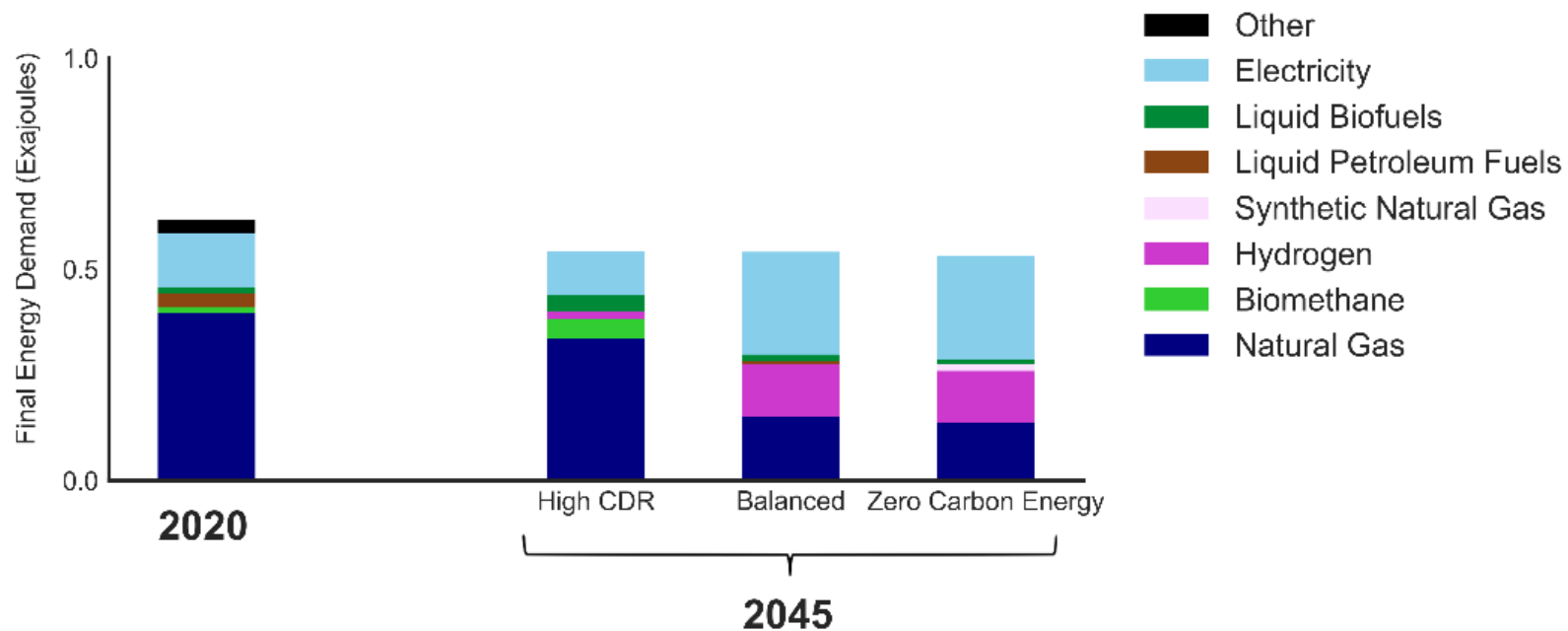
Decarbonization strategies assumed for industrial manufacturing, by end use
(percentages indicate share of final energy demand for each fuel)

End Use	Renewable Diesel	Natural Gas with CCS	Electricity	Hydrogen
Conventional Boiler Use	0%	0%	0%	100%
Lighting	0%	0%	100%	0%
HVAC	0%	0%	100%	0%
Machine Drive	0%	0%	100%	0%
Process Heating	0%	53%	47%	0%
Process Cooling & Refrigeration	0%	0%	100%	0%
Other	7%	31%	31%	31%



Industrial Manufacturing

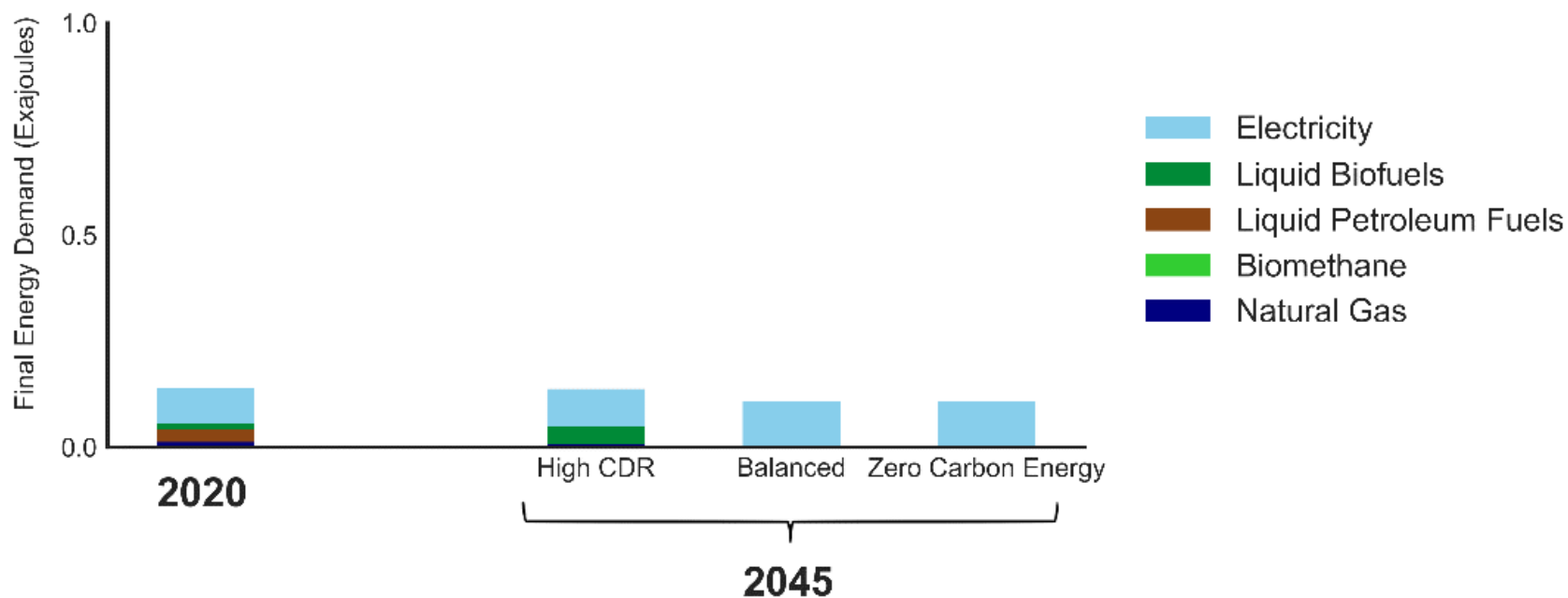
Final energy demand in **industrial manufacturing**:
today, and in 2045 across scenarios





Agriculture

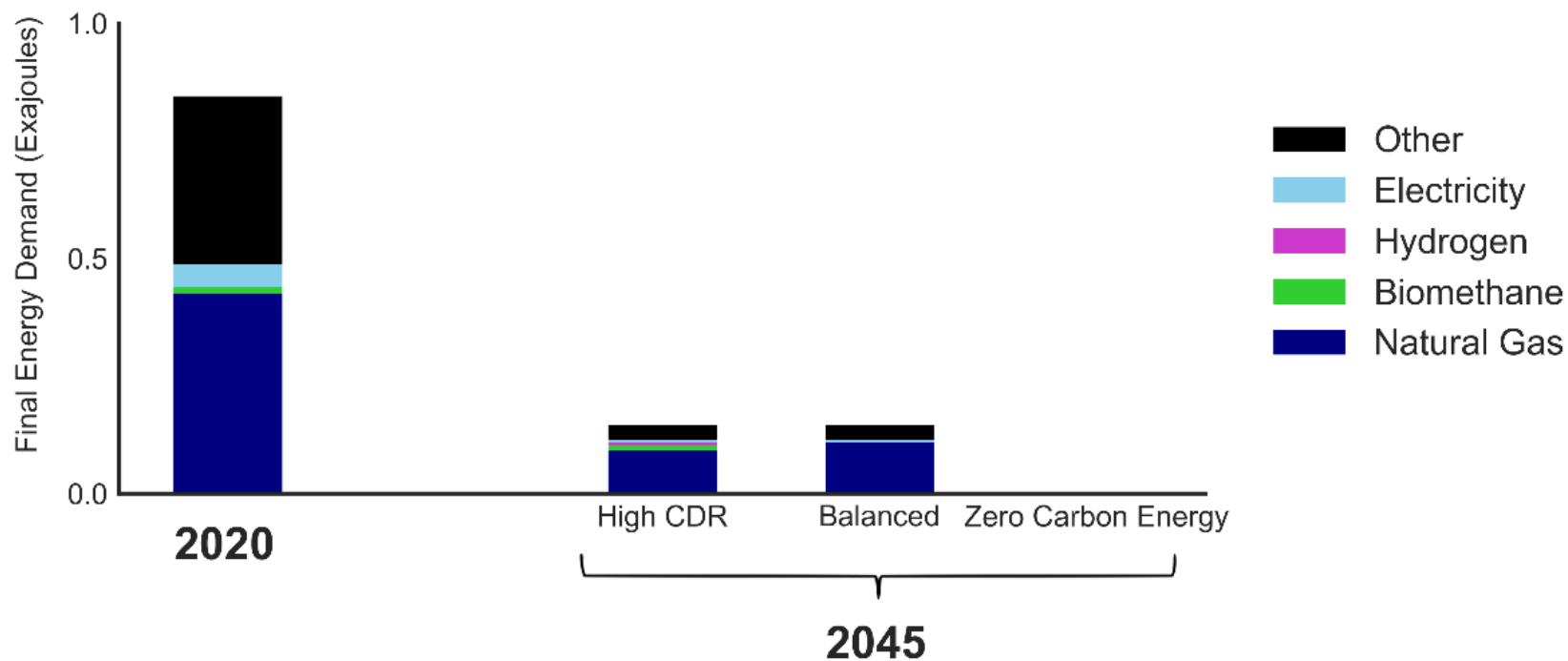
Final energy demand in **agriculture**:
today, and in 2045 across scenarios





Oil & Gas Extraction & Petroleum Refining

Final energy demand in **oil & gas extraction and petroleum refining**: today, and in 2045 across scenarios

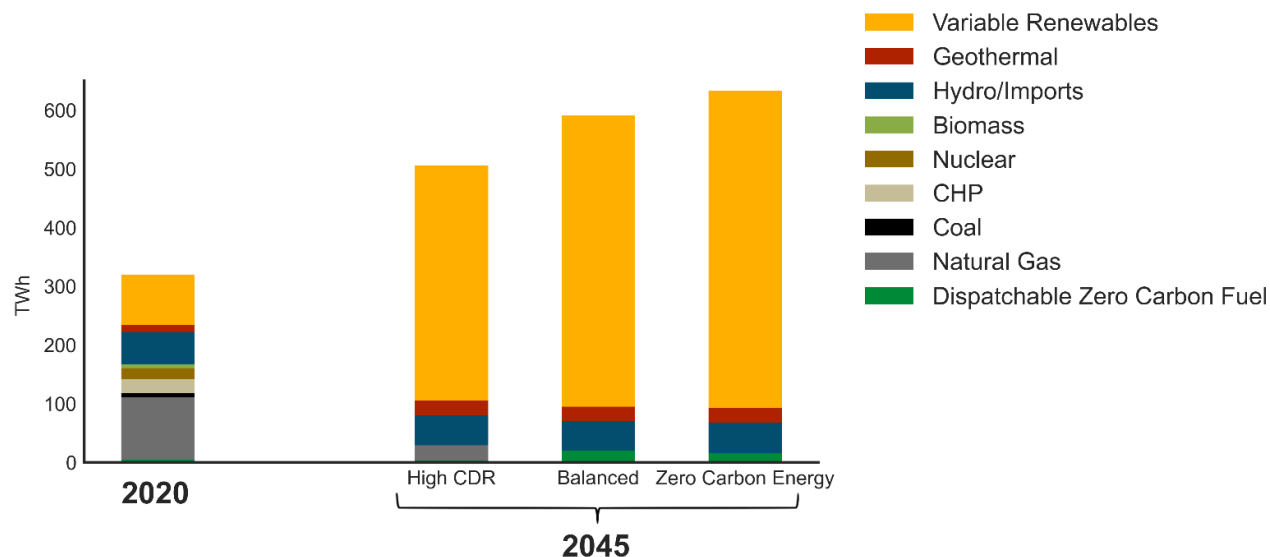




Electricity Generation

- + All scenarios assume a near or complete transition to **zero-carbon electricity generation**
- + In Balanced and Zero Carbon Energy scenarios, **zero-carbon dispatchable resources** are used for about **5% of generation** to reach **100% zero carbon electricity** (dispatchable generation could be provided by any mix of H2, RNG, and long-duration energy storage)

Electricity generation by resource: today, and in 2045 across scenarios

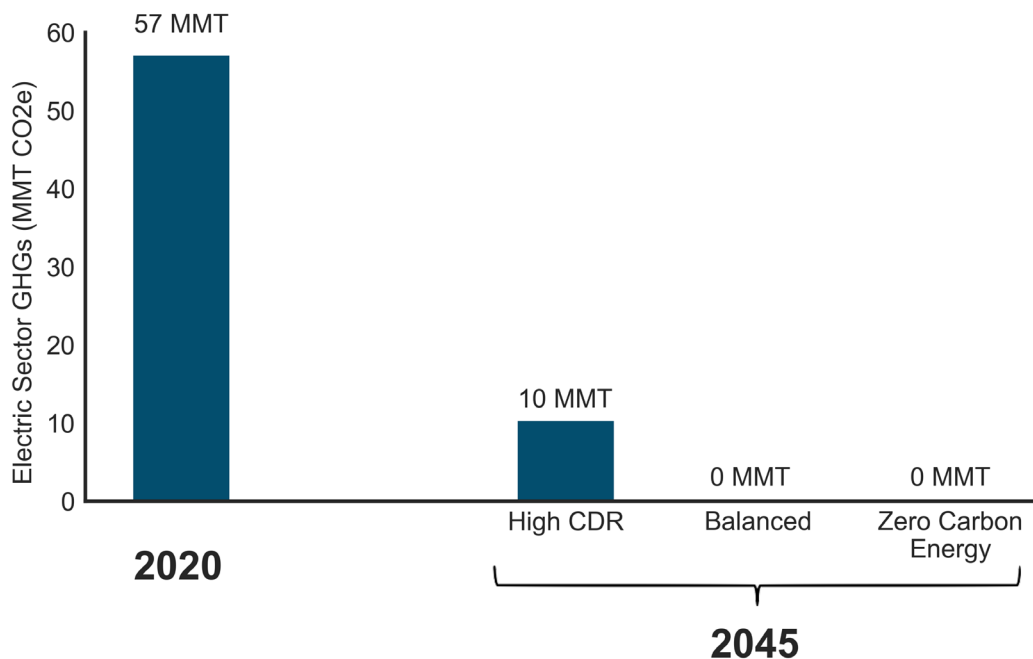




Electricity GHGs

- + Natural gas serves 5% of generation in the High CDR scenario, leaving 10 MMT of GHGs in 2045 in the electricity sector
- + In the Balanced scenario and Zero Carbon Energy scenario, this 5% of generation is served with zero-carbon fuels

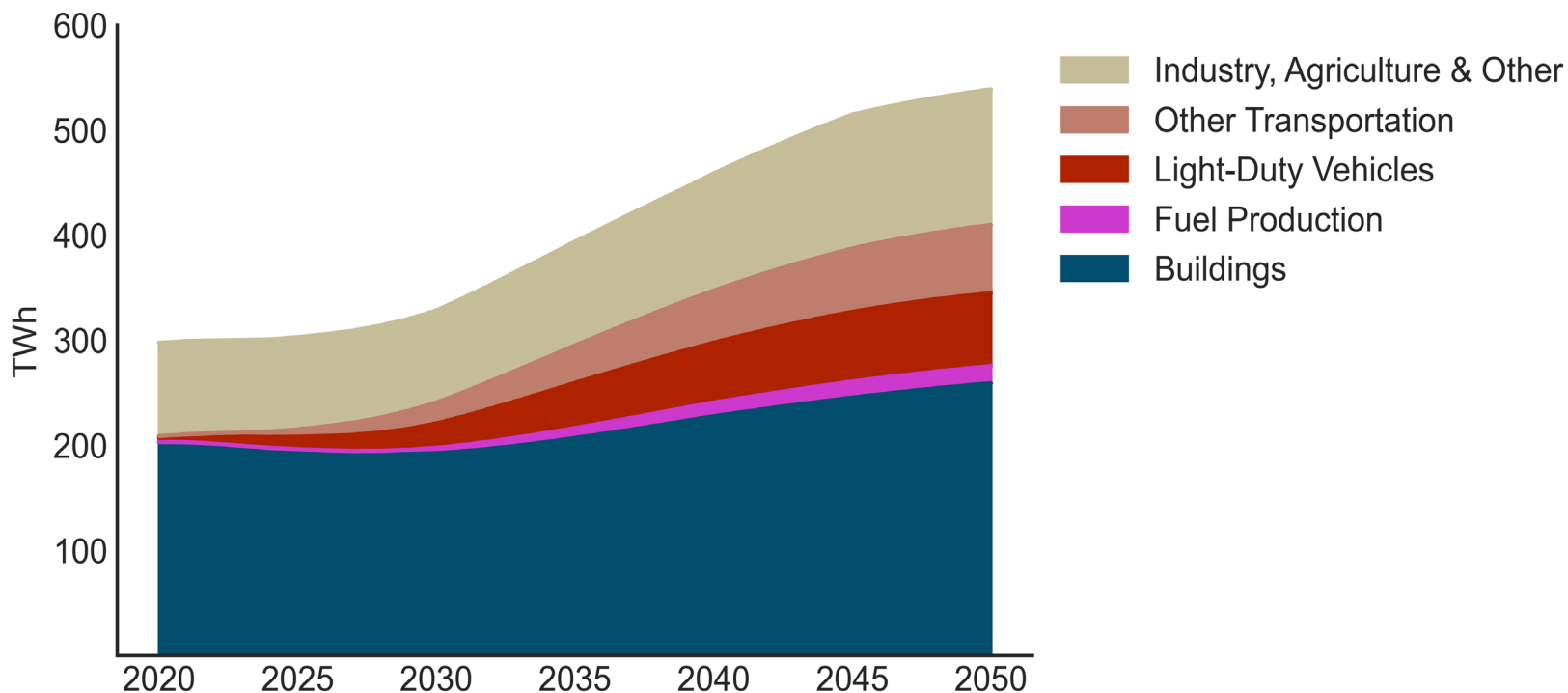
Electric sector GHGs: today, and in 2045 across scenarios





Electric Loads by Sector: Balanced Scenario

Electricity Demand by Sector (TWh): Balanced scenario, 2020 - 2050

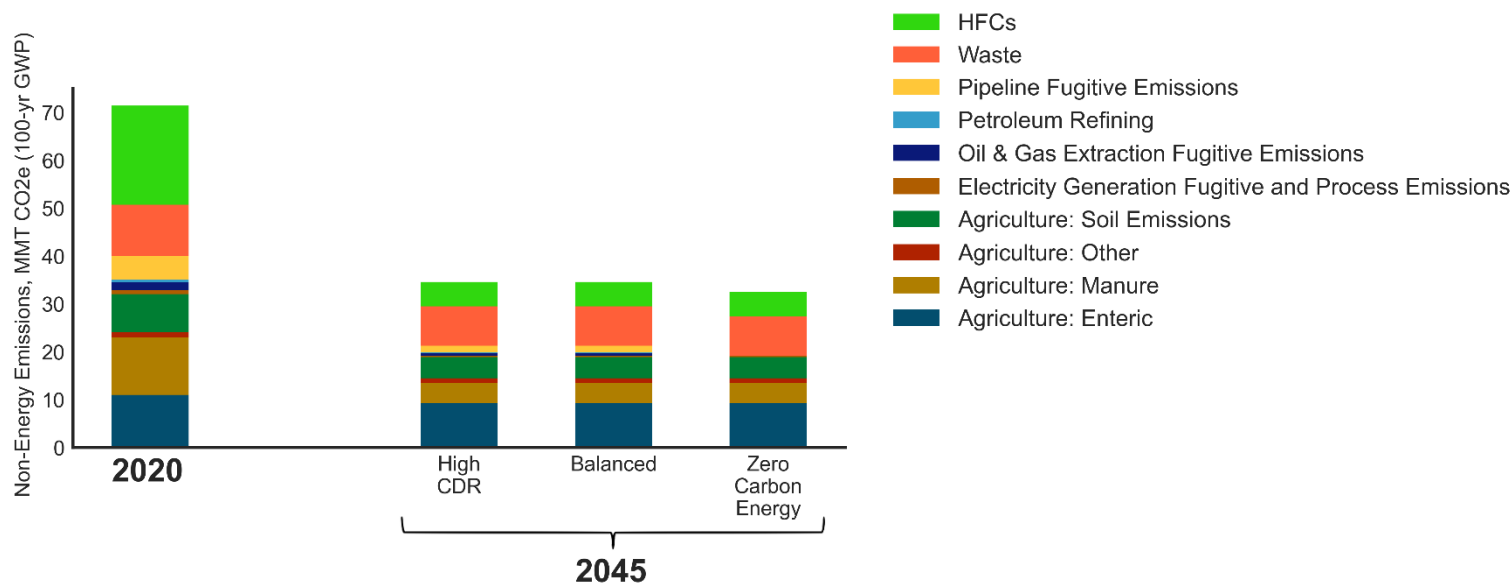




Non-Combustion, High Global Warming Potential Gases

- + All scenarios assume a **~50% reduction in non-energy emissions by 2045** due to ongoing CARB efforts to address **HFCs and methane emissions** from agriculture, natural gas pipelines, and waste
 - Retirement of natural gas distribution grid in Zero Carbon Energy scenario leads to near elimination of methane leakage in this scenario
 - Some of these emissions, particularly in agriculture, are unlikely to be possible to fully mitigate, meaning there are **~33 MMT of non-energy emissions remaining** in all scenarios

Non-energy emissions by category: today, and in 2045 across scenarios





Carbon Dioxide Removal

- + All scenarios require **significant levels of carbon dioxide removal (CDR)**, with annual amount varying by scenario
- + This study **does not prescribe specific recommendations on CDR strategies**, but rather **highlights the necessity for them** and discusses the range of options, which includes **direct air capture with storage (DACCS)**, **bioenergy with carbon capture and storage (BECCS)**, and **natural and working lands strategies (NWL)**
 - These strategies are all uncertain in their future commercialization potential and cost, meaning that relying on them is risky
 - Additionally, direct air capture in particular requires **significant amounts of energy**, with ~500 MW of solar nameplate capacity required if solar is the energy source

Carbon Dioxide Removal: amount required in 2045, by scenario

High CDR	Balanced	Zero Carbon Energy
80 MMT CDR required	56 MMT CDR required	33 MMT CDR required