# Identifying a Least Cost CO2 Pathway

Charging Ahead Webinar

February 20, 2024

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# Speaker – Ezra Beeman, Energeia

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This webinar is being recorded and distributed to all registrants along with this presentation.

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# CO2 Targets and Outlooks

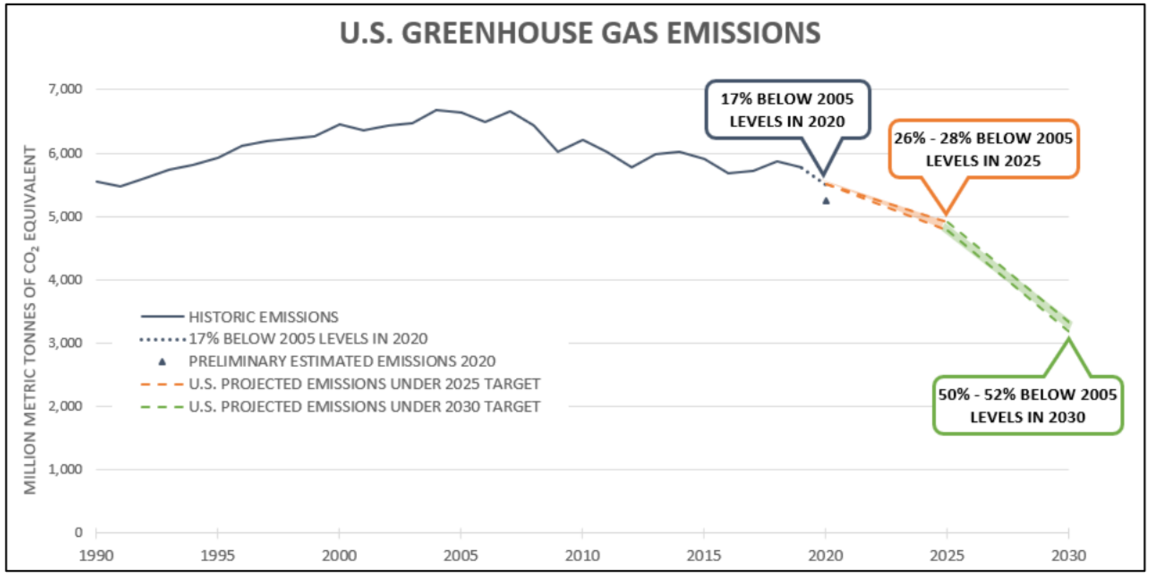
Targets

Current Emissions

Emissions Outlook

# Paris Agreement and the US

## US Historic and Projected Emissions Under 2030 Target



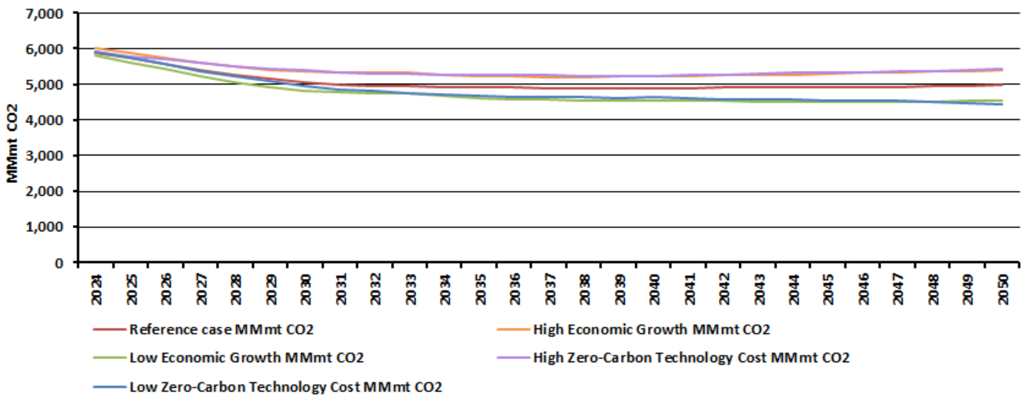

- The Paris Agreement targets limiting global warming below 2°C, with an additional goal to keep global temperatures below 1.5°C, from pre-industrial levels
- The US rejoined the Paris Agreement in 2021, signaling a commitment to global climate action
- US targets include a 50-52% reduction in 2005-level (baseline) emissions by 2030, and a net-zero goal for 2050
  - Energeia notes that the UNFCCC has modeled US targets to be insufficient to achieve those temperature goals
- Every 5 years, each country must submit a climate action plan, known as a Nationally Determined Contribution (NDC)
- The United States NDC highlights key roles for renewable energy, efficiency improvements, transport electrification, carbon capture, and aiming to curb methane emissions
- Some US States, which are detailed later, have committed to more ambitious emissions reduction targets

Source: United Nations Framework Convention on Climate Change (2022)

Source: The Paris Agreement, United Nations (2015)

# United States Emissions Projections

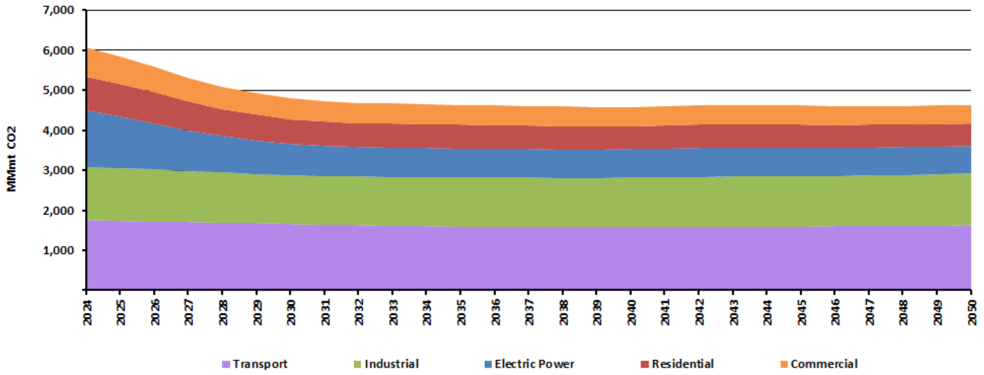
## US Baseline Emissions Projections by Scenario




Source: Energeia Research, US EIA (2022)

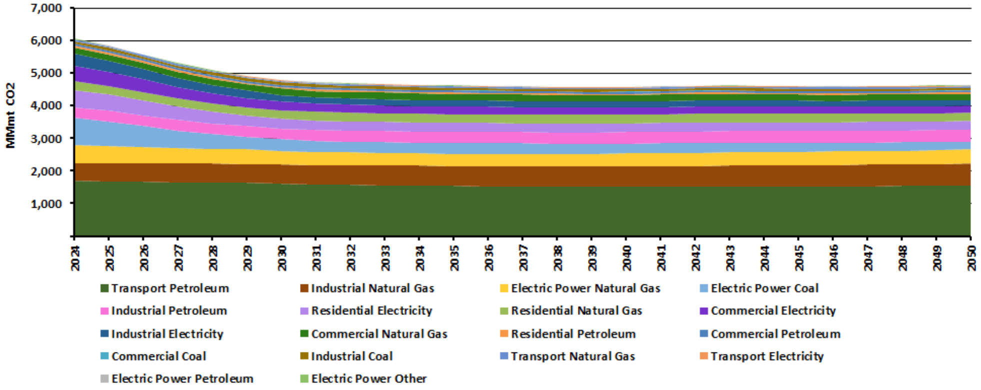
- Baseline US emissions projections show a steady increase or minimal change, even with high development and adoption of new technology
- Majority of US emissions from transport, coal, and residential and commercial end uses
- Transport emissions remain relatively constant throughout the forecast period

## Reference Case Emissions Projections by Sector




Source: Energeia Research, US EIA (2022)

## Reference Case Transport Projections by Sector and Fuel




Source: Energeia Research, US EIA (2022)

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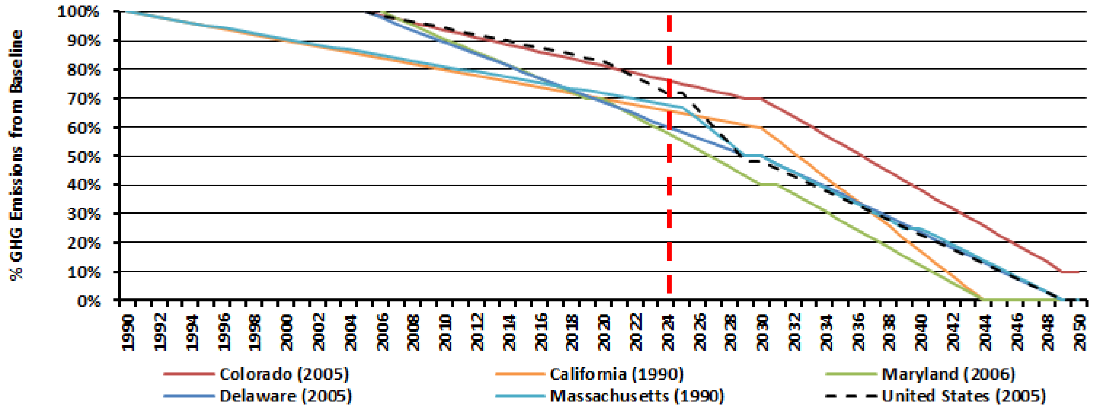
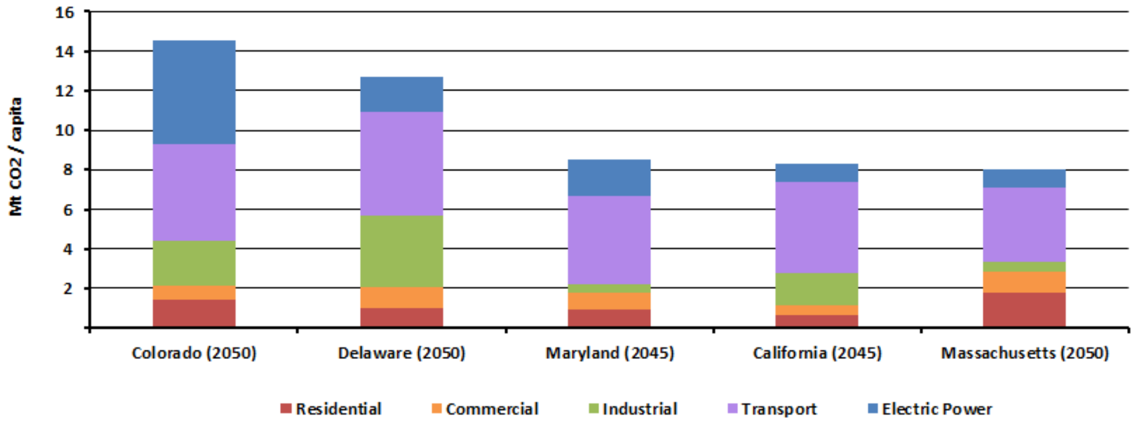
# United States CO2 Targets by Key State

## Leading State and Federal CO2 Targets




Note: legend includes "State" ("Baseline Year") = Current Year
Source: Energeia Research, US EIA (2022)

## Leading States Emissions per Capita by Sector




Note: labeling includes "State" ("Target Year")
Source: Energeia Research, US EIA (2022)

- The United States has adopted a trajectory to reduce emissions by 50-52% of 2005 baseline levels by 2030 under its NDC to the Paris Agreement
- The federal government has also developed a net-zero goal by 2050 via executive order[1], though this target was not included in its 2021 NDC
- State CO2 targets vary substantially in terms of baseline year, target sectors, and trajectory, with California, Colorado, Massachusetts, and Maryland undertaking some of the most comprehensive climate action plans, driven by state policy
  - States with most comprehensive CO2 roadmaps have been included, but may not represent the states with the most stringent targets
- *Key questions for policymakers and key stakeholders include how much each of these trajectories will cost to achieve and how costs can be minimized*

[1] Executive Order 14057: Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability

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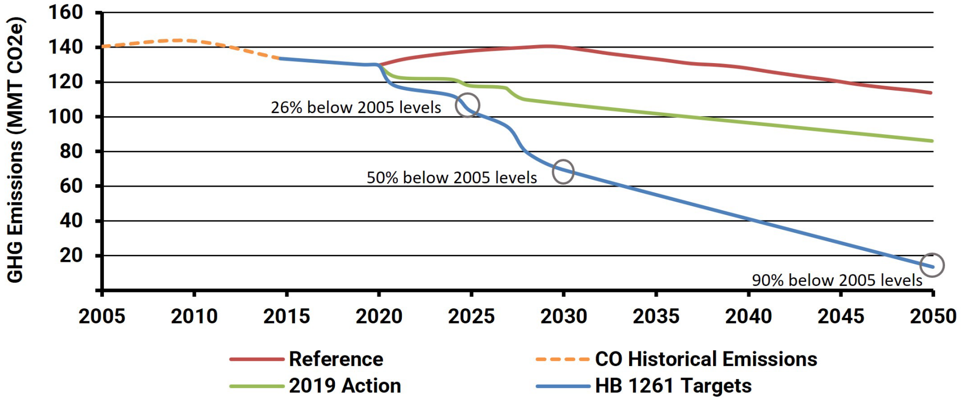
# Detailed Emissions Inventories by Sector – Colorado Example

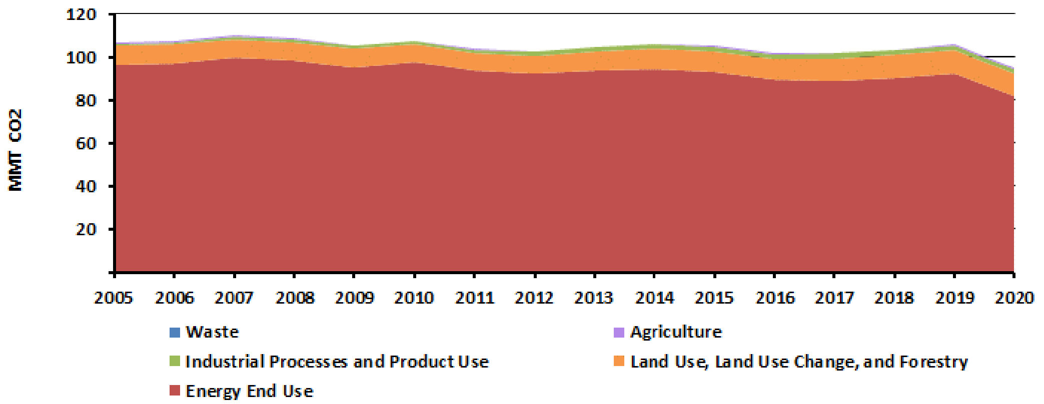
## Colorado's Potential Pathways to CO2 Targets




Source: Colorado Energy Office (2019)

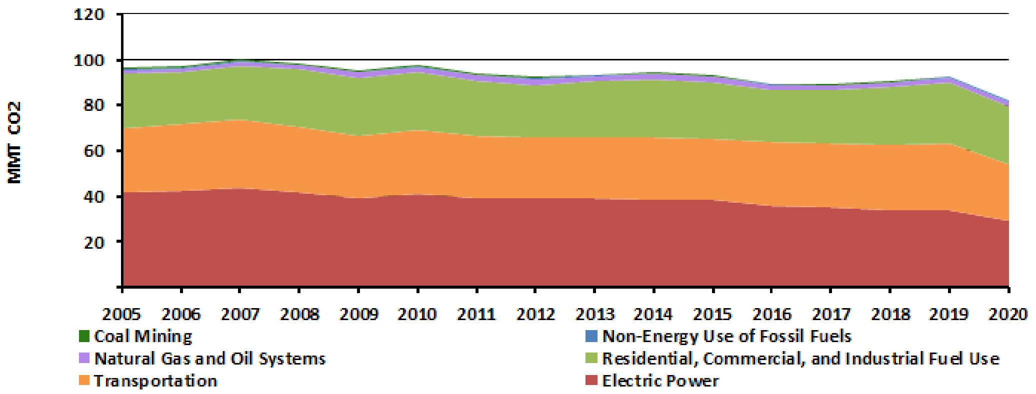
- Colorado translated international warming scenarios into emissions targets under HB19-1261, CO Climate Action Plan
- Detailed emissions inventories are being used to target key emitting sectors and inform policy
- Identifying the cost of reducing CO2 over time by sector, and how to minimize costs, requires detailed, segment level analytics

## Emissions Inventory by Sector




Source: Colorado Energy Office, Dept. of Public Health and Environment (2023)

## Emissions Inventory by End-Use Segment




Source: Colorado Energy Office, Dept. of Public Health and Environment (2023)

# Best Practice CO2 Pathways Modeling

Modeling Methodologies

Emission Sources

Abatement Options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# Best Practice CO2 Modeling – Emissions Sources

| Model Information | PATHWAYS | EnergyPathways | Pathways to Carbon Neutral NYC | cSim |
|---|---|---|---|---|
| Report Year | 2018 | 2022 | 2021 | 2022 |
| Report Jurisdiction | California | United States | New York City | User Specific |
| Developer | E3 | Evolved Energy Research (EER) | ICF | Energeia |
| **Buildings** | | | | |
| Residential | ✓ | ✓ | ✓ | ✓ |
| Commercial | ✓ | ✓ | ✓ | ✓ |
| Industrial / Productive | ✓ | ✓ | ✓ | ✓ |
| **Electricity** | | | | |
| Generation | ✓ | ✓ | ✓ | ✓ |
| Transmission | ✓ | ✓ | ✓ | ✓ |
| Imports / Exports | ✓ | ✓ | ✓ | ✓ |
| Renewables / DER | ✓ | ✓ | ✓ | ✓ |
| **Natural Gas** | | | | |
| Hydrogen | ✓ | ✓ | ✓ | ✓ |
| Synthetic Methane | ✓ | ✓ | ✓ | ✓ |
| Biofuels | ✓ | ✓ | ✓ | ✓ |
| Oil and Gas Extraction | ✓ | ✓ | ✓ | ✓ |
| Refining | ✓ | ✓ | ✓ | ✓ |
| **Transport** | | | | |
| Passenger Vehicles | ✓ | ✓ | ✓ | ✓ |
| Trucks | ✓ | ✓ | ✓ | ✓ |
| Buses | ✓ | ✓ | ✓ | ✓ |
| Rail | × | ✓ | ✓ | ✓ |
| Aviation | × | ✓ | × | ✓ |
| Marine | × | ✓ | × | ✓ |
| Military | × | ✓ | × | × |
| **Waste** | | | | |
| Landfills | × | ✓ | × | ✓ |
| Wastewater Treatment | × | ✓ | × | ✓ |
| Biological Treatment | × | × | × | × |

Source: E3 (2018), EER (2022), NYC (2021), Energeia (2023)

- Technology advances and investment have enabled highly granular, whole-of-system modeling of CO2 abatement costs and pathways

# Best Practice CO2 Modeling – Methodologies

| Model Information | PATHWAYS | EnergyPathways | Pathways to Carbon Neutral NYC | cSim |
|---|---|---|---|---|
| **Methodology** | | | | |
| Impact Assessment Methodology | Bottom-up, stock rollover model | Bottom-up, stock rollover model | Bottom-up, stock rollover model | Bottom-up, stock rollover model |
| Technology Adoption Methodology | User-defined scenario inputs | User-defined scenario inputs | User-defined scenario inputs | Calibrated demand function |
| Technology Adoption Drivers | Least cost or user defined | Least cost or user defined | Least cost or user defined | Technology costs, technology availability, demand function |
| **Key Outputs** | | | | |
| Annual Energy Demand | ✓ | ✓ | ✓ | ✓ |
| Annual Tech / Fuel Costs | ✓ | ✓ | ✓ | ✓ |
| Annual GHG Emissions by Sector | ✓ | ✓ | ✓ | ✓ |
| Hourly Energy Demand | ✓ | ✓ | ✓ | ✓ |
| Hourly Tech / Fuel Costs | ✗ | ✗ | ✗ | ✗ |
| Hourly GHG Emissions | ✗ | ✓ | ✗ | ✓ |

Source: E3 (2018), EER (2022), NYC (2021), Energeia (2023)

- Technology advances and investment have enabled highly granular, whole-of-system modeling of CO2 abatement costs and pathways
  - Only a few examples of this modeling have been published in detail, which are highlighted above
- All examples cover most sectors and segments, and report impacts by fuel, end-use, and customer segment basis
  - Best practice it to report on a spatial and hourly basis
- All methods use stock and turnover modeling to estimate CO2 abatement and linear optimization to identify least cost pathways
  - Best practice is to use customer behavior models to accurately forecast demand and the impacts of incentives

# Best Practice CO2 Modeling – Abatement Options

| Sector | CO2 Abatement Options | E3 | EER | NYC | cSim |
|---|---|---|---|---|---|
| Electricity | Renewable Energy (Solar, Wind) | ✓ | ✓ | ✓ | ✓ |
| | Renewable Storage | ✓ | ✓ | ✓ | ✓ |
| | Zero Carbon Combustion (H2, RNG) | ✓ | ✓ | ✓ | ✓ |
| | Fuel Cells (H2, RNG) | ✓ | ✓ | ✓ | ✓ |
| Transport | Battery-Electric | ✓ | ✓ | ✓ | ✓ |
| | H2 Fuel-Cell | ✓ | ✓ | ✗ | ✓ |
| | Plug-in Hybrid | ✓ | ✓ | ✓ | ✓ |
| | Renewable Diesel | ✗ | ✓ | ✗ | ✓ |
| | Hybrid Diesel | ✓ | ✓ | ✗ | ✓ |
| | CNG/LNG | ✓ | ✓ | ✗ | ✓ |
| Buildings | Air Source Heat Pumps | ✓ | ✓ | ✓ | ✓ |
| | Heat Pump Water Heaters | ✓ | ✓ | ✓ | ✓ |
| | Electric Boilers | ✗ | ✗ | ✓ | ✓ |
| | High Efficiency Gas Equipment | ✓ | ✓ | ✓ | ✓ |
| | Low-flow Water Fixtures | ✓ | ✓ | ✓ | ✓ |
| | Air Sealing | ✓ | ✓ | ✓ | ✓ |
| | Building Controls | ✗ | ✗ | ✓ | ✓ |
| | Lighting Upgrades | ✓ | ✓ | ✓ | ✓ |
| | Elevator and Building Management | ✗ | ✗ | ✓ | ✓ |
| | Insulation and Window Replacement | ✓ | ✓ | ✓ | ✓ |
| | Exterior Wall Insulation | ✓ | ✓ | ✓ | ✓ |
| Oil & Gas | Green Hydrogen | ✓ | ✓ | ✓ | ✓ |
| | Biofuels | ✓ | ✗ | ✓ | ✓ |
| | Synthetics | ✓ | ✓ | ✓ | ✓ |
| | RNG | ✗ | ✗ | ✓ | ✓ |
| Waste | Biomass | ✗ | ✓ | ✓ | ✓ |

Source: E3 (2018), EER (2022), NYC (2021), Energeia (2023)

- The scope of potential CO2 reduction options, including technologies, standards and incentives, are a key driver of optimization accuracy
- Modeling customer behavior is key to accurately estimating the impact of incentives on CO2 reduction measures where the measure is voluntary
- Voluntary measures are much easier to implement from a political perspective and enable optimization of the measure at the customer level
- Best practice assessments therefore include all key mitigation measures now and over time, as well as customer behavior modeling

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# A Case Study in Developing a Least Cost Pathway

Buildings

Transport

Power System

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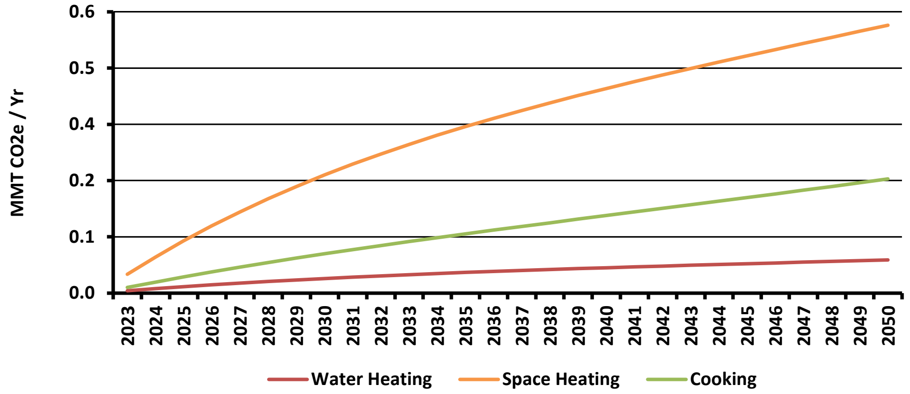
# Illustrative Building Sector CO2e Abatement Results

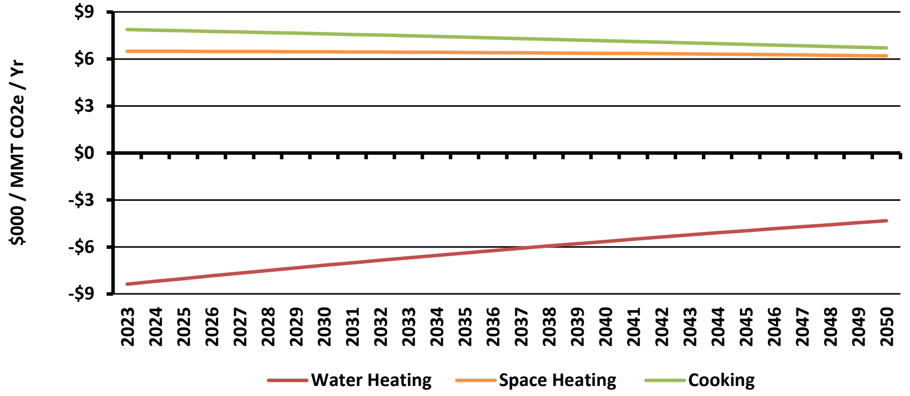
## Cumulative CO2 Supply Curve




Source: Energeia research and modeling

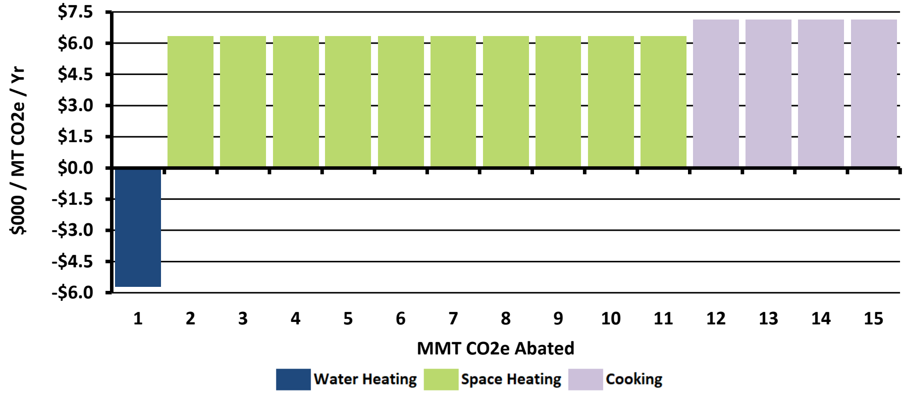
- Only emissions savings from gas appliances are considered
- The majority of buildings CO2e savings come from space heating
- Total natural gas emissions savings from buildings is estimated to be 15 MMT CO2e from 2022 to 2050
- The supply cost curve reports volume-weighted average cost per MT CO2e abated

## Annual Potential $/MMT CO2e Savings ($2021)




Source: Energeia research and modeling

## Cumulative CO2 Supply Curve




Source: Energeia research and modeling

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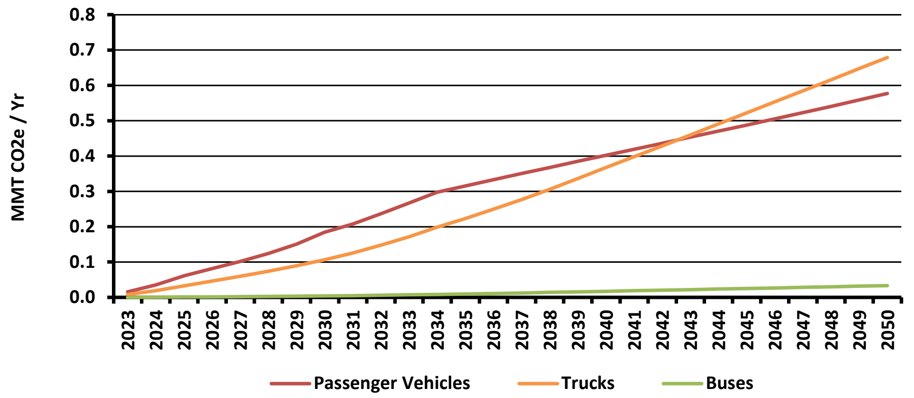
# Illustrative Transport Sector CO2e Abatement

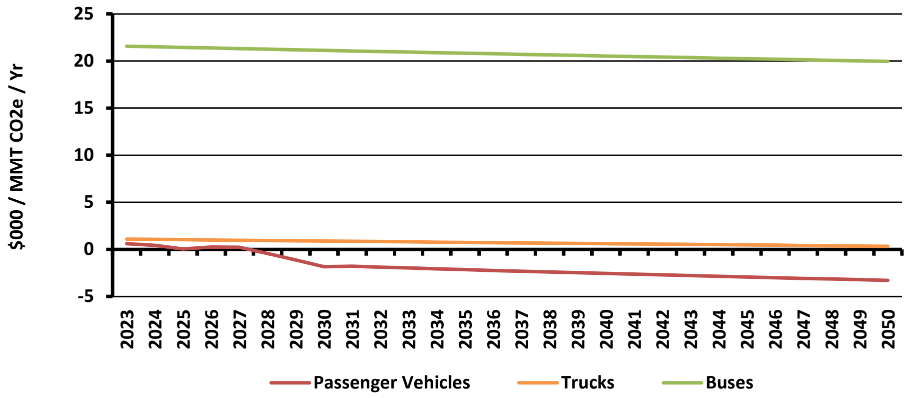
## Cumulative CO2 Supply Curve




Source: Energeia research and modeling

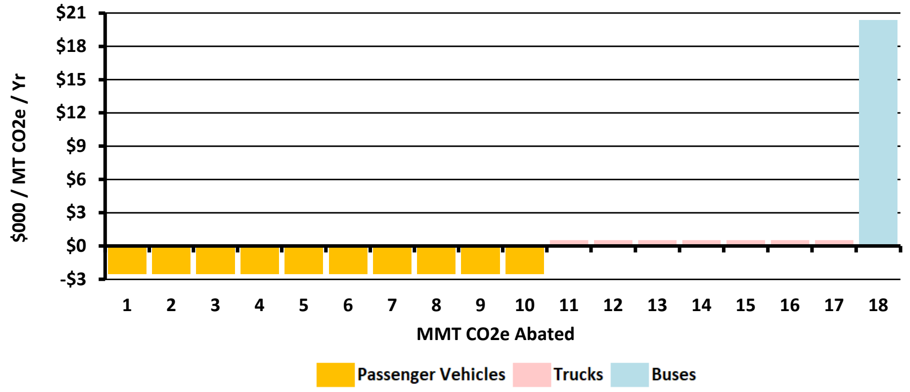
- Only gross (emissions from electricity excl.) emissions savings from internal combustion vehicles are considered
- Passenger vehicles and light and heavy trucks (trucks) contribute a nearly equal amount of emissions savings
- Buses are expected to incur the largest cost for emission abatement followed by trucks, then passenger vehicles
- Total emissions savings from transport is estimated to be 18 MMT CO2e from 2022 to 2050, slightly above buildings

## Annual Potential $/MMT CO2e Savings ($2021)




Source: Energeia research and modeling

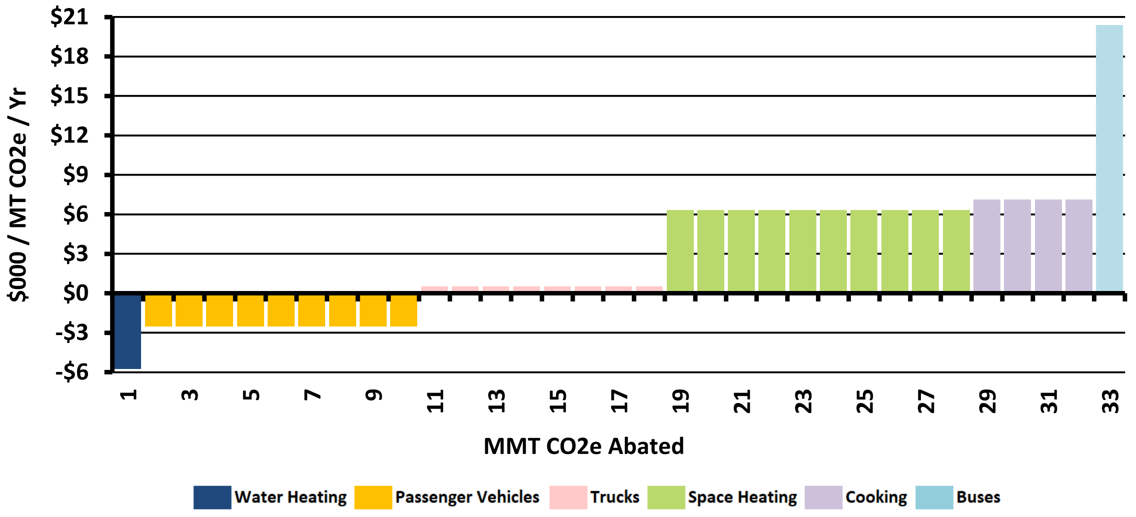
## Cumulative CO2 Supply Curve




Source: Energeia research and modeling

# Illustrative end-use CO2 Abatement – Key Insights

## Supply Cost Curve (Natural Gas and Oil GHG Only)



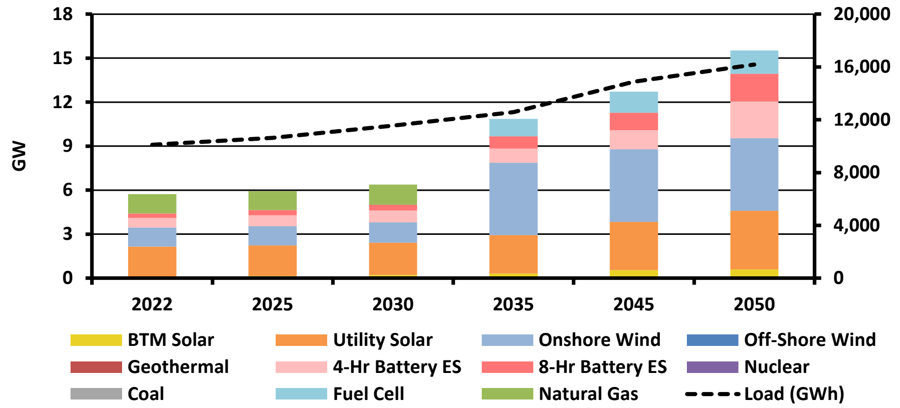

## Key Insights

- This chart shows the supply cost curve for CO2e abatement from the transport and building sectors
  - They reflect the avoided emissions from natural gas, gasoline, and diesel, depending on the sector
- Insights:
  - Water heating and passenger vehicles should be prioritized as expected to be economically positive
  - Cooking may want to focus on resistive technology to keep costs lower
  - R&D could be focused on bringing down the cost of heat pumps for space heating
  - Bus costs are likely to come down with battery costs and scale; consumers may benefit from back-ending their conversion

Source: Energeia research and modeling

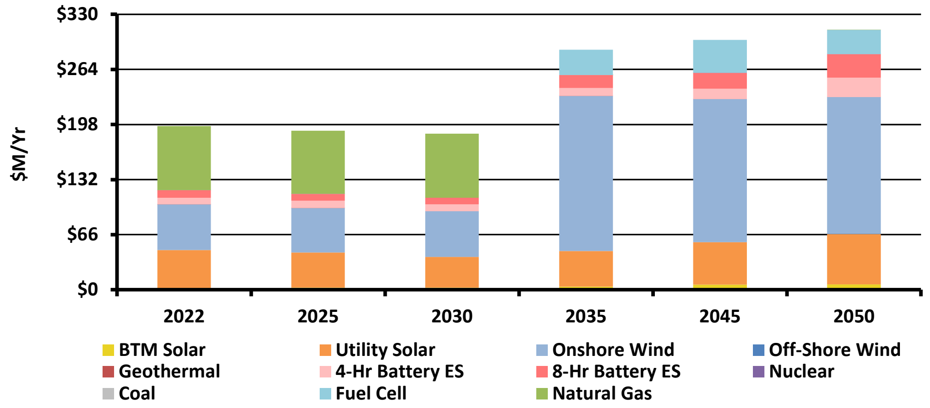
# Illustrative end-use CO2 Abatement – Key Insights

## Resource Portfolio Capacities by Year




Source: Energeia analysis

## Resource Portfolio Costs by Year




Source: Energeia analysis

- 27/4 zero carbon modeling showed utility scale to be to be significantly cheaper than BTM resources
  - BTM may be preferred for achieving social equity objectives
- Onshore wind and fuel cells expected to be least cost resource solution for the step to 100% zero carbon in 2035
  - Fuel cells represent a key technology risk as relatively immature
  - Significant additional storage will also be required
- *Costs expected to be lower if not 24/7, however, Energeia expects all jurisdictions will become 24/7 as annual accounting will not work if everyone does it*

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# Key Takeaways and Recommendations

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# Key Takeaways and Recommendations

- Key Takeaways
  - The Paris Accord requires periodic reviews of cost, and raising targets if costs fall
  - US targets may need to rise to meet Paris Accord agreement
  - Some states aiming higher than the Paris Accord, may increase targets if costs fall
  - Optimizing CO2 Pathways key to identifying sustainable, least cost CO2 Pathways at the state and federal level
  - Pathway modeling tools have improved, and now allow for more accurate modeling, including customer behavior
  - It is important that the modeling include changes to key cost drivers over time, especially emerging technology like heat pumps
- Key Recommendations
  - Develop a CO2 Pathways model that can be updated annually, using best available information
  - Include customer behavior as a key factor in voluntary pathways
  - Ensure the model factors in inter-sector impacts, e.g. electrification’s impact on the grid and workforce, etc.
  - Ensure the model enables identification of key cost drivers and mitigation strategies, to arrive at the least cost solution
  - Best practice CO2 Pathways models include spatial considerations important to grids and vulnerable customer segments

# Next Steps

Q&A

Follow-up

Webinar Series

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# Energeia's Charging Ahead Webinar Series

- Q&A
  - Add your questions in the chat
  - Unanswered questions will be answered via email
- Vote for your favorite Power Session webinar topic
  - The State of the Art in Virtual Power Plants
  - Public Charging Infrastructure Sizing
  - Minimizing the Cost of Solar PV Integration
  - Building a Resiliency Backbone with Microgrids
  - Best Practice Behind-the-Meter Forecasting

Reserve your place at the next **Charging Ahead** discussion

**Removing Building Electrification Barriers:**
*Costs, Grid Impacts, and Funding Strategies*

April 23, 2024
9:30 AM – 10:00 (PDT)

**Where to find Energeia and Ezra Beeman**

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**Watch for a follow-up email with recording and presentation links to share**

# Thank you!

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