Industrial Decarbonization with Thermal Energy Storage

Optimal Charging Strategy Case Studies

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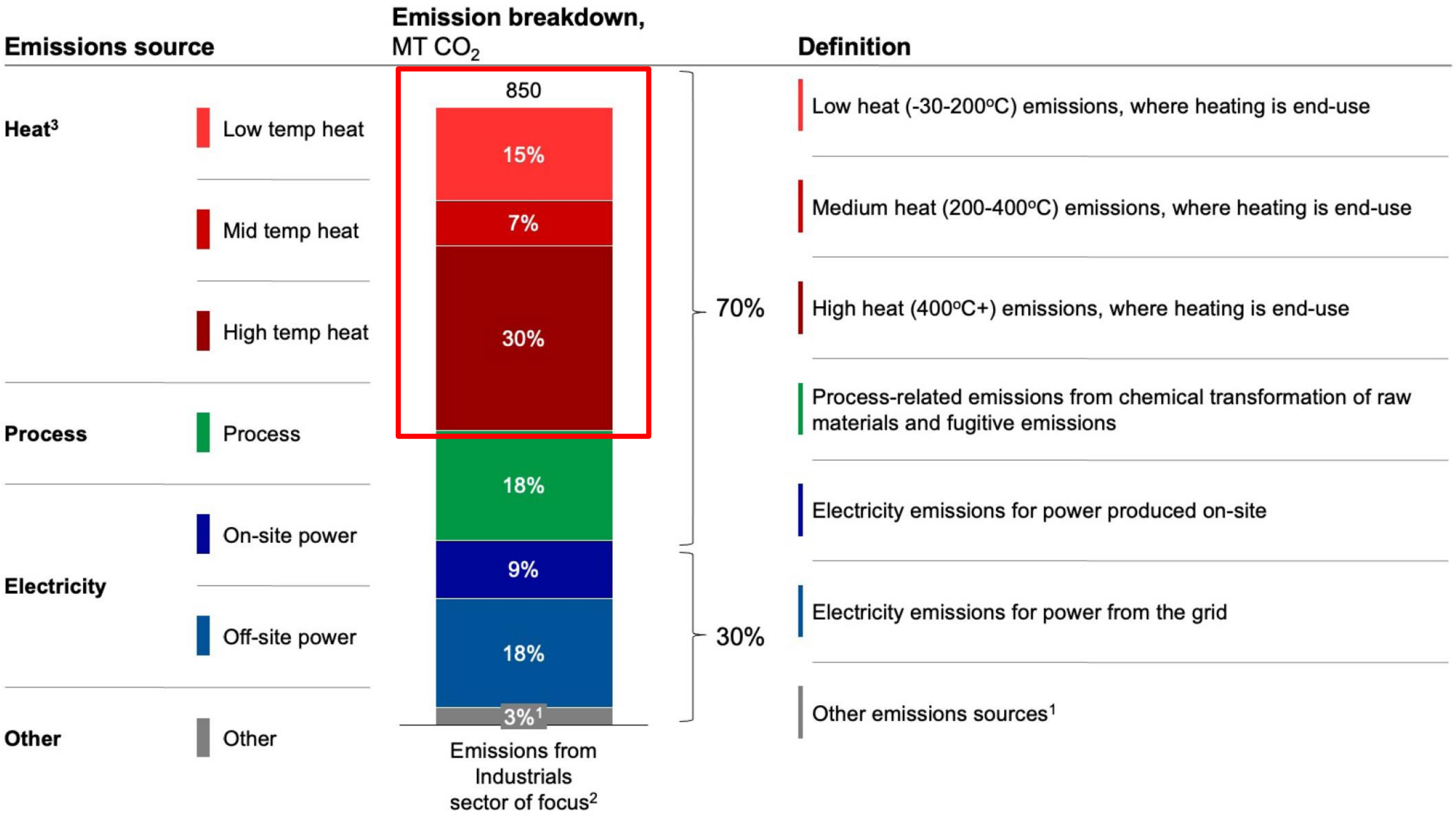
Emissions from Process Heat

Source: DOE Pathways to Commercial Liftoff: Industrial Decarbonization, 2023

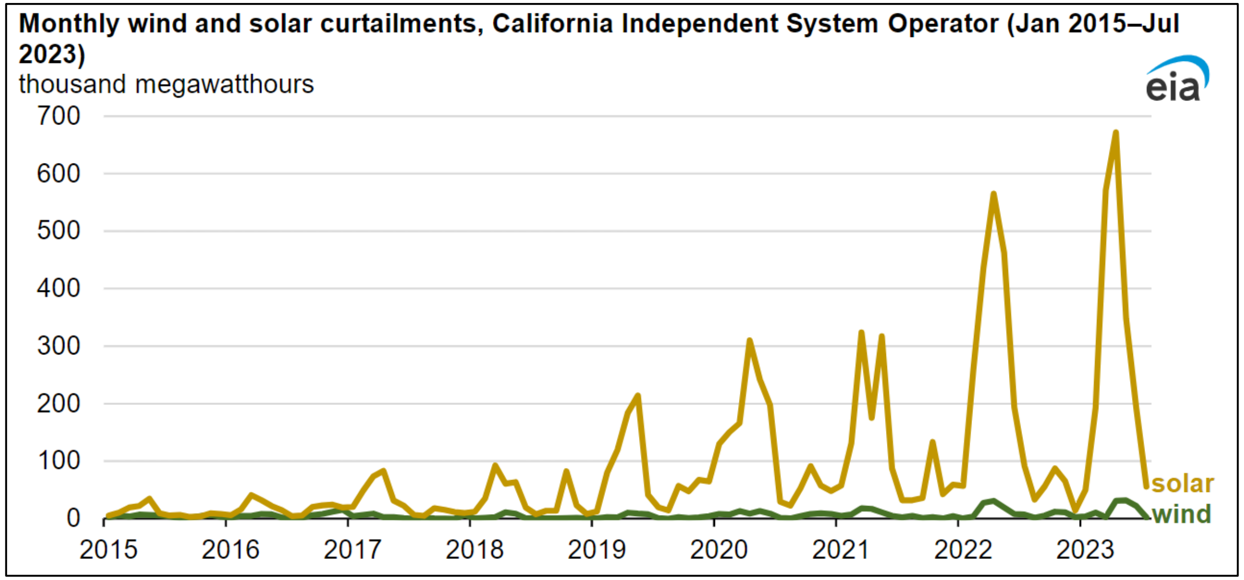
- Many industrial processes are driven by high temperatures achieved via combustion of fossil fuels
- There is an opportunity to use thermal energy storage (TES) to electrify and decarbonize a wide variety of industrial processes
- Two key trends are converging:
  - TES technologies are being developed that can store heat at temperatures high enough for industrial processing
  - Low-carbon, low-cost electricity is becoming increasingly available. TES can be charged intermittently with electrical heaters and discharged continuously to produce a steady output of heat.



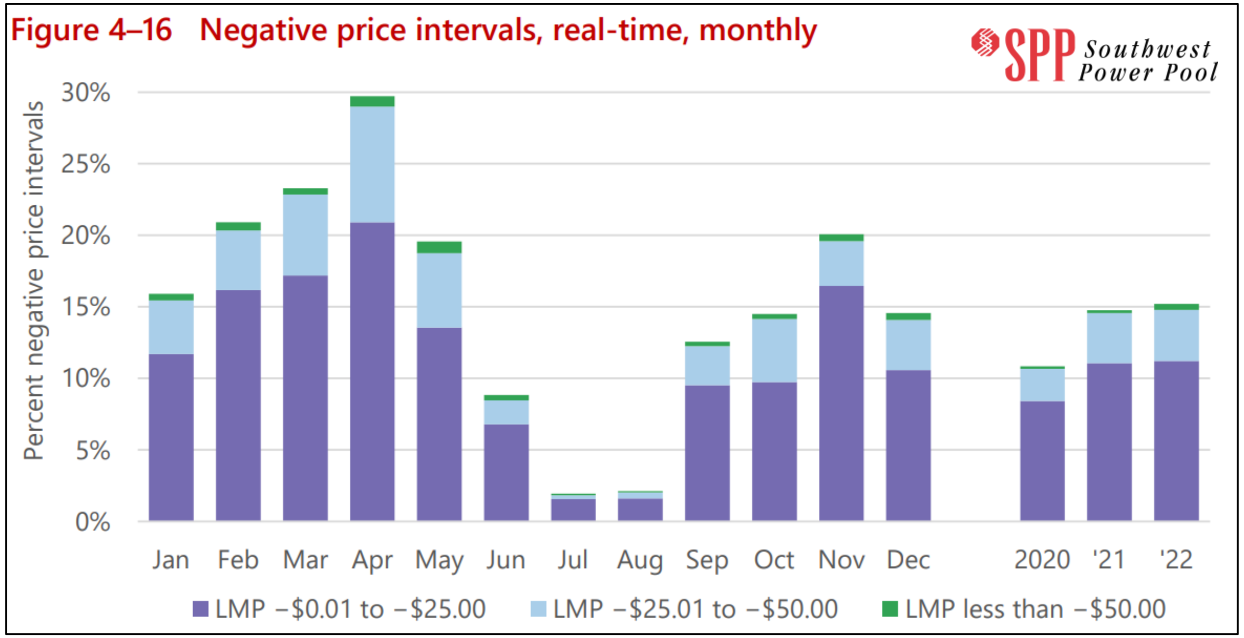
Emissions from heating represent 52% of U.S. industrial emissions

Low-Carbon, Low-Cost Energy Trends

More generation and curtailment of renewable electricity



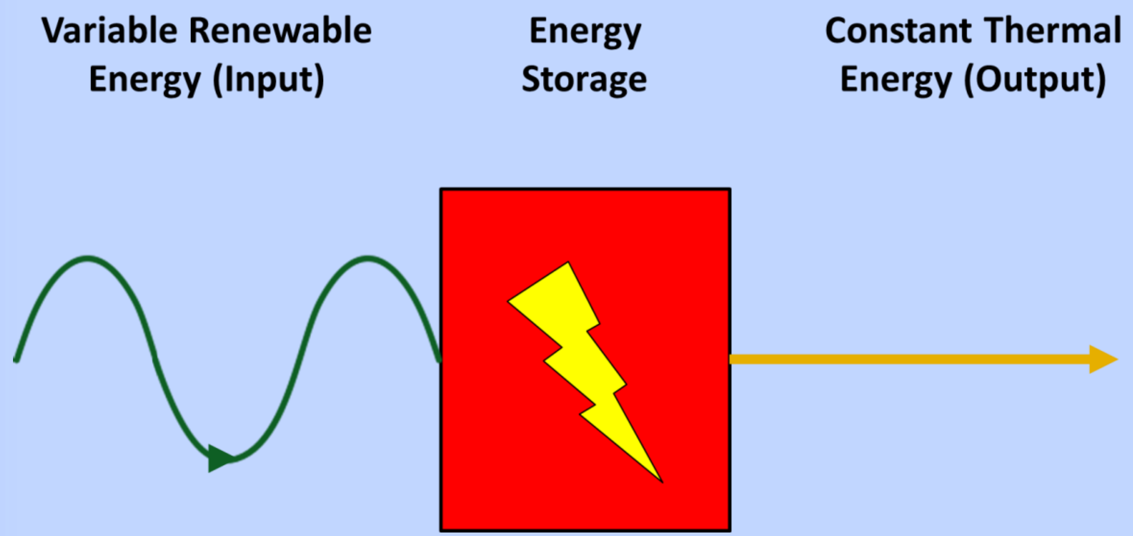
More hours of negative energy prices in California, the Midwest, Europe, and other regions



Using Low-Carbon Electricity + TES for Decarbonization

Key Questions

1. How do you charge with low-carbon and low-cost electricity?
2. How do you store the energy effectively?
3. How do you deliver the stored energy to the desired process?
4. How is the carbon intensity and cost of electricity expected to change in the future?



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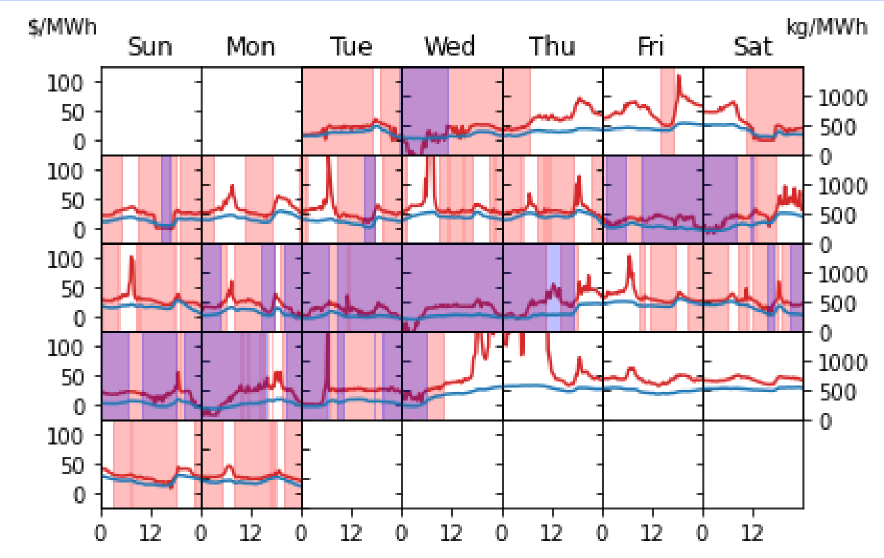
Proposed Solution

- Develop a charging strategy to minimize carbon intensity and energy cost

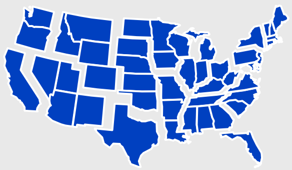


EPRI

Approach

Scenarios: Zero Emissions in Power Sector by 2035

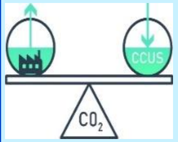
REFERENCE



On-the-books federal and state electric sector policies and incentives.

POLICY

NET ZERO

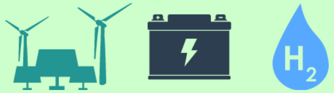


Net carbon emissions in 2035 equal zero. Any emissions produced from operations are balanced by an equivalent amount of carbon removal.

POLICY

100% RENEWABLES

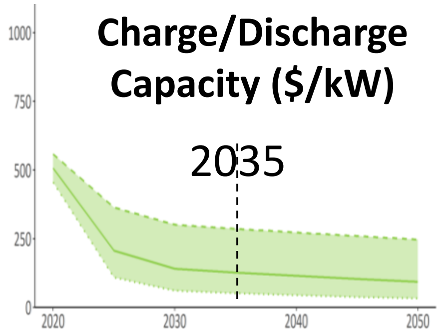
Electricity generation from only renewables by 2035.

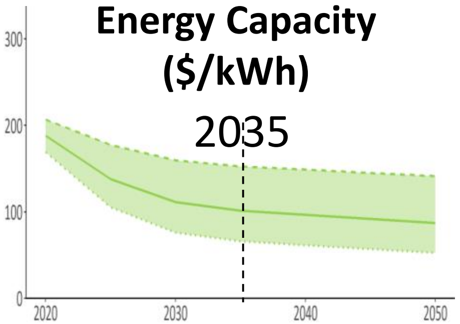


STORAGE COSTS

Reference / Optimistic

(storage technology costs varied simultaneously)





WEATHER YEAR

Base: meteorological data from 1999 (mild summer and winter temps)

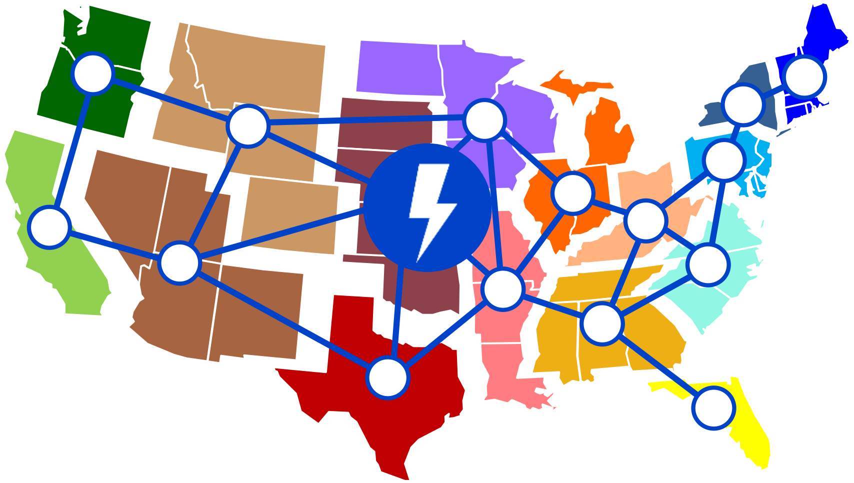
Worst Event: synthetic year of region-specific scenarios with low VRE resource

Net Zero scenario used for this study

US-REGEN

Regional Economy, GHG, and Energy

Electric Generation



Detailed representation of:

- Energy and capacity requirements
- Renewable integration, transmission, storage
- State-level policies and constraints

Synchronized

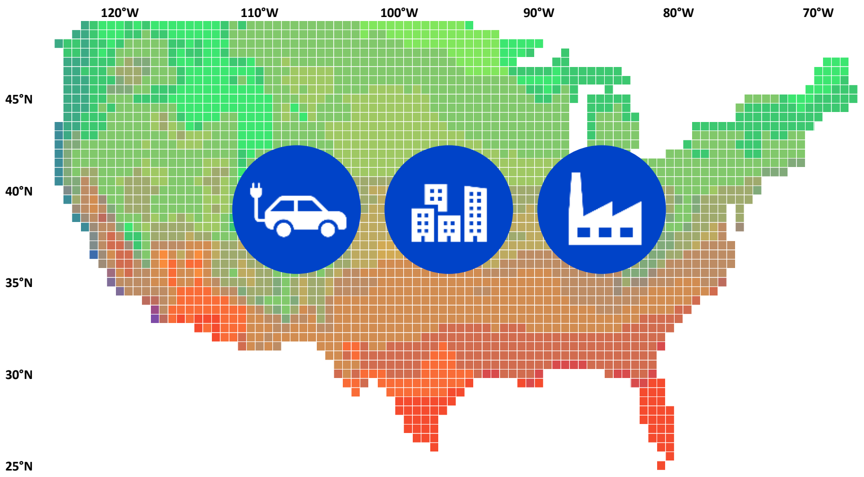
Hourly Load, Renewables, and Prices

Model Outputs:

Economic equilibrium for generation, capacity, and end-use mix

Emissions, air quality, and water

Energy Use



Detailed representation of:

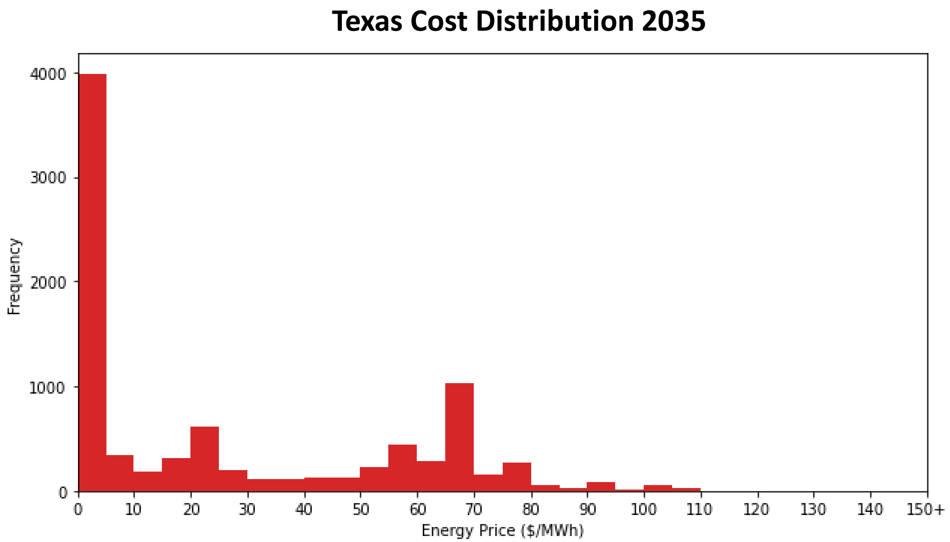
- Customer heterogeneity across end-use sectors
- End-use technology trade-offs
- Electrification and efficiency opportunities

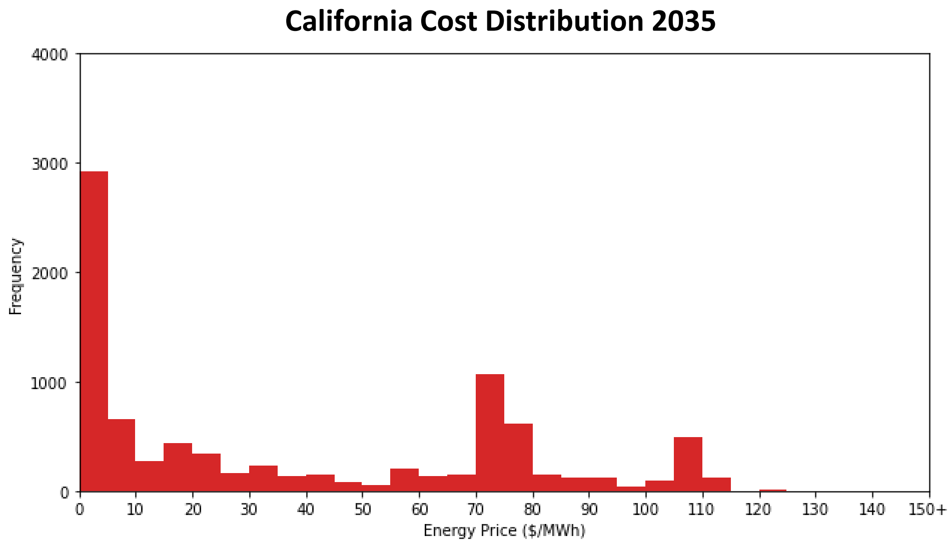
Documentation, articles, and reports available at https://esca.epri.com

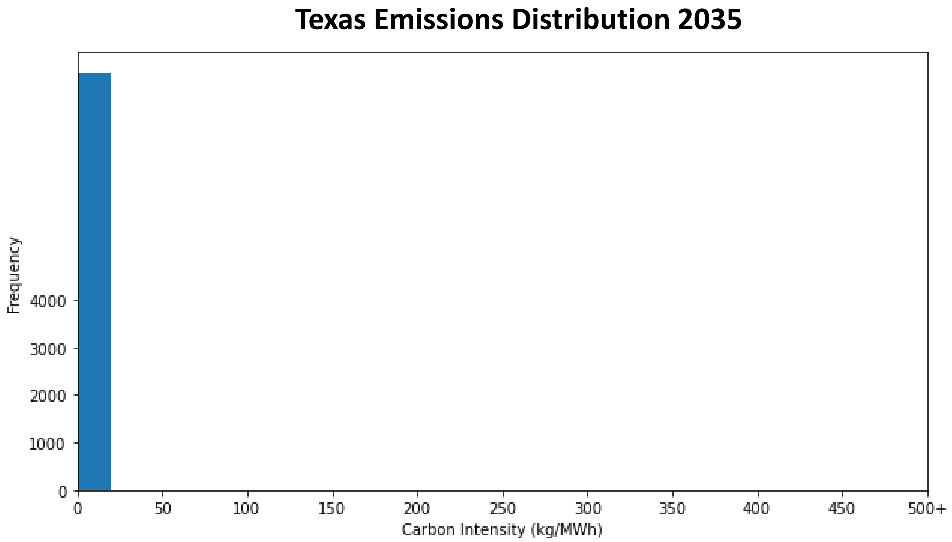
Approach Using US-REGEN Model

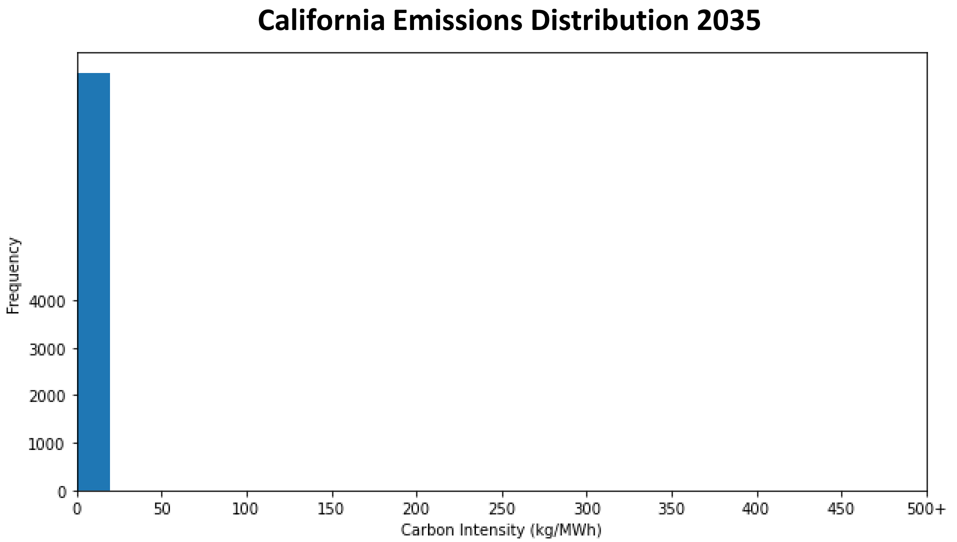
Energy Price ($/MWh)
Carbon Emissions (kg/MWh)

- Use projected 2035 wholesale energy price and carbon emissions data modeled with US-REGEN as described in recent EPRI report "Energy Storage Deployment and Dispatch in Decarbonization Scenarios"
- Assign a cost to the carbon emissions
- Size a representative TES system
- Develop an algorithm to minimize the cost of charging energy + emissions while maintaining continuous thermal output



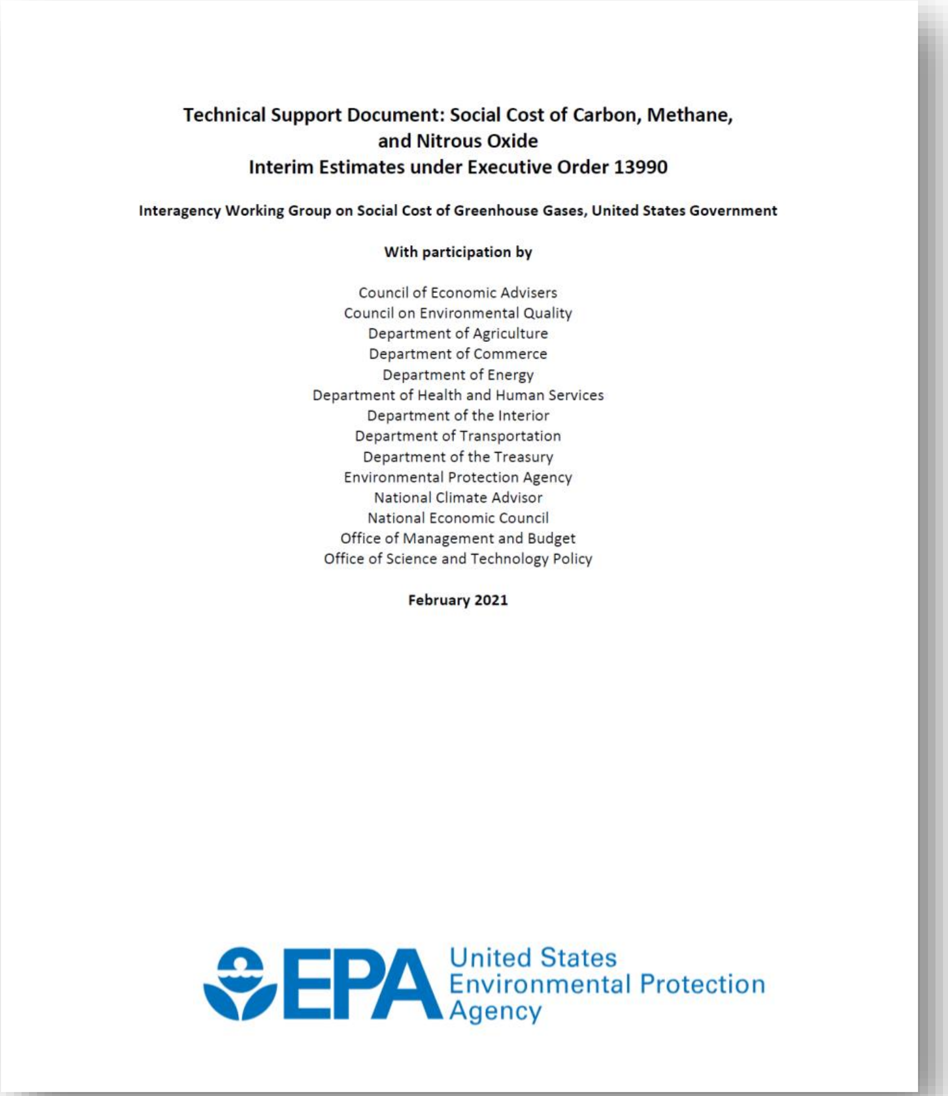






Social Cost of Carbon

- U.S. Government publication calculated social cost of carbon emissions by discounting future costs to the present
- Emissions in 2035 were calculated to cost a nominal $144/tonne
- These costs were applied to the emissions resulting from natural gas combustion or the embodied carbon intensity of the electrical energy used for charging the TES system



Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide
Interim Estimates under Executive Order 13990

Interagency Working Group on Social Cost of Greenhouse Gases, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Health and Human Services
Department of the Interior
Department of Transportation
Department of the Treasury
Environmental Protection Agency
National Climate Advisor
National Economic Council
Office of Management and Budget
Office of Science and Technology Policy

February 2021

EPA United States Environmental Protection Agency

EPRI

System Sizing

Storage (with representative TES technology)

- 50 MW thermal discharge rate (171 MMBtu/hr
- Resistive heater with 3:1 charge/discharge ratio (150 MW charge rate)
- 36 hour discharge duration (1800 MWh)
- 1% heat loss per day
- $62/kWh installed cost
  - Includes equipment, materials, labor, and engineering cost
  - Excludes contingencies
- 90% round trip efficiency (thermal energy delivered / electrical energy input)
- 7% weighted average cost of capital, 30 year asset life

Electrification

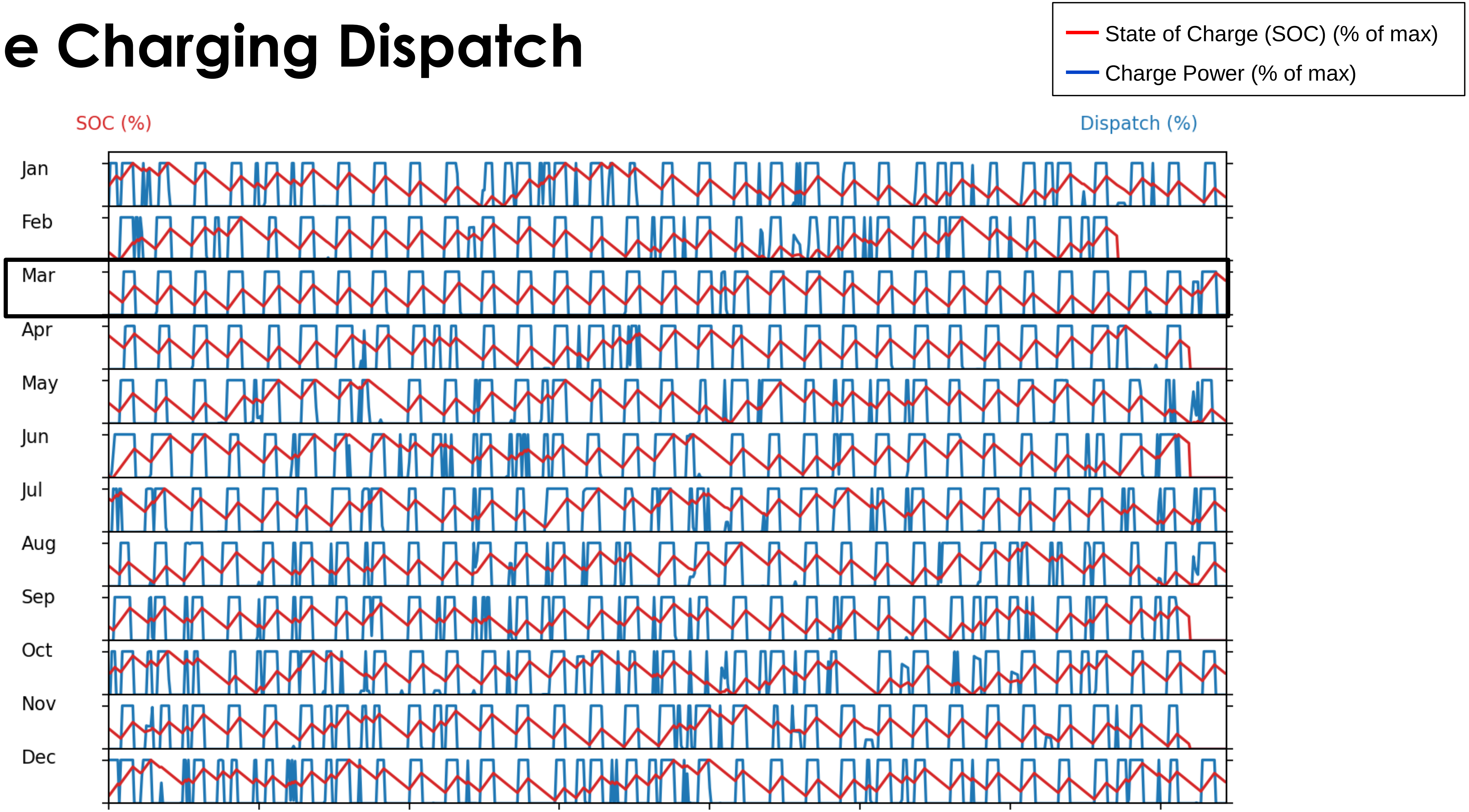
- 50 MW electrode boiler (E-boiler)
- Runs continuously so must buy electricity at wholesale price each hour
- $360/kW installed cost
- 7% weighted average cost of capital, 30 year asset life

Fuel

- 50 MW gas-fired boiler (171 MMBtu/hr)
- 85% efficiency (thermal energy delivered / fuel energy input)
- Natural gas cost of $5/MMBtu in 2035 (EIA AEO 2022 projections)
- Assume boiler is currently installed (neglect capital costs)

Results

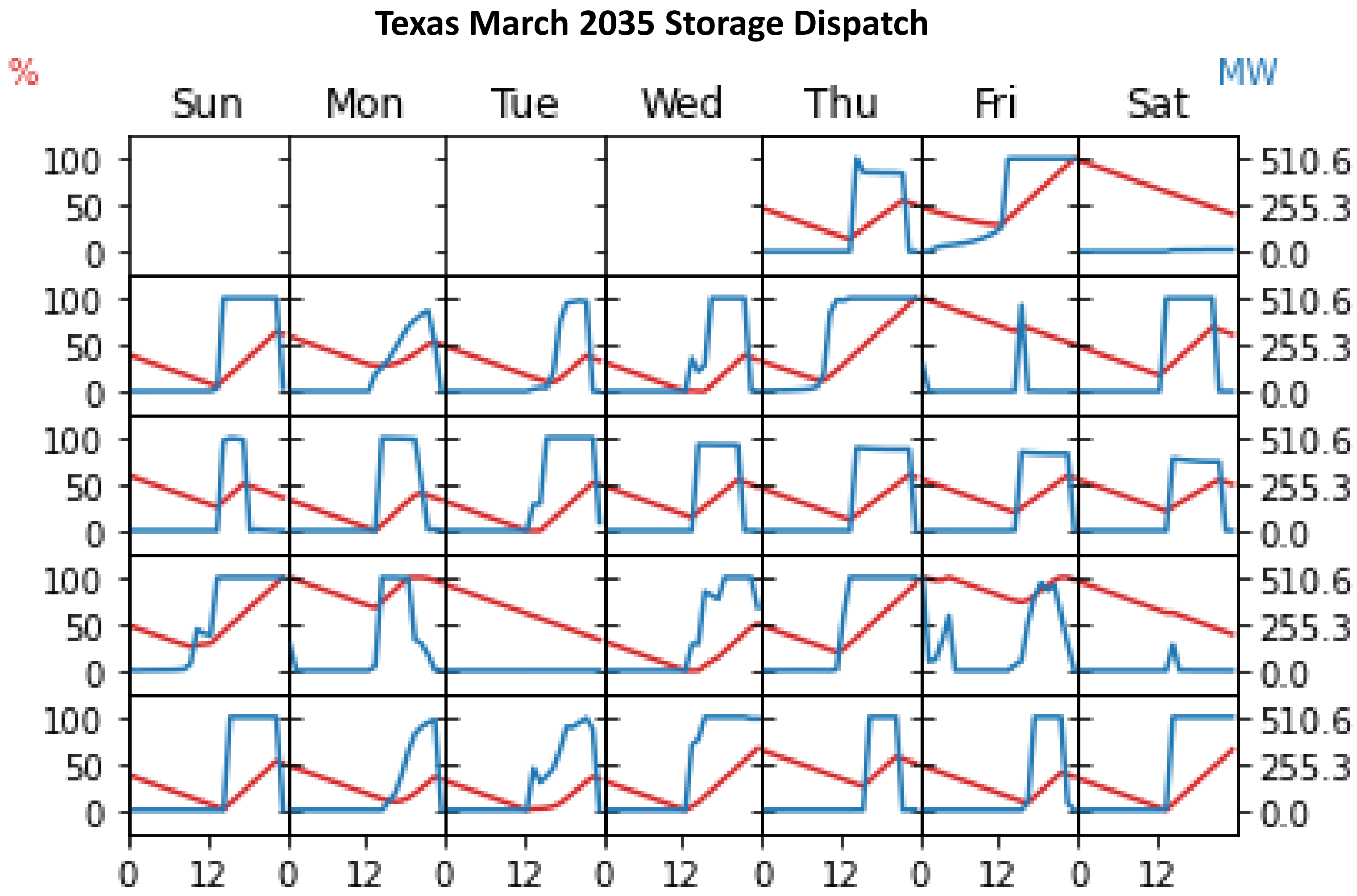
Example Charging Dispatch



TES charges daily, manages state of charge as needed

Example Charging Dispatch

State of Charge (SOC) (% of max)
Charge Power (% of max)

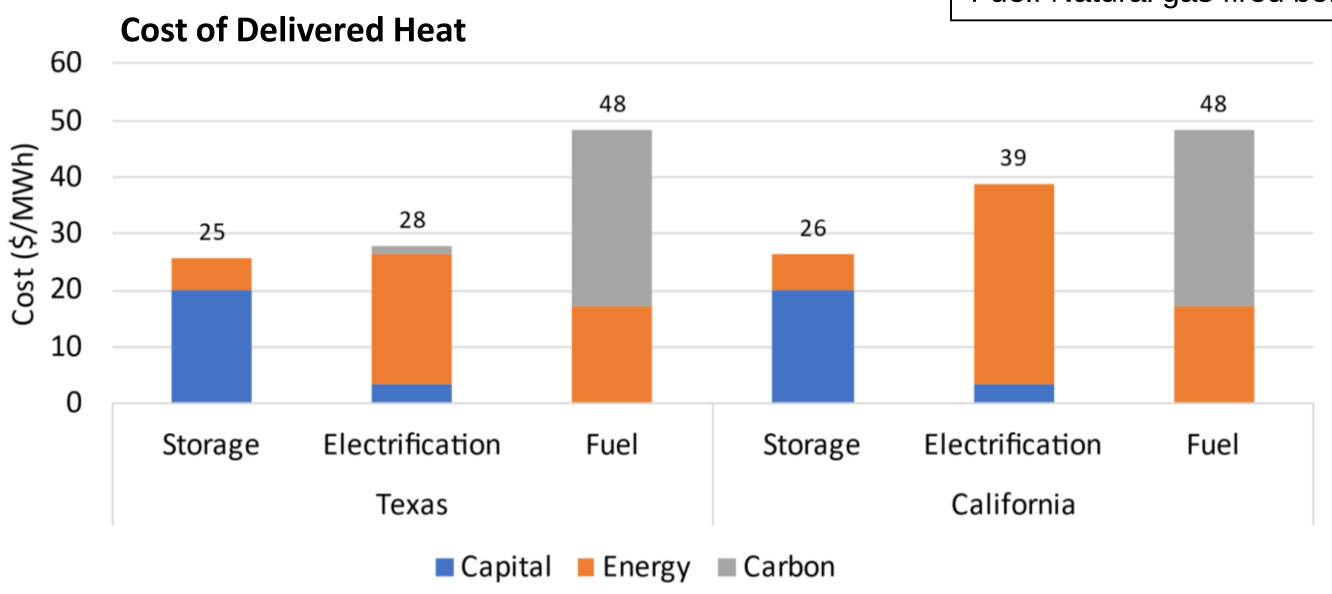


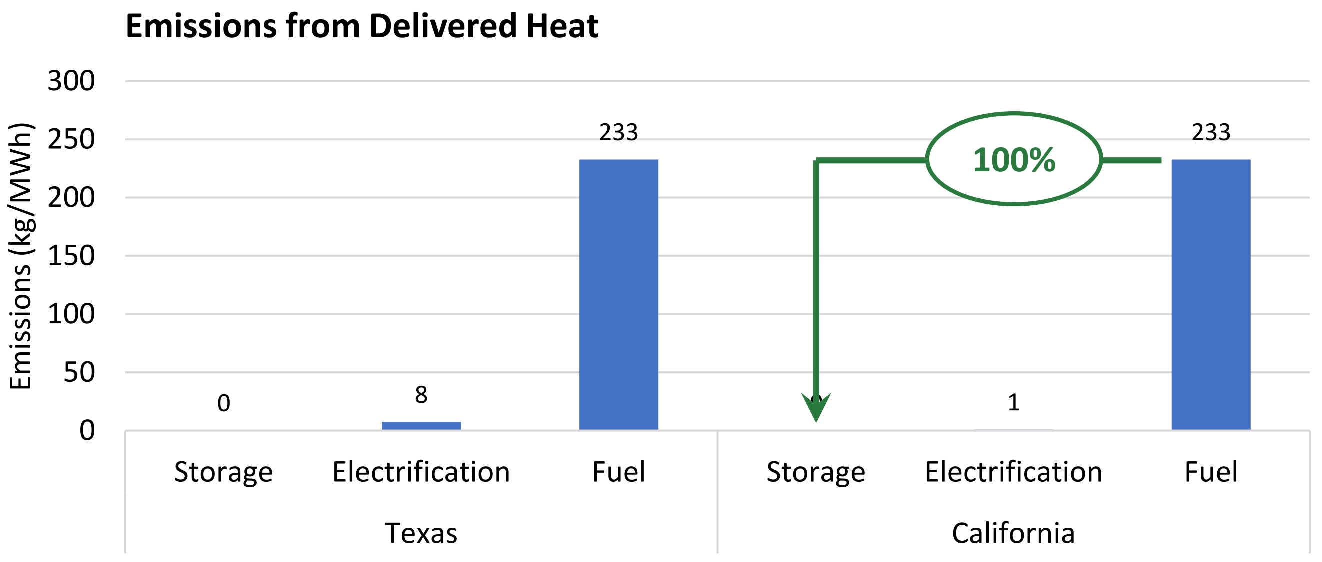
TES charges daily, manages state of charge as needed

Cost and Emissions

Storage: Resistive heater with TES
Electrification: E-boiler, no TES
Fuel: Natural gas fired boiler

- Decarbonization with TES is lowest-cost option for delivered heat
- Higher capital cost is outweighed by energy savings vs. electrification with E-boiler
- The TES approach has similar costs in Texas and California
- TES approach allows elimination of carbon emissions due to use of carbon-free electricity
- Electrification with an E-boiler is higher cost in California than Texas due to higher energy costs





Conclusions

- It may be possible to decarbonize industrial processes at lower cost vs. natural gas in some future scenarios, assuming there is a cost assigned to carbon emissions
- Without assigning a cost to carbon emissions, burning natural gas will remain lower cost than electrification with or without TES
- The economics of decarbonization with TES are driven by the availability and timing of low-cost, low-carbon electricity
- The capital cost of the TES system outweighs the cost of electrical energy for charging
- The relative favorability of decarbonization with TES varies by region. Site-specific case studies should be done.

Continued work with government and industry funding

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