US Industrial Decarbonization Pathways

Electrification & Indirect Electrification

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LCRI - End Use TSC Leader

US DOE-IEDO Industrial Decarbonization Workshop
May 14-15, 2024

www.epri.com

Agenda

- Introduction
  - EPRI and LCRI
- Industrial Decarbonization Analytics
  - Boilers
  - Other Process Heat
- Decarbonization Pathway Optionality
- Economy-Wide Infrastructure Considerations
- Impact of Recent Policy
- Appendix
  - Other Important Considerations
  - LCRI Overview
  - Hydrogen & Low-carbon Fuels for Power Generation

EPRI and LCRI

EPRI

Leading Global Collaborative Energy R&D

EPRI is advancing energy technologies and informing decision-making through ~$420M in collaborative annual research with more than 450 entities in 45 countries – spanning the production, delivery, and use of energy.

Independent

Non-Profit

Collaborative

www.EPRI.com

EPRI

Low-Carbon Resources Initiative

FOCUS

Multiple options and solutions to establish viable low-carbon pathways

Technologies for hard-to-decarbonize areas of the energy economy

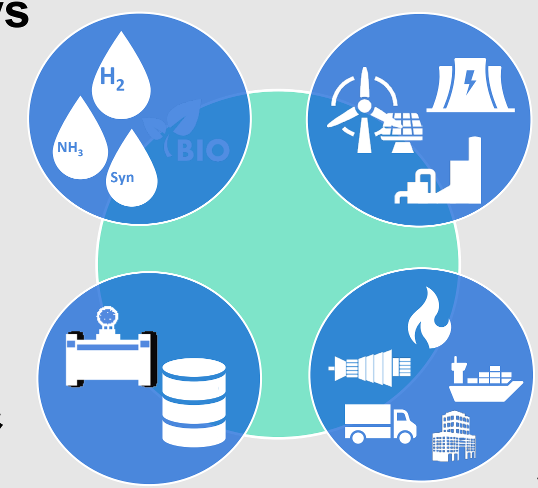
Affordable, reliable, and resilient integrated energy systems for the future

RESEARCH AREAS

Hydrogen | **Ammonia** | **Synthetic/ Derivative Fuels** | **Biofuels**

Production Pathways

Integrated Energy Systems



Storage & Delivery

End Use Applications

VALUE

Independent, objective research leveraged by global engagement and collaboration

Comprehensive approach to low-carbon value chain and technology analyses

High-impact results from technology evaluations, and safety, environmental, and economic assessments

Evaluating Hydrogen's Role | Where does it play and what does it cost?

Economy-Wide Modeling

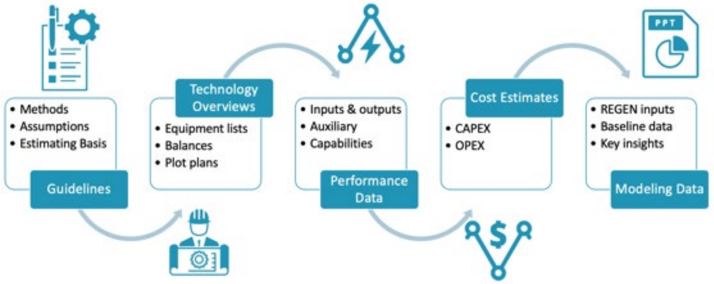
Developing energy-economy models allowing analysis of how economy-wide energy policies and technological improvements impact electric demand and load shapes. More details here.

U.S. 2050 Net-Zero Analysis

www.lowcarbonLCRI.com/netzero

Techno-Economic Analyses

Creating standardized cost and performance tools that support technology evaluations and trend analysis.

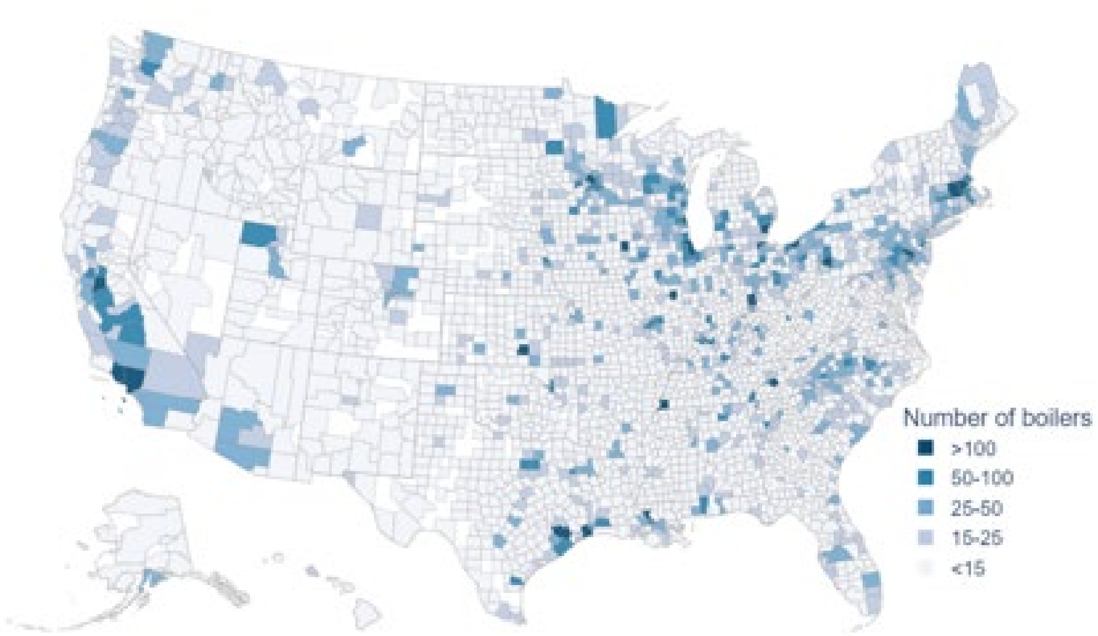


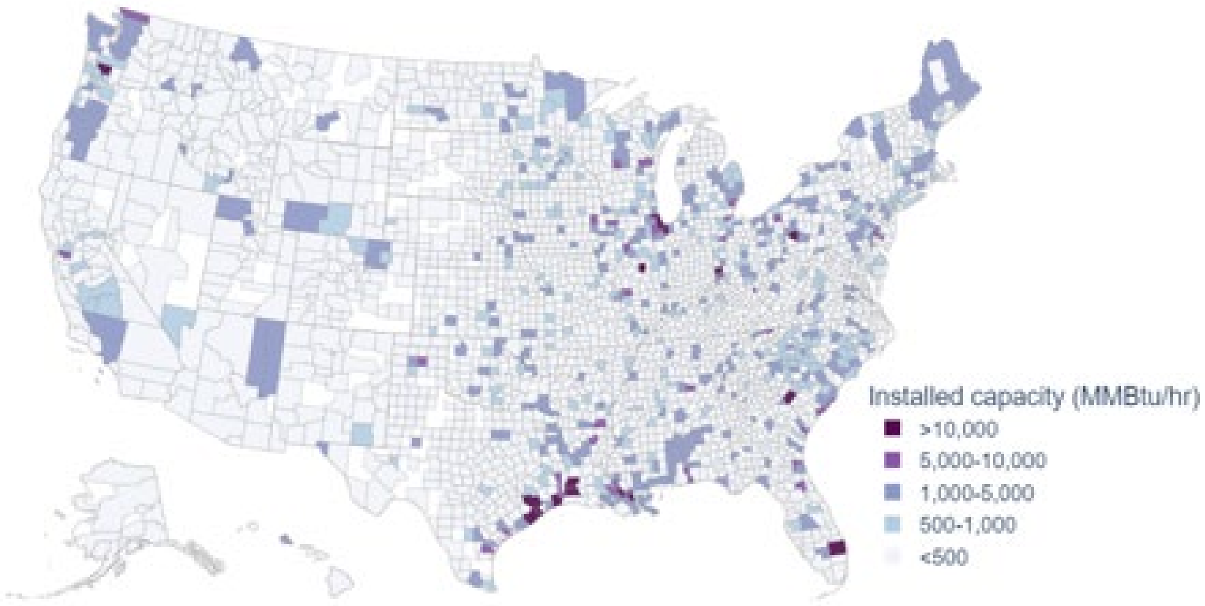
End Use Application Potential

Identifying and quantifying trade-offs between end-use technologies and fuels for a wide range of disaggregated sectors and activities with economy-wide coverage. Evaluations of the total cost of each option. More details here.

Industrial Analytics: Boilers

Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen



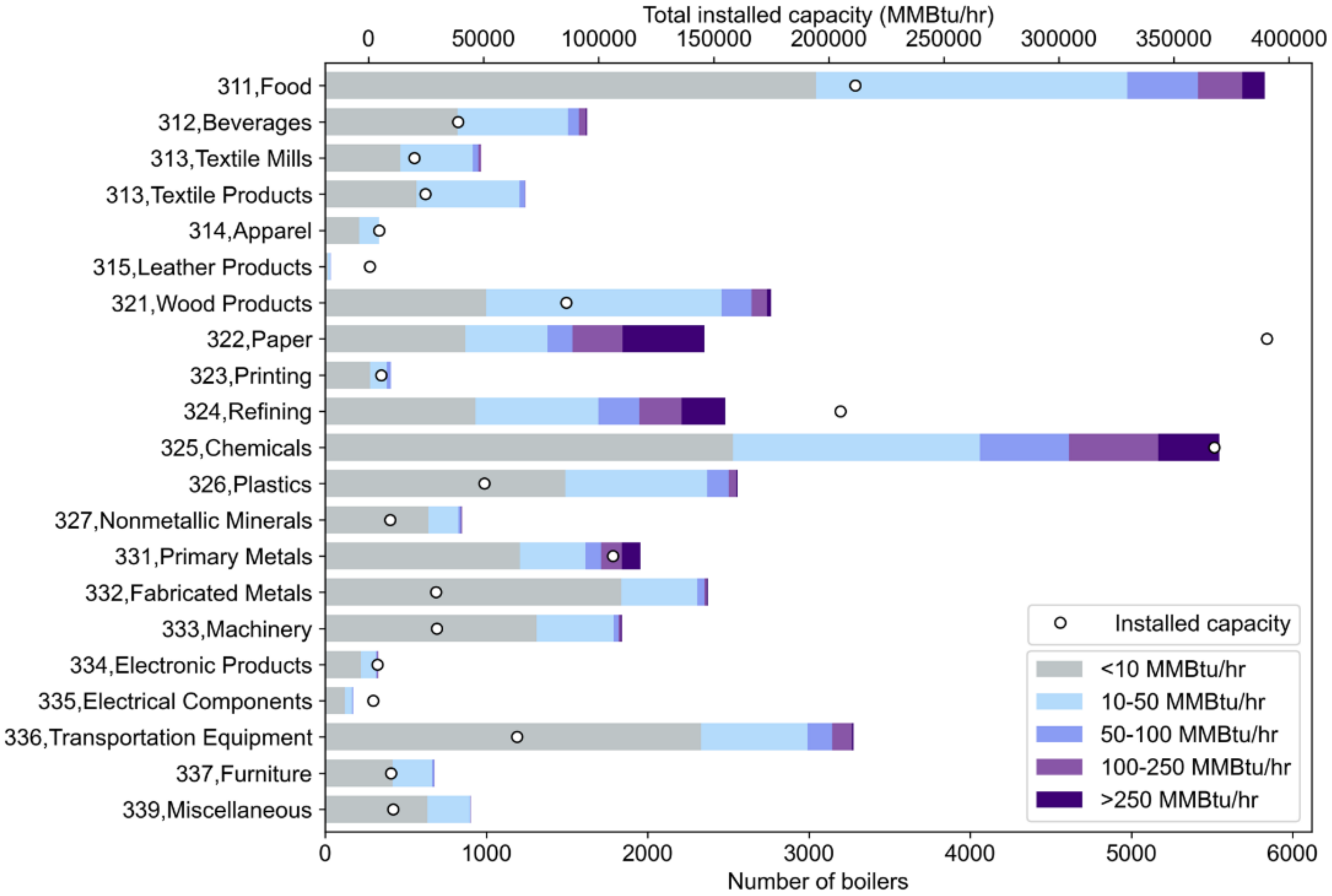


Schoeneberger, C., Zhang, J., McMillan, C., Dunn, J. B., & Masanet, E. (2022). Electrification potential of U.S. industrial boilers and assessment of the GHG emissions impact. *Advances in Applied Energy*, 5, 100089. https://doi.org/10.1016/j.adapen.2022.100089

Energy and Environmental Analysis, Inc., "Characterization of the U.S. Industrial/Commercial Boiler Population, "U.S. DOE, Oak Ridge National Lab- oratory, 2005. [Online]. Available: https://www.energy.gov/sites/prod/files/2013/11/f4/characterization_industrial_commerical_boiler_population.pdf .

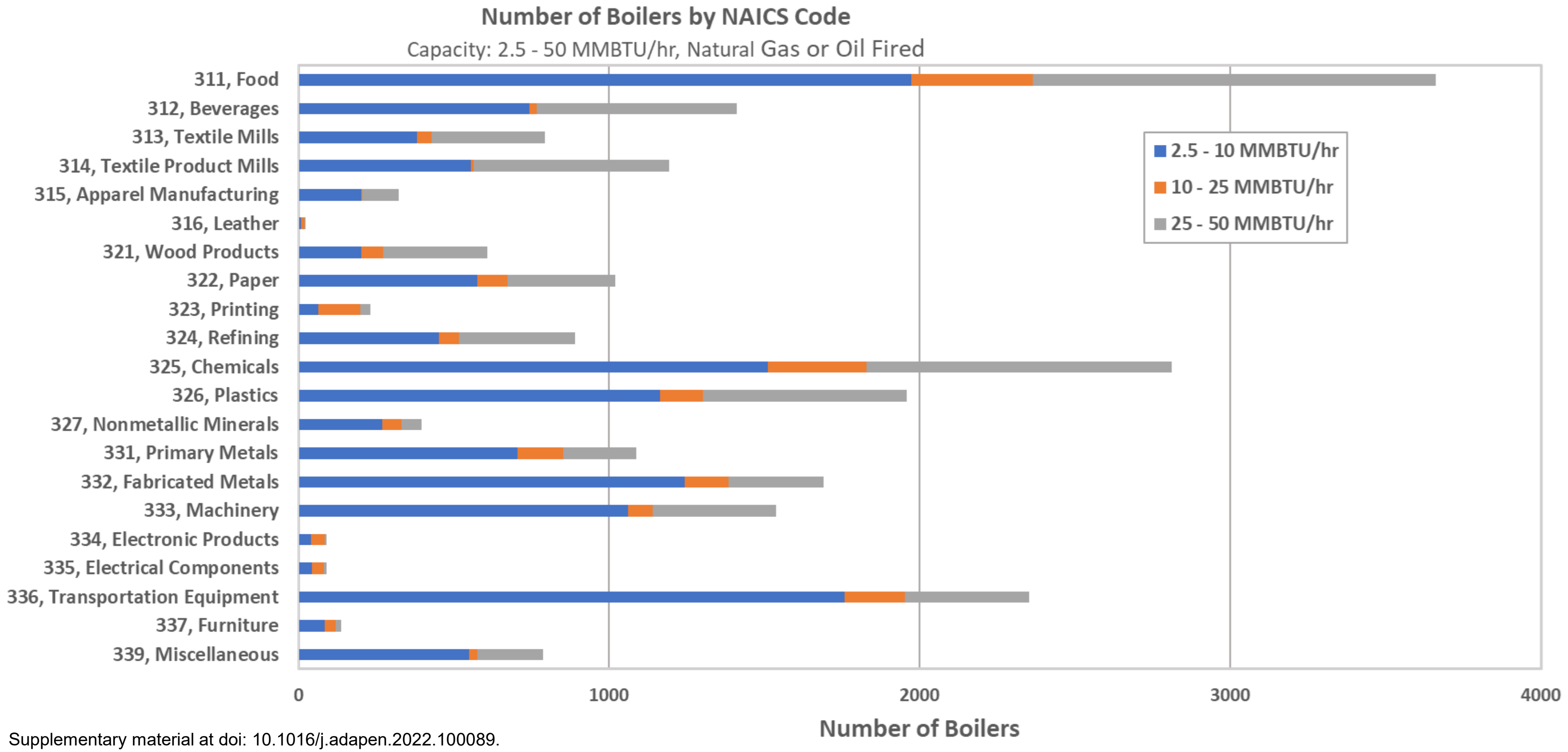
Comprehensive and useful survey of the U.S. Industrial boilers was performed to evaluate electrification potential and builds on earlier boiler characterizations

Conversion of Existing Gas-Fired Commercial and Small Industrial Boilers to Hydrogen



Database from this study was used to develop the number of boilers and installed capacity specifically for the 2.5 to 50 MMBtu/h range for the present study.

Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen



Supplementary material at doi: 10.1016/j.adapen.2022.100089.

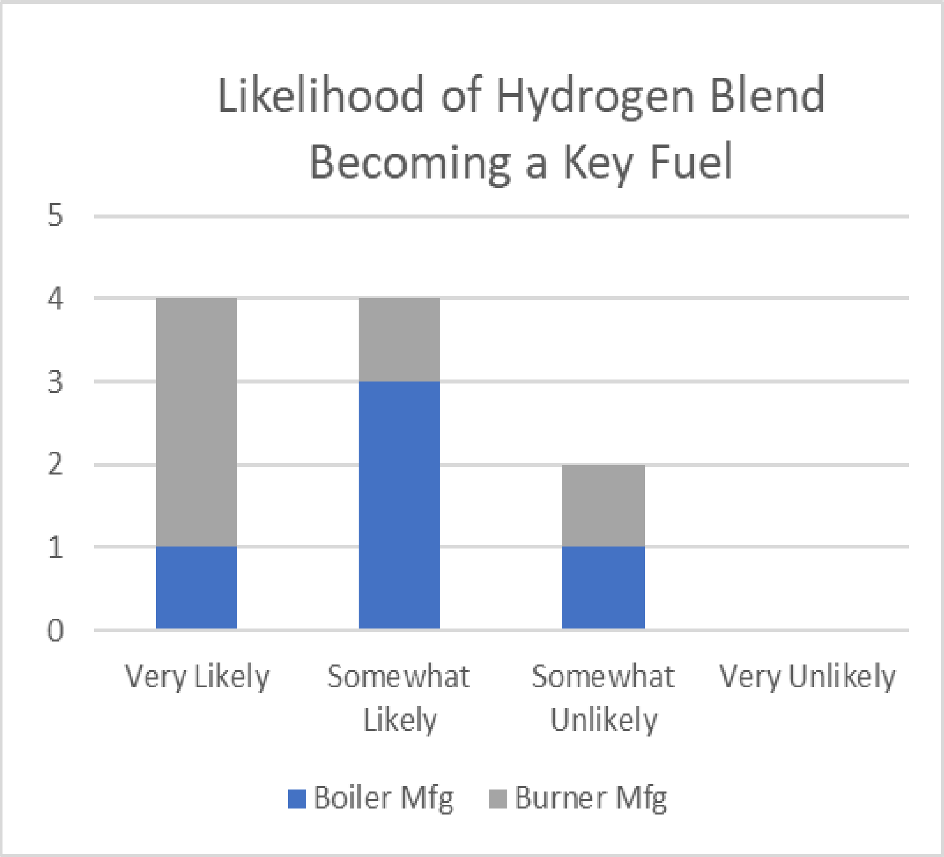
- **23,100 C&I Fossil-fueled Boilers @ 2.5 to 50 MMBtu/h with an installed capacity of 420,472 MMBtu/h.**

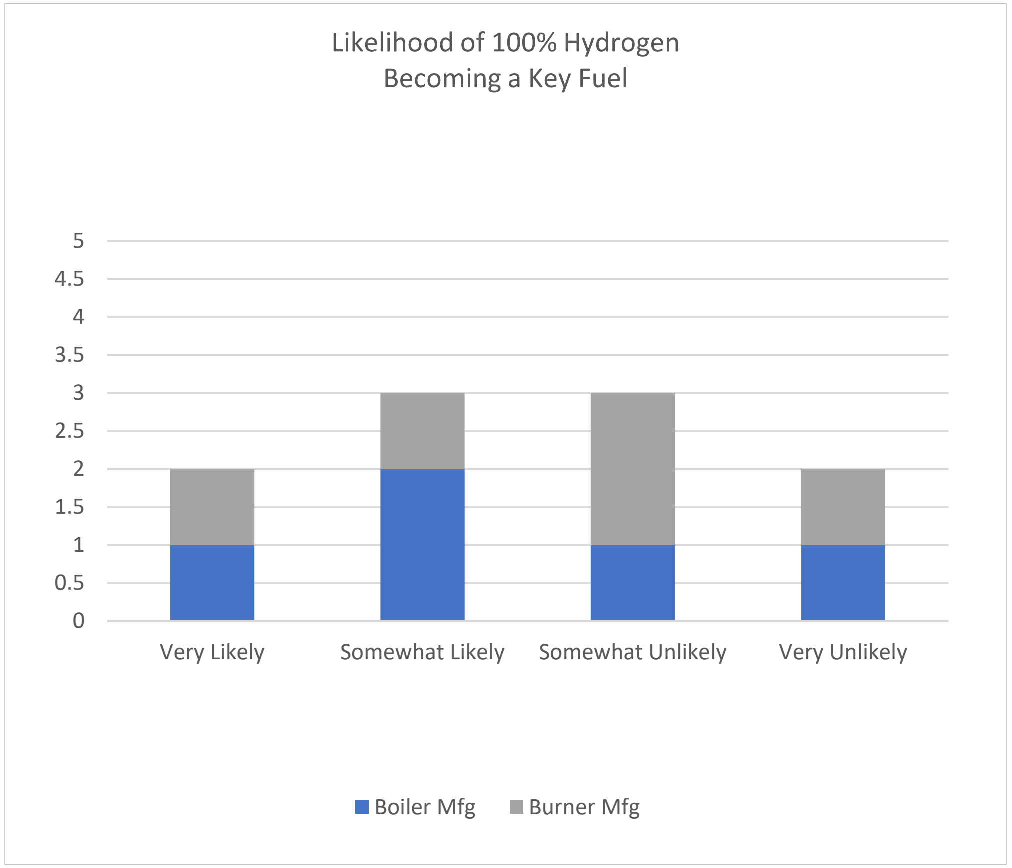
Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen

Boiler OEM Survey Results	U.S.			International		
Number of OEMs Reviewed	50			34		
OEMs with Steam (>15 psi) and Hot Water Boilers	Steam		Hot Water Boilers	Steam		Hot Water Boilers
	24		39	26		18
OEM Steam Boilers by Classification	Water Tube	Fire Tube		Water Tube	Fire Tube	
	13	13		18	20	

- Survey included capturing capacities offered, boiler types (hot water, low pressure steam and high pressure steam), configurations (water tube, fire tube).
- Given that the majority of industrial boilers provide high pressure steam (that is, greater than 15 psi), the majority of effort was involved in analyzing this area.

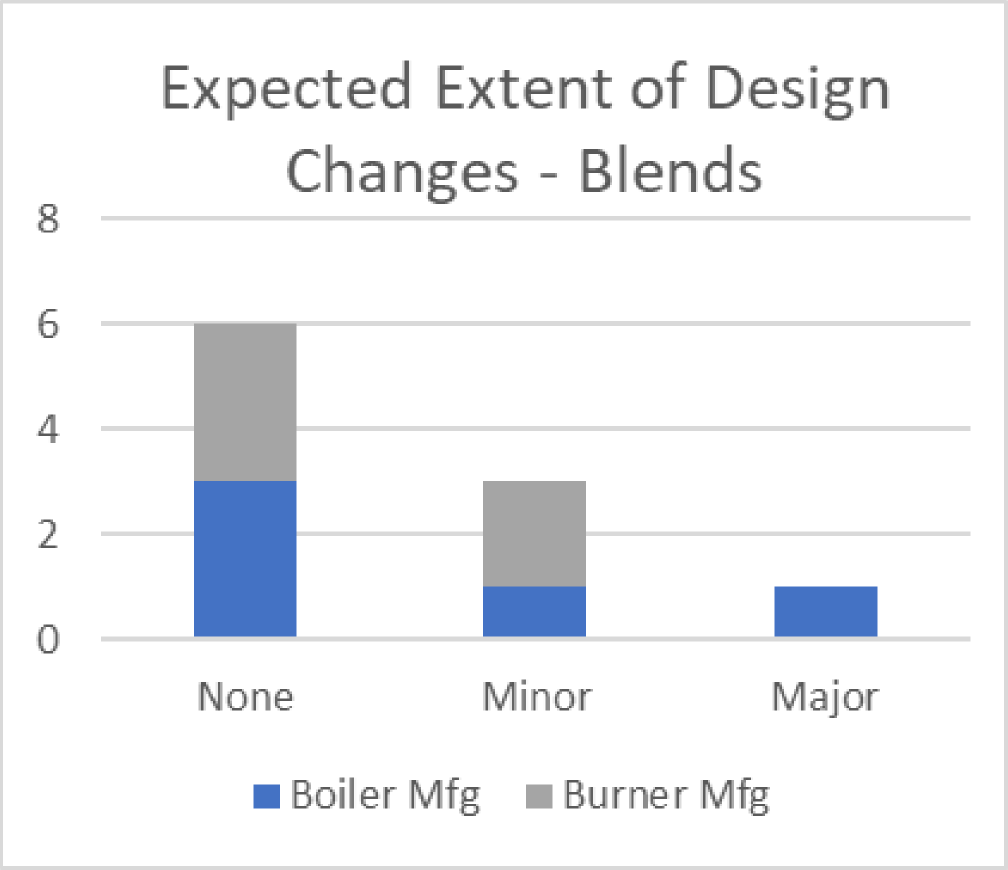
Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen

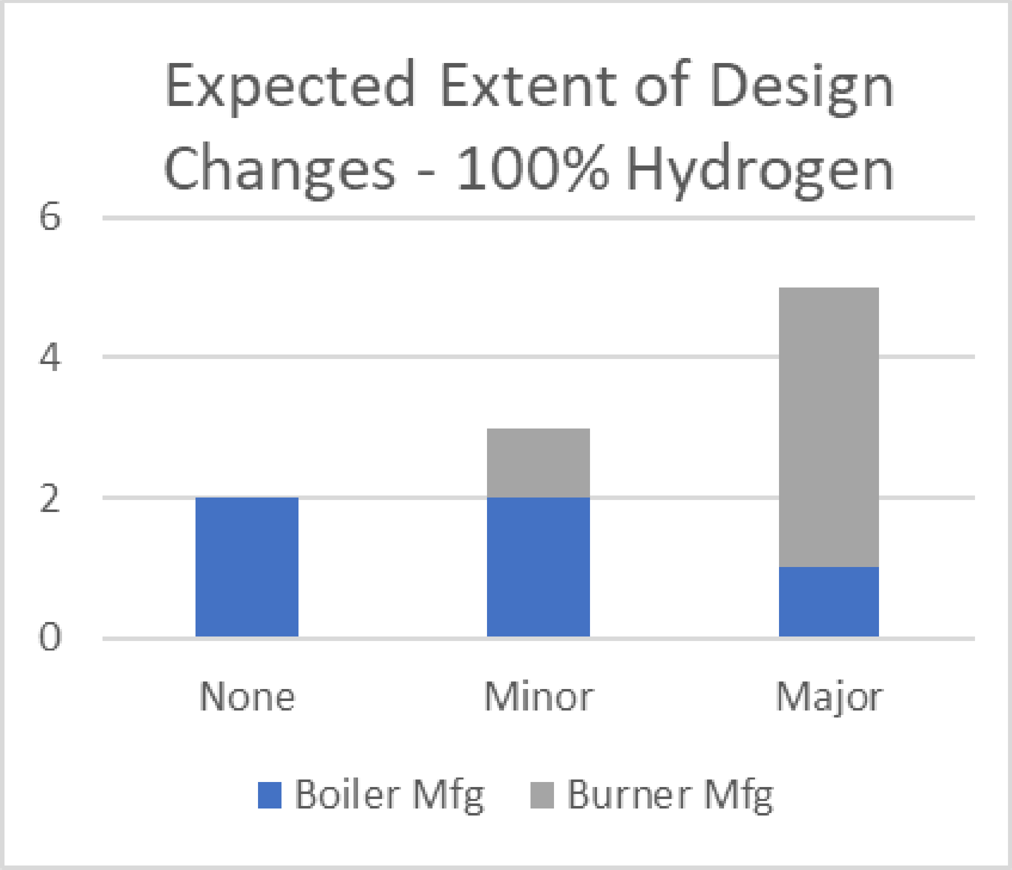




- OEMs were asked whether they expected hydrogen to be a key boiler fuel in their markets
  - Some with participation in steel manufacturing, refineries and petro-chemical installations fully expect blends
  - Most others felt that lower blends may become common but higher blends less so

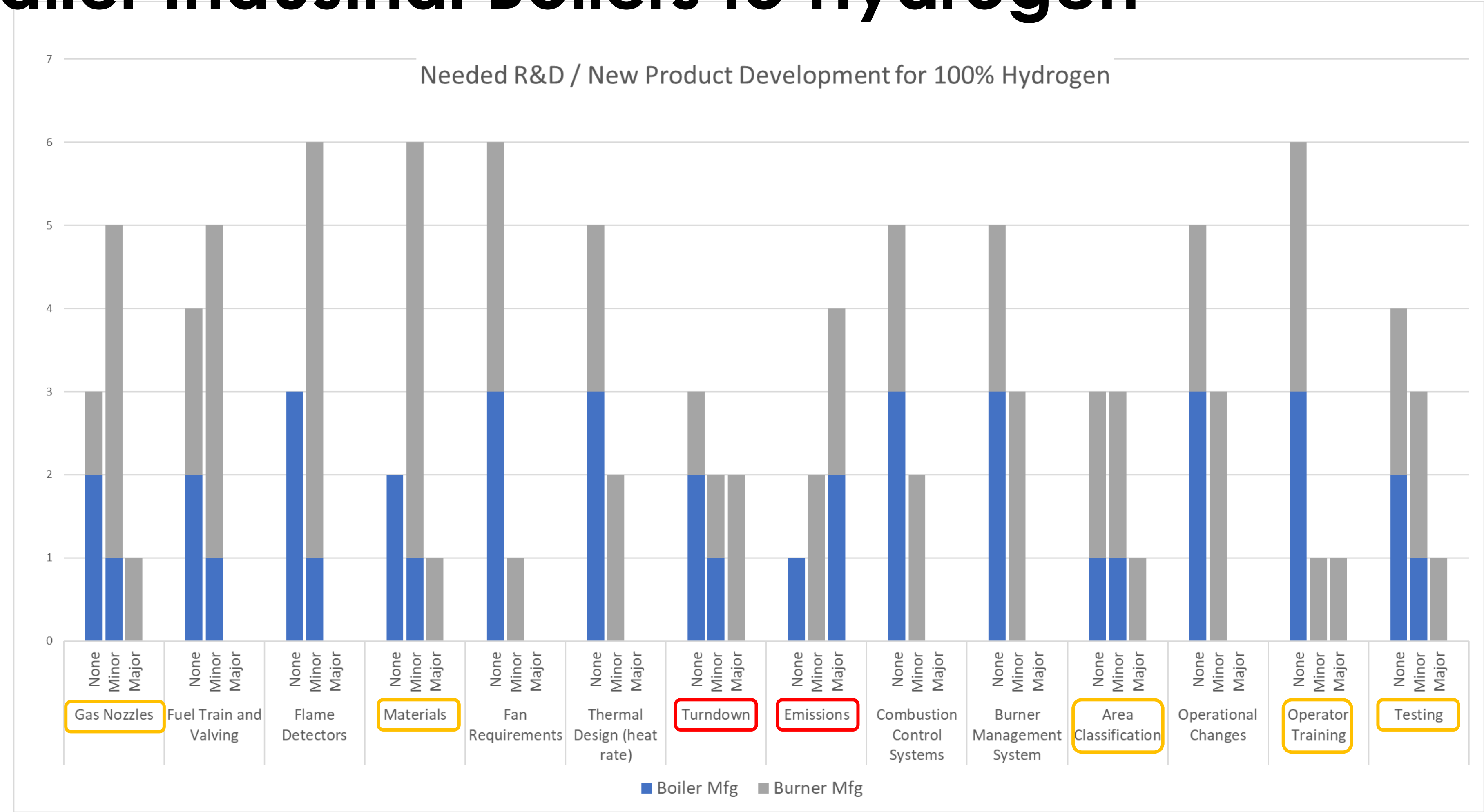
Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen





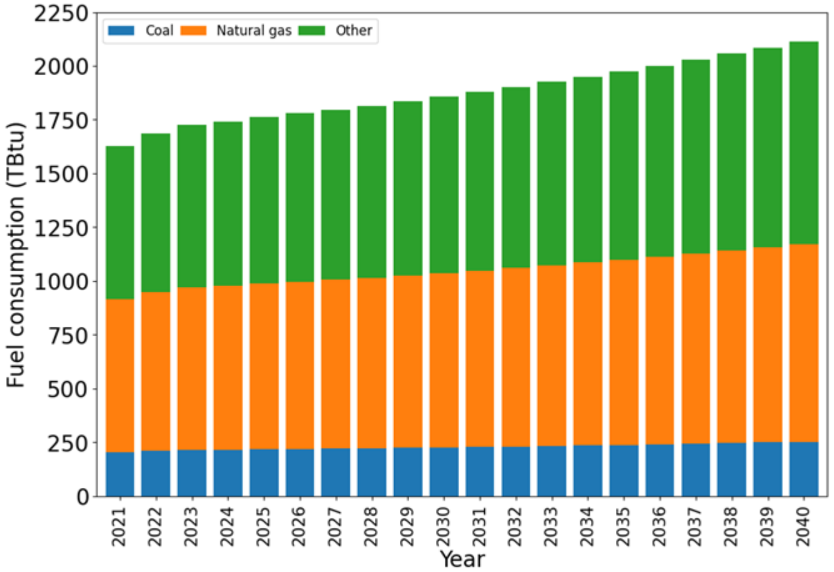
- OEMs stated that for firing blends to 20% by volume, the changes needed are quite minimal.
- For firing 100% hydrogen, they expected major design changes from standard natural gas units

Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen

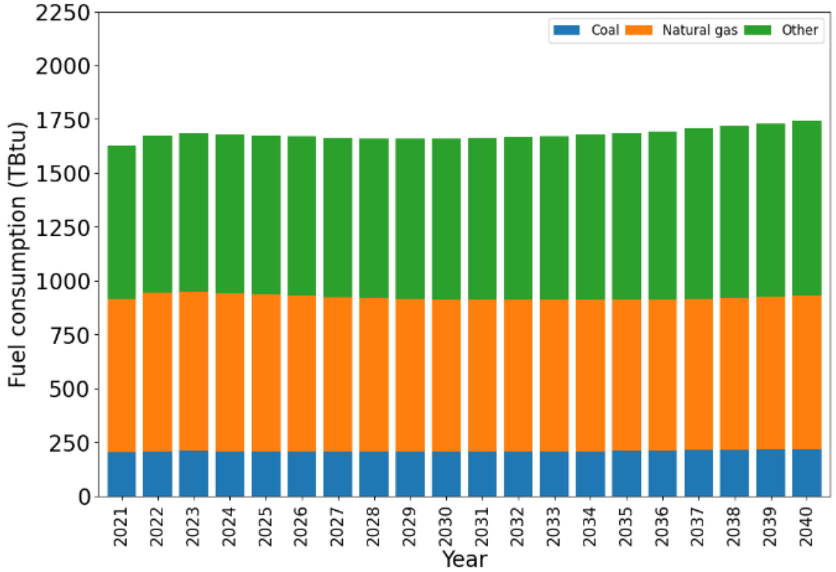


- OEM's provided feedback on the R&D needs for 100% hydrogen firing

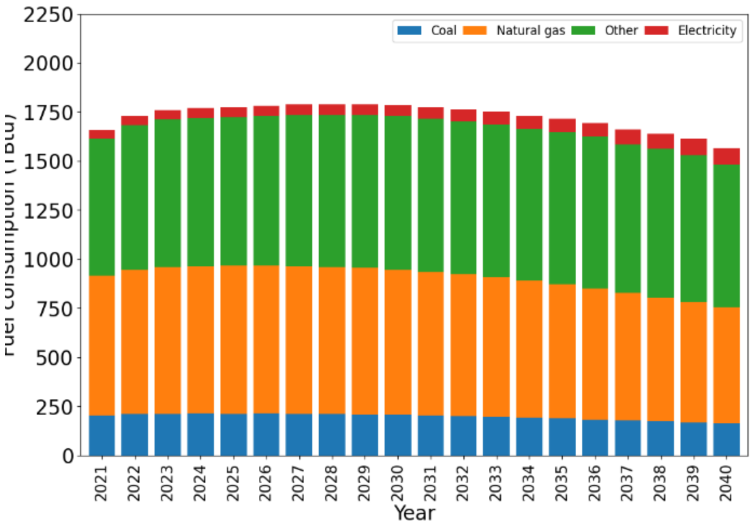
Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen



Energy consumption forecast under Scenario 1: Reference Case

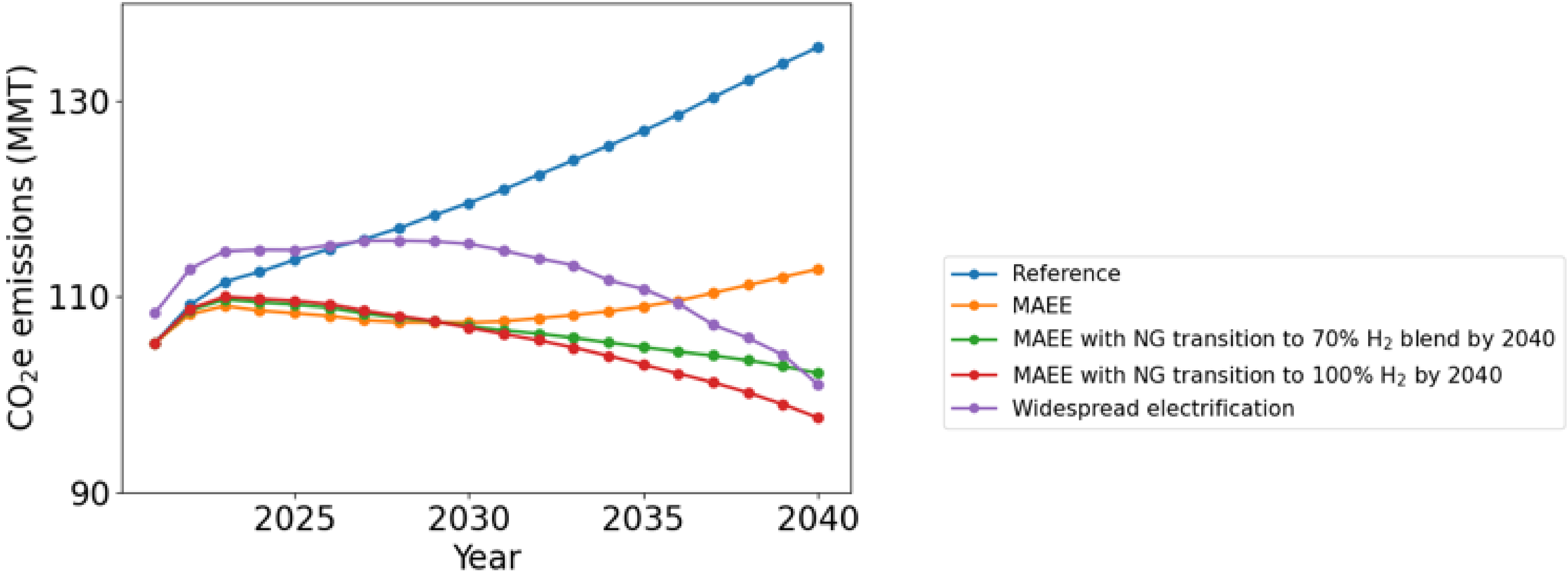


Energy consumption forecast under Scenarios 2, 3, 4:
Scenario 2: Maximum Achievable Energy Efficiency (MAEE) with Fossil Fuel Boilers
Scenario 3: MAEE + progressive natural gas – hydrogen blend fuel (70% hydrogen/ 30% natural gas by 2040)
Scenario 4: MAEE + progressive natural gas – hydrogen blend fuel (100% hydrogen/ 0% natural gas by 2040).



Energy consumption forecast under Scenario 5: Widespread Electrification

Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen



- Equivalent CO_2 emissions for Scenarios 1-5

Industrial Analytics: Process Heat

Conversion of Existing Gas-Fired Commercial and Smaller Industrial Boilers to Hydrogen

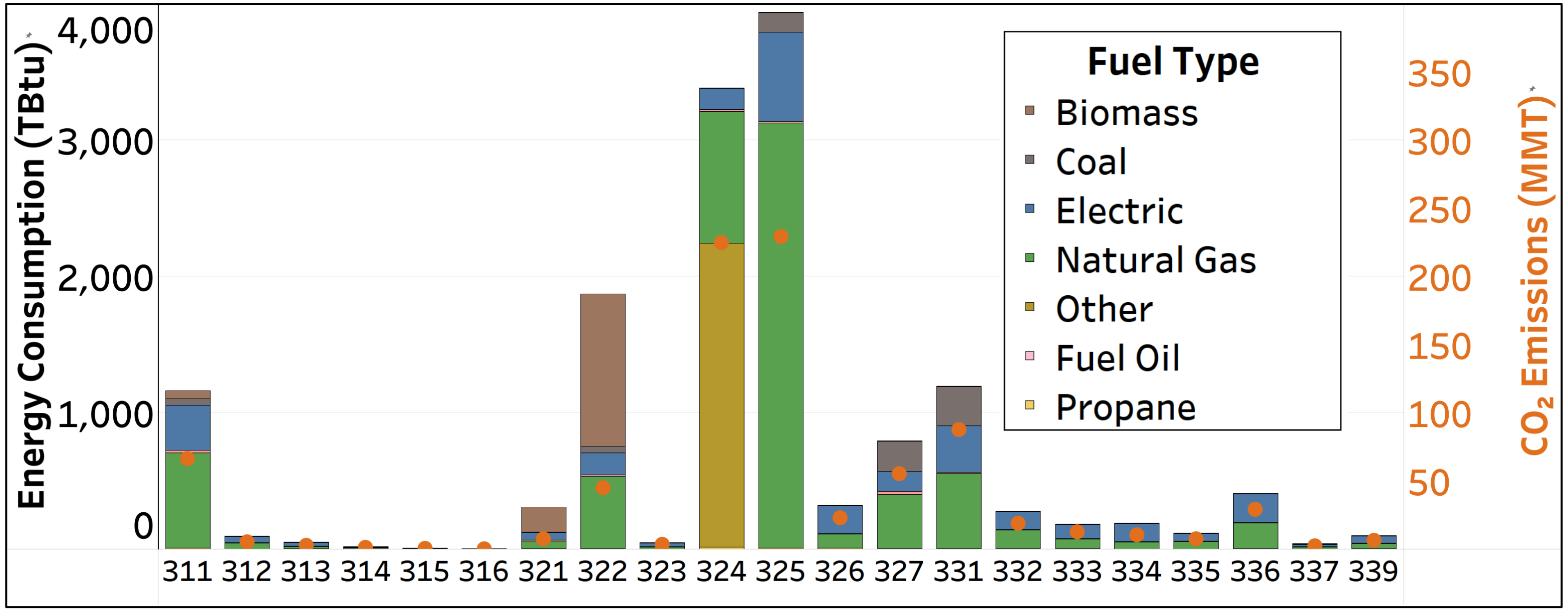
Process Heat Survey Results	US				International			
Number of OEMs Reviewed	44				25			
Fuels	Fossil Fuel & Electric			Electric Only	Fossil Fuel & Electric			Electric Only
OEM System Type	Ovens/Duct Heaters	Furnaces, Kilns & Process Heaters	Combustion Systems & Burners		Ovens/Duct Heaters	Furnaces, Kilns & Process Heaters	Combustion Systems & Burners	
OEM's Offering	27	19	3	2	8	11	11	1
Indicating AECs	0	2	3	N/A	2	5	8	N/A
% Indicting AECs	0%	11%	100%		25%	45%	73%	

Low temperature applications currently targeted for development.
International & combustion systems/burner OEMs most active in AEC capability.

Scenario Analysis

Scenario 1: Reference case

- Future energy consumption determined as a function of growth in value of shipments with modest levels of energy efficiency increase;
- No fuel switching considered
- Total CO_2 Emissions in 2050: 1424 MMT



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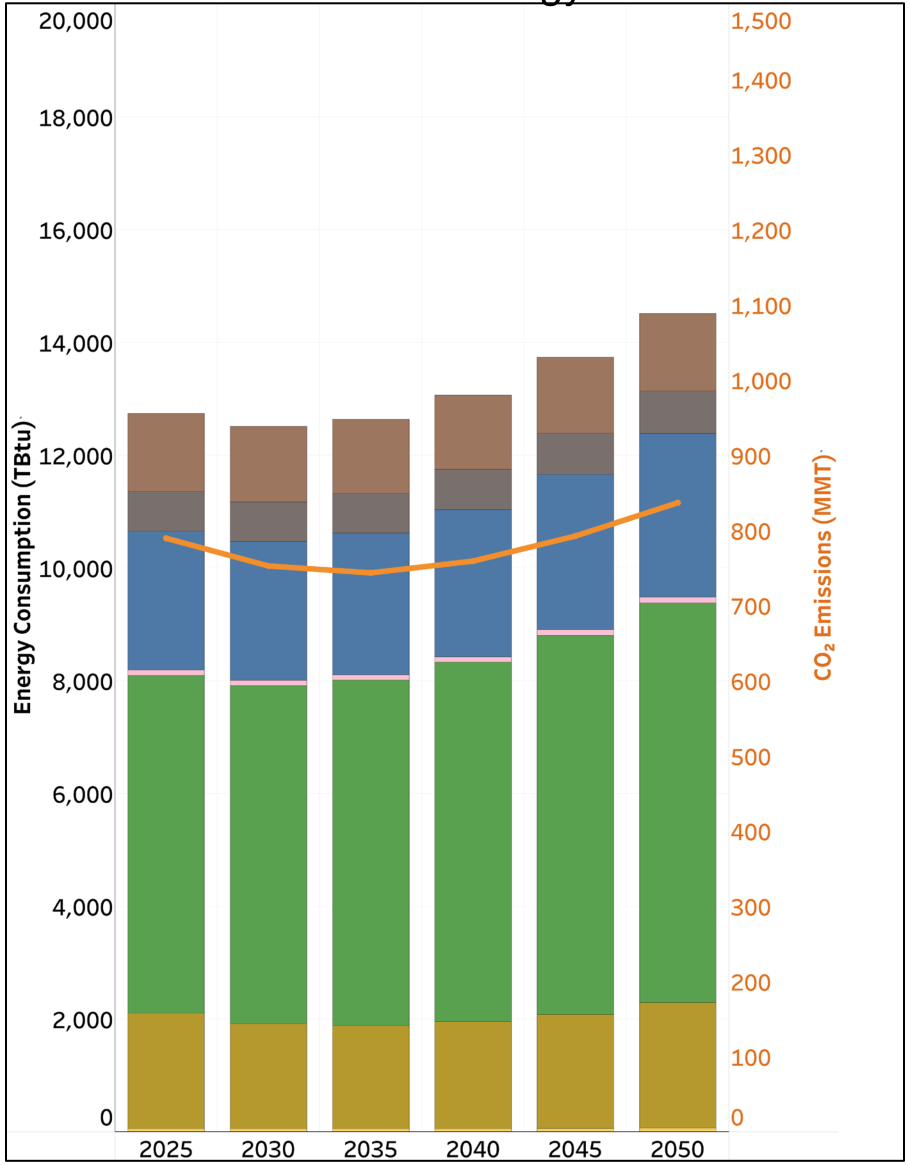


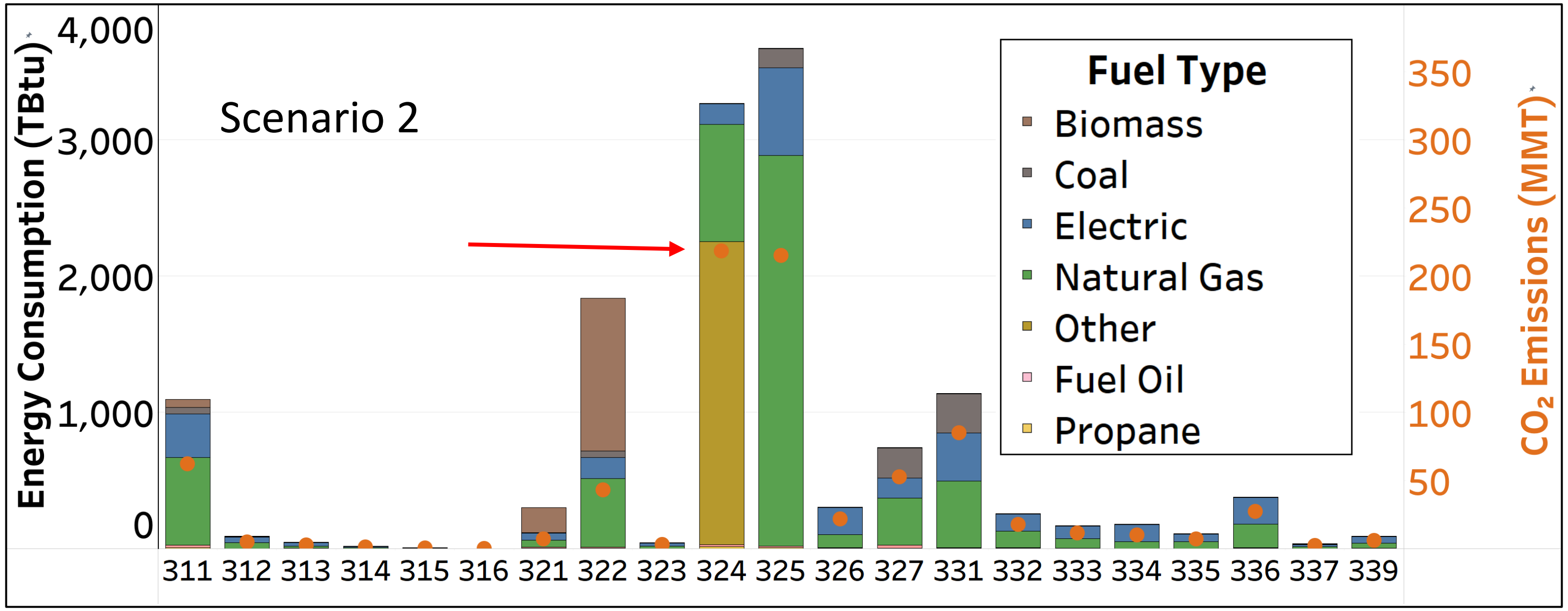
Scenario Analysis

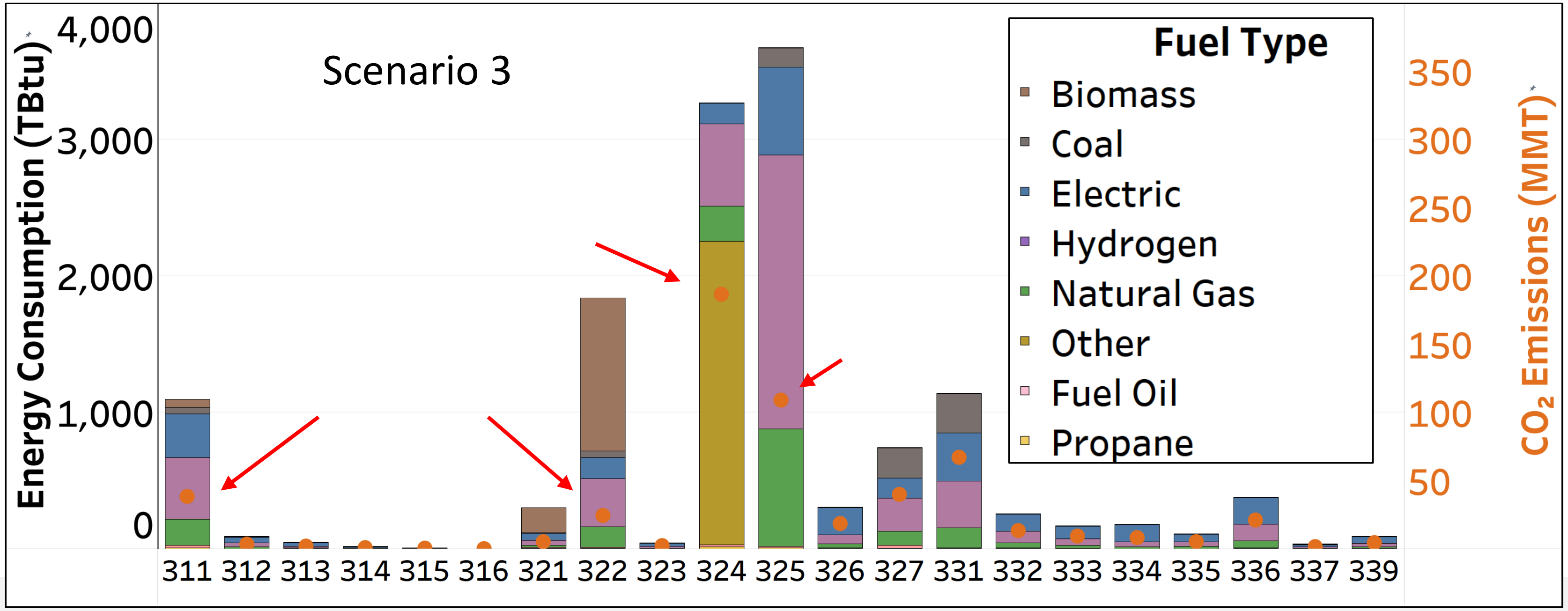
Scenario 2: Maximum Achievable Energy Efficiency (MAEE) case

- Inclusion of energy-efficient equipment reduces energy consumption and total CO_2 emissions by ~8% by 2050 compared to the Reference case

Scenario 3: MAEE with NG transitioning to 70% H_2 by 2050 case

- H_2 blending fractions with NG increase from 0% in 2021 to 70% in 2050
- Energy consumption remains the same as the MAEE case
- H_2 blending with NG results in an additional ~24% reduction in total CO_2 emissions by 2050 as compared to the MAEE case





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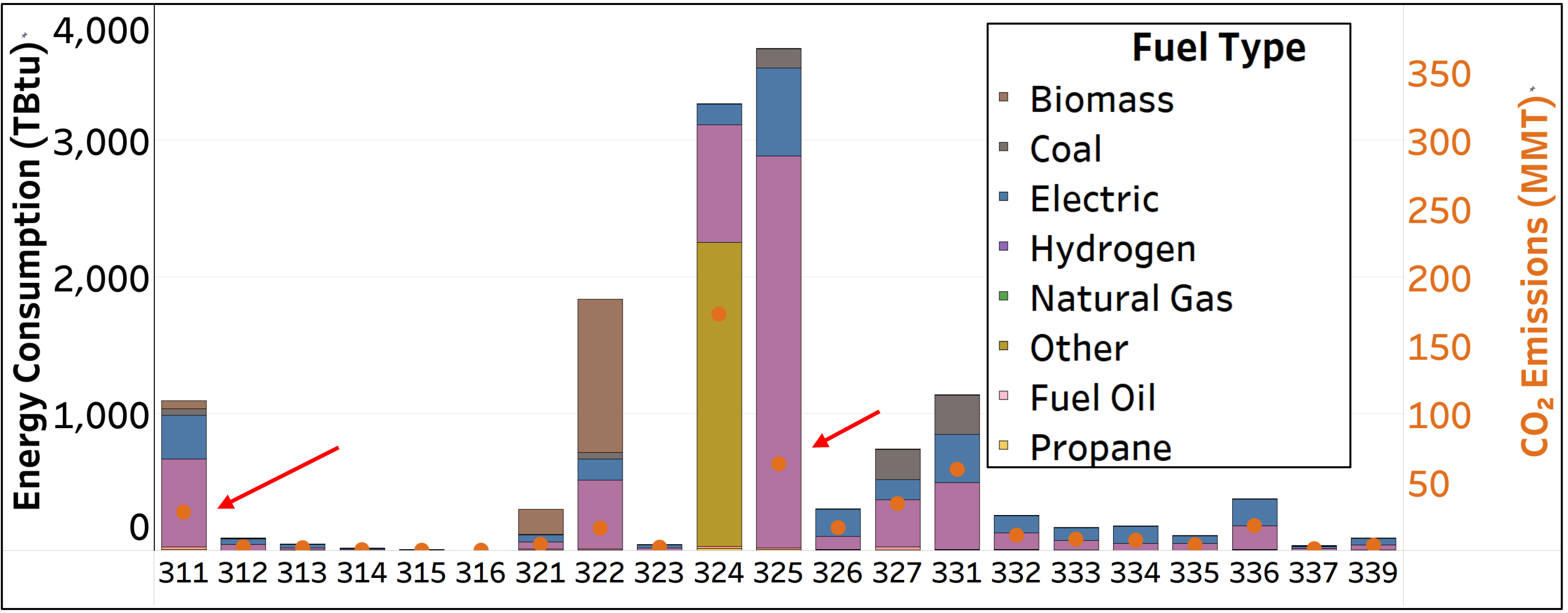
Scenario Analysis

Scenario 4: MAEE with NG transitioning to 100% H_2 by 2050 case

- H_2 blending fractions with NG increase from 0% in 2021 to 100% in 2050
- Energy consumption remains the same as the MAEE case
- H_2 blending with NG results in an additional ~34% reduction in total CO_2 emissions by 2050 as compared to the MAEE case



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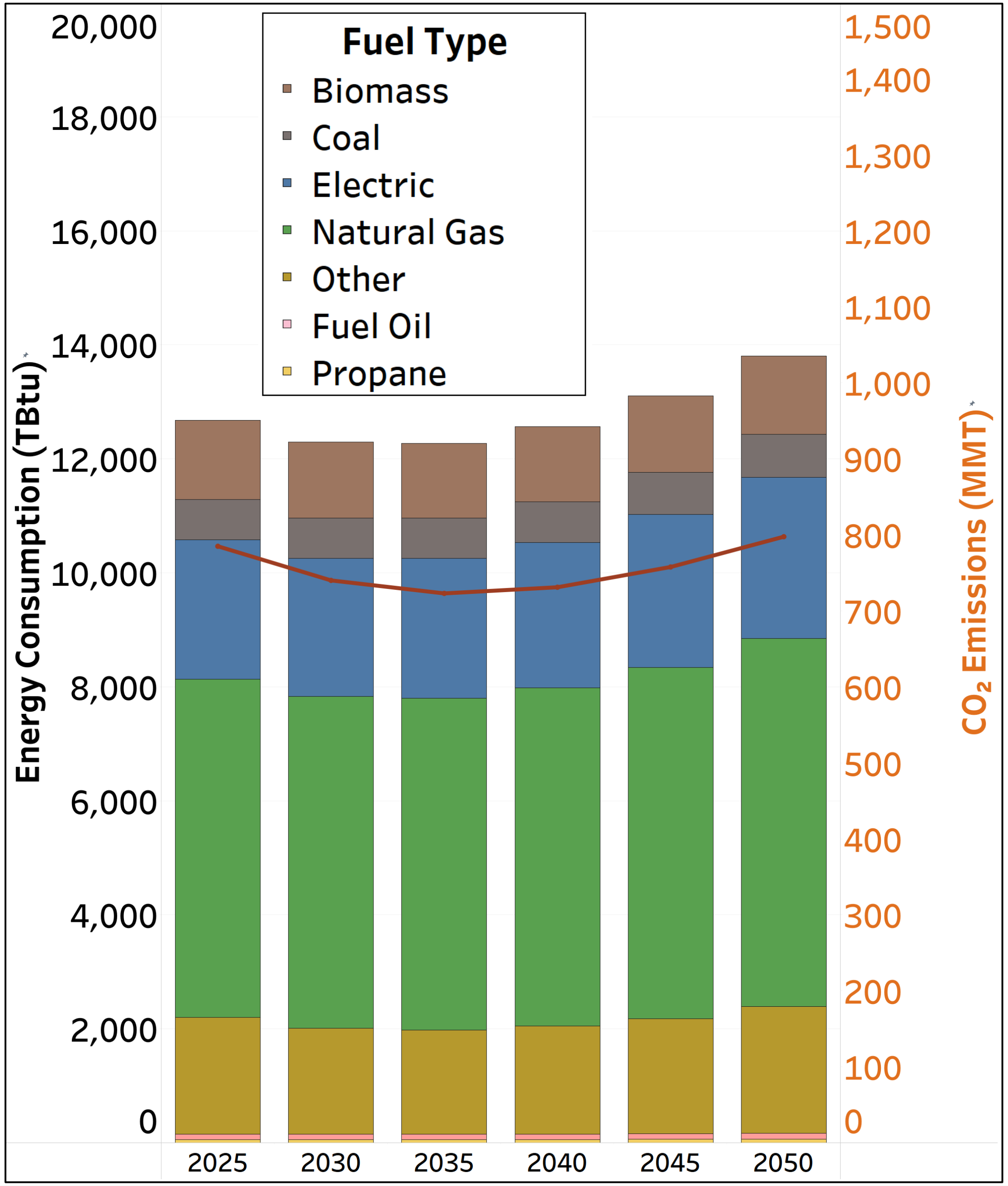
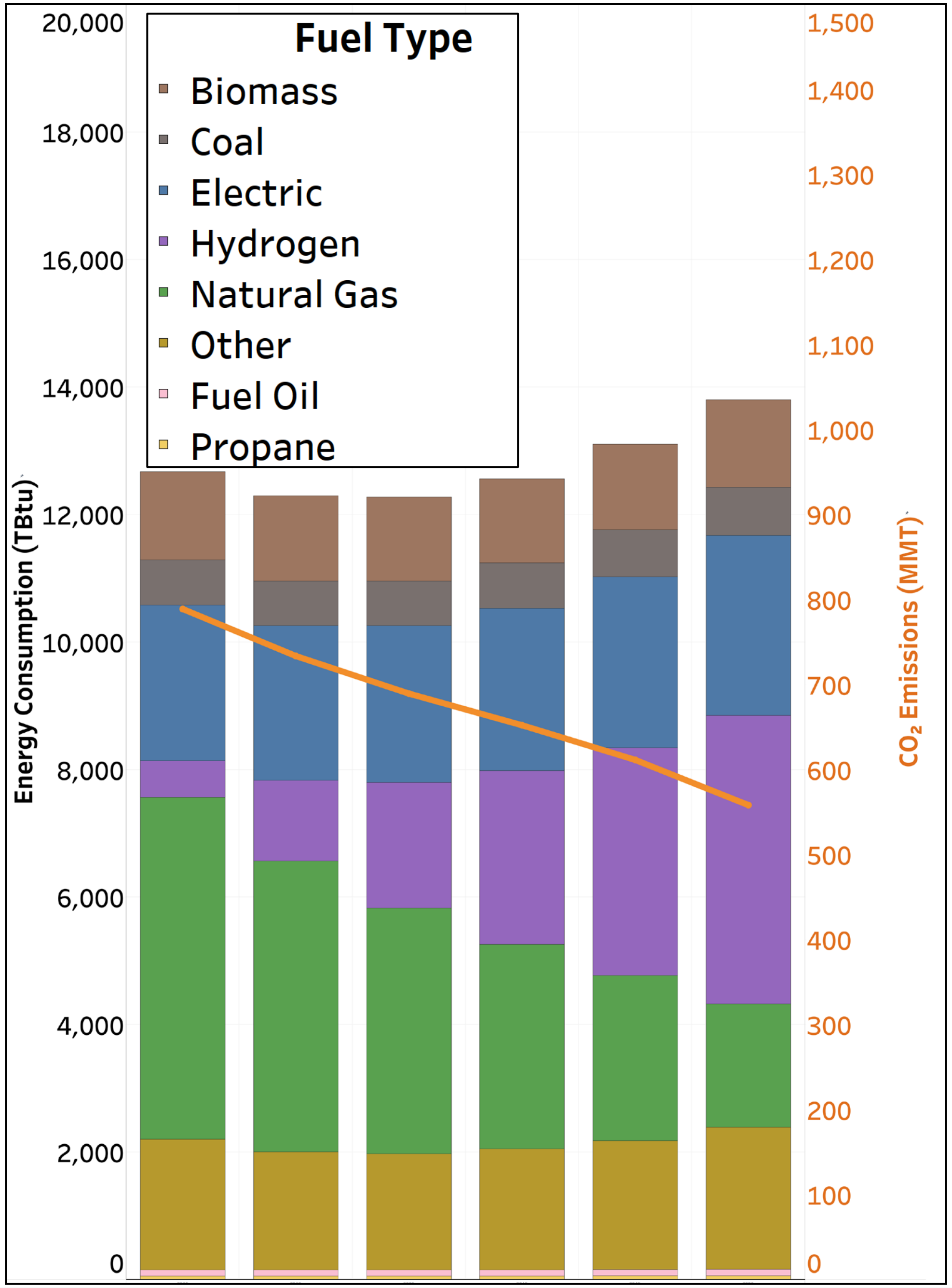
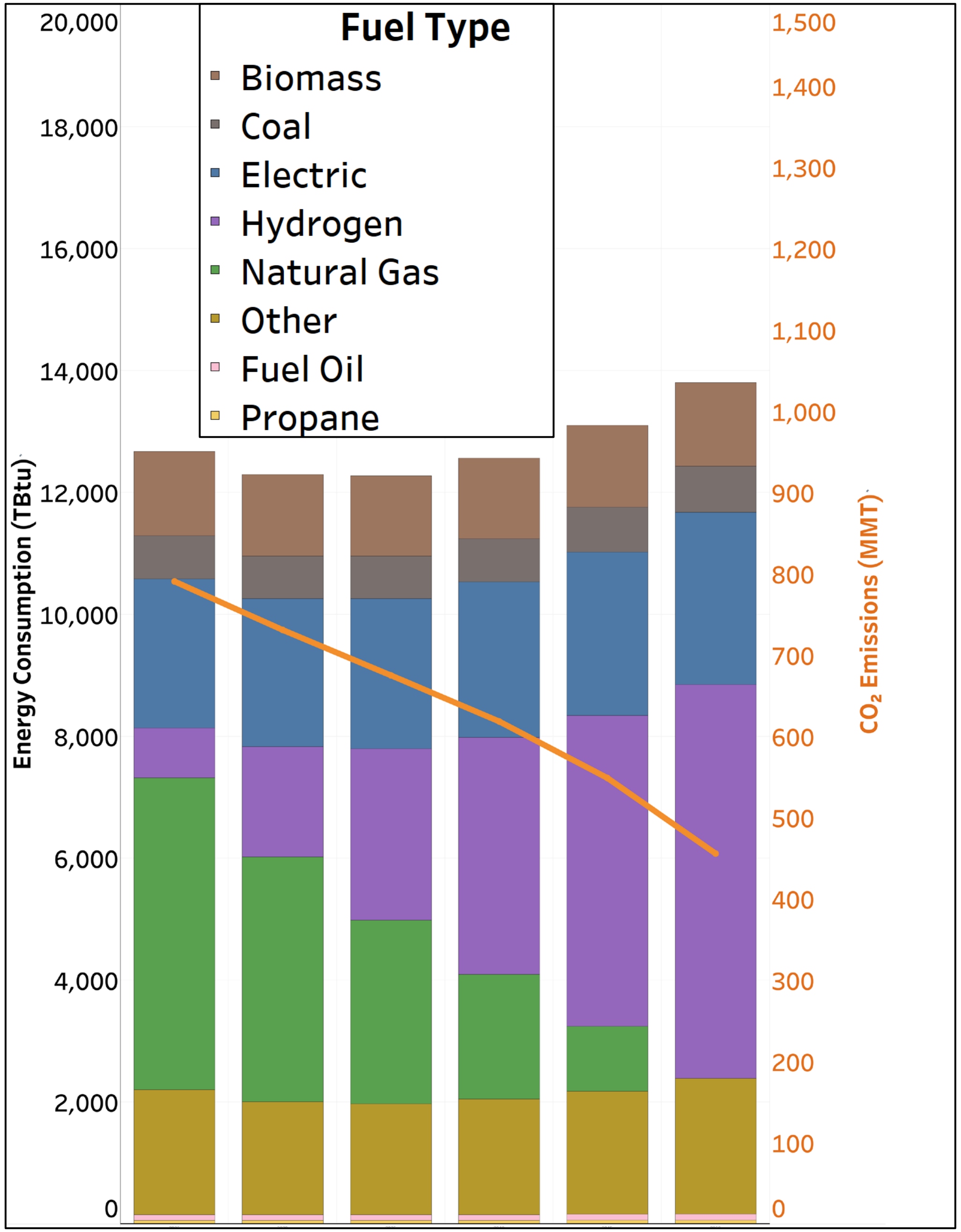
Scenario 2: Maximum Achievable Energy Efficiency (MAEE) case



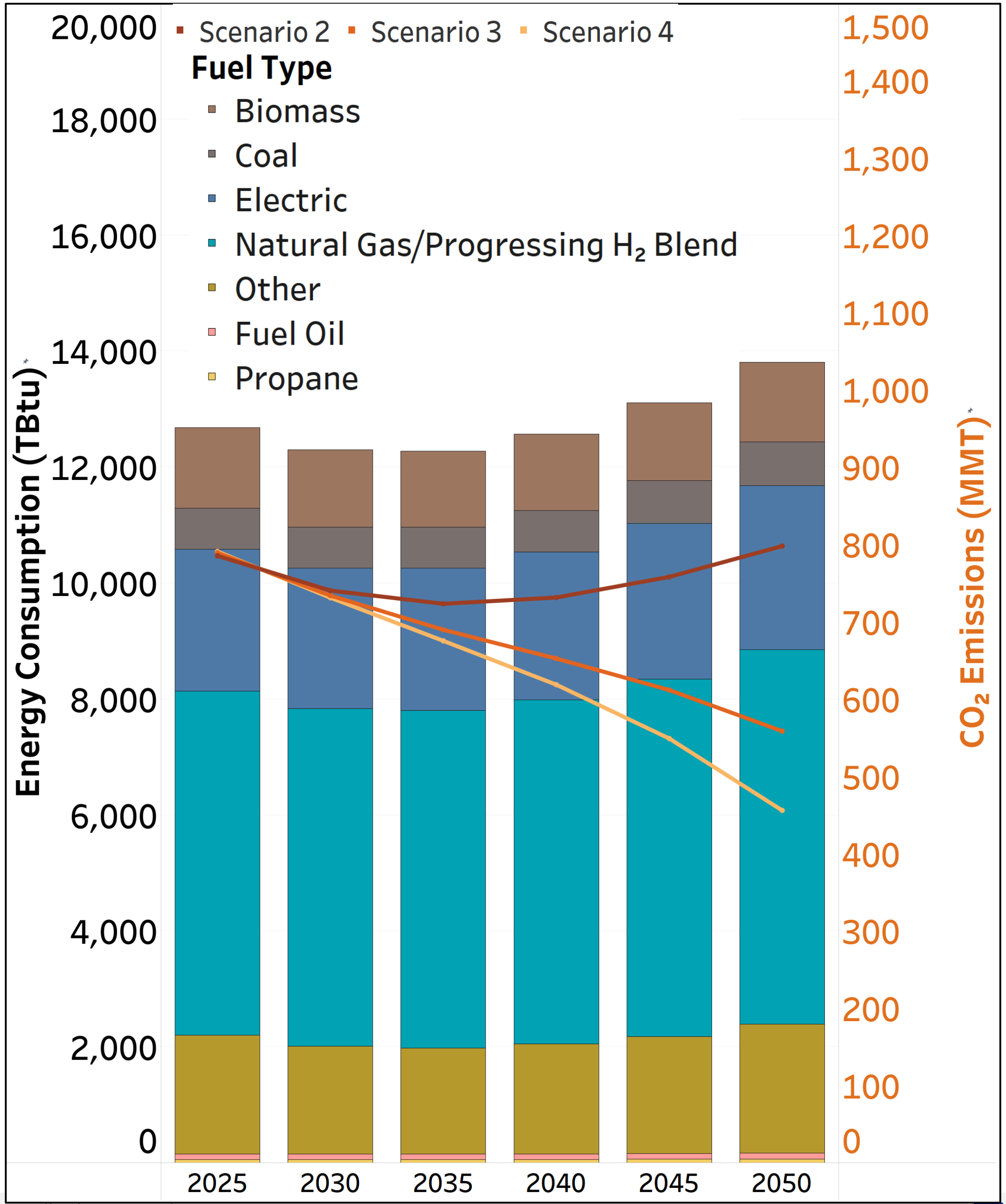
Scenario 3: MAEE with NG transitioning to 70% H_2 by 2050 case



Scenario 4: MAEE with NG transitioning to 100% H_2 by 2050 case

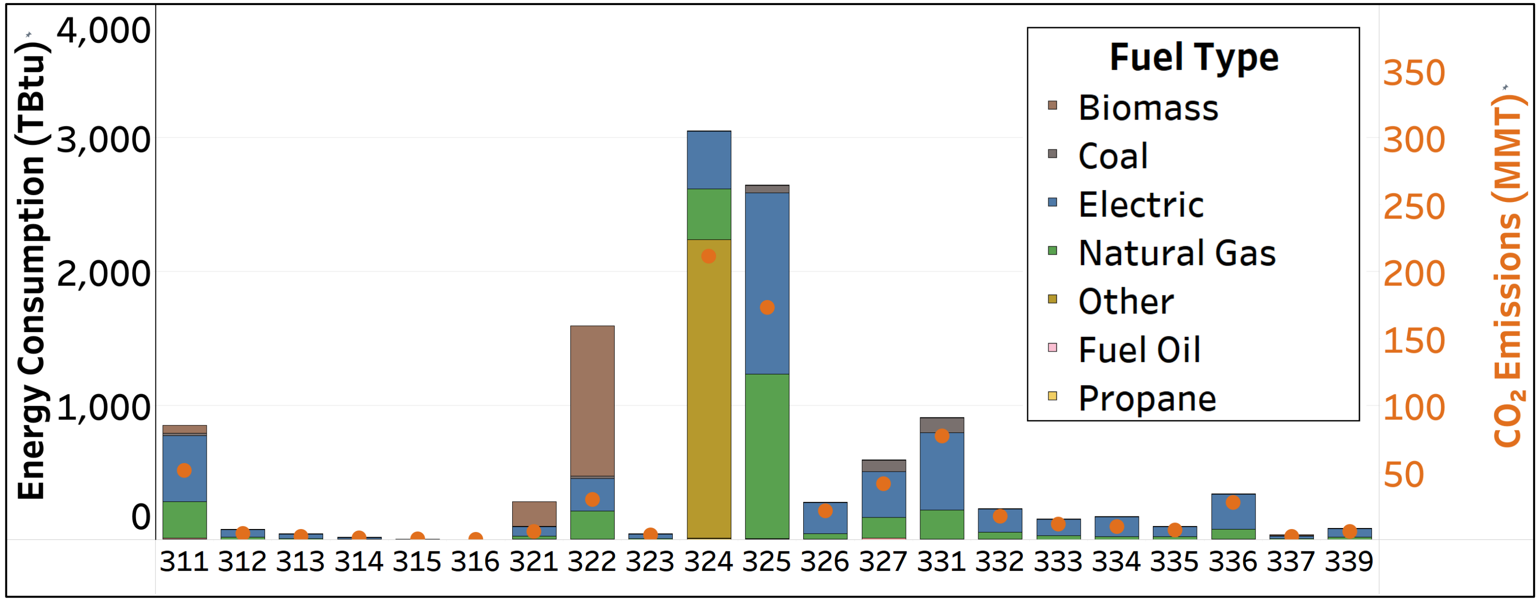


CO_2 Emission trends for Scenario 2,3 and 4



Scenario Analysis

Scenario 5: Widespread electrification case



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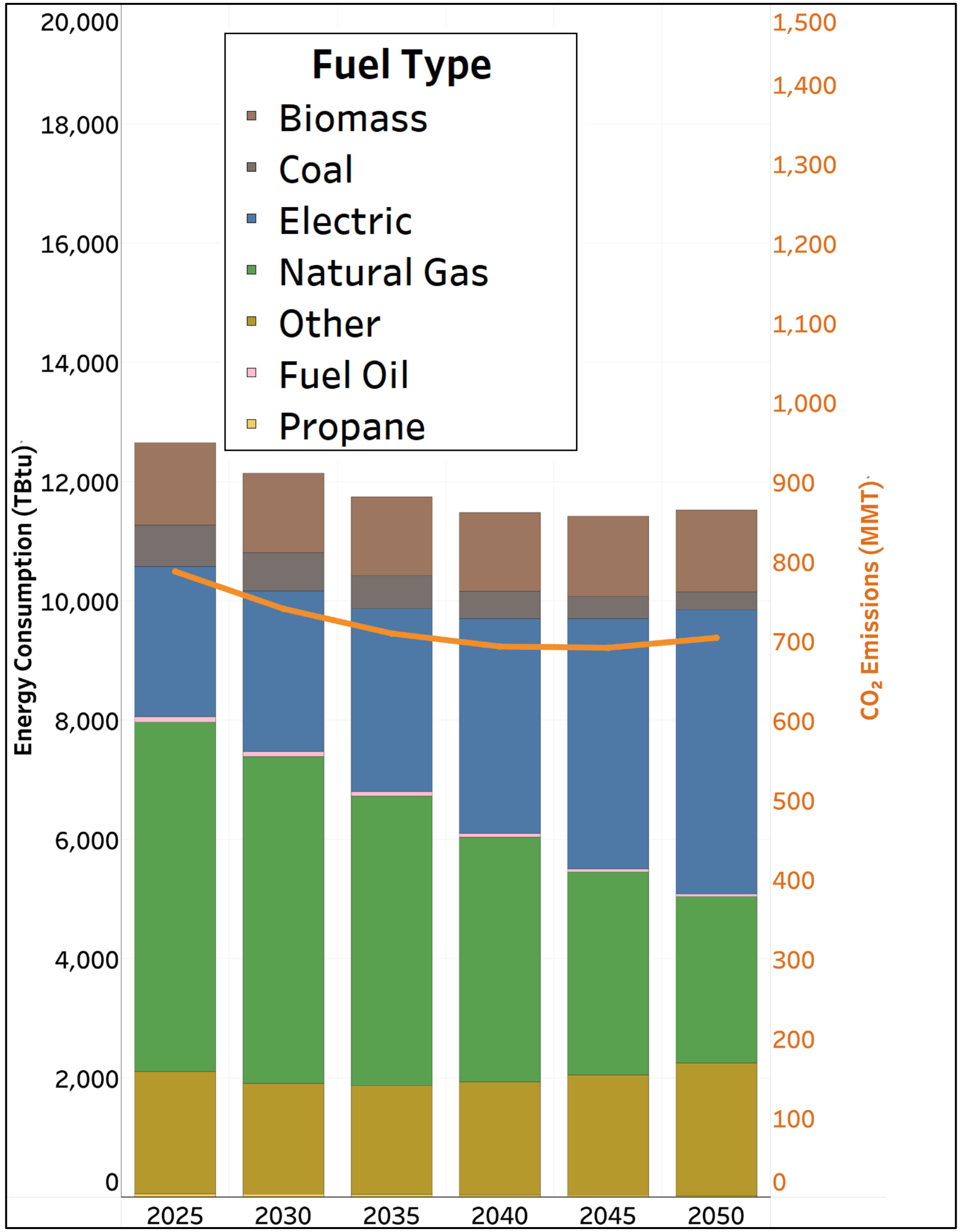
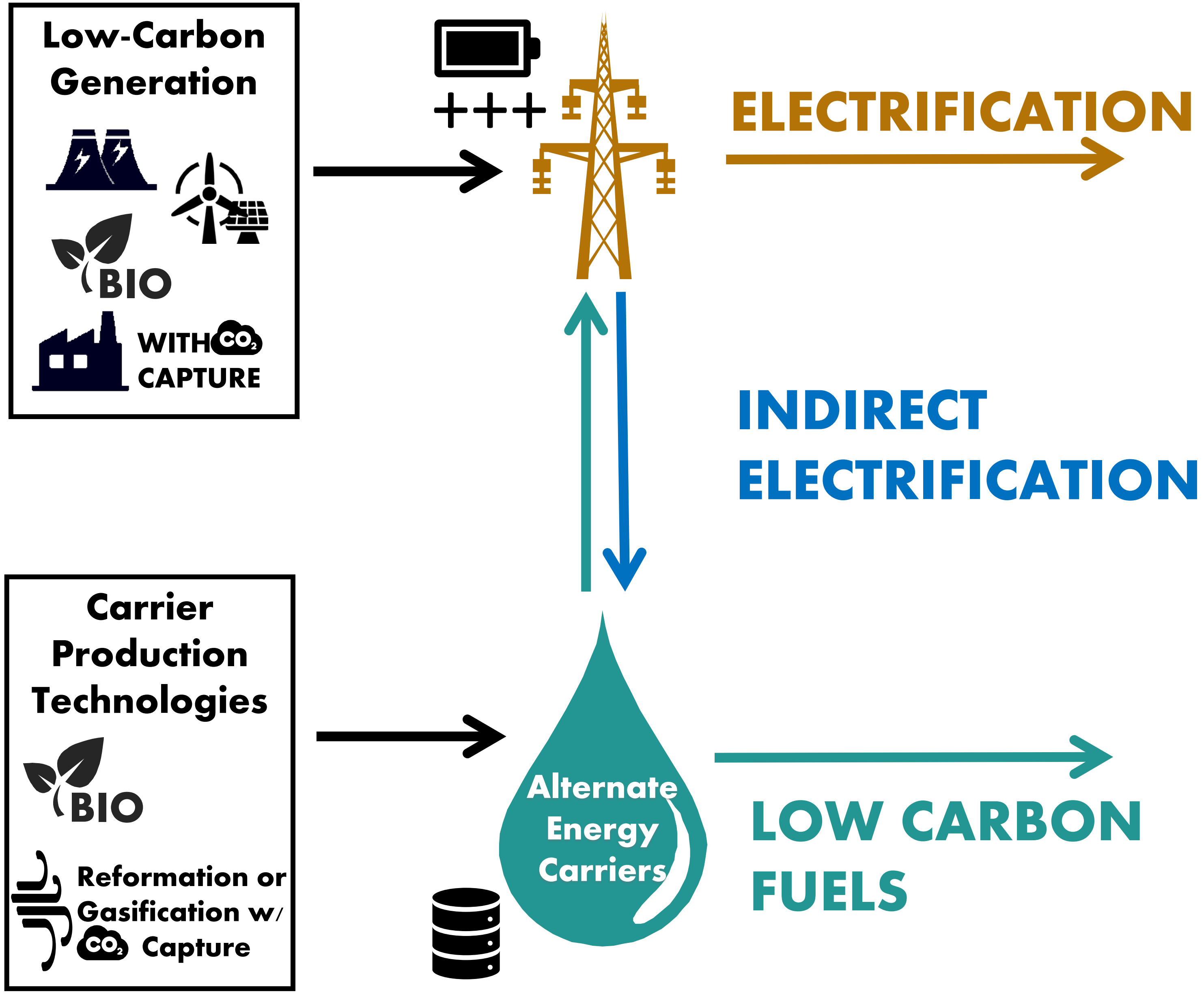
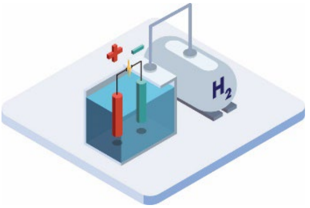


Decarbonization Pathway Optionality

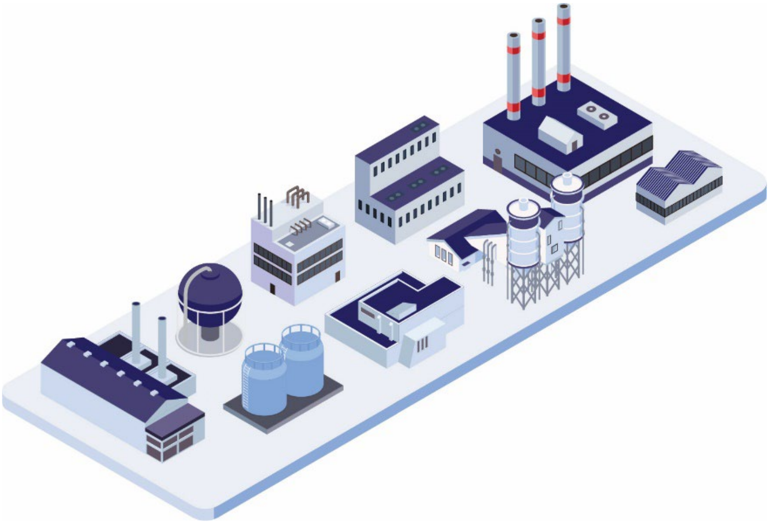

Low-Carbon Generation
BIO
WITH CO2 CAPTURE
+++
ELECTRIFICATION
INDIRECT ELECTRIFICATION
Carrier Production Technologies
BIO
Reformation or Gasification w/ CO2 Capture
Alternate Energy Carriers
LOW CARBON FUELS

Considering Direct and Indirect Electrification for Industrial Decarbonization

Electrification
- Resource adequacy
- Reliability
- Grid integration
- Resiliency
- Transmission & distribution



Indirect Electrification
- Additional electrification
- Integration with existing grids/networks
- Timing of resources and costs
- Infrastructure & end use readiness



U.S. Activities on Industrial Decarbonization

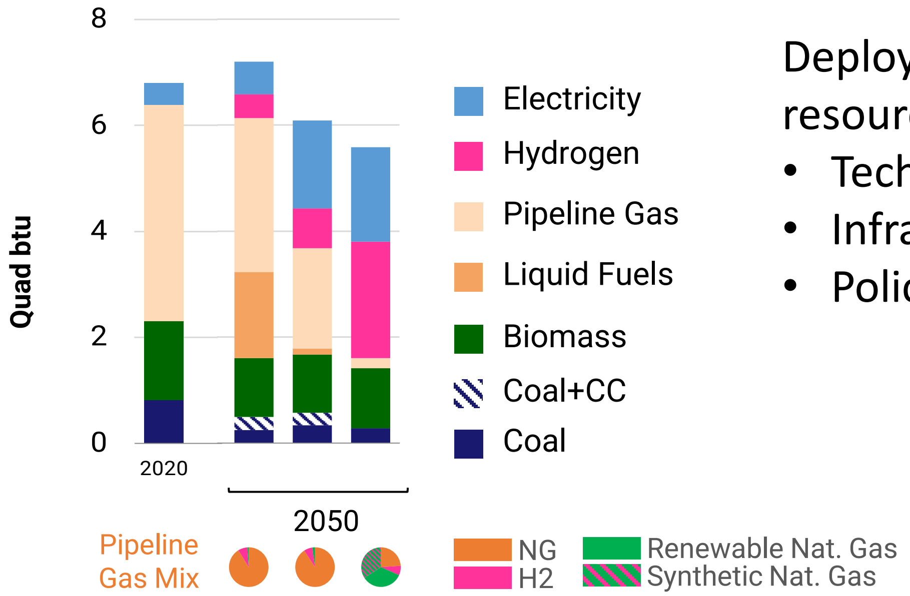
ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Industrial Heat™

Goal: 85% CO_2 reduction by 2035 (link)

Pathways:
- ➢ Electrification
- ➢ Low-emissions resources
- ➢ Innovative approaches

Process Heat/Steam
2050 Decarbonization Scenarios

www.lowcarbonLCRI.com/netzero



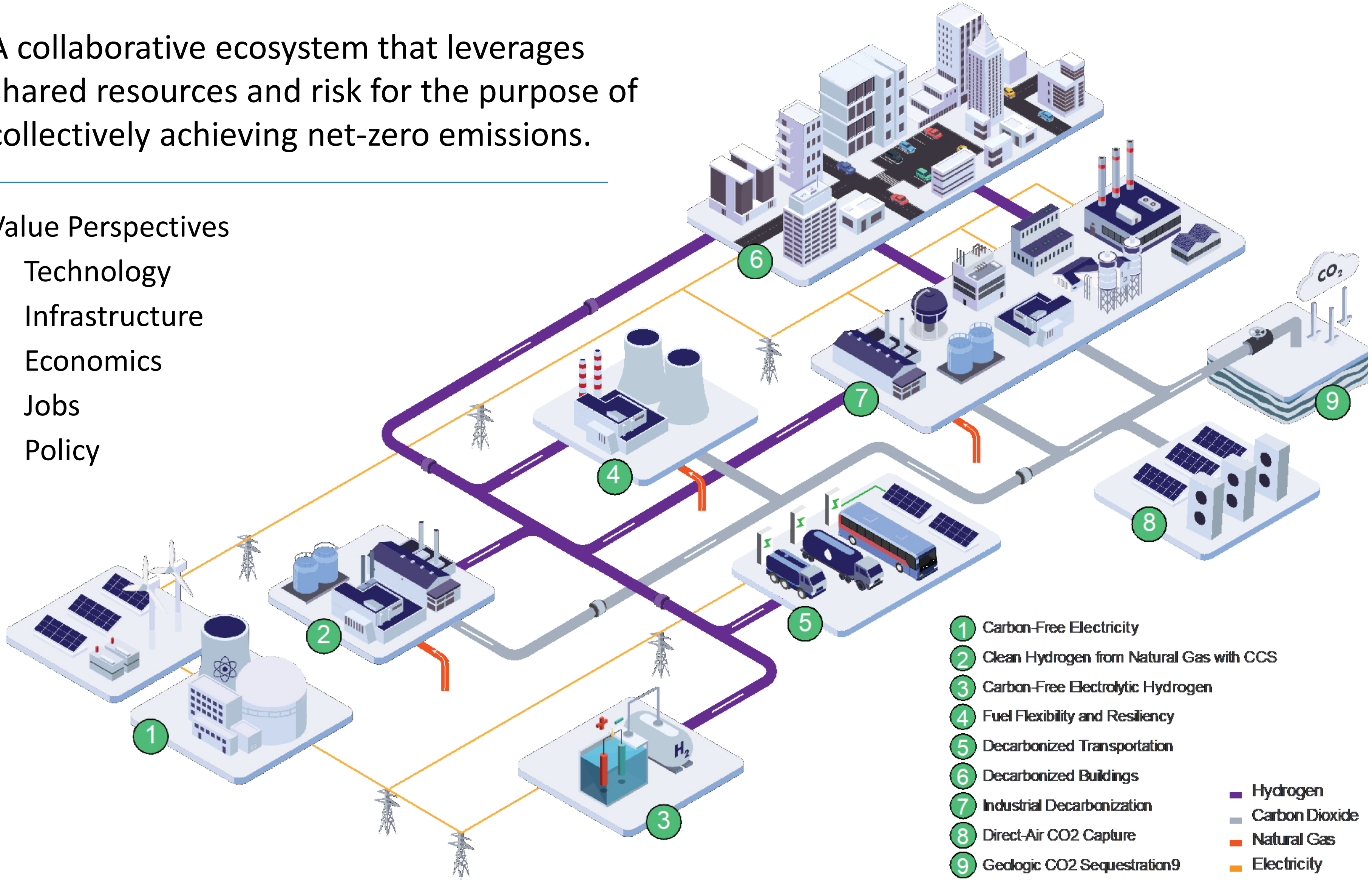
Deployment of new energy resources potentially impacted by:
- Technology cost and performance
- Infrastructure availability
- Policies

NET-ZERO INDUSTRIAL CLUSTER

A collaborative ecosystem that leverages shared resources and risk for the purpose of collectively achieving net-zero emissions.

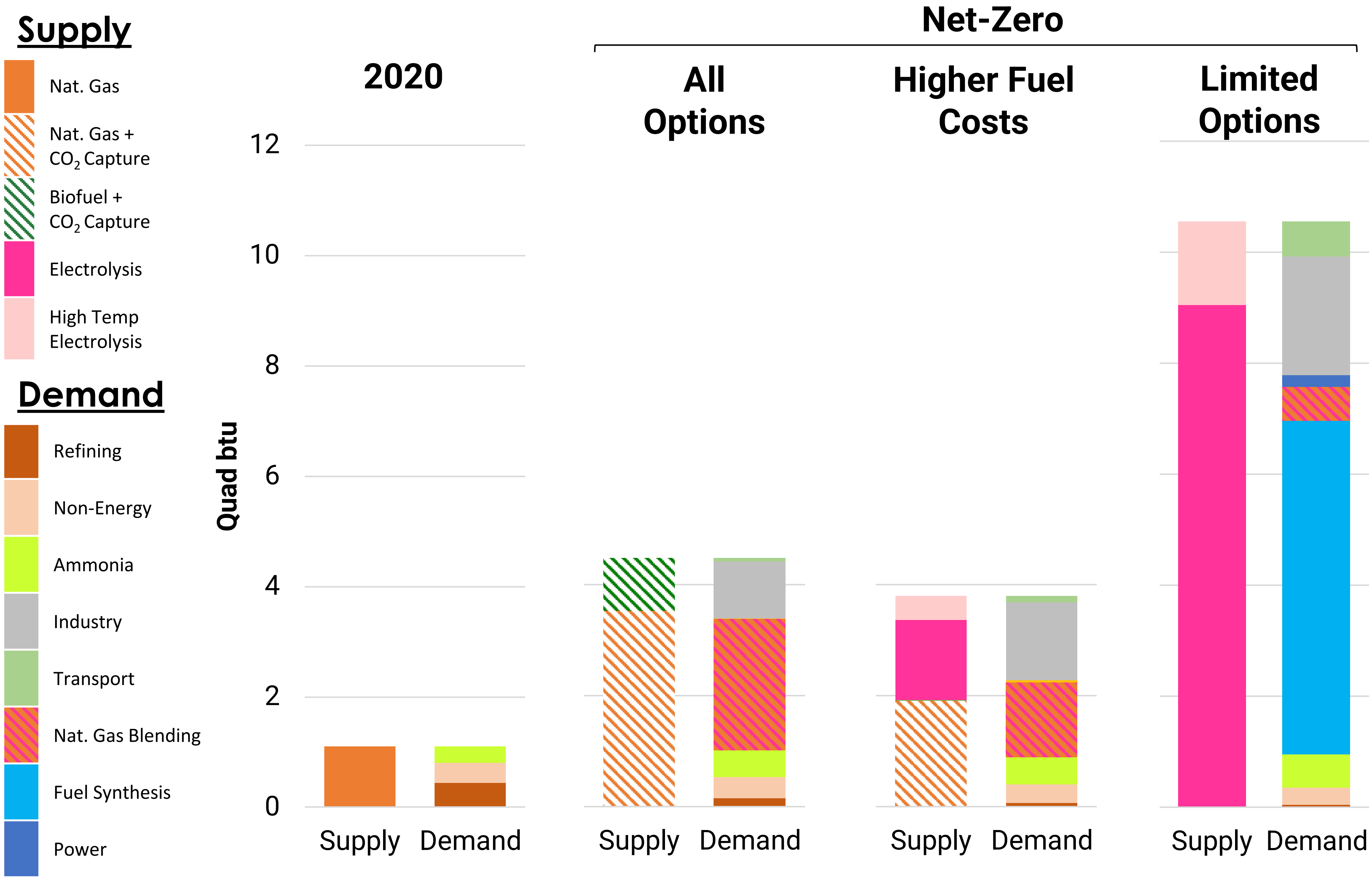
Value Perspectives

- Technology
- Infrastructure
- Economics
- Jobs
- Policy



Economy-Wide Infrastructure Considerations

Potential Scale of Hydrogen in a 2050 Net-Zero Economy



In a Net-Zero Economy…

- Electricity demand may increase ~1.5 – 2.5x
- 40% of electricity may go to hydrogen production
- Hydrogen may provide 4 – 10x the amount of energy it does today

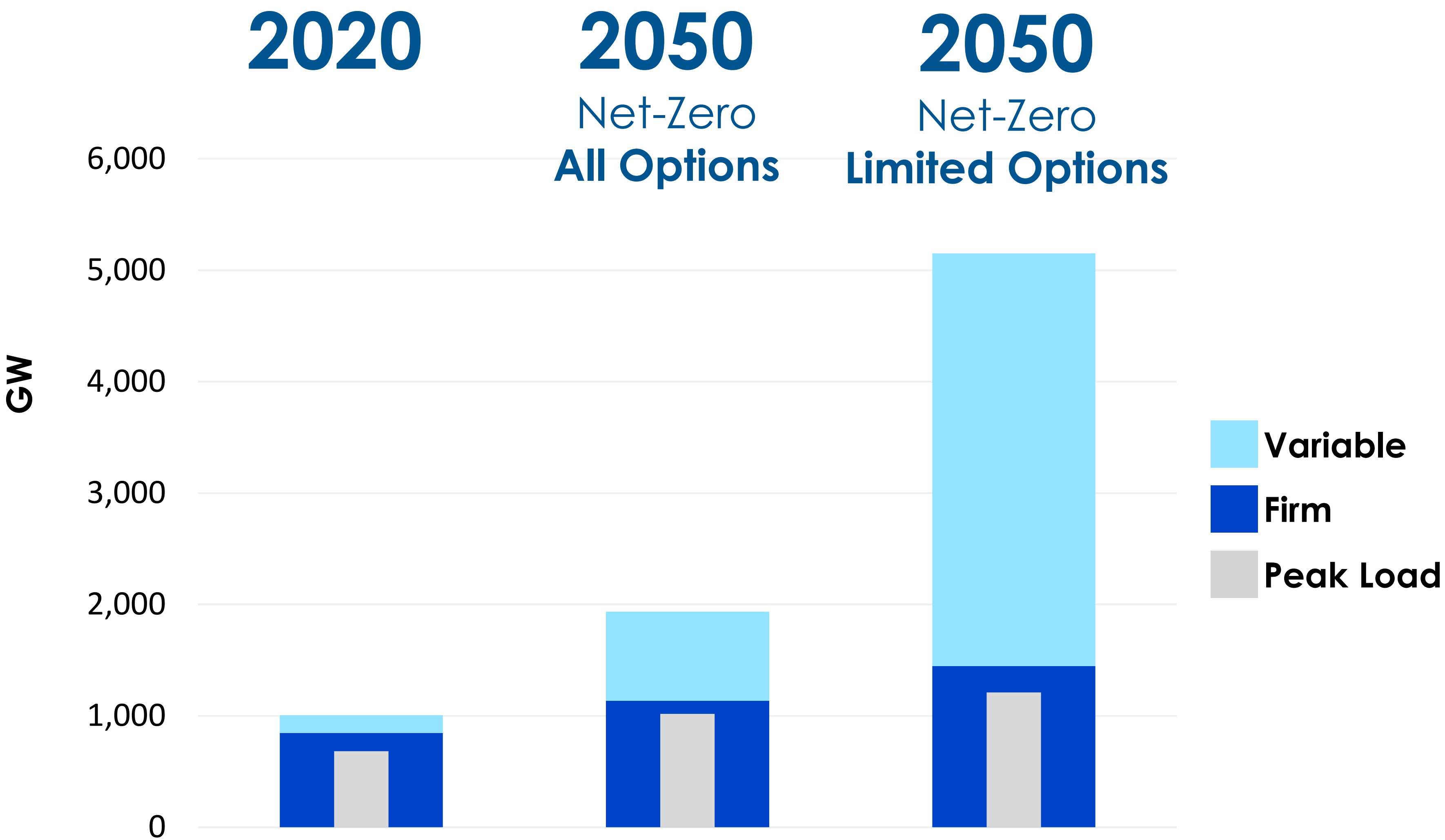
Note: Does not include potential impacts from Inflation Reduction Act

Source: LCRI Report 3002024993

Electricity Capacity

Net-Zero Load Growth

Clean, firm capacity is critical

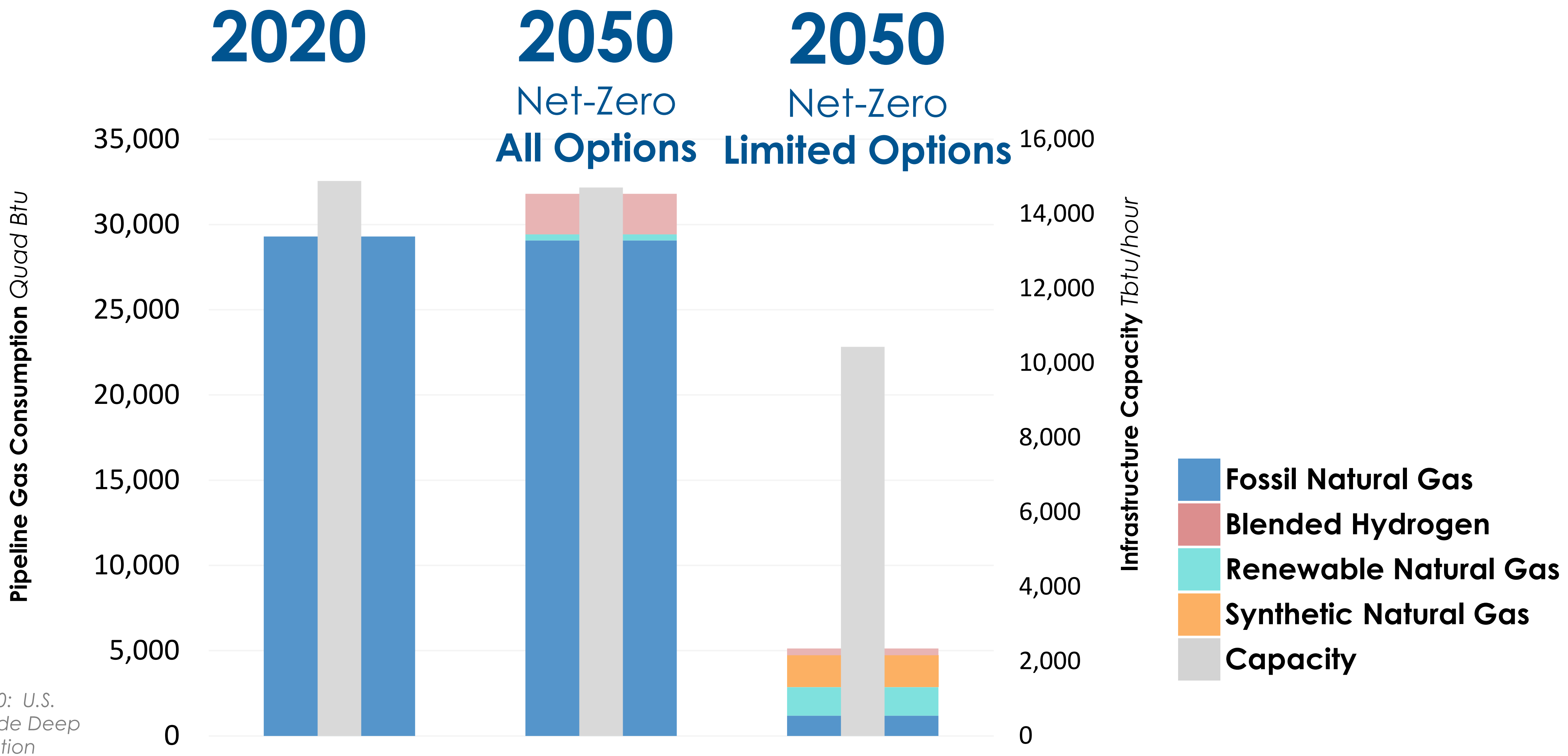


Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis

Gas Capacity

Demand & Capacity Changes

Infrastructure remains a critical enabler

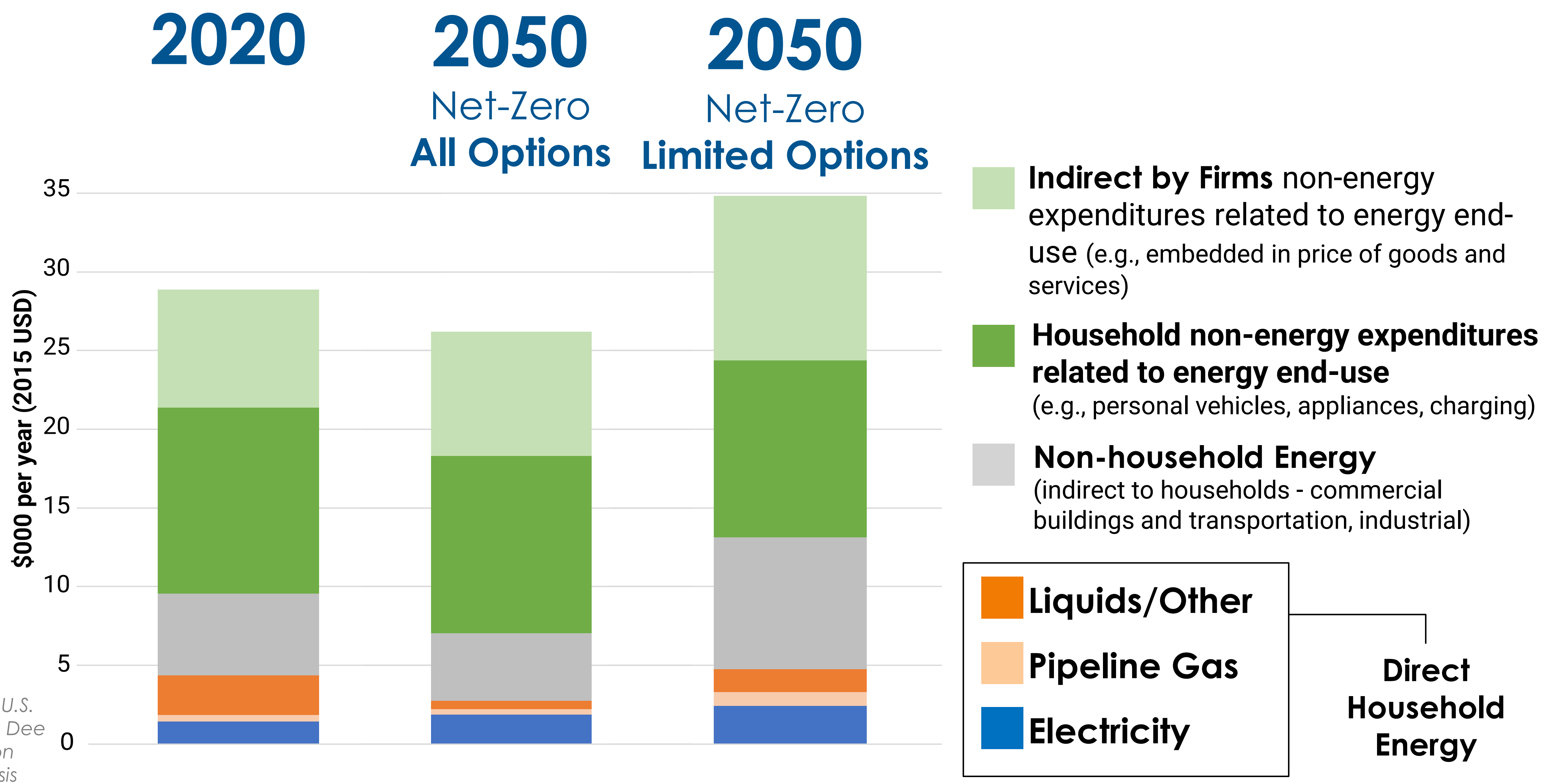


Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis

Household Expenditures

Total Energy Services

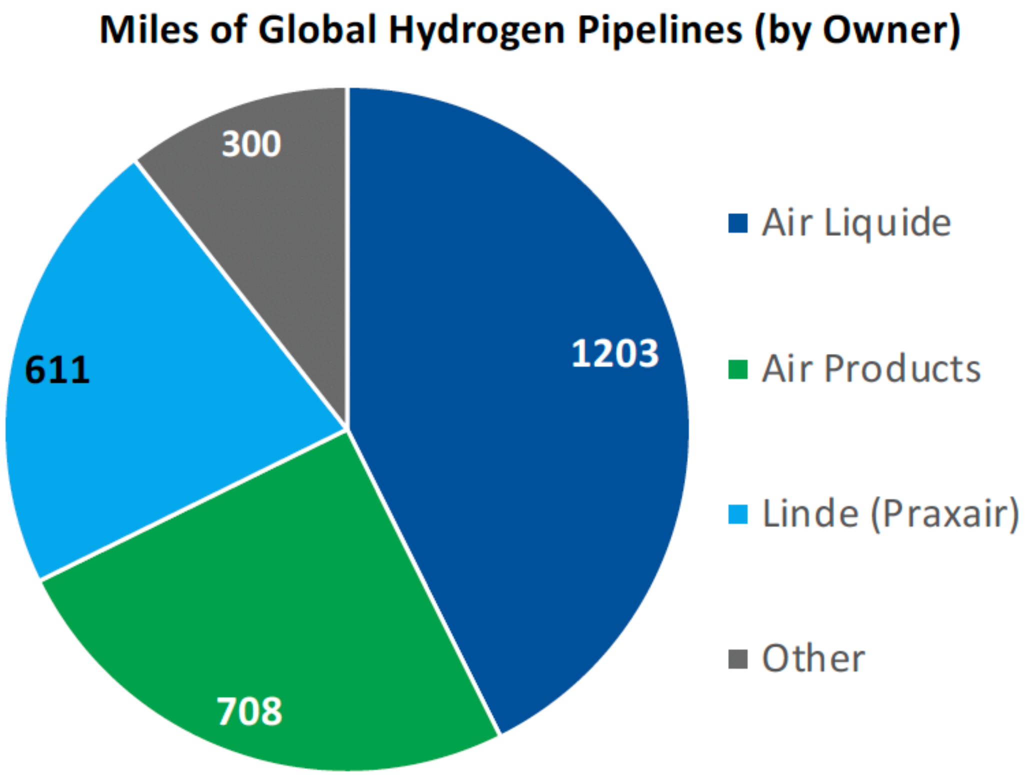
Annual energy expenditures

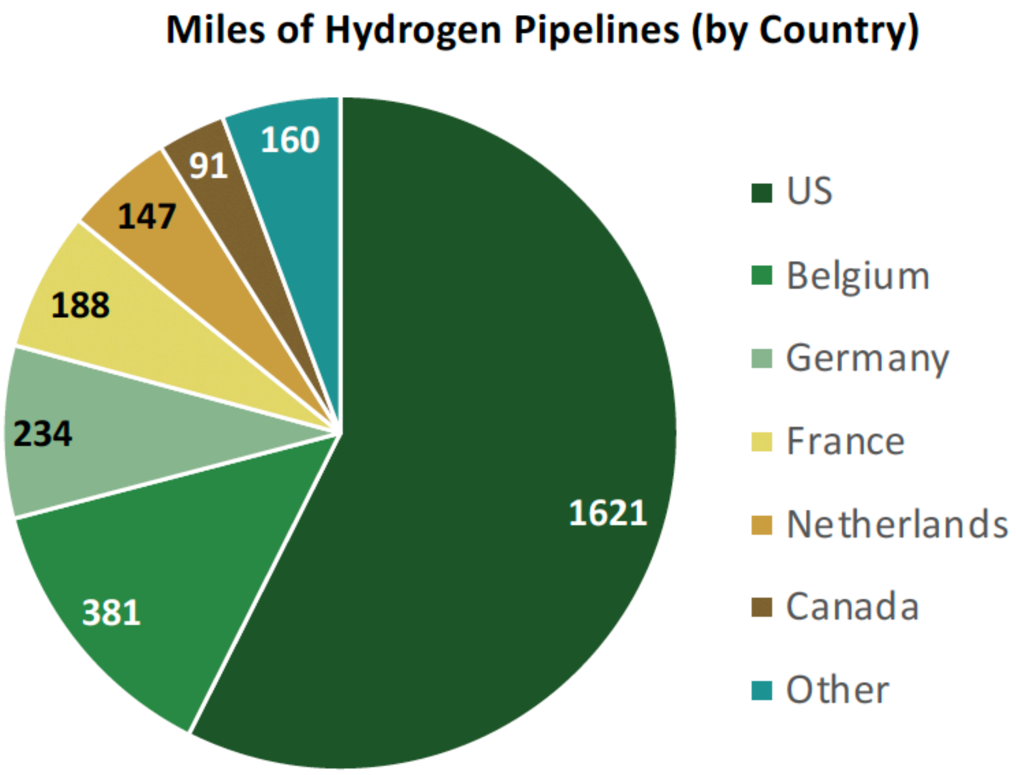


Net-Zero 2050: U.S. Economy-Wide Dee Decarbonization Scenario Analysis

EPRI

Global Hydrogen Pipelines





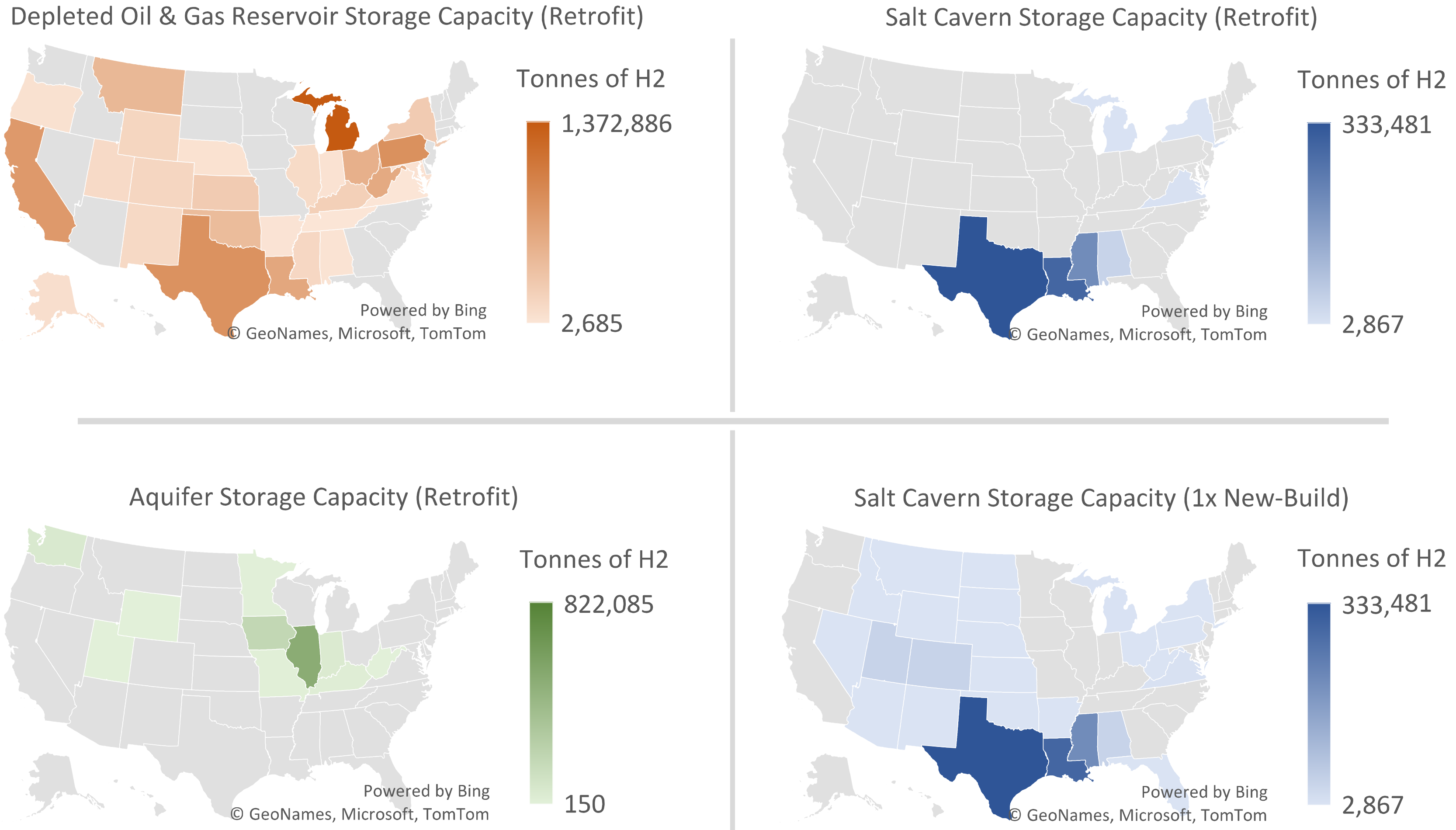
- H_2 has been transported via pipeline since 1938
- Almost all H_2 pipelines are owned by merchant gas companies, this provides security of supply for contracted sale of gas to end users
- Most H_2 pipelines are purpose-built; however, some have been transitioned from other service

Large-scale Hydrogen Storage

Deliverable: [Hydrogen Storage for US-REGEN Model: Cost and Availability](#) (3002028358)

- The **capital costs of underground hydrogen storage** facilities are an important input for energy system models that assess the role that different technologies play in decarbonizing the energy sector.
- This report describes the methodology and assumptions used to estimate the **cost of building new** underground storage facilities and **retrofitting** existing underground natural gas facilities for hydrogen service.
- Cost estimates for three types of underground hydrogen storage facilities were modeled: **depleted oil and gas reservoirs, aquifers, and salt caverns**.
- The study collects and analyzes data from various sources, including public databases, published papers, and EPRI and LCRI cost studies, to estimate the capital costs of these technologies.
- The results also present spatial data on the availability and location of existing natural gas storage in the United States, which could be retrofitted **to store hydrogen** as well as scenarios for potential new hydrogen storage capacity.

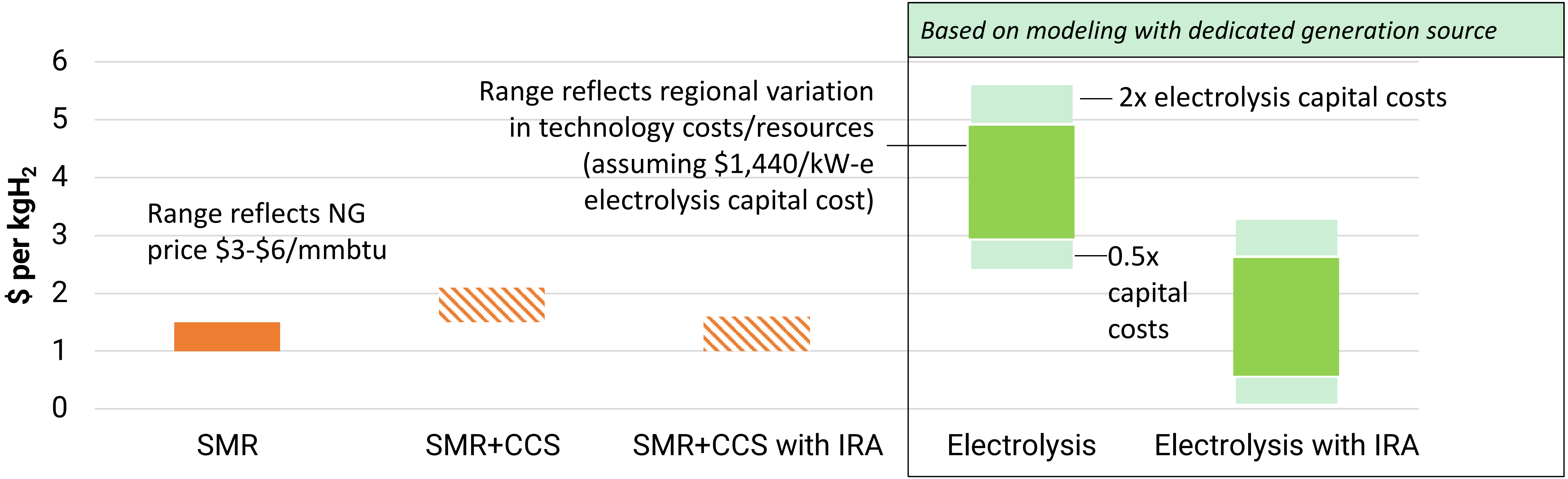
Regional Storage Capacity Results



Impact of Recent Policy

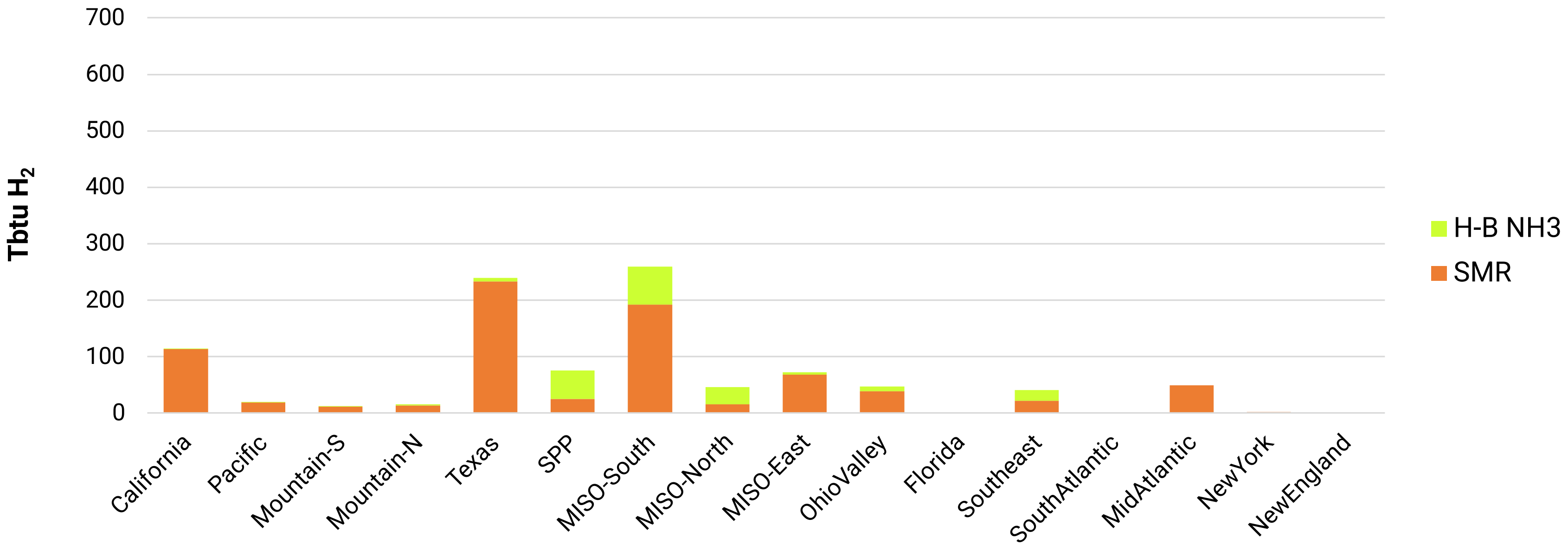
Initial estimates of IRA hydrogen price impacts

- Incentives for SMR+CCS or pyrolysis could make realized cost of low-carbon hydrogen from gas similar to conventional SMR
- Incentives for zero-carbon electrolysis provide a potential pathway for costs lower than conventional SMR

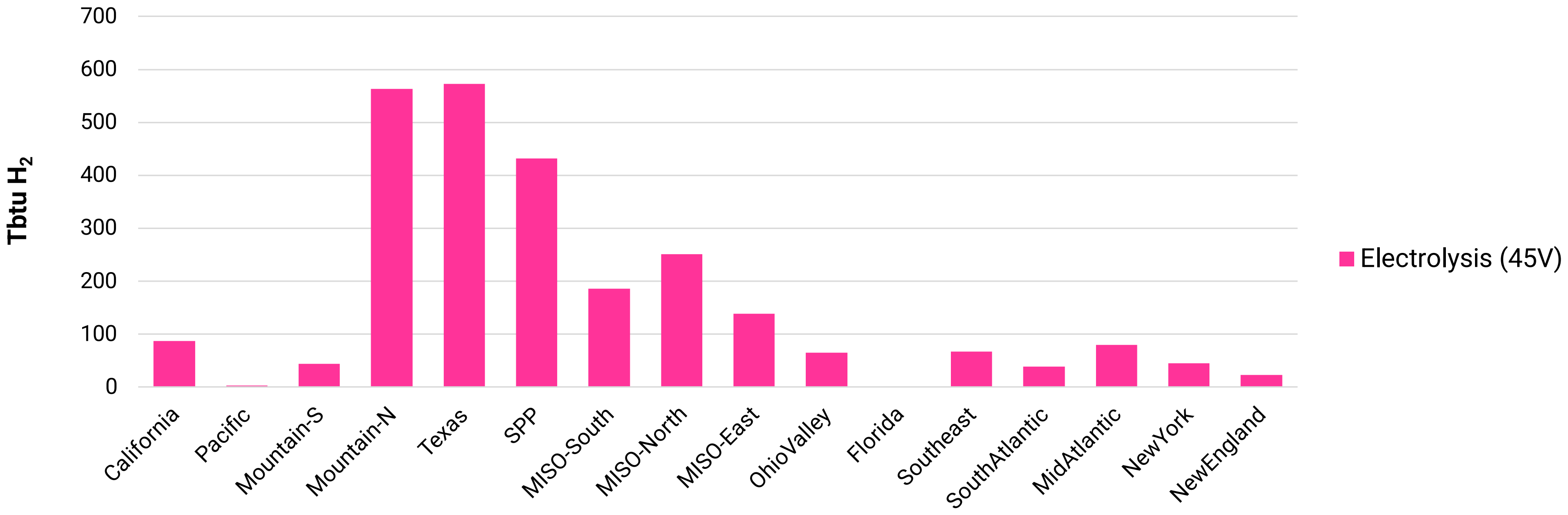


Regional Shifts in Hydrogen Production

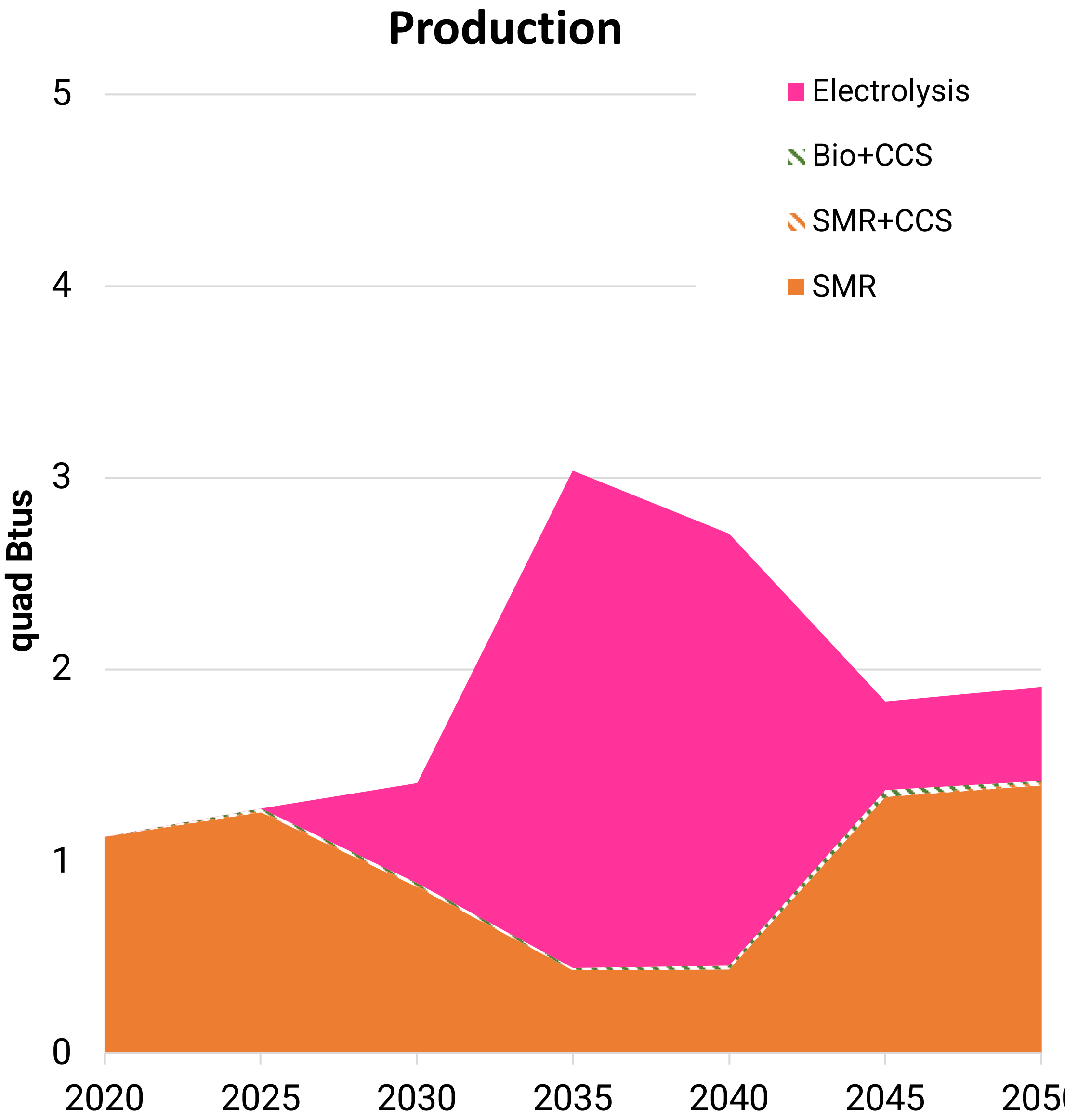
2020 Current Production

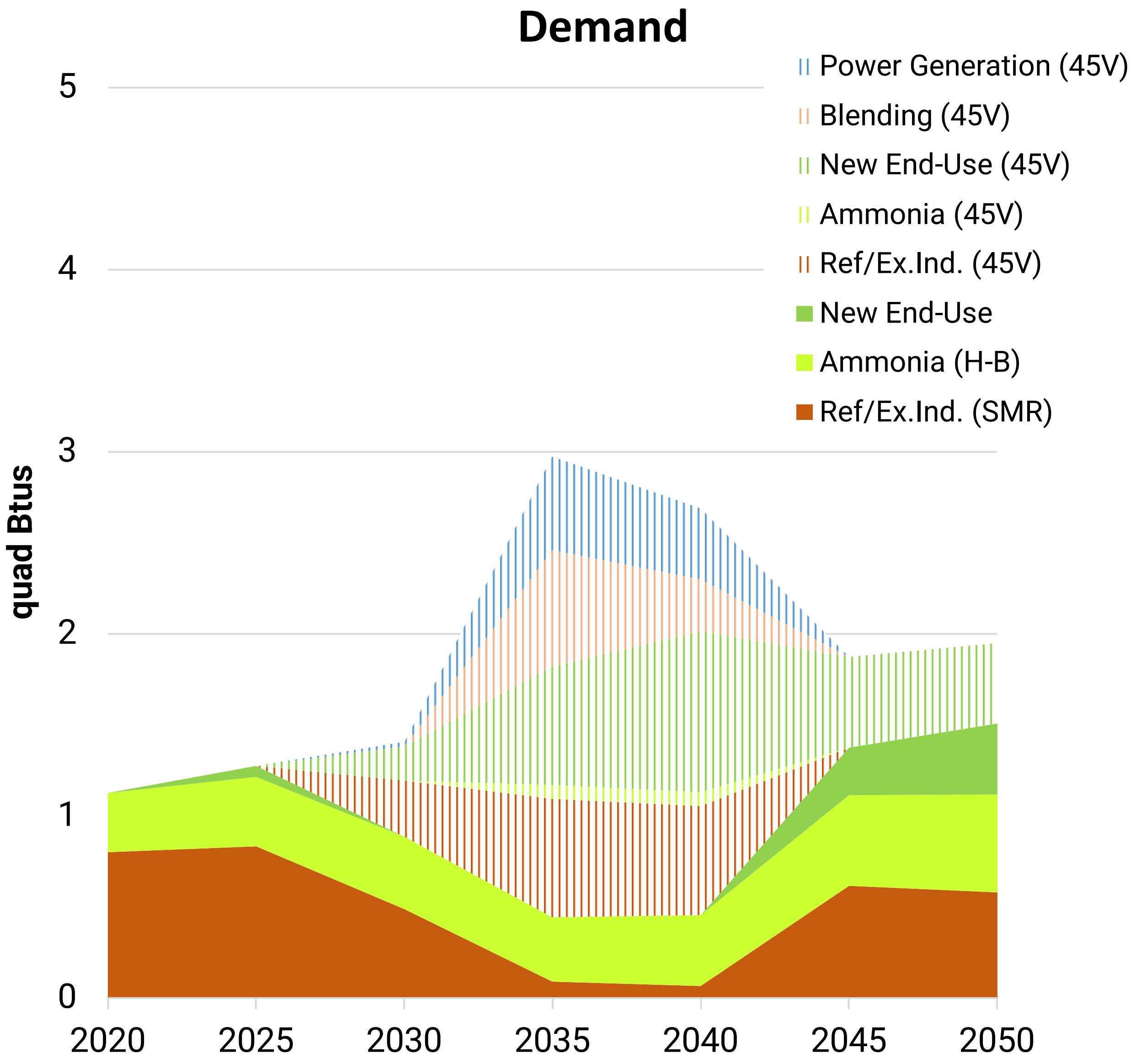


2035 New Production with IRA + 45V



U.S. Hydrogen: IRA Only (with 45V)





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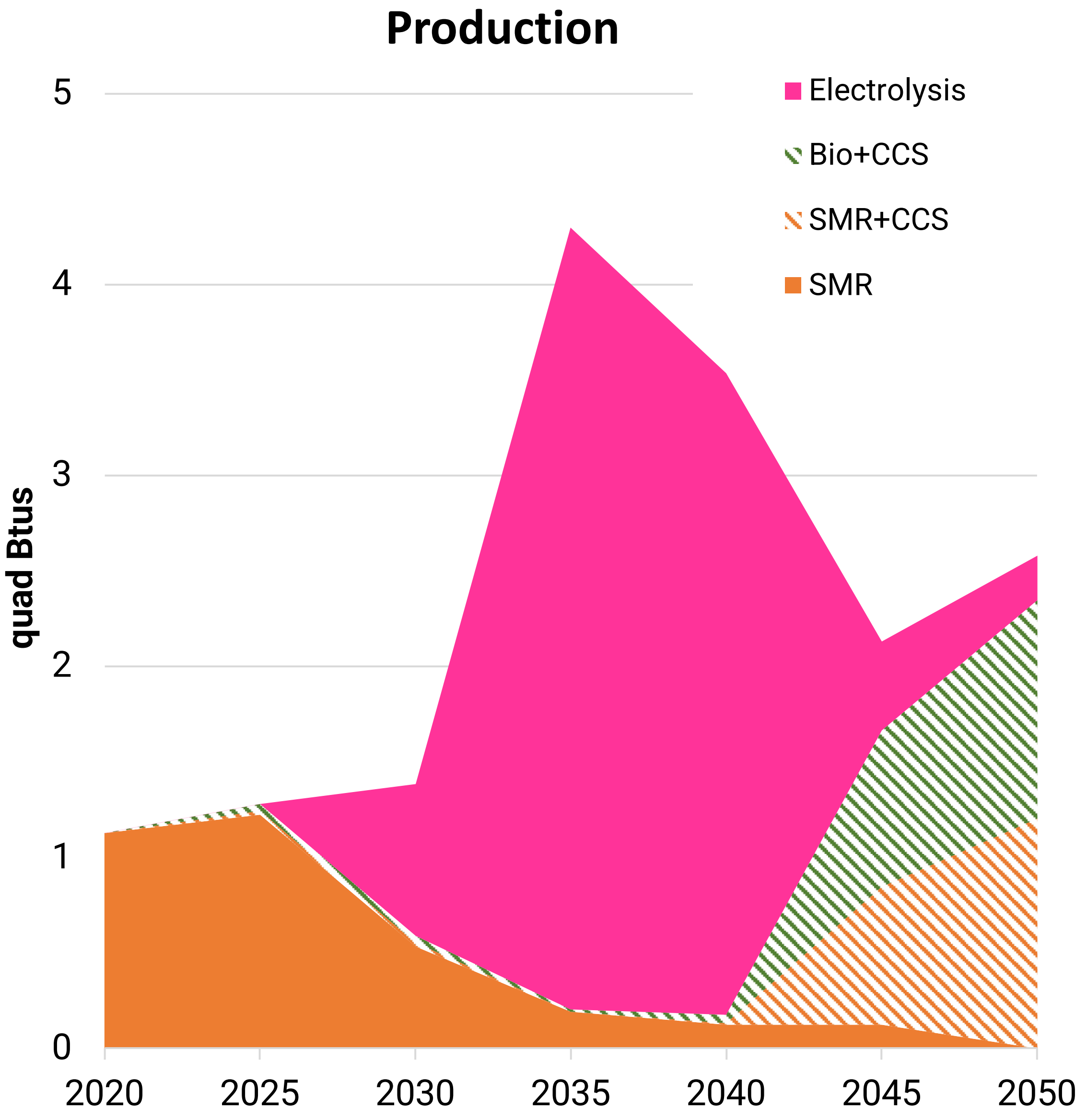
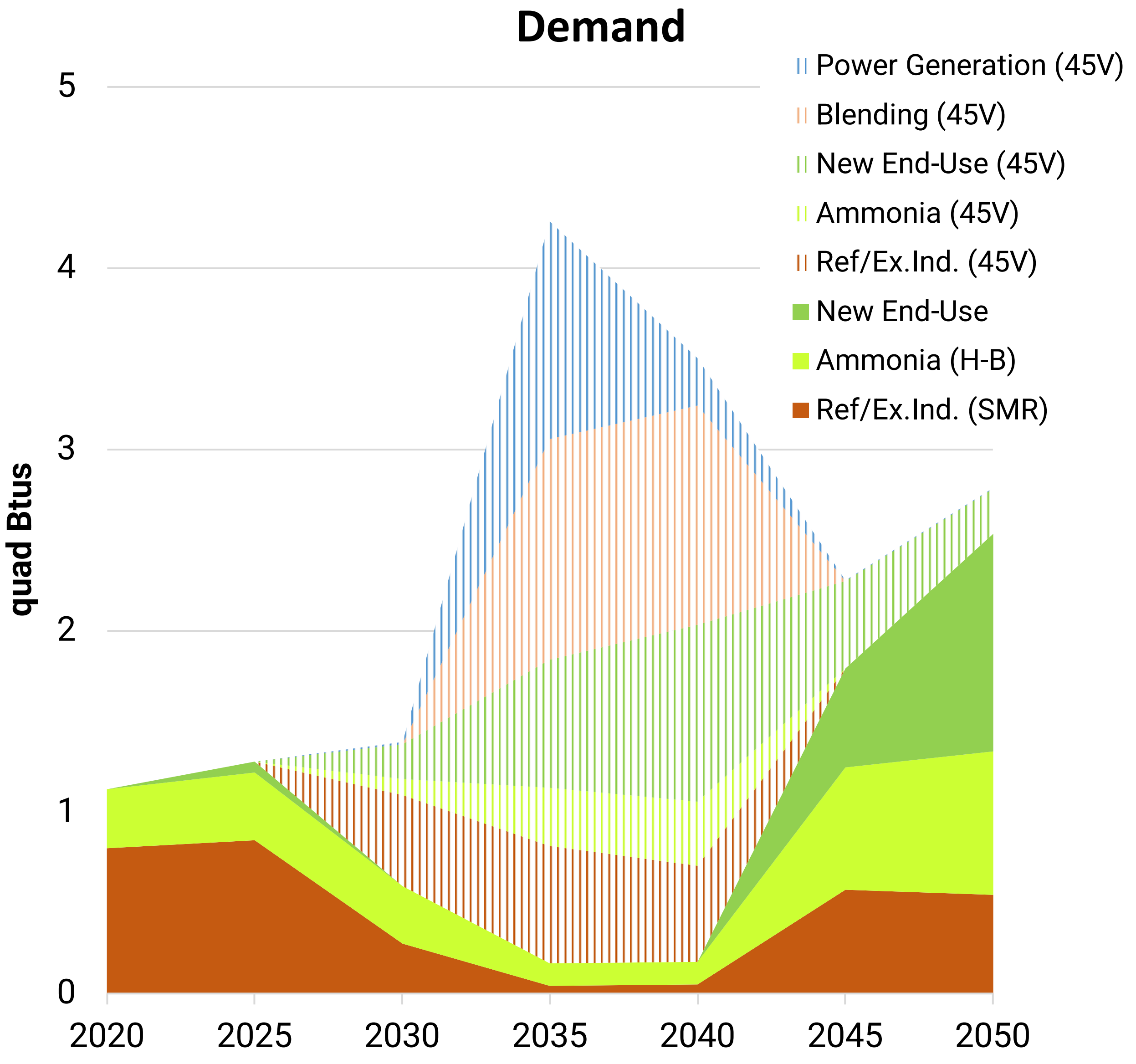
U.S. Hydrogen: IRA + Net-Zero (with 45V)





Industrial Sector Decarbonization to Achieve Carbon Neutrality

Planning should include both
direct and indirect electrification pathways

Processes and equipment may need to be changed, but there are opportunities to improve efficiency and reliability while minimizing costs

Integrated approaches across regional activities could enable accelerated solutions with lower risk

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