National
Petroleum
Council

Harnessing Hydrogen: A Key Element of the U.S. Energy Future

National Petroleum Council Meeting

April 23rd, 2024

Diverse Perspectives Inform Response to Study Request from Secretary of the Department of Energy

Study addresses seven questions

Executive Summary

Led by Chevron and McKinsey & Company

Chapter 1: Role of LCI Hydrogen in the U.S.

Led by University of Texas at Austin

Chapter 2: LCI Hydrogen Production At-Scale

Led by Air Liquide

Chapter 3: LCI Hydrogen – Connecting Infrastructure

Led by Southern California Gas

Chapter 4: Integrated Supply Chain

Led by Wood Mackenzie, partnering with MIT

Chapter 5: Demand Drivers for LCI Hydrogen in the U.S.

Led by ExxonMobil

Chapter 6: Policy

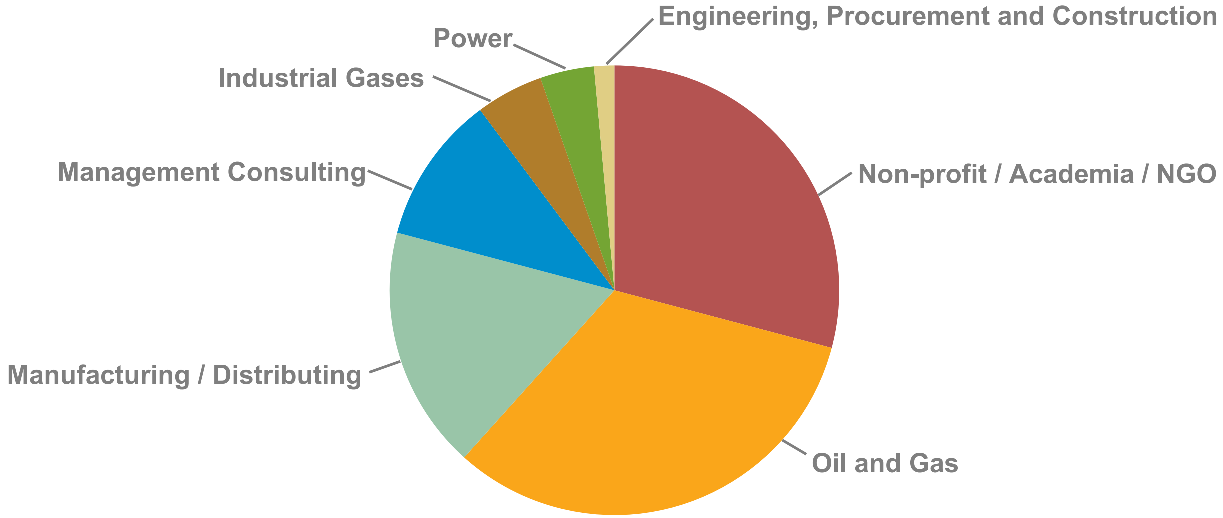
Led by bp

Chapter 7: Societal Considerations, Impacts, and Safety

Led by Great Plains Institute and Mitchell Foundation

Appendices

Impact



>**200 participants** from **100 organizations** participated; developing **19 key findings**

Coordinating Subcommittee (CSC) **members** represent **29 organizations**

23 key recommendations developed

Delivering the Study through Extensive Contribution and Exceptional Peer Review Process with a Diverse Team

Current stage

Q2 2022 — Study kickoff

- Launch **Leadership governance, membership, and process**
- Finalize **Workplan**
- Launch **Task Groups into analysis phase**

Q3 2022 to Q3 2023 — Research and analysis

- Chapter development
- **Analytical partnership** with MIT
- Develop and commence **stakeholder engagement plan**

Q3 2023 to Q4 2023 — Consolidate report, seek alignment

- **Refine analysis** and **consolidate** into single report
- **Identify and resolve** areas of **disagreement** on study **findings and recommendations**

Q1 to Q2 2024 — Finalize report

- **Iterate** on report content based of SteerCo and StudyCo feedback
- Develop **communications plans** for syndication and release

April 23, 2024 — Hand over report

- Receive **Council endorsement** of report
- **Submit final report** to Secretary Granholm and **publish report**
- Commence **communications**

Key Attributes of This Study

Expert Input – Technoeconomic modeling informed by diversity and experience of the study participants

Targeted Role of LCI hydrogen – Identify recommendations to enable LCI hydrogen adoption at a lower cost to society

Regionality – Groundbreaking, comprehensive regional analysis across the LCI hydrogen value chain (supply, infrastructure, demand)

Modeling Collaboration Between NPC and MIT Energy Initiative

Key Inputs

iea International Energy Agency

NREL

U.S. DEPARTMENT OF ENERGY

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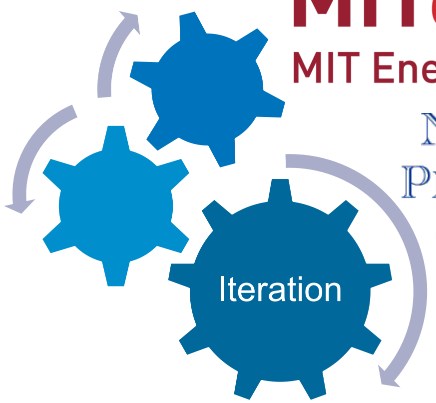
Analysis



MITei MIT Energy Initiative

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Key Outputs

Economy-wide **energy mix, emissions trajectories** and **costs**

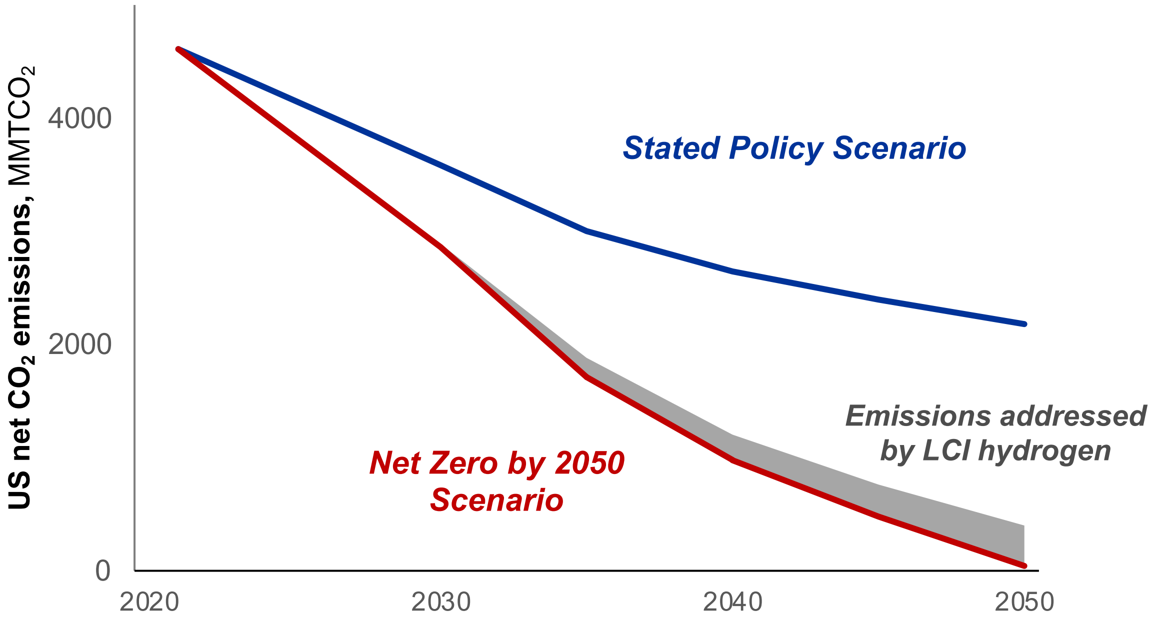
Two scenarios: **Stated Policies** and **U.S. Net Zero by 2050**

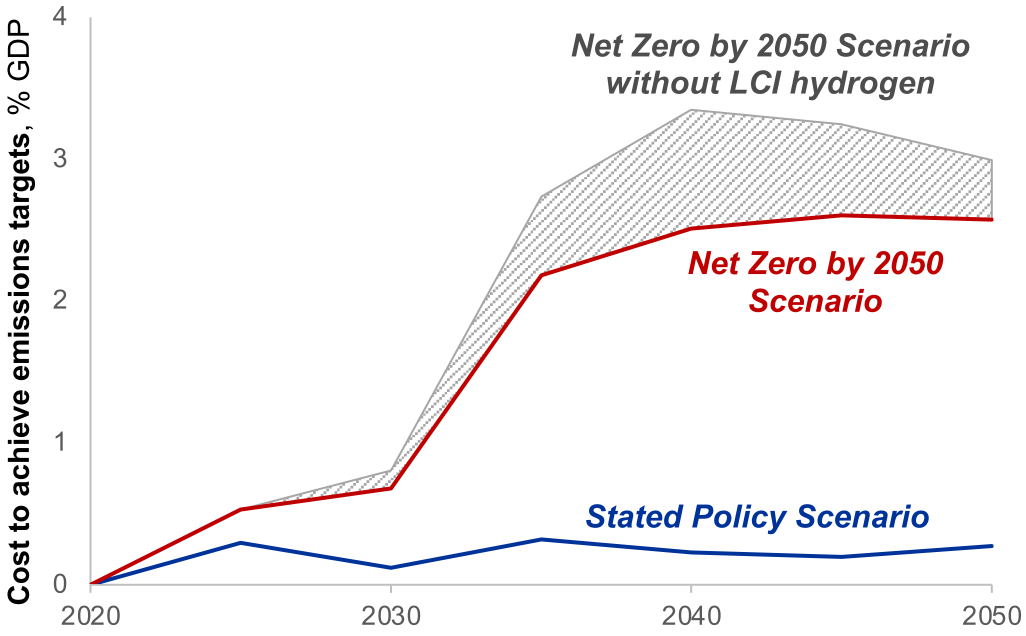
National and regional **supply** and **demand techno-economics**

Select **regional infrastructure optimization**

Key Modeling Findings

LCI Hydrogen Plays a Key Role in Achieving Emissions Reduction at a Lower Cost to Society





LCI hydrogen accounts for **~8% of US emissions reductions**

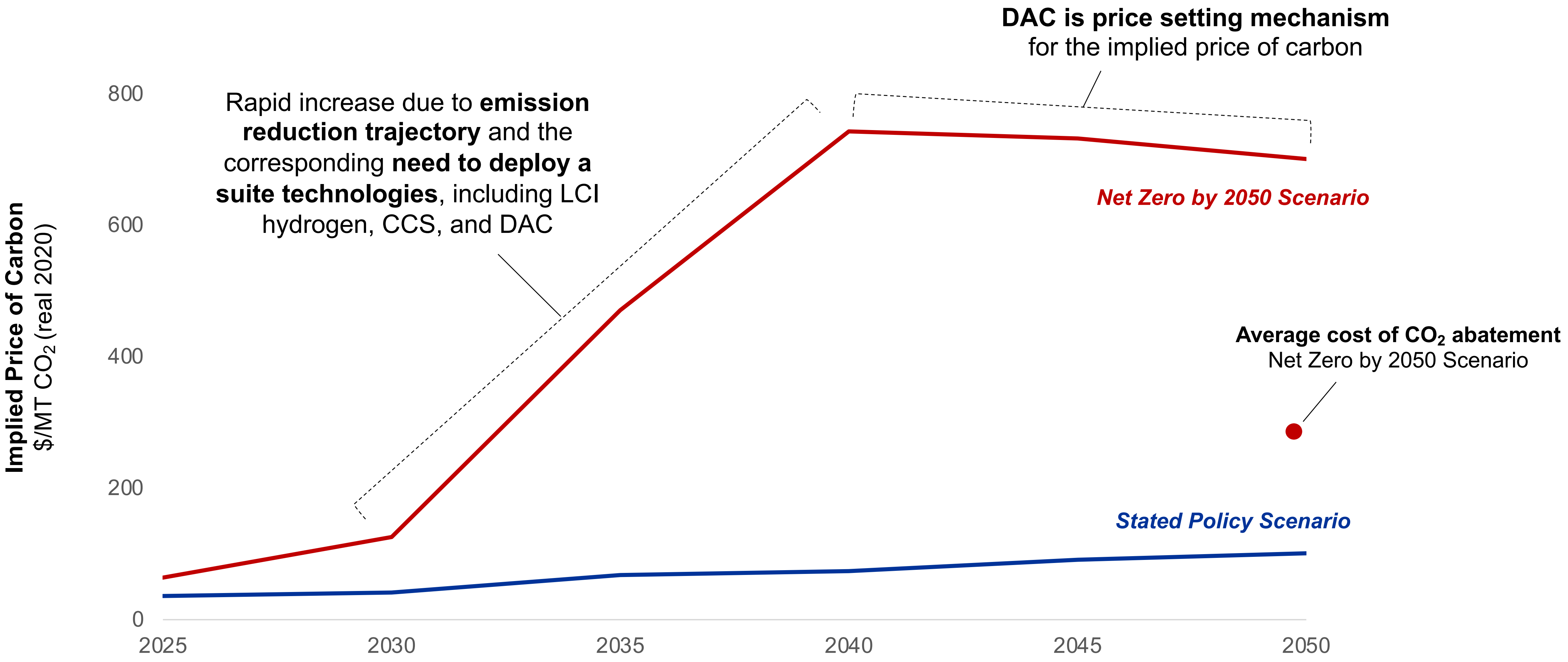
Targeted at **hard-to-abate sectors**

Costs to achieve Net Zero increases to **~3% of GDP** by 2050

Without LCI hydrogen, costs to achieve Net Zero could **increase by an additional 0.5-1% GDP**

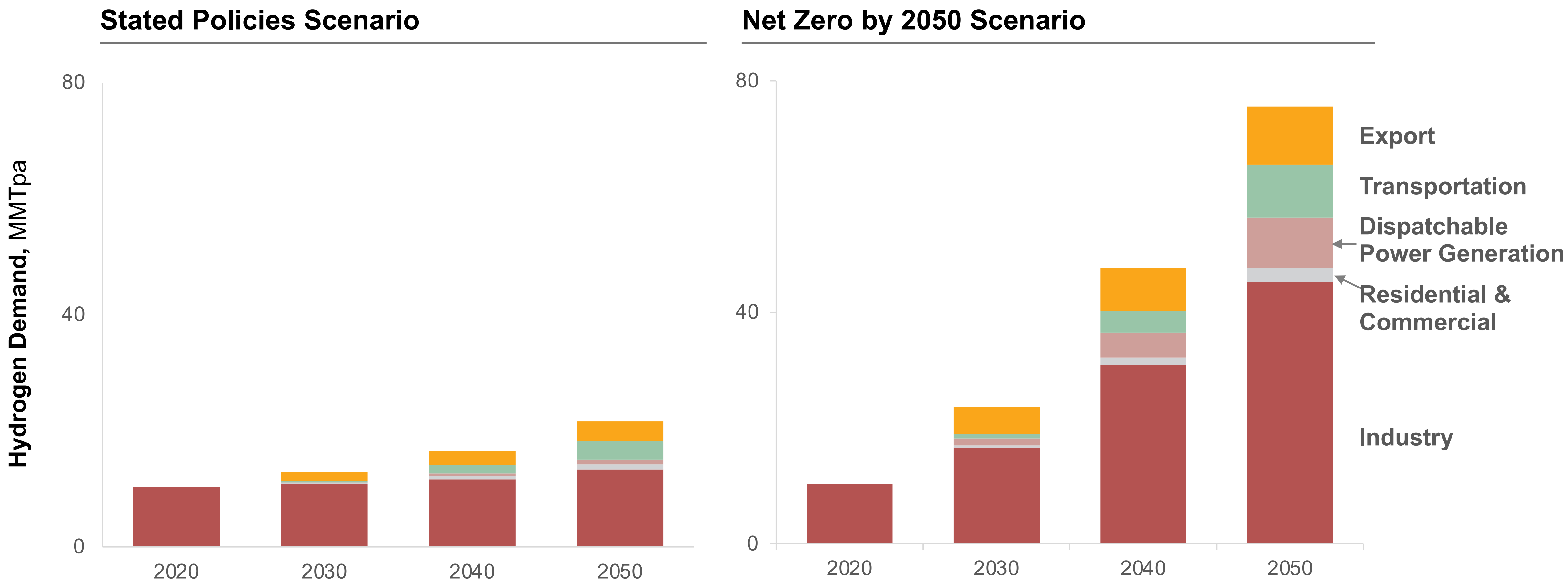
Source: MIT modeling for NPC Hydrogen study; MMTCO$_2$ – million metric tons CO_2 equivalents; GDP – Gross Domestic Product

Price of Carbon to Reach Price Parity for Marginal CO_2 Emitter



Source: MIT modeling for NPC Hydrogen study;
$/MT CO_2 : dollars per metric ton of carbon dioxide emissions (in real 2020 dollars)
CCS: carbon capture and storage
DAC : Direct Air Capture

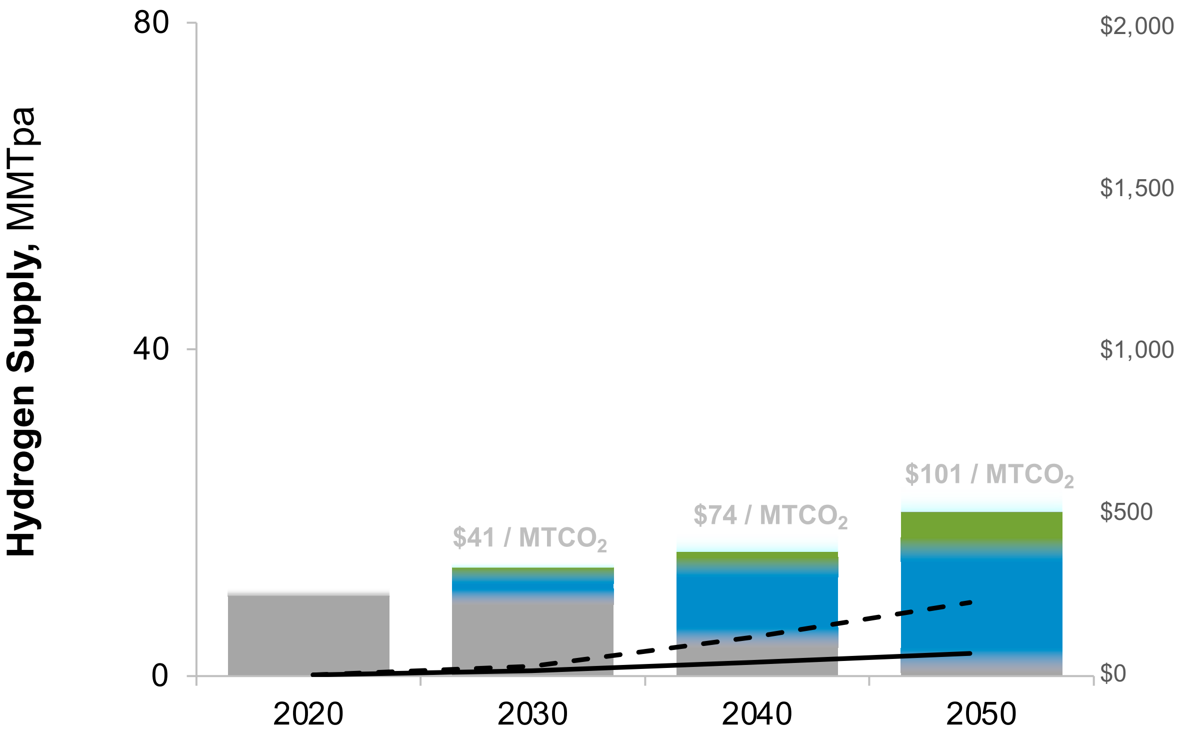
Unlocking Demand Sectors Will Require Significant and Immediate Action



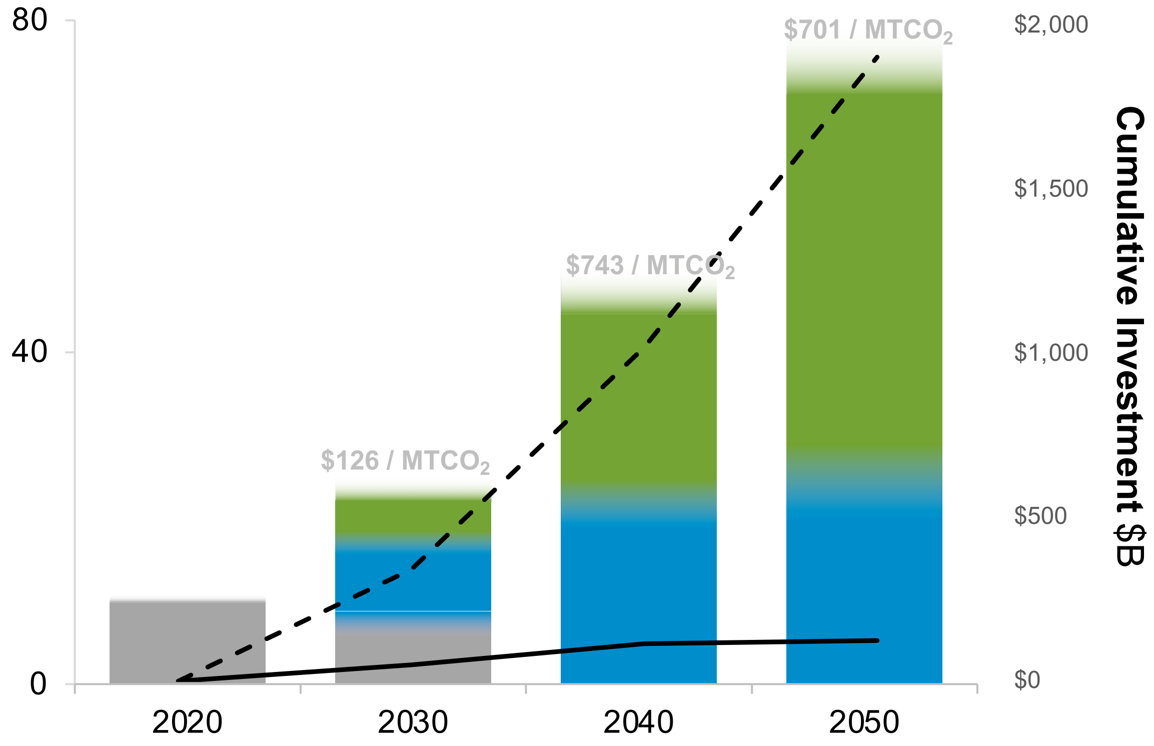
Source: MIT modeling for NPC Hydrogen study
MMTpa – Million metric tons per annum

Optimal Supply Mix Driven by Speed to Scale, Cost and Carbon Intensity

Stated Policies Scenario



Net Zero by 2050 Scenario



Supply Investment

Renewable electrolytic hydrogen

Natural gas reformed hydrogen with carbon capture and storage

Unabated hydrogen

$X / MTCO$_2$ Implied marginal price of carbon at indicated year and policy scenario in real 2020 dollars per metric ton of CO_2 abated

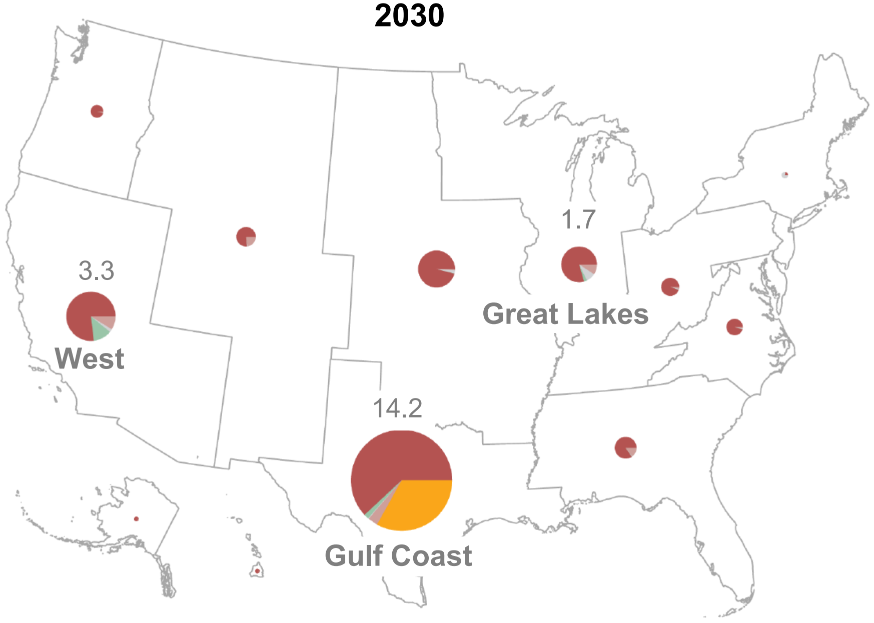
Source: MIT modeling for NPC Hydrogen study
MMTpa – Million metric tons per annum

Three Advantaged Regions Could Lead U.S. LCI Hydrogen Market Development

Regional development also driven by proven demand, abundant natural resources (solar, wind, natural gas), infrastructure and supportive State policies

Regional Demand by Sector – U.S. Net Zero by 2050 Scenario

2030



Regional Competitive Advantages

Gulf Coast

Natural gas and solar/wind resource advantages; Access to infrastructure; Potential and anchor demand

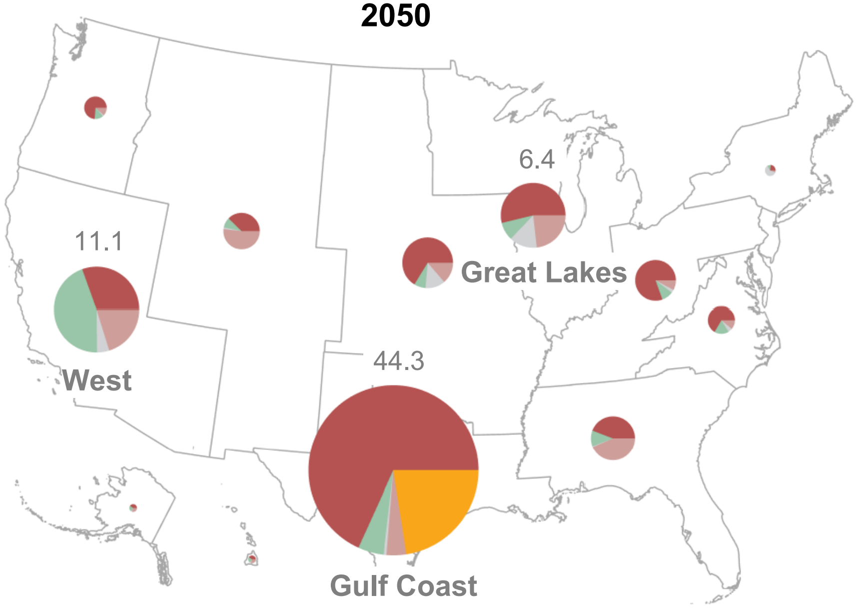
West

Policy for mobility applications such as LCFS, ACT/ACF

Great Lakes

High wind capacity; Appalachia natural gas access

2050

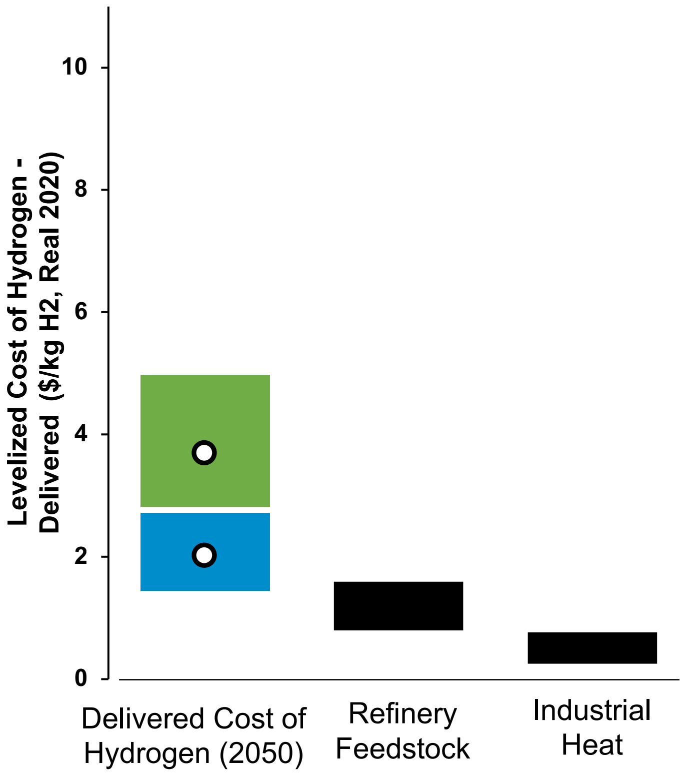


Exports | Residential & Commercial | Power | Transportation | Industrial

Source: MIT modeling for NPC Hydrogen study
Demand in MMTpa (Million metric tons per annum)
LCFS– Low Carbon Fuel Standard
ACT– Advanced Clean Transportation
ACF– Advanced Clean Fleets

Cost Gap Between Incumbents and Low Carbon Alternatives in 2050

Gulf Coast – Industrial Demand Sector



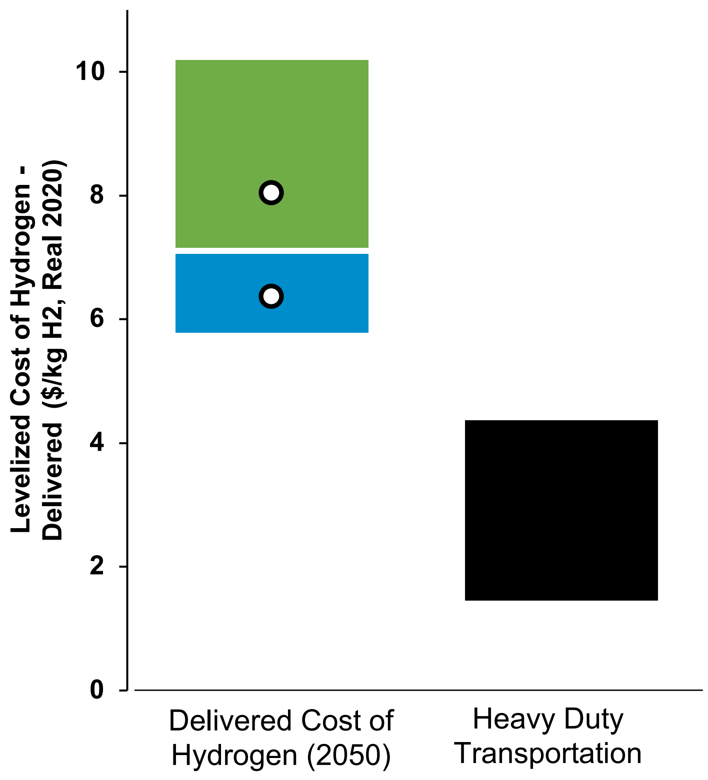
By 2050 **significant cost parity gaps** to incumbent fuels and feedstocks **still exist**

Different demand sectors need hydrogen at **different costs to reach parity to incumbents**

Carbon intensity comparisons between incumbent and LCI hydrogen

	Incumbent	NG+CCS Hydrogen	RE Hydrogen
Refinery Feedstock kg CO_2e / kg H_2	~ 10	~ 1	0
Industrial Heat kg CO_2e / MMBTU	~ 56	~ 8	0
Heavy Duty Transportation kg CO_2e / 100 miles	~ 55 – 175	~ 9	< 0.1

Gulf Coast – Transportation Demand Sector



- Delivered Cost Range - Renewable Electrolytic (RE) Hydrogen (2050)
- Delivered Cost Range - Natural Gas Reformed Hydrogen with Carbon Capture and Storage (NG+CCS) (2050)
- Hydrogen Cost Range Needed to Reach Parity with Incumbent Feedstock or Fuel
- Reference Hydrogen Cost

Source: MIT modeling for NPC Hydrogen study
$/kg – Levelized cost of hydrogen, Real 2020 $
*Range of carbon intensities based on bio-based and unabated diesel
CO_2e – carbon dioxide equivalents
MMBTU – Million British Thermal Units, higher heating value

Key Recommendations

Study Key Recommendations Summary

Policy and Regulation

Item	Topic
1	Price on Carbon
2	National Low Carbon Intensity Industry Standard
3	National Low Carbon Intensity Transportation Standard
4	Production-Side Incentives
5	Global Trade
6	Infrastructure Incentives
7	General Permitting Reform
8	Unblended Interstate Hydrogen Pipeline Regulatory Authority
9	Class VI Primacy and Well Permitting

Societal Considerations, Impacts and Safety

Item	Topic
10*	Commitment to social considerations, transformative community engagement, and net positive outcomes
11*	Community Engagement Improvement Opportunities
12	Outreach materials to increase community understanding of LCI hydrogen development
13*	Role Clarity for Community Benefits
14*	Community Benefits Planning
15	Tracking and communicating commitments to community engagement to increase public confidence
16	Workforce Readiness
17*	Additional Study on Societal Considerations and Impacts

Technology and Research, Development and Deployment

Item	Topic
18	Technology – Reducing the Cost Gap
19	Supply Chain
20	Technology – Detecting, Quantifying and Mitigating Environmental Impact
21	Pipeline Safety Codes & Standards
22	Grid Integration
23	Grid Resiliency

*Joint recommendation with *Charting the Course* study

Policy and Regulation

- **Legislative action** to implement a long-term, economy-wide transparent **price on carbon**
- Without or as a bridge to carbon pricing**, advance** both **demand and production side incentives**
  - **Low-carbon intensity standards** in the industrial and transportation sectors
  - **Adjustments** to the **45V production tax credits:**
    - **Match credit claiming period** of asset investment lifecycle
    - **Utilize GREET capabilities** including co-product allocation and use of verifiable values for lifecycle analysis
- **Infrastructure capital** access and **global carbon intensity certification** systems
- Develop **efficient regulatory frameworks** associated with **permitting processes:**
  - General permitting processes
  - Unblended, interstate hydrogen pipelines
  - Class VI wells permitting primacy and approvals

Societal Considerations, Impacts and Safety

- **Transformation of community engagement** that develops and encourages **best practices** that include **equitable representation** (industry, NGOs, government)

- **Clear structures to communicate and partner** – outreach materials to provide education, role clarity for community benefits and planning, performance tracking of commitments

- Enabling **workforce development** and **labor engagement**

- Developing **reliable value-chain solutions** while **ensuring public safety** and **providing societal benefits** inclusive of environment, health and economic impacts

Technology and Research, Development and Deployment (RD&D)

- **Targeted technology and RD&D investments** in areas with **gaps in commercially available technology** across the LCI hydrogen value chain
  - **Improve efficiency** and **lower costs** for **production technologies** and **end-use applications**
  - Hydrogen **storage and infrastructure**
  - Hydrogen **leak detection**

- Address potential **technical bottlenecks** that could **inhibit deployment** of commercially available technologies including:
  - **Materials sourcing**
  - Clarity in **technical codes and standards**
  - **Reliability and resilience** of the electrical grid

Key Messages

LCI hydrogen can play a key role in **reducing emissions** in the **hard-to-abate sectors at a lower cost to society**.

Significant and immediate actions beyond current policies are necessary to unlock various LCI hydrogen demand sectors at the scale needed to support U.S. Net Zero by 2050 aspirations.

The LCI hydrogen production mix will be driven by **speed to scale, reduced delivery cost, and the carbon intensity** of various hydrogen pathways

LCI hydrogen deployment will be marked by **regional variances** in production development and sectoral demand activation.

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Study website:
harnessinghydrogen.npc.org

Appendix

Modeling Methodology and Assumptions

- MIT Energy Initiative modeling methodology and platforms
  - USREP platform couples macroeconomic energy demand and GHG emissions projections.
  - SESAME platform calculates techno-economics and life cycle assessment of GHG emissions.
- Stated Policies scenario is calibrated to International Energy Agency (IEA) World Energy Outlook (WEO) 2022 Stated Policies (STEPS) scenario.
- U.S. Net Zero by 2050 (NZ2050) scenario is calibrated to IEA WEO 2022 Announced Pledges Scenario (APS).
- Costs are calculated on a levelized basis assuming 10% WACC, 25% tax rate, 7-year MACRS depreciation schedule, and expressed in real 2020$.
- The macroeconomic modeling utilized an implied carbon price, which was allowed to vary over time, to achieve the emissions trajectory assumed for each scenario.
- CO_2 Direct Air Capture (DAC) assumed to be the backstop negative emissions technology. Under the NZ2050 scenario, the cost of DAC was projected to be $750/tCO2 when it starts scaled deployment in 2040, and to decrease to $700/tCO2 by 2050. It was not observed to deploy at material scale in Stated Policies scenario.
- Technoeconomic assumptions for hydrogen production technologies (NG+CCS H2 and RE H2) developed by consensus among study participants.
- Variable renewable energy (VRE) costs taken from 2023 Annual Technology Baseline (ATB) from National Renewable Energy Laboratory (NREL).
- VRE capacity factors developed by MIT Zephyr model on hourly basis over a one-year timeframe, leveraging NREL assessments of solar and wind potential.
- Electrolysis plants modeled in “behind the meter” configuration powered by dedicated renewables (i.e. no grid connection)
- Natural gas value chain GHG emissions developed at regional level with National Energy Technology Laboratory (NETL) data, assuming by 2050 a 0.1% methane emissions intensity and 75% reduction in CO_2 and N_2O emissions. This represents an aggressive reduction and would require an acceptable certification and validation system.
- The modeling does not incorporate the indirect warming effects from H_2 emissions.