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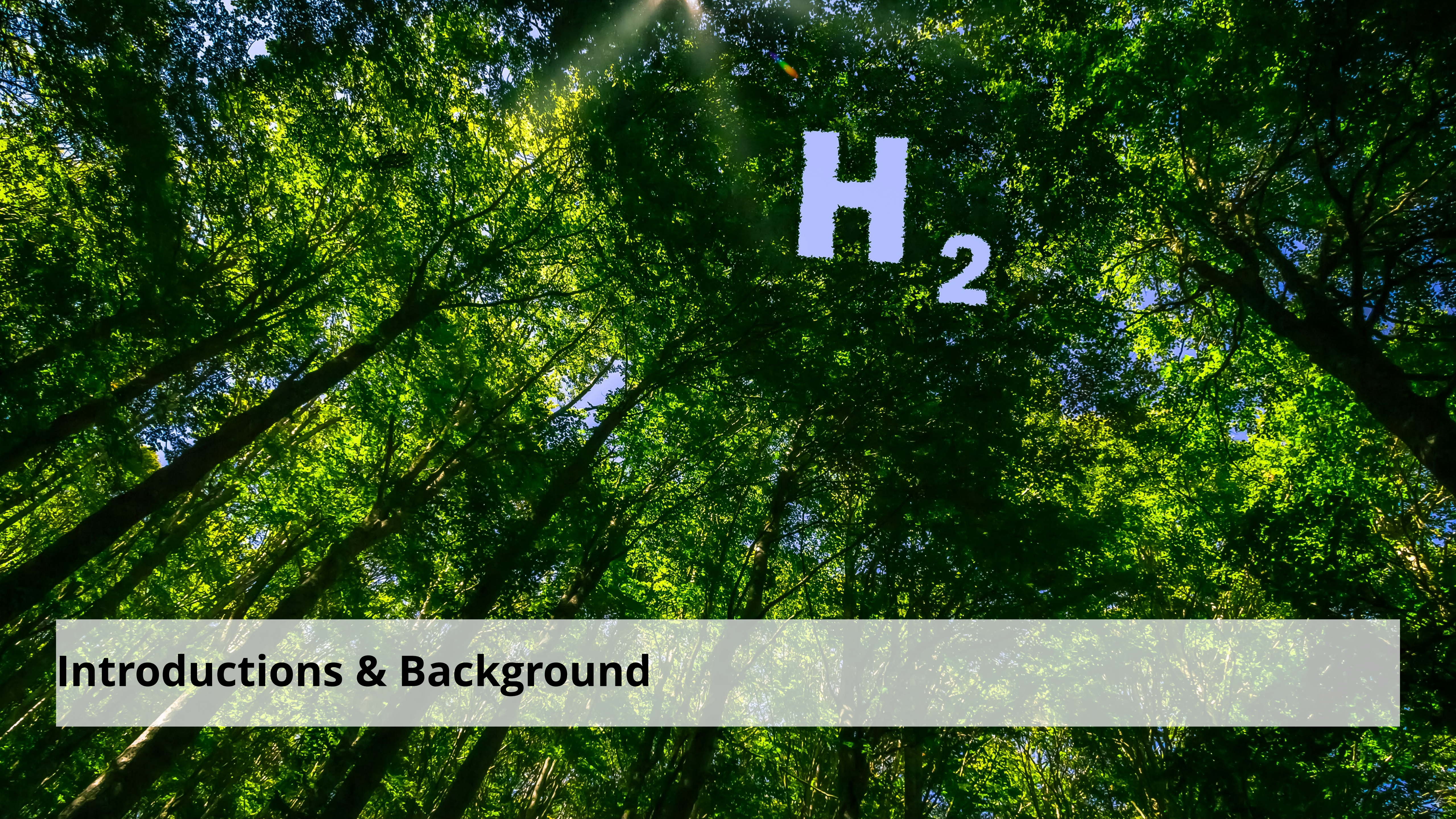
RENEWABLE THERMAL COLLABORATIVE

Green Hydrogen Technology Assessment: Opportunities for Industrial Heat

Contents



Introductions & Background

Project Background: Assessment of Green Hydrogen for Industrial Heat

Our collaboration with WWF and RTC centered around analyzing the potential for scaling green hydrogen for industrial heat and making green hydrogen part of the broader decarbonization movement.

Welcome to the preview of our paper on the use of green hydrogen for industrial heat which examines:

- The current state of green hydrogen in the United States
- Barriers and opportunities for scaling green hydrogen for industrial heat
- Considerations for market participants to undertake to promote the scaling of green hydrogen

Main Takeaways

Based on our assessment, we've identified the following:

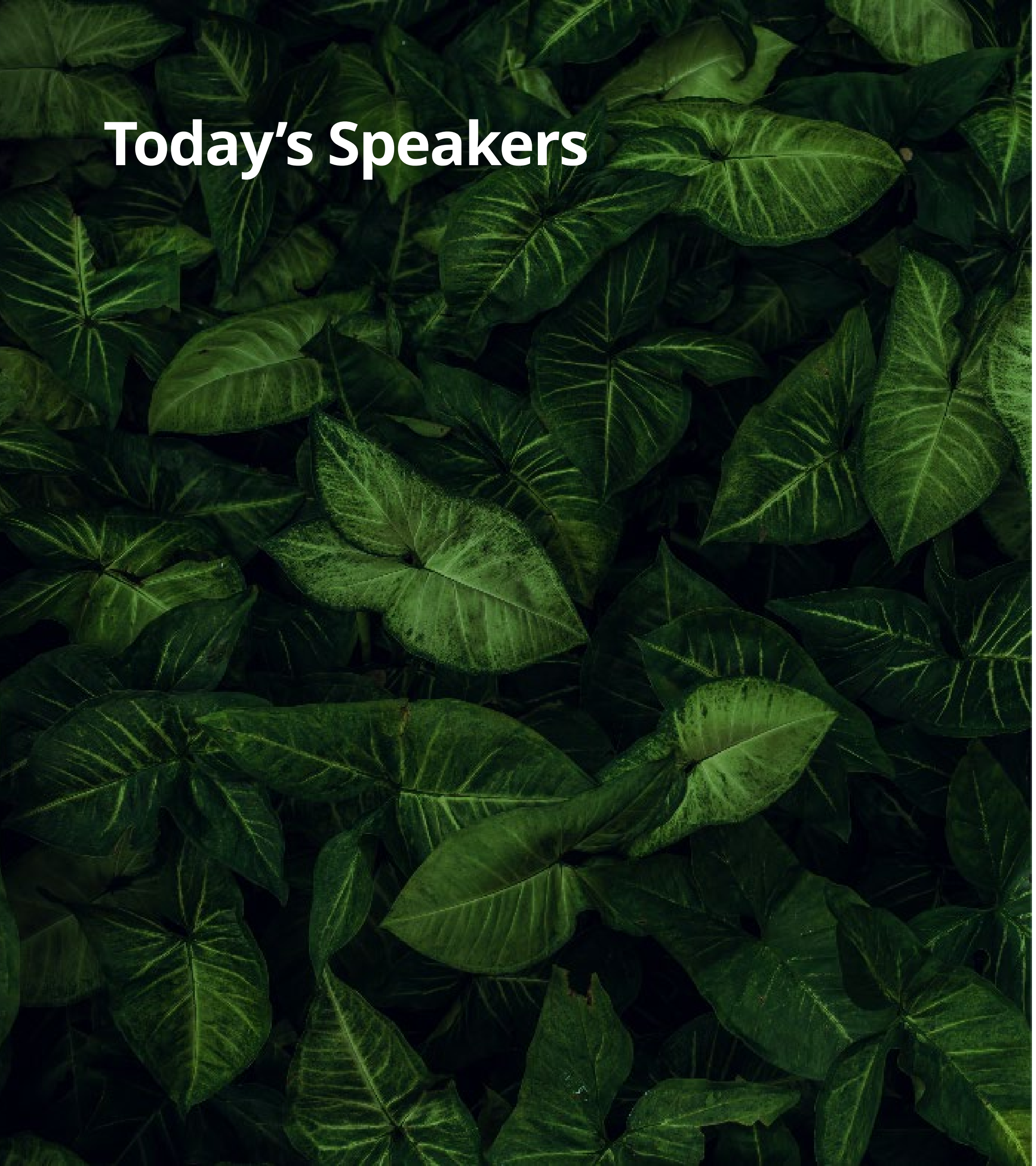
INFLATION REDUCTION ACT (IRA): The IRA could dramatically lower green hydrogen production costs.

However, infrastructure and cost barriers persist in other parts of the hydrogen value chain.

HARD TO ABATE SECTORS: Green hydrogen will likely be an important component of decarbonization strategies for hard to abate sectors.

Early adopters should begin to take advantage of current policies related to hydrogen as part of their broader plan to decarbonize.

INNOVATIVE PROCUREMENT OPTIONS: Outside of hard to abate sectors, end users could consider geographic proximity to developing hubs and buying consortiums to accelerate the hydrogen economy.



Today's Speakers

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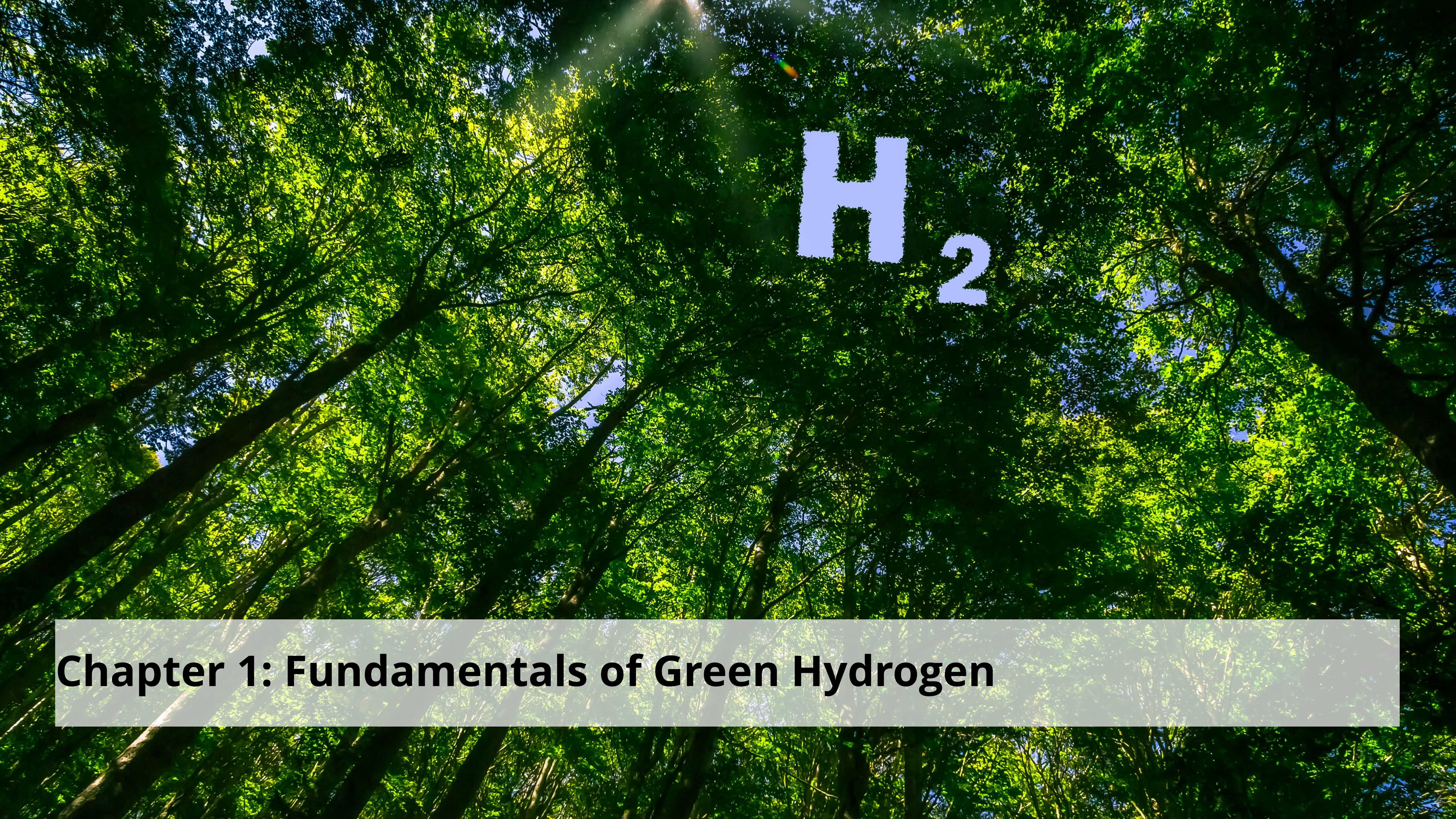


Chapter 1: Fundamentals of Green Hydrogen

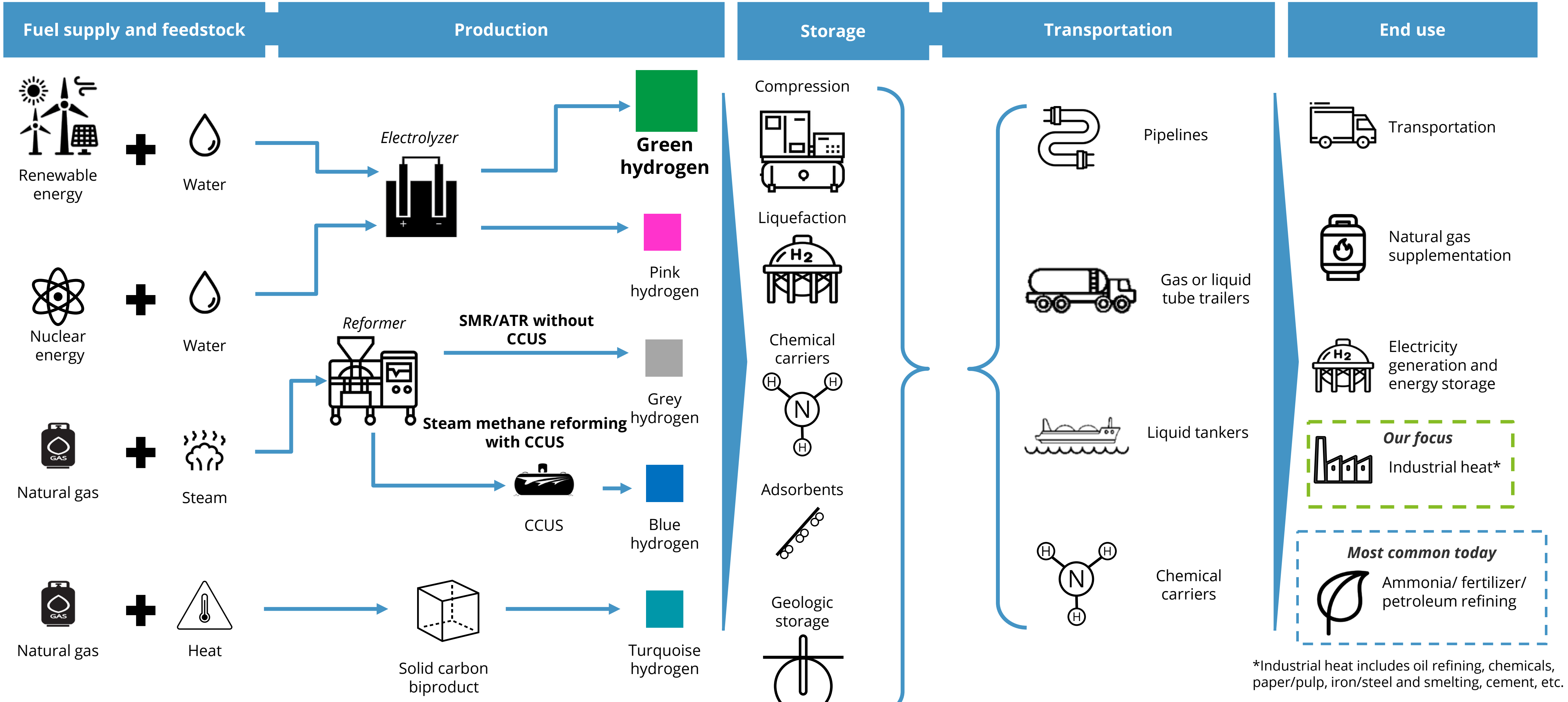
Ch 1: Summary & Takeaways

1. Certain methods of producing hydrogen (i.e., pink, green, blue) do not emit large amounts of CO_2 depending on the feedstock and energy source used during production.

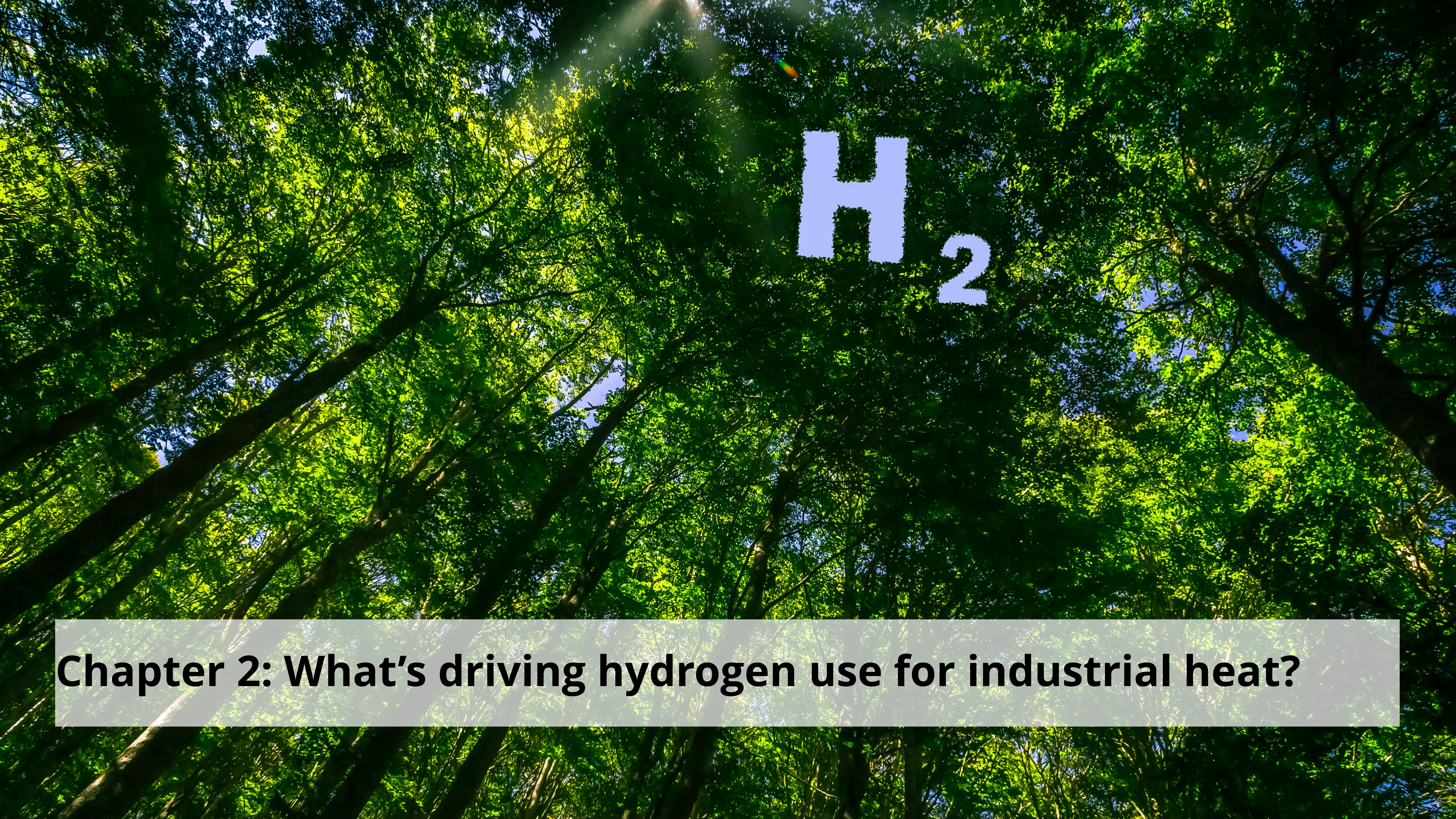
2. As governments work through the energy transition, a combination of low-carbon hydrogen types will likely continue to be produced in the United States.

3. The future market for hydrogen is expected to grow significantly driven by government support, geopolitical energy security concerns, decarbonization objectives, and tech advancements.

A spotlight on green hydrogen within the low-carbon H_2 ecosystem



*Industrial heat includes oil refining, chemicals, paper/pulp, iron/steel and smelting, cement, etc.



Chapter 2: What’s driving hydrogen use for industrial heat?

Chapter 2: Summary & Takeaways

1. Governments, corporations, and countries have introduced a broad range of climate commitments and policies aimed at decarbonization and net zero. The industrial sector (including industrial heat) is expected to play a vital role decarbonization.

2. Existing options for decarbonizing industrial heat include technologies mostly fit for low-heat processes.

3. Five major subsectors, including chemical production, oil refining, iron and steel, pulp and paper, and cement and lime are expected to demand over 10 quadrillion btu of energy for heating by 2050.

Hydrogen unlocking decarbonization for industrial heat

INDUSTRIAL HEAT POTENTIAL

- The industrial sector is the third largest emitter in the US accounting for 24% of total emissions. Over half of these emissions are from process heat.
- Chemicals, oil refining, iron and steel, pulp and paper, and cement and lime account for more than 70% of US manufacturing process heat demand today.
- Chemicals will likely continue to be the fastest growing sector, followed by oil refining, steel, pulp & paper, and cement and lime.

Higher green hydrogen adoption* (top) → Lower green hydrogen adoption* (bottom)

Temperature Profiles

	Low	Medium	High
Chemicals	37%	37%	26%
Iron & Steel	4%	36%	60%
Cement, Concrete & Lime	0%	18%	82%
Oil Refining	25%	63%	12%
Paper & Pulp	76%	18%	6%

Sources: EIA, "Use of energy explained"; EIA, Annual Energy Outlook 2022, March 3, 2022; EIA, "Petroleum & other liquids – Fuel consumed at refineries," June 21, 2022; Deloitte analysis.

Obstacles and opportunities for unlocking green hydrogen potential

Sub Sector	Obstacles	Opportunities
Chemicals	• Capital expenses to replace high-heat processes (i.e. chemical cracking) are very high	• Wide variety of low- and medium-temperature processes that could potentially convert to hydrogen • Chemicals sector is already part of the hydrogen value chain, potentially lowering the barrier to entry
Iron & Steel	• Capital expenses to convert existing, coal-based plants are very high • Utilization of more efficient electric arc furnaces limits the use for hydrogen within the sector to iron reduction	• Hydrogen is a low-carbon options for iron reduction and is already utilized in the sector, potentially lowering the barrier to entry for end-users
Cement, Concrete & Lime	• Cement kilns utilize a large percentage of waste or waste biomass for heating at low cost, making some producers more likely to utilize waste products and carbon capture & storage • Burning pure hydrogen does not produce the strongest flame for cement production, limiting potential hydrogen utilization	• Capital expenses to blend hydrogen into the fuel mix are relatively low compared to other sectors
Oil Refining	• Refineries primarily utilize by-products of the refining process for heating at low- or no-cost, making fossil fuels difficult to displace	• Lower, insignificant opportunity for utilizing hydrogen in heating processes
Paper & Pulp	• Significant electrification and utilization of waste biomass are expected to crowd out demand for hydrogen in heating processes	• Lower, insignificant opportunity for utilizing hydrogen in heating processes

*Deloitte modelling; Oil refining as well as paper and pulp has little to no adoption potential based on our model

There is a strong market outlook for the hydrogen market

HYDROGEN MARKET

Globally, ~100 million metric tons (MMT) of hydrogen is produced annually and **~10 MMT are produced in the U.S.**

U.S. hydrogen demand is expected to reach **~72 MMT by 2050**, driven by **'Other' applications such as mobility, electricity generation and storage, natural gas supplementation, and industrial heat.**

Market size, per annum, in 2050:

$284B
U.S. low-carbon Hydrogen Market Size for production, distribution, infrastructure, and retail

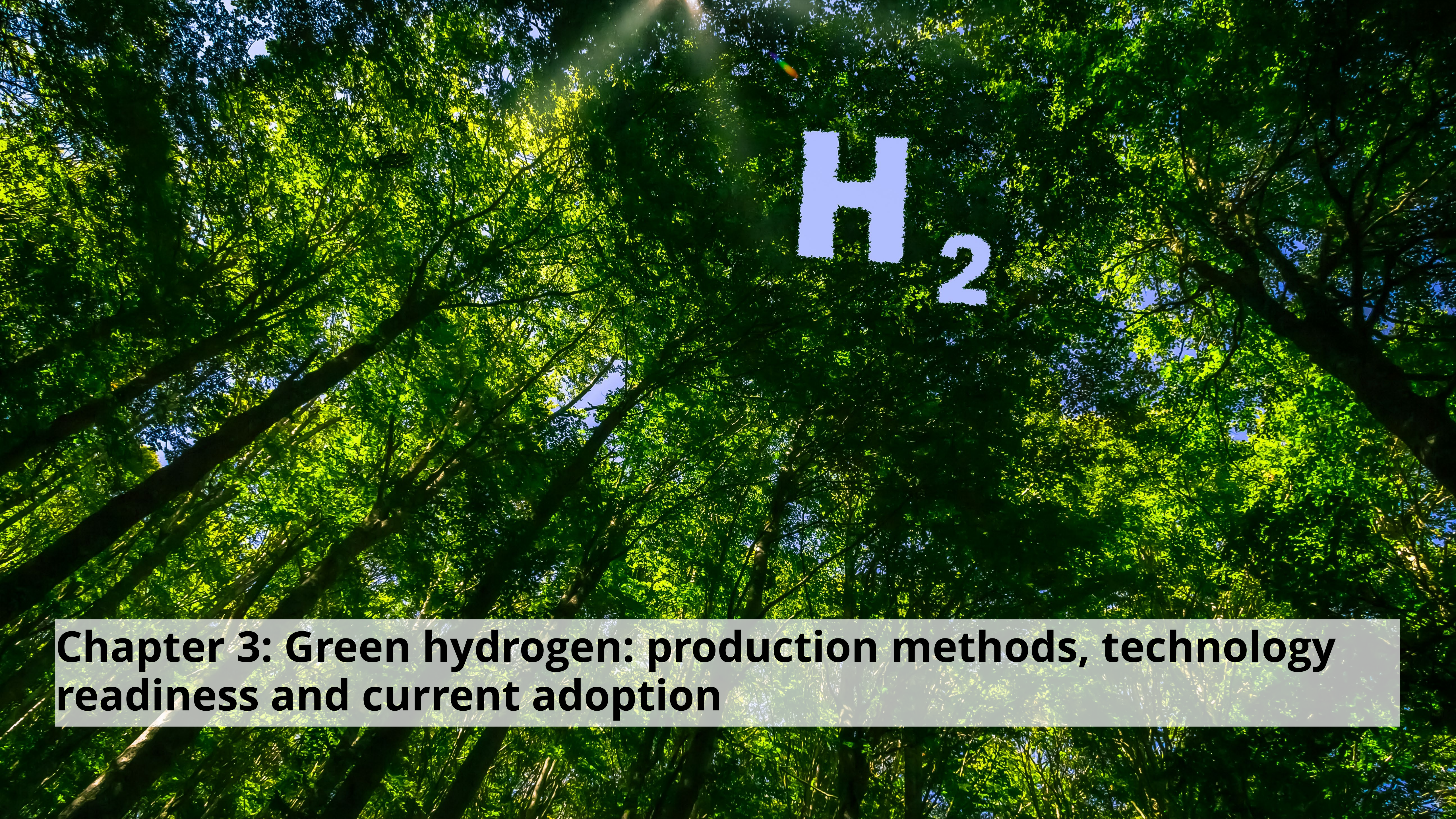
$170B
U.S. Hydrogen Produced from Electrolysis Market Size for production, distribution, infrastructure, and retail*

Source: Deloitte Analysis

*Applies to the production of green and pink hydrogen

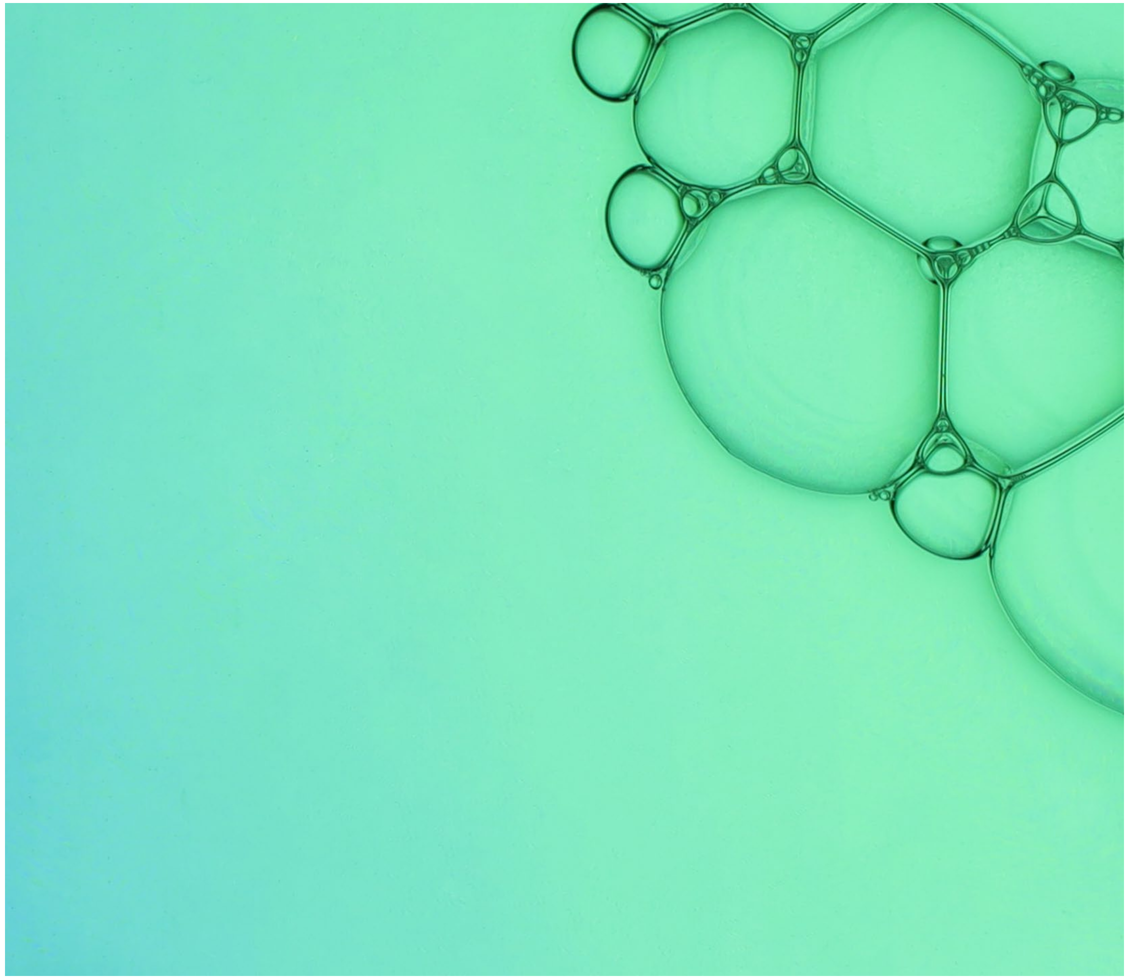
Future State

- 7x expected increase in U.S. production by 2050
- ~60% of hydrogen expected to be produced using electrolysis by 2050



Chapter 3: Green hydrogen: production methods, technology readiness and current adoption

Chapter 3: Summary & Takeaways



1. Green hydrogen will likely need to become cost-competitive with alternatives to be adopted for industrial heat.

2. Increased electrolyzer capacity, large-scale storage and cost-effective transportation will likely be required to drive hydrogen industry development.

3. Chicken-and-egg dynamic between producers and users creates risk and delays investments as firms face future market uncertainty.

Green H_2 market expansion presents challenges and opportunities

CHALLENGES

- SUSTAINABILITY
- FUTURE DEMAND
- HIGH COSTS
- CONTRACT TRANSPARENCY
- REGULATORY
- PUBLIC PERCEPTION

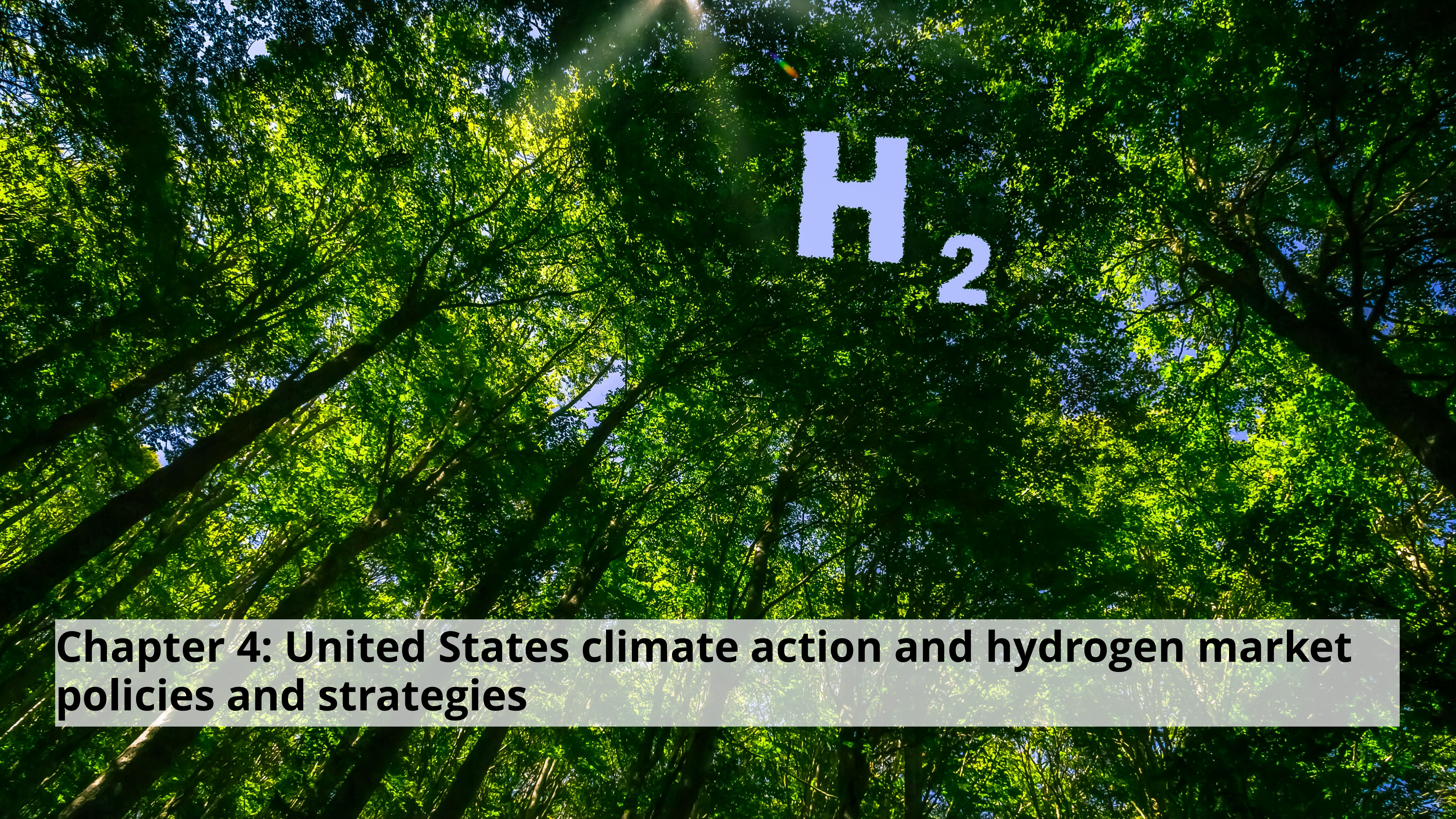
OPPORTUNITIES

INDUSTRIAL HEAT USE CASES

- Chemicals
- Steel
- Concrete

HYDROGEN USE CASES

- Mobility
- Energy Storage
- Export Markets



Chapter 4: United States climate action and hydrogen market policies and strategies

Chapter 4: Summary & Takeaways

1. In the US, policies have two goals: increase cost competitiveness and create market certainty.

2. The IRA and the IIJA's hub funding are critical enablers for lower production costs and support in building critical infrastructure.

3. Gaps remain including safety regulations, and further public investment in RD&D across the hydrogen value chain.

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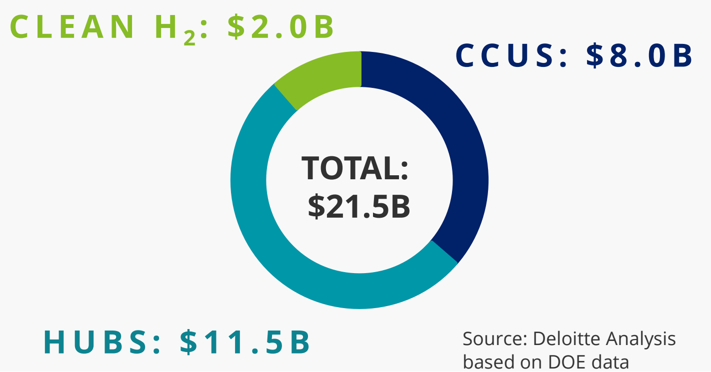
Government policy is rapidly driving H_2 market development

The Bipartisan Infrastructure Law (BIL) – November 2021

- Allocates **~$10 billion** for clean hydrogen over five years
- Tasks DOE with developing **a standard for carbon intensity** of clean hydrogen production
- Funds a DOE Clean Electrolysis Program ($1B) to reduce the cost of clean hydrogen produced using electrolyzer to **less than $2/kg of hydrogen by 2026**
- Establishes the **DOE hubs program** and competition for $7B in funding (due April 2023)



Source: Deloitte Analysis based on DOE data

The Inflation Reduction Act (IRA) – August 2022

- Tax & spend bill that allocates Does **~$400 billion** for climate-related causes
- Includes significant support **for H_2 and CCUS** in the form of tax credits

45V Production Tax Credit by Lifecycle Emissions per kilogram of hydrogen

Lifecycle emissions per kg of H2	2.5-4kg CO_2e	1.5- to less than 2.5 kg CO_2e	0.45- to less than 1.5 kg CO_2e	<0.45 kg CO_2e
Credit value with prevailing wages & apprenticeship	$0.60	$0.75	$1.00	$3.00

45Q Tax Credit Amount

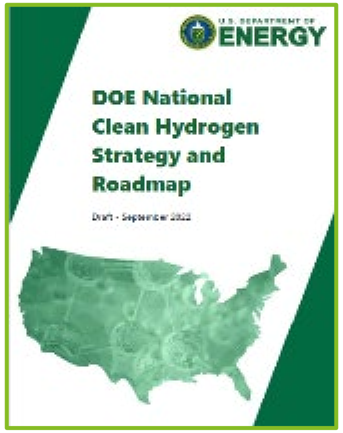
Extends the Section 45Q tax credit and makes it fully transferable

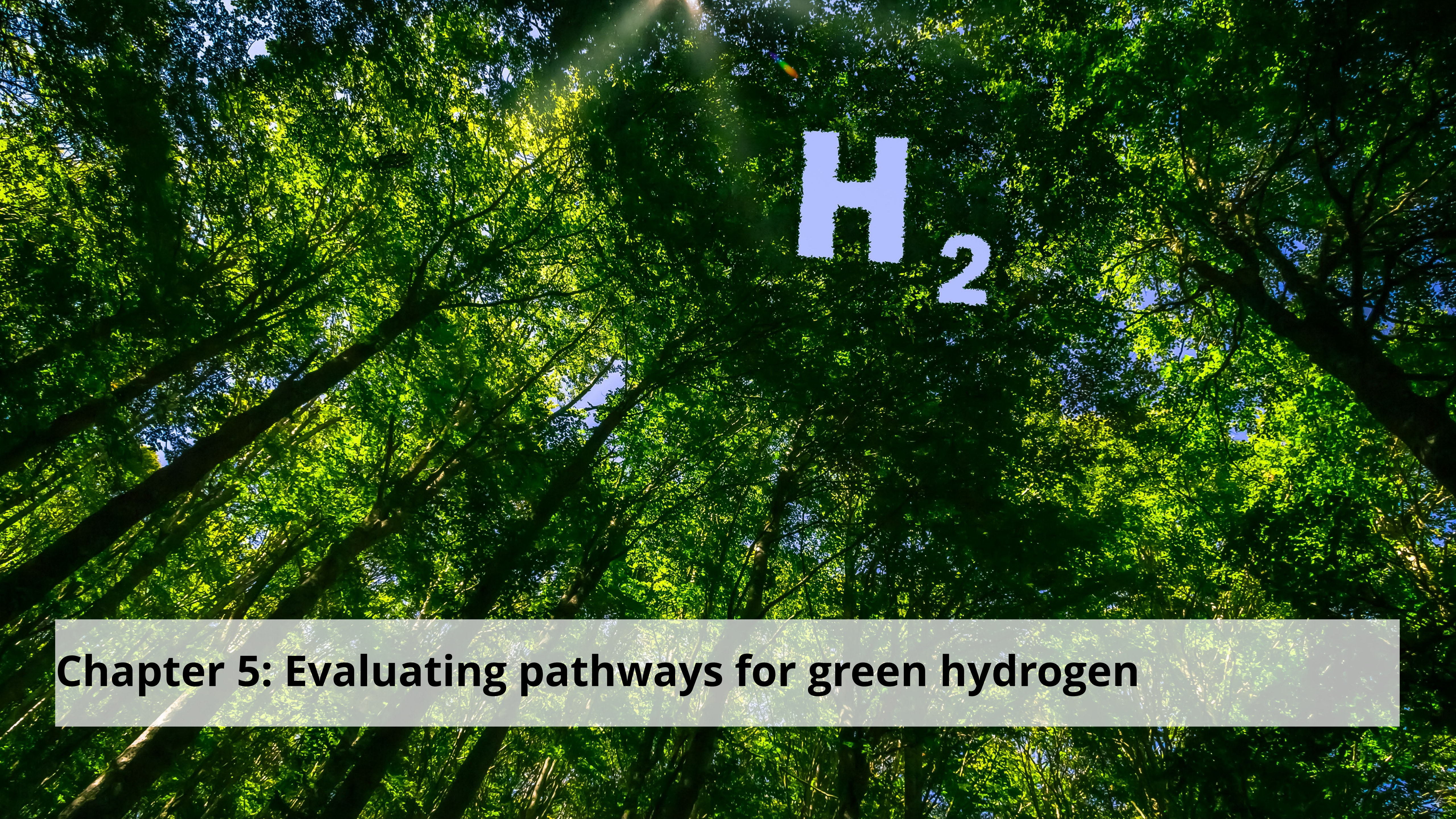
$85 /ton	$180 /ton
Qualified point source CO2 capture (CCS)	Direct air capture (DAC)

Source: US Gov

DOE National Clean Hydrogen Strategy & Roadmap – Sept. 2022

- Previously, **the US lacked a national hydrogen strategy** that could align the industry and lay the foundation for the clean hydrogen economy
- **17 governments published hydrogen strategies** and roadmaps from January 2020-September 2021 (e.g., Japan, AUS, Canada)
- **Electrolyzer capacity deployment goals** and **development of hydrogen hubs** are integral parts of hydrogen strategies for many governments globally





Chapter 5: Evaluating pathways for green hydrogen

Chapter 5: Summary & Takeaways

1. Of the 5 sectors analyzed: chemicals, iron & steel, and cement have more potential for green hydrogen utilization.
2. The market for green hydrogen in industrial heat will likely be dependent on policy support given low energy prices in the industrial sector and the capex required for end-users to convert from fossil fuels.
3. Full decarbonization in industrial sectors will likely require further innovation and policy support to decrease capex costs for switching to hydrogen.

Modeling Methodology

Demand Module

Calculates:
- Demand for industrial heat
- Electrification reductions
- Emissions estimates
- Annual marginal demand for industrial heat based on changes in demand and prior adoption of low-carbon fuels

LCOE Module

Calculates:
- LCOE of alternatives over time
- Cost impact of incentives, transportation and storage
- NPV comparison of status quo vs. alternative adoption

Supply Module

Calculates:
- Supply of various H2 types
- Wright's law calculations based on cumulative adoption
- Annual marginal supply based on changes in supply, prior adoption, and demand from other sectors

Decision Engine

- Matches marginal demand with marginal supply under cost constraints in each period
- Calculates current period adoption as limited by capital constraints for sectors
- Calculates demand signals for future periods

Scenario planning analysis involved

Policy

Electrification

Low electrification and high policy

Less electrification, more policy activity, highest supply of low-carbon hydrogen, lowest cost of low-carbon hydrogen

High electrification and high policy

Widespread electrification, more policy activity, high supply of low-carbon hydrogen, lower cost of low-carbon hydrogen

Low electrification and low policy

High barriers to entry for low-carbon hydrogen and electrification, low supply of low-carbon hydrogen, high cost of low-carbon hydrogen

High electrification and low policy

Widespread electrification, higher barriers to entry for low-carbon hydrogen, lowest supply of low-carbon hydrogen, highest cost of low-carbon hydrogen

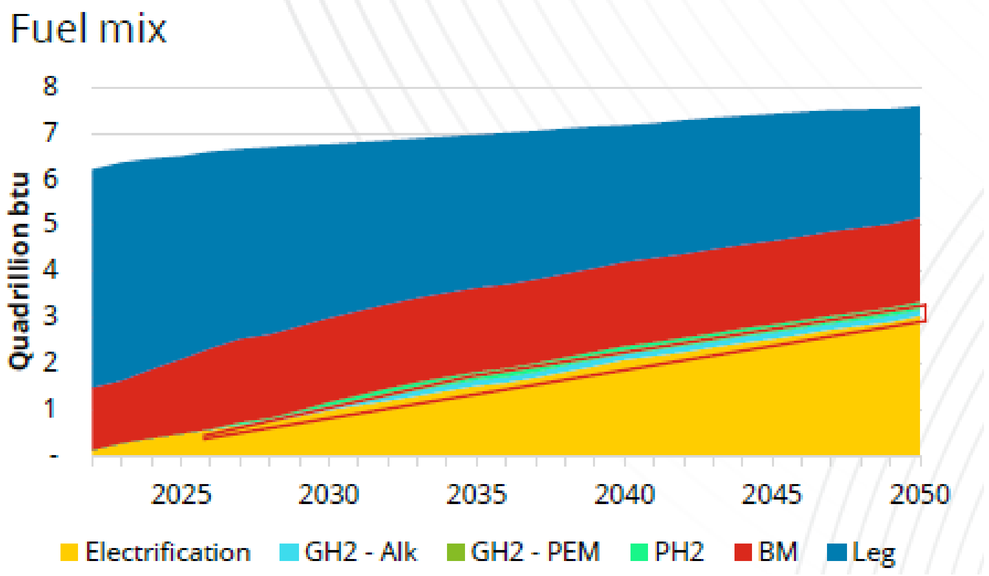
High Electrification, Low Policy

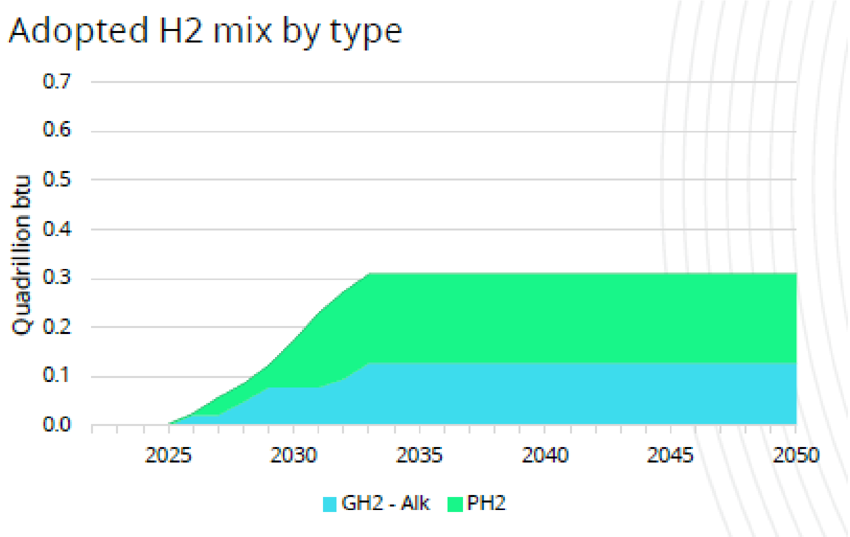
Key Assumptions

- IRA incentives for hydrogen expire in 2033
- Low-carbon hydrogen supply meets the DOE's target for supply, but no further action to stimulate the sector is undertaken
- Roughly 40% of industrial fuel use will electrify, driven by the paper & pulp, chemicals, and iron & steel sectors

Summary Results

- All hydrogen adoption occurs before incentives expire in 2033
- Hydrogen potential in this scenario is limited, only accounting for 4% of total fuel supply
- Green hydrogen makes up 1% of the total fuel supply in this scenario
- Hydrogen utilization in this scenario is driven by pink hydrogen, with green H2 accounting for roughly 1% of total energy utilization by 2050





*Overall fuel mix excludes oil & gas, as the sector is projected to only utilize fossil fuels
GH2 – Alk = Alkaline Green Hydrogen; GH2 PEM = PEM Green Hydrogen; PH2 = Pink Hydrogen; BM = Biomass; Leg = Legacy Fossil Fuels

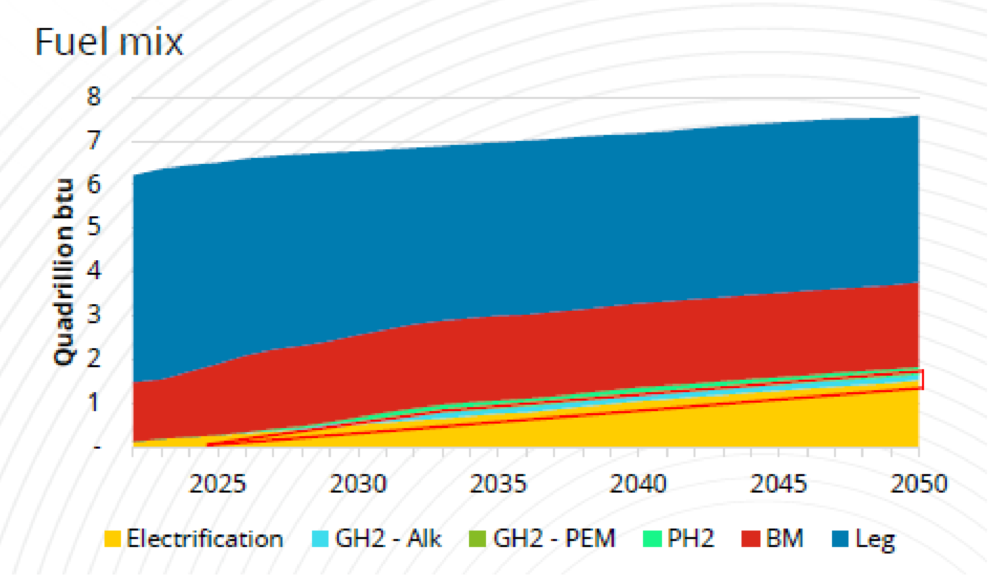
Low Electrification, Low Policy

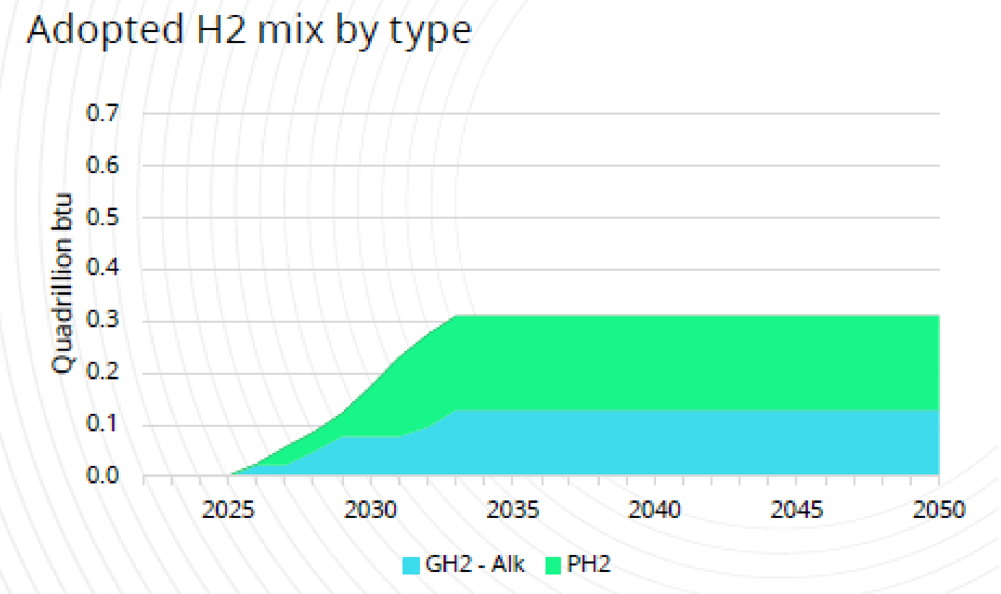
Key Assumptions

- IRA incentives for hydrogen expire in 2033
- Low-carbon hydrogen supply meets the DOE's target for supply, but no further action to stimulate the sector is undertaken
- Roughly 20% of industrial fuel use will electrify, driven by the paper & pulp, chemicals, and iron & steel sectors

Summary Results

- The hydrogen adoption profile is the same in this scenario as in the high electrification, low policy scenario
- Adoption in the low policy scenarios is limited by cost constraints, as the price of hydrogen remains too high to overcome retrofitting costs for H2
- Overall adoption in the low policy scenarios is roughly half of current hydrogen utilization in the United States





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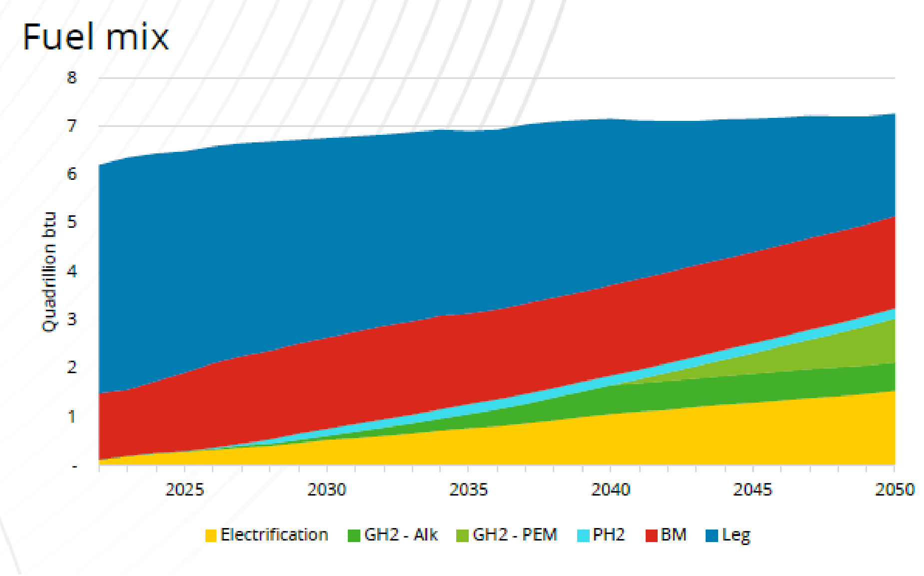
Low Electrification, High Policy

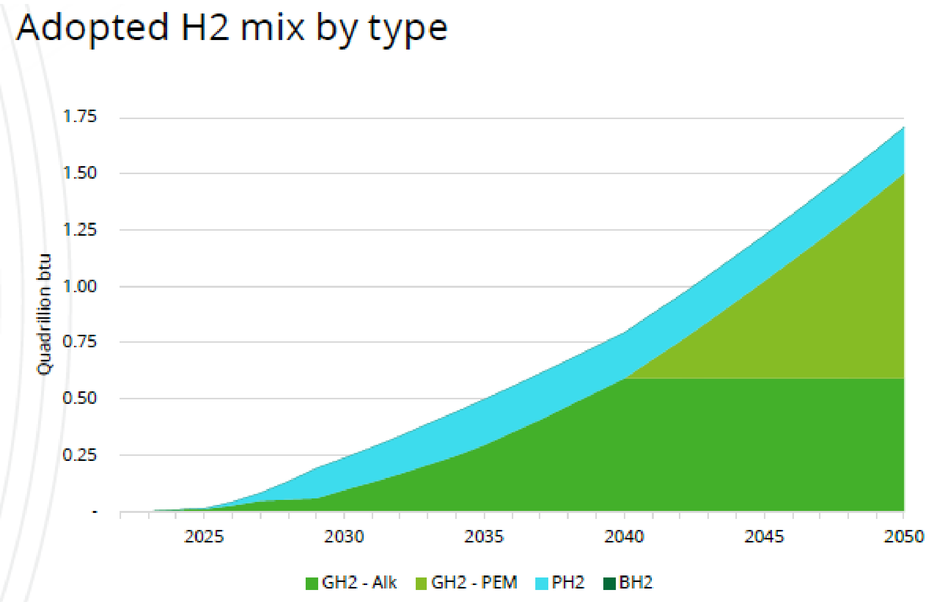
Key Assumptions

- IRA incentives for hydrogen expire in 2040
- Federal policy and DOE investment in the low-carbon hydrogen market spurs a supply increase of 50% over the DOE's goals by 2050
- Roughly 20% of industrial fuel use will electrify, driven by the paper & pulp, chemicals, and iron & steel sectors

Summary Results

- The potential for hydrogen in industrial heating is relatively unchanged by decreased electrification, primarily due to barriers for adoption in high-heat applications
- 1.5 quads of green hydrogen vs 1.3 in the high electrification scenario
- Earlier adoption of green hydrogen crowds out pink hydrogen adoption, decreasing adoption of pink hydrogen in this scenario by roughly 30% compared to the high electrification, high policy scenario





*Overall fuel mix excludes oil & gas, as the sector is projected to only utilize fossil fuels
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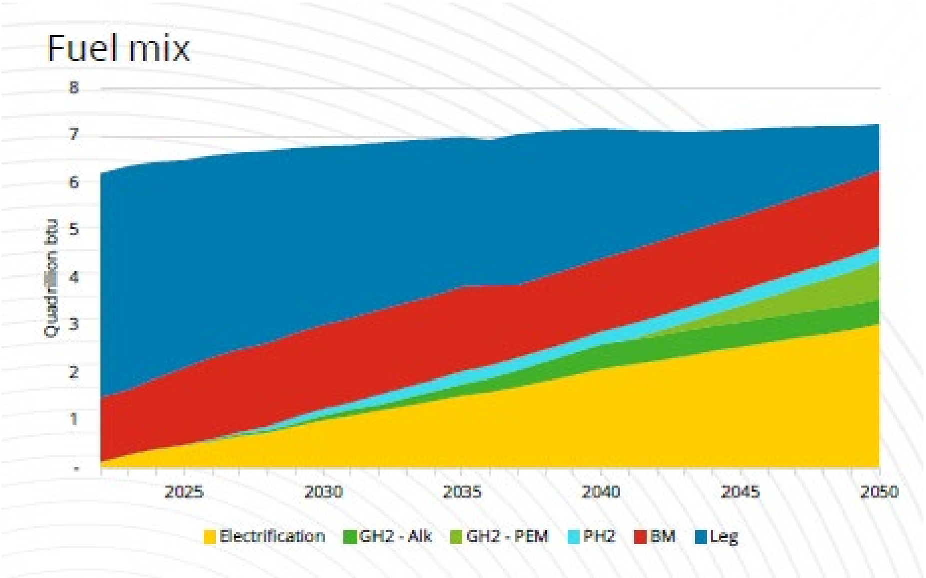
High Electrification, High Policy

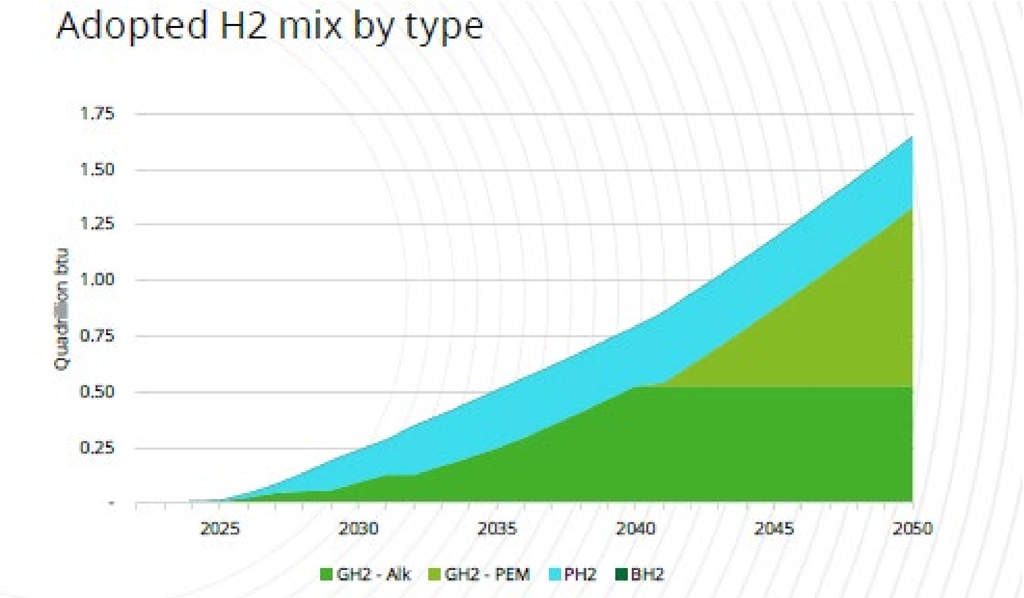
Key Assumptions

- IRA incentives for hydrogen expire in 2040
- Federal policy and DOE investment in the low-carbon hydrogen market spurs a supply increase of 20% over the DOE's goals by 2050
- Roughly 40% of industrial fuel use will electrify, driven by the paper & pulp, chemicals, and iron & steel sectors

Summary Results

- Roughly 1.3 quadrillion btu's of green hydrogen are utilized in industrial heating, roughly twice as much as is currently in use in the whole economy today
- Green hydrogen accounts for 18% of total thermal energy in this scenario
- PEM overtakes alkaline hydrolysis as the most cost-effective production method around 2040 and is the dominant source of green H2 in industrial heating





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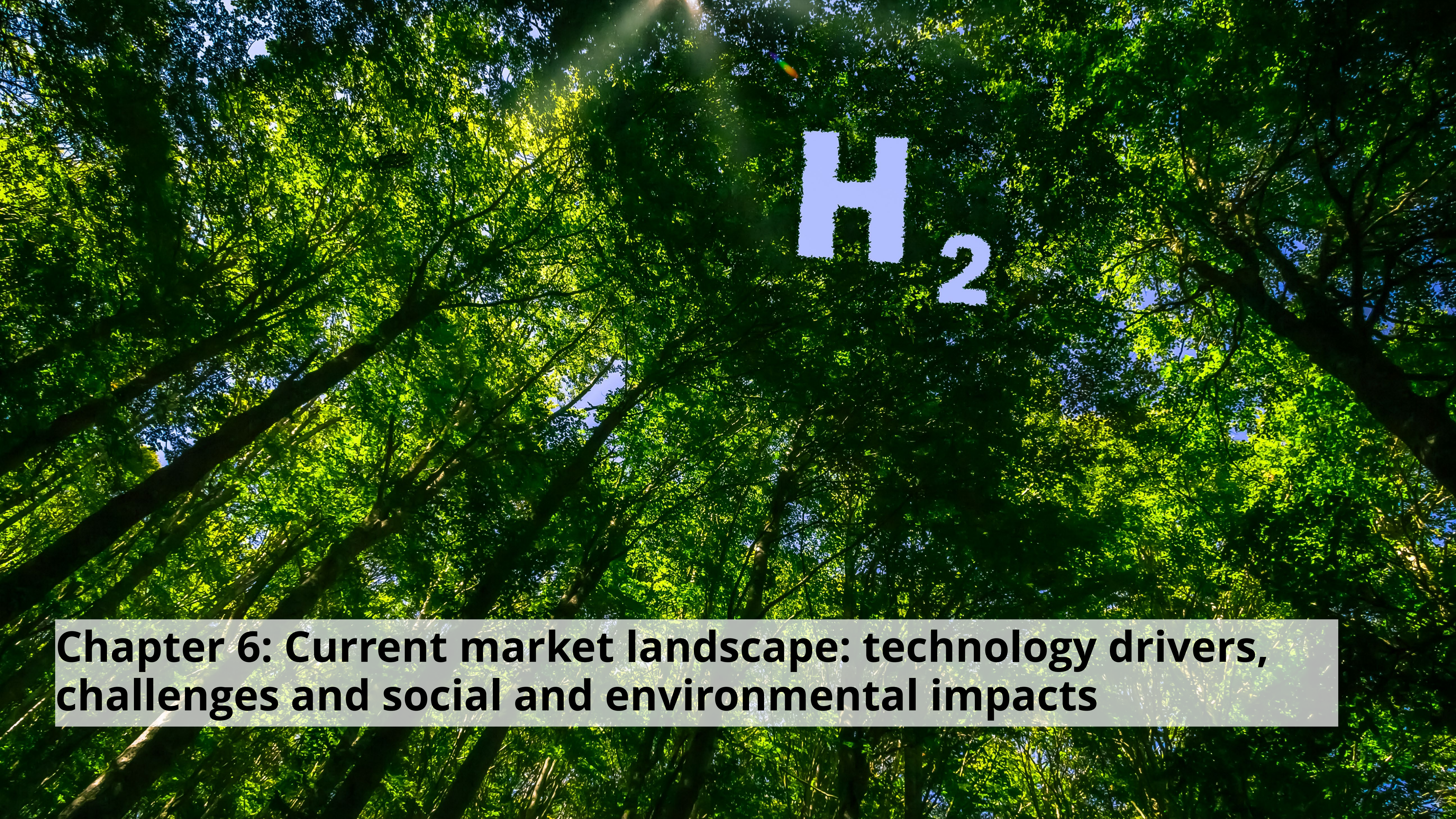
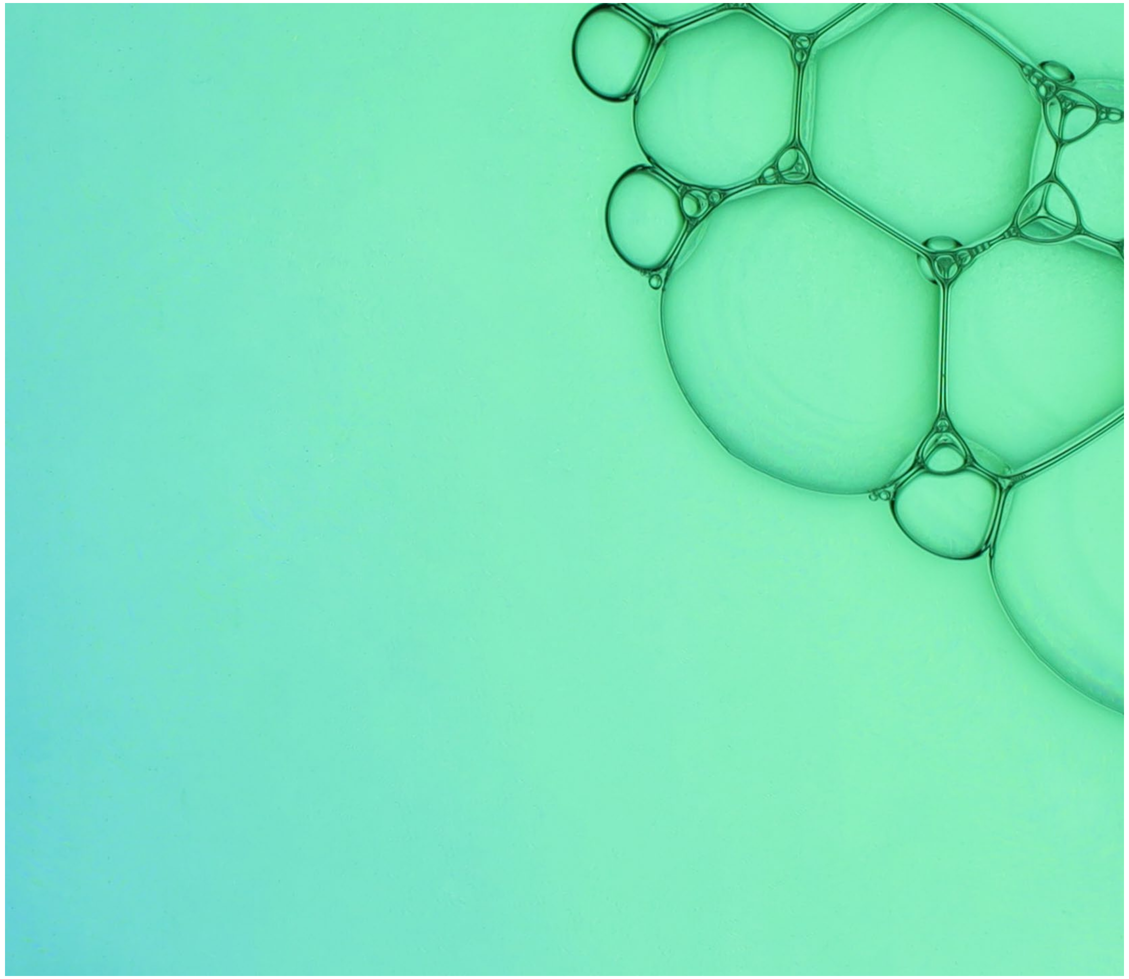


Chapter 6: Current market landscape: technology drivers, challenges and social and environmental impacts

Chapter 6: Summary & Takeaways



1. Due to the costs associated with transporting hydrogen over large distances, hydrogen supply and demand will likely benefit from being in proximity in the short-term. Existing use-cases, expected competition to hydrogen uptake.

2. Across both existing and competing use cases, green hydrogen will likely be cheaper to produce where there is plentiful and cheap renewable power.

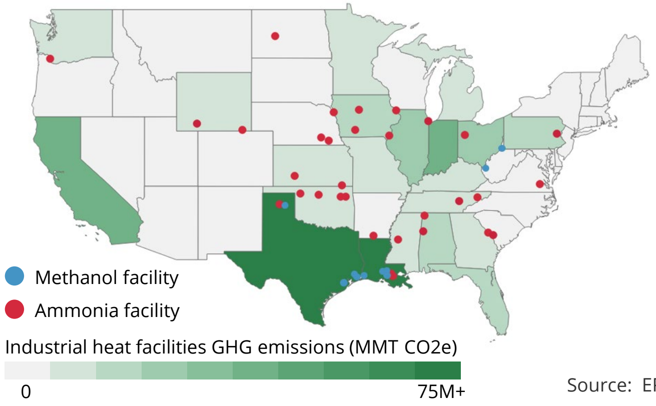
3. Scaling green hydrogen should be closely monitored to avoid negative environmental, climate and social impacts.

Existing and competing use-case for hydrogen provide regional indicators for green H_2

LOCALIZING HYDROGEN DEMAND

- Areas where current uses, renewable generation and competing uses overlap with industrial heat and potential hydrogen hub locations may help us predict where green hydrogen for industrial heat will likely be more viable.
- Due to the costs associated with transporting hydrogen over large distances, hydrogen supply and demand will likely benefit from being in proximity in the short-term.
- If hub regions put significant numbers of industrial heat consumers into close contact with hubs, this could reduce major transport cost barriers.

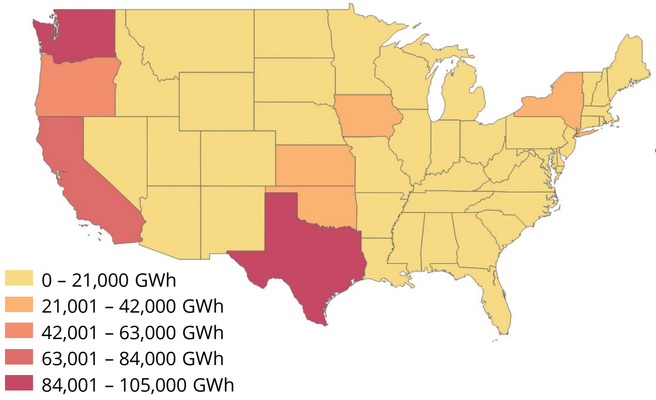
AMMONIA, METHANOL, AND INDUSTRIAL HEAT



Gulf Coast and Midwest have clusters of industrial heat facilities and existing use cases of hydrogen (i.e., ammonia and methanol facilities)

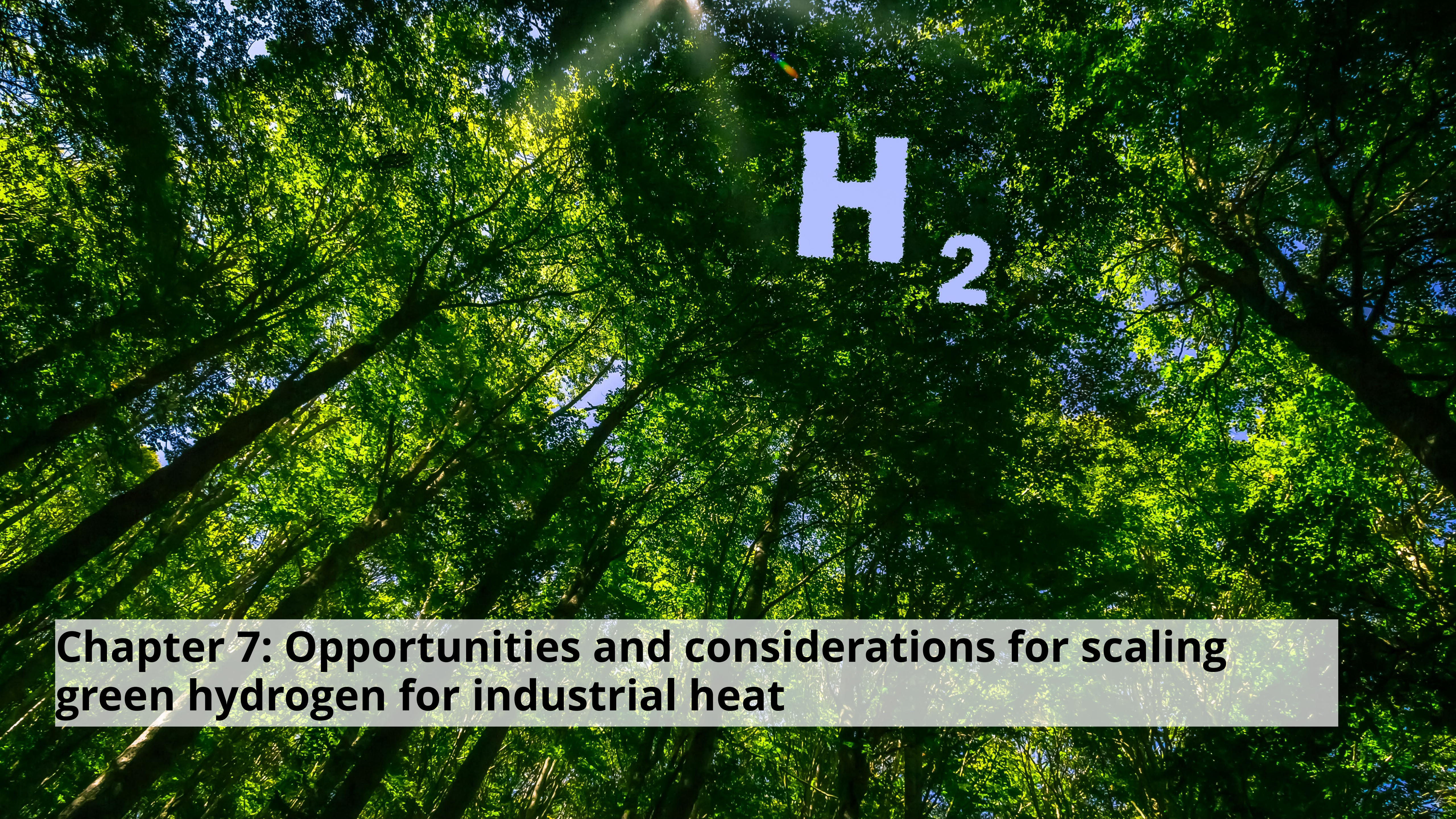
Source: EPA, "Facility-level GHG emissions data," 2021.

RENEWABLE GENERATION BY STATE



Texas and California generate more renewable energy than many other states in the US which may be utilized to produce green hydrogen

Source: EPA eGRID 2021 data



Chapter 7: Opportunities and considerations for scaling green hydrogen for industrial heat

Chapter 7: Summary & Takeaways

11 main considerations and actions for buyers for adopting green hydrogen for industrial heat applications

Main Considerations

- Hydrogen Policy Extensions & New Policy Create Market Certainty
- Planning, Permitting, and Approval Reduce Costs and Time Constraints
- Hub Ecosystems Foster Dependable Supply & Demand
- Information Campaigns on Green Hydrogen for Potential Value Chain Players
- Increase Social License to Operate
- RD&D and Investments Support Scale and Decrease Costs Across the Value Chain
- Community Engagement During Design & Development for a Just Transition
- Rapid Deployment of RE Generation Assets Supports Green Hydrogen Expansion
- Standardizing Supply Contracts Eases Market Entry
- Develop Sustainability Criteria for Hydrogen
- Consistent Technical and Safety Standards May Fill Policy Gaps

Thank-you

Appendix

Sources

I: Scene Setting: Fundamentals of Green Hydrogen

- A spotlight on green hydrogen within the low-carbon H2 ecosystem: EIA
- Promising market outlook for the hydrogen market: Deloitte Analysis; Reuters; IEA; US DOE
- Hydrogen can unlock decarbonization for industrial heat: Deloitte analysis; EIA

II: Modeling Approach & Outcomes

- Deloitte statistical model based on EIA and IEA data sets

III. Impacts of an Expanding Green Hydrogen Economy: Challenges & Opportunities

- Existing and competing use-case for hydrogen provide regional indicators for green H2: EPA
- Social and environmental implications can inform a just transition to green hydrogen: Deloitte analysis