Wood Mackenzie

Implications of 45V Guidance for the Future of the Green Hydrogen Industry – Executive Summary

Prepared for American Clean Power

February 2024

Wood Mackenzie was engaged by ACP to provide independent analysis on 45V and its implications for the green hydrogen industry

We explored implications of two scenarios for how the 45V PTC guidelines could be defined and implemented

45V Objective: *Enable the low-carbon hydrogen industry to scale and contribute to US decarbonization goals*

US Treasury Guidance

In December 2023, the **US Treasury** issued three pillars outlining how the 45V Production Tax Credit (PTC) will be implemented:

Temporality: Annual matching through 2027, with hourly matching starting in 2028 for all facilities, regardless of construction start or in-service date

Incrementality: Power must be sourced from generators coming online no earlier than 3 years of H_2 facilities' COD

Deliverability: Power supply from same DOE energy region

ACP Proposal

In the Summer of 2023, **ACP** prepared a different proposal with two key recommendations to change the US Treasury guidelines:

Temporality: Annual matching for the first 10 years of operations for plants beginning construction before 2029 and in service before 2033. Hourly matching for plants starting operations post-2032 or beginning construction post-2028

Incrementality: No proposed changes

Deliverability: No proposed changes

	Key Metric	Type of Analysis
Our analysis focuses primarily on the **Temporality** dimension, in order to understand the implications of the US Treasury Guidance and the ACP proposal to achieve the objective of 45V	A LCOH of Green H_2	LCOH estimation in ERCOT and CAISO by Scenario
	B Deployment of Low CI H_2 Projects	Demand & supply of low-carbon H_2 projects by Scenario
	C Emissions	Emissions associated with project deployment by Scenario

Key takeaways

1

Green hydrogen is key to decarbonization

- To reach net-zero emission target by 2050, the US requires 50-80 mmtpa of low-carbon H_2 deployment, of which over 50% will be sourced from green H_2
- The lower carbon intensity of green H_2 is key to driving a lower CI H_2 supply mix in support of net-zero ambitions

2

Market context is already challenging for green hydrogen

- Scalability of green H_2 industry is necessary to lower costs and improve its competitiveness
- However, green H_2 projects face a significant number of challenges across the project lifecycle, limiting progress for green H_2 project commercialization and potentially leading to delays in low-carbon H_2 deployment

3

45V has the potential to make a big impact in accelerating green hydrogen deployment

- 45V's PTC can catalyze the H_2 industry by reducing the LCOH of green H_2 and bringing it to parity with blue H_2 and other fuels
- However, requiring hourly 45V CI matching in 2028 impacts green H_2 CF and LCOH, at a critical time for innovation and growth

4

UST Guidelines make economics, adoption and deployment challenging for green hydrogen

- LCOH is estimated to be orders of magnitude above the price range for adoption at scale, driven largely by the complexity the UST guidelines drive in H_2 power procurement
- UST guidelines will likely lead to greater blue H_2 deployment, limited scaling of green H_2, and ultimately a higher CI for H_2 supply

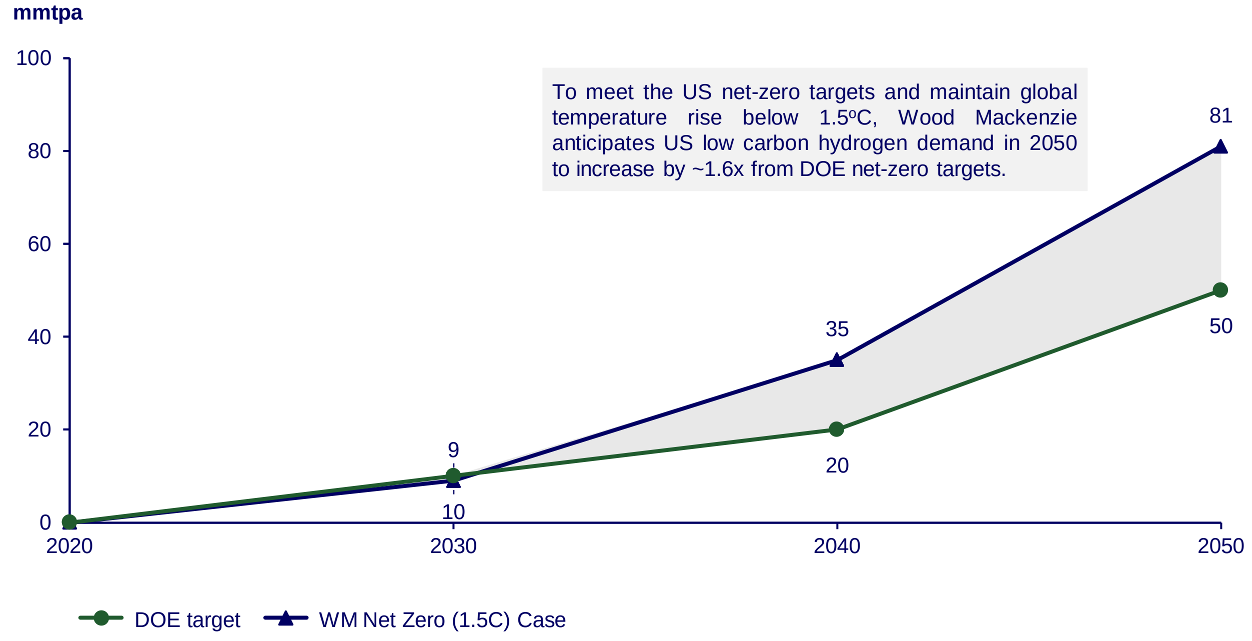
5

ACP's proposal would enable greater green hydrogen deployment, enabling the industry to get closer to key DOE Targets for the industry which are needed to support wider decarbonization goals

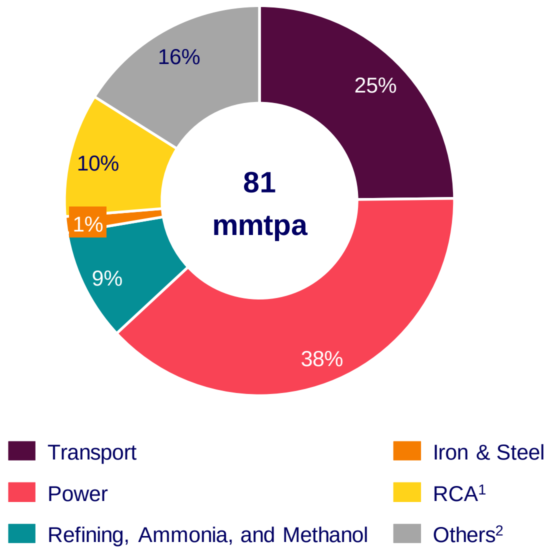
To reach net-zero, the US requires 50-80 mmtpa of low-carbon H_2 adoption by 2050

Domestic low-carbon hydrogen adoption is expected to occur most quickly in existing applications; long-term growth is driven by power, mobility, and high-heat applications

Wood Mackenzie US hydrogen demand outlook (net-zero case) vs DOE target



2050 WM net-zero hydrogen demand by sector



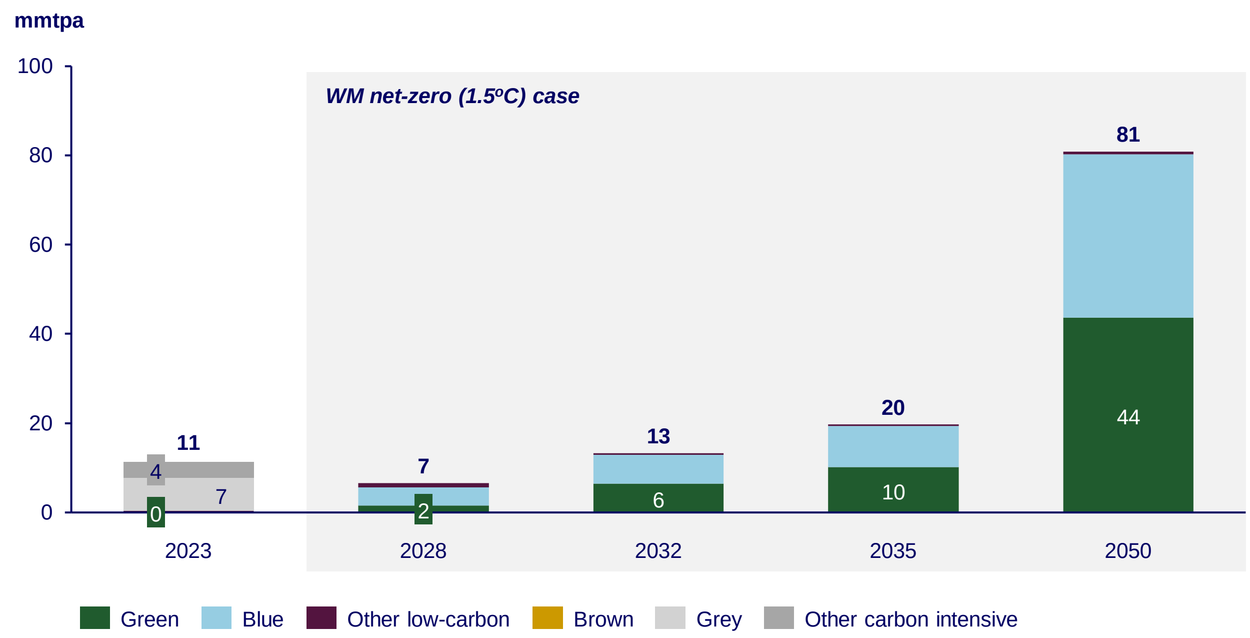
1. RCA: residential, commercial, and agriculture; 2. Others include cement, glass, ceramics, semiconductors, polysilicon, food hydrogenation, and various applications, as well as losses and gains during transportation process

Source: Wood Mackenzie Energy Transition Service

Green hydrogen must be deployed at scale to achieve net-zero ambitions

New energy markets have typically taken 30-50 years to scale, action is needed today to support the industry

Wood Mackenzie US low carbon hydrogen production[1] by type



- Wood Mackenzie's net-zero (1.5ºC warming) case estimates that roughly 80 mmtpa of low-carbon hydrogen will be needed in the U.S. to meet 2050 net-zero target
- To get to 80 mmtpa of low-carbon hydrogen by 2050, ~20 mmtpa must be deployed by 2035
- Current investment trends are not enough to achieve net-zero. There are 134 announced projects trying to achieve commercial operation date (COD), reflecting 17.2 mmtpa of capacity and an estimated investment of US$70 billion.
- Green hydrogen plays a key role in the U.S. decarbonization journey, reflecting ~55% (44 mmtpa) of low-carbon hydrogen supply by 2050
- Meaningful policy intervention is needed to scale the market from virtually zero

1. Hydrogen production only includes domestic production catered for domestic consumption and excludes supply for exports.
Note: Wood Mackenzie's net zero case outlook considers only low carbon hydrogen supply will meet the incremental demand from the rapid decarbonization effort
Source: Wood Mackenzie Lens Hydrogen, Energy Transition Service

The low-carbon H_2 industry is nascent and needs to overcome challenges to scale

Project Development Challenges

Feedstock Sourcing
Complex sourcing strategies are needed to source reliable, low CI, and low-cost renewables or natural gas for sustaining continuous commercial operations at a competitive cost

Policy / Regulatory Guidance
Despite the momentum of 45V PTC and BIL, stringent regulatory requirements may deter first movers from scale-up operations, impeding growth potential and keeping costs higher for longer

EPC / Supply Chain / Technology
Clean hydrogen production technology and supply chain have yet to achieve commercial maturity to fully achieve large-scale production

Project Bankability / Financing Progress
High capital costs, uncertain future revenue streams, technical risk, and uncertainty around 45V eligibility create a high-risk profile, limiting investor interest and capability

Market Access and Delivery
Lack of existing and emerging demand markets, as well as limited infrastructure for connecting production to demand centers

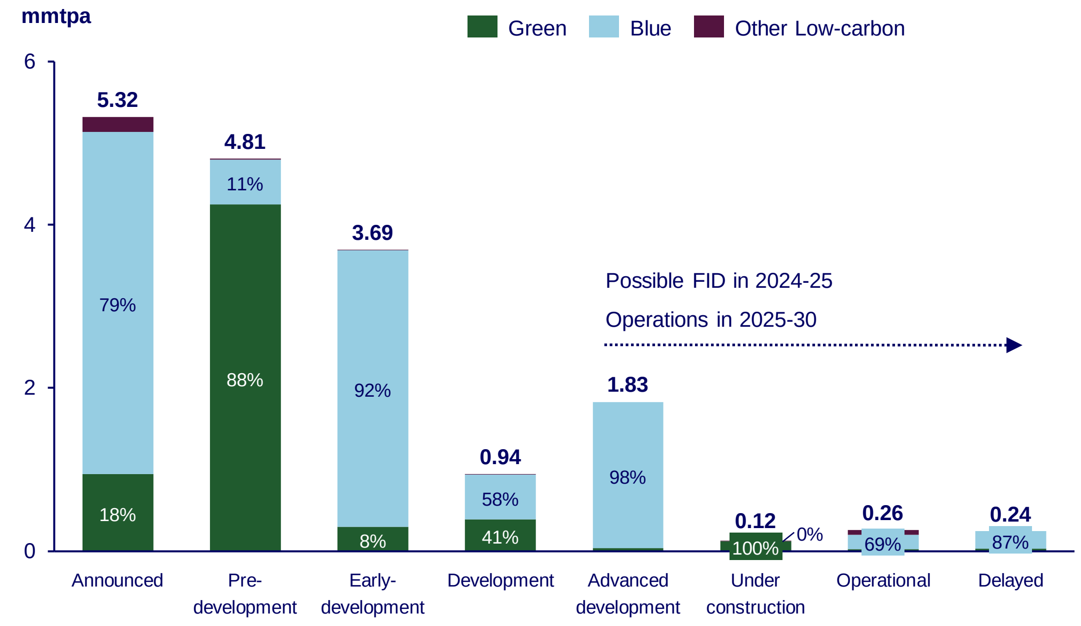
Marketing Progress (Offtakers & Revenues)
Hydrogen producers face challenges securing offtakers with sufficient demand who are willing to sign long-term contracts for costly low-carbon hydrogen

Source: Wood Mackenzie

Lack of cost competitiveness limits green H_2 commercialization and deployment…

Only 5% of projects likely to take FID in the next 2 years will be green hydrogen projects

US low carbon hydrogen project announcements by status



Over 95% of low-carbon hydrogen project capacities have yet to achieve commercial operations

- 27 projects are currently operational and contribute 0.26 mmtpa of capacity
- 9 projects are under construction and will potentially come online before 2028, but only account for 0.12 mmtpa of capacity
- 80+ projects are still progressing to achieve FID, reflecting 15.75 mmtpa capacity
- 4 projects are delayed or cancelled, totaling 0.24 mmtpa capacity

Blue hydrogen projects are advancing faster than green hydrogen projects

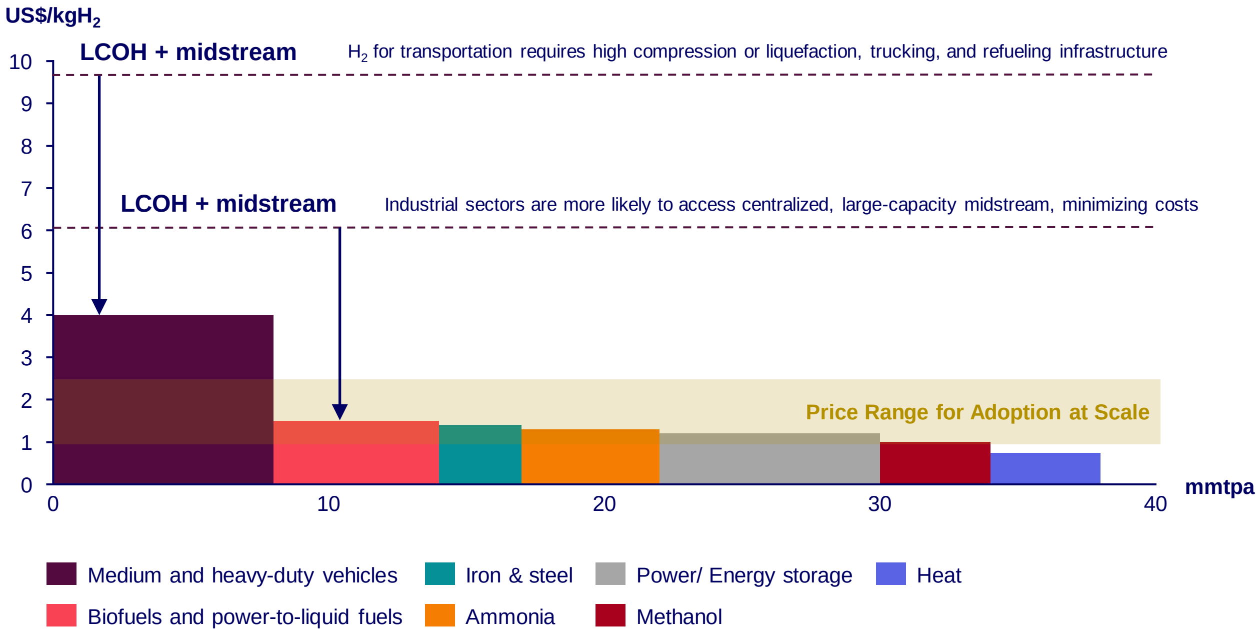
- Green hydrogen projects face major barriers to completion due to strict PTC guidance, alongside persistent challenges related to EPC, offtake agreements and financing
- Meanwhile, blue hydrogen projects leverage declining gas prices and supportive policies to enhance economic viability and progress

Source: Wood Mackenzie Lens Hydrogen

…which in turn limits economies of scale required to reduce costs and drive adoption

Green H_2 economics must fall within $1-2/kg, on a delivered to customer basis, to encourage adoption at scale

Potential low-carbon H_2 demand sectors and corresponding price range for adoption at scale



- H_2 price range of adoption at scale for each demand sector represents the price at which end-users are willing to adopt hydrogen in their operations
- Green H_2 production costs could be competitive in the medium and heavy-duty vehicle sectors compared to other competing fuels, such as electricity and petroleum derivatives. However, it becomes less competitive when factoring in the costs of compression/liquefaction and trucking to the end user
- Other sectors, including biofuels, ammonia, and power, currently consume cheap fossil feedstocks, so green H_2 must be low cost to be competitive. Large-scale consumers benefit from the ability to access feedstock supplies via lower cost high-capacity delivery infrastructure
- The 45V incentive could bring green H_2 cost closer to the Hydrogen Shot's goal and boost green H_2 demand creation, yet strict guidelines may prolong high costs, risking adoption and future deployment

Source: Department of Energy, Wood Mackenzie

CONCEPTUAL

The 45V PTC aims to catalyze the nascent low-carbon hydrogen industry

In this report, we analyze the implications of capping the duration of annual matching to 2028

Motivation for a LCI H_2 45V Production Tax Credit

US Decarbonization Need

- H_2 is required for US to reach net-zero by 2050
- Green H_2 supply is necessary as blue supply will be insufficient

Current Obstacle – Current Costs & Competition

- Without government support, there will be limited progression of green H_2 projects given costs are currently higher than competing fuels

Proposed Solution

- 45V Production Tax Credit (PTC) introduced by the Inflation Reduction Act (IRA) in 2022

Implementation challenges

Treasury-issued Guidelines – Awaiting Comments

- Proposed 45V implementation includes three main pillars:

Rule	Description	Challenge
Temporality	Annual matching allowed initially, but all projects must shift to **hourly matching starting in 2028**	Hourly matching typically results in electrolyzers running at low load factors, resulting in higher LCOH
Incrementality	Clean power must be sourced from generators coming online no earlier than 3 years of H_2 facilities' COD	Potential H_2 project delays due to bottlenecks (e.g. interconnection queue, supply chain issue, costs, etc.) in developing renewables assets linked to the project
Deliverability	H_2 producers must source power from within 1 of the 15 regions in the DOE's National Transmission Needs	Potential H_2 project delays due to having to ensure interregional transfers when there is physical delivery between them

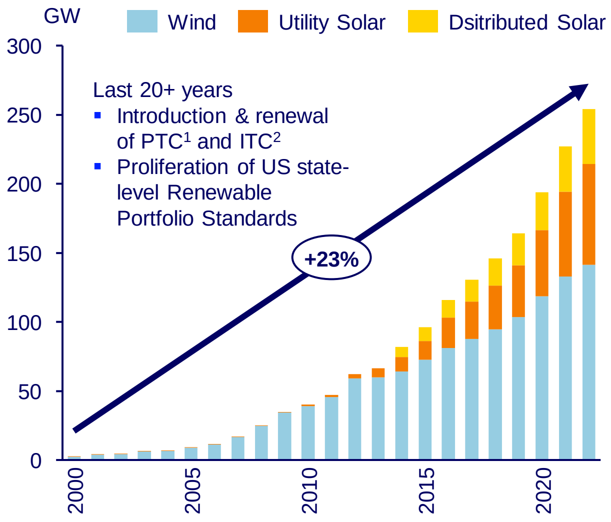
Note: The 45V production tax credit (PTC) generates a tax credit for each kilogram of clean hydrogen produced after 2022 for ten years starting at the commercial operations date (COD); it can amount to up to $3.00/kg for qualified clean hydrogen production

Source: Wood Mackenzie, US Treasury

Energy markets take decades to develop, which is why implementing 45V with a long-term view is critical…

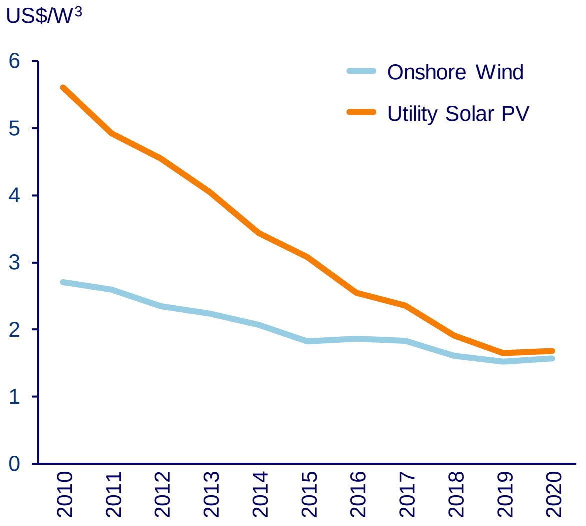
The renewables industry is an example of how the successful development of a new industry can take 20+ years

US Wind & Solar Installed Capacity



With a CAGR of 23% in 2000-2022, wind and solar have gone from being a new technology to acquiring a pivotal role in the US energy matrix

Unit Capex for Wind & Solar PV (2010-2020)



Only after at least two decades of continued support, costs are becoming more competitive, allowing the industry to reach record investment levels

- Developing an industry takes several decades
- Scaling it is only possible by lowering its costs
- The case of hydrogen is more complex than the case of renewables because most of the associated midstream and downstream infrastructure needs to be developed

1. PTC = Production Tax Credit; 2. ITC = Investment Tax Credit; 3. 2021 real US$ median values as reported by NREL; excludes labor and overhead
Source: EIA, NREL, Wood Mackenzie

CONCEPTUAL

…however, the currently defined 45V pillars impact capacity factor and costs

The lower the CF, the higher the cost of hydrogen on a levelized basis due to a lower volume of production

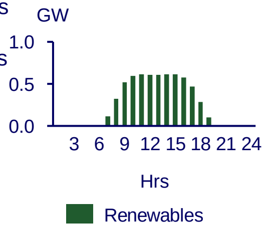
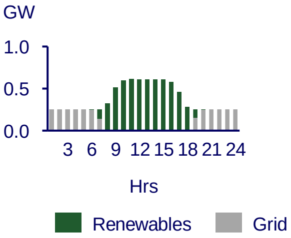
What is LCOH?

- Levelized cost of hydrogen (LCOH) is the preferred industry metric to compare a project's hydrogen production economics (US$/kg) across the different color production pathways

$$LCOH = \frac{PV\ (Costs)}{PV(Production)}$$

- The biggest driver of ***Costs*** are power price and capex
- The biggest driver of ***Production*** is the Capacity Factor (CF) since less operating time simply translates into less production
- The 45V Production Tax Credit (PTC) aims to make low-carbon hydrogen competitive vs. carbon-intensive hydrogen by reducing the costs and resulting LCOH of low-carbon hydrogen, driving H_2 producers to adopt the least carbon intensive technologies

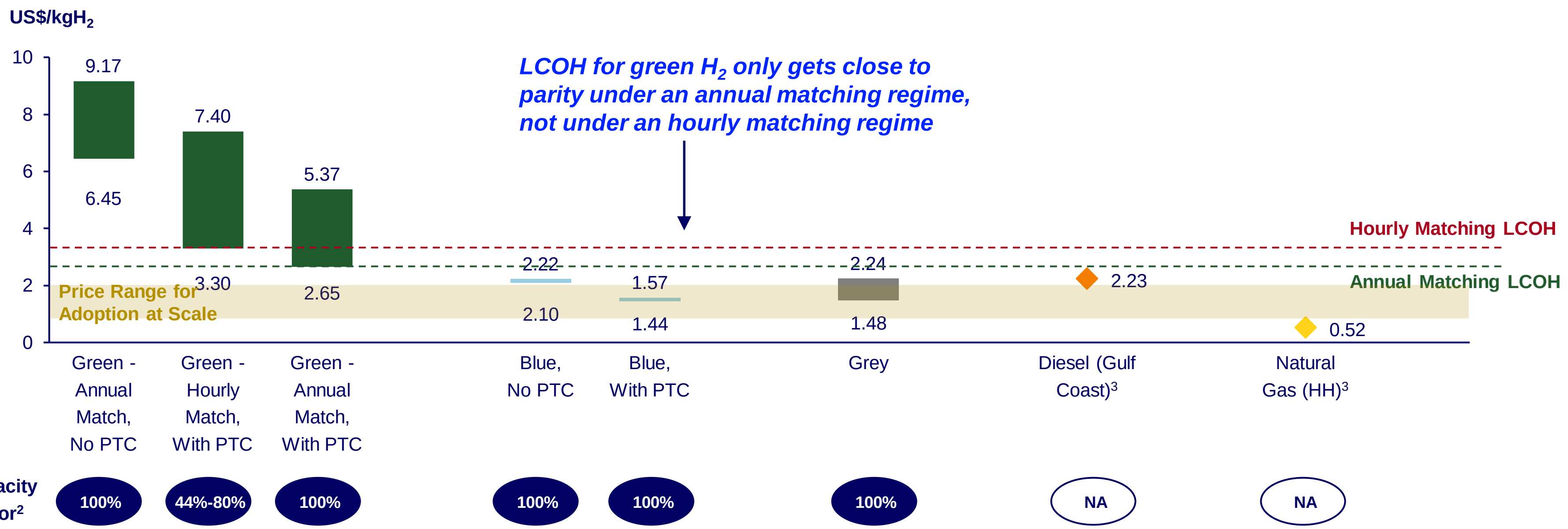
How does temporality affect the capacity factor and LCOH?

	Description	Typical power configuration	Capacity Factor (CF)	LCOH impact
1 Hourly Matching	▪ Electrolyzer demand matches the availability of renewable generation on an hourly basis ▪ H_2 is produced only at times when renewable generation occurs		Power Supply CF: **20-40%** Electrolyzer CF: **<50%**	Lower H_2 production from low CF results in high LCOH
2 Annual Matching	▪ Electrolyzer demand is met annually by renewables but needs grid power supply to sustain continuous operations ▪ RECs from excess renewables generation in peak generation hours are used to verify renewable attributes of grid supplied power		Power Supply CF: **100%** Electrolyzer CF: **90-100%**	High H_2 production from high CF results in lower LCOH

A longer annual match eligibility period supports a higher capacity factor (CF) and lower LCOH during a critical period for growth and innovation

Hourly match requires load following of renewables, limiting project CFs and challenging green H_2 economics

Estimated LCOH range by temporality, fiscal regime and technology[1] (2032 COD)



1. Green LCOH range is based on the electricity cost ranges between ERCOT (low range) and CAISO (high range). Green H_2 refers to solar and wind-based electrolytic H_2, while blue H_2 refers to natural gas-based H_2 with CCS technology; 2. These capacity factors reflect the renewables uptime; 3. kg energy-equivalent of H_2

Note: detailed assumptions for LCOH calculation can be found in the Appendix

Source: Wood Mackenzie

ACP proposed an alternative to US Treasury Guidelines, which delays the hourly matching requirement, supporting the emergence of new green H_2 projects

ACP proposed changes to the three pillars of the US Treasury Guidelines to 45V

Pillars		US Treasury Guidelines (**UST Scenario**)		ACP Proposal **(ACP Scenario)**	
TEMPORALITY	**Annual Matching**	**Timing:**	Through 2027	**Timing:**	1st 10 years of operation
		Eligibility:	All H_2 facilities	**Eligibility:**	Construction start before 2029, COD before 2033
	Hourly Matching	**Timing:**	2028 & beyond	**Timing:**	2033 & beyond
		Eligibility:	All H_2 facilities	**Eligibility:**	All H_2 facilities except those eligible for annual matching
INCREMENTALITY		Clean power must be sourced from generators coming online no earlier than 3 years of H_2 facilities' COD			
DELIVERABILITY		Electrolyzers and power generation facilities must be in the **same DOE energy region – defined by markets**			

We have focused on the **TEMPORALITY** proposed changes since they have the most material impact on project viability

Source: US Treasury, American Clean Power, Wood Mackenzie

The impact of each proposal was evaluated in California and Texas power markets

These markets are located in major US H_2 hubs and reflect over 60% of announced low-carbon H_2 projects

Key assumptions for green H_2 and renewable energy projects in CAISO and ERCOT power markets

California

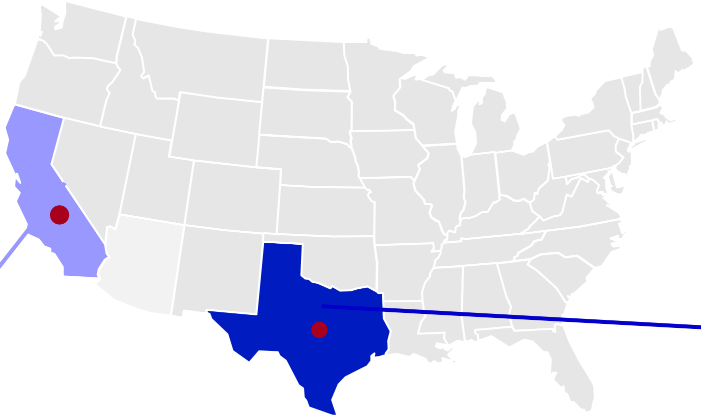
Power market	CAISO	
Zone	SP15	
Electrolyzer type and size	PEM | 200 MW	
Renewables source	**Size**	810 MW
	Overbuild	4.1x
	Capacity factor	25%

Power costs (US$/MWh)

	Hourly matching	**Annual matching**
2028	99.20	136.51
2032	84.35	124.44

Electrolyzer capacity factor (%)

Hourly matching	44%
Annual matching	100%



Texas

Power market	ERCOT		
Zone	South		
Electrolyzer type and size	PEM | 200 MW		
Renewable sources	**Size**	340 MW	340MW
	Overbuild	1.7x	1.7x
	Capacity factor	23%	40%

Power costs (US$/MWh)

	Hourly matching	**Annual matching**
2028	59.47	63.85
2032	60.15	66.78

Electrolyzer capacity factor (%)

Hourly matching	80%
Annual matching	100%

Wood Mackenzie assumptions

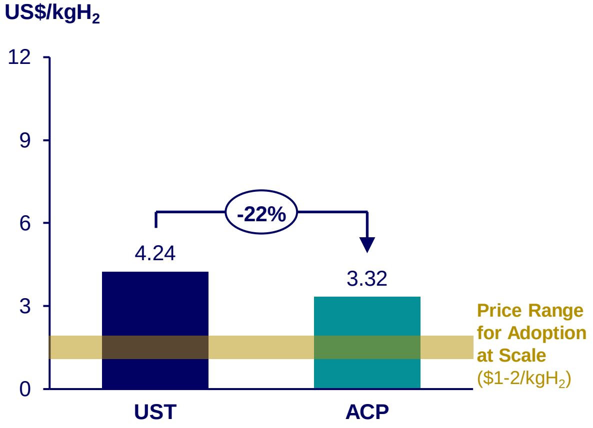
Wood Mackenzie's hourly renewables profiles and renewables capacity overbuild factor were optimized to achieve the highest H_2 capacity factor (CF) in the hourly matching scenario. H_2 producers may deploy different procurement strategies based on commercial decisions, such as choosing a smaller overbuild factor, to balance costs and production, resulting in lower H_2 CF

Source: Wood Mackenzie

In 2028, H_2 production costs are still too high to drive adoption in most sectors; annual matching reduces the cost to consumers by 20-30%

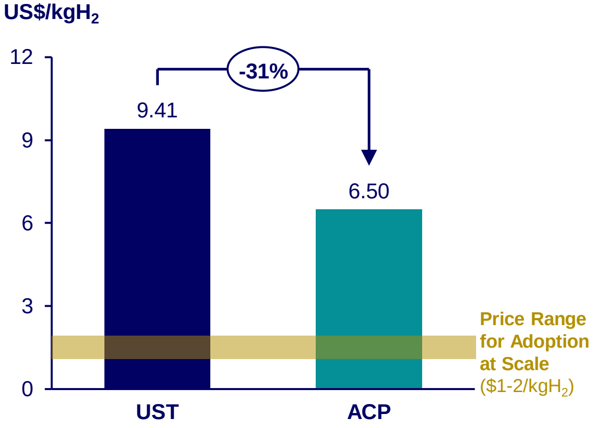
Regions with high quality wind are economically advantaged, but not enough to meet DOE H_2 shot goals

2028 ERCOT LCOH under UST vs ACP scenario (post 45V tax credit)



	UST	ACP
RE overbuild	3.4	3.4
Power config.	Hourly matching	Annual matching
Power cost (US$/MWh)	59.47	63.85
H_2 CF (%)	80%	100%

2028 CAISO LCOH under UST vs ACP scenario (post 45V tax credit)



	UST	ACP
RE overbuild	4.1	4.1
Power config.	Hourly matching	Annual matching
Power cost (US$/MWh)	99.20	136.51
H_2 CF (%)	44%	100%

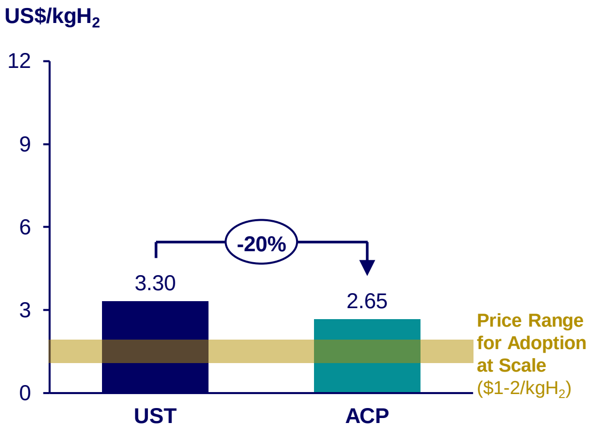
- In ERCOT, high-quality solar and wind resources and overbuild capacity yield 80% H_2 capacity factor (CF) in the UST scenario, narrowing the gap between proposals. This highlights that hourly matching has the least negative consequences only in regions with robust solar and wind resources to support sufficient H_2 production
- In CAISO, higher power costs and lower H_2 CF drive a significantly higher LCOH compared to the ERCOT LCOH
- Despite substantial LCOH reduction from ACP proposals, the resulting LCOH is 3-6x higher than the DOE's H_2 Shot goal of US$1/kg and significantly above the price range for adoption at scale for end-use customers, potentially impeding green H_2 adoption

Note: All green H2 analysis in this study assumes green H2 production to receive the full 45V tax credits ($3/kgH2) by having <0.45kgCO2/kgH2 of carbon intensity. Detailed assumptions for LCOH calculation can be found in the Appendix
Source: Wood Mackenzie

In 2032, renewable & electrolyzer CapEx reductions lessen the impact of a lower capacity factor; ACP's proposal brings LCOH closer to the price for adoption at scale

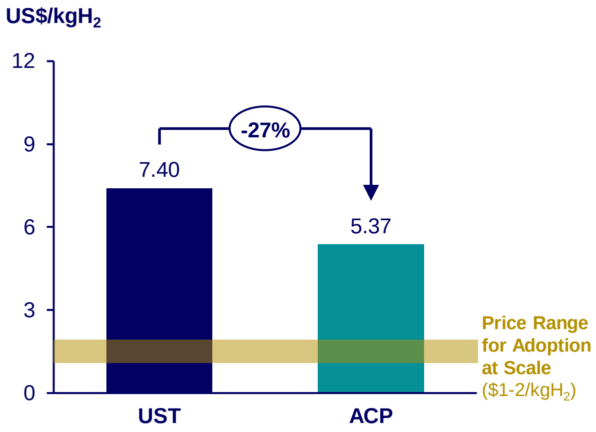
Still, even advantaged renewable resource regions like ERCOT are not able to fall in the $1-2/kg range

2032 ERCOT LCOH under UST vs ACP scenario (post 45V tax credit)



	UST	ACP
RE overbuild	3.4	3.4
Power config.	Hourly matching	Annual matching
Power cost (US$/MWh)	60.15	66.78
H_2 CF (%)	80%	100%

2032 CAISO LCOH under UST vs ACP scenario (post 45V tax credit)



	UST	ACP
RE overbuild	4.1	4.1
Power config.	Hourly matching	Annual matching
Power cost (US$/MWh)	84.35	124.44
H_2 CF	44%	100%

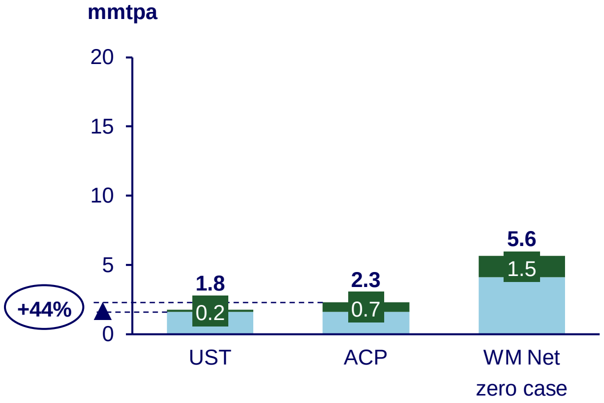
- LCOH under the UST hourly match regime has fallen by ~20% in both regions relative to 2028, signaling significant progress
- However, cost reductions are not enough to get into a price range for adoption at scale of US$1-2/kg$H_2$ by 2032 in either scenario, which reflects an inflection point for large-scale green hydrogen adoption
- Annual matching supports lower costs, but the current market context drives a starting point for green H_2 LCOH that may require more time or additional support beyond the 45V to achieve production costs needed to drive adoption at-scale

Note: All green H2 analysis in this study assumes green H2 production to receive the full 45V tax credits ($3/kgH2) by having <0.45kgCO2/kgH2 of carbon intensity.
Detailed assumptions for LCOH calculation can be found in the Appendix
Source: Wood Mackenzie

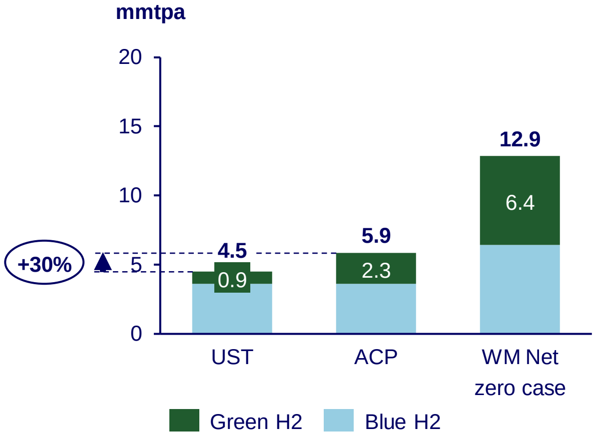
Lower LCOH under ACP's proposal drives higher low-carbon H_2 deployment long-term, accelerating the deployment required to approach net-zero ambitions

The deployment of blue H_2 increases under the UST guidelines to fill in for lost green H_2

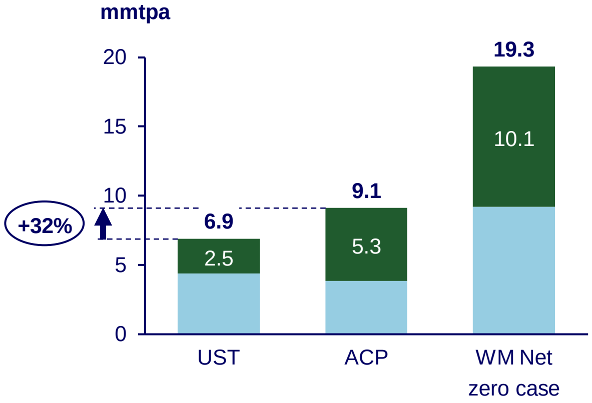
2028 US low-carbon H_2 supply by type under ACP vs UST scenarios



2032 US low-carbon H_2 supply by type under ACP vs UST scenarios



2035 US low-carbon H_2 supply by type under ACP vs UST scenarios



Extending the timeframe for annual match eligibility could drive a 44% increase in green hydrogen in 2028 (0.7 mmtpa vs. 0.2 mmtpa)

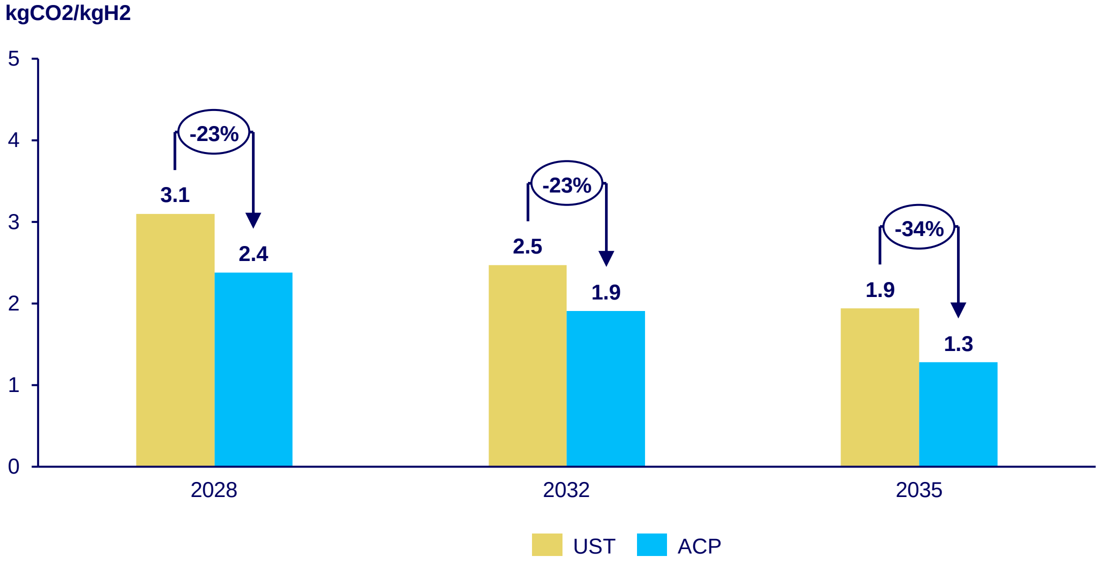
In 2032, an annual match regime could drive 2.3 mmtpa of green hydrogen as opposed to 0.9 mmtpa

- Under the ACP proposal, green H_2 surpasses 5 mmtpa
- In the UST scenario, green H_2 costs stay higher for longer, stagnating deployment and widening the gap. Blue H_2 supply, on the other hand, resumes deployment growth in the mid-2030s to fill the demand gap from the subdued green H_2 deployment

Note: The "green H2" mentioned in this slide refers to all electrolytic hydrogen (both green and pink H2), whereas "blue H2" refers to both blue and turquoise H2
Source: Wood Mackenzie

Higher green H_2 development under the ACP scenario, results in a lower CI of low-carbon H_2 supply

Carbon intensity of US low-carbon H_2 supply under UST vs ACP scenario



- Wood Mackenzie's low-carbon H_2 carbon intensity (CI) analysis focuses on how the green vs. blue H_2 evolution will impact decarbonization. The analysis is done by evaluating the average of green and blue H_2 CI, weighted by their respective deployment levels
- Blue H_2 CI is estimated based on a lifecycle emissions analysis of the natural gas value chain inclusive of CO_2 and CH_4, while green H_2 CI has zero CI:
  - For UST scenario, H_2 production results in zero CI
  - For ACP scenario, H_2 production uses annual RECs from dedicated renewables assets (incrementality pillar) to match grid power requirements, where the grid CI is above zero[1]
- The ACP scenario anticipates higher green H_2 deployment, which contributes to the 20-35% CI reduction in the ACP scenario compared to the UST scenario, and the gap widens in the later years

1. Although the current policy guidance lacks detail on this mechanism, developing a demand-agnostic carbon matching scheme is critical to ensure new electricity loads are served by renewable energy, supporting a broader decarbonization strategy
Note: The "green H2" mentioned in this slide refers to all electrolytic hydrogen (both green and pink H2), whereas "blue H2" refers to both blue and turquoise H2. All green H2 analysis in this study assumes green H2 production to receive the full 45V tax credits ($3/kgH2) by having <0.45kgCO2/kgH2 of carbon intensity.
Source: Wood Mackenzie

Key conclusions

Market Takeaways

- Green H_2 is critical to meeting **US decarbonization goals**
- However, as a new energy market, getting it off the ground is challenging. Historically, new energy markets have taken **30-50 years** to develop and decades of policy support
- **The IRA 45V production tax credit** incentivizes **low-carbon hydrogen development** (low CI H_2) and potentially **enables the green H_2 industry to scale**
- However, the **US Treasury guidelines** for 45V implementation **create hurdles for the growth of the green H_2 industry**

US Treasury Guidance

- US Treasury guidance **does not provide adequate support** to help green H_2 move towards its tipping point
- Having **an hourly matching market mechanism** starting in 2028 leads to **low-capacity factors**, which results in:
  - **Higher unit costs** due to less production to amortize the costs on
  - **Stagnation of deployment** caused by higher costs, creating barriers for many new entrants
  - **Increased carbon intensity**, resulting from greater blue H_2 supply filling in for lost green H_2

ACP Proposal

- **ACP proposed an alternative** to US Treasury Guidelines, which **delays the hourly matching requirement** to support green H_2 as the market is activated
- Based on Wood Mackenzie analysis in ERCOT and CAISO, extending annual matching has the following benefits:
  - **20-30% Cost reduction** to end-use consumers
  - **Viability** for many green H_2 projects, **doubling green H_2 supply** by 2035
  - **Lower carbon intensity** of low-carbon H_2, with over 30% CI reduction vs UST scenario less by 2035