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Impact of IRA, IIJA, CHIPS, and Energy Act of 2020 on Clean Technologies

Deep Dive | Low-carbon Hydrogen

APRIL 2023

Background | Objectives and context of this work

Objective

- Explore impacts of recent legislation[1] on U.S. opportunity and remaining challenges for emerging clean technology deployment

Stakeholders involved

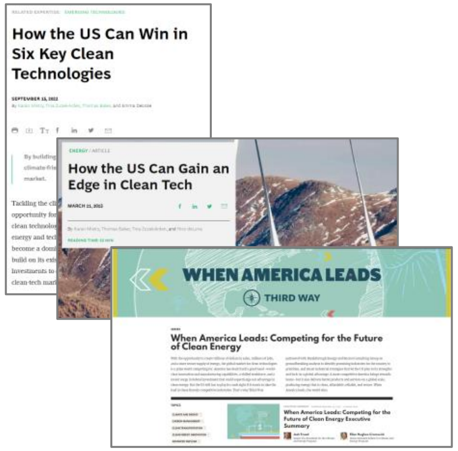
- Analysis was commissioned by Breakthrough Energy and Third Way, with input from stakeholders across the public and private sectors

Breakthrough Energy

THIRD WAY

Related publications

- BCG report | How the US Can Win in Six Key Clean Technologies
- BCG report | How the US Can Gain an Edge in Clean Tech
- Third Way publication | When America Leads: Competing for the Future of Clean Energy



1. Legislation assessed here includes Inflation Reduction Act (IRA), Infrastructure Investment and Jobs Act, CHIPS and Science Act, and the Energy Act of 2020
Source: BCG analysis

4,000-4,200 Mtpa
Annual global abatement potential in 2050

$500-600B
Cumulative U.S. domestic market '20-'50

$700-900B
Cumulative US exports '20-'50

~110k[2]
Cumulative job creation through 2050

Low-carbon hydrogen | Executive Summary

- Low-carbon hydrogen (H_2) plays a central role in a net-zero energy system as a solution for hard to decarbonize applications (e.g., fertilizer production, clean steel, fuel cells) and could be the next super-commodity, a strategically and geopolitically tradeable molecule

- IRA and IIJA present the US an opportunity to build early leadership in low-carbon H_2 with significant demand and supply incentives, which will boost volumes deployed ~20-35x by 2030, grow the US low-carbon H_2 market to ~$55B by 2030, and reduce electrolyzer capital costs up to 75% through learnings and scale by 2050

- An enhanced PTC of up to $3/kg will enable low-carbon H_2 to be a cost-competitive input for a broad range of applications by 2030, driving an increase in domestic demand and potentially positioning the US as a lead exporter to major markets[1]

- Further, supply-side incentives for manufacturers and supporting infrastructure buildout will help rapidly enable economies of scale to reduce long-term costs of low-carbon H_2 and accelerate innovation across the value chain

- Realizing the potential benefits of the IRA and IIJA on US durable competitive advantage in low-carbon H_2 will require addressing additional key non-cost barriers, including:
  - Rapidly expanding supporting transport and storage infrastructure to capture strong economies of scale
  - Preventing development bottlenecks that slow domestic deployment (e.g., permitting delays, demand lag)
  - Quickly deploying low-cost renewables by addressing permitting and grid interconnection bottlenecks
  - Leveraging and coordinating research to keep US players at the forefront of a nascent industry

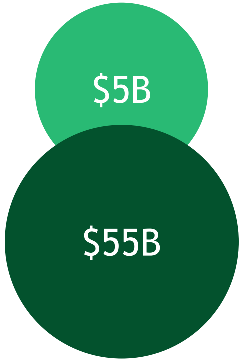
1. EU ETS near peak value of ~$100/tCO2e but not applicable for carbon removals as of 2022 2. Total number of positions created through 2050; incremental new jobs calculated as the sum of all non-negative one-year differences in # job-years (e.g., 2021 job-years minus 2020 job-years gives 2021 new jobs); incremental new jobs added to sum from prior period for cumulative calculation
Note: All numbers on lefthand side are based on projections from the IEA's 2021 Announced Pledges (APS) scenario and are cumulative from 2020-50 for all value chain segments
Source: DOE; IEA; BCG Analysis

Recent US policies (e.g., IRA, IIJA) have significantly increased the projected size of the US market and domestic jobs in clean hydrogen

US domestic market

US cumulative domestic market through 2030 increased from ~$5B to ~$55B after IRA/IIJA due to increase in domestic deployments from PTC[1] and infrastructure investment

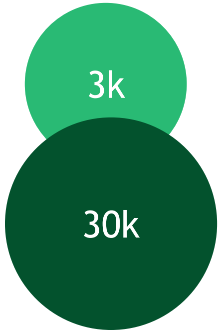
$B in market size



US job creation

New job creation in US H_2 industry through 2030 increased from ~3k to ~30K after IRA/IIJA due primarily to increased domestic deployments

Number of jobs



Pre-IRA   Post-IRA

Note: All numbers based on IEA STEPS scenario based on change over timeframe from 2020-2030, across all segments including offtake of H_2 produced. Capital investments post-IRA comprise ~$25B of the $55B shown here
Source: BCG analysis
1. Including all production related tax credits (45V and 45Q) for both green and blue H_2, as well as ITC/PTC for renewables that enable green H_2

Key decarbonization lever | Low-carbon H_2 can help decarbonize several hard-to-abate sectors with potential for strategic geopolitical importance

Trucking	H_2 production tax credit substantially pulls forward FCEV TCO parity relative to diesel Clean vehicles credit reduces purchase cost for both BEV and FCEV
Shipping	H_2 credit makes clean shipping fuels competitive and, in some cases, cheaper than LSFO
Aviation	PtL SAF likely to be cost competitive with jet fuel through Clean Fuels Credit or H_2 PTC FT SAF to reach parity through Clean Fuels Credit paired with other incentives for biofuels
Steel	Majority of U.S. plants are EAF (60–70%) and can use green H_2-DRI or H_2 electricity for EAF scrap plants
Power	H_2 production tax credit dramatically lowers cost and makes H_2 a possible substitution for gas peakers as a source of grid balancing and power generation going forward
Cement/ Concrete	While data sources vary dramatically on CCS capture costs for cement kilns, CCS credits likely to place low-emissions cement production near-or in-the-money, and H_2 can be used as input fuel

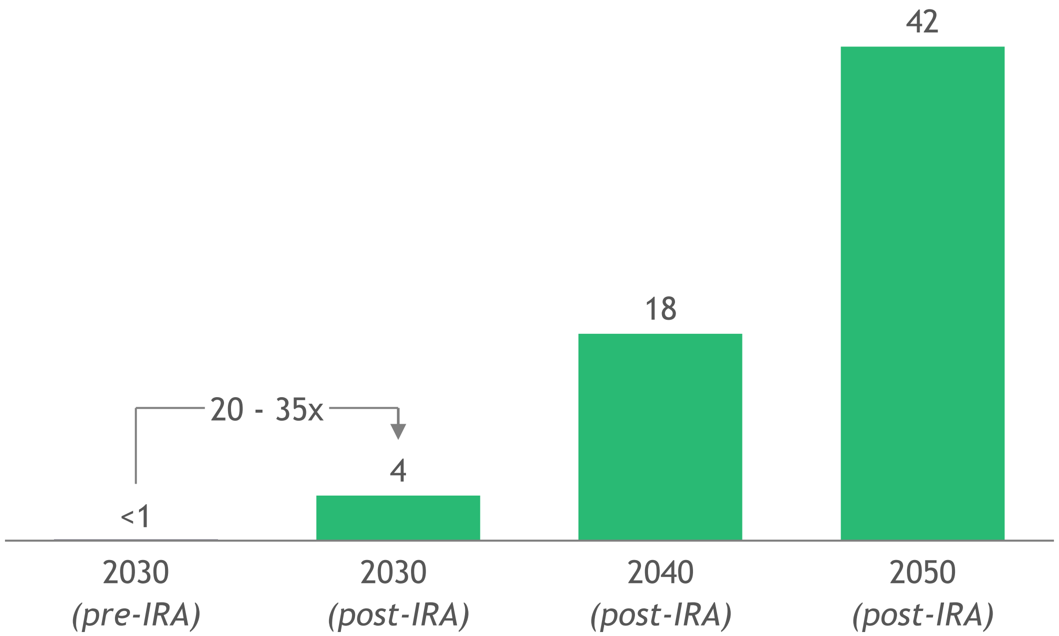
Hydrogen could become the next super-commodity—a strategically and geopolitically tradable energy asset. Like fossil fuels, hydrogen can be transported by pipe and ship as ammonia, making it highly exportable

Source: BCG analysis

Legislation impacts | Combined incentives will boost H_2 volumes deployed over 20x by 2030 and decrease unit costs an additional ~10% through 2050

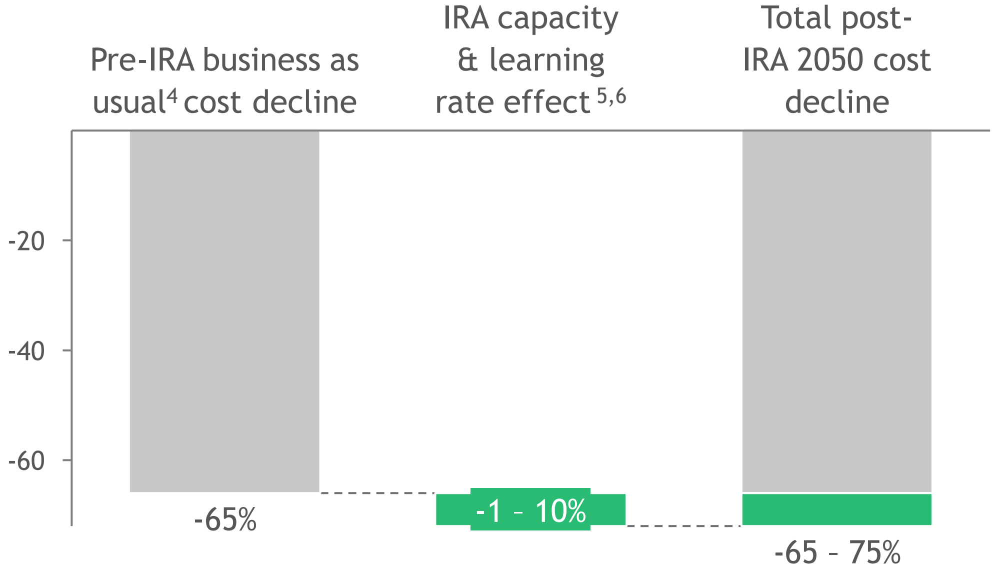
Legislation increases US low-carbon H_2 over 20-35x in 2030, opening path to 40+ Mtpa market by 2050

Est. US low-carbon H_2 demand (Mtpa)[1,2]



Deployment drives electrolyzer cost decline of up to 75%, with IRA enabling up to an incremental 10%

% decrease in electrolyzer capital cost in 2050 relative to 2022[3]



1. Individual share of NAMR forecasted demand is estimated using 2018 IEA energy consumption date. 2. Pre-IRA figures based on IEA 2021 STEPS scenario. Post-IRA is based on IEA 2022 SDS scenario energy consumption, which represents the 2-degree pathway 3. Results are based solely on PEM electrolyzers; learning from other electrolyzer types could influence final cost decline 4. Business as usual: 2030 capacity projection pre-IRA based on IEA stated policy (STEPS) scenario 5. Capacity effect: incremental cost reduction due to added US capacity and additional global deployment (assumed 3x US increase) 6. Learning rate effect: incremental cost reduction due to de-risked commercialization (US moving early) and innovation (improved learning rates)

Source: BCG Global H_2 Demand Model – Feb 2023

Demand implications | IRA production tax credit accelerates path to cost parity, making effective production costs for green H_2 competitive by 2030

Two forms of low-carbon hydrogen (H_2):

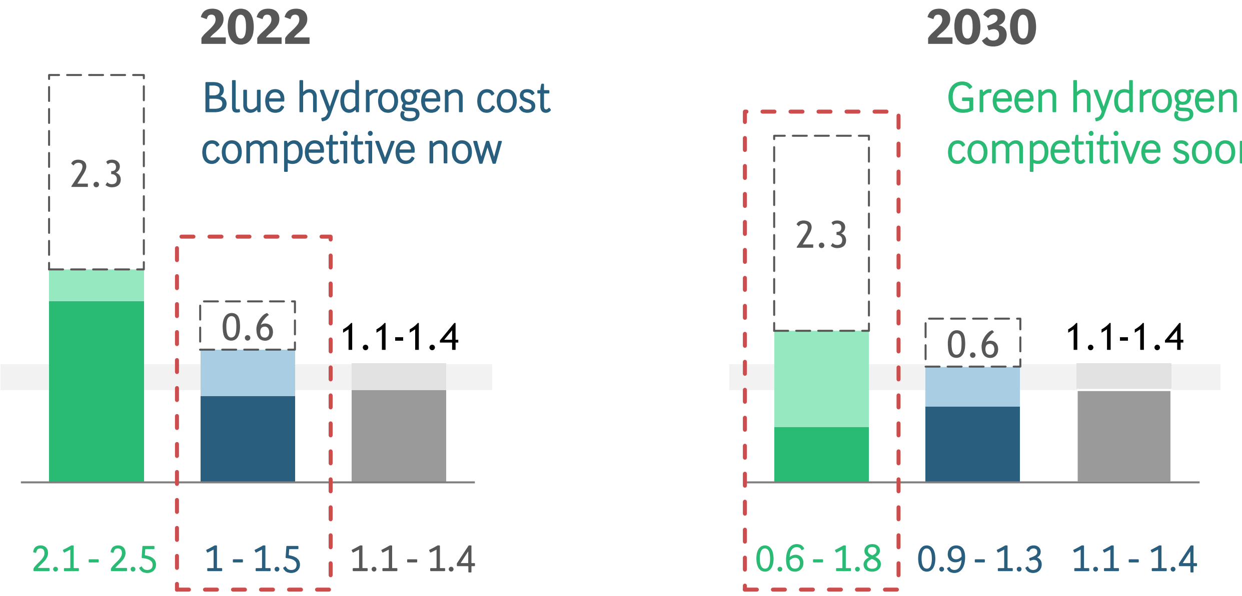
Green: Renewable energy + water electrolysis

Blue: Fossil-derived hydrogen + carbon capture

United States Levelized Cost of Hydrogen (LCOH)

($/kg hydrogen, production cost)[1,2]

Lighter shades reflects range of cost uncertainty[2]



Est. LCOH
($/kg hydrogen, production cost)[1,2]

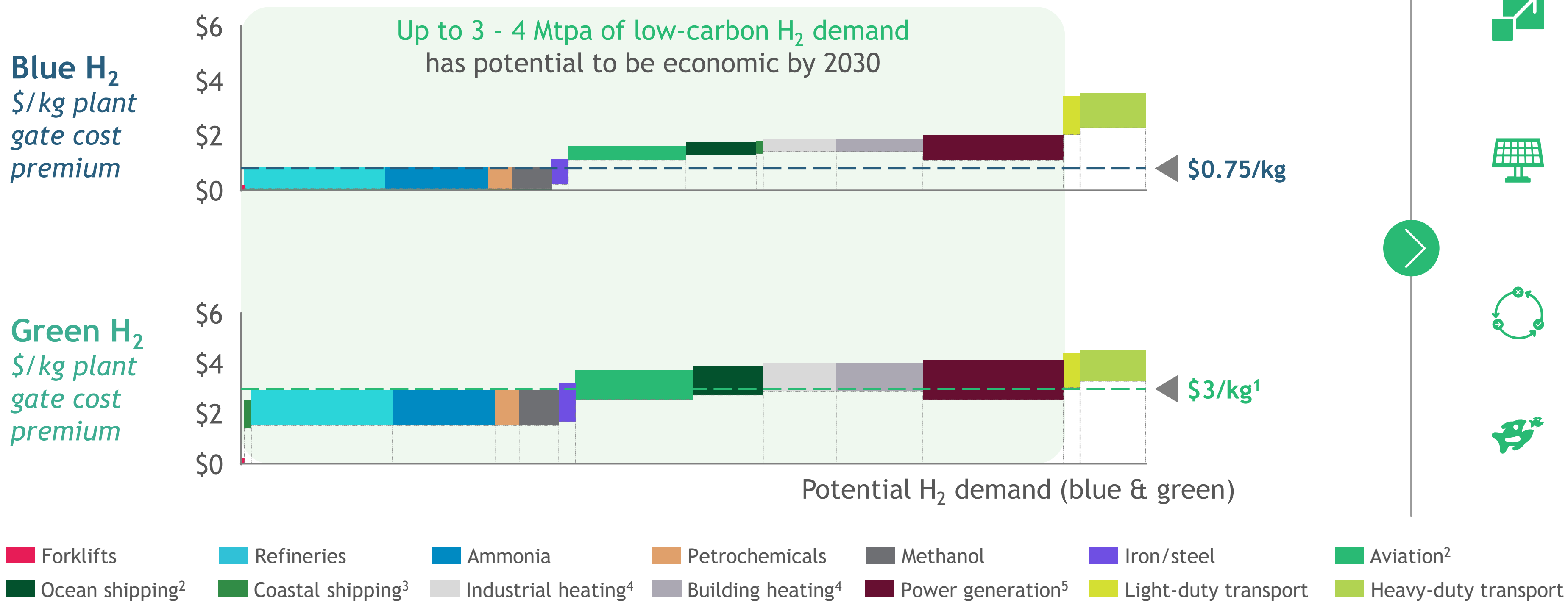
Production tax credit | Green Hydrogen | Blue Hydrogen[2] | Fossil-derived[2]

Notes: 1. Excludes infrastructure costs associated with storage and delivery to end consumer 2. Lighter shade reflects pricing uncertainty regarding natural gas (lower limit $2/MMBTU, upper limit $5/MMBTU) and electricity Note: assuming 15-year electrolyzer lifetime; discounted 10 yr $3 PTC for Green hydrogen with 6.0% discount rate over 15 years. 20-year lifetime for blue hydrogen; discounted 10 yr $0.6-1 PTC for Blue hydrogen with 7.2% discount rate over 20 years ($0.56 is an average assuming mix of SMR and ATR applications)
Source: BCG North America H2 Supply Model

Demand implications | PTC incentives offset cost premium, making additional applications economic and boosting demand, particularly for green H_2

Range of $/kg H_2 subsidy for cost parity with *incumbent* alternatives in 2030

U.S. example, non-exhaustive



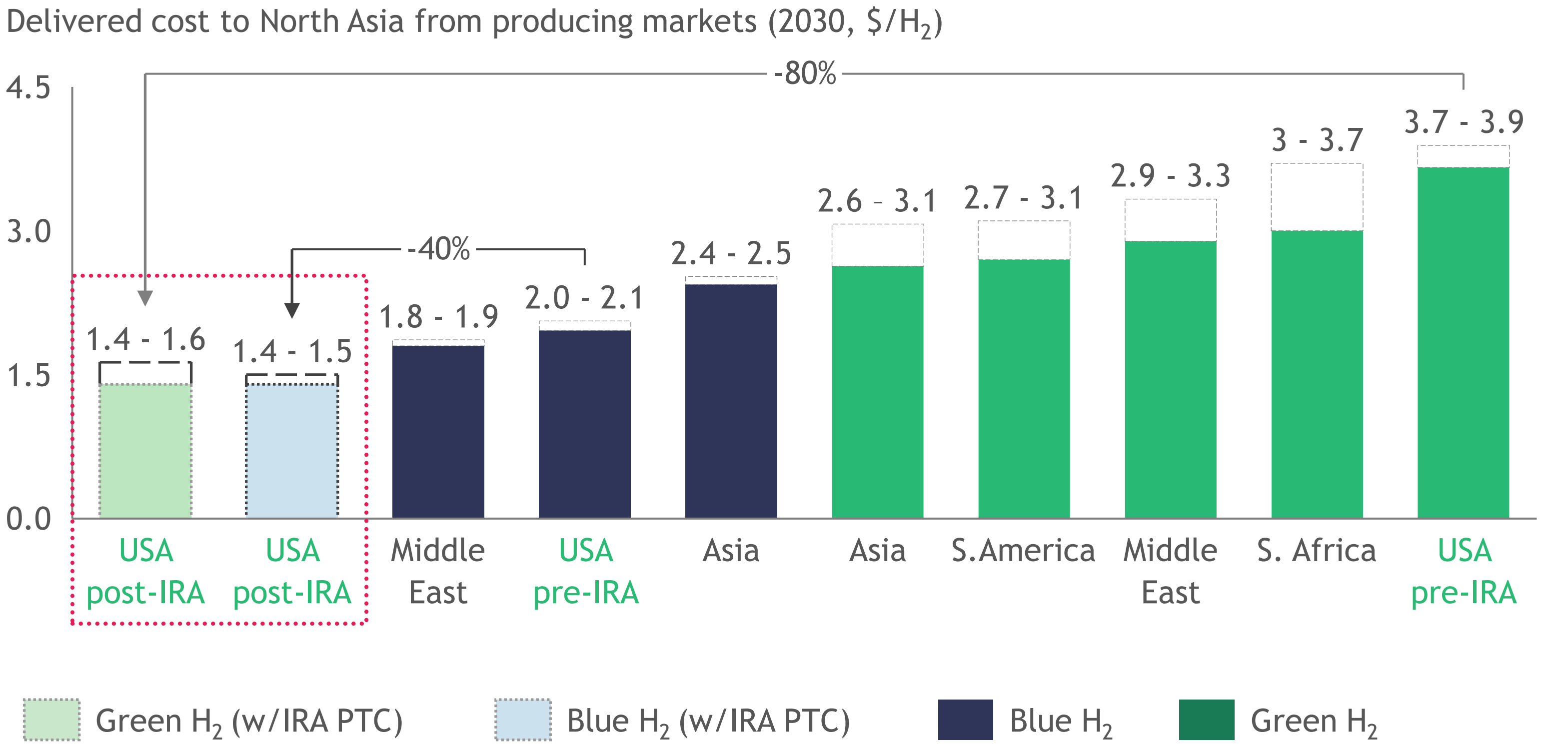
Demand materialization risks

- Achieving economies of scale in supporting transport and storage
- Realizing renewable and storage deployment and cost declines
- Confirming feasibility of end-use applications
- Remaining competitive against other potential low-carbon options

Notes: Model considers total cost of ownership including application upgrade cost, excludes T&S costs (i.e., assumes H_2 production on-site). Potential demand accounts for adoption rates and off-taker announcements but does not forecast the industry demand. Incumbents defined as grey H_2 (refineries, NH_3, petrochemicals, methanol), natural gas (steel, shipping, power), ICE (HDT, LDT), and fuel (shipping, aviation). Rail is excluded due to small market size. Not all use cases are carbon-efficient and may not be valuable. 1. Assumes 45V PTC, but 45Q may be more profitable in some cases (though this does not materially change the results). 2. E-kerosene PtL and E-methanol are low-carbon H_2 uses for aviation and ocean shipping. 3. Coastal shipping assumes a fuel cell-powered ferry run on e-methanol 4. Assumes 3% of H_2 blend in natural gas grid. 5. Assumes running an existing CCGT with H_2. **Source:** BCG NAMR H_2 Applications Economics Model

Demand implications | Incentives position the US to be the lowest-cost H_2 producer globally, enabling both green and blue exports to multiple markets

Example: Delivered Levelized Cost of Low-Carbon Ammonia (LCOH) to key markets in North Asia[1]



Key takeaways

Pre-IRA: U.S.-produced blue H_2 competitive with but not cheapest source of clean hydrogen for N. Asia consumption

Post-IRA: U.S. H_2 becomes the most competitive option for N. Asia imports

The incentives have the potential to move the U.S. from a lagging position to global leader in both green and blue H_2

1. N. Asia chosen because it is expected to be one of the largest importing regions and is meant to be illustrative; Median delivered cost shown where applicable; Note: Includes high-potential supply sources into N. Asia, not exhaustive; Middle East, S. America and Asia are representative of individual countries in region; Source: BCG Hydrogen Supply Model; BCG analysis

Supply impacts | Economies of scale, particularly in transport and storage, can unlock 15-45% cost reductions to support long-term competitiveness

Illustrative example; COD 2024

Anticipated low-carbon H_2 cost decreases from scale[2] (vs 10 ktpa)

H_2 demand (ktpa[1])	Example H_2 demand site		Production[3] Blue H_2[7]	Production[3] Green H_2[8]	Compression[4]	Transport[5]	Storage[6]	Overall Blue H_2	Overall Green H_2
10	Glass, HDT	*$/kg->*	2.15	3.60	0.12	0.40	0.15	2.85	4.30
50	H_2, Steel (EAF), PetChem, CH_3OH		25%	5%	10%	70%	65%	30%	14%
100	NH_3, Steel (BOF), Refinery, Power		30%	5%	15%	80%	75%	40%	16%
1,000+	Aggregation of demand sites		35%+	5%	25%+	90%+	85%+	45%+	18%
		Returns from Scale	MED	LOW	MED	HIGH	HIGH	MED - HIGH	LOW - MED

1. Thousand metric tonnes of hydrogen per year 2. Values in 2021$; assumes COD 2024 3. Texas reference case with grid pricing for electricity 4. Yang & Ogden. 2007; Leeuwen et al. 2018; Perry's Chemical Eng. Handbook 5. Reuß et al. Applied Energy. 2017; assumes pipeline transport with transport distance of 50 mi 6. Ahluwalia et al., ANL. 2019; assumed salt cavern storage with enough supply to cover 3 days worth of demand 7. Production cost includes CCUS expenses; no returns to scale included for CO_2 capture and storage expenses; scale returns for CO2 transport expense describe ~50% of the total cost decline for Blue H_2; assumes 10 mile transport distance to adequate CO_2 geological storage 8. Electrolyzer sized linearly, 60MW for every 10 ktpa H_2 demand; No returns to scale assumed above 200MW electrolyzer modules

Note: Scale of H_2 production/demand quickly rising; supply side: (10/2021) Air Products announced plans for Louisiana 650 ktpa blue H_2 production facility; demand side: (08/2019) Perdaman announced plans for world's largest ammonia plant at 3500 tpd (~110 ktpa H_2 required)

Source: BCG H_2 Hub tool; BCG analysis

Pre-legislation challenges | As a nascent industry, low-carbon H_2 needed significant policy support to jumpstart and accelerate deployment

Illustrative

Value chain segments	Primary activities (Timeline →)	Key pre-IRA gaps to be addressed
OEM	1 Electrolyzer manufacturing	1 **High cost and lack of commercialization funding for new technology** slows the learning curve and deployment of novel technology to drive down costs
Project development	2 Customer / site selection Permitting and infra. planning	2 **Risk and cost associated with new development** constrains demand and supply side investment
Production enablers	3 Production and conversion	3 **Shortage of renewables and aging grid** limits the number of possible sites for green H_2
Transport & Storage	4 Compression, storage, and transport	4 **Insufficient transport and storage infrastructure** to support build out at scale
Offtake	5 Sell in domestic markets[1]	5 **Lack of subsidies and high costs** make low-carbon H_2 not competitive with most traditional fuels
	6 Sell in international markets[1]	6 **Potential lack of alignment with trade partners** on H_2 standards

1. Fuel, ammonia, methanol, electricity, and other industrial applications
Source: BCG Analysis

Remaining challenges | Legislation changes US low-carbon H_2 landscape; further action needed to enable transformation and acelerate deployment

	FROM: Pre-legislation priority challenges	TO: Changes from recent legislation (IRA, IIJA, CHIPS, and EA 2020)	FUTURE: Remaining areas to target with future policies
OEM	1 High cost and lack of commercialization funding for new technology	• 48C mfg. tax credits for electrolyzers • $1.5B funding for research and commercialization (IIJA 40314)	✩ Lack of coordination across research institutions and manufacturers to get the most out of every dollar
Project development	2 Risk and cost associated with new development	• IIJA prvides $8B for development of at least 4 regional clean hydrogen hubs to leverage scale, reduce costs, and de-risk development	✩ Demand side lag from uncertainty about availability of new supply, preventing necessary demand-side investment
Production enablers	3 Shortage of renewables and aging grid	• ITC, PTC, and other subsidies across legislation will increase renewable saturation	• Expediting the deployment of renewables to support green H_2 production and investment in grid upgrades
Transport & Storage	4 Insufficient transport and storage infrastructure	• $1.25B IIJA funding for clean fuel charging stations • $8B for development of 4 regional hubs	✩ Permitting and regulations that slow deployment of H_2 and prevent scaling benefits
Offtake	5 Lack of subsidies and high cost of production	• PTC of $0.6/kg and up to $3/kg for H_2 produced between 0-0.45 kg of CO2/kg	• Achieve scale and pathway to cost parity without subsidies
	6 Lack of consistent emission standards for international trade partners		✩ Potential lack of alignment with trade partners on low-carbon H_2 standards

✩ Priority areas

1. Transportation and storage is seen as the largest potential blocker for H_2
Source: DOE; White House; IRA; IIJA; BCG Analysis

Summary | Actions to further boost U.S. competitiveness

Key levers that will enable the U.S. to win the H_2 market

Build out transportation & storage infrastructure

Invest in and streamline regulations for transportation and storage (e.g., tanks, trucks, pipelines, and more regional hubs) to support the additional H_2 capacity

Ensure trade partners accept blue H_2

Align on standards and acceptance (e.g., carbon intensity, certificate of origin, acceptability with emissions targets) for low-/zero–carbon H_2 with key import regions (e.g., EU)

Reform permitting

Streamline and prioritize review/approvals process for zoning, safety, and environmental impact reviews for storage facilities

Rapidly deploy renewables to enable production

Streamline permitting and interconnection to rapidly deploy renewables that can be used to produce H_2 and put U.S. on path to cost parity without subsidies

Leverage and coordinate research

Create opportunities and processes to increase research collaboration among national labs, universities, and private sector

Source: BCG analysis

Backup | New legislation provides incentives for hydrogen (I/II)

Provision	Summary	Type	Total investment
1 IRA Section 13204	Green H_2 production tax credit of \$0.6/kg and up to \$3/kg for hydrogen produced between 0-0.45 kg of CO2/kg	Production Tax Credit (PTC)	\$13B(shared with blue H_2)
2 IRA Section 13204	Blue H_2 production tax credit of \$0.75/kg	Production Tax Credit (PTC)	\$13B (shared with green H_2)
3 IRA Section 13501	Extension of the advanced energy manufacturing project credit (48C). Base rate of 6% and 30% tax credit if wage and apprentice requirements are satisfied	Manufacturing Tax Credit	\$10B
4 IIJA Sec. 40314	Supports the development of at least 4 regional clean hydrogen hubs to improve clean hydrogen production, processing, delivery, storage, and end use	Grant Funding	\$8B
5 IIJA Sec. 40314	Establishes a research, development, demonstration, and deployment program for purposes of commercialization to improve the efficiency, increase the durability, and reduce the cost of producing clean hydrogen using electrolyzers	Grant Funding	\$1B
6 IIJA Sec. 40314	Provides Federal financial assistance to advance new clean hydrogen production, processing, delivery, storage, and use equipment manufacturing technologies and techniques.	Grant Funding	\$0.5B

Source: DOE, White House, IRA, IIJA, BCG Analysis

Backup | New legislation provides incentives for hydrogen (II/II)

Provision	Summary	Type	Total investment
6 IIJA Sec. 11101; 11401	Charging and Fueling Infrastructure Grants to deploy electric vehicle charging and hydrogen/propane/natural gas fueling infrastructure along designated alternative fuel corridors and in communities	Grant Funding	$1.25B
7 CHIPS Section 10771: Advanced Research Projects Agency—Energy[3]	Allocates funding to Department of Energy research, development, and demonstration activities (ARPA-E) for energy projects	Grant	$1.2B
8 CHIPS Section 10771: Office of Electricity[3]	Allocates funding to Department of Energy research, development, and demonstration activities related to electricity	Grant	$1B
9 CHIPS Section 10622: Regional Clean Energy Innovation Program[3]	Authorizes a Regional Clean Energy Innovation Program at DOE to establish partnerships that promote the economic development of diverse geographic areas of the US by supporting clean energy innovation	Grant	$0.25B

Source: CHIPS, BCG Analysis

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