Green Hydrogen Briefing

April 27th 2022
What I’ll cover today

• Hydrogen 101
• Cost
• U.S. policy landscape
• Green Hydrogen Catapult
“Hydrogen 101”
What is hydrogen?

A molecule…

Similar to fossil fuels…

- Combustion produces high temperatures
- It is energy dense
- It can be involved in chemical reactions

Unlike fossil fuels…

- As a fuel where high temperatures are needed
- As a fuel where high energy density is needed
- As a chemical feedstock

Giving it a unique role in net zero

What role will hydrogen play in achieving net zero?

1. Replace hydrogen in existing end uses

- **Fertilizer**
- **Refining**
- **Chemicals**

10 MMT H₂/yr → ~100 MMT CO₂/yr
(2% of total US emissions)

2. Replace fossil fuels in heavy industry & transport

- **Steel**
- **Shipping**
- **Trucking**
- **Aviation**

200-300 MMT CO₂/yr
(4-6% of total US emissions)

Hydrogen is vital for net zero, but is only one piece of the puzzle

Share of total final energy consumption by fuel in the NZE, 2020-2050

- **Coal**
- **Oil**
- **Natural gas**
- **Renewables**
- **Electricity**
- **Hydrogen**
- **District heat**

Source: IEA, Global Hydrogen Review 2021, [link]
How is hydrogen produced?

- **GRAY HYDROGEN**: Made from natural gas (typically methane) through process known as steam methane reforming.
- **GREEN HYDROGEN**: Made from electrolysis of water, powered by renewable energy with zero carbon emissions.
- **BROWN HYDROGEN**: Made from coal or lignite through process of gasification.
- **PINK HYDROGEN**: Made from electrolysis of water, powered by nuclear energy.
- **BLUE HYDROGEN**: Same as gray or brown hydrogen, but with CO₂ emissions captured and stored (lower-carbon solution).
- **WHITE HYDROGEN**: Naturally-occurring hydrogen found in underground deposits (generally not accessible today).

Source: Heliogen, [link](#)
Grey Hydrogen Pathway

Natural Gas → Steam Methane Reforming → CO₂ → H₂

Emissions: ~10-12 kgCO₂/kgH₂

Blue Hydrogen Pathway

Natural Gas → Steam Methane Reforming → CO₂ → CO₂ captured & stored/utilized → H₂

Emissions: ~2-9 kgCO₂/kgH₂

Green Hydrogen Pathway

Renewable Energy + Water → Electrolyzer → H₂ → O₂

Emissions: 0 kgCO₂/kgH₂

Today’s approximate values shown, emissions dependent on efficiency of capture, upstream emissions, electricity sourcing. Capture rate used: 56-95%. Based on RMI analysis, the best blue (95% capture, 0.05% leakage) case still results in ~1.7kgCO₂/kgH₂ based on a typical grid emissions.
Cost
How much does hydrogen cost?

Hydrogen costs – now and future, $/kg H2

- Gray H2: $1.00-$1.50
- Blue H2: $1.70-$2.20
- Green H2 (today): $3.00-$7.00
- Green H2 (2025): $2.00
- Green H2 (2030): $1.00

Applications in metal processing, ammonia production, transport become commercially viable.

Source: RMI analysis; RFF analysis, [link]; DOE Hydrogen Shot; Carbon Brief / BloombergNEF, [link]
Why are green hydrogen costs expected to drop?

**Today**

- Renewables and electrolyzer are two Capex drivers
- Electrolyzers need high utilization due to Capex of ~$700/KW
- Combined wind and solar generation to improve renewable energy system availability

**Tomorrow**

- Improved manufacturing and system design drives electrolyzer Capex down to $200/KW
- Electrolyzer operation moves to capture generation, making utilization less critical
- Shift to use the least cost generation resource more heavily
Today assumes $700/kW electrolyzer capex, $800/kW solar capex, $1000/kW wind capex, and $516/kg hydrogen storage capex.

Tomorrow assumes $200/kW electrolyzer capex, $500/kW solar capex, $800/kW wind capex, and $516/kg hydrogen storage capex.

At $2/kg green hydrogen becomes competitive with fossil alternatives.
U.S. Policy Landscape
U.S. federal policy landscape

**Bipartisan Infrastructure Law**
- 4+ hydrogen hubs ($8bn)
- RD&D ($1.5bn)
- National strategy; clean hydrogen definition

**Reconciliation**
- Production incentive of $3/kg for cleanest hydrogen; bringing renewable ‘green’ close to parity with fossil ‘blue’ and ‘grey’

**Sector-based proposals**
- Support for priority end-use sectors:
  - Fertilizer
  - Trucking
  - Shipping
  - H2 Distrib.

**Notes**
- Requirements for:
  - Feedstock diversity
  - End use diversity
  - Geographic diversity
  - Max. employment

**Tiered incentive:**
- $3/kg for cleanest hydrogen
- <0.45 kgCO2e/kgH2 = $3
- <1.5 = $1.00
- <2.5 = $0.75
- <4 = $0.60
- <6 = $0.45

- $500m for H2 equipment at ports and for shipping
- $1.2b for H2 in industrial end use applications
- $500m in grants/loans for H2 transport/storage infra.
What's needed next?

The hydrogen economy needs local and state support to be successful

**Prioritizing end uses** — directing $$$ toward high-value long-term uses

**Integrated planning** — considering system design including feedstocks

**Permitting** — siting and building necessary infrastructure

**Safety and handling** — updating regulations for new hydrogen industries

**Standards/certification** — verifying emissions of hydrogen production
# U.S. state policy landscape

<table>
<thead>
<tr>
<th>Current</th>
<th>In development</th>
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<td>States with hydrogen strategies and/or incentives:</td>
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<tr>
<td>• California (LCFS, ZEV targets)</td>
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<td>• Washington</td>
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<td>States with interest in H2 hub funding:</td>
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<td>• AR, AZ, CA, CO, CT, IL, LA, MA, MS, NC, ND, NJ, NM, NY, OH, OK, OR, PA, SC, TX, UT, WA, WV, WY</td>
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Califonia, Colorado, Illinois (stalled), New Mexico (stalled), New York

Half of U.S. states have announced interest in H2 Hub funding:

AR, AZ, CA, CO, CT, IL, LA, MA, MS, NC, ND, NJ, NM, NY, OH, OK, OR, PA, SC, TX, UT, WA, WV, WY

Not exhaustive
Green Hydrogen Catapult
GHC is a private sector coalition, convened with the support of the UN High-Level Climate Champions and coordinated by RMI. It bring together the world’s biggest green hydrogen project developers to drive down the production cost of green hydrogen.

**Our members** include ACWA Power, Arcelor Mittal, CWP Renewables, Fortescue Future Industries, H2 Green Steel, HyStor, Iberdrola, Mærsk Mc-Kinney Møller Institute for Zero Carbon Shipping, Ørsted, ReNew Power, Snam, and Yara.

**Our Mission** is to mobilize **80GW of green hydrogen capacity by mid-2026** to catalyze market growth, making possible a future where **green hydrogen is produced well below $2/kg**.

**Our Approach** is focused on 1) Developing “breakthrough” green hydrogen production solutions that can meet the cost target in many regions of the world, not just the most favorable, 2) Rally coordinated action in key sector supply chains 3) Equip policy makers with insights, targets, and policy options to drive down costs to stimulate market formation.

Taking action now is critical to meet out global climate targets. Scaling Giga-Watts requires a **whole system approach** that begins with designing-in the future, the GHC is helping to lead the way.
GHC areas of focus for 2022

Mobilize GW-scale Projects and Demand
*Work with demand sectors to translate commitments to real projects*

Hub Demand Aggregation in Key Regions (US, EU, Global South)
- Support operationalization of medium-term targets into near-term procurement
- Aggregate portfolios of projects into hydrogen clusters

**Steel**
- Domestic green production pathways
- Establish procurement coalitions

**Shipping**
- Green corridors
- Port infrastructure and value chains
- Book and claim system

**Fertilizer**
- Switch production assets to green H2
- Demand aggregation via certification and buyer schemes

Supercharge policy
- Support enabling policy to foster demand in select hubs
- Demand stimulation policy blueprints
- Support to develop global Green H2 Standard
Thank you!

Questions or feedback welcome
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