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Building the Clean Hydrogen Economy

Guidehouse Hydrogen Consortium
Public Document

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Background on the Guidehouse 2021 Hydrogen (H_2) Consortium

- In 2021, Guidehouse launched a H_2 Consortium to help accelerate H_2 deployment in the US.
- Over 20 companies brainstormed potential H_2 projects that could stimulate H_2 demand and ensure adequate, cost-competitive supply by 2025.
- Analysis was conducted on six (6) of the projects which were then prioritized for three (3) deeper dive assessments.
- Detailed business cases and financial analyses were developed for:
  - Southwest H_2 corridor for heavy transport
  - Clean ammonia production from nuclear generation
  - Integrated blue and green H_2 in the Gulf Coast

A very high-level summary of the above three business cases are presented in this public document

The participants in the 2021 Guidehouse Hydrogen Consortium included

Other consortium participants included Walmart and active discussions with the Port of LA

The organizations that participated are recognized for their contributions to the working group discussions. Recognition does not convey attribution. Moreover, in no way should recognition for participation be deemed as endorsement or adoption of the recommendations and policy proposals herein. The research and recommendations herein are exclusively attributed to the authors.

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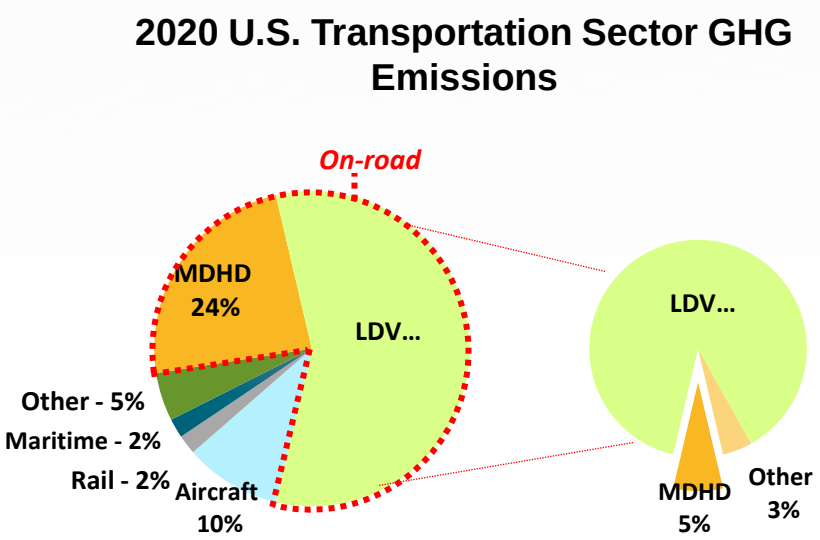
Southwest H_2 Corridor

For Heavy Transport

The Medium-Heavy Duty transportation segment presents a major decarbonization opportunity, but obstacles to H_2 adoption remain unaddressed

The MDHD segment makes up 24% of transportation emissions, despite only accounting for 5% of the total vehicles on road

The business opportunity for decarbonizing Heavy Transport is attractive, but adoption suffers from the following barriers



- **The "Chicken and Egg" Dilemma:** Overcoming early market hesitancy to build momentum for necessary value chain investments in supply and vehicles. Coupling vehicle deployments with fuel supply can help overcome risk.
- **Cost Competitive Fuel:** Finding creative strategies to deliver low-cost H_2 is critical for advancing a compelling total cost of ownership to customers and stimulating adoption. Current H_2 fueling costs in CA of $16/kg is 2-3x as expensive compared to diesel.
- **Ensuring Supply Availability:** Ensuring supply constancy is critical for truck-owner operators who require strict up-time requirements to service "just-in-time" supply chains and remain profitable in a competitive industry that operates on narrow margins.
- **Building the H_2 Ecosystem:** Achieving large-scale deployments of H_2 vehicles and building local markets will be a key factor in supporting an expansive fuelling station ecosystem that will unlock long-haul trucking corridors and more diverse applications in addition to reducing overall fuelling costs.

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The H_2 Consortium studied the entire value chain and, leveraging member assets, developed a pilot concept that addressed barriers to H_2 adoption

Pilot Goal

1. Stimulate the H_2 ecosystem in Los Angeles and Phoenix regions with the goal of connecting the two corridors for long haul trucking and supplying H_2 near parity with diesel cost by 2025-2030.
2. "Scaling up" of market would be key in achieving cost competitive supply and developing fueling infrastructure.
3. Have shovel-ready projects ready for when robust policy support is available.

Known Competitive Advantages

- ✓ Existing biogas/renewable electricity assets near demand clusters
- ✓ Partnerships across value chain players to help couple vehicle deployments with H_2 supply
- ✓ Supportive regulatory environment in California

Uncertainties that Needed to be Explored

- ✓ Future scaled-up market potential in the region
- ✓ Most effective distribution strategies in terms of fuel delivery and fueling station deployments
- ✓ Production costs of H_2 from member assets
- ✓ H_2 supply grow over time
- ✓ Need for federal incentives, like the Production Tax Credit (PTC)

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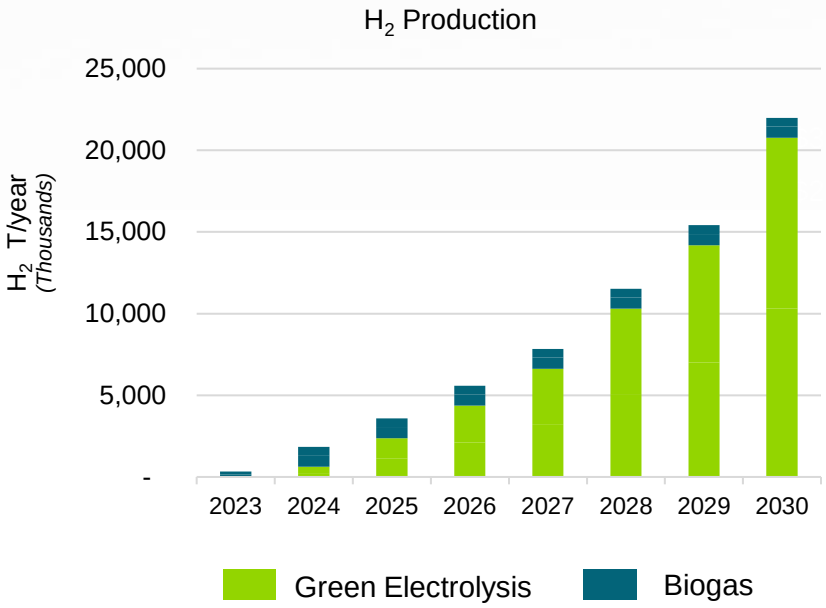
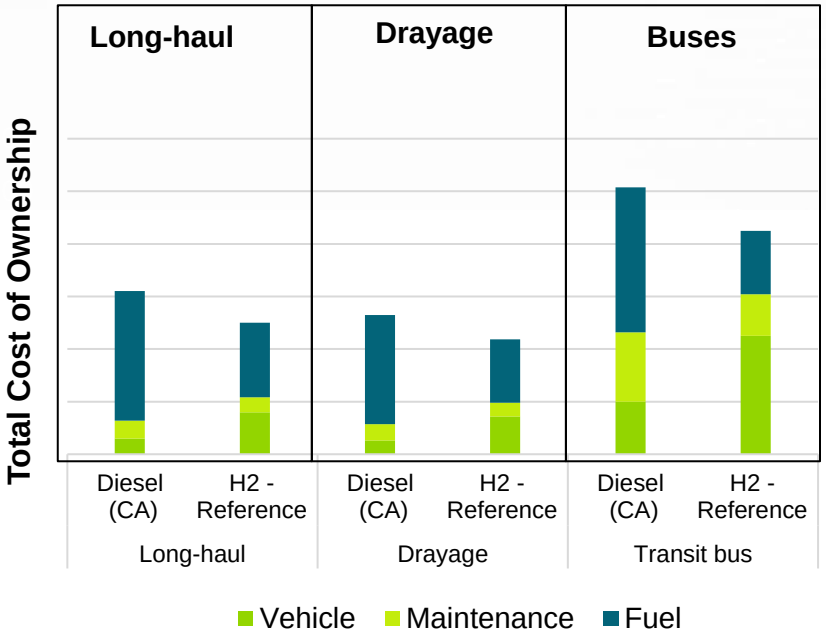
Guidehouse found that reliable, cost-competitive, clean H_2 supply can be achieved to support early vehicle deployments

Consortium H_2 production from renewable natural gas and renewables ramps up incrementally to match vehicle deployments to optimize costs and fueling infrastructure build-out



From a cost of ownership perspective, the dispensed costs of H_2 achieved at scale would be attractive to end-users while still supporting fueling infrastructure investments and H_2 production capacity assuming robust policy support from LCFS and grant programs



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Key Takeaways for Heavy Transportation

Opportunities

- Competitive dispensed costs of H_2 are within-reach in the SW with incentives and additional policy support.
- More-stringent fuel economy standards at the federal level, and zero emission sales mandates in California are building the momentum for early adopters, as are incentives (LCFS* credits).
- Abundant supply resources in the region will be available to meet early forecasted market demand.
- The combination of low-cost renewables and biogas resources near demand clusters can support early market development.

Challenges

- It's uncertain how quickly demand will materialize. Availability of vehicles is critical, as there are no commercialized vehicle sales yet.
  - Vehicle developers need to move from prototype to production phases and to lower the weight of vehicles to avoid payload penalties
- Lack of a Renewable Fuel Standard pathway for RNG to H_2 challenges renewable H_2 economics, even with the LCFS in California.
- A competitive cost of H_2 will be difficult to achieve in Phoenix and other localities without more robust state and federal policy support.

*Low Carbon Fuel Standard

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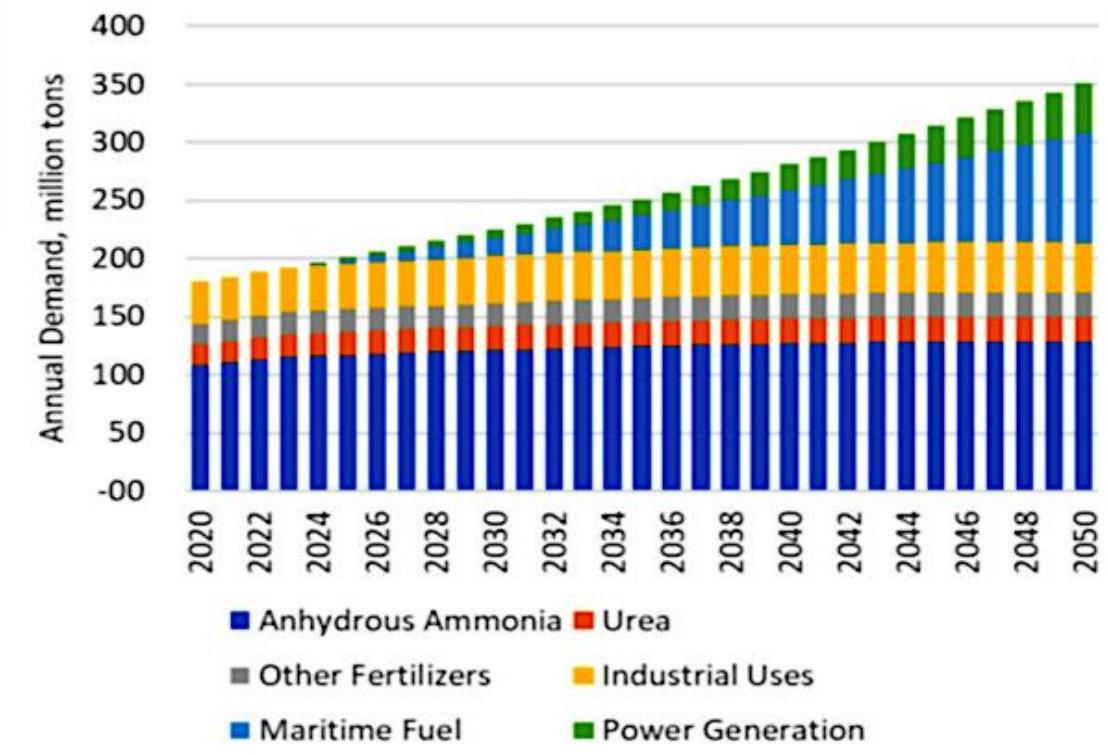
Clean Ammonia Production

From Nuclear Generation

Based on current market prices, the global ammonia market is $270 billion, and it is expected to grow significantly

Global ammonia market is approximately 180 million tons per year, and is expected to double

Current and forecasted global ammonia demand (million tons)



Source: IEA

The core market for ammonia is fertilizer with growth opportunities in marine fuel, combustion fuel and as a hydrogen carrier

Fertilizer	▪ Fertilizer dominates the market for ammonia. ▪ At present there are 3 new clean ammonia projects representing 1.5 million tons per year and 5 retrofit projects representing 366,000 tons per year. ▪ In the U.S., CF Industries and Monolith are both investing in green ammonia.
Maritime Fuel	▪ The first ammonia fueled/capable ships are expected to be operating by 2024. ▪ The International Maritime Organization has targeted 40% reduction in maritime ship emissions by 2030 with 2008 as the baseline year.
Hydrogen Carrier	▪ The NEOM project includes global distribution of green ammonia to be converted to H_2 for fueling heavy transport. ▪ JERA, a joint venture in Japan has offered a tender for 500,000 tons per year of green ammonia.
Combustion Fuel	▪ Japan is aggressively pursuing integrating carbon reduced ammonia into their economy, including supplementing coal in power production. This is not expected to be replicated elsewhere.
Other	▪ Fortescue has a green hydrogen and ammonia supply agreement (MOU) with Covestro, a leading manufacturer of polyurethanes. ▪ There are several projects to reduce the carbon intensity of explosives. These are generally small projects.

A clean ammonia pilot definition was developed based on known competitive advantages of the Consortium members

Pilot Definition

Use existing nuclear generation assets for clean ammonia production to meet demand in the Northeast, Mid-West and Mid-Atlantic market.

Starting assumptions:

1) Assumed nuclear generation is supplied behind the meter (capacity factor 92%)
2) Target region was the Northeast and Mid-Atlantic market

Known Competitive Advantages

- ✓ Access to low-cost electricity supply
- ✓ Existing electricity generation assets
- ✓ High-capacity-factor electricity generation
- ✓ Supportive regulatory trends within target jurisdiction

Uncertainties that Needed to be Explored

- ❑ Markets to go after…their size and attractiveness
- ❑ Access to effective distribution channels
- ❑ Direct competitors within the same region and right to win
- ❑ Production cost of ammonia at a given location
- ❑ Market and other barriers

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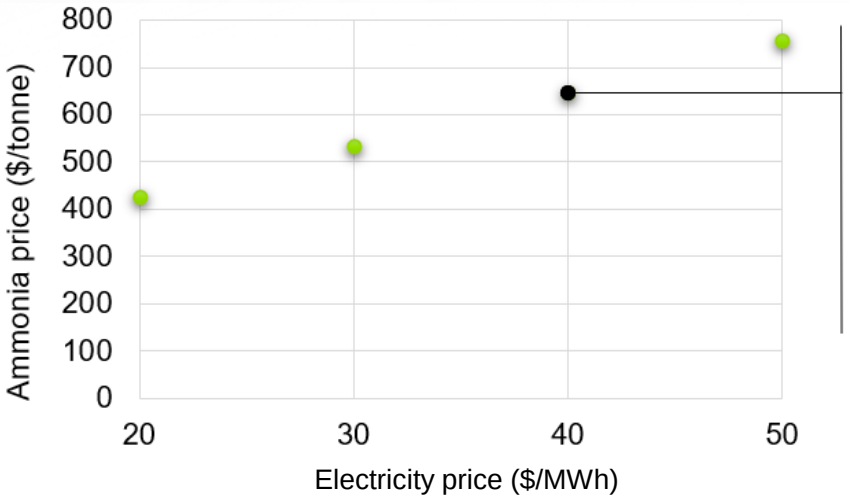
Behind the meter electricity supply coupled with existing power generation assets strengthen the pilot business case

Electricity price has a significant impact on the cost competitiveness ammonia produced.

Price of Ammonia at Different Electricity Prices
(600 tons per day production)



Project assumed an electricity source price of $40/MWh

Nuclear Power $40/MWh

- Utilize existing nuclear generating station
- Behind the meter to avoid Transmission &Distribution charges
- Wholesale price is set as a proxy for behind the meter electricity price ($22.68/MWh)
- Nuclear stations in selected state are under the Zero Emissions Credit program. Thus, behind the meter Zero Emissions Credit penalty is $17.48/MWh in opportunity cost.
- Capacity factor: 92%

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Targeted policy and regulatory mechanisms are key to supporting the competitiveness of clean ammonia pilot projects

Potential mechanisms to support market entry

Supply Side

- Remove Transmission & Distribution charges
- Production Tax Credit to incentivize H_2 production
- Need to be wary of existing policies and goals
  - For the pilot definition Guidehouse analysed, the Zero Emissions Credit program negatively impacts electricity sourcing price

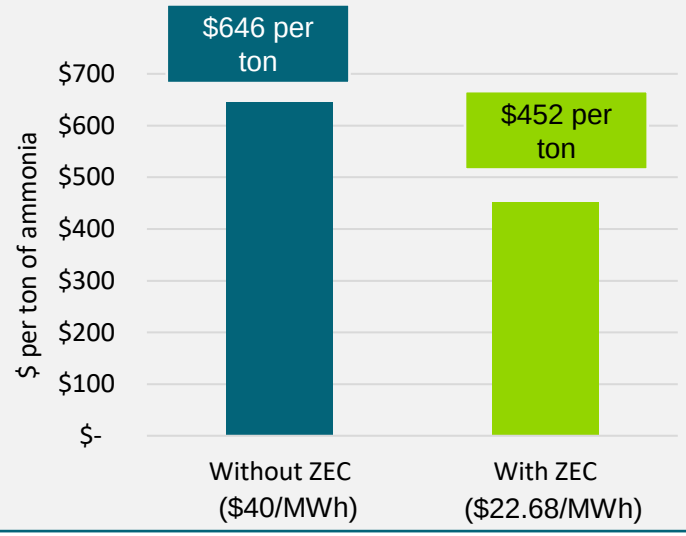
Demand Side

- Mandates on greening of agriculture sector
- International Maritime Organisation targets and mandates on greening of maritime sector
- Carbon contracts for difference to de-risk long-term investments

Infrastructure

- Grants to support early-stage commercial development activities
- "Green" loan programs to support construction activities

Price of ammonia impact if the ZEC did not exist or is paid for "behind-the-meter" electricity supply



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The clean ammonia market represents a good opportunity, but projects must have strong competitive advantages to succeed

Nuclear generation brings compelling advantages, particularly from a low cost production perspective

+ The ammonia market is a large and mature market that is ripe for decarbonization. This presents an opportunity for entry into H_2 production.
+ The combination of low marginal cost and high-capacity factor are clear advantages for nuclear production of H_2 vs other renewable sources.
+ The large electricity supply capacity of a nuclear facility can support at scale ammonia production “behind the meter”, exploiting both low-cost energy supply and economy of scale benefits.

Location, regulatory environment and ease of implementation are factors that also need to be competitively attractive

- It is debatable as to whether the Northeast and Mid-Atlantic market demand is enough to support large scale production alone. In addition, the ability to reach the more valuable markets is challenging.
- Electricity procurement price is critical. Therefore, it would be advantageous to locate production at a site that is not under a regulatory program like the Zero Emissions Credit (ZEC).
- The health and safety regulations associated with locating facilities around a nuclear plant are an implementation consideration that cannot be ignored. They are likely to extend timelines.

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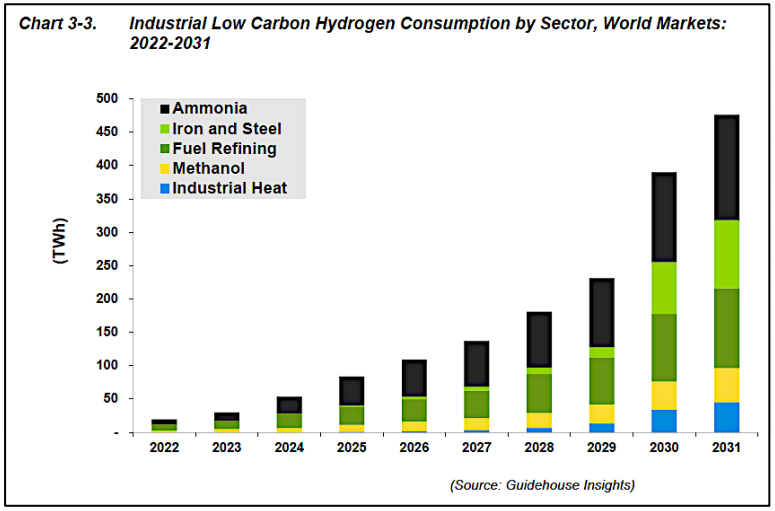
Integrated Blue and Green Hydrogen

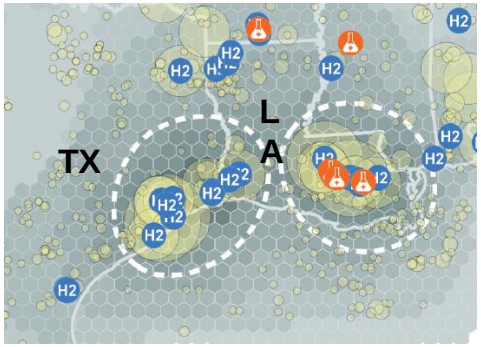
In the Gulf Coast

The Gulf Coast is already an epicenter of H_2 production and consumption in the US

… Yet a huge amount of decarbonization is needed

- There are more than 50 gray H_2 production facilities along the Gulf Coast. TX alone accounts for 34% of US H_2 consumption.
- There are already 1,600 miles of (privately operated) H_2 pipelines and 3 major underground storage facilities.
- The "gray" H_2 produced locally is primarily used by refineries and chemical companies.
- **However,** many large consumers of H_2 in the Gulf are not (yet) motivated to decarbonize – in the region – given their need to clean up plants in other regions that do mandate reduction in GHG emissions and lack of adequate incentives for green H_2.
  - As markets for clean chemicals and products develop elsewhere in the US/globally, expect some movement in this regard
  - Given the good economics of production in the region, clean H_2 and H_2-derived products produced in the Gulf should be competitive in global markets
  - Activity centered around producing & using clean H_2 is already intensifying





Hydrogen or ammonia production and industrial fuel use

Industrial facility
Sized by fuel use

H2 Existing hydrogen production

Existing ammonia production

(Source: Great Plains Institute)

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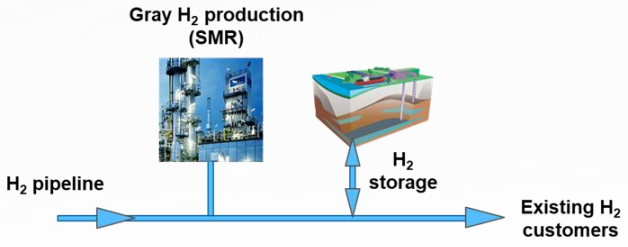
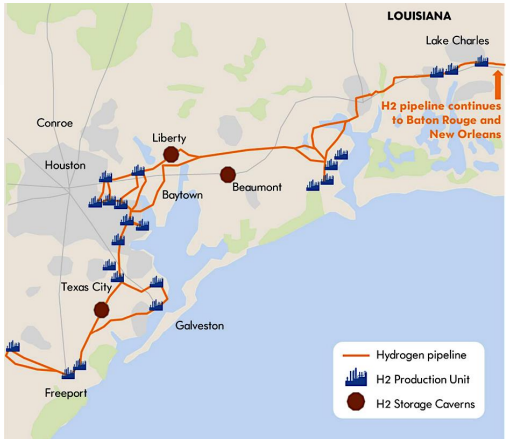
Ambitious Vision for Decarbonization Developed by Guidehouse Hydrogen Consortium

Decarbonization of Existing and New H_2 Uses along the US Gulf Coast

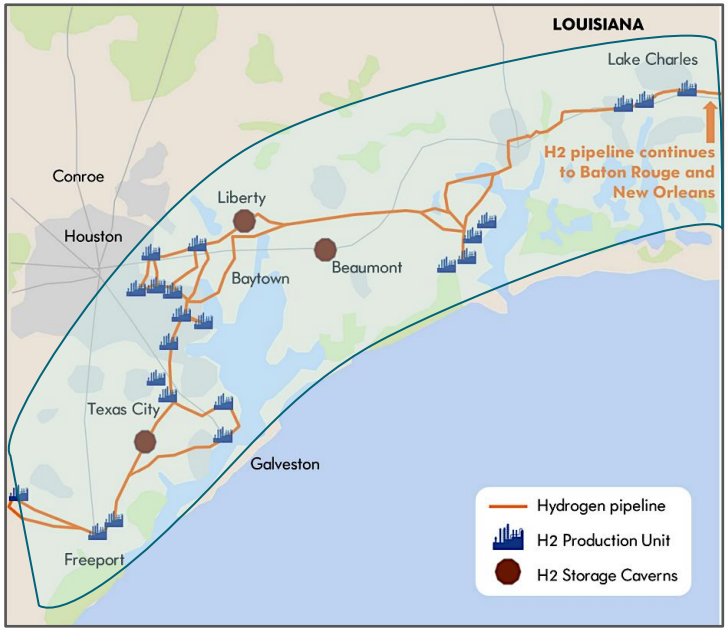
Present Day Infrastructure*





Hydrogen Consortium Future Vision

- ***Large-scale decarbonization*** **of H_2 production using carbon capture**
- ***Responsibly sourced*** **supply chain**
- ***Wind- and solar-*** **powered electrolytic H_2 production**
- ***New uses for H_2*** **in clean chemicals, heavy-duty transport vehicles, and electric power production**



* Also, some low CI hydrogen from byproduct sources and chemical sequestration of CO_2

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The Consortium studied the entire value chain

From resources to end-users, to ensure a viable, scalable and environmentally beneficial business

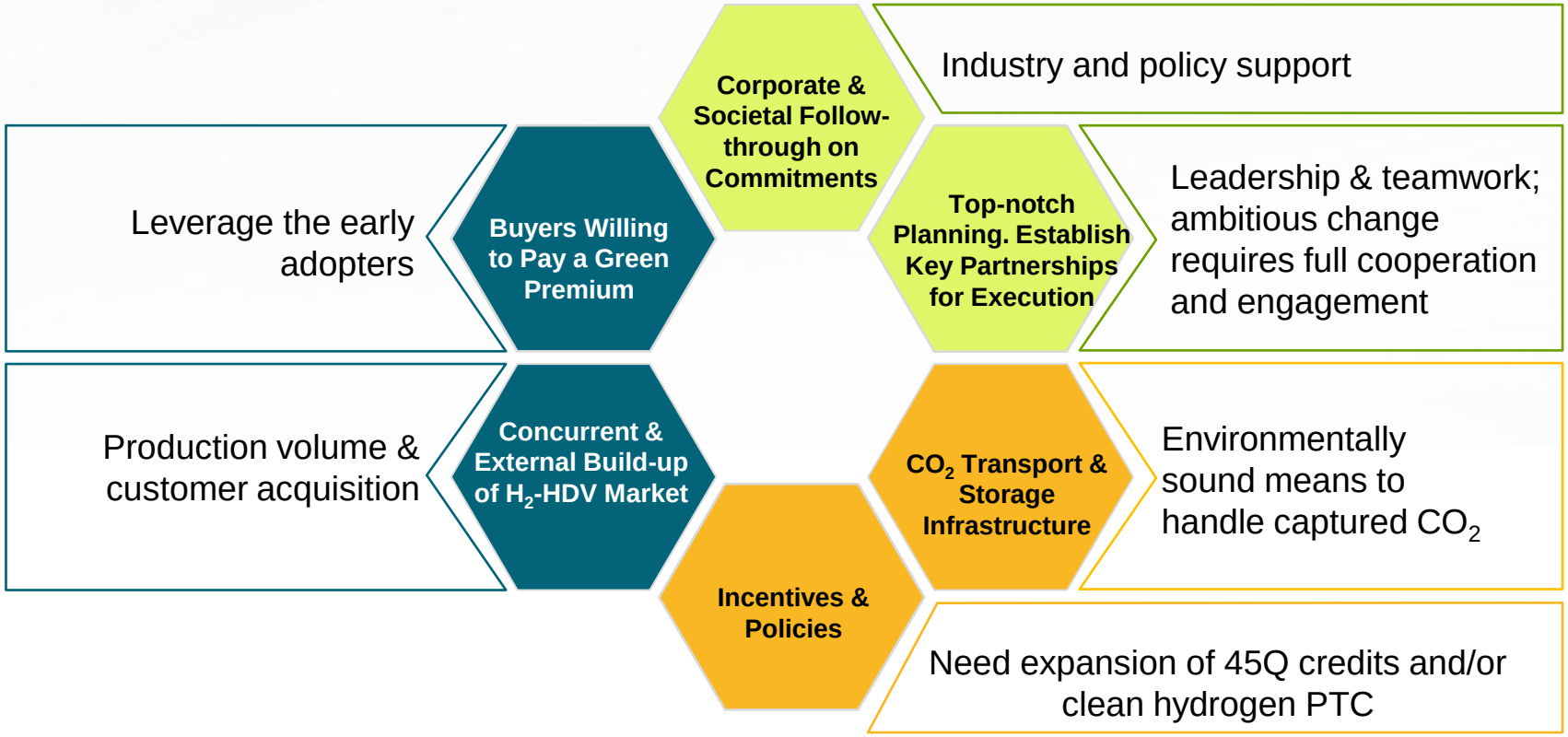
The Guidehouse analysis included financial modeling of major components and considered factors such as distribution and storage

Components included:

- Resources – natural gas, electricity
- H_2 production facilities
- Major blue chemical production from blue H_2
- Heavy-duty H_2 vehicle market
- Electric power generation

The Guidehouse analysis shows that the Gulf Coast project is a viable, integrated H_2 hub with a long-term vision that is aligned with the Infrastructure Investment and Jobs Act (IIJA)

Key Success Factors for the Gulf Coast Project



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