Houston As the Capital of a Low Carbon Energy World





C. T. BAUER COLLEGE of BUSINESS Gutierrez Energy Management Institute



Overview

- The University of Houston and the Center for Houston's Future are launching a project to create a vision for what Houston's Low Carbon Energy future might look like and what would be required to achieve it.
- We plan to examine four critical Low Carbon Energy technologies: Carbon Capture Utilization and Storage (CCUS), Hydrogen, Massive Electrification and the Circular Economy, since we believe that Texas, and the Houston region in particular, has unique strengths and capabilities in these areas.
- The study will look at the size of the potential opportunity, timing and the barriers that must be overcome to accomplish this goal.
- This presentation contains an overview of the Houston region's potential for CCUS and blue hydrogen.

Two Areas for Catalyzing Houston's Role in a Low Carbon Energy Future

- 1. CCUS: Houston can become an "early adopter" for deploying CCUS technologies.
 - The Houston Ship Channel has significant of large, centralized and concentrated sources of CO2 from power and plants and industrial facilities
 - The Gulf Coast region has many large locations (deleted hydrocarbon reservoirs, salt domes) for CO2 sequestration and/or storage
 - Opportunities exist to create new industries based on captured CO2, such as using CO2 for enhanced oil recovery or capturing CO2 from hydrogen production used in the petrochemical for new applications
- 2. Hydrogen: Houston has most aspects of the supply chain required to produce both significant amounts of blue and green hydrogen.
 - "Blue Hydrogen" production will be driven by the large base of existing steam reforming plants with carbon capture added
 - "Green Hydrogen" production can be created from new electrolysis plants fueled by low cost renewable energy
 - Houston can be a pioneer for using hydrogen in new ways such as in transportation, in energy storage or as a low carbon replacement fuel source for industrial processes. It can even be exported and shipped to other parts of the world

Industrial Facilities on Houston Ship Channel





Houston Industrial Sector



Note: discrepancies in estimated emissions due to different data sources used

NPC Study -- Phases of Implementation

Study lays out a three phases – Activation, Expansion and At-Scale:

- Prioritized based on economics and ease of implementation
- Specific recommendations
- Economic benefits GDP and jobs



Gulf Coast CCUS Potential

Million metric tons CO2 equivalent



Source: Great Plains Institute

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Houston has unique assets and capabilities, which position Houston as a potential leader in advancing the hydrogen economy

Hydrogen	value	chain
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Production	Storage Transport	Customers
 Among the world's largest source of hydrogen production (eg, refining and chemical production) Access to methane production and depleted reservoirs / CCUS sites 2nd largest state producer of renewable energy today (potential source via 	 Established network of hydrogen pipelines to service US Gulf Coast refining and related industrial area Storage that may be currently available or readily converted to hydrogen storage Largest foreign trade port and second largest tonnage port in US 	 2nd largest US manufacturing area Established base of hydrogen feedstock customers Multiple potential industrial users of hydrogen based heat Mature gas grid with pumorous residential &

- Deep experience with steam methane reformation hydrogen production technology
- Multiple global energy leaders with CCUS and hydrogen technical capabilities, including global hydrogen leader (Air) Liquide) with Houston presence

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Civic leadership, commitment to clean transportation

Source: KPMG

The Houston area has unique assets and capabilities, which could create advantages to becoming a leader in advancing the hydrogen economy

Existing hydrogen system in the TX-Gulf Coast area (Praxair)^{1,2}



Source: H2Tools Merchant & Captive Plant Capacities in North America; USDOT PHMSA - National Pipeline Mapping System; Industry subject matter professional interviews; Seeking Alpha

Notes: (1) Houston MSA defined Austin, Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery and Waller counties; (2) TX Gulf Coast includes a region from Corpus Christi, TX to Lake Charles, LA

TX Gulf Coast advantages

46 production plants



Over 900 miles of dedicated, interconnected H2 pipelines



~3.4 million metric tons of H2 produced annually



Depleted oil reservoirs for and world's largest storage caverns for H2



- Opportunity to significantly reduce CO2 emissions in Houston, TX, and US
- Multiple potential expanded uses of H2 (e.g, heavy transport, energy storage, process heat)
- Potential low carbon energy capital of future



Emerging H2 strategies generally follow a pattern of converting/scaling grey H2 to blue to achieve 2050 net zero, while pursuing the ambition of cheap, abundant green H2

Hydrogen penetration and mix (illustrative)



Drivers/limiters

- Electrolyzer economics and supply chain
- Offshore wind power economics and supply chain
- Hydrogen volumes and timing to achieve net zero by 2050 targets
- Country specific attributes (e.g.; industrialization, renewable resources)

Today

2050



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Preliminary Houston Hydrogen Roadmap

	2020-2025	2025-2030	2030-2040
Production	 Blue: Incremental use of existing SMR system (100-500 tonnes/day) Green: Build pilot electrolyzer projects 	 Blue: Scale CCUS to transform SMR from grey to blue hydrogen Green: Reduce electrolyzer costs 	 Blue: Complete full switch from grey t blue hydrogen as SMR costs decrease; build biofuels SMR technology Green: Scale electrolyzers to be cost competitive with SMR
Infrastructure	 Build hydrogen fueling stations at port Build liquification plants for moving liquid hydrogen 	 Create hydrogen salt dome storage Build out CCUS infrastructure Extend hydrogen pipeline network 	 Build export terminals for ammonia an liquid hydrogen
Applications	• Transportation : Houston Ship Channel, Houston Airport and Metro (trucks, drayage vehicles, tugs, and buses)	 Long Duration Energy Storage 20% blended hydrogen for gas distribution Low carbon refining 	 Transform steel and cement industries Convert natural gas plants to be hydrogen
Supply Chain	Build Electrolyzer supply capacityBuild fuel cell capacity	 Develop an export market for hydrogen technology 	 Export hydrogen to world markets

Could Houston Become A Global Hydrogen Hub?

Area	Discussion	Current capacity
Production Capacity	• Largest U.S. (and potentially global) hydrogen production capacity with potential for significant renewable hydrogen through electrolysis given large wind and solar electricity	
Energy Infrastructure	 Interconnected "purpose built" hydrogen pipeline network could be extended to deliver hydrogen for transportation and other applications Port of Houston could build capacity for global hydrogen exports 	
Demand Potential	 Initial opportunity to create demand by reducing local air pollution at the Port of Houston, Houston Airport System and Metro through hydrogen powered vehicles Many future opportunities as hydrogen (long term energy storage, high temperature applications, blended gas) as prices decrease or carbon is priced 	
Energy eco-system	 Houston's "can-do" attitude, engineering and technical knowledge, and access to capital are pluses for building an energy eco-system 	
Regulatory Framework/ incentive structure	• Texas lacks the appropriate regulatory framework and incentive structure (such as a low carbon fuel standard) to create a new market in hydrogen	



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