

Houston As the Capital of a Low Carbon Energy World

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.

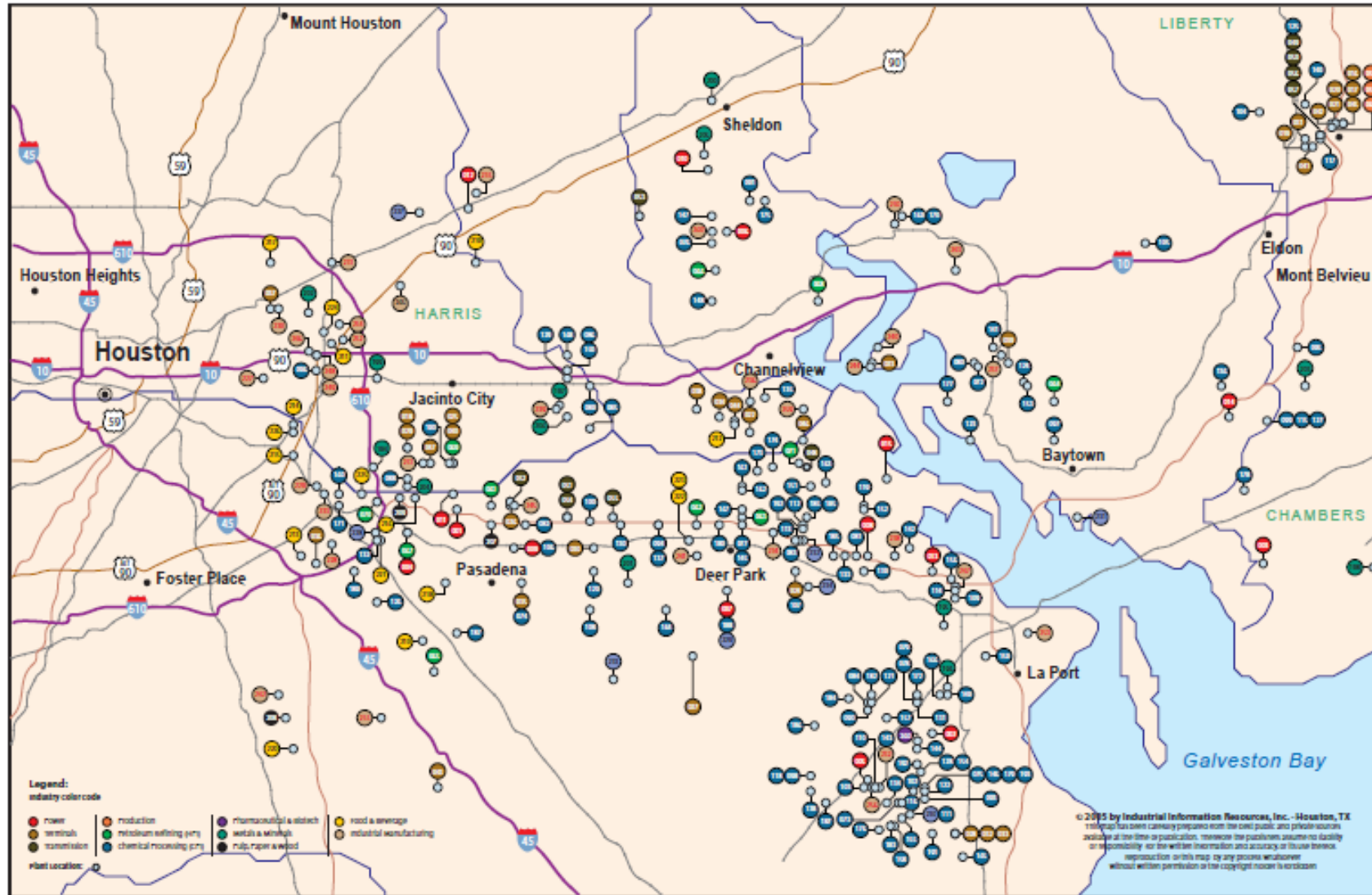


Two Areas for Catalyzing Houston's Role in a Low Carbon Energy Future

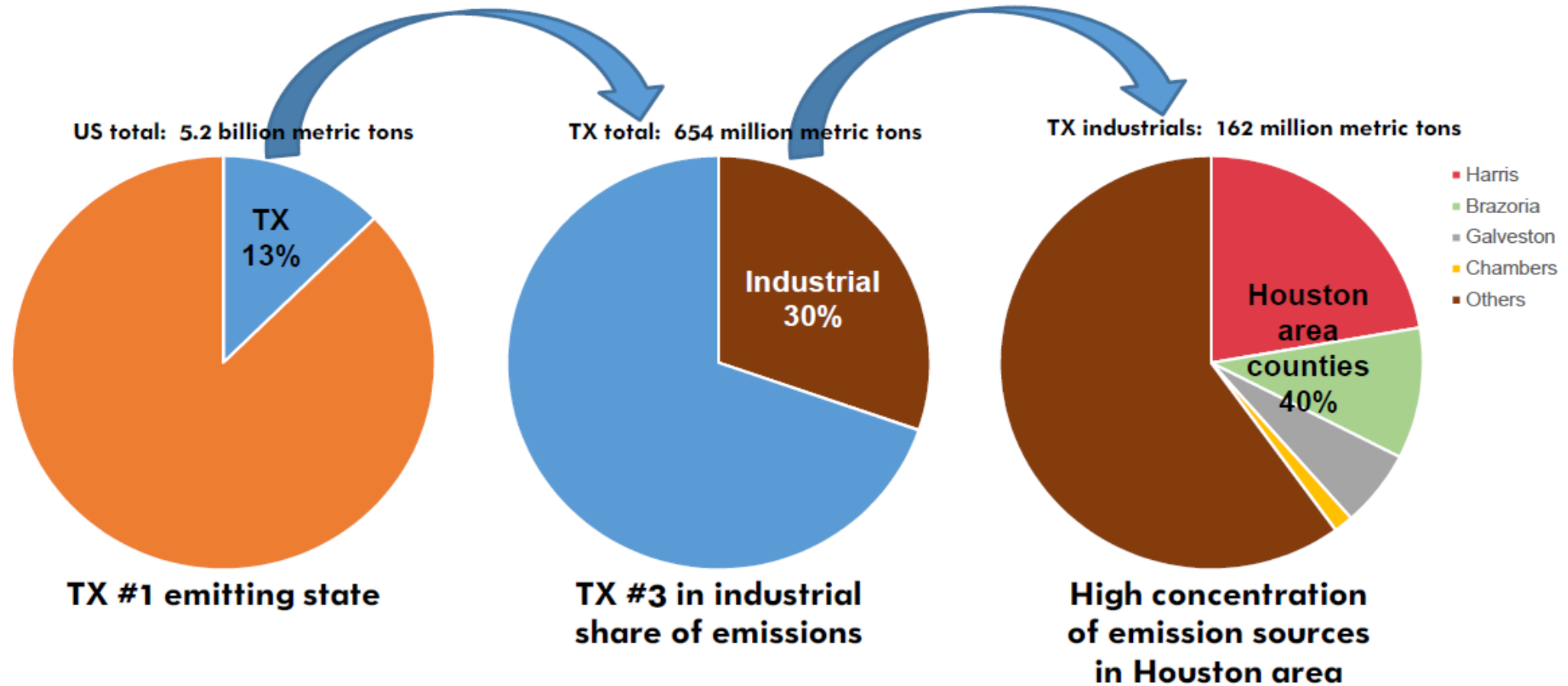
1. CCUS: Houston can become an "early adopter" for deploying CCUS technologies.
 - The Houston Ship Channel has significant of large, centralized and concentrated sources of CO₂ from power and plants and industrial facilities
 - The Gulf Coast region has many large locations (deleted hydrocarbon reservoirs, 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



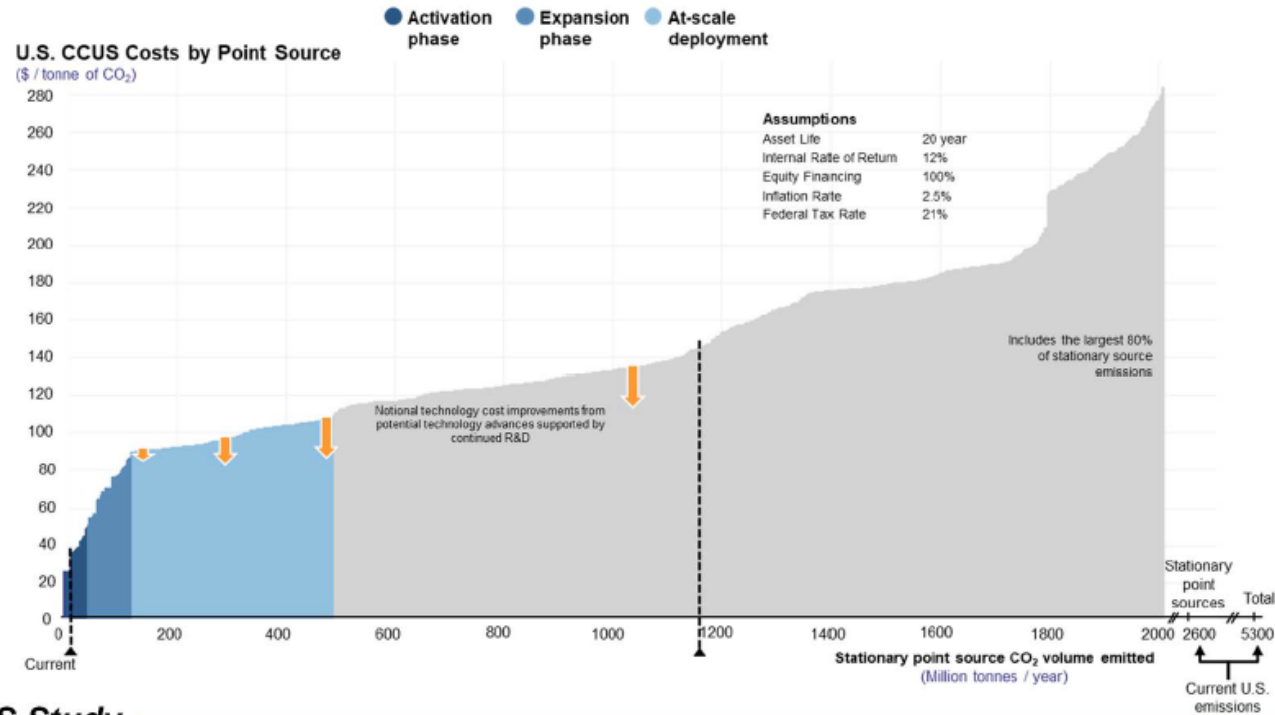
Note: discrepancies in estimated emissions due to different data sources used



NPC Study -- Phases of Implementation

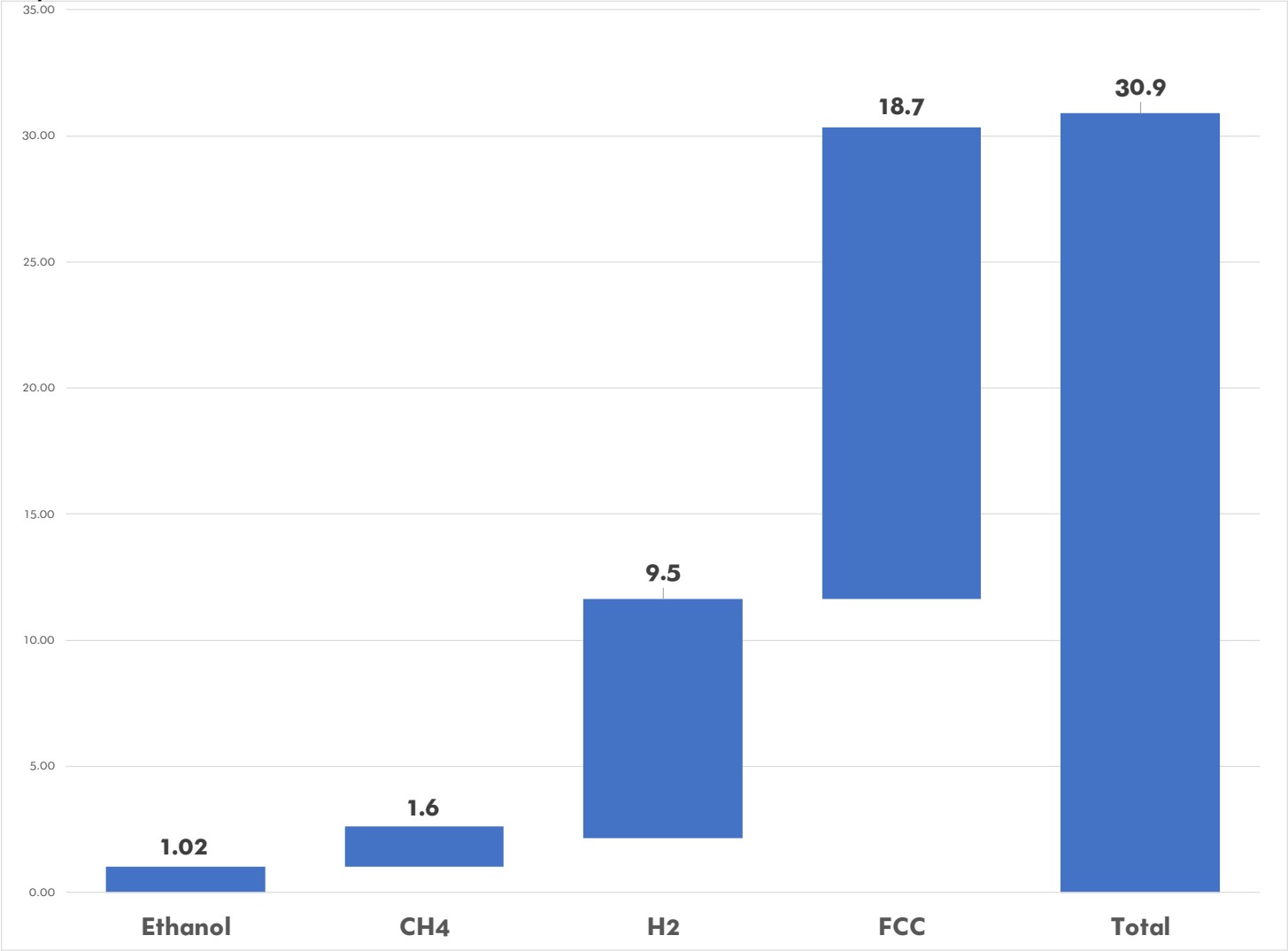
Study lays out a three phases – Activation, Expansion and At-Scale:

- 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



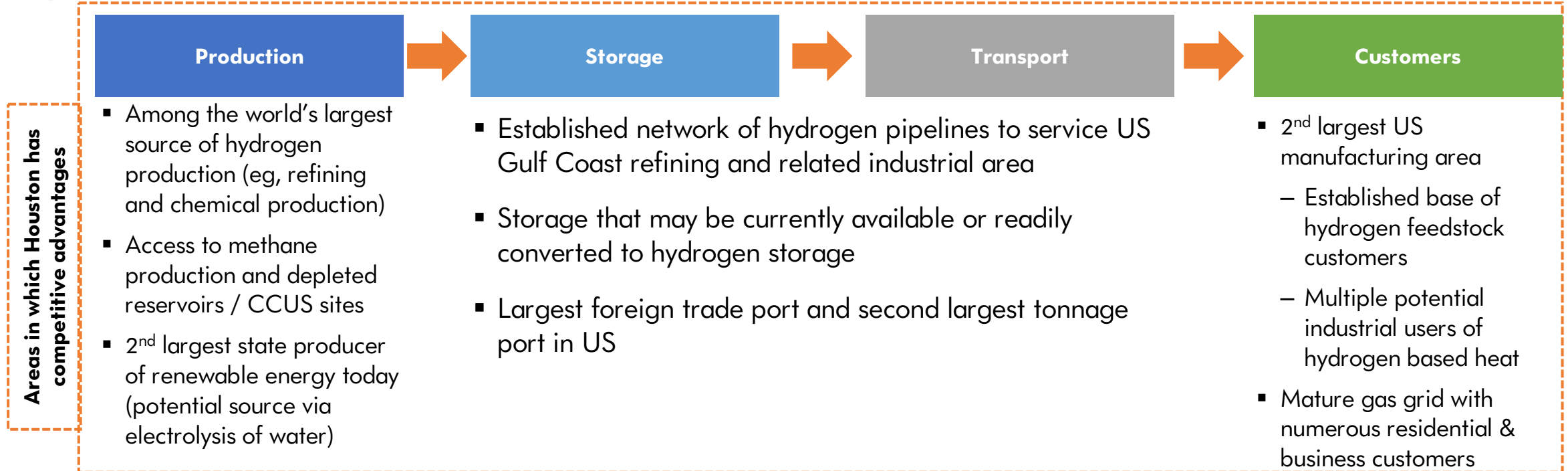
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Houston has unique assets and capabilities, which position Houston as a potential leader in advancing the hydrogen economy

Hydrogen value chain



Development support

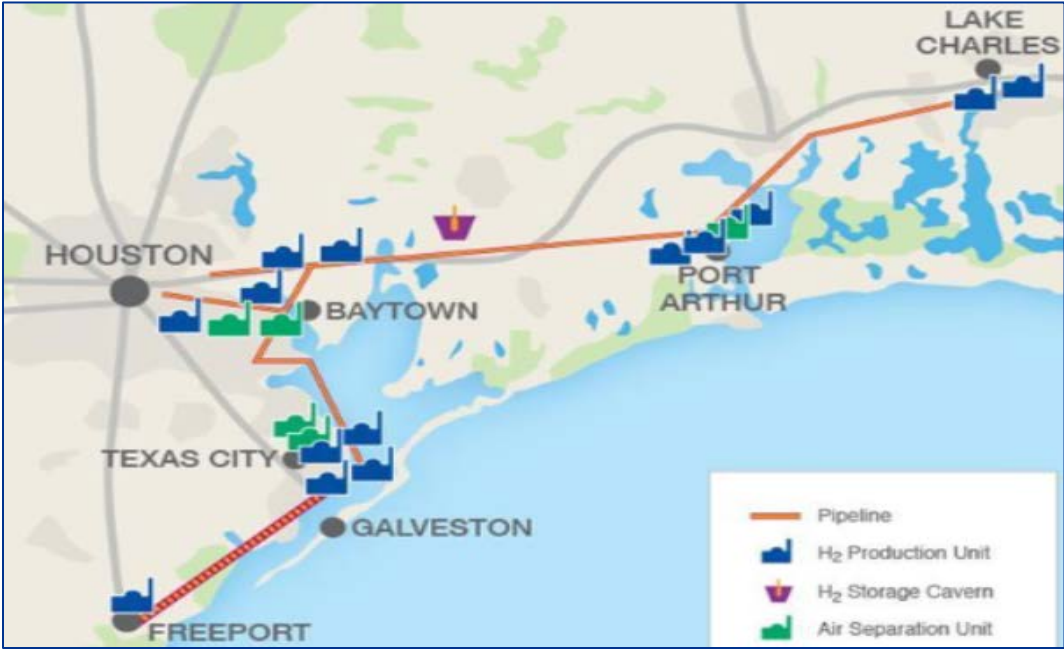
- Deep experience with steam methane reformation hydrogen production technology
- Multiple global energy leaders with CCUS and hydrogen technical capabilities, including global hydrogen leader (Air Liquide) with Houston presence
- Civic leadership, commitment to clean transportation

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

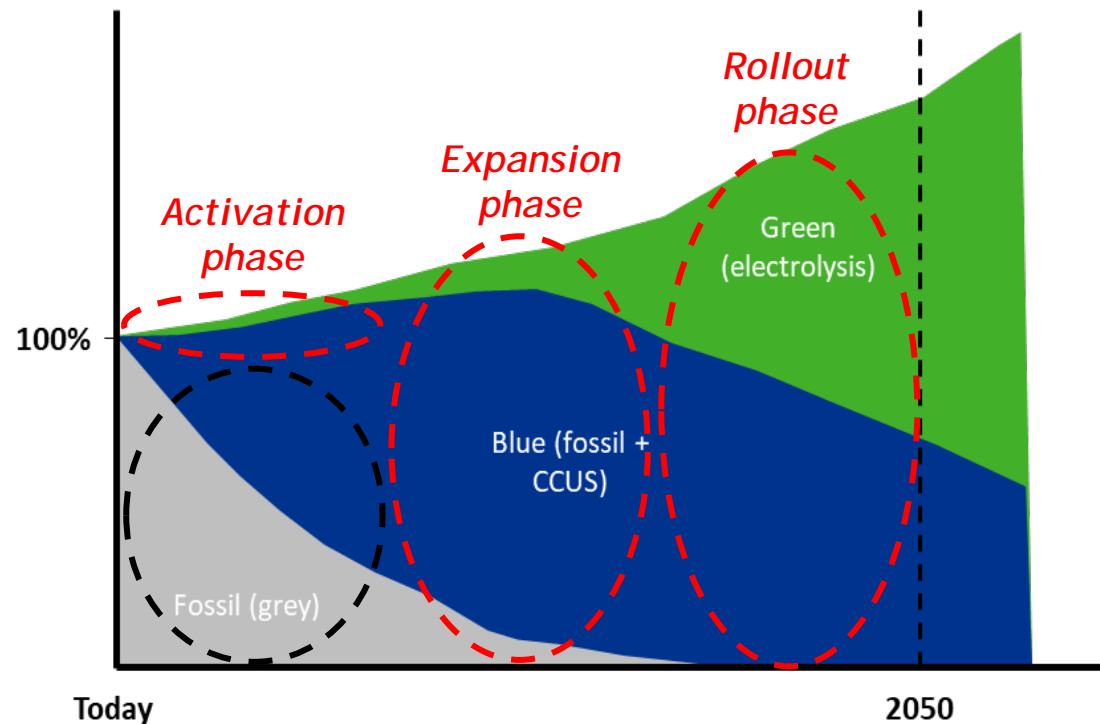


- Opportunity to significantly reduce CO2 emissions in Houston, TX, and US
- Multiple potential expanded uses of H2 (e.g., heavy transport, energy storage, process heat)
- Potential low carbon energy capital of future



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

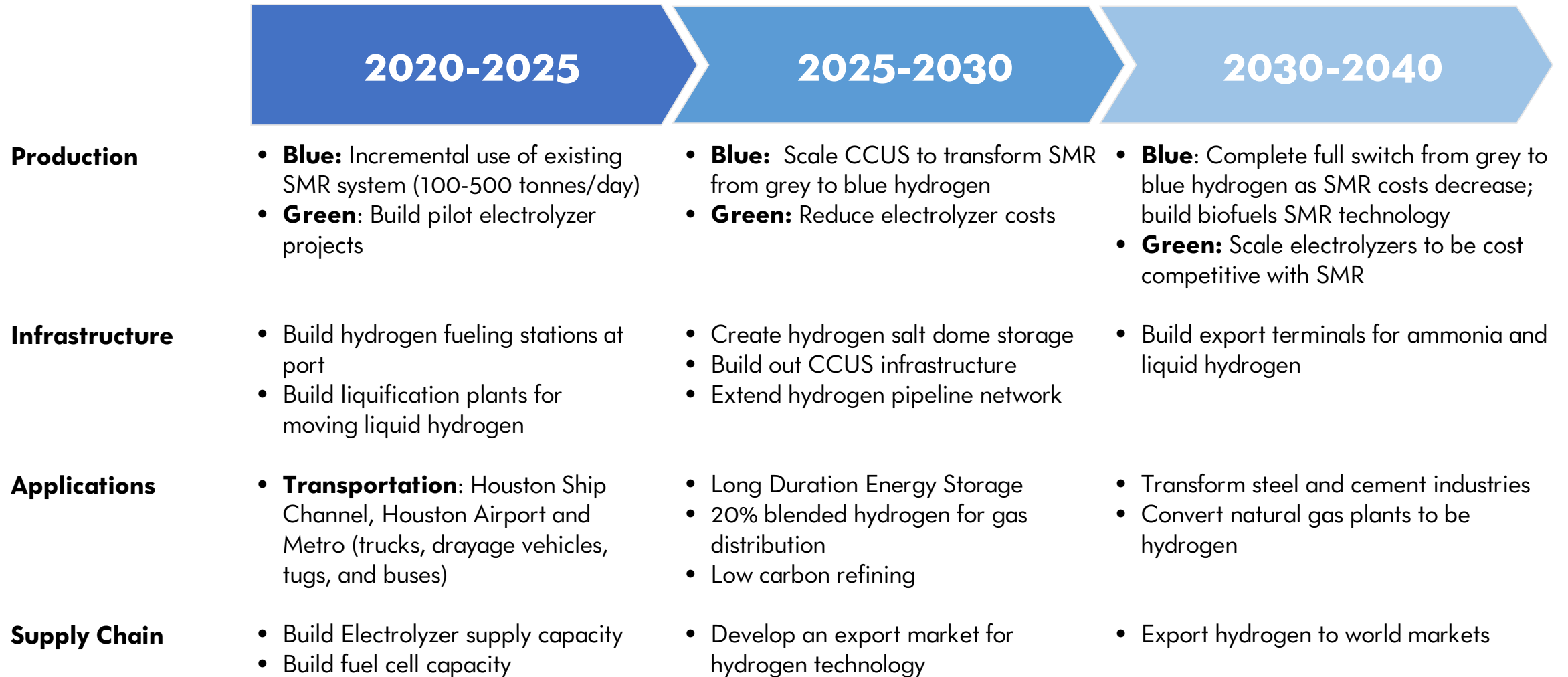
Hydrogen penetration and mix (illustrative)








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)

Preliminary Houston Hydrogen Roadmap



Could Houston Become A Global Hydrogen Hub?

Area	Discussion	Current capacity
Production Capacity	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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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