UNIVERSITY of **HOUSTON** UH ENERGY

CARBON CAPTURE UTILIZATION AND STORAGE

2020–2021 | Energy Symposium Series | **Critical Issues in Energy**

FRIDAY, OCTOBER 9TH 2020 | 10:00AM – 11:30AM CST VIRTUAL SYMPOSIUM



Dr. Ramanan Krishnamoorti Chief Energy Officer *UH Energy*

UNIVERSITY of **HOUSTON** UH ENERGY

HOUSTON'S LOW-CARBON ENERGY FUTURE: FOUR WAYS FORWARD

2020–2021 | Energy Symposium Series | Critical Issues in Energy

OCTOBER 9, 16, 23, 30 | 10:00AM – 11:30AM CST VIRTUAL SYMPOSIUM

October 16th Low Carbon Electricity Grid

October 23rd Hydrogen

October 30th Circular Plastics Economy

To learn more about the "Houston: Low-Carbon Energy Capital – Four Ways Forward" series visit: https://uh.edu/uh-energy/energy-symposium-series/lowcarbon-energy-capital/

THANK YOU to our research partners



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Brett Perlman and Laura Goldberg of CHF Greg Bean of GEMI / Bauer College of Business Jeannie Kever of UH

THANK YOU to our promotional partner





Charles McConnell Energy Center Officer (CCME) University of Houston

Student Presenters

- Paty Hernandez, BBA in Finance, Minor in Accounting,
- Brad Peurifoy, Professional MBA
- Makpal Sariyeva, BS in Petroleum Engineering

Houston as a CCUS hub

Why CCUS?

- CCUS essential to meet global climate targets
- Immediate emissions reductions from decarbonization
- Emission targets can't be achieved with clean energy alone
- Affordable, reliable, sustainable energy needed to reduce energy poverty

What Impacts?

- Long term sustainability of industries
- Set the stage for Houston as a decarbonization center of USA
- Globally recognized for energy skillset, knowledge, and technology
- Low carbon products advantage in global market

Why Houston?

- "Energy capital to sustainable energy capital"
- Infrastructure and scale suitable for "cluster" economics
- Vast, proximal geologic storage resources
- Energy companies strategies are shifting to "net-zero"







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Objectives and Findings

Objectives

- Develop a staged 3x10yr CCUS deployment analysis roadmap
- Utilize the NPC national analysis construct and regionalize for local impacts
- Analyze the emissions AND economic investment impact in the Houston Area
- Assess and position CCUS "optionality" to alternative geologic formations for both storage and EOR – as well as -for the extended energy producing network in the greater US Gulf Coast in all directions from Houston

FINDINGS

- Investment and risk hurdles will require "strategic investment"
- A mix of EOR and pure storage provides an investment portfolio approach for CCUS
- Current base of target geologies and infrastructure options are far greater than the stationary emissions in the 9 county Houston region long term expansion impact
- Federal, state and local government policies must support/accelerate this transition







Key Challenges to Address in Project



Transportation





- Technology maturity
- Capture Cost of CO₂ (3/4 of total CCUS cost)
- Electricity cost for compression
- Separation cost to purify CO₂

- Permits & Regulations
- Public acceptance
- Eminent Domain
- Cost of pipeline design and operating expense
- Infrastructure improvements

- Primacy
- Class 6 wells
- Low cost of oil
- Cost of surveillance (Liability for releases)
- Induced seismicity

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Taking Houston to Net-Zero

Phase I: Activation (2030)

Capture

Facility type	Captured emissions (MM tons/yr)	Total investment (bil US\$)
Hydrogen	5.7	\$1.1
Natural gas power plants	7	\$2.5
Transport		

Pipeline	Available capacity (MM tons/yr)	Total investment (bil US\$/yr)
Denbury	12.9	\$0.12

- Hydrogen emissions prioritized due ٠ to cheaper capture cost.
- Natural gas power plants second ٠ due to increasing pressure from investors.
- Denbury currently utilized at 1/3 ٠ capacity.

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Phase I: Activation (2030)

Storage

Location	Available storage (bil tons)	Total investment (bil US\$/yr)
Gulf Coast EOR	1.4	
Gulf Coast saline	1,500	\$0.12

- Significant EOR storage is available along Gulf Coast in the form of disparate oil fields.
- Denbury has identified multiple
 EOR fields along the pipeline's path.
- Saline storage is sufficient to handle Denbury capacity for 75 years.









Phase I: Economic Model

Discounted cash flow model

- Phase I only
- Combined hydrogen/natural gas
- Denbury pipeline
- Toggle ratio of saline storage to EOR
- Outputs NPV and IRR

Assumptions

- NPC capture facility reference costs
- Gaffney Cline estimates for regional gas and electricity costs
- Discount rate: 12%
- Inflated oil, gas, and electricity annually

Scenarios

- 100% EOR scenario and varied key inputs by +/-25%
- 100% saline scenario and varied key inputs by +/-25%
- Oil price/45Q rate required for positive NPV

Online perc % saline sto Oil Price (ini Gas price (it Electricity p Years 45Q Revenue	per capture unit installed reentage (infated annually) (infated annually) price (inflated annually) price (inflated annually) nue (salne storage) nue (salne storage) reenue reenue	5,414,923 to 400,000 to 100% % 0% % 9% % \$40,00 \$2,00 \$10,00 \$2,00 \$10,00 \$2,00 \$10,00 \$0,00 \$0,00 \$0,00 \$0,00	nsiyear nsiyear	Assum metric ton C 02 injected Project II (COR) 450 rate (scile) WT oil price Infation Expression 52 (b) 52 (b) 52 (c) 52 (c) 53 (c) 53 (c) 53 (c) 53 (c) 50 (2 2 2 3 3 5 5 5 5 5 0 4 4 7 7 5 4 3 0 6 5 2 16 5 3 2 16 5 3 2 16 5 3 2 16 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	\$bbl 96 96 96 96 96 96 96 96 \$221 \$11.04 5 \$221 \$11.04 \$12.04 \$13.00 \$435,945,548.85	\$2.26 \$11.31 6 \$0.00 \$435,945,548.85	13.54 1.063.289.854 50% 76.545,000 5 2.000.000.00 5 2.000.000.00 5 3.020,000.000 5 3.020,000.000 5 46.30 5 2.32 \$ 11.60 7 \$ 30.000 7 \$ 50.000 7 \$ 50.000 7 \$ 50.000 7 \$ 50.000 7 \$ 50.000 50.00000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.0000 50.00000 50.00000 50.00000 50.000000 50.0000000 50.0000000 50.00000000 50.0000000000	\$ E % C % C % C	Opex Electricity usage Electricity price 3as price 9as, non-energy, annus Aldstream tariff Storage cost \$46 74 \$2 44 \$12 18 9 9 \$000	0 18 100 2 55 2 8 10 10 10 10 10 540 95 \$2 50 \$2 50 \$12 49 10		\$52.48 \$2.62 \$13.12 12 \$0.00	Input Captured emissions Capacity per capture Ornline percentage % saline storage \$53.800 \$2.69 \$13.45	7,040,854 1,504,200 100% 0% \$55,514 \$2,76 \$13,79 14	ons/year % % \$56.52 \$2.83 \$14.13 15	\$2.90 \$14.48 16	2,468,925 527,505 \$5 \$1 \$1
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Electricity (H					1,110,000,011.00	\$1,535,836,557.84	\$1,563,333,833.06	\$1,591,518,540.17	\$1,620,407,864.95	\$1,650,019,422.85	\$1,680,371,269.70	\$1,711,481,912.72	\$1,743,370,321.82	\$1,776,055,941.14	\$1,809,558,700.95	\$1,843,899,029.75	\$1,879,097,866.78	\$1,915,176,6
Tie-in line car Electricity (H		\$212,657,970.77		\$318,986,956.16	\$0.00	\$0.00	\$0.00		\$0.00	\$0.00		\$0.00						
Electricity (H		\$493,785,114.72 \$		\$740,677,672.08	\$0.00				\$0.00	\$0.00		\$0.00		\$0.00				
	capex	\$100,666,666.67	\$100,666,666.67	\$100,666,666.67	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	
	(Hydrogen)	\$0.00	\$0.00	\$0.00	\$10,496,323.77	\$10,758,731.88	\$11,027,700,16	\$11,303,392.66	\$11,585,977,48	\$11,875,626.91	\$12,172,517,59	\$12,476,830,53	\$12,788,751,29	\$13,108,470.07	\$13,436,181,82	\$13,772,086.37	\$14,116,388,53	\$14,469.3
		\$0.00	\$0.00		\$29,739,584.00	\$30,483,073.60			\$32,826,936.19	\$33,647,609.59	\$34,488,799.83	\$35,351,019.83	\$36,234,795.32	\$37,140,665.20	\$38,069,181.83	\$39,020,911.38	\$39,996,434.16	\$40,996,
Opex, non-er	-energy (Hydrogen)	\$0.00	\$0.00	\$0.00	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,797.08	\$21,265,3
Electricity (National Structure)		\$0.00	\$0.00		\$11,265,045.98	\$11,265,045.98	\$11,265,045.98	\$11,265,045.98	\$11,265,045.98	\$11,265,045.98	\$11,265,045.98	\$11,265,045.98	\$11,265,045.98	\$11,265,045.98			\$11,265,045.98	\$11,265,0
Gas (Natural		\$0.00	\$0.00	\$0.00	\$39,427,660.94				\$39,427,660.94	\$39,427,660.94		\$39,427,660.94	\$39,427,660.94	\$39,427,660.94			\$39,427,660.94	\$39,427,
	-energy (Natural gas)	\$0.00	\$0.00	\$0.00	\$49,378,511.47				\$49,378,511.47	\$49,378,511.47	\$49,378,511.47	\$49,378,511.47	\$49,378,511.47	\$49,378,511.47			\$49,378,511.47	\$49,378,5
Transport tar		\$0.00	\$0.00		\$124,555,871.10		\$124,555,871.10		\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10				\$124,555,8
Storage cost	st	\$0.00	\$0.00	\$0.00	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,871.10	\$124,555,8
EBITDA (Rev	Rev-capex-opex)	-\$807,109,752.16	1,866,774,380.40	-\$1,160,331,294.91	\$1,098,325,282.41	\$1,124,145,994.69	\$1,150,612,224.78	\$1,177,740,110.62	\$1,205,546,193.61	\$1,234,047,428.67	\$1,263,261,194.61	\$1,293,205,304.69	\$1,323,898,017.53	\$1,355,358,048.19	\$1,387,604,579.62	\$1,420,657,274.33	\$1,454,536,286.40	\$1,489,262
Depreciation	on	\$547,745,061.07	\$547,745,061.07	\$547,745,061.07	\$547,745,061.07	\$547,745,061.07	\$547,745,061.07	\$547,745,061.07										
		\$1,354,854,813.23		-\$1,708,076,355.98	\$550,580,221.35		\$602,867,163.71		\$1,205,546,193.61		\$1,263,261,194.61	\$1,293,205,304.69					\$1,454,536,286.40	
		\$1,070,335,302.45 -\$		-\$1,349,380,321.22	\$434,958,374.86		\$476,265,059.33		\$952,381,492.95	\$974,897,468.65		\$1,021,632,190.71	\$1,045,879,433.85				\$1,149,083,666.26	
FCF		\$1,329,699,993.54 -\$		-\$1,961,966,555.06		\$1,003,101,798.63		\$1,045,441,150.22	\$952,381,492.95	\$974,897,468.65		\$1,021,632,190.71	\$1,045,879,433.85				\$1,149,083,666.26	
PV of FCF		\$1,187,232,137.09 -\$	2,572,145,789.30	-\$1,396,489,040.76	\$624,525,799.24	\$569,186,899.56	\$518,795,395.40	\$472,904,483.98	\$384,650,911.64	\$351,557,800.52	\$321,321,673.43	\$293,694,842.01	\$268,451,200.89	\$245,384,335.59	\$224,305,797.36	\$205,043,530.32	\$187,440,437.24	\$171,353,
Project NPV	V	\$113,543,909.91																
IRR		12%																

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Phase I: Economic Model Results

Combined hydrogen and natural gas power plant model - 100% EOR

Sens	sitivity 1				
Base Case Assumptions (100% EOR)					
Online %	100				
bbls produced per metric ton of CO2	2	barrels			
45Q rate (EOR)	\$35	\$/metric ton			
45Q rate (saline)	\$50	\$/metric ton			
WTI oil price	\$40	\$/bbl			
Avg Hydrogen capex	\$78,545,000.00	\$/unit			
Avg Nat Gas Power Plant capex	\$527,505,000.00	\$/unit			
Tie-in pipeline cost per mile	\$2,000,000.00	\$/mile			
Length of tie-in line	151	miles			
Electricity usage (Hydrogen)	0.18	MWh/ton			
Electricity usage (Nat gas)	0.16	MWh/ton			
Electricity price	\$10	\$/MWhr			
Gas usage (Hydrogen)	\$2.55	MMBtu/ton			
Gas usage (Nat Gas)	\$2.80	MMBtu/ton			
Gas price	\$2	\$/MMBtu			
Opex, non-energy, annual	0.02	% of capex			
Midstream tariff	\$10.00	\$/ton			
Storage cost	\$10.00	\$/ton			
NPV	\$ 113,543,909.91				
IRR	12%				

- Project can be NPV positive with 12% IRR today.....however
- US40/bbl price required for 20 years for project with high risk potential
- Most influential parameters include: oil price, recovery factor, nat gas capex. and 450 rate







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Key Take-aways

- Phase I (present to 2030):
 - Focus on low cost strategic CO₂ Houston emissions: 5.7million tons/yr from Hydrogen SMR
 7 million tons/yr from Natural Gas Power
 - **Transport on existing/available Denbury pipeline:** 13 million ton/yr available capacity
 - Gulf coast accessible geologic storage: 1.4 Billion tons for EOR and 1.5 Trillion tons of saline
 - EOR most economically attractive with current tax credits BUT with Highest Risk
 - Parameters needed for overall positive system NPV: (with 12% all equity hurdle)
 - 100% EOR storage requires \$40/bbl oil price PLUS 45Q credit of \$35/ton
 - 100% saline storage only requires 45Q Tax credit significantly above current \$50/ton
- Phase II (2040):
 - Expand capture to include: 6.4 million tons/yr from Natural Gas Power Plant
 13.5 million tons/yr from Industrial Processes Refining and Pet Chem
 - Build pipelines to the East/Central Texas: 20-30 million tons/yr available capacity at \$500 million cost (250 miles X US\$2 million/mile). On and offshore geologic target zones
 - East/Central Texas available storage: 3.6 billion tons for EOR and 500 billion tons of saline
- Phase III (2050):
 - Expand capture to include: 11.4 million tons/yr from Industrial Furnaces
 7.8 million tons/yr from Refinery Catalytic Cracker
 - Build pipeline to the Permian: 20 million tons/yr available capacity at US\$1 billion cost (500 miles X US\$2 million/mile)
 - **Permian available geologic storage:** 4.8 billion tons of EOR and 1 trillion tons of saline







Acknowledgements



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<u>Special thanks</u>: Jane Stricker, Mike Godec, Steve Melzer, Scott Nyquist, and Nigel Jenvey!

Thank you!



Scott Nyquist Moderator Senior Advisor McKinsey & Company

Submit your Q&A questions now for Scott Nyquist at:

uh.edu/energy/ask



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