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


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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

CARBON CAPTURE UTILIZATION AND STORAGE

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/low-carbon-energy-capital/

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Brett Perlman and Laura Goldberg of CHF

Greg Bean of GEMI / Bauer College of Business

Jeannie Kever of UH

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TEXAS INDUSTRIAL ENERGY EFFICIENCY PROGRAM

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"

Objectives and Findings

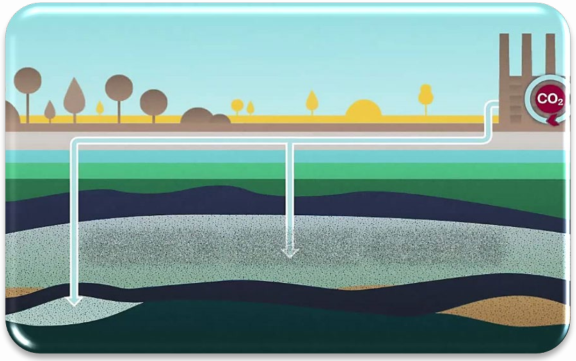
Objectives

- 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

Carbon Capture	Transportation	Storage
		
- Technology maturity - Capture Cost of CO_2 (3/4 of total CCUS cost) - Electricity cost for compression - Separation cost to purify CO_2	- 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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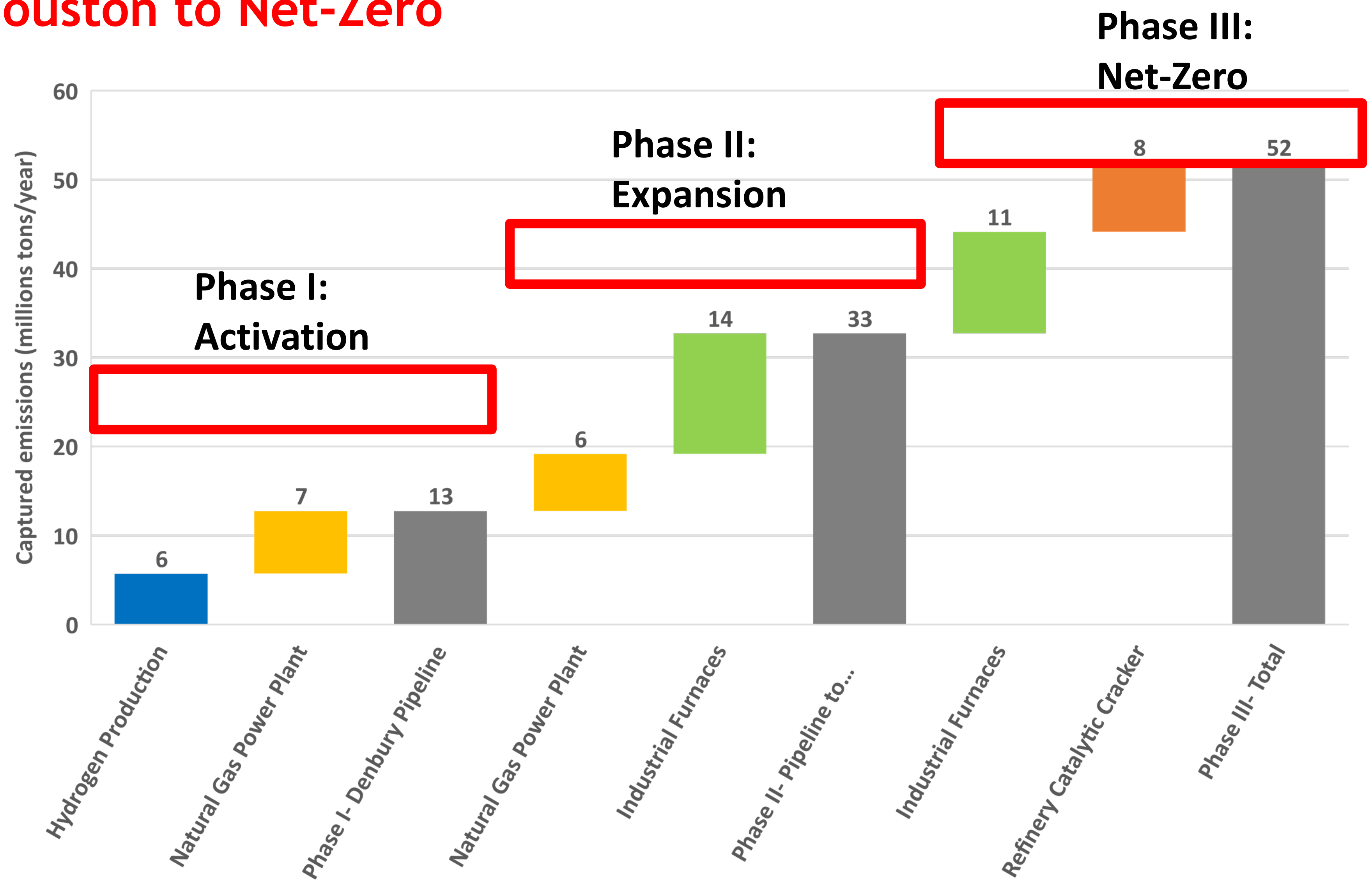
Taking Houston to Net-Zero



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Phase I: Activation (2030)

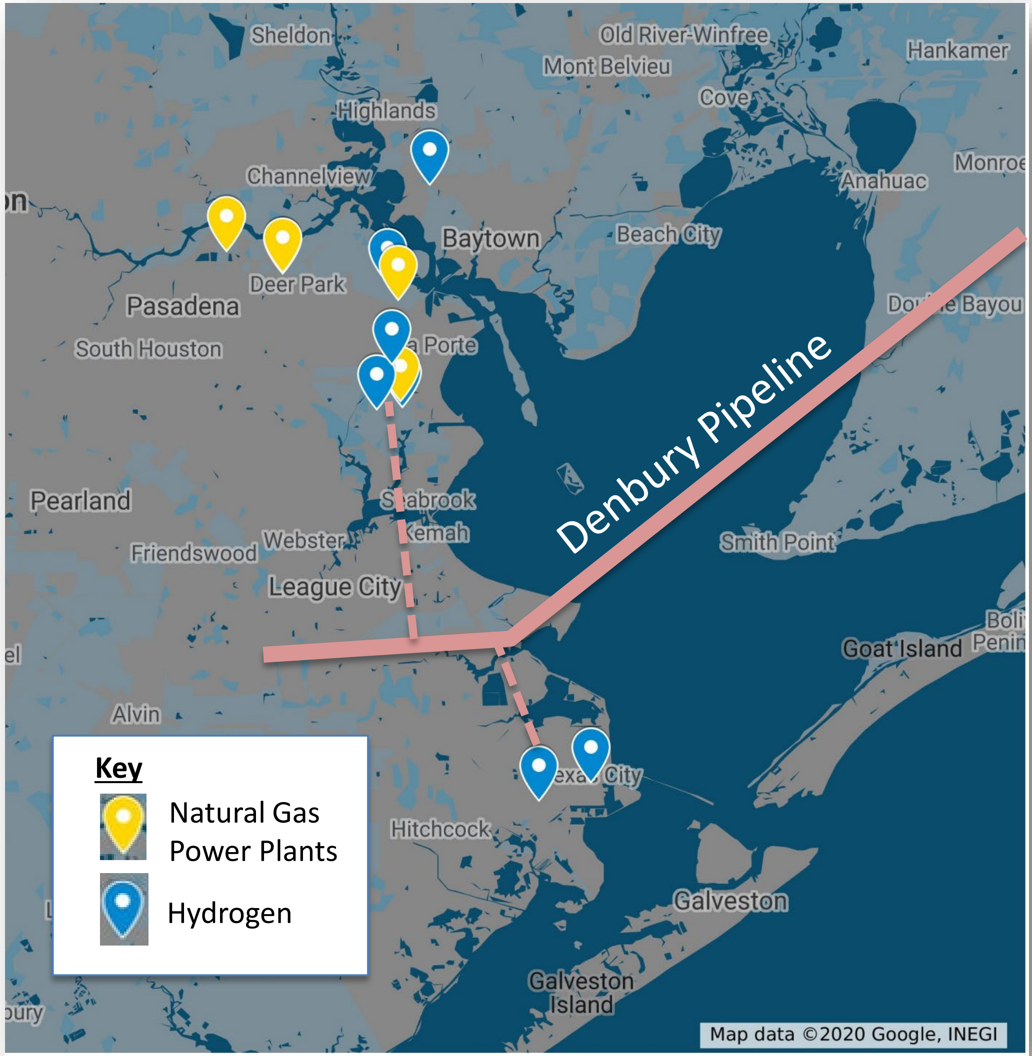
Capture

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

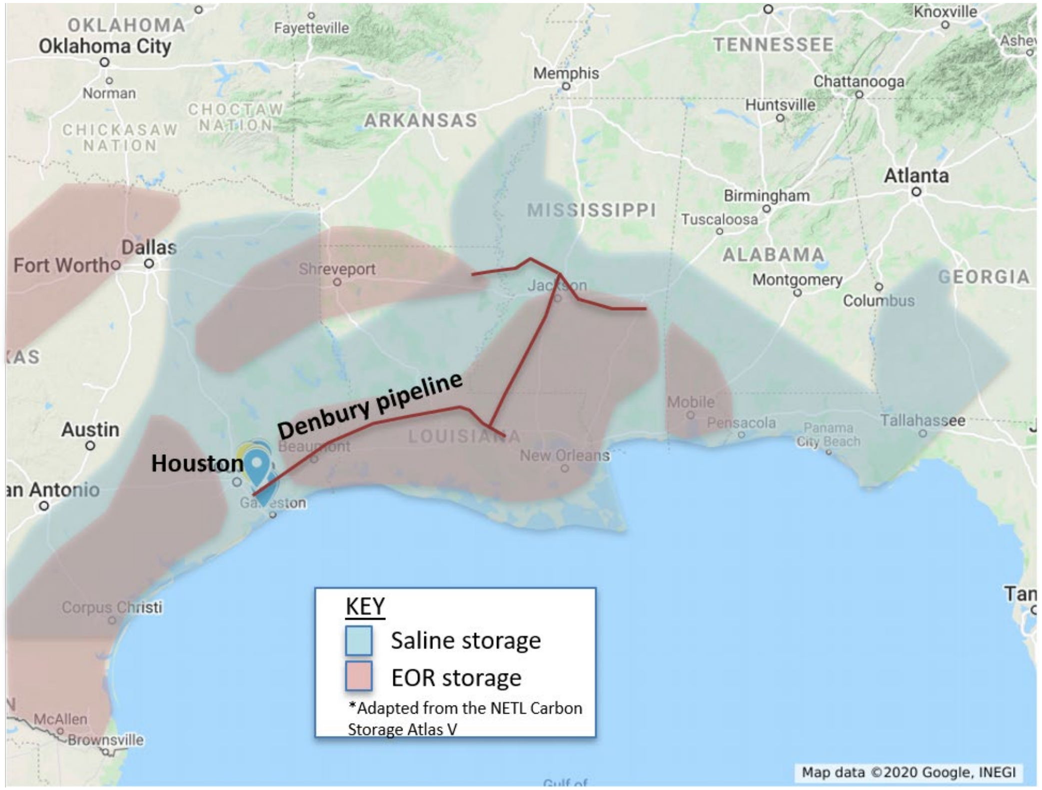


Phase I: Activation (2030)

Storage

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

- **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

Hydrogen Capture

Inputs		units
Captured emissions	5,414,933	tons/year
Capacity per capture unit installed	400,000	tons/year
Online percentage	100%	%
% saline storage	0%	%

Assumptions		units
bbls produced per metric ton of CO2 injected	2	barrels
Project life	20	years
45Q rate (EOR)	35	$/metric ton
45Q rate (saline)	50	$/metric ton
WTI oil price	40	$/bbl
Inflation	3%	%
Tax rate	21%	%
Discount rate	12%	%
Depreciation	7	years

Capex		units
Multiplier	13.54	X
Capture capex (total)	1,063,289,854	$
1st year capex	20%	%
2nd year capex	50%	%
3rd year capex	30%	%
Avg Hydrogen capex	78,545,000	
Tie-in pipeline cost per m	$ 2,000,000.00	$/mile
Length of tie-in line	151	miles
Total cost of tie-in line	$ 302,000,000.00	$

Opex		units
Electricity usage	0.18	MWh/ton
Electricity price	10	$/MWhr
Gas usage	2.55	MMBtu/ton
Gas price	2	$/MMBtu
Opex, non-energy, annua	2%	% of capex
Midstream tariff	10	$/ton
Storage cost	10	$/ton

Natura

Inputs		units
Captured emissions	7,040,654	tons/year
Capacity per capture	1,504,290	tons/year
Online percentage	100%	%
% saline storage	0%	%

Capex	
Multiplier	4.68
Capture capex (tota	2,468,925,574
1st year capex	20%
2nd year capex	50%
3rd year capex	30%
Avg Nat Gas Power	527,505,000

		1	2	3	4	5	6	7	8
	Oil Price (infated annually)	$40.00	$41.00	$42.03	$43.08	$44.15	$45.26	$46.39	$47.55
	Gas price (inflated annually)	$2.00	$2.05	$2.10	$2.15	$2.21	$2.26	$2.32	$2.38
	Electricity price (inflated annually)	$10.00	$10.25	$10.51	$10.77	$11.04	$11.31	$11.60	$11.89
	Years	1	2	3	4	5	6	7	8
Revenue	45Q Revenue (saline storage)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	45Q Revenue (EOR storage)	$0.00	$0.00	$0.00	$435,945,548.85	$435,945,548.85	$435,945,548.85	$435,945,548.85	$435,945,548.85
	Petroleum revenue	$0.00	$0.00	$0.00	$1,073,064,399.01	$1,099,891,008.99	$1,127,388,284.21	$1,155,572,991.32	$1,184,462,316.10
	Total Revenue	$0.00	$0.00	$0.00	$1,509,009,947.86	$1,535,836,557.84	$1,563,333,833.06	$1,591,518,540.17	$1,620,407,864.95
Capex	Hydrogen capture capex	$212,657,970.77	$531,644,926.93	$318,986,956.16	$0.00	$0.00	$0.00	$0.00	$0.00
	Nat gas power plant capex	$493,785,114.72	$1,234,462,786.80	$740,677,672.08	$0.00	$0.00	$0.00	$0.00	$0.00
	Tie-in line capex	$100,666,666.67	$100,666,666.67	$100,666,666.67	$0.00	$0.00	$0.00	$0.00	$0.00
Opex	Electricity (Hydrogen)	$0.00	$0.00	$0.00	$10,496,323.77	$10,758,731.86	$11,027,700.16	$11,303,392.66	$11,585,977.48
	Gas (Hydrogen)	$0.00	$0.00	$0.00	$29,739,584.00	$30,483,073.60	$31,245,150.44	$32,026,279.21	$32,826,936.19
	Opex, non-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
	Electricity (Natural gas)	$0.00	$0.00	$0.00	$11,265,045.98	$11,265,045.98	$11,265,045.98	$11,265,045.98	$11,265,045.98
	Gas (Natural gas)	$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
	Opex, non-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
	Transport tariff	$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
	Storage cost	$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
	EBITDA (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
	Depreciation	$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	
	EBIT (Rev-OPEX-Depreciation)	-$1,354,854,813.23	-$2,414,519,441.47	-$1,708,076,355.98	$550,580,221.35	$576,400,933.63	$602,867,163.71	$629,995,049.55	$1,205,546,193.61
	NOPLAT (EBIT*(1-Tax Rate))	-$1,070,335,302.45	-$1,907,470,358.76	-$1,349,380,321.22	$434,958,374.86	$455,356,737.57	$476,265,059.33	$497,696,089.15	$952,381,492.95
	FCF	-$1,329,699,993.54	-$3,226,499,678.10	-$1,961,966,555.06	$982,703,435.93	$1,003,101,798.63	$1,024,010,120.40	$1,045,441,150.22	$952,381,492.95
	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
	Project NPV	$113,543,909.91							
	IRR	12%							

		9	10	11	12	13	14	15	16	17
	Oil Price (infated annually)	$48.74	$49.95	$51.20	$52.48	$53.80	$55.14	$56.52	$57.93	$59.38
	Gas price (inflated annually)	$2.44	$2.50	$2.56	$2.62	$2.69	$2.76	$2.83	$2.90	$2.97
	Electricity price (inflated annually)	$12.18	$12.49	$12.80	$13.12	$13.45	$13.79	$14.13	$14.48	$14.85
	Years	9	10	11	12	13	14	15	16	17
Revenue	45Q Revenue (saline storage)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	45Q Revenue (EOR storage)	$435,945,548.85	$435,945,548.85	$435,945,548.85	$435,945,548.85	$435,945,548.85	$435,945,548.85	$435,945,548.85	$435,945,548.85	$435,945,548.85
	Petroleum revenue	$1,214,073,874.00	$1,244,425,720.85	$1,275,536,363.87	$1,307,424,772.97	$1,340,110,392.29	$1,373,613,152.10	$1,407,953,480.90	$1,443,152,317.93	$1,479,231,125.87
	Total Revenue	$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	$1,915,176,674.72
Capex	Hydrogen capture capex	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	Nat gas power plant capex	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	Tie-in line capex	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Opex	Electricity (Hydrogen)	$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	$14,469,298.24
	Gas (Hydrogen)	$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	$40,996,345.02
	Opex, non-energy (Hydrogen)	$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
	Electricity (Natural gas)	$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
	Gas (Natural gas)	$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	$39,427,660.94	$39,427,660.94
	Opex, non-energy (Natural gas)	$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	$49,378,511.47
	Transport tariff	$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
	Storage cost	$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
	EBITDA (Rev-capex-opex)	$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	$1,489,262,273.79
	Depreciation									
	EBIT (Rev-OPEX-Depreciation)	$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	$1,489,262,273.79
	NOPLAT (EBIT*(1-Tax Rate))	$974,897,468.65	$997,976,343.74	$1,021,632,190.71	$1,045,879,433.85	$1,070,732,858.07	$1,096,207,617.90	$1,122,319,246.72	$1,149,083,666.26	$1,176,517,196.29
	FCF	$974,897,468.65	$997,976,343.74	$1,021,632,190.71	$1,045,879,433.85	$1,070,732,858.07	$1,096,207,617.90	$1,122,319,246.72	$1,149,083,666.26	$1,176,517,196.29
	PV of FCF	$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	$171,353,071.65

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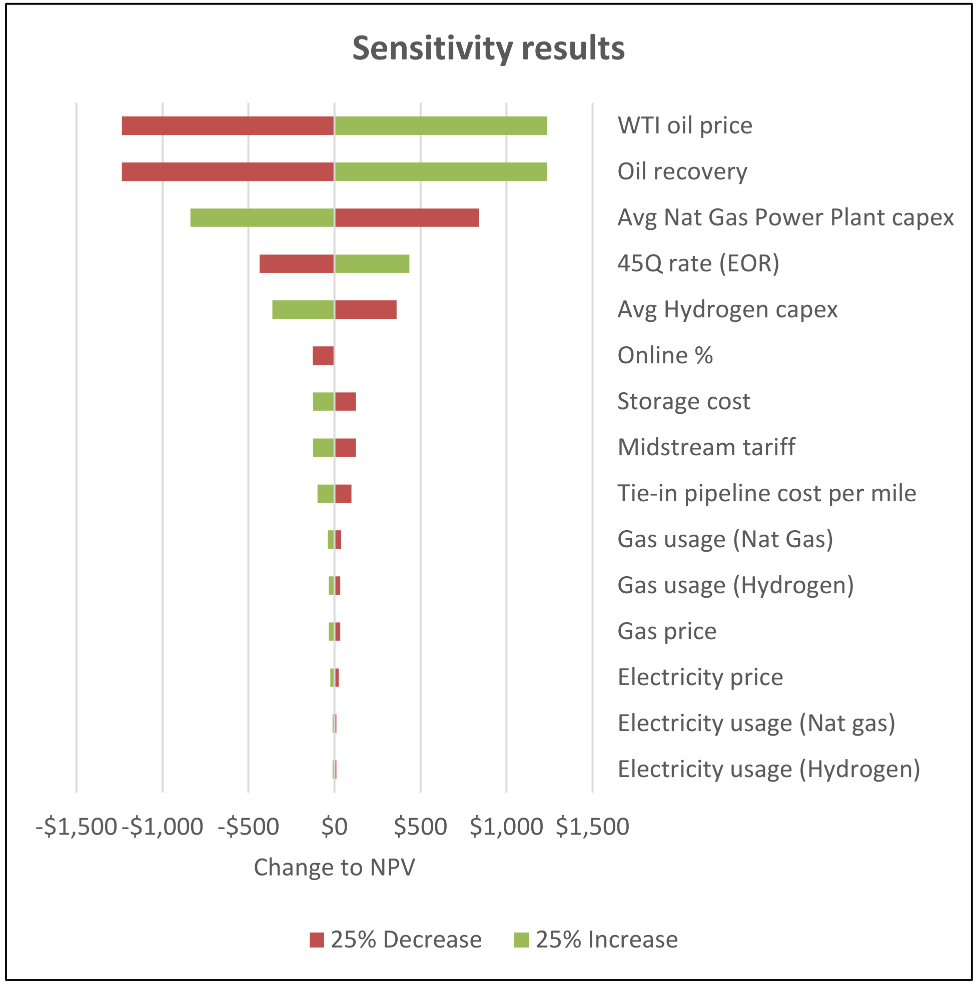
Phase I: Economic Model Results

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

Sensitivity 1		
Base Case Assumptions (100% EOR)		
Online %	100	
bbls produced per metric ton of CO_2	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 45Q rate**



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Key Take-aways

- **Phase I (present to 2030):**
  - **Focus on low cost strategic CO_2 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

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Gaffney Cline

Special thanks: 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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US Cities

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University of Houston

Submit your Q&A questions now for the panelists at:

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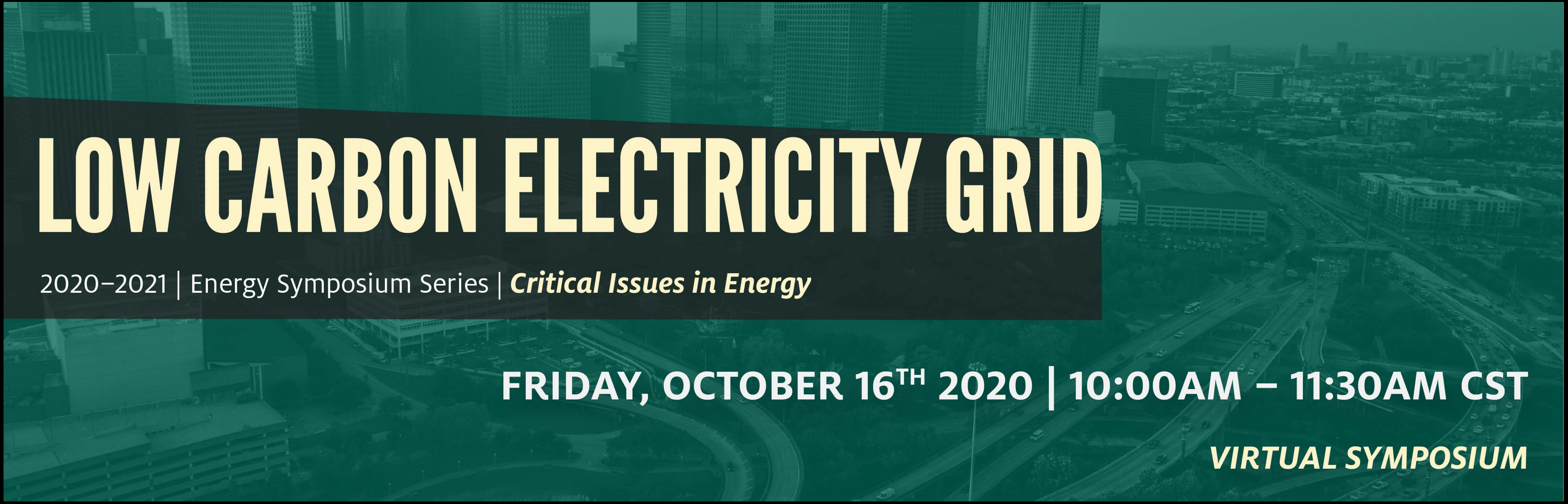

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