The 8RH2 Process for Producing Clean Hydrogen with Autothermal Reforming and Carbon Capture

DE-FE0032127

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8 Rivers

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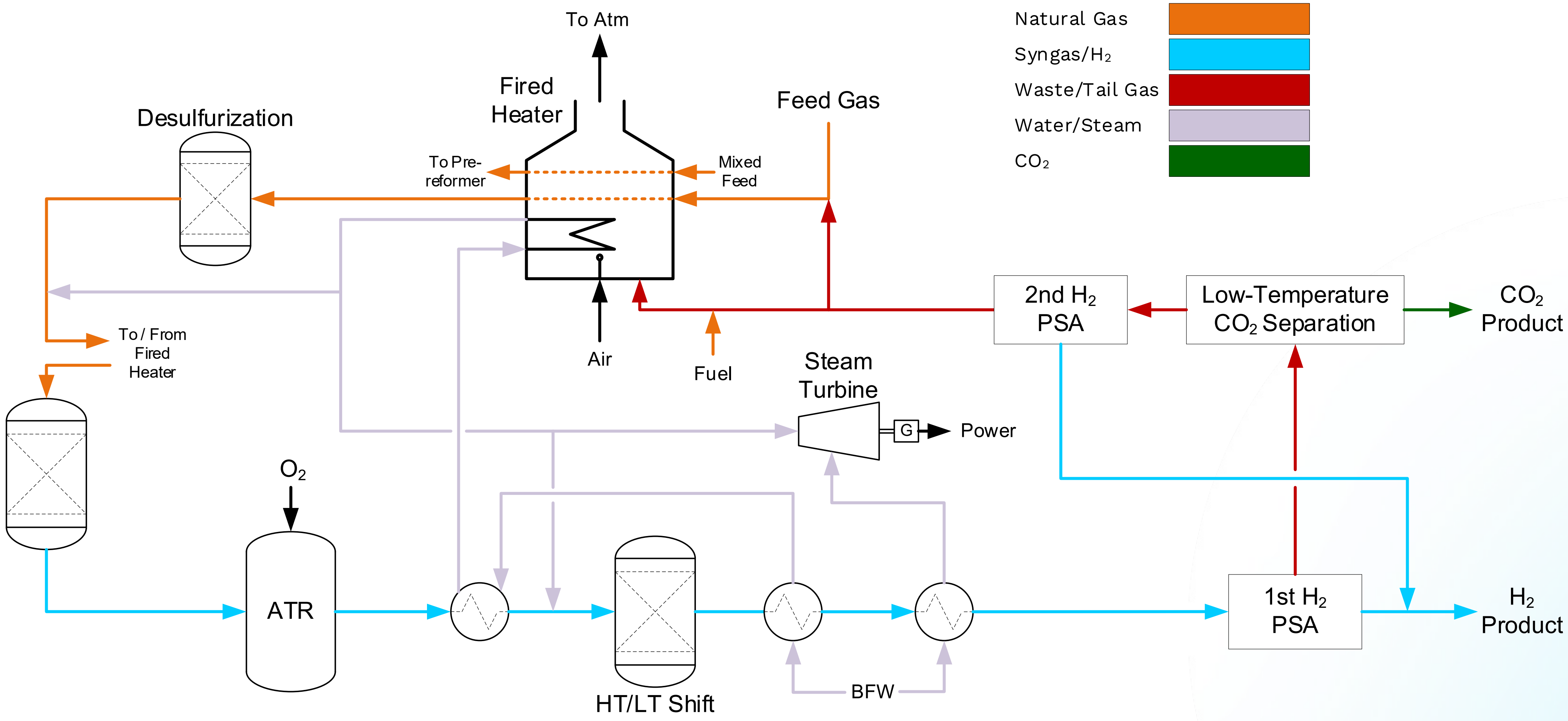
Project Overview

Funding (DOE / Cost Share)	$1,412,863 / $390,000 (21.6%)
Project Performance Dates	Feb 07, 2022 – May 14, 2024
Project Participants	8 Rivers Capital, LLC (Prime) Technip Energies (Sub Recipient) North Shore Energy, LLC (Host Site) Wyoming Energy Authority (Co-funder)
Project Objectives	*Deliver:* Hydrogen facility Class IV cost estimate CO_2 capture facility Class III cost estimate *Demonstrate:* 90+% carbon capture efficiency H_2 purity of 99.9% Cost of CO_2 capture <$50/mt

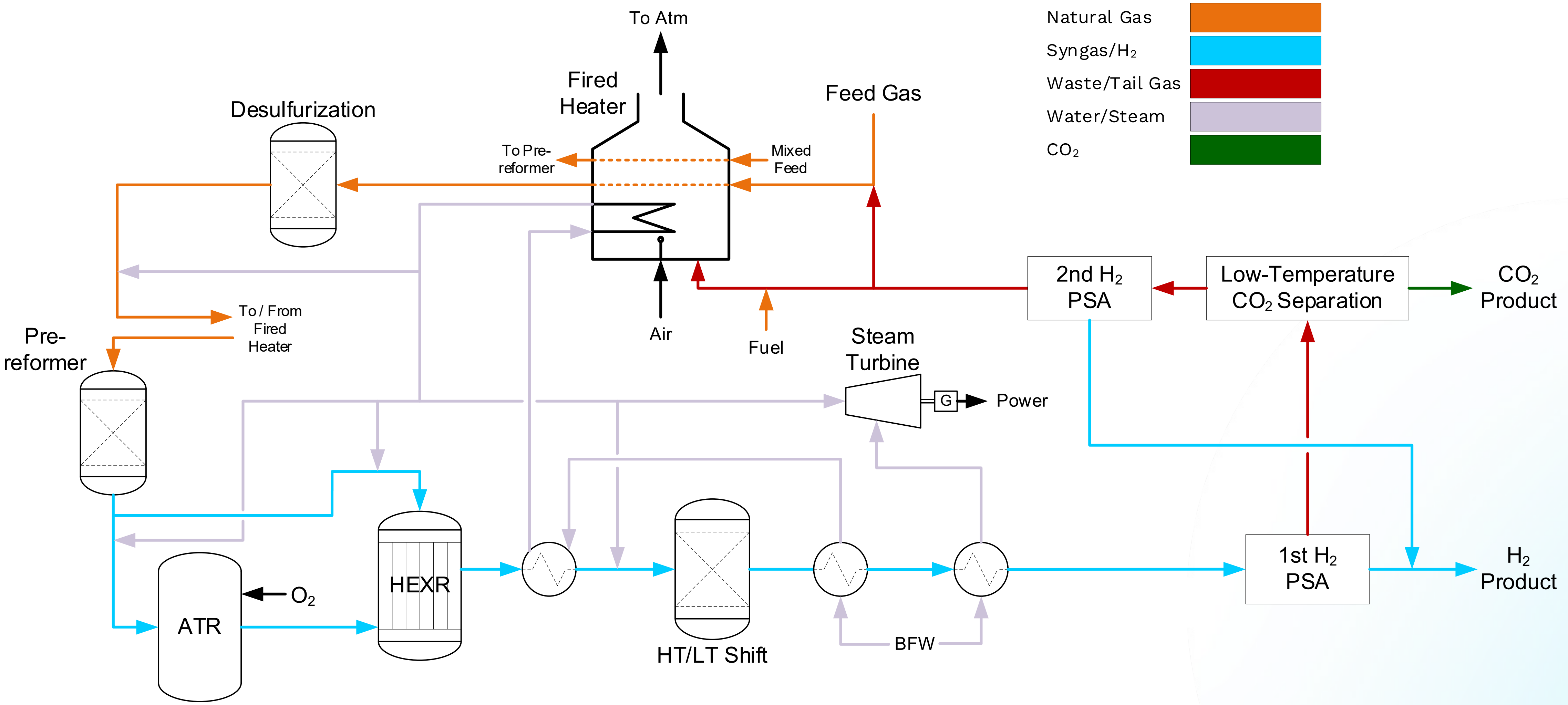
Technology Background

Case 1: 8R base case with ATR + air fired heater and cryogenic CO_2 capture



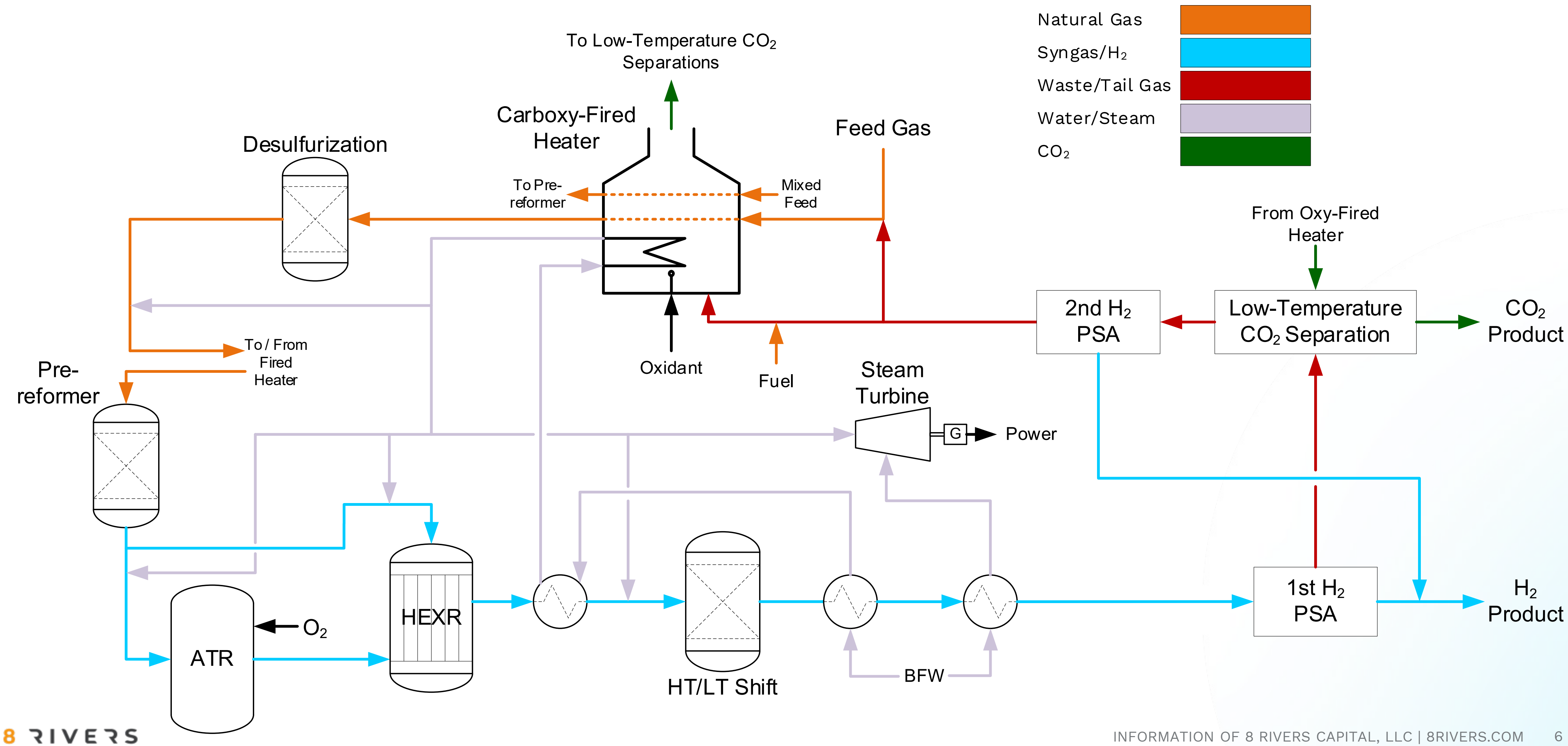
Technology Background

Case 2: 8R case ATR + air fired heater with a heat exchanger reformer and cryogenic CO_2 separation



Technology Background

Case 3: 8R case ATR + carboxy-fired heater with a heat exchange reformer and cryogenic CO_2 separation



Technology Background

Benefits

- Low-energy cryogenic CO_2 separation system that maximizes hydrogen recovery while minimizing the carbon footprint of the operation
- Integrating a heat exchange reformer (HEXR) with the ATR improves thermal efficiency through more effective heat utilization
- Case 3 can handle high inert natural gas and offers high CO_2 capture (99%+)

Technology offers efficient 99%+ CO_2 capture

Challenges

Carboxy-fired Process Heater (for Case 3)

- Challenges with novel kit
- Limited supply chain

CO_2 Cold Box

- Precise process control is required as equipment operates near the CO_2 freezing point

Cost

- Additional cost is required to capture the last molecules of CO_2

Required operating conditions of novel kit

Study Site

Benefits

- Brownfield – existing gas supply and electrical infrastructure
- Proximity to rail

Drawbacks

Known at study start:

- Assumed no cooling water system (water scarcity)

Learned during study:

- Local/regional demand cannot support supply and transport to larger markets is cost prohibitive

Painter Gas Complex in Evanston, WY

Project Scope

Task	Milestone
1	Kick-off meeting
2	Basis of design completed
3	PFD and HMB completed
4	Plot plan completed
5	3D model and P&IDs completed
6	Emissions and waste stream analysis completed
7	Cost estimate completed
8	Techno-economic analysis generates levelized cost of hydrogen production
9	Final Pre-FEED package approved

Success Criteria

Minimum net carbon capture efficiency of 90+% with goal of 93-99% for the plant as defined within the boundary limits of the PFDs

Minimum CO_2 purity of 95% with <500 ppm H_2O, <0.001% vol oxygen, <1% vol hydrogen, <35 ppm CO, and <1% vol argon as per exhibit 2-1 of the NETL "Quality Guidelines for Energy System Studies: CO_2 Impurity Design Parameters."

Minimum CO_2 captured above 100,000 tonne/year with goal of over 600,000 tonne/year with 90% plant utilization

CO_2 delivery pressure at or above 2,215 psia

H_2 purity of 99.97 mol% with CO and CO_2 is less than 10 ppm, final H_2 product has minimal impurities, and will be delivered at or above 360 psi

Cost of CO_2 capture goal of <\$50/tonne

Delivery of Final Report Approved by DOE with all deliverables, including finalized Techno-Economic Analysis and EH&S Report.

Risks and Mitigation

	Mitigation/Response Strategy
Financial Risks	
Techno-economic analysis determines insufficient ROI for revenue streams	Host Site has significant existing infrastructure. Competitive bids for equipment packages will be solicited from qualified vendors. Three alternate designed are being evaluated. Low Carbon Fuel Standard / 45Q to be maximized.
Low Carbon Fuel Standard Market Risk	Changes to the structure or market price of LCFS that lower value could make export to California un-economic. Mitigation would include pipeline exports, in-state usage, and sales of fertilizer.
Insufficient budget to meet objectives	Active project management from Prime Recipient, EPC will ensure project costs remain within budget.
Personnel availability due to sickness (COVID)	Develop cross-functional team with strong communication and solid documentation for others to pick up where others leave off.
CCUS technology integration	Early engagement of licensors & vendors related to CCUS technology
High temperature (>1700 F) design of ATR outlet transfer line & syngas cooler design	Selection of appropriate refractory material and shell material for transfer line. Selection of appropriate flux design criteria to minimize stresses at susceptible locations.
TRL of Hydrogen burners	More than 1000 LSV burners are currently operating in furnace applications. Developing the burner for 100% hydrogen firing is underway at Technip Energies test center. Technip Energies to stay engaged in development.
Mgmt./Planning Risks	
Communication	Establish and follow a robust communication plan.
Schedule, Budget, Scope Creep	Define stage gates in conjunction w/ project milestones to monitor & control project w/ PMP, Scope of Work, Division of Responsibility, Clarity of Deliverables, Schedule & budget
ES&H Risks	
Environmental	Site and environmental considerations are very well understood
External Factors	
COVID-19 impact to execution	Incorporate virtual collaboration techniques into execution plan. Parties have already become accustomed to software (MS Teams) and have internal COVID polices in place.
Unforeseen Risks	Regular updates with DOE and project partners will help solve issues as they arise.

Progress and Current Status of Project

Study Outcomes

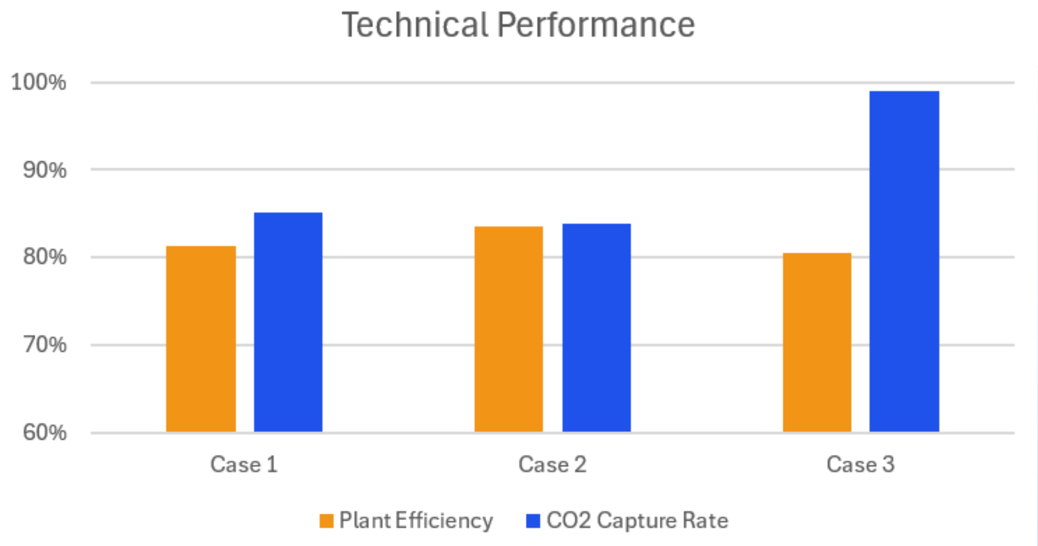
Study Success Criteria	
Success Criteria	**Outcome**
Minimum net carbon capture efficiency of 90+% with goal of 93-99% for the plant as defined within the boundary limits of the PFDs	**Success**; Case 3 achieves a carbon capture rate of 99%
Minimum CO_2 purity of 95% with <500 ppm H_2O, <0.001% vol oxygen, <1% vol hydrogen, <35 ppm CO, and <1% vol argon as per exhibit 2-1 of the NETL "Quality Guidelines for Energy System Studies: CO_2 Impurity Design Parameters."	**Success**; Each case has >99.5% CO_2 purity and meets other specifications
Minimum CO_2 captured above 100,000 tonne/year with goal of over 600,000 tonne/year with 90% plant utilization	**Success**; CO_2 capture for each case, respectively: 603,577; 565,602; 674,074 tonne/yr
CO_2 delivery pressure at or above 2,215 psia	**Partial***; CO_2 export pressure of 2,175 psia
H_2 purity of 99.97 mol% with CO and CO_2 is less than 10 ppm, final H_2 product has minimal impurities, and will be delivered at or above 360 psi	**Success**; All criteria achieved
Cost of CO_2 capture goal of <$50/tonne	**Partial**; Cases 1: $42.95; Case 2: $45.16; and Case 3: $61.26
Delivery of Final Report Approved by DOE with all deliverables, including finalized Techno-Economic Analysis and EH&S Report.	**Pending;** DOE approval pending

*CO_2 export basis updated after criteria established to 150 bar

Technical Performance

Case 3 has the lowest plant efficiency (80.6%) and the highest carbon capture rate (99%)

Performance Summary				
		Case 1	**Case 2**	**Case 3**
Hydrogen Product	MMSCFD	100	100	100
Gross Power Requirement	MWe	32.1	29.6	36.2
Power Generation	MWe	19.1	15.6	18.9
Net Power Requirement	MWe	13.0	14.0	17.3
Natural Gas Feed, HHV	mmbtu/hr	1,570	1,522	1,558
HHV Thermal Input of NG Feed	kWt	459,521	445,428	455,842
HHV Plant Efficiency	%	81.3	83.5	80.6
HHV CGE	%	85.9	88.8	86.7
Water Consumption	gpm	138.7	152.8	152.3
CO_2 Emissions	kg/hr	13,356	13,815	863
CO_2 Captured	kg/hr	76,557	71,741	85,499
CO_2 Capture	%	85	84	99

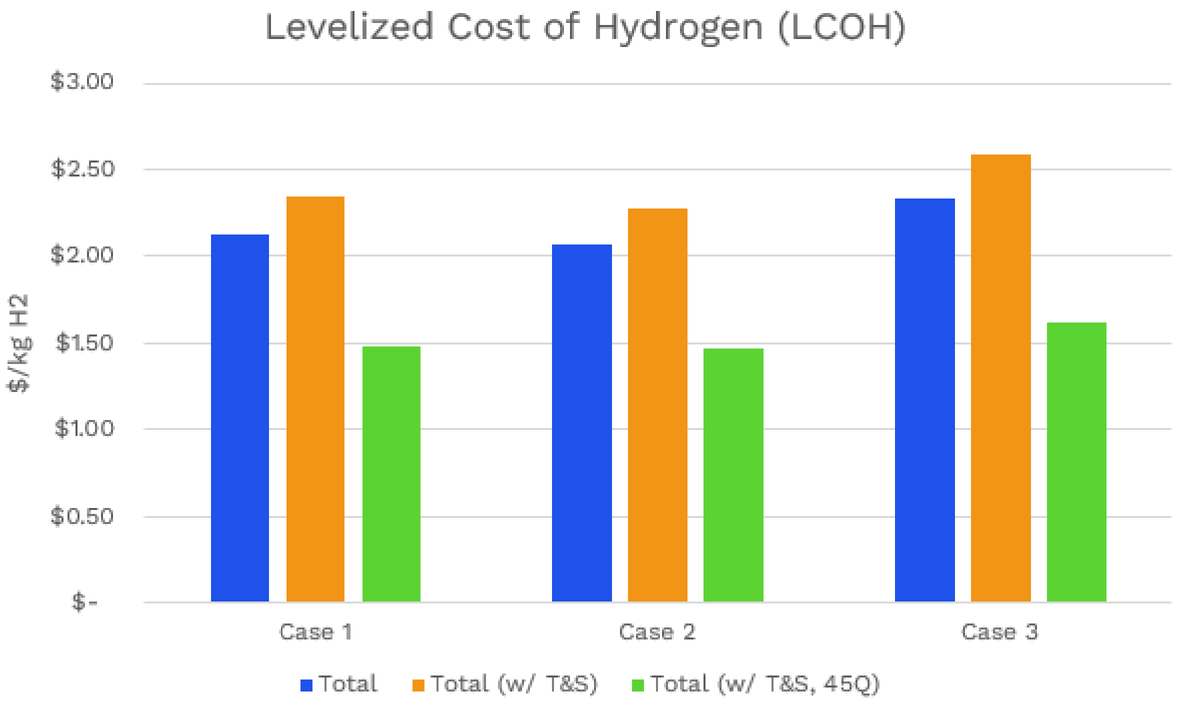


Economic Performance

Case 3 has the highest levelized cost of hydrogen, 10% higher than 8R baseline ATR (Case 1)

Levelized Cost of Hydrogen			
\$/kg H_2	**Case 1**	**Case 2**	**Case 3**
Levelized Capital	\$0.57	\$0.56	\$0.71
O&M	\$0.22	\$0.21	\$0.27
Fuel	\$1.19	\$1.16	\$1.19
Variable - Other	\$0.14	\$0.14	\$0.17
Total	**\$2.12**	**\$2.07**	**\$2.34**
CO_2 T&S	\$0.23	\$0.21	\$0.25
Total (w/ T&S)	**\$2.35**	**\$2.28**	**\$2.59**
45Q	(\$0.87)	(\$0.81)	(\$0.97)
Total (w/ T&S, 45Q)	**\$1.48**	**\$1.47**	**\$1.62**

Levelized Cost of CO_2 Capture			
\$/mt CO_2	**Case 1**	**Case 2**	**Case 3**
Levelized Capital	\$19.00	\$20.06	\$32.96
O&M	\$6.90	\$7.28	\$10.04
Variable Operating	\$17.04	\$17.82	\$18.25
Total	**\$42.95**	**\$45.16**	**\$61.26**



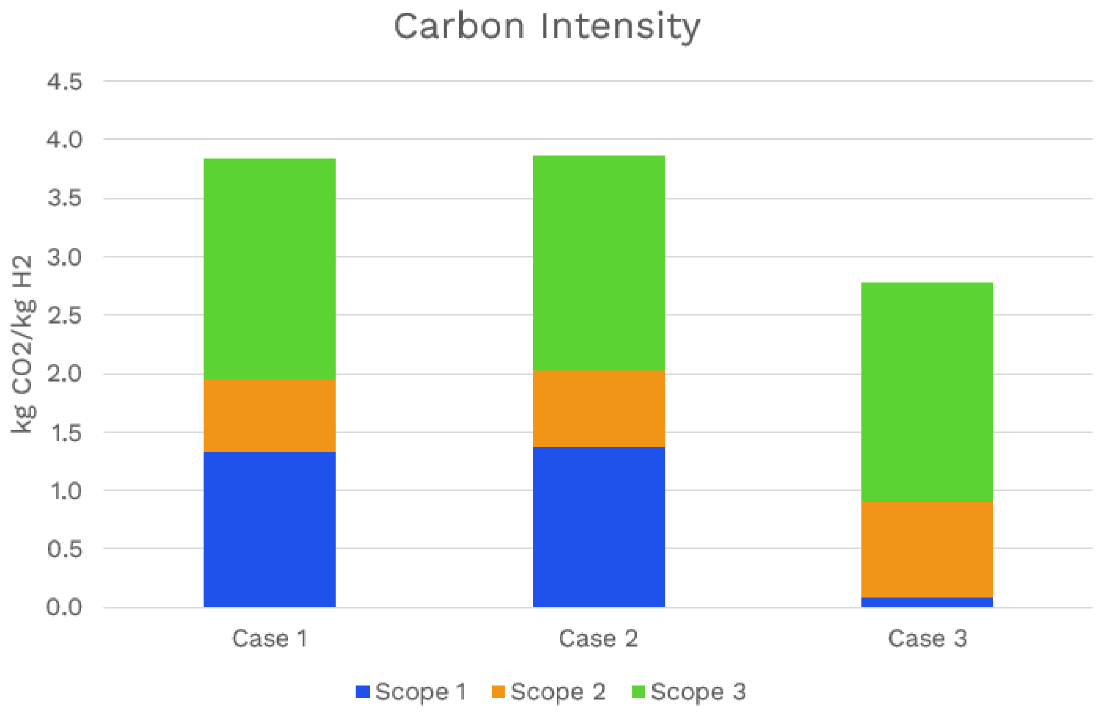
Life Cycle Analysis

Case 3 has the lowest carbon intensity, 26% lower than baseline ATR (Case 1), by producing nearly no Scope 1 emissions (99% carbon capture)

Life Cycle Analysis			
kg $CO_2e/kg\ H_2$	**Case 1**	**Case 2**	**Case 3**
Scope 1	1.3	1.4	0.1
Scope 2	0.6	0.7	0.8
Scope 3	1.9	1.8	1.9
Total	**3.8**	**3.9**	**2.8**

Emissions Factors

Upstream Natural Gas	kg CO_2e/mmbtu	13.41
Power - Grid	kg CO_2e/MWh	471



Lessons Learned

Pre-FEED study lessons learned

Site selection impacts technical and economic performance

- It was assumed during site selection that products could be transported to demand centers (mining, farming, refining, energy export). However, low demand for local use and higher than expected transportation costs impacted the project's economic viability.

Indirect labor costs are higher than expected

- The Pre-FEED exposed higher indirect costs for installing plant than expected from previous work (pre-Covid)

Early iterations increase study efficiency

- As a process licensor, it is important to iterate early when collaborating with engineering firm

Future Development

Future Deployment – Cormorant Clean Energy

CORMORANT CLEAN ENERGY | 8RH2

Cormorant Clean Energy (CCE) is an ultra-low-carbon ammonia production facility to be located in the Texas Gulf Coast. CCE will be the first commercial-scale deployment of 8 Rivers' proprietary 8RH2 technology.

Ultra-low-carbon ammonia can be used for agriculture, transportation fuels, power production, and industrial processes.

Ammonia production annually
~900,000 tonnes

CO_2 captured annually
~1.5 million tonnes

Permanent Jobs Created
95+

CO_2 capture rate
>99%

Location
Port Arthur, TX

$8RH_2$ Technical Overview

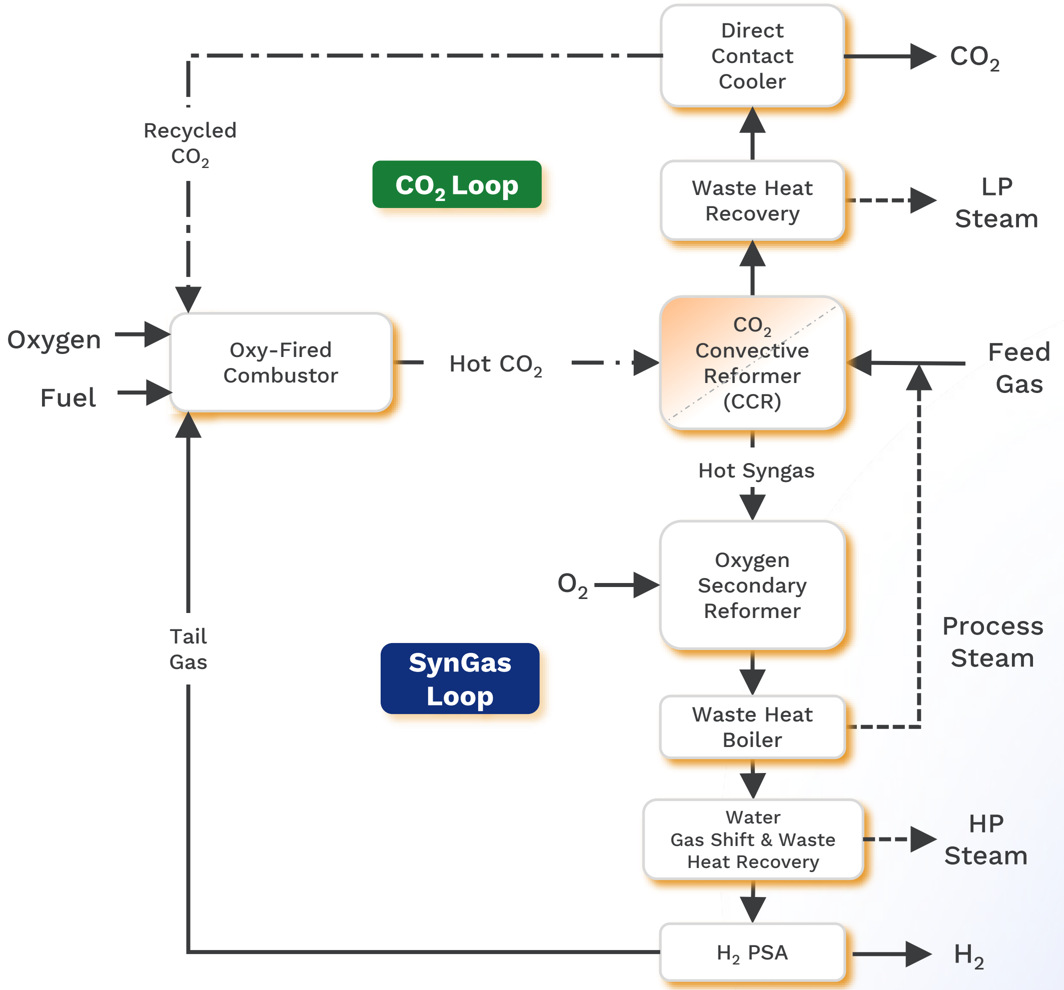
Our product outcompetes similar technologies on key metrics like levelized cost and carbon intensity

$8RH_2$ vs ATR+95% CCS

10-15% Lower levelized cost

15-20% Lower carbon intensity

5-7% More thermally efficient



ATR basis: Comparison of Commercial, State-of-the-Art, Fossil-Based Production Technologies (NETL, 2022)

Summary

Key takeaways from the Pre-FEED study

1. The study demonstrated technical feasibility of an 8RH2 configuration with >99% carbon capture, however increased capture came at an additional economic cost
2. The Wyoming site proved non-ideal for the time being mainly due to geographic isolation from hydrogen (or hydrogen product) demand centers
3. 8 Rivers has advanced a modified 8RH2 design which offers ultra-high carbon capture at lower levelized cost than ATR with 95% capture. The improved process will be deployed commercially through Cormorant Clean Energy, a 200 MMSCFD hydrogen production facility (exported as ammonia) to be located in Port Arthur, Texas.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