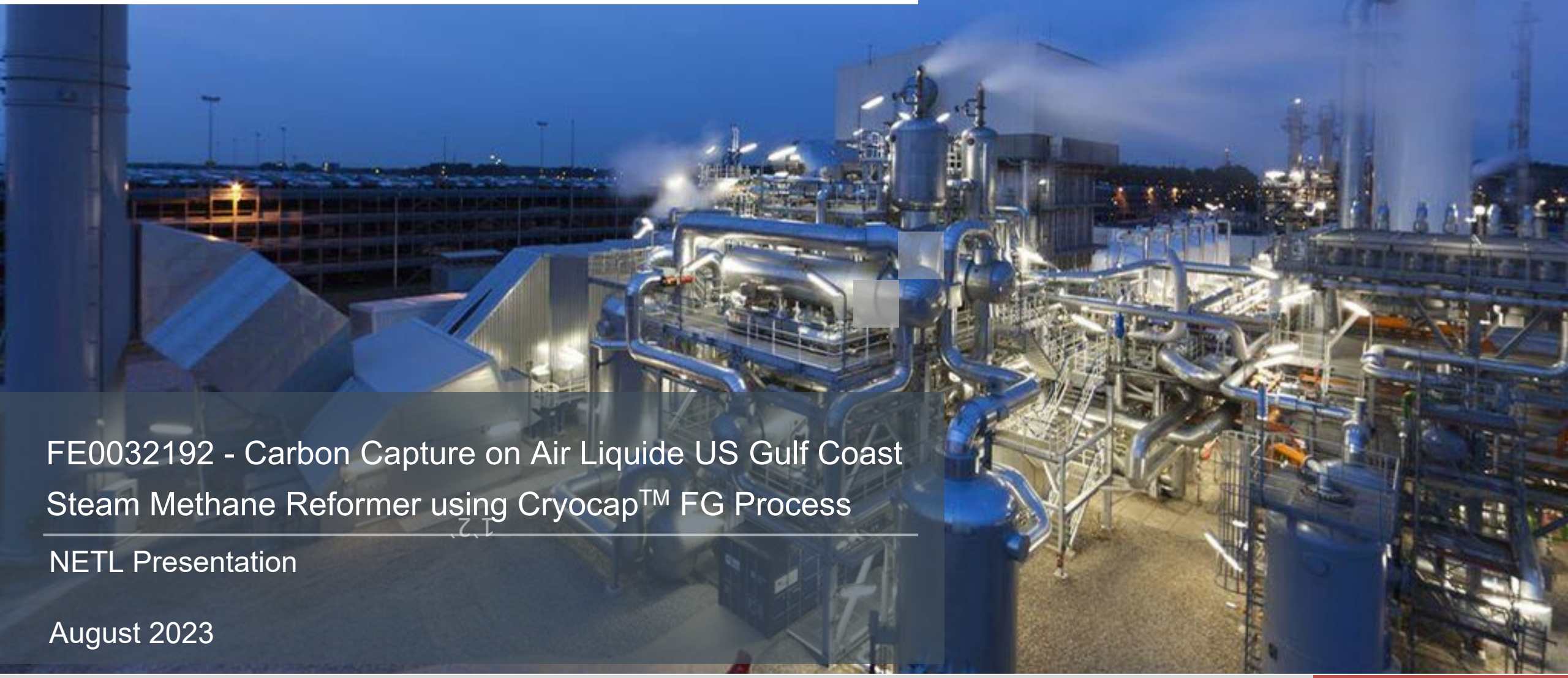

FE0032192 - Carbon Capture on Air Liquide US Gulf Coast Steam Methane Reformer using Cryocap™ FG Process

NETL Presentation

August 2023

Acknowledgement and Disclaimer

a. Acknowledgment:

This material is based upon work supported by the Department of Energy under Award Number DE-FE0032192.

b. Disclaimer:

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Outline

1. Overview, Scope & Objective
2. Scientific/Technical Merit
3. Preliminary Results
4. Project Schedule & Milestone
5. Budget Breakdown

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Project Team and Key People

US DOE
Nicole Shamitko-Klingensmith, DOE Project Manager

Prime – Dastur International

Atanu Mukherjee, PI
Abhijit Sarkar, PM

Key tasks: All SOPO Tasks (1-8)

Host Site - Air Liquide Large Industries (AL LI)

Patrick Murphy, Co-PI

Key tasks: SOPO Tasks 1, 2, 3, 5 (PMP, FEED Package, BCA, LCA)

CC Technology - Air Liquide E&C

Vincent Gueret

Key tasks: SOPO Tasks 2 and 3 (FEED Package, BCA)

Dastur Energy
Phil Amick

Key tasks: SOPO Task 2.1, 2.2, 2.11, 3, 5, 6 (Project Cost, BCA, LCA, TEA)

UT-BEG
Sue Hovorka

Key tasks: SOPO Task 2.5 OSBL FEED (CO_2 storage options)

EPC - Air Liquide Capital Implementation (AL CI)

Teresa Brito

Key tasks: SOPO Tasks 1, 2, 3, 5 (PMP, FEED Package, BCA, LCA)

AL Global E&C Solutions France (AL E&C France)

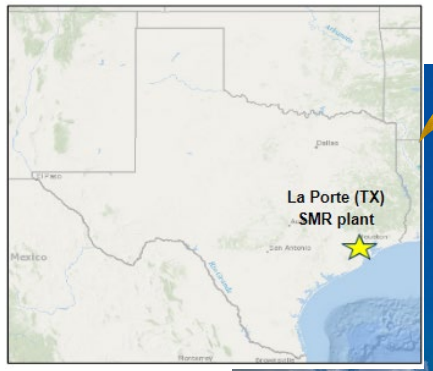
Vincent Gueret, E&C US Liaison

Key tasks: SOPO Task 2 (FEED Package)

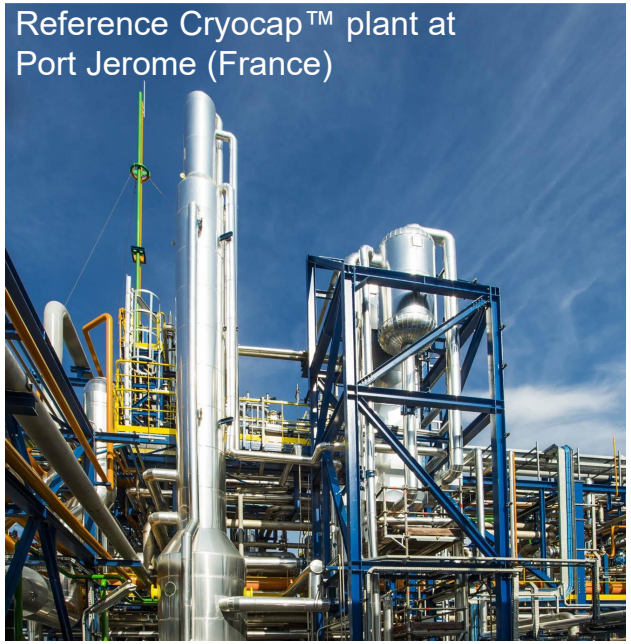
Recipient/Subrecipient **Vendor**

Background and Objectives of the FEED Study

- **Host Site**
  - Air Liquide owned and operated Steam Methane Reformer (SMR) located in La Porte, TX
  - World Scale SMR supplying H_2 to US Gulf Coast industrial customers as part of Air Liquide's Gulf Coast Hydrogen Pipeline network
  - The La Porte SMR produces approximately 950 ktpy CO_2
  - Favorable regional geology for CO_2 sequestration with high density of 3rd party emission sources supporting market development and offerings for storage solutions



- **Technical objective of the FEED Study**
  - **Capture 900 ktpy CO_2** (95%+ C capture efficiency)
  - Based on Air Liquide's **Cryocap™** technology:



Host Site: AL La Porte SMR, TX

FEED Study

Key Deliverables of the FEED Study

- **Design** of a commercial scale carbon capture plant: Engineering Design Package, HAZOP, Electricity Sourcing and Waste Disposal Study, Constructability Review
- **Capital cost estimate** (AACE Class 3)
- **Techno Economic Analysis** for the carbon capture project
- **Assessments:** Business Case, Life Cycle, EH&S, EJ Questionnaire, Economic Revitalization & Job Creation Questionnaire

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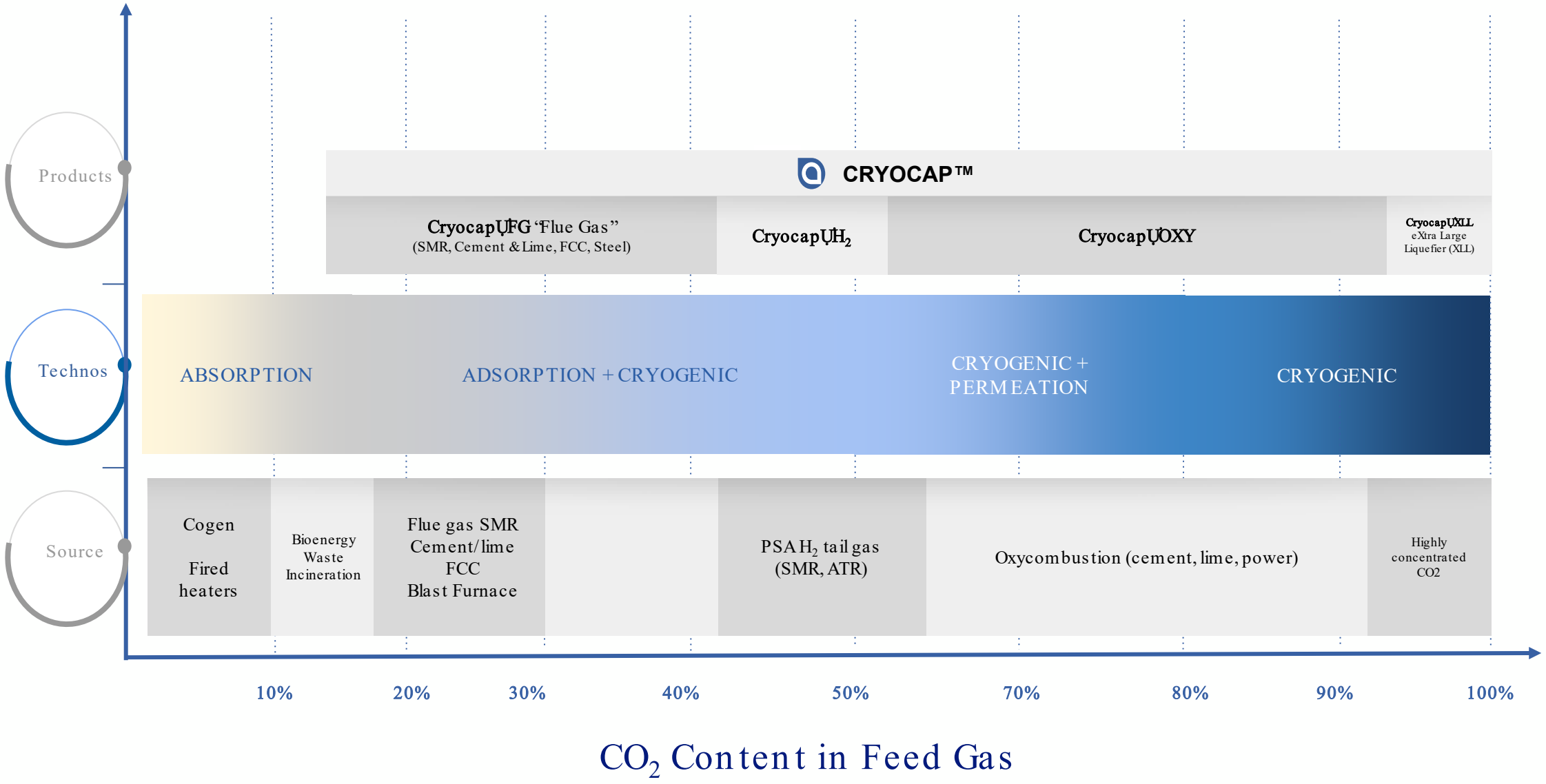
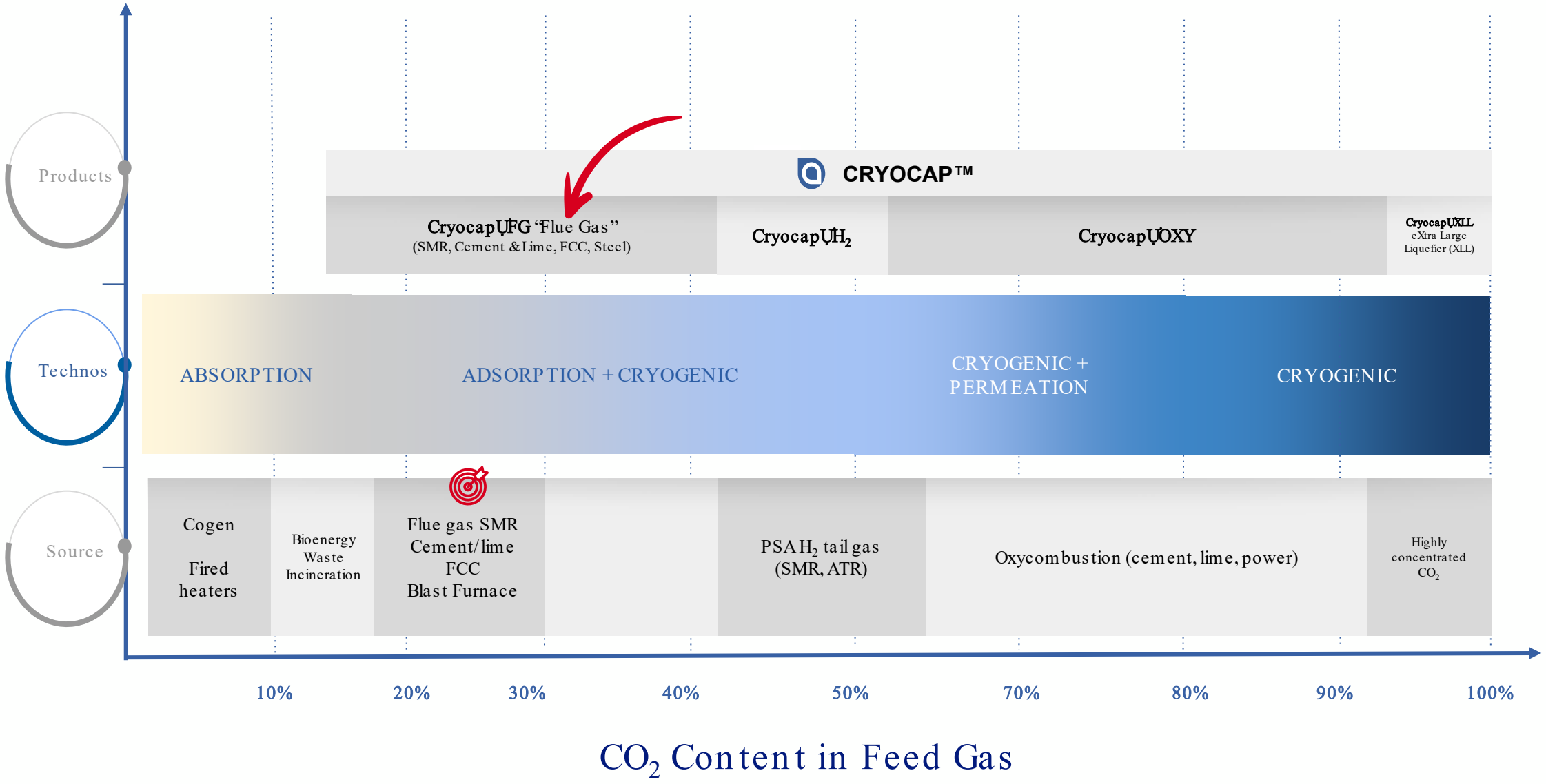
Cryocap™ Technology and Development



Cryocap™ Technology and Development



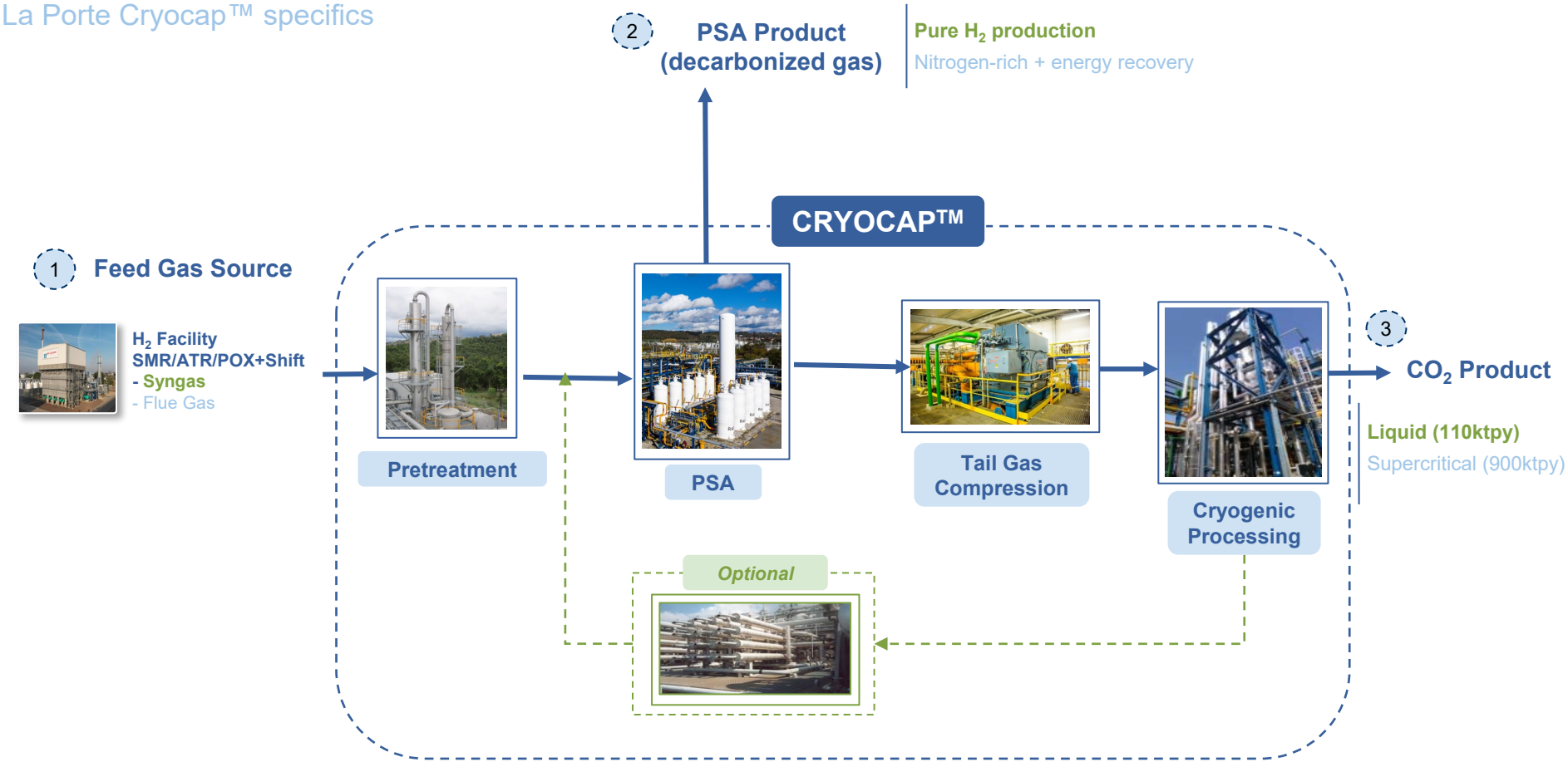
Cryocap™ & Commercial Demonstration Plant Overview (Port Jerome)

Port Jerome Cryocap™ (France)

- 110 ktpy CO_2 captured
- World Unique Cryogenic CO_2 Capture in Operation

Port Jerome Cryocap™ plant specifics

La Porte Cryocap™ specifics



Scientific/Technical Merits

1. **Technology** leveraging Air Liquide's experience in **integrating and operating** process solutions utilizing referenced technology bricks such as compression, PSA and cryogenic separation

1. **Environmentally sustainable**, as the main utility is electricity (leading to very low carbon intensity when renewable power is used) and the process does not use any chemicals or flammables (expect caustic soda or equivalent for the pre-treatment). **No large amount of heat** required like amine wash.

1. **Limited amount of integration** with the SMR, which reduces the potential disruption of SMR operation and associated risks

1. **Pressurized and clean CO_2** exiting the cryogenic section, allowing to reduce significantly the CAPEX/OPEX required for the product CO_2 compression vs amine based system

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Preliminary Results – Engineering progress overview

- **Design Basis**: preliminary version completed, to be potentially updated based on upcoming gas testing
- **Site Data Sheet**: preliminary version completed
- **Technology Maturity Plan**: preliminary version completed
- **Solution Development**: core separation process of Cryocap™ frozen
- **Interface with SMR**: preliminary review + site visit
- **Next steps**:
  - PFDs
  - Heat & Mass Balance
  - Process Data Sheets

Preliminary Results – Design Basis (1/2)

Stream	Unit	SMR Flue Gas
Temperature	°F	~170
Pressure	psig	atmospheric
State	-	Vapor
Molar Flow (1)	Nm^3/h	~287910
Composition (3)		
CO_2	mol%	19.193
H_2O	mol%	19.114
N_2	mol%	59.787
O_2	mol%	1.186
Ar	mol%	0.713
H_2	ppm mol	~60

Notes:

(1) Not including any potential air ingress from the flue gas stack/duct.

(2) Additional air flow on top of the indicated Flue Gas Molar Flow will be considered to model air ingress in the flue gas duct. This additional flow will be determined during the execution of the FEED.

(3) Balance of the composition is composed of the impurities below:

- CO: 20 ppm mol dry @ 3% O_2
- NOx: 5 ppm mol dry @ 3% O_2
- SOx: 1 ppm mol dry @ 3% O_2
- NH_3: 10 ppm mol dry @ 3% O_2
- VOCs: 3 ppm mol dry @ 3% O_2
- Particulate Matter: 5 mg/Nm3 @ 3% O_2

Preliminary Results – Design Basis (2/2)

Stream	Unit	CO_2 Product
Temperature	°F	< 100
Pressure	psig	1330 to 2350
Composition		
Carbon Dioxide	vol%	> 97 (dry basis)
Hydrogen Sulfide	ppm wt	< 10 ppm
Total Sulfur	ppm wt	< 30 ppm
Methane	vol%	< 3
Ethane plus	vol %	< 1
Oxygen	ppm wt	< 10
Glycol	gallons per MMCF	< 0.3
Carbon Monoxide	ppm wt	< 4250
NOx	ppm wt	< 1
SOx	ppm wt	< 1
Particulates	ppm wt	< 1
Amines	ppm wt	< 1
Hydrogen	vol%	< 1 v
Mercury	ng/l	< 5
Ammonia	ppm wt	< 50
Inerts (incl. N_2 and Ar)	vol%	< 0.5
Liquids	-	(1)
Compressor Lube Oil Carry Over	-	(2)
Water Vapor	lbs/MMCF	< 30

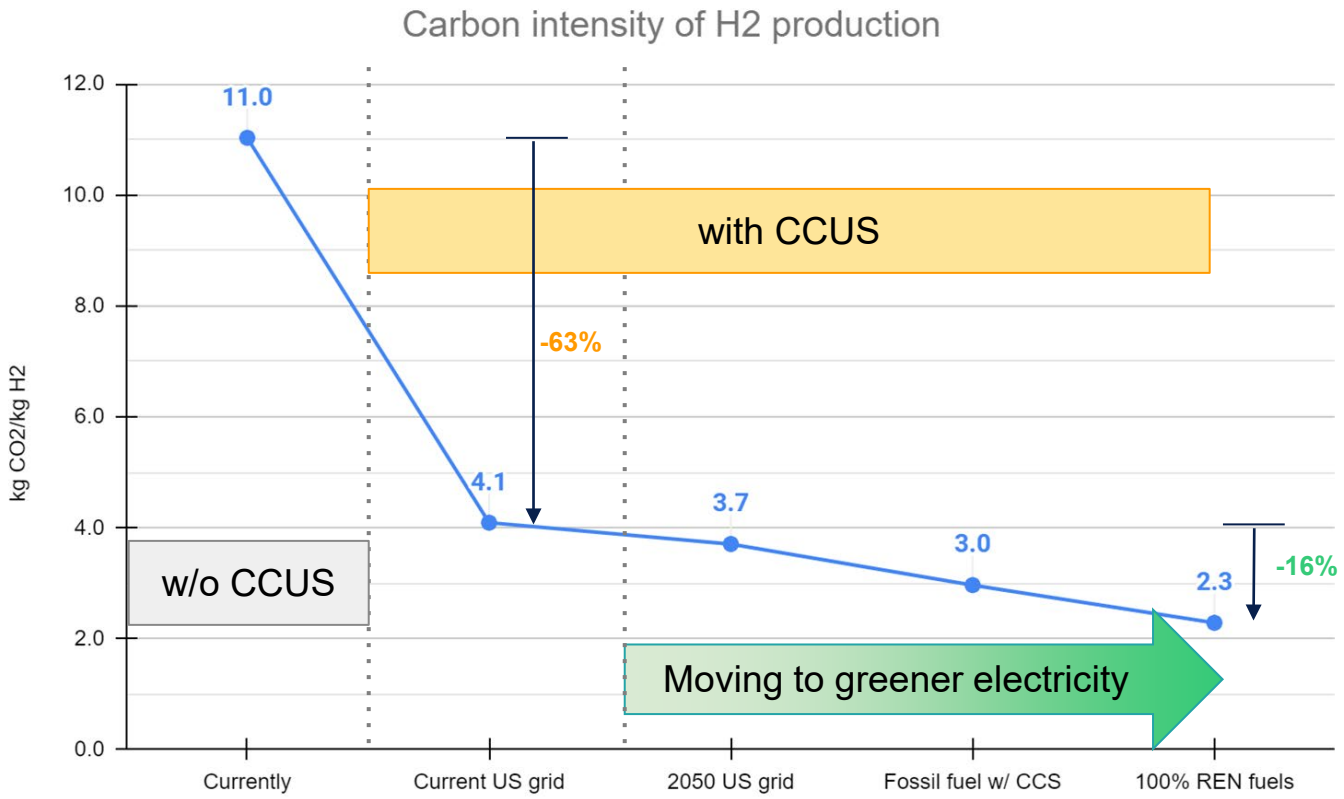
Notes:

(1) Product shall be free of liquids at delivery conditions and shall not produce condensed liquids in the pipeline at pipeline pressure and temperature.

(2) Not more than 50 ppm by weight and shall not cause fouling of pipeline, pipeline equipment downstream systems or reservoirs.

Preliminary Results – from Application Stage

- Key advantage of Cryocap™ FG technology – main utility consumption is electricity which can be supplied from RE
- With progressive greening of US electricity grid, life cycle CO_2 emissions can reduce from 11 kg CO_2/kg of H_2 (w/o CCUS) down to 2.3 kg/kg



Notes:

- Life cycle CO_2e emission estimated considering 1.4% leakage of Methane of total usage in the SMR and 100-year GWP value of 36 as per AR5 (IPCC 2013)
- Current U.S grid mix: 546 kg CO_2e/MWh
- 2050 U.S grid mix (EIA-AEO): 434 kg CO_2e/MWh
- Fossil power with CCS (50% coal and 50% NG with CCS): 220 kg CO_2e/MWh
- 100% Renewables (50% solar PV and 50% wind): 23 kg CO_2e/MWh

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Updates to the Project Management Plan (PMP)

1. Project organization structure - updated to indicate organization wise tasks and activities in the project
1. Workplan – updated (shown in subsequent pages) and milestones added on % of engineering completed
1. Key team members – updated
1. Project budget – updated
1. Project success criteria – updated

    a) Completion of the study as per the scope, budget, and schedule and development of AACE Class 3 capex estimates

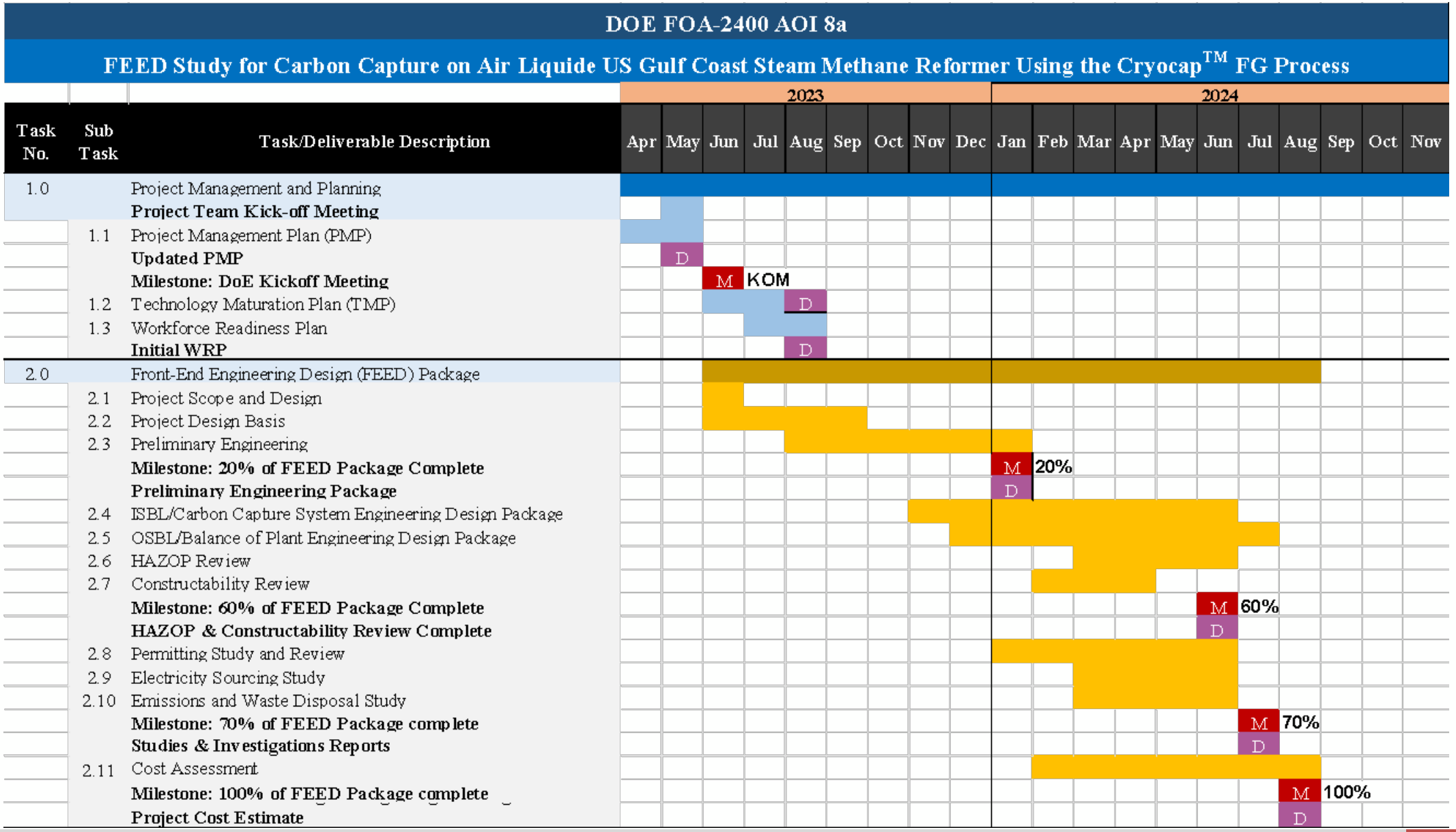
    a) Engineering design and solution for 95% CO_2 capture with 95% purity and 99.97% H_2 purity at competitive costs

        i) 0.9 mtpa of carbon capture
        ii) Meeting capital cost, CO_2 capture cost and LCOH targets
        iii) Minimal disruptions to exist plant operation and hydrogen production

    a) Engineering design package and techno-economic analysis that demonstrates that carbon capture can be implemented at the Host Site to achieve the following metrics:

    a) Acceptance of the study deliverables and reports by DOE

Updated Project Work Plan (1/2)



Project Work Plan (2/2)

DOE FOA-2400 AOI 8a

FEED Study for Carbon Capture on Air Liquide US Gulf Coast Steam Methane Reformer Using the Cryocap™ FG Process

Task No.	Sub Task	Task/Deliverable Description	2023 Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2024 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
3.0		Business Case Analysis (BCA)																				
	3.1	Business Case Analysis																				
	3.2	Technical Overview																				
	3.3	Market Analysis																				
	3.4	Future Deployment Projection																				
	3.5	Quantification of Benefits																				
4.0		EH&S Analysis																				
5.0		Life Cycle Analysis (LCA)																				
6.0		Techno-Economic Analysis (TEA)																				
	6.1	System Boundaries																				
	6.2	Process Design Assumptions																				
	6.3	Process Flow Diagram & Material Energy Balances																				
	6.4	Calculated Output from Analysis																				
		Milestone: 100% of TEA complete																	M	TEA complete		
		BCA, EH&S, LCA and TEA																	D			
7.0		Environmental Justice Analysis																				
8.0		Economic Revitalization and Job Creation Outcomes Analysis																				
		Environmental Justice, Economic Revitalization and Job																				D
		Milestone: Study Complete & Final Report Submission																FEED study complete				M

M Milestone

D Deliverable

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Budget Spending Till July 2023

Total project budget	Total budget	Share
Federal share	US$ 5,994,689	80%
Non-federal share	US$ 1,499,303	20%
Total	**US$ 7,493,992**	**100%**

Cost type	Apr 2023 – Jul 2023	Share	Remaining budget	% Remaining
Federal share	US$ 184,688	100%	US$ 5,810,001	98%
Non-federal share	0	0%	US$ 1,499,303	100%
Total	**US$ 184,688[1]**	**100%**	**US$ 7,309,304**	**97%**

Note 1: Additional invoices expected to bring this number by end August to US$ 1,083,625 with US$ 216,725 as 20% non-federal cost share contributed

DASTUR

Abhijit Sarkar
Project Manager

abhijit.sr@dastur.com
+1 (415) 216-8660