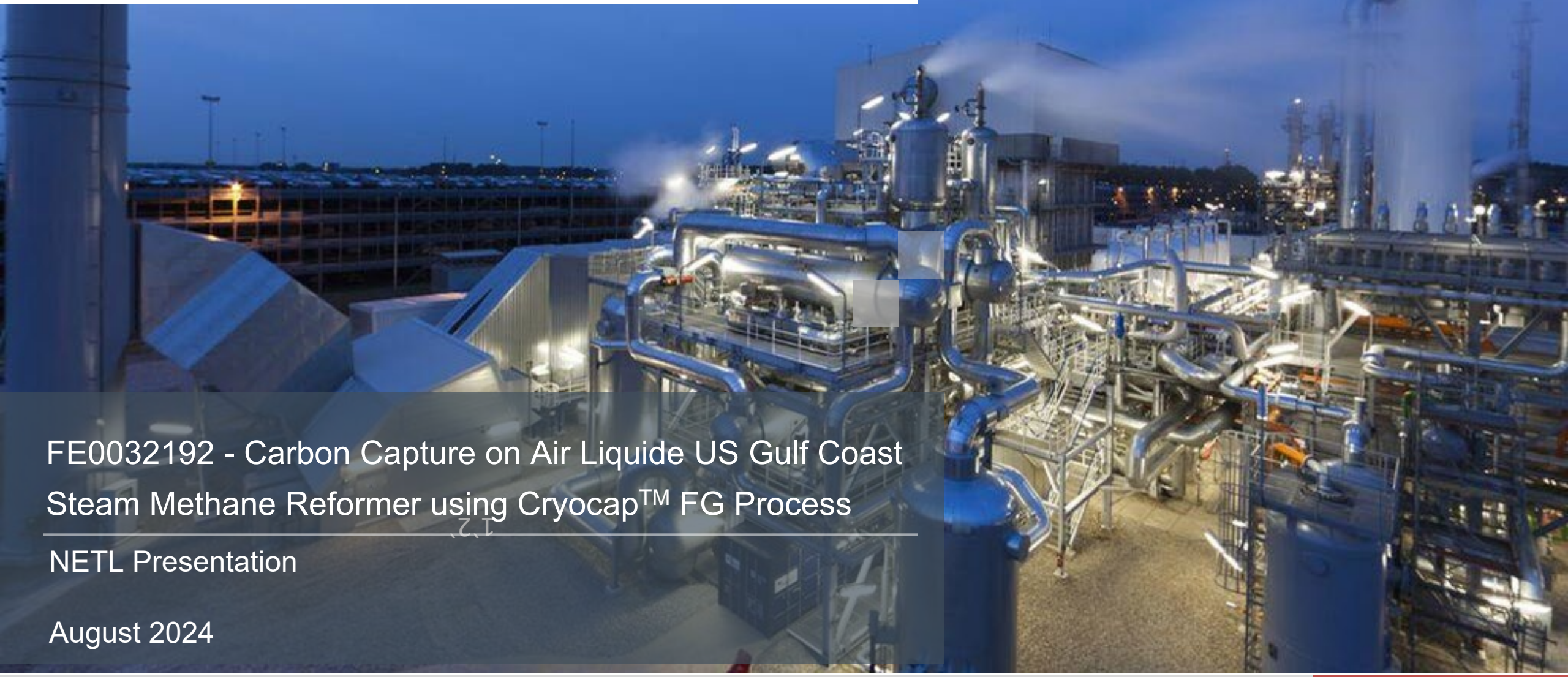

FE0032192 - Carbon Capture on Air Liquide US Gulf Coast Steam Methane Reformer using Cryocap™ FG Process

NETL Presentation

August 2024

Acknowledgement and Disclaimer

a. Acknowledgment:

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

b. Disclaimer:

Outline

1. **Project Overview and Present Status**
2. **Technology Overview**
3. **Engineering Results To Date**
4. **Timelines & Budget**

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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 and high density of 3rd party emission sources supporting market devpt and storage solutions offerings

- **Objective of the FEED Study**
  - **Capture 900 ktpy CO_2** from SMR flue gas with 95%+ C capture efficiency and >95% purity
  - Based on Air Liquide's **Cryocap™FG** technology

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)

Air Liquide E&C France & Canada

Vincent Gueret, E&C US Liaison

Key tasks: SOPO Task 2 (FEED Package)

Recipient/Subrecipient **Vendor**

Project Status & Progress

- ~60% completion to date
- Preliminary Engineering Package delivered in Feb 2024, presented to DOE in March
- Key deliverables completed: TMP, PFDs, H&MB, P&IDs, control strategy, ISBL equipment list & interface list, geotechnical report, waste & emission disposal study, …
- FEED study ongoing tasks and deliverables:
  - Plot plan, lighting and security layouts
  - Material Take-Offs
  - Electrical one-line, load list, equipment list, grounding drawing
  - Constructability review
  - HAZOP review scheduled at La Porte site in August
- No-Cost Extension mutually agreed with DOE for submission of all FEED deliverables by March 2025 + 6 months for DOE review and report finalization

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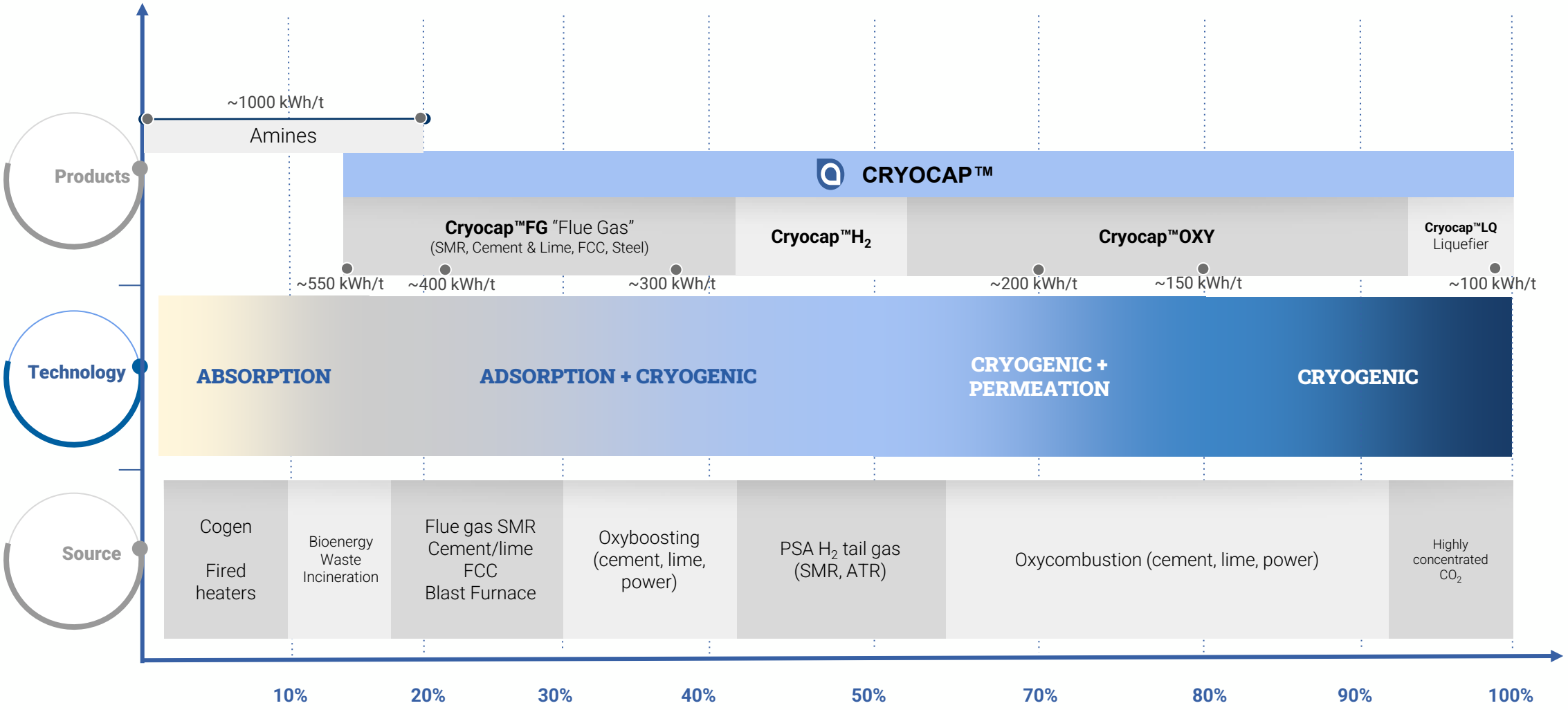
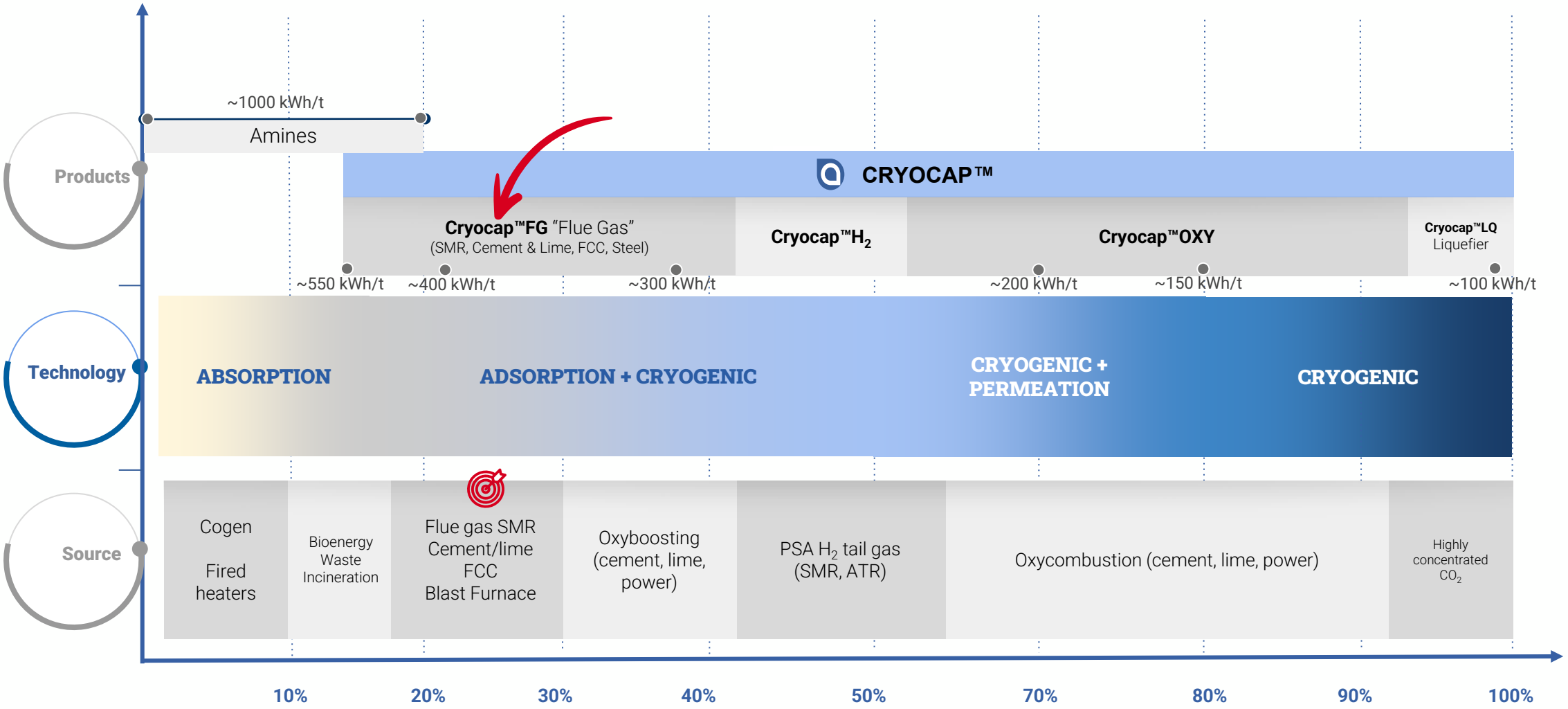
Air Liquide CO_2 capture techno mapping (low pressure streams)



CO_2 Content in Feed Gas

● Liquid or dense phase production

Air Liquide CO_2 capture techno mapping (low pressure streams)



CO_2 Content in Feed Gas

● Liquid or dense phase production

Cryocap™FG Block Flow Diagram

2 **Decarbonized flue gas to atmosphere**
Nitrogen-rich + energy recovery

3 **CO_2 Product**
Supercritical, ready for geological storage

CRYOCAP™FG

1 **SMR Flue Gas**

Pretreatment
Quench, dust filtration

PSA
CO_2 pre-concentration

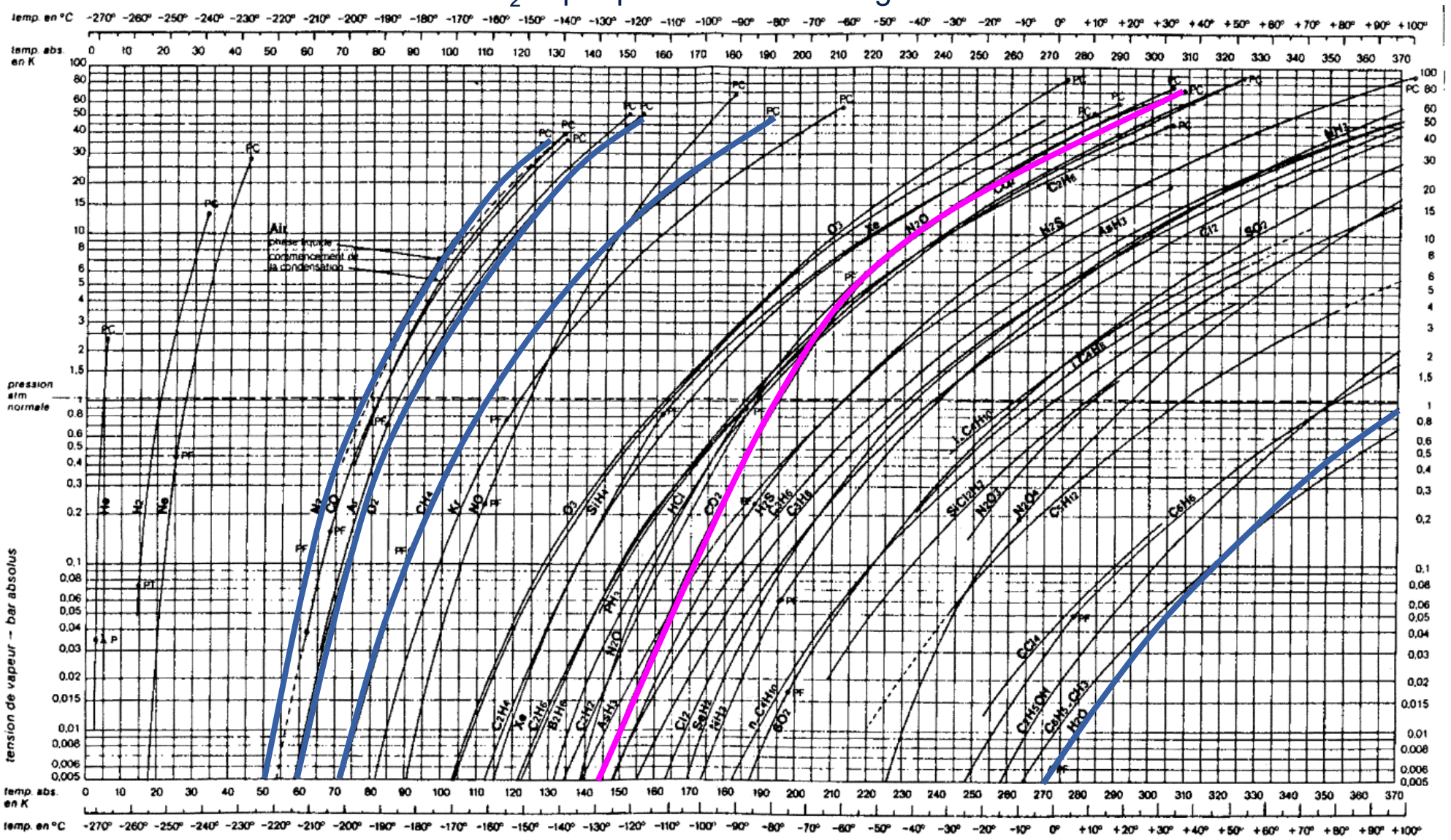
Rich CO_2

Compressor
CO_2-rich gas compression

Cryogenic Processing
CO_2 separation & purification

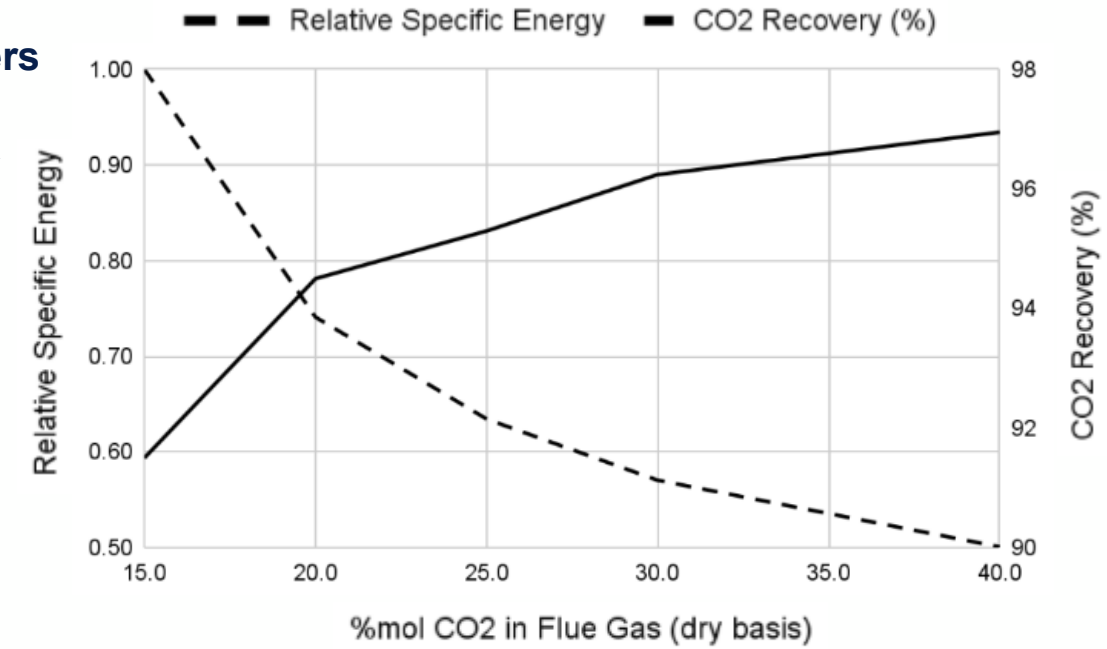
Cryocap™FG thermodynamics fundamentals (cryogenics separation)

CO_2 vapor pressure vs. other gases



Cryocap™FG Carbon Capture Process Model

- **In-house process simulation tools and proprietary models & parameters**
  - Typical sensitivity analysis of Cryocap™FG vs. Flue Gas composition →
  - Cryocap™FG economically optimal for CO_2 content **> 15% dry basis**
  - Performances significantly improve as %CO_2 content in Flue Gas increases



Cryocap™ is a **versatile** technology to capture CO_2 from sources with >15% dry vol CO_2 content

- **Models used to design and optimize pilot and industrial plants (providing operation feedback)**

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:**
   - The main utility is electricity, leading to very low carbon intensity when renewable power is used,
   - No large amount of heat required (minimum steam usage) compared amine wash,
   - No use of any chemicals, except caustic soda or equivalent for the pre-treatment,
   - No use of any flammables,
   - Intrinsic high NOx abatement.

1. **CO_2 quality** produced by the cryogenic section **adaptable** to specific requirements:
   - **High purity CO_2** (>99.9%mol): meets the geological storage specifications (upgrade to food-grade possible)
   - **Flexibility** to easily meet a variety of end user requirements / product specifications
   - Produced in gaseous or liquid state → **supercritical** is considered for this FEED

1. **Compact and flexible** footprint

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Feed Gas Composition

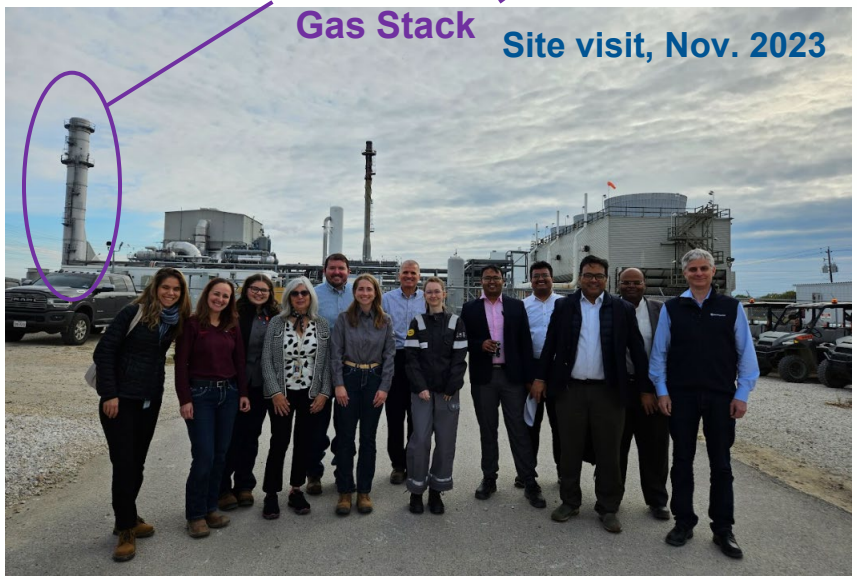
Parameters	UOM	Nominal
Temperature	°F (°C)	346 (174)
Pressure	psia (bara)	14.7 (1.012)
Flue gas volumetric flow	Nm^3/hr	287,910
Composition		
Carbon dioxide (CO_2)	mol% (dry)	23.7
Nitrogen (N_2)	mol% (dry)	73.9
Oxygen (O_2)	mol% (dry)	1.5
Argon (Ar)	mol% (dry)	0.9
Hydrogen (H_2)	mol% (dry)	< 0.01
Water (H_2O)	mol%	19.1
Impurities		
CO	ppm mol (dry)	21.7
Nitrogen Oxides ($NO+NO_2$)	ppm mol (dry)	5.4
Sulfur Oxides (SOx)	ppm mol (dry)	1.1
Ammonia	ppm mol (dry)	10.9
VOCs	ppm mol (dry)	3.3
Particulate Matter	mg/Nm^3 (dry)	5.4

CO_2 Product Specifications (based on offtaker requirements)

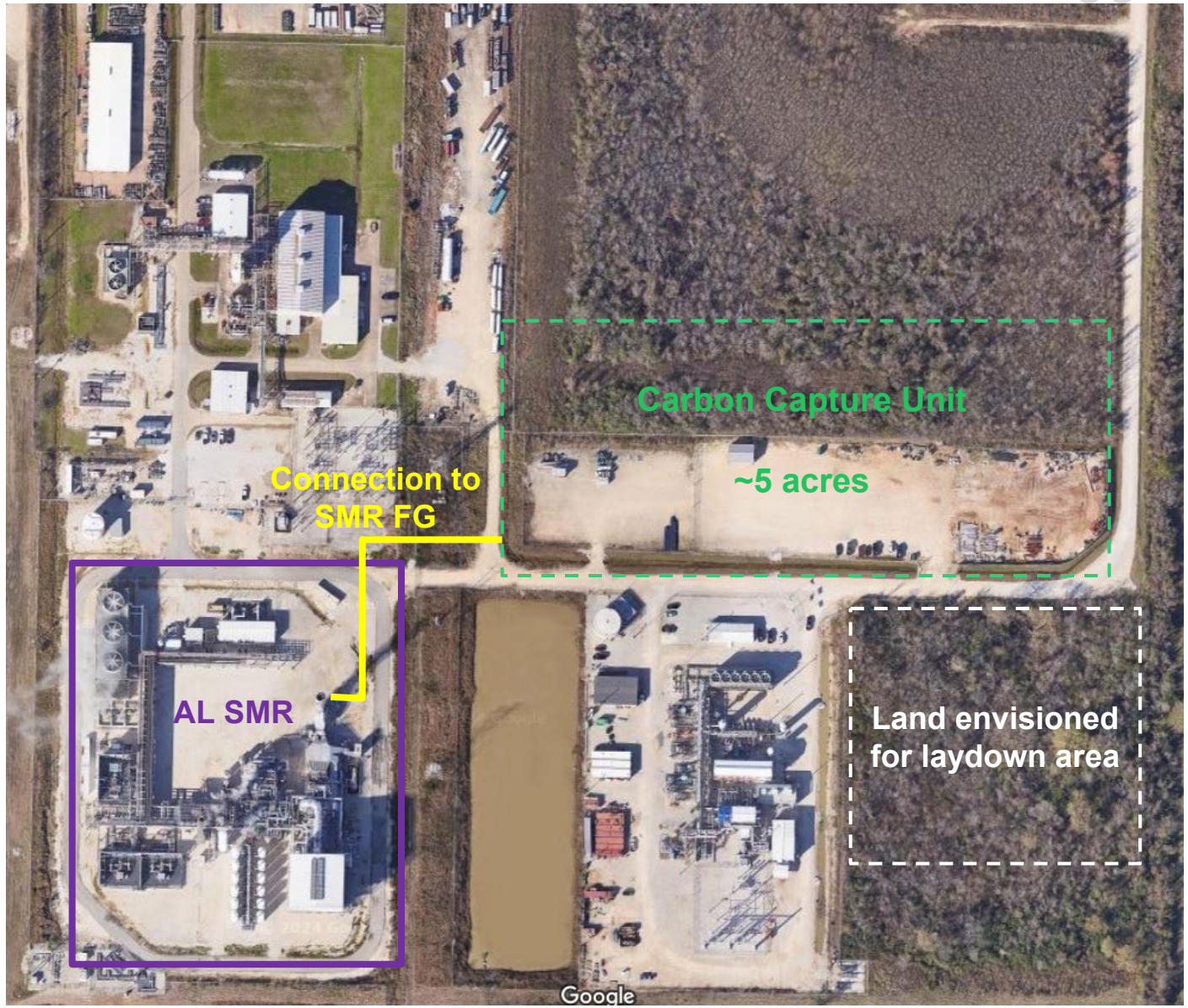
Parameters	CO_2-rich stream for sequestration
Temperature °F (°C)	< 105 (< 40)
Pressure psig (bar)	2,000 - 2,350 (138 - 163)
Composition	
CO_2	> 97 vol% (dry basis)
H_2S	< 10 ppmw
Total S	< 30 ppmw
Methane	< 3 vol%
Ethane plus	< 1 vol%
Oxygen	< 10 ppmw
Glycol	< 0.3 gallons per MMCF
Carbon monoxide	< 4,250 ppmw
NOx, SOx, PM, amines	< 1 ppmw each
Hydrogen	< 1 vol%
Mercury	< 5 ng/l
Ammonia	< 50 ppmw
Inert (incl. N_2 and Ar)	< 0.5 vol%
Liquids	Products shall be free of liquids at delivery conditions and shall not produce condensed liquids in the pipeline at specific pressure and temperature
Compressor lube oil carryover	Not more than 50 ppmw and shall not cause fouling of pipeline or any downstream systems/reservoirs

Cryocap™FG implantation at site

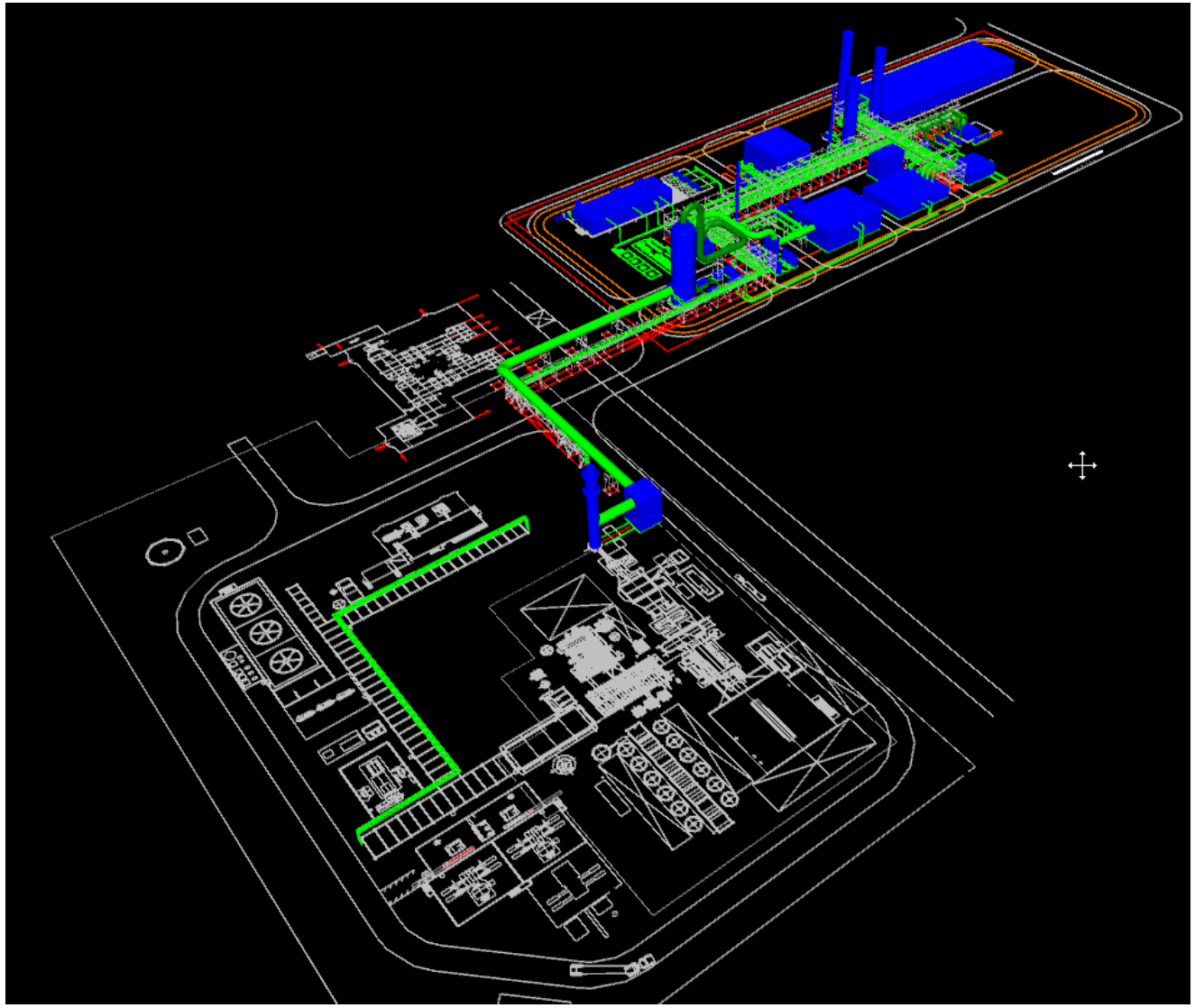
SMR Flue Gas Stack

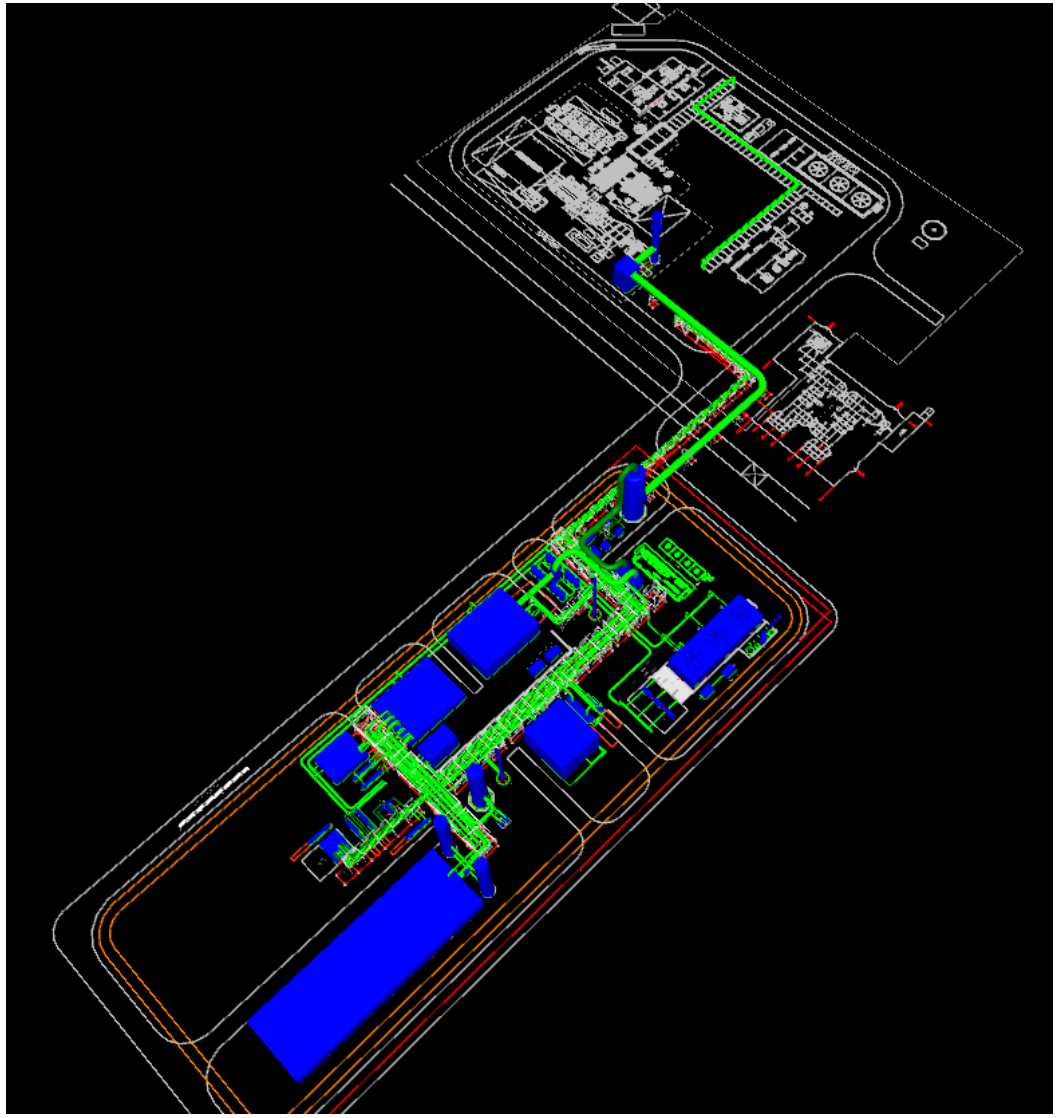


Site visit, Nov. 2023



Cryocap™FG 3D Model (ongoing)

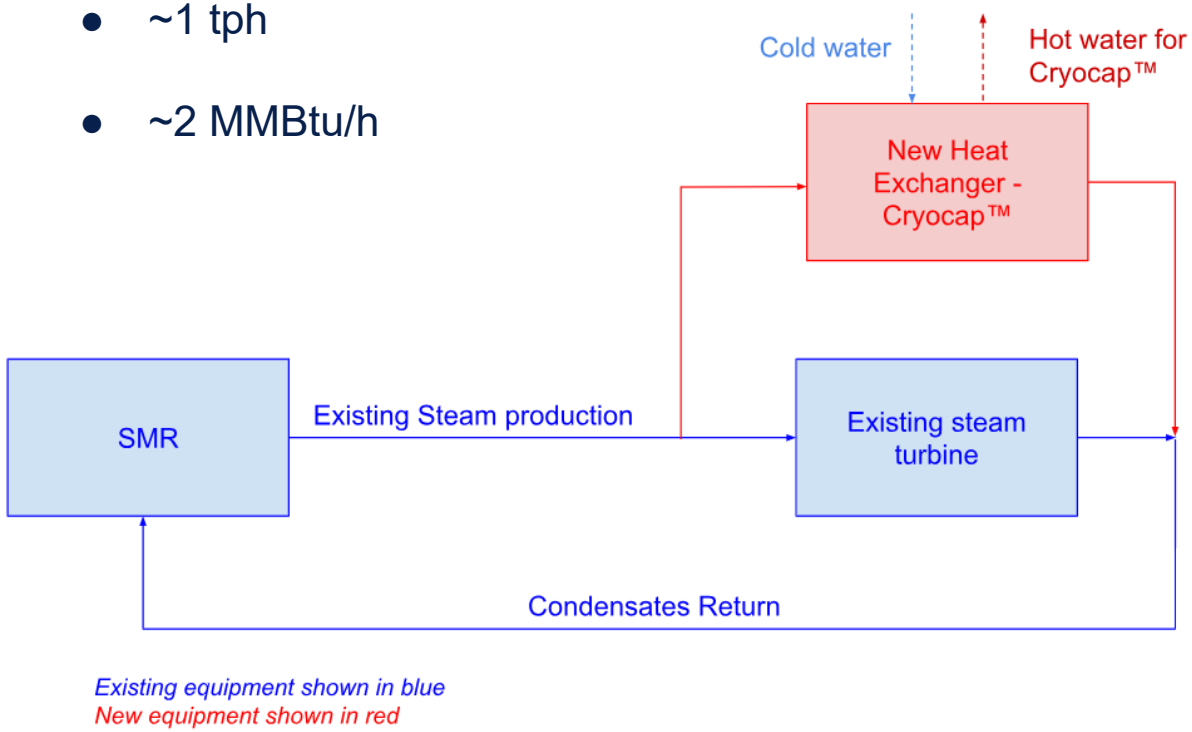




Integration with Existing Site: Steam and Wastewater Treatment

Steam duty

- ~1 tph
- ~2 MMBtu/h



Wastewater treatment: cooling tower blowdown

- ~140 gpm
- Combined with existing blowdown

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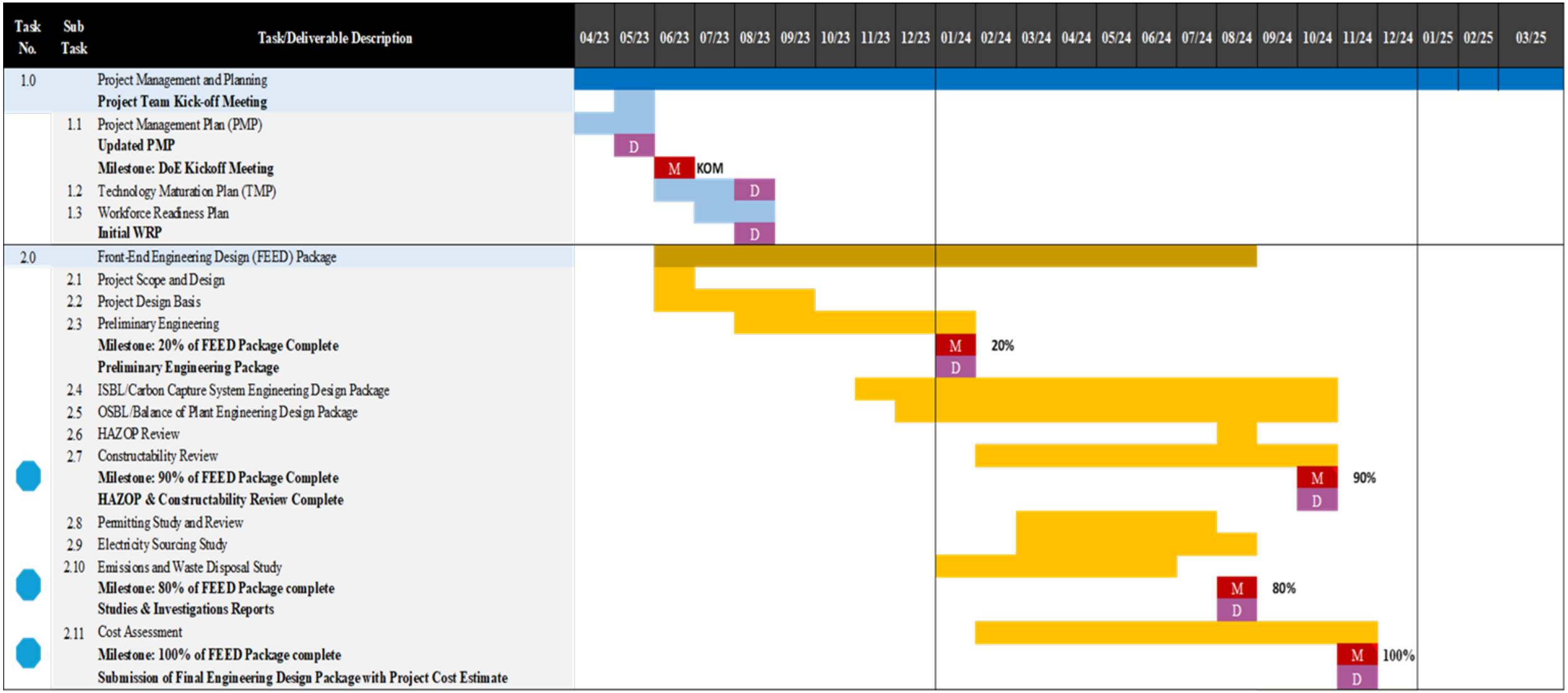
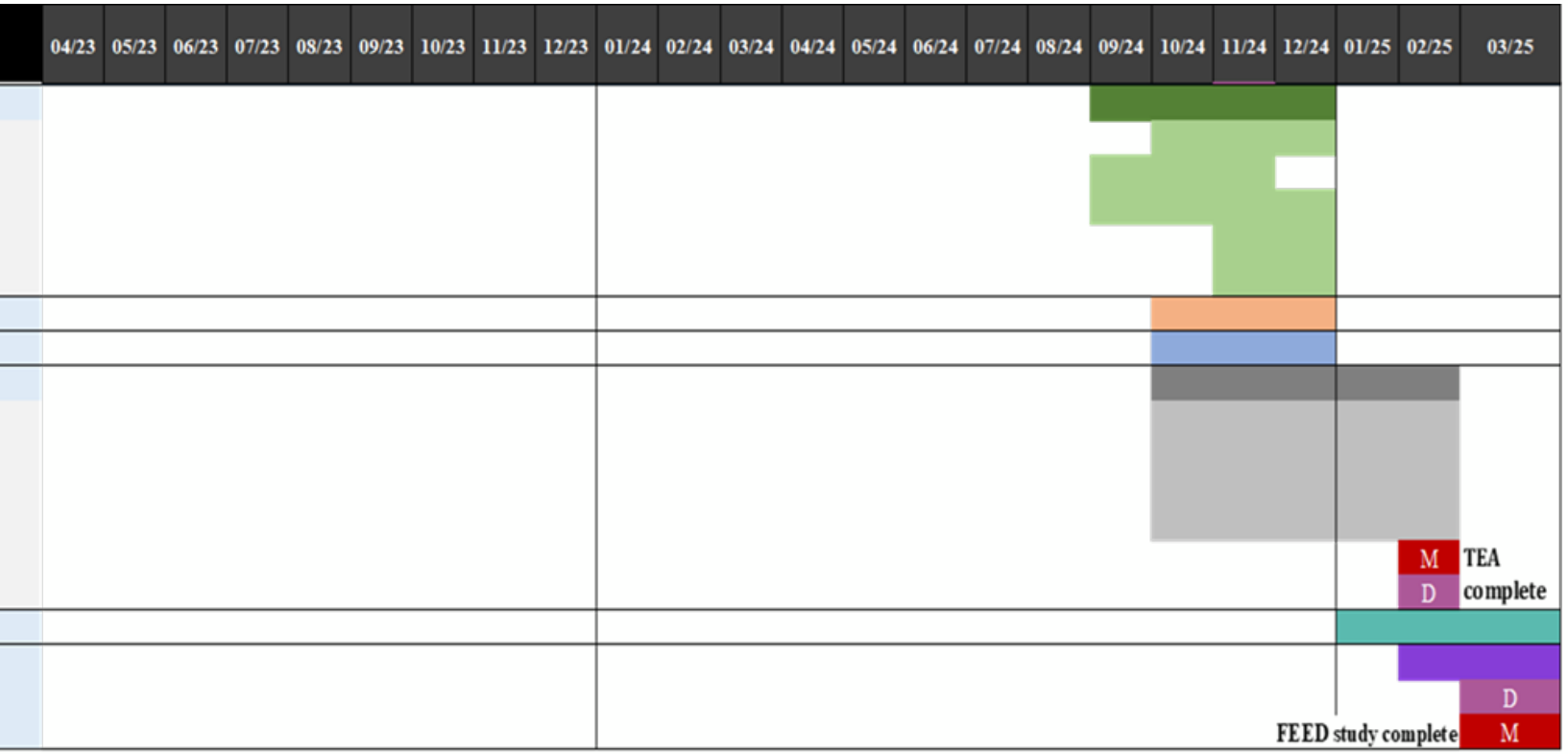
Project Timelines (1 of 2)



Key upcoming deliverables and milestones

Project Timelines (2 of 2)

Task No.	Sub Task	Task/Deliverable Description
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
		BCA, EH&S, LCA and TEA
7.0		Environmental Justice Analysis
8.0		Economic Revitalization and Job Creation Outcomes Analysis
		Environmental Justice, Economic Revitalization and Job Creation Questionnaires
		Milestone: Study Complete & Final Report Submission



Key upcoming deliverables and milestones

Budget Spending Till May 2024

Total project budget	Total budget	Share
Federal share	US$ 5,995 K	80%
Non-federal share	US$ 1,499 K	20%
Total	**US$ 7,494 K**	**100%**

Cost type	Apr 2023 – May 2024	Share	Remaining budget	% Remaining
Federal share	$ 3,098 K	80%	US$ 2,987 K	48%
Non-federal share	$ 774 K	20%	US$ 725 K	48%
Total	$ 3,872 K	**100%**	**$ 3,622 K**	**48%**

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