Engineering Study of Svante's Solid Sorbent CO_2 Capture Technology at Linde's SMR H_2 Plant

DOE Award No. DE-FE0032113

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Acknowledgement and Disclaimer

Acknowledgement

- This material is based upon work supported by the Department of Energy under Award Number DE-FE0032113.

Disclaimer

Project Overview

- Funding:

	Total	DOE	Linde		Svante/Kiewit	
			Scope	Share	Scope	Share
Budget	~$1.9 MM	$1.5 MM	~$1.0 MM	$0.2 MM	~$0.9 MM	~$0.18 MM

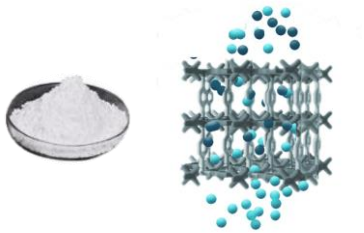
- Project duration: 26 months (October 2021 to November 2023)
- Project participants:

Project Objectives:

- Engineering design of a Svante solid sorbent post-combustion CO_2 capture technology at the H_2 Plant
- Site-specific engineering study
  - Capture CO_2 from SMR and aux. boiler flue gas and compress to 2200 psia – target 90% reduction vs. SMR baseline
  - Estimate CAPEX and OPEX and perform technoeconomic analysis to determine CO_2 capture cost

Meet the Svante Carbon Capture Ecosystem

Svante

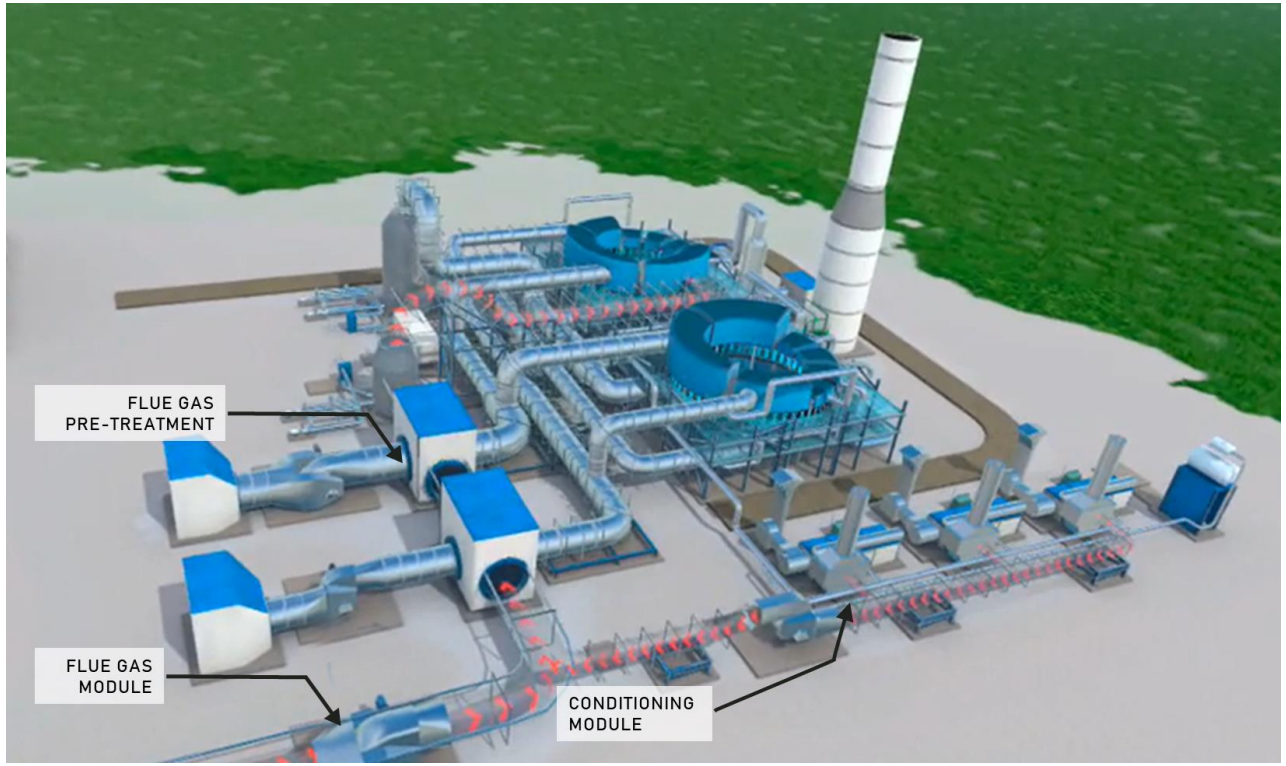


Solid Sorbents (MOFs)

Engineered to have high selectivity over water & high capacity for CO_2.

Nanoengineered Carbon Capture Filters

Solid sorbents laid onto thin sheets of film & stacked to create a filter.

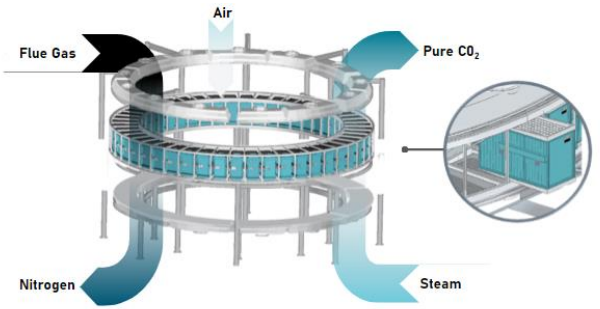


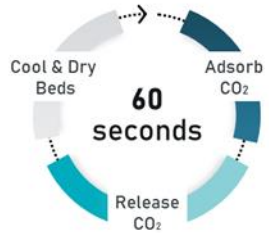
Carbon Capture Plant

The overall design, integration and optimization of the entire CO_2 capture plant that goes around the machine and process cycle.

Rotary Adsorption Machine (RAM) with Filters Inside

Solid sorbents laid onto thin sheets of film & stacked to create a filter.





Plan for Rapid Commercial Deployment in 2024/25

Svante

01 Manufacturing Capacity

Adsorbent Manufacturing Scale Up: BASF We create chemistry

SAB Manufacturing Facility: 10 - 1MMt/yr plants per year ~$100MM

02 Rotary Adsorption Machine

"Buck" In-house build of 14m RAM by 1st Quarter 2023

Design Two RAM Sizes: 14m | 500 TPD
24m | 2000 TPD

Seal Material Testing: Testing on Buck and test stations

03 Capture Plant Engineering

Scoping Studies: Expand pipeline of Class 4&5 projects

FEED To FID: Projects to FID 2024
SMR, Pulp & Paper, FCC, Cement

Gov't Funding: Jointly apply to US DOE and Canadian Gov't

04 Demonstrate KPI's

In house Dev: 3 Single bed test stations
3 Process Demonstration Units

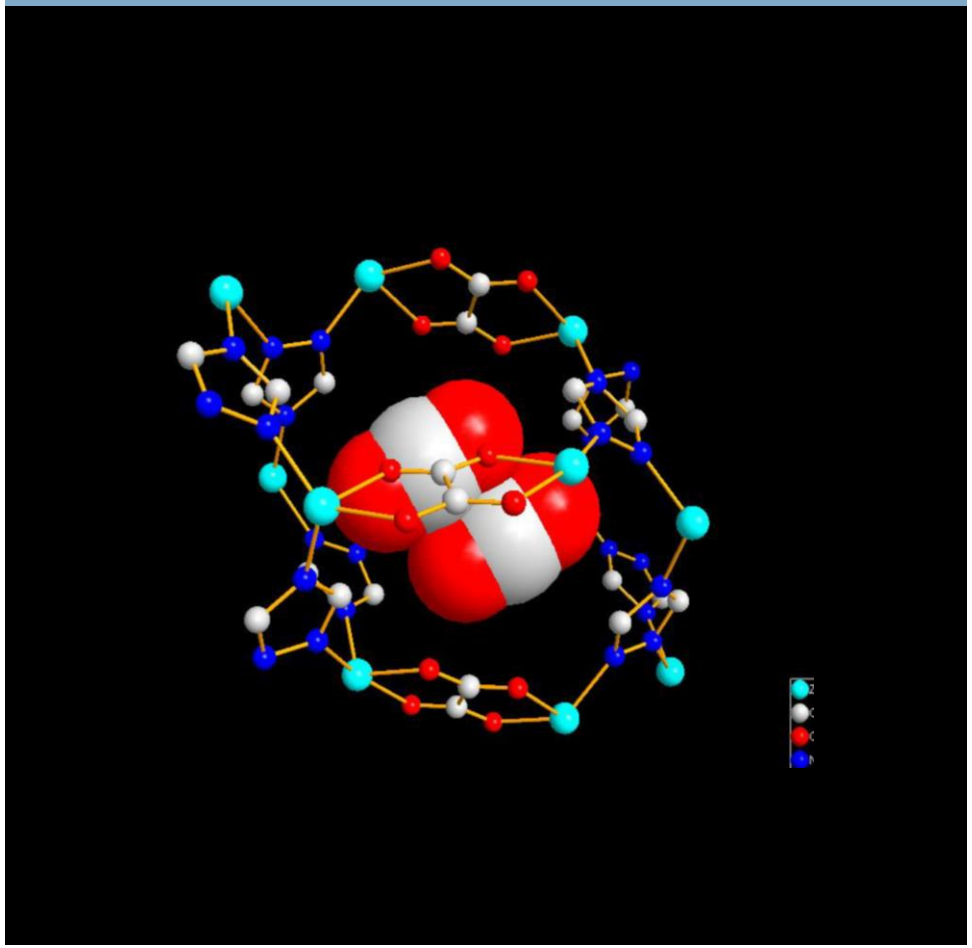
External Dev Pilots: Lafarge 1 TPD
Total Energies 0.1 TPD

External Large Pilots: Cenovus 30 TPD
Chevron 25 TPD

CALF-20, current status of process development

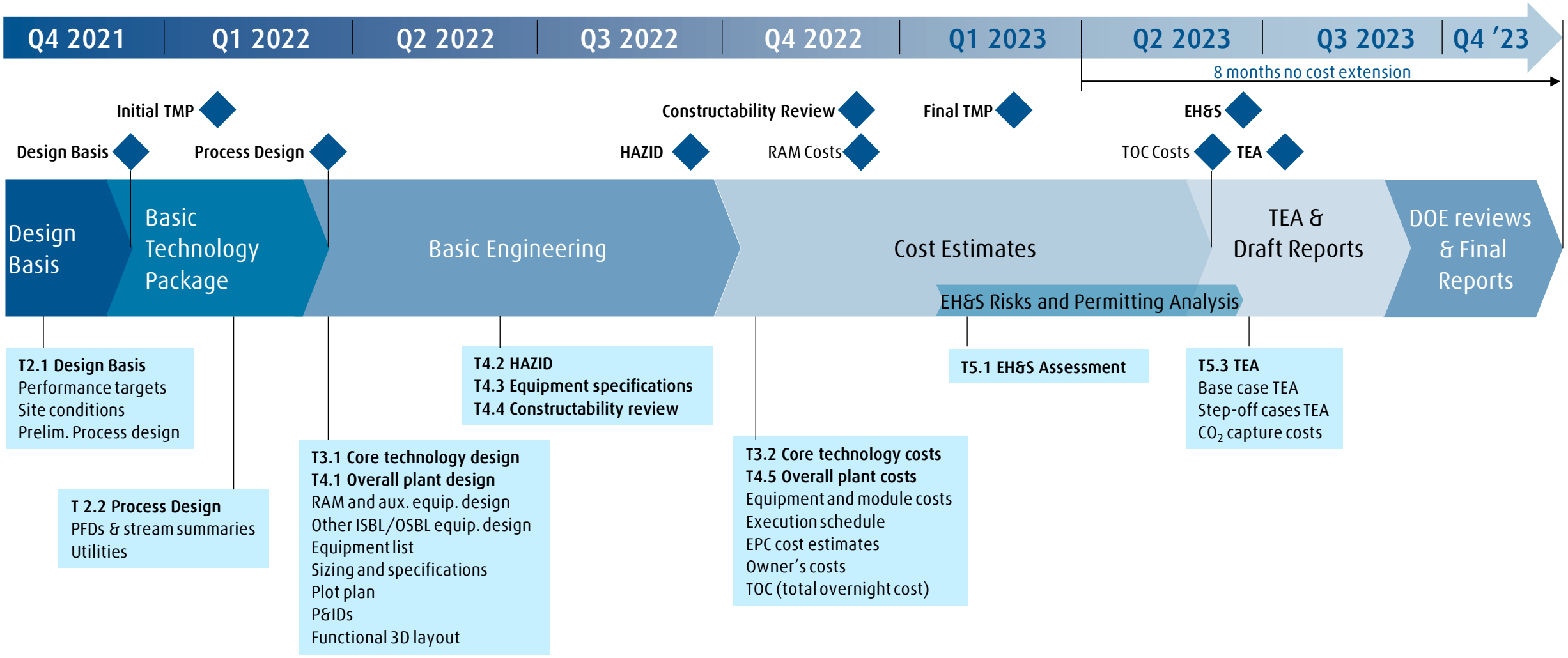
Svante

CALF-20 MOF



- Current application range between 8-25 % CO_2
- Main process characteristics:
  - Intrinsically lower regeneration energy compared to absorption process
  - No secondary degradation products detected due to stability of the structure minimizing environmental impact (emissions to air, waste, etc)
  - Regeneration taking place at vacuum allowing the use of non-utilized low value heat for regeneration not usable by other technologies
  - Flexible performance for processes allowing tight load following
- Carbon Capture plants using Svante Carbon Capture Ecosystem with CALF-20 currently in FEL2/FEL3
- Process improvements currently being validated:
  - Lower regeneration pressure to reduce energy requirements further
  - Simplification of cycles reducing electricity consumption
- Research into developing new MOF for lower concentrations

Technical Approach & Major Milestones



Project Success Criteria

Decision Point	Date	Success Criteria
End of Project goal	11/30/2023	Cost estimate completed for CO_2 capture and compression plant from SMR with accuracy of +/- 25%

→ +/-20% achieved

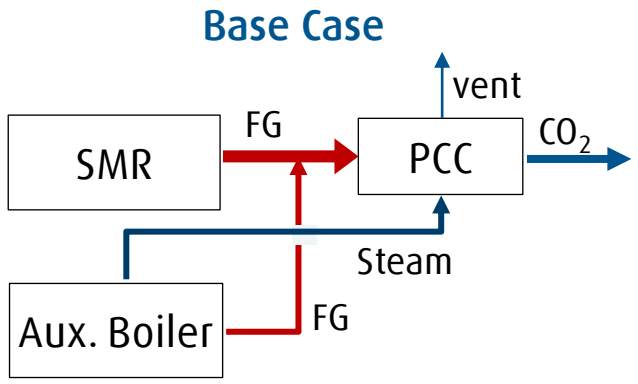
Host Site Selection

- One of the largest SMR H_2 plants in Linde's Gulf Coast fleet
  - Sufficient space available adjacent to existing SMR
  - Sufficient capacity for additional utilities
- 400+ miles of pipeline network connects multiple plants
  - Includes H_2 storage cavern
- Proximity to CO_2 sequestration sites
  - Saline aquifers
  - Depleted oil and gas fields
  - Large storage capacities for >20 years operation

Design Basis – Base CCS Case

Svante

Linde



Feeds at 100%	SMR	Aux. Boiler
Temperature, F	~300	~317
Pressure, psia	14.7	14.7
N_2 + Ar + O_2	~66%	~75%
CO_2	~16%	~8%
H_2O	~18%	~17%
Trace impurities	< 100 ppm	<100 ppm

CO_2 Product Specifications	
CO_2 purity	>95%
Temperature, F	<120 F
Pressure, psia	2200
Water	< 630 ppm
Oxygen	<10 ppm
Nitrogen	<4%

- Plant concept
  - Single train design; two RAMs
  - 100% PCC Unit Steam Supplied by new Aux Boiler
  - CO_2 captured from SMR and Aux Boiler flue gas to achieve 90% reduction vs. baseline
- Equipment is sized for 110% of normal capacity
- CO_2 capture capacity is ~1.435 million tonnes/year at 100% of normal operation

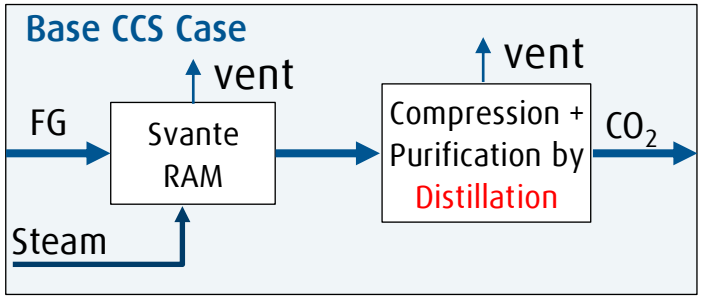
CCS Cases

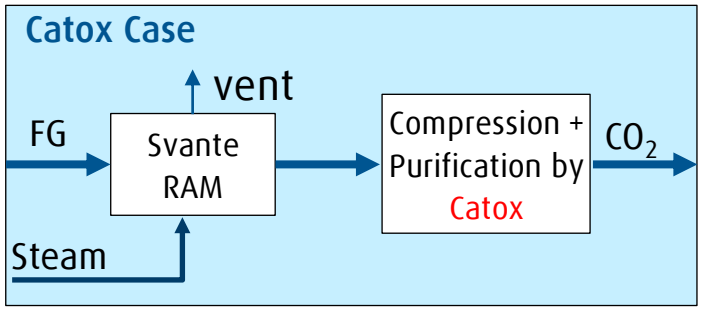
- Base CCS Case – Main focus of the engineering study
  - CO_2 separation by Svante RAM to produce ~95% purity CO_2; ~92.3 % recovery
  - Linde CO_2 purification process to meet <10 ppm O_2 spec; ~99.7% recovery

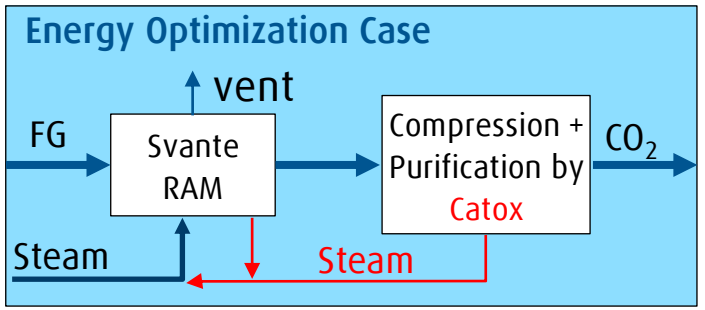
Two step-off cases evaluated – Detailed HMB and utilities estimates; Budgetary cost estimates

- Catox Case
  - CO_2 purification by catalytic oxidation with H_2 to remove residual O_2
  - 100% CO_2 recovery in purification section

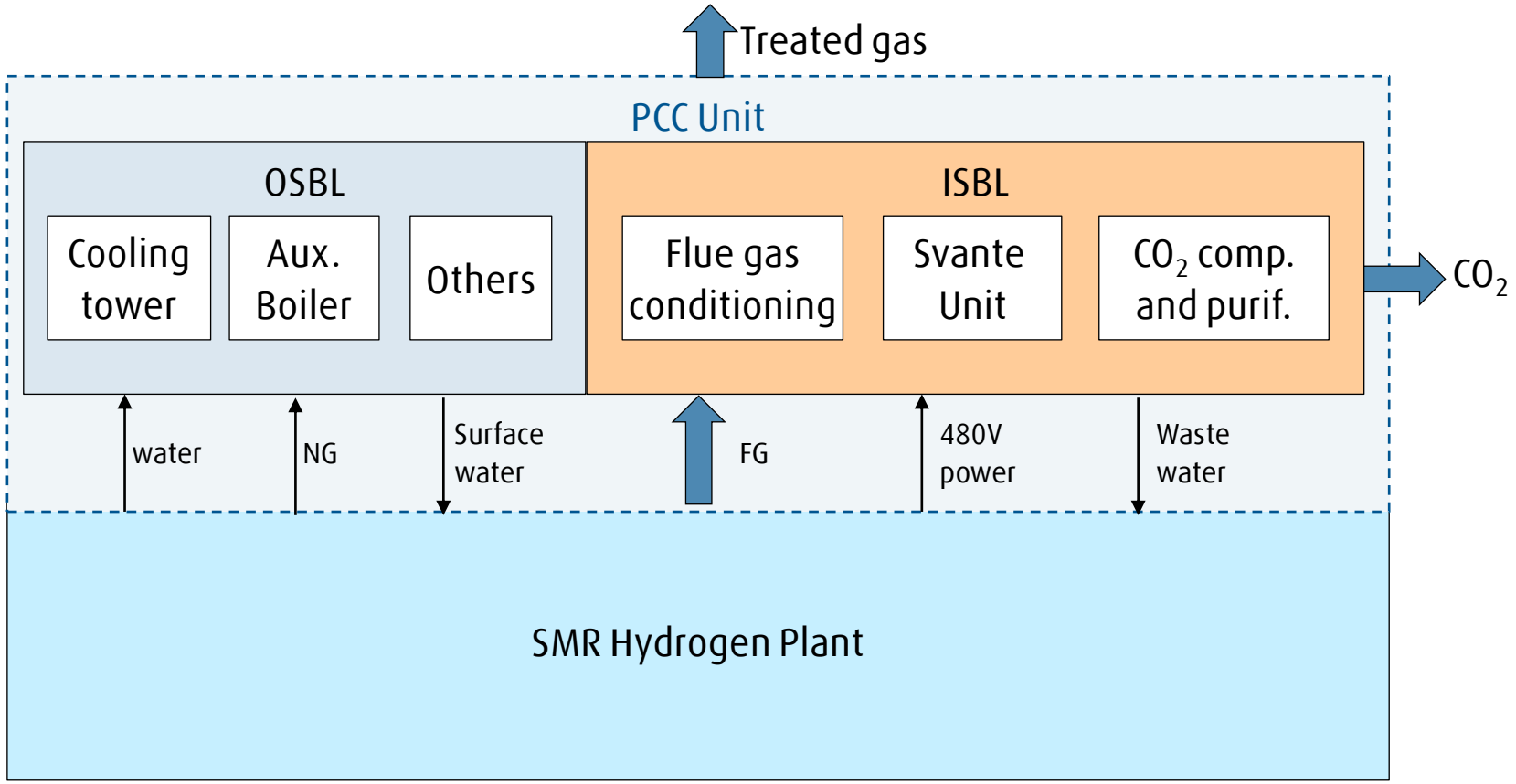
- Energy Optimization Case
  - Heat of CO_2 compression and heat from CO_2 separation section (RAM) used to generate part of steam
  - Reduces NG consumption by ~20% and overall CO_2 volume by ~5%



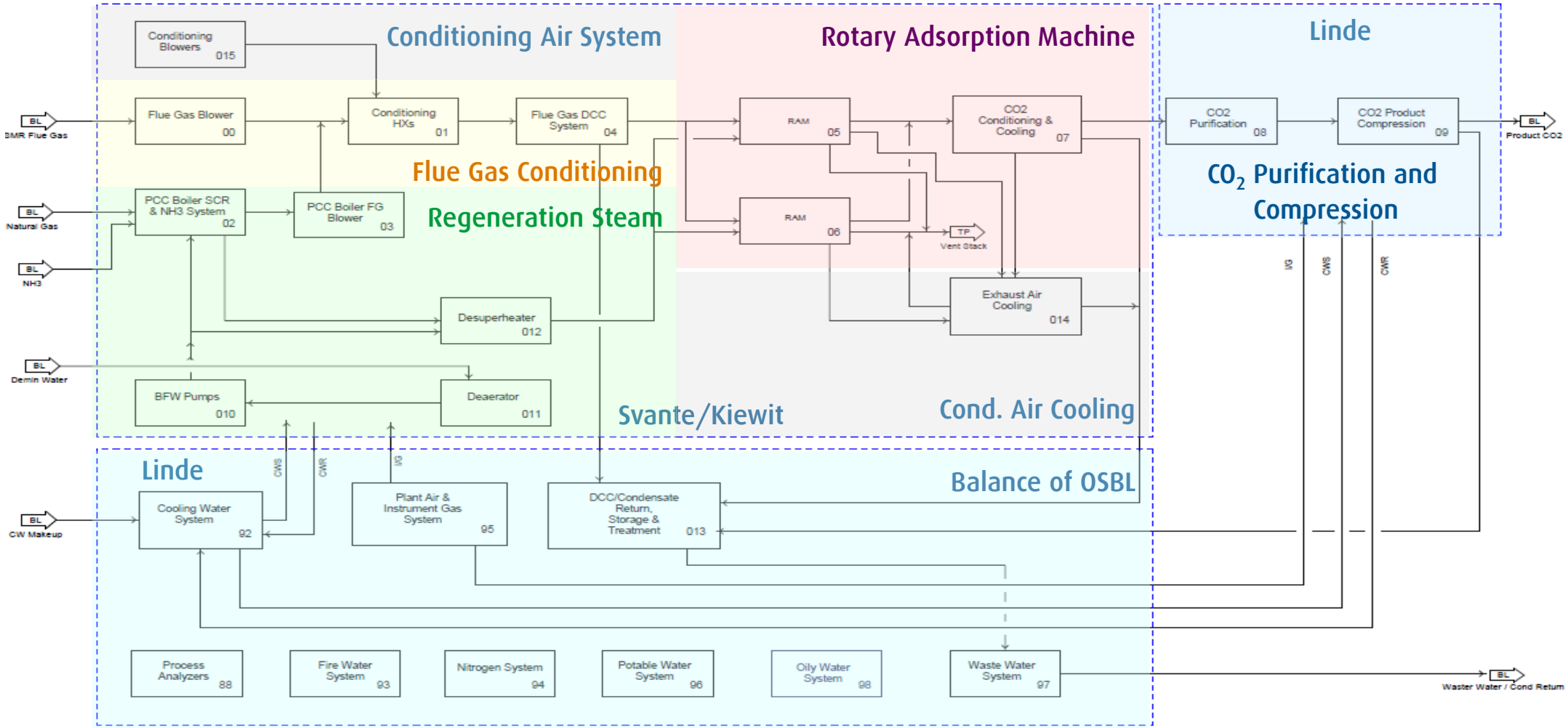




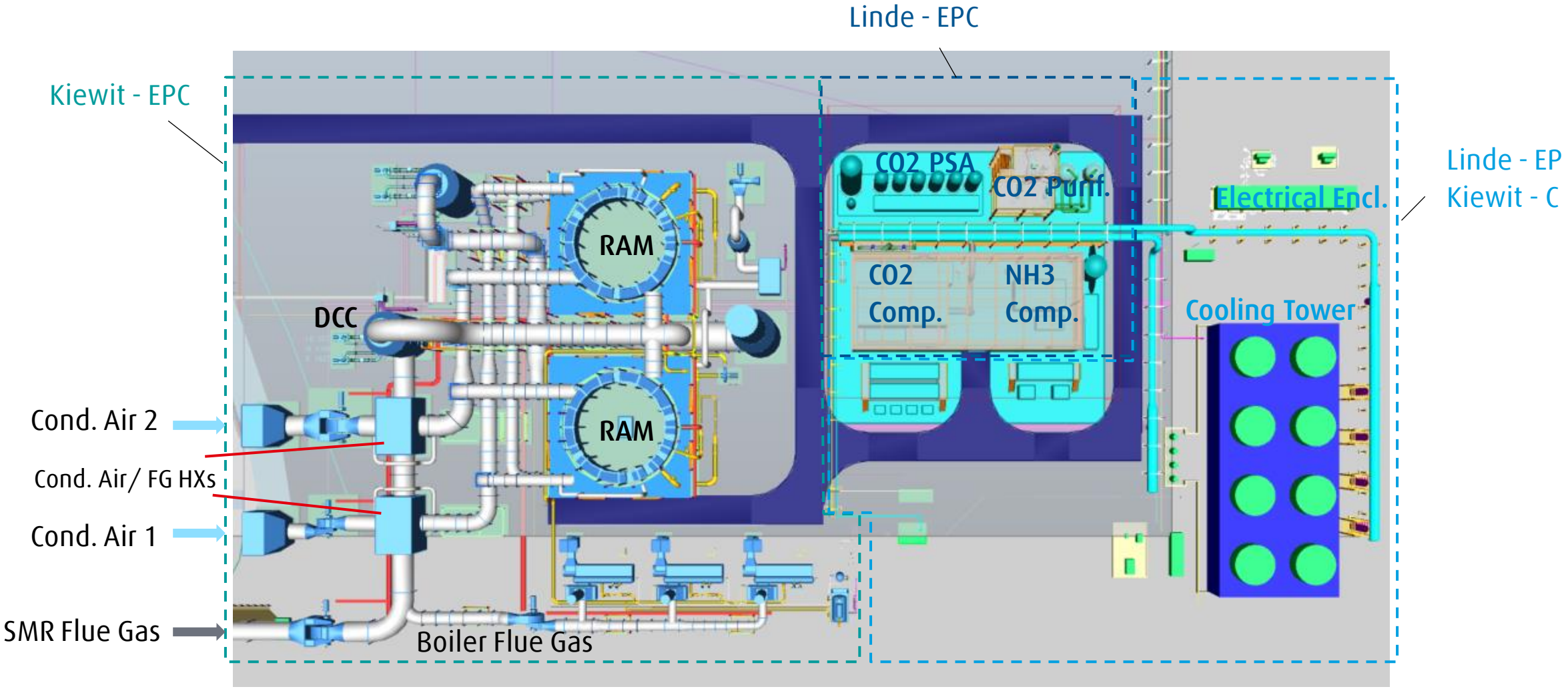
System Boundary



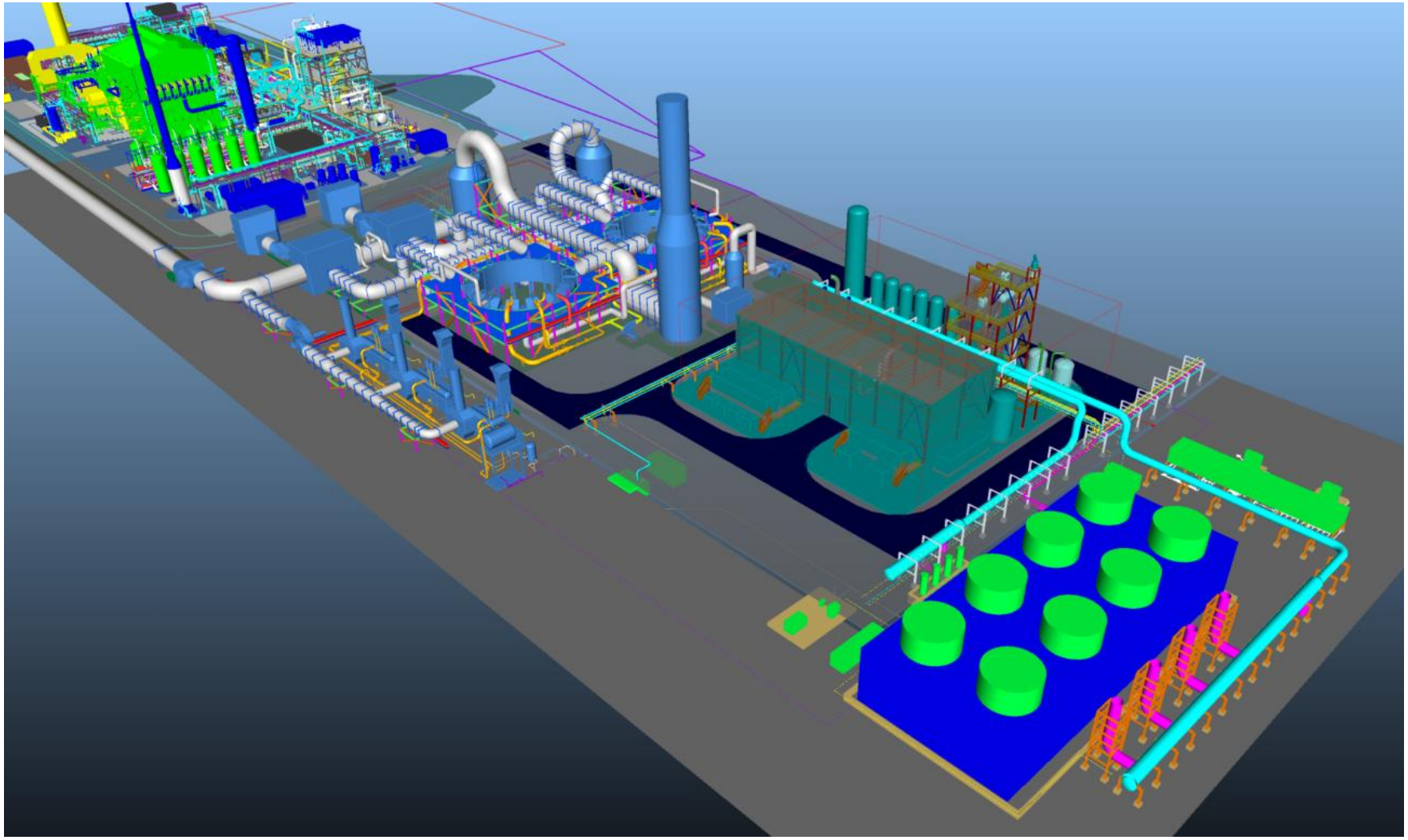
BFD
Base Case



Plot Plan
Base Case



3D Model
Base Case

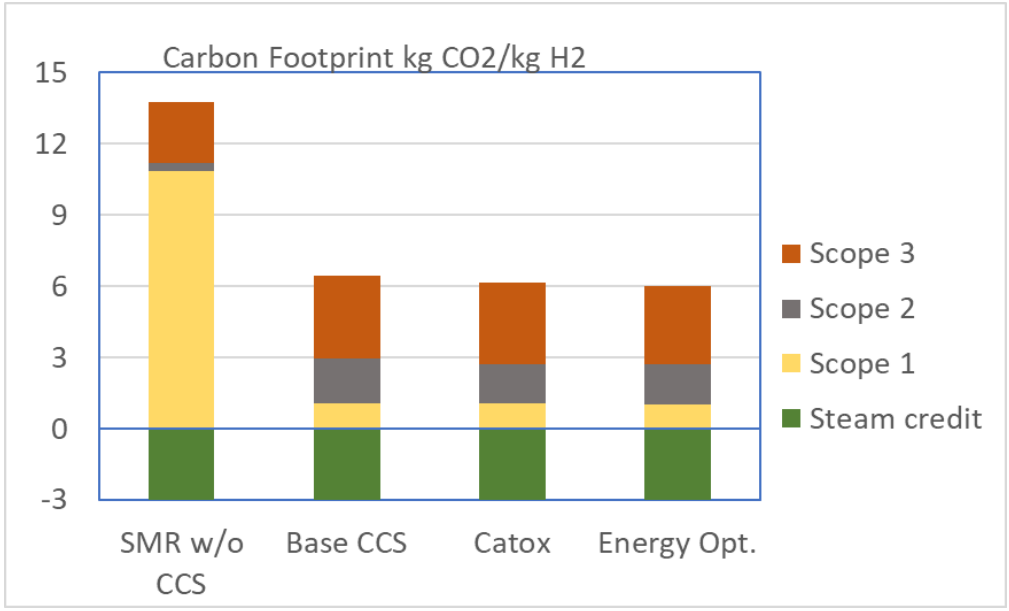


Performance Summary

Process Performance

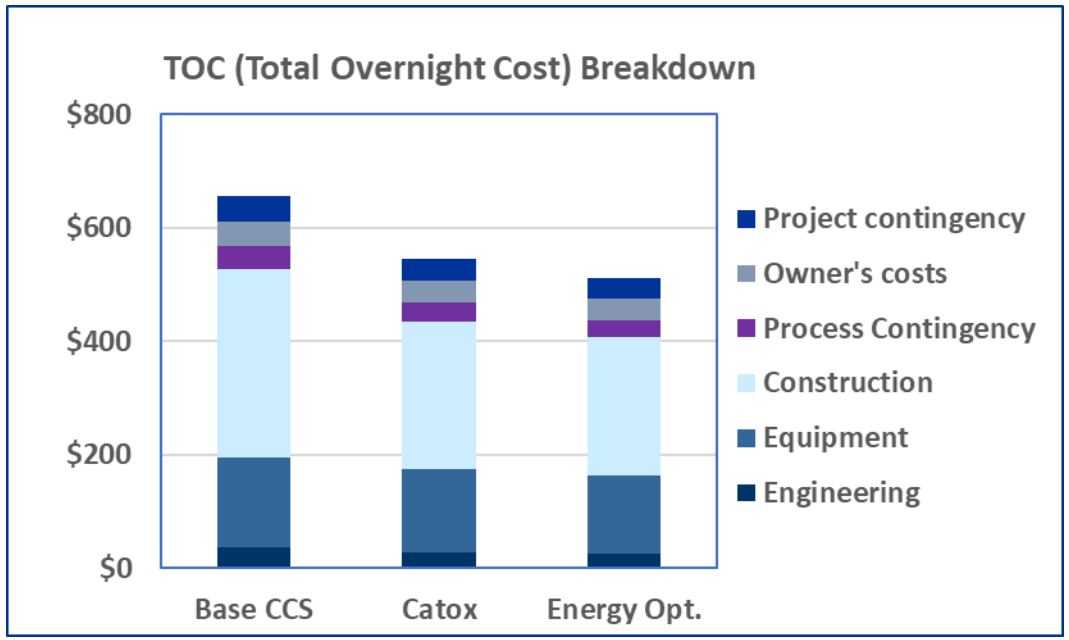
Value/T CO_2	Base CCS	Catox	Energy Opt.
NG, GJ (HHV)	3.9	3.9	3.0
Power, kWh	322	272	290
Water, gal	950	910	770
Demin water, gal	125	125	120
CW blowdown, gal	275	260	225
FG Condensate, gal	100	100	95

Carbon Footprint



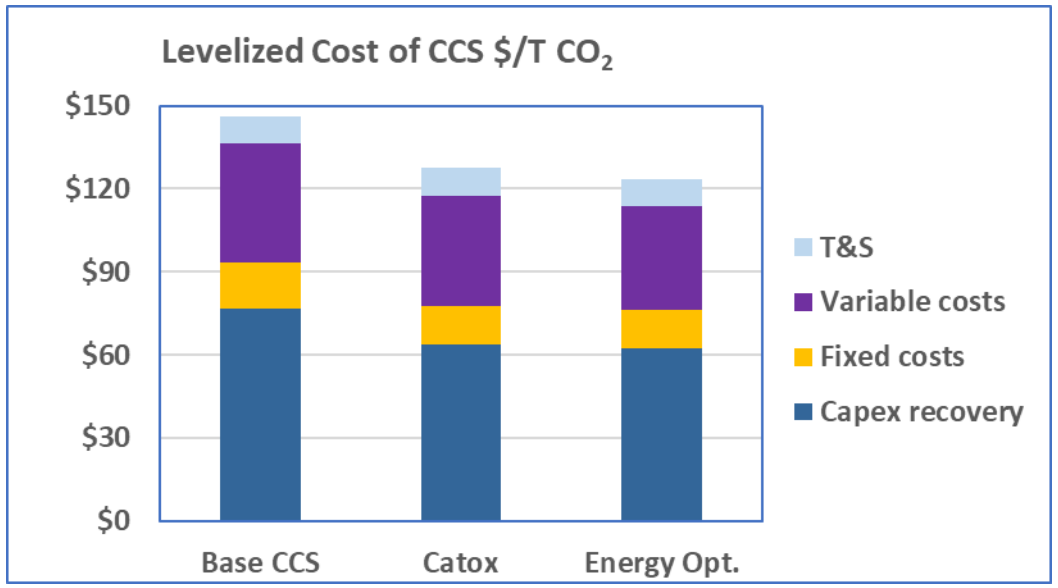
- Significant reduction in power (~10%) and NG requirements (~24%) in the energy optimization case
- Carbon intensity (CI) reduced from ~13.7 kg CO2/kg H_2 in no CCS case to ~6 in the energy opt. CCS case
  - Scope 1 CI reduction of ~9.8 offset partly by increase in Scope 2 and Scope 3 CI values

CAPEX Estimate



- Equipment costs generally in line with the expectations
- Construction accounted for large portion of total
- Capex for the Catox cases showed significant improvement due to simpler CO_2 purification process
- Energy Optimization case resulted in further improvement due to simpler layout for large ducts and ~5% lower CO_2 volume

Technoeconomic Analysis Results



CCS – CO_2 capture and storage

Key TEA Assumptions	
Project life, yrs	15
Equity	100%
Real $ cost of equity	7.84%[1]
Capacity factor, %	90%
Fixed costs, % of TOC/yr	3.3%
TASC[2]/TOC ratio	1.14[1]
Capex recovery factor, % of TASC/yr	13.2%[1]
LFP[3] for NG, $/MMBtu HHV	$4.17
Power, $/MWh	$71.7
Water, $/1000 gal	$1.90

1 Financial parameters from 'QGESS Cost Estimation Methodology ..' NETL-PUB-22580
2 TASC – Total as-spent cost
3 Levelized fuel price

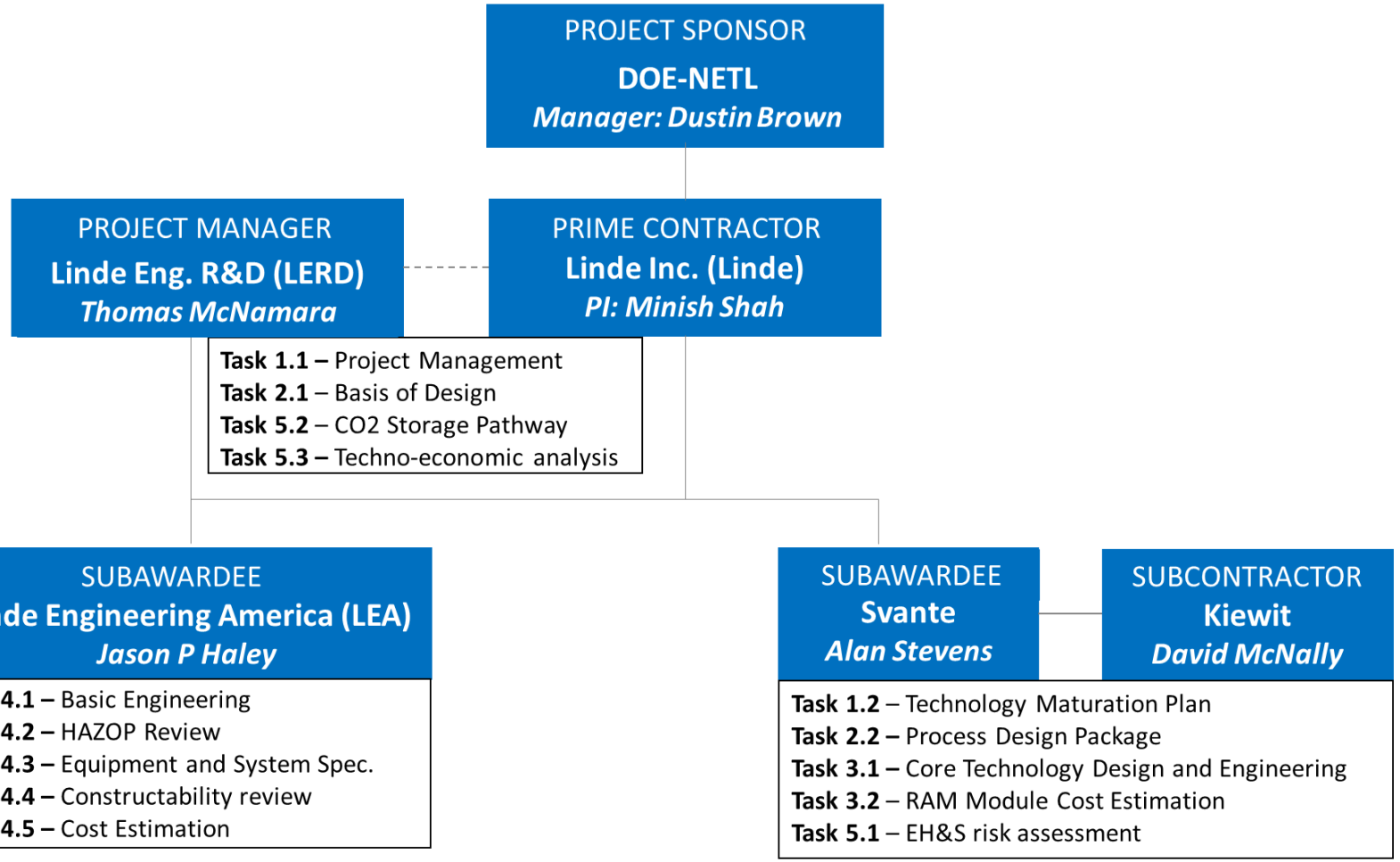
- NETL methodology adapted for levelized cost of CO_2 capture
- CCS cost for the base case is projected to be $146/T CO_2
- It decreases to ~$124/T CO_2 for the energy optimization case
- Further improvements needed for financial viability based on 45Q tax credits

Summary

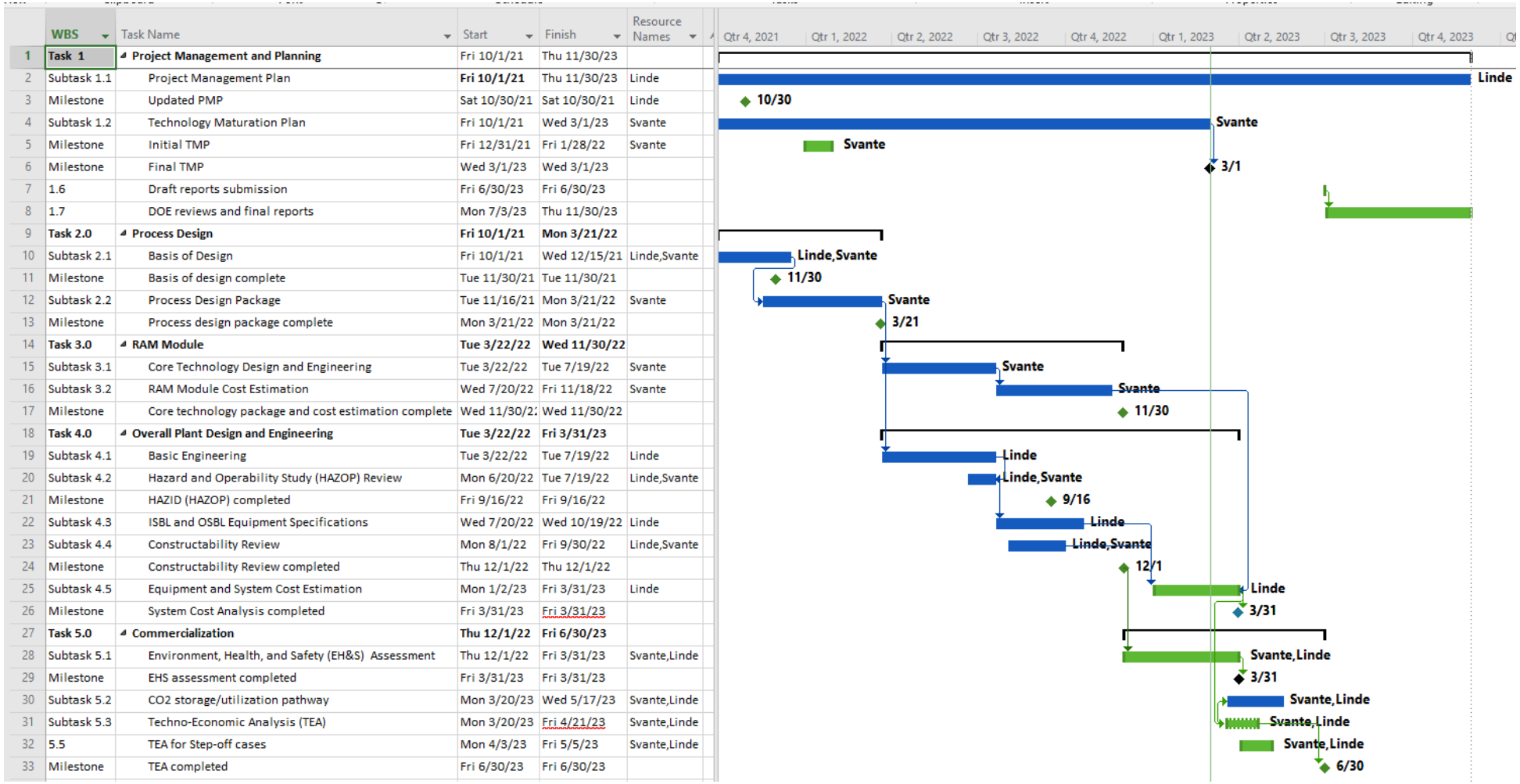
- Completed site-specific engineering study for retrofitting Linde's SMR H_2 plant with Svante's PCC technology
- System designed to reduce ~90% Scope 1 CO_2 emissions
- Capture capacity of ~1.435 MM tonnes/yr
- With energy optimization and simpler CO_2 purification, CCS cost is projected to be $124/T CO_2
- Further technology improvements needed for financial viability based on 45Q tax credits
- Process improvements currently being validated by Svante will increase likelihood of attaining financial viability

Backup

Organization Chart



Gantt Chart



	WBS	Task Name	Start	Finish	Resource Names
1	**Task 1**	**Project Management and Planning**	Fri 10/1/21	Thu 11/30/23	
2	Subtask 1.1	Project Management Plan	**Fri 10/1/21**	Thu 11/30/23	Linde
3	Milestone	Updated PMP	Sat 10/30/21	Sat 10/30/21	Linde
4	Subtask 1.2	Technology Maturation Plan	Fri 10/1/21	Wed 3/1/23	Svante
5	Milestone	Initial TMP	Fri 12/31/21	Fri 1/28/22	Svante
6	Milestone	Final TMP	Wed 3/1/23	Wed 3/1/23	
7	1.6	Draft reports submission	Fri 6/30/23	Fri 6/30/23	
8	1.7	DOE reviews and final reports	Mon 7/3/23	Thu 11/30/23	
9	**Task 2.0**	**Process Design**	**Fri 10/1/21**	**Mon 3/21/22**	
10	Subtask 2.1	Basis of Design	Fri 10/1/21	Wed 12/15/21	Linde,Svante
11	Milestone	Basis of design complete	Tue 11/30/21	Tue 11/30/21	
12	Subtask 2.2	Process Design Package	Tue 11/16/21	Mon 3/21/22	Svante
13	Milestone	Process design package complete	Mon 3/21/22	Mon 3/21/22	
14	**Task 3.0**	**RAM Module**	**Tue 3/22/22**	**Wed 11/30/22**	
15	Subtask 3.1	Core Technology Design and Engineering	Tue 3/22/22	Tue 7/19/22	Svante
16	Subtask 3.2	RAM Module Cost Estimation	Wed 7/20/22	Fri 11/18/22	Svante
17	Milestone	Core technology package and cost estimation complete	Wed 11/30/22	Wed 11/30/22	
18	**Task 4.0**	**Overall Plant Design and Engineering**	**Tue 3/22/22**	**Fri 3/31/23**	
19	Subtask 4.1	Basic Engineering	Tue 3/22/22	Tue 7/19/22	Linde
20	Subtask 4.2	Hazard and Operability Study (HAZOP) Review	Mon 6/20/22	Tue 7/19/22	Linde,Svante
21	Milestone	HAZID (HAZOP) completed	Fri 9/16/22	Fri 9/16/22	
22	Subtask 4.3	ISBL and OSBL Equipment Specifications	Wed 7/20/22	Wed 10/19/22	Linde
23	Subtask 4.4	Constructability Review	Mon 8/1/22	Fri 9/30/22	Linde,Svante
24	Milestone	Constructability Review completed	Thu 12/1/22	Thu 12/1/22	
25	Subtask 4.5	Equipment and System Cost Estimation	Mon 1/2/23	Fri 3/31/23	Linde
26	Milestone	System Cost Analysis completed	Fri 3/31/23	Fri 3/31/23	
27	**Task 5.0**	**Commercialization**	**Thu 12/1/22**	**Fri 6/30/23**	
28	Subtask 5.1	Environment, Health, and Safety (EH&S) Assessment	Thu 12/1/22	Fri 3/31/23	Svante,Linde
29	Milestone	EHS assessment completed	Fri 3/31/23	Fri 3/31/23	
30	Subtask 5.2	CO2 storage/utilization pathway	Mon 3/20/23	Wed 5/17/23	Svante,Linde
31	Subtask 5.3	Techno-Economic Analysis (TEA)	Mon 3/20/23	Fri 4/21/23	Svante,Linde
32	5.5	TEA for Step-off cases	Mon 4/3/23	Fri 5/5/23	Svante,Linde
33	Milestone	TEA completed	Fri 6/30/23	Fri 6/30/23	

Thank you for your attention.

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