RTI INTERNATIONAL

Carbon Capture Plant FEED Study for Cement Manufacturing

DE-FE003220

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2024 FECM / NETL Carbon Management Research Project Review Meeting

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DE-FE0032220 : Carbon Capture Plant FEED Study for Cement Manufacturing

- Complete FEED study for CO_2 capture from cement flue gas using RTI's non-aqueous solvent (NAS) with 95% capture efficiency
- Develop AACE Class 3 cost estimate for a commercial 1,600,000 t-CO_2/year scale CO_2 capture system integrated with a cement facility
- Project Funding:

US DOE	$3.68 MM
Cost-share	$0.92 MM
TOTAL	$4.60 MM

- Period of Performance (21 months)

  April 14, 2023 – Jan 13, 2025

R&D Strategic Approach

Breakdown of the Thermal Regeneration Energy Load

$$q_R = \left[\frac{C_P(T_R - T_F)}{\Delta\alpha} \cdot \frac{M_{sol}}{M_{CO_2}} \cdot \frac{1}{x_{sol}}\right] + \left[\Delta H_{V,H_2O} \cdot \frac{p_{H_2O}}{p_{CO_2}} \cdot \frac{1}{M_{CO_2}}\right] + \left[\frac{\Delta H_{abs,CO_2}}{M_{CO_2}}\right]$$

Reboiler Heat Duty

Sensible Heat

Heat of Vaporization

Heat of Absorption

Heat of vaporization of water becomes a negligible term to the heat duty

Sensible heat term is decreased due to lower heat capacity, higher loadings, and higher amine concentration relative to baseline

NAS Technology

NAS - formulation of hydrophobic amine, an organic diluent and water (0-10 wt.%)

Negligible heat of vaporization	▪ Lowers specific reboiler duty (SRD ~ 2.3-2.4 GJ/t-CO_2)
Low heat capacity	▪ Lowers SRD ▪ Requires intercooling of the absorber ▪ Larger lean/rich heat exchanger
Regeneration temperature < 100 °C	▪ Use of lower quality steam
Higher pressure regeneration	▪ leading to elimination of the 1^{st} stage of CO_2 compression lowering OPEX and CAPEX
Lower corrosion compared to aqueous solvents	▪ Use of lower cost materials of construction leading to lower CAPEX.
Faster CO_2 absorption kinetics	▪ Reduces column height lowering CAPEX
Commodity scale production of NAS components	▪ Ready for scale-up and commercialization

Technology Overview – NAS Technology Development Path

Lab-Scale Development & Evaluation

(2010-2013)

Solvent screening and lab-scale evaluation

0.0015 t-CO_2/day

TRL 2-3

Large Bench-Scale System (RTI facility)

(2014-2016)

Demonstration of key process features (≤ 2.3 GJ/t CO_2) at bench scale

0.11 t-CO_2/day

TRL 4

Pilot Testing at Tiller Plant Norway,

(2015-2018)

Demonstration of all process components at pilot scale

1.0 t-CO_2/day

TRL 5

Pilot Testing at SSTU, NCCC

(2018)

Degradation, emission, corrosion characterizations under real flue gas

1.1 t-CO_2/day

TRL 5

Engineering-Scale Validation, TCM, Norway

(2018-2022)

Pre-commercial demonstration at TCM, Norway (~12 MWe)

220 t-CO_2/day

TRL 6

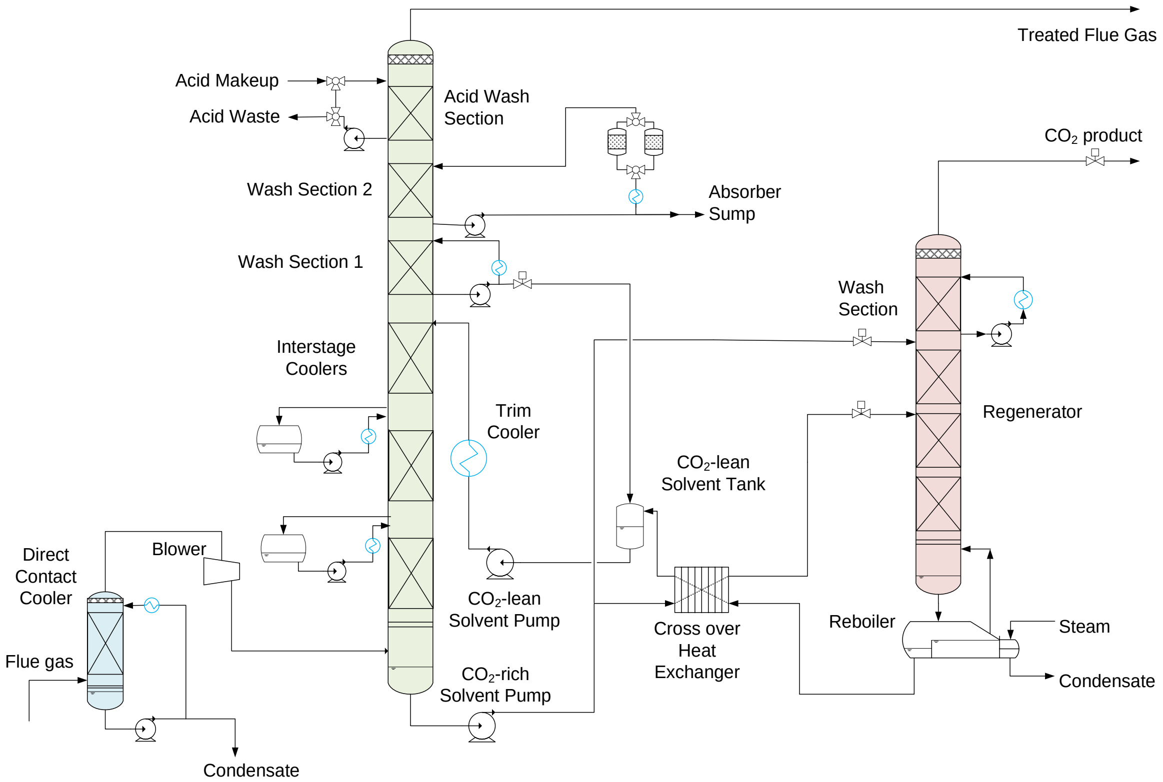
Summary of SOPO Tasks

- Task 1 - Project Management and Planning
- ✓ Task 2 - Project Design Basis Definition
- ✓ Task 3 - Basic Design Package (BDP)
- Task 4 - Front-End Engineering Design Study
- Task 5 - Tech to Market

Host site – Balcones Plant

- Host site - CEMEX Balcones plant Located in New Braunfels, TX
- 2 cement kilns with combined design capacity of 6,725 tons clinker/day.
- Selective non-catalytic reduction (SNCR) to reduce NO_X
- Dry sorbent injection (DSI) to reduce SO_X
- Fabric filter baghouse to reduce particulate matter (PM)
- CO_2 emissions of 1.5 MM tonnes per year.
- 11-12% CO_2 in the flue gas.
- SO_2 is < 5 ppm, NO_X is 20-230 ppm.
- capture 95% of cement plant emissions + emissions from the natural gas steam boiler
- Limited water availability

NAS Process Flow Diagram



- DCC for flue gas conditioning
- Absorber intercoolers
- Kettle / Forced recirculation reboiler
- Reboiler temperatures <120 °C
- CO_2 regeneration up to 4.5 bar

- Emissions Control
  - Dual water wash
  - Activated carbon beds
  - Acid wash for treated gas polishing, demonstrated at engineering scale at TCM

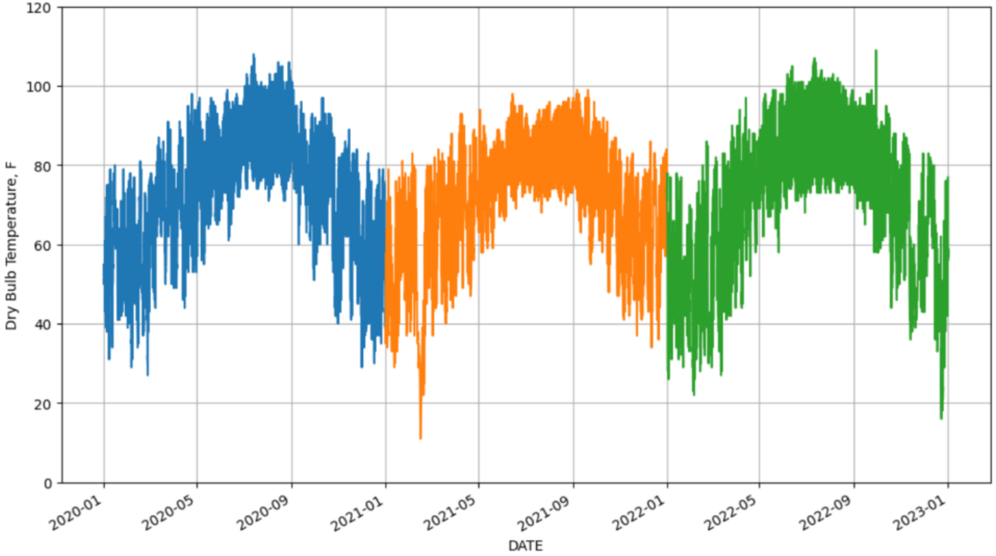
Task 2: Site Data and Design Basis Document

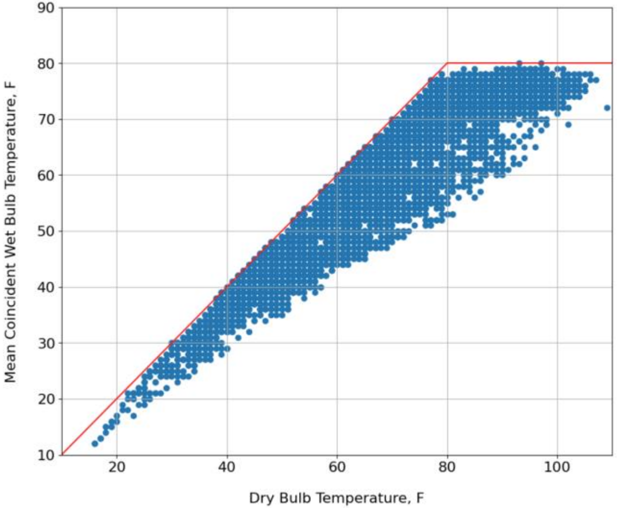
- ✓ Host site data
- ✓ Ambient conditions
- ✓ Detailed flue gas composition and flow conditions (T,P)
- ✓ CO_2 design specifications
- ✓ Applicable codes and standards for engineering design
- ✓ Design margin and sparing philosophy
- ✓ NAS Basis of Design

Task 3 – Basic Design Package

- ✓ Develop a BDP of the proposed CO_2 capture plant that will later be refined into the FEED package
  - ✓ Integration points with the cement plant
  - ✓ Process Flow Diagrams (PFD)
  - ✓ Heat and Materials Balance (HMB)
  - ✓ Sized Equipment List
  - ✓ Required Utilities
  - ✓ Identify areas for detailed evaluation
    - Cooling strategy and sourcing of makeup water for cooling towers
    - CO_2 product polishing to meet pipeline specifications

New Braunfels – Ambient temperature conditions, 2020-2022





- MCWBT of 80 °F allows for process temperatures of 95 °F
  - 9 °F / 5 °C approach T for heat exchangers
  - 6 °F / 3.5 °C approach T for cooling tower

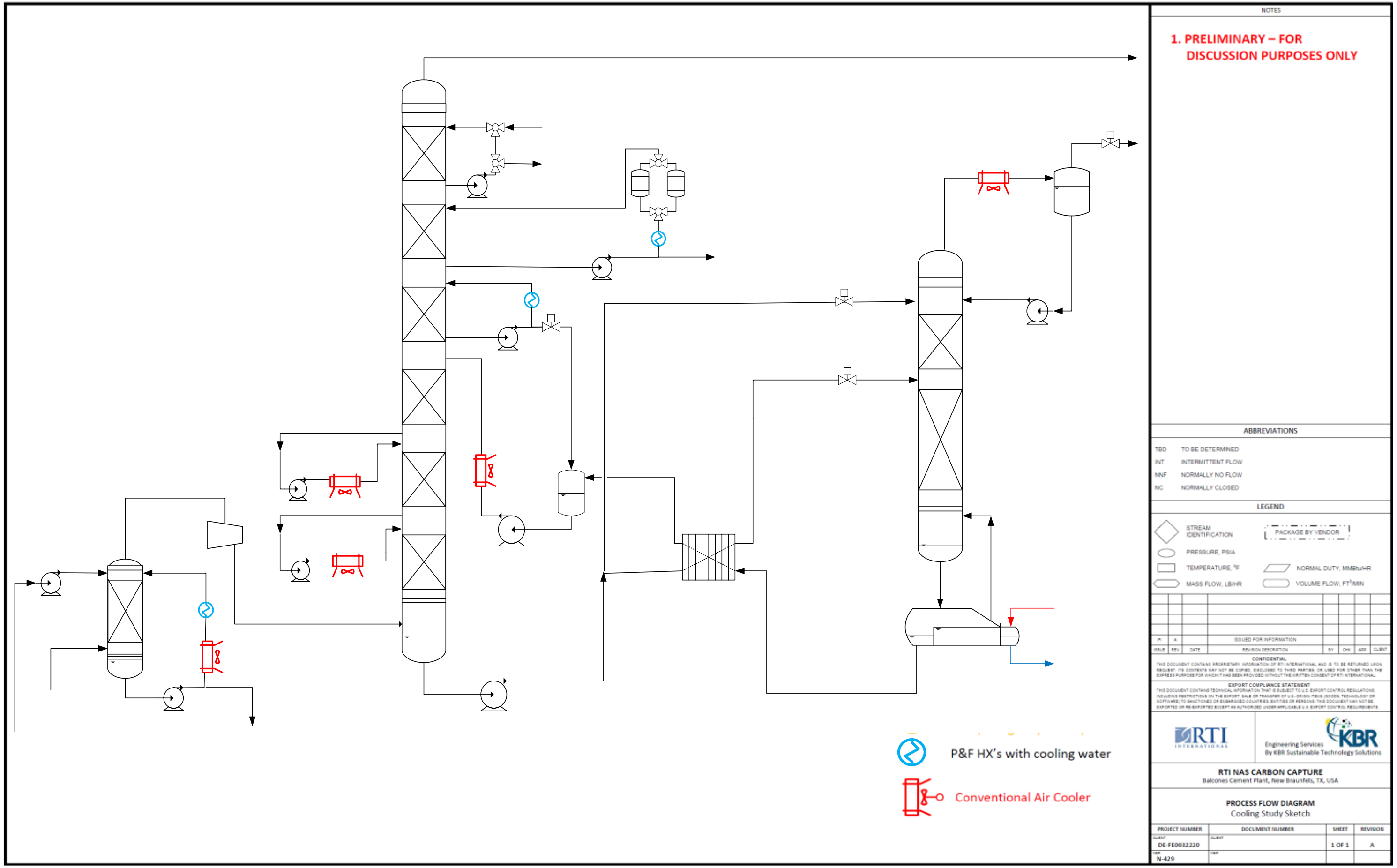
- Combination of air cooling and water cooling to control flue gas dew point and water wash temperatures, and to maintain water balance

Cooling Options Summary

	Base Case	A	B	C	C.1	D	D.1	E	F
	Water	WSAC	Air/Water 99% ASHRAE	Air/WSAC 99% ASHRAE	Air/WSAC 98% ASHRAE	Air/Heat Pump 99% ASHRAE	Air/Heat Pump 98% ASHRAE	Air/CWT/ Heat Pump 98% ASHRAE	Air/Water 80F Ambient Design Temp
Heat Loads (Fractional)									
Air Cooling	0	0	24%	24%	32%	24%	32%	32%	84%
Water Cooling	100%	0	76%	0	0	0	0	15%	16%
WSAC Cooling	0	100%	0	76%	68%	0	0	0	0
Heat Pump	0	0	0	0	0	76%	68%	53%	0
Meets Water Constraints	No	No	No	No	No	Yes	Yes	Yes	Yes
Electrical Consumption*	1.0	0.2	1.3	0.7	1.3	10.6	9.4	7.7	2.5
Indicative Capex, TDC*	1.0	7.2	2.9	7.7	8.1	5.4	5.9	6.0	5.7
Footprint	0.4	1.8	1.7	3.1	2.9	4.2	3.6	4.0	4.1

* Normalized values

Cooling Options – Air Cooling / Water



CO_2 Compression – Heat-integrated Integrally Geared Compressor

Illustration Of compressor train with integrated Carbon Capture Heat Recovery (CCWHR) technology
(Image courtesy of MAN Energy Solutions)

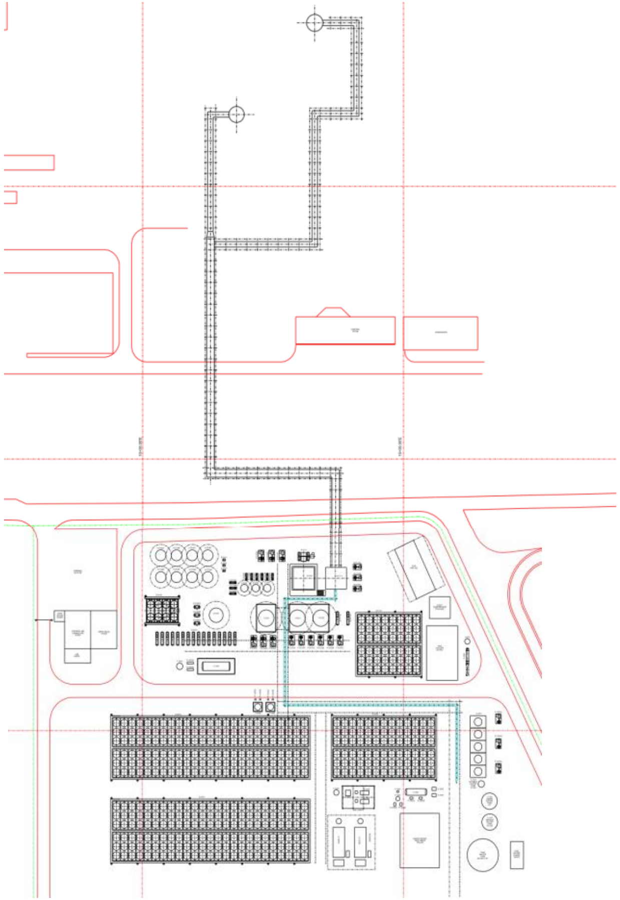
CCWHR Technology

- Heat of compression recovered as steam generation.
- Heat removed after 3rd and 5th stage
- Dehydration occurs after 3rd stage
- Can provide up to 30% of steam required for solvent regeneration
- Reduces need for cooling water
- Higher shaft power due to higher interstage temperatures.

Task 4 – Front-end Engineering Design (FEED) Study

- ✓ Task 4.1 – Engineering Design Package
- Task 4.2 – Integration and Utilities Design
- ✓ Task 4.3 – HAZOP Review
- Task 4.4 – Schedule and Cost Estimation
- ✓ Task 4.5 – Constructability Review

Plot Plan with ducting to cement kilns

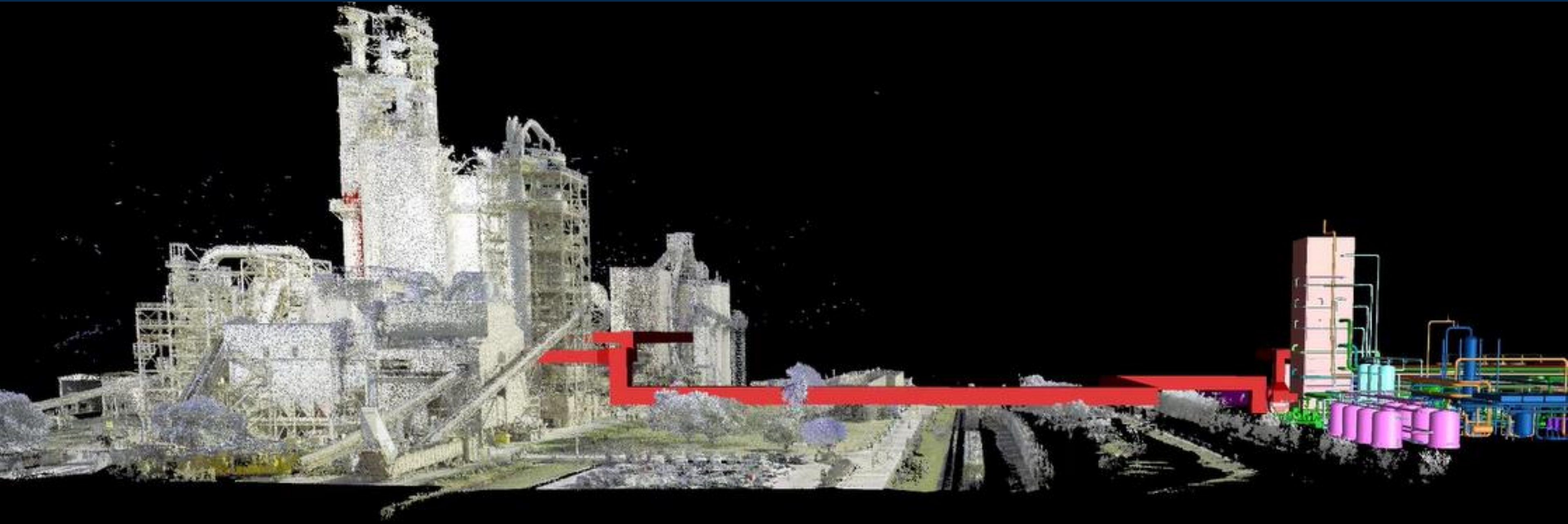


Carbon Capture and Cement Plant tie-ins

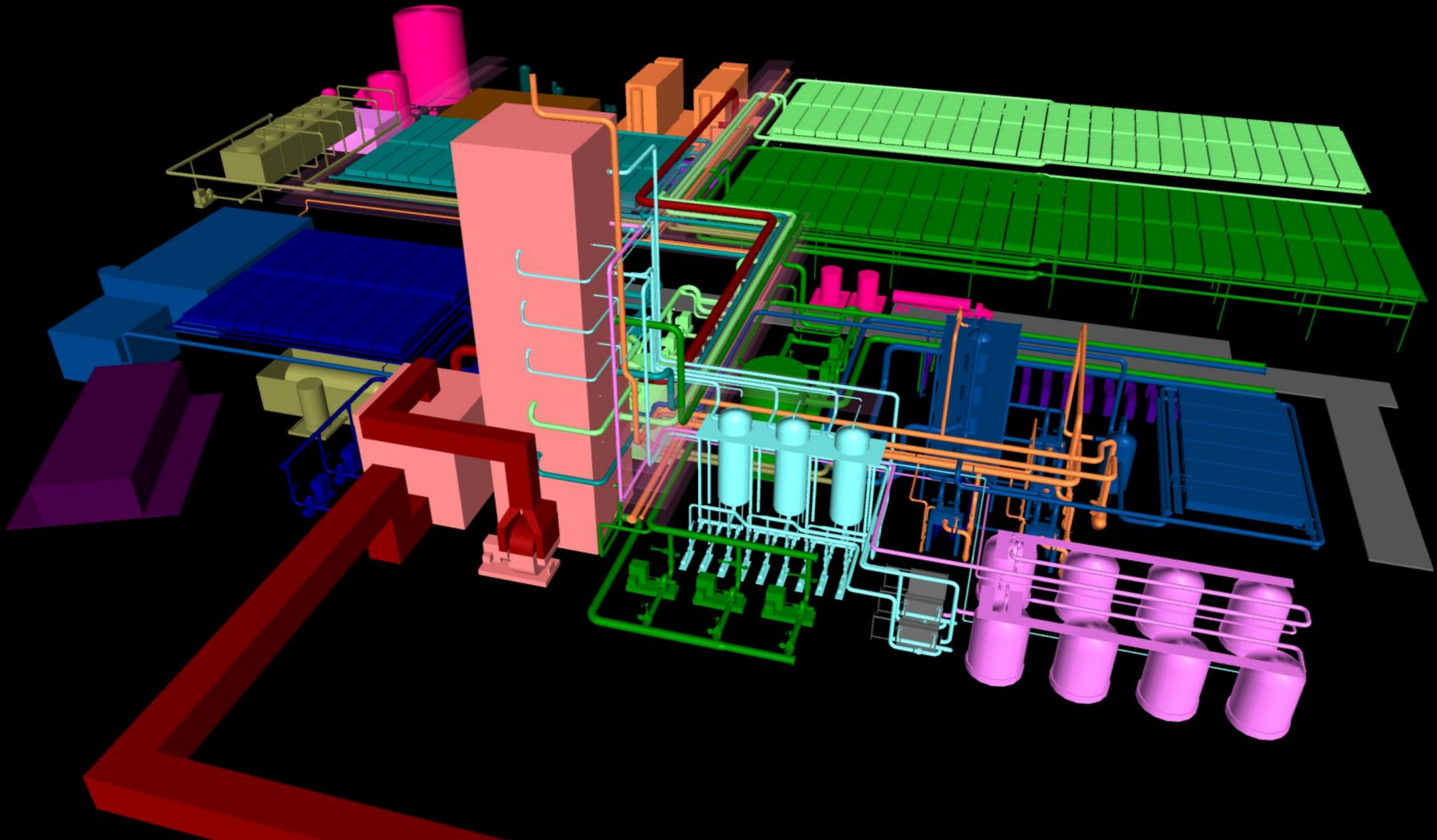
Discussions held with CEMEX on plant tie-ins.

- Flue Gas Ducting Tie-Ins
  - Over rail spur and Wald Road
  - Under utility electric and communication along Wald Road
- Dampers
  - Slide guillotine style considered for isolation of CC plant from cement plant.
  - Multi-louver style for diverting flow to/from CC/cement plant.
- Vent stack
  - Stack on top of absorber tower for venting treated gas.
  - A 200 ft umbilical planned for CEMS monitoring of the treated gas.
  - Avoids having to re-duct the treated gas across the road to existing stack. Does add in the cost of additional CEMS.
  - Platform to be provided for annual stack testing
- Electric
  - New substation adjacent to existing Cemex substation
  - Connects directly to electric utility provider

Carbon Capture Plant – 3D Model



Carbon Capture Plant – 3D Model



Task 5 – Tech to Market

In Progress

Task 5.1 – Technoeconomic Analysis

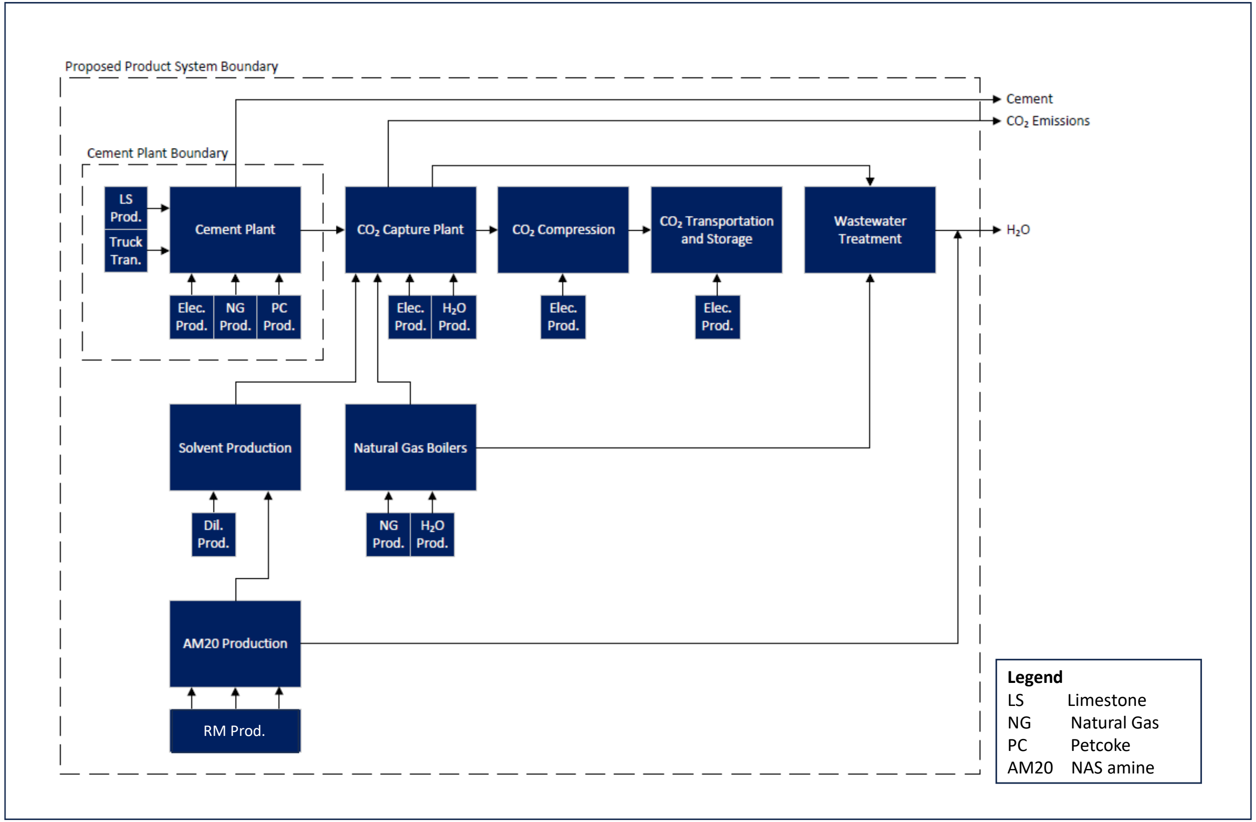
Task 5.2 – Business Case Analysis

Task 5.3 – Lifecycle Analysis

Task 5.4 – Environmental Health & Safety Risk Analysis

Task 5: Lifecycle Analysis

- Currently In Progress
- Being developed using OpenLCA with NETL LCI and Ecoinvent databases
- Functional Unit is 1MT of cement



Technology Maturation Plan

Process Development:

- Amine recovery from acid wash
- Amine reclamation process

Reducing cost of capture

- Use of rotating packed beds for CAPEX reduction
- DOE-EERE project to demonstrate NAS process at 1 TPD scale at CEMEX cement plant, Victorville, CA
- ARPA-E project on flexible CO_2 capture for NGCC using RPBs.

Demonstration

- DOE-OCED project on building and operating a large CO_2 capture pilot (120,000 TPY) at International Paper's containerboard mill in Vicksburg, MS.

Commercial

- Technology licensed by SLB for joint development and commercialization

Milestone Log

Task or Subtask	Description	Planned Completion	Actual Completion	Verification Method
1.1	Project Management Plan (PMP)	May 14, 2023	May10, 2023	Submission of PMP
1.2	Initial Technology Maturation Plan (TMP)	Jul 14, 2023	Jul 14, 2023	Submission of initial TMP
2.0	Project Design Basis	Jul 31, 2023	Aug 29, 2023	Submission of Design Basis Definition Report
4.0	Initial Engineering Design Package	Oct 14, 2023	Oct 13, 2023	Submission of Initial Engineering Design Package
5.2	Initial Life Cycle Analysis (LCA)	Oct 14, 2023	Oct 14, 2023	Submission of initial LCA
4.5	Constructability Review	Feb 29, 2024	May 10, 2024	Summarized in Quarterly report
1.3	Initial Workforce Readiness Plan	Apr 14, 2024	Apr 14, 2024	Submission of Workforce Readiness Plan
4.3	HAZOP review	May 31, 2024	May 24, 2024	Summarized in Quarterly report
1.2	Final TMP	Oct 14, 2024		Submission of final TMP
1.4	Environmental Justice Analysis	Oct 14, 2024		Submission of Environmental Justice Analysis
1.5	Economic Revitalization & Job Creation Outcomes Analysis	Oct 14, 2024		Submission of Job Creation Outcome Analysis
4.0	Final Engineering Design Package	Oct 14, 2024		Submission of Final Engineering Design Package
5.1	Business Case Analysis (BCA)	Oct 14, 2024		Submission of BCA report
5.3	Final LCA	Oct 14, 2024		Submission of final LCA
5.4	Technology EH&S Analysis	Oct 14, 2024		Submission of EH&S Analysis
1.3	Updated Workforce Readiness Plan	Jan 14, 2025		Submission of Workforce Readiness Plan

Summary Slide

RTI working with CEMEX, SLB and KBR to develop a FEED package for CO_2 capture from Balcones cement plant, with 1.6 MM t/year CO_2 capture at 95% capture efficiency.

Activities Completed:

- ✓ Design Basis Definition
- ✓ Limited cooling water availability has been addressed by use of hybrid cooling – combination of air and water cooling, and heat integrated CO_2 compressor.
- ✓ Preliminary Engineering work completed (BFD, PFD, P&IDs)
- ✓ Geotechnical and soil analysis
- ✓ HAZOP and Constructability Review.
- ✓ 3D model is nearing 30% completion.

Summary Slide II

Activities In progress:

- Plant cost estimation – Have started reaching out to vendors for cost-estimation.
- Technoeconomic Analysis
- Lifecycle Analysis
- Technology EH&S Risk Assessment
- Business Case Analysis
- Environmental Justice Analysis
- Economic Revitalization and Job Creation Outcomes Analysis

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Disclaimer

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Award Number
DE-FE003220

Cost share Partners:

Thank you

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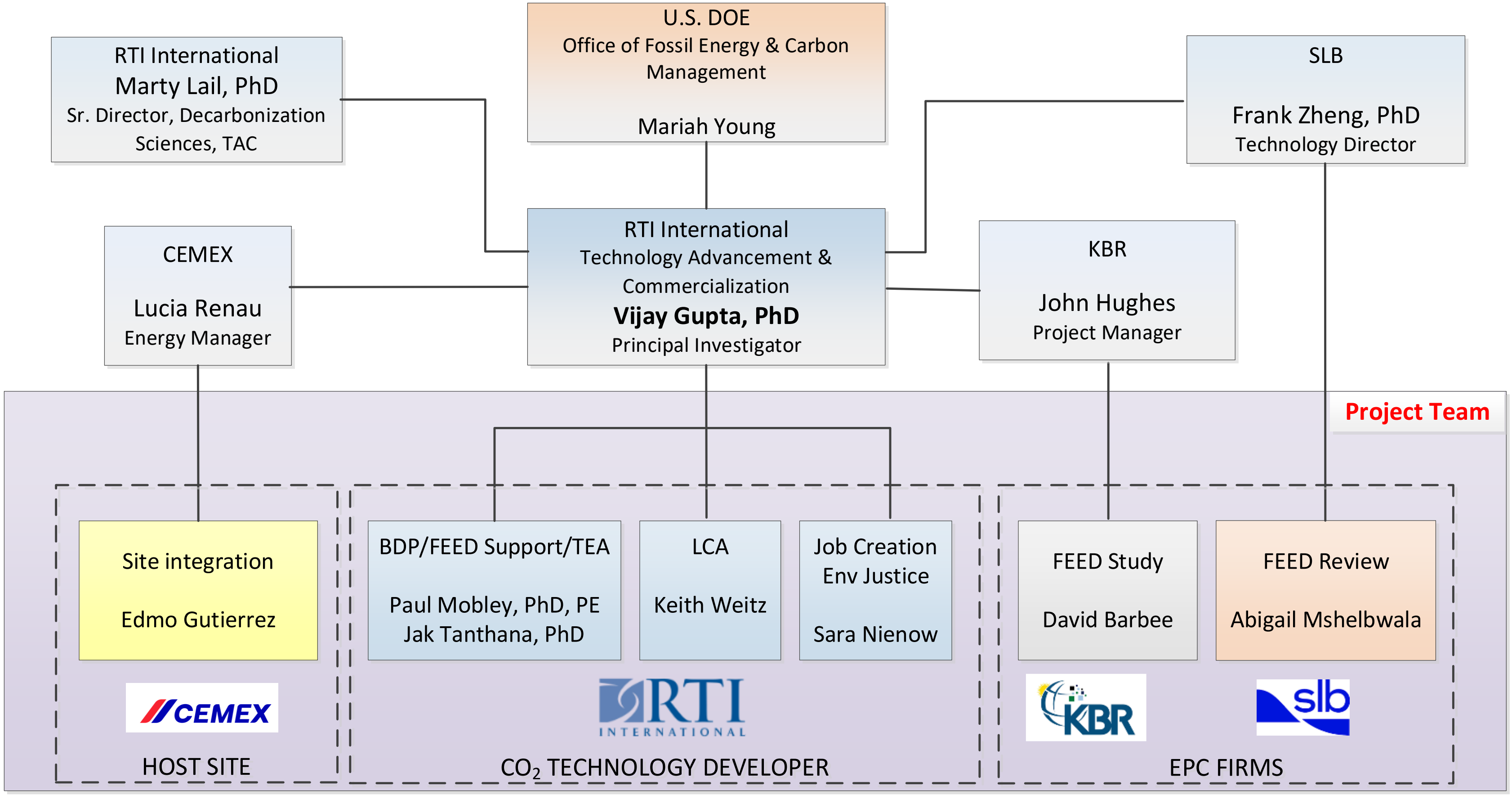
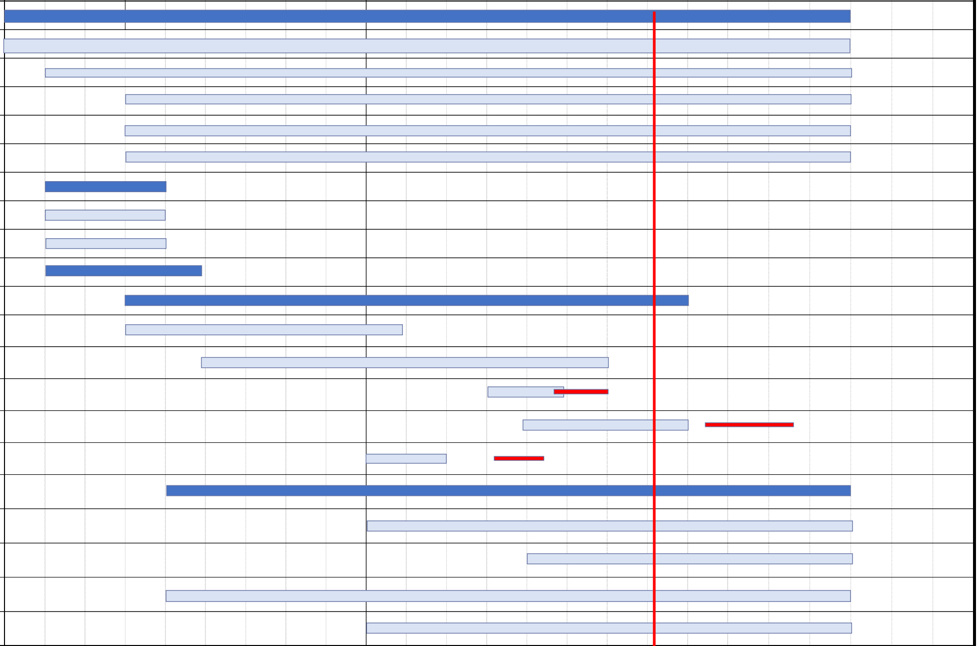
APPENDIX SLIDES

Project Team



Project Timeline - Updated

Task	Task Description	4/14/2023	1/13/2025
1.0	Project Management	04/14/23	01/13/25
	1.1 Project Management Plan	04/14/23	01/13/25
	1.2 Technology Maturation Plan	5/1/203	01/13/25
	1.3 Workforce Readiness for Technology Development	07/01/23	01/13/25
	1.4 Environment Justice Analysis	07/01/23	01/13/25
	1.5 Economic Revitalization and Job Creation Outcomes Analysis	07/01/23	01/13/25
2.0	Project Design Basis Definition	05/01/23	07/31/23
	2.1 Host site review	05/01/23	07/31/23
	2.2 Permitting requirements review	05/01/23	07/31/23
3.0	Basic Design Package	05/01/23	08/31/23
4.0	Front-End Engineering Design Study	07/01/23	08/31/24
	4.1 Engineering Design Package	07/01/23	01/31/24
	4.2 Integration and Utilities Design	09/01/23	06/30/24
	4.3 HAZOP Review	05/20/24	06/30/24
	4.4 Schedule and Cost Estimate	09/18/24	11/18/24
	4.5 Constructability Review	04/24/24	05/10/24
5.0	Tech to Market	01/01/24	01/13/25
	5.1 Techno-Economic Analysis	01/01/24	01/13/25
	5.2 Business Case Analysis	05/01/24	01/13/25
	5.3 Life Cycle Analysis	08/01/23	01/13/25
	5.4 EH&S Risk Analysis	01/01/24	01/13/25
Total		**04/14/23**	**01/13/25**



Months after contract award										Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Milestone Log *(Table 3)*	A		B,C			D,E				F								G-M						
Reporting / Deliverables *(See footnote)*				Q			Q			Q			Q			Q			Q					FR
Project Meeting *(See footnote)*	KM				PB				L							PB					PC			

Q = Quarterly report due 1 month after quarter's end; FR = Final report due 3 months after project end.
KM = Project kick-off meeting; PB = Project briefing (annual); PC = Project closeout meeting