Front-End Engineering Design Study for Retrofit Post-Combustion Carbon Capture on a Natural Gas Combined Cycle Power Plant

Award Number: DE-FE0031842

NETL Federal Project Manager: Carl Laird

Abhoyjit S. Bhown, Ph.D.
Program Manager, Advanced Generation and CCS

February 23, 2022

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Acknowledgment

Acknowledgment

This material is based upon work supported by the Department of Energy under Award Number DE-FE0031842.

Disclaimer

Agenda

- Project Overview – Electric Power Research Institute
  - Structure
  - Timeline
  - Team
  - Deliverables
- Project Background and Scope – California Resources Corporation
  - Project background and commercial drivers
  - Elk Hills Power Plant Site
- FEED Study – Fluor Corporation
  - Econamine FG+^{SM} Background and Experience
  - Process Description and Application to Project Site
- Confidential Session
  - Fluor and CRC only
  - CRC only
- Conclusion – Electric Power Research Institute

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Project Overview

- **Title**: Front-End Engineering Design Study for Retrofit Post-Combustion Carbon Capture on a Natural Gas Combined Cycle Power Plant
- **Project Period**: October 1, 2019 – February 28, 2022 (29 months, ~10 quarters)
- **Funding:** $8,644,807 = $6,915,845 (Federal) + $1,728,962 (Cost-Share)
- **Spent through Dec 31, 2021:** $8,520,345 (80% Federal, 20% cost-share)
- **Federal Project Manager**: Carl Laird
- **EPRI**: Abhoyjit Bhown (PI), Adam Berger, Des Dillon
- **CRC**: Kenneth Haney, Christopher Kolar
- **Fluor**: Satish Reddy, Timothy Simonson, John Gilmartin
- **Overall Goal**: Conduct FEED study for capturing 4,000 t CO_2/day at CRC's 550 MWe NGCC Elk Hills Power Plant using Fluor Econamine FG+^{SM} aqueous amine technology. The captured CO_2 will be used by CRC for enhanced oil recovery or storage in fields adjacent to the power plant.

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Project Structure

- **Task 1 – Project Management and Planning**

- **Task 2 – Feed Scope**
  - Objective is to develop design basis document (FEED Scope) to be used by Fluor under Task 3

- **Task 3 – Feed Study**
  - Objective is to develop FEED document as defined in SOPO-1

Feed Package = Feed Scope (Task 2) + FEED Study (Task 3)

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Project Timeline

	Oct 1, 2019 - Feb 28, 2022 (~10 Quarters)										
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Task 1.0 - Project Management and Planning											
Milestones											
Finalize Project Management Plan	◊										
Feed Package Submitted										◊	
Final Report Submitted (90 days post close)											◊
Task 2.0 – FEED Scope											
Milestones											
Project Design Basis Package		◊									
Task 3.0 – FEED Study											
Subtask 3.1 – Design and Engineering of Primary Plant Systems											
Subtask 3.2 – Constructability, Cost, and Supporting Systems											
Milestones											
Design of Primary Plant Systems					◊						
Engineering FEED Package										◊	

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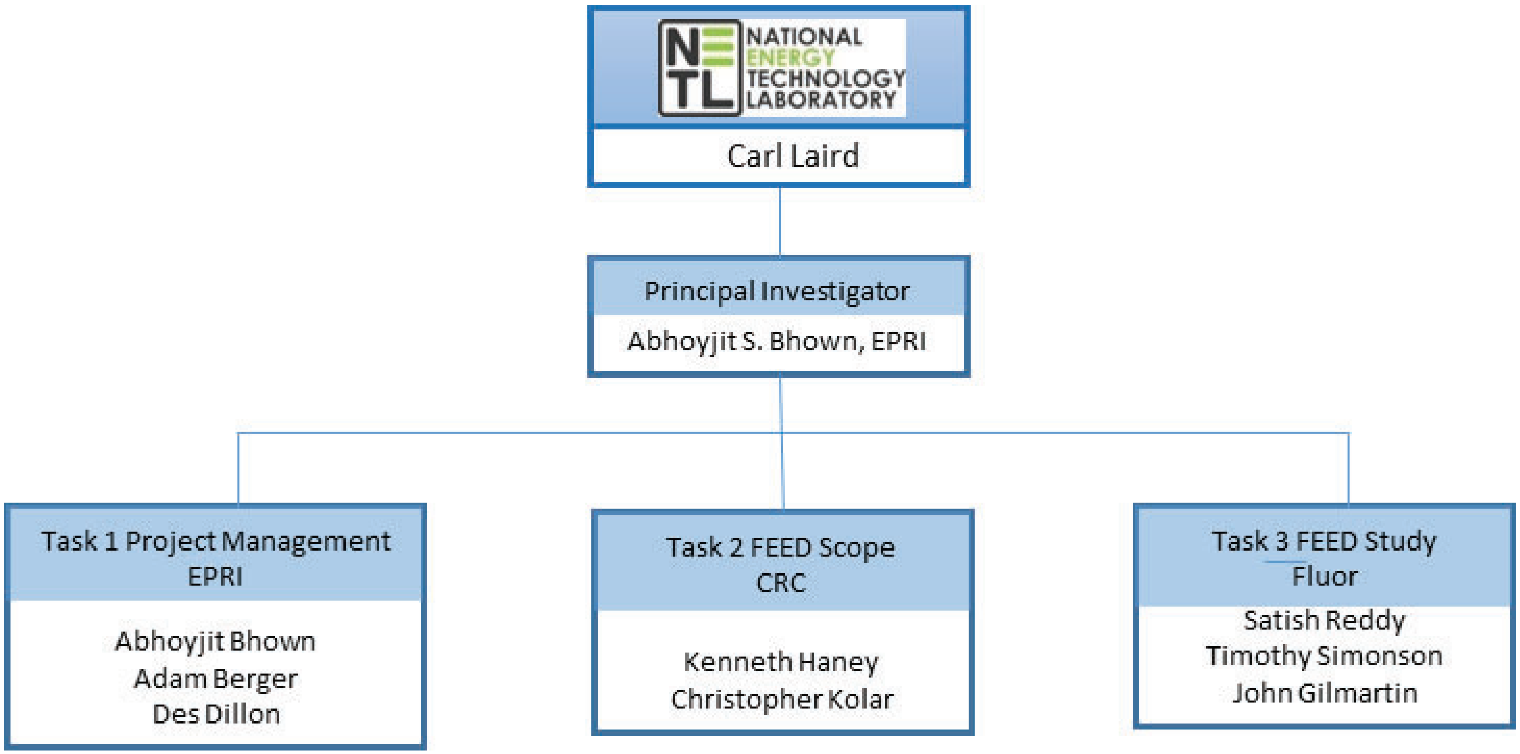
Deliverables

Deliverable Title	Due Date
Project Management Plan	Due 30 days after award with updates resulting from negotiations. Revisions to the PMP shall be submitted as requested by the NETL FPM (Complete)
FEED Package (SOPO-1)	Due to the NETL FPM by end date of project
Final Report - A non-proprietary publicly disclosable overview of the sections of the FEED Study	Due 90 days after the completion of the project per the Federal Assistance Reporting Checklist and instructions

Project Team



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"Positioned to be a premier carbon management provider in California"

CalCapture and CTV

CalCapture FEED Study: DOE Final Report

February 23, 2021

CALIFORNIA RESOURCES CORPORATION | CARBON TERRAVAULT

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CRC's Elk Hills Oil & Gas Complex is Primed For CCS

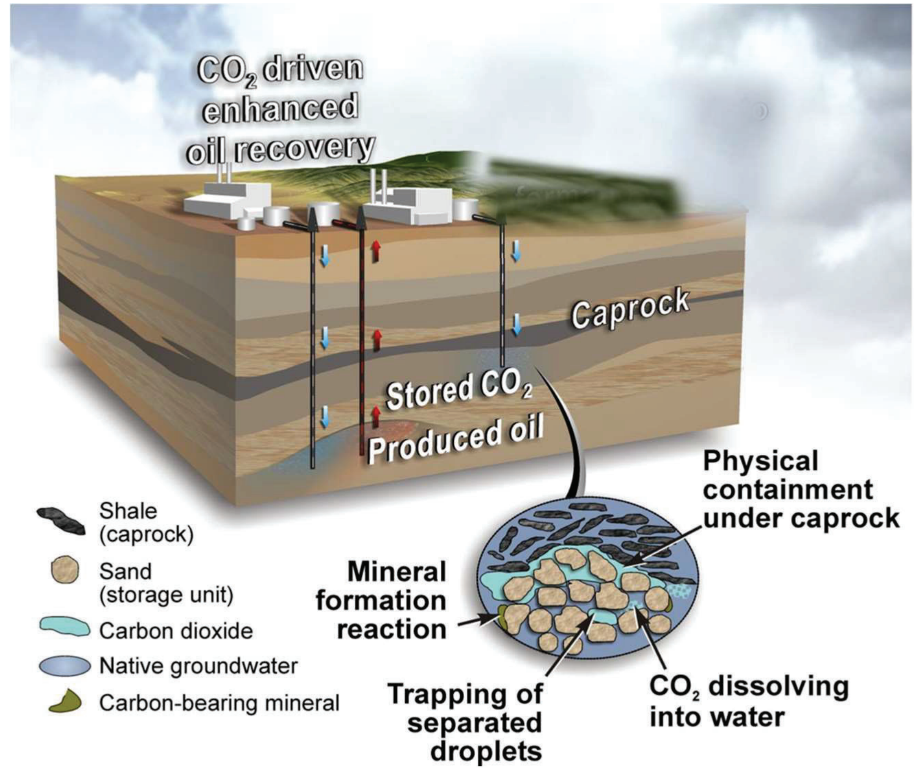
CRC-Owned
- ✓ Surface/minerals/pore space
- ✓ Infrastructure

Commercial Readiness
- ✓ Reservoirs fully delineated
- ✓ Monterey storage complex
- ✓ Stevens Sand EOR Targets

Advantaged Commercial
- ✓ Carbon credits
- ✓ Storage versatility
- ✓ Corporate Commitment

A “Real” Solution: CalCapture Implements California’s Carbon Goals at Elk Hills

- ✓ Significant immediate emissions reductions
- ✓ Clean, safe, affordable energy and reliable base-load power generation for California
- ✓ Prolific economic impact on local, state and national economies
- ✓ NGCC power plant capture technology deployment



Source: California Air Resources Board

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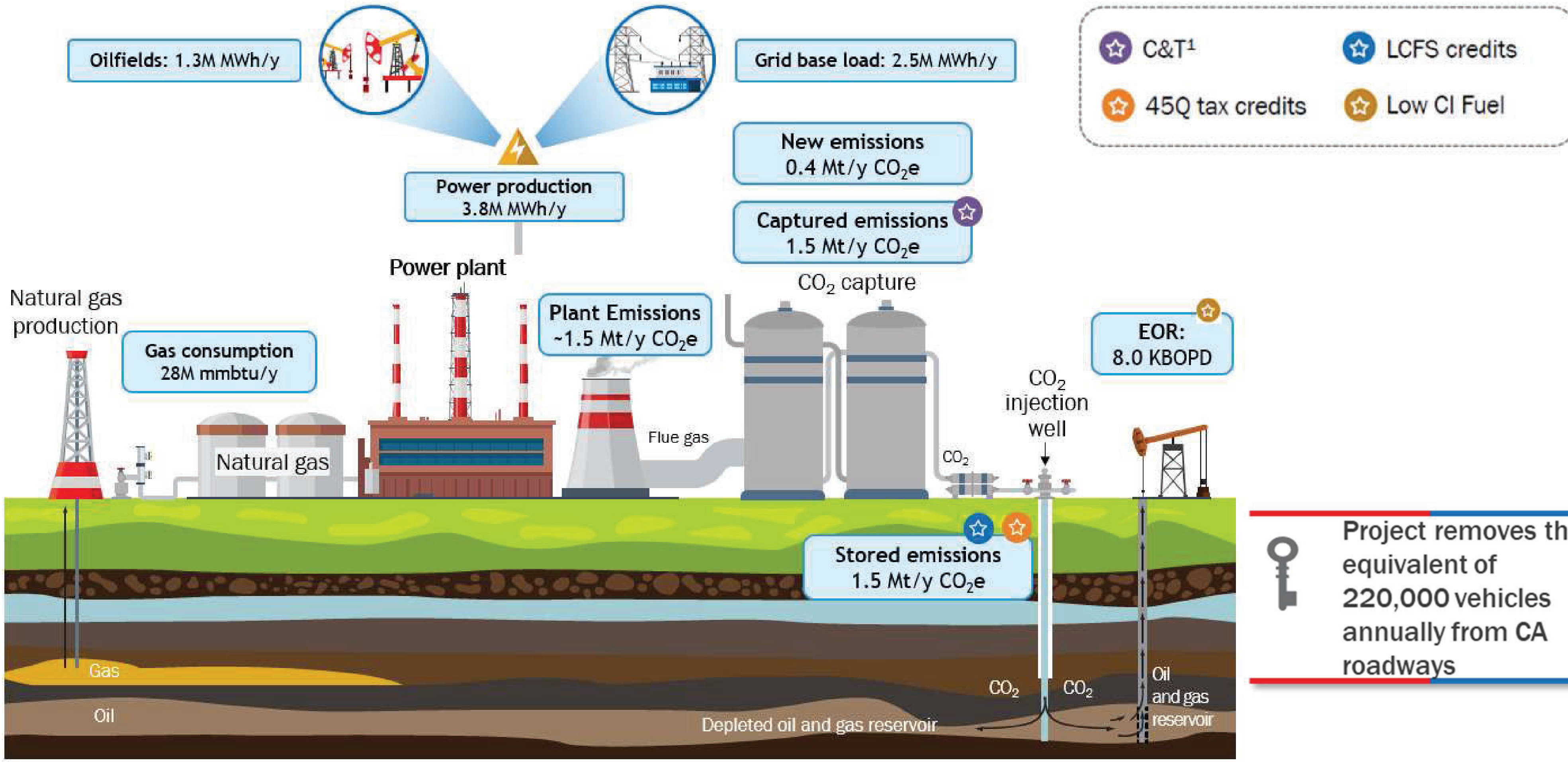
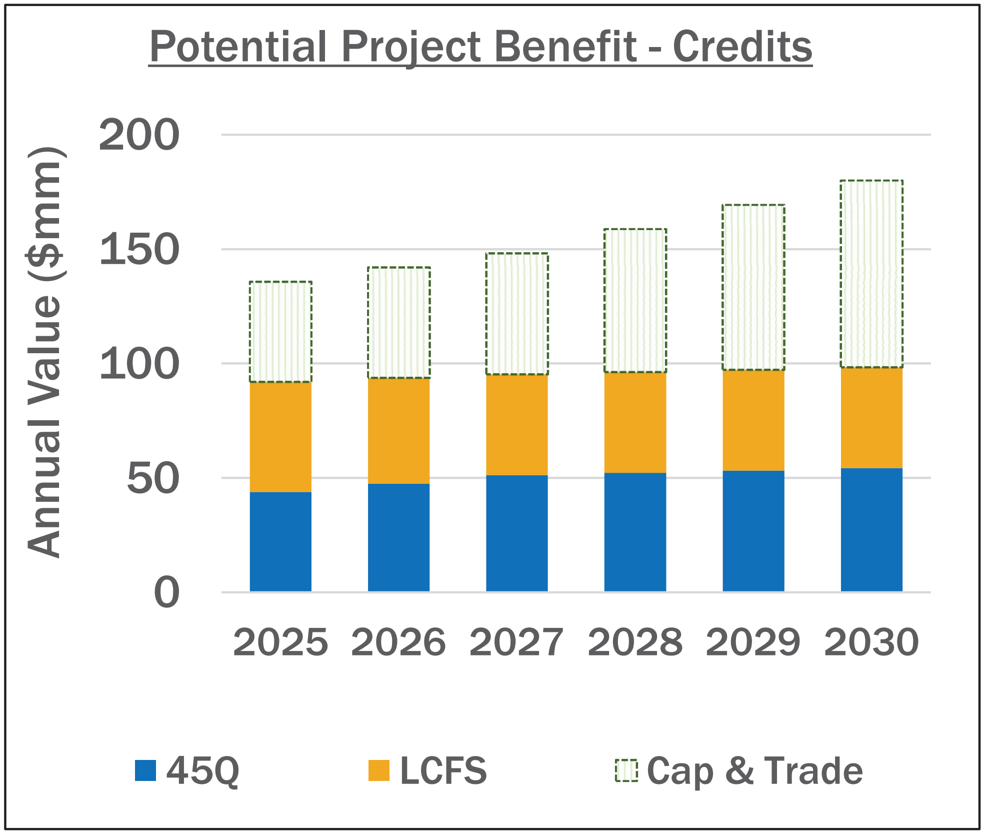
1.5 Million Tonnes of CO_2 Stored per Year



Project removes the equivalent of 220,000 vehicles annually from CA roadways

1 Pending adoption of a CCS protocol into CA Cap & Trade

Carbon Credits are a Strong Economic Enabler



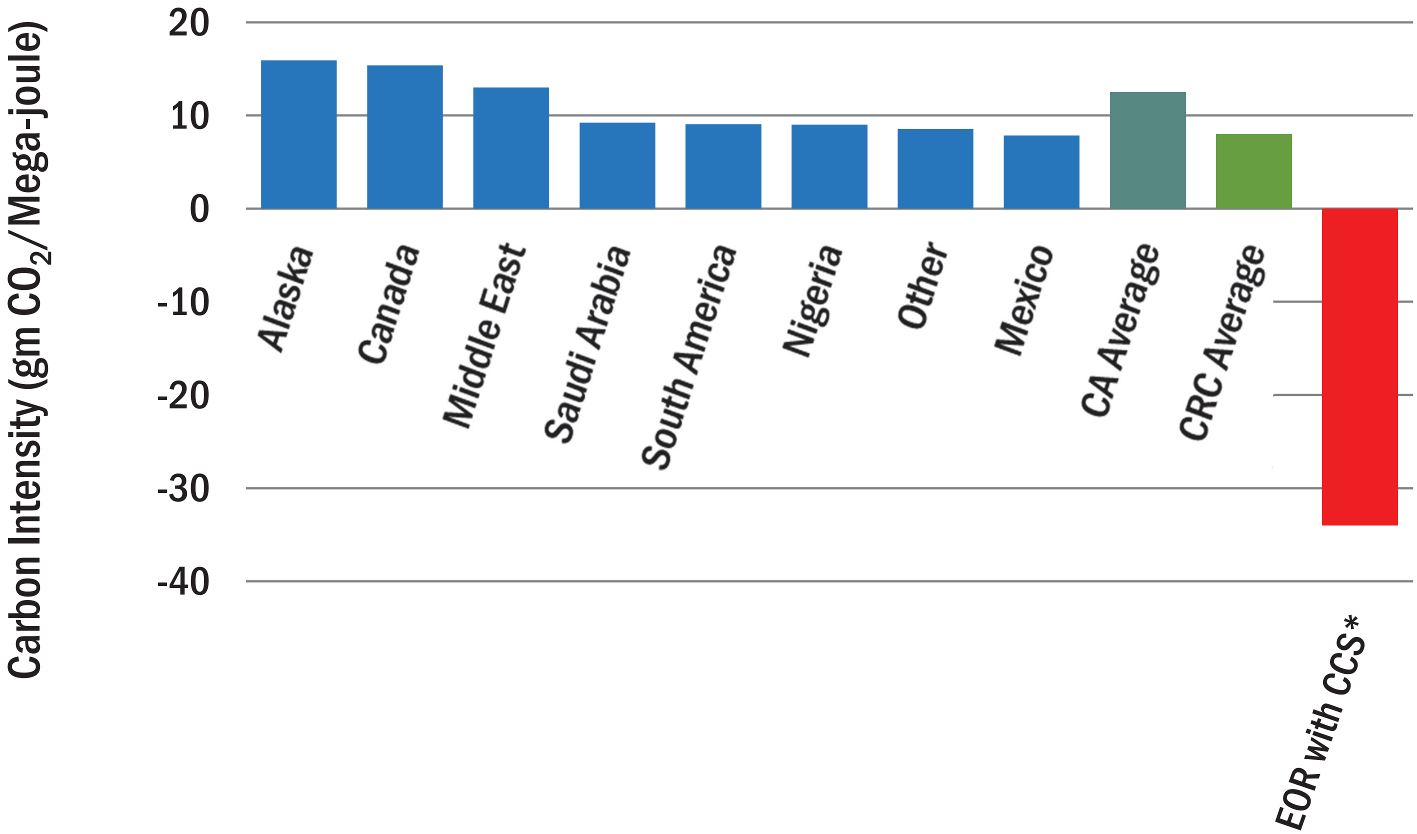
CalCapture: Strategic Plan

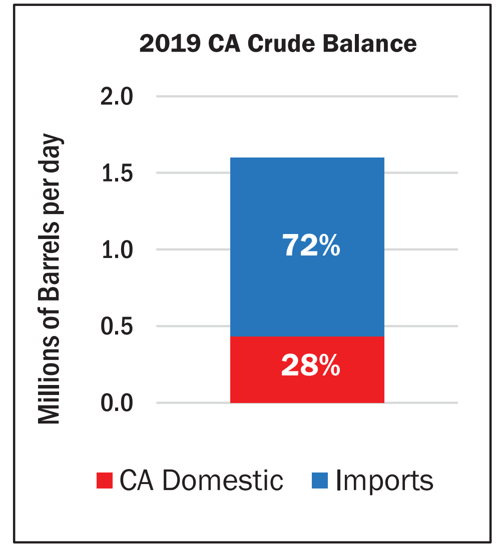
☆ Planned Submittal	2020				2021				2022			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Regulatory and Permitting												
- CEQA/EIR/CUP's					☆							
- UIC Expansions					☆							
- LCFS					☆							
- 45Q					☆							

Additional Upside

- Cap & Trade Escalation
- Clean Power Contract

CalCapture with EOR Cuts Oil Production Emissions to Far Below all California Imports





Data from CARB 2019 Calculation of Production/Transport Crude Carbon Intensity
* Elk Hills Crude produced with CO_2 EOR and CCS (Utilization ~.34 tonnes CO_2 per bbl oil)

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CalCapture Economic Impacts will be Significant

Study by IMPLAN Group, LLC. Data reflects US impacts per project design estimates 6/2020	Annual Jobs	Millions of $	
		Economic Output	Taxes
Capture Plant (3 yr. construction)	3,890	1,624	222
Capture Plant (20 yr. operation)	217	1,454	197
EOR (CAPEX/OPEX) 20 years	857	3,249	421

$6.3B Total Economic Output
$840 million Taxes

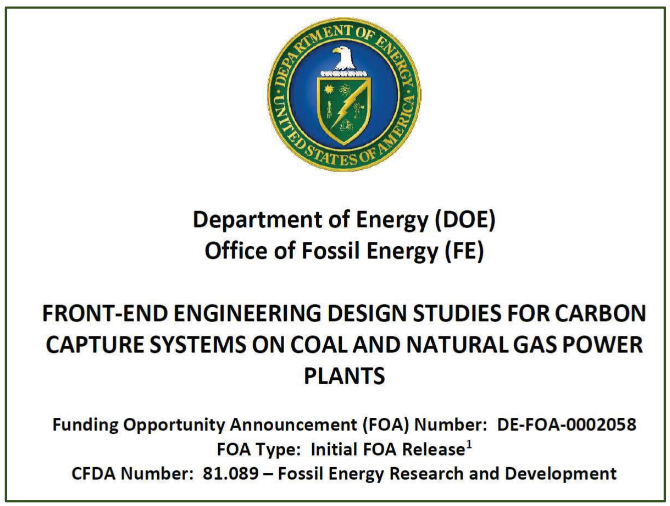
IMPLAN

CalCapture FEED: 1/2020 – 2/2022

US Department of Energy

- **CRC Awarded Funding for Carbon Capture FEED**
  - $7mm federal award
- **Partners**
  - FLUOR – Amine Absorption Technology/Construction
  - Electric Power Research Institute (EPRI) - Lead Applicant and Project Manager

FLUOR®



Department of Energy (DOE)
Office of Fossil Energy (FE)

FRONT-END ENGINEERING DESIGN STUDIES FOR CARBON CAPTURE SYSTEMS ON COAL AND NATURAL GAS POWER PLANTS

Funding Opportunity Announcement (FOA) Number: DE-FOA-0002058
FOA Type: Initial FOA Release[1]
CFDA Number: 81.089 – Fossil Energy Research and Development

EPRI
ELECTRIC POWER RESEARCH INSTITUTE

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CO_2 Sourcing Alternatives Reviewed 2018 - Present

EHPP Capture

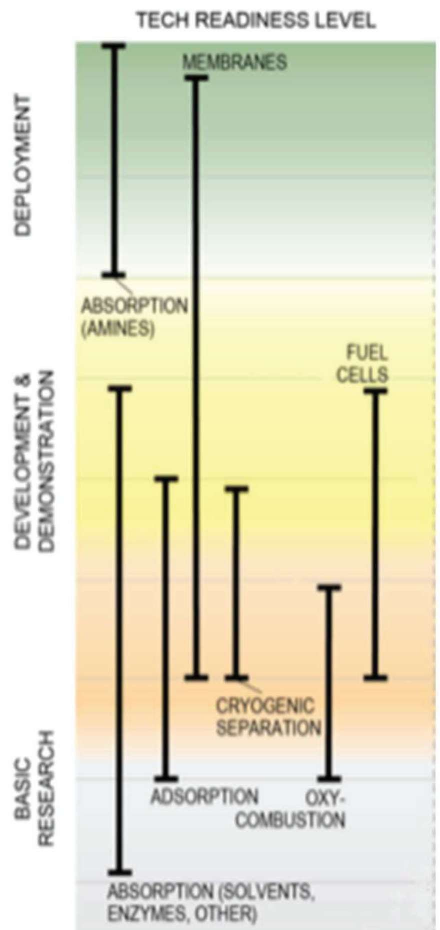
Absorption - Amines
- Fluor Econamine FG+
- Shell Cansolv
- Mitsubishi Heavy Industries
- Compact Carbon
- Linde
- Next Decade

Absorption - Other
- General Electric - Chilled Ammonia

Adsorption
- ARI
- Svante (Inventys)

Membranes
- Membrane Technical Research

Fuel Cells
- Fuel Cell Energy



Alternative CO2 Sources

- Refinery – Renewable Diesel
- H_2/CO_2 ATR from NATGAS
- Oxy Combustion
- Bio Fuels (3 Technologies)
- Ammonia Plants
- Ethanol Plants
- Gas Processing

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Fluor Technology Selection

Amine Absorption

- Highest TRL
- Ready to scale

Fluor's Econamine FG+SM

- 30+ commercial Econamine FG operating plants
- 15 years of operating experience on a gas turbine
- Solvent maintenance system provides for low air emissions and waste generation
- Low solvent make-up

Demonstration Plant, Germany FLUOR®

Elk Hills Power Plant

- Commissioned 2003
- Dual GE 7FA combustion turbine generators (CTG's).
- Two supplementary-fired heat recovery steam generators (HRSG's)
- GE D11 Steam Turbine Generator (STG)
- Selective Catalytic Reduction (SCR) systems for the control of NO_x, CO & VOC.
- Natural gas fuels CTG's/Duct Burners.

Image from CRC

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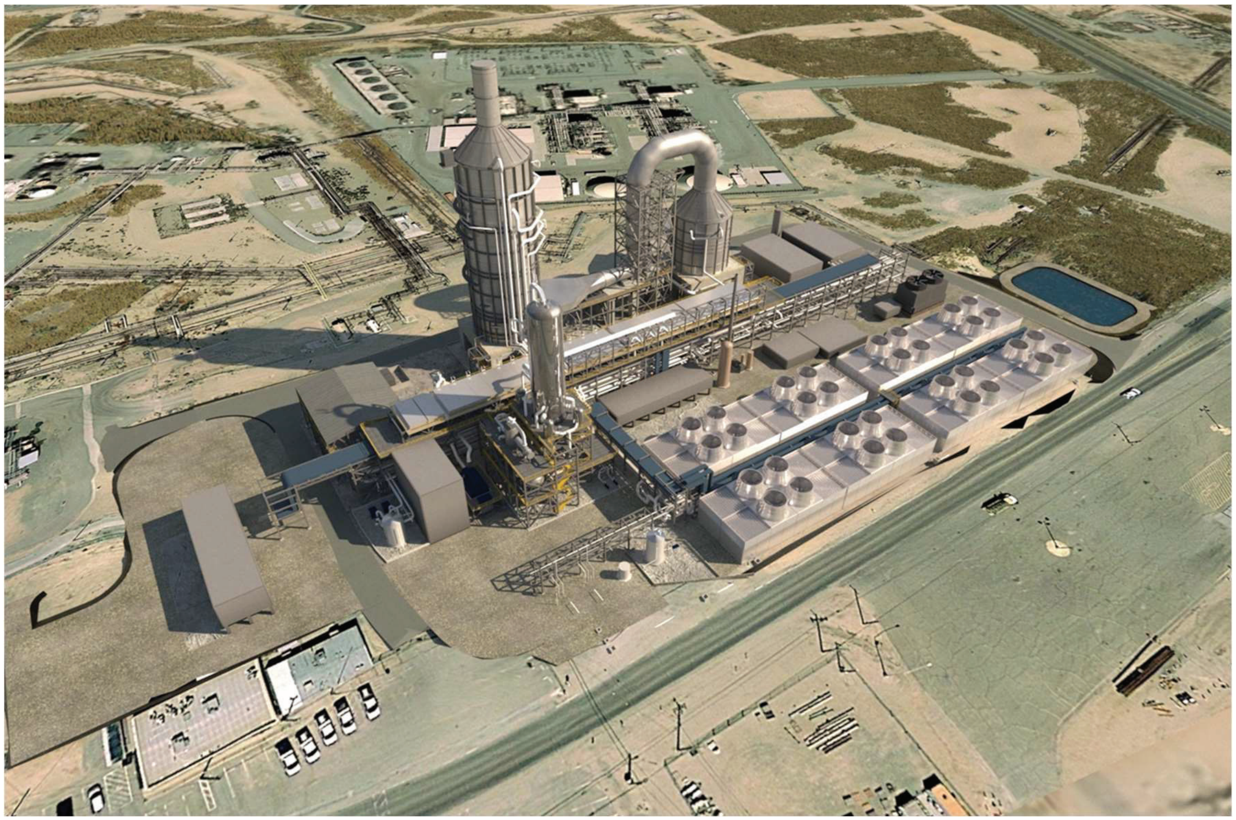
Fluor Capture Plant FEED Study



FEED
- ✓ Class III Estimate(+/-15%)
- ✓ Validated ~8% Savings
- ✓ Black & Veatch OE Review

Optimization
- Steam integration
- "Fit for Purpose" PLA
- Contracting Strategy

Next Steps
- Alternatives Benchmarking
- FOA 2660 Application
- Open/Closed Book EPC

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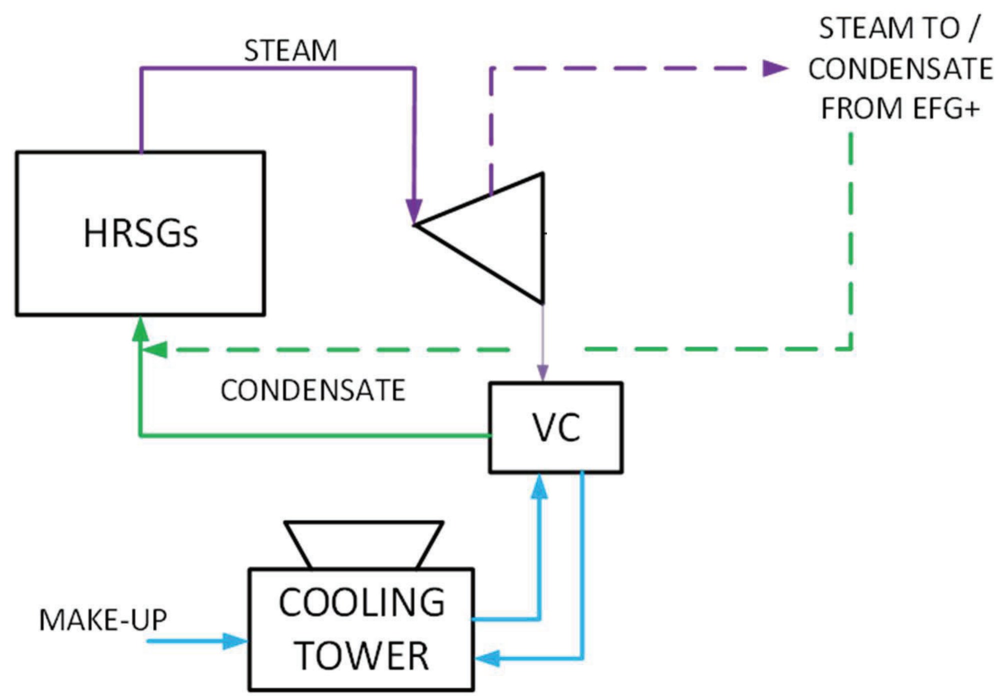
Value Engineering: Steam Integration with Power Plant

Modify existing steam turbine to allow capture plant to draw 100% of regeneration steam requirement

- Eliminates natural gas fired boiler packages
  - More CO_2 captured from power plant
  - Higher CO_2 emissions avoided
- Frees up capacity in existing cooling tower
  - Eliminates some Wet Surface Air Coolers
- CAPEX and OPEX Savings
  - Adds ~450k lb./hr steam
  - Parasitic load addition 30-35MW
  - Turbine modifications cost TBD
- GE Engagement
  - Phase 1 Feasibility complete
  - Progressing to Phase II Design



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CRC Energy Transition Positioning

STABLE CONVENTIONAL ASSETS PROVIDE STRONG FINANCIAL FOUNDATION

- Low decline, conventional assets with integrated infrastructure
- Disciplined capital allocation with strong financial foundation
- Robust Free Cash Flow generation
- Potential enhanced oil recovery through CalCapture in the future

PROVIDING LOW CARBON INTENSITY ENERGY TO CALIFORNIA

- Delivering lowest carbon intensity hydrocarbon production of the top 100 US producers[1]
- Incorporating and developing renewable solar opportunities | 45 MW BTM[2,3] solar in active development | Up to 1,000 MW FTM[3] solar in early-stage development

ADVANCING LOW CARBON FUTURE THROUGH CARBON TERRAVAULT

- Anticipate establishing one or more CCS projects that inject CO_2 into depleted underground reservoirs
- Dedicated business group and leadership structure
- Identified up to 1 BMT of potential permanent CO_2 storage capacity[3]
- **Targeted Early-Stage Development Goals**: 1st Injection by 2025[4] | 200 MMT permitted by 2025 | 5 MMTPA injection by 2027[3]

(1) According to Clean Air Task Force, June 2021. (2) 45 MW of BTM solar represents opportunities with SunPower in CRC owned land. (3) Source: Internal estimates. (4) First injection date dependent on permitting, capture facility type and the structure, financing and ownership of the project which have not yet been negotiated.

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Front-End Engineering Design Study for Retrofit Post-Combustion Carbon Capture on a Natural Gas Combined Cycle Power Plant

Summary of Key Findings

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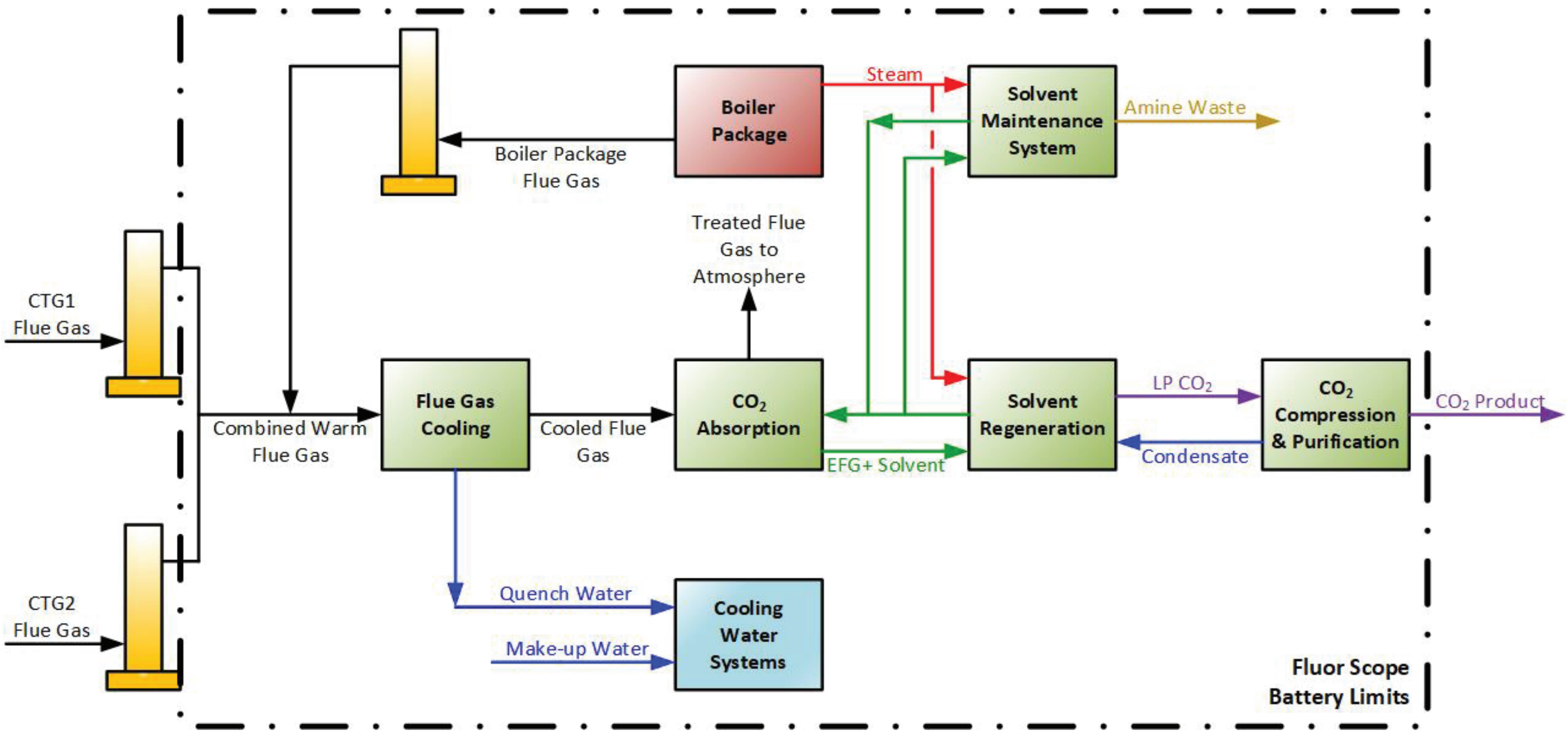
Background

- FEED study objective – determine technical and economic feasibility to retrofit post-combustion carbon capture on 550 MW commercially operating NGCC power plant at Elk Hills
- Carbon capture unit based on Fluor's proprietary Econamine FG Plus[SM] (EFG+) technology
- Designed to recover 4,000 MTPD CO_2 from flue gas streams produced by two existing CTGs along with flue gas produced from new boiler package

Block Flow Sketch for Post Combustion Carbon Capture at Elk Hills



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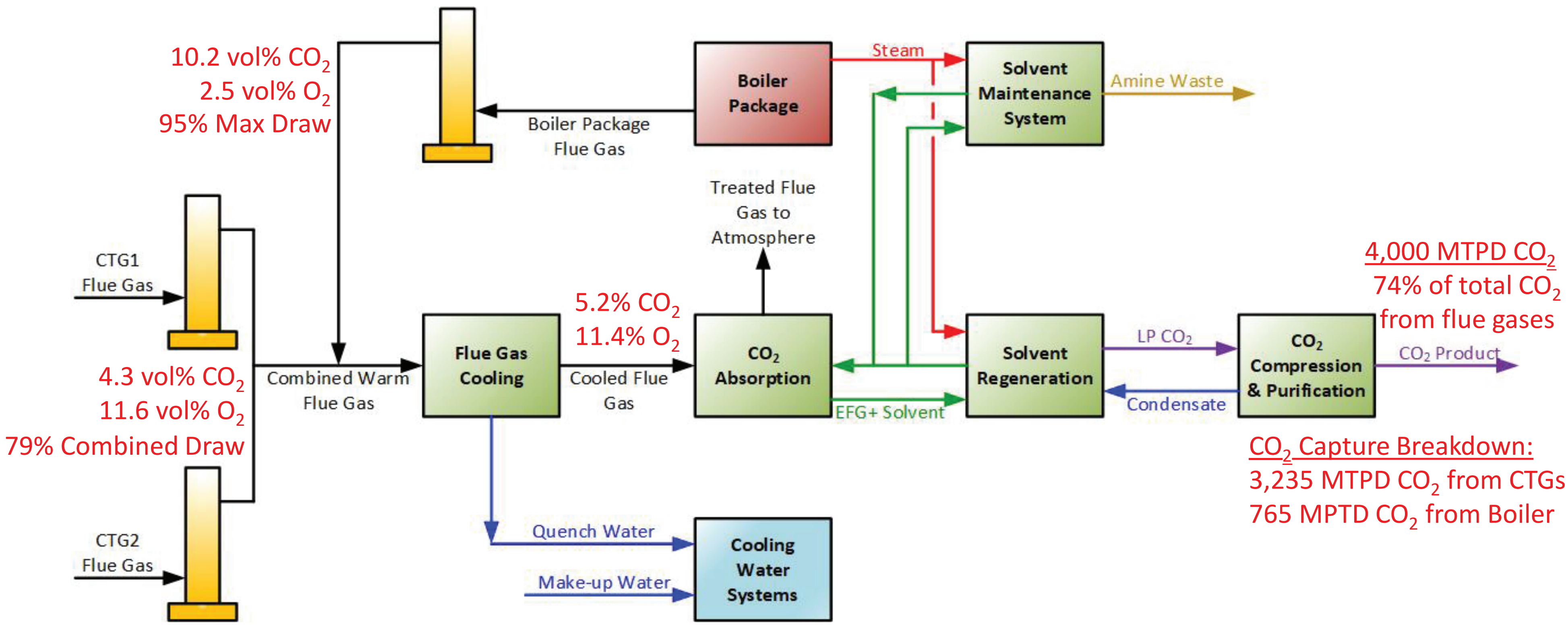
Block Flow Sketch for Post Combustion Carbon Capture at Elk Hills



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Flue Gas Design Basis

	CTG1	CTG2	New Boiler	Total
Total Available Flue Gas (MMSCFD)	990 (Max)	990 (Max)	166	2,146 (Max)
Total Flue Gas Draw (MMSCFD)	630 – 941	630 – 941	157	1,728
Percent Flue Gas Draw (%)	63% - 95%	63% - 95%	95%	-
Temperature (°F) / Pressure (psig)	210 / 0.0	210 / 0.0	298 / 0.0	218 / 0.0
N_2 / Ar (vol%)	73.75	73.75	69.78	73.39
O_2 (vol%)	11.59	11.59	2.50	10.76
H_2O (vol%)	10.31	10.31	17.46	10.96
CO_2 (vol%)	4.35	4.35	10.25	4.89
CO (ppmv dry)	< 0.1	< 0.1	< 61	< 5.7
NO_X (ppmv (dry)	< 1.9	< 1.9	< 2.5	< 1.8
NH_3 (ppmv dry)	< 5.9	< 5.9	< 6.1	< 5.9

Site Specific Design Requirements

- EFG+ unit designed to capture 90% of CO_2 from flue gas to unit
- On-stream factor of 95% with 40% turndown
- Solvent make-up storage capacity of 30 days
- Water minimization is required
  - Priority to significantly reduce water requirement associated with Pre-FEED design ➔revised cooling strategy to reduce water make-up
- Modularization highly investigated to reduce site construction hours
  - Nearest viable port is Port of Stockton (225 miles from project site)
  - Module envelope limited to 120 ft (L) x 20 ft (W) x 18 ft (H) at 250,000 lb
  - Conclusion was that modularization was not beneficial due to transport window limitations

Project Site Location

- Capture plant to be placed on site located just to the south of EHPP
- Project site was a location of a different process unit which has been demolished
  - Owner will bathtub site to remove subsurface interferences
- Seismic Zone 3
- Design dry / wet bulb temperatures: 92°F / 66°F

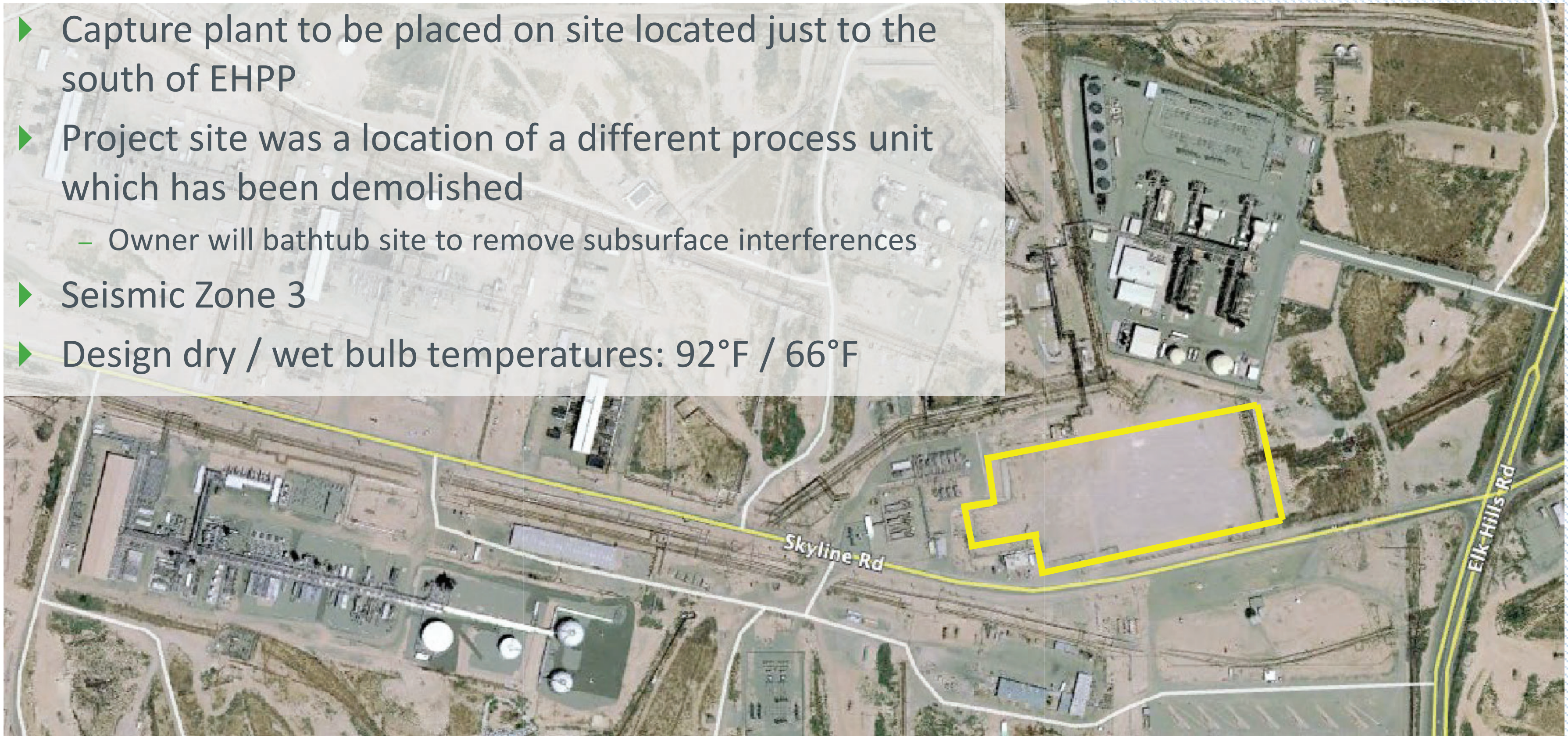


Image from CRC

Water Minimization

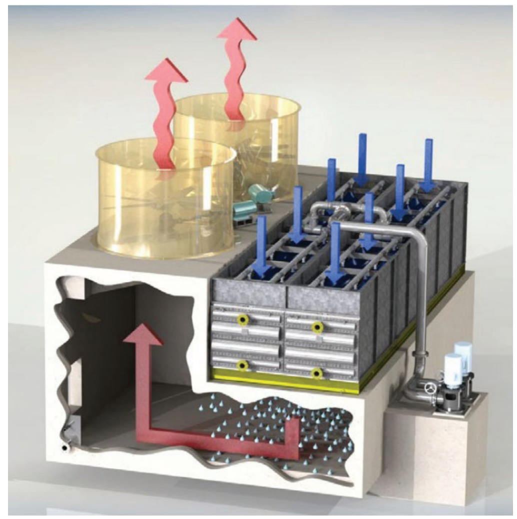
- Initial design was a 100% water-cooled plant
  - Quench water from DCC used to supplement cooling water make-up
  - RO Unit provided to treat and recover 65% of cooling tower blowdown
  - Water consumption was still too high to meet CRC requirements
- Consideration given to 100% air-cooled plant
  - Design ruled out due to hot ambient conditions
    - Required significantly large number of air cooler bays leading to higher CAPEX
    - Hot Summer conditions would result in inefficient plant operation leading to higher OPEX
- Final design based on hybrid air and water-cooled solution

Hybrid Air and Water-Cooled Approach

Courtesy Alfa Laval

Air Coolers

Services that do not need to be below ambient conditions + Approach



Courtesy Alfa Laval

Wet Surface Air Coolers

Large Duty Process Water Services

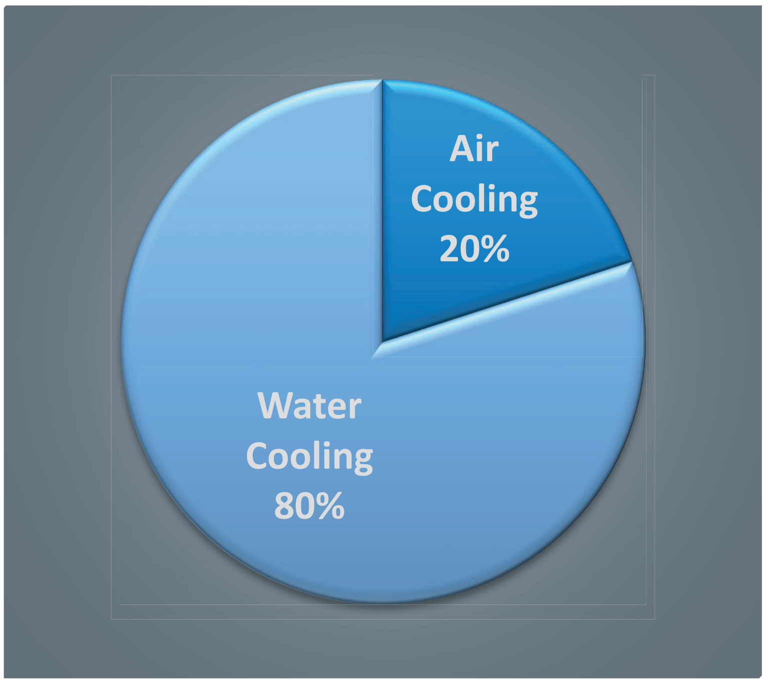
Courtesy SPX Cooling

Cooling Tower

For streams impractical to use other methods

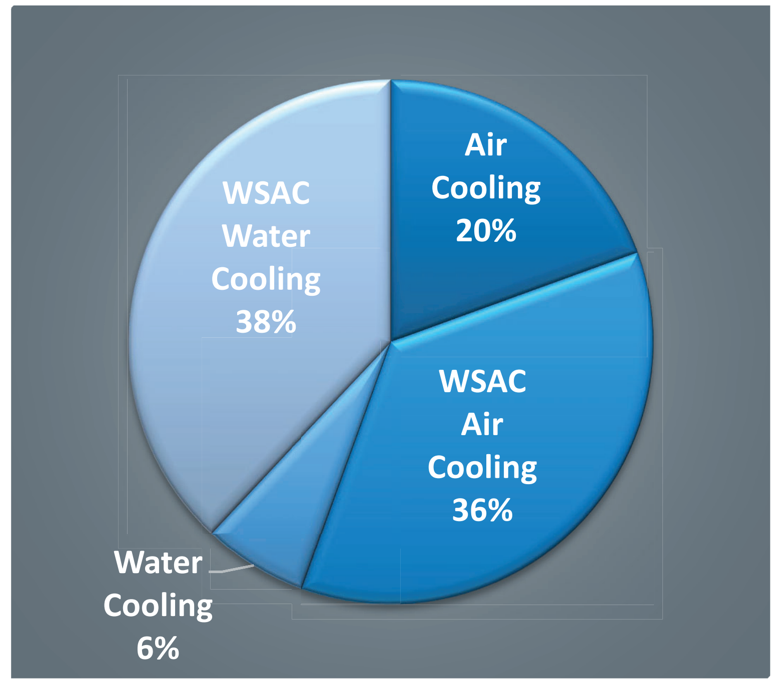
Breakdown of Cooling

PRE-FEED DESIGN



Raw Water Make-up Reduced by 63%

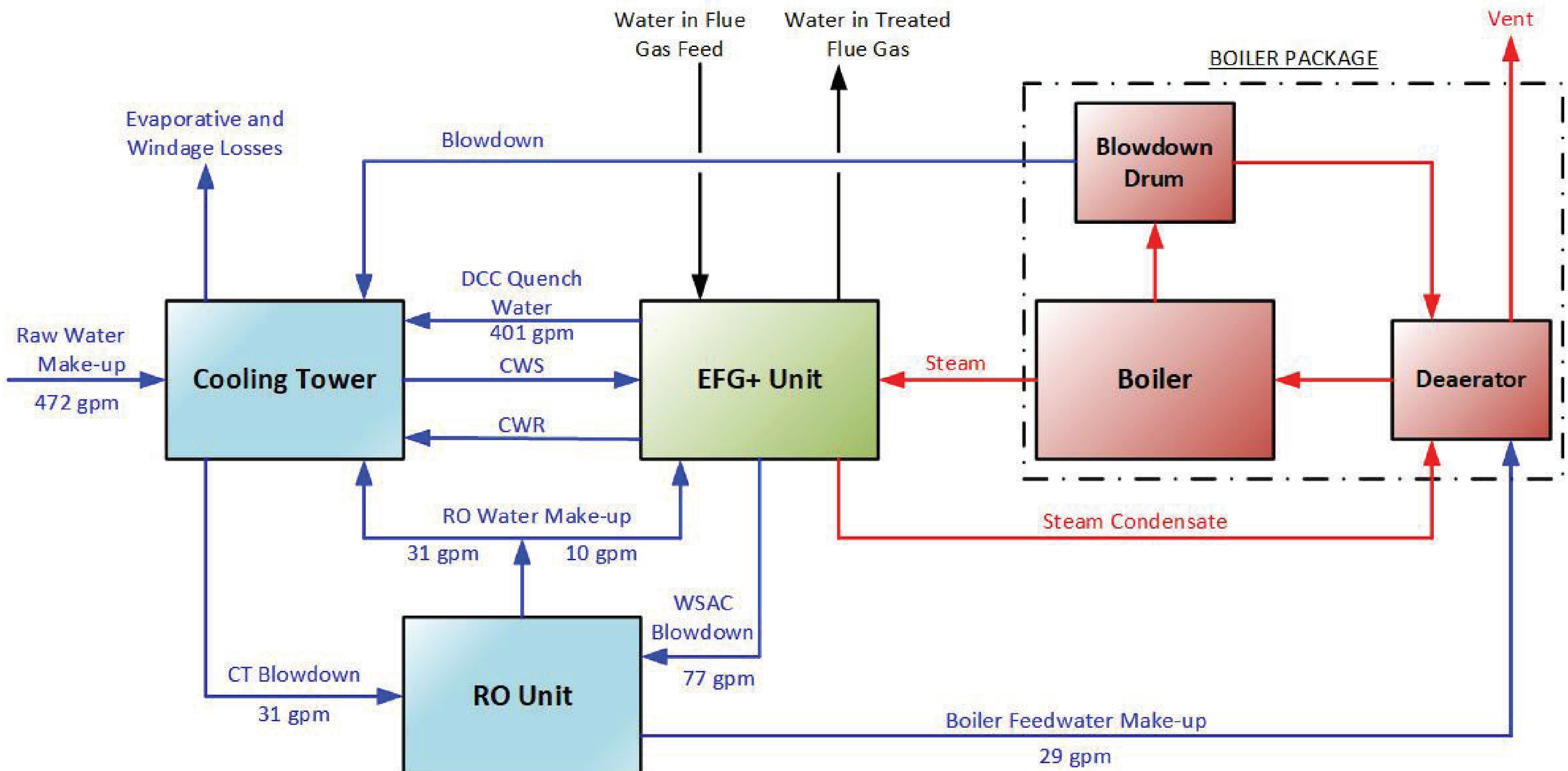
FEED DESIGN



Steam Supply and Water Recovery

- Dedicated Boiler Packages provided to meeting all CCU steam demands
  - Water tube boiler burns a nominal 550 MMBtu/hr of mixed fuel gas blend provided by CRC
  - Make-up water to Boiler Packages provided from an RO Unit, included within CCU scope
  - RO Unit treats blowdown from Cooling Tower and WSACs to recover 65% of the water
  - No material change to EHPP performance with inclusion of dedicated Boiler Packages versus use of steam extraction

Steam and Water System Block Flow Diagram

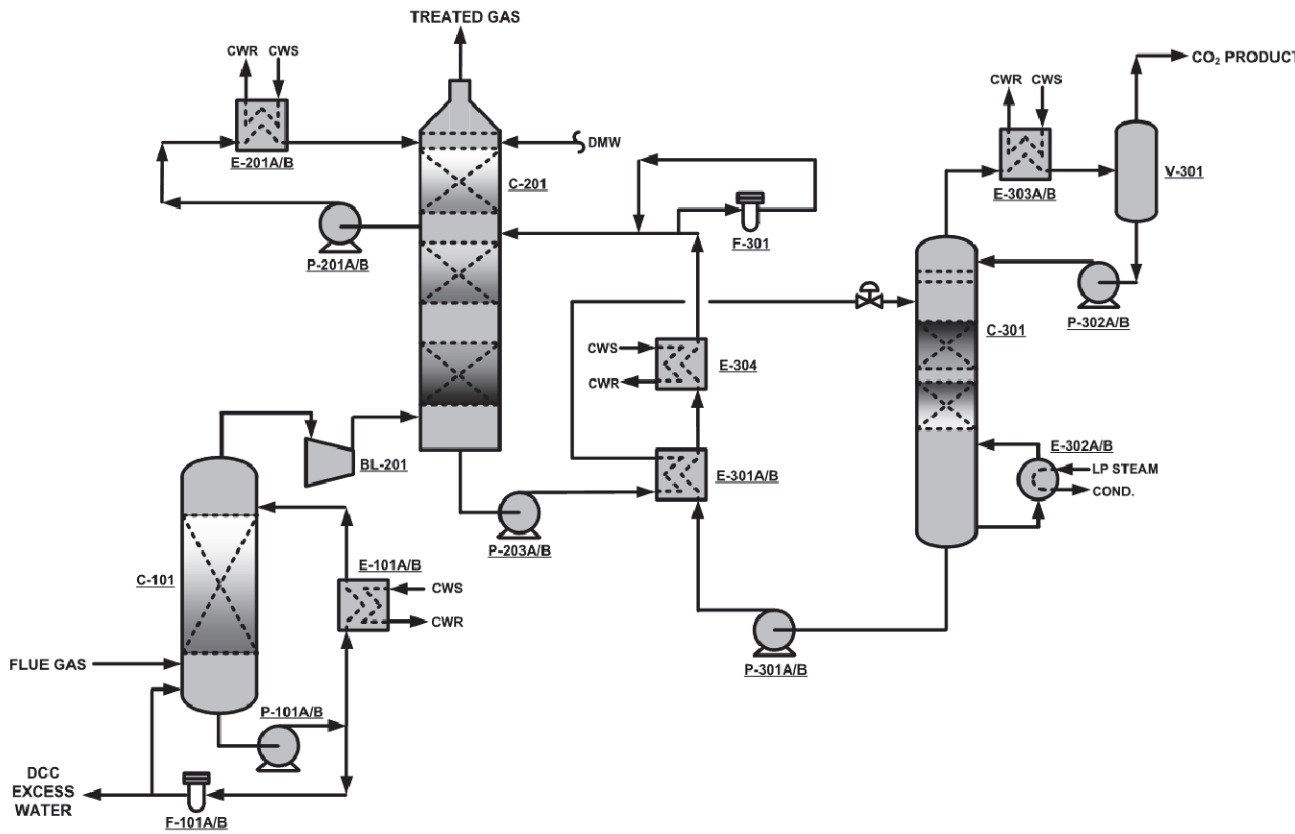


Other CCU Utility Requirements

- Instrument and plant air
  - CCU equipped with dedicated instrument and plant air package
- Raw water, potable water, nitrogen and fuel gas
  - Provided by CRC at the CCU battery limits
- Electrical power (~35 MW)
  - Provided through the existing CRC Elk Hills transmission system
  - New 115 kV line brought from existing CRC substation to new CCU substation where it is stepped down to 13.8 kV / 4160 V / 480 V

Simplified EFG+ Process Flow Sketch

- Combined flue gases routed to DCC (C-101) for cooling
- 90% of CO_2 in flue gas chemically absorbed in the Absorber (C-201)
- CO_2 loaded solvent is routed to Stripper (C-301) where CO_2 is desorbed
- Low pressure CO_2 product from C-301 overhead routed to compression and dehydration



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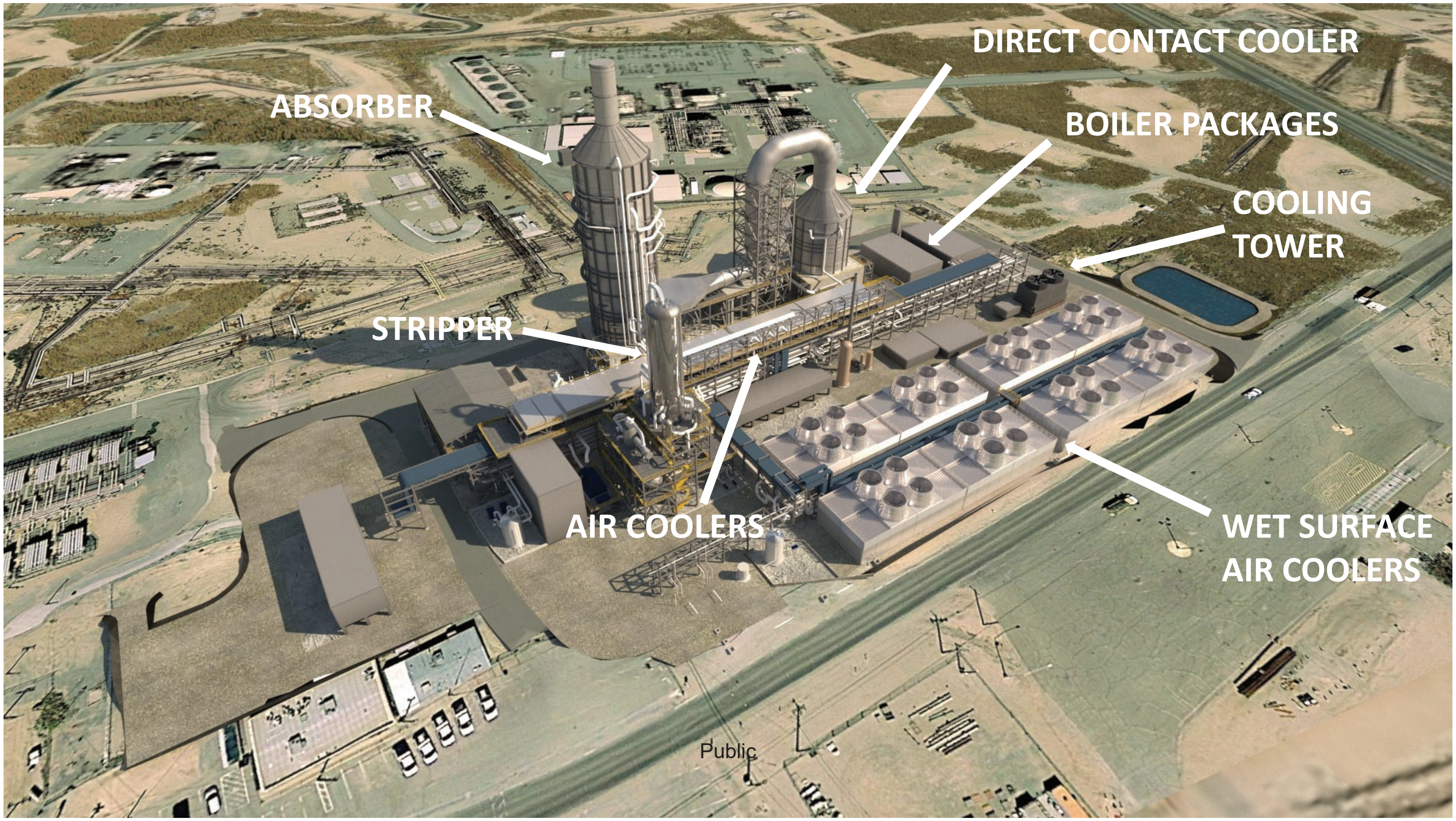
Overall H&MB

	Combined Flue Gas Feed	DCC Excess Water to CT Basins	Treated Flue Gas to Atm.	Treated RO Water to Abs.	Compressed CO2 Product
Temperature	218 °F	123 °F	95 °F	105 °F	130 °F
Pressure	13.8 psia	60 psia	14.0 psia	14.2 psia	2,314 psia
Composition					
H_2O	11.0 mol%	100 mol%	5.9 mol%	100 mol%	526 ppmv
CO_2	4.9 mol%	40 ppmw	0.5 mol%	0.0 mol%	99.9 mol%
N_2 / Ar	73.4 mol%	10 ppmw	81.6 mol%	0.0 mol%	184 ppmv
O_2	10.8 mol%	3 ppmw	12.0 mol%	0.0 mol%	13 ppmv
CO	4.7 ppmv	0.0 mol%	5.2 ppmv	0.0 mol%	0.0 ppmv
NO_X (as NO_2)	1.8 ppmv	0.0 mol%	1.9 ppmv	0.0 mol%	0.0 ppmv
SO_2	0.6 ppmv	0.0 mol%	0.0 ppmv	0.0 mol%	0.0 ppmv
Total Flow Rate	1,200,101 SCFM	401 gpm	1,079,627 SCFM	10 gpm	8,355 lbmol/hr
Total Mass Flow Rate	5,359,820 lb/hr	198,450 lb/hr	4,799,460 lb/hr	4,970 lb/hr	367,510 lb/hr

Rendering of CCU Facility



End of FEED Cost Cutting Measures

- Towards end of FEED, Fluor and CRC teams brainstormed and evaluated several potential cost cutting measures
- Those with positive outcome have been incorporated into final FEED design
- One item is still under evaluation
  - Reconsider extracting steam from EHPP and eliminate boiler packages
  - Reduces power plant output by an estimated 35 MW
  - Frees up significant portion of EHPP cooling load
  - Apply freed up cooling load to CCU and eliminate up to 5 of the 8 WSACs
  - Fluor has roughly estimated a potential savings of up to $35-$45 MM

Final Capital Cost Estimate

Plant Area	Total Installed Cost
CO_2 Capture Island	$387 MM USD
CO_2 Compression	$61 MM USD
Utility Systems	$267 MM USD
Balance of Plant	$33 MM USD
TOTAL	**$748 MM USD**

- Estimate accuracy ➔ ±15%
- Lump Sum EPC with performance guarantees and liquidated damages
- Forward escalation included from 2020 to project completion ➔$39 MM
- Project execution based on Union labor
- Sales Tax included at $8.5 MM
- Pre-commissioning, commissioning, Startup and Performance Testing included
- Contingency included at $57 MM
- Licensor fee excluded
- Mass excavation of site excluded

Level 1 Schedule

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NET ZERO 2023

Adya Deshmukh

Elk Hills CO2 Recovery Project

Econamine FG PlusSM

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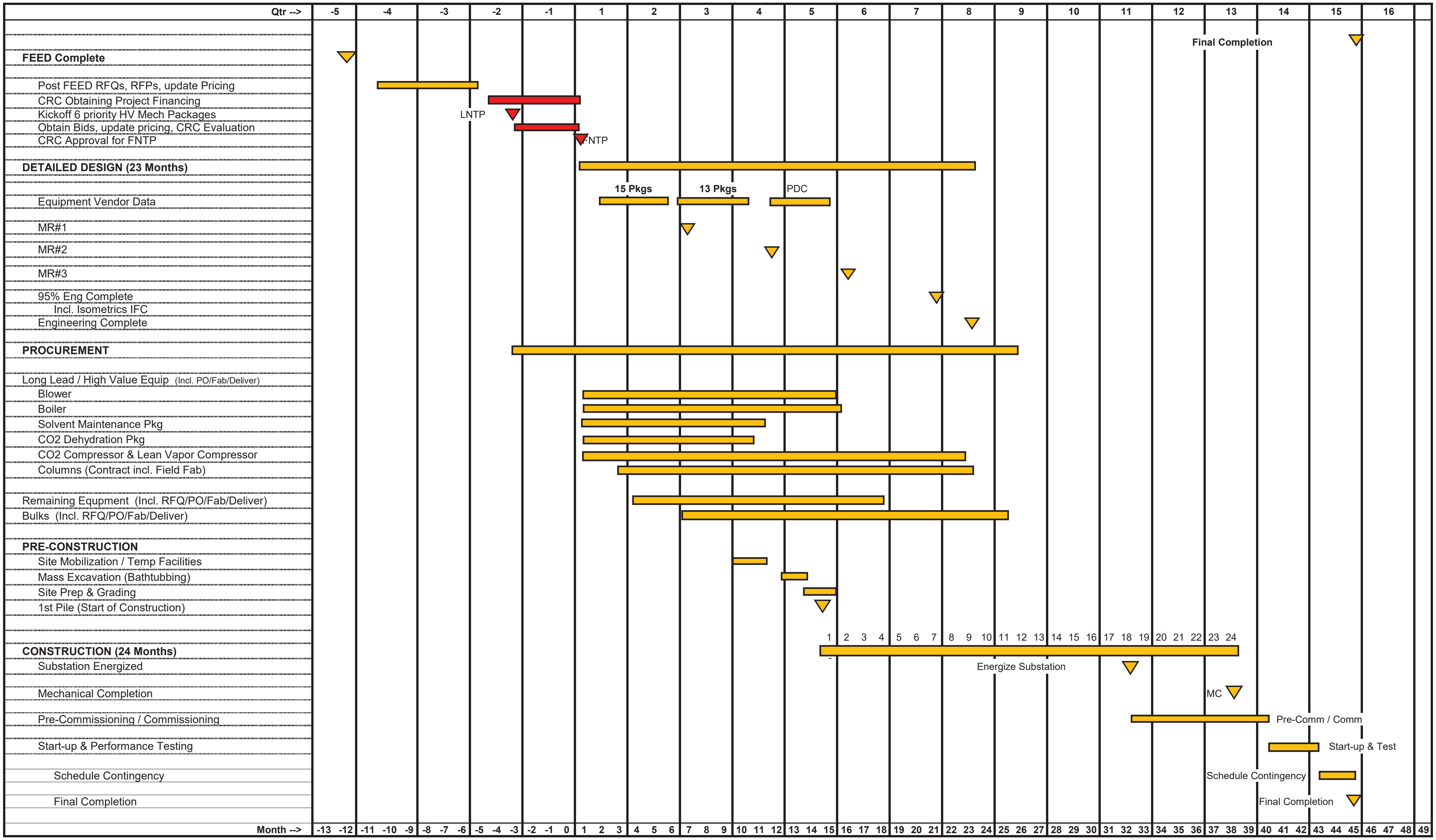
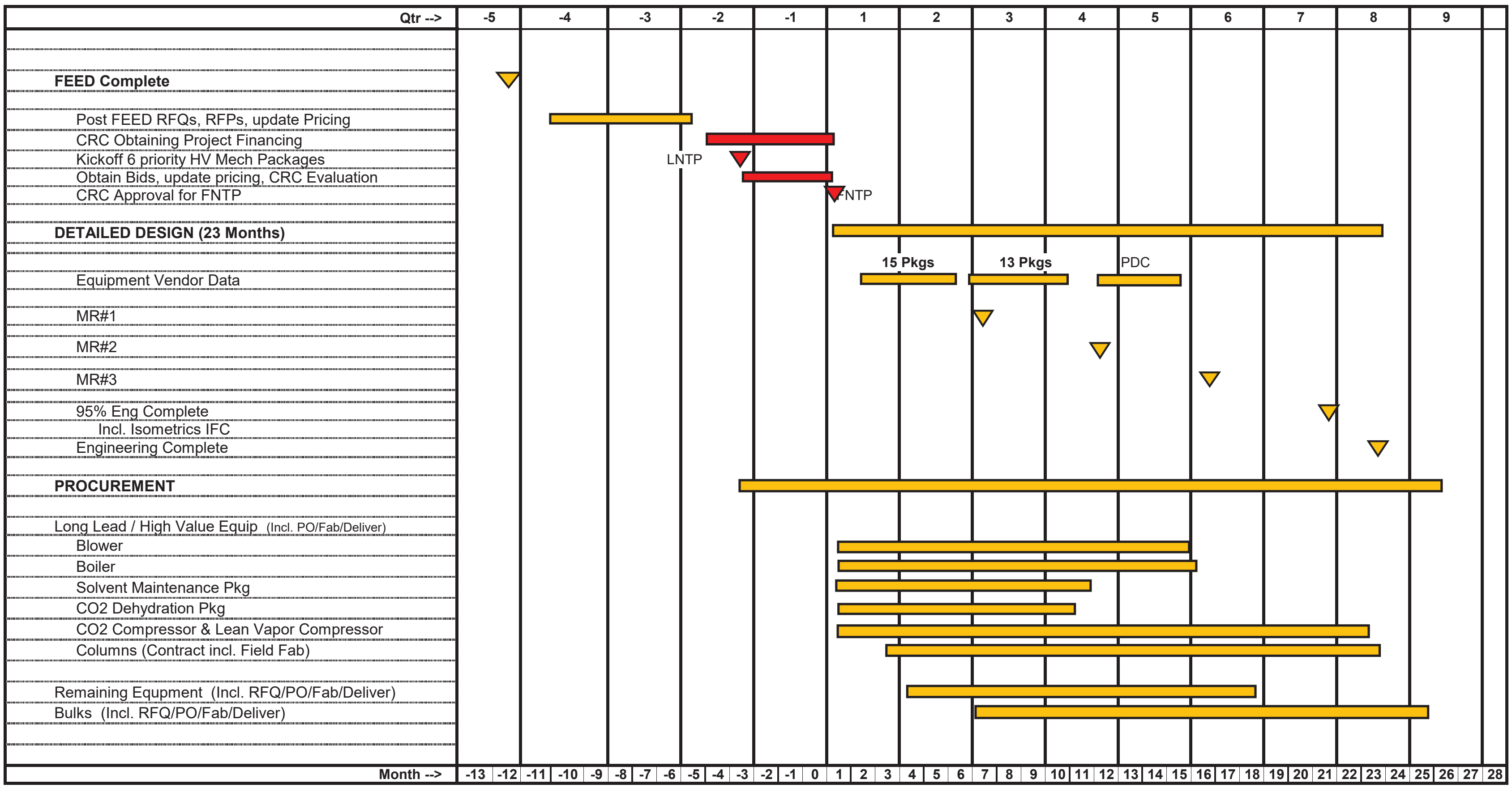
EPCC Summary Schedule



Elk Hills CO2 Recovery Project

Econamine FG PlusSM

EP Summary Schedule



Elk Hills CO2 Recovery Project

Econamine FG PlusSM

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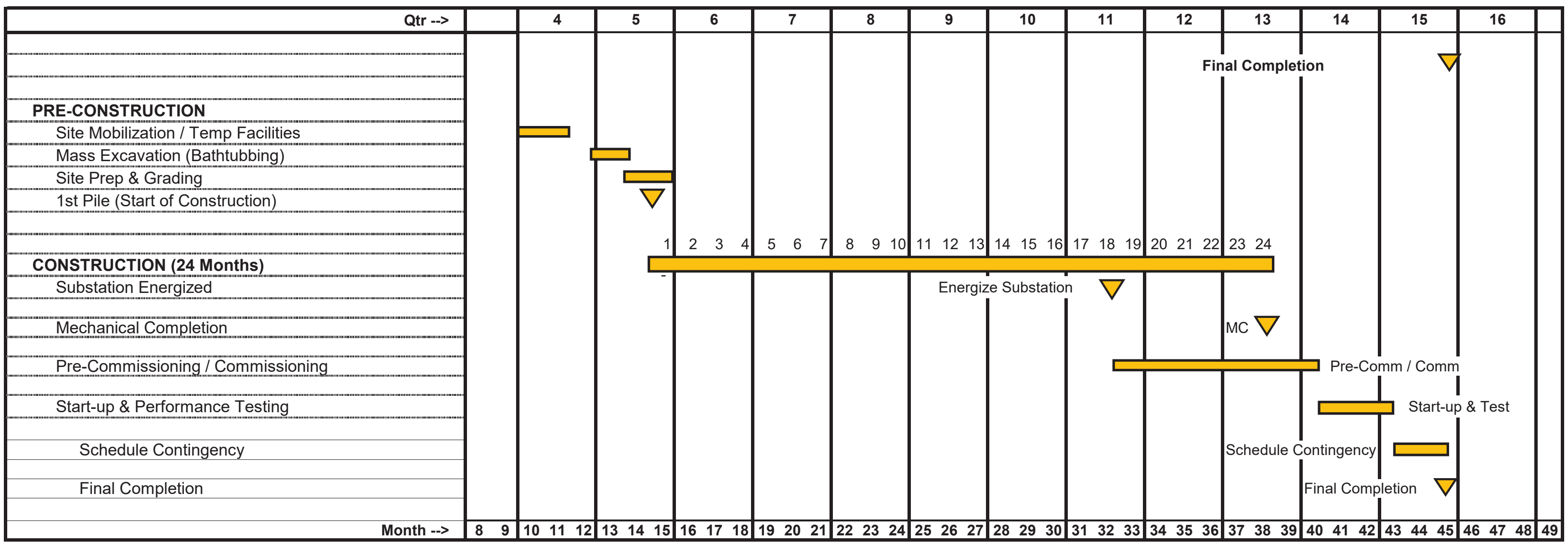
CC Summary Schedule



Thank You

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NET ZERO 2023

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Project Highlights

- 4,000 t CO_2/day captured: 3,325 t/day from CTGs + 765 t/day from auxiliary boiler
  - 90% CO_2 captured from flue gas entering EFG+ process
  - 74% capture of total CO_2
- CO_2 to be used for enhanced oil recovery or saline storage adjacent to power plant
- Economic drivers exist for commercial deployment
- This FEED study could lead to world's first full-scale, commercial deployment of carbon capture on NGCC power plant, and can be readily duplicated at other NGCCs across the world

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