Front-End Engineering & Design: Project Tundra Carbon Capture System

Virtual Closeout Meeting
Project DE-FE0031845
May 22, 2023

PROJECT TUNDRA

Minnkota Power COOPERATIVE
A Touchstone Energy® Cooperative

Square Butte ELECTRIC COOPERATIVE

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Today's Agenda

1. Introduction (**Minnkota**) 15 min
    a. Welcome and Introductions
    b. Overview of Study
        i. Project Team
        ii. Host Site description
        iii. Technology employed
        iv. Project Tasks
        v. Site Selection
        vi. Scope Split
    c. Executive Summary of Results
2. Capture System Detailed Engineering and Design (**Fluor**) 20-30 min
    a. Design Basis
    b. EFG+ Capture Technology
    c. Design Overview and Deliverables
    d. ISBL Detailed Design Review (**Fluor**) +60 minutes
        i. Block Flow Diagram
        ii. Plot Plan
        iii. Thermal and Electrical Loads
        iv. Process Flow Diagram Review (live walk-through with Q/A)
        v. 3D Model with Q/A (live walk-through with Q/A)
    e. Constructability
    f. HAZID and HAZOP
    g. Steam Cycle Integration
3. OSBL/BOP Design Results (**Minnkota**)15 min
    a. Highlights of Major System Results
    b. Water Supply to CCS
        a. Availability of Water
    c. Air Emissions and Permitting
        a. Dispersion Modeling and Monitoring
    d. Water Discharges
    e. Waste Disposal Planning
4. Review of Overall Plant Performance - 5 min
5. Review of Overall Plant Cost (**Minnkota**) 10-15 min
6. Framing of Results and Closing Discussions (**Minnkota**) 5 min
7. ACKNOWLEDGEMENTS

Cooperative Agreement No. DE-FE0031845

Original Project Budget

- Total: $12,276,972
- DOE: $ 9,821,578
- NDIC: $ 2,455,394

Current Project Budget

- Total: $13,058,042
- DOE: $ 9,821,578
- NDIC: $ 3,236,464

Original Period of Performance

- Oct 1, 2019 – Dec 31, 2020

Current Period of Performance

- Oct 1, 2019 – June 30, 2023

PROJECT OBJECTIVES:

Perform a FEED study to install a post-combustion carbon dioxide capture system on Milton R. Young Station Unit 2, a 477-MW power plant fueled by North Dakota lignite, that will demonstrate next-generation CCS feasibility and economics.

The FEED study was completed with Fluor's Econamine FG Plus^{SM} (EFG+) technology to retrofit the larger of two generating units at the station. The FEED study enables Minnkota to take the next steps in developing the project and moving toward construction.

Project Organization Chart

Lead Organization

Minnkota Power Cooperative (MPC)

Principal Investigator

Gerry Pfau

Craig Bleth replaced Gerry Pfau as Principal Investigator in September of 2022

Project Participants/Sponsors

Fluor Enterprises, Inc. (Fluor)
Energy & Environmental Research Center (EERC)
Golder Associates
AECOM
North Dakota Industrial Commission
U.S. Department of Energy

Project Consultants

David Greeson Consulting (DGC)
Hunt International Energy Services (Hunt)

Owner's Engineer

Burns & McDonnell (BMcD)

Task 1: Project Management and Planning

Lead: G. Pfau (MPC)
Assist: J. Laumb (EERC), D. Greeson (DGC)

Task 2: Project Engineering and Design

Lead: G. Adams (Fluor)
Assist: G.Pfau (MPC), M.Cole (Hunt), S. Reddy (Fluor)

Task 3: Permitting Strategy

Lead: G.Pfau (MPC)
Assist: MPC Env. Mgr

Task 4: Project Cost Estimation

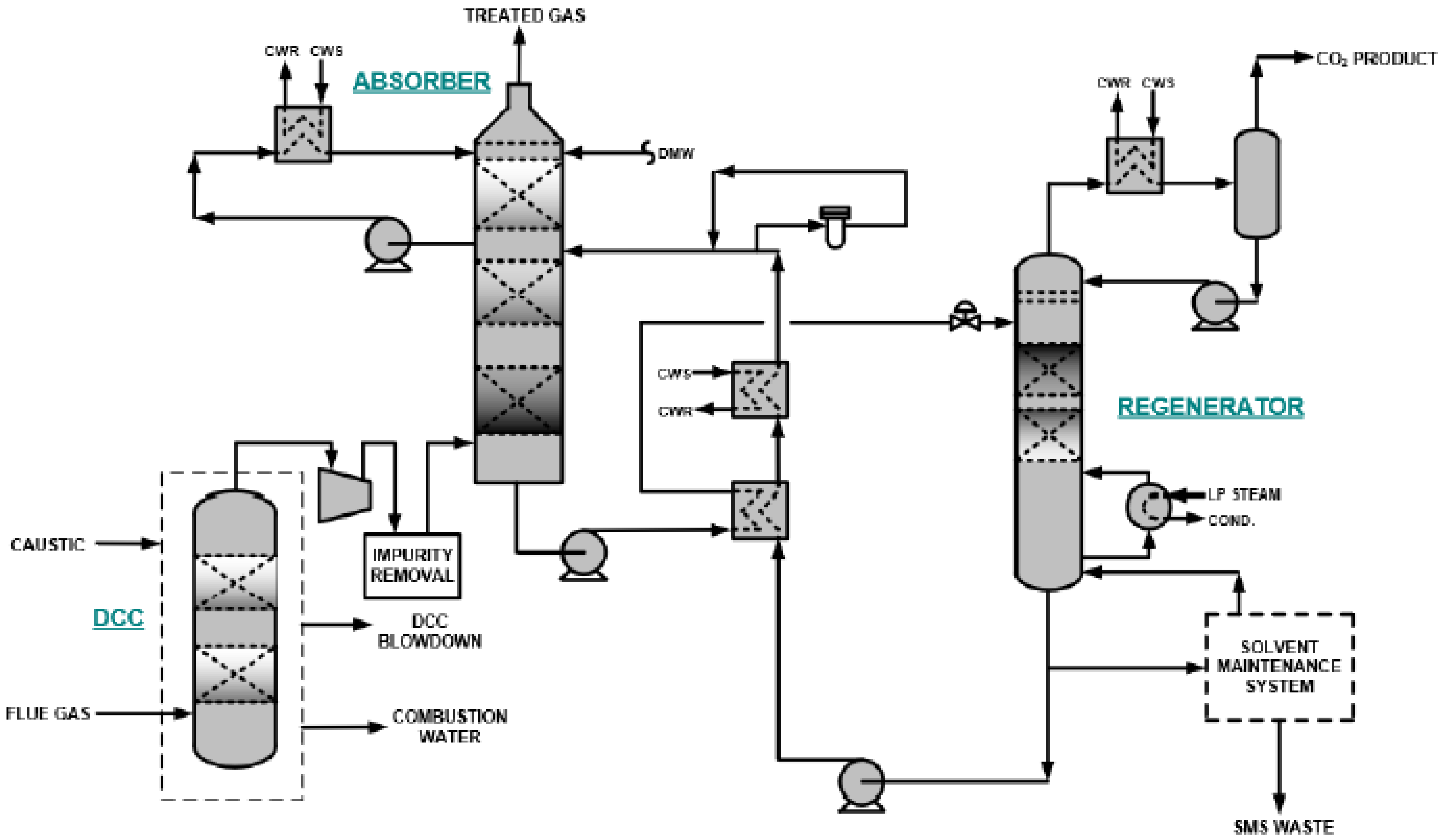
Lead: G. Adams (Fluor)
Assist: G Pfau (MPC), R Bryant (BMcD)

Host Site – Milton R. Young Station

- Unit 2 – Subject of the FEED
  - Nameplate design output 488.2 MWg/430 MWn
  - Entered commercial service in May, 1977
  - B&W cyclone-fired boiler
  - Westinghouse STG

- Unit 1 – Second Unit at site
  - Nameplate design output 256.2 MWg/230 MWn
  - Entered commercial service in November, 1970
  - B&W cyclone-fired boiler
  - General Electric STG

Capture Technology
Fluor's Econamine FG Plus℠



Project Tasks

- Task 1 – Project Management and Planning
- Task 2 – Engineering and Design
  - Subtask 2.1 – Project Design Basis
  - Subtask 2.2 – Carbon Capture System Design
  - Subtask 2.3 – Steam Cycle Integration
  - Subtask 2.4 – BOP Integration and Design
- Task 3 – Development of Permitting Strategies
  - Subtask 3.1 – Air Emissions
  - Subtask 3.2 – Water Discharge
  - Subtask 3.3 – Waste Disposal Planning
- Task 4 – Project Tundra Cost Estimating

Site Selection

- Undeveloped land adjacent to coal stockpiles
- Shortest path for ductwork
- Provides access points during construction from south and east

Carbon Capture System Design Scope Split

CCS Scope - Fluor

- CCS Capture Plant
- Dehydration and Compression of CO_2
- Utility Systems to support the CCS
- Package Boilers
- Flue Gas Ducting
- Cooling Tower

Balance of Plant Scope

- Water Treatment Process (BMcD)
- Makeup Water Supply (BMcD)
- Potable Water (BMcD)
- Utility Water Supply (BMcD)
- Wastewater Return Piping (BMcD)
- Class I Disposal Well (Golder)
- Natural Gas Tie (BMcD)
- Fire Water Supply (BMcD)
- Stormwater Management (BMcD)
- Cooling Tower Icing Studies (BMcD)
- Absorber Tower Icing Studies (Nels)
- Air Dispersion Modeling (AECOM)
- 230 kV Power Supply (MPC)
- Emission Monitoring Plan (Agora)
- Flue gas duct interconnect (BMcD)
- RAM Study (MPC)

Summary of Results

- 12,978 ston/day of CO_2
- Project Cost Estimate ($\pm$15%)
- Total Project CAPEX - $1,938MM
- Cost of Capture – $80.60/metric tonne CO_2
    - Includes transport and storage

Project Design Basis

- Carbon Capture System Design
  - Minimum 90% CO_2 removal using amine-based solvent
  - Process 100% of flue gas from Young 2 and natural gas-fired boilers
  - Capacity of 12,978 short tons of CO_2 per day at 1675 psig and ≤125°F
  - Composition: ≥95% v/v CO_2, ≤30 lb/MMscf H_2O, ≤20 ppmv O_2
  - Turndown capability to 40%
  - Minimum 20-year service life
  - 90% design availability

EFG+ Capture Technology

Fluor's EFG+ technology is an advanced amine-based process specialized for removal of CO_2 from low-pressure, oxygen-containing flue gas.

1. Two-stage direct contact cooler (DCC) for flue gas cooling and SO_2 removal
2. Blower to convey the flue gas through the process
3. Flue gas treatment equipment to remove fine aerosol particles
4. Absorber with intercooling for CO_2 separation
5. Regenerator with lean solvent flash/vapor compression for solvent regeneration and the release of pure CO_2
6. Fluor's proprietary Solvent Maintenance System (SMS) to remove heat-stable salts (HSS) and other nonvolatile degradation products
7. Compression and dehydration system to supply pipeline-ready CO_2

EFG+ Key Advantages

- EFG+ is the only commercial technology available with extensive operating experience capturing CO_2 from high-oxygen containing flue gases (up to 15 vol%).
- Process advancements offer improvements over conventional MEA
  - Regeneration steam requirements – 30% lower
  - Electrical power requirements - 20% lower
  - Solvent Consumption – 50% lower
- Two-stage DCC
- Absorber Temperature Optimization
- Regeneration Heat Integration Configurations
- Minimizing Pressure Drop
- Solvent Maintenance System

Carbon Capture System Design Overview

Nine Primary Subsystems

1. Flue Gas Cooling and Conditioning
2. Flue Gas Blower
3. Flue Gas Particulate Removal
4. CO_2 Absorption
5. Solvent Regeneration
6. Solvent Maintenance
7. Chemical Storage and Supply
8. CO_2 Compression
9. Utility Support Systems

Four Major Facility Enclosures/Building

1. Process Enclosure
2. Compressor Enclosure
3. Boiler Enclosure
4. Multi-Purpose Building

Deliverables

Key Deliverables Produced

- Plot Plan
- Process flow diagrams
- Utility flow diagrams
- Heat and material balances
- P&IDs
- Tie-in list
- Process equipment list
- Preliminary structural, civil and architectural drawings (3D model)
- HAZOP review
- Effluent and Emissions

2.2 Block Flow Diagram

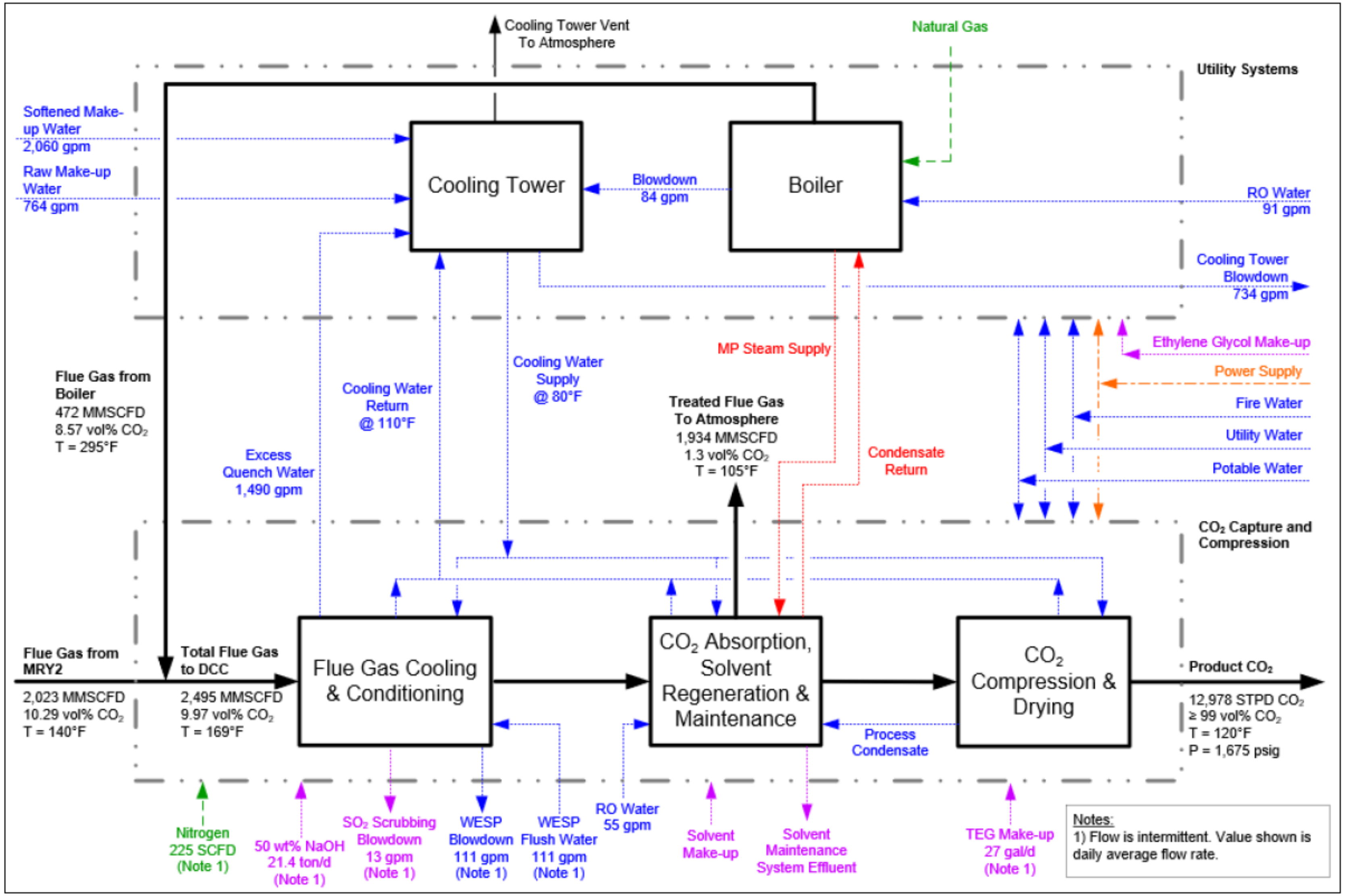
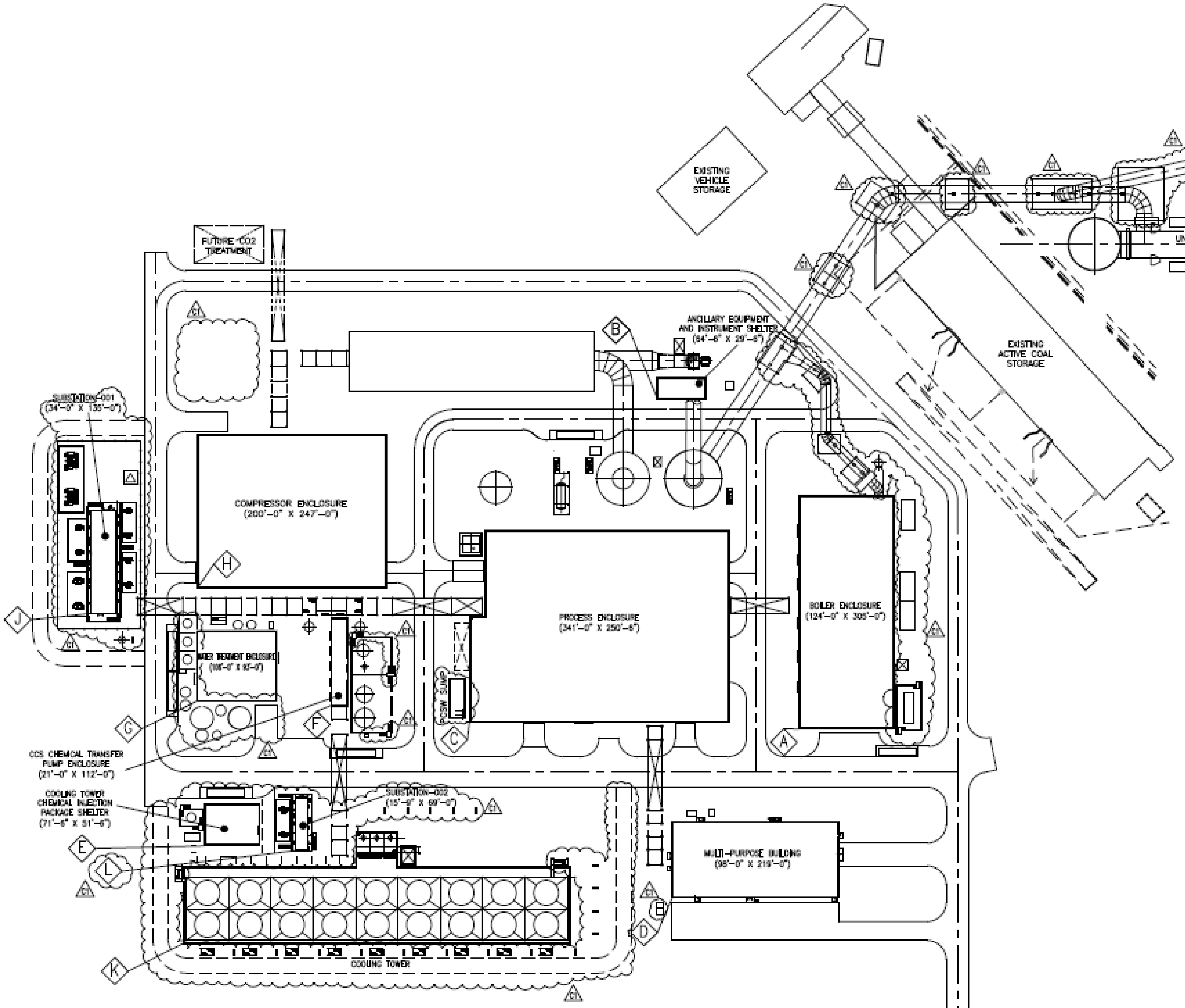
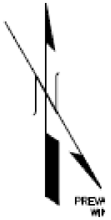


Figure 4. Block flow diagram for the EFG+ CCS plant

Plot Plan Drawing





CCS UNIT
BUILDING LOCATION COORDINATES

Point Letter	Description	Southwest Corner in Plant Coordinates (Decimal Feet) Easting	Northing	Southwest Corner in State Plane Coordinates (Decimal Feet) (NAD83 North Dakota State Plane Coordinate) Easting	Northing
A	Boiler Enclosure	[illegible]	[illegible]	[illegible]	[illegible]
B	Ancillary Equipment and Instrument Shelter	[illegible]	[illegible]	[illegible]	[illegible]
C	Process Enclosure	[illegible]	[illegible]	[illegible]	[illegible]
D	Multi-Purpose Building	[illegible]	[illegible]	[illegible]	[illegible]
E	Cooling Tower Chemical Injection Package Shelter	[illegible]	[illegible]	[illegible]	[illegible]
F	CCS Chemical Transfer Pump Enclosure	[illegible]	[illegible]	[illegible]	[illegible]
G	Water Treatment Enclosure	[illegible]	[illegible]	[illegible]	[illegible]
H	Compressor Enclosure	[illegible]	[illegible]	[illegible]	[illegible]
J	Substation-001	[illegible]	[illegible]	[illegible]	[illegible]
K	Cooling Tower Basin	[illegible]	[illegible]	[illegible]	[illegible]
L	Substation-002	[illegible]	[illegible]	[illegible]	[illegible]

Capture Plant Rendering

Thermal and Electrical Loads

Table 17. Total thermal and electrical auxiliary loads

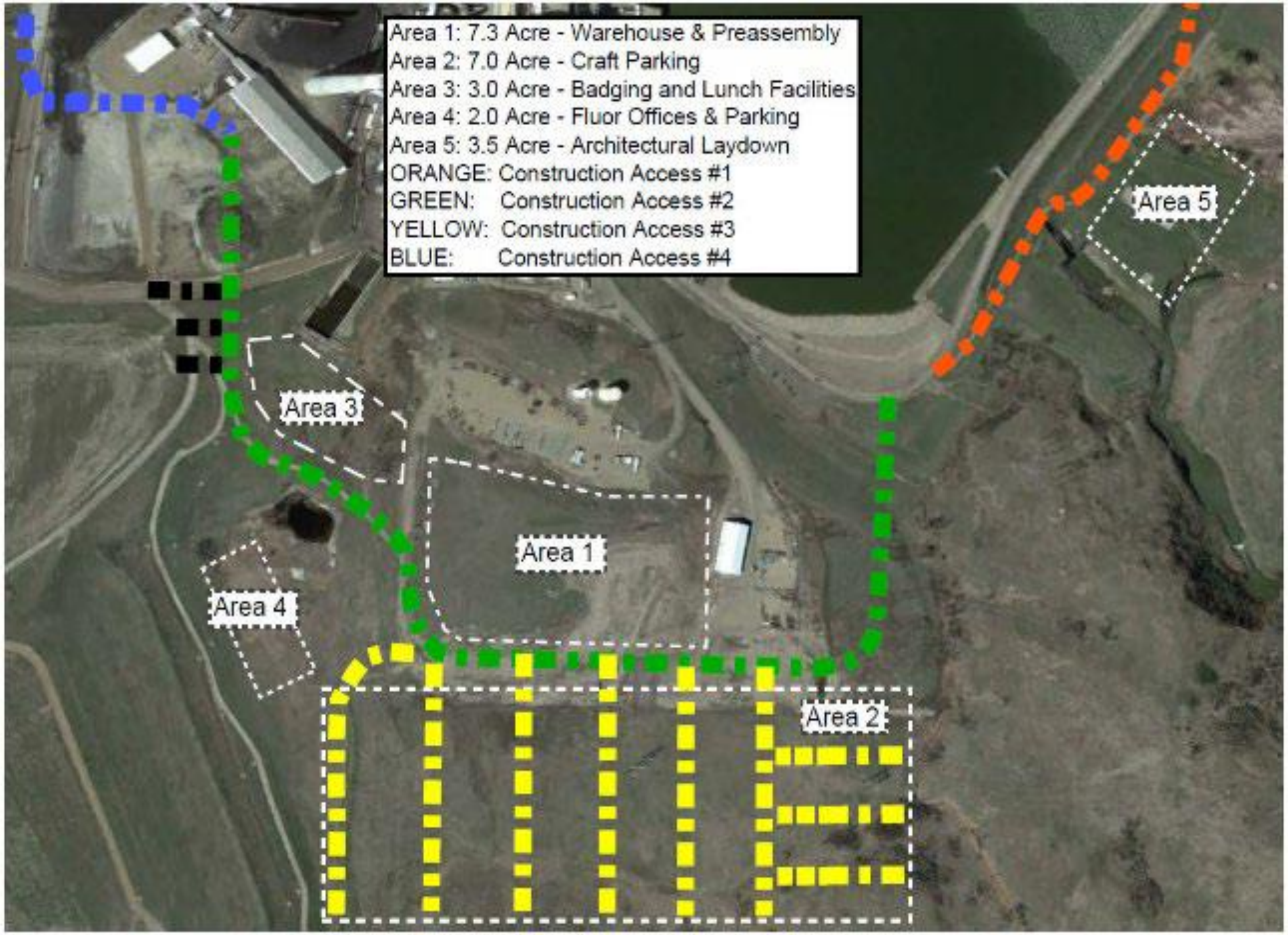
Source	Auxiliary Load	Unit
Thermal	37,124	MMBtu/day (natural gas input)
Blower	7.8	MW_e
Capture Plant	14	MW_e
Compression	44.4	MW_e
Cooling Tower	8.2	MW_e
Flue Gas Conditioning	5.5	MW_e
Misc.	0.4	MW_e
Natural Gas Boilers	3	MW_e
Total Electrical Load	83.3	MW_e

Process Flow Diagram Review
(Live walk-through with Q/A)

3D Model Review
(Live walk-through with Q/A)

Constructability/Transport

- Shipping limitations - large modules and preassemblies to the site will be cost-prohibitive
- Preassembly of large components 6 miles away, with 100+' wide gravel road to transport to CCS



HAZOP and HAZID

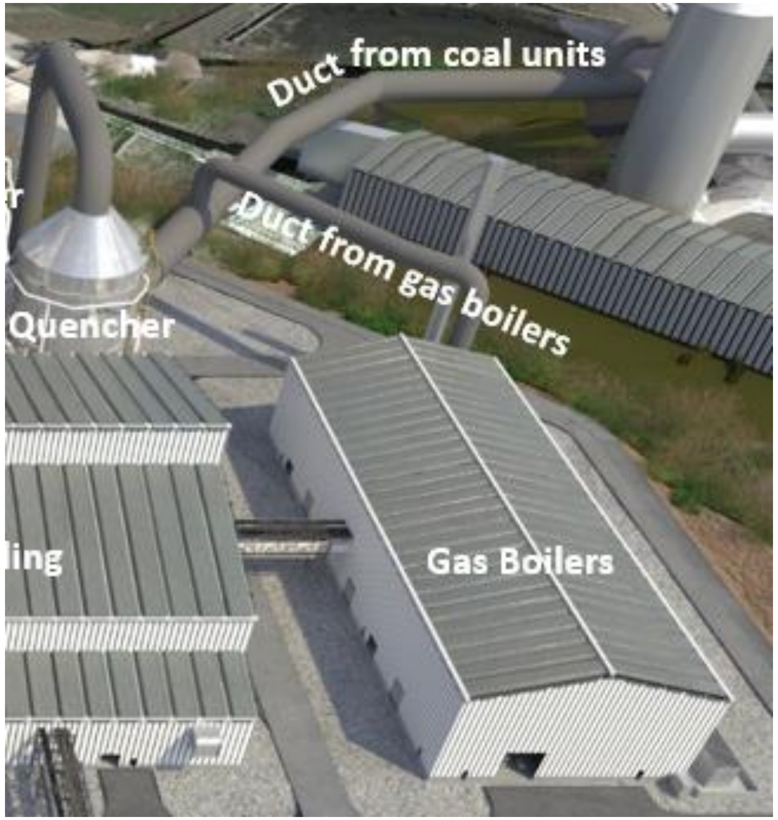
- HAZOP
  - 105 total recommendations
    - 61 were closed during FEED
    - 44 were deferred to the EPC Phase
      - 16 recommended for Vendor HAZOPs during detailed EPC design
- HAZID
  - 25 total recommendations
    - 19 were closed during FEED
    - 6 were deferred to the EPC Phase

Table 12. Breakdown and status of FEED recommendations by study

Workshops/Study	Status		Total
	Defer to EPC	Final (Closed)	
PHA I - HAZID	6	19	25
PHA II - HAZOP	44	61	105
Total	50	80	130

Steam Cycle Integration

- Steam for solvent regeneration and SMS
- Pre-FEED selection of natural gas-fired package boilers
  - Required three 33% boilers, two 100% feedwater pumps, and a common deaerator
  - Building to house package boilers
  - Larger CCS to handle flue gas from package boilers
  - Independent of Unit 2, allowing for tie-in of Unit 1
- New natural gas pipeline (owned & operated by 3rd party)



FEED Steam Source Selection Design/Cost from Two Supply Options

1. Auxiliary NG boilers
   - Higher capital cost
   - Greater operating flexibility
   - Less technical risk than steam extraction
   - Subject to volatile natural gas market
   - Pipeline and easements, environmental permitting
2. Steam extraction from Unit 2
   - Preliminary Study – no fatal flaws
   - Lower capital cost
   - Stable and predictable fuel cost
   - Reduces generation in a low-priced market
   - Revenue sale of steam to project

- <u>For FEED, selected auxiliary NG boilers</u>
  - Reduced technical/financial risk
  - Definitive information on steam extraction from Unit 2 STG and modifications necessary were not known
  - **…..However, a key conclusion of the FEED was that NG boiler option was higher cost than expected, and extraction steam should be reconsidered.**
    - **Much higher than pre-FEED had estimated**

Balance of Plant Integration and Design

- Water Treatment Process – BMcD
- Water Treatment Makeup Supply – BMcD
- Potable Water Supply – BMcD
- Utility Water Supply – BMcD
- Wastewater Return Piping – BMcD
- Wastewater Class I Disposal Well – Golder Associates
- Natural Gas Tie (From supply to NG Boilers) – BMcD
- Fire Water Supply – BMcD
- Stormwater Management – BMcD
- Cooling Tower Icing Studies – BMcD
- Absorber Tower Icing Studies – Nels
- Air Dispersion Modeling – AECOM
- Emissions Monitoring Plan – Agora
- 230 kV Power Supply – MPC

Water Supply to CCS

- Raw water treatment system – 3,100 gpm (4.5 million gallons/day) of softened water
  - Includes:
    - make-up to the cooling tower
    - CCS service water
    - Pre-treated feed water to the DMW system
    - Manage chlorides to 100 mg/l maximum in cooling tower blowdown
- Demineralized water treatment system – 120 gpm
  - Auxiliary NG boilers steam requirements
  - DMW users in the CCS

Availability of Water

- Supply is delivered to water treatment from existing pumphouse on Nelson Lake
- 10,000 acre-feet capacity of Nelson Lake will be supplemented by water from the Missouri River
- Water appropriation from ND State Water Commission for CCS
  - 15,000 acre-feet annually from the Missouri River
  - Utilize existing Minnkota pumping station on Missouri River and 13-mile pipeline to Nelson Lake

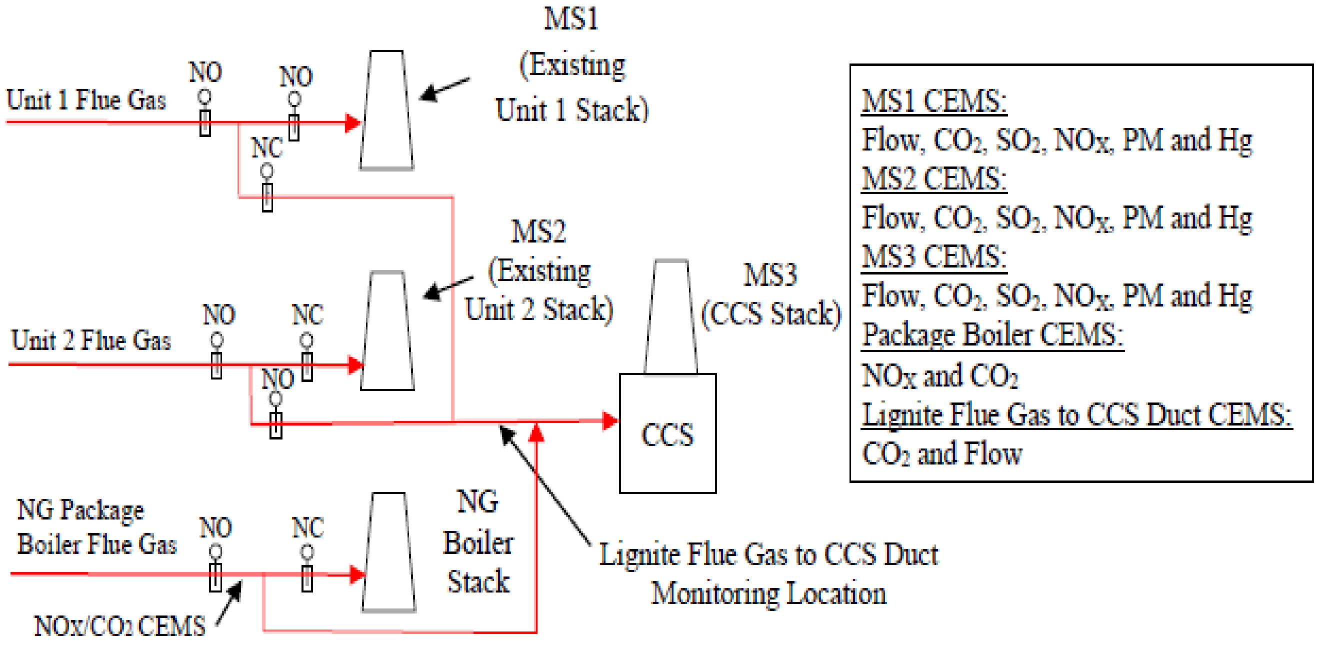
Air Emissions and Permitting

- CCS Permit Application - Minor Source Permit to Construct Required
- Separate Source from MRYS
- Emissions sources (units) required to be permitted

    1. Absorber Process Gases
    2. Natural gas boilers
    3. Cooling Tower
    4. Emergency Diesel Fire Pumps
    5. Hydrated Lime Storage Silos
    6. Soda Ash Storage Silo
    7. Facility Haul Roads
    8. Amine Solvent Storage Tanks
    9. Organic Liquid Storage Tanks
    10. CCS island deliveries

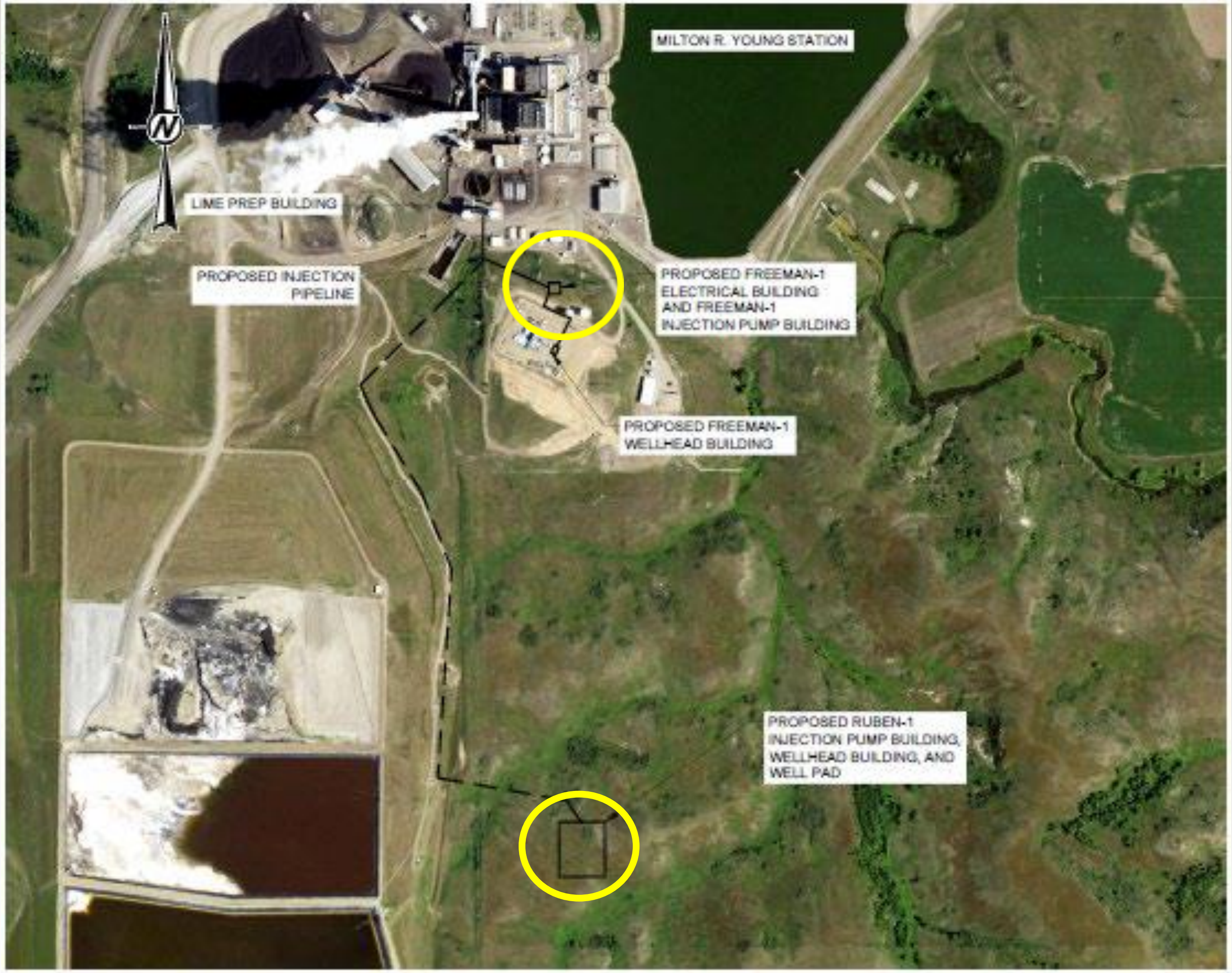
Dispersion Modeling and Monitoring Plan

- Air dispersion modeling (NAAQS) – AECOM
  - Fluor emissions estimates based on CCS design and performance estimates
- New emissions monitoring plan necessary (Agora)
  - New emission point for flue gas
  - Account for commingling of coal and NG flue gas



Water Discharges

- MPC will pursue Class I (non-hazardous) injection wells to dispose of CCS wastewater
  - Class I permit required
  - Aquifer exemption from EPA (3,000-10,000 mg/l aquifer TDS required)
  - Golder Associates led development of information for permitting, and disposal well/infrastructure design
- Runoff from facility will be managed under the existing NDPDES Permit
- Construction stormwater permit will be required, and SWPP Plan



3.3 Waste Disposal Planning

- Non-hazardous waste
  - Amend existing MRYS landfill permit as necessary
  - Identify new CCS waste compositions and quantities for on-site disposal
- Fluor solvent maintenance system separates heat stable salts (HSS), producing an effluent that also contains some unrecovered solvent and water
    - Anticipating this waste will require off-site disposal via third-party contractor.

Cost Estimates

- General assumptions
  - Tax equity financing with a commercial bank construction loan taken out by tax equity investors at COD.
  - Host power plant life is through 2042.
  - Power plant (i.e., flue gas supply) annual capacity factor 85%.
  - Steam supply is from new natural gas boilers with exhaust routed through the CCS.
  - Power is supplied by host power plant at a cost of $30/MWh (marginal energy-only cost of power).
  - Cost of natural gas plus firm transport is $2.85/MMBtu (escalated).
  - Unit 1 flue gas will be supplied to CCS during Unit 2 outages (improves CCS utilization factor).
  - MPC Services such as water, site lease, stormwater, snow removal, and other misc. site services provided by host at cost.

CCS Operating Cost Estimate

Operating Costs ($/ton)	
VAR (EFG+ Solvent, Caustic Soda, TEG, reclaimed solvent disposal, misc. annual testing for CCS)	4.02
Labor (based on MPC operator costs)	0.54
MPC Services (raw water treatment, wastewater disposal, site security, modifications to existing infrastructure)	1.79
Power (PPA priced at $30/MWh escalated)	4.46
Natural Gas ($2.85 per MMBTU)	7.70
MPC G&A	0.06
Misc.	0.05
Insurance	0.04
Total Cost per short ton of CO_2	18.66

Total Cost per metric ton = $20.57

CCS System Cost Estimate (Excludes Owner’s Costs)

Capital Cost Breakdown		
Description		**Cost in Millions**
Base Carbon Capture Plant (12,978 stpd) (11,773 metric tons/day)		**$745**
Balance of Plant Scope (NG boiler, cooling tower, multipurpose building and 230 substation)		**$330**
Project Tundra-Specific Requirements	Earthwork Associated with Carbon Capture	**$85**
	Impurity Removal Package	**$56**
	Enclosures/Buildings	**$79**
	Regional Adjustment for Labor	**$87**
Total Cost Excluding Cost Savings		**$1,382**

Estimated Owner's Costs (Non-Fluor Scope)

Table 16. Estimated Owner's Costs (Non-Fluor Scope)

Cost Item	Amount	Notes
Project Management / Construction Management & Owner's Engineer	$19,938,000	Based on 42-month schedule
Operations & Startup	$7,095,659	Based on 42-month schedule
Spare Parts	$10,365,000	
RUS / American Vessels	$1,000,000	
License Fee	$10,000,000	
Insurance	$6,640,000	
Warranty and Upgrade	$500,000	
Water Supply and Treatment	$36,687,569	
Wastewater	$5,000,000	
Drainage	$300,000	
Power Supply	$4,932,774	
Controls & Internet	$250,300	
Services	$24,131,000	
LNTP Activities	$8,696,000	
Owner Facilities	$2,208,800	
Miscellaneous	$35,555,000	
Base Total Owner's Cost	$173,300,102	
Contingency on Owner's Cost	$22,574,054	13%
EPC Contingency	$356,250,997	25%
Escalation (Owner's Cost Only)	$4,159,202	Based on 40% of OC @ 2% for 3 years
TOTAL Owner's Cost	**$556,284,355**	

Summary of Total Project Cost

- Total Project CAPEX - $1,938MM
- Cost of CO_2 Capture
  - $20.57/metric ton operating cost (un-escalated 2021 dollars)
  - $78.46/metric ton (breakeven CO_2 value, levelized over LOP)
  - $80.60/metric ton (breakeven CO_2 emissions penalty, levelized over LOP)

Conclusions and Closing

- Fluor's Econamine FG Plus℠ technology
- Auxiliary boilers were evaluated for steam supply, however steam extraction will likely be pursued
- Power and water supply are well understood
- Permitted Class VI storage on-site
- Capital cost - $1.94 billion