Design and costing of ION's CO_2 capture plant retrofitted to a 700 MW coal-fired power plant

2021 NETL CO_2 Capture Technology Project Review Meeting

August 3, 2021

Project: Commercial Carbon Capture Design and Costing: Part 2 (C3DC2) - DE-FE0031840

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ION Clean Energy, Boulder, CO, USA

ION's CO_2 Capture Technology Development

Accelerated development path leveraging existing research facilities

ION CLEAN ENERGY

2010

ION Engineering
Lab-pilot
0.001 MWe
Boulder, CO, USA

2012

Univ. of N. Dakota
EERC
0.05 MWe
Grand Forks, ND, USA

2015

National Carbon
Capture Center
0.5 MWe
Wilsonville, AL, USA

2016 - 2017

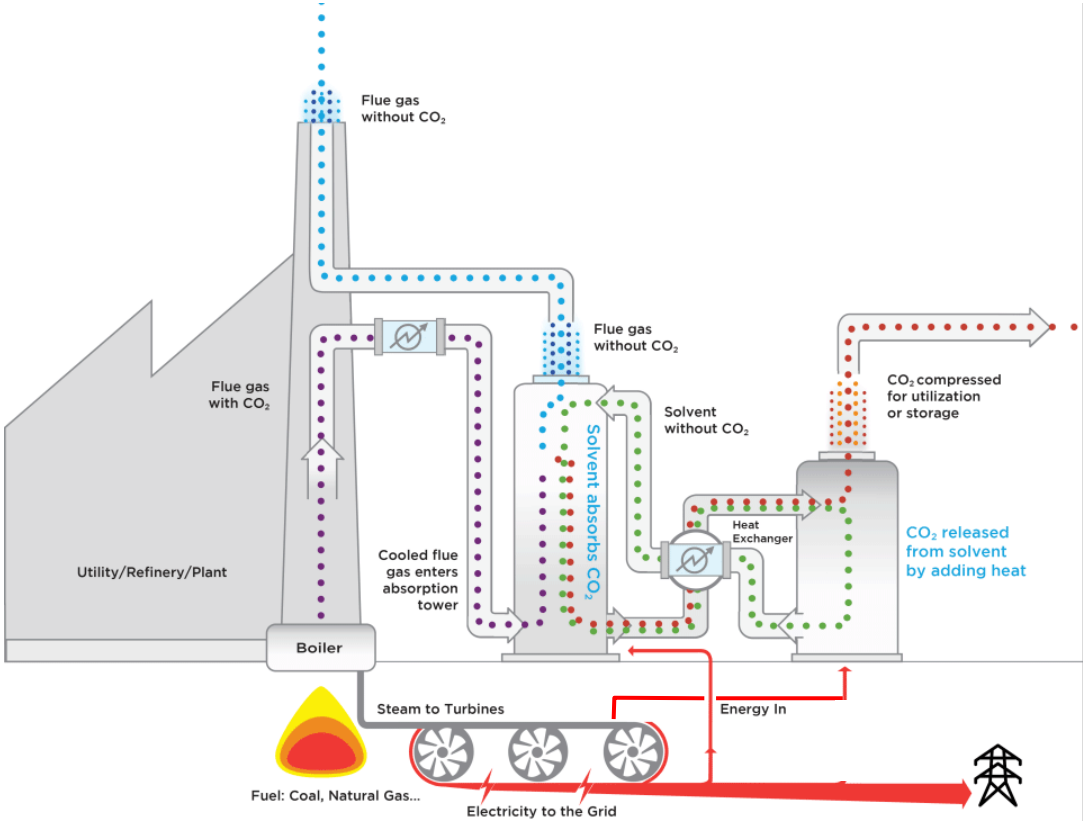
CO_2 Technology
Centre Mongstad
12 MWe
Mongstad, Norway

2018 - 2021

Design & Costing
Commercial Retrofit
300 & 700 MWe
Sutherland, NE, USA

ION Technology Overview

- Proprietary Solvent-based Technology
  - Liquid absorbent-based capture
  - Low aqueous
  - Worldwide Patents
- Established Engineering Process
  - Learnings from Boundary Dam
  - Learnings from Petra Nova
- Basis of Performance
  - Fast kinetics (on par or faster than MEA)
  - Working capacity (higher than MEA)
  - Low heat capacity (much lower than MEA)
  - < 1,090 Btu/lb CO_2 (2.5 MJ/kg CO_2)



ION Technology Overview

Value Added

- High Capture Efficiency
  - Up to 96% CO_2 Capture
- Design System for CAPEX/OPEX savings
  - Smaller absorber column(s) vs higher carrying capacity
  - Pumps/HEXs are smaller due to lower liquid flow rates
- Low regeneration energy requirement
  - Low parasitic load
  - Low steam demand – reduction in plant de-rate if integrated into the steam cycle
- Demonstrated lower corrosion rates than MEA
- Demonstrated lower total emission rates than MEA

Nebraska Public Power District

Host Site – Gerald Gentleman Station

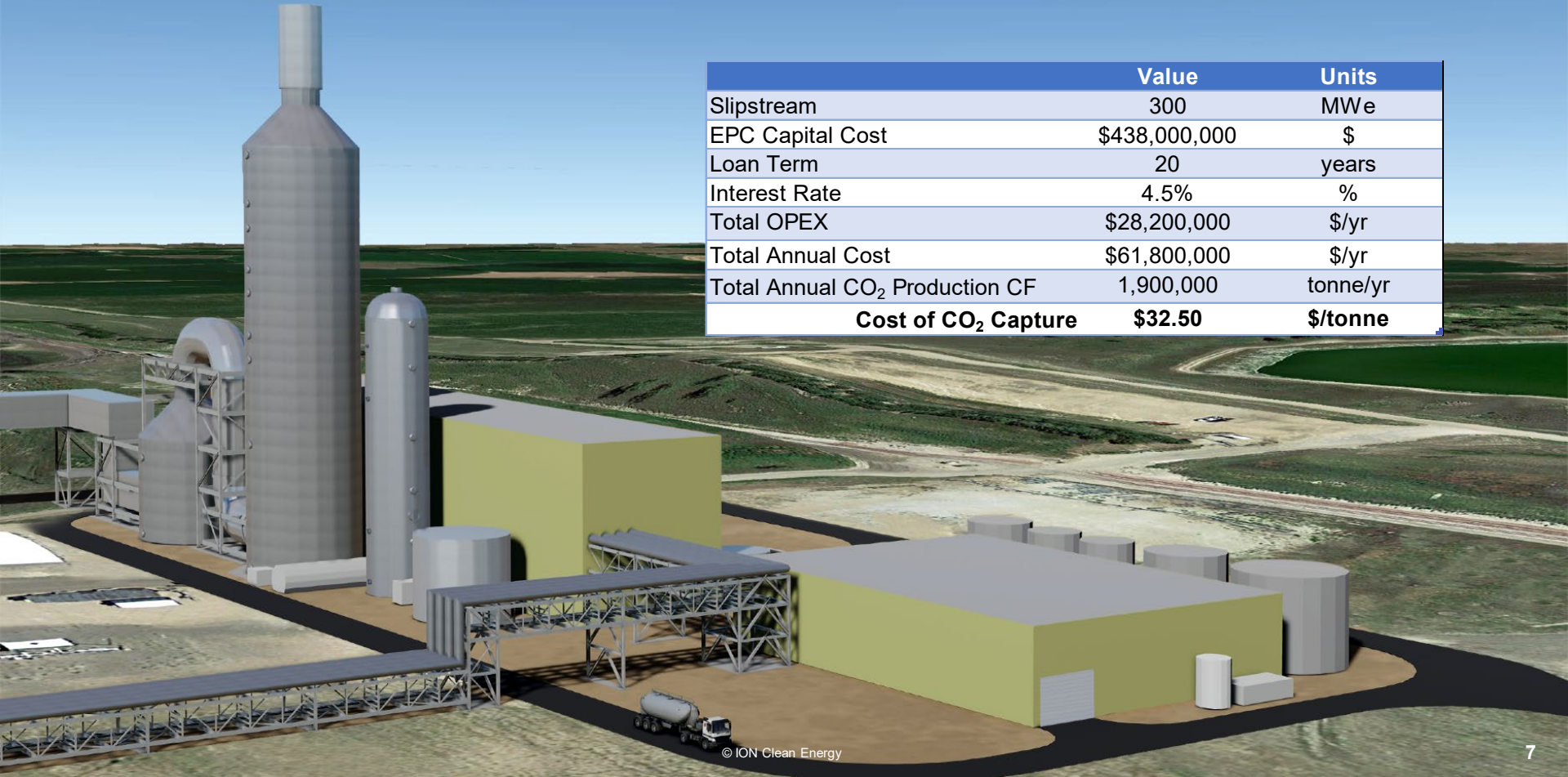
- Located in Sutherland, Nebraska
- Largest generating station in Nebraska
- Two units with total capacity of 1,365 MW
  - Unit 1 – 1979 – 665 MW
  - Unit 2 – 1982 – 700 MW
- Burns Powder River Basin Coal

Commercial Carbon Capture Design & Costing

(C3DC) DE-FE0031595 – Previous Award, Completed Q4 2019

- Objective: Retrofit a Carbon Capture System at a power station
  - Nebraska Public Power District's (NPPD) Gerald Gentleman Station (GGS)
  - 300 MWe Slipstream for carbon capture
  - Ownership model: NPPD owns and operates the capture island
  - Design Basis: CO_2 product for enhanced oil recovery (not regulatory driven)
- Class 3 (AACE) Cost Estimate
  - Cost Estimate is -20% to +30%
  - Completed about 20% of Engineering Effort
- Completed 18mo Project in Q4 of 2019

Commercial Carbon Capture Design & Costing Study



	Value	Units
Slipstream	300	MWe
EPC Capital Cost	$438,000,000	$
Loan Term	20	years
Interest Rate	4.5%	%
Total OPEX	$28,200,000	$/yr
Total Annual Cost	$61,800,000	$/yr
Total Annual CO_2 Production CF	1,900,000	tonne/yr
Cost of CO_2 Capture	**$32.50**	**$/tonne**

COMMERCIAL CARBON CAPTURE DESIGN & COSTING STUDY: PART 2

DE-FE0031840

Commercial Carbon Capture Design & Costing Study: Part 2

(C3DC2) DE-FE0031840

- Retrofit a Carbon Capture System at an existing power station
  - Nebraska Public Power District's (NPPD) Gerald Gentleman Station (GGS)
  - **700 MWe carbon capture system (2x 350 MWe trains)**
  - **Ownership model: Capture System is 3rd Party Owned and Operated**
  - Design Basis: CO_2 product for EOR (not regulatory driven)
- **Class 2 (AACE)** Capital Cost Estimate
  - Estimate Accuracy Range: **-15% to +20%**
  - Complete about **50-60%** of Engineering Effort
- 18-month project; to be completed in Q1 of 2021
- $5.8M project budget
  - $4.6M DOE-NETL
  - $1.2M ION & Partners

C3DC2 Study

Project Team and Roles

ION Clean Energy

- Technology Developer
- Process Design and Project Management

Nebraska Public Power District

- Host Site (GGS)
- Power Generation Engineering, Operational and Financial Expertise

Sargent and Lundy

- Balance of Plant (BOP) Engineering
- Overall Cost Estimate Development
- Constructability Review
- Construction Cost Estimating

Koch Modular Process System

- Carbon Capture pilot experience and expertise
- Capture Process Oversight, Design and Costing

Siemens

- Compressor Vendor

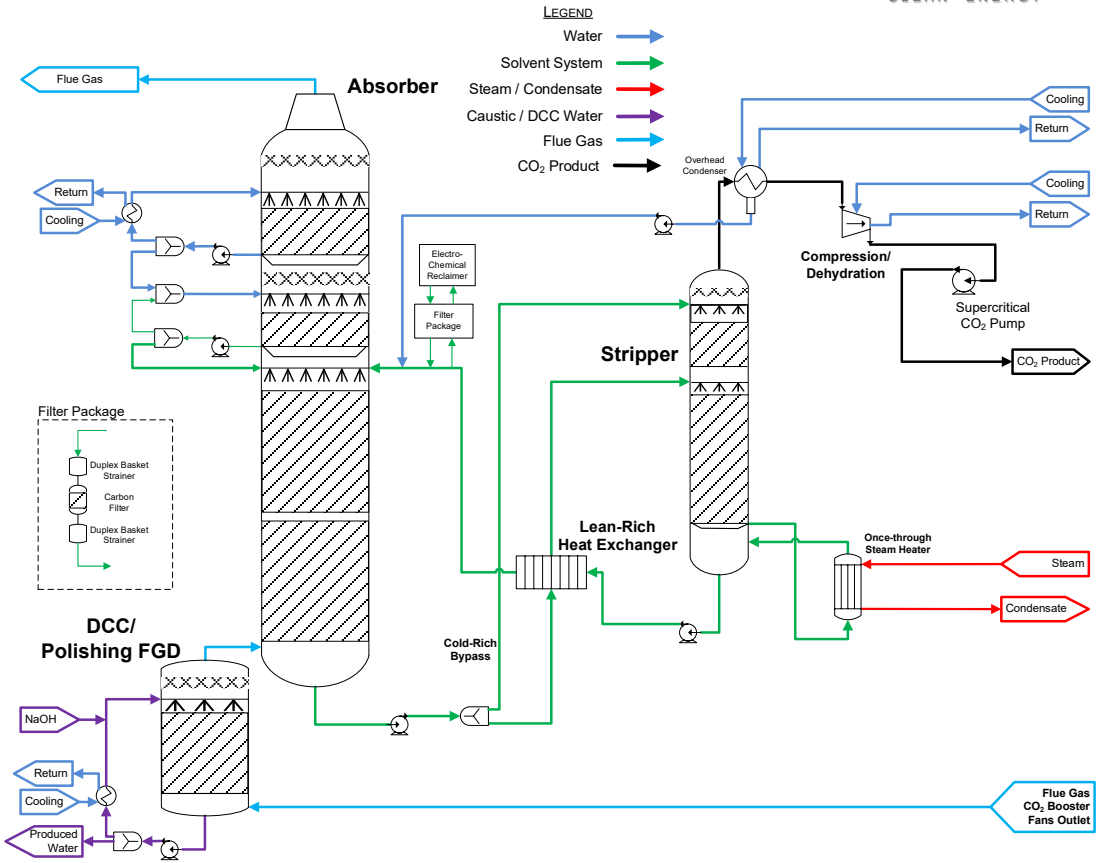
ProTreat® Process Model

ION CO_2 Capture Process

Key features of ION process compared to ‘common’ MEA-designed plant

- Cold-Rich By-pass
- Optimized lean rich cross exchanger (LRXC) design
- Caustic addition to DCC to act as SO_x Polishing Scrubber
- Compressor Selection

ProTreat output provides stream tables, key performance indices, and steam, cooling and electrical duties



System Design

700MWe CO_2 Capture Plant

- Capture System Design
  - 2x 50% trains for the Capture Island
  - 2x 50% on major pieces of equipment to assist in turndown and provide some risk mitigation
  - Designed for operation at full load, and track plant load to maximum turndown
  - Designed for 90% capture of CO_2; resulting in >95% capture at turndown
  - CO_2 product at historic plant CF (2018-2019): 4.3M tonnes of CO_2/yr
- BOP Design
  - Steam sourcing from GGS2 steam cycle
  - Cooling water from a hybrid system

C3DC2

C3DC2

C3DC2

C3DC2

Bioenergy w/ Carbon Capture & Sequestration (BECCS)

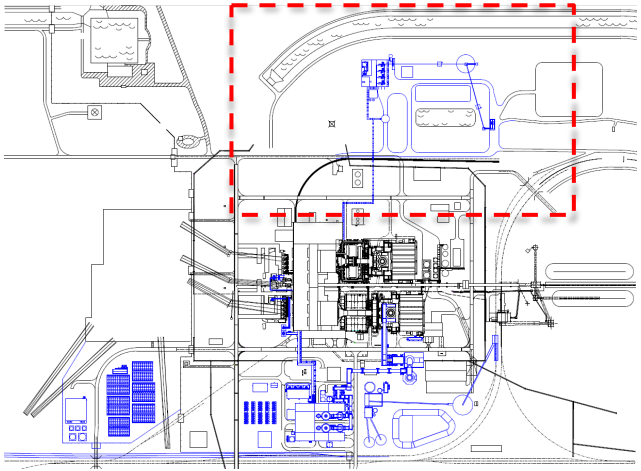
700MWe (4.3M TPA) CO_2 Capture Plant

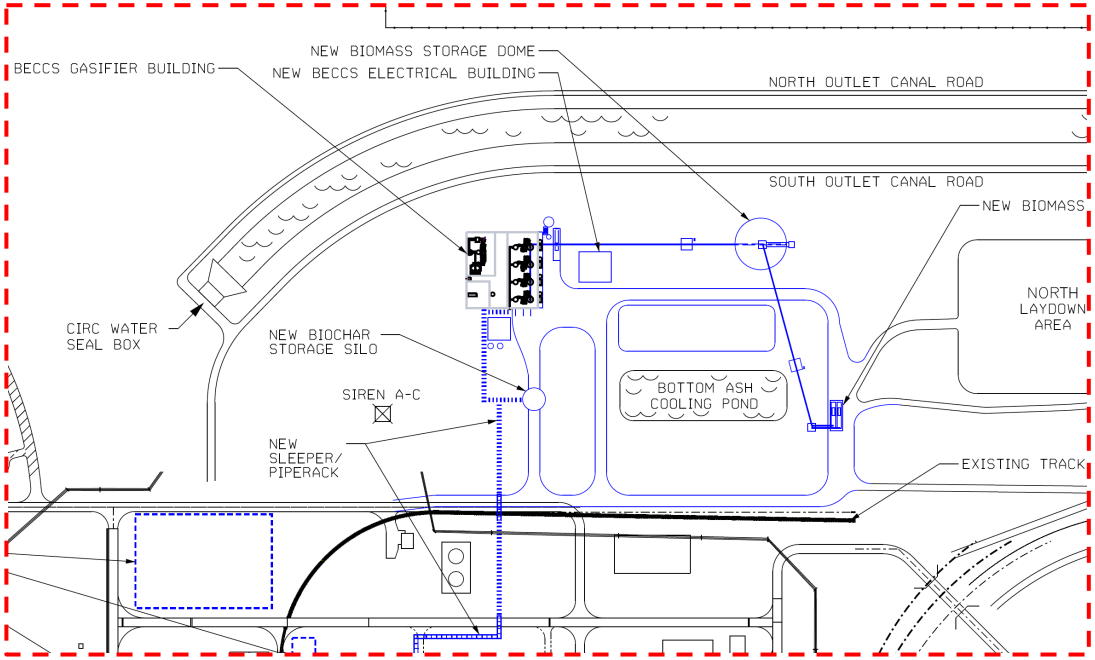
- Overall cost evaluation for potential net zero and net negative emissions
- Engineering Design
  - Biofuel Sourcing
    - Corn Stover vs Eastern Red Cedar
    - Pellets vs Bales
  - Gasifier Design
    - Design for 10-15% coal offset
    - Evaluate boiler performance
  - Balance of Plant Design
  - Evaluation of capture performance on the existing CO_2 capture process design

Bioenergy w/ Carbon Capture & Sequestration (BECCS)

BECCS General Arrangement Drawing

- Corn Stover Pellets delivered by truck
- Gasifier converts pellets to syngas
- Boiler mods and resulting flue gas by B&W





Bioenergy w/ Carbon Capture & Sequestration (BECCS)

Flue Gas Comparison and CCS Performance

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- Max Design is the Base Design Case, assuming full load of the power plant
- BECCS case replaces 10% of the coal with the syngas from the gasifier
  - 5.5% reduction in CO_2 flow to the capture island
  - Increase in capture efficiency to 93.3% (holding steam consumption constant)
  - 1.6% reduction in CO_2 product flow
  - Reduced CO_2 by 98% relative to coal emissions
  - CO_2 reduction >100% with 10% increase in packing and 23% more plates in LRXC

Parameter	Units	Max Design Value	BECCS (Corn Stover)	BECCS (Corn Stover)
DCC Inlet Conditions (1x50% train)				
Temperature	°F	145	144	144
Pressure	psia	13.75	13.75	13.75
O_2 Concentration	vol %	4.34	5.43	5.43
CO_2 Rate	vol %	11.5	10.78	10.78
	lb/hr	711,831	672,890	672,890
Flue Gas Flowrate	acfm	1,107,000	1,114,000	1,114,000
	lb/hr	3,973,000	4,003,000	4,003,000
CO_2 Capture Performance (1x50% train)				
Capture Efficiency	%	90	93	95
CO_2 Captured	lb/hr	638,000	628,000	640,745
L/G	lb/lb	1.93	1.81	1.81
Electrical Duty	kW	31,900	31,700	31,700
SRD	MJ/kg CO2	2.51	2.55	2.55
Steam Consumption	lb/hr	765,100	765,100	765,100

Cost of CO_2 Capture

Costing Basis

- Designed to produce a reliable CO_2 product stream for EOR/Sequestration; not regulatory driven CO_2 capture
- Used historical data for the unit to model cumulative captured CO_2 based on observed power plant load factor, capture plant uptime, and ambient conditions
- Calculated the cost with and without the additional flue gas pre-conditioning to isolate the cost of CO_2 capture for comparison to sites that may already have this equipment
- BECCS evaluation was performed as a sensitivity study and its incremental capital and operating expenses are separate
- 3rd Party Ownership impact on overall costing being further investigated

	C3DC1 Results (300 MWe)	C3DC2 Cost Results	
		C3DC2 Results (700 MWe)	Cooling System Selection Sensitivity
Total CAPEX	$437,500,000	$1,172,900,000	-$140,300,000
Annualized CAPEX	$33,600,000	$90,200,000	-$10,800,000
OPEX	$28,200,000	$60,700,000	-$4,100,000
Annual Cost	$61,800,000	$150,900,000	-$14,900,000
CO2 Product	1,900,000	4,310,000	4,310,000
Cost of Capture	$32.53	$35.01	-$3.46

Acknowledgement and Disclaimer

Acknowledgement

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Disclaimer

Thanks

C3DC2 Team:
ION, NPPD, S&L, KMPS, Siemens

BECCS TEAM:
Trestle Energy, Frontline BioEnergy, Babcock & Wilcox

Department of Energy:

Commercial Carbon Capture Design & Costing Study: Part 2

(C3DC2) DE-FE0031840

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#	Task	Milestone Title / Description	Completion Date	Verification Method
M1	1.0	DOE Kickoff Meeting	12/5/2019	Meeting Held
M2	1.0	Updated PMP	11/7/2019	PMP Transmitted to DOE FPM
M3	2.0	Basis of Design for Project Finalized	1/10/2019	Meeting Held w/ Results Project SharePoint Site; Completion Memo to DOE
M4	3.0	Preliminary Design Review Complete	3/30/2020	Meeting Held w/ Results Project SharePoint Site; Completion Memo to DOE
M5	4.0	Critical Design Review Complete	9/30/2020	Meeting Held w/ Results Project SharePoint Site; Completion Memo to DOE
M6	5.4	HAZOP Complete	11/24/2020	HAZOP Report Completed
M7	6.0	Overall Cost Estimate and Cost of Capture	1/12/2021	Meeting Held w/ Results Project SharePoint Site; Completion Memo to DOE
M10	4.2	BioMass Co-firing BOP Design	4/1/2021	Meeting Held w/ Results Project SharePoint Site; Completion Memo to DOE
M8	7.0	Front-End Engineering Design (FEED) Report	9/1/2021	Report Delivered to DOE/NETL
M9	7.0	Final DOE Report & Presentation	9/30/2021	Report Delivered to DOE/NETL

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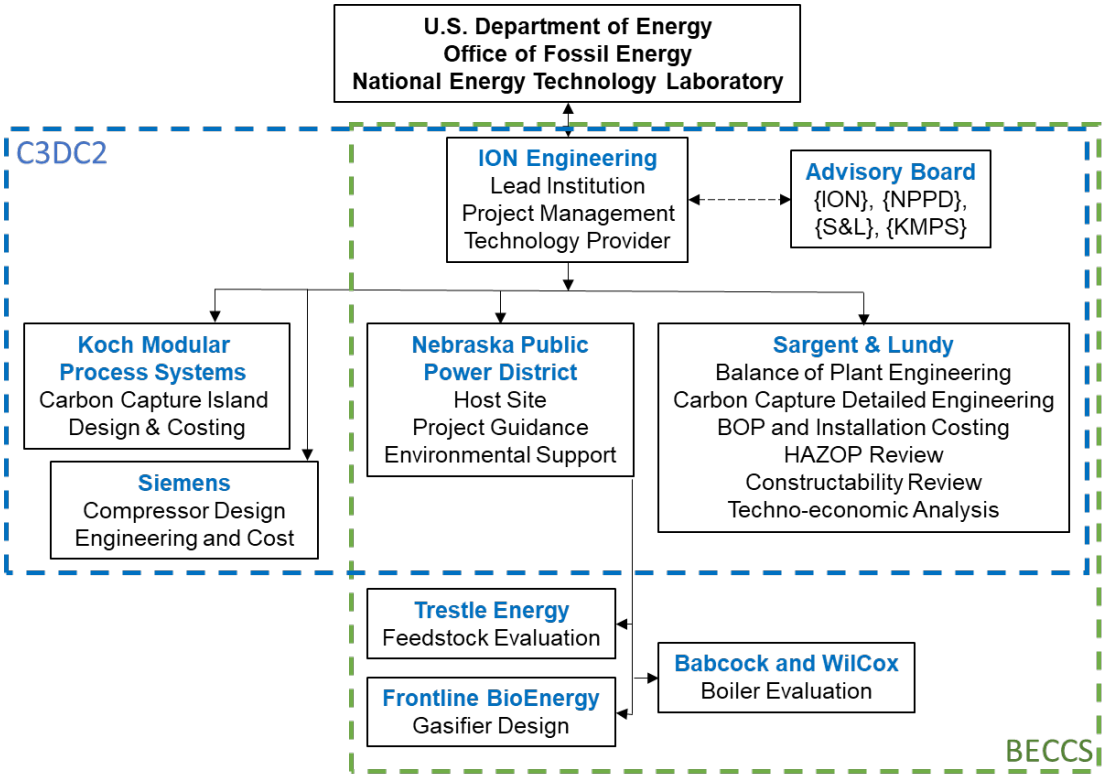

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(C3DC2) DE-FE0031840

	Task Name	Duration	Start	Finish
1	**C3DC2 Project - FEED Study**	**526 days**	**Mon 9/2/19**	**Thu 9/30/21**
2	**1.0 Project Management and Planning**	**460 days**	**Mon 9/2/19**	**Wed 6/30/21**
20	**2.0 Overall Project Design Basis**	**361 days**	**Thu 10/31/19**	**Tue 4/13/21**
51	**3.0 Process Design - CO2 Capture Island Design**	**290 days**	**Mon 9/30/19**	**Wed 11/25/20**
52	**Preliminary Design - CO2 Capture Island**	**254 days**	**Mon 9/30/19**	**Tue 10/6/20**
103	M4: Preliminary Design Review	0 days	Fri 4/24/20	Fri 4/24/20
104	**Detailed Design - CO2 Capture Island**	**159 days**	**Thu 4/16/20**	**Wed 11/25/20**
136	**4.0 Engineering & Design - Integration and BOP**	**340 days**	**Fri 12/20/19**	**Fri 4/30/21**
137	**Detailed Design - Integration and BOP**	**340 days**	**Fri 12/20/19**	**Fri 4/30/21**
383	M5: Critical Design Review	10 days	Wed 9/16/20	Tue 9/29/20
384	**BECCS - Biomass Co-firing**	**121 days**	**Thu 11/5/20**	**Thu 4/29/21**
430	**5.0 Studies and Investigation**	**412 days**	**Tue 12/3/19**	**Fri 7/23/21**
540	**6.0 Cost Estimate**	**199 days**	**Tue 7/21/20**	**Fri 4/30/21**
574	**7.0 Reporting**	**158 days**	**Tue 2/23/21**	**Thu 9/30/21**
575	**M8: Front-End Engineering Design (FEED) Report**	**137 days**	**Tue 2/23/21**	**Wed 9/1/21**
583	**M9: Final DOE Project Report**	**71 days**	**Thu 6/24/21**	**Thu 9/30/21**
589	**BECCS Reporting**	**70 days**	**Thu 4/1/21**	**Wed 7/7/21**