Design and costing of ION's CO_2 capture plant retrofitted to a 300 MW slipstream of a coal-fired power plant

2019 NETL CO_2 Capture Technology Project Review Meeting

Pittsburgh, PA, Aug 2019

Project: Commercial Carbon Capture Design and Costing (C3DC) - DE-FE0031595

Andy Awtry, Ph.D. – VP Engineering

ION Clean Energy, Boulder, CO, USA

ION's CO_2 Capture Technology Development

Accelerated development path leveraging existing research facilities

2010

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

2012

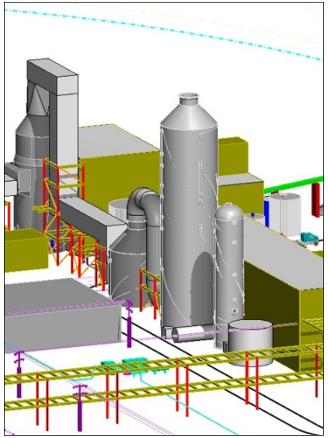
Univ. of N. Dakota EERC
0.05 MWe
Grand Forks, ND, USA

2015

National Carbon Capture Center
0.5 MWe
Wilsonville, AL, USA

2016 - 2017

CO_2 Technology Centre Mongstad
12 MWe
Mongstad, Norway

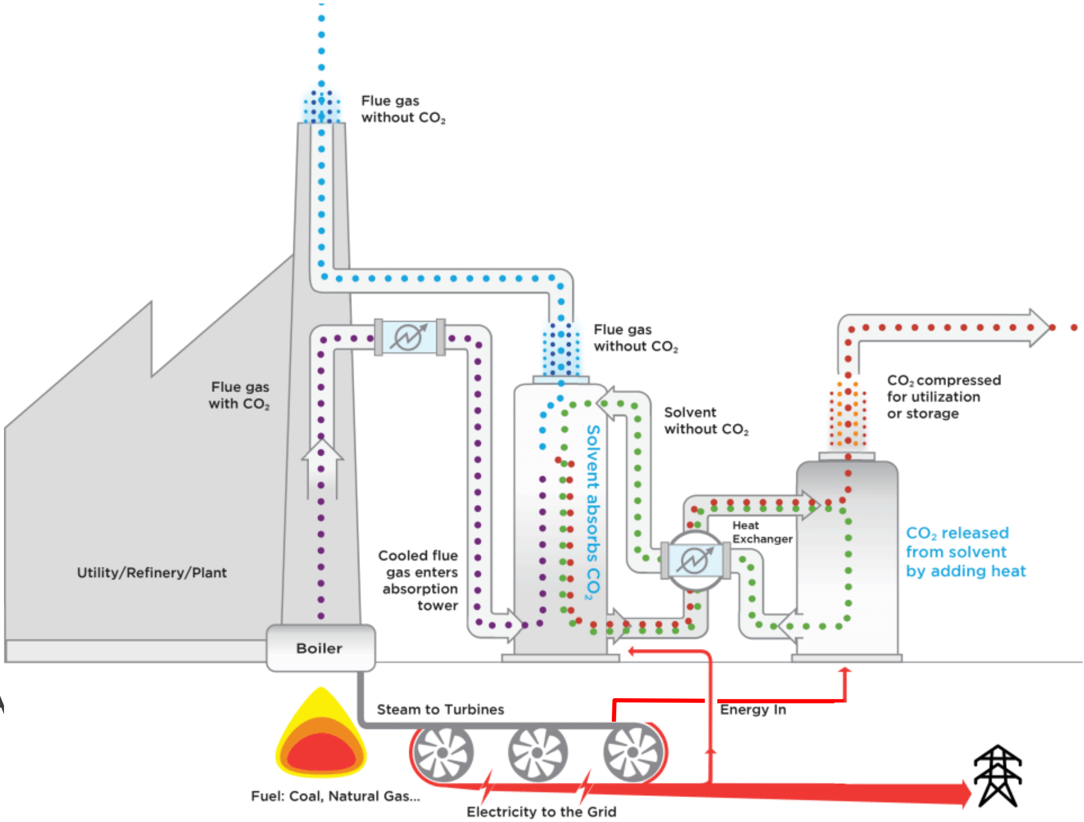


2018 - 2019

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

ION Technology Overview

- Proprietary Solvent-based Technology
  - Low aqueous
  - Fast Kinetics
- Reduced CAPEX & OPEX
  - Smaller columns, HXs and footprint
  - Lower energy requirements
  - Lower parasitic load
  - Lower breakdown & emission rates
- Established Engineering Process
- Basis of Performance
  - Working capacity (higher than MEA)
  - Low heat capacity (much lower than MEA
  - Lower corrosion (much lower than MEA)
  - < 1,090 Btu/lb CO_2 (< 2.5 MJ/kg CO_2)



Commercial Carbon Capture Design & Costing Study
(C3DC) DE-FE0031595

- 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
- Class 3 (AACE) Cost Estimate – Currently Underway
  - Low Cost Estimate is -10% to -20%
  - High Cost Estimate is +10% to +30%
  - Typically <40% of Engineering Effort
  - For the purpose of Budget Authorization or Control
- 15 months completed of the 18-month project
- $3.5M project budget
  - $2.8M DOE-NETL
  - $700k ION & Partners

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

C3DC 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**
  - Engineering Firm that is familiar with GGS
  - Participated in Petra Nova FEED
  - All Balance of Plant Engineering
- **Koch Modular Process System**
  - Carbon Capture pilot experience and expertise
  - Capture Process Oversight, Design and Costing
- **Siemens** (Dresser-Rand / Ramgen)
  - Compressor Vendor – Supersonic CO_2 Compressors

ProTreat® Results

300MWe CO_2 Capture Plant - Performance

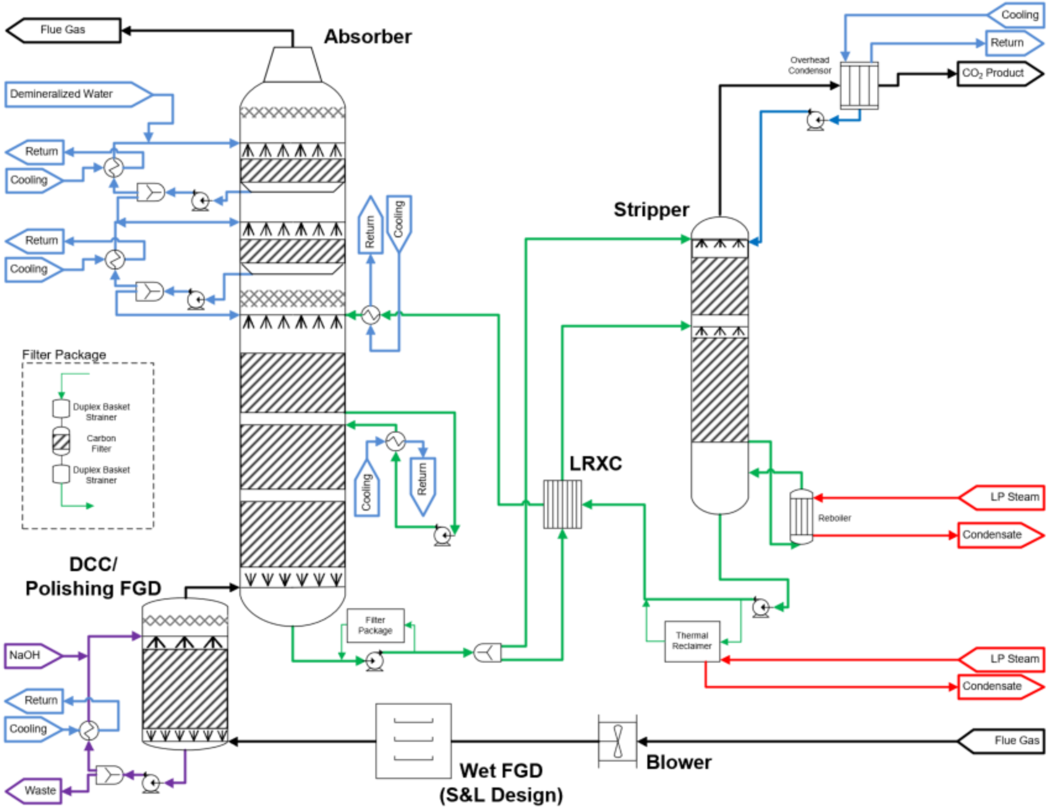
- Predicts capture efficiency (and total CO_2 captured) based on target operating conditions
- Predicts steam, electrical and cooling duties required for operation
- Predicts absorber and stripper column diameters and models solvent parameters throughout the columns
- Sizes Heat Exchangers
- Model results provide stream tables throughout the process:
  - Flow Rate
  - Temperature
  - Pressure
  - Composition

ProTreat® Process Model

ION CO_2 Capture Process

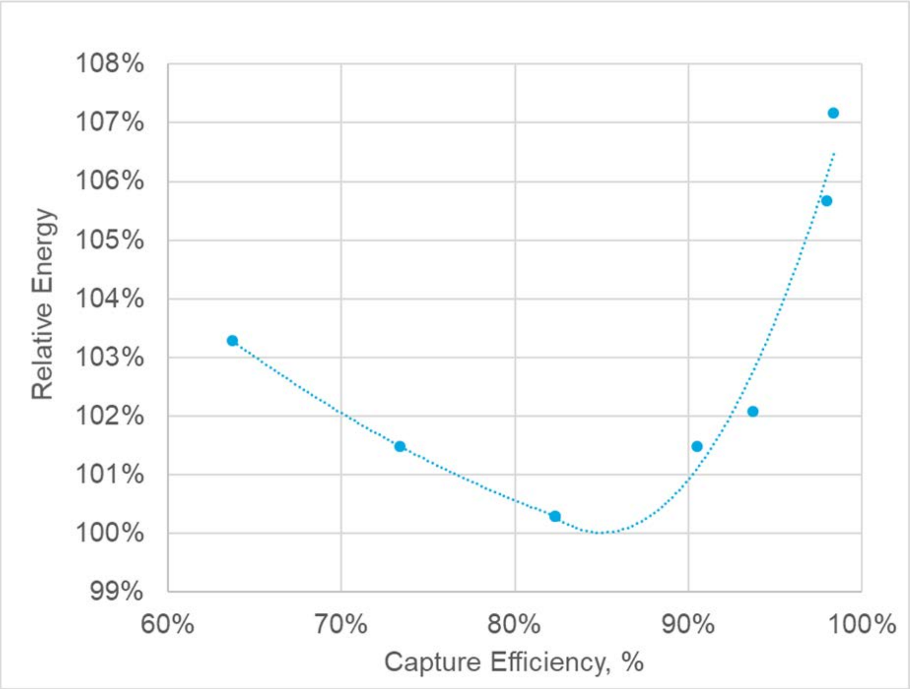
Key features of ION process compared to ‘common’ MEA-designed plant

- Cold-Rich By-pass
- Optimized lean rich cross exchanger (LRXC) design
- Caustic addition to DCC for SO_x Polishing Scrubber
- Supersonic Compressors w/ heat recovery strategy



CO_2 Capture Efficiency

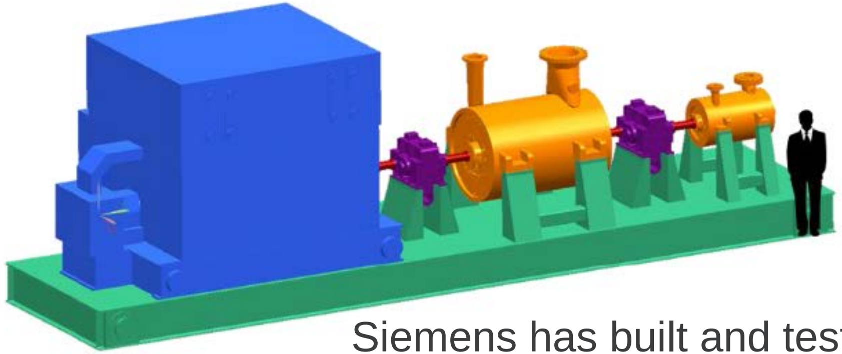
- CO_2 Capture process designed at 89-91% capture for power plant operating at full load
  - 2.5 MJ/kg CO_2 (1090 BTU/lb CO_2)
- When GGS2 load decreases the capture efficiency can increase up to >95%
  - Flue gas flow rate at max turndown is greater than the design flow rate for the 300MW capture system
  - CO_2 concentration in the flue gas drops with load



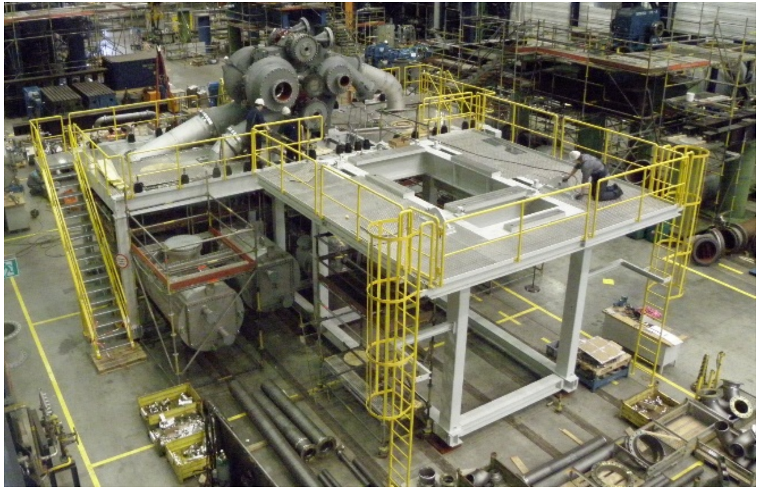
Compression System Design

Benefits of DATUM-S (Siemens)

- Capital and Operating Cost is roughly the same as IG compression solution
- Installation cost is roughly 40-45% lower for DATUM-S
- Operates at 81% efficiency, but provides usable heat for the CCS process



IG Compression System



Siemens has built and tested LP and HP CO_2 supersonic compressor units at a size necessary for 90% capture at 182MWe (Award FE0026727)

C3DC Study

CO_2 Capture System Design

Task Name	Finish
2.0 CO2 Capture Island Process Design	2/15/19
ION Process Model	7/3/18
Process Design Basis	7/3/18
Process Flow Diagram	7/3/18
System Design Description	8/15/18
AutoCAD PFD with Heat and Mass Balance	9/26/18
Utility Requirements	9/26/18
Process Equipment List	12/12/18
Data Sheets	12/7/18
CO2 Island Process Control Description	10/10/18
CO2 Capture System P&IDs	11/30/18
CO2 Equipment Arrangement Drawings	2/15/19
Budgetary CO2 Capture Equipment Cost	2/13/19

C3DC Study

Balance of Plant Engineering and Design

Task Name	Finish
Critical Design	5/31/19
BOP Budgetary Quotes	3/22/19
Overall Mass Balance	11/14/18
Overall Heat Balance	11/7/18
Overall Water Balance	11/7/18
Overall Control Description	2/26/19
Controls Architecture Diagram	5/2/19
P&IDs	2/6/19
Terminal Point List	2/11/19
Equipment List	2/15/19
Pipeline List	3/27/19
Valve List	3/27/19
Instrument List	4/17/19

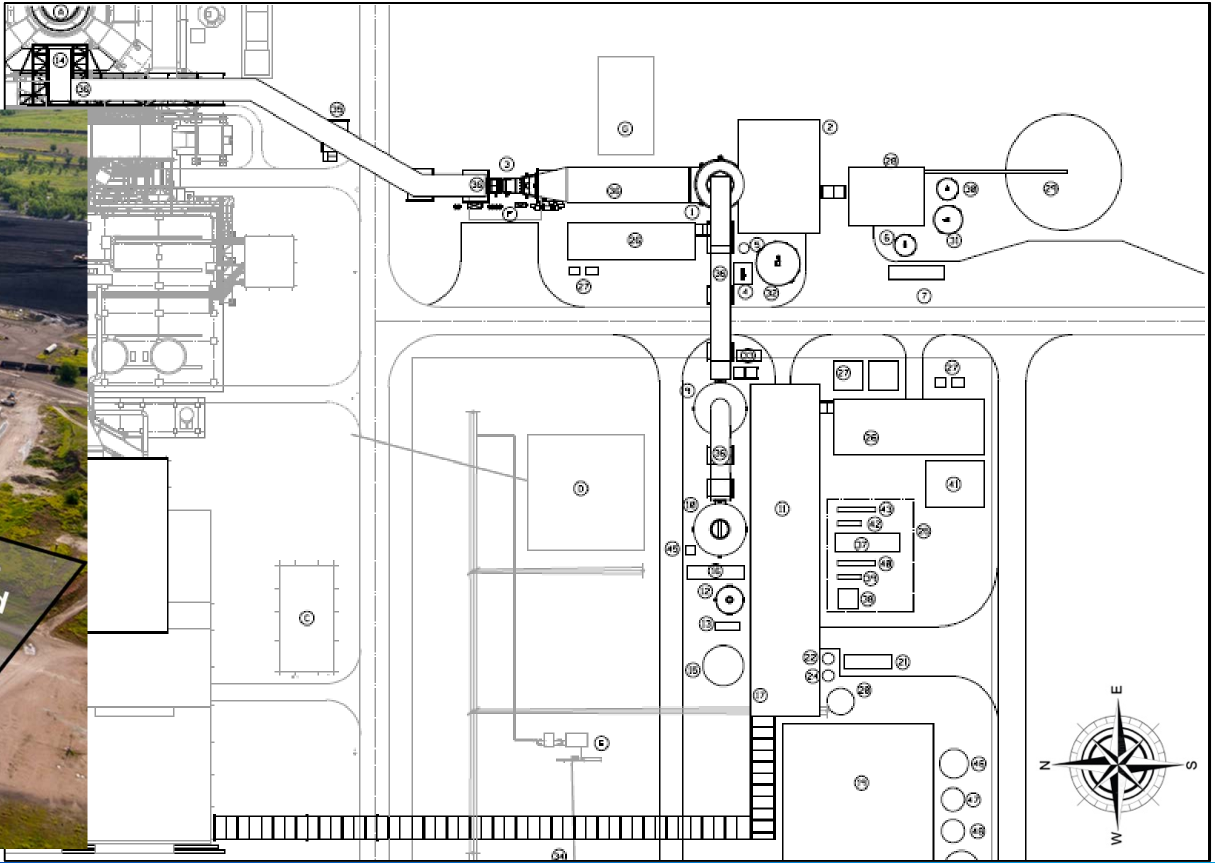
C3DC Study

Balance of Plant Engineering and Design

Task Name	Finish
Sitework Design	5/16/19
Foundation Design	5/24/19
Ductwork Design	5/24/19
Structural Steel Design	5/22/19
Pipe Rack Design	5/22/19
Architectural Design	5/22/19
Single Line Diagrams	4/26/19
Control / Electrical Room Layout	5/10/19
Electrical Load List	3/15/19
Electrical and Instrument Layout Drawings	5/31/19
Cable and Cable Tray Layouts	5/31/19
Grounding and Protection Plans	5/31/19
Electrical Equipment Drawings	5/31/19
Overall General Arrangement Drawing	5/8/19

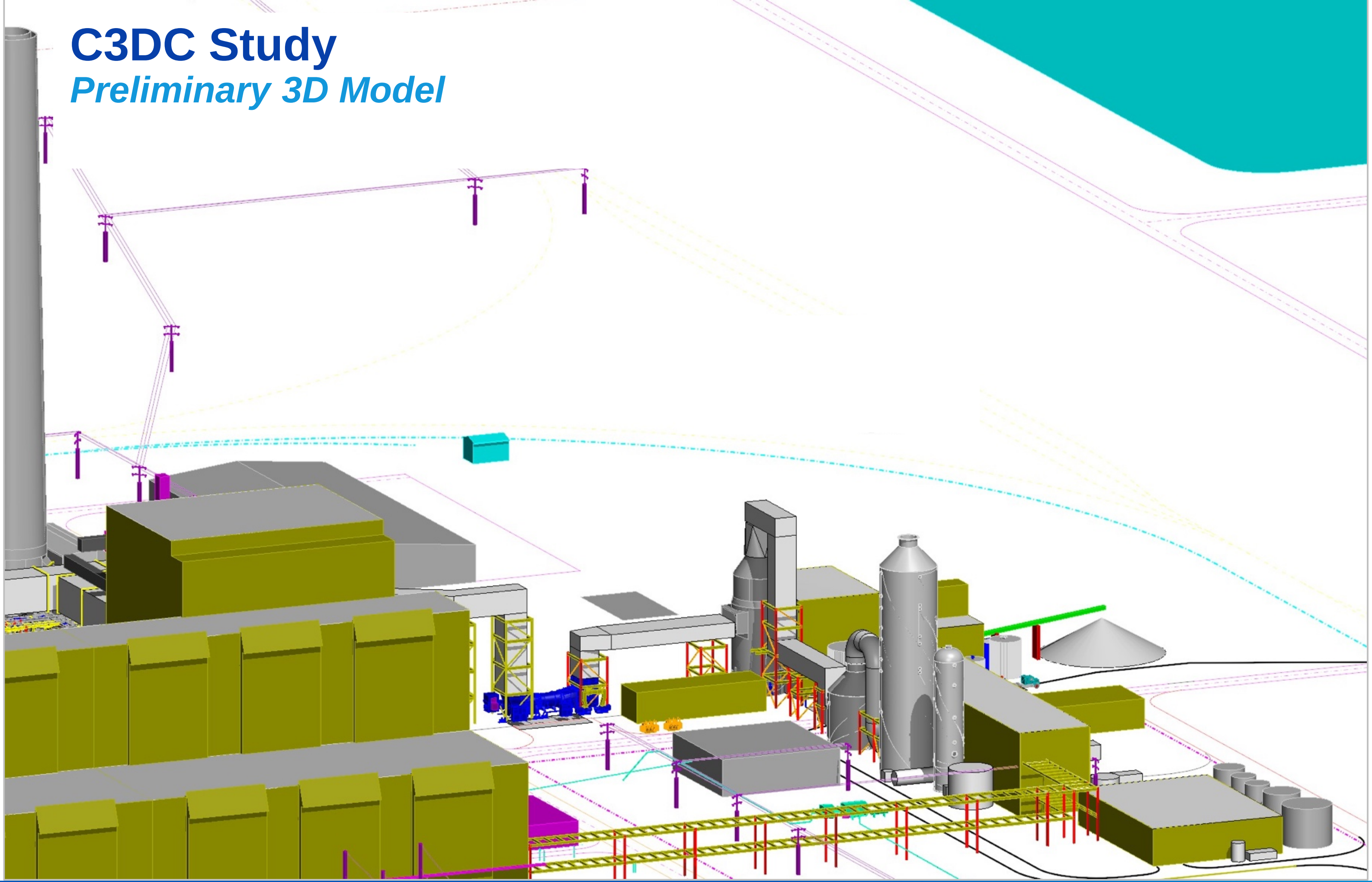
C3DC Study

Proposed General Arrangement Drawing



C3DC Study

Preliminary 3D Model



C3DC Study

Studies and Investigations

Task Name	Finish
4.0 Studies and Investigation	10/4/19
Solvent Disposal Investigation (ION)	1/11/19
Steam and Electric Sourcing Study (Plant Integration)	11/7/18
Heat Rate Improvement Study	6/14/19
Unit Tie-In Location CFD Modeling	5/16/19
Wastewater Treatment Study	10/31/18
Permitting Study	3/1/19
HAZOP Review	4/23/19
Project Execution Schedule	6/28/19
Detailed Project DOR	6/28/19
Constructability Review	5/8/19
Techno Economic Assessment (TEA) Study	10/4/19

Cost of CO_2 Capture

Costing Basis

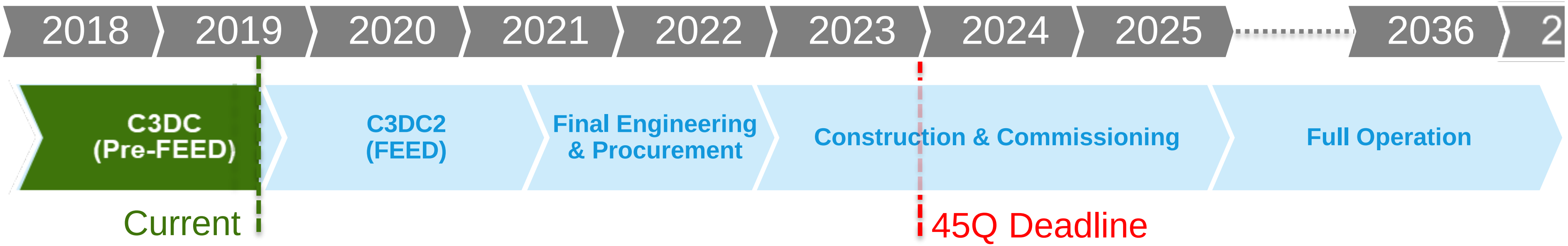
- Utilized a model where NPPD would own and operate the carbon capture island as part of normal operations
- Designed the CO_2 Capture Island to produce a reliable CO_2 product stream for EOR; Not regulation driven CO_2 capture
- Assumed full load of the generating unit (GGS2) to model capture rates then applied 85% Capacity Factor
- Included the cost of electricity in the OPEX, where a generic (non-GGS specific) rate of $25/MWh was used for electricity and steam
- 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

Cost of Capture

ION CLEAN ENERGY

	CO_2 Island	Units
Slipstream	300	MWe
EPC Capital Cost	$446,850,000	$
Loan Term	20	years
Interest Rate	7.0%	%
Annualization Factor	0.0944	
Annualized CAPEX	$42,179,000	$/yr
Variable O&M Cost	$19,254,000	$/yr
Fixed O&M Cost	$8,930,000	$/yr
Total OPEX	$28,184,000	$/yr
Total Annual Cost	$70,363,000	$/yr
Total Annual CO_2 Production at 85% CF	1,894,000	tonne/yr
Cost of CO_2 Capture:	$37.15	$/tonne

Path Forward



- 45Q changed the landscape for deploying carbon capture
- Development Path for Potential Deployment of CO_2 Capture
- 2018-2019 Completion of C3DC Project (pre-FEED)
  - First phase of a FEED study → **process development and integration**
  - Outcome of project will provide key learnings and necessary details for evaluation of deployment of CO_2 capture
    - Resource needs
    - Plant specific challenges
    - Provide accurate costs (-20% to +30%) to feed a business model
  - Currently on track to qualify for 45Q tax credits

Conclusions

ION CLEAN ENERGY

- The C3DC project has resulted in a **\$37/tonne CO_2** cost of capture for the integration and operation of the CO_2 capture island
- Results from the C3DC design study provided the Project Team with a solid foundation to continue into a FEED Study which would look to achieve:
  - Further investigation of plant specific challenges require more problem solving
  - Refined cost estimate to an AACE Class 2 Estimate (-15%/+20%)
    - Complete up to 70% of the engineering effort
- Results suggest that with the new and revised tax credit legislation, 45Q (and potentially 48A), there is a strong business case for CO_2 capture

Acknowledgement and Disclaimer

Acknowledgement

This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under cooperative award number DE-FE0031595.

Disclaimer

"This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

Thanks

C3DC Team:

ION: Andrew Awtry, Tyler Silverman, Greg Staab, René Kupfer, Jenn Atcheson, Erik Meuleman, Buz Brown
NPPD: John Swanson, John Meacham, Bob Nitsch, Kirk Everett, Roman Estrada
S&L: Danielle Koren, Emily Kunkel, John Spence, Tim Laughlin
KMPS: Stan Lam, Paul Jaipersaud, Tom Schafer
Siemens: Mark Kuzdzal

Department of Energy:

Jason Hissam, Steve Mascaro, Lynn Brickett, Bethan Young