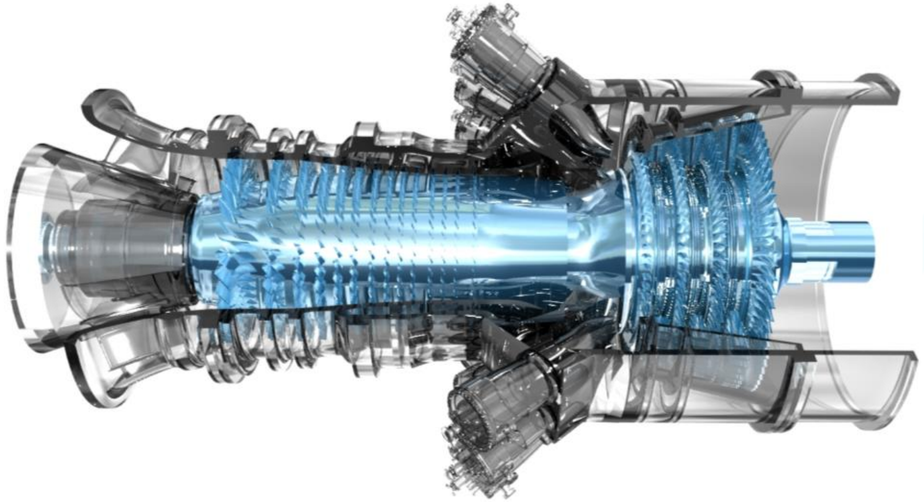
Retrofittable Advanced Combined Cycle Integration for Flexible Decarbonized Generation

Carbon Management Conference

Aug 28, 2023



Agenda

Project Overview

- Project Schedule
- Site Overview
- EGR Overview
- GT Modifications/Uprates
- ST Integration

Performance Results

EGR Detailed Design

CO_2 Capture Island (ISBL) Detailed Design

CCS Plant Integration (OSBL) Detailed Design

Plant model screenshots

Art of the Possible – pathway to 99% CO2 reduction

Some comments on the LCA

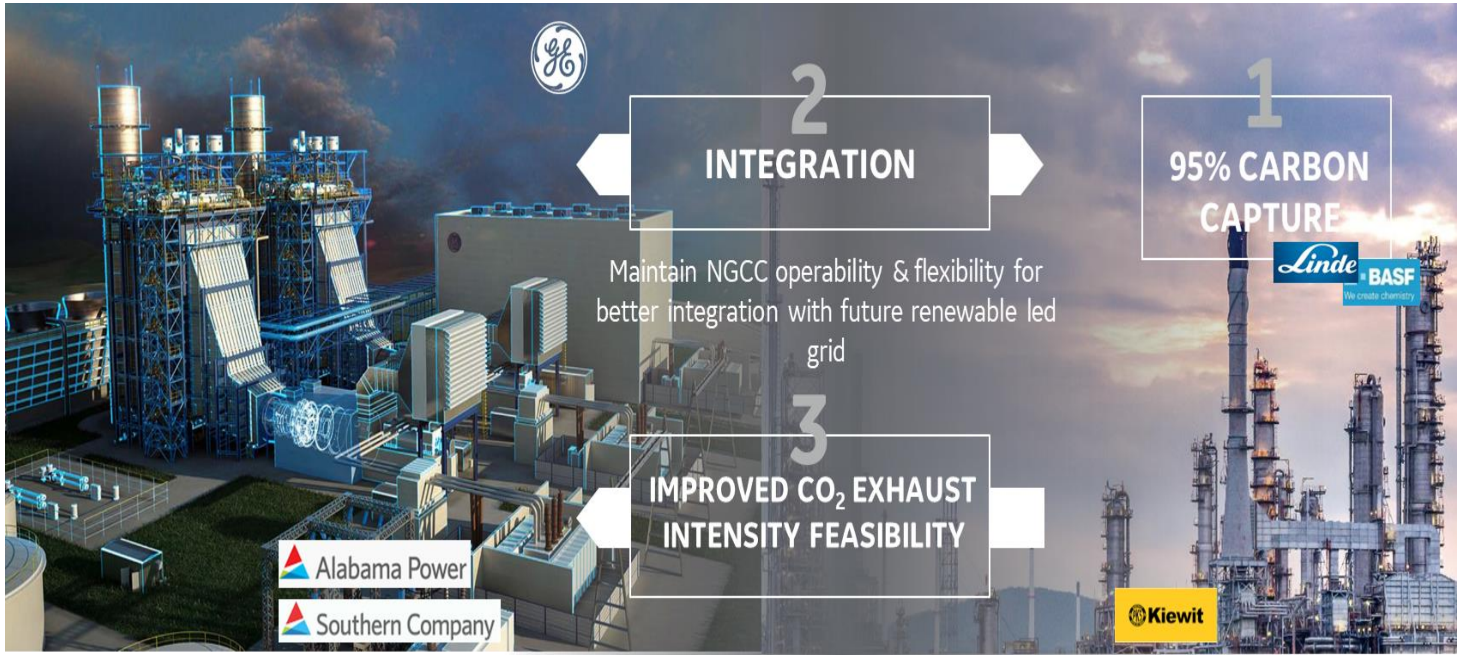
Project Overview

Problem Statement:

Current State of the Art CCS designs have not explored integration into NGCC plants, missing major technical risks to operation of NGCC plants and major opportunities to improve and enhance the technical and economic viability of CCS in a modern NGCC plant.

Objectives

GEGP will investigate integration concepts leading to a single NGCC/CCS configuration and conclude with a detailed design, TEA, and LCA focused on integration of CCS with the NGCC power plant. Milestones have been identified to track progress on improving CCS economic viability thru the course of the Project.

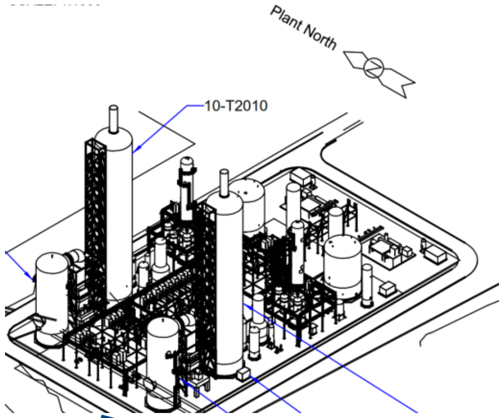


GEGP will focus on 2 primary Objectives to be completed thru the execution of this CCS FEED Study:

- Identify CCS integration and operation risks and recommend solutions to eliminate or manage Risks
- Identify GT, ST, HRSG, and Plant CCS integration concepts that lead to improved CCS economic viability

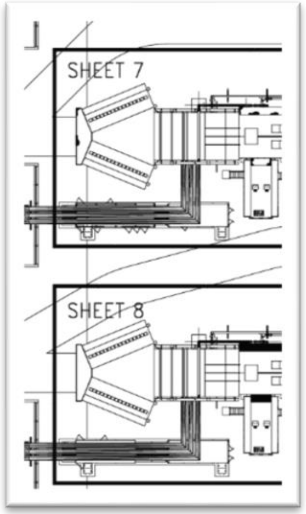
Project Site

New CCS Island

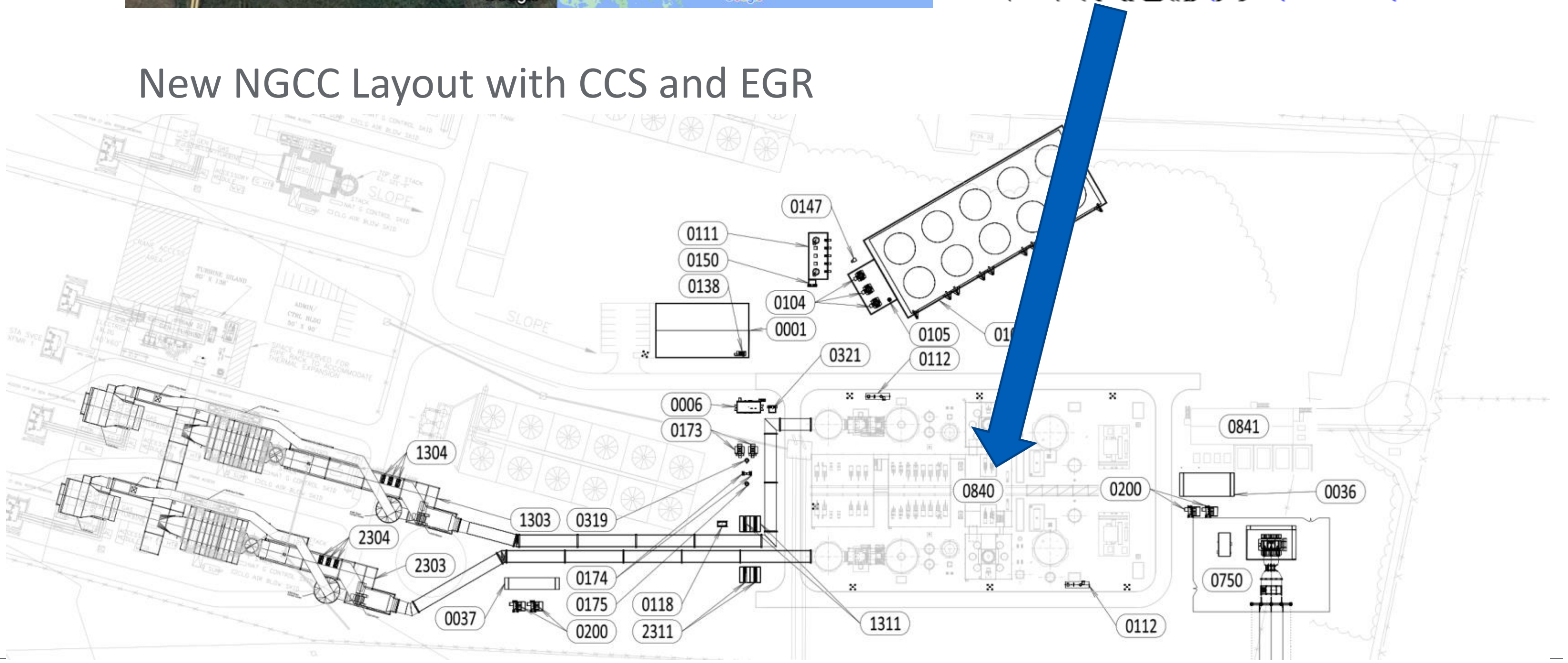


Existing 2x1 7FA.03 (COD 2001)

- "Arrowhead" Inlets w/ Evap Coolers
- Small Duct Burners
- Natural Gas Only
- Wet Cooling Tower
- GE D650 Steam Turbine
- Existing GT "Arrowhead" Inlets



New NGCC Layout with CCS and EGR



EGR Overview

Exhaust Gas Recirculation (EGR) recycles a portion of the HRSG exhaust flow back to the GT inlet

Primary Values (i.e. why apply EGR)

- Elevated CO_2 concentrations to CCS – reduces CCS technology risk and cost
- Reduced O_2 concentrations to CCS – reduces solvent degradation significantly
- Reduced Steam for CCS (higher ST output / lower CCS performance penalty)

Primary Challenges

- Added cost and complexity to add to existing GT
- Corrosion risk to GT compressor
- GT combustor lean blowout risk with lower O_2

Maximum EGR limited by GT corrosion risk

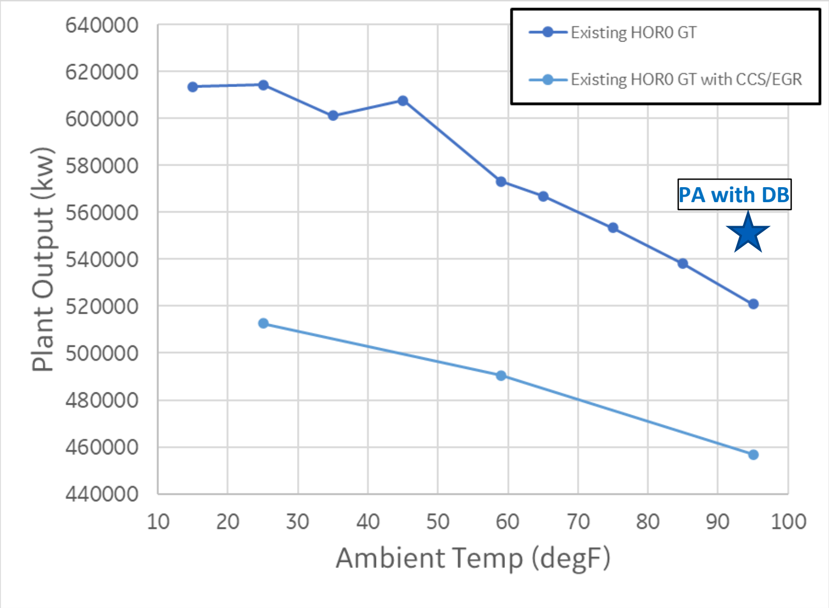
(based on GT fuel contaminants) and GT combustor dynamics

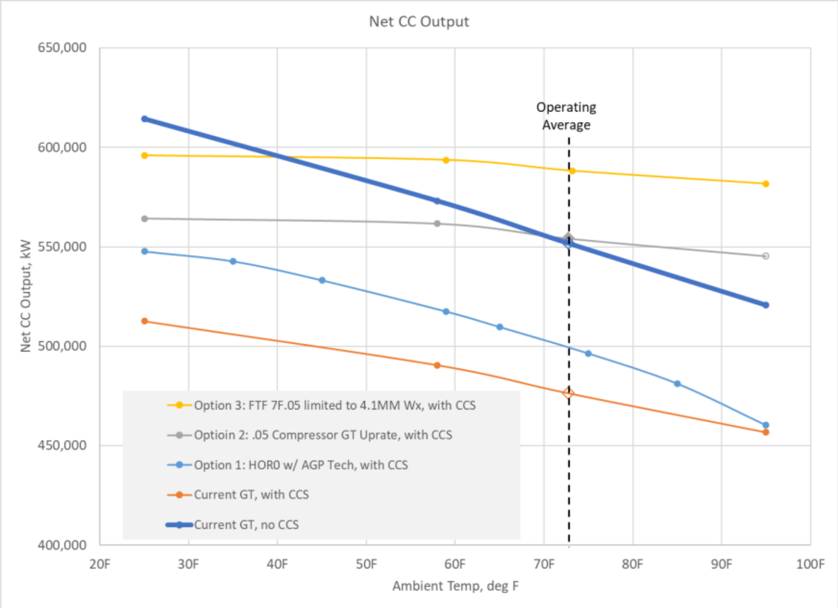
EGR flame– visually more diffuse

EGR assessment shows >$40MM net savings with EGR applied

GT Modifications/Uprates Overview

- DLN 2.6+ combustion system (***Required for EGR***) – improved flexibility, lower turndown and increased Modified Wobbe Index (MWI) range
- Advanced Compressor (aka 7F.04-200) – adds significantly more airflow and output, especially hot day
- Gen-V Turbine Rotor (aka 3SAR) – adds higher compressor discharge operating temp (i.e. higher hot day output)
- Advanced Gas Path Tech 1.0 – allows elevated GT firing temps (with DLN 2.6+) for higher output and CO_2 concentrations
- Increased GT shaft capability – coupling bolts (with 3SAR) allows higher sustained GT output level
- Robust GT exhaust frame – upgraded design to address common wear and tear conditions for improved Reliability
- Turbine compartment insulation and ventilation mod – to manage higher GT firing temps





Preliminary NGCC assessment shows >$30MM net added value with GT mods

Including +$19MM CCS cost, and +15% increase in CO_2 tonnes/yr

ST Modifications/CCS Steam Supply Overview

Steam Flows increased due to GT mods and uprates

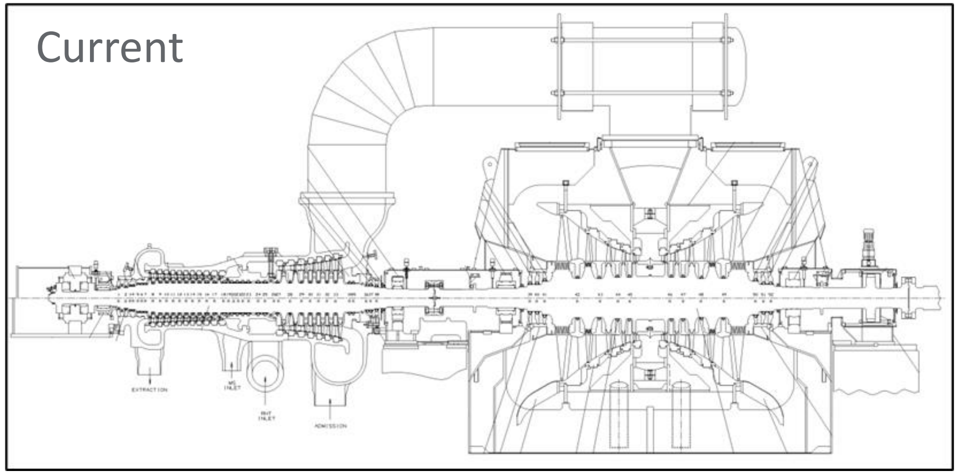
- HP steam flow up 16-18%
- Hot Reheat steam flow up 18-20%
- LP Admission steam flow down 5-7%
- LP ST steam flow up 14-16%

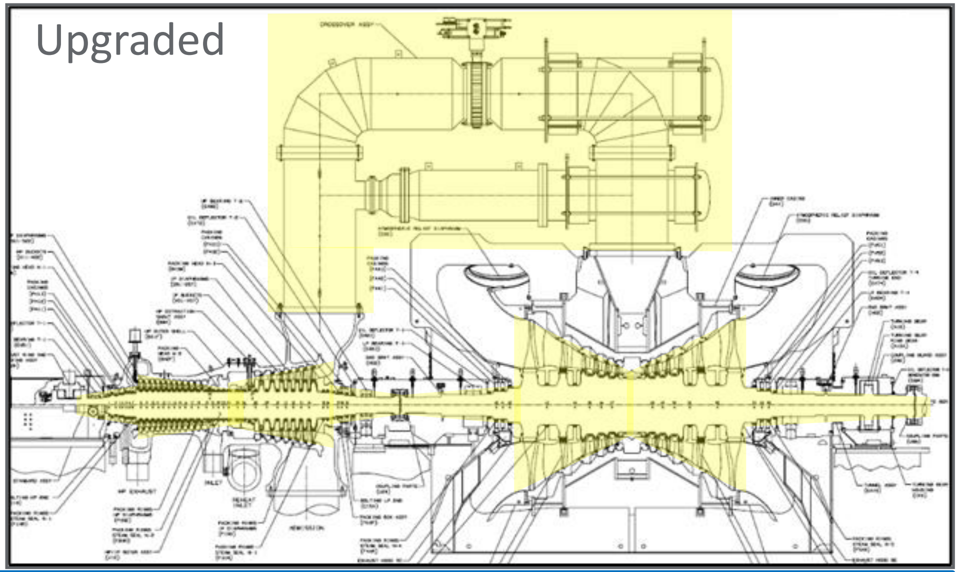
✓ With current ST, can modify HP and IP swallowing capacity up to 15% within current casings

- HP more limited by inlet piping and valves – will need to bypass 6-10% of steam to CCS

✓ LP can have throttling butterfly valve added to crossover to maintain steam extraction pressure to CCS

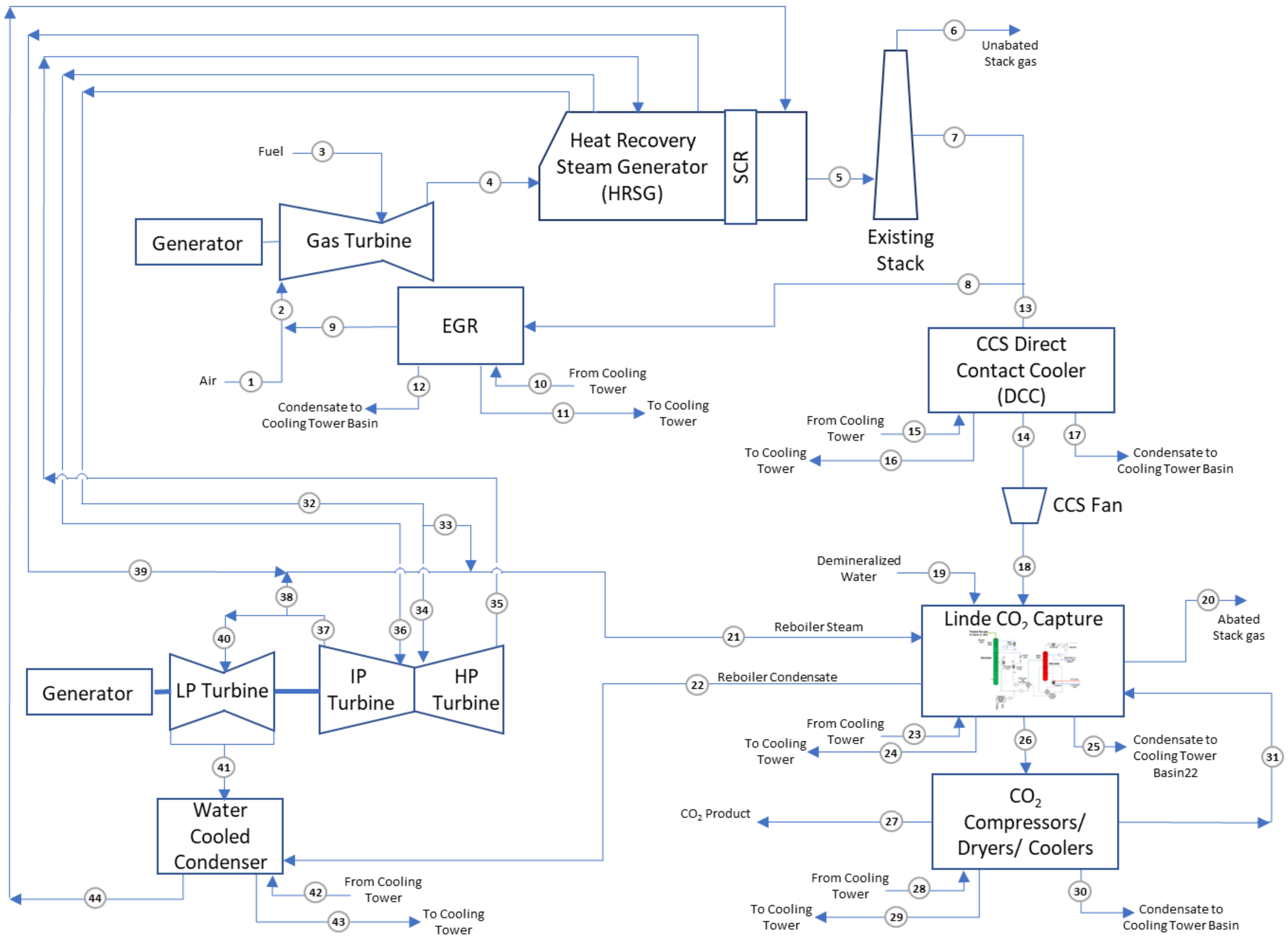
- Max continuous throttling is ~35%
- Max reduction of LP swallowing capacity within current casing is ~15%





Existing ST can be modified to fit new CCS and GT operating conditions

NGCC Performance



Carbon In[A]		Carbon Out[A]	
	kg/hr (lb/hr)		kg/hr (lb/hr)
Pipeline Gas	229,044 (504,956)	Stack Gas	11,523 (25,404)
Air (CO_2)	1,416 (3,122)	CO2 Product	218,938 (482,674)
Total	**230,461 (508,078)**	**Total**	**230,461 (508,078)**

A Calculations based on an 85% capacity factor

Carbon Input to Cycle (total for 2x1 7FA plant):

Inlet Air: Standard Ambient Air @ 75% relative humidity
Fuel to GT's Pipeline Natural Gas (LHV = 20866.9 Btu/lb)

95.69%vol	Methane (CH_4)
2.14%vol	Ethane (C_2H_6)
0.80%vol	Carbone Dioxide (CO_2)
0.62%vol	Propane (C_3H_8)
0.29%vol	Butane (C_4H_{10})
0.28%vol	Nitrogen (N_2)
0.11%vol	Hexane (C_6H_{14})
0.07%vol	Pentane (C_5H_{12})

With 100% complete combustion, produces 2.73662 lb CO_2 per lb fuel

Air Flow to GT's	4,846,176 lb/hr	3,122 lb/hr CO_2
Fuel to GT's	184,518 lb/hr fuel	504,956 lb/hr CO_2
EGR Recirculation Flow (40%)	3,145,096 lb/hr	338,718 lb/hr CO_2
GT Exhaust Flow	8,175,790 lb/hr	846,796 lb/hr CO_2
HRSG Exhaust	8,175,790 lb/hr	846,796 lb/hr CO_2
Flow to EGR (40%)	3,270,316 lb/hr	338,718 lb/hr CO_2
Flow to CCS System	4,905,474 lb/hr	508,078 lb/hr CO_2
Captured CO2		482,674 lb/hr CO_2 (95% Capture)
CCS Absorber Exhaust	4,336,276 lb/hr	25,404 lb/hr CO_2

Net CO2 inlet	508,078 lb/hr CO_2
Net CO2 captured	482,674 lb/hr CO_2
Net CO2 exhaust	25,404 lb/hr CO_2

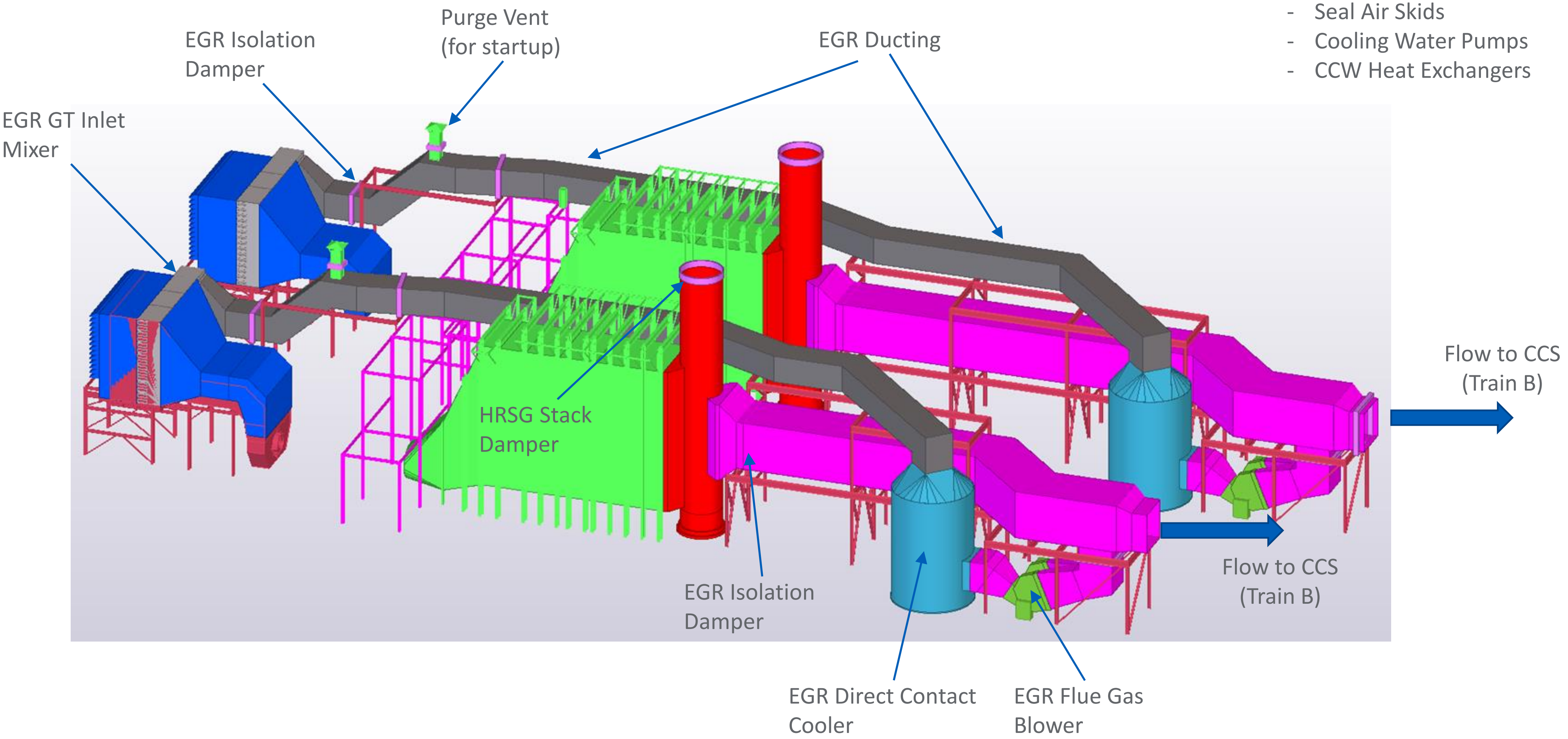
Annual CO_2 Capture (based on 7446 hr/yr operation) 1.6302 MM Metric tonnes/yr

NGCC Performance – Peak Loading

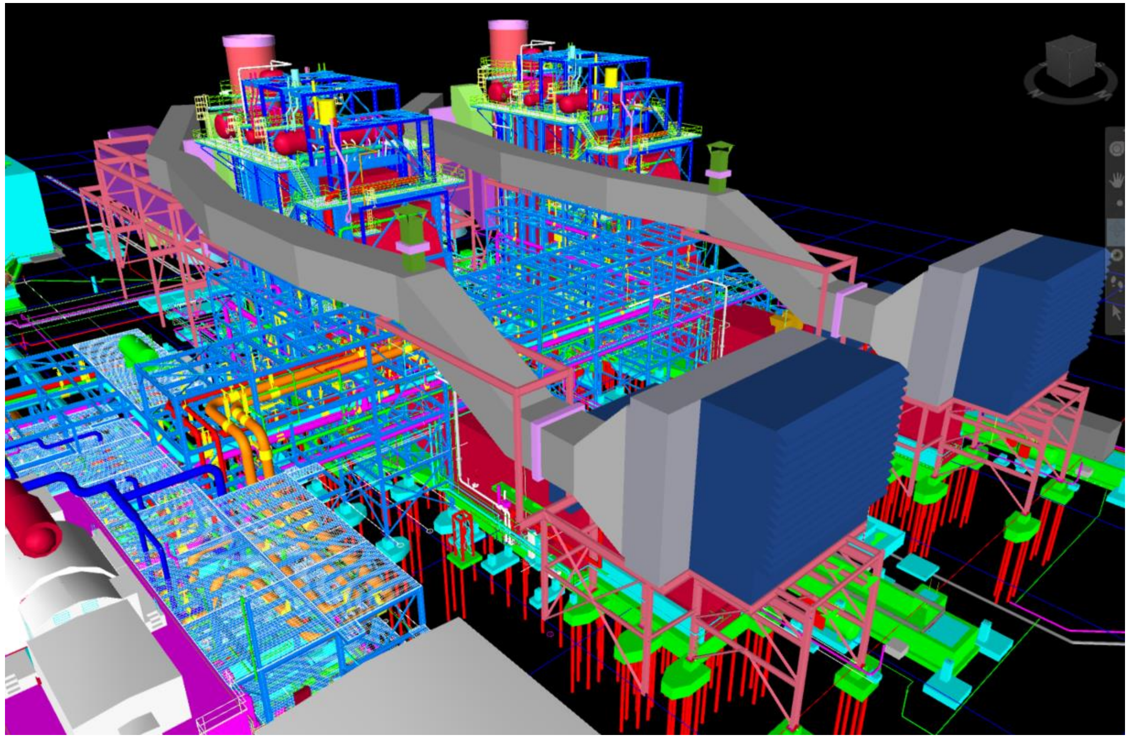
Operating Mode	Peaking Capability	CCS Status	EGR Status	GT Status	GT Evap Cooler	HRSG Duct Burner	Notes
Normal	none	ON	ON (required for >70% GT load)	MECL to Baseload (no GT MF)	ON above 50F ambient	OFF	Max use of CO2 Tax Credit
CCS offset peaking	+76MW (+76MW total)	OFF	OFF	Baseload (no GT MF)	ON above 50F ambient		Limited by 45Q tax credit to 25% of op hrs
Airflow Peaking	+24MW (+100 MW total)	OFF	OFF	Peak Airflow (GT rotor MF)	ON above 50F ambient		Moderate NGCC efficiency loss
Standard Peaking	+25MW (+125MW total)	OFF	OFF	Peak Load (GT MF)	ON above 50F ambient		Moderate NGCC efficiency gain
Maximum Peaking	+25MW (+150MW total)	OFF	OFF	Steam Injection (GT MF++)	ON above 50F ambient		Moderate NGCC efficiency gain

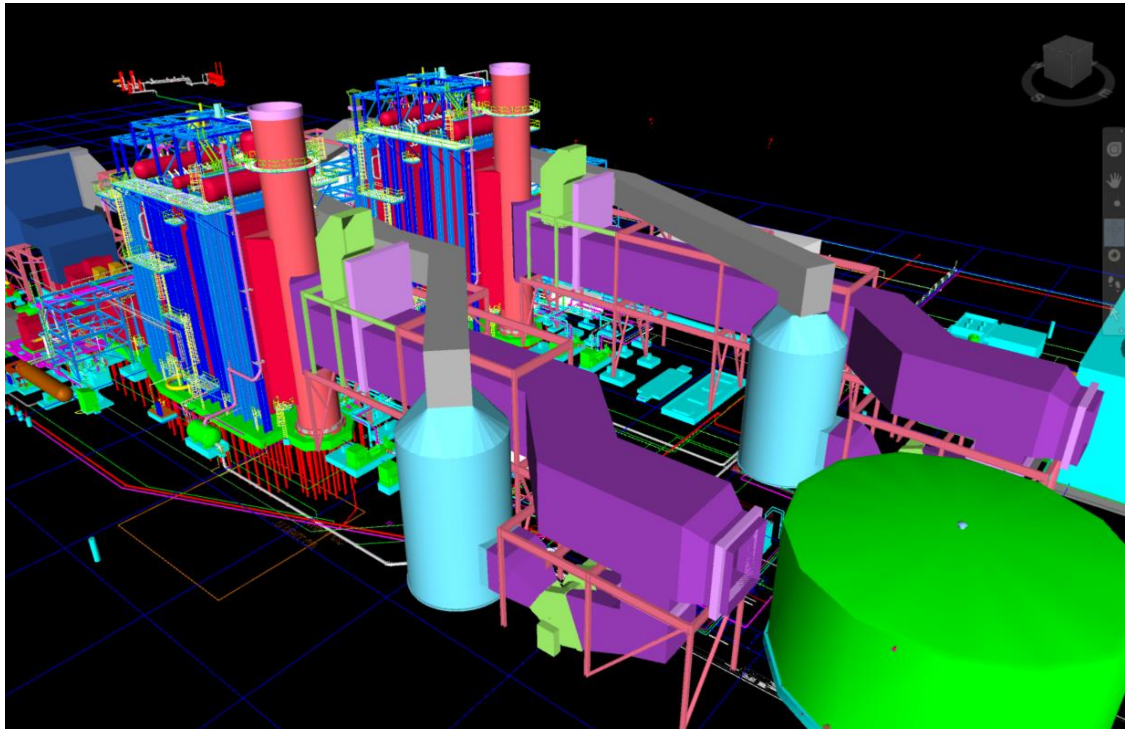
EGR – Detailed Design

Not Shown:
- Seal Air Skids
- Cooling Water Pumps
- CCW Heat Exchangers



EGR – Ducting





System Description

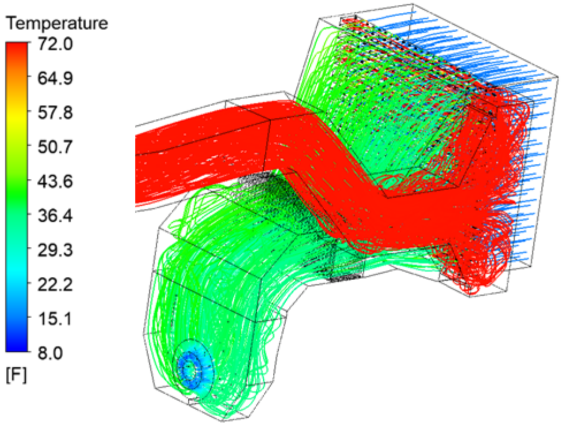
- EGR System arranged to minimize impact to existing plant
- Layout also minimizes length of expensive ducts which carry wet flue gas

- Interface points have been reviewed and agreed to with Kiewit and SoCo
- Constructability has been reviewed with Kiewit. Kiewit comments have been incorporated

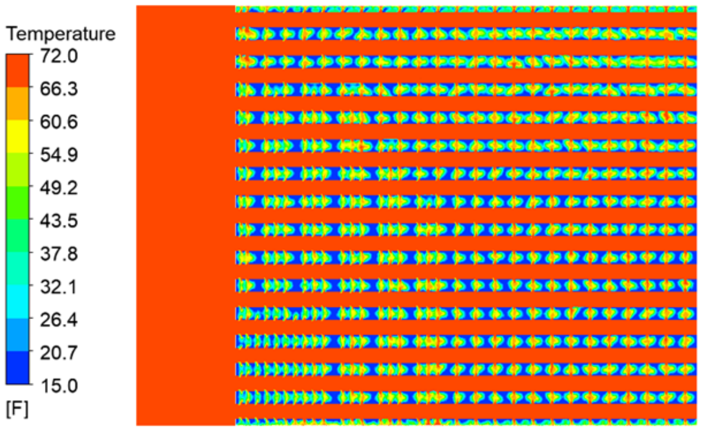
EGR – Inlet Mixer CFD Study

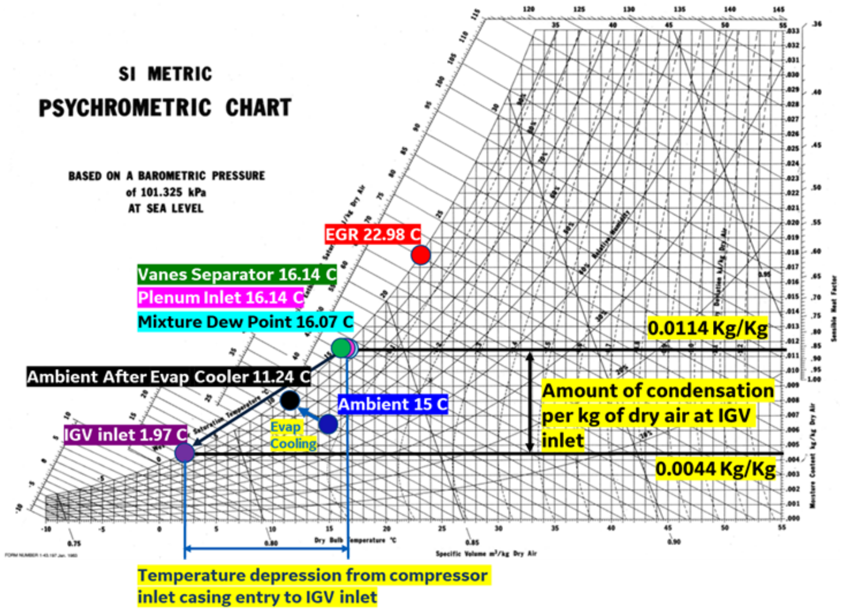
Typical results pictures from CFD Study

Streamlines from Inlet & EGR duct, colored by temperature



Temperature distribution at section passing through orifices in static mixer duct

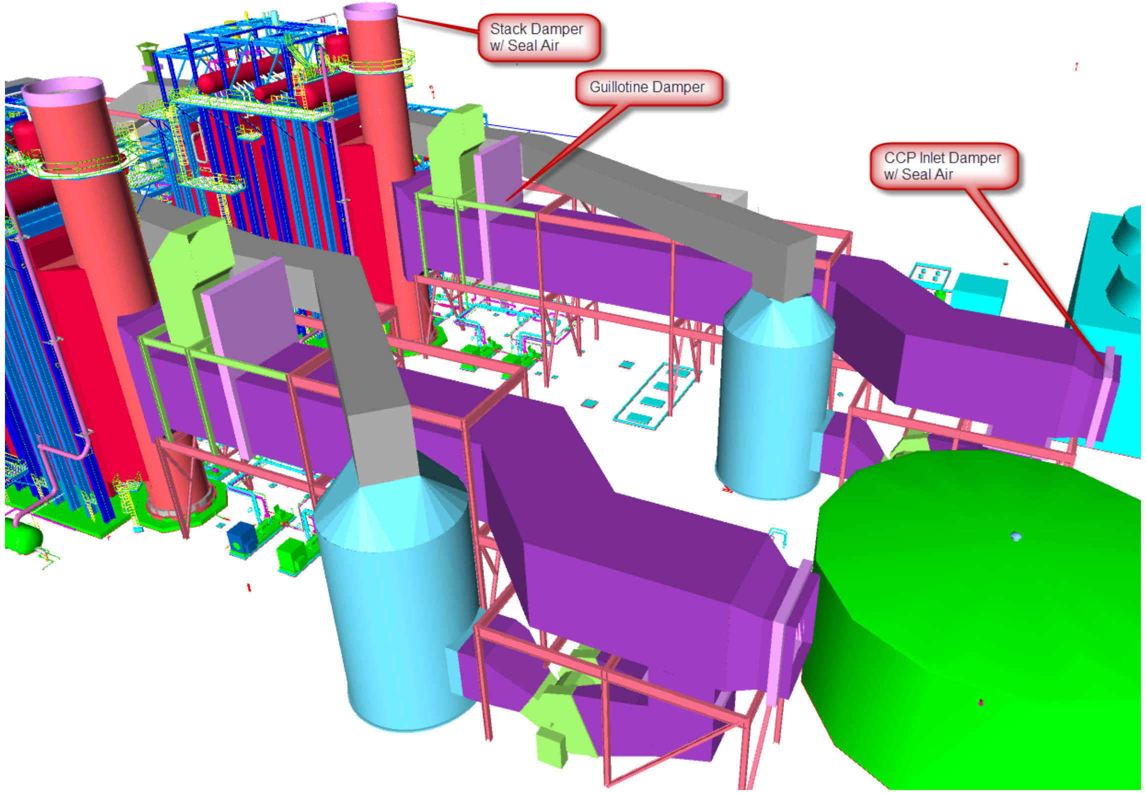




Major conclusions

- Static mixer and inlet system design meets the system CTQs (Aero CTQs) for the operating conditions analysed.
- The major amount of condensation formation will occur in the region “Compressor inlet casing entry to IGV inlet” due to temperature depression resulting from the high flow acceleration in this region.
- The amount of condensation formation observed at compressor inlet with currently analysed EGR cases seem to be higher than that forms for the units with evap cooler (~50% higher).

HRSG Stack & CCP Inlet Dampers

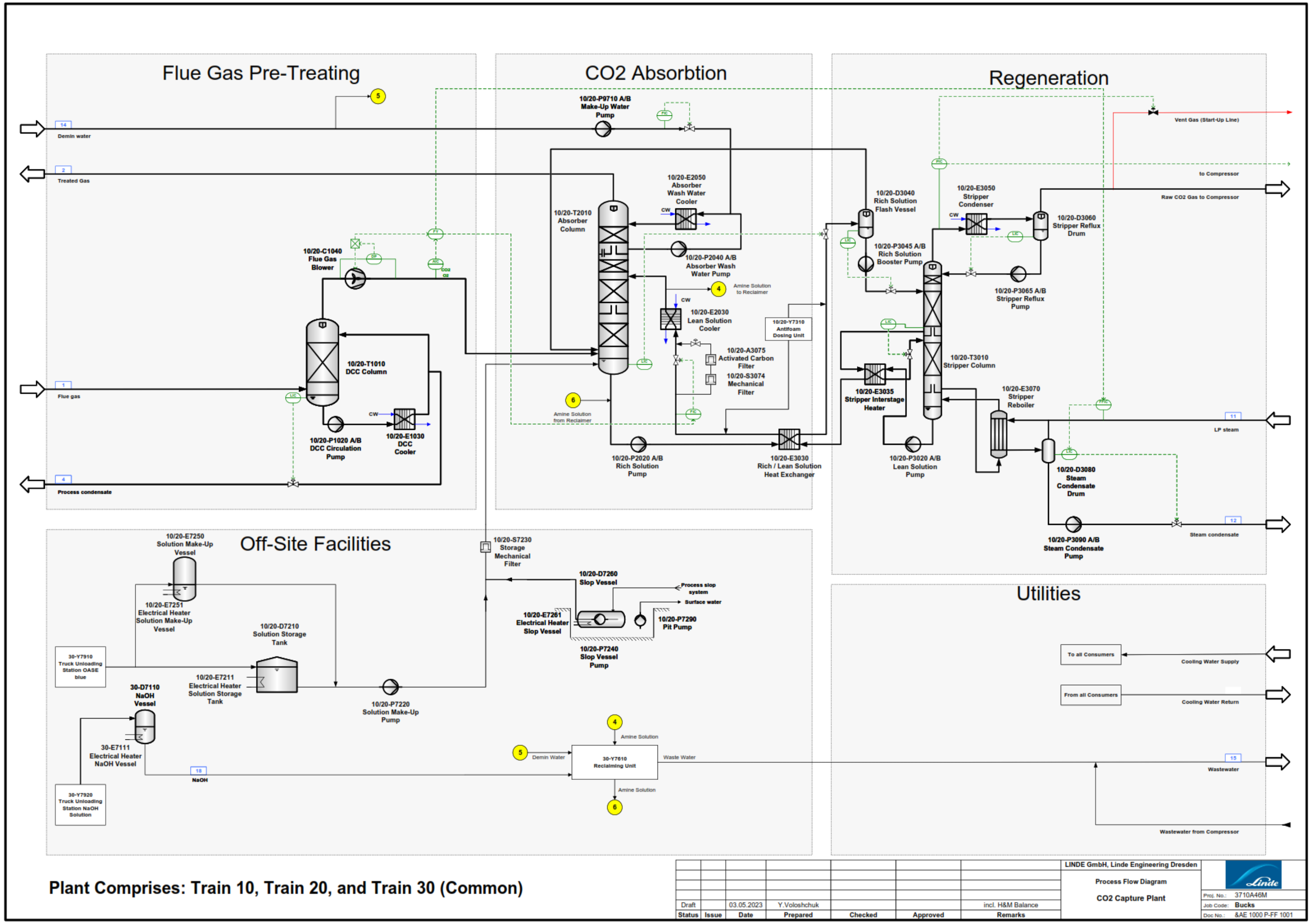


- HRSG Stack CCP Breech Retrofit
  - Retrofit a new breech opening into the existing HRSG stack based on calculations and FEA developed for the Luminous Project
- Stack Damper (16’-10” Dia.)
  - Located at top of stack
  - Seal Air included to provide 100% sealing during Abated Operation.
  - 50-60 sec to fully open or close blades using motor actuator
- Guillotine Damper (22’-2” x 22’-2” square)
  - Located just after the transition from the stack to the CCP Duct
  - Provided for double isolation of the CCP for maintenance activities inside the CCP Duct during unabated operation
- CCP Inlet Damper (16’-0” wide x 18’-3” tall)
  - Located in CCP Duct just after the EGR Duct takeoff
  - Seal included to provide 100% sealing during Unabated Operation
  - 50-60 sec to fully open or close blades using motor actuator
- Seal Air
  - One system will be shared by HRSG Stack and CCP Inlet Dampers as only one damper will be closed at a time
- CCP Duct Support
  - An expansion joint upstream of the CCP Inlet Damper will isolate the CCP Duct from the HRSG Stack
  - The HRSG Stack will not support the CCP Duct or Dampers

CO_2 Capture Island (ISBL)

- 2 Trains (1 for each GT)
- Common loading/unloading stations
- Common Cooling Water system

CCS Auxiliary Load Summary	
CO2 Capture/Removal Auxiliaries, kW	18,356
CCS Flue Gas Fan	7,480
CCS Pumps	4,849
EGR Flue Gas Fan	2,610
CCS Cooling Tower Fans	1,990
CCS Cooling Water Circulation Pumps	1,427
CO2 Compression, kW	20,824



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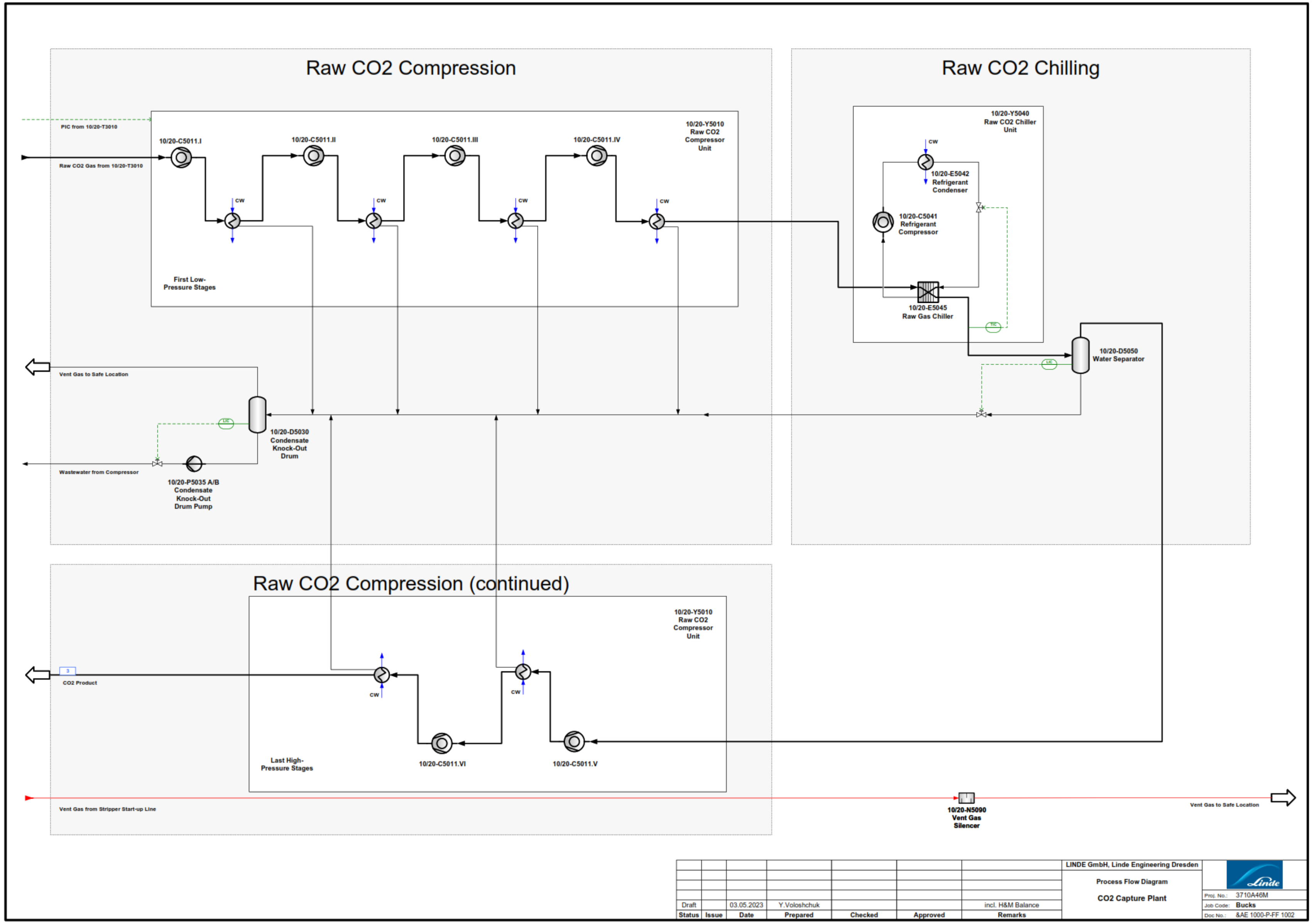
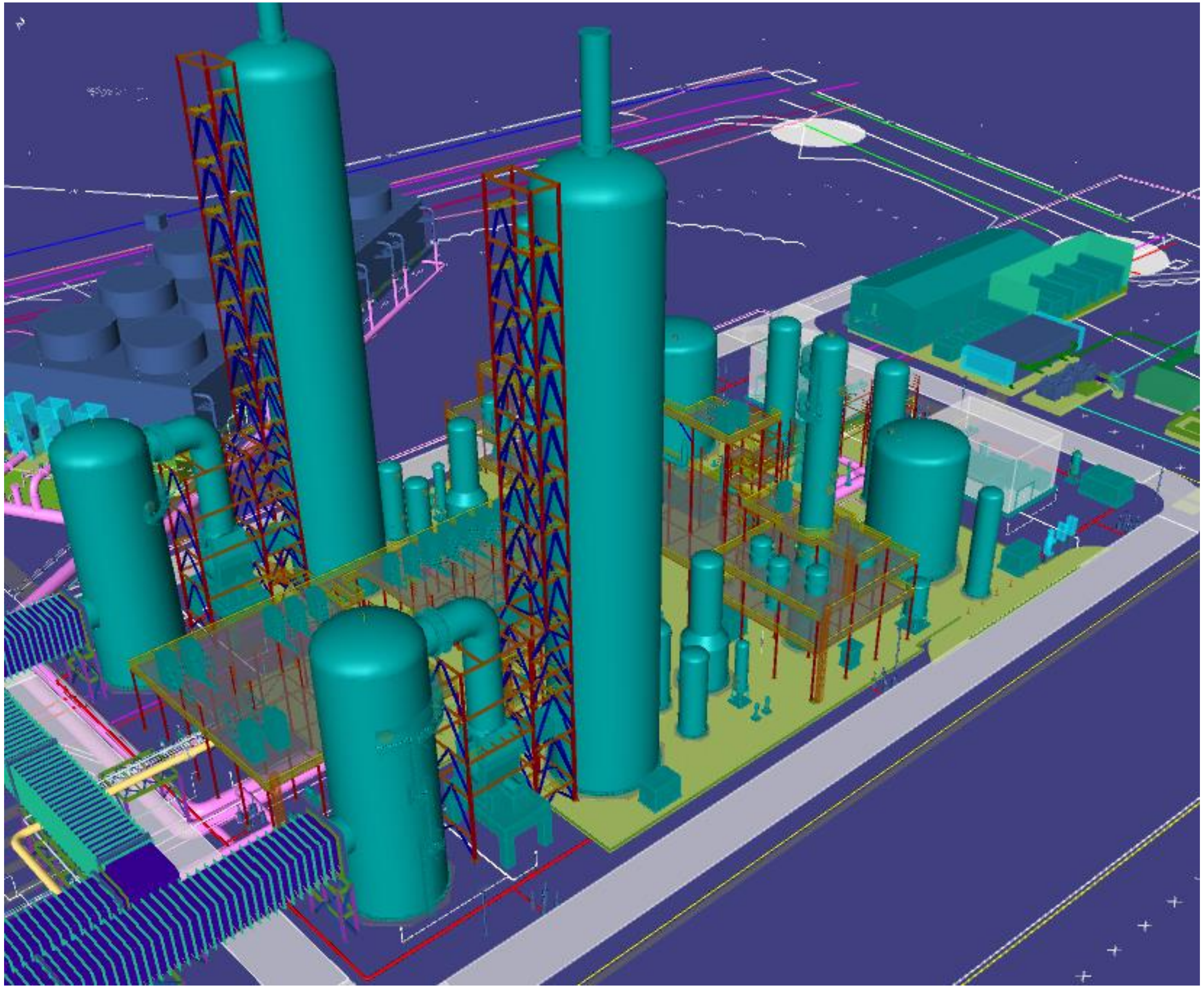


CO_2 Capture Island (ISBL)

- 2 Trains (1 for each GT)
- Common loading/unloading stations
- Common Cooling Water system



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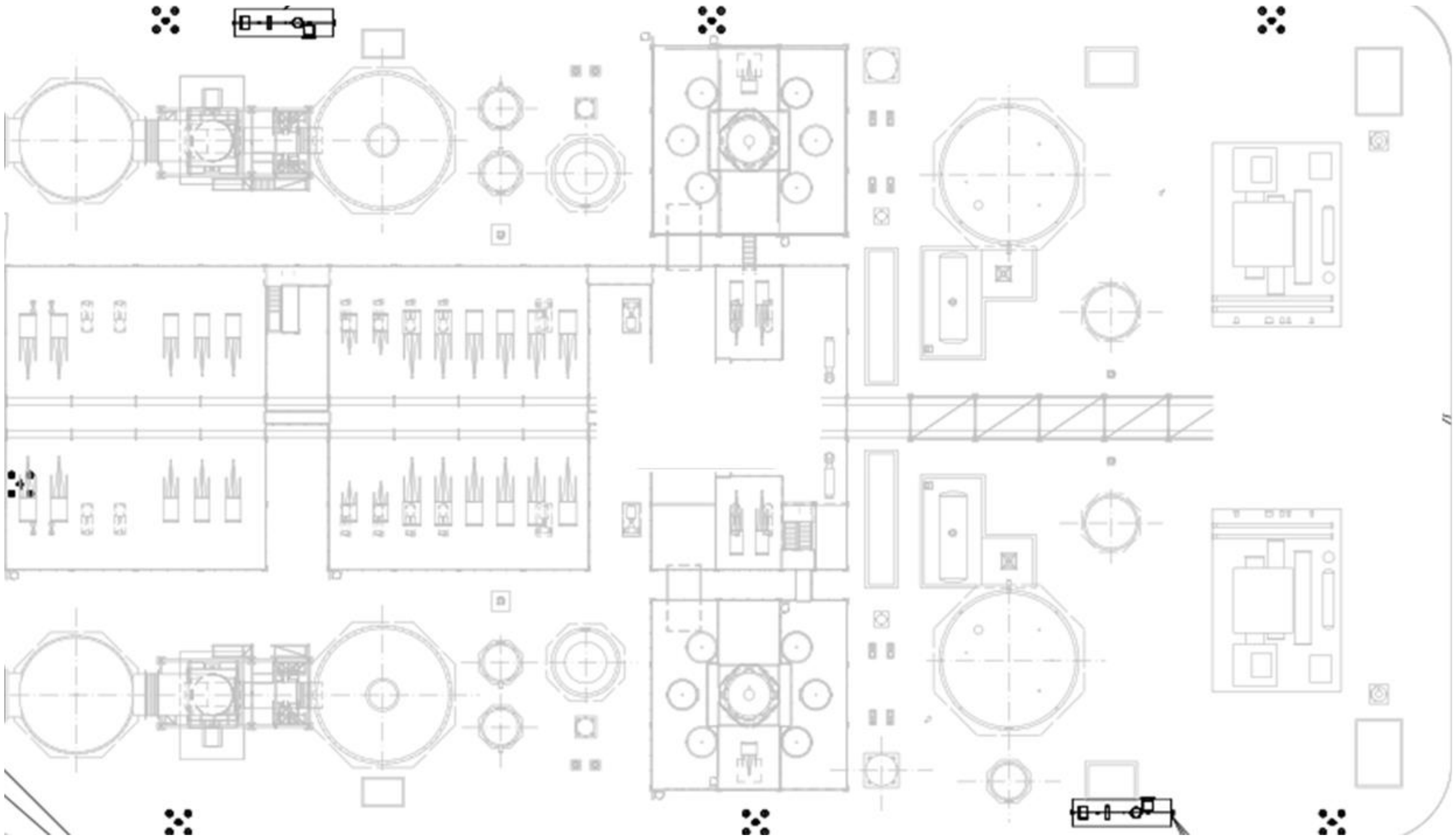

CCS Plant Integration (OSBL) Detailed Design

- 2 Trains (1 for each GT)
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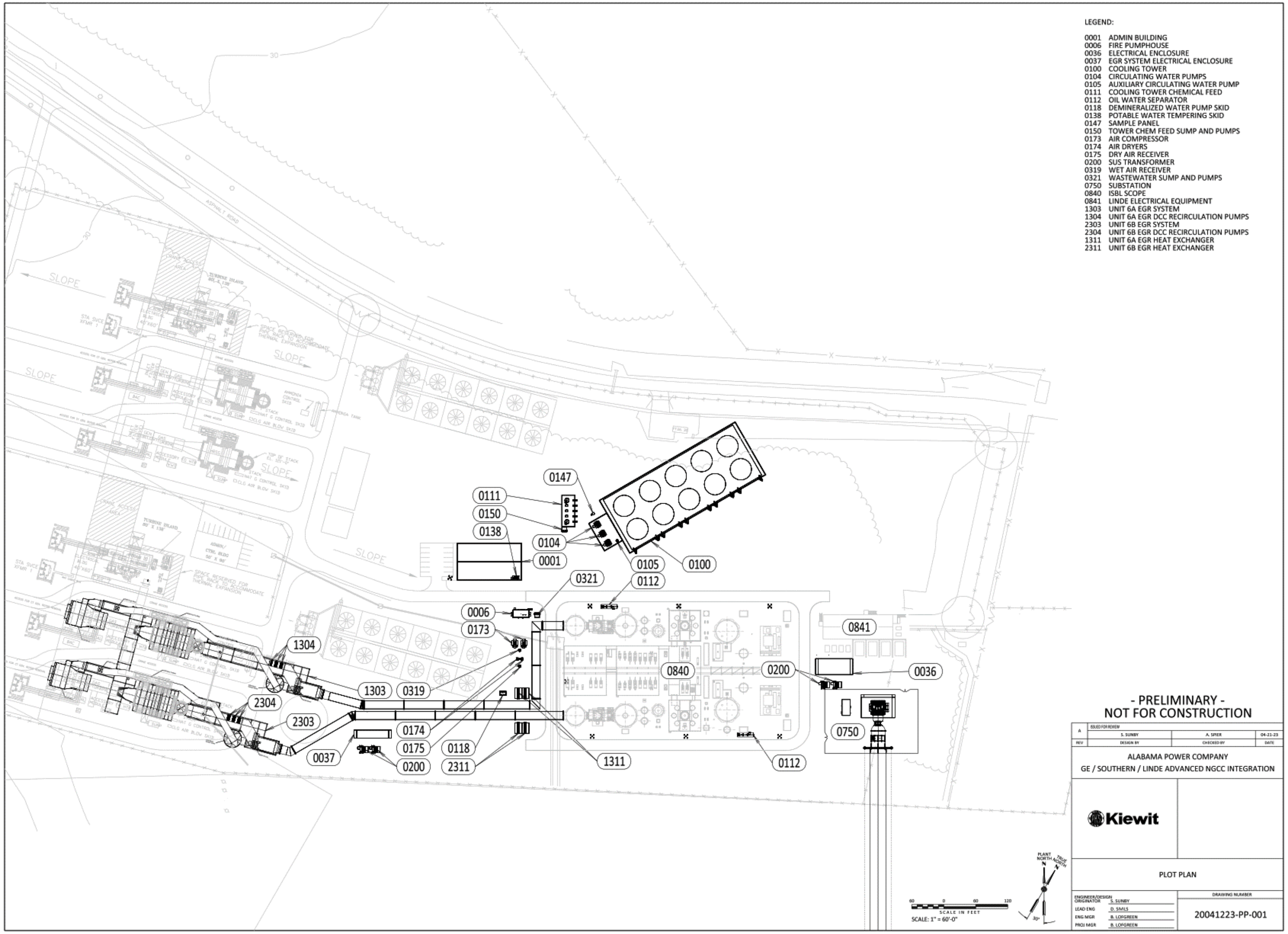
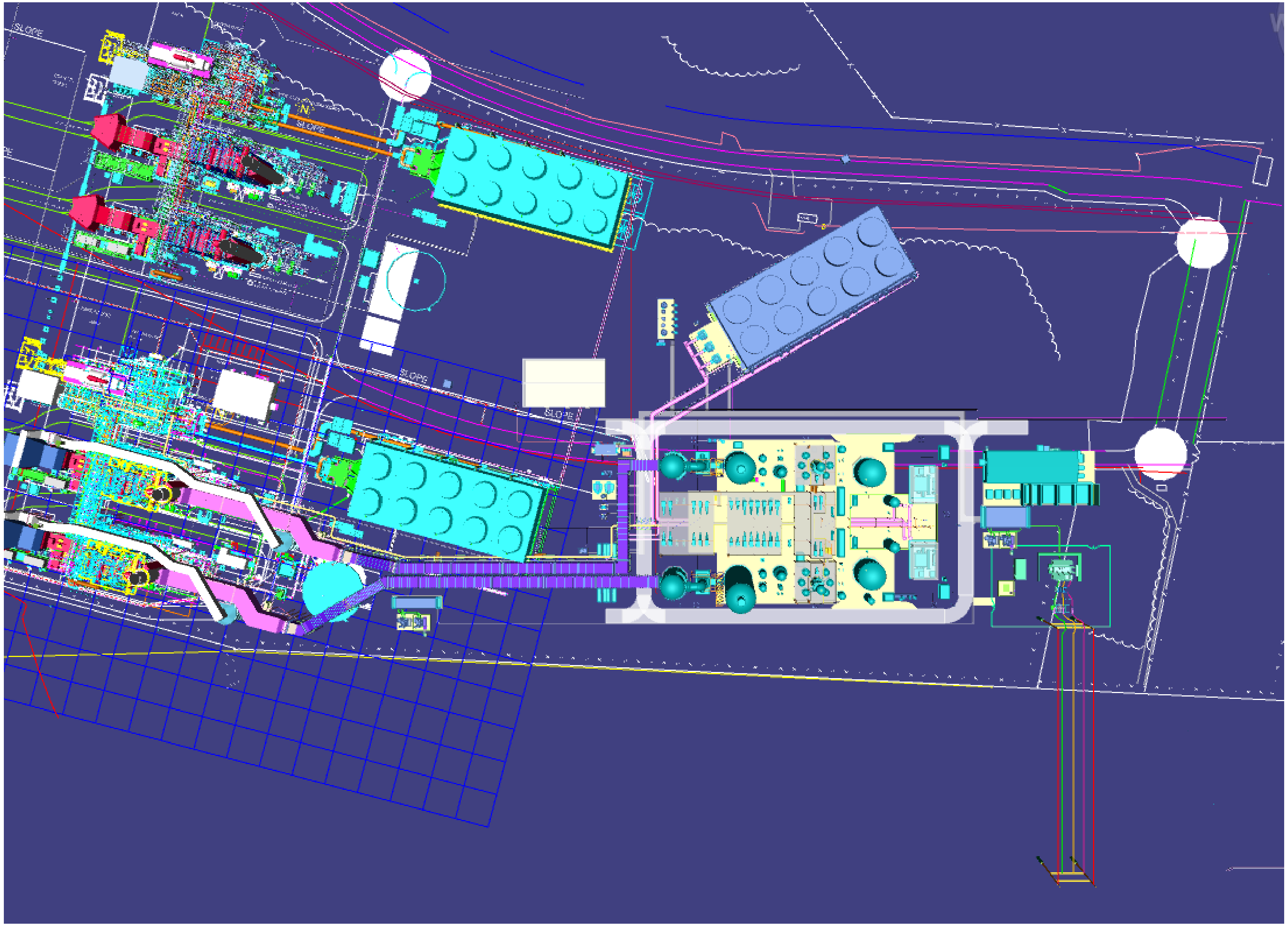


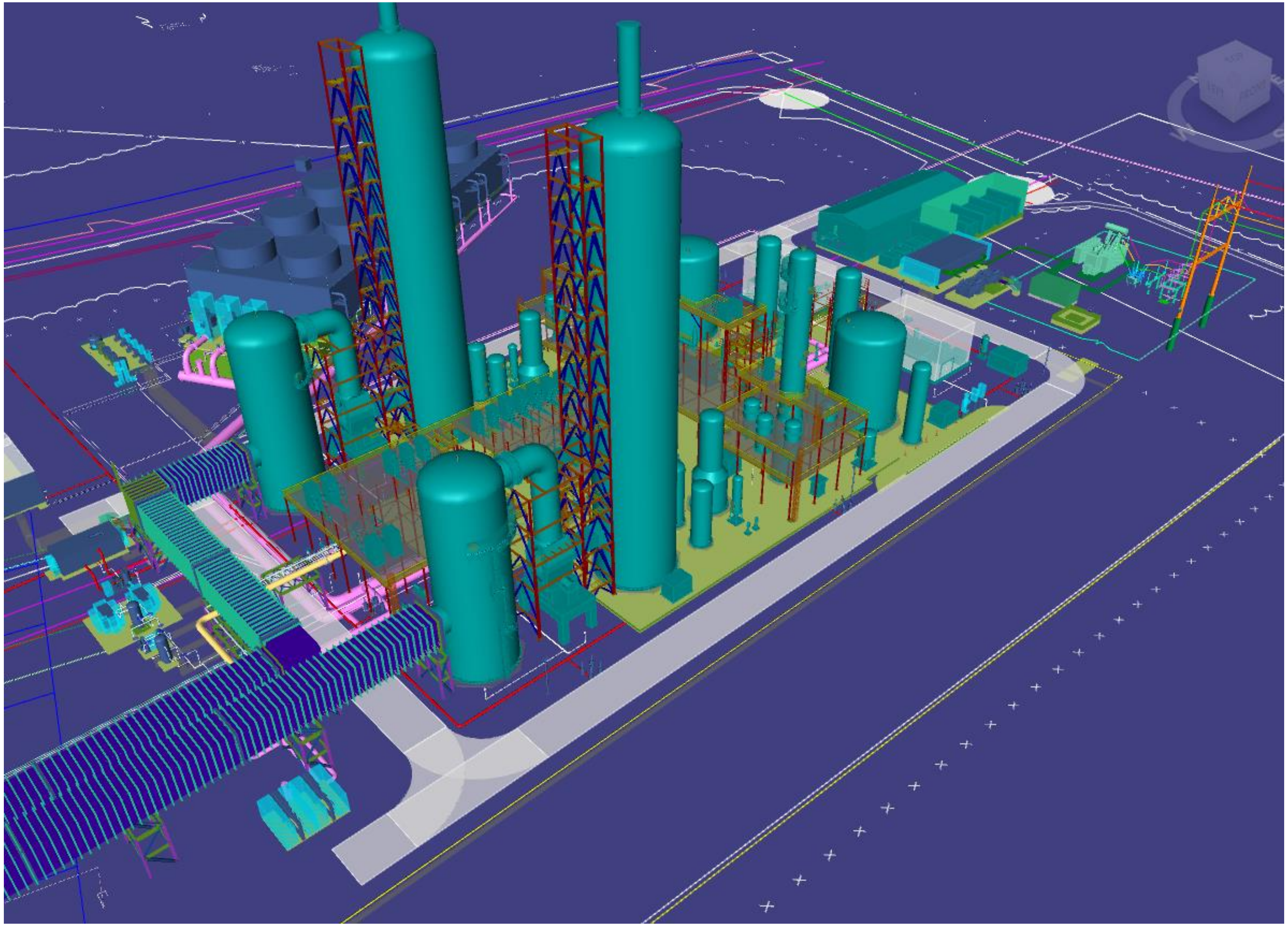
CCS Plant Integration (OSBL) 3-D Model

Overall Plot Plan view



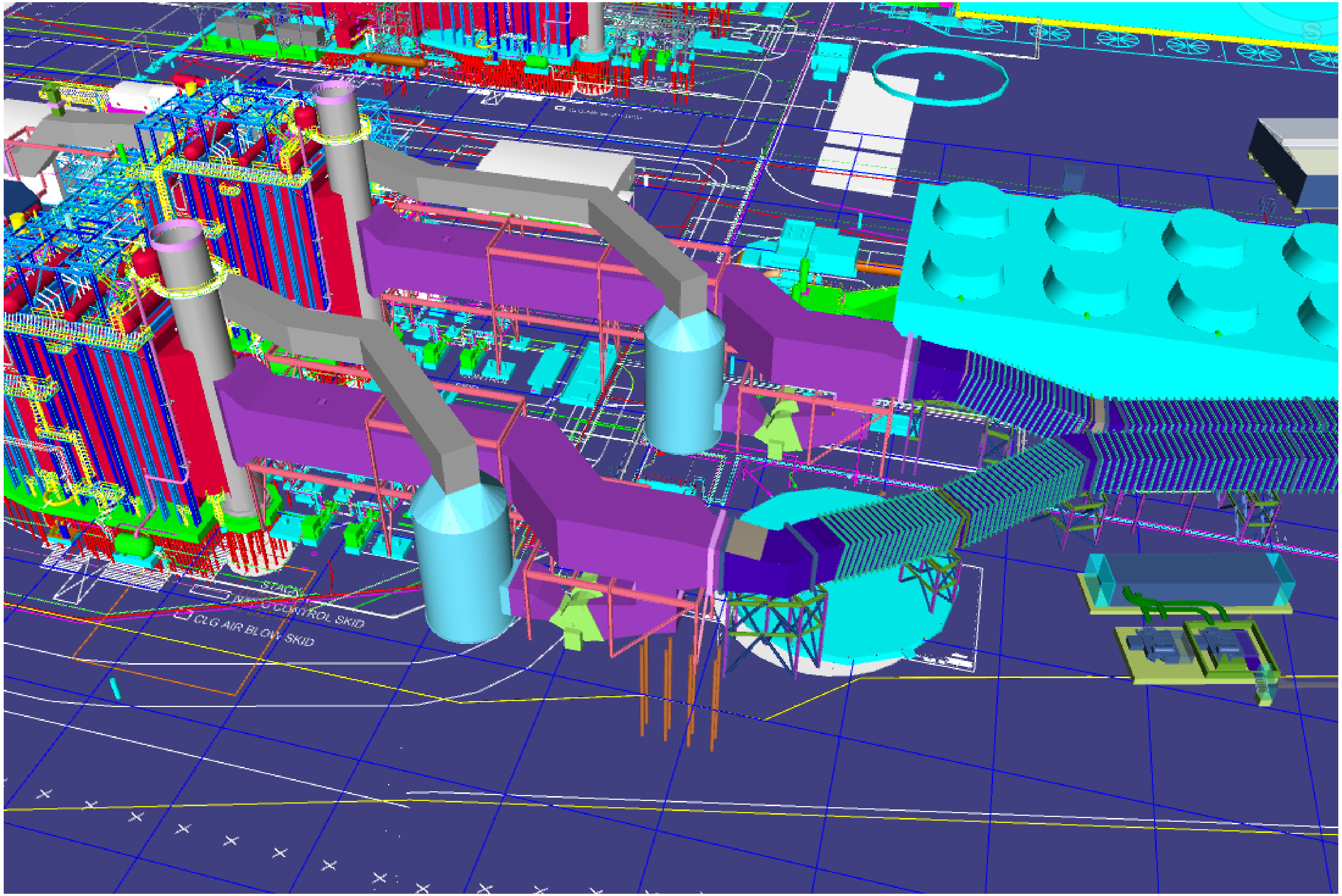
CCS Plant Integration (OSBL) 3-D Model

Carbon Capture Island



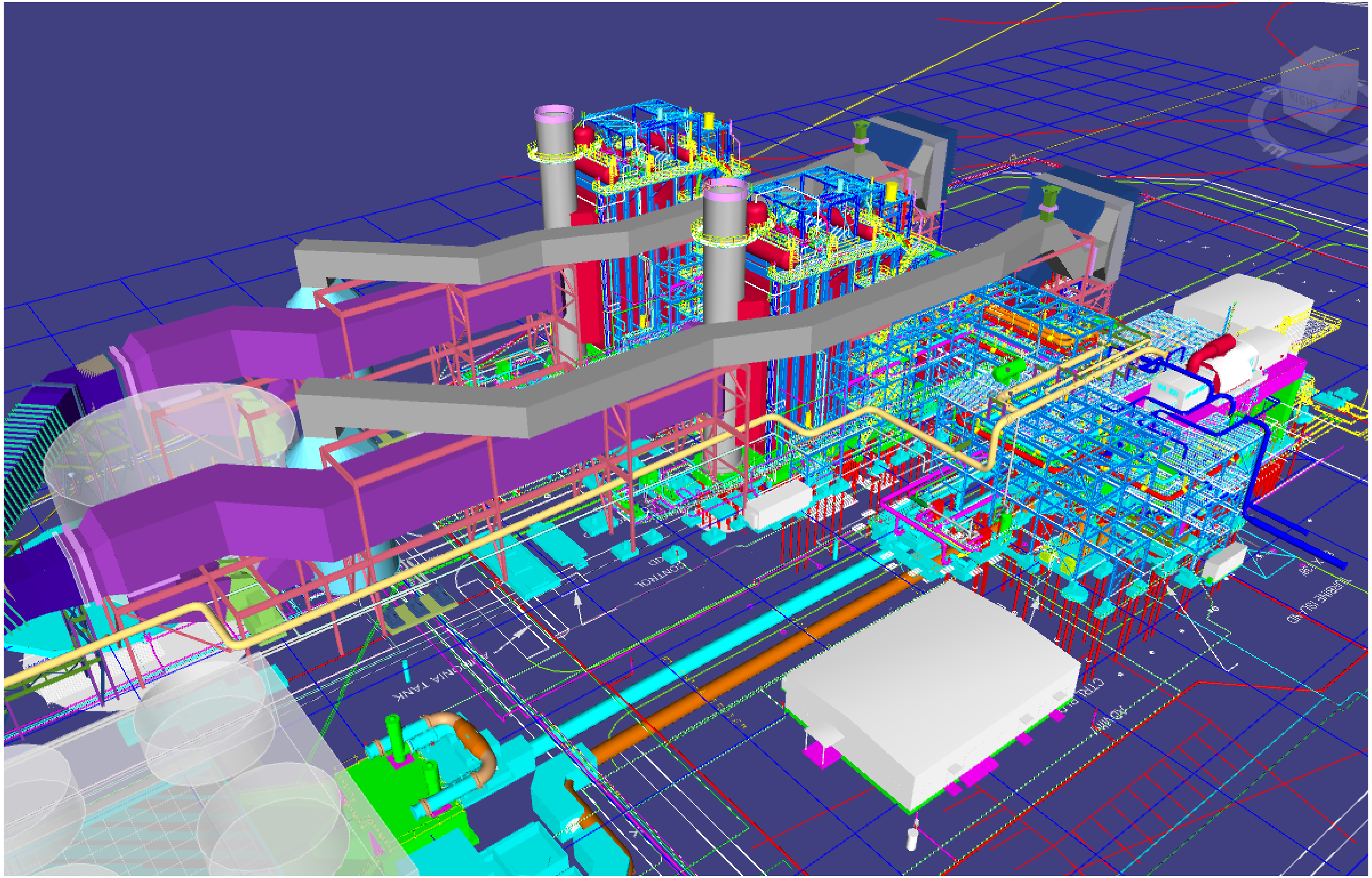
CCS Plant Integration (OSBL) 3-D Model

EGR System
(from south)



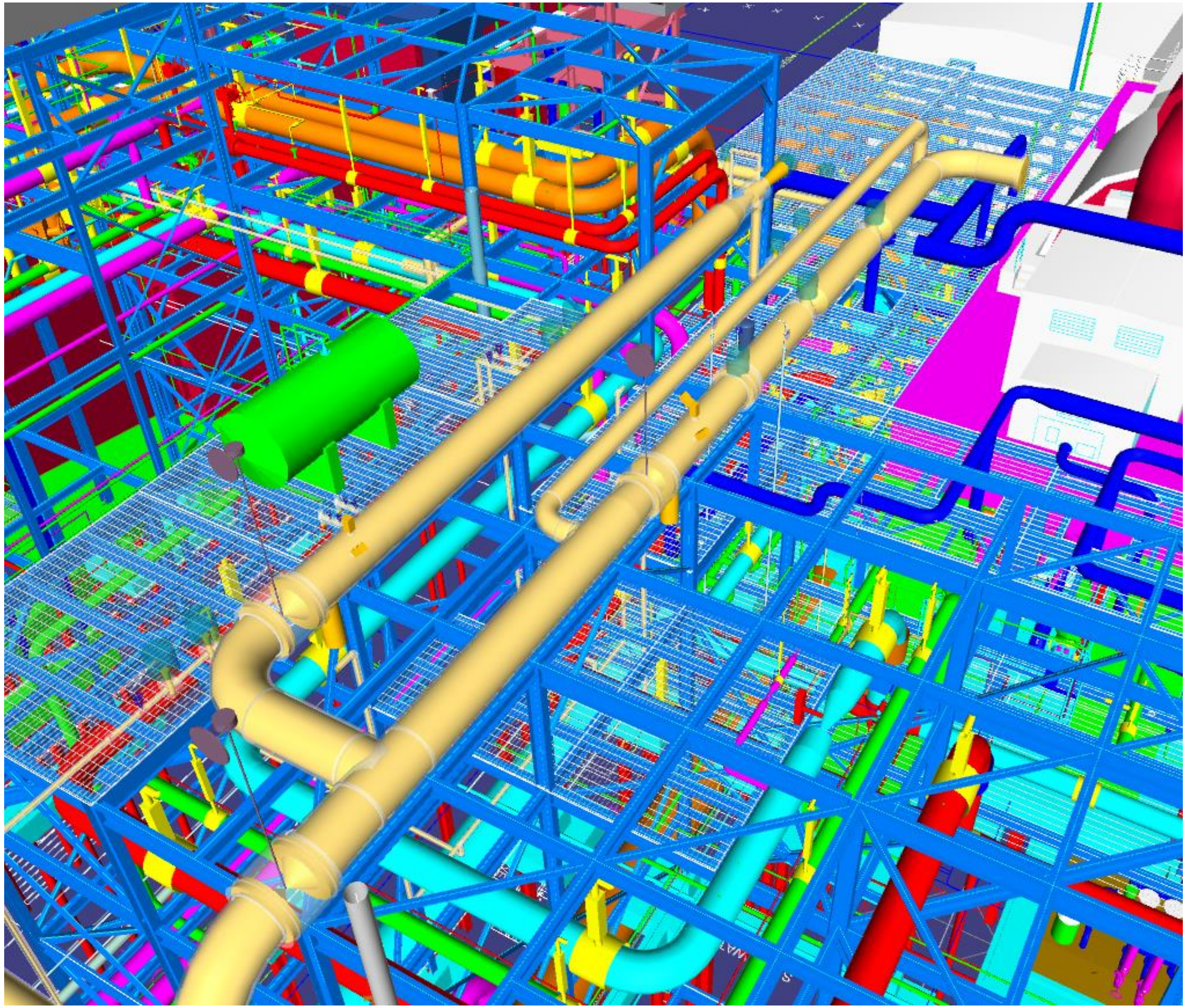
CCS Plant Integration (OSBL) 3-D Model

EGR System
(from north)



CCS Plant Integration (OSBL) 3-D Model

New Steam Extraction
piping for Steam Turbine



Art of the Possible – Pathway to 99% CO_2 reduction

What is "net-zero"?

- That depends on the source of the fuel used for the power plant
- Best case scenario – "clean" natural gas with little or no carbon footprint to extract it from the ground, filter it, purify it, compress it and transport to the power plant
  - Fresh air into plant is ~0.04% CO_2 from surrounding ambient
  - Depending on GT cycle and firing temperature, ~4% CO_2 exits GT/CC
  - 99% capture of CO_2 results in 0.04% out stack, so approximately "net-zero"
  - With 40% EGR, GT/CC exhaust increases to ~6.7% CO_2
  - 99%* capture of CO_2 results in 0.07% out stack, so not quite "net-zero"
  - Need 99.4%** capture of CO_2 results to get 0.04% out stack (i.e. "net-zero")

*All TEA work on pathway to "net-zero" stopped at 99% capture of CO_2
**LCA study went all of the way to 99.4%

Art of the Possible – Pathway to 99% CO_2 reduction

To answer how to get to 99% CO2 reduction, is done is several steps:

1. What is the maximum proven capability of the current CCS technology/solvent?

   Answer: 98% if the CO2 inlet concentration is in 6-7% range (i.e. use EGR)

2. What is the maximum expected capability of the current CCS technology/solvent?

   Answer: 99% may very well be capable (but not likely 99.4%)

1. What are other technologies that could be added to go from current proven capability (98%) to 99%?

   a) How about 30% blended H2 we hear about from EPA in the press releases?
      Answer: This would boost 98% to 98.1-98.2%
   b) How about adding Direct Air Capture (DAC) to absorber exhaust
      Answer: This could reach 99%+ but at very high cost
   c) How about offsets by using renewable natural gas (from agricultural and animal waster recycling)
      Answer: This could reach 99%+ at increased costs, but limited by amount of available waste

LCA approach

The goal of this LCA is to demonstrate robust accounting of full life cycle emissions and “zero net carbon emissions”[1] of the proposed product system by calculating the life cycle greenhouse gas (GHG) emissions and water consumption (cradle-to-delivered electricity) of producing electricity from the NGCC plant with carbon capture and proposed NETs

Standards and guidance

- Follows requirements of FOA Number DE-FOA-0002515
- Aligns with NETL CO2U LCA Guidance and ISO 14040/14044

Functional unit

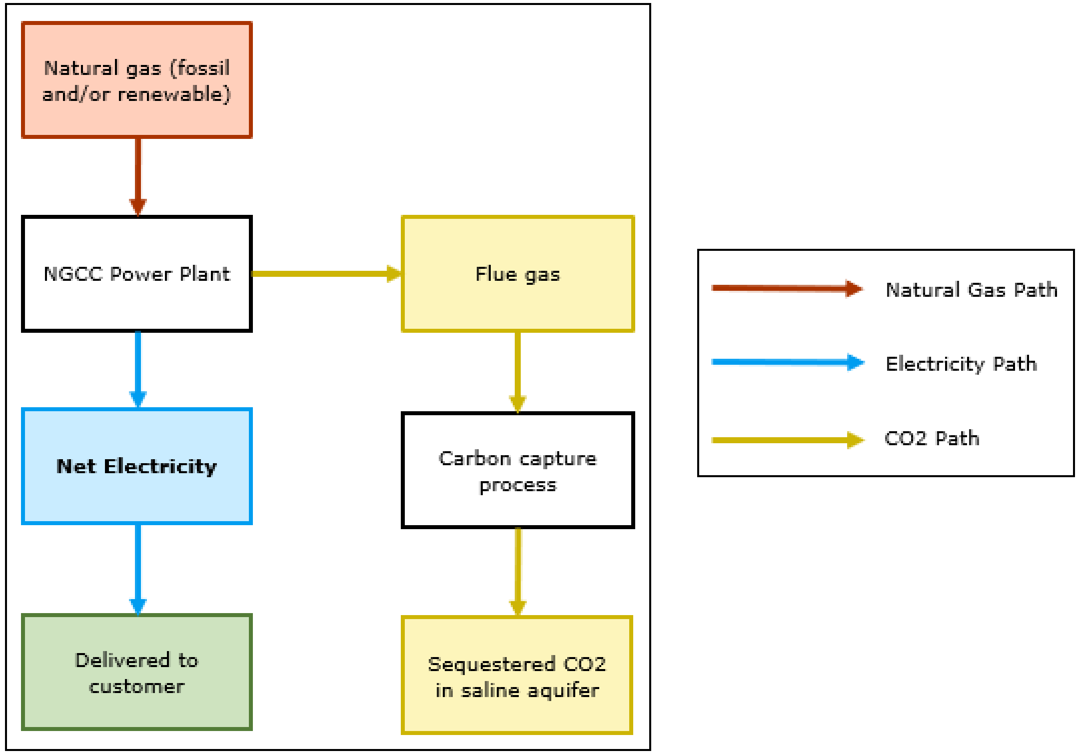
- Production of baseload electricity delivered in the SERC power grid for 30 years, represented by the reference flow of 1 megawatt-hour (MWh) delivered to the customer

System boundary

- Cradle-to-delivered electricity

Impact categories

- GWP
- Water consumption



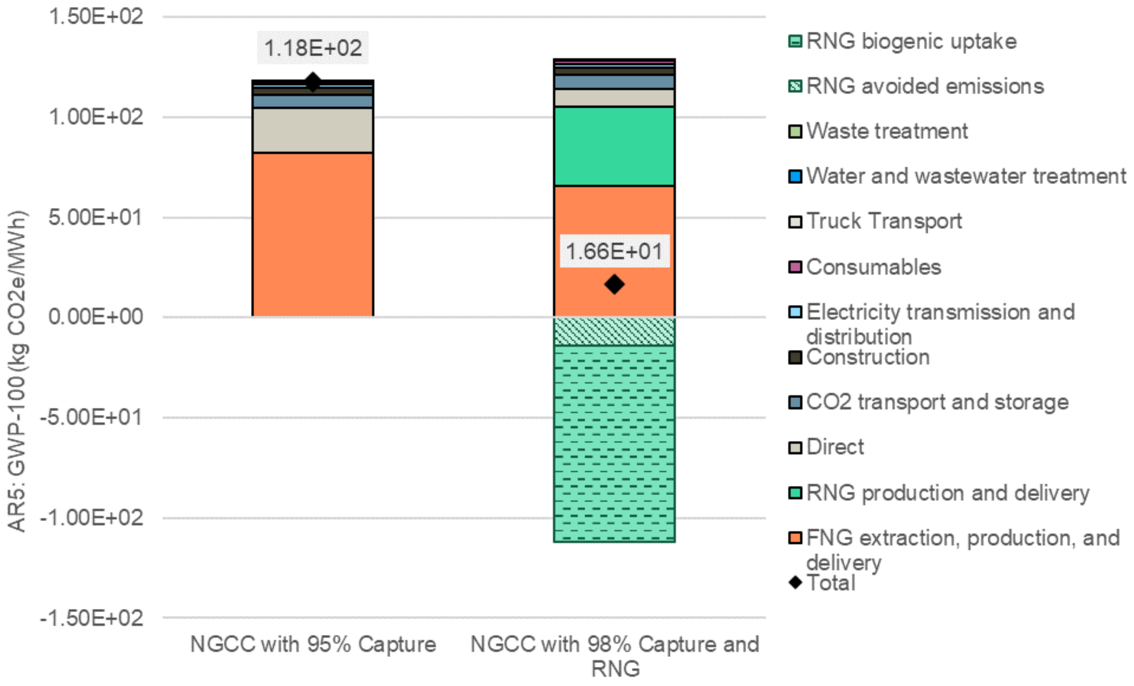
Simple system boundary diagram

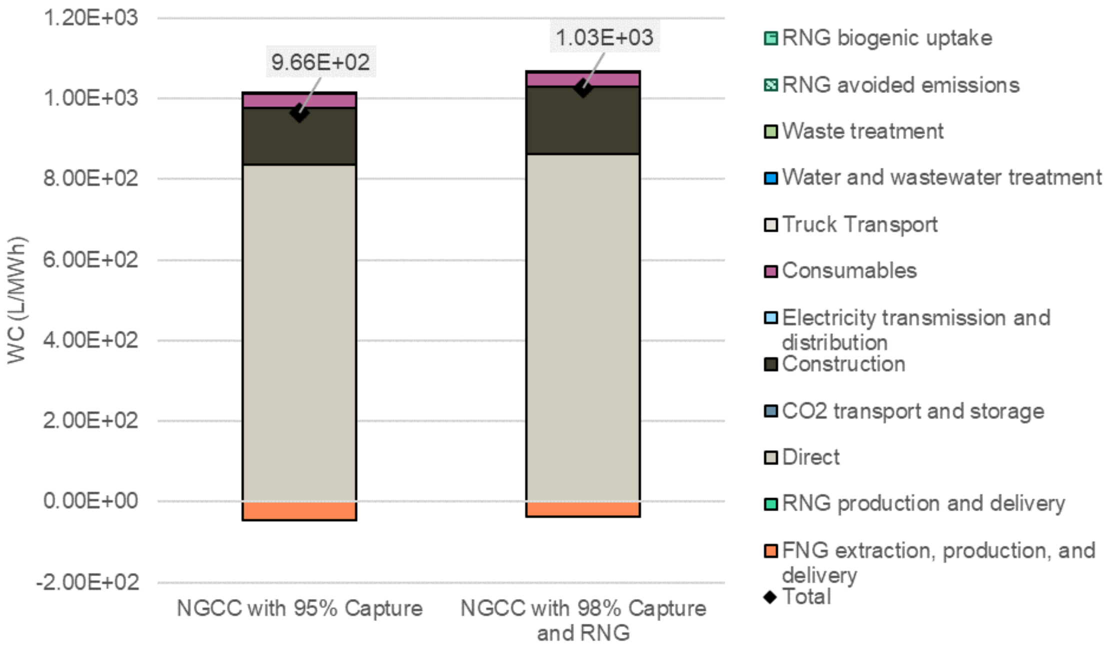
1. For the purposes of this LCA study, “zero net carbon emissions” is interpreted as net zero upstream and direct emissions from the fuel. Furthermore , “net zero direct emissions” is defined as the direct emissions not captured having an effective CO_2e concentration equivalent to that of ambient air, i.e., a 99.4% reduction in direct emissions relative to the NGCC unit without carbon capture.

LCA best practices

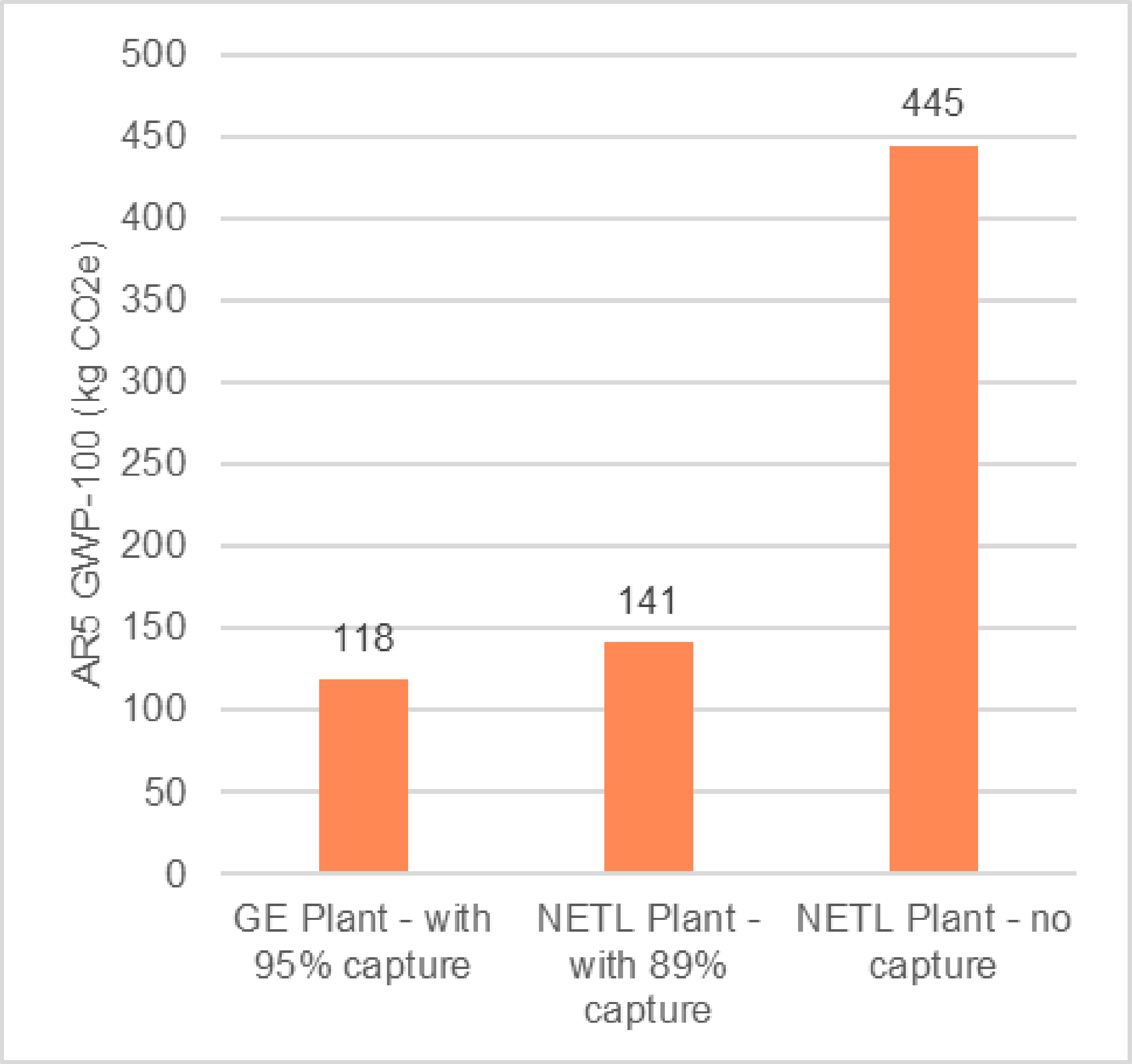
Best practice	This study
Align with internationally accepted standards, i.e., ISO 14040/14044	• Follows requirements of FOA Number DE-FOA-0002515 • Aligns with NETL CO2U LCA Guidance and ISO 14040/14044
Transparently document assumptions	• Study documented in ISO/NETL-compliant report, with full assumptions and model documentation in appendices and openLCA model
Conduct a data quality assessment	• Qualitative data quality assessment included in report
Test assumptions and uncertainty with sensitivity analyses	• Conducted sensitivity analysis for 9 different parameters, including 2 different capture rates
Include more than one impact category relevant to the product system under study	• Included GWP and water consumption (WC)
Identify areas for improvement and future work	• Where applicable, use higher quality or project-specific data if it becomes available • Refine NETs scenario • Incorporate real operating data

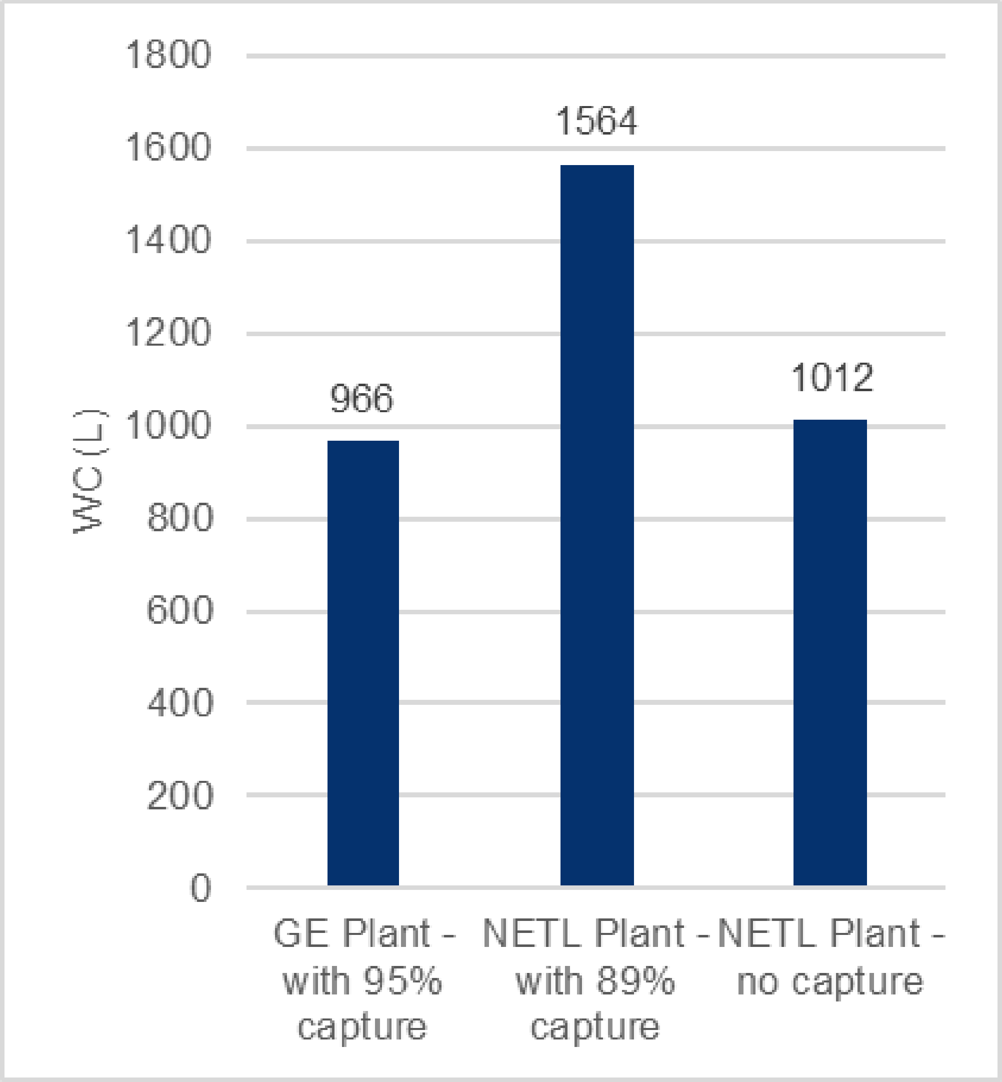
Increasing capture efficiency to 98% and blending 22% RNG greatly reduces life cycle GWP and slightly increases water consumption





LCA – Benchmarking results





Thank You

Questions?