FOCUSS – Industrial requirements definition report

CCUS Innovation 2.0

Key Knowledge Deliverable 2.1

October 2022

Key Knowledge Deliverable Cover Sheet

This Key Knowledge Deliverable (KKD) has been produced by SSE Thermal as part of the BEIS CCUS Innovation 2.0 programme. The document is reflective of the status of the project at the time of writing. The material presented may be subject to change as the project matures. These documents should not be considered a full representation of the final project.

The Flexibly Operated Capture Using Solvent Storage project (FOCUSS), explores options to achieve high CO2 capture levels by effective capture plant operation and to maintain this capture level during start-ups and shut-downs using solvent storage, and to reduce time to market for such techniques for use on commercial projects. Through a combination of pilot scale testing, system modelling and engineering analysis, this innovative project will demonstrate and develop a concept currently at a TRL of 3 to a TRL of 6 once the project is completed.

This Deliverable 2 Industrial Requirement Definition defines a set of design, performance and operational condition requirements for carbon capture plants that will meet industry expectations to ensure relevance and ease of adoption. This document is part of a suite of project deliverables for the FOCUSS project. The following is a full list of FOCUSS project KKDs:

1. Project Management Plan
2. Industrial Requirement Definition report
3. Initial modelling report
4. Final modelling report
5. Interim test campaign report
6. Final test report
7. Standard design modification note
8. Final report

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nzip@energysecurity.gov.uk

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Background

Increasing renewables penetration in the UK electrical grid will require complementary support from firm, low-carbon flexible generation. Combined Cycle Gas Turbine (CCGT) power plants with post-combustion Carbon Capture and Storage (CCGT + CCS) can provide such support as part of a diverse energy mix that also includes other measures (such as hydrogen power generation, energy storage and support from overall energy efficiency techniques).

Frequent start-ups are expected for all gas fired CCS projects and a high capture level is required to support the UK's net zero carbon emission target by 2050. CCS is a mature technology having been commercially operated in chemical industries and demonstrated in large scale plants, however, design optimisations and cost reduction aimed at supporting flexible operation and high capture level have been limited to date.

The Flexibly Operated Capture Using Solvent Storage project (FOCUSS), explores options to achieve high CO2 capture levels by effective capture plant operation and to maintain this capture level during start-ups and shut-downs using solvent storage, and to reduce time to market for such techniques for use on commercial projects. Through a combination of pilot scale testing, system modelling and engineering analysis, this innovative project will demonstrate and develop a concept currently at a TRL of 3 to a TRL of 6 once the project is completed.

This document defines a set of design, performance and operation condition requirements for PCC plants that will meet industry expectations to ensure relevance and ease of adoption. This document is part of a suite of project deliverables for the FOCUSS project.

Scope

The FOCUSS project is designed to:

Test a high capture level of 95% and above at all times, including steady state, start up, shut down and loading ramping using world-leading pilot facilities at the Translational Energy Research Centre (TERC) in the UK, with supporting test data from the National Carbon Capture Centre (NCCC) in the US.

Conduct modelling and engineering analyses to back up and extend the pilot testing.

Use the modelling and test results to design and engineer a set of public guidance documents including a Standard Design Modification Note to support plant designers, researchers and operators.

Exclusions

This document sets out the overall industrial requirements for the test objectives. The detailed test plans themselves will follow as part of a future deliverables.

Industrial Requirements

Test preparation and safety requirement

1. The FOCUSS test plant modifications shall be designed to replicate essential elements of the commercial operational regime as much as is reasonably practicable.
2. Where replication is not practicable, the difference between the test plant and commercial plant shall be recorded; commentary shall be provided in relation to the significance of this difference and potential impact of applying the FOCUSS conclusions at full scale.
3. The project should make sure their test facility is able to replicate commercial start up procedures and regime as much as reasonably practicable. An indicative CCGT start up profile is presented in Figures 1&2.
4. Test plans should be developed and should be reviewed by industrial partners before any tests take place.
5. The project should consider and develop detailed modification requirements to the test plant to facilitate the FOCUSS project specific testing.
6. The project should conduct a full safety review of modification work and procedures which should be approved by relevant safety teams and authorities.
7. The test site shall ensure safe operation and maintenance of the plant and all equipment.

Pilot plant test requirements

8. The test plant shall perform tests to achieve target capture level of 95% to 99% at steady state.
    a. Identification of absorber and stripper operating parameters to achieve high levels of CO2 capture
    b. KPI is recorded at each capture level from 95%-99%, key parameters are indicated in Table 1.
    c. Solvent performance stability monitoring, e.g. operation condition maintained for 1 hour or more depending on test programme.
9. The test plant should perform tests to achieve target capture level of up to 99% during start up, shutdown and load ramping.
    a. Absorber and stripper operated satisfactorily under stored solvent conditions
    b. Operation using solvent storage and transition to normal operation should be demonstrated for start up conditions.
    c. Practical verification (against modelling where appropriate) of absorber and stripper operation with high levels of CO2 capture under other transient conditions with support from solvent storage.

10. The test plant shall demonstrate the 'Solvent Segregation' concept, start up and shut down times of power carbon capture, usage and storage (CCUS) facilities[1].
    a. The project should develop a start-up sequence which defines solvent flows in the stripper and absorber and how the solvent switch over can be achieved.
    b. A detailed test matrix should be prepared for each test carried out at the facility and a control philosophy (possible manual change over) should be also developed.
11. The project may assess solvent stability under lean and rich storage conditions, e.g. degradations over a typical storage period, to the extent that such degradation can be measured.
12. The project should develop a solvent sampling protocol which includes location, timing (e.g., during dynamic phases, steady state phases), frequency, and the total number of samples.
13. The project should make sure the laboratory facility is able to accommodate the analysis/tests required.
14. Tests should follow a set of the types of parameters and plant testing conditions outlined in Table 2.

Modelling and modelling tool development requirements

15. Prior to physical testing, the project should conduct heat-and-material balance modelling (include solvent volumes and circulation time) to underpin the pilot testing and aid translation into full scale deployment, including optimum use of solvent storage capacity for capture during starts and stops.
16. The project should assess FOCUSS design performance, including the option to increase solvent storage capacity to allow time-shifting of the solvent regeneration penalty.
17. Develop a functional PCC plant modelling approach to support industrial designs for 95-99% capture PCC plant.
    a. Assess the CCSI MEA steady state model being used in this study against available experimental data and note any differences.
    b. Use a combination of steady-state performance predictions and engineering analysis to predict performance with solvent storage under start-up and shut-down and other transient conditions.
    c. Determine the accuracy of the modelling approach for both steady state and transient operation.

Control Philosophy

18. A control philosophy should be developed for solvent segregation and storage method. This philosophy shall be developed from the necessary modifications at the test facilities and provide useful high level general requirements for use of solvent segregation methods at full-scale plant.
19. Recommendations should cover both start/stop operation and examples of other transients.

Data interpretation and industry deployment

20. The project shall use the test and modelling results to design and engineer a set of guidance documents to support plant designers and operators.

[1] Start up and shut down times of power carbon capture, usage and storage (CCUS) facilities - GOV.UK (www.gov.uk)

21. To provide robust guidance to industry, the interpretation of the test results shall show the connection between the test data and the application to full-scale plant.

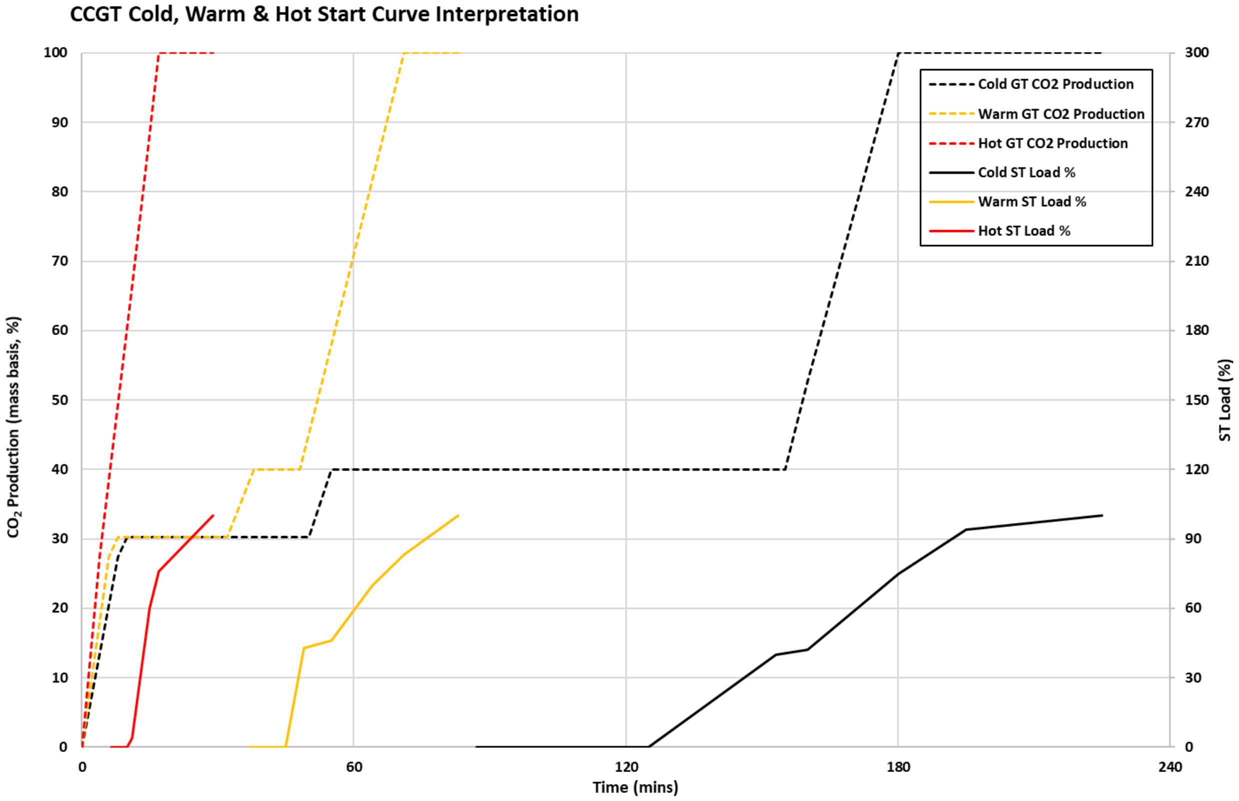

Figure 1 Indicative CCGT Start Up Profiles (ST Load)

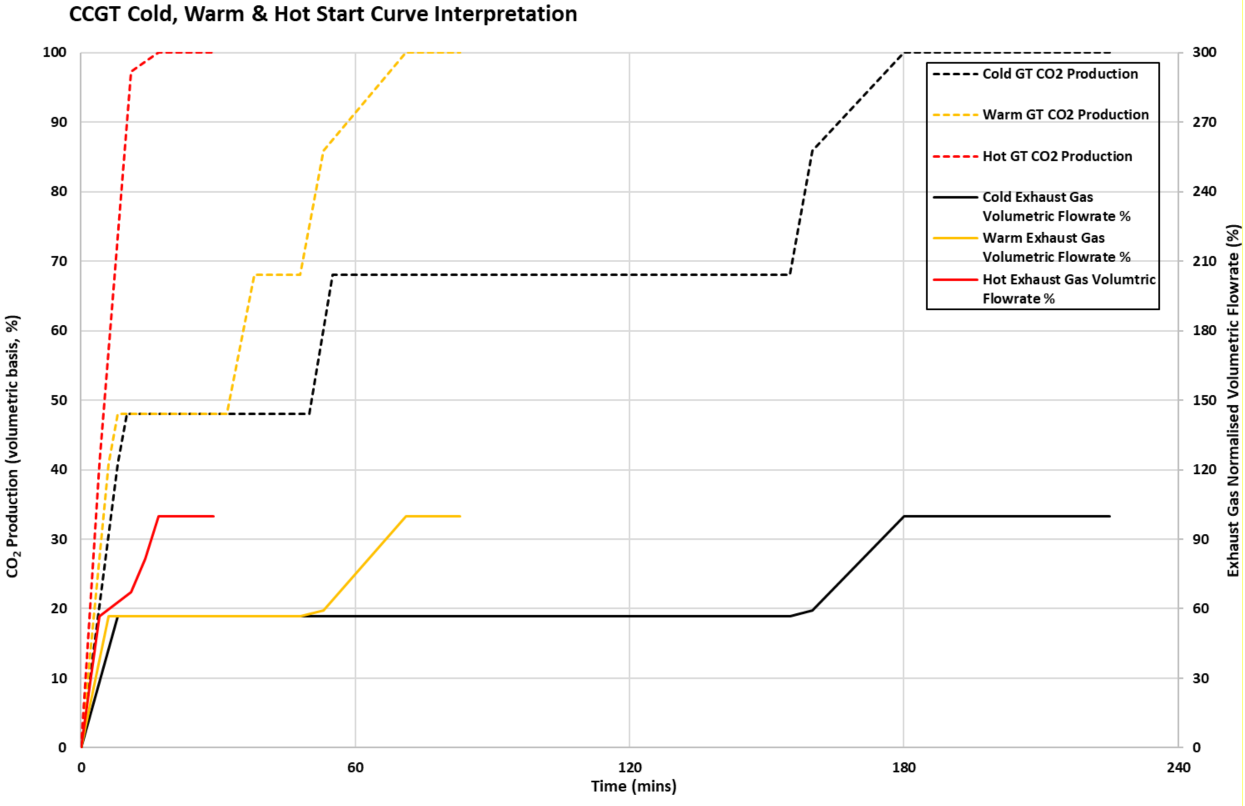

Figure 2 Indicative CCGT Start Up Profiles (Exhaust Gas Flowrate)

Table 1 Test Parameters

Parameters	Units
Flue gas flow rate into absorber (0°C, 1.01325 bara, wet basis)	Nm3/h / kg/hr
Flue gas CO2 concentration into absorber (wet/dry basis)	vol%
Flue gas O2 concentration into absorber (wet/dry basis)	Vol%
Flue gas temperature into absorber	°C
Flue gas temperature out of absorber	°C
Lean solvent flow rate	kg/h
Rich solvent flow to stripper through HE	kg/h
Lean loading	molCO2/molMEA
Amine concentration	wt%
Lean solvent temperature	°C
Absorber bottom temperature	°C
Absorber liquid level	mm
Rich amine loading	molCO2/molMEA
Stripper pressure	bara
Stripper bottom temp.	°C
Stripper top temp.	°C
Heat flow to reboiler (average)	kg/h
Reboiler bottom temperature	°C

L/G	kg/kg
Flue gas CO_2 concentration out of the absorber (wet/dry basis)	Vol%
CO_2 stream flow rate out of the stripper	Nm3/h or kg/h
CO_2 concentration out of the stripper	Vol%
CO_2 capture level (target)	%

Table 2 Plant Testing Conditions

Test	Conditions
Flue Gas CO_2 concentration	Constant CO_2 concentration between 4% and 5% (start-up and steady state)
Flue gas ramp rate	15 min-20min (from 0 to 70%/full load, as permitted by existing fans etc at the test facility)
Reboiler initial temp.	1. Cold start-up with the reboiler at ambient temp. 2. Hot start-up with the reboiler at 80°C or higher.
Heat to reboiler	1. Heat available instantly 2. Delayed heat supply (e.g. 20 min/30 min to mimic CCGT start up steam availability)
Load ramping	1. Reduce flue gas flow rate to minimal (50% of full load) 2. Increase flue gas flow rate to maximum (rate of change to be defined)
Shutdown	Staged flue gas shutdown

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