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Tees Carbon Capture Sizing Studies

Support to Carbon Capture Readiness Report

Sembcorp Utilities (UK) Limited

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1. Introduction

1.1 AECOM received a request from Sembcorp Utilities (UK) Limited to prepare a series of plant layouts and equipment lists for potential carbon capture and storage (CCS) options for their planned Tees Combined Cycle Power Plant Project to be located on land at the Wilton International Site on the south side of the river Tees.

1.2 AECOM received the proposed plant layout and land area allocations for the CCS systems to support this study to develop the CCS systems which could be employed for the largest commercially available combined cycle gas turbines (CCGT) systems for the land area allocated.

2. Assumptions

2.1 Basic Design Assumptions

The proposed development is assumed to be based upon two CCGT units of a size determined by the availability of land for future installation of CCS equipment [Tees CCPP - Carbon Capture Readiness Statement 15 May 2018]. AECOM was provided with two proposed areas for CCS to consider.

2.2 Design Cases

The client has requested plant layouts and equipment tables for the following cases:-

Case Number	0	1	2	Comment
Target Net Power Output/MWe	1290	1385	1520	Net power is before CCS retrofit
Work Plan Area/ha	4.84	5.20 [1]	5.70 [2]	Area for $C0_2$ capture and compression equipment
Notional specific area / m^2/MWe	37.5	37.5	37.5	

Notes:

1. Indicative areas for consideration have been provided by the Client.
2. Indicative areas for consideration have been provided by the Client in line with work plan drawings provided.

The modelling of the CCGTs and CCS systems employed the use of Version 27 of the THERMOFLOW suite of programmes.

A baseline case was run for a typical installation using two single shaft H class units. This model has been adjusted to use a consistent set of THERMOFLOW GT models for Cases 0, 1, and 2 (Thermoflow Model references #652, #654, #653).

Note that these values do not match exactly the requested target net power, but are sufficiently close to development indicative CCS readiness plant models. Prior to detailed CCGT plan selection, the plant modelling has been carried out based upon the available model net power rather than the Client target net power.

Case Number	0	1	2
GT model	GE9HA01 (#652)	Siemens 8000H (#654)	GE9HA02 (#653)
Model net power/ MWe	1269	1335	1528
Target net power/MWe	1290	1385	1520
Power ratio	0.98	0.96	1.001

3. Methodology

3.1 Initial Sizing Assessment

The current CCR guidelines for sizing define the reference case site dimensions for CO_2 capture and compression equipment of a 500 MWe CCGT with post combustion capture of 2.4 ha, with scope further reduction to 1.875 ha based upon consideration of advances in technology and layout optimisation on the basis of detailed design. This results in a minimum notional specific area of 37.5 m^2/MWe.

AECOM has used thermodynamic design models for pre-conversion combined cycle plant and a separate combined cycle plant model which has been used to investigate preliminary cycle models. These models have been modified to match the Client performance parameters and re-run to generate plant layouts and equipment lists as requested.

4. Performance Data

4.1 Plant Performance

Plant performance has been generated using sea level standard conditions assumptions run at ISO conditions for the purposes of comparative studies. Typical gas turbine models have been selected to provide a range of plant sizes. However these values will be subject to change for actual site design conditions and detailed performance modelling. The values are indicative for the purposes of generating comparative data and do not represent any performance guarantees.

Case Number	Tees Power CCR report	0	1	2
Model number	unknown	652	654	653
Net Power Export Capacity/MWe	1700	1269	1335	1527
Net heat rate MJ/MWh	~6000	5848	5960	5796

Case Number	Tees Power CCR report	0	1	2
eta	~60	61.56	60.4	62.11
RH/%	unknown	60	60	60
Ambient temperature/C	unknown	15.5	15.5	15.5
Ambient pressure/ bar	unknown	1.013	1.013	1.013

4.2 It is important to note that the current combined cycle plant net efficiencies are in excess of 60%. This represents a 10% improvement over the equivalent figures of ~ 55% assumed in the current CCR guidance.

4.3 Flue Gas Composition and Conditions

The following gas conditions have been used to determine indicative system sizing of the potential CCS system using AECOM preliminary models.

Case Number	0	1	2
	652	654	653
Power/MWe	1269	1335	1527
Flow(total)(kg/s)	1684	1862	1974
Flow / GT(kg/s)	842	931	987
Stack exhaust gas /C	80.39	80.11	80.22
Composition (mole %) at HRSG exit			
N2	74.00	74.06	73.94
O2	11.21	11.5	11.05
CO2	4.42	4.21	4.50
H2O	9.48	9.34	9.6

5. Layout

5.1 The CCS plant layouts have been generated based upon 2 single shaft CCGT arrangements feeding separate carbon capture trains using air cooled condenser technology. Calculations have been normalised on target net power as the model plant power is within ~ 4%. Subject to water availability being confirmed – which appears probable for the Tees Power project – hybrid cooling could potentially be used instead of air cooling for the CCS plant; the CCGT units will be hybrid cooled. This could reduce the area requirements for the CCS plant and is being evaluated.

5.2 The required plant areas in accordance with equipment table on Section 6 are shown in Appendix A for the 1385 MWe on the 5.2 ha work area basis and in Appendix B for the 1520 MWe on the 5.74 ha work area.

Case Number	0	1	2
Target Net Power Output/MWe	1290	1385	1520
As modelled Net Power Output/MWe	1269	1335	1527
Required plant area for modelled output/ha	4.79	5.08	5.49
As modelled specific area/ m^2/MWe based on modelled power	37.7	38.1	36.0
Available area on site /ha	4.84	5.20	5.70
Available specific area/ m^2/MWe based on target power	37.5	37.5	37.5

5.3 The minimum as modelled specific area requirements are met by all three cases. According to the methodology expressed in this study the CCS plant has been modelled for a given CCGT configuration. This yields an 'as modelled' specific area. In all cases the 'available' specific area based upon the available area and Client target power meets the CCR guidance as amended by Imperial College and the 'as modelled' plant area required is less than the available area.

5.4 The layout and area requirements calculated do not include any laydown land required during construction of any carbon capture plant in the future. The exact approach to be taken to provision of laydown would be determined and evaluated at the consenting stage of any carbon capture plant, as and when it is required. It is envisaged that the carbon capture plant construction would be sequenced in such a manner that the areas incorporating the cooling system are used as laydown for the construction of the main capture equipment; the cooling system would then be installed last. SembCorp has a significant land holding outside the Tees CCGT Order Limits, as shown in Figure EN010082-000503 that was submitted as part of the DCO application. Part of this land would be allocated to the construction of the capture plant at that time.

5.5 Given the scale of landholding held by the Applicant adjacent to the Order Limits for the Tees CCGT, it is considered that there are no barriers to the construction of any carbon capture plant in the future and that sufficient laydown area can be made available when required.

6. Equipment Tables

6.1 Worst Case Footprint Estimate for principal equipment (m^2). Note that these calculations assume the use of air cooled heat exchangers for CCS equipment as the future water abstraction availability has not been determined in this study. Availability of water for hybrid cooling technology is likely to reduce the required space allocation. The table indicates the estimated size of major plant items per CCGT train. A margin is applied to allow for separation, operation and maintenance access and ductwork. These figures are doubled to arrive at the overall CCS plant footprint.

Case Number	0	1	2
DCC Filter Pump	5	5	5
DCC Circulating Water Pump	10	10	10
Blower	408	408	408
Solvent Make-up Pump	2	2	2
Rich Solvent Pump	18	18	18
Lean Solvent Pump	18	18	18
Wash Water Circulating Pump	5	5	5
Reflux Pump	5	5	5
Condensate to Deaerator Pump	8	8	8
HCT Recirculation Pump	8	8	8
Waste Water Sump Pump	2	2	2
Solvent Sump Pump	5	5	5
H2SO4 Solution Pump	5	5	5
NaOH Solution Pump	5	5	5
DCC column	269	314	314
Wash Water Cooler	8	8	8
Solvent Cross Exchanger	348	348	348
Lean Amine Cooler	130	130	130
DCC Water Cooler ACC	4193	4485	5167
Reclaimer	119	119	119
Stripper Condenser	39	39	39
ACC coolers	12906	13670	14683
Re-boiler	269	314	314
Amine Storage Tank	269	314	314
Overhead Accumulator	24	24	24

Case Number	0	1	2
H2SO4 Solution Tank	14	14	14
NaOH Solution Tank	8	8	8
Absorber	8	8	8
Stripper	269	314	314
DCC Circulating Water Filter	1	1	1
Wash Water Filter	1	1	1
Lean Solvent Filter	59	59	59
Solvent Sump Filter	1	1	1
Waste Water Sump Filter	1	1	1
Activated Carbon Filter	41	41	41
Compressor Stage 1 Intercooler	16	16	16
Compressor Stage 2 Intercooler	16	16	16
Compressor Stage 3 Intercooler	16	16	16
Compressor Stage 4 Intercooler	16	16	16
Compressor Stage 5 Intercooler	16	16	16
Compressor Stage 1 Drum	3	3	3
Compressor Stage 2 Drum	1	1	1
Compressor Stage 3 Drum	0	0	0
Compressor Stage 4 Drum	0	0	0
Compressor Stage 5 Drum	0	0	0
CO2 Compression Unit	77	77	77
CO2 Dehydration Unit	200	200	200
Antifoam System	36	36	36
Instrument Air System	64	64	64
Nitrogen Blanketing System	25	25	25
Total per CCGT/m^2	19959	21196	22891
Total per CCGT including margins/m^2	23950	25435	27469
Total for 2 CCGT/m^2	47900	50870	54938

Case Number	0	1	2

The layouts of the CCS equipment are shown on the drawings contained as Appendix A & B.

6.2 Power Consumption Estimate (excluding margins in MWe). Note that these calculations provide the indicative electrical power requirements for the major plant items. The table indicates the estimated power required for major plant items per CCGT train. These figures are doubled to arrive at the overall CCS plant footprint. Design margins have not been applied to these figures and no account has been made of the implications on the CCGT net power available for export.

Case Number	0	1	2
CO_2 capture and compression	37	40	44
ACC fans	8	9	10
Coolant pumps	3	3	3
Total per CCGT in MW	48	51	57
Total for 2 CCGT in MW	96	102	113

7. Conclusions

7.1 A number of currently available CCGT options have been modelled at site ISO conditions in order to generate the exhaust gas conditions necessary to carry out preliminary CCS plant design using models developed by AECOM. Worst case footprint estimates for principal equipment indicate that current DECC guidelines – as amended by the Imperial College review - for site dimensions for CO_2 capture and compression equipment are achievable for net powers of up to ~ 1520 MWe.

7.2 It is concluded that cases 0, 1 and 2 are compliant with the minimum CCR footprint requirements as outlined in the DECC 2009 guidance as amended by the Imperial College paper. In addition, switching to a hybrid or wet cooling system for the CCS plant instead of the ACC design modelled could achieve a further reduction in footprint; this is being evaluated.

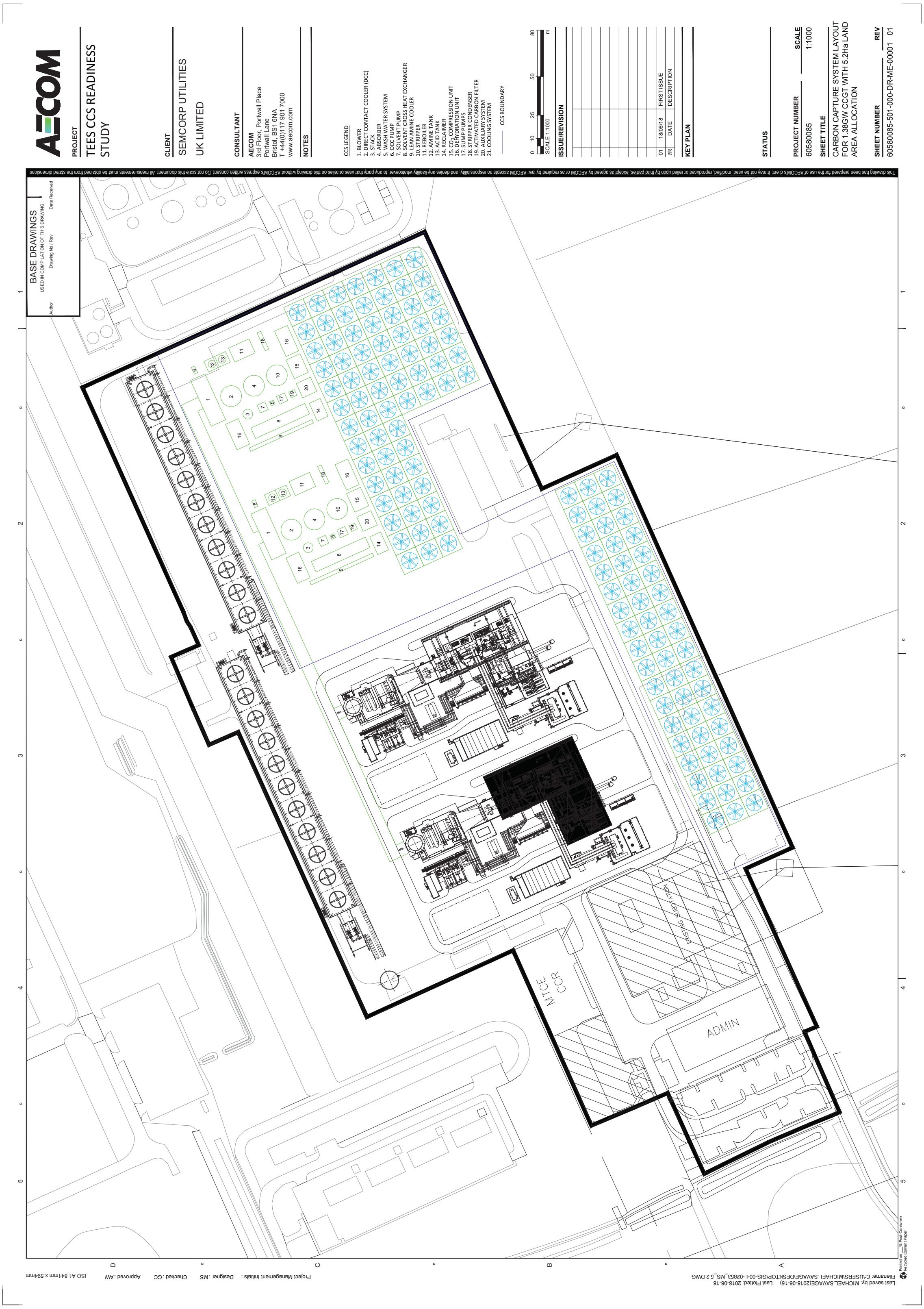
7.3 The technology selected for the CCR plant cooling has a significant influence on the size of land allocation for Carbon Capture Readiness. AECOM modelling has been pessimistic assuming that air cooled technology will be required. Where hybrid or once through water cooling is available this will lead to a substantial reduction on required plant size as indicated by the GE 9AH02 assessment. (The calculated specific area of 36.5 m^2/MWe reduces to 21.5 m^2/MWe based on indicative calculations and layouts.)

7.4 SembCorp have assumed water cooled or hybrid cooling technology can be installed on the Tees plant and any future supporting CCS plant. Based on such an approach, the AECOM layout model indicates that a CCR layout for a 1,700MW plant could be achieved within the 5.7 ha CCR area available (equating to 33.5 m^2/MWe), recognising that this is below the currently accepted minimum area requirement specified in the modified CCR guidance (37.5m2/MW).

7.5 The Imperial College review team affirm that the current CCR guidance is out of date, and that a further reduction in the minimum area using hybrid cooling should be achievable, given that other schemes have proposed air cooling for CCR reports and have met the guidance. Gas turbine technology has advanced, including significant efficiency improvements and reduction in required cooling duty for a given power output, and as a result an update to the guidance is due. The Imperial College review team consider that without specific assessment of all of the underlying assumptions it is challenging to state the specific reduction that could be achievable, but they confirm that 33 m^2/MW is reasonable with hybrid cooling.

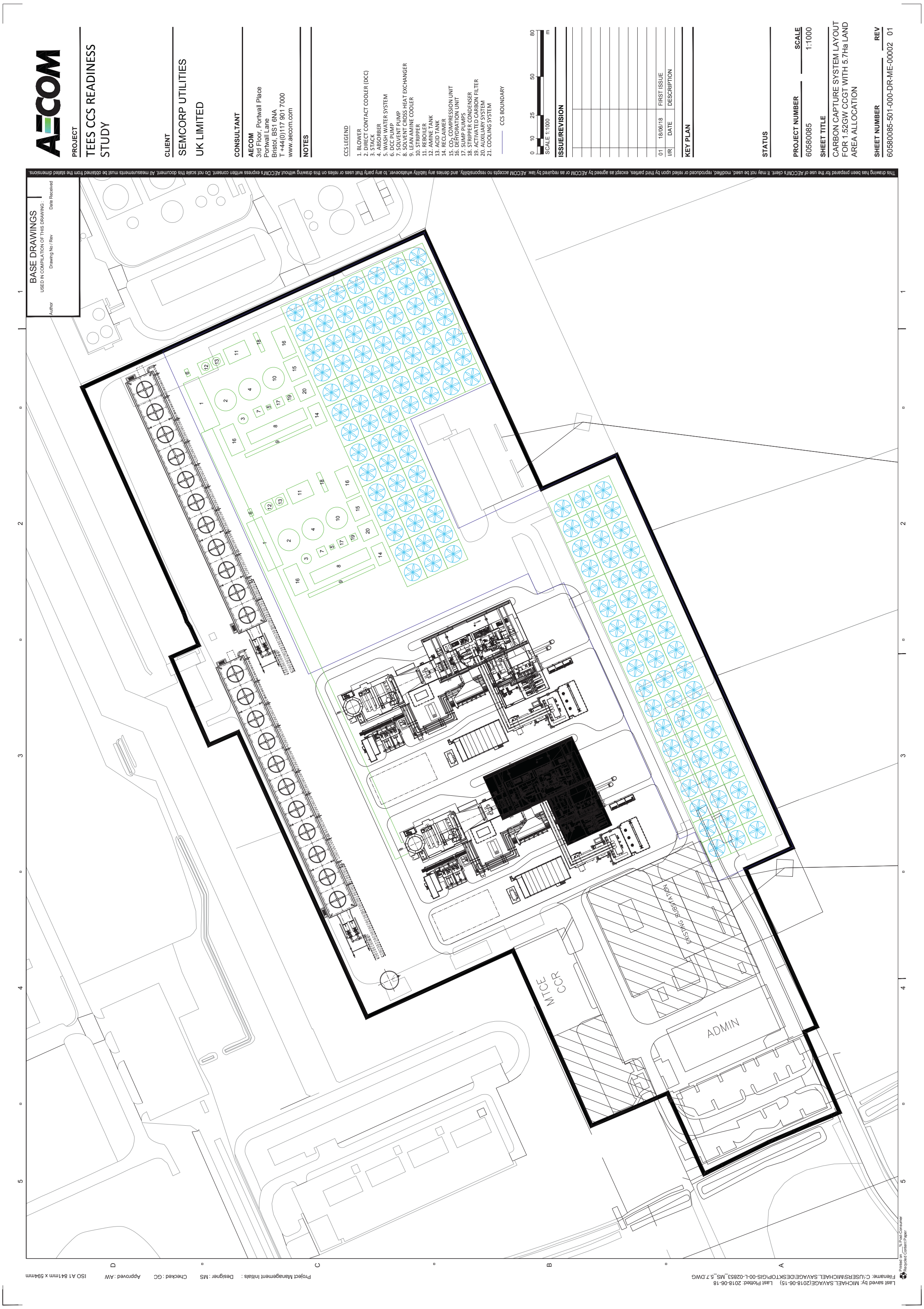
Appendix A

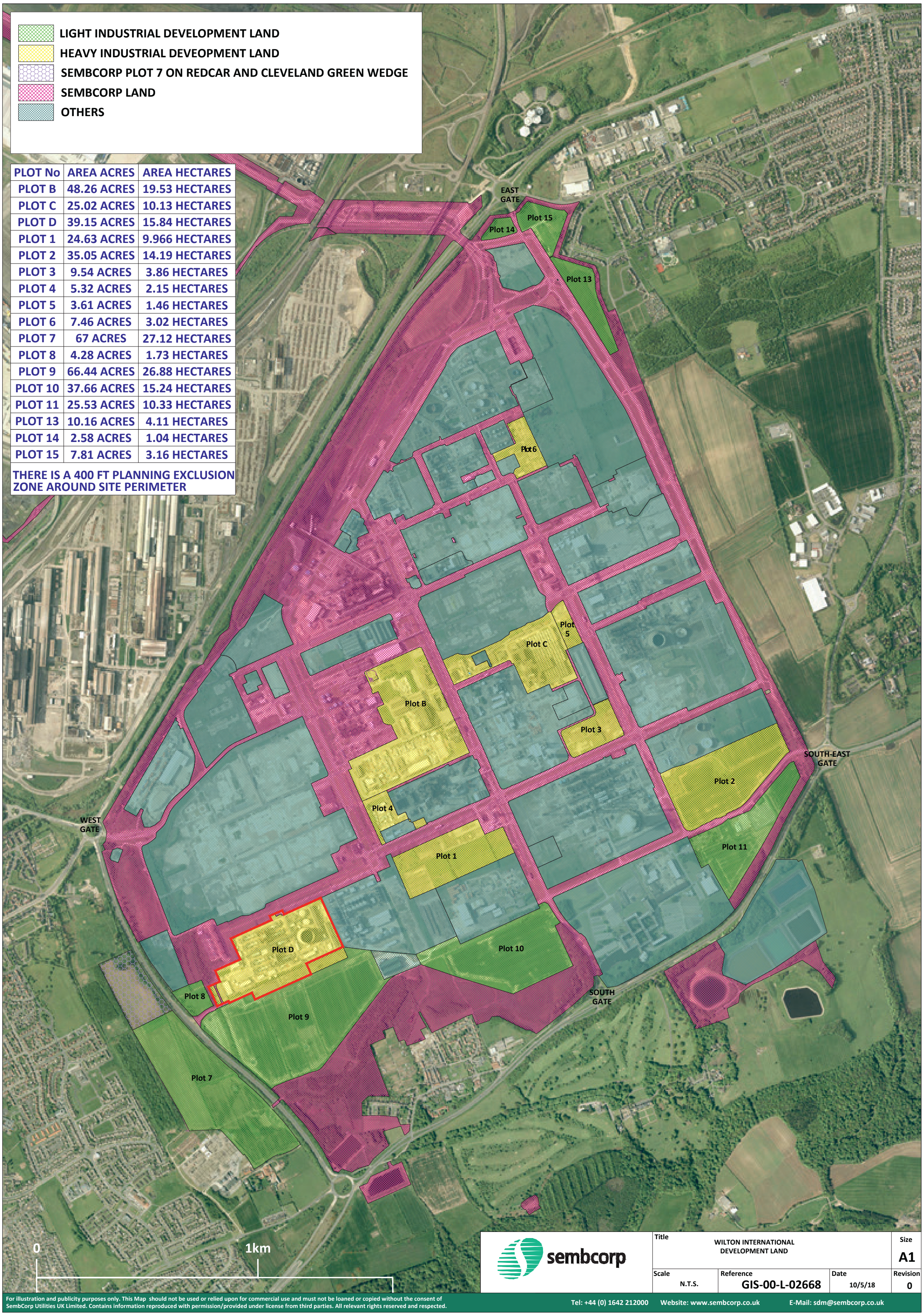
60580085-501-000-DR-ME-00001 - Carbon Capture System Layout for 1.38GW CCGT with 5.2 Ha Land Area Allocation



Appendix B

60580085-501-000-DR-ME-00002 - Carbon Capture System Layout for 1.52GW CCGT with 5.7 Ha Land Area Allocation





PLOT No	AREA ACRES	AREA HECTARES
PLOT B	48.26 ACRES	19.53 HECTARES
PLOT C	25.02 ACRES	10.13 HECTARES
PLOT D	39.15 ACRES	15.84 HECTARES
PLOT 1	24.63 ACRES	9.966 HECTARES
PLOT 2	35.05 ACRES	14.19 HECTARES
PLOT 3	9.54 ACRES	3.86 HECTARES
PLOT 4	5.32 ACRES	2.15 HECTARES
PLOT 5	3.61 ACRES	1.46 HECTARES
PLOT 6	7.46 ACRES	3.02 HECTARES
PLOT 7	67 ACRES	27.12 HECTARES
PLOT 8	4.28 ACRES	1.73 HECTARES
PLOT 9	66.44 ACRES	26.88 HECTARES
PLOT 10	37.66 ACRES	15.24 HECTARES
PLOT 11	25.53 ACRES	10.33 HECTARES
PLOT 13	10.16 ACRES	4.11 HECTARES
PLOT 14	2.58 ACRES	1.04 HECTARES
PLOT 15	7.81 ACRES	3.16 HECTARES

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