Programme Area: Carbon Capture and Storage

Project: Thermal Power with CCS

Title: Technical Note: District Heat Networks

Abstract:

This note provides a summary of potential opportunities to recover low grade heat from the plant for use in district heat networks.

Context:

The ETI's whole energy system modelling work has shown that CCS is one of the most cost effective technologies to help the UK meet its 2050 CO2 reduction targets. Without it the energy system cost in 2050 could be £30bn per annum higher. Consequently, ETI invested £650,000 in a nine month project to support the creation of a business case for a large scale gas with CCS power plant, to include an outline scheme and a 'template' power plant design (Combined Cycle Gas Turbine with post combustion capture), identify potential sites in key UK industrial hubs and build a credible cost base for such a scheme, benchmarked as far as possible against actual project data and as-built plant. The ETI appointed engineering and construction group SNC-Lavalin to deliver the project working with global infrastructure services firm AECOM and the University of Sheffield's Energy 2050 Institute.

SNC-Lavalin UK Limited
Woodcote Grove
Ashley Road, Epsom, Surrey
KT18 5BW, United Kingdom

TECHNICAL NOTE

To:	The ETI	**Document No.:**	181869-0001-T-EM-TNT-AAA-00-01010 - ETI ref D8.1(d)
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Distribution:	Kannan Sreenivasan Sheryl Durham Talal Ali		

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3 Introduction

The UK Government retains the belief that CCS could play a crucial role in the future energy system. The ETI's analysis has shown that the best route to reliable, cost-effective and investable CCS in the UK is to build one or more power with CCS schemes, using best-proven technologies in the most beneficial locations at size which maximises the benefits of scale. However, stakeholders in CCS would need compelling evidence of the business case for a power with CCS project. Therefore the ETI has identified a need to develop a clear vision of what a cost-effective gas power with CCS scheme might look like and provide a clear and credible performance and cost information for such a scheme. To achieve this, the Generic Business Case project involved developing an outline scheme and 'template' power plant design (Combined Cycle Gas Turbine (CCGT) with post combustion capture) and identifying how this might be built and operated at selected sites around the UK.

SNC-Lavalin has developed a template plant design, a capital cost estimate, and an operating cost model for a large scale deployment of CCGT + CCS for the UK. SNC-Lavalin has been supported by AECOM who have identified potential site locations for such a plant and the University of Sheffield who have supported the project with technical and policy expertise.

The GBC project reviewed and compared 5 separate regions in the UK for the deployment of CCGT + CCS and analysed the scale of such a scheme for 1 to 5 trains[1] of CCGT + CCS.

The Power Generation Units for the GBC project use the largest credible Combined Cycle Gas Turbine (CCGT) Power Blocks available today. The Generic Business Case aims to capture around 10 million tonnes of CO_2 per annum from Combined Cycle Gas Turbines (CCGT). An engineered best in class amine has been selected for the plant in order to generate an optimised performance for the plant. The benchmark amine solvent (MEA) has a high energy penalty. Using engineered amines reduces this penalty, thereby maximising the power output from the CCGT.

The best in class amine technology is licensed by the owners of the technology: the performance of the technology is confidential. Unable to publish a licensed technology design SNC-Lavalin have made use of publicly available information regards post combustion carbon capture from the Key Knowledge Documents published regarding the Shell Peterhead project in order to develop a design sized for the gas turbines of the Generic Business Case.

The ETI have asked SNC-Lavalin to estimate the potential low grade heat recovery from the key potential sources in a single CCGT + CCC train for use in District Heat Networks.

3.1 District Heat Networks (DHN)

District Heating is to use heat sources that under normal circumstances would be lost or remain unused. DHNs consist of supply and return pipelines connecting waste thermal sources with heat demand. The heat demand can be residential, commercial (e.g. warehouses, office blocks), municipal (e.g. schools, shopping centres, hospitals), or industrial (processes needing low grade heat).

The use of waste heat from combustion sources can increase the useful cycle efficiency, resulting in reduced overall combustion of fossil fuels, and lower CO_2 emissions compared to burning fuels for heat and power individually.

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[1] A 'train' in this context means a single gas turbine with a heat recovery steam generator (and steam turbine), a single capture unit with one absorber vessel and one stripper and a single compressor. Multiple trains then feed into a single CO_2 export pipeline.

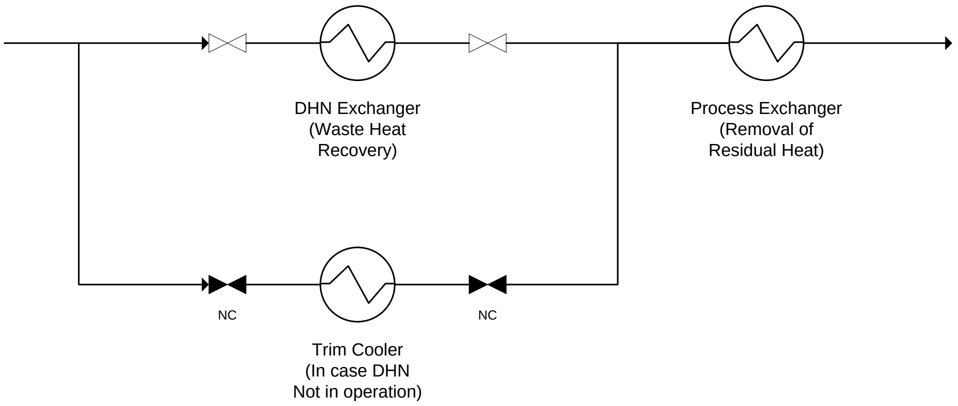
4 Design Basis for Study

The following is the design basis used for the study:

Heat Transfer Network		**Units**
Water Circuit Return Temperature	55	°C
Water Circuit Supply Temperature	85	°C
Fluid	Water	with additives
Process Equipment Sizing		
Exchanger Approach	10	°C
Minimum Outlet Temperature (Process Side)	65	°C
General		
Guideline pressure losses for design purposes[2]		
main lines	100	Pa/m
network branches	250	Pa/m
Heat Exchanger Pressure Drops[3]	20	kPa

The approach temperature has been set at a generally accepted level for heat exchanger sizing to ensure cost effective surface area selections. Allowing for a 55°C return temperature from the DHN the minimum outlet temperature on the outlet side of the exchanger is 65°C. The existing site cooling water utility will have to cool the process stream from 65°C to that required for the operation of the plant.

Trim coolers (cooling water) shall be provided within the plant to conduct process cooling when district heating is not required or in commission: i.e. DHN fault, start-up, shut down, and plant commissioning. This is shown in the following figure:



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[2] District heating manual for London, Copyright Greater London Authority (2013), https://www.cibse.org/getmedia/843f2dbd-55eb-4c6c-b219-88fe9eb83949/DH_Manual_for_London_February_2013_v1-0.pdf.aspx

[3] District heating manual for London, https://www.cibse.org/getmedia/843f2dbd-55eb-4c6c-b219-88fe9eb83949/DH_Manual_for_London_February_2013_v1-0.pdf.aspx

We have not considered in the design a redundant heat source for DHN when the CCGT + CCC onshore plant is not in operation and producing heat.

Per instruction, we have not considered derating the steam turbine for Combined Heat and Power (CHP) low pressure steam offtake.

5 Sources of Heat

5.1 Investigation into Sources of Heat

There are significant sources of waste heat around the CCGT + Carbon Capture and Compression Plant. However, the sources of heat need to have sufficient temperature difference to be able to transfer energy to the DHN.

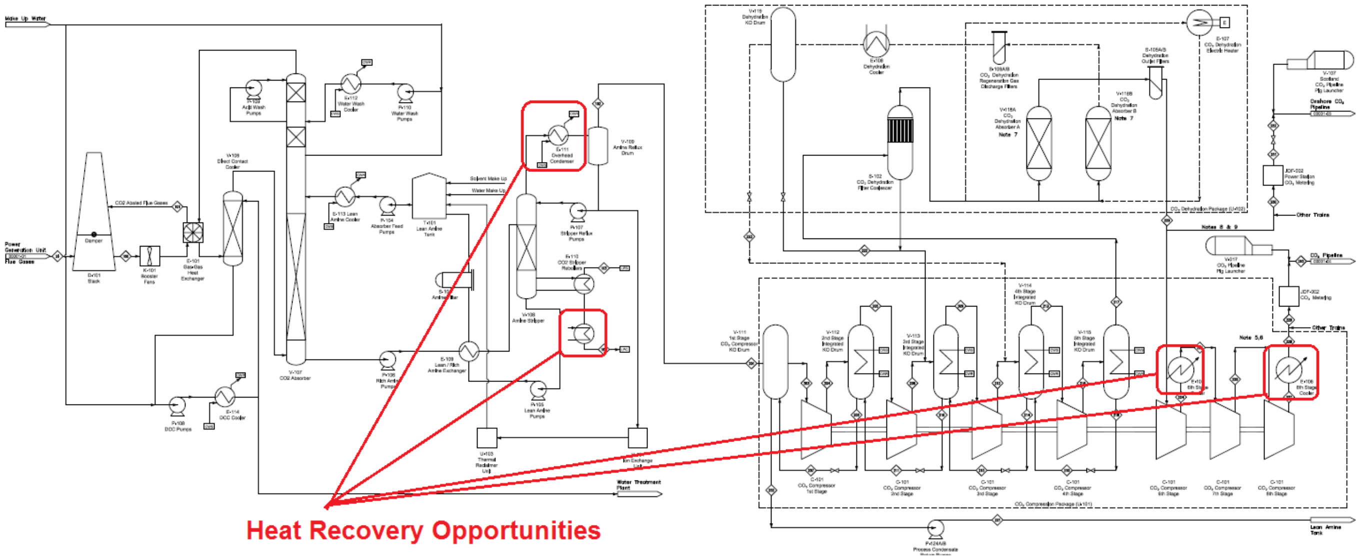

Figure – Identification of Heat Recovery Opportunities in the Scheme

A review of the equipment list (document reference 181869-0001-T-EM-MEL-AAA-00-0001), heat and mass balance (181869-0001-D-EM-HMB-AAA-00-00001-01), and the utility schedule (181869-0001-T-EM-LST-AAA-00-00001) published in ETI documents D4.1 and D5.1 showed:

- There are no suitable sources of waste heat from the CCGT unit
- There are two sources of useful waste heat from the CC unit
- There are two sources of useful heat from the compression unit

The sources of useful heat are summarised in table 1 below.

Table 1 - Current heat sources from the Carbon Capture plant.

Tag No	Cooler Name	Total *	Mass Flow (tonne/h)	Temperature		Q=MCPDT	
		Q-1		Inlet	Outlet	DT	MCp
		kW		(C)	(C)	C	kW/C
E-111A/B	Overhead Condenser**	65037	230.2	100	26.3	73.7	882
E-116A/B	CC Unit Condensate Cooler	23797	252.9	130.7	50.4	80.3	296
E-105	6th Stage Cooler	6216	228.5	97.5	36	61.5	101
E-106	8th Stage Cooler	13200	228.5	120.3	36	84.3	157

Notes:
* Cooler duty as per equipment list except the CC Unit Condensate Cooler is based on the Copy of Updated Utility Schedule
** Overhead Condenser inlet temperature assumed to be 100°C.

5.2 Available Useful Heat

The available heat recovery has been calculated based on the available process temperature and the minimum outlet temperature (Process Side) .

The available heat recovery can be seen in table 2 below.

Table 2 - District Heating potential heat recovery in a single GT/CCS train.

Tag No	Temperature		Approach Temp	Q=MCPDT	
	Inlet	Outlet		DT	Q-2
	(C)	(C)	(C)	C	kW
E-111A/B	100	65	10	35	30886
E-116A/B	130.7	65	10	65.7	19470
E-105	97.5	65	10	32.5	3285
E-106	120.3	65	10	55.3	8659

The total available heat recovery is 62.3 MW.

Based on domestic boiler sizes the average UK home would need 15-30 kW of heat: therefore the heat available is enough for around 2,000 to 4,000 houses (allowing also for some heat loss in network). This is of a similar scale to Sheffield's heat network which uses 60 MW of heat for 140 public buildings and 2,800 homes.[4]

5.3 DHN Mass Flow

The auxiliary equipment required for the DHN will be based on the DHN flow required for the heat transfer.

Table 3 - District Heating Rate

Tag No	Temperature		Q=MCPDT		Mass Flow (tonne/h)
	export	return	DT	MCp	
	(C)	(C)	C	kW/C	
E-111A/B	85	55	30	1030	123.5
E-116A/B	85	55	30	649	77.88
E-105	85	55	30	109	13.14
E-106	85	55	30	289	34.64

The recovered heat will be extracted in a water circuit fed to the plant battery limit.

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[4] https://en.wikipedia.org/wiki/District_heating#Size_of_systems

5.4 Residual Cooling

The following table shows the residual cooling required to meet the process duty once useful waste heat has been extracted:

Table 4 - Addition cooling required to meeting the process temperature

Tag No	Temperature		Q=MCPDT	
	Inlet	Outlet	DT	Q-3
	(C)	(C)	C	kW
E-111A/B	65	26.3	38.7	34151
E-116A/B	65	50.4	14.6	4327*
E-105	65	36	29	2931
E-106	65	36	29	4541

Notes:

(*) If the district heating return temperature were reduced to 40°C, and with a 10°C minimum approach, this stage of cooling could be recovered and the other cooling will be reduced. For domestic and commercial heating hot water tanks need to target 50°C to 60°C for suppression of bacteria so district heating may not present this opportunity but an industrial user may be able to make use of additional heating.

6 Equipment Sizing

6.1 Heat Exchanger Selection

Plate heat exchangers would be preferred for water service of the DHN as they are lower cost, have smaller footprints, and the turbulence over plated surfaces gives very good heat transfer performance.

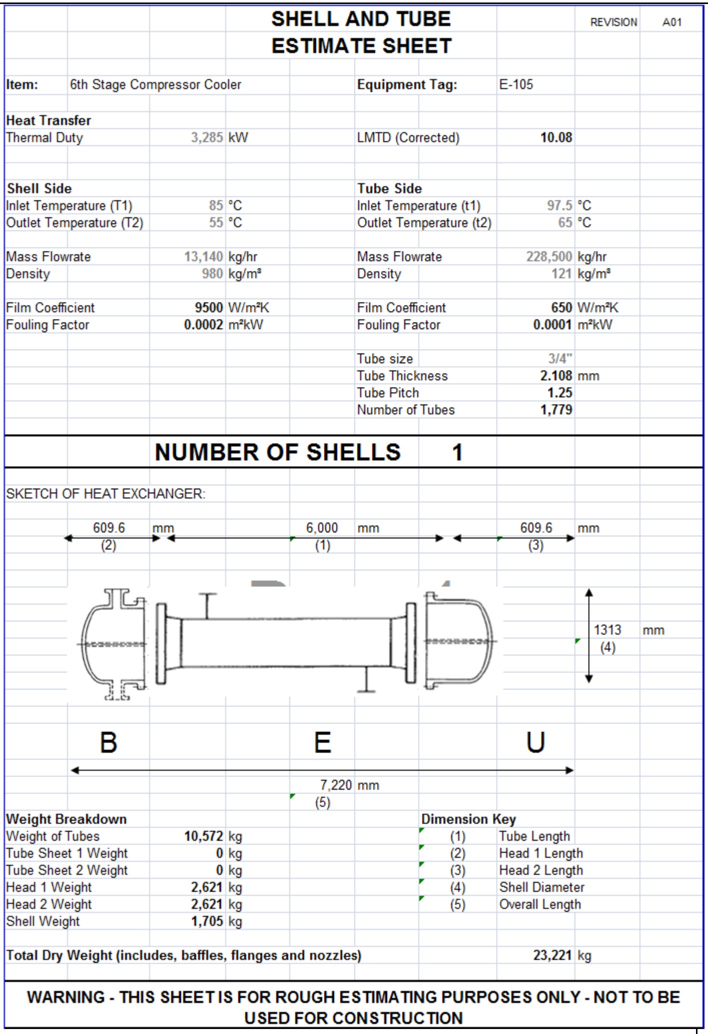
Plate exchangers are not so good for high pressure service because their sealing through gaskets or welding is limited in its capacity to seal against the plate deformations from higher pressures. Alternative heat exchange designs as pressure retaining equipment are required: our traditional design for this application is the shell and tube heat exchanger.

Table 5 - Addition cooling required to meeting the process temperature

Tag No	Cooler Name	Selection	Comment
E-111A/B	Overhead Condenser	Welded Plate	Toxic CO_2 content needs containment design. i.e. welded. Design pressure > 10 barg means Plate & Frame Unsuitable
E-116A/B	CC Unit Condensate Cooler	Plate and Frame	Water to water exchanger at low design pressure means lower cost solution is acceptable
E-105	6th Stage Cooler	Shell & Tube	High design pressure means shell & tube is cost effective solution for a pressure contained design
E-106	8th Stage Cooler	Shell & Tube	High design pressure means shell & tube is cost effective solution for a pressure contained design

6.2 Exchanger Sizing

Shell & Tube Exchangers



SHELL AND TUBE ESTIMATE SHEET REVISION A01

Item:	6th Stage Compressor Cooler	**Equipment Tag:**	E-105

Heat Transfer

Thermal Duty	3,285 kW	LMTD (Corrected)	**10.08**

Shell Side		**Tube Side**	
Inlet Temperature (T1)	85 °C	Inlet Temperature (t1)	97.5 °C
Outlet Temperature (T2)	55 °C	Outlet Temperature (t2)	65 °C
Mass Flowrate	13,140 kg/hr	Mass Flowrate	228,500 kg/hr
Density	980 kg/m³	Density	121 kg/m³
Film Coefficient	**9500** W/m²K	Film Coefficient	**650** W/m²K
Fouling Factor	**0.0002** m²kW	Fouling Factor	**0.0001** m²kW
		Tube size	3/4"
		Tube Thickness	**2.108** mm
		Tube Pitch	**1.25**
		Number of Tubes	**1,779**

NUMBER OF SHELLS 1

SKETCH OF HEAT EXCHANGER:

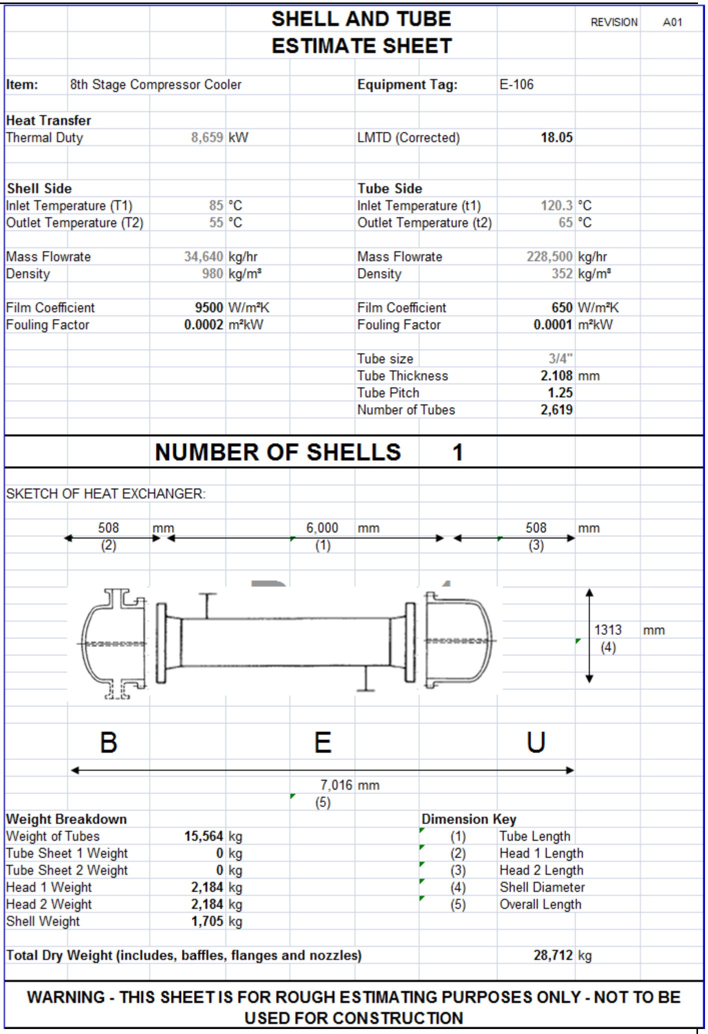
Weight Breakdown	
Weight of Tubes	**10,572** kg
Tube Sheet 1 Weight	**0** kg
Tube Sheet 2 Weight	**0** kg
Head 1 Weight	**2,621** kg
Head 2 Weight	**2,621** kg
Shell Weight	**1,705** kg

Dimension Key	
(1)	Tube Length
(2)	Head 1 Length
(3)	Head 2 Length
(4)	Shell Diameter
(5)	Overall Length

Total Dry Weight (includes, baffles, flanges and nozzles) 23,221 kg

WARNING - THIS SHEET IS FOR ROUGH ESTIMATING PURPOSES ONLY - NOT TO BE USED FOR CONSTRUCTION

Estimate: £244,000 per unit



SHELL AND TUBE ESTIMATE SHEET REVISION A01

Item:	8th Stage Compressor Cooler	**Equipment Tag:**	E-106

Heat Transfer

Thermal Duty	8,659 kW	LMTD (Corrected)	**18.05**

Shell Side		**Tube Side**	
Inlet Temperature (T1)	85 °C	Inlet Temperature (t1)	120.3 °C
Outlet Temperature (T2)	55 °C	Outlet Temperature (t2)	65 °C
Mass Flowrate	34,640 kg/hr	Mass Flowrate	228,500 kg/hr
Density	980 kg/m³	Density	352 kg/m³
Film Coefficient	**9500** W/m²K	Film Coefficient	**650** W/m²K
Fouling Factor	**0.0002** m²kW	Fouling Factor	**0.0001** m²kW
		Tube size	3/4"
		Tube Thickness	**2.108** mm
		Tube Pitch	**1.25**
		Number of Tubes	**2,619**

NUMBER OF SHELLS 1

SKETCH OF HEAT EXCHANGER:

Weight Breakdown	
Weight of Tubes	**15,564** kg
Tube Sheet 1 Weight	**0** kg
Tube Sheet 2 Weight	**0** kg
Head 1 Weight	**2,184** kg
Head 2 Weight	**2,184** kg
Shell Weight	**1,705** kg

Dimension Key	
(1)	Tube Length
(2)	Head 1 Length
(3)	Head 2 Length
(4)	Shell Diameter
(5)	Overall Length

Total Dry Weight (includes, baffles, flanges and nozzles) 28,712 kg

WARNING - THIS SHEET IS FOR ROUGH ESTIMATING PURPOSES ONLY - NOT TO BE USED FOR CONSTRUCTION

Estimate: £388,000 per unit

Plate Exchangers

Table 6 - Plate Exchanger Sizing

Tag	E-111 A/B	Tag	E-116 A/B
Description	Overhead Condenser	Description	Carbon Capture Unit Condensate Cooler
Heat Duty	30,886 kW 2 x 15,443 kW	Heat Duty	19,470 kW 2 x 9735 kW
DHN Side		**DHN Side**	
Inlet	55°C	Inlet	55°C
Outlet	85°C	Outlet	85°C
Process		**Process**	
Inlet	100°C	Inlet	130.7°C
Outlet	65°C	Outlet	65°C
LMTD	12.3°C	**LMTD**	23.5°C
LMTD Corrected	11.1°C	**LMTD Corrected**	21.1°C
Heat Transfer Coefficient	1240 W/m^{2}K	**Heat Transfer Coefficient**	1,588 W/m^{2}K
Surface Area Calculation $A = \frac{Q}{U\Delta T}$	2 x 1122 m^2	**Surface Area Calculation** $A = \frac{Q}{U\Delta T}$	2 x 291 m^2
Estimated Cost	2 x €140,615	**Estimated Cost**	2 x €75,936

6.3 Network Design

The overall network design is assumed to follow Figure 9 of the District Heating Manual for London produced by ARUP.

- Water Treatment
- Expansion Tank
- Network Pressurisation Pumps
- District Heating Circulation Pumps
- Heat Recovery Exchangers
- Auxiliary Heat Source
- Flow & Temperature Control Valves
- Monitoring Instrumentation: flow, pressure, differential pressure, temperature
- Protection: alarm and trip instrumentation (relief valves if required)
- In line strainers to protect pumps and exchangers
- Side stream filtration and deionisation to maintain integrity of network
- Pipeline network
- Radiators / heat exchangers / industrial user (assumed in ownership of consumer)
- Chemical Dosing
- Heat Metering
- Accumulators (thermal stores) if required to balance daily demand

It is assumed that nitrogen blanketing of expansion tank, utility power, control system, and water treatment would all be provided by the utility systems on the CCGT + CCS Plant making district heating lower cost to deploy.

6.4 Pump

Total flow from Table 3 = 249.2 tonnes per hour

Estimated flow = 249.2 *0.98 = 244 m^3/hr

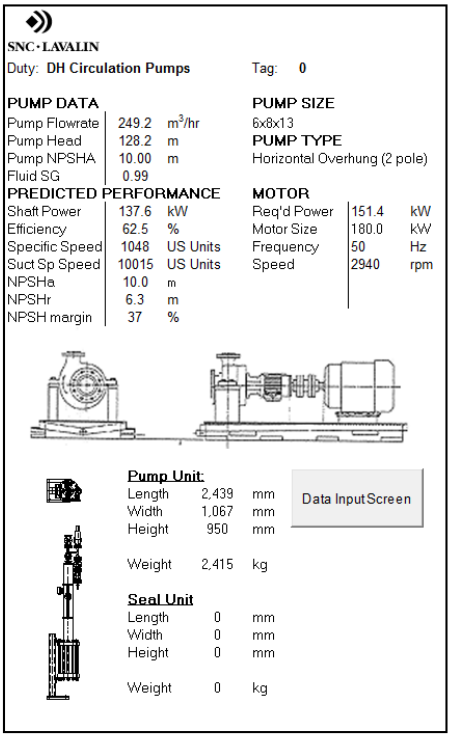
Density of housing is roughly 30 houses per hectare[5]. Therefore hectares = 133 hectares for roughly 4,000 houses for DHN.

Assuming a regular area, the size of the DHN would be 12 Ha x 12 Ha, or 1200m x 1200m.

Assuming each branch runs 1200m served by a main, maximum 1200m long, and this were served by 2000m long line from pump the pressure drop would be:

Table 7 **Pressure Drop Estimation**	3200m * 100 Pa/m =	320,000 Pa
	1200m * 250 Pa/m =	300,000 Pa
	Total	620,000 Pa 6.2 bar The total pressure drop is doubled as there is a supply and return = 12.4 bar

Using the flow rate and the pressure drop the following preliminary pump selection has been made:



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Duty: **DH Circulation Pumps** Tag: **0**

PUMP DATA

Pump Flowrate	249.2	m^3/hr
Pump Head	128.2	m
Pump NPSHA	10.00	m
Fluid SG	0.99	

PREDICTED PERFORMANCE

Shaft Power	137.6	kW
Efficiency	62.5	%
Specific Speed	1048	US Units
Suct Sp Speed	10015	US Units
NPSHa	10.0	m
NPSHr	6.3	m
NPSH margin	37	%

PUMP SIZE

6x8x13

PUMP TYPE

Horizontal Overhung (2 pole)

MOTOR

Req'd Power	151.4	kW
Motor Size	180.0	kW
Frequency	50	Hz
Speed	2940	rpm

Pump Unit:

Length	2,439	mm
Width	1,067	mm
Height	950	mm
Weight	2,415	kg

Seal Unit

Length	0	mm
Width	0	mm
Height	0	mm
Weight	0	kg

A pair of centrifugal pumps of this size could be assumed to cost € 510,000 (£440,000).

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[5] https://www.theguardian.com/society/2002/jul/31/urbandesign.architecture

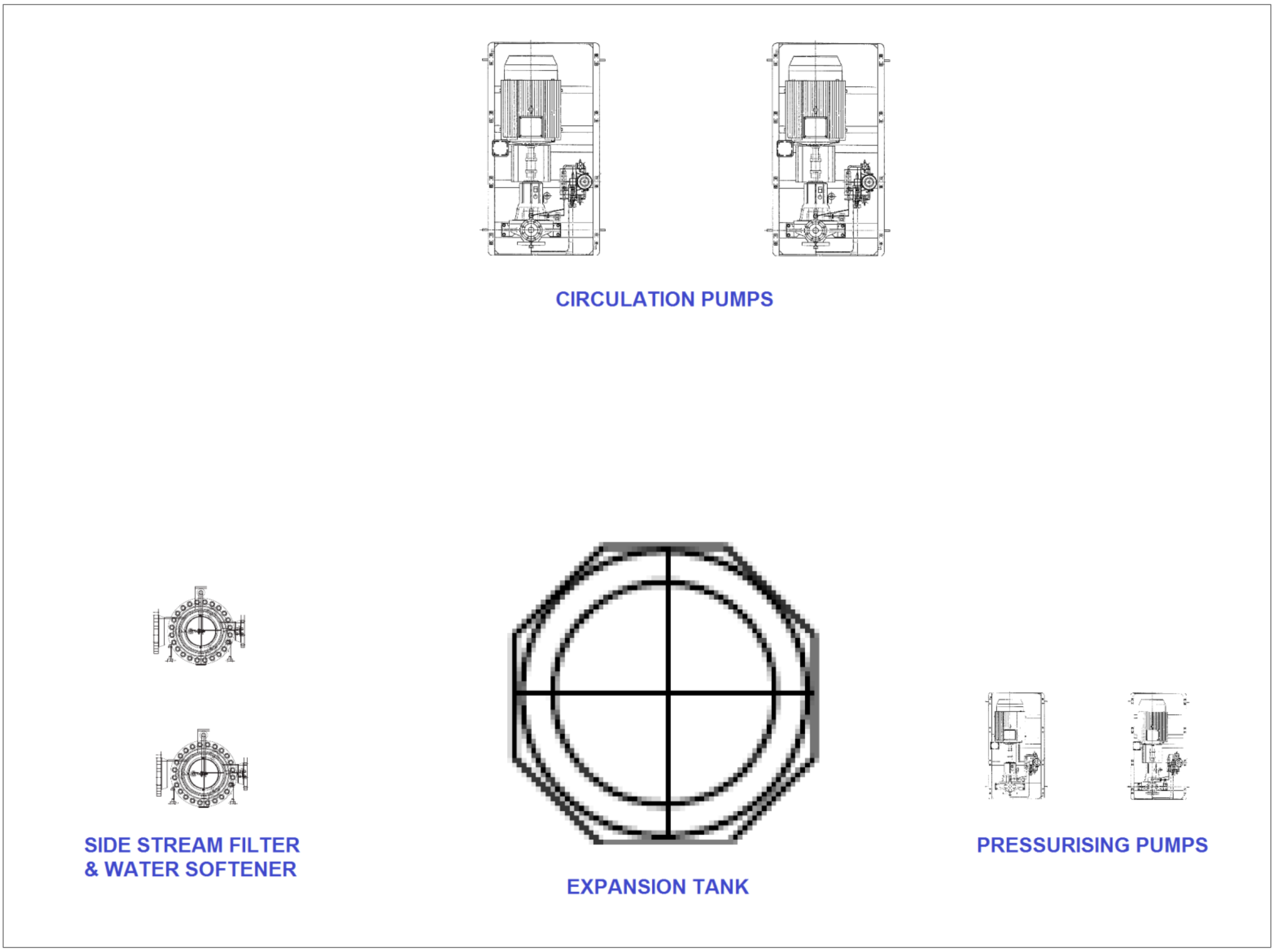
6.5 Approximate Cost Impact

The following is a very approximate cost impact for the deployment of the district heating system within the plant:

Table 8 – Approximate Cost Impact	
Existing Exchangers	Assume no impact for same surface area (not quite true as 2 exchangers now required)
New Exchangers	2 x €140,615 (£123,855) 2 x €75,936 (£66,885) £244,000 £388,000
Pumps	€ 510,000 (£440,000) £50,000
Expansion Vessel	£95,000
Filter & Softener	£31,623 £21,158
Equipment Total	£1,064,521
Total (For the Carbon Capture the equipment cost is approximately 20% of unit cost)	£5,322,605

7 Plot Plan Impact

The plot impact is not significant considering that the exchangers, pumps, and vessels are of small size compared to the overall layout of the CCGT + CCS plant. An approximate footprint would be 12m x 12m assuming that utility systems are supported by those on the CCGT + CCS plant.



8 Conclusion

8.1 Opportunity

There is useful waste heat available within the plant which could be used for DHN.

The opportunity size is 62.5 MW which is enough heat for 2,000 to 4,000 houses.

8.2 Design Safety

Consideration should be given to the application of a CCUS scheme to provide heat to district heating networks. The CCGT + CCC onshore plants are likely to be located away from areas of high domestic or business occupation because of the hazards from Natural Gas, CO_2, and HV Electricity.

A leak of CO_2 from the compressor coolers could lead to CO_2 in the DHN circulation: this could pose a hazard to domestic users if this leaks into their homes.