FICHTNER
Consulting Engineers Limited

Protos ERF EP Variation

Encyclis

CHP Report

ENGINEERING + CONSULTING

Document approval

	Name	Signature	Position	Date
Prepared by:	Vildan Taylor		Associate Senior Consultant	20/11/2023
Approved by:	Stephen Othen		Technical Director	20/11/2023

Document revision record

Revision no	Date	Details of revisions	Prepared by	Checked by
0	05/09/2023	For Client	VBT	SMO
1	11/09/2023	For Client approval	VBT	SMO
2	12/09/2023	For Client approval	VBT	SMO
3	20/11/2023	For re-issue – updated process flow figure	VBT	SMO

Contents

1 Introduction

1.1 Background

Protos ERF Limited is constructing an Energy from Waste plant at Protos Resource Recovery Park (RRP) near Chester, the Protos Energy Recovery Facility (ERF). The ERF is a 2-line plant, processing residual Municipal Solid Waste (MSW).

The Environment Agency (EA) granted an Environmental Permit (EP) (Ref: TP3135LS) for the ERF in December 2006. Subsequently, the EP was transferred from Peel Environmental Ince Limited to Covanta Energy Limited (CEL) and the EP was issued with a new reference number (Ref: EPR/LP3132FX). There have since been 8 varied and consolidated permits issued. The latest varied and consolidated permit was issued in May 2023 (Ref: EPR/LP3132FX/V008).

Encyclis is proposing to install a carbon capture (CC) facility (the CC facility) to capture carbon dioxide (CO_2) from the ERF and exporting this to the local HyNet cluster. The CC facility is based on capturing 95% of the carbon dioxide from both ERF flue gas streams under the design nominal case CO_2 loading: operation at 100% maximum continuous rating (MCR) with a fuel NCV of 10.5 MJ/kg (point B on the ERF firing diagram). This equates to a capture rate of 49.1 t/h. At this capture rate, the CC facility requires 56.4 MW_{th} of heat and 7.1 MW_e of electrical power.

1.2 Objective

The ERF will supply heat and power to the CC facility, which will be a ‘heat user’. On this basis, this Combined Heat and Power (CHP) Report will support the application for the Permit Variation to add the CC facility.

The CHP Report will identify the heat requirements of the CC facility and explain how the export of heat from the ERF has been optimised to maximise the energy efficiency of the CC facility in accordance with the EP and Article 11 of the Industrial Emissions Directive (IED) (Directive 2010/75/EU), which requires regulators to ensure that regulated facilities use energy efficiently.

The CHP Report will consider how the energy efficiency of the ERF relates to the relevant energy efficiency requirements of the Waste Incineration BREF.

2 The CC Facility

2.1 The carbon capture process

In a CC process, CO_2 is extracted from a mixture of gases to create a CO_2 rich stream. The CO_2 captured can then be injected into underground formations (storage), used in the manufacture of a wide range of products, or used as a plant growth enhancer in agriculture. Overall, the process is referred to as carbon capture and storage (CCS). Where the CO_2 can be used as a resource in another process, the process is referred to as carbon capture, usage and storage (CCUS). CCUS can be applied to large scale point sources of carbon including energy intensive industries, power generation, heat production, transport and maritime sectors. The process can be divided into three main steps which are:

1. separation of CO_2 from the gas stream;
2. compression and transportation of the CO_2 (via pipeline or shipping); and
3. use of the captured CO_2 as a resource for other industries or storage within suitable geological formations (saline aquifers, depleted oil and gas reservoirs).

The full flue gas flow will be extracted from each line of the ERF using dampers. The dampers will isolate the flue gas from the existing ERF stacks. A duct will be used to send the flue gases from each line of the ERF to the CC facility. Exhaust gases from each line of the ERF will be treated as separate lines in the CC facility.

The CC facility will utilise heat from the waste incineration processes for CO_2 stripping, amine regeneration and flue gas re-heating. Steam produced from the ERF will be extracted for use in the CC facility and electrical power for the operation of the CC facility will also be provided by the ERF.

An indicative overview of the proposed CC facility is provided in Appendix A.

2.2 Integrating the CC facility into the ERF

The CC facility is designed so that the flue gases from the ERF can either be treated within the CC facility or released to atmosphere through the existing stack without treatment, i.e. via a by-pass.

The CC facility will export CO_2 to the HyNet Cluster for onward transportation to redundant gas fields in Liverpool Bay where it will be sequestered.

The CC facility will utilise heat, in the form of steam, from the waste incineration processes for CO_2 stripping, amine regeneration, and in the form of hot condensate for flue gas re-heating. Steam produced from the ERF will be extracted for use in the CC facility and electrical power for the operation of the CC facility will also be provided by the ERF. As explained in later sections, the ERF turbine does not have sufficient bleed steam capacity to meet the needs of the CC facility. The ERF turbine would need to be modified to meet the CC facility steam demand on its own. This means that the installation of a back-pressure turbine, using high pressure steam from the boiler to generate power while expanding the steam to the required pressure, is the most economic and efficient option for supplying steam to the CC facility. Bleed steam from a modified ERF turbine has a slightly higher cost than the back pressure turbine. This is primarily due to the cost of lost electrical generation whilst the turbine modification works are carried out. Therefore, the most favourable solution is the back-pressure turbine.

Electrical power for the operation of the CC facility will be provided by the back pressure turbine, which will produce a surplus of power.

3 The ERF

The main activities associated with the ERF are the combustion of incoming non-hazardous waste to raise steam and the generation of electricity in a steam turbine/generator.

The ERF includes two waste incineration lines, a waste reception hall, main thermal treatment process, turbine hall, on-site facilities for the treatment or storage of residues and wastewater, flue gas treatment, stack, boiler, systems for controlling operation of the waste incineration plant and recording and monitoring conditions.

In addition to the main elements described, the ERF also includes weighbridges, water, auxiliary fuel and air supply systems, site fencing and security barriers, external hardstanding areas for vehicle manoeuvring, internal access roads and car parking, transformers, a grid connection compound, a firewater storage tank, offices, workshop, stores and staff welfare facilities.

The ERF will have a design gross electrical output of 49.9 MW_e when operating in fully condensing mode, with an estimated parasitic load of approximately 4.8 MW_e and the balance exported to the national grid. Therefore, the ERF will export approximately 45.1 MW_e in full condensing mode.

The ERF will supply high pressure steam to a new back pressure steam turbine generator within the CC facility, resulting in an average total electrical generation of approximately 38.4 MW_e (14.5 MW_e from the new back pressure steam turbine in the CC facility and 21.6 MW_e from the existing fully condensing steam turbine). With the increase of site parasitic load to approximately 11.7 MW_e, the Facility will export approximately 24.4 MW_e. Net heat of 56.4 MW_{th} will be supplied as steam from the back pressure turbine to the CC facility, with the condensate being returned from the CC facility to the ERF.

The design throughput of the ERF at full load in heat export mode is 51.8 tph of mixed non-hazardous waste, with a nominal calorific value of 10.5 MJ/kg.

The heat released by the combustion of the incoming waste will be recovered by means of a water tube boiler, which is integral to the furnace and will produce (in combination with superheaters) high pressure superheated steam at 67 bar(a) and 440°C. The steam from the boiler will then feed a high-efficiency steam turbine which will generate electricity. The turbine will have a series of extractions at different pressures that will be used for preheating air and water in the steam cycle.

The remainder of the steam, after expanding to 62 mbar(a), will be condensed back to water using an air-cooled condenser. The condensed steam will be returned as feed water in a closed-circuit pipework system to the boiler.

3.1 Details of heat supply system from the ERF

Heat is typically supplied from the energy recovery process in the form of steam and / or hot water, depending on the grade of heat required by the end consumers.

The most commonly considered options for recovering heat are discussed below.

3.1.1 Steam extraction from the existing steam turbine bleed

The existing ERF turbine is not designed to supply the volume of steam required by the CC facility without modifications which would involve creating a controlled extraction by installing a control diaphragm as blade carrier within the steam turbine and replacement of another blade carrier within the steam turbine. A turbine outage would be required to accommodate these works. The boilers may continue to operate, but no electrical generation would be possible, limiting the revenue and reducing efficiency during this period.

3.1.2 Steam extraction from a new back pressure steam turbine

A new back pressure steam turbine generator (in addition to the ERF fully condensing steam turbine generator) will be installed to take high pressure steam from the ERF boiler and reducing its pressure to the CC facility steam requirements. The ERF steam turbine will therefore have its flowrate reduced and will be operated at part load. The drop in electrical power this causes will be offset by generation from the back-pressure turbine. However, the total generation from the ERF and back pressure turbine will still be reduced compared to the current design, as the steam expanded through the back pressure turbine is only expanded to 3.5 bar(a) rather than 62 mbar(a) in the existing fully condensing steam turbine.

A back pressure steam turbine will expand the steam to a fixed pressure above atmospheric, for use in the CC process as a heat offtake. The back pressure turbine will generate electrical power from expanding this steam. The flow rate through the turbine will be determined by the process demand required at the exhaust pressure.

Implementing this option will require the construction of an additional steam turbine generator. New high pressure (HP) steam supply pipework to the inlet of the back pressure turbine from the HP steam header will also be required for this option. Electrical cabling will also be required, to import ERF power or export power from the CC facility.

The HP steam will be extracted from the HP header, which is located within the ERF turbine hall. The HP steam will progress along a pipe-bridge, following the road east of the turbine hall and then south, parallel to the existing air-cooled condensers (ACC).

3.1.3 Summary

Taking the above into consideration, the most appropriate approach to supply heat to the CC facility is by extracting steam from the back pressure turbine (as described in 3.1.2). This method for the supply of heat is considered favourable for the following reasons.

1. The heat requirements of the CC facility (as described in section 4) are too high for the temperatures attainable from the existing turbine exhaust steam.
2. Extraction of steam from the back pressure turbine offers the most flexibility for varying heat quality and capacity to supply for the CC facility steam requirements.
3. Extraction of steam from the back pressure turbine offers a higher overall electricity generation from the CC facility.
4. Extraction of steam from the existing turbine would have higher capital cost when compared to the back pressure turbine.
5. The existing ERF turbine would need to be modified in order to meet the CC facility steam demand on its own. Bleed steam from a modified ERF turbine has a slightly higher cost than the back pressure turbine. This is primarily due to the cost of lost electrical generation whilst the turbine modification works are carried out.

4 HP Steam Supply to the CC Facility

4.1 Back pressure turbine

A back pressure steam turbine expands HP steam to a fixed pressure above atmospheric, for use in a process or as a heat offtake. The back pressure turbine is sized such that the exhaust flow rate matches the requirements for the CC facility. A bleed will be included for the supply of steam to the reclaimer at higher pressure. The back pressure turbine has been modelled with results presented in Table 1.

Table 1: Back pressure turbine

Parameter	Unit	Value
CCS heat requirement	MW_{th}	56.4
CCS power requirement	MW_{e}	7.1
Back pressure turbine generation	MW	14.5
HP steam from the ERF to back pressure turbine:		
• pressure	bar (a)	67
• temperature	°C	440
• flow rate	t/h	89.8
Exhaust steam from back pressure turbine to reboiler:		
• pressure	bar (a)	3.5
• temperature	°C	139
• flow rate	t/h	89.4
Bleed steam from back pressure turbine to reclaimer:		
• pressure	bar (a)	6.7
• temperature	°C	164
• flow rate	t/h	0.4

4.2 Backup supply

The back pressure turbine will be supplied with steam from the ERF HP header. This steam will be expanded across the turbine to a pressure of 3.5 bar (a) and exhaust to the steam header.

If the back pressure turbine is out of service, the CC facility will be supplied with steam via a bypass system. The bypass system will consist of a let-down valve, which reduces the pressure of the steam from 67 bar(a) to 3.5 bar (a), with a spray valve, which doses condensate from the condensate tank into the bypass steam. The flow of condensate will be controlled by measuring the outlet temperature of the bypass steam.

4.3 Steam supply and condensate return pipe routing

HP steam extracted from the HP header, which is located within the ERF turbine hall, will be supplied to the CC facility. The HP steam will be supplied along a pipe-bridge, following the road east of the turbine hall and then south, parallel to the ACC.

Condensate will be returned along a similar route, with the terminal point at the condensate tank within the ERF. The condensate tank is located beneath the ACC. To remove condensed water from the steam pipes transporting to the CC facility, drain lines will be required. As the condensate pipework will be running parallel to the steam pipework for much of the route, linking of these pipes via let down valves/steam traps is feasible.

4.4 CC facility interconnecting pipework

Within the CC facility, a main pipe rack is proposed between sections of the plant to allow for easy connection to all the utilities and between the various plant elements. This pipe rack will be elevated over the road network which lies between the CC facility components.

5 ERF Energy Efficiency Calculations

5.1 Heat and power export

The heat and power export has been modelled across a range of load cases and the results are presented in Table 2.

For modelling and calculation purposes, the Facility has been divided, virtually, into two parts when the CC facility is operating.

- Part A - the portion of the ERF boilers which supply high pressure steam to the fully condensing ERF turbine, and the fully condensing turbine.
- Part B - the remaining portion of the ERF boilers which supply high pressure steam to the new back pressure turbine, the back pressure turbine itself, and the heat export to the CC facility.

Table 2: Heat and power export

Parameter	Unit	Value
ERF fully condensing turbine with no heat supply to CC facility		
Net thermal input from waste to the boiler, NCV	MW_{th}	151.0
Gross power generated	MW_e	49.9
Parasitic load	MW_e	4.8
Net power exported	MW_e	45.1
Gross electrical efficiency, NCV	%	33.1
Heat supply to CC facility via the back pressure turbine		
Part A: Fully condensing ERF turbine		
• Effective net thermal input from waste to the boiler, NCV	MW_{th}	70.8
• Gross power generated from ERF turbine	MW_e	21.6
• Gross electrical efficiency, NCV	%	30.5
Part B: Back pressure turbine		
• Effective net thermal input from waste to the boiler, NCV	MW_{th}	80.2
• Gross power generated from back pressure turbine	MW_e	14.5
• Net Heat supply from back pressure turbine to CC facility	MW_{th}	56.4
• Gross energy efficiency, NCV	%	88.4
Total gross power generated (Part A+B)	MW_e	36.1
Total power used (ERF + CC facility)	MW_e	11.7
• ERF parasitic load	MW_e	4.6[1]
• CC facility power requirement	MW_e	7.1

[1] Parasitic load has reduced due to a reduced steam flow to the air cooled condenser, reducing the fan duty.

Parameter	Unit	Value
Net power exported (Part A+B)	MW_e	24.4

5.2 BAT 20 of WI BREF

The Waste Incineration BREF[2] was published in December 2019. In accordance with the requirements of the IED, the ERF is required to demonstrate compliance with the requirements of the WI BREF prior to December 2023.

BAT 20 states that the BAT-Associated Energy Efficiency Levels (referred to as BAT-AEELs) given in these BAT conclusions are expressed as:

- gross electrical efficiency in the case of an incineration plant or part of an incineration plant that produces electricity using a condensing turbine; and
- gross energy efficiency in the case of an incineration plant or part of an incineration plant that:
  - produces only heat, or
  - produces electricity using a back-pressure turbine and heat with the steam leaving the turbine.

As the ERF with CC facility will have both a condensing turbine and a back pressure turbine, it does not fit into either category. This is why it has been divided, for modelling purposes, into Part A and Part B, as described earlier. For compliance purposes, it is then assumed that:

- the Gross Electrical Efficiency formula applies to the ERF fully condensing turbine (Part A); and
- The Gross Energy Efficiency formula applies to the back pressure turbine (Part B).

BAT 20 states that the BAT-AEELs for Gross Electrical Efficiency for part of a new waste incineration plant that produces electricity using a condensing turbine (Part A) is 25-35%.

BAT 20 states that the BAT-AEELs for Gross Energy Efficiency for part of a new waste incineration plant that produces electricity using a back-pressure turbine and heat with the steam leaving the turbine (Part B) is 72-91%.

The Gross Electrical and Energy Efficiency of Part A and Part B respectively have been calculated in accordance with the requirements of BAT 20. The results are shown in Table 3.

Table 3: BAT 20 - gross efficiency

Part of Facility	Unit	Value
Part A: ERF fully condensing turbine		
Net thermal input from waste to the boiler, NCV	MW_{th}	70.8
Gross power generated from ERF turbine	MW_e	21.6
Gross electrical efficiency, NCV	%	30.5
BAT-AEEL (%)	*%*	*25-35*
Pass or Fail		***Pass***
Part B: Back pressure turbine		
Net thermal input from waste to the boiler, NCV	MW_{th}	80.2

[2] https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC118637_WI_Bref_2019_published_0.pdf

Part of Facility	Unit	Value
Gross power generated from back pressure turbine	MW_e	14.5
Net Heat supply from back pressure turbine to CC facility	MW_{th}	56.4
Gross energy efficiency, NCV	%	88.4
BAT-AEEL (%)	*%*	*72-91*
Pass or Fail		***Pass***

The EA's BREF Implementation Plan states:

"BAT for these plants is to become CHP by connecting to a heat network or supplying a heat user direct where viable opportunities exist."

and

"Existing plants will also be expected to demonstrate that they have maximised their GEE as far as possible and have minimised their parasitic heat and electrical loads."

As explained in section 2, the CC facility will require heat and is a potential heat user for the ERF. In addition, as shown in Table 3, Part A of the facility, which is the ERF fully condensing turbine, would achieve a gross electric efficiency of more than 25% whilst the Part B of the facility, supplying heat to the CC facility from the back pressure would achieve gross energy efficiency of more than 72%. Taking this into consideration, the proposed supply of heat from the ERF via the back pressure turbine to the CC facility is considered to represent BAT.

5.3 Primary energy saving

To be considered high-efficiency cogeneration, the scheme must achieve at least 10% savings in primary energy usage compared to the separate generation of heat and power. The Primary Energy Saving (PES) has been calculated in accordance with European Commission Delegated Regulation (EU) 2015/2402 of 12 October 2015 Annex II part (b).

Efficiency reference values for the separate production of heat and electricity have been taken as 75% and 25% respectively as defined in Commission Delegated Regulation (EU) 2015/2402 of 12 October 2015[3].

When operating in heat supply mode from the ERF via the back pressure turbine to the CC facility (Table 3), the PES has been calculated in accordance with the draft Article 14 guidance[4] and the results are presented in Table 4.

Table 4: Primary energy saving (%)

	Primary energy saving (%)
The ERF + new back pressure turbine	31.2

The Facility achieves a PES of 31.2%. This is more than the technical feasibility threshold defined in the draft Article 14 guidance. On this basis, the heat supply from the ERF via a new back pressure turbine to the CC facility qualifies as a high-efficiency cogeneration operation when operating in CHP mode.

[3] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015R2402

[4] Draft guidance on completing cost-benefit assessments for installations under Article 14 of the Energy Efficiency Directive, V0.9 April 2015

6 Summary

6.1 Technical solution

1. The ERF with no steam supply to the CC facility will have a gross electrical output of 49.9 MWe, (design value when operating in fully condensing mode), with an estimated parasitic load of approximately 4.8 MW_e, with the balance exported to the National Grid. Therefore, the ERF is expected to export approximately 45.1 MW_e in fully condensing mode.
2. Encyclis is proposing to construct a CC facility which is based on capturing 95% of the capture CO_2 from both ERF flue gas streams under the design nominal case CO_2 loading: operation at 100% MCR with a fuel NCV of 10.5 MJ/kg (point B on the ERF firing diagram). This equates to a capture rate of 49.1 t/h. At this capture rate, the CC facility requires 56.4 MW_{th} of heat and 7.1 MW_e of electrical power.
3. The CC facility will utilise heat from the ERF for CO_2 stripping, amine regeneration and flue-gas re-heating. Steam extracted from the ERF via the new back pressure turbine will be used in the reboiler of the CC facility to heat the amine solution drawn from the bottom of the amine regenerator and to the vaporise water in the CO_2 rich amine solvent solution. Power for the operation of the CC facility will be provided by the new back pressure turbine.
4. The current turbine existing bleed is not able to supply the required volume of steam for the CC facility. The most economic option for supplying steam to the CC facility, at the required pressure, is installation of a back-pressure turbine. The ERF will be designed with the capability to export up to 56.4 MW_{th} of heat and 7.1 MW_e of electrical power to meet the CC facility demand. This would result in an average electrical generation of approximately 36.1 MW_e (21.6 MW_e from the existing fully condensing steam turbine and 14.5 MW_e from the back pressure steam turbine).
5. New HP steam supply pipework to the inlet of the back pressure turbine from the HP steam header will be required. HP steam will be extracted from the HP header, which is located within the ERF turbine hall. The HP steam will progress along a pipe-bridge, following the road east of the existing turbine hall and then south, parallel to the ACC. Condensate will be returned along a similar route, with the terminal point at the condensate tank located beneath the ACC.

6.2 Energy efficiency measures

1. The Facility as proposed will have both a fully condensing turbine and a back pressure turbine. Around 47% of the boiler capacity will be used to supply high pressure steam to the fully condensing turbine whilst the remaining capacity supply high pressure steam to the back pressure turbine.
2. The Gross Electrical Efficiency (NCV) for Part A of the facility is 30.5 %, which compares favourably with the BAT-AEELs for Gross Electrical Efficiency (25–35% for a new plant). The Gross Energy Efficiency (NCV) for Part B, is 88.4%, within the range of the BAT-AEELs for Gross Energy Efficiency (72–91%).
3. In order to qualify as technically feasible under the draft Article 14 guidance, the heat demand must be sufficient to achieve high efficiency cogeneration, equivalent to at least 10 % savings in primary energy usage compared to the separate generation of heat and power. With the average heat demand of 56.4 MW_{th} from the CC facility, the ERF achieves a PES of 31.2 %, which is in excess of the technical feasibility threshold defined in the draft Article 14 guidance and would therefore be technically feasible to supply.

6.3 Overall

The EA's BREF Implementation Plan states:

"BAT for these plants is to become CHP by connecting to a heat network or supplying a heat user direct where viable opportunities exist."

and

"Existing plants will also be expected to demonstrate that they have maximised their GEE as far as possible and have minimised their parasitic heat and electrical loads."

As set out above:

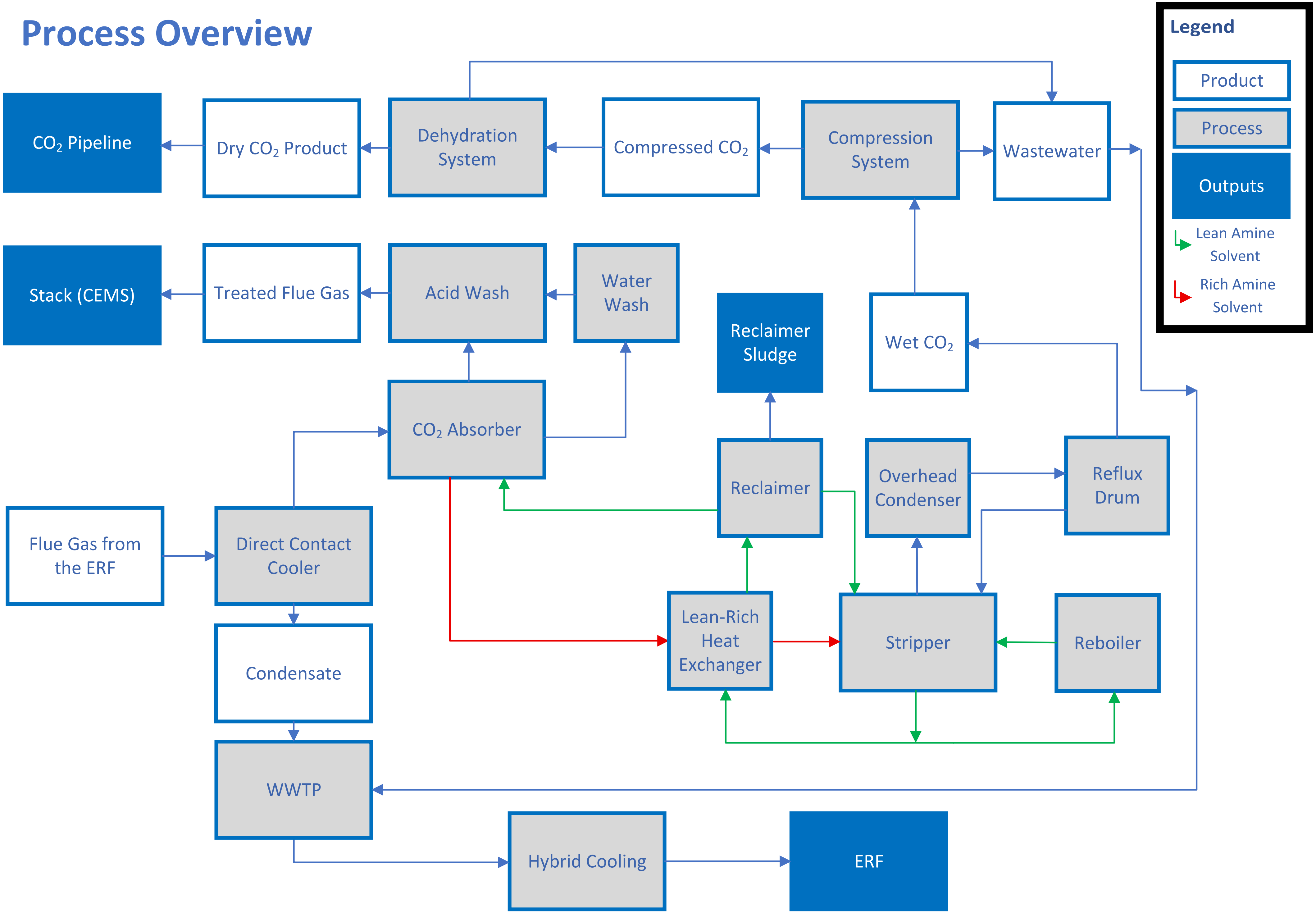
1. the CC facility will require heat and is considered to be a potential heat user for the ERF; and
2. the export of heat to the CC facility via the new back pressure turbine will have gross electrical efficiency and gross energy efficiency more than BAT-AEELs and PES of more than 10%.

Taking this into consideration, the proposed supply of heat from the ERF to the CC facility via the new back pressure turbine is considered to represent BAT.

Appendices

A Indicative Process Overview

Process Overview



ENGINEERING + CONSULTING

FICHTNER
Consulting Engineers Limited

Kingsgate (Floor 3), Wellington Road North,
Stockport, Cheshire, SK4 1LW,
United Kingdom

t: +44 (0)161 476 0032
f: +44 (0)161 474 0618

www.fichtner.co.uk