ERVIA CCS PRE-FEED STUDY

Process & Utilities Design Philosophy - Cork

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Holds

HOLDS	Description	Responsibility
N/A		

Glossary

Term	Definition
CCS	Carbon Capture and Storage
CPF	Central Processing Facility
FEED	Front End Engineering Design
NPSH	Net Positive Suction Head
NPSHA	Net Positive Suction Head Available
NPSHR	Net Positive Suction Head Required
Essential Power	Essential power will supply backup power to critical equipment in case of loss of normal power

References

1. Ervia CCS Pre-FEED Study, MDE1234-RPS-01-CX-RP-Z-0001.
2. Guide to the Safety, Health and Welfare at Work (General Application) (Amendment) Regulations 2012 (S.I. No. 445 of 2012), Pressure Systems.
3. Design of Earthworks, Drainage, Network Drainage, Attenuation & Pollution Control (Transport Infrastructure Ireland (TII), DN-DNG-03066, March 2015).
4. Communications and Control Philosophy, MDE1234-RPS-01-CX-RP-Z-0013.
5. Process Control and Safeguarding Philosophy, MDE1234-RPS-01-CX-RP-Z-0004.
6. Process Safety Design Basis, MDE1234-RPS-01-CX-RP-Z-0011.
7. Material Selection Philosophy, MDE1234-RPS-01-CX-RP-Z-0006.
8. Gas dispersion study report, MDE1234-RPS-05-CX-RP-Z-0003.
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1 INTRODUCTION AND SCOPE

1.1 Project Background

Ervia is assessing how Carbon Capture and Storage (CCS), located close to large-scale CO_2 emitters can play a role in reducing Ireland's CO_2 emissions. A technical feasibility study on the potential for large-scale CCS in Ireland was completed by Ervia in 2020.

The general location of Aghada Power Station in County Cork was selected as a potential site for a Central Processing Facility (CPF) for liquefaction, storage, and export of CO_2 overseas via a new marine jetty. The CPF will cater for CO_2 captured at 3 emitter locations (Whitegate Power Station, Irving Oil Whitegate Refinery and Aghada CCGT). A new CO_2 gas pipeline gathering network will transport CO_2 from the emitters to the CPF.

Ervia has appointed RPS / Bechtel to carry out a Pre-FEED study that involves a detailed assessment of the key CPF, pipeline and storage infrastructure necessary to condition, compress, transport and store liquid CO_2 at Cork harbour for subsequent loading onto ships for export. (Note: The scope of this project does not include the carbon capture facilities at each emitter).

Additionally, the new marine jetty in Cork will also be used for import of liquid CO_2. This scenario considers the regasification of liquid CO_2 at Cork for transport via pipeline to the Inch terminal which is the link to indigenous offshore permanent storage at the depleted Kinsale Head Gas Field.

1.2 Scope

The purpose of this document is to compile criteria and methodology to be used for sizing & specifying equipment and piping associated with the Ervia CCS Project. This document is intended to standardise general process design criteria consistent with industry accepted practices.

The criteria specified in this philosophy are based on best process engineering practices and need to be complied with unless there is any deviation from current code or legislation.

All designs should be in compliance with Reference 3, 'Guide to the Safety, Health and Welfare at Work (Amendment) Regulations 2012 (S.I. No. 445 of 2012), Pressure Systems'.

2 DESIGN CONDITIONS FOR EQUIPMENT

2.1 Design Pressure

2.1.1 Internal Design Pressure

Equipment and piping design pressure shall be set according to greatest among the following:

- Design Pressure: Maximum Operating Pressure (MOP) plus margin from Table 2-1.

Table 2-1 Design Pressure Margin

Range of Maximum Operating Pressure	Design Pressure
Full Vacuum to 1.7 barg	3.5 barg
1.8 to 17 barg	MOP + 1.7 bar
17.2 to 35 barg	MOP X 1.1
35 to 70 barg	MOP + 3.5 bar
Over 70 barg	MOP X 1.05

Maximum operating pressure is highest operating pressure of all operating cases such as normal operation (design case), alternate operating mode, start-up, shutdown, turndown, expansion.

- Pump shut-off pressure for pumped circuits and liquid-full vessels where applicable (see Section 6.3 for definition of shut-off pressure).
- Settle out pressure.

2.1.2 External Design Pressure

Equipment in the following services will be designed for full vacuum:

- External design pressure will be specified for equipment which normally operates at vacuum and for systems which can experience vacuum such as loss of vapour to condensing services, decrease in ambient temperature for blocked-in liquid services, compressor blocked suction.
- Suction drum for a compressor or vacuum pump.
- Liquid filled equipment shall be designed for full vacuum.

2.2 Design Temperature

2.2.1 Upper Design Temperature

The equipment and piping design temperature shall be at least the highest of the following:

- Maximum operating temperature plus a minimum of 28°C. Maximum operating temperature corresponding to highest operating temperature of all operating cases like normal operation (design case), alternate operating mode, start-up, shutdown, turndown, expansion.
- Sun metal design temperature - High temperature that material may be exposed to as a result of solar radiation.
- The maximum anticipated upset temperature with no margin. Upset cases includes utility failure, blocked-in operation, instrument failure, cooling medium failure, air cooler failure etc.
- Operating modes other than normal operating case (such as depressurising) must be considered when setting design temperature. These alternative operating modes often result in extreme temperatures at lower pressures. The equipment should be designed for all modes of operation. This requirement may force dual pressure/temperature ratings for equipment.
- Maximum temperature coinciding with Pressure Safety Valve (PSV) relieving pressure except temperature in fire scenario. Fire scenarios will be addressed by depressurisation and firefighting procedures. Refer Process Safety Design Basis (Ref.6) and Process Control and Safeguarding Philosophy (Ref 5).

2.2.2 Minimum Design Metal Temperature

MDMT shall be at most the lowest among the following:

- Minimum operating conditions minus a minimum of 5.5°C. Minimum operating conditions corresponding to lowest operating temperature of all operating cases. Does not apply to auto-refrigeration or cryogenic processes where it is not practically possible for the system to see lower temperatures than what can be achieved by the process.
- Minimum ambient design temperature. Lowest ambient design temperature that system must be designed for as stated in Study Basis document (Ref.1).
- Auto refrigeration temperature (in case of depressurisation).
- Temperature, the equipment content will reach, if pressure is reduced from working pressure to atmospheric pressure. Refer Material Selection Philosophy (Ref.7).

3 VESSELS

Vessels shall be designed per vessel design code EN 13445 and complied with Pressure Equipment Directive (PED) (2014/68/EU).

3.1 Design Pressure

The design pressure shall be in accordance with Section 2.1 and with the following clarifications:

- The internal design pressure may need to be higher than the Section 2.1 requirements depending on location of relief protection or other considerations such as hydrostatic head and differential pressure.
- The vessel design pressure does not include the liquid static head within the vessel. The maximum liquid density and liquid level must be specified on the process datasheet.
- The settling out pressure of centrifugal compressors shall be considered when setting design pressures for the suction and interstage knockout drums. Design pressure for these drums is settling out pressure plus margin from Table 2-1.
- Where multiple pieces of equipment are protected by a common relieving device, consideration should be given to using the same design pressure for all pieces. Otherwise, the relief device shall be set at the lowest design pressure.
- The design pressure of liquid-filled equipment should equal the discharge pressure of any feed pump when operating at shut-off with the pump suction pressure at its maximum (corresponding to maximum liquid level and design pressure of pump suction vessel or tank). After vendor information on pumps is available, check all pumps to ensure that the maximum discharge condition does not exceed downstream vessel design pressure.
- Liquid filled vessels shall be designed for full vacuum.

3.2 Design Temperature

The design temperature shall be in accordance with Section 2.2.

3.3 Process Nozzle Sizing

Table 3-1 sets the general nozzle sizing criteria for vapor / liquid separator vessels.

Table 3-1 Process Nozzle Sizing Criteria

Service	Velocity (m/s)
Liquid	
Pump suction	0.6 – 1.2
Pump discharge or pressure out	1.5 – 3.0
Feed inlet	1.5 – 3.0
Vapour	
Feed	9.0 – 24.0
Outlet	15.0 – 45.0
Mixed Phase inlet momentum criteria	**Kg/m.s^2**

Diffuser / Inlet vane	< 6000
Half open pipe	< 1500
V-baffle	< 1500
No inlet device	< 1500

For a self-venting nozzle, the Froude Number must be no greater than 0.3.

3.4 Non-Process Nozzles

Each vessel shall be provided with vent and drain nozzles as shown in Table 3-2 of this guideline. Purge nozzles shall also be provided when required by the process design.

All connections to vessels shall be flanged. Vortex breakers are required on all vessel bottom outlet nozzles to pump suctions.

Table 3-2 Minimum Nozzle Sizes

Volume of Vessels (m^3)	Vent Size (NPS)	Drain Size (NPS)
1.4 or less	50 mm	50 mm
1.5 to 17	50 mm	50 mm
17.1 to 57	80 mm	80 mm
57.1 to 285	100 mm	100 mm
Above 285	150 mm	150 mm

In addition, vessels shall be provided with a circulating air nozzle (vessel vent) i.e., air mover or air horn. This nozzle is required for air circulation during maintenance vessel entry. The vessel vent nozzle size shall be as follows:

Table 3-3 Vent Nozzle Size

Vessel Size ID	Vent Nozzle Size
Under 910 mm	Not Required
910 – 1,500 mm	150 mm
> 1,500 mm	200 mm

The vessel vent nozzle location will be as follows:

- Vertical vessel: Top Head
- Horizontal vessel: On top, opposite end of the manway

3.5 Manways and Inspection Openings

- All vessels shall normally be provided with at least one manway or two inspection hand holes for each pressure compartment.
- Inspection openings shall be located so that representative shell joints and critical parts of the vessel interior are visible.
- For vessels, unless there are special considerations for installations of internals and maintenance, manhole/handhole sizes shall be as follows:
    - For vessels up to 900 mm ID (no internals): 2 x 200 mm handholes
    - For vessels up to 900 mm ID (with internals): Provide flanged cover
    - For vessels above 900 to 1500 mm ID: 1 x 500 mm manway
    - For vessels above 1500 mm ID: 1 x 600 mm manway
- To assist airflow through the vessel during maintenance, horizontal vessels up to 6,000 mm tangent/tangent should have one manway located in the end opposite the vessel vent. Horizontal vessels over 6,000 mm tangent/tangent should have one manway in the top and one manway in the side or end located at the opposite end of the vessel.

3.6 Corrosion Allowance

Corrosion allowances will be in accordance with the Material Selection Diagram (MSD).

3.7 Minimum Sizes

Minimum drum size shall be 610mm ID.

4 SPHERES

Spheres shall be designed in accordance with vessel design code EN 13445 and shall comply with Pressure Equipment Directive (PED) (2014/68/EU).

4.1 Design Pressure

The design pressure shall be in accordance with Section 2.1 and with the following clarifications:

- The internal design pressure may need to be higher than the Section 2.1 requirements depending on location of relief protection or other considerations such as hydrostatic head and differential pressure.
- The sphere design pressure does not include the liquid static head within the sphere. The maximum liquid density and liquid level must be specified on the process datasheet.

4.2 Design Temperature

The design temperature shall be in accordance with Section 2.2.

4.3 Corrosion Allowance

Corrosion allowances will be in accordance with the Material Selection Diagram (MSD).

5 HEAT EXCHANGERS

Heat exchangers shall be designed per relevant ISO or EN standard.

For example, shell and tube heat exchange equipment shall be designed in accordance with the latest edition of the standards of the Tubular Exchangers Manufacturer's Association (TEMA), EN 13445 and comply with Pressure Equipment Directive (PED) (2014/68/EU).

5.1 Design Pressure

The design pressure shall be in accordance with Section 2.1 and with the following clarifications:

- Exchanger tube side or shell side design pressures shall normally be set at set pressure (plus static head) of the safety relief valve that protects the exchanger.

5.2 Design Temperature

The design temperature shall be in accordance with Section 2.2.

5.3 Fouling Factors

Fouling resistances for utilities shall be according to below Table 5-1.

Table 5-1 Fouling Factors

Fluid	Fouling Resistance (m^2.K/W)
Sea Water	0.000088
Carbon Dioxide (liquid/gaseous)	0.000176
Ammonia	0.000176
Compressed air	0.000176
Air Side of Air-Cooled Exchangers	0.000176

6 PUMPS

6.1 Rated Capacity

Table 6-1 Design Factors for Pumps

Equipment Services	Design Factor
CO_2 Export Pump	1.0 x Design capacity
Intermittent Pumps	1.0 x Design capacity
Other Process Pumps	1.1 x Normal capacity

6.2 Net Positive Suction Head

In calculating Net Positive Suction Head (NPSH), observe the guidelines described below. However, each case should be evaluated for specific situation.

- Static head for pump rated capacity shall be measured from the bottom of horizontal drums, the bottom tangent line of vertical vessels with bottom draw offs and the bottom elevation of the outlet nozzle for side draw offs or Low Low Liquid Level (LLLL) if there is pump stop interlock. Suction from a storage tank should be based on the lowest specified liquid level in the tank.
- Net Positive Suction Head Available (NPSHA) shall be referenced to foundation top and Pump Bidder to be advised accordingly. This NPSHA shall be converted by Pump Bidders to NPSHA at pump impeller centreline for selecting the pump model and verifying specified NPSH margin.
- No safety factor should be deducted from the calculated NPSHA. Pump data sheets must clearly state that a NPSHA safety factor has not been deducted.
- NPSH margin shall be according to below Table 6-2.

Table 6-2 NPSH Margin

Conditions	Margin	Comments
High energy pumps (1,000 HP (746 KW) & above) in water service	1.5 x NPSHR	
Two (2) 100% Pumps, NPSH @ rated flow	1.0 m	
Two (2) 100% Pumps, NPSH @ 120% of Best Efficiency Point (BEP) flow	0.3 m	Calculate NPSHA @ 120% of BEP Flow & Compare to NPSHR @ 120% of BEP Flow. Consider normal liquid level while calculating NPSHA.
Three (3) 50% Pumps; NPSH @ 200% of Normal Flow or @ End of Pump Curve	0.3 m	Calculate NPSHA @ End of Curve or 200% of Normal Flow (Whichever smaller) & Compare to NPSHR @ End of Curve or 200% of Normal Flow Use Normal Liquid Level while calculating NPSHA.

- Vertical sump pump will have flooded suction. Flooded suction shall be specified in datasheet instead of NPSHA and sump liquid levels shall be mentioned in datasheet.
- Vertical canned pump - NPSHA will be calculated at suction flange of pump or barrel and submergence/depth to ensure cavitation free operation will be calculated by vendor. Note should be added in datasheet stating that the NPSHA is specified at pump suction nozzle flange.

6.3 Pump Shut-off Pressure

- The shut-off pressure of pumps is used to set the design pressure of downstream equipment and piping.
- For centrifugal pumps, the shut-off pressure shall be calculated as the maximum suction pressure plus differential pressure at shut off condition.
- Maximum suction pressure is based on the suction vessel at relief valve set pressure and the vessel liquid level at the high level (HLL).
- In the absence of vendor data, initial estimates for the pump shut-off differential pressure may be based on 125% for motor driven and 166% for turbine driven pumps (includes turbine tolerances) of the differential pressure at the rated flow rate. Pump shut-off pressure shall consider pump performance tolerances on pump shut-off head.
- The shut-off pressure shall be rechecked when the certified standard characteristic curves of the selected pumps are available. Once this is done the piping and equipment design pressure in the system or the relief device settings shall be checked and updated as necessary.
- Positive displacement pumps should be equipped with relief valves to protect the downstream equipment and piping. Maximum shut-off pressure for these pumps is the relief valve set pressure.

7 EQUIPMENT DESIGN MARGIN

Equipment is to be designed with design margins as listed in the following table.

Table 7-1 Equipment Design Margin

Equipment Type	Design Margin
Vessels	10% of normal vapour & liquid flow
Shell & tube heat exchanger	10% on flow & duty
Air coolers	10% on flow & duty
Pumps	Refer Section 6.1 of this document
Compressor	10% on normal flow

8 LINE SIZING CRITERIA

The following tables are a general guide for sizing lines.

8.1 Liquid Line Sizing Criteria

Table 8-1 Liquid Lines Velocity and Pressure Drop Criteria

Type of Liquid Hydraulic Service	Maximum Friction Loss (bar/km)	Maximum Velocity (m/s)
Centrifugal Pump Suction	-	25 mm Pipe – 0.3 40 mm - 50 mm Pipe – 0.61 80 mm Pipe – 0.76 100 mm Pipe – 0.91 150 mm - 200 mm Pipe – 1.52 >200 mm Pipe – 2.13
Process Liquid Lines	25 mm – 150 mm Pipe – 6.79 200 mm Pipe – 5.66	25 mm Pipe – 1.52 40 mm Pipe – 1.68 50 mm Pipe – 2.13 80 mm Pipe – 2.44 100 mm Pipe – 3.05 150 – 200 mm Pipe – 3.66 >200 mm Pipe – 4.57
Water Lines	25 mm – 50 mm Pipe – 4.53 80 mm – 150 mm Pipe – 3.39 200 mm Pipe – 2.26	25 mm Pipe – 0.91 40 mm Pipe – 1.22 50 mm – 80 mm Pipe – 1.52 100 mm Pipe – 1.83 150mm – 200 mm Pipe – 2.44 >200 mm Pipe – 4.57
Fire Water	-	(Notes 1,2)
CO_2 Saturated	-	4.57

1. *For fire water systems the appropriate National Fire Protection Association (NFPA) regulations and any site specific requirements of the Local Authority Fire Department shall apply, therefore full details regarding the design of the fire water systems are not considered within this document. Refer Process Safety design basis (Ref # 6) for details of fire water design.*

2. *Underground pipe size will be based on 3 m/s maximum velocity, per manufacturer's recommendations for HDPE. Aboveground pipe size will be based on 6.1 m/s maximum velocity.*
   Pump suction and discharge pipe size should be such that, with the pumps operating at 150% of rated capacity, the velocity in the suction lines does not exceed 4.57 m/s and discharge line (which extend up to the main grid) does not exceed 6.1 m/s. When determining the fire water systems, a maximum allowable velocity of 6.1m/s on both the pump discharge piping and the underground fire water piping shall be used.

8.2 Vapour Line Sizing Criteria

Table 8-2 Gas Vapour Line Sizing Criteria

Type of Vapour Hydraulic Service	Maximum Velocity (m/s)
Vapour lines (solid free) in continuous service, Carbon Steel (C.S.) piping	$V \leq \frac{C}{\sqrt{\rho m}}$ ρm = Avg. vapour density, kg/m^3 C = Constant, 122
Vapour lines (solid free) in intermittent service, C.S. piping	$V \leq \frac{C}{\sqrt{\rho m}}$ ρm = Avg. vapour density, kg/m^3 C = Constant, 152.5
Vapour lines (solid free) in continuous service that use alloy piping	$V \leq \frac{C}{\sqrt{\rho m}}$ ρm = Avg. vapour density, kg/m^3 C = Constant, 183 to 244
Vapour lines (solid free) in intermittent service that use alloy piping	$V \leq \frac{C}{\sqrt{\rho m}}$ ρm = Avg. vapour density, kg/m^3 C = Constant, 305

8.3 Mixed Phase Line Sizing Criteria

The criteria for sizing two phase lines (liquid and vapour flow) shall avoid slug flow regime and excessive velocity which can cause vibration or erosion. Baker chart methodology which identifies following flow regimes shall be used:

a.) Stratified
b.) Wave
c.) Annular
d.) Dispersed
e.) Slug
f.) Plug
g.) Bubble or froth

Table 8-3 Mixed Lines Velocity and Pressure Drop Criteria

Type of two-phase Hydraulic Service	Maximum Friction Loss (bar/km)	Recommended Velocity (m/s)
General Service	Detailed two-phase Hydraulic calculations will be developed for horizontal and vertical flow paths	$73 / \rho_{avg}^{0.5}$ - $122 / \rho_{avg}^{0.5}$ Where: ρ_{avg} is homogeneous density (kg/m^3)

9 UTILITY SYSTEM DESIGN BASIS

9.1 Electric Power Generation and Distribution

Power for the CPF facility shall be supplied from the electricity grid.

Stand-by low sulphur diesel powered generators will be provided for supplying essential power in the event of loss of import power. Diesel fuel is used for the essential diesel generator package and for the diesel driven fire water pumps. Diesel fuel will be trucked in and stored in 100% bunded diesel day tanks. Diesel storage of 24 hours shall be specified within the essential diesel generation package and no additional storage for diesel is considered. Diesel storage tank in essential diesel generation package to be provided with low level alarm.

9.2 Refrigerant Supply and Storage

Based on environmental and economic consideration, external refrigeration with ammonia has been selected.

Ammonia Source:	Imported via tanker trucks
Ammonia Storage:	Pressurised horizontal bullets
Ammonia Storage Capacity:	One train inventory + three months of losses from three trains

9.3 Vent Stack

Two vent stacks will be provided, one for CO_2 and one for NH_3. CO_2 will be routed in gaseous phase to CO_2 vent stack for safe disposal. NH_3 will be routed in gaseous phase to NH_3 vent stack for safe disposal. Refer gas dispersion study report (Ref 8).

9.4 Instrument Air

Instrument air required for the CPF facility will be supplied by N+1 capacity motor-driven Air Compressors and Instrument Air Dryer Package via plant wide header systems. Instrument air (IA) is required for instrumentation and control valves.

Instrument air will be supplied at the following conditions at discharge header:

Table 9-1 Instrument Air conditions at Discharge Header

Properties	
Pressure	6.5 – 9.5 bara
Minimum Pressure	6.5 bara
Temperature	Ambient, 28°C maximum
Maximum Dew point	-40°C
Entrainment	Clean, dry and oil free

The sizing basis for instrument air is based on continuous and intermittent users. The system will be designed to allow online filter replacement.

The system will be sized for availability and flexibility of operation during normal operation, start-up, emergency shutdown and pre-commissioning. The system will be connected to normal / continuous power supply and one out of two motor-driven air compressors will also be connected to the essential power supply. In the event of a decrease in instrument air pressure, the spare air compressor is brought online to meet the increased demand.

The instrument air receiver will be sized to provide 20 minutes storage capacity between the maximum (9.5 bara) and minimum (6.5 bara) operating pressures based on the normal flow of instrument air.

Plant air is not required during normal operations. Equipment hire can be considered if required for maintenance purposes.

9.5 Nitrogen System

The primary source of gaseous nitrogen will be provided via gaseous nitrogen cylinders from third party. The system will be designed to supply nitrogen for inerting, pad gas, compressor gas seal and utility station. The nitrogen requirement for start-up/shutdown purging will be fulfilled by bringing additional facilities such as liquid nitrogen vaporiser during start-up/shutdown.

Nitrogen will be supplied at the following conditions at the discharge header:

Table 9-2 Nitrogen conditions at Discharge Header

Properties	
Supply pressure	8.5 – 9.5 bara
Supply temperature	Ambient

Table 9-3 Supplied Nitrogen Composition

Product Composition	
Nitrogen	>99.99 mol%
Oxygen	<100 ppm maximum
Water	< 1 ppmv maximum
Oil & hydrocarbon	None

9.6 Water

Water will be required for a variety of uses in the project, including firewater, potable water for human consumption, eyewash, safety showers (EW/SS) and utility water for general washdown. Water will be supplied from the local mains supply.

9.7 Fire Water

Mains water will be fed into the Fire Water System. Fire water is stored in Fire Water Tank and distributed to the underground fire water network using Main Fire Water Pumps. One electric driven fire water main pump and one diesel driven fire water main pump to be provided. Jockey Pumps are also provided to maintain pressure in the Firewater System. Low level alarm to be provided in diesel tank provided for diesel driven fire water main pump.

9.8 Wastewater Treatment and Disposal

Sanitary wastewater will be collected in a septic tank and removed from site by vacuum tanker for disposal in an authorised wastewater treatment facility.

Storm water will be collected within a dedicated surface water drainage network and discharged at a designated location that has been approved at planning stage. Requirements for attenuation / storm water storage will be assessed in accordance with TII methodology (Ref.3).

In addition to measures for the safe handling of fuels and lubricants (to be detailed in a site Environmental Management Plan (EMP)), the system will also be equipped with a hydrocarbon interceptor on the outlet. Any contamination of surface water will be captured in the hydrocarbon interceptor for off-site disposal at an authorised disposal facility.

Refuelling of diesel tanks for the electric generator package will take place within a bunded area where the surface water drainage network is equipped with a hydrocarbon interceptor. Any contaminated run-off will be captured in the hydrocarbon interceptor for off-site disposal at an authorised disposal facility.