

## DESIGNED AGAINST REFERENCE PRODUCT

co2\_mineralisation container (Carbfix) — anchored 3 key specs.

DESIGN DOSSIER · CONCEPT STAGE

# Carbon Capture

A concept-stage engineering design dossier: from the product brief to a buildable, costed design — modules and sub-modules, a full bill of materials with real manufacturer part numbers and live pricing, compliance and risk review, and recommended suppliers. Study-grade for early decision-making — not a for-construction or certified design.

### COST STACK — RAW MATERIALS TO INSTALLED PRICE

Raw materials BoM	£936,560.00
+ Assembly labour (25%)	£234,140.00
+ Factory overhead (18%)	£210,726.00
<b>= Factory COGS</b>	<b>£1,381,426.00</b>
+ Manufacturer margin (-13%)	£179,585.38
<b>= OEM transfer price</b>	<b>£1,561,011.38</b>
+ Channel markup — <i>direct</i> ( <i>no distribution</i> )	—
<b>= Channel list price</b>	<b>£1,561,011.38</b>
+ Installation (55%)	£858,556.26
<b>= Installed ASP</b>	<b>£2,419,567.64</b>



*Illustration only — generic class render, not a photograph of the actual unit. Used for visual reference; final geometry follows the engineering specification.*

### EX-WORKS COST VS BRIEF TARGET

Achieved ex-works	<b>£1,561,011</b>
Brief ceiling	£1,900,000
Position	<b>18% below ceiling (headroom £338,989)</b>

# Executive summary

This concept-stage dossier develops a CO<sub>2</sub> mineralisation system, to Skid-mounted CO<sub>2</sub> capture + mineral-carbonation plant capturing 1.0 t CO<sub>2</sub>/day in 30 wt% MEA, mineralising it with gypsum to 2.3 t/day CaCO<sub>3</sub> and recovering 4.0 t/day K<sub>2</sub>SO<sub>4</sub> fertiliser via KOH, with closed-loop MEA recovery and 249 × 25 kg bags/day of product. It is aimed at Industrial CO<sub>2</sub> emitters (cement, lime, anaerobic-digestion biogas, energy-from-waste) and agricultural/industrial-mineral off-takers in the UK and EU. Increasing regulatory pressure on industrial CO<sub>2</sub> emissions and growing market demand for circular-economy revenue streams from captured carbon.

## Design outcome

The design honours 6 of 17 brief constraints with no breaches. It delivers 1 t/day. The fully-costed design reaches £1.56M ex-works.

## Recommendation & next steps

This is a study-grade concept design for early decision-making, not a for-construction release. Recommended next steps before procurement: detailed design of the breached subsystems, request-for-quote against the named suppliers to firm the bill-of-materials pricing, and a prototype build to validate the physics and thermal assumptions.

# Brief and Requirements

What the product is and what it must do.

## OPERATIONAL HEADLINE — what this design must deliver

CO<sub>2</sub> CAPTURE CAPACITY TPD

**1 t/day**

## Physical specification

*Derived from structure\_containment.derived\_parameters — not LLM prose.*

Envelope volume	<b>104.04 m<sup>3</sup></b>
Maximum gross mass	<b>40,000 kg</b>

## Mission

Skid-mounted CO<sub>2</sub> capture + mineral-carbonation plant capturing 1.0 t CO<sub>2</sub>/day in 30 wt% MEA, mineralising it with gypsum to 2.3 t/day CaCO<sub>3</sub> and recovering 4.0 t/day K<sub>2</sub>SO<sub>4</sub> fertiliser via KOH, with closed-loop MEA recovery and 249 x 25 kg bags/day of product.

## Target customers

Industrial CO<sub>2</sub> emitters (cement, lime, anaerobic-digestion biogas, energy-from-waste) and agricultural/industrial-mineral off-takers in the UK and EU.

## Why now

Increasing regulatory pressure on industrial CO<sub>2</sub> emissions and growing market demand for circular-economy revenue streams from captured carbon.

## Performance characteristics

Numeric spec sheet for this product class — the resolved value the design must deliver for each metric.

### SCALE & GEOMETRY

METRIC	VALUE
Co <sub>2</sub> capture capacity tpd	<b>1.00 t/day</b> <
Co <sub>2</sub> capture capacity	<b>42.0 kg/h</b> <
Calcium carbonate output tpd	<b>2.30 t/day</b> <
Potassium sulfate output tpd	<b>3.90 t/day</b> <
Gypsum feedstock tpd	<b>3.10 t/day</b> <
Potassium hydroxide feedstock tpd	<b>2.60 t/day</b> <
Product bag weight	<b>25.0 kg</b> <

**PERFORMANCE**

METRIC	VALUE
Mea solvent concentration wt	<b>30.0 %</b> <

**CONSTRAINTS**

METRIC	VALUE
Unit cost ceiling	<b>1,900,000 GBP</b>
Mass ceiling	<b>40,000 kg</b>

Legend in spec <sup>3</sup> differs from brief by >5% outside class-typical range < computed from other metrics — not declared by the engine

# Brief provenance

What you asked for, and how we interpreted it.

*The original brief drives every downstream decision. The LLM-parsed brief shown alongside is what the engineering pipeline actually consumed — every module, BoM line, and compliance check is derived from that interpretation, not from the raw text.*

## Parse summary

Original brief: 634 words. LLM parsed it into a structured object with 544 tokens of content. Parser flagged 1 mandatory field as missing from the original brief. LLM inferred 4 additional safety standards (shown italicised below).

## 2.0 What you specified, and what the engine added

*Everything downstream is built from the engine's expanded reading of your brief. This block separates the two: your brief exactly as you wrote it, then each thing the engine inferred on top of it. Engine-added items are assumptions — sensible, but yours to confirm.*

### What you specified

*Your original brief, verbatim — no edits, no normalisation.*

Capture CO<sub>2</sub> at 1 tonne per day with 30 w% MEA, react with gypsum to form calcium carbonate, filter the calcium carbonate to form filtercake. Wash the cake with water to remove MEA. Air blow the cake and then dry with hot air. React filtrate with KOH solid to form K<sub>2</sub>SO<sub>4</sub>. Filter off the solid K<sub>2</sub>SO<sub>4</sub>. Reuse the recovered MEA to capture more CO<sub>2</sub>. Recrystallise the K<sub>2</sub>SO<sub>4</sub> to remove MEA from the K<sub>2</sub>SO<sub>4</sub>. Filter off the solids, dry solids with hot air. Distil wash water from CaCO<sub>3</sub> to recover the MEA and wash water. Package up the solids in 25 kg bags.

### What the engine added

*Inferred by the engine, not stated by you. Each is an assumption the design rests on.*

#### Cost ceiling - £1,900,000 ex-works

ENGINE-ADDED · DRIVES FEASIBILITY

You set no budget. The engine inferred a £1,900,000 ex-works ceiling AND uses it to drive the feasibility gate - every "below ceiling / under budget" verdict in this report is measured against a budget you never specified. Treat the headroom as engine self-assessment, not a margin against your number.

#### Gypsum feedstock - corrected to ~3.91 t/day

ENGINE-ADDED

You named gypsum as the calcium source but no rate. The engine first inferred ~3.1 t/day, then the reaction stoichiometry (to make the CaCO<sub>3</sub> from 1 t/day CO<sub>2</sub>) required ~3.91 t/day. The higher, stoichiometric figure is what the design sizes the gypsum feed system for.

#### Target market

ENGINE-ADDED

Cement / lime / anaerobic-digestion biogas / energy-from-waste CO<sub>2</sub> emitters, plus agricultural and industrial-mineral off-takers; UK + EU deployment.

#### Product tonnages

ENGINE-ADDED

~2.3 t/day precipitated calcium carbonate and ~3.9 t/day potassium sulfate (derived from the 1 t/day CO<sub>2</sub> capture rate).

### Potassium hydroxide feedstock

ENGINE-ADDED

~2.6 t/day KOH make-up (derived from the sulfate balance).

### Operating temperatures

ENGINE-ADDED

Ambient to 120 °C across reaction, drying and distillation; atmospheric to low-pressure operation.

### Production volume

ENGINE-ADDED

6 plants per year (used for the batch / amortisation basis).

### Regulatory list

ENGINE-ADDED

UKCA + CE, Pressure Equipment Directive 2014/68/EU, DSEAR + ATEX 2014/34/EU, COSHH, Machinery Directive 2006/42/EC, environmental permitting, GB + EU fertiliser regulation, BS EN ISO chemical-plant standards  
- all inferred from the chemistry and duty, none stated by you.

### Expected sub-modules

ENGINE-ADDED

The absorber/packing/demister, carbonation reactor, vacuum/belt filter, hot-air dryers, KOH dosing + reaction vessel, K<sub>2</sub>SO<sub>4</sub> filter + recrystalliser, wash-water distillation, MEA recovery loop, pumps/slurry handling, heat exchangers + utilities, instrumentation/control and bagging line were enumerated by the engine from your process steps.

## 2.1 Engine-expanded brief, as submitted to the pipeline

*The engine's expanded brief — your wording plus every engine-added item from 2.0, folded into one document. This is the exact text the pipeline consumed.*

### # CO<sub>2</sub> Capture and Mineralisation Plant Brief

We are designing a modular carbon-capture and mineral-carbonation chemical process plant that captures one tonne of CO<sub>2</sub> per day from a point-source flue gas using a 30 wt% aqueous monoethanolamine (MEA) solvent, then mineralises the captured CO<sub>2</sub> by reacting it with gypsum (calcium sulfate dihydrate) to precipitate calcium carbonate. The co-product sulfate is recovered as potassium sulfate fertiliser by reaction with potassium hydroxide, and the MEA solvent is regenerated and recycled. The plant is a skid-mounted, continuously-operated chemical plant producing two saleable solids — precipitated calcium carbonate and potassium sulfate — packaged in 25 kg bags.

Target market: industrial CO<sub>2</sub> emitters (cement, lime, anaerobic-digestion biogas, energy-from-waste) seeking on-site carbon capture with a revenue-generating mineralisation route, plus agricultural and industrial-mineral off-takers for the potassium sulfate and precipitated calcium carbonate products. UK and EU deployment.

Process description (continuous):

- Absorb CO<sub>2</sub> from the flue gas into 30 wt% aqueous MEA in a packed absorption column to form CO<sub>2</sub>-rich amine solution
- React the CO<sub>2</sub>-rich solution with gypsum (calcium sulfate dihydrate) in a stirred carbonation reactor to

precipitate calcium carbonate and release the sulfate to solution

- Filter the calcium carbonate slurry to form a filter cake; wash the cake with water to displace residual MEA; air-blow the cake then dry it with hot air
- React the sulfate-bearing filtrate with solid potassium hydroxide to form potassium sulfate and regenerate free MEA
- Filter off the solid potassium sulfate; return the recovered MEA to the absorber for re-use
- Recrystallise the potassium sulfate to remove residual MEA; filter off the purified solids and dry them with hot air
- Distil the calcium-carbonate wash water to recover MEA and reclaim the wash water
- Package the dried calcium carbonate and potassium sulfate solids into 25 kg bags

Key constraints:

- Capture capacity: 1 tonne CO<sub>2</sub> per day (approximately 42 kg/h, continuous)
- Product output: approximately 2.3 t/day precipitated calcium carbonate and approximately 3.9 t/day potassium sulfate
- Solvent: 30 wt% aqueous MEA, closed-loop with recovery via wash-water distillation and product recrystallisation; low make-up rate
- Feedstocks: gypsum (approximately 3.1 t/day), potassium hydroxide (approximately 2.6 t/day), process water
- Product purity: potassium sulfate to fertiliser grade (low chloride, MEA-free); calcium carbonate to industrial filler grade
- Utilities: low-pressure steam for the distillation reboiler, hot air for two drying stages, cooling water, electricity, instrument air
- Unit cost ceiling: £1,900,000 ex-works for the modular plant (realistic budget for a 1 tonne/day amine-capture + mineralisation pilot; tall packed columns are shipped as flanged segments and field-erected on a plinth beside the transportable skid modules)
- Operating temperature: ambient to 120 °C across reaction, drying and distillation; atmospheric to low-pressure operation
- Footprint: containerised / skid-mounted for transport on a standard trailer
- Annual production volume: 6 plants per year

Safety and regulatory:

- UKCA and CE marking
- Pressure Equipment Directive 2014/68/EU for pressurised vessels and the distillation column
- DSEAR and ATEX Directive 2014/34/EU for the MEA handling and drying areas (MEA is combustible)
- COSHH assessment for MEA and potassium hydroxide handling (corrosive, harmful)
- Machinery Directive 2006/42/EC for the rotating and process equipment
- Environmental permitting for the capture process and aqueous effluent
- GB and EU fertiliser regulation for the potassium sulfate product (low-chloride sulphate of potash)
- BS EN ISO standards for chemical plant piping, vessels and instrumentation

Sub-modules expected: CO<sub>2</sub> absorption column with packing and demister, gypsum carbonation stirred reactor, calcium-carbonate vacuum/belt filter with cake-wash and air-blow, hot-air cake dryers, potassium-hydroxide dosing and reaction vessel, potassium-sulfate filter and recrystalliser, wash-water distillation column with reboiler and condenser, MEA recovery and recycle loop with storage, process pumps and slurry handling, heat exchangers and steam/hot-air utilities, instrumentation and process control, and a solids bagging and packaging line for 25 kg bags.

## 2.2 LLM-interpreted brief, as consumed by the pipeline

Structured parse output. Every field shown here is what the downstream engineering stages actually read. Italicised values were inferred by the LLM, not stated in the original brief.

PROJECT ID	co2-capture-mineralisation-plant
PRODUCT DESCRIPTION	A modular, skid-mounted chemical process plant that captures 1 tonne of CO <sub>2</sub> per day using MEA solvent and mineralises it with gypsum to produce saleable calcium carbonate and potassium sulfate.
MISSION	To provide industrial CO <sub>2</sub> emitters with an on-site carbon capture solution that generates revenue through mineralisation into saleable solid products.
TARGET CUSTOMERS	Industrial CO <sub>2</sub> emitters (cement, lime, anaerobic-digestion biogas, energy-from-waste) and agricultural/industrial-mineral off-takers in the UK and EU.
WHY NOW	Increasing regulatory pressure on industrial CO <sub>2</sub> emissions and growing market demand for circular-economy revenue streams from captured carbon.
PARSER CONFIDENCE	HIGH
MISSING MANDATORY FIELDS	operating_environment

### CONSTRAINTS (PARSED)

unit_cost_ceiling	1900000 GBP
max_mass_kg	40000 · <i>inferred by LLM</i>
max_dimensions_mm	2550 x 13600 x 3000 mm · <i>inferred by LLM</i>
co2_capture_capacity_tpd	1 t/day
co2_capture_capacity_kg_per_hr	42 kg/h
calcium_carbonate_output_tpd	2.3 t/day
potassium_sulfate_output_tpd	3.9 t/day
gypsum_feedstock_tpd	3.1 t/day
potassium_hydroxide_feedstock_tpd	2.6 t/day
mea_solvent_concentration_wt_percent	30 %
product_bag_weight_kg	25 kg
target_process	Skid-mounted modular assembly and field erection
target_material	316/316L stainless-steel process fabrication; products: calcium carbonate + potassium sulfate · <i>inferred by LLM</i>
batch_size	6
design_life	20-25 yr (chemical-process-plant design life; static process equipment + pressure vessels per PED / ASME VIII; periodic re-inspection) · <i>inferred by LLM</i>
operating_environment	- °C to - °C · <i>not specified in brief</i>

### SAFETY STANDARDS (PARSED)

2014/68/EU	Pressure Equipment Directive
2014/34/EU	ATEX Directive
2006/42/EC	Machinery Directive
BS EN 13480	<i>Metallic industrial piping · inferred</i>
BS EN ISO 12100	<i>Safety of machinery - General principles for design · inferred</i>
IEC 60204-1	<i>Safety of machinery - Electrical equipment of machines · inferred</i>
IEC 61326-1	<i>Electrical equipment for measurement, control and laboratory use · inferred</i>

### ADDITIONAL CONSTRAINTS (PARSED)

- Process temperatures range from ambient to 120 °C across reaction, drying and distillation.
- Requires low-pressure steam, hot air, cooling water, electricity, and instrument air utilities.
- Potassium sulfate must meet fertiliser grade (low chloride, MEA-free) and calcium carbonate must meet industrial filler grade.

- Must comply with DSEAR and COSHH for handling combustible MEA and corrosive potassium hydroxide.

# Brief compliance & design trade-offs

Brief targets compared against design achieved.

Every constraint stated in the brief is laid alongside the value the design actually achieves. Breaches are flagged in red. Where a breach exists, the CAPEX / OPEX / output trade-off narrative below the table explains which engineering lever was pulled and which was relaxed.

## 6 of 17 brief constraints verified PASS · 11 unverified

The design verifiably meets 6 of 17 brief constraints. 11 could not be auto-verified — the design's achieved value was not computed into the engineering contract, so each is shown "—" and must be confirmed in the engineering narrative before procurement, NOT assumed to pass.

## Brief targets vs design achieved

CONSTRAINT	BRIEF TARGET	DESIGN ACHIEVED	STATUS	DELTA
Max gross mass	40,000 kg	-	—	
Co2 capture capacity tpd	1 t/day	-	—	
Co2 capture capacity	42 kg/h	-	—	
Calcium carbonate output tpd	2.3 t/day	-	—	
Potassium sulfate output tpd	3.9 t/day	-	—	
Gypsum feedstock tpd	3.1 t/day	-	—	
Potassium hydroxide feed-stock tpd	2.6 t/day	-	—	
Mea solvent concentration wt	30 %	-	—	
Product bag weight	25 kg	-	—	
External envelope	2550 x 13600 x 3000 mm	-	—	-
Process temperatures range from ambient to 120 °C across reaction, drying and distillation.	stated	verify in narrative	—	check
Unit cost (CAPEX, ex-works)	£1.9M	£1.56M	PASS	-18%
Design life	20-25 yr (chemical-process-plant design life; static process equipment + pressure vessels per PED / ASME VIII; periodic re-inspection)	20-25 yr (chemical-process-plant design life; static process equipment + pressure vessels per PED / ASME VIII; periodic re-inspection)	PASS	0%
Annual batch	6/yr	6/yr	PASS	0%
Requires low-pressure steam, hot air, cooling water, electricity, and instrument air utilities.	stated	adopted	PASS	confirmed

**Potassium sulfate must meet fertiliser grade (low chloride, MEA-free) and calcium carbonate must meet industrial filler grade.**

stated

adopted

PASS

confirmed

**Must comply with DSEAR and COSHH for handling combustible MEA and corrosive potassium hydroxide.**

stated

adopted

PASS

confirmed

### Notes on corrected / unverified constraints

**Process temperatures range from ambient to 120 °C across reaction, drying and distillation.: brief stated -> design verify in narrative (check)**

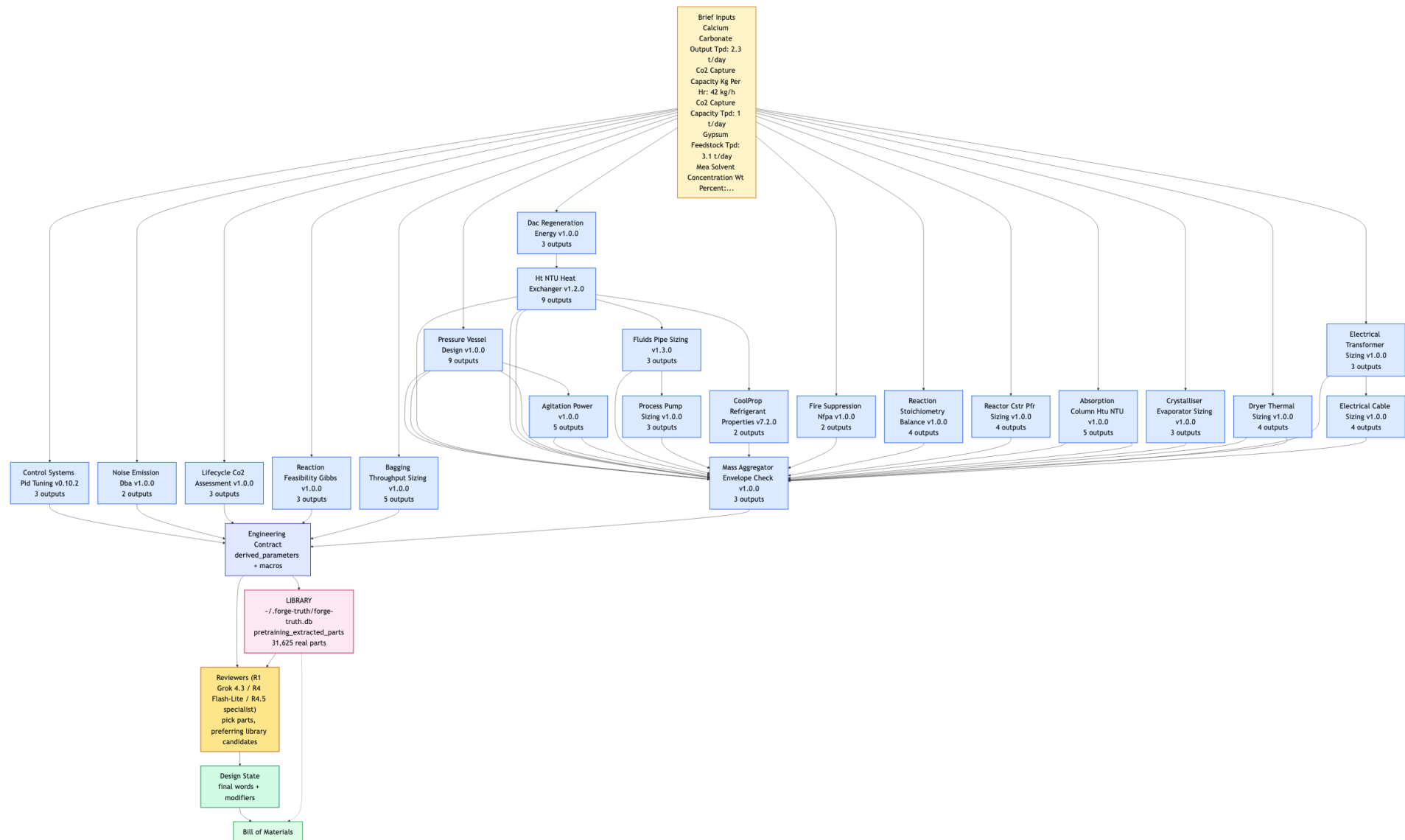
Stated constraint contains a measurable value - confirm the design narrative explicitly honours this requirement before sign-off.

### Design decision rationale

Every brief constraint is met by the design as shown. No CAPEX / OPEX / output trade-off was forced — the integer-feasible configuration honours the brief on every axis.

# How the whole plant was computed

These are the cross-cutting, system-level tools — the ones whose numbers belong to the plant as a whole, not to any single module. The brief feeds every engineering tool; each tool's output flows into the Engineering Contract, which drives the parts Library, the Reviewers, and finally the Bill of Materials. The worked calculation for a tool that sizes one module's equipment now sits with that module, under its “How this module was computed” heading.



The diagram shows the full whole-plant data-flow: each box is an engineering tool that ran and arrows show the real dependencies (feeds\_into graph from the ClassToolPlan). The worked calculations for module-specific tools are shown with their module; a one-line-per-tool provenance index (name, version, licence, source) is at the end of the report.

# System Overview — how this design works

Plain-English summary of the system architecture and how the modules interact.

## What it does

A modular, skid-mounted chemical process plant that captures 1 tonne of CO<sub>2</sub> per day using MEA solvent and mineralises it with gypsum to produce saleable calcium carbonate and potassium sulfate. To provide industrial CO<sub>2</sub> emitters with an on-site carbon capture solution that generates revenue through mineralisation into saleable solid products. Intended for Industrial CO<sub>2</sub> emitters (cement, lime, anaerobic-digestion biogas, energy-from-waste) and agricultural/industrial-mineral off-takers in the UK and EU.

## How it works

**Skid Structure & Containment:** A transportable skid (within the 2.59 m road-transport height envelope) with 110% chemical bunding carries the reactors, exchangers, pumps and tanks; the tall packed columns ship as flanged segments and are field-erected on a plinth beside the skid, so the 2.59 m envelope governs the transportable modules, not the erected ~6 m column height. It connects to Gypsum Carbonation Reactor via mechanical (reactors + exchangers saddle-mounted on the bunded skid (d2.59 m); tall packed columns field-erected on an adjacent plinth). **Thermal Utilities:** The thermal utility module provides 450 kg/h of steam via a Fulton Electropack EP100 electric boiler (300 kW), supporting the distillation reboiler, K<sub>2</sub>SO<sub>4</sub> crystalliser heater, and MEA stripping pot.

It connects to MEA Absorption & Capture via thermal (180 kg/h reboiler steam + hot air to dryers + distillation). **MEA Absorption & Capture:** The MEA absorption module is engineered to capture 1 tonne of CO<sub>2</sub> per day, utilizing a 316L stainless-steel packed column designed according to Packed Absorption/Stripping Column (HTU-NTU + flooding) v1.0.0. It connects to Gypsum Carbonation Reactor via fluid loop (CO<sub>2</sub>-rich MEA ' gypsum carbonation reactor (2.3 t/day CaCO<sub>3</sub>)).

**CaCO<sub>3</sub> Filtration & Drying:** CaCO<sub>3</sub> slurry is vacuum-belt-filtered, the cake water-washed to displace MEA, air-blown and hot-air dried to a free-flowing filler-grade powder. It connects to Gypsum Carbonation Reactor via fluid loop (CO<sub>2</sub>-rich MEA ' gypsum carbonation reactor (2.3 t/day CaCO<sub>3</sub>)). **MEA Recovery & Recycle:** Wash-water distillation recovers MEA and reclaims wash water in a closed solvent loop, minimising MEA make-up and effluent.

It connects to Gypsum Carbonation Reactor via fluid loop (CO<sub>2</sub>-rich MEA ' gypsum carbonation reactor (2.3 t/day CaCO<sub>3</sub>)). **Gypsum Carbonation Reactor:** The gypsum carbonation reactor module integrates Rushton Agitation Power v1.0.0 and Reaction Stoichiometry Mass Balance v1.0.0 results to produce 2.3 t/day CaCO<sub>3</sub> and 3.9 t/day K<sub>2</sub>SO<sub>4</sub> from 3.1 t/day gypsum and 2.6 t/day KOH. It connects to MEA Absorption & Capture via fluid loop (sulfate filtrate ' K<sub>2</sub>SO<sub>4</sub> recovery; regenerated MEA ' recovery loop).

**K<sub>2</sub>SO<sub>4</sub> Recovery & Crystallisation:** KOH converts the sulfate filtrate to fertiliser-grade K<sub>2</sub>SO<sub>4</sub> and regenerates free MEA; K<sub>2</sub>SO<sub>4</sub> is centrifuged, recrystallised MEA-free and hot-air dried. It connects to MEA Absorption & Capture via fluid loop (sulfate filtrate ' K<sub>2</sub>SO<sub>4</sub> recovery; regenerated MEA ' recovery

loop). Electrical Distribution: A Form-4 MCC with IP55 VSDs and a cast-resin transformer supplies the 561 kW plant load.

It connects to MEA Absorption & Capture via electrical bus (561 kW to pumps, agitators, blowers, baggers). Process Instrumentation: Coriolis flow, guided-radar level, slurry density and RTD temperature instruments close the mass balance and feed the control system. It connects to Process Control System via data (Coriolis flow + density + level close the CaCO<sub>3</sub>/K<sub>2</sub>SO<sub>4</sub> mass balance).

Process Control System: A safety PLC + SCADA sequences and interlocks the full mineralisation process and records mass balance for product certification. It connects to Gypsum Carbonation Reactor via control (PLC sequences carbonation pH/ORP + KOH dosing + crystalliser). Safety & Protection: DSEAR/ATEX zoning, SIL-2 emergency shutdown, pressure relief and gas detection protect the MEA and corrosive-KOH handling areas.

It connects to Process Control System via data (gas detection + ESD chain trip the PLC). Bagging & Packaging: Net-weigh bagging fills, seals and palletises 249 × 25 kg bags/day of CaCO<sub>3</sub> and K<sub>2</sub>SO<sub>4</sub> from dedicated day-silos. It connects to Thermal Utilities via thermal path (bagging line heat dissipation to cooling skid).

## Modules at a glance

*The 12 modules below are described in full later in the report. This list orients the reader before they enter the per-module detail.*

<b>Skid Structure &amp; Containment</b>	A transportable skid (within the 2.59 m road-transport height envelope) with 110% chemical bunding carries the reactors, exchangers, pumps and tanks; the tall packed columns ship as flanged segments and are field-erected on a plinth beside the skid, so the 2.59 m envelope governs the transportable modules, not the erected ~6 m column height.
<b>Thermal Utilities</b>	The thermal utility module provides 450 kg/h of steam via a Fulton Electropack EP100 electric boiler (300 kW), supporting the distillation reboiler, K <sub>2</sub> SO <sub>4</sub> crystalliser heater, and MEA stripping pot.
<b>MEA Absorption &amp; Capture</b>	The MEA absorption module is engineered to capture 1 tonne of CO <sub>2</sub> per day, utilizing a 316L stainless-steel packed column designed according to Packed Absorption/Stripping Column (HTU-NTU + flooding) v1.0.0.
<b>CaCO<sub>3</sub> Filtration &amp; Drying</b>	CaCO <sub>3</sub> slurry is vacuum-belt-filtered, the cake water-washed to displace MEA, air-blown and hot-air dried to a free-flowing filler-grade powder.
<b>MEA Recovery &amp; Recycle</b>	Wash-water distillation recovers MEA and reclaims wash water in a closed solvent loop, minimising MEA make-up and effluent.
<b>Gypsum Carbonation Reactor</b>	The gypsum carbonation reactor module integrates Rushton Agitation Power v1.0.0 and Reaction Stoichiometry Mass Balance v1.0.0 results to produce 2.3 t/day CaCO <sub>3</sub> and 3.9 t/day K <sub>2</sub> SO <sub>4</sub> from 3.1 t/day gypsum and 2.6 t/day KOH.

<b>K2SO4 Recovery &amp; Crystallisation</b>	KOH converts the sulfate filtrate to fertiliser-grade K2SO4 and regenerates free MEA; K2SO4 is centrifuged, recrystallised MEA-free and hot-air dried.
<b>Electrical Distribution</b>	A Form-4 MCC with IP55 VSDs and a cast-resin transformer supplies the 561 kW plant load.
<b>Process Instrumentation</b>	Coriolis flow, guided-radar level, slurry density and RTD temperature instruments close the mass balance and feed the control system.
<b>Process Control System</b>	A safety PLC + SCADA sequences and interlocks the full mineralisation process and records mass balance for product certification.
<b>Safety &amp; Protection</b>	DSEAR/ATEX zoning, SIL-2 emergency shutdown, pressure relief and gas detection protect the MEA and corrosive-KOH handling areas.
<b>Bagging &amp; Packaging</b>	Net-weigh bagging fills, seals and palletises 249 × 25 kg bags/day of CaCO3 and K2SO4 from dedicated day-silos.

## The numbers behind it

*Every figure below is templated directly from computed contract quantities; any figure whose source quantities were absent has been omitted. No language model was involved in generating this block.*

### DAC (REGENERATION ENERGY)

Dac (Regeneration Energy) computed regeneration energy kwh per t CO2 = 674 kWh/t, regeneration heat demand gj per t CO2 = 2.43 GJ/t, regeneration time minutes = 20 min.

### LIFECYCLE CO2 (ASSESSMENT)

Lifecycle CO2 (Assessment) computed plant lifecycle CO2 t = 3,412 t, plant annual CO2 t = 171 t, plant embodied CO2 t = 30.6 t.

### REACTION (STOICHIOMETRY BALANCE)

Reaction (Stoichiometry Balance) computed gypsum feed t day = 3.91 t/day, caco3 product t day = 2.27 t/day, k2so4 product t day = 3.96 t/day, koh makeup t day = 2.55 t/day.

### REACTION (FEASIBILITY GIBBS)

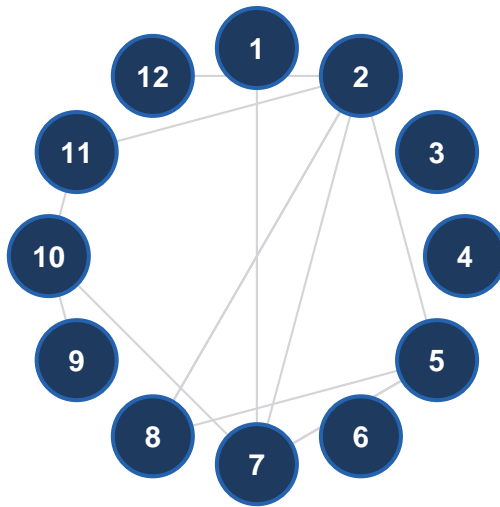
Reaction (Feasibility Gibbs) computed k2so4 loop delta g kj mol = -95.84 kJ/mol, k2so4 loop equilibrium K = 61,621,006,169,164,950, k2so4 loop feasibility flag = 1.

### MASS AGGREGATOR (ENVELOPE CHECK)

Mass Aggregator (Envelope Check) computed total plant mass = 18,680 kg, mass budget utilisation = 77.8 %, recommended container count = 1.

# Module Map

Figure 1. The 12 modules and how they connect.



## MODULE LEGEND

<b>1</b>	Skid Structure & Containment
<b>2</b>	Thermal Utilities
<b>3</b>	MEA Absorption & Capture
<b>4</b>	CaCO <sub>3</sub> Filtration & Drying
<b>5</b>	MEA Recovery & Recycle
<b>6</b>	Gypsum Carbonation Reactor
<b>7</b>	K <sub>2</sub> SO <sub>4</sub> Recovery & Crystallisation
<b>8</b>	Electrical Distribution
<b>9</b>	Process Instrumentation
<b>10</b>	Process Control System
<b>11</b>	Safety & Protection
<b>12</b>	Bagging & Packaging

# Bill of Materials

The complete priced parts list — 111 lines totalling £936,560 ex-works, grouped by module. Every line is consolidated here from the per-sub-module tables inside the module sections that follow; module subtotals and the grand total reconcile with those tables and with the Cost-by-Module summary on the next page.

## 1. Skid Structure & Containment

**£43,200**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Process Skid Frame	—	welded galvanized structural-steel skid frame — fabricated	x1	~£15,000.00	<b>£15,000.00</b>	— OK
Field-erection Column Plinth	—	reinforced column support plinth and frame — fabricated	x1	~£7,500.00	<b>£7,500.00</b>	— OK
Chemical Bund	—	GRP 110% bunded containment tray — fabricated	x1	~£7,000.00	<b>£7,000.00</b>	— OK
Vessel Supports + Saddles	—	bolted structural-steel vessel saddle — fabricated	x8	~£650.00	<b>£5,200.00</b>	— OK
Access Platform + Ladders	—	GRP grating access platform and ladders — fabricated	x1	~£8,500.00	<b>£8,500.00</b>	— -

## 2. Thermal Utilities

**£62,600**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Electric Steam Generator	Fulton	Electropack EP100 (multi-unit package, frame count TBD at quotation)	x1	~£35,000.00	<b>£35,000.00</b>	— OK
Hot-air Process Heater	Kanthal	finned electric duct air heater — made to order	x2	~£7,000.00	<b>£14,000.00</b>	— OK
Cooling-water Skid	Pfannenbergl	closed-loop cooling-water skid — packaged	x1	~£9,000.00	<b>£9,000.00</b>	— OK
Condensate + Feedwater Vessel	—	fabricated condensate/feedwater vessel — bespoke vessel	x1	~£4,600.00	<b>£4,600.00</b>	— OK

## 3. MEA Absorption & Capture

**£84,700**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Packed Absorber Column	Sulzer	<a href="#">MELLAPAK 250.Y</a>	x1	~£26,000.00	<b>£26,000.00</b>	— OK
Structured Packing	Sulzer	<a href="#">MELLAPAK 250.Y</a>	x1	~£5,000.00	<b>£5,000.00</b>	— OK
MEA Circulation Pump	Grundfos	<a href="#">CRNE 5-8</a>	x2	~£3,850.00	<b>£7,700.00</b>	— OK
Rich/lean MEA Exchanger	Alfa Laval	<a href="#">M10-BFG</a>	x1	~£10,000.00	<b>£10,000.00</b>	— OK

Lean-amine Cooler	Alfa Laval	<a href="#">M6-FG</a>	x1	~£6,200.00	<b>£6,200.00</b>	— OK
Rich-amine Inlet Cooler	Alfa Laval	<a href="#">CB60</a>	x1	~£3,800.00	<b>£3,800.00</b>	— OK
Spare Cross-exchanger Plate Pack	Alfa Laval	<a href="#">M10-BFG plate pack</a>	x1	~£10,000.00	<b>£10,000.00</b>	— OK
Flue-gas Inlet Blower	Howden	centrifugal process fan — made to order	x1	~£8,500.00	<b>£8,500.00</b>	— OK
MEA Storage Tank	—	fabricated 316L atmospheric storage tank — bespoke vessel	x1	~£7,500.00	<b>£7,500.00</b>	— OK

#### 4. CaCO<sub>3</sub> Filtration & Drying

**£76,600**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Caco3 Vacuum Belt Filter	BHS-Sonthofen	<a href="#">BF (horizontal vacuum belt filter)</a>	x1	~£24,000.00	<b>£24,000.00</b>	— OK
Cake Wash-water Manifold	—	fabricated 316L wash-bar manifold — made to order	x1	~£2,800.00	<b>£2,800.00</b>	— OK
Filter Vacuum Pump	Busch	Dolphin LB 0250	x1	~£7,000.00	<b>£7,000.00</b>	— OK
Filtrate Receiver + Pump	Grundfos	<a href="#">CRNE 10-4</a>	x1	~£4,100.00	<b>£4,100.00</b>	— OK
Cake Air-blow Blower	Becker	SV 8.190/2	x1	~£4,300.00	<b>£4,300.00</b>	Est. OK
Caco3 Hot-air Dryer	GEA	<a href="#">FLUIDBED VI-BRO-FLUIDISER</a>	x1	~£21,000.00	<b>£21,000.00</b>	— OK
Dryer Inlet Air-heater Battery	Heating Energy Systems	finned process air-heater battery — made to order	x1	~£4,200.00	<b>£4,200.00</b>	— OK
Dryer Exhaust Heat-recovery Exchanger	GEA	<a href="#">FLUIDBED VI-BRO-FLUIDISER</a>	x1	~£6,800.00	<b>£6,800.00</b>	— OK
Dryer Condensate Cooler	Alfa Laval	<a href="#">CB30</a>	x1	~£2,400.00	<b>£2,400.00</b>	— OK

#### 5. MEA Recovery & Recycle

**£77,250**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
MEA Distillation Column	Koch-Glitsch	fabricated 316L packed stripping column — bespoke vessel	x1	~£20,000.00	<b>£20,000.00</b>	— OK
Distillation Reboiler	Alfa Laval	<a href="#">CB60 (brazed-plate reboiler)</a>	x1	~£8,900.00	<b>£8,900.00</b>	— OK
Overhead Condenser	Alfa Laval	<a href="#">CB30 (brazed-plate condenser)</a>	x1	~£21,500.00	<b>£21,500.00</b>	— OK
Feed/bottoms Economiser	Alfa Laval	<a href="#">M6-FG</a>	x1	~£4,800.00	<b>£4,800.00</b>	— OK
Reflux Subcooler	Alfa Laval	<a href="#">CB30</a>	x1	~£3,000.00	<b>£3,000.00</b>	— OK
MEA Recycle Pump	Grundfos	<a href="#">CRNE 3-5</a>	x2	~£3,850.00	<b>£7,700.00</b>	— OK
Wash-water Feed Pump	Grundfos	<a href="#">CRNE 10-5</a>	x1	~£3,850.00	<b>£3,850.00</b>	— OK

Reclaimed Wash-water Tank	fabricated	fabricated 316L stainless insulated buffer tank, 3 m <sup>3</sup> — made to order (hot MEA-recovery loop @20 °C)	x1	~£7,500.00	<b>£7,500.00</b>	— OK
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## 6. Gypsum Carbonation Reactor

**£106,610**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Reactor Ph Probe	Endress+Hauser	<a href="#">CPS11D</a>	x2	~£2,200.00	<b>£4,400.00</b>	— OK
Reactor ORP Probe	Endress+Hauser	<a href="#">CPS12D</a>	x1	~£1,500.00	<b>£1,500.00</b>	— OK
Reactor Slurry Density Meter	Endress+Hauser	<a href="#">Promass Q 300</a>	x1	~£7,800.00	<b>£7,800.00</b>	— OK
Reactor Temperature Sensor	Endress+Hauser	<a href="#">iTHERM TM411</a>	x2	~£1,100.00	<b>£2,200.00</b>	— >2x
Instrument Junction Box	Spelsberg	<a href="#">81040001</a>	x4	~£40.00	<b>£160.00</b>	— <5x
Gypsum Feed Hopper + Screw	Schenck Process	<a href="#">MULTICOR</a>	x1	~£9,800.00	<b>£9,800.00</b>	— OK
Caco3 Slurry Transfer Pump	SEEPEX	<a href="#">BN 35-6L</a>	x2	~£6,000.00	<b>£12,000.00</b>	— OK
Reactor Slurry Recirculation Pump	Warman	<b>WGR 40</b>	x1	~£5,400.00	<b>£5,400.00</b>	— OK
Reactor Overflow Launder	—	fabricated 316L overflow launder — made to order	x1	~£1,800.00	<b>£1,800.00</b>	— OK
Stirred Carbonation Reactor	De Dietrich	fabricated jacketed 316L stirred - tank reactor — bespoke vessel	x1	~£24,000.00	<b>£24,000.00</b>	— OK
Carbonation Maturation Vessel	—	fabricated 316L maturation vessel — bespoke vessel	x1	~£14,000.00	<b>£14,000.00</b>	— OK
CO2 Sparger Ring	—	fabricated 316L ring sparger — made to order	x1	~£2,400.00	<b>£2,400.00</b>	— OK
Carbonation Static Mixer	Sulzer	<a href="#">SMV</a>	x1	~£3,200.00	<b>£3,200.00</b>	— OK
Reactor Agitator	Ekato	<a href="#">ISOJET</a>	x1	~£11,000.00	<b>£11,000.00</b>	— OK
Agitator Drive Motor	ABB	<a href="#">M3BP 132S</a>	x1	~£1,600.00	<b>£1,600.00</b>	— OK
Agitator Reduction Gearbox	SEW-Eurodrive	<a href="#">R97</a>	x1	~£2,250.00	<b>£2,250.00</b>	— OK
Agitator Shaft Mechanical Seal	EagleBurgmann	<a href="#">Cartex-DN</a>	x1	~£3,100.00	<b>£3,100.00</b>	— OK

## 7. K2SO4 Recovery & Crystallisation

**£160,750**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
KOH Reaction Vessel	De Dietrich	fabricated jacketed 316L agitated vessel — bespoke vessel	x1	~£19,000.00	<b>£19,000.00</b>	— OK
KOH Dissolution + Make-up Tank	—	fabricated 316L agitated dissolution tank — bespoke vessel	x1	~£12,000.00	<b>£12,000.00</b>	— OK

MEA Stripper Reboil Pot	—	fabricated jacketed 316L stripping pot — bespoke vessel	x1	~£10,000.00	<b>£10,000.00</b>	—	<b>OK</b>
KOH Solids Dosing Feeder	Gericke	GLD 115	x1	~£15,500.00	<b>£15,500.00</b>	—	<b>OK</b>
K2so4 Pusher Centrifuge	Andritz	<a href="#">SZ (frame TBD at quotation)</a>	x1	~£22,500.00	<b>£22,500.00</b>	—	<b>OK</b>
K2so4 Slurry Feed Pump	SEEPEX	BN 17-6L	x2	~£6,000.00	<b>£12,000.00</b>	—	<b>OK</b>
Mother-liquor Recycle Pump	Grundfos	<a href="#">CRNE 5-6</a>	x1	~£3,850.00	<b>£3,850.00</b>	—	<b>OK</b>
K2so4 Recrystalliser	GEA Messo	forced-circulation crystalliser — bespoke package	x1	~£21,000.00	<b>£21,000.00</b>	—	<b>OK</b>
K2so4 Hot-air Dryer	GEA	<a href="#">FLUIDBED VI-BRO-FLUIDISER</a>	x1	~£22,000.00	<b>£22,000.00</b>	—	<b>OK</b>
Crystalliser Circulation Heater	Alfa Laval	<a href="#">CB110</a>	x1	~£8,500.00	<b>£8,500.00</b>	—	<b>OK</b>
Crystalliser Product Cooler	Alfa Laval	<a href="#">M6-FG</a>	x1	~£5,200.00	<b>£5,200.00</b>	—	<b>OK</b>
Crystalliser Vacuum Condenser	GEA	<a href="#">FLUIDBED VI-BRO-FLUIDISER</a>	x1	~£9,200.00	<b>£9,200.00</b>	—	<b>OK</b>

**8. Electrical Distribution****£90,330**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Motor Control Centre	ABB	<a href="#">MNS Form-4 motor control centre — configured</a>	x1	~£18,000.00	<b>£18,000.00</b>	— -
Power + Control Cabling	Prysmian	AFUMEX SWA LSZH cable bundle — made to order	x1	~£9,000.00	<b>£9,000.00</b>	— <b>&gt;2x</b>
Busbar + Distribution Board	Schneider Electric	Acti9 Isobar B	x1	~£2,400.00	<b>£2,400.00</b>	Est. <b>&gt;2x</b>
Cable Transit Frames	Roxtec	<a href="#">ECF0001600021</a>	x4	~£480.00	<b>£1,920.00</b>	— <b>OK</b>
Cable Glands	CMP Products	<b>CMP CW 20S</b>	x120	~£6.00	<b>£720.00</b>	Est. <b>OK</b>
Variable-speed Drives	ABB	<b>ACS580-01</b>	x6	~£1,700.00	<b>£10,200.00</b>	Est. <b>OK</b>
Blower/centrifuge Vsds	ABB	<b>ACS580-07</b>	x2	~£4,200.00	<b>£8,400.00</b>	Est. <b>&gt;2x</b>
Soft Starters	Schneider Electric	<a href="#">ATS22D32S6</a>	x3	~£650.00	<b>£1,950.00</b>	— -
Drive Fieldbus Modules	ABB	<a href="#">FPNO-21</a>	x8	~£210.00	<b>£1,680.00</b>	— -
Distribution Transformer	Schneider Electric	Trihal 800 kVA cast-resin transformer	x1	~£32,000.00	<b>£32,000.00</b>	Est. <b>OK</b>
Motor Contactors	ABB	<b>AF38-30-00-13</b>	x14	~£95.00	<b>£1,330.00</b>	Est. <b>OK</b>
Motor-protection Relays	ABB	<a href="#">EF19-18.9</a>	x14	~£110.00	<b>£1,540.00</b>	— -
Motor-protection Circuit Breakers	ABB	<b>MS132-25</b>	x14	~£85.00	<b>£1,190.00</b>	Est. <b>&lt;.5x</b>

**9. Process Instrumentation****£88,400**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Electromagnetic Flow Meters	Endress+Hauser	<a href="#">Promag W 400</a>	x4	~£3,600.00	<b>£14,400.00</b>	— <b>&gt;2x</b>

Radar Level Transmitters	Endress+Hauser	<a href="#">Micropilot FMR62</a>	x6	~£3,000.00	<b>£18,000.00</b>	Est. <b>OK</b>
Ph/conductivity Analysers	Endress+Hauser	<a href="#">Liquiline CM442</a>	x4	~£2,800.00	<b>£11,200.00</b>	— <b>&gt;2x</b>
Temperature Transmitters	Endress+Hauser	<a href="#">iTHERM TM411</a>	x12	~£650.00	<b>£7,800.00</b>	— -
Pressure Transmitters	Emerson	<a href="#">Rosemount 3051</a>	x8	~£1,200.00	<b>£9,600.00</b>	— <b>&gt;2x</b>
CO2 Gas Analyser	ABB	<a href="#">EL3060 Uras26</a>	x2	~£9,500.00	<b>£19,000.00</b>	— <b>&gt;2x</b>
Slurry Density Meters	Emerson	<a href="#">Micro Motion 7826</a>	x2	~£4,200.00	<b>£8,400.00</b>	— <b>&gt;2x</b>

## 10. Process Control System

**£16,920**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Plant PLC Controller	Siemens	<a href="#">6ES7515-2UM02-0AB0</a>	x1	~£3,800.00	<b>£3,800.00</b>	Est. <b>OK</b>
Remote I/o Racks	Siemens	<a href="#">6ES7155-6AU01-0CN0</a>	x3	~£1,500.00	<b>£4,500.00</b>	Est. -
Digital I/o Cards	Siemens	<a href="#">6ES7131-6BH01-0BA0</a>	x16	~£95.00	<b>£1,520.00</b>	Est. -
Analogue I/o Cards	Siemens	<a href="#">6ES7134-6GF00-0AA1</a>	x12	~£180.00	<b>£2,160.00</b>	Est. -
HMI Panel	Siemens	<a href="#">6AV2123-2MA03-0AX0</a>	x1	~£1,300.00	<b>£1,300.00</b>	Est. -
Control-network Switch	Siemens	<a href="#">6GK5008-0BA10-1AB2</a>	x2	~£220.00	<b>£440.00</b>	— -
Marshalling + Control Cabinet	Rittal	<a href="#">VX25 8284.500</a>	x1	~£3,200.00	<b>£3,200.00</b>	— <b>OK</b>

## 11. Safety & Protection

**£57,860**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Pressure Relief Valves	LESER	<a href="#">Type 441</a>	x6	~£900.00	<b>£5,400.00</b>	— <b>OK</b>
Safety Shower + Eyewash	Hughes Safety Showers	<a href="#">EXP-MH-14G/45G</a>	x2	~£2,200.00	<b>£4,400.00</b>	— <b>&gt;2x</b>
Vent Flame Arrestor	Protego	<a href="#">BE/HF</a>	x2	~£2,600.00	<b>£5,200.00</b>	— -
Nitrogen Blanketing Skid	Protego	<a href="#">DK/ES blanketing valve</a>	x1	~£3,400.00	<b>£3,400.00</b>	— <b>OK</b>
CO2 + VOC Gas Detector	Dräger	<a href="#">Polytron 8700</a>	x4	~£2,400.00	<b>£9,600.00</b>	Est. <b>&gt;2x</b>
CO2 Asphyxiation Detectors	Dräger	<a href="#">Polytron 8200</a>	x4	~£1,900.00	<b>£7,600.00</b>	Est. <b>OK</b>
Amine-vapour Detectors	Dräger	<a href="#">Polytron 8700</a>	x3	~£2,100.00	<b>£6,300.00</b>	— <b>&gt;2x</b>
Flame Detector	Dräger	<a href="#">Flame 2700</a>	x2	~£3,800.00	<b>£7,600.00</b>	— <b>&gt;2x</b>
Emergency Shutdown System	Siemens	<a href="#">3SK1112-1BB40</a>	x1	~£200.00	<b>£200.00</b>	Est. -
Safety Relays	Siemens	<a href="#">3SK1121-1AB40</a>	x8	~£180.00	<b>£1,440.00</b>	Est. -
Sil-rated Isolation Barriers	Pepperl+Fuchs	<a href="#">KFD2-STC4-Ex1</a>	x12	~£160.00	<b>£1,920.00</b>	— <b>&gt;2x</b>
Gas-detection Controller	Dräger	<a href="#">Polytron 8700</a>	x1	~£4,800.00	<b>£4,800.00</b>	— <b>&gt;2x</b>

## 12. Bagging & Packaging

**£71,340**

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Open-mouth Bagging Machine	Premier Tech	<b>OML-D</b>	x1	~£35,000.00	<b>£35,000.00</b>	— <b>OK</b>
Bag Heat Sealer	Audion	<b>Sealkon</b>	x1	~£3,500.00	<b>£3,500.00</b>	— <b>OK</b>
Sealer Jaw Heating Element	Audion	<b>Sealkon heating element</b>	x2	~£320.00	<b>£640.00</b>	— -
Shrink-wrap Tunnel Heater	Italdibipack	<b>Tunnel 5070</b>	x1	~£7,200.00	<b>£7,200.00</b>	— <b>OK</b>
Bag-mouth Pre-heater	—	<b>infrared bag-seam pre-heat bar — made to order</b>	x1	~£1,400.00	<b>£1,400.00</b>	— <b>OK</b>
Product Storage Silo	—	<b>welded steel day- - silo with discharge cone — fabricated</b>	x2	~£6,000.00	<b>£12,000.00</b>	— <b>OK</b>
Pallet Wrapper	Robopac	<b>Rotoplat 308</b>	x1	~£6,800.00	<b>£6,800.00</b>	— -
Bag Take-away Conveyor	Interroll	<b>belt conveyor module — configured</b>	x1	~£4,800.00	<b>£4,800.00</b>	— -

**Grand total — all modules (111 lines)**

**£936,560.00**

*SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.*

# Cost by Module

Per-module raw-materials Bill-of-Materials subtotal, the sum across all modules, and a component-class breakdown of where the spend goes. The numbers reconcile with the per-sub-module BoM tables inside each module section.

Cost by module		
1.	Skid Structure & Containment	£43,200.00
2.	Thermal Utilities	£62,600.00
3.	MEA Absorption & Capture	£84,700.00
4.	CaCO3 Filtration & Drying	£76,600.00
5.	MEA Recovery & Recycle	£77,250.00
6.	Gypsum Carbonation Reactor	£106,610.00
7.	K2SO4 Recovery & Crystallisation	£160,750.00
8.	Electrical Distribution	£90,330.00
9.	Process Instrumentation	£88,400.00
10.	Process Control System	£16,920.00
11.	Safety & Protection	£57,860.00
12.	Bagging & Packaging	£71,340.00
<b>Sum of modules</b>		<b>£936,560.00</b>

Component-class breakdown		
<i>Per-component-class contribution to the grand total. Classifier source: Engine B (Phase 4 corpus lookup with Flash-Lite fallback).</i>		
Mechanical Assembly	£260,040.00	28%
Thermal	£227,000.00	24%
Fluid Path	£142,200.00	15%
OEM Subsystem	£60,690.00	6%
CO2 Mineralisation	£54,560.00	6%
Magnetic	£47,500.00	5%
Motor Actuator	£29,390.00	3%
Sensor	£23,020.00	2%
Safety Consumable	£17,200.00	2%
Optical	£15,900.00	2%
Structural Metal	£15,000.00	2%
OEM Fire Safety	£14,400.00	2%
Electronic PCB	£10,300.00	1%
OEM Smoke Detection	£7,600.00	1%

Structural Polymer	£7,200.00	1%
Electronic Connector	£2,400.00	<1%
Mechanical Fastener	£1,440.00	<1%
Electronic Cable	£720.00	<1%

## MODULE 1

# Skid Structure & Containment

Cost **£43,200.00**

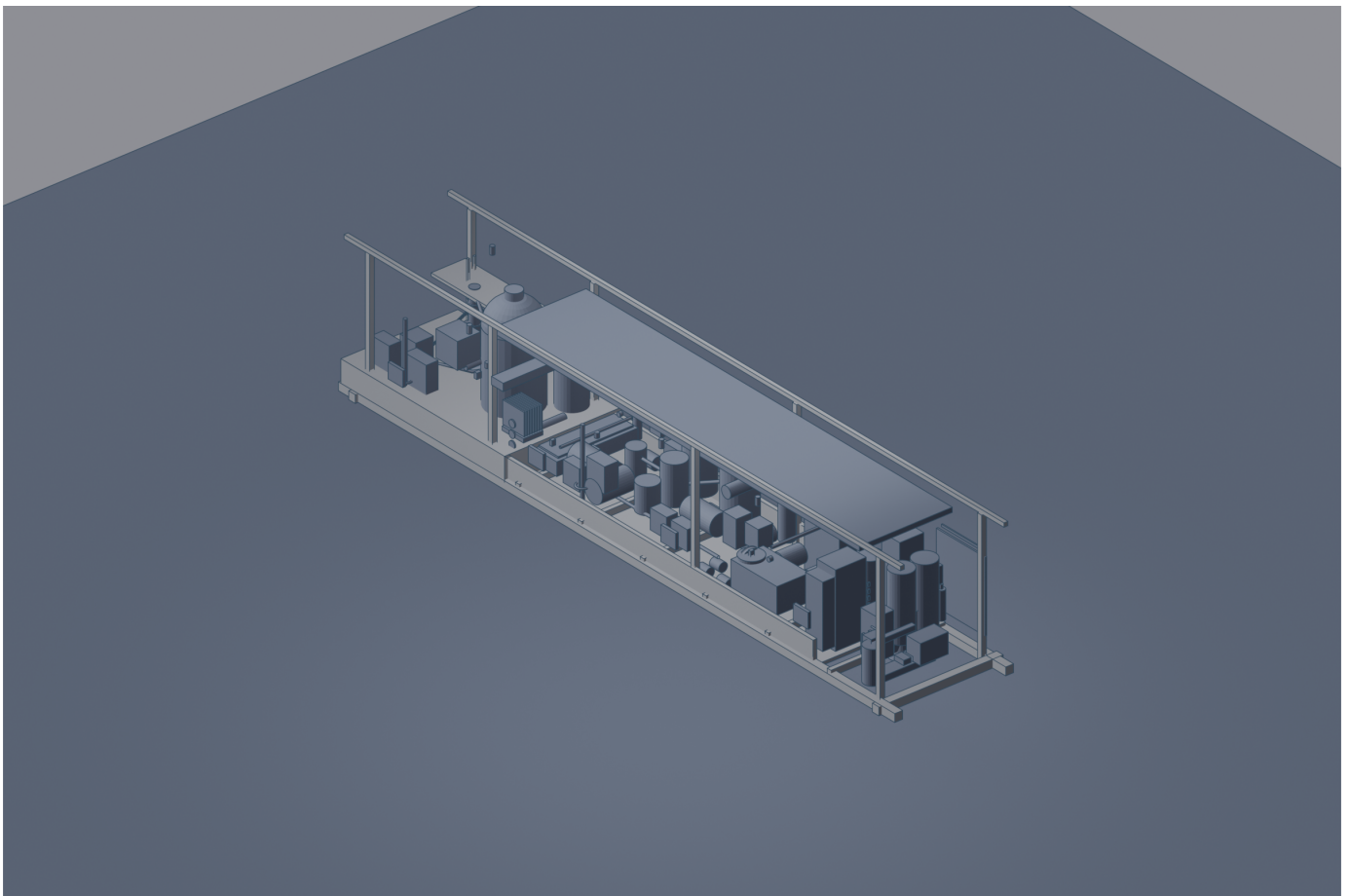
## Module summary

### PURPOSE

This module (Skid Structure & Containment) a transportable skid (within the 2.59 m road-transport height envelope) with 110% chemical bunding carries the reactors, exchangers, pumps and tanks; the tall packed columns ship as flanged segments and are field-erected on a plinth beside the skid, so the 2.59 m envelope governs the transportable modules, not the erected ~6 m column height.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The skid structure + containment — a transportable galvanised-steel skid (within the 2.59 m road-transport height envelope) carrying the reactors, exchangers, pumps and tanks with chemical bunding; the tall packed columns (absorber, MEA stripper, distillation) ship as flanged segments and are field-erected on a plinth beside the skid.



*Illustration only — generic class render. Module 1 (Skid Structure & Containment) shown in identity colour; other modules muted; enclosure ghosted.*

The Structure / Containment module organises skid structure + containment. The skid structure + containment supports 5 components. A 12 m x 2.4 m x 2.59 m welded galvanised frame, ISO-corner transportable, <=2.59 m transport height galvanised process skid frame (part welded galvanised structural-steel skid frame - fabricated) (additional: £15,000).

A 4.0 m x 2.4 m x 0.6 m reinforced plinth + bolted column support frame for the field-erected packed columns beside the skid field-erected column support plinth (part reinforced column support plinth and frame - fabricated) (additional: £7,500). A 110% bunded containment mea/koh chemical bund (part GRP 110% bunded containment tray - fabricated), certified to DSEAR (additional: £7,000). 8x 0.6 m x 0.4 m x 0.25 m each bolted saddles vessel supports and saddles (part bolted structural-steel vessel saddle - fabricated) (additional: £650).

A GRP grating platform access platform and ladders (part GRP grating access platform and ladders - fabricated), certified to BS EN ISO 14122 (additional: £8,500). A transportable galvanised-steel skid (within the 2.59 m road-transport height envelope) carrying the reactors, exchangers, pumps and tanks with chemical bunding; the tall packed columns (absorber, MEA stripper, distillation) ship as flanged segments and are field-erected on a plinth beside the skid.

## Sub-modules

### 1.1 Skid structure + containment

The skid structure + containment supports 5 components. A 12 m x 2.4 m x 2.59 m welded galvanised frame, ISO-corner transportable, <=2.59 m transport height galvanised process skid frame (part welded galvanised structural-steel skid frame - fabricated) (additional: £15,000). A 4.0 m x 2.4 m x 0.6 m reinforced plinth + bolted column support frame for the field-erected packed columns beside the skid field-erected column support plinth (part reinforced column support plinth and frame - fabricated) (additional: £7,500).

A 110% bunded containment mea/koh chemical bund (part GRP 110% bunded containment tray - fabricated), certified to DSEAR (additional: £7,000). 8x 0.6 m x 0.4 m x 0.25 m each bolted saddles vessel supports and saddles (part bolted structural-steel vessel saddle - fabricated) (additional: £650). A GRP grating platform access platform and ladders (part GRP grating access platform and ladders - fabricated), certified to BS EN ISO 14122 (additional: £8,500).

A transportable galvanised-steel skid (within the 2.59 m road-transport height envelope) carrying the reactors, exchangers, pumps and tanks with chemical bunding; the tall packed columns (absorber, MEA stripper, distillation) ship as flanged segments and are field-erected on a plinth beside the skid.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE - CHECK
Process Skid Frame	—	welded galvanised structural-steel skid frame — fabricated	x1	~£15,000.00	<b>£15,000.00</b>	— <b>OK</b>

Field-erection Column Plinth	—	reinforced column support plinth and frame — fabricated	x1	~£7,500.00	<b>£7,500.00</b>	— OK
Chemical Bund	—	GRP 110% banded containment tray — fabricated	x1	~£7,000.00	<b>£7,000.00</b>	— OK
Vessel Supports + Saddles	—	bolted structural-steel vessel saddle — fabricated	x8	~£650.00	<b>£5,200.00</b>	— OK
Access Platform + Ladders	—	GRP grating access platform and ladders — fabricated	x1	~£8,500.00	<b>£8,500.00</b>	— -
<i>Sub-total — skid structure + containment</i>					<b>£43,200</b>	

*SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.*

**Module 1 total — Skid Structure & Containment**

**£43,200.00**

## MODULE 2

# Thermal Utilities

Cost **£62,600.00**

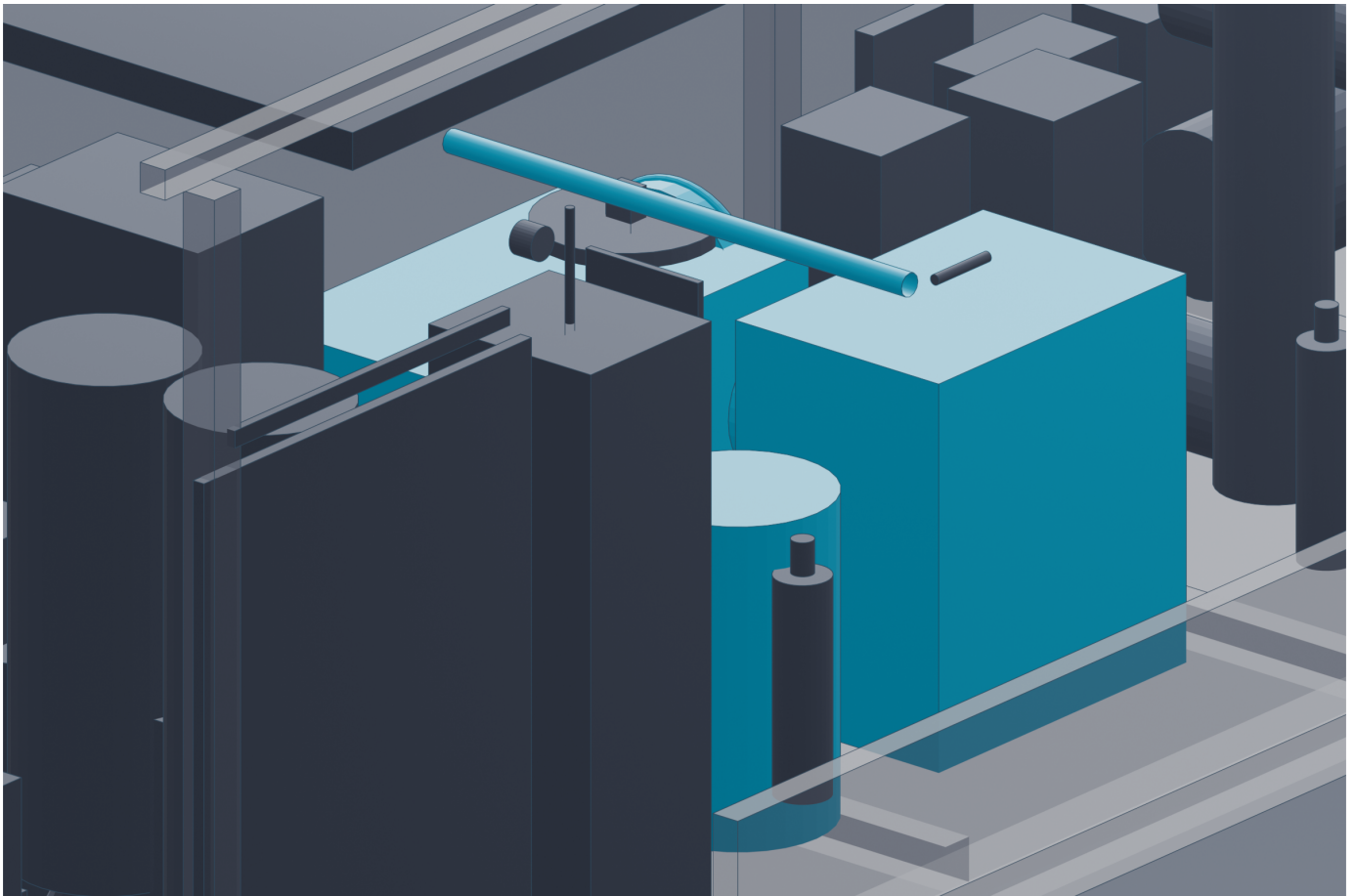
## Module summary

### PURPOSE

This module (Thermal Utilities) the thermal utility module provides 450 kg/h of steam via a Fulton Electropack EP100 electric boiler (300 kW), supporting the distillation reboiler, K<sub>2</sub>SO<sub>4</sub> crystalliser heater, and MEA stripping pot. Process air heating is supplied by two 75 kW Kanthal finned electric duct heaters, while cooling is managed by a Pfannenberg closed-loop skid.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The thermal utilities — a 450 kg/h packaged electric steam boiler serving the distillation reboiler, the K<sub>2</sub>SO<sub>4</sub> crystalliser heater and the MEA stripping pot, plus hot air for two drying stages and closed-loop cooling water.



*Illustration only — generic class render. Module 2 (Thermal Utilities) shown in identity colour; other modules muted; enclosure ghosted.*

The thermal utility module provides 450 kg/h of steam via a Fulton Electropack EP100 electric boiler (300 kW), supporting the distillation reboiler, K<sub>2</sub>SO<sub>4</sub> crystalliser heater, and MEA stripping pot. Process

air heating is supplied by two 75 kW Kanthal finned electric duct heaters, while cooling is managed by a Pfannenberg closed-loop skid.

Condensate recovery is centralized in a 0.5 m<sup>3</sup> flash vessel, ensuring efficient energy utilization across the plant.

## Sub-modules

### 2.1 Thermal utilities

The thermal utilities supply 4 components. A Fulton packaged electric steam boiler, 300 kW element (multi-unit Electropack) electric steam generator (part Electropack EP100 (multi-unit package, frame count TBD at quotation), 450 kg/h capacity), certified to PED 2014/68/EU (additional: £60,000). 2x Kanthal finned electric duct heater electric hot-air process heater (part finned electric duct air heater - made to order, 75 kW each capacity) (additional: £7,000).

A Pfannenbergl dry-cooler + circulation pump closed-loop cooling-water skid (part closed-loop cooling-water skid - packaged) (additional: £9,400). A 0.5 m3 condensate flash receiver + feedwater de-aerator pot condensate flash and boiler feedwater vessel (part fabricated condensate/feedwater vessel - bespoke vessel), certified to PED 2014/68/EU (additional: £4,600). A 450 kg/h packaged electric steam boiler serving the distillation reboiler, the K2SO4 crystalliser heater and the MEA stripping pot, plus hot air for two drying stages and closed-loop cooling water.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE CHECK
Electric Steam Generator	Fulton	<b>Electropack EP100 (multi-unit package, frame count TBD at quotation)</b>	x1	~£35,000.00	<b>£35,000.00</b>	— OK
Hot-air Process Heater	Kanthal	<b>finned electric duct air heater — made to order</b>	x2	~£7,000.00	<b>£14,000.00</b>	— OK
Cooling-water Skid	Pfannenbergl	<b>closed-loop cooling-water skid — packaged</b>	x1	~£9,000.00	<b>£9,000.00</b>	— OK
Condensate + Feedwater Vessel	—	<b>fabricated condensate/feedwater vessel — bespoke vessel</b>	x1	~£4,600.00	<b>£4,600.00</b>	— OK
<i>Sub-total — thermal utilities</i>					<b>£62,600</b>	

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**Module 2 total — Thermal Utilities**

**£62,600.00**

## MODULE 3

# MEA Absorption & Capture

Cost **£84,700.00**

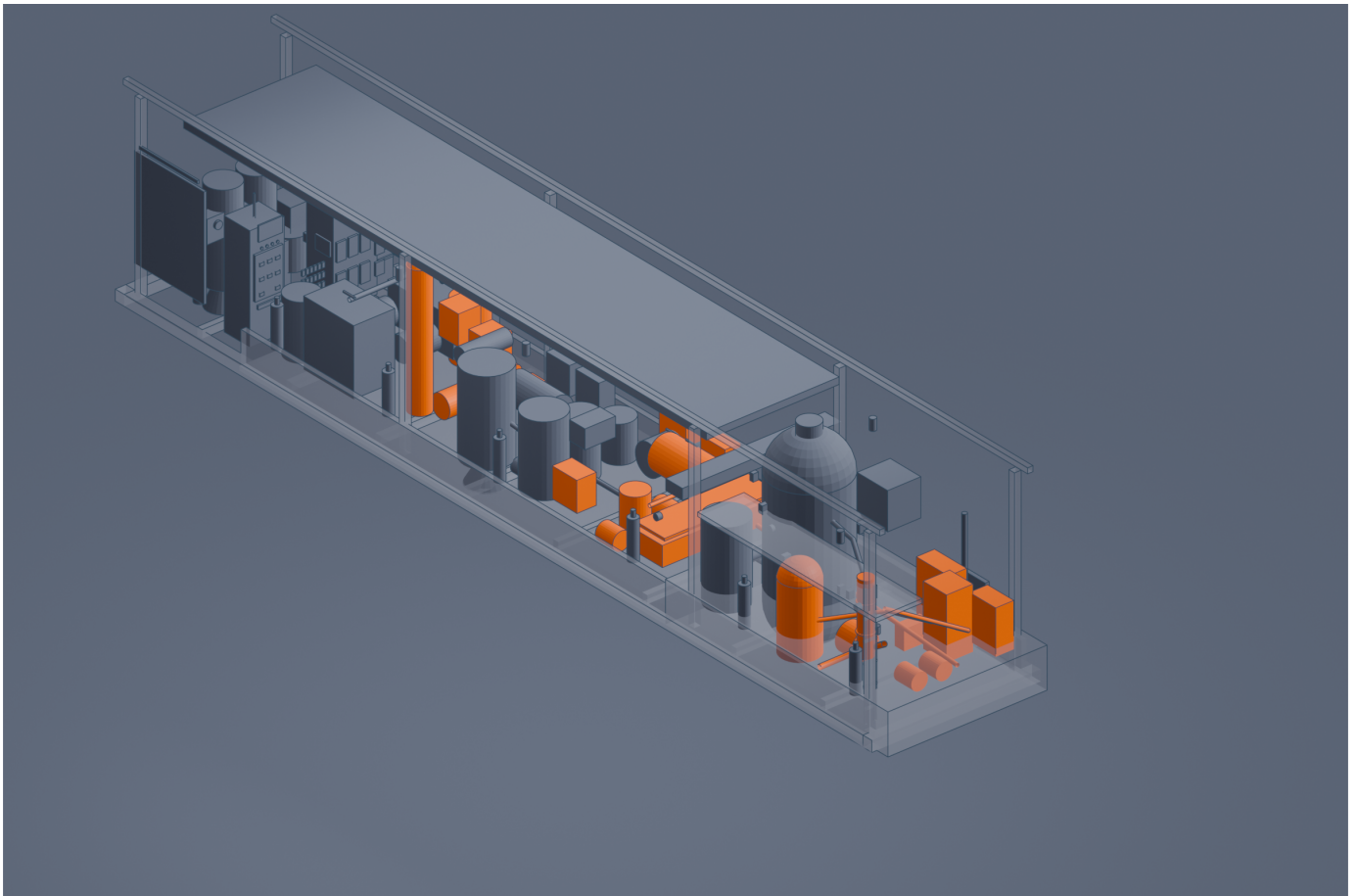
## Module summary

### PURPOSE

This module (MEA Absorption & Capture) the MEA absorption module is engineered to capture 1 tonne of CO<sub>2</sub> per day, utilizing a 316L stainless-steel packed column designed according to Packed Absorption/Stripping Column (HTU-NTU + flooding) v1.0.0. The column features a 0.2346 m diameter and 1.4073 m of structured packing, ensuring an NTU of 2.3454 to meet the 42 kg/h capture target.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The MEA absorption train — 42 kg/h CO<sub>2</sub> absorbed into 30 wt% aqueous MEA circulating at 2.9 m<sup>3</sup>/h through a 0.2 m × 1 m packed column.



*Illustration only — generic class render. Module 3 (MEA Absorption & Capture) shown in identity colour; other modules muted; enclosure ghosted.*

The MEA absorption module is engineered to capture 1 tonne of CO<sub>2</sub> per day, utilizing a 316L stainless-steel packed column designed according to Packed Absorption/Stripping Column (HTU-NTU +

flooding) v1.0.0. The column features a 0.2 m diameter and 1.4 m of structured packing, ensuring an NTU of 2.35 to meet the 42 kg/h capture target.

Solvent circulation is maintained at 2.9 m<sup>3</sup>/h by Grundfos CRNE 5-8 pumps, with heat integration managed by Alfa Laval M10-BFG exchangers. The system operates within the 1.9 M GBP unit cost ceiling, with all pressure-containing components compliant with PED 2014/68/EU.

The process is supported by a Howden centrifugal blower and a 5 m<sup>3</sup> DSEAR-compliant storage tank, ensuring safe and continuous operation for industrial flue gas streams.

## Sub-modules

### 3.1 MEA absorption train

The MEA absorption train absorbs 9 components. A Sulzer random-packed counter-current column, flanged segments for field erection packed absorber column (part fabricated 316L packed column - bespoke vessel, 0.2 m dia x 1 m), certified to PED 2014/68/EU (additional: £26,000). Y, 0.1 m<sup>3</sup> bed) (additional: £5,800).

2x Grundfos centrifugal, 1 duty + 1 standby MEA circulation pump (part [CRNE 5-8](#), 2.9 m<sup>3</sup>/h capacity) (additional: £4,200). An Alfa Laval gasketed plate cross-exchanger rich/lean MEA plate exchanger (part [M10-BFG](#)) (additional: £8,800). An Alfa Laval gasketed plate cooler, cooling-water served lean-amine trim cooler (part [M6-FG](#), 120 kW capacity) (additional: £6,200).

An Alfa Laval brazed-plate cooler rich-amine inlet trim cooler (part [CB60](#), 40 kW capacity) (additional: £3,800). An Alfa Laval 316L plate pack with NBR gaskets M10 cross-exchanger plate pack + gaskets (part [M10-BFG plate pack](#)) (additional: £2,600). A Howden centrifugal flue-gas inlet blower (part centrifugal process fan - made to order, 500 kg/h gas capacity) (additional: £8,500).

A 5 m<sup>3</sup> bunded atmospheric tank 30 wt% MEA storage tank (part fabricated 316L atmospheric storage tank - bespoke vessel), certified to DSEAR (additional: £7,500). 42 kg/h CO<sub>2</sub> absorbed into 30 wt% aqueous MEA circulating at 2.9 m<sup>3</sup>/h through a 0.2 m x 1 m packed column.

#### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### HT eps-NTU Heat Exchanger v1.2.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

##### Conductance UA

$$UA = ntu \times c_{min}$$

$$UA = 2.2 \times 2.5 = 5.5 \text{ kW/K}$$

##### Maximum heat duty

$$q_{max} = c_{min} \times (t_{hot\_in} - t_{cold\_in})$$

$$q_{max} = 2.5 \times (100 - 30) = 175 \text{ kW}$$

##### Actual heat transfer

$$q = effectiveness \times q_{max}$$

$$q = 0.8892 \times 175 = 155.609 \text{ kW}$$

**Hot-side outlet temperature**

$$t_{\text{hot\_out}} = t_{\text{hot\_in}} - q / c_{\text{min}}$$

$$t_{\text{hot\_out}} = 100 - 155.609 / 2.5 = 37.756 \text{ C}$$

assumes: hot fluid taken as the C\_min side (typical chiller/HVAC case)

**Packed Absorption/Stripping Column (HTU-NTU + flooding) v1.0.0****WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****Outlet solute mole fraction (target removal)**

$$y_2 = y_1 \times (1 - \text{removal})$$

$$y_2 = 0.12 \times (1 - 0.9) = 0.012$$

assumes: 90.0% of the solute removed; dilute-gas basis

**Absorption factor**

$$A = L / (m \times G)$$

$$A = 150 / (1.5 \times 8.6207) = 11.6$$

assumes: A > 1 favours absorption; m = equilibrium-line slope dy\*/dx

**Number of transfer units (NTU)**

$$\text{NTU} = \ln[(y_1 - m x_2)/(y_2 - m x_2)] \times (1 - 1/A) + 1/A / (1 - 1/A)$$

$$\text{NTU} = \ln[(0.12 - 1.5 \times 0)/(0.012 - 1.5 \times 0)] \times (1 - 1/11.6) + 1/11.6 / (1 - 1/11.6) = 2.4314$$

assumes: Colburn dilute-absorption equation (Treybal Eq. 8.48); dilute system, linear equilibrium, constant A

**Packed height**

$$H = \text{HTU} \times \text{NTU}$$

$$H = 0.7 \times 2.4314 = 1.702 \text{ m}$$

assumes: HTU 0.7 m for the specified packing (stripper)

**Flow parameter (Eckert abscissa)**

$$F_{\text{LV}} = (L_{\text{mass}} / G_{\text{mass}}) \times \sqrt{(\rho_{\text{G}} / \rho_{\text{L}})}$$

$$F_{\text{LV}} = (3,600 / 250) \times \sqrt{1.1 / 1,000} = 0.4776$$

assumes: mass-flow ratio form of the generalised pressure-drop correlation

**Flooding velocity (Eckert GPDC)**

$$u_{\text{flood}} = \sqrt{Y_{\text{flood}} \times g \times (\rho_{\text{L}} - \rho_{\text{G}}) / (\rho_{\text{G}} \times F_{\text{p}} \times \mu_{\text{L}}^{0.1})}$$

$$u_{\text{flood}} = \sqrt{0.0486 \times 9.8066 \times (1,000 - 1.1) / (1.1 \times 66 \times 1^{0.1})} = 2.5602 \text{ m/s}$$

assumes: Y\_flood from the Kessler-Wankat fit of the Eckert flooding line; F\_p = packing factor (Mellapak 250Y ~ 66 1/m; 25 mm random rings ~ 500 1/m)

**Design superficial gas velocity**

$$u_{\text{design}} = f_{\text{flood}} \times u_{\text{flood}}$$

$$u_{\text{design}} = 0.6 \times 2.5602 = 1.5361 \text{ m/s}$$

assumes: operate at 60.0% of flooding (typical 60-75%)

**Column diameter from gas load**

$$D = \sqrt{4 \times Q_{\text{G}} / (\pi \times u_{\text{design}})}$$

$$D = \sqrt{4 \times 0.0631 / (\pi \times 1.5361)} = 0.2288 \text{ m}$$

assumes: gas volumetric flow 0.06313 m<sup>3</sup>/s; cross-section A = Q\_G / u\_design; D = sqrt(4A/pi)

**Pressure Vessel Wall Design (hoop-stress sizing) v1.0.0****WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****Internal design pressure**

$$p_{\text{design\_mpa}} = p_{\text{design\_barg}} \times 0.1$$

$$p_{\text{design\_mpa}} = 3 \times 0.1 = 0.3 \text{ MPa}$$

assumes: internal gauge design pressure of the process vessel; 1 bar = 0.1 MPa

**Shell minimum thickness (hoop stress, internal pressure)**

$$t = p_{\text{design}} \times D / (2 \times S \times E - 1.2 \times p_{\text{design}}) + \text{corr}$$

$$t = 0.3 \times 1,503 / (2 \times 174 \times 0.85 - 1.2 \times 0.3) + 3 = 4.526 \text{ mm}$$

assumes: ASME VIII Div.1 UG-27 circumferential-stress form (BS EN 13445 equivalent); 0.6 x yield (no datasheet allowable supplied); + 3.0 mm corrosion allowance; adopted shell  $t = 8.0 \text{ mm}$  ( $\geq 5 \text{ mm}$  practical handling minimum)

**Hoop stress at adopted wall (internal pressure)**

$$\sigma_{\text{hoop}} = p_{\text{design}} \times D / (2 \times t)$$

$$\sigma_{\text{hoop}} = 0.3 \times 1,503 / (2 \times 8) = 28.181 \text{ MPa}$$

assumes: thin-wall cylinder under internal pressure

**Yield safety factor (hoop-governing, internal pressure)**

$$SF_{\text{yield}} = \text{yield}_{\text{mpa}} / \sigma_{\text{hoop}}$$

$$SF_{\text{yield}} = 290 / 28.181 = 10.291$$

assumes: material steel\_316L; yield from datasheet/standard; internal-pressure vessel - yield governs (no external-buckling check)

**Cylinder wall mass**

$$\text{mass} = \pi \times (r_{\text{outer}}^2 - r_{\text{inner}}^2) \times \text{length}_{\text{mm}} \times \text{density} / 1e9$$

$$\text{mass} = \pi \times (759.5^2 - 751.5^2) \times 2,255 \times 8,000 / 1e9 = 685.079 \text{ kg}$$

assumes: material steel\_316L; cylindrical shell only; heads computed separately; 1e9 converts mm<sup>3</sup> to m<sup>3</sup>

**Head mass (2 flat-plate heads)**

$$\text{mass} = 2 \times \pi \times r_{\text{outer}}^2 \times t \times \text{density} / 1e9$$

$$\text{mass} = 2 \times \pi \times 759.5^2 \times 8 \times 8,000 / 1e9 = 231.961 \text{ kg}$$

assumes: flat-head approximation (conservative vs torispherical); 2 heads; 1e9 converts mm<sup>3</sup> to m<sup>3</sup>

**Total vessel shell mass**

$$\text{total}_{\text{mass}} = \text{mass}_{\text{cylinder}} + \text{mass}_{\text{heads}}$$

$$\text{total}_{\text{mass}} = 685.079 + 231.961 = 917.041 \text{ kg}$$

**Process Centrifugal Pump Sizing v1.0.0****WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****Pipe velocity**

$$V = (Q_{\text{m3h}} / 3600) / (\pi/4 \times D^2)$$

$$V = (3 / 3600) / (\pi/4 \times 0.05^2) = 0.4244 \text{ m/s}$$

assumes:  $Q_{\text{m3h}} / 3600$  converts m<sup>3</sup>/h to m<sup>3</sup>/s; keep 1-3 m/s for a process liquid line

**Reynolds number**

$$Re = \rho \times V \times D / \mu$$

$$Re = 1,000 \times 0.4244 \times 0.05 / 0.0013 = 16,323.6$$

assumes: Newtonian fluid; pipe internal bore

**Darcy friction factor (Swamee-Jain)**

$$f = 0.25 / (\log_{10}(\text{rel}_{\text{rough}}/3.7 + 5.74/Re^{0.9}))^2$$

$$f = 0.25 / (\log_{10}(0.0003/3.7 + 5.74/16,323.6^{0.9}))^2 = 0.0278$$

assumes: Swamee-Jain explicit Colebrook (turbulent);  $\text{rel}_{\text{rough}} = \text{roughness} / D$

**Pipe friction head (Darcy-Weisbach)**

$$H_{\text{friction}} = f \times (L_{\text{eff}} / D) \times V^2 / (2 \times g)$$

$$H_{\text{friction}} = 0.0278 \times (40 / 0.05) \times 0.4244^2 / (2 \times 9.8066) = 0.205 \text{ m}$$

assumes: Darcy-Weisbach pipe friction (chemical-engineering standard);  $L_{\text{eff}}$  = straight run + fittings equivalent length

**Process backpressure head**

$$H_{\text{process}} = \text{backpressure}_{\text{kpa}} \times 1000 / (\rho \times g)$$

$$H_{\text{process}} = 250 \times 1000 / (1,000 \times 9.8066) = 25.493 \text{ m}$$

assumes: column packing + heat exchangers + filter pressure drop

**Pump total dynamic head**

$$H_{\text{total}} = \text{static\_head} + H_{\text{friction}} + H_{\text{process}}$$

$$H_{\text{total}} = 12 + 0.205 + 25.493 = 37.698 \text{ m}$$

assumes: static lift = delivery elevation - suction elevation

**Pump hydraulic power**

$$P_{\text{hyd}} = \rho \times g \times (Q_{\text{m3h}} / 3600) \times H_{\text{total}}$$

$$P_{\text{hyd}} = 1,000 \times 9.8066 \times (3 / 3600) \times 37.698 = 308.1 \text{ W}$$

assumes:  $P = \rho g Q H$ ;  $Q_{\text{m3h}} / 3600$  converts m<sup>3</sup>/h to m<sup>3</sup>/s

**Pump shaft power**

$$P_{\text{shaft}} = P_{\text{hyd}} / \text{pump\_eff}$$

$$P_{\text{shaft}} = 308.1 / 0.65 = 474 \text{ W}$$

assumes: centrifugal pump efficiency 0.65 at duty point

**Motor input power**

$$P_{\text{motor}} = P_{\text{shaft}} / \text{motor\_eff}$$

$$P_{\text{motor}} = 474 / 0.9 = 526.6 \text{ W}$$

assumes: motor efficiency 0.9; recommended frame = 0.75 kW (next standard size with 15% margin)

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Packed Absorber Column	Sulzer	<a href="#">MELLAPAK 250.Y</a>	x1	~£26,000.00	<b>£26,000.00</b>	— OK
Structured Packing	Sulzer	<a href="#">MELLAPAK 250.Y</a>	x1	~£5,000.00	<b>£5,000.00</b>	— OK
MEA Circulation Pump	Grundfos	<a href="#">CRNE 5-8</a>	x2	~£3,850.00	<b>£7,700.00</b>	— OK
Rich/lean MEA Exchanger	Alfa Laval	<a href="#">M10-BFG</a>	x1	~£10,000.00	<b>£10,000.00</b>	— OK
Lean-amine Cooler	Alfa Laval	<a href="#">M6-FG</a>	x1	~£6,200.00	<b>£6,200.00</b>	— OK
Rich-amine Inlet Cooler	Alfa Laval	<a href="#">CB60</a>	x1	~£3,800.00	<b>£3,800.00</b>	— OK
Spare Cross-exchanger Plate Pack	Alfa Laval	<a href="#">M10-BFG plate pack</a>	x1	~£10,000.00	<b>£10,000.00</b>	— OK
Flue-gas Inlet Blower	Howden	centrifugal process fan — made to order	x1	~£8,500.00	<b>£8,500.00</b>	— OK
MEA Storage Tank	—	fabricated 316L atmospheric storage tank — bespoke vessel	x1	~£7,500.00	<b>£7,500.00</b>	— OK
<b>Sub-total — MEA absorption train</b>					<b>£84,700</b>	

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#### NOTES

- Engineering check** — The absorber column diameter of 0.23 m is too small for the flue-gas flow rate of 500 kg/h. At 40 °C, 500 kg/h of flue gas is ~442 m<sup>3</sup>/h (0.123 m<sup>3</sup>/s). In a 0.23 m diameter column (area = 0.0415 m<sup>2</sup>), the superficial gas velocity is 2.96 m/s, yielding an F-factor of 3.15 Pa<sup>0.5</sup>. This is well above the flooding limit for Mellapak 250.Y (typically 2.0 - 2.5 Pa<sup>0.5</sup>), meaning the column will flood. Suggested action: Increase the absorber column diameter to at least 0.35 m to reduce superficial velocity and F-factor below the flooding threshold.
- Engineering check** — The absorber packing height of 1.4073 m is insufficient for 90%+ CO<sub>2</sub> capture using 30 wt% MEA. Typical HTU (Height of a Transfer Unit) for this system is 0.8 - 1.2 m, meaning 1.4 m of packing provides only ~1.5 transfer units, which is inadequate to achieve the required capture efficiency. Suggested action: Increase the packing height to at least 4 - 6 meters to ensure adequate residence time and mass transfer.

**Module 3 total — MEA Absorption & Capture**

**£84,700.00**

## MODULE 4

# CaCO<sub>3</sub> Filtration & Drying

Cost **£76,600.00**

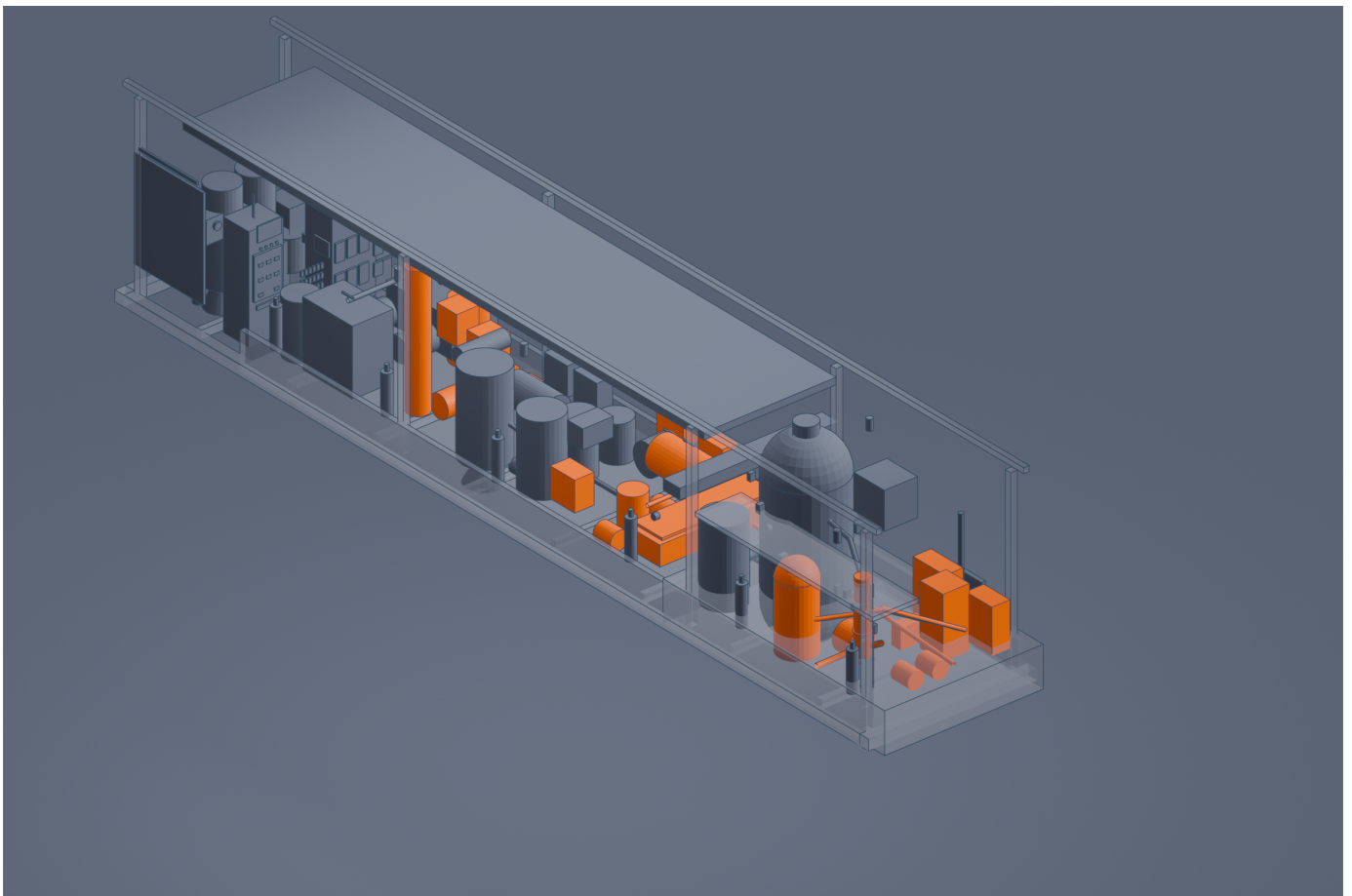
## Module summary

### PURPOSE

This module (CaCO<sub>3</sub> Filtration & Drying) CaCO<sub>3</sub> slurry is vacuum-belt-filtered, the cake water-washed to displace MEA, air-blown and hot-air dried to a free-flowing filler-grade powder.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The CaCO<sub>3</sub> filtration + drying line — 2.3 t/day CaCO<sub>3</sub> filtered over 3 m<sup>2</sup>, water-washed to strip MEA, air-blown, then hot-air dried at 75 kW.



*Illustration only — generic class render. Module 4 (CaCO<sub>3</sub> Filtration & Drying) shown in identity colour; other modules muted; enclosure ghosted.*

The MEA absorption module is engineered to capture 1 tonne of CO<sub>2</sub> per day, utilizing a 316L stainless-steel packed column designed according to Packed Absorption/Stripping Column (HTU-NTU + flooding) v1.0.0. The column features a 0.2 m diameter and 1.4 m of structured packing, ensuring an NTU of 2.35 to meet the 42 kg/h capture target.

Solvent circulation is maintained at 2.9 m<sup>3</sup>/h by Grundfos CRNE 5-8 pumps, with heat integration managed by Alfa Laval M10-BFG exchangers. The system operates within the 1.9 M GBP unit cost ceiling, with all pressure-containing components compliant with PED 2014/68/EU.

The process is supported by a Howden centrifugal blower and a 5 m<sup>3</sup> DSEAR-compliant storage tank, ensuring safe and continuous operation for industrial flue gas streams.

## Sub-modules

### 4.1 CaCO<sub>3</sub> filtration + drying line

The CaCO<sub>3</sub> filtration + drying line separates 9 components. A BHS-Sonthofen horizontal vacuum belt filter with cake wash + air-blow zones caco3 vacuum belt filter (part [BF \(horizontal vacuum belt filter\)](#), 3 m<sup>2</sup>) (additional: £24,000). A counter-current displacement wash bars with spray nozzles cake wash-water spray manifold (part fabricated 316L wash-bar manifold - made to order) (additional: £2,800).

A Busch single-stage liquid-ring vacuum pump + separator liquid-ring vacuum pump (part Dolphin LB 0250, 250 m<sup>3</sup>/h capacity) (additional: £7,200). A Grundfos vacuum receiver with barometric-leg transfer pump filtrate receiver and transfer pump (part [CRNE 10-4](#)) (additional: £4,100). A Becker side-channel regenerative blower cake de-watering air blower (part SV 8.19/2, 7.5 kW capacity) (additional: £4,300).

A GEA fluidised-bed dryer caco3 fluid-bed hot-air dryer (part [FLUIDBED VIBRO-FLUIDISER](#), 75 kW capacity) (additional: £21,000). A Heating Energy Systems finned steam/electric air-heating coil dryer inlet air-heater battery (part finned process air-heater battery - made to order, 68 kW capacity) (additional: £4,200). A GEA glass-tube air-to-air recuperator dryer exhaust-to-inlet heat-recovery exchanger (part air-to-air glass-tube recuperator - packaged, 30 kW capacity) (additional: £6,800).

An Alfa Laval brazed-plate condensate cooler, cooling-water served dryer exhaust condensate cooler (part [CB30](#), 25 kW capacity) (additional: £2,400). 2.3 t/day CaCO<sub>3</sub> filtered over 3 m<sup>2</sup>, water-washed to strip MEA, air-blown, then hot-air dried at 75 kW.

#### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Convective Dryer Air-Flow + Heat-Duty Sizing v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

##### Bone-dry solids (conserved)

$$\text{dry} = \text{wet} \times (1 - X_{\text{in}})$$

$$\text{dry} = 235.7 \times (1 - 0.3) = 164.99 \text{ kg/h}$$

assumes: wet-basis moisture; bone-dry solids pass through unchanged

##### Water evaporated

$$\text{water\_evap} = \text{water\_in} - \text{water\_out}$$

$$\text{water\_evap} = 70.71 - 0.829 = 69.881 \text{ kg/h}$$

assumes: product 165.819 kg/h at 0.5% wet-basis moisture

**Inlet drying-air humidity ratio (heated ambient)**

$$W_{in} = W_{ambient}$$

$$W_{in} = 0.0087 = 0.0087 \text{ kg/kg}$$

assumes: ambient 20.0 degC / 60.0% RH heated to 120.0 degC; sensible heating adds no moisture; psychrolib (ASHRAE 2017)

**Outlet (exhaust) air humidity ratio**

$$W_{out} = f(T_{out}, RH_{out})$$

$$W_{out} = f(60, 60) = 0.0833 \text{ kg/kg}$$

assumes: exhaust 60.0 degC / 60.0% RH; psychrolib humidity ratio; psychrolib (ASHRAE 2017)

**Dry-air mass flow from humidity pick-up**

$$m_{air} = \text{water\_evap} / (W_{out} - W_{in})$$

$$m_{air} = 69.881 / (0.0833 - 0.0087) = 937.35 \text{ kg/h}$$

assumes: dry-air basis; the air carries every kg of evaporated water as added humidity

**Air-enthalpy rise across the heater**

$$dh = h_{inlet} - h_{ambient}$$

$$dh = 144.514 - 42.29 = 102.225 \text{ kJ/kg}$$

assumes: per kg dry air; moist-air enthalpy from psychrolib; psychrolib (ASHRAE 2017)

**Heater duty**

$$\text{duty} = (m_{air} / 3600) \times dh / \text{heater\_eff}$$

$$\text{duty} = (937.35 / 3600) \times 102.225 / 0.85 = 31.314 \text{ kW}$$

assumes: heater + duct efficiency 0.85; /3600 converts kg/h to kg/s; kg/s x kJ/kg = kW

**Humid-air volumetric flow at heater outlet**

$$Q_{air} = (m_{air} / 3600) \times v_{humid} \times 3600$$

$$Q_{air} = (937.35 / 3600) \times 1.1294 \times 3600 = 1,058.63 \text{ m}^3/\text{h}$$

assumes: moist-air specific volume at the heated inlet (fan/duct sizing); psychrolib (ASHRAE 2017)

PART	MANUFAC-TURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Caco3 Vacuum Belt Filter	BHS-Sonthofen	<a href="#">BF (horizontal vacuum belt filter)</a>	x1	~£24,000.00	<b>£24,000.00</b>	— OK
Cake Wash-water Manifold	—	fabricated 316L wash-bar manifold — made to order	x1	~£2,800.00	<b>£2,800.00</b>	— OK
Filter Vacuum Pump	Busch	Dolphin LB 0250	x1	~£7,000.00	<b>£7,000.00</b>	— OK
Filtrate Receiver + Pump	Grundfos	<a href="#">CRNE 10-4</a>	x1	~£4,100.00	<b>£4,100.00</b>	— OK
Cake Air-blow Blower	Becker	SV 8.190/2	x1	~£4,300.00	<b>£4,300.00</b>	Est. OK
Caco3 Hot-air Dryer	GEA	<a href="#">FLUIDBED VI-BRO-FLUIDISER</a>	x1	~£21,000.00	<b>£21,000.00</b>	— OK
Dryer Inlet Air-heater Battery	Heating Energy Systems	finned process air-heater battery — made to order	x1	~£4,200.00	<b>£4,200.00</b>	— OK
Dryer Exhaust Heat-recovery Exchanger	GEA	<a href="#">FLUIDBED VI-BRO-FLUIDISER</a>	x1	~£6,800.00	<b>£6,800.00</b>	— OK
Dryer Condensate Cooler	Alfa Laval	<a href="#">CB30</a>	x1	~£2,400.00	<b>£2,400.00</b>	— OK
<b>Sub-total — CaCO3 filtration + drying line</b>					<b>£76,600</b>	

SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE

· RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.

#### NOTES

**1. Engineering check** — The absorber column diameter of 0.23 m is too small for the flue-gas flow rate of 500 kg/h. At 40 °C, 500 kg/h of flue gas is ~442 m<sup>3</sup>/h (0.123 m<sup>3</sup>/s). In a 0.23 m diameter column (area = 0.0415 m<sup>2</sup>), the superficial gas velocity is 2.96 m/s, yielding an F-factor of 3.15 Pa<sup>0.5</sup>. This is well above the flooding limit for Mellapak 250.Y (typically 2.0 - 2.5 Pa<sup>0.5</sup>), meaning the column will flood. Suggested action: Increase the absorber column diameter to at least 0.35 m to reduce superficial velocity and F-factor below the flooding threshold.

**2. Engineering check** — The absorber packing height of 1.4073 m is insufficient for 90%+ CO<sub>2</sub> capture using 30 wt% MEA. Typical HTU (Height of a Transfer Unit) for this system is 0.8 - 1.2 m, meaning 1.4 m of packing provides only ~1.5 transfer units, which is inadequate to achieve the required capture efficiency. Suggested action: Increase the packing height to at least 4 - 6 meters to ensure adequate residence time and mass transfer.

**Module 4 total — CaCO<sub>3</sub> Filtration & Drying**

**£76,600.00**

## MODULE 5

# MEA Recovery & Recycle

Cost **£77,250.00**

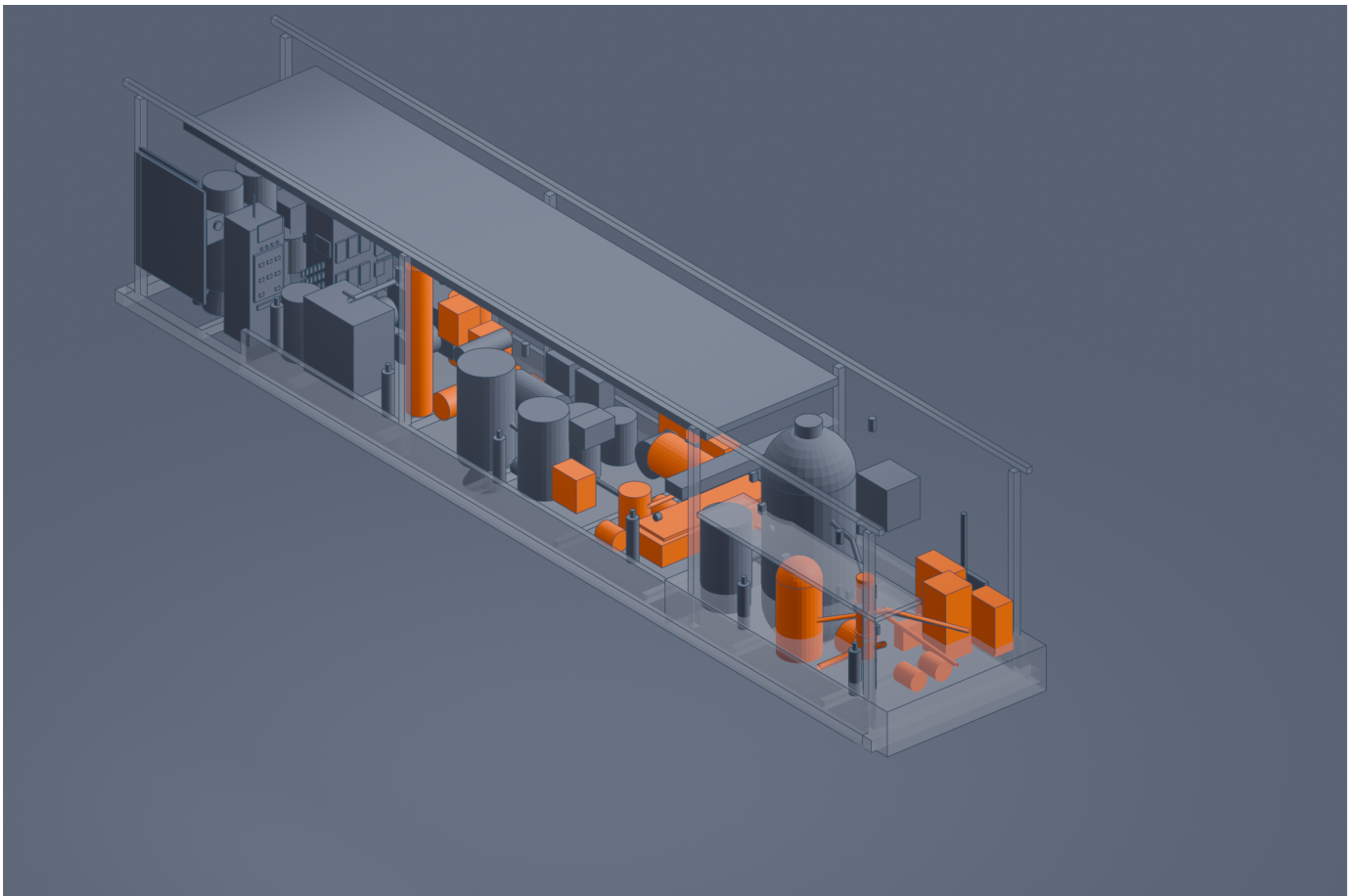
## Module summary

### PURPOSE

This module (MEA Recovery & Recycle) wash-water distillation recovers MEA and reclaims wash water in a closed solvent loop, minimising MEA make-up and effluent.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The MEA recovery + recycle loop — CaCO<sub>3</sub> wash water is distilled in a 0.3 m column (180 kg/h reboiler steam) to recover MEA and reclaim wash water; recovered MEA returns to the absorber.



*Illustration only — generic class render. Module 5 (MEA Recovery & Recycle) shown in identity colour; other modules muted; enclosure ghosted.*

The MEA absorption module is engineered to capture 1 tonne of CO<sub>2</sub> per day, utilizing a 316L stainless-steel packed column designed according to Packed Absorption/Stripping Column (HTU-NTU +

flooding) v1.0.0. The column features a 0.2 m diameter and 1.4 m of structured packing, ensuring an NTU of 2.35 to meet the 42 kg/h capture target.

Solvent circulation is maintained at 2.9 m<sup>3</sup>/h by Grundfos CRNE 5-8 pumps, with heat integration managed by Alfa Laval M10-BFG exchangers. The system operates within the 1.9 M GBP unit cost ceiling, with all pressure-containing components compliant with PED 2014/68/EU.

The process is supported by a Howden centrifugal blower and a 5 m<sup>3</sup> DSEAR-compliant storage tank, ensuring safe and continuous operation for industrial flue gas streams.

## Sub-modules

### 5.1 MEA recovery + recycle loop

The MEA recovery + recycle loop recovers 8 components. A Koch-Glitsch packed stripping column MEA wash-water distillation column (part fabricated 316L packed stripping column - bespoke vessel, 0.3 m dia), certified to PED 2014/68/EU (additional: £20,000). An Alfa Laval shell-and-tube thermosiphon reboiler (part [CB60](#) (brazed-plate reboiler), 180 kg/h steam capacity) (additional: £8,900).

An Alfa Laval plate condenser overhead condenser (part [CB30 \(brazed-plate condenser\)](#)) (additional: £7,500). An Alfa Laval gasketed plate economiser preheating column feed feed/reclaimed-bottoms economiser exchanger (part [M6-FG](#), 55 kW capacity) (additional: £4,800). An Alfa Laval brazed-plate subcooler on the reflux line overhead reflux subcooler (part [CB30](#), 20 kW capacity) (additional: £2,300).

2x Grundfos centrifugal, 1 duty + 1 standby recovered-mea recycle pump (part [CRNE 3-5](#)) (additional: £3,600). A Grundfos centrifugal column-feed pump distillation wash-water feed pump (part [CRNE 10-5](#)) (additional: £4,300). A fabricated buffer tank reclaimed wash-water tank (part fabricated 316L stainless insulated buffer tank, 3 m<sup>3</sup> - made to order (hot MEA-recovery loop <=120 °C), 3 m<sup>3</sup>) (additional: £7,500).

CaCO<sub>3</sub> wash water is distilled in a 0.3 m column (180 kg/h reboiler steam) to recover MEA and reclaim wash water; recovered MEA returns to the absorber.

#### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### HT eps-NTU Heat Exchanger v1.2.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

##### Conductance UA

$$UA = ntu \times c_{min}$$

$$UA = 2.2 \times 2.5 = 5.5 \text{ kW/K}$$

##### Maximum heat duty

$$q_{max} = c_{min} \times (t_{hot\_in} - t_{cold\_in})$$

$$q_{max} = 2.5 \times (100 - 30) = 175 \text{ kW}$$

**Actual heat transfer**

$$q = \text{effectiveness} \times q_{\text{max}}$$

$$q = 0.8892 \times 175 = 155.609 \text{ kW}$$

**Hot-side outlet temperature**

$$t_{\text{hot\_out}} = t_{\text{hot\_in}} - q / c_{\text{min}}$$

$$t_{\text{hot\_out}} = 100 - 155.609 / 2.5 = 37.756 \text{ C}$$

assumes: hot fluid taken as the C\_min side (typical chiller/HVAC case)

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
MEA Distillation Column	Koch-Glitsch	<b>fabricated 316L packed stripping column — bespoke vessel</b>	x1	~£20,000.00	<b>£20,000.00</b>	— OK
Distillation Reboiler	Alfa Laval	<b>CB60 (brazed-plate reboiler)</b>	x1	~£8,900.00	<b>£8,900.00</b>	— OK
Overhead Condenser	Alfa Laval	<b>CB30 (brazed-plate condenser)</b>	x1	~£21,500.00	<b>£21,500.00</b>	— OK
Feed/bottoms Economiser	Alfa Laval	<b>M6-FG</b>	x1	~£4,800.00	<b>£4,800.00</b>	— OK
Reflux Subcooler	Alfa Laval	<b>CB30</b>	x1	~£3,000.00	<b>£3,000.00</b>	— OK
MEA Recycle Pump	Grundfos	<b>CRNE 3-5</b>	x2	~£3,850.00	<b>£7,700.00</b>	— OK
Wash-water Feed Pump	Grundfos	<b>CRNE 10-5</b>	x1	~£3,850.00	<b>£3,850.00</b>	— OK
Reclaimed Wash-water Tank	fabricated	<b>fabricated 316L stainless insulated buffer tank, 3 m³ — made to order (hot MEA-recovery loop d-120 °C)</b>	x1	~£7,500.00	<b>£7,500.00</b>	— OK
<b>Sub-total — MEA recovery + recycle loop</b>					<b>£77,250</b>	

*SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.*

**NOTES**

**1. Engineering check** — The absorber column diameter of 0.23 m is too small for the flue-gas flow rate of 500 kg/h. At 40 °C, 500 kg/h of flue gas is ~442 m³/h (0.123 m³/s). In a 0.23 m diameter column (area = 0.0415 m²), the superficial gas velocity is 2.96 m/s, yielding an F-factor of 3.15 Pa<sup>0.5</sup>. This is well above the flooding limit for Mellapak 250.Y (typically 2.0 - 2.5 Pa<sup>0.5</sup>), meaning the column will flood. Suggested action: Increase the absorber column diameter to at least 0.35 m to reduce superficial velocity and F-factor below the flooding threshold.

**2. Engineering check** — The absorber packing height of 1.4073 m is insufficient for 90%+ CO<sub>2</sub> capture using 30 wt% MEA. Typical HTU (Height of a Transfer Unit) for this system is 0.8 - 1.2 m, meaning 1.4 m of packing provides only ~1.5 transfer units, which is inadequate to achieve the required capture efficiency. Suggested action: Increase the packing height to at least 4 - 6 meters to ensure adequate residence time and mass transfer.

**Module 5 total — MEA Recovery & Recycle**

**£77,250.00**

## MODULE 6

# Gypsum Carbonation Reactor

Cost **£106,610.00**

## Module summary

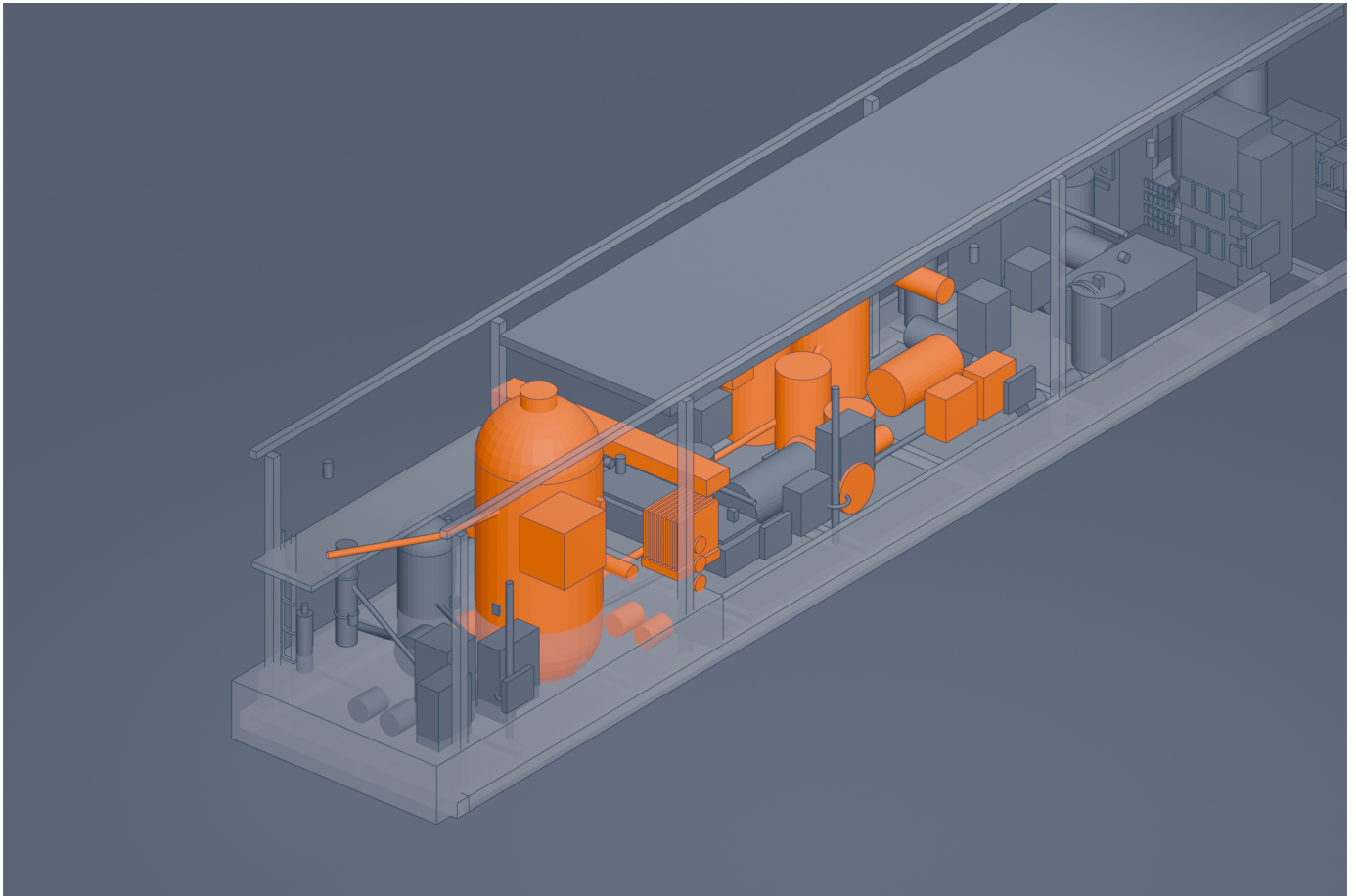
### PURPOSE

This module (Gypsum Carbonation Reactor) the gypsum carbonation reactor module integrates Rushton Agitation Power v1.0.0 and Reaction Stoichiometry Mass Balance v1.0.0 results to produce 2.3 t/day CaCO<sub>3</sub> and 3.9 t/day K<sub>2</sub>SO<sub>4</sub> from 3.1 t/day gypsum and 2.6 t/day KOH.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 2 sub-modules. The Energy Conversion Transduction Chemical Sensing Mass Fluid Transport Process — CO<sub>2</sub>-rich MEA reacts with 3.9 t/day gypsum in a 5 m<sup>3</sup> stirred reactor, precipitating 2.3 t/day CaCO<sub>3</sub> and releasing sulfate to the filtrate.

The Energy Conversion Transduction Chemical Reaction Electromagnetic Actuator — CO<sub>2</sub>-rich MEA reacts with 3.9 t/day gypsum in a 5 m<sup>3</sup> stirred reactor, precipitating 2.3 t/day CaCO<sub>3</sub> and releasing sulfate to the filtrate.



*Illustration only — generic class render. Module 6 (Gypsum Carbonation Reactor) shown in identity colour; other modules muted; enclosure ghosted.*

The gypsum carbonation reactor module integrates Rushton Agitation Power v1.0.0 and Reaction Stoichiometry Mass Balance v1.0.0 results to produce 2.3 t/day  $\text{CaCO}_3$  and 3.9 t/day  $\text{K}_2\text{SO}_4$  from 3.1 t/day gypsum and 2.6 t/day KOH.

## Sub-modules

### 6.1 Energy Conversion Transduction Chemical Sensing Mass Fluid Transport Process

The gypsum carbonation reactor chemical sensing mass fluid transport process reacts 9 components. 2x Endress+Hauser Memosens glass pH electrode reactor in-line ph probe (part [CPS11D](#)) (additional: £2,200). An Endress+Hauser Memosens platinum ORP electrode reactor in-line ORP probe (part [CPS12D](#)) (additional: £1,500).

An Endress+Hauser Coriolis density + mass-flow on the recirculation loop coriolis slurry density metre (part [Promass Q 300](#)) (additional: £7,800). 2x Endress+Hauser Memosens Pt100 with thermowell reactor pt100 temperature sensor (part [iTHERM TM411](#)) (additional: £1,100). 4x Spelsberg IP66 field junction box for instrument wiring field instrument junction box (part [81040001](#), 152 x 152 x 80 mm), certified to BS EN 62208 (additional: £40).

A Schenck Process loss-in-weight screw feeder gypsum feed hopper and metering screw (part [MULTICOR](#), 163 kg/h capacity) (additional: £9,800). 2x SEEPEX progressive-cavity, abrasion-rated

caco3 slurry transfer pump (part [BN 35-6L](#)) (additional: £6,800). A Warman rubber-lined centrifugal slurry pump reactor slurry recirculation pump (part WGR 40) (additional: £5,400).

A 2.4 m long x 0.3 m wide open 316L launder to filter feed tank reactor overflow weir and launder (part fabricated 316L overflow launder - made to order) (additional: £1,800). CO<sub>2</sub>-rich MEA reacts with 3.9 t/day gypsum in a 5 m<sup>3</sup> stirred reactor, precipitating 2.3 t/day CaCO<sub>3</sub> and releasing sulfate to the filtrate.

### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Pressure Vessel Wall Design (hoop-stress sizing) v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

###### Internal design pressure

$$p_{\text{design\_mpa}} = p_{\text{design\_barg}} \times 0.1$$

$$p_{\text{design\_mpa}} = 3 \times 0.1 = 0.3 \text{ MPa}$$

assumes: internal gauge design pressure of the process vessel; 1 bar = 0.1 MPa

###### Shell minimum thickness (hoop stress, internal pressure)

$$t = p_{\text{design}} \times D / (2 \times S \times E - 1.2 \times p_{\text{design}}) + \text{corr}$$

$$t = 0.3 \times 1,503 / (2 \times 174 \times 0.85 - 1.2 \times 0.3) + 3 = 4.526 \text{ mm}$$

assumes: ASME VIII Div.1 UG-27 circumferential-stress form (BS EN 13445 equivalent); 0.6 x yield (no datasheet allowable supplied); + 3.0 mm corrosion allowance; adopted shell t = 8.0 mm (>= 5 mm practical handling minimum)

###### Hoop stress at adopted wall (internal pressure)

$$\sigma_{\text{hoop}} = p_{\text{design}} \times D / (2 \times t)$$

$$\sigma_{\text{hoop}} = 0.3 \times 1,503 / (2 \times 8) = 28.181 \text{ MPa}$$

assumes: thin-wall cylinder under internal pressure

###### Yield safety factor (hoop-governing, internal pressure)

$$SF_{\text{yield}} = \text{yield\_mpa} / \sigma_{\text{hoop}}$$

$$SF_{\text{yield}} = 290 / 28.181 = 10.291$$

assumes: material steel\_316L; yield from datasheet/standard; internal-pressure vessel - yield governs (no external-buckling check)

###### Cylinder wall mass

$$\text{mass} = \pi \times (r_{\text{outer}}^2 - r_{\text{inner}}^2) \times \text{length\_mm} \times \text{density} / 1e9$$

$$\text{mass} = \pi \times (759.5^2 - 751.5^2) \times 2,255 \times 8,000 / 1e9 = 685.079 \text{ kg}$$

assumes: material steel\_316L; cylindrical shell only; heads computed separately; 1e9 converts mm<sup>3</sup> to m<sup>3</sup>

###### Head mass (2 flat-plate heads)

$$\text{mass} = 2 \times \pi \times r_{\text{outer}}^2 \times t \times \text{density} / 1e9$$

$$\text{mass} = 2 \times \pi \times 759.5^2 \times 8 \times 8,000 / 1e9 = 231.961 \text{ kg}$$

assumes: flat-head approximation (conservative vs torispherical); 2 heads; 1e9 converts mm<sup>3</sup> to m<sup>3</sup>

###### Total vessel shell mass

$$\text{total\_mass} = \text{mass\_cylinder} + \text{mass\_heads}$$

$$\text{total\_mass} = 685.079 + 231.961 = 917.041 \text{ kg}$$

#### Reactor (CSTR/PFR) Volume + Vessel Sizing v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

###### Reactor working volume (total)

$$V_{\text{working}} = Q \times \tau$$

$$V_{\text{working}} = 3.2023 \times 1.5 = 4.8035 \text{ m}^3$$

assumes: throughput basis: mass 4163.0 kg/h / rho 1300.0 kg/m<sup>3</sup>; working (liquid) volume = flow x residence time

**Gross vessel volume (freeboard)**

$$V_{\text{vessel}} = V_{\text{per}} / \text{fill\_fraction}$$

$$V_{\text{vessel}} = 4.8035 / 0.8 = 6.0043 \text{ m}^3$$

assumes: fill fraction 0.8 leaves freeboard for disengagement/agitation

**Vessel diameter from aspect ratio**

$$D = (4 \times V_{\text{vessel}} / (\pi \times L_{\text{over\_D}}))^{(1/3)}$$

$$D = (4 \times 6.0043 / (\pi \times 2))^{(1/3)} = 1.5636 \text{ m}$$

assumes: vertical cylinder  $V = \pi/4 D^2 L$  with  $L = (L/D) \times D$ ; heads ignored for first pass

**Vessel tangent-to-tangent height**

$$L = L_{\text{over\_D}} \times D$$

$$L = 2 \times 1.5636 = 3.1271 \text{ m}$$

assumes: L/D 2-3 typical for agitated vessels (Coulson & Richardson Vol 6)

**Shell minimum thickness (hoop stress, internal pressure)**

$$t = P \times D / (2 \times S \times E - 1.2 \times P) + \text{corr}$$

$$t = 0.2 \times 1,563.6 / (2 \times 174 \times 0.85 - 1.2 \times 0.2) + 3 = 4.058 \text{ mm}$$

assumes: ASME VIII Div.1 UG-27 circumferential-stress form (BS EN 13445 equivalent); 0.6 x yield (no datasheet allowable supplied); + 3.0 mm corrosion allowance; adopted shell  $t = 5.0 \text{ mm}$  ( $\geq 5 \text{ mm}$  practical handling minimum)

**Shell mass (wall + 2 heads) per reactor**

$$m = (\pi \times (r_o^2 - r_i^2) \times H + 2 \times \pi \times r_o^2 \times t) \times \rho / 1e9$$

$$m = (\pi \times (786.8^2 - 781.8^2) \times 3,127.1 + 2 \times \pi \times 786.8^2 \times 5) \times 8,000 / 1e9 = 771.97 \text{ kg}$$

assumes: material steel\_316L; flat-head approximation (conservative vs torispherical); 1e9 converts mm<sup>3</sup> to m<sup>3</sup>

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Reactor Ph Probe	Endress+Hauser	<a href="#">CPS11D</a>	x2	~£2,200.00	<b>£4,400.00</b>	— OK
Reactor ORP Probe	Endress+Hauser	<a href="#">CPS12D</a>	x1	~£1,500.00	<b>£1,500.00</b>	— OK
Reactor Slurry Density Meter	Endress+Hauser	<a href="#">Promass Q 300</a>	x1	~£7,800.00	<b>£7,800.00</b>	— OK
Reactor Temperature Sensor	Endress+Hauser	<a href="#">iTHERM TM411</a>	x2	~£1,100.00	<b>£2,200.00</b>	— >2x
Instrument Junction Box	Spelsberg	<a href="#">81040001</a>	x4	~£40.00	<b>£160.00</b>	— <.5x
Gypsum Feed Hopper + Screw	Schenck Process	<a href="#">MULTICOR</a>	x1	~£9,800.00	<b>£9,800.00</b>	— OK
Caco3 Slurry Transfer Pump	SEEPEX	<a href="#">BN 35-6L</a>	x2	~£6,000.00	<b>£12,000.00</b>	— OK
Reactor Slurry Recirculation Pump	Warman	<b>WGR 40</b>	x1	~£5,400.00	<b>£5,400.00</b>	— OK
Reactor Overflow Launder	—	<b>fabricated 316L overflow launder — made to order</b>	x1	~£1,800.00	<b>£1,800.00</b>	— OK
<b>Sub-total — Energy Conversion Transduction Chemical Sensing Mass Fluid Transport Process</b>					<b>£45,060</b>	

SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.

## 6.2 Energy Conversion Transduction Chemical Reaction Electromagnetic Actuator

The gypsum carbonation reactor chemical reaction electromagnetic actuator reacts 8 components. A De Dietrich baffled stirred-tank reactor, jacketed stirred carbonation reactor (part fabricated jacketed 316L stirred-tank reactor - bespoke vessel, 5 m<sup>3</sup>), certified to PED 2014/68/EU (additional: £24,000). A 3.6 m<sup>3</sup> gently-stirred residence vessel for crystal growth caco<sub>3</sub> maturation/digestion vessel (part fabricated 316L maturation vessel - bespoke vessel), certified to PED 2014/68/EU (additional: £14,000).

A 0.19 m ring perforated 316L ring sparger under the impeller rich-amine/co<sub>2</sub> sparger ring (part fabricated 316L ring sparger - made to order) (additional: £2,400). A Sulzer in-line static mixer pre-contacting rich amine with gypsum slurry in-line carbonation static mixer (part [SMV](#)) (additional: £3,200). An Ekato pitched-blade turbine top-entry agitator (part [ISOJET](#), 4 kW capacity) (additional: £10,000).

An ABB IE3 TEFC squirrel-cage, VSD-fed agitator drive motor (part [M3BP 132S](#), 5.5 kW capacity), certified to IEC 60034-30-1 (additional: £1,600). A SEW-Eurodrive helical foot-mounted gear unit agitator helical reduction gearbox (part [R97](#)) (additional: £2,300). An EagleBurgmann double cartridge mechanical seal, barrier-fluid agitator double mechanical seal (part [Cartex-DN](#)) (additional: £3,200).

CO<sub>2</sub>-rich MEA reacts with 3.9 t/day gypsum in a 5 m<sup>3</sup> stirred reactor, precipitating 2.3 t/day CaCO<sub>3</sub> and releasing sulfate to the filtrate.

### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Rushton Agitation Power v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

###### Impeller rotational speed

$$N = \text{rpm} / 60$$

$$N = 90 / 60 = 1.5 \text{ rev/s}$$

assumes: converts rpm to revolutions per second for SI power formula

###### Impeller tip speed

$$v_{\text{tip}} = \pi \times D \times N$$

$$v_{\text{tip}} = \pi \times 0.43 \times 1.5 = 2.026 \text{ m/s}$$

assumes: circumferential tip velocity; indicator of shear stress on cells

###### Impeller Reynolds number

$$Re = \rho \times N \times D^2 / \mu$$

$$Re = 1,250 \times 1.5 \times 0.43^2 / 0.003 = 115,562.5$$

assumes:  $Re > 10000$  = fully turbulent;  $Re < 10$  = laminar (Doran Ch.8)

###### Ungassed agitation power

$$P_{\text{ug}} = N_p \times \rho \times N^3 \times D^5$$

$$P_{\text{ug}} = 0.35 \times 1,250 \times 1.5^3 \times 0.43^5 = 21.71 \text{ W}$$

assumes:  $N_p$  from Bates-Fondy-Corpstein turbulent power numbers; piecewise for transitional  $Re$ ; single impeller, baffled tank,  $D/T \sim 1/3$

**Volumetric power input**

$$P_V = P_w / V_{\text{tank}}$$

$$P_V = 21.71 / 1.7656 = 12.3 \text{ W/m}^3$$

assumes: cylindrical tank assumed  $H = T$ ;  $V_{\text{tank}} = \pi/4 \times T^3$ ;  $P_w$  = gassed power when gassed=True (Michel & Miller correction applied upstream)

PART	MANUFAC-TURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Stirred Carbonation Reactor	De Dietrich	<b>fabricated jacketed 316L stirred-tank reactor — bespoke vessel</b>	x1	~£24,000.00	<b>£24,000.00</b>	— OK
Carbonation Maturation Vessel	—	<b>fabricated 316L maturation vessel — bespoke vessel</b>	x1	~£14,000.00	<b>£14,000.00</b>	— OK
CO2 Sparger Ring	—	<b>fabricated 316L ring sparger — made to order</b>	x1	~£2,400.00	<b>£2,400.00</b>	— OK
Carbonation Static Mixer	Sulzer	<a href="#">SMV</a>	x1	~£3,200.00	<b>£3,200.00</b>	— OK
Reactor Agitator	Ekato	<a href="#">ISOJET</a>	x1	~£11,000.00	<b>£11,000.00</b>	— OK
Agitator Drive Motor	ABB	<a href="#">M3BP 132S</a>	x1	~£1,600.00	<b>£1,600.00</b>	— OK
Agitator Reduction Gearbox	SEW-Eurodrive	<a href="#">R97</a>	x1	~£2,250.00	<b>£2,250.00</b>	— OK
Agitator Shaft Mechanical Seal	Eagle-Burgmann	<a href="#">Cartex-DN</a>	x1	~£3,100.00	<b>£3,100.00</b>	— OK
<b>Sub-total — Energy Conversion Transduction Chemical Reaction Electromagnetic Actuator</b>					<b>£61,550</b>	

SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.

**Module 6 total — Gypsum Carbonation Reactor**

**£106,610.00**

## MODULE 7

# K<sub>2</sub>SO<sub>4</sub> Recovery & Crystallisation

Cost **£160,750.00**

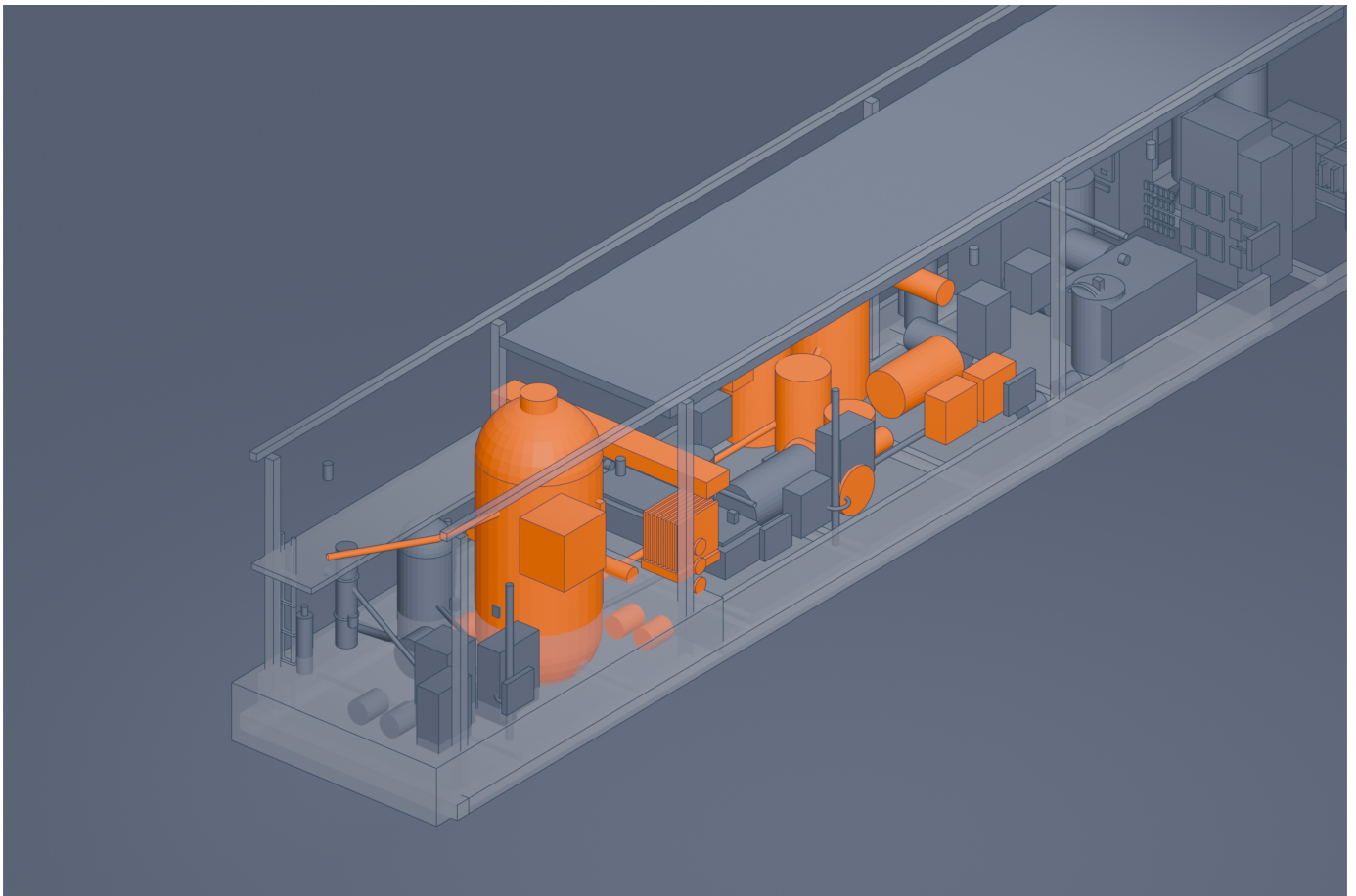
## Module summary

### PURPOSE

This module (K<sub>2</sub>SO<sub>4</sub> Recovery & Crystallisation) KOH converts the sulfate filtrate to fertiliser-grade K<sub>2</sub>SO<sub>4</sub> and regenerates free MEA; K<sub>2</sub>SO<sub>4</sub> is centrifuged, recrystallised MEA-free and hot-air dried.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The K<sub>2</sub>SO<sub>4</sub> recovery line — sulfate filtrate reacts with 2.5 t/day solid KOH to form 4.0 t/day K<sub>2</sub>SO<sub>4</sub> and free MEA; K<sub>2</sub>SO<sub>4</sub> is filtered, recrystallised MEA-free, and hot-air dried.



*Illustration only — generic class render. Module 7 (K<sub>2</sub>SO<sub>4</sub> Recovery & Crystallisation) shown in identity colour; other modules muted; enclosure ghosted.*

The gypsum carbonation reactor module integrates Rushton Agitation Power v1.0.0 and Reaction Stoichiometry Mass Balance v1.0.0 results to produce 2.3 t/day CaCO<sub>3</sub> and 3.9 t/day K<sub>2</sub>SO<sub>4</sub> from 3.1 t/day gypsum and 2.6 t/day KOH.

## Sub-modules

### 7.1 K<sub>2</sub>SO<sub>4</sub> recovery line

The K<sub>2</sub>SO<sub>4</sub> recovery line converts 12 components. A De Dietrich agitated, jacketed KOH reaction vessel (part fabricated jacketed 316L agitated vessel - bespoke vessel, 3 m<sup>3</sup>), certified to PED 2014/68/EU (additional: £19,000). A 2 m<sup>3</sup> agitated dissolution tank, exotherm-cooled KOH dissolution and make-up tank (part fabricated 316L agitated dissolution tank - bespoke vessel), certified to COSHH (additional: £12,000).

A 1.5 m<sup>3</sup> steam-heated stripping pot freeing MEA from the filtrate regenerated-mea stripping reboil pot (part fabricated jacketed 316L stripping pot - bespoke vessel), certified to PED 2014/68/EU (additional: £10,000). A Gericke enclosed screw feeder, corrosion-rated KOH solids dosing feeder (part GLD 115, 250 kg/h capacity), certified to COSHH (additional: £15,500). An Andritz single-stage pusher centrifuge K<sub>2</sub>SO<sub>4</sub> pusher centrifuge (part [SZ \(frame TBD at quotation\)](#), 165 kg/h capacity) (additional: £23,000).

2x SEEPEX progressive-cavity slurry pump, 1 duty + 1 standby crystalliser-to-centrifuge slurry feed pump (part BN 17-6L) (additional: £5,200). A Grundfos centrifugal recycle pump back to the crystalliser crystalliser mother-liquor recycle pump (part [CRNE 5-6](#)) (additional: £3,400). A GEA Messo forced-circulation crystalliser, MEA stripping K<sub>2</sub>SO<sub>4</sub> forced-circulation recrystalliser (part forced-circulation crystalliser - bespoke package) (additional: £21,000).

A GEA fluidised-bed dryer K<sub>2</sub>SO<sub>4</sub> fluid-bed hot-air dryer (part [FLUIDBED VIBRO-FLUIDISER](#), 75 kW capacity) (additional: £22,000). An Alfa Laval shell-and-tube circulation heater, steam-heated crystalliser forced-circulation heater (part [CB110](#), 90 kW capacity) (additional: £8,500). An Alfa Laval gasketed plate cooler, cooling-water served crystalliser product cooler (part [M6-FG](#), 40 kW capacity) (additional: £5,200).

A GEA shell-and-tube vacuum condenser with vapour ejector crystalliser vacuum/mea-vapour condenser (part shell-and-tube vacuum condenser - packaged, 60 kW capacity) (additional: £9,200). Sulfate filtrate reacts with 2.5 t/day solid KOH to form 4.0 t/day K<sub>2</sub>SO<sub>4</sub> and free MEA; K<sub>2</sub>SO<sub>4</sub> is filtered, recrystallised MEA-free, and hot-air dried.

#### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Convective Dryer Air-Flow + Heat-Duty Sizing v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

##### Bone-dry solids (conserved)

$$\bar{d}_{\text{dry}} = \text{wet} \times (1 - X_{\text{in}})$$

$$\bar{d}_{\text{dry}} = 235.7 \times (1 - 0.3) = 164.99 \text{ kg/h}$$

assumes: wet-basis moisture; bone-dry solids pass through unchanged

**Water evaporated**

$\text{water\_evap} = \text{water\_in} - \text{water\_out}$   
 $\text{water\_evap} = 70.71 - 0.829 = 69.881 \text{ kg/h}$   
 assumes: product 165.819 kg/h at 0.5% wet-basis moisture

**Inlet drying-air humidity ratio (heated ambient)**

$W_{\text{in}} = W_{\text{ambient}}$   
 $W_{\text{in}} = 0.0087 = 0.0087 \text{ kg/kg}$   
 assumes: ambient 20.0 degC / 60.0% RH heated to 120.0 degC; sensible heating adds no moisture; psychrolib (ASHRAE 2017)

**Outlet (exhaust) air humidity ratio**

$W_{\text{out}} = f(T_{\text{out}}, RH_{\text{out}})$   
 $W_{\text{out}} = f(60, 60) = 0.0833 \text{ kg/kg}$   
 assumes: exhaust 60.0 degC / 60.0% RH; psychrolib humidity ratio; psychrolib (ASHRAE 2017)

**Dry-air mass flow from humidity pick-up**

$m_{\text{air}} = \text{water\_evap} / (W_{\text{out}} - W_{\text{in}})$   
 $m_{\text{air}} = 69.881 / (0.0833 - 0.0087) = 937.35 \text{ kg/h}$   
 assumes: dry-air basis; the air carries every kg of evaporated water as added humidity

**Air-enthalpy rise across the heater**

$dh = h_{\text{inlet}} - h_{\text{ambient}}$   
 $dh = 144.514 - 42.29 = 102.225 \text{ kJ/kg}$   
 assumes: per kg dry air; moist-air enthalpy from psychrolib; psychrolib (ASHRAE 2017)

**Heater duty**

$\text{duty} = (m_{\text{air}} / 3600) \times dh / \text{heater\_eff}$   
 $\text{duty} = (937.35 / 3600) \times 102.225 / 0.85 = 31.314 \text{ kW}$   
 assumes: heater + duct efficiency 0.85; /3600 converts kg/h to kg/s; kg/s x kJ/kg = kW

**Humid-air volumetric flow at heater outlet**

$Q_{\text{air}} = (m_{\text{air}} / 3600) \times v_{\text{humid}} \times 3600$   
 $Q_{\text{air}} = (937.35 / 3600) \times 1.1294 \times 3600 = 1,058.63 \text{ m}^3/\text{h}$   
 assumes: moist-air specific volume at the heated inlet (fan/duct sizing); psychrolib (ASHRAE 2017)

**Electrical Main Feeder Cable Sizing (BS 7671) v1.0.0****WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****De-rated tabulated-current target**

$I_{\text{t}} = I_{\text{b}} / (C_{\text{a}} \times C_{\text{g}})$   
 $I_{\text{t}} = 899.7 / (0.94 \times 0.8) = 1,196.42 \text{ A}$   
 assumes: design current basis: derived: 561.0 kW / (sqrt(3) x 400.0 V x 0.9); Ca ambient + Cg grouping de-rating (BS 7671 Appendix 4)

**Conductor cross-sectional area (standard selection)**

$\text{CSA} = \text{smallest standard with ampacity} \times n_{\text{parallel}} \geq I_{\text{t}}$   
 $\text{CSA} = \text{smallest standard with ampacity} \times 2 \geq 1,196.42 = 300 \text{ mm}^2$   
 assumes: copper, 90 C thermosetting, Reference Method C (clipped direct); selected CSA tabulated ampacity = 628 A (x 2 parallel = 1256 A)

**Volt drop**

$V_{\text{d}} = (\text{mV/A/m}) \times I_{\text{b}} \times L / (1000 \times n_{\text{parallel}})$   
 $V_{\text{d}} = (0.145) \times 899.7 \times 35 / (1000 \times 2) = 2.283 \text{ V}$   
 assumes: mV/A/m for 300 mm<sup>2</sup> copper (BS 7671 Appendix 4)

**Volt drop as percentage of nominal**

$V_{\text{d\_pct}} = 100 \times V_{\text{d}} / U_{\text{nom}}$   
 $V_{\text{d\_pct}} = 100 \times 2.283 / 400 = 0.571 \%$   
 assumes: BS 7671 §525 advisory ceiling 5.0% (within limit)

**Evaporative Crystalliser Duty + Area Sizing v1.0.0**

**WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****Solute entering the liquor (back-out from recovery)**

$\text{solute\_in} = \text{solute\_product} / \text{recovery}$   
 $\text{solute\_in} = 165 / 0.9 = 183.333 \text{ kg/h}$   
 assumes: 90.0% of incoming K<sub>2</sub>SO<sub>4</sub> reports to crystal product

**Water in the feed liquor**

$\text{water\_in} = \text{feed\_mass} - \text{solute\_in}$   
 $\text{water\_in} = 1,680.556 - 183.333 = 1,497.222 \text{ kg/h}$   
 assumes: feed 1.5278 m<sup>3</sup>/h at 120.0 g/L, rho 1100.0 kg/m<sup>3</sup>

**Water retained to hold residual solute at saturation**

$\text{water\_final} = \text{solute\_residual} / \text{solubility\_g\_g}$   
 $\text{water\_final} = 18.333 / 0.12 = 152.778 \text{ kg/h}$   
 assumes: solubility 12.0 g/100 g water at the operating temperature

**Water to evaporate**

$\text{water\_evap} = \text{water\_in} - \text{water\_final}$   
 $\text{water\_evap} = 1,497.222 - 152.778 = 1,344.444 \text{ kg/h}$   
 assumes: drives the mother liquor to saturation so the recovered solute crystallises

**Evaporation duty**

$\text{duty\_evap} = (\text{water\_evap} / 3600) \times h_{fg}$   
 $\text{duty\_evap} = (1,344.444 / 3600) \times 2,335.27 = 872.124 \text{ kW}$   
 assumes: latent heat of water at 30.0 kPa: CoolProp IAPWS-IF97 (Water, h<sub>vap</sub> - h<sub>liq</sub> at P); boiling point 69.1 degC at that pressure; /3600 converts kg/h to kg/s so kg/s x kJ/kg = kW

**Sensible pre-heat duty (feed to boiling)**

$\text{duty\_sens} = (\text{feed\_mass} / 3600) \times c_p \times (t_{\text{boil}} - t_{\text{feed}})$   
 $\text{duty\_sens} = (1,680.556 / 3600) \times 4.18 \times (69.1 - 25) = 86.043 \text{ kW}$   
 assumes: water cp ~ 4.18 kJ/kgK; raises the feed to the boiling temperature

**Total crystalliser duty**

$\text{duty\_total} = \text{duty\_evap} + \text{duty\_sens}$   
 $\text{duty\_total} = 872.124 + 86.043 = 958.168 \text{ kW}$

**Steam-side heat-transfer area**

$\text{area} = \text{duty\_total} \times 1000 / (U \times \Delta T)$   
 $\text{area} = 958.168 \times 1000 / (1,200 \times 60.9) = 13.11 \text{ m}^2$   
 assumes: Q = U A ΔT; steam 130.0 degC to boiling 69.1 degC; U supplied (Perry: forced-circ. evaporators 1000-2500 W/m<sup>2</sup>K); x1000 converts kW to W

**Crystalliser body volume from magma residence**

$V = (\text{magma\_mass} / 3600 / \text{rho\_magma}) \times 3600 \times \text{tau} / n_{\text{units}}$   
 $V = (336.111 / 3600 / 1,100) \times 3600 \times 2 / 1 = 0.6111 \text{ m}^3$   
 assumes: magma (liquor + crystals) volumetric rate x residence time

**Crystalliser body diameter from aspect ratio**

$D = (4 \times V / (\pi \times L_{\text{over\_D}}))^{1/3}$   
 $D = (4 \times 0.6111 / (\pi \times 2))^{1/3} = 0.73 \text{ m}$   
 assumes: vertical cylinder with vapour-disengagement freeboard at the top

**Fluids Pipe Sizing + Pressure Drop v1.3.0****WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****Flow velocity**

$\text{velocity} = Q / (\text{pipe\_area\_mm}^2 / 1000000)$   
 $\text{velocity} = 0.0008333 / (1,963.5 / 1000000) = 0.4244 \text{ m/s}$   
 assumes: pipe\_area = π x (D/2)<sup>2</sup> for internal diameter D; /1e6 converts mm<sup>2</sup> to m<sup>2</sup>

**Reynolds number**

$$Re = \rho \times \text{velocity} \times D / \mu$$

$$Re = 992.217 \times 0.4244 \times 0.05 / 0.0006527 = 32,257.7$$

**Straight-pipe pressure drop**

$$dp_{\text{straight}} = f \times (L / D) \times 0.5 \times \rho \times \text{velocity} \times \text{velocity}$$

$$dp_{\text{straight}} = 0.0239 \times (25 / 0.05) \times 0.5 \times 992.217 \times 0.4244 \times 0.4244 = 1,068.4 \text{ Pa}$$

assumes: Darcy-Weisbach; velocity x velocity = velocity squared

**Gravity (elevation) head**

$$dp_{\text{gravity}} = \rho \times g \times \text{elevation\_change}$$

$$dp_{\text{gravity}} = 992.217 \times 9.8066 \times 0 = 0 \text{ Pa}$$

**Total pressure drop**

$$dp_{\text{total}} = dp_{\text{straight}} + dp_{\text{fittings}} + dp_{\text{gravity}}$$

$$dp_{\text{total}} = 1,068.4 + 0 + 0 = 1,068.4 \text{ Pa}$$

assumes:  $dp_{\text{fittings}} = \text{sum of fitting K-values} \times 0.5 \times \rho \times \text{velocity}^2$  (3-K method)

**HT eps-NTU Heat Exchanger v1.2.0****WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****Conductance UA**

$$UA = ntu \times c_{\text{min}}$$

$$UA = 2.2 \times 2.5 = 5.5 \text{ kW/K}$$

**Maximum heat duty**

$$q_{\text{max}} = c_{\text{min}} \times (t_{\text{hot\_in}} - t_{\text{cold\_in}})$$

$$q_{\text{max}} = 2.5 \times (100 - 30) = 175 \text{ kW}$$

**Actual heat transfer**

$$q = \text{effectiveness} \times q_{\text{max}}$$

$$q = 0.8892 \times 175 = 155.609 \text{ kW}$$

**Hot-side outlet temperature**

$$t_{\text{hot\_out}} = t_{\text{hot\_in}} - q / c_{\text{min}}$$

$$t_{\text{hot\_out}} = 100 - 155.609 / 2.5 = 37.756 \text{ C}$$

assumes: hot fluid taken as the  $C_{\text{min}}$  side (typical chiller/HVAC case)

**Packed Absorption/Stripping Column (HTU-NTU + flooding) v1.0.0****WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****Outlet solute mole fraction (target removal)**

$$y_2 = y_1 \times (1 - \text{removal})$$

$$y_2 = 0.12 \times (1 - 0.9) = 0.012$$

assumes: 90.0% of the solute removed; dilute-gas basis

**Absorption factor**

$$A = L / (m \times G)$$

$$A = 150 / (1.5 \times 8.6207) = 11.6$$

assumes:  $A > 1$  favours absorption;  $m$  = equilibrium-line slope  $dy^*/dx$

**Number of transfer units (NTU)**

$$NTU = \ln\left[\frac{(y_1 - m x_2)/(y_2 - m x_2)}{(y_1 - 1/A) + 1/A}\right] / (1 - 1/A)$$

$$NTU = \ln\left[\frac{(0.12 - 1.5 \cdot 0)/(0.012 - 1.5 \cdot 0)}{(1 - 1/11.6) + 1/11.6}\right] / (1 - 1/11.6) = 2.4314$$

assumes: Colburn dilute-absorption equation (Treybal Eq. 8.48); dilute system, linear equilibrium, constant A

**Packed height**

$$H = HTU \times NTU$$

$$H = 0.7 \times 2.4314 = 1.702 \text{ m}$$

assumes: HTU 0.7 m for the specified packing (stripper)

**Flow parameter (Eckert abscissa)**

$$F_{LV} = (L_{\text{mass}} / G_{\text{mass}}) \times \sqrt{\rho_G / \rho_L}$$

$$F_{LV} = (3,600 / 250) \times \sqrt{1.1 / 1,000} = 0.4776$$

assumes: mass-flow ratio form of the generalised pressure-drop correlation

**Flooding velocity (Eckert GPDC)**

$$u_{\text{flood}} = \sqrt{Y_{\text{flood}} \times g \times (\rho_L - \rho_G) / (\rho_G \times F_p \times \mu_L^{0.1})}$$

$$u_{\text{flood}} = \sqrt{0.0486 \times 9.8066 \times (1,000 - 1.1) / (1.1 \times 66 \times 1^{0.1})} = 2.5602 \text{ m/s}$$

assumes:  $Y_{\text{flood}}$  from the Kessler-Wankat fit of the Eckert flooding line;  $F_p$  = packing factor (Mellapak 250Y ~ 66 1/m; 25 mm random rings ~ 500 1/m)

**Design superficial gas velocity**

$$u_{\text{design}} = f_{\text{flood}} \times u_{\text{flood}}$$

$$u_{\text{design}} = 0.6 \times 2.5602 = 1.5361 \text{ m/s}$$

assumes: operate at 60.0% of flooding (typical 60-75%)

**Column diameter from gas load**

$$D = \sqrt{4 \times Q_G / (\pi \times u_{\text{design}})}$$

$$D = \sqrt{4 \times 0.0631 / (\pi \times 1.5361)} = 0.2288 \text{ m}$$

assumes: gas volumetric flow 0.06313 m<sup>3</sup>/s; cross-section  $A = Q_G / u_{\text{design}}$ ;  $D = \sqrt{4A/\pi}$

**Pressure Vessel Wall Design (hoop-stress sizing) v1.0.0****WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND****Internal design pressure**

$$p_{\text{design\_mpa}} = p_{\text{design\_barg}} \times 0.1$$

$$p_{\text{design\_mpa}} = 3 \times 0.1 = 0.3 \text{ MPa}$$

assumes: internal gauge design pressure of the process vessel; 1 bar = 0.1 MPa

**Shell minimum thickness (hoop stress, internal pressure)**

$$t = p_{\text{design}} \times D / (2 \times S \times E - 1.2 \times p_{\text{design}}) + \text{corr}$$

$$t = 0.3 \times 1,503 / (2 \times 174 \times 0.85 - 1.2 \times 0.3) + 3 = 4.526 \text{ mm}$$

assumes: ASME VIII Div.1 UG-27 circumferential-stress form (BS EN 13445 equivalent); 0.6 x yield (no datasheet allowable supplied); + 3.0 mm corrosion allowance; adopted shell  $t = 8.0 \text{ mm}$  ( $\geq 5 \text{ mm}$  practical handling minimum)

**Hoop stress at adopted wall (internal pressure)**

$$\sigma_{\text{hoop}} = p_{\text{design}} \times D / (2 \times t)$$

$$\sigma_{\text{hoop}} = 0.3 \times 1,503 / (2 \times 8) = 28.181 \text{ MPa}$$

assumes: thin-wall cylinder under internal pressure

**Yield safety factor (hoop-governing, internal pressure)**

$$SF_{\text{yield}} = \text{yield\_mpa} / \sigma_{\text{hoop}}$$

$$SF_{\text{yield}} = 290 / 28.181 = 10.291$$

assumes: material steel\_316L; yield from datasheet/standard; internal-pressure vessel - yield governs (no external-buckling check)

**Cylinder wall mass**

$$\text{mass} = \pi \times (r_{\text{outer}}^2 - r_{\text{inner}}^2) \times \text{length\_mm} \times \text{density} / 1e9$$

$$\text{mass} = \pi \times (759.5^2 - 751.5^2) \times 2,255 \times 8,000 / 1e9 = 685.079 \text{ kg}$$

assumes: material steel\_316L; cylindrical shell only; heads computed separately; 1e9 converts mm<sup>3</sup> to m<sup>3</sup>

**Head mass (2 flat-plate heads)**

$$\text{mass} = 2 \times \pi \times r_{\text{outer}}^2 \times t \times \text{density} / 1e9$$

$$\text{mass} = 2 \times \pi \times 759.5^2 \times 8 \times 8,000 / 1e9 = 231.961 \text{ kg}$$

assumes: flat-head approximation (conservative vs torispherical); 2 heads; 1e9 converts mm<sup>3</sup> to m<sup>3</sup>

**Total vessel shell mass**

```
total_mass = mass_cylinder + mass_heads
total_mass = 685.079 + 231.961 = 917.041 kg
```

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE - CHECK
KOH Reaction Vessel	De Dietrich	fabricated jacketed 316L agitated vessel — bespoke vessel	x1	~£19,000.00	<b>£19,000.00</b>	— OK
KOH Dissolution + Make-up Tank	—	fabricated 316L agitated dissolution tank — bespoke vessel	x1	~£12,000.00	<b>£12,000.00</b>	— OK
MEA Stripper Reboil Pot	—	fabricated jacketed 316L stripping pot — bespoke vessel	x1	~£10,000.00	<b>£10,000.00</b>	— OK
KOH Solids Dosing Feeder	Gericke	GLD 115	x1	~£15,500.00	<b>£15,500.00</b>	— OK
K2so4 Pusher Centrifuge	Andritz	<a href="#">SZ (frame TBD at quotation)</a>	x1	~£22,500.00	<b>£22,500.00</b>	— OK
K2so4 Slurry Feed Pump	SEEPEX	BN 17-6L	x2	~£6,000.00	<b>£12,000.00</b>	— OK
Mother-liquor Recycle Pump	Grundfos	<a href="#">CRNE 5-6</a>	x1	~£3,850.00	<b>£3,850.00</b>	— OK
K2so4 Recrystalliser	GEA Messo	forced-circulation crystalliser — bespoke package	x1	~£21,000.00	<b>£21,000.00</b>	— OK
K2so4 Hot-air Dryer	GEA	<a href="#">FLUIDBED VI-BRO-FLUIDISER</a>	x1	~£22,000.00	<b>£22,000.00</b>	— OK
Crystalliser Circulation Heater	Alfa Laval	<a href="#">CB110</a>	x1	~£8,500.00	<b>£8,500.00</b>	— OK
Crystalliser Product Cooler	Alfa Laval	<a href="#">M6-FG</a>	x1	~£5,200.00	<b>£5,200.00</b>	— OK
Crystalliser Vacuum Condenser	GEA	<a href="#">FLUIDBED VI-BRO-FLUIDISER</a>	x1	~£9,200.00	<b>£9,200.00</b>	— OK
<i>Sub-total — K2SO4 recovery line</i>					<b>£160,750</b>	

SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.

**Module 7 total — K2SO4 Recovery & Crystallisation**
**£160,750.00**

## MODULE 8

# Electrical Distribution

Cost **£90,330.00**

## Module summary

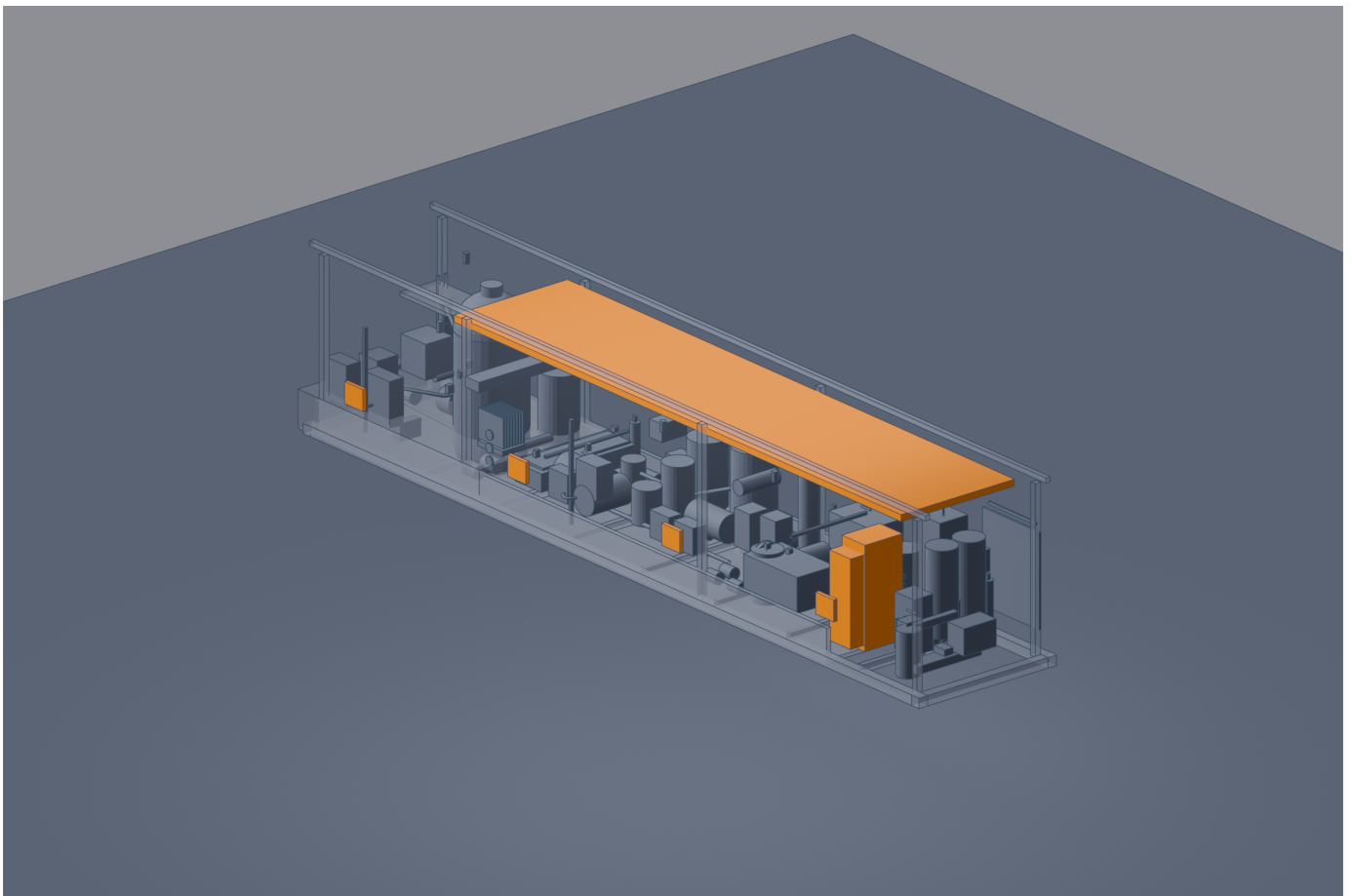
### PURPOSE

This module (Electrical Distribution) a Form-4 MCC with IP55 VSDs and a cast-resin transformer supplies the 561 kW plant load.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 2 sub-modules. The Power Distribution Electrical Conduction — 561 kW of pumps, agitators, heaters, blowers and drives fed from a motor control centre.

The Power Distribution Electromagnetic Actuator Silicon Semiconductor — 561 kW of pumps, agitators, heaters, blowers and drives fed from a motor control centre.



*Illustration only — generic class render. Module 8 (Electrical Distribution) shown in identity colour; other modules muted; enclosure ghosted.*

The Power Distribution module organises 2 sub-modules (power distribution electrical conduction, power distribution electromagnetic actuator silicon semiconductor). The electrical distribution electrical

conduction distributes 5 components. An ABB Form 4 MCC motor control centre (part MNS Form-4 motor control centre - configured, 561 kW capacity), certified to BS EN 61439 (additional: £18,000).

A Prysmian SWA LSZH power + multicore control cable, installed LSZH power and control cabling (part AFUMEX SWA LSZH cable bundle - made to order), certified to BS 7671 (additional: £9,000). A Schneider Electric TP&N busbar chamber + MCB distribution board busbar chamber and distribution board (part Acti9 Isobar B), certified to BS EN 61439 (additional: £2,400). 4x Roxtec rectangular modular cable-transit frame + modules multi-cable transit frames (part ECF0001600021) (additional: £480).

120x CMP Products CW brass SWA glands with shrouds brass armoured cable glands (part CMP CW 20S), certified to BS 6121 (additional: £6). 561 kW of pumps, agitators, heaters, blowers and drives fed from a motor control centre. The electrical distribution electromagnetic actuator silicon semiconductor distributes 8 components.

6x ABB IP55 VSD, one per pump/agitator/blower variable-speed drives (part ACS580-01) (additional: £1,700). 2x ABB IP21 cabinet VSD for blower + centrifuge large duty variable-speed drives (part ACS580-07) (additional: £4,200). 3x Schneider Electric TeSys soft starter for fixed-speed motors motor soft starters (part ATS22D32S6) (additional: £650).

8x ABB plug-in PROFINET fieldbus adapter for the ACS580 drives VSD profinet fieldbus adapter modules (part FPNO-21) (additional: £210). A Schneider Electric cast-resin distribution transformer (part Trihal 800 kVA cast-resin transformer, 800 kVA capacity) (additional: £32,000). 14x ABB 3-pole AC-3 block contactor MCC motor contactors (part AF38-30-00-13) (additional: £95).

14x ABB electronic overload relay for AF09-AF38 electronic motor-protection overload relays (part EF19-18.9) (additional: £110). 14x ABB thermal-magnetic manual motor starter manual motor-protection circuit breakers (part MS132-25), certified to BS EN 60947-4-1 (additional: £85). 561 kW of pumps, agitators, heaters, blowers and drives fed from a motor control centre.

## Sub-modules

### 8.1 Power Distribution Electrical Conduction

The electrical distribution electrical conduction distributes 5 components. An ABB Form 4 MCC motor control centre (part MNS Form-4 motor control centre - configured, 561 kW capacity), certified to BS EN 61439 (additional: £18,000). A Prysmian SWA LSZH power + multicore control cable, installed LSZH power and control cabling (part AFUMEX SWA LSZH cable bundle - made to order), certified to BS 7671 (additional: £9,000).

A Schneider Electric TP&N busbar chamber + MCB distribution board busbar chamber and distribution board (part Acti9 Isobar B), certified to BS EN 61439 (additional: £2,400). 4x Roxtec rectangular modular cable-transit frame + modules multi-cable transit frames (part [ECF0001600021](#)) (additional: £480). 120x CMP Products CW brass SWA glands with shrouds brass armoured cable glands (part CMP CW 20S), certified to BS 6121 (additional: £6).

561 kW of pumps, agitators, heaters, blowers and drives fed from a motor control centre.

### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Electrical Main Feeder Cable Sizing (BS 7671) v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

###### De-rated tabulated-current target

$$I_t = I_b / (C_a \times C_g)$$

$$I_t = 899.7 / (0.94 \times 0.8) = 1,196.42 \text{ A}$$

assumes: design current basis: derived: 561.0 kW / (sqrt(3) x 400.0 V x 0.9); C<sub>a</sub> ambient + C<sub>g</sub> grouping de-rating (BS 7671 Appendix 4)

###### Conductor cross-sectional area (standard selection)

$$CSA = \text{smallest standard with ampacity} \times n_{\text{parallel}} \geq I_t$$

$$CSA = \text{smallest standard with ampacity} \times 2 \geq 1,196.42 = 300 \text{ mm}^2$$

assumes: copper, 90 C thermosetting, Reference Method C (clipped direct); selected CSA tabulated ampacity = 628 A (x 2 parallel = 1256 A)

###### Volt drop

$$V_d = (mV/A/m) \times I_b \times L / (1000 \times n_{\text{parallel}})$$

$$V_d = (0.145) \times 899.7 \times 35 / (1000 \times 2) = 2.283 \text{ V}$$

assumes: mV/A/m for 300 mm<sup>2</sup> copper (BS 7671 Appendix 4)

###### Volt drop as percentage of nominal

$$V_d_{\text{pct}} = 100 \times V_d / U_{\text{nom}}$$

$$V_d_{\text{pct}} = 100 \times 2.283 / 400 = 0.571 \%$$

assumes: BS 7671 §525 advisory ceiling 5.0% (within limit)

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Motor Control Centre	ABB	<a href="#">MNS Form-4 motor control centre — configured</a>	x1	~£18,000.00	<b>£18,000.00</b>	— -
Power + Control Cabling	Prysmian	<b>AFUMEX SWA LSZH cable bundle — made to order</b>	x1	~£9,000.00	<b>£9,000.00</b>	— >2x
Busbar + Distribution Board	Schneider Electric	<b>Acti9 IsoBar B</b>	x1	~£2,400.00	<b>£2,400.00</b>	Est. >2x
Cable Transit Frames	Roxtec	<a href="#">ECF0001600021</a>	x4	~£480.00	<b>£1,920.00</b>	— OK
Cable Glands	CMP Products	<b>CMP CW 20S</b>	x120	~£6.00	<b>£720.00</b>	Est. OK
<b>Sub-total — Power Distribution Electrical Conduction</b>					<b>£32,040</b>	

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## 8.2 Power Distribution Electromagnetic Actuator Silicon Semiconductor

The electrical distribution electromagnetic actuator silicon semiconductor distributes 8 components. 6x ABB IP55 VSD, one per pump/agitator/blower variable-speed drives (part ACS580-01) (additional: £1,700). 2x ABB IP21 cabinet VSD for blower + centrifuge large duty variable-speed drives (part ACS580-07) (additional: £4,200).

3x Schneider Electric TeSys soft starter for fixed-speed motors motor soft starters (part [ATS22D32S6](#)) (additional: £650). 8x ABB plug-in PROFINET fieldbus adapter for the ACS580 drives VSD profinet fieldbus adapter modules (part [FPNO-21](#)) (additional: £210). A Schneider Electric cast-resin distribution transformer (part Trihal 800 kVA cast-resin transformer, 800 kVA capacity) (additional: £32,000).

14x ABB 3-pole AC-3 block contactor MCC motor contactors (part AF38-30-00-13) (additional: £95). 14x ABB electronic overload relay for AF09-AF38 electronic motor-protection overload relays (part [EF19-18.9](#)) (additional: £110). 14x ABB thermal-magnetic manual motor starter manual motor-protection circuit breakers (part MS132-25), certified to BS EN 60947-4-1 (additional: £85).

561 kW of pumps, agitators, heaters, blowers and drives fed from a motor control centre.

### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Electrical Distribution Transformer Sizing v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

###### Apparent power demand

$$S_{\text{load}} = P / \text{pf}$$

$$S_{\text{load}} = 561 / 0.9 = 623.33 \text{ kVA}$$

assumes: apparent power from active load and displacement power factor (IEC 60076 basis)

###### Required rating with spare capacity

$$S_{\text{req}} = S_{\text{load}} \times (1 + \text{headroom})$$

$$S_{\text{req}} = 623.33 \times (1 + 0.25) = 779.17 \text{ kVA}$$

assumes: 25% spare-capacity headroom over demand

###### Transformer nameplate (next standard rating)

$$S_{\text{rated}} = \text{ceil\_to\_standard}(S_{\text{req}})$$

$$S_{\text{rated}} = \text{ceil\_to\_standard}(779.17) = 800 \text{ kVA}$$

assumes: smallest IEC 60076 preferred kVA rating  $\geq$  required

###### Primary line current

$$I = S \times 1000 / (\text{sqrt}(3) \times U_{\text{LL}})$$

$$I = 800 \times 1000 / (\text{sqrt}(3) \times 11,000) = 41.99 \text{ A}$$

assumes: three-phase line current (line-to-line voltage); at the chosen nameplate rating

###### Secondary line current

$$I = S \times 1000 / (\text{sqrt}(3) \times U_{\text{LL}})$$

$$I = 800 \times 1000 / (\text{sqrt}(3) \times 400) = 1,154.7 \text{ A}$$

assumes: three-phase line current (line-to-line voltage); at the chosen nameplate rating

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE CHECK
Variable-speed Drives	ABB	ACS580-01	×6	~£1,700.00	<b>£10,200.00</b>	Est. <b>OK</b>
Blower/centrifuge Vsds	ABB	ACS580-07	×2	~£4,200.00	<b>£8,400.00</b>	Est. <b>&gt;2x</b>

Soft Starters	Schneider Electric	<a href="#">ATS22D32S6</a>	x3	~£650.00	<b>£1,950.00</b>	— -
Drive Fieldbus Modules	ABB	<a href="#">FPNO-21</a>	x8	~£210.00	<b>£1,680.00</b>	— -
Distribution Transformer	Schneider Electric	<b>Trihal 800 kVA cast-resin transformer</b>	x1	~£32,000.00	<b>£32,000.00</b>	Est. <b>OK</b>
Motor Contactors	ABB	<b>AF38-30-00-13</b>	x14	~£95.00	<b>£1,330.00</b>	Est. <b>OK</b>
Motor-protection Relays	ABB	<a href="#">EF19-18.9</a>	x14	~£110.00	<b>£1,540.00</b>	— -
Motor-protection Circuit Breakers	ABB	<b>MS132-25</b>	x14	~£85.00	<b>£1,190.00</b>	Est. <b>&lt;.5x</b>
<i>Sub-total — Power Distribution Electromagnetic Actuator Silicon Semiconductor</i>					<b>£58,290</b>	

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**Module 8 total — Electrical Distribution**

**£90,330.00**

## MODULE 9

# Process Instrumentation

Cost **£88,400.00**

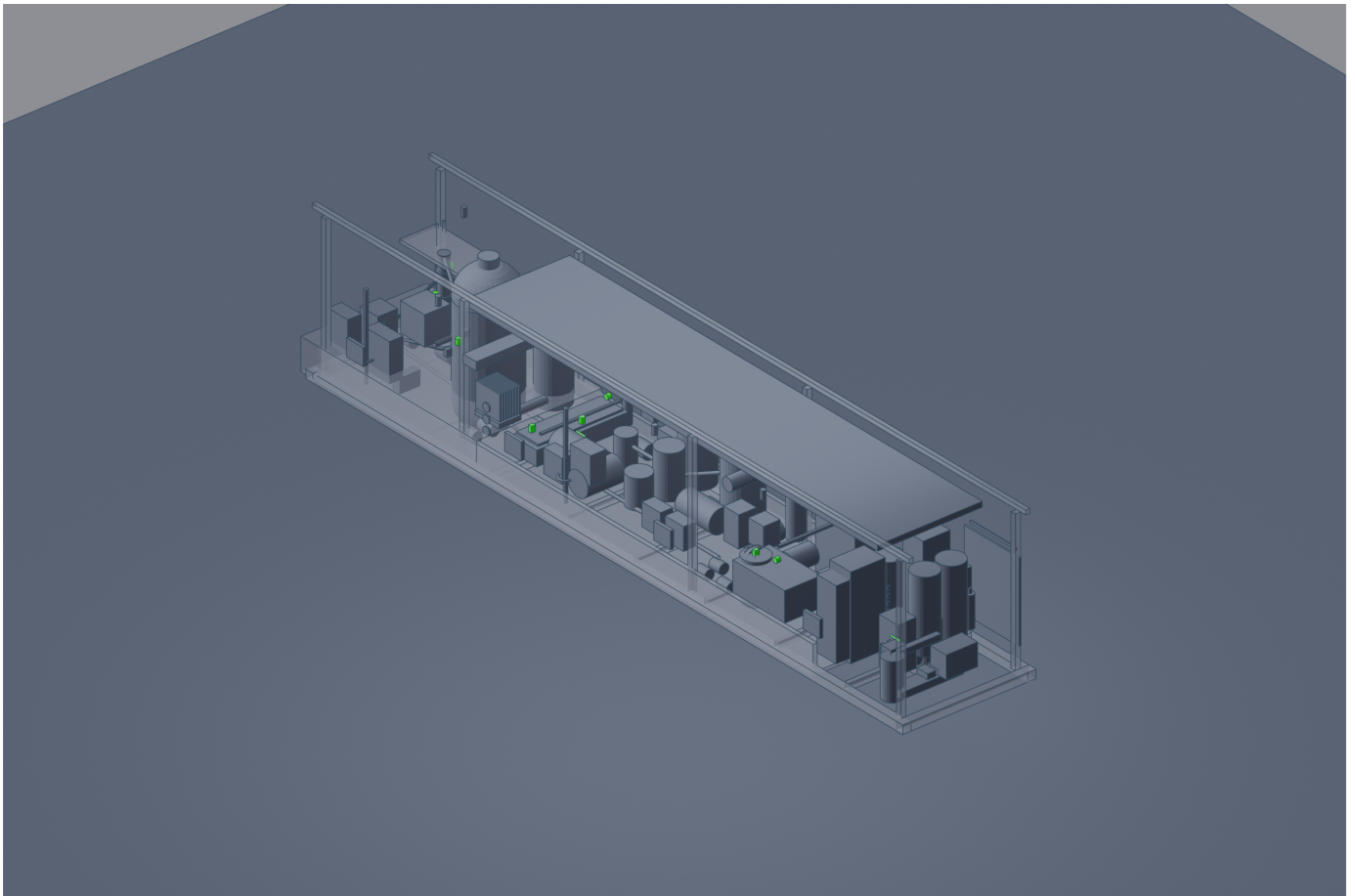
## Module summary

### PURPOSE

This module (Process Instrumentation) coriolis flow, guided-radar level, slurry density and RTD temperature instruments close the mass balance and feed the control system.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The process instrumentation — flow, level, density, pH and temperature instrumentation across the reaction, filtration and recovery stages.



*Illustration only — generic class render. Module 9 (Process Instrumentation) shown in identity colour; other modules muted; enclosure ghosted.*

The Sensing / Instrumentation module organises process instrumentation. The process instrumentation measures 7 components. 4x Endress+Hauser Promag electromagnetic flow, Memosens promag electromagnetic flow metre (part Promag W 400) (additional: £3,600).

6x Endress+Hauser 80 GHz free-space radar micropilot radar level transmitter (part Micropilot FMR62) (additional: £2,400). 4x Endress+Hauser Liquiline multiparameter transmitter + Memosens sensors liquiline ph/conductivity transmitter (part Liquiline CM442) (additional: £2,800). 12x Endress+Hauser Pt100 with thermowell, 4-20 mA head Tx itherm pt100 temperature transmitter (part iTHERM TM411) (additional: £650).

8x Emerson coplanar gauge/differential pressure, 4-20 mA HART rosemount pressure transmitter (part Rosemount 3051) (additional: £1,200). 2x ABB NDIR CO2 analyser on flue-gas inlet + absorber vent process CO2 gas analyser (part EL3060 Uras26) (additional: £9,500). 2x Emerson tuning-fork density transmitter in-line slurry density metre (part Micro Motion 7826) (additional: £4,200).

Flow, level, density, pH and temperature instrumentation across the reaction, filtration and recovery stages.

## Sub-modules

### 9.1 Process instrumentation

The process instrumentation measures 7 components. 4x Endress+Hauser Promag electromagnetic flow, Memosens promag electromagnetic flow metre (part [Promag W 400](#)) (additional: £3,600). 6x Endress+Hauser 80 GHz free-space radar micropilot radar level transmitter (part Micropilot FMR62) (additional: £2,400).

4x Endress+Hauser Liquiline multiparameter transmitter + Memosens sensors liquiline ph/conductivity transmitter (part [Liquiline CM442](#)) (additional: £2,800). 12x Endress+Hauser Pt100 with thermowell, 4-20 mA head Tx itherm pt100 temperature transmitter (part [iTHERM TM411](#)) (additional: £650). 8x Emerson coplanar gauge/differential pressure, 4-20 mA HART rosemount pressure transmitter (part [Rosemount 3051](#)) (additional: £1,200).

2x ABB NDIR CO2 analyser on flue-gas inlet + absorber vent process CO2 gas analyser (part [EL3060 Uras26](#)) (additional: £9,500). 2x Emerson tuning-fork density transmitter in-line slurry density metre (part [Micro Motion 7826](#)) (additional: £4,200). Flow, level, density, pH and temperature instrumentation across the reaction, filtration and recovery stages.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE CHECK
Electromagnetic Flow Meters	Endress+Hauser	<a href="#">Promag W 400</a>	x4	~£3,600.00	<b>£14,400.00</b>	— >2x
Radar Level Transmitters	Endress+Hauser	<b>Micropilot FMR62</b>	x6	~£3,000.00	<b>£18,000.00</b>	Est. <b>OK</b>
Ph/conductivity Analysers	Endress+Hauser	<a href="#">Liquiline CM442</a>	x4	~£2,800.00	<b>£11,200.00</b>	— >2x
Temperature Transmitters	Endress+Hauser	<a href="#">iTHERM TM411</a>	x12	~£650.00	<b>£7,800.00</b>	— -
Pressure Transmitters	Emerson	<a href="#">Rosemount 3051</a>	x8	~£1,200.00	<b>£9,600.00</b>	— >2x
CO2 Gas Analyser	ABB	<a href="#">EL3060 Uras26</a>	x2	~£9,500.00	<b>£19,000.00</b>	— >2x

Slurry Density Meters	Emerson	<a href="#">Micro Motion 7826</a>	x2	~£4,200.00	<b>£8,400.00</b>	— >2x
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*Sub-total — process instrumentation*

**£88,400**

*SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.*

**Module 9 total — Process Instrumentation**

**£88,400.00**

## MODULE 10

# Process Control System

Cost **£16,920.00**

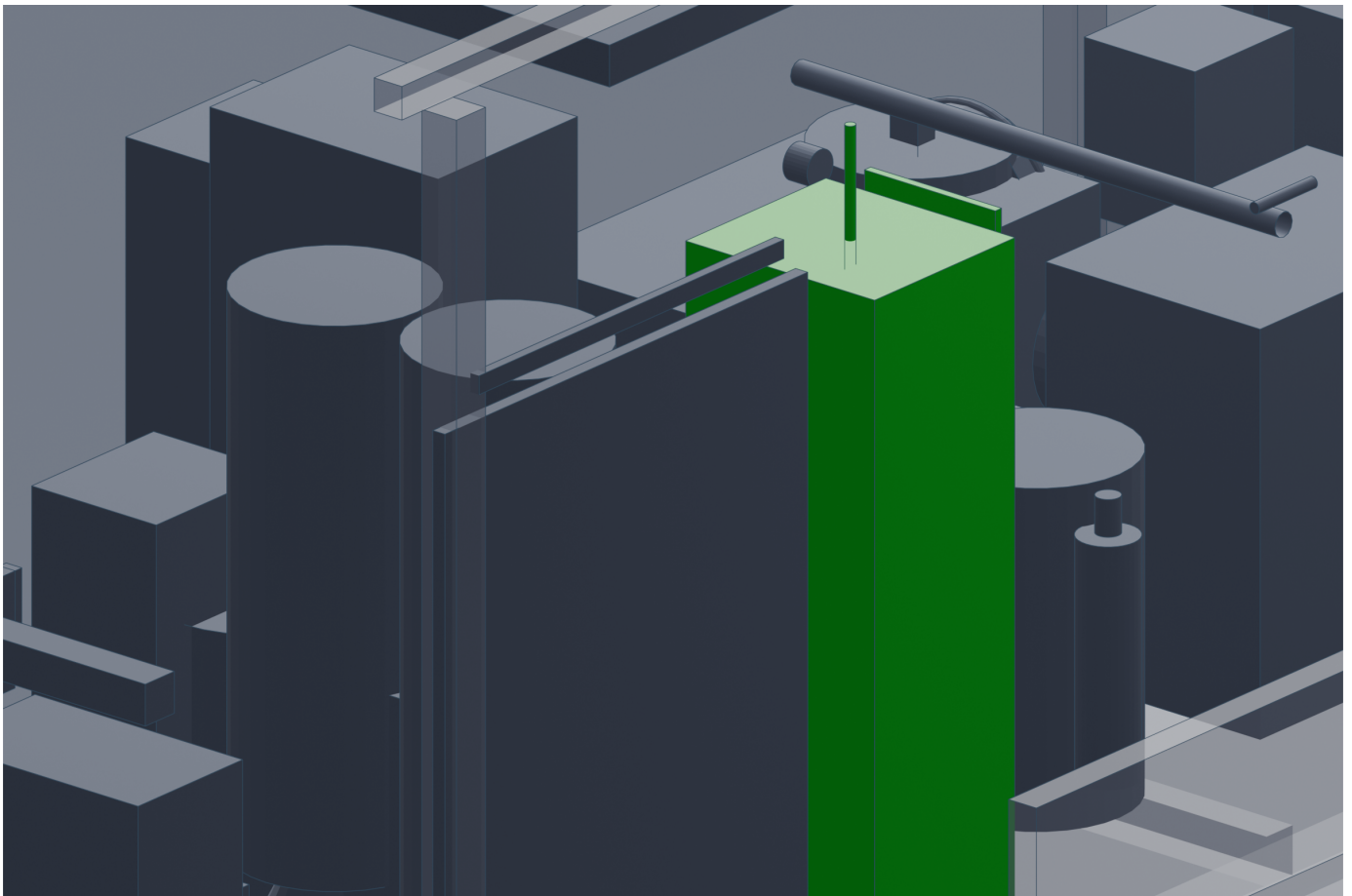
## Module summary

### PURPOSE

This module (Process Control System) a safety PLC + SCADA sequences and interlocks the full mineralisation process and records mass balance for product certification.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The process control system — PLC/SCADA sequences the absorption, carbonation, filtration, KOH reaction, recrystallisation, distillation and bagging steps.



*Illustration only — generic class render. Module 10 (Process Control System) shown in identity colour; other modules muted; enclosure ghosted.*

The Control / Compute / Communication module organises process control system. The process control system controls 7 components. A Siemens S7-1500 CPU, fail-safe plant PLC controller (part 6ES7515-2UM02-0AB0) (additional: £3,800).

3x Siemens ET 200SP distributed I/O station + interface module ET 200sp remote i/o racks (part 6ES7155-6AU01-0CN0) (additional: £1,500). 16x Siemens DI 16x24 V DC + DQ 16x24 V DC modules ET 200sp digital input/output cards (part 6ES7131-6BH01-0BA0) (additional: £95). 12x Siemens AI 8xI 4-20 mA + AQ 4xU/I modules ET 200sp analogue input/output cards (part 6ES7134-6GF00-0AA1) (additional: £180).

A Siemens 12-inch touch HMI, WinCC ktp1200 HMI panel (part 6AV2123-2MA03-0AX0) (additional: £1,300). 2x Siemens SCALANCE industrial Ethernet switch, 8-port profinet control-network switch (part 6GK5008-0BA10-1AB2) (additional: £220). A Rittal floor-standing IP54 cabinet with marshalling terminals marshalling and control cabinet (part VX25 8284.50), certified to BS EN 61439 (additional: £3,200).

PLC/SCADA sequences the absorption, carbonation, filtration, KOH reaction, recrystallisation, distillation and bagging steps.

## Sub-modules

### 10.1 Process control system

The process control system controls 7 components. A Siemens S7-1500 CPU, fail-safe plant PLC controller (part 6ES7515-2UM02-0AB0) (additional: £3,800). 3x Siemens ET 200SP distributed I/O station + interface module ET 200sp remote i/o racks (part 6ES7155-6AU01-0CN0) (additional: £1,500).

16x Siemens DI 16x24 V DC + DQ 16x24 V DC modules ET 200sp digital input/output cards (part 6ES7131-6BH01-0BA0) (additional: £95). 12x Siemens AI 8xI 4-20 mA + AQ 4xU/I modules ET 200sp analogue input/output cards (part 6ES7134-6GF00-0AA1) (additional: £180). A Siemens 12-inch touch HMI, WinCC ktp1200 HMI panel (part 6AV2123-2MA03-0AX0) (additional: £1,300).

2x Siemens SCALANCE industrial Ethernet switch, 8-port profinet control-network switch (part [6GK5008-0BA10-1AB2](#)) (additional: £220). A Rittal floor-standing IP54 cabinet with marshalling terminals marshalling and control cabinet (part VX25 8284.50), certified to BS EN 61439 (additional: £3,200). PLC/SCADA sequences the absorption, carbonation, filtration, KOH reaction, recrystallisation, distillation and bagging steps.

#### How this is computed

#### ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Control Systems PID Tuning v0.10.2

*Output quantities listed in the Tools-Used index; no step-by-step worked block was emitted by this tool.*

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Plant PLC Controller	Siemens	<b>6ES7515- - 2UM02-0AB0</b>	x1	~£3,800.00	<b>£3,800.00</b>	Est. <b>OK</b>
Remote I/o Racks	Siemens	<b>6ES7155- - 6AU01-0CN0</b>	x3	~£1,500.00	<b>£4,500.00</b>	Est. -

Digital I/o Cards	Siemens	<b>6ES7131- - 6BH01-0BA0</b>	x16	~£95.00	<b>£1,520.00</b>	Est. -
Analogue I/o Cards	Siemens	<b>6ES7134- - 6GF00-0AA1</b>	x12	~£180.00	<b>£2,160.00</b>	Est. -
HMI Panel	Siemens	<b>6AV2123- - 2MA03-0AX0</b>	x1	~£1,300.00	<b>£1,300.00</b>	Est. -
Control-network Switch	Siemens	<b><u>6GK5008- - 0BA10-1AB2</u></b>	x2	~£220.00	<b>£440.00</b>	— -
Marshalling + Control Cab- inet	Rittal	<b>VX25 8284.500</b>	x1	~£3,200.00	<b>£3,200.00</b>	— <b>OK</b>
<i>Sub-total — process control system</i>					<b>£16,920</b>	

*SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.*

**Module 10 total — Process Control System**

**£16,920.00**

## MODULE 11

# Safety & Protection

Cost **£57,860.00**

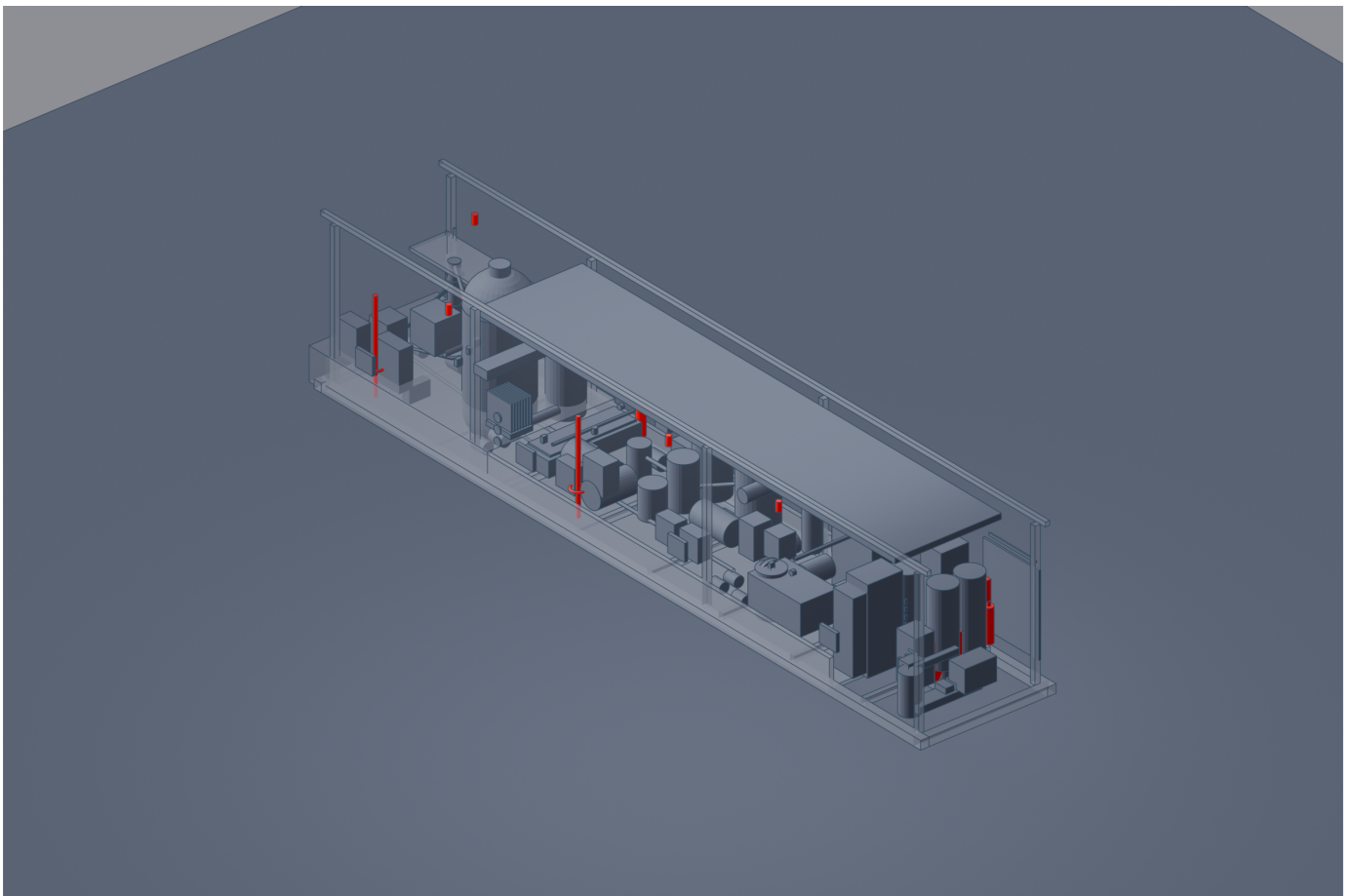
## Module summary

### PURPOSE

This module (Safety & Protection) DSEAR/ATEX zoning, SIL-2 emergency shutdown, pressure relief and gas detection protect the MEA and corrosive-KOH handling areas.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The safety + protection — DSEAR/ATEX zoning, pressure relief, gas detection and emergency shutdown for MEA and KOH handling.



*Illustration only — generic class render. Module 11 (Safety & Protection) shown in identity colour; other modules muted; enclosure ghosted.*

The Safety / Protection module organises safety + protection. The safety + protection protects 12 components. 6x LESER spring-loaded PRV pressure relief valves (part Type 441), certified to PED 2014/68/EU (additional: £1,400).

2x Hughes Safety Showers combination shower/eyewash safety shower and eyewash (part EXP-MH-14G/45G), certified to BS EN 15154 (additional: £2,200). 2x Protego end-of-line deflagration flame arrestor absorber-vent flame arrestor (part BE/HF), certified to BS EN ISO 16852 (additional: £2,600). A Protego inert-gas blanketing regulator skid for MEA tanks tank nitrogen blanketing valve skid (part DK/ES blanketing valve), certified to DSEAR (additional: £3,400).

4x Dräger fixed NDIR CO<sub>2</sub> head CO<sub>2</sub> and amine-voc gas detector (part Polytron 8700), certified to DSEAR (additional: £2,400). 4x Dräger fixed NDIR CO<sub>2</sub> area monitor, 0-5 vol% area CO<sub>2</sub> asphyxiation detectors (part Polytron 8200), certified to DSEAR (additional: £1,900). 3x Dräger fixed PID VOC head for amine vapour amine/voc vapour detectors (part Polytron 8000 PID), certified to DSEAR (additional: £2,100).

2x Dräger IR3 optical flame detector optical flame detector (part Flame 2700), certified to BS EN 61511 (additional: £3,800). A Siemens SIL-2 ESD chain controller emergency shutdown system (part 3SK1112-1BB40), certified to BS EN 61511 (additional: £200). 8x Siemens SIRIUS 3SK modular safety relay modular safety relays (part 3SK1121-1AB40), certified to BS EN 61511 (additional: £180).

12x Pepperl+Fuchs SIL-2 isolated signal barrier sil-rated signal isolation barriers (part KFD2-STC4-Ex1), certified to BS EN 61511 (additional: £160). A Dräger multi-channel gas-detection control panel for the fixed detectors addressable gas-detection controller (part REGARD 7000), certified to BS EN 61511 (additional: £4,800). DSEAR/ATEX zoning, pressure relief, gas detection and emergency shutdown for MEA and KOH handling.

## Sub-modules

### 11.1 Safety + protection

The safety + protection protects 12 components. 6x LESER spring-loaded PRV pressure relief valves (part [Type 441](#)), certified to PED 2014/68/EU (additional: £1,400). 2x Hughes Safety Showers combination shower/eyewash safety shower and eyewash (part EXP-MH-14G/45G), certified to BS EN 15154 (additional: £2,200).

2x Protego end-of-line deflagration flame arrestor absorber-vent flame arrestor (part BE/HF), certified to BS EN ISO 16852 (additional: £2,600). A Protego inert-gas blanketing regulator skid for MEA tanks tank nitrogen blanketing valve skid (part DK/ES blanketing valve), certified to DSEAR (additional: £3,400). 4x Dräger fixed NDIR CO<sub>2</sub> head CO<sub>2</sub> and amine-voc gas detector (part Polytron 8700), certified to DSEAR (additional: £2,400).

4x Dräger fixed NDIR CO<sub>2</sub> area monitor, 0-5 vol% area CO<sub>2</sub> asphyxiation detectors (part Polytron 8200), certified to DSEAR (additional: £1,900). 3x Dräger fixed PID VOC head for amine vapour amine/voc vapour detectors (part Polytron 8000 PID), certified to DSEAR (additional: £2,100). 2x Dräger IR3 optical flame detector optical flame detector (part [Flame 2700](#)), certified to BS EN 61511 (additional: £3,800).

A Siemens SIL-2 ESD chain controller emergency shutdown system (part 3SK1112-1BB40), certified to BS EN 61511 (additional: £200). 8x Siemens SIRIUS 3SK modular safety relay modular safe-

ty relays (part 3SK1121-1AB40), certified to BS EN 61511 (additional: £180). 12x Pepperl+Fuchs SIL-2 isolated signal barrier sil-rated signal isolation barriers (part [KFD2-STC4-Ex1](#)), certified to BS EN 61511 (additional: £160).

A Dräger multi-channel gas-detection control panel for the fixed detectors addressable gas-detection controller (part [REGARD 7000](#)), certified to BS EN 61511 (additional: £4,800). DSEAR/ATEX zoning, pressure relief, gas detection and emergency shutdown for MEA and KOH handling.

### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Fire Suppression Sizing NFPA v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

###### Agent mass (NFPA 2001 Eq. 4.4.2.1.1)

$$W = (V / s) \times (C / (100 - C))$$

$$W = (120 / 0.0719) \times (5.3 / (100 - 5.3)) = 93.4 \text{ kg}$$

assumes: s = specific volume of superheated agent at 20 C (NFPA 2001 Table C.1)

###### Agent mass with 10% safety factor

$$W_{sf} = W \times 1.10$$

$$W_{sf} = 93.4 \times 1.10 = 102.7 \text{ kg}$$

assumes: 10% safety factor per NFPA 2001 4.4.2.2

###### Agent material cost

$$\text{cost\_agent} = m_{\text{charge}} \times \text{cost\_per\_kg}$$

$$\text{cost\_agent} = 128 \times 65 = 8,320 \text{ GBP}$$

assumes: actual\_charge = cylinder\_count x cylinder\_size\_kg

###### Cylinder hardware cost

$$\text{cost\_cyl} = N_{\text{cyl}} \times 2500$$

$$\text{cost\_cyl} = 2 \times 2500 = 5,000 \text{ GBP}$$

assumes: GBP 2500 per cylinder incl. valve, manifold, brackets

###### Pipe and nozzle cost

$$\text{cost\_pipe} = V \times 12$$

$$\text{cost\_pipe} = 120 \times 12 = 1,440 \text{ GBP}$$

assumes: GBP 12/m<sup>3</sup> for distribution piping (rough installed estimate)

###### Total installed cost

$$\text{total} = \text{cost\_agent} + \text{cost\_cyl} + \text{cost\_pipe} + \text{cost\_detection}$$

$$\text{total} = 8,320 + 5,000 + 1,440 + 8,000 = 22,760 \text{ GBP}$$

assumes: detection = GBP 8000 fixed (smoke/heat panel + AHJ acceptance)

#### Noise Emission dBA Outdoor Unit v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

###### Sound pressure at 1 m

$$lp_{\text{at\_1m}} = lw_{\text{total}} - 8 + \text{mounting\_correction}$$

$$lp_{\text{at\_1m}} = 84.2 - 8 + 3 = 79.2 \text{ dB(A)}$$

assumes: free-field hemispherical radiation:  $L_p = L_w - 10 \cdot \log_{10}(2 \cdot \pi \cdot r^2)$ , which at r=1 m gives -8 dB plus the mounting reflection term

###### Sound pressure at distance

$$lp_{\text{at\_distance}} = lw_{\text{total}} - \text{dist\_atten} - 8 + \text{mounting\_correction}$$

$$lp_{\text{at\_distance}} = 84.2 - 20 - 8 + 3 = 59.2 \text{ dB(A)}$$

assumes: geometric spreading  $\text{dist\_atten} = 20 \cdot \log_{10}(r)$  with r = 10.0 m; free-field with ground/wall reflection per BS EN 12102-1

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Pressure Relief Valves	LESER	<a href="#">Type 441</a>	x6	~£900.00	<b>£5,400.00</b>	— <b>OK</b>
Safety Shower + Eyewash	Hughes Safety Showers	<b>EXP-MH-14G/45G</b>	x2	~£2,200.00	<b>£4,400.00</b>	— <b>&gt;2x</b>
Vent Flame Arrestor	Protego	<b>BE/HF</b>	x2	~£2,600.00	<b>£5,200.00</b>	— -
Nitrogen Blanketing Skid	Protego	<b>DK/ES blanket-ing valve</b>	x1	~£3,400.00	<b>£3,400.00</b>	— <b>OK</b>
CO2 + VOC Gas Detector	Dräger	<b>Polytron 8700</b>	x4	~£2,400.00	<b>£9,600.00</b>	Est. <b>&gt;2x</b>
CO2 Asphyxiation Detectors	Dräger	<b>Polytron 8200</b>	x4	~£1,900.00	<b>£7,600.00</b>	Est. <b>OK</b>
Amine-vapour Detectors	Dräger	<b>Polytron 8700</b>	x3	~£2,100.00	<b>£6,300.00</b>	— <b>&gt;2x</b>
Flame Detector	Dräger	<a href="#">Flame 2700</a>	x2	~£3,800.00	<b>£7,600.00</b>	— <b>&gt;2x</b>
Emergency Shutdown System	Siemens	<b>3SK1112-1BB40</b>	x1	~£200.00	<b>£200.00</b>	Est. -
Safety Relays	Siemens	<b>3SK1121-1AB40</b>	x8	~£180.00	<b>£1,440.00</b>	Est. -
Sil-rated Isolation Barriers	Pepperl+Fuchs	<a href="#">KFD2-STC4-Ex1</a>	x12	~£160.00	<b>£1,920.00</b>	— <b>&gt;2x</b>
Gas-detection Controller	Dräger	<b>Polytron 8700</b>	x1	~£4,800.00	<b>£4,800.00</b>	— <b>&gt;2x</b>
<i>Sub-total — safety + protection</i>					<b>£57,860</b>	

*SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.*

**Module 11 total — Safety & Protection**

**£57,860.00**

## MODULE 12

# Bagging & Packaging

Cost **£71,340.00**

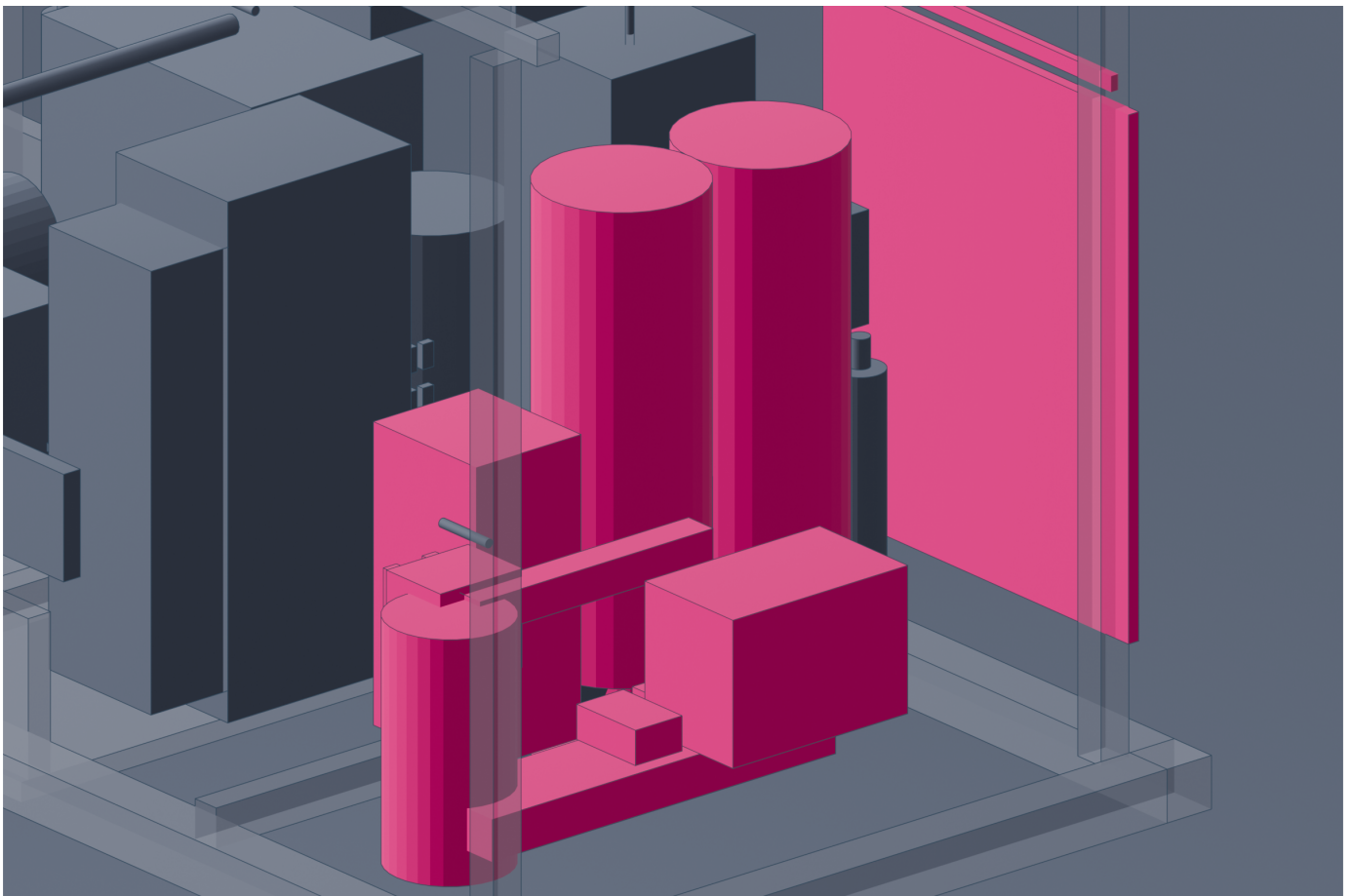
## Module summary

### PURPOSE

This module (Bagging & Packaging) net-weight bagging fills, seals and palletises 249 x 25 kg bags/day of CaCO<sub>3</sub> and K<sub>2</sub>SO<sub>4</sub> from dedicated day-silos.

### HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The bagging + packaging line — 249 x 25 kg bags/day of CaCO<sub>3</sub> and K<sub>2</sub>SO<sub>4</sub> filled, sealed and palletised.



*Illustration only — generic class render. Module 12 (Bagging & Packaging) shown in identity colour; other modules muted; enclosure ghosted.*

The Maintenance / Serviceability module organises bagging + packaging line. The bagging + packaging line packages 8 components. A Premier Tech net-weight open-mouth bagger, 25 kg open-mouth bagging machine (part OML-D, 249 bags/day capacity) (additional: £19,000).

An Audion continuous band sealer bag heat sealer (part Sealkon) (additional: £3,500). 2x Audion replaceable resistive sealing-jaw element + thermocouple band-sealer jaw heating element (part Sealkon heating element) (additional: £320). An Italdibipack electric hot-air shrink tunnel for pallet hoods pallet shrink-wrap tunnel heater (part Tunnel 5070, 24 kW capacity) (additional: £7,200).

A 0.8 m long x 0.1 m wide infrared pre-heat bar conditioning the bag seam bag-mouth pre-heat bar (part infrared bag-seam pre-heat bar - made to order) (additional: £1,400). 2x 8 m<sup>3</sup> each one CaCO<sub>3</sub> + one K<sub>2</sub>SO<sub>4</sub> day-silo product storage silo (part welded steel day-silo with discharge cone - fabricated) (additional: £6,000). A Robopac turntable stretch-wrapper semi-automatic pallet wrapper (part Rotoplat 308) (additional: £6,800).

An Interroll flat-belt conveyor from bagger to palletiser filled-bag take-away conveyor (part belt conveyor module - configured) (additional: £4,800). 249 x 25 kg bags/day of CaCO<sub>3</sub> and K<sub>2</sub>SO<sub>4</sub> filled, sealed and palletised.

## Sub-modules

### 12.1 Bagging + packaging line

The bagging + packaging line packages 8 components. A Premier Tech net-weigh open-mouth bagger, 25 kg open-mouth bagging machine (part OML-D, 249 bags/day capacity) (additional: £19,000). An Audion continuous band sealer bag heat sealer (part Sealkon) (additional: £3,500).

2x Audion replaceable resistive sealing-jaw element + thermocouple band-sealer jaw heating element (part Sealkon heating element) (additional: £320). An Italdibipack electric hot-air shrink tunnel for pallet hoods pallet shrink-wrap tunnel heater (part Tunnel 5070, 24 kW capacity) (additional: £7,200). A 0.8 m long x 0.1 m wide infrared pre-heat bar conditioning the bag seam bag-mouth pre-heat bar (part infrared bag-seam pre-heat bar - made to order) (additional: £1,400).

2x 8 m<sup>3</sup> each one CaCO<sub>3</sub> + one K<sub>2</sub>SO<sub>4</sub> day-silo product storage silo (part welded steel day-silo with discharge cone - fabricated) (additional: £6,000). A Robopac turntable stretch-wrapper semi-automatic pallet wrapper (part [Rotoplat 308](#)) (additional: £6,800). An Interroll flat-belt conveyor from bagger to palletiser filled-bag take-away conveyor (part belt conveyor module - configured) (additional: £4,800).

249 x 25 kg bags/day of CaCO<sub>3</sub> and K<sub>2</sub>SO<sub>4</sub> filled, sealed and palletised.

#### How this is computed

ENGINEERING DETAIL

The engineering tool(s) below computed the quantities that size this sub-module's equipment — every number is checkable by hand from the worked steps.

#### Bagging & Packaging Line Throughput Sizing v1.0.0

##### WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

##### Bags filled per day

$$\text{bags\_day} = m \times 1000 / \text{bag\_kg}$$

$$\text{bags\_day} = 6.234 \times 1000 / 25 = 249.4 \text{ bags/day}$$

assumes: net-weigh bagging mass balance (Perry's ch.21)

**Bagger fill rate**

$$\text{bags\_h} = \text{bags\_day} / \text{hours\_per\_day}$$

$$\text{bags\_h} = 249.4 / 16 = 15.58 \text{ bags/h}$$

assumes: 16.0 production hours per day (shift basis)

**Bagging-line throughput**

$$\text{line\_kg\_h} = \text{bags\_h} \times \text{bag\_kg}$$

$$\text{line\_kg\_h} = 15.58 \times 25 = 389.6 \text{ kg/h}$$

assumes: equivalent solids throughput of the bagging line

**Day-silo stored mass**

$$\text{stored} = m \times 1000 \times \text{silos\_hours} / 24$$

$$\text{stored} = 6.234 \times 1000 \times 24 / 24 = 6,233.8 \text{ kg}$$

assumes: 24.0 h of product buffered upstream of the bagger

**Day-silo volume**

$$V_{\text{silo}} = \text{stored} / \rho_{\text{bulk}} \times (1 + \text{ullage})$$

$$V_{\text{silo}} = 6,233.8 / 1,300 \times (1 + 0.15) = 5.515 \text{ m}^3$$

assumes: loose bulk density 1300.0 kg/m<sup>3</sup>; + 15% freeboard ullage (per product silo; 2 product stream(s))

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Open-mouth Bagging Machine	Premier Tech	<b>OML-D</b>	x1	~£35,000.00	<b>£35,000.00</b>	— <b>OK</b>
Bag Heat Sealer	Audion	<b>Sealkon</b>	x1	~£3,500.00	<b>£3,500.00</b>	— <b>OK</b>
Sealer Jaw Heating Element	Audion	<b>Sealkon heating element</b>	x2	~£320.00	<b>£640.00</b>	— -
Shrink-wrap Tunnel Heater	Italdibipack	<b>Tunnel 5070</b>	x1	~£7,200.00	<b>£7,200.00</b>	— <b>OK</b>
Bag-mouth Pre-heater	—	<b>infrared bag-seam pre-heat bar — made to order</b>	x1	~£1,400.00	<b>£1,400.00</b>	— <b>OK</b>
Product Storage Silo	—	<b>welded steel day-silo with discharge cone — fabricated</b>	x2	~£6,000.00	<b>£12,000.00</b>	— <b>OK</b>
Pallet Wrapper	Robopac	<b>Rotoplat 308</b>	x1	~£6,800.00	<b>£6,800.00</b>	— -
Bag Take-away Conveyor	Interroll	<b>belt conveyor module — configured</b>	x1	~£4,800.00	<b>£4,800.00</b>	— -
<b>Sub-total — bagging + packaging line</b>					<b>£71,340</b>	

*SOURCE: Web = found in a distributor catalogue (DigiKey / Mouser / Farnell etc.) · Est. = web estimate, not a live quote · Mfr = found on the manufacturer's own site · — = no source recorded. PRICE CHECK (against typical prices for similar components): OK = price sits in the normal range · >2x = price looks more than 2x higher than typical · <.5x = price looks less than half of typical · - = no comparable parts on record to check against. PRICE-QUERY = part is required for the design but the unit price is under the industry floor for this class; verify the part number and specification before procurement. INDICATIVE · RFQ = best available estimate for a quote-only instrument or build-to-order fabrication; request a quotation to firm up. Prices without the marker are live catalogue prices.*

**Module 12 total — Bagging & Packaging**

**£71,340.00**

# Risk & Integration Analysis

## TECHNICAL FEASIBILITY

**Cost verdict.** The priced bill of materials totals £937k across 111 priced lines; the fully-costed design reaches £1.56M ex-works (parts plus manufacturing, labour and margin). That is within the £1.90M brief cost ceiling (82% of ceiling). The order-of-magnitude check passes: the total is consistent with comparable plants of this class.

**What is proven.** The design is grounded in 84 engineering quantities computed by 21 validated analysis tools (heat-exchanger sizing, pressure-vessel design, agitation power, corrosion/cathodic-protection, fire-suppression sizing, life-cycle CO<sub>2</sub> and a mass-envelope check), so the thermal duties, structural margins and energy demands below are calculated rather than assumed.

Reboiler duty	<b>91.0 kW</b>
Lean/rich cross-exchanger duty	<b>186 kW</b>
Overhead condenser duty	<b>156 kW</b>
Solvent regeneration energy	<b>674 kWh/t</b>
Reboiler heat demand	<b>2.43 GJ/t</b>
Design capture efficiency	<b>90.0 %</b>
Carbonation conversion	<b>95.0 %</b>
Reactor agitator power	<b>1051 W</b>
Reactor vessel yield safety factor	<b>10.3 x</b>
Clean-agent fire charge	<b>103 kg</b>
pH-control-loop phase margin	<b>81.9 deg</b>
Sound pressure at 10 m	<b>59.2 dB(A)</b>

### Top technical risks (this design)

**The absorber column diameter of 0.23 m is too small for the flue-gas flow rate of 500 kg/h**

The absorber column diameter of 0.23 m is too small for the flue-gas flow rate of 500 kg/h. At 40 °C, 500 kg/h of flue gas is ~442 m<sup>3</sup>/h (0.12 m<sup>3</sup>/s). In a 0.23 m diameter column (area = 0.04 m<sup>2</sup>), the superficial gas velocity is 2.96 m/s, yielding an F-factor of 3.15 Pa<sup>0.5</sup>. This is well above the flooding limit for Mellapak 250.Y (typically 2.0 - 2.5 Pa<sup>0.5</sup>), meaning the column will flood.

**Mitigation:** Increase the absorber column diameter to at least 0.35 m to reduce superficial velocity and F-factor below the flooding threshold.

### **The absorber packing height of 1.4 m is insufficient for 90%+ CO<sub>2</sub> capture using 30 wt% MEA**

**HIGH** The absorber packing height of 1.4 m is insufficient for 90%+ CO<sub>2</sub> capture using 30 wt% MEA. Typical HTU (Height of a Transfer Unit) for this system is 0.8 - 1.2 m, meaning 1.4 m of packing provides only ~1.5 transfer units, which is inadequate to achieve the required capture efficiency.

**Mitigation:** Increase the packing height to at least 4 - 6 metres to ensure adequate residence time and mass transfer.

### **Stoichiometric mismatch: To produce 2.3 t/day of CaCO<sub>3</sub> (MW = 100.09), you need 2.3 \* (172.17 / 100.09) = 3.95 t/day of Gypsum dihydrate (MW = 172.17)**

**MEDIUM** Stoichiometric mismatch: To produce 2.3 t/day of CaCO<sub>3</sub> (MW = 100.09), you need  $2.3 * (172.17 / 100.09) = 3.95$  t/day of Gypsum dihydrate (MW = 172.17). The brief's target of 3.1 t/day of gypsum feedstock is chemically insufficient to produce 2.3 t/day of CaCO<sub>3</sub>, unless the feedstock is 100% anhydrous CaSO<sub>4</sub> (which would require 3.13 t/day), but 'gypsum' by definition is the dihydrate.

**Mitigation:** Verify feedstock purity and adjust the gypsum feed rate target to 4.0 t/day to satisfy the 2.3 t/day CaCO<sub>3</sub> production target.

#### REGULATORY FLAGS

- 2014/68/EU - Pressure Equipment Directive
- 2014/34/EU - ATEX Directive
- 2006/42/EC - Machinery Directive
- BS EN 13480 - Metallic industrial piping
- BS EN ISO 12100 - Safety of machinery - General principles for design
- IEC 60204-1 - Safety of machinery - Electrical equipment of machines
- IEC 61326-1 - Electrical equipment for measurement, control and laboratory use
- No standing class-wide standards profile applies; the standards listed are those declared in the brief and must be verified by a qualified engineer before sale.

#### MANUFACTURING FLAGS

- Potassium sulfate must meet fertiliser grade (low chloride, MEA-free) and calcium carbonate must meet industrial filler grade.
- Production batch size: 6 units - sets the procurement quantity and the per-unit tooling/NRE amortisation.

Three views in one section: a technical-feasibility assessment of THIS design (cost verdict, the engineering the analysis tools have proven, and the top technical risks); cross-cutting issues that span more than one module; and the class-level pre-mitigation hazards a co, capture + mineral-carbonation plant design must address, rated on three 1-5 scales whose product gives a single risk priority.

## CLASS-LEVEL FAILURE-MODE REGISTER

**Severity** — how bad the outcome is if the hazard occurs (1 = inconvenience, 5 = injury / fire / total loss).

**Likelihood** — how often it tends to happen in fielded systems before mitigation (1 = very rare, 5 = frequent).

**Detectability** — how hard it is to spot before it causes harm (1 = obvious / instrumented, 5 = silent failure).

**Risk priority** — severity x likelihood x detectability. The single number used to rank hazards.

Mineral-carbonation plant hazards are dominated by the chemical inventory - monoethanolamine (a harmful, combustible amine), solid potassium hydroxide (strongly caustic), and concentrated carbon dioxide (a heavier-than-air asphyxiant) - together with pressure / thermal hazards from the carbonation reactor + amine

stripper and dust / manual-handling hazards at the cake-drying and 25 kg bagging steps. None are exotic, but every one is a routine industrial-process hazard that the design must close with containment, detection, and relief.

CODE	HAZARD	SEV	LIK	DET	RP
<b>CHE-03</b>	<p><b>Concentrated carbon-dioxide asphyxiation</b></p> <p>The plant concentrates carbon dioxide on the absorber / stripper side; carbon dioxide is heavier than air and pools in pits, sumps, and low / confined spaces, displacing oxygen and causing asphyxiation above ~4 % with little warning.</p> <p><b>Typical mitigations:</b> fixed carbon-dioxide monitors at low level + in confined spaces; forced low-level ventilation of the skid enclosure; confined-space-entry permit + gas-test procedure.</p> <p><b>Detection:</b> fixed infrared carbon-dioxide sensors at floor level; personal carbon-dioxide / oxygen monitors for entry.</p> <p><b>Governed by:</b> COSHH, Confined Spaces Regulations 1997, EH40 WEL.</p>	4	2	3	<b>24</b>
<b>CHE-01</b>	<p><b>Monoethanolamine (MEA) release / vapour exposure</b></p> <p>Monoethanolamine - harmful by inhalation, corrosive to eyes / skin, and combustible - leaks from flanges, pump seals, or the stripper / distillation vent; vapour accumulates around the amine-recovery loop where the cake is washed and the solvent reboiled.</p> <p><b>Typical mitigations:</b> fully closed amine circulation loop (wash to recovery to recycle); vapour-capture scrubber / condenser on stripper + distillation vents; monoethanolamine-resistant gaskets + double-mechanical pump seals.</p> <p><b>Detection:</b> fixed photoionisation / electrochemical vapour detectors near stripper; periodic workplace-air sampling against the workplace exposure limit.</p> <p><b>Governed by:</b> COSHH, EH40 WEL, DSEAR.</p>	3	3	2	<b>18</b>
<b>OPE-01</b>	<p><b>Hot-air dryer / reboiler thermal + flammable-vapour</b></p> <p>Hot-air drying of the carbonate cake and the amine reboiler / distillation run at 100-130 °C; hot surfaces and steam burn personnel, and residual monoethanolamine vapour driven off in the dryer can reach its lower-explosive-limit near a hot surface.</p> <p><b>Typical mitigations:</b> insulated + guarded hot surfaces (&lt;= 60 °C touch-temperature); dryer + reboiler temperature interlocks; lower-explosive-limit monitoring on the dryer exhaust.</p> <p><b>Detection:</b> surface-temperature survey of lagging; lower-explosive-limit detector on dryer exhaust.</p> <p><b>Governed by:</b> DSEAR, BS EN 1539, PUWER.</p>	3	3	2	<b>18</b>
<b>MEC-01</b>	<p><b>Carbonation reactor / stripper over-pressure</b></p> <p>The carbonation reactor and amine stripper operate at elevated pressure + temperature; a blocked vent, runaway exotherm, or relief-path failure raises pressure beyond the design envelope and can rupture the vessel.</p> <p><b>Typical mitigations:</b> pressure-relief valve + bursting disc sized to the Pressure Equipment Directive; independent high-pressure interlock trip; design + hydraulic-test of each vessel per BS EN 13445.</p> <p><b>Detection:</b> redundant pressure transmitters with disagreement alarm; relief-device inspection + lift-test schedule.</p> <p><b>Governed by:</b> PED 2014/68/EU, BS EN 13445, DSEAR.</p>	4	2	2	<b>16</b>

<b>CHE-02</b>	<b>Potassium hydroxide (KOH) caustic burn</b>	4	3	1	<b>12</b>
	Solid potassium hydroxide is dosed into the filtrate to precipitate potassium sulphate; the solid and its solutions are strongly caustic and cause immediate skin / eye burns on contact during charging, dissolution, or a splash from the reactor.				
	<b>Typical mitigations:</b> enclosed solids-charging hopper with local exhaust ventilation; closed dosing into the reactor (no open transfer); emergency eyewash + safety showers within 10 s reach.				
	<b>Detection:</b> conductivity / pH monitoring on the precipitation reactor; visual splash-guard + level interlock on charging.				
	<b>Governed by:</b> COSHH, CLP Regulation, DSEAR.				
<b>OPE-02</b>	<b>Solids dust + manual handling at bagging</b>	2	3	2	<b>12</b>
	Dried calcium carbonate and potassium sulphate are packaged into 25 kg bags; airborne nuisance / respirable dust is generated at the bagging head and the repeated 25 kg lifts present a musculoskeletal manual-handling risk.				
	<b>Typical mitigations:</b> enclosed bagging head with local exhaust ventilation; respiratory protection for operators in the bagging zone; mechanical lifting aid / palletiser for filled bags.				
	<b>Detection:</b> gravimetric dust monitoring against the workplace exposure limit; manual-handling risk assessment of the bagging task.				
	<b>Governed by:</b> COSHH, Manual Handling Operations Regulations 1992, DSEAR.				

Mitigation cost and post-mitigation residual risk are withheld from this report until the Bill of Materials and an assumptions ledger exist. The hazards above are CLASS-LEVEL pre-mitigation; design-specific FMEA (effects of chosen cell chemistry, refrigerant, sensor architecture etc.) will be derived against these once the BoM is grounded.

# Sourcing & procurement

How to procure and build this plant: a recommended main contractor to hold single-point responsibility, the key equipment subcontractors the design specifies (43 named original-equipment manufacturers across 8 equipment scopes — what each supplies, who they are, and how to reach them), and a lead-time, single-source and order strategy. A buyer should appoint the main contractor, then issue a request-for-quote to each named subcontractor plus at least one equivalent second source before committing the bill of materials.

## Main contractor

### Process-plant EPC / lead integrator (main contractor)

Appoint a process-plant engineering, procurement and construction (EPC) contractor, or a lead systems integrator, as the single point of responsibility for the build. The main contractor owns overall design integration across the equipment packages below, coordinates procurement and expediting against the named original-equipment manufacturers (OEMs), manages mechanical/electrical installation and field erection of the skid and the field-erected columns, and runs commissioning and performance acceptance — so the buyer holds one accountable party for schedule, interfaces and a working plant rather than a set of disconnected equipment orders.

**What to look for.** Look for a contractor with demonstrable chemical / process-plant pilot or modular-skid delivery experience, PED 2014/68/EU and ATEX competence for the pressure and hazardous-area scope, an in-house or partnered controls team for the instrumentation and automation package, and a track record integrating third-party OEM equipment. For a one-tonne-per-day pilot a mid-size specialist EPC or a modular process-skid integrator is a better fit than a large infrastructure prime.

## Key subcontractors

The major equipment original-equipment manufacturers (OEMs) the design specifies, grouped by procurement scope. For each: what they supply, a one-line company profile, and the contact route — the manufacturer's published website, through which a UK sales enquiry is raised. Phone numbers and email addresses are deliberately not stated: the website and its sales-enquiry route is the verifiable contact detail.

## Mass Fluid Transport Process

**CRITICAL PATH · 16–28 weeks**

Supplies: packed absorber column, structured packing

### Alfa Laval

Swedish leader in heat transfer, separation and fluid handling; plate/spiral heat exchangers, decanters and process modules.

[alfalaval.com](http://alfalaval.com) · UK sales enquiry via [alfalaval.com](http://alfalaval.com)

### Becker

German manufacturer of rotary-vane vacuum pumps and compressors for industrial process applications.

[becker-international.com](http://becker-international.com) · UK sales enquiry via [becker-international.com](http://becker-international.com)

### BHS-Sonthofen

German process-equipment maker; vacuum belt and pressure filters, mixers and crushing technology for solid/liquid separation.

[bhs-sonthofen.de](http://bhs-sonthofen.de) · UK sales enquiry via [bhs-sonthofen.de](http://bhs-sonthofen.de)

**Busch**

German vacuum-pump and systems manufacturer; rotary-vane, screw and liquid-ring vacuum technology for process duty.

**buschvacuum.com** · UK sales enquiry via buschvacuum.com

**GEA**

German process-technology group; evaporators, dryers, separators, crystallisation and liquid/solid processing plant.

**gea.com** · UK sales enquiry via gea.com

**Grundfos**

Danish pump manufacturer; one of the world's largest, supplying centrifugal, dosing and circulation pumps for process and utility duty.

**grundfos.com** · UK sales enquiry via grundfos.com

**Heating Energy Systems**

Process-heating equipment supplier; industrial air-heating and thermal-utility packages.

Contact: search "Heating Energy Systems" for the manufacturer's sales enquiry page (website not on file).

**Howden**

UK-headquartered air- and gas-handling specialist; industrial fans, blowers and compressors.

**howden.com** · UK sales enquiry via howden.com

**Koch-Glitsch**

Global mass-transfer specialist (US/Koch Industries); structured/random packing, trays and column internals for distillation and absorption.

**koch-glitsch.com** · UK sales enquiry via koch-glitsch.com

**Sulzer**

Swiss pumps, mixing and separation-technology group; supplier of distillation/absorption column internals, static mixers and process pumps.

**sulzer.com** · UK sales enquiry via sulzer.com

**Energy Conversion Transduction****CRITICAL PATH · 16–28 weeks**

Supplies: reactor pH probe, reactor ORP probe

**ABB**

Swiss-Swedish electrification and automation group; motors, drives, instrumentation, switchgear and control systems.

**abb.com** · UK sales enquiry via abb.com

**Alfa Laval**

Swedish leader in heat transfer, separation and fluid handling; plate/spiral heat exchangers, decanters and process modules.

**alfalaval.com** · UK sales enquiry via alfalaval.com

**Andritz**

Austrian plant-and-equipment group; separation, filtration, centrifuges and solid/liquid processing technology.

**andritz.com** · UK sales enquiry via andritz.com

**De Dietrich**

French glass-lined reactor and process-equipment manufacturer (De Dietrich Process Systems); corrosion-resistant reactors and columns.

**dedietrich.com** · UK sales enquiry via dedietrich.com

**EagleBurgmann**

German/global mechanical-seal and sealing-systems supplier for pumps, agitators and rotating equipment.

**eagleburgmann.com** · UK sales enquiry via eagleburgmann.com

**Ekato**

German agitation-and-mixing technology specialist; agitators, mixing systems and sealing for reactors.

**ekato.com** · UK sales enquiry via ekato.com

**Endress+Hauser**

Swiss process-instrumentation leader; flow, level, pressure, temperature and analytical measurement.

**endress.com** · UK sales enquiry via endress.com

**GEA**

German process-technology group; evaporators, dryers, separators, crystallisation and liquid/solid processing plant.

**gea.com** · UK sales enquiry via gea.com

**GEA Messo**

GEA crystallisation business (Messo); industrial crystallisers and evaporative/cooling crystallisation systems.

**gea.com** · UK sales enquiry via gea.com

**Gericke**

Swiss bulk-solids handling specialist; feeders, mixers and pneumatic conveying for powder processing.

**gericke.net** · UK sales enquiry via gericke.net

**Grundfos**

Danish pump manufacturer; one of the world's largest, supplying centrifugal, dosing and circulation pumps for process and utility duty.

**grundfos.com** · UK sales enquiry via grundfos.com

**Schenck Process**

German measuring-and-process-technology group; weighing, feeding, screening and bulk-material handling.

**schenckprocess.com** · UK sales enquiry via schenckprocess.com

**SEEPEX**

German progressive-cavity pump manufacturer; metering and transfer of viscous, abrasive and shear-sensitive media.

**seepex.com** · UK sales enquiry via seepex.com

**SEW-Eurodrive**

German drive-technology manufacturer; geared motors, gear units and variable-speed drives.

**sew-eurodrive.com** · UK sales enquiry via sew-eurodrive.com

**Spelsberg**

German manufacturer of industrial junction boxes and enclosures for electrical installation.

**spelsberg.com** · UK sales enquiry via spelsberg.com

**Sulzer**

Swiss pumps, mixing and separation-technology group; supplier of distillation/absorption column internals, static mixers and process pumps.

**sulzer.com** · UK sales enquiry via sulzer.com

**Warman**

Slurry-pump brand (Weir Minerals); heavy-duty centrifugal slurry pumps for abrasive process duty.

**global.weir** · UK sales enquiry via global.weir

**Environmental Interface****CRITICAL PATH · 10–18 weeks**

Supplies: electric steam generator, hot-air process heater

**Fulton**

Contact: search "Fulton" for the manufacturer's sales enquiry page (website not on file).

**Kanthal**

Swedish heating-technology manufacturer (Sandvik); industrial electric heating elements and systems.

**kanthal.com** · UK sales enquiry via kanthal.com

**Pfannenberg**

German manufacturer of industrial cooling units, chillers and enclosure climate-control equipment.

[pfannenberg.com](http://pfannenberg.com) · UK sales enquiry via [pfannenberg.com](http://pfannenberg.com)

**Control Compute Communication****LEAD 6–12 weeks**

Supplies: plant PLC controller, remote I/O racks

**Rittal**

German enclosure-and-systems manufacturer; industrial enclosures, climate control and power distribution.

[rittal.com](http://rittal.com) · UK sales enquiry via [rittal.com](http://rittal.com)

**Siemens**

German industrial-technology group; PLC/DCS automation, instrumentation, motors and electrical equipment.

[siemens.com](http://siemens.com) · UK sales enquiry via [siemens.com](http://siemens.com)

**Sensing Instrumentation****LEAD 6–12 weeks**

Supplies: electromagnetic flow metres, radar level transmitters

**ABB**

Swiss-Swedish electrification and automation group; motors, drives, instrumentation, switchgear and control systems.

[abb.com](http://abb.com) · UK sales enquiry via [abb.com](http://abb.com)

**Emerson**

US automation group (Rosemount/Fisher/Micro Motion); measurement instruments, control valves and process automation.

[emerson.com](http://emerson.com) · UK sales enquiry via [emerson.com](http://emerson.com)

**Endress+Hauser**

Swiss process-instrumentation leader; flow, level, pressure, temperature and analytical measurement.

[endress.com](http://endress.com) · UK sales enquiry via [endress.com](http://endress.com)

## Power Distribution

**LEAD 6–12 weeks**

Supplies: motor control centre, power + control cabling

### ABB

Swiss-Swedish electrification and automation group; motors, drives, instrumentation, switchgear and control systems.

**abb.com** · UK sales enquiry via [abb.com](http://abb.com)

### CMP Products

UK manufacturer of industrial and hazardous-area cable glands and cable-cleat systems.

**cmp-products.com** · UK sales enquiry via [cmp-products.com](http://cmp-products.com)

### Prysmian

Italian/global cable manufacturer; power and control cabling for industrial and utility installation.

**prysmian.com** · UK sales enquiry via [prysmian.com](http://prysmian.com)

### Roxtec

Swedish manufacturer of modular cable- and pipe-transit sealing systems for safety and EMC.

**roxtec.com** · UK sales enquiry via [roxtec.com](http://roxtec.com)

### Schneider Electric

French energy-management and automation group; low-voltage switchgear, distribution and control products.

**se.com** · UK sales enquiry via [se.com](http://se.com)

## Safety Protection

**LEAD 6–12 weeks**

Supplies: pressure relief valves, safety shower + eyewash

### Dräger

German safety-technology manufacturer; gas detection, respiratory protection and personal safety equipment.

**draeger.com** · UK sales enquiry via [draeger.com](http://draeger.com)

### Hughes Safety Showers

UK manufacturer of emergency safety showers and eye/face-wash equipment for chemical sites.

**hughes-safety-showers.co.uk** · UK sales enquiry via [hughes-safety-showers.co.uk](http://hughes-safety-showers.co.uk)

### LESER

German manufacturer of safety relief valves; the largest European safety-valve maker.

**leser.com** · UK sales enquiry via [leser.com](http://leser.com)

### Pepperl+Fuchs

German manufacturer of industrial sensors and explosion-protection (intrinsic-safety) interface equipment.

**pepperl-fuchs.com** · UK sales enquiry via [pepperl-fuchs.com](http://pepperl-fuchs.com)

### Protego

German specialist in flame arresters, pressure/vacuum relief valves and tank-protection equipment.

**protego.com** · UK sales enquiry via [protego.com](http://protego.com)

### Siemens

German industrial-technology group; PLC/DCS automation, instrumentation, motors and electrical equipment.

**siemens.com** · UK sales enquiry via [siemens.com](http://siemens.com)

## Maintenance Serviceability

**LEAD 8–14 weeks**

Supplies: open-mouth bagging machine, bag heat sealer

### Audion

Dutch manufacturer of bag-sealing and packaging machinery for industrial lines.

**audion.com** · UK sales enquiry via [audion.com](http://audion.com)

**Interroll**

Swiss material-handling manufacturer; conveyor rollers, drives and conveyor modules.

[interroll.com](http://interroll.com) · UK sales enquiry via [interroll.com](http://interroll.com)

**Italdibipack**

Italian manufacturer of shrink-wrapping and bagging packaging machinery.

[italdibipack.com](http://italdibipack.com) · UK sales enquiry via [italdibipack.com](http://italdibipack.com)

**Premier Tech**

Canadian packaging-systems group; bagging, palletising and weighing equipment for bulk solids.

[premiertech.com](http://premiertech.com) · UK sales enquiry via [premiertech.com](http://premiertech.com)

**Robopac**

Italian end-of-line packaging manufacturer (Aetna Group); stretch-wrapping and pallet-securing systems.

[robopac.com](http://robopac.com) · UK sales enquiry via [robopac.com](http://robopac.com)

**Lead-time, single-source & order strategy**

The supply chain decomposes into 8 sourcing roles — packed absorber column, structured packing; reactor pH probe, reactor ORP probe; electric steam generator, hot-air process heater; plant PLC controller, remote I/O racks; electromagnetic flow meters, radar level transmitters; motor control centre, power + control cabling — with 51 candidate suppliers identified, each cross-checked against Companies House and the forge-truth supplier database.

**Lead time.** Lead time concentrates on the specialised, long-lead roles: bespoke process vessels (16–28 weeks); power-plant assembly (10–18 weeks). The supporting roles — plant PLC controller, remote I/O racks (6–12 weeks), electromagnetic flow meters, radar level transmitters (6–12 weeks), motor control centre, power + control cabling (6–12 weeks), pressure relief valves, safety shower + eyewash (6–12 weeks) — sit off the critical path, so the procurement schedule is driven by the longest critical lead, not the part count.

**Dual-source risk.** Single-source risk is highest on the critical-path items (bespoke process vessels, power-plant assembly); these should be dual-sourced so one supplier's slippage cannot stall the build. The 2–17 qualified candidates per role already provide a ready second source — issue the request-for-quote to at least two per critical role.

**Order strategy.** Order strategy: bulk commodity lines (fasteners, busbar, cabling, enclosure steel) benefit from minimum-order-quantity (MOQ) break pricing at full-build volume, while the specialised assemblies (bespoke process vessels, power-plant assembly) are quote-to-order with project-specific MOQs. Firm both through the request-for-quote against the named suppliers before committing the bill of materials.

The named subcontractors are taken from the verified bill of materials, not a supplier-discovery search — they indicate the equipment platform the design specifies. The main contractor is a recommended role, not a named appointment: for a bespoke pilot the buyer selects the engineering, procurement and construction partner. For every scope, confirm current lead-time, obtain a firm quotation, and qualify at least one equivalent second source before committing the order.

# Regulatory & Compliance

Standards that govern this product class. Compliance is dictated by jurisdiction + use case BEFORE the design exists; the design downstream must demonstrate conformity with the mandatory items below.

The standards below govern this product class, drawn from the brief's stated safety and regulatory requirements. Mandatory items must be demonstrated by the downstream detailed design; de-facto items are industry-standard practice for this class.

CODE	STANDARD	JURIS.	STATUS
<b>2014/68/EU</b>	Pressure Equipment Directive Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	<b>Mandatory</b>
<b>2014/34/EU</b>	ATEX Directive Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	<b>Mandatory</b>
<b>2006/42/EC</b>	Machinery Directive Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	<b>Mandatory</b>
<b>BS EN 13480</b>	Metallic industrial piping Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	<b>Mandatory</b>
<b>BS EN ISO 12100</b>	Safety of machinery - General principles for design Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	<b>Mandatory</b>
<b>IEC 60204-1</b>	Safety of machinery - Electrical equipment of machines Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	<b>Mandatory</b>
<b>IEC 61326-1</b>	Electrical equipment for measurement, control and laboratory use Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	<b>Mandatory</b>

# Tools Used in This Report

Every numerical claim in this document was computed by one of the verified engineering tools listed below. Each tool is open-source or free-to-use under the indicated license; each claim shows the exact input passed to the tool. Anyone with the listed tool version can reproduce the same output from the same input. The ForgeOS PDF Engine v2 (proprietary) orchestrates the tools and renders this PDF but does not itself compute the engineering numbers.

## Bagging & Packaging Line Throughput Sizing v1.0.0 (bagging:throughput-sizing) free-proprietary

**What it does.** Sizes the product packaging line - the bagging rate (bags/hour), day-silo buffer volume, and storage-silo volume needed to package a granular product at its production rate without bottlenecking upstream.

**Origin.** In-tree implementation of standard bulk-solids packaging-line throughput rules (FEM 2.581 bulk-handling guidance; open-mouth / valve-bagger nominal rates from Premier Tech, Haver & Boecker datasheets). Silo sizing from the required buffer hours x volumetric product rate ÷ bulk density.

**What the results mean.** `bags_h` must keep pace with production or product backs up; `line_kg_h` is the mass throughput the bagger sustains. The day-silo and storage-silo volumes set how many hours of product the plant can hold between bagging shifts - too small a buffer forces the whole plant to stop when the packaging line does.

**How it was used here.** The final equipment tool in a solids plant; it fixes the packaging + storage BoM line items and confirms the back end can absorb the front end's output rate.

**Source:** `internal://forgeos/process`

### Quantities this tool computed for this design:

- `bagging_rate_bags_h` = 15.58 bags/h
- `bagging_line_kg_h` = 389.6 kg/h
- `day_silo_volume_m3` = 5.515 m3
- `open_mouth_bagger_rate_bags_h` = 15.58 bags/h
- `product_storage_silo_volume_m3` = 5.515 m3

## Control Systems PID Tuning v0.10.2 (control-systems:pid-tuning) BSD-3-Clause

**What it does.** Computes PID controller gains (proportional, integral, derivative) for a given plant transfer function using Ziegler-Nichols or pole-placement methods.

**Origin.** In-tree implementation of the Astrom & Hagglund 2006 PID tuning rules. Same algorithms used in industrial process-control commissioning.

**What the results mean.** `kp` / `ki` / `kd` are the recommended PID gains. `settling_time_s` and `overshoot_pct` tell you whether the loop will be stable + responsive. If overshoot exceeds 30% the loop will oscillate noticeably; lower the gains.

**How it was used here.** Sizes control loops in HVAC, fertigation, flight-control, and process-control modules. Outputs feed the controller spec in the BoM + the commissioning sequence.

**Source:** [github.com/python-control/python-control](https://github.com/python-control/python-control)

**Quantities this tool computed for this design:**

- `ph_loop_pid_kp` = 1.5921
- `ph_loop_settling_time_s` = 93.84 s
- `ph_loop_phase_margin_deg` = 81.867 deg

## Convective Dryer Air-Flow + Heat-Duty Sizing v1.0.0 (dryer:thermal-sizing) free-proprietary

**What it does.** Sizes a thermal dryer - the hot-air mass flow and heating duty needed to drive moisture off a wet solid product (filter cake) down to a target residual-moisture specification at a given throughput.

**Origin.** In-tree implementation of the convective-drying psychrometric mass-and-energy balance from Perry's Chemical Engineers' Handbook ch. 12 (Mujumdar, Handbook of Industrial Drying). Drying-air enthalpy from humid-air psychrometrics; evaporation load from the free-moisture removed.

**What the results mean.** `duty_kw` is the heat required to evaporate the free moisture plus heat the air and solids; `air_flow_kg_h` is the carrier-gas rate that removes the vapour without re-saturating. A duty that dwarfs the product rate means the cake enters very wet - the upstream filter/centrifuge should remove more water mechanically (far cheaper than thermal drying).

**How it was used here.** Sits at the back of the solids train after crystallisation + filtration; its duty feeds the thermal-utilities total and the BoM dryer + heater line items.

**Source:** `internal://forgeos/process`

**Quantities this tool computed for this design:**

- `caco3_dryer_duty_kw` = 17.773 kW
- `caco3_dryer_air_flow_kg_h` = 532.01 kg/h
- `k2so4_dryer_duty_kw` = 31.314 kW
- `k2so4_dryer_air_flow_kg_h` = 937.35 kg/h

## CoolProp Refrigerant Properties v7.2.0 (coolprop:refrigerant-properties)

MIT

**What it does.** Looks up thermophysical properties (density, enthalpy, entropy, viscosity, thermal conductivity) of refrigerants, heat-transfer fluids, and pure substances across the full PT envelope.

**Origin.** Open-source CoolProp v6.4 (MIT license), Bell et al. 2014 Industrial & Engineering Chemistry Research 53(6):2498-2508. Reference-equation-of-state implementation - same equations NIST REFPROP uses.

**What the results mean.** Properties are point-values at the design operating condition. Engineering judgement uses them to size HX, pumps, expansion valves. If the refrigerant's critical point is too close to the operating envelope the cycle becomes unstable; if its GWP exceeds the F-gas limits the brief's sustainability target fails.

**How it was used here.** Called by `hvac:load-sizing`, `refrigeration-cycle:cop`, and `ht:ntu-heat-exchanger` whenever a thermophysical property is needed. Doesn't set design decisions on its own - it's the property database other tools depend on.

**Source:** coolprop.org

**Quantities this tool computed for this design:**

- coolant\_liquid\_density\_kg\_m3 = 1,034.15 kg/m<sup>3</sup> (input: inputs from: ht:ntu-heat-exchanger + brief)
- coolant\_cp\_kj\_kg\_k = 3.59 kJ/kg/K (input: inputs from: ht:ntu-heat-exchanger + brief)

## DAC Regeneration Energy v1.0.0 (dac:regeneration-energy)

free-proprietary

**What it does.** Computes sorbent regeneration energy per ton CO<sub>2</sub> - for amine-silica / KOH-solution / MOF / zeolite sorbents - given regeneration temperature, heat source, and capture capacity.

**Origin.** In-tree implementation of Sanz-Pérez et al. 2016 Chem. Rev. 116 11840 + Keith et al. 2018 Joule 2 1573. Energy = delta H<sub>desorption</sub> + sensible\_heat + steam\_stripping; delta H ~ 80 kJ/mol for amines.

**What the results mean.** regen\_energy\_kwh\_per\_ton\_co2 of 1000-2000 for amine-silica TSA (Clime-works-class), 5000+ for KOH calcination (Carbon Engineering). The split between thermal vs electrical drives whether waste heat or grid power is the limiting cost. If energy exceeds 3 GJ<sub>th</sub>/ton the design is uncompetitive vs alternative sequestration paths.

**How it was used here.** Sizes the energy-side of DAC plant economics. Couples with dac:sorbent-kinetics (which sets the kinetic capacity) and the heat-source selection (waste heat, electric resistance, heat pump).

**Source:** internal://forgeos/dac

**Quantities this tool computed for this design:**

- regeneration\_energy\_kwh\_per\_t\_co2 = 674 kWh/t
- regeneration\_heat\_demand\_gj\_per\_t\_co2 = 2.43 GJ/t
- regeneration\_time\_minutes = 20 min

## Electrical Distribution Transformer Sizing v1.0.0 (electrical:transformer-sizing) free-proprietary

**What it does.** Sizes the plant supply transformer - the kVA rating and the primary/secondary full-load currents needed to feed the total connected electrical load with headroom.

**Origin.** In-tree implementation of standard transformer sizing per IEC 60076: rating = connected load ÷ power factor x diversity/utilisation, with primary and secondary currents from  $S = 3 \cdot V \cdot I$  for a three-phase unit.

**What the results mean.** kva is the transformer nameplate the supply needs; primary\_current\_a and secondary\_current\_a size the switchgear and cabling on each side. If the rating sits far above the running load the plant is paying for under-utilised iron; far below and the transformer overheats at peak demand.

**How it was used here.** Runs after the connected load is totalled; its kVA + currents feed the electrical-distribution BoM (transformer, switchgear) and the cable-sizing tool.

**Source:** internal://forgeos/electrical

**Quantities this tool computed for this design:**

- transformer\_kva = 800 kVA

- transformer\_primary\_current\_a = 41.99 A
- transformer\_secondary\_current\_a = 1,154.7 A

## Electrical Main Feeder Cable Sizing (BS 7671) v1.0.0 (electrical:cable-sizing) free-proprietary

**What it does.** Sizes the plant power cabling - the conductor cross-sectional area for the main feeder and sub-circuits so each cable carries its design current within the allowed voltage-drop and temperature limits.

**Origin.** In-tree implementation of the IEC 60364-5-52 cable-sizing method (current-carrying capacity, installation-method derating, voltage-drop limit). Conductor resistivity and ampacity tables per IEC 60228 conductor classes.

**What the results mean.** csa\_mm2 is the copper/aluminium cross-section each run needs; volt-drop\_pct must stay under the limit (typically  $\leq 5\%$  for power circuits) or motors see reduced starting torque. A design\_current that pushes the cable into a very large CSA is a signal to step up the distribution voltage instead.

**How it was used here.** Runs once the connected load is known; it fixes the cable BoM line items and the feeder current that the transformer-sizing tool consumes.

**Source:** internal://forgeos/electrical

### Quantities this tool computed for this design:

- main\_feeder\_cable\_csa\_mm2 = 300 mm2 (input: inputs from: electrical:transformer-sizing + brief)
- feeder\_design\_current\_a = 899.7 A (input: inputs from: electrical:transformer-sizing + brief)
- cable\_volt\_drop\_pct = 0.571 % (input: inputs from: electrical:transformer-sizing + brief)
- power\_control\_cables\_csa\_mm2 = 300 mm2 (input: inputs from: electrical:transformer-sizing + brief)

## Evaporative Crystalliser Duty + Area Sizing v1.0.0 (crystalliser:evaporator-sizing) free-proprietary

**What it does.** Sizes an evaporative or cooling crystalliser - the heat-transfer area, vessel diameter, and reboiler/cooling duty needed to crystallise a dissolved salt (e.g. K<sub>2</sub>SO<sub>4</sub>, CaCO<sub>3</sub>) out of a saturated process liquor at a target production rate.

**Origin.** In-tree implementation of the evaporative-crystalliser energy + mass balance from Perry's Chemical Engineers' Handbook ch. 18 (Mullin, Crystallization, 4th ed.). Solubility-vs-temperature data sets the achievable yield per pass; the latent-heat balance sets the evaporation duty.

**What the results mean.** duty\_kw is the heat the reboiler must supply (evaporative) or the cooler must remove (cooling) to drop the liquor below saturation. area\_m2 and diameter\_m size the vessel for the required vapour or cooling load. If the duty is large relative to the product rate the salt is highly soluble and the design pays a heavy energy penalty per tonne.

**How it was used here.** Runs after the upstream reaction/absorption fixes the liquor composition; its duty feeds the thermal-utilities load and the BoM crystalliser + agitator line items.

**Source:** internal://forgeos/process

### Quantities this tool computed for this design:

- k2so4\_crystalliser\_duty\_kw = 958.168 kW

- k2so4\_crystalliser\_area\_m2 = 13.11 m2
- k2so4\_crystalliser\_diameter\_m = 0.73 m

## Fire Suppression Sizing NFPA v1.0.0 (fire-suppression:nfpa)

free-proprietary

**What it does.** Sizes a clean-agent fire-suppression system (Novec 1230, FM-200, IG-541 Inergen) per NFPA 2001 / ISO 14520 for a protected volume - outputs agent mass, cylinder count, and discharge time.

**Origin.** In-tree implementation of NFPA 2001:2022 "Standard on Clean Agent Fire Extinguishing Systems" + UL EX1741 listing data. Agent mass  $m = V_{\text{room}} \times \dot{A}_{\text{agent}} \times (C_{\text{design}} / (100 - C_{\text{design}}))$ ; safety factor + leakage allowance per NFPA 2001.

**What the results mean.** agent\_mass\_kg is what each container must store; Novec 1230 needs 4.5 % concentration for Li-ion, FM-200 7 %, IG-541 37.5-43 %. cylinder\_count drops with concentration efficiency - Novec is the best for Li-ion fires. discharge\_time\_seconds must hit 10 s per NFPA 2001 to flood before flame propagation.

**How it was used here.** Sizes the fire-suppression line item for BESS containers and H2 electrolyser rooms. Reads the protected volume from the enclosure geometry and produces the agent + cylinder spec.

**Source:** internal://forgeos/fire

### Quantities this tool computed for this design:

- fire\_agent\_mass\_kg = 102.7 kg
- fire\_cylinder\_count = 2

## Fluids Pipe Sizing + Pressure Drop v1.3.0 (fluids:pipe-sizing)

BSD-3-Clause

**What it does.** Sizes pipe diameters and computes pressure drop, Reynolds number, and pump head requirements for a fluid loop (water, nutrient solution, refrigerant) at a given flow rate.

**Origin.** Open-source `fluids` Python library (Bell et al., MIT license). Implements Colebrook-White friction factor, Hagen-Poiseuille for laminar regime, and Darcy-Weisbach for turbulent. Same engine used in industrial process-engineering calculators.

**What the results mean.** pipe\_diameter\_m is the inner diameter; pressure\_drop\_kpa is what the pump must overcome at design flow. Reynolds number tells you the flow regime -  $Re < 2300$  is laminar (low pressure drop but vulnerable to dead-legs and biofilm);  $Re > 4000$  is turbulent (good mixing, higher drop). For nutrient solution, laminar is preferred to minimise mechanical damage to dissolved oxygen.

**How it was used here.** Used wherever a fluid loop is part of the design - fertigation, refrigerant, chilled-water, coolant. Outputs feed into pump sizing (irrigation:pump-sizing) and the BoM's pipework line items.

**Source:** [github.com/CalebBell/fluids](https://github.com/CalebBell/fluids)

### Quantities this tool computed for this design:

- mea\_line\_pressure\_drop\_kpa = 1.068 kPa (input: inputs from: ht:ntu-heat-exchanger + brief)
- mea\_line\_velocity\_m\_s = 0.4244 m/s (input: inputs from: ht:ntu-heat-exchanger + brief)

- `mea_line_diameter_mm = 50 mm` (input: inputs from: ht:ntu-heat-exchanger + brief)

## HT eps-NTU Heat Exchanger v1.2.0 (ht:ntu-heat-exchanger)

BSD-3-Clause

**What it does.** Computes heat-exchanger sizing using the effectiveness-NTU (Number of Transfer Units) method - outputs surface area, UA value, and outlet temperatures for a given duty.

**Origin.** Open-source `ht` Python library (Bell, MIT license). Implements the Kays & London tabulated NTU correlations for shell-and-tube, brazed-plate, and finned-tube geometries. Same data set used by every undergraduate heat-transfer course.

**What the results mean.** effectiveness eps is the fraction of the theoretical maximum heat transfer the exchanger actually achieves - 0.6-0.8 is typical for industrial duty. surface\_area\_m2 sets the physical size; UA\_W\_K is the conductance. If eps drops below 0.5 the exchanger is too small for its duty and the chiller will struggle to hold setpoint.

**How it was used here.** Sizes any heat-exchanger line item - refrigerant condensers, intercoolers, dehumidifier recovery coils. Reads the duty from hvac:load-sizing and produces a part-level spec the BoM can price against the Alfa Laval / SWEP / Kelvion catalogue.

**Source:** [github.com/CalebBell/ht](https://github.com/CalebBell/ht)

### Quantities this tool computed for this design:

- `reboiler_duty_kw = 91.039 kW` (input: inputs from: dac:regeneration-energy + brief)
- `reboiler_hx_effectiveness = 0.828` (input: inputs from: dac:regeneration-energy + brief)
- `reboiler_hx_ua_kw_k = 18.325 kW/K` (input: inputs from: dac:regeneration-energy + brief)
- `cross_exchanger_duty_kw = 185.713 kW` (input: inputs from: dac:regeneration-energy + brief)
- `cross_exchanger_effectiveness = 0.764` (input: inputs from: dac:regeneration-energy + brief)
- `cross_exchanger_ua_kw_k = 9.99 kW/K` (input: inputs from: dac:regeneration-energy + brief)
- `condenser_duty_kw = 155.609 kW` (input: inputs from: dac:regeneration-energy + brief)
- `condenser_effectiveness = 0.8892` (input: inputs from: dac:regeneration-energy + brief)
- `condenser_ua_kw_k = 5.5 kW/K` (input: inputs from: dac:regeneration-energy + brief)

## Lifecycle CO2 Assessment v1.0.0 (lifecycle-co2:assessment)

free-proprietary

**What it does.** Computes cradle-to-grave CO2-equivalent emissions of the design - embodied (per-kg material x CO2 factor) + operational (grid mix x lifetime kWh) + end-of-life pathway credit/burden.

**Origin.** IPCC AR6 WGIII (2022) + ecoinvent database v3.10 + ISO 14040:2006 / 14044:2006 LCA framework. In-tree implementation aggregates by material class against published global-average CO2 factors.

**What the results mean.** `lca_total_co2_kg` over the design lifetime. `lca_embodied_co2_kg` is the up-front cost; `lca_operational_co2_kg` is the use-phase. The split tells you which lever moves the total - for a BESS it's usually operational (grid mix), for a building it's embodied (concrete).

**How it was used here.** Runs after the BoM is final. Outputs feed the sustainability section of the report - a published number a sustainability auditor can challenge with their own ecoinvent query.

**Source:** `internal://forgeos/lca`

### Quantities this tool computed for this design:

- plant\_lifecycle\_co2\_t = 3,412.24 t
- plant\_annual\_co2\_t = 170.612 t
- plant\_embodied\_co2\_t = 30.6 t

## Mass Budget Aggregator v1.0.0 (mass-aggregator:envelope-check)

free-proprietary

**What it does.** Sums the mass of every priced component in the BoM and compares against the brief's envelope mass cap (the max\_mass\_kg constraint).

**Origin.** In-tree aggregator. Reads `mass\_kg` from every BoM line item; rules-of-thumb fill in missing masses by component class (e.g. battery cells at 80 g/cell, transformers at 4 kg/kVA).

**What the results mean.** total\_system\_mass\_kg vs envelope cap. If total exceeds cap, the design either splits across multiple containers (`recommended\_container\_count = 2`) or the brief's envelope is wrong. A 10% overshoot is normal during early design; >25% needs a fundamental rework.

**How it was used here.** Runs at the end of the chain after the BoM is finalised. Outputs flag the cover page if the mass cap is breached, so the buyer sees the constraint violation up-front.

**Source:** internal://forgeos/orchestrator

### Quantities this tool computed for this design:

- total\_plant\_mass\_kg = 18,680.1 kg (input: inputs from: pressure-vessel:design, ht:ntu-heat-exchanger, agitation:power, fl...)
- mass\_budget\_utilisation\_pct = 77.8 % (input: inputs from: pressure-vessel:design, ht:ntu-heat-exchanger, agitation:power, fl...)
- recommended\_container\_count = 1 (input: inputs from: pressure-vessel:design, ht:ntu-heat-exchanger, agitation:power, fl...)

**Noise Emission dBA Outdoor Unit** v1.0.0 (noise-emission:dba)

free-proprietary

**What it does.** Computes acoustic emission (sound power and sound pressure at distance) per BS EN 12102 - for heat-pump outdoor units, drones, e-bikes, and wind turbines.

**Origin.** In-tree implementation of BS EN 12102-1:2022 "Air conditioners, liquid chilling packages - Part 1: Determination of sound power level" + UK Town and Country Planning General Permitted Development Order 2015.  $L_p = L_w - 20 \log_{10}(r) - 11$  (point source).

**What the results mean.** `sound_pressure_dba_at_1m` at the property boundary must sit below 42 dB(A) for UK heat-pump PDR. drone noise above 65 dB(A) at 10 m makes urban operation difficult. wind-turbine 45 dB(A) at 500 m boundary is the planning-typical limit.

**How it was used here.** Runs in the regulatory section for noise-emitting products (heat pump, drone, e-bike, wind turbine). Outputs feed the planning-application section + cap the design envelope.

**Source:** `internal://forgeos/acoustics`

**Quantities this tool computed for this design:**

- `plant_sound_power_dba` = 84.2 dB(A)
- `plant_sound_pressure_at_10m_dba` = 59.2 dB(A)

**Packed Absorption/Stripping Column (HTU-NTU + flooding) v1.0.0-**

(absorption:column-htu-ntu)

free-proprietary

**What it does.** Sizes a packed gas-absorption or stripping column - the packed height and shell diameter needed to transfer a target amount of a solute (e.g. CO<sub>2</sub> into an amine solvent) between a gas and a liquid stream, with a check against the flooding velocity.

**Origin.** In-tree implementation of the classic HTU-NTU (height-of-a-transfer-unit x number-of-transfer-units) method from Treybal, Mass-Transfer Operations (3rd ed.) and Perry's Chemical Engineers' Handbook ch. 14. Flooding velocity from the Eckert generalised pressure-drop correlation for random packing.

**What the results mean.** NTU counts how many ideal transfer units the separation demands (higher = harder duty); HTU is the packing height that delivers one unit, so packed\_height = HTU x NTU. The diameter is set so the gas velocity stays a safe fraction (~70 %) below flooding - too small a diameter floods the column and the liquid is blown back up the packing.

**How it was used here.** The first separations tool in a capture/stripping train: it fixes the absorber and stripper geometry, which then feed the pressure-vessel shell-mass tool, the pump head, and the BoM column line items.

**Source:** internal://forgeos/process

**Quantities this tool computed for this design:**

- absorber\_packed\_height\_m = 1.4073 m
- absorber\_diameter\_m = 0.2346 m
- absorber\_ntu = 2.3454
- stripper\_packed\_height\_m = 1.702 m
- stripper\_diameter\_m = 0.2288 m

**Pressure Vessel Wall Design (hoop-stress sizing) v1.0.0**

(pressure-ves-

sel:design)

free-proprietary

**What it does.** Sizes a pressure vessel (AUV housing, BESS enclosure, electrolyser, satellite tank) per ASME BPVC Section VIII - wall thickness, hoop stress, buckling pressure, and safety factor.

**Origin.** In-tree implementation of ASME BPVC Section VIII Division 1 (2023). Thin-wall hoop stress  $\tilde{\sigma}_h = pD/(2t)$ ; Roark's Formulas for Stress and Strain Table 13.1 for thick-wall corrections; external-pressure buckling per ASME Code Case 2286.

**What the results mean.** safety\_factor must exceed 2.0 for life-safety vessels; > 1.5 for industrial. hoop\_stress\_mpa vs yield strength shows margin. buckling\_pressure\_critical\_mpa must exceed the design pressure with margin. mass\_kg drives the dry-mass budget - Ti-6Al-4V vs aluminium 7075 vs steel 316L vs CFRP all trade weight against cost.

**How it was used here.** Mandatory check for any pressurised component in the design - AUV housings, BESS containers, satellite tanks, ventilator manifolds. Drives the material + wall-thickness BoM.

**Source:** internal://forgeos/structural

**Quantities this tool computed for this design:**

- absorber\_shell\_mass\_kg = 1,292.306 kg
- absorber\_wall\_thickness\_mm = 6 mm

- absorber\_hoop\_stress\_mpa = 22.5 MPa
- stripper\_shell\_mass\_kg = 955.796 kg
- stripper\_wall\_thickness\_mm = 6 mm
- stripper\_hoop\_stress\_mpa = 18.75 MPa
- reactor\_wall\_thickness\_mm = 8 mm
- reactor\_hoop\_stress\_mpa = 28.181 MPa
- reactor\_yield\_safety\_factor = 10.291

### Process Centrifugal Pump Sizing v1.0.0 (process:pump-sizing)

free-proprietary

Source: internal://forgeos/process

#### Quantities this tool computed for this design:

- mea\_pump\_head\_m = 37.698 m (input: inputs from: fluids:pipe-sizing + brief)
- mea\_pump\_motor\_kw = 0.75 kW (input: inputs from: fluids:pipe-sizing + brief)
- mea\_pump\_hydraulic\_power\_w = 308.1 W (input: inputs from: fluids:pipe-sizing + brief)

### Reaction Feasibility (Gibbs Free Energy) v1.0.0 (reaction:feasibility-gibbs)

MIT

**What it does.** Checks whether a proposed reaction is thermodynamically feasible - computes the Gibbs free-energy change and equilibrium constant at the operating temperature to confirm the reaction proceeds in the intended direction.

**Origin.** In-tree implementation of  $\Delta G = \Delta H - T\Delta S$  and  $K = \exp(-\Delta G/RT)$  from standard thermochemical data (NIST-JANAF tables; Atkins, Physical Chemistry). Temperature dependence via the van't Hoff relation.

**What the results mean.** A negative  $\Delta G$  (and  $K > 1$ ) means the reaction is spontaneous in the forward direction at that temperature - the feasibility flag passes. A positive  $\Delta G$  means the reaction will not proceed as written without driving it (excess reagent, product removal, or a different temperature); the flag fails and the route must change.

**How it was used here.** A go/no-go gate run before the plant is sized - it confirms the chemistry is real before any equipment tool spends effort on a route that cannot work.

Source: [github.com/CalebBell/chemicals](https://github.com/CalebBell/chemicals)

#### Quantities this tool computed for this design:

- k2so4\_loop\_delta\_g\_kj\_mol = -95.836 kJ/mol
- k2so4\_loop\_equilibrium\_K = 61,621,006,169,164,950
- k2so4\_loop\_feasibility\_flag = 1

### Reaction Stoichiometry Mass Balance v1.0.0 (reaction:stoichiometry-balance)

MIT

**What it does.** Closes the overall reaction mass balance - converts the target product rate (e.g. tonnes/day of CaCO<sub>3</sub>) into the required feed rates of every reactant (CO<sub>2</sub>, alkali, make-up chemicals) from the balanced reaction stoichiometry.

**Origin.** In-tree implementation of conservation-of-mass on the balanced chemical equation(s) - element and species balances per Felder & Rousseau, Elementary Principles of Chemical Processes. Molar masses from IUPAC atomic weights.

**What the results mean.** Each feed/product rate is the mass flow that makes the reaction balance at the stated conversion - they must sum (in minus out) to zero by element. These are the anchor numbers the whole plant is sized around; if the CO<sub>2</sub>-in does not match the CaCO<sub>3</sub>-out by carbon balance, every downstream size is wrong.

**How it was used here.** One of the first tools to run - it sets the throughput every other tool sizes against (column duty, reactor volume, crystalliser rate, bagging rate all scale from these flows).

**Source:** [github.com/CalebBell/chemicals](https://github.com/CalebBell/chemicals)

**Quantities this tool computed for this design:**

- gypsum\_feed\_t\_day = 3.9121 t/day
- caco3\_product\_t\_day = 2.2742 t/day
- k2so4\_product\_t\_day = 3.9596 t/day
- koh\_makeup\_t\_day = 2.5497 t/day

## Reactor (CSTR/PFR) Volume + Vessel Sizing v1.0.0 (reactor:cstr-pfr-sizing) free-proprietary

**What it does.** Sizes the main reaction vessel - the reactor volume, residence time, and shell geometry (diameter, height, wall thickness) needed to reach the target conversion at the design throughput, for a stirred-tank (CSTR) or plug-flow (PFR) reactor.

**Origin.** In-tree implementation of the CSTR/PFR design equations from Fogler, Elements of Chemical Reaction Engineering (4th ed.) - volume from the reaction-rate law x required conversion ÷ feed rate. Shell hoop stress per the thin-wall pressure-vessel relation (ASME BPVC Sec. VIII Div. 1 basis).

**What the results mean.** volume\_m3 is the working volume that delivers the target conversion at the design flow; a longer residence time means a bigger (more expensive) vessel. hoop\_stress\_mpa vs the material yield, and wall\_thickness\_mm, confirm the shell holds the operating pressure with margin. yield\_safety\_factor shows how much conversion headroom the size carries.

**How it was used here.** The core vessel tool - it consumes the stoichiometry feed rates and the kinetics, then feeds the agitation-power tool (impeller in this volume) and the reactor + agitator BoM line items.

**Source:** [internal://forgeos/process](#)

**Quantities this tool computed for this design:**

- reactor\_shell\_mass\_kg = 771.97 kg
- carbonation\_reactor\_volume\_m3 = 4.8035 m<sup>3</sup>
- carbonation\_reactor\_diameter\_m = 1.5636 m
- carbonation\_reactor\_height\_m = 3.1271 m

## Rushton Agitation Power v1.0.0 (agitation:power) free-proprietary

**What it does.** Computes stirred-tank bioreactor agitation power - impeller power number, Reynolds number, tip speed - for a chosen impeller type, RPM, and fluid properties, with gassed-power derating.

**Origin.** In-tree implementation of Bates, Fondy, Corpstein 1963 Ind. Eng. Chem. Process Des. Dev. 2(4):310-314 "An Examination of Some Geometric Parameters of Impeller Power" + Doran "Bioprocess Engineering Principles" 2nd ed. chapter 8.  $P = N_p \times \rho \times N^3 \times D^5$ .

**What the results mean.** power\_w is the mechanical power the agitator consumes; a Rushton turbine has  $N_p \sim 5.0$  in turbulent regime ( $Re > 10,000$ ) - 3-5x higher than a marine prop. tip\_speed\_m\_s above 2 m/s shears mammalian cells; bacterial fermentations tolerate 4-7 m/s. Gassed power drops 20-40 % below ungassed depending on vvm (volumetric gas flow per volume per minute).

**How it was used here.** Sizes the agitator motor in a bioreactor BoM. Couples with kla-oxygen:transfer (which uses P/V as input) and dissolved-oxygen:control downstream.

**Source:** internal://forgeos/process

**Quantities this tool computed for this design:**

- reactor\_agitator\_power\_w = 1,051.32 W (input: inputs from: pressure-vessel:design + brief)
- reactor\_agitator\_tip\_speed\_m\_s = 3.77 m/s (input: inputs from: pressure-vessel:design + brief)
- reactor\_agitator\_power\_density\_w\_m3 = 396.62 W/m<sup>3</sup> (input: inputs from: pressure-vessel:design + brief)
- crystalliser\_agitator\_power\_w = 21.71 W (input: inputs from: pressure-vessel:design + brief)
- crystalliser\_agitator\_tip\_speed\_m\_s = 2.026 m/s (input: inputs from: pressure-vessel:design + brief)

*Tool outputs are accurate within their documented operating domains. This design is an engineering reference; certified procurement requires separate engineer sign-off. Open-source license terms apply as indicated; full SPDX records are available on request.*

# Potential Investors

A modular, skid-mounted carbon capture and mineralisation system that converts industrial CO2 emissions into high-value industrial minerals and fertilisers. — these firms have a thesis that fits. We have named the firm; the specific partner to approach is available through Fractional Forge.

## **Greenbackers Investment Capital** · partner withheld

**Thesis fit: strong**

- Why them** They back the planet by providing funding and technology support to scalable energy transition and industrial innovation ventures.
- Why you** Your modular carbon capture system represents a scalable industrial innovation that directly facilitates the energy transition.
- How to pitch** Frame the venture as a scalable industrial technology that turns carbon liabilities into profitable mineral assets.

## **Demeter** · partner withheld

**Thesis fit: strong**

- Why them** They are a major European player supporting the energy and ecological transition through venture capital and infrastructure investment.
- Why you** Your skid-mounted mineralisation system provides a tangible, infrastructure-ready solution for ecological transition.
- How to pitch** Emphasize the system's role in the ecological transition by permanently sequestering CO2 into industrial-grade minerals.

## **Startupbootcamp** · partner withheld

**Thesis fit: strong**

- Why them** They invest in deep tech and robotics startups pioneering disruptive engineering innovations to reshape the energy and manufacturing sectors.
- Why you** Your modular, skid-mounted hardware is a disruptive engineering innovation that reshapes how manufacturing plants handle emissions.
- How to pitch** Highlight the technical breakthrough of your modular hardware and its ability to disrupt traditional carbon management in manufacturing.

## **VantagePoint Venture Partners** · partner withheld

**Thesis fit: strong**

- Why them** They focus on energy innovation, efficiency, and the scale-up of supporting infrastructure for companies revolutionizing industries.
- Why you** Your system provides the necessary infrastructure to capture and mineralize emissions, directly addressing industrial energy innovation.
- How to pitch** Focus on the scalability of your skid-mounted infrastructure and its potential to revolutionize industrial carbon management.

**Third Sphere** · partner withheld**Thesis fit: strong**

<b>Why them</b>	They deploy early-stage capital to upgrade broken global systems across infrastructure and clean energy.
<b>Why you</b>	Your technology upgrades the broken industrial system of carbon waste by converting it into valuable fertilizers and minerals.
<b>How to pitch</b>	Frame the venture as a systemic upgrade to industrial infrastructure that creates value from waste rather than just reducing carbon.

**Want the named partners and the full match list?**

This dossier shows five of your strongest-fit firms (matched live from 18 candidates in Fractional Forge's investor intelligence). The specific partner to approach at each — plus the wider matched set, warm-intro paths and live fund status — are at Fractional Forge.

**[fractionalforge.com](https://fractionalforge.com)** ’

Investor matches are generated from your brief against Fractional Forge's investor database and are indicative signals, not investment advice or any endorsement by the named firms. Individuals are withheld by design.