DESIGNED AGAINST REFERENCE PRODUCT
1000 t/yr Sustainable Aviation Fuel (SAF) via single-step Power-to-Liquid Fischer-Tropsch ($CO_2 + 3 H_2 \rightarrow -CH_2- + 2 H_2O$ over an iron catalyst) + ~667 t/yr naphtha co-product. SAF ~125 kg/h (~3750 L/day)(Norsk e-Fuel)- anchored 4 reference subsystems + 6 key specs.

DESIGN DOSSIER · CONCEPT STAGE

UK Power-to-Liquid Sustainable Aviation Fuel Synthesis Plant (First Commercial, ~1,000 t/yr e-SAF

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	£9,841,070 £9,841/unit
+ Assembly labour (25%)	£2,460,268
+ Factory overhead (18%)	£2,214,241
= Factory COGS	**£14.5M**
+ Manufacturer margin (-13%)	£1,887,025
= OEM transfer price	**£16.4M** £16,403/unit
+ Channel markup — *direct (no distribution)*	—
= Channel list price	**£16.4M**
+ Installation (55%)	£9,021,432
= Installed ASP	**£25.4M** £25,424/unit

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	**£16,402,603**
Brief ceiling	£45,000,000
Position	**64% below ceiling (headroom £28,597,397)**

Table of Contents

Sections run front to back in the order below; the two appendices close the report.

SECTIONS

APPENDICES

Executive summary

> ### About this document
>
> This is a concept-stage engineering and cost design — a complete, numbers-backed picture of the plant built from first-principles calculations, not placeholders. It is built to let a founding team understand everything involved in designing and procuring this plant: the system, the engineering issues, the costs (to about ±30% at this stage), and the decisions still open.
>
> It is a strong first basis — not a final engineering package. Its job is to ready you for the conversations that come next: throughout, it flags what to get quoted, what to validate with specialists, and what to ask them. Every cost is traceable — Section 9 (Cost Methodology) sets out exactly how each number was built and from what rates, and the Bill of Materials (Section 8) shows the line-by-line working. Use it to understand the system, frame the right questions, and decide with confidence. The consolidated next steps are in 'Taking this forward' (Section 12).

This concept-stage dossier develops an e fuel synthesis system: first-commercial Power-to-Liquid Fischer-Tropsch plant producing ~1000 t/yr Sustainable Aviation Fuel (~125 kg/h) plus ~667 t/yr naphtha from ~1000 kg/h biogenic CO2 and ~140 kg/h renewable H2 via single-step CO2 hydrogenation ($CO_2 + 3 H_2 \rightarrow -CH_2- + 2 H_2O$) over a shaped iron catalyst at 300 °C / 25 bar, recovering the ~677 kW exotherm as ~1290 kg/h raised steam (net steam exporter), to ASTM D7566 Annex A1 (FT-SPK). It is aimed at UK and European SAF producers, project developers, airlines, airport fuel operators, biogenic CO2 hosts, and renewable-hydrogen producers. The timing is driven by driven by the UK SAF Mandate (in force from 2025) and the European ReFuelEU Aviation Regulation setting rising synthetic-aviation-fuel sub-targets.

Design outcome

The design honours 17 of 23 brief constraints with no breaches (the remaining 6 are recorded in the Brief Compliance table but not assessed at this stage), delivering 1,000 t/yr. The fully-costed design reaches £16.40M 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 highest-cost and longest-lead 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

SAF PRODUCTION TPY

1,000 t/yr

Mission

First-commercial Power-to-Liquid Fischer-Tropsch plant producing ~1000 t/yr Sustainable Aviation Fuel (~125 kg/h) plus ~667 t/yr naphtha from ~1000 kg/h biogenic CO_2 and ~140 kg/h renewable H_2 via single-step CO_2 hydrogenation ($CO_2 + 3 H_2 \rightarrow -CH_2- + 2 H_2O$) over a shaped iron catalyst at 300 °C / 25 bar, recovering the ~677 kW exotherm as ~1290 kg/h raised steam (net steam exporter), to ASTM D7566 Annex A1 (FT-SPK).

Target customers

UK and European SAF producers, project developers, airlines, airport fuel operators, biogenic CO2 hosts, and renewable-hydrogen producers.

Why now

Driven by the UK SAF Mandate (in force from 2025) and the European ReFuelEU Aviation Regulation setting rising synthetic-aviation-fuel sub-targets.

Performance characteristics

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

SCALE & GEOMETRY

METRIC	VALUE	
Saf production tpy	**1,000 t/yr**	<
Saf production kg per	**125 kg/h**	<
Hydrogen feed kg per	**140 kg/h**	<
Co2 feed kg per	**1,000 kg/h**	<
Electrical load	**3.00 MW**	<

PERFORMANCE

METRIC	VALUE	
Jet range selectivity	**60.0 %**	<
Synthesis temp min	**200 °C**	<
Synthesis temp max	**350 °C**	<
Synthesis pressure min	**20.0 bar**	<

Synthesis pressure max	**30.0 bar**	<

EFFICIENCY

METRIC	VALUE	
Conversion efficiency	**65.0 %**	<
Ghg reduction	**70.0 %**	<

DURABILITY & LIMITS

METRIC	VALUE	
Operating hours per	**8,000 h/yr**	<

COST TARGETS

METRIC	VALUE	
Levelised cost saf gbp per	**2,200 GBP/t**	<

CONSTRAINTS

METRIC	VALUE	
Unit cost ceiling	**45,000,000 GBP**	

Legend in spec ³ 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: 1,485 words. LLM parsed it into a structured object with 718 tokens of content.

2.1 Original brief, as submitted

Verbatim text from the submitted brief file. No edits, no normalisation.

> # UK Power-to-Liquid Sustainable Aviation Fuel Synthesis Plant (First Commercial, ~1,000 t/yr e-SAF via single-step CO2 hydrogenation)
>
> We are designing a first-commercial Power-to-Liquid synthesis plant that converts captured biogenic CO2 and renewable hydrogen into Sustainable Aviation Fuel (SAF) and a co-product naphtha. The plant's distinctive core is a single-step Fischer-Tropsch synthesis over a proprietary iron-based catalyst that hydrogenates CO2 directly to jet-range paraffins, eliminating the separate reverse water-gas-shift stage that conventional cobalt Fischer-Tropsch trains require to first convert CO2 to CO. CO2 and renewable hydrogen are blended, preheated and reacted at approximately 200-350 °C and 20-30 bar; the catalyst is supplied in a shaped, structured form engineered for high jet-range selectivity, low reactor pressure-drop and long mechanical life. The raw synthesis product is separated into a tail gas, a process-water phase and a liquid syncrude; the syncrude is hydrocracked and isomerised, then fractionated into an on-specification SAF (jet) cut plus a lighter naphtha cut; unconverted tail gas is recompressed and recycled to near-extinction with a small purge to a thermal oxidiser. The plant is the first commercial unit in a scale-up from a 1.2 litre/day proof-of-concept and a 10-30 litre/day demonstration unit, and is engineered for standardised replication across the United Kingdom and Europe. Renewable hydrogen is supplied to the plant boundary from an adjacent low-emission hydrogen plant (typically water electrolysis powered by renewable electricity); CO2 is supplied from a biogenic point source (biomethane or biogas upgrading, bioethanol plants, or energy-from-waste). Both are treated as delivered feedstocks at the plant battery limit, with on-site receipt, conditioning and compression in scope.
>
> Process description (continuous):
> - Receive renewable hydrogen and biogenic CO2 at the battery limit; dry, polish (guard beds remove sulphur and oxygen traces that would poison the catalyst) and compress each stream to synthesis pressure
> - Blend make-up hydrogen and CO2 with recycled tail gas to the target reactor feed ratio; preheat the combined feed
> - React the feed in a single-step Fischer-Tropsch reactor over the iron-based catalyst to form jet-range paraffins and water, recovering the reaction exotherm as raised steam
> - Separate the reactor effluent in staged hot and cold separators into a tail gas, an aqueous process-water phase, and a liquid syncrude/wax phase
> - Recompress and recycle unconverted tail gas (CO2, CO, hydrogen, light ends) to the reactor; take a small purge to a thermal oxidiser to prevent inert build-up
> - Hydrocrack and isomerise/dewax the syncrude and wax to break heavy chains and meet jet cold-flow properties, consuming a hydrogen slip-stream

> - Fractionate the upgraded liquid into an on-specification SAF (jet) cut, a naphtha co-product, and a small recycle residue
> - Treat and reuse the Fischer-Tropsch process water; additise, certify and store the finished SAF; load SAF and naphtha to road tanker
>
> Target market: United Kingdom and European SAF producers and project developers responding to the UK SAF Mandate (in force from 2025, with a Power-to-Liquid sub-obligation) and the European ReFuelEU Aviation Regulation (which sets a rising synthetic-aviation-fuel sub-target). Off-takers include airlines and fuel suppliers seeking certified low-emission jet fuel; airport fuel operators; biogenic CO2 hosts (anaerobic-digestion biomethane plants, bioethanol plants, and energy-from-waste sites) co-locating a synthesis plant to monetise their CO2; and renewable-hydrogen producers seeking a high-value off-take. Deployment target: a first commercial plant in the United Kingdom, then replication of standardised ~1,000 t/yr trains and larger multi-train sites across the United Kingdom and Europe.
>
> Key constraints:
> - SAF output: >= 1,000 tonnes/year of finished Sustainable Aviation Fuel (~ 1,250,000 litres/year at 0.80 kg/litre), plus a naphtha co-product, at >= 8,000 operating hours/year (~ 125 kg/h finished SAF)
> - Product slate: jet-range (SAF) selectivity >= 60% of the liquid product; balance recovered as naphtha co-product; heavy residue recycled to the upgrading section
> - Feedstock — renewable hydrogen: ~140 kg/h (~ 1,120 t/yr) delivered at the battery limit, >= 99.9% purity, low emission intensity; on-site buffer storage and compression to synthesis pressure in scope
> - Feedstock — biogenic CO2: ~1,000 kg/h (~ 8,000 t/yr) delivered at the battery limit, biogenic origin; conditioned on-site (drying plus sulphur and oxygen guard beds) before synthesis
> - Conversion efficiency: >= 65% of the feed CO2 converted to liquid product over the recycle loop (recycle-to-near-extinction; the unconverted balance is purged and combusted in the thermal oxidiser). The Fischer-Tropsch synthesis is strongly exothermic — the reaction heat is recovered as raised steam for feed preheat and reboil (net steam exporter)
> - Synthesis conditions: single-step CO2 hydrogenation at 200-350 °C and 20-30 bar over a shaped iron-based catalyst; no separate reverse water-gas-shift reactor
> - Lifecycle emission intensity: >= 70% greenhouse-gas reduction versus fossil Jet A-1 (the qualifying threshold), target >= 90% on biogenic CO2 and renewable hydrogen
> - Product specification: finished jet cut to meet ASTM D7566 Annex A1 (Fischer-Tropsch Synthetic Paraffinic Kerosene) for blending up to 50% with fossil Jet A-1; finished blend to meet ASTM D1655 and UK DEF STAN 91-091
> - Target levelised cost of SAF: <= £2,200/tonne (~ £1.75/litre) at nth-of-a-kind commercial scale; first-of-a-kind plant economics accepted higher. Provide a sensitivity to the renewable-hydrogen price at £3/kg, £4/kg and £6/kg (the dominant operating-cost driver)
> - Installed capital cost: <= £45,000,000 for the first-of-a-kind commercial synthesis-and-upgrading plant (Power-to-Liquid plants are capital-intensive at first-of-a-kind scale) (battery limit: feedstock receipt and conditioning, synthesis, separation, recycle, upgrading, fractionation, utilities, controls, and product storage/loading; excludes the renewable-hydrogen supply plant, the CO2 source, land, and grid reinforcement); nth-of-a-kind target <= £20,000,000
> - Plant electrical load: <= 3.0 MW for the synthesis-and-upgrading plant itself (feedstock and recycle compression, pumps, heat-tracing, controls), excluding the hydrogen supply plant; drawn from the local grid or on-site renewable generation
> - Steam balance: self-sufficient or a net steam exporter — the Fischer-Tropsch exotherm raises process steam recovered for feed preheat, fractionation reboil and tracing
> - Footprint: field-erected process plant on a fixed site; equipment ships as modular skids plus field-erected columns and vessels; total plot area <= 60 m x 40 m for the first commercial plant. No single plant-wide

> gross-mass cap applies (a fixed installation, not a containerised product); the individual skids stay within standard road-transport abnormal-load limits.
> - Design life: >= 20 years for the plant; the catalyst charge is a replaceable line item with a >= 2-year service interval to end-of-run
> - Operating environment: United Kingdom outdoor installation, -15 °C to +35 °C ambient; continuously operated (>= 8,000 h/yr)
> - Annual build rate: 4 standardised plants per year by year 3 as the design is replicated
>
> Safety and regulatory:
> - Control of Major Accident Hazards Regulations 2015 (COMAH) — flammable and toxic inventory (hydrogen, CO, flammable liquids); tier determined by inventory assessment
> - Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) and ATEX Directive 2014/34/EU with the BS EN 60079 series — hazardous-area classification for hydrogen, CO and flammable process vapours
> - Pressure Equipment Directive 2014/68/EU / UK Pressure Equipment (Safety) Regulations 2016 — synthesis reactor, separators, compressors and pressurised vessels (Category II-IV by fluid group and pressure)
> - IEC 61511 and IEC 61508 — functional safety, safety-instrumented systems and SIL-rated emergency shutdown (overpressure, high-temperature and gas-detection trips)
> - ASTM D7566 Annex A1 (Fischer-Tropsch SPK), ASTM D1655 (Jet A-1) and UK DEF STAN 91-091 — finished aviation-fuel product specification and blending limit
> - UK SAF Mandate 2025 (under the Renewable Transport Fuel Obligation) and European ReFuelEU Aviation Regulation (EU) 2023/2405 — renewable-fuel-of-non-biological-origin qualification and the synthetic-aviation-fuel sub-target
> - Energy Institute EI 1530 and Joint Inspection Group standards — aviation-fuel storage, handling and road-tanker loading
> - Environmental Permitting (England and Wales) Regulations 2016 — process emissions, thermal-oxidiser permitting and aqueous effluent
> - BS EN ISO 4126 — safety relief devices; BS EN ISO 10628 — process flow diagrams and plant documentation
> - Machinery Directive 2006/42/EC, Low Voltage Directive 2014/35/EU and IEC 60204-1 — machinery and electrical safety
> - Process-safety study: HAZOP and LOPA expected; the reduced iron catalyst is pyrophoric and CO is acutely toxic — both are specific handling hazards to be designed out
>
> Sub-modules expected: CO2 receipt and conditioning (drying, sulphur and oxygen guard beds, compression to synthesis pressure); renewable-hydrogen receipt, buffer storage and compression to synthesis pressure; feed conditioning and preheat (make-up plus recycle blending to the target hydrogen-to-CO2 ratio, fired or electric preheater); single-step Fischer-Tropsch synthesis reactor (shaped iron-based catalyst, multitubular fixed-bed or slurry configuration, steam-raising heat recovery on the exotherm); staged product separation (hot and cold three-phase separators for tail gas, process water and syncrude/wax); tail-gas recompression and recycle loop with a purge to a thermal oxidiser; product upgrading (hydrocracker/hydrotreater plus isomerisation/dewaxing for jet cold-flow, hydrogen slip-stream); product fractionation column splitting the SAF, naphtha and residue cuts; Fischer-Tropsch process-water treatment and reuse; utilities (steam generation and distribution, cooling-water circuit, nitrogen inerting, instrument air, electrical distribution and a medium-voltage transformer); thermal oxidiser and emissions abatement; product storage and road-tanker loading (SAF and naphtha tanks, additisation, loading gantry to EI 1530); and process control with functional safety (distributed control system plus safety-instrumented system, hydrogen, CO and flammable-gas detection, fire-and-gas and SIL-rated emergency shutdown).

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	ptl-saf-plant-001
PRODUCT DESCRIPTION	A first-commercial Power-to-Liquid synthesis plant converting biogenic CO2 and renewable hydrogen into Sustainable Aviation Fuel (SAF) and naphtha via single-step Fischer-Tropsch synthesis.
MISSION	To provide a standardized, scalable Power-to-Liquid solution that directly hydrogenates CO2 to jet-range paraffins, enabling certified low-emission aviation fuel production.
TARGET CUSTOMERS	UK and European SAF producers, project developers, airlines, airport fuel operators, biogenic CO2 hosts, and renewable-hydrogen producers.
WHY NOW	Driven by the UK SAF Mandate (in force from 2025) and the European ReFuelEU Aviation Regulation setting rising synthetic-aviation-fuel sub-targets.
PARSER CONFIDENCE	HIGH

CONSTRAINTS (PARSED)

unit_cost_ceiling	45000000 GBP
max_dimensions_mm	60000 x 40000 mm
saf_production_tpy	1000 t/yr
saf_production_kg_per_h	125 kg/h
jet_range_selectivity_percent	60 %
hydrogen_feed_kg_per_h	140 kg/h
co2_feed_kg_per_h	1000 kg/h
conversion_efficiency_percent	65 %
synthesis_temp_min_c	200 °C
synthesis_temp_max_c	350 °C
synthesis_pressure_min_bar	20 bar
synthesis_pressure_max_bar	30 bar
ghg_reduction_percent	70 %
levelised_cost_saf_gbp_per_tonne	2200 GBP/t
electrical_load_mw	3 MW
operating_hours_per_year	8000 h/yr
target_process	Single-step Fischer-Tropsch synthesis
target_material	Iron-based catalyst
batch_size	4
design_life	20 years
operating_environment	-15 °C to 35 °C
_dropped_inferred	-

SAFETY STANDARDS (PARSED)

2014/34/EU	ATEX Directive
BS EN 60079	Explosive atmospheres
2014/68/EU	Pressure Equipment Directive
IEC 61511	Functional safety - Safety instrumented systems for the process industry sector
IEC 61508	Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems
ASTM D7566	Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons

ASTM D1655	Standard Specification for Aviation Turbine Fuels
DEF STAN 91-091	Turbine Fuel, Aviation Kerosine Type, Jet A-1
BS EN ISO 4126	Safety devices for protection against excessive pressure
BS EN ISO 10628	Diagrams for the chemical and petrochemical industry
2006/42/EC	Machinery Directive
2014/35/EU	Low Voltage Directive
IEC 60204-1	Safety of machinery - Electrical equipment of machines

ADDITIONAL CONSTRAINTS (PARSED)

- Catalyst charge is a replaceable line item with a >= 2-year service interval to end-of-run
- Steam balance: self-sufficient or a net steam exporter
- Lifecycle emission intensity target >= 90% on biogenic CO2 and renewable hydrogen
- NOAK installed capital cost target <= £20,000,000

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.

> **17 of 23 brief constraints verified PASS · 2 below target · 4 pending verification**
> The design verifiably meets 17 of 23 brief constraints. 2 operate below the brief target by a disclosed margin (a deliberate design choice, see the notes below). 4 are design targets that require downstream verification (lifecycle assessment / lifecycle cost model) before they can be claimed.

Brief targets vs design achieved

CONSTRAINT	BRIEF TARGET	DESIGN ACHIEVED	STATUS	DELTA
Synthesis temperature	200 °C	300 °C	DELTA	**+50%**
Synthesis pressure	20 bar	25 bar	DELTA	**+25%**
GHG reduction vs fossil	70 %	design target - requires full lifecycle assessment (ISO 14067 / CORSIA) to verify	TARGET	requires verification
Levelised cost of SAF	2200 GBP/t	indicative 8,620 GBP/t (unverified) - requires a full lifecycle cost model (electricity price, capital recovery, feedstock + utility OPEX over plant life) to verify	TARGET	requires verification
Plot area (field-erected)	60 m x 40 m plot	requires site plot plan	TARGET	requires verification
Lifecycle emission intensity target >= 90% on biogenic CO2 and renewable hydrogen	stated (stretch target)	design target - requires full lifecycle assessment (ISO 14067 / CORSIA) to verify	TARGET	requires verification
Unit cost (CAPEX, ex-works)	£45M	£16.4M	PASS	-64%
SAF production	1000 t/yr	1000 t/yr	PASS	0%
SAF production (hourly)	125 kg/h	125 kg/h	PASS	0%
Jet-range selectivity	60 %	60.11 %	PASS	0%
H2 feedstock rate	140 kg/h	140 kg/h	PASS	0%
CO2 feedstock rate	1000 kg/h	1000 kg/h	PASS	0%
CO2 conversion efficiency	65 %	65 %	PASS	0%
Synthesis temperature	200-350 °C	300 °C	PASS	within range
Synthesis pressure	20-30 bar	25 bar	PASS	within range
Electrical load	3 MW	3 MW	PASS	0%

Operating hours per year	8000 h/yr	8000 h/yr	PASS	0%
Design life	20 years	20 years	PASS	0%
Operating temperature	-15°C to 35°C	-15°C to 35°C	PASS	within
Annual batch	4/yr	4/yr	PASS	0%
Catalyst charge is a replaceable line item with a >= 2-year service interval to end-of-run	stated	adopted	PASS	confirmed
Steam balance: self-sufficient or a net steam exporter	stated	adopted	PASS	confirmed
NOAK installed capital cost target <= £20,000,000	stated	adopted	PASS	confirmed

Notes on below-target / corrected / unverified constraints

Synthesis temperature: brief 200 °C -> design 300 °C (+50%)

The brief specifies 200 °C for synthesis temperature; the design operates at 300 °C (+50%, above target). This is a deliberate design choice, not a deficiency - it is flagged as a medium-severity engineering deviation in the feasibility notes (Section 7). Confirm the operating point with a process engineer before locking the design; synthesis temperature trades against conversion, selectivity, equipment rating and cost.

Synthesis pressure: brief 20 bar -> design 25 bar (+25%)

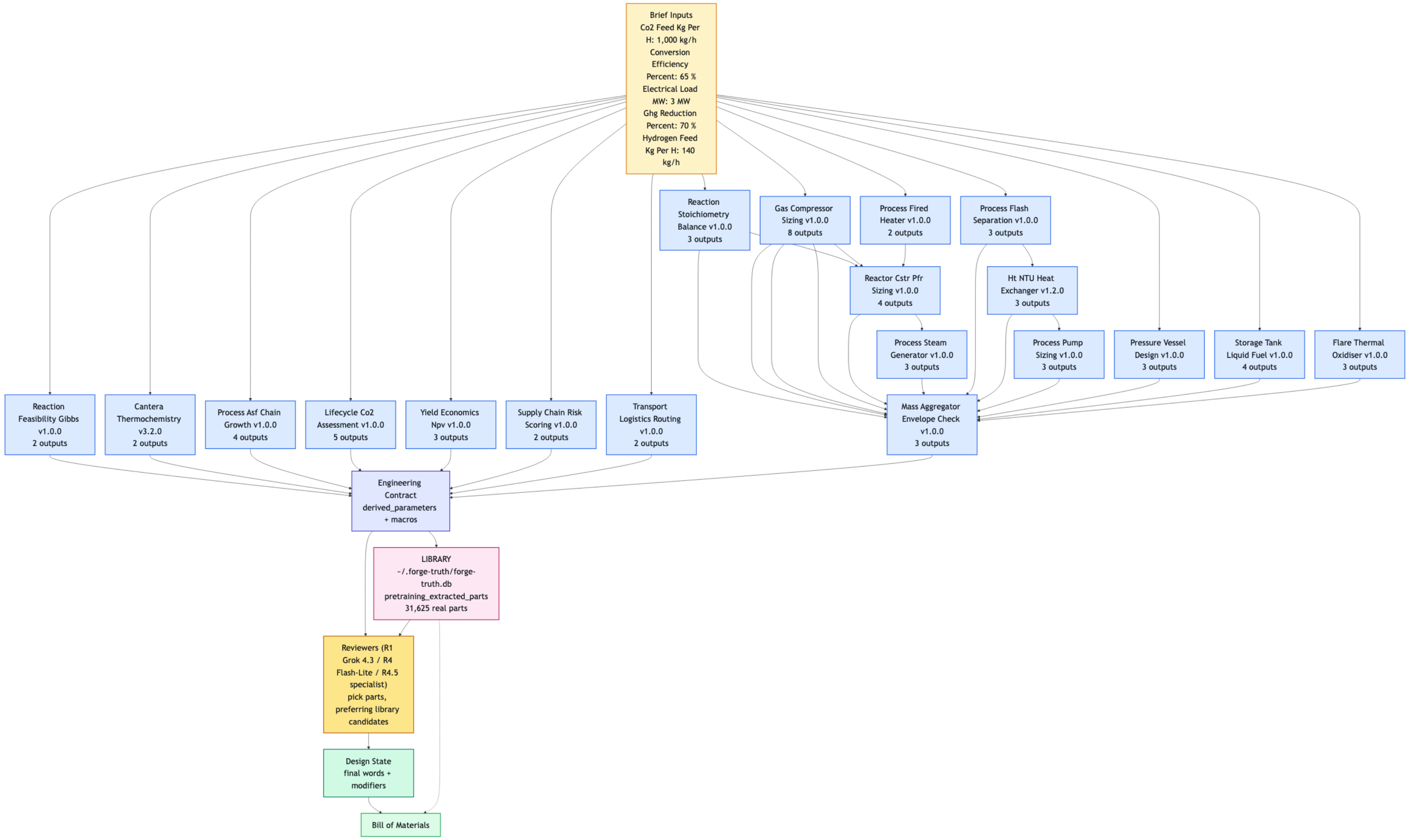
The brief specifies 20 bar for synthesis pressure; the design operates at 25 bar (+25%, above target). This is a deliberate design choice, not a deficiency - it is flagged as a medium-severity engineering deviation in the feasibility notes (Section 7). Confirm the operating point with a process engineer before locking the design; synthesis pressure trades against conversion, selectivity, equipment rating and cost.

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 first-commercial Power-to-Liquid synthesis plant converting biogenic CO2 and renewable hydrogen into Sustainable Aviation Fuel (SAF) and naphtha via single-step Fischer-Tropsch synthesis. To provide a standardized, scalable Power-to-Liquid solution that directly hydrogenates CO2 to jet-range paraffins, enabling certified low-emission aviation fuel production. Intended for UK and European SAF producers, project developers, airlines, airport fuel operators, biogenic CO2 hosts, and renewable-hydrogen producers.

How it works

M5 Utilities & Offsites: The environmental interface manages heat rejection, purge treatment and utility supply for the Fischer-Tropsch plant. It connects to M2 Fischer-Tropsch Synthesis via electrical bus (3.0 MW MV/LV supply -> compressors, pumps, heaters, drives). M1 Feedstock Receipt & Conditioning: The mass fluid transport process receives 1000 kg/h of biogenic CO, and 140 kg/h of renewable H,.

It connects to M2 Fischer-Tropsch Synthesis via fluid loop (conditioned + compressed CO2 + H2 (+ recycle) -> FT reactor at 25 bar). M3 Separation & Recycle: The mass fluid transport process receives reactor effluent at 300 °C and 25 bar and routes it through the separation & recycle train. It connects to M2 Fischer-Tropsch Synthesis via fluid loop (conditioned + compressed CO2 + H2 (+ recycle) -> FT reactor at 25 bar).

M2 Fischer-Tropsch Synthesis: The energy conversion transduction module hydrogenates CO, directly to jet-range paraffins in a boiling-water-cooled multitubular Fischer-Tropsch reactor operated at 300 °C and 25 bar. It connects to M1 Feedstock Receipt & Conditioning via fluid loop (reactor effluent -> hot/cold 3-phase separation (tail gas / process water / syncrude)). M4 Upgrading & Fractionation: The energy conversion transduction module converts Fischer-Tropsch syncrude into on-specification sustainable aviation fuel by hydrocracking, isomerisation and dewaxing followed by fractionation.

It connects to M1 Feedstock Receipt & Conditioning via fluid loop (reactor effluent -> hot/cold 3-phase separation (tail gas / process water / syncrude)). M8 Process Instrumentation & Control: The sensing instrumentation module acquires field measurements and executes control actions throughout the plant. It connects to M7 Control & Safety via data (field transmitters (4–20 mA HART + PROFINET PA) + control valves ’ DCS + SIS signal loops; VFD speed references + status from DCS; gas-detector trips from Polytron 8700 ’ F&G controller ’ SIS ESD chain).

M7 Control & Safety: The control compute communication silicon semiconductor houses the distributed control system that sequences synthesis, separation, recycle, upgrading, fractionation and loading together with the independent safety instrumented system, while the control compute communication chemical sensing mass fluid transport process supplies H,/CO/hydrocarbon gas detectors, optical flame detectors and emergency shutdown valves that initiate trips. It connects to M2 Fischer-Tropsch

Synthesis via control (DCS sequences synthesis + upgrading; SIS/ESD + fire-&-gas trip the plant to a safe state). M6 Product Storage & Loading: The maintenance serviceability module receives finished sustainable aviation fuel at 125 kg/h and 3750 L/day.

It connects to M7 Control & Safety via data (custody metering to DCS).

Modules at a glance

The 8 modules below are described in full later in the report. This list orients the reader before they enter the per-module detail.

M5 Utilities & Offsites	The environmental interface manages heat rejection, purge treatment and utility supply for the Fischer-Tropsch plant.
M1 Feedstock Receipt & Conditioning	The mass fluid transport process receives 1000 kg/h of biogenic CO, and 140 kg/h of renewable H,.
M3 Separation & Recycle	The mass fluid transport process receives reactor effluent at 300 °C and 25 bar and routes it through the separation & recycle train.
M2 Fischer-Tropsch Synthesis	The energy conversion transduction module hydrogenates CO, directly to jet-range paraffins in a boiling-water-cooled multitubular Fischer-Tropsch reactor operated at 300 °C and 25 bar.
M4 Upgrading & Fractionation	The energy conversion transduction module converts Fischer-Tropsch syncrude into on-specification sustainable aviation fuel by hydrocracking, isomerisation and dewaxing followed by fractionation.
M8 Process Instrumentation & Control	The sensing instrumentation module acquires field measurements and executes control actions throughout the plant.
M7 Control & Safety	The control compute communication silicon semiconductor houses the distributed control system that sequences synthesis, separation, recycle, upgrading, fractionation and loading together with the independent safety instrumented system, while the control compute communication chemical sensing mass fluid transport process supplies H,/CO/hydrocarbon gas detectors, optical flame detectors and emergency shutdown valves that initiate trips.
M6 Product Storage & Loading	The maintenance serviceability module receives finished sustainable aviation fuel at 125 kg/h and 3750 L/day.

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.

LIFECYCLE CO2 (ASSESSMENT)

Lifecycle CO2 (Assessment) computed plant lifecycle CO2 t = 14,426 t, plant annual CO2 t = 721 t, plant embodied CO2 t = 64.6 t, saf lifecycle CO2 per = 0.72 kgCO2e/kg, saf avoided CO2 t yr = 3,099 t/yr.

SUPPLY CHAIN RISK (SCORING)

Supply Chain Risk (Scoring) computed supply chain risk score = 73, supply chain tariff exposure = 88,500 GBP.

MASS AGGREGATOR (ENVELOPE CHECK)

Mass Aggregator (Envelope Check) computed total plant mass = 26,011 kg, site mass = 26,011 kg.

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.	M5 Utilities & Offsites	**£1,580,000**
2.	M1 Feedstock Receipt & Conditioning	**£1,722,800**
3.	M3 Separation & Recycle	**£889,800**
4.	M2 Fischer-Tropsch Synthesis	**£1,724,000**
5.	M4 Upgrading & Fractionation	**£2,728,200**
6.	M8 Process Instrumentation & Control	**£452,710**
7.	M7 Control & Safety	**£280,960**
8.	M6 Product Storage & Loading	**£462,600**
	Sum of modules	**£9,841,070**

Component-class breakdown

Per-component-class contribution to the grand total. Classifier source: Engine B (Phase 4 corpus lookup with Flash-Lite fallback).

Rotating & mechanical equipment	£4,184,560	43%
Piping, vessels & valves	£1,841,000	19%
Heat transfer & thermal	£1,286,500	13%
Engineered subsystems	£1,187,900	12%
Transformers & magnetics	£850,000	9%
Consumables & media	£460,000	5%
Structural & enclosure	£190,520	2%
Instrumentation & control	£172,400	2%
Sensors & measurement	£96,590	1%
Motors & actuators	£31,600	<1%

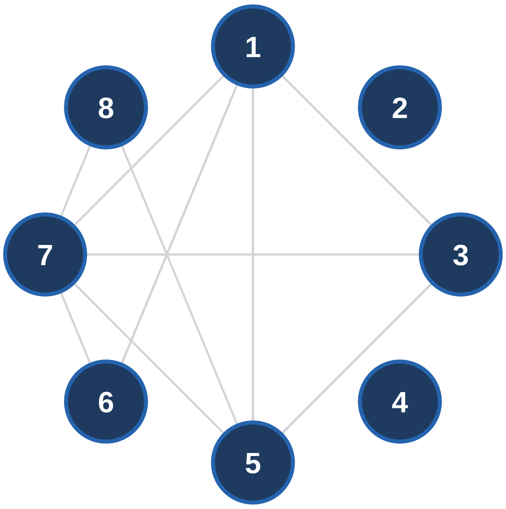
Consumables (per production cycle)

Replenished each cycle — excluded from the capital total above, not a one-time build cost.

Shaped Iron FT Catalyst Charge	×1	£300,000
Catalyst Reduction/activation Heater	×1	£60,000
Hydroprocessing Catalyst Charge	×1	£100,000
Consumables sub-total (per cycle)		**£460,000**

Module Map

Figure 1. The 8 modules and how they connect.



MODULE LEGEND

1	M5 Utilities & Offsites
2	M1 Feedstock Receipt & Conditioning
3	M3 Separation & Recycle
4	M2 Fischer-Tropsch Synthesis
5	M4 Upgrading & Fractionation
6	M8 Process Instrumentation & Control
7	M7 Control & Safety
8	M6 Product Storage & Loading

MODULE 1

M5 Utilities & Offsites

Cost **£1,580,000**

Module summary

PURPOSE

This module (M5 Utilities & Offsites) the environmental interface manages heat rejection, purge treatment and utility supply for the Fischer-Tropsch plant. Waste heat from the 677 kW exotherm is recovered in the utilities & offsites through a waste-heat steam generator that raises 1290 kg/h of process steam over 15.4 m² of boiling surface for net export, while the enclosed thermal oxidiser treats the 150 kg/h purge stream in a 2.02 m³ chamber releasing 833 kW.

HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The utilities & offsites — the FT exotherm raises ~1290 kg/h steam (net export) over ~15 m² of boiling-HX area; cooling water, N2 inerting, instrument air and an 3.0 MW MV electrical supply serve the plant; a 833 kW enclosed thermal oxidiser destroys the purge.

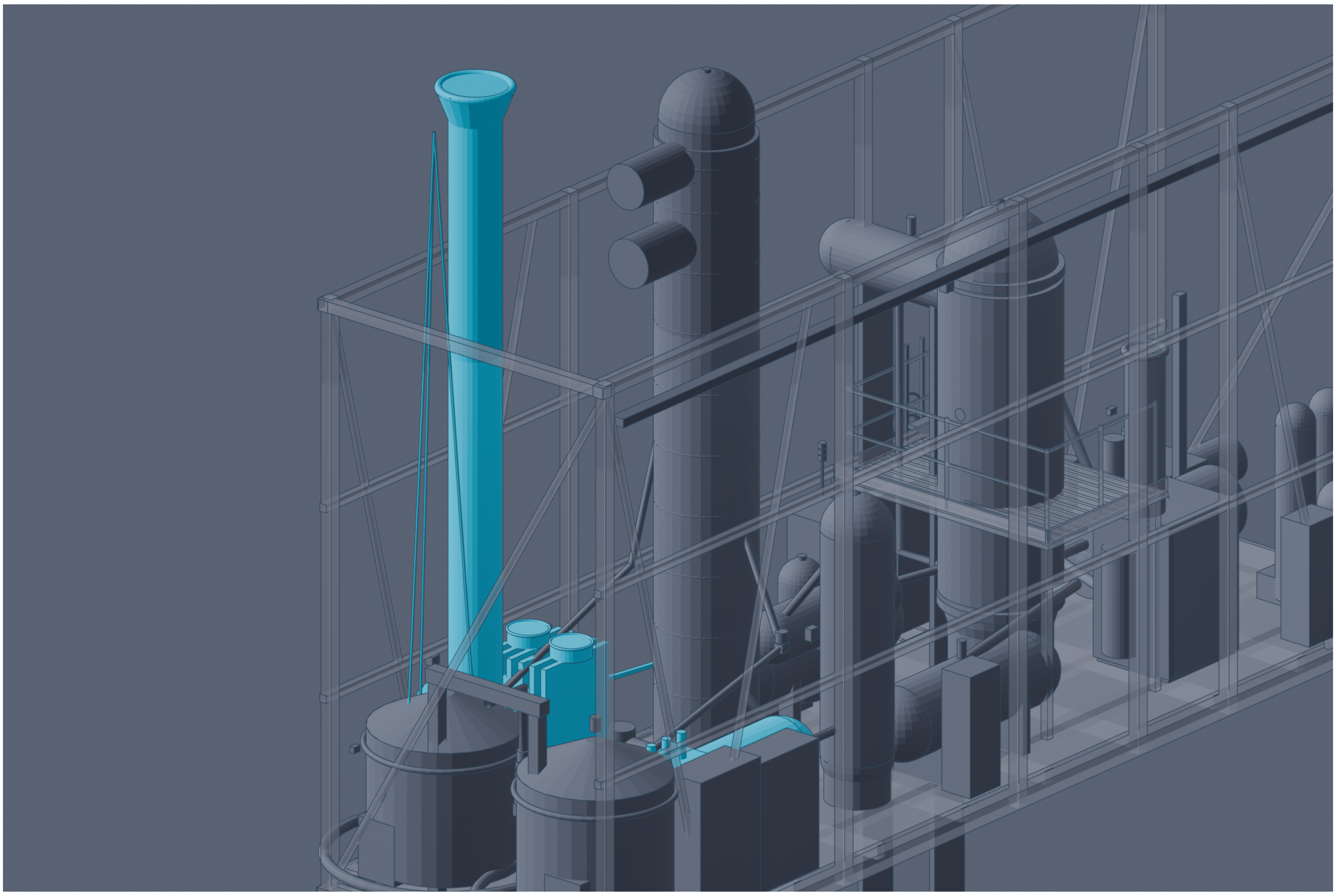


Illustration only — generic class render. Module 1 (M5 Utilities & Offsites) shown in identity colour; other modules muted; enclosure ghosted.

The environmental interface manages heat rejection, purge treatment and utility supply for the Fischer-Tropsch plant. Waste heat from the 677 kW exotherm is recovered in the utilities & offsites through a waste-heat steam generator that raises 1290 kg/h of process steam over 15.4 m2 of boiling surface for net export, while the enclosed thermal oxidiser treats the 150 kg/h purge stream in a 2.02 m3 chamber releasing 833 kW.

Cooling-water, nitrogen-inerting and instrument-air skids maintain process conditions, and the MV/LV distribution transformer together with the MV switchgear and LV board deliver the 3000 kW connected electrical load. These provisions ensure safe, continuous operation at the design throughput.

The module therefore supplies all external services and closes the plant material and energy balances.

Sub-modules

1.1 Utilities & offsites

The utilities & offsites supply 7 components. A made-to-order fabrication boiling-water waste-heat steam generator recovering the FT exotherm as raised steam (net exporter) FT exotherm waste-heat steam generator (part fabricated boiling-water waste-heat steam generator - bespoke package, 15 m2 area, 1290 kg/h capacity), certified to PED 2014/68/EU. A Zeeco enclosed thermal oxidiser/flare for the tail-gas purge, ~1000 °C / ~1.0 s residence for CO + VOC destruction enclosed purge thermal oxidiser, certified to API 537.

A Kelvion dry-cooler/cooling-tower + circulation-pump skid serving the product cooler + condensers closed-loop cooling-water skid. An Atlas Copco PSA/membrane N2 generation + blanketing skid for vessels, purging and start-up/shutdown inerting N2 generation + inerting/blanketing skid, certified to DSEAR. An Atlas Copco oil-free instrument-air compressor + dryer + receiver package instrument + plant air package.

A Schneider Electric 11 kV / 415 V cast-resin distribution transformer feeding the plant LV board 11 kv / 415 V distribution transformer, certified to IEC 60076. An ABB 11 kV ring-main unit + Form-4 LV main distribution board MV switchgear + LV main board, certified to BS EN 61439. The FT exotherm raises ~1290 kg/h steam (net export) over ~15 m2 of boiling-HX area; cooling water, N2 inerting, instrument air and an 3.0 MW MV electrical supply serve the plant; a 833 kW enclosed thermal oxidiser destroys the purge.

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.

Flare / Thermal Oxidiser (purge destruction) Sizing v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Heat release from purge combustion

```
Q = m / 3600 x LHV x 1000
Q = 150 / 3600 x 20 x 1000 = 833.33 kW
```

assumes: m[kg/s] = kg/h / 3600; LHV[kJ/kg] = MJ/kg x 1000; Q[kW] = m x LHV; lower heating value basis (water leaves as vapour)

Combustion air (stoichiometric + excess)

```
air = m x stoich_air x (1 + excess)
air = 150 x 10 x (1 + 0.2) = 1,800 kg/h
```

assumes: stoichiometric air/fuel mass ratio from fuel composition; 20.0% excess air for complete combustion

Flue-gas mass rate (mass conservation)

```
flue = m + air
flue = 150 + 1,800 = 1,950 kg/h
```

assumes: mass in = mass out (fuel + combustion air -> flue gas)

Flue-gas density at combustion temperature (ideal gas)

```
rho = (MW / 1000) x P / (R x T)
rho = (28 / 1000) x 101,325 / (8.314 x 1,273.15) = 0.268 kg/m3
```

assumes: ideal-gas law at atmospheric pressure and the combustion temperature; combustion temperature 1000.0 degC = 1273.15 K

Flue-gas volumetric flow

```
Qv = (flue / 3600) / rho
Qv = (1,950 / 3600) / 0.268 = 2.0209 m3/s
```

assumes: mass flow / density at the combustion temperature

Combustion-chamber volume (residence time)

```
V_chamber = Qv x residence
V_chamber = 2.0209 x 1 = 2.0209 m3
```

assumes: 1.0 s residence at 1000.0 degC for CO/VOC destruction; API 521 / API 537 / enclosed thermal-oxidiser practice

Stack diameter (continuity at exit velocity)

```
D = sqrt(4 x Qv / (pi x v_exit))
D = sqrt(4 x 2.0209 / (pi x 15)) = 0.4142 m
```

assumes: Qv = (pi/4) x D^2 x v_exit (continuity for a circular stack); exit velocity 15.0 m/s (flame stability / dispersion)

Steam Generator (FT reactor heat recovery) Sizing v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Saturated steam raised (latent-heat balance)

```
steam = Q / h_fg x 3600
steam = 677 / 1,890 x 3600 = 1,289.52 kg/h
```

assumes: h_fg at 20.0 bar from IAPWS-IF97 table (interpolated between 10.0 and 20.0 bar); kW = kJ/s, so (kJ/s)/(kJ/kg) = kg/s; x3600 -> kg/h; latent-heat basis (feedwater sensible pre-heat excluded)

Log-mean temperature difference (isothermal boiling)

```
LMTD = T_reactor - T_sat
LMTD = 573.15 - 485.5 = 87.65 K
```

assumes: boiling side isothermal at T_sat, so LMTD reduces to a single dT; steam saturation T_sat = 485.5 K (212.35 degC)

Boiler heat-transfer area

```
A = Q x 1000 / (U x LMTD)
A = 677 x 1000 / (500 x 87.65) = 15.448 m2
```

assumes: boiling heat exchanger, Q = U x A x dT (Coulson & Richardson Vol 6); Q x 1000 converts kW -> W to match U in W/m2K

Steam-drum volume (10-min vapour holdup)

```
V_drum = (steam / 60 x 10) / rho_g
V_drum = (1,289.52 / 60 x 10) / 10 = 21.4921 m3
```

assumes: ~10-minute saturated-vapour holdup for level control / disengagement; saturated-vapour density rho_g at 20.0 bar from IAPWS-IF97 table

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK

Waste-Heat Steam Generator	made-to-order fabrication	**fabricated boiling-water waste-heat steam generator - bespoke package**	×1	~£280,000	**£280,000**	—	>2x
Enclosed Thermal Oxidiser	Zeeco	**enclosed ground thermal oxidiser - engineered package**	×1	~£300,000	**£300,000**	—	>2x
Cooling-Water Skid	Kelvion	**closed-loop cooling-water skid - packaged**	×1	~£130,000	**£130,000**	—	>2x
Nitrogen Inerting Skid	Atlas Copco	**membrane nitrogen generation + inerting skid - packaged**	×1	~£90,000	**£90,000**	—	>2x
Instrument-Air Package	Atlas Copco	**oil-free instrument-air package - configured**	×1	~£80,000	**£80,000**	—	-
Mv/lv Distribution Transformer	Schneider Electric	**Trihal cast- - resin distribution transformer**	×1	~£350,000	**£350,000**	Est.	>2x
MV Switchgear + LV Board	ABB	**MV ring-main unit + Form-4 LV board - configured**	×1	~£350,000	**£350,000**	—	-
Sub-total — utilities & offsites					**£1,580,000**		

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 2× 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 — M5 Utilities & Offsites **£1,580,000**

Validate this design with: Senior thermal process engineer, Senior utility systems engineer — full questions in the Engagement Plan (Section 13).

MODULE 2

M1 Feedstock Receipt & Conditioning

Cost **£1,722,800**

Module summary

PURPOSE

This module (M1 Feedstock Receipt & Conditioning) the mass fluid transport process receives 1000 kg/h of biogenic CO, and 140 kg/h of renewable H,. Within this sub-module the CO, passes through a feed dryer before both streams enter their respective compressors, the CO, unit operating over three stages at 73.1 kW and the H, unit over two stages at 140 kW, raising each gas to the 25 bar synthesis pressure.

HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 2 sub-modules. The Fluid transport — ~1000 kg/h biogenic CO2 is dried and compressed to the 25 bar synthesis pressure, then heated and passed over ZnO/deoxo sulphur+oxygen guard beds (~360 °C chemisorption temperature); ~140 kg/h renewable H2 is received into buffer storage and compressed to the same pressure.

The Fluid transport - chemical reaction — ~1000 kg/h biogenic CO2 is dried and compressed to the 25 bar synthesis pressure, then heated and passed over ZnO/deoxo sulphur+oxygen guard beds (~360 °C chemisorption temperature); ~140 kg/h renewable H2 is received into buffer storage and compressed to the same pressure.

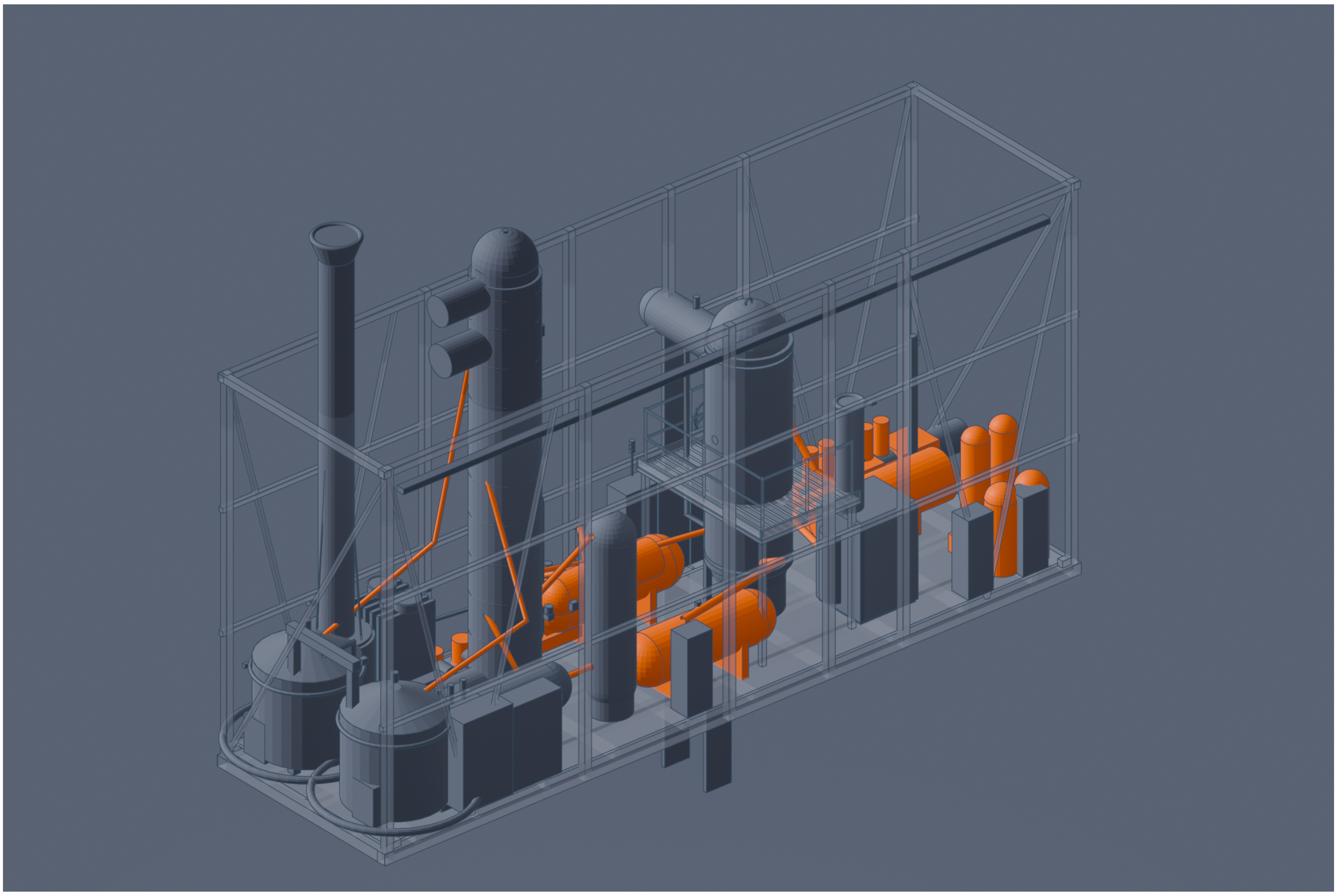


Illustration only — generic class render. Module 2 (M1 Feedstock Receipt & Conditioning) shown in identity colour; other modules muted; enclosure ghosted.

The mass fluid transport process receives 1000 kg/h of biogenic CO2 and 140 kg/h of renewable H2. Within this sub-module the CO2 passes through a feed dryer before both streams enter their respective compressors, the CO2 unit operating over three stages at 73.1 kW and the H2 unit over two stages at 140 kW, raising each gas to the 25 bar synthesis pressure.

The streams are then combined with recycle gas in a static mixer and filtered before delivery. The chemical reaction sub-module follows, where the blended feed contacts the sulphur/oxygen guard bed to remove trace contaminants prior to reactor entry.

Together the two sub-modules prepare and condition the synthesis gas at the required pressure and purity.

Sub-modules

2.1 Fluid transport

The feedstock receipt conditioning mass fluid transport process conditions 6 components. A Burckhardt Compression multistage process gas compressor, 3-stage, intercooled, VSD-driven multistage CO2 feed compressor (part API 618 multistage reciprocating process compressor - engineered package, 2.8 m x 1.6 m x 2.1 m, 1000 kg/h capacity), rated 73 kW, certified to API 618.

A Howden multistage hydrogen-service diaphragm/reciprocating compressor, 2-stage, leak-tight for >=99.9% H2 multistage hydrogen feed compressor (part API 618 hydrogen-service multistage compressor - engineered package, 2.4 m x 1.4 m x 1.9 m, 140 kg/h capacity), rated 140 kW, certified to API 618.

A Parker Hiross twin-tower regenerative molecular-sieve gas dryer, duty/standby twin-tower regenerative CO2 dryer (part twin-tower regenerative molecular-sieve gas dryer - packaged skid, 1.8 m x 1.2 m x 2.4 m, 1000 kg/h capacity). A made-to-order fabrication horizontal H2 buffer receiver smoothing the battery-limit supply renewable-H2 buffer storage vessel, certified to PED 2014/68/EU. A Sulzer in-line static mixer blending make-up CO2 + H2 with recycled tail gas to the reactor feed ratio make-up + recycle feed-gas static mixer.

2x Pall high-efficiency gas filter/coalescer on each compressed feed feed-gas filter coalescer. ~1000 kg/h biogenic CO2 is dried and compressed to the 25 bar synthesis pressure, then heated and passed over ZnO/deoxo sulphur+oxygen guard beds (~360 °C chemisorption temperature); ~140 kg/h renewable H2 is received into buffer storage and compressed to the same pressure.

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.

Gas Compressor (Multi-Stage Polytropic) Sizing v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Number of compression stages

```
n_stages = ceil(ln(Pout / Pin) / ln(max_stage_ratio))
n_stages = ceil(ln(25 / 22) / ln(3.5)) = 1
```

assumes: equal pressure ratio per stage (GPSA EDB §13); overall ratio Pout/Pin = 1.1364; at least 1 stage

Per-stage pressure ratio

```
r = (Pout / Pin)^(1 / n_stages)
r = (25 / 22)^(1 / 1) = 1.1364
```

assumes: equal-ratio staging keeps each stage discharge T within limits

Mixture molecular weight

```
MW = SUM x_i * MW_i
MW = SUM x_i * MW_i = 24.9151 g/mol
```

assumes: mole-fraction-weighted; component MW from critical-constant table

Mixture heat-capacity ratio k

```
k = Cp / (Cp - R)
k = 33.255 / (33.255 - 8.314) = 1.3333
```

assumes: ideal-gas Cp (mole-weighted from table); Cv = Cp - R

Real-gas Z (Peng-Robinson) - stage-1 inlet & discharge

```
Z_avg = (Z_in + Z_out) / 2
Z_avg = (0.9666 + 0.9679) / 2 = 0.9672
```

assumes: Peng-Robinson 1976 cubic, largest real positive (vapour) root; van-der-Waals one-fluid mixing, geometric-mean a_ij (k_ij=0); stage-1 inlet (313.15 K, 22.0 bar), discharge (326.97 K, 25.0 bar)

Polytropic exponent group (n-1)/n

```
(n-1)/n = (k - 1) / (k * eta_p)
(n-1)/n = (1.3333 - 1) / (1.3333 * 0.74) = 0.3378
```

assumes: polytropic compression (GPSA EDB §13)

Polytropic head per stage

```
H_poly = Z_avg * (R / M) * T_in * (n/(n-1)) * (r^((n-1)/n) - 1)
H_poly = 0.9672 * (8.314 / 0.0249) * 313.15 * (n/(n-1)) * (1.1364^(0.3378)
- 1) = 13,203.5 J/kg
```

assumes: n/(n-1) = 1 / ((n-1)/n); stage inlet T = t_in_k after intercool

Compressor shaft (gas) power - all stages

```
P_shaft = n_stages * mdot * H_poly / eta_p / 1000
P_shaft = 1 * 0.19 * 13,203.5 / 0.74 / 1000 = 3.39 kW
```

assumes: identical stages summed; /1000 W->kW shown in formula so the printed arithmetic evaluates to the kW result (worked_calc_arithmetic_sound, 2026-06-06); per-stage Z recomputed; representative head shown

Driver (electric motor / turbine) power

```
P_driver = P_shaft / eta_mech
P_driver = 3.39 / 0.95 = 3.569 kW
```

assumes: mechanical/transmission losses (gearbox, bearings, seals)

Stage discharge temperature

```
T_disch = T_in * r^((n-1)/n)
T_disch = 313.15 * 1.1364^(0.3378) = 326.97 K
```

assumes: per-stage; intercooled back toward intercool_t_k between stages

Total intercooler heat-rejection duty

```
Q_ic = n_inter * mdot * Cp_spec * (T_disch - T_cool) / 1000
Q_ic = 1 * 0.19 * 1,334.73 * (326.97 - 313.15) / 1000 = 3.505 kW
```

assumes: sensible-heat cooling of each stage discharge; /1000 W->kW shown in formula so the printed arithmetic evaluates to the kW result (worked_calc_arithmetic_sound, 2026-06-06); Cp_spec = Cp_molar / MW (specific heat at constant pressure)

Transport + Logistics Cost v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Total shipping cost (GBP)

```
cost_gbp = base_cost_usd x containers_needed x USD_GBP
cost_gbp = 2,000 x 0 x 0.78 = 0 GBP
```

assumes: base_cost_usd from SHIPPING_COST table (2026 spot rates, Drewry/Freightos); USD_GBP = 0.78

Shipping cost per unit

```
cost_per_unit = cost_gbp / qty
cost_per_unit = 0 / 1 = 0 GBP/unit
```

CO2 per unit (grams)

```
co2_g = co2_intensity x (prod_kg / 1000) x distance_km
co2_g = 80 x (19,000 / 1000) x 5,000 = 7,600,000 g CO2
```

assumes: CO2 intensity 80.0 g/t-km for road_eu_truck (IMO MEPC.337(76) / IEA Transport 2024); distance 5000 km from DISTANCE_KM table

CO2 per unit (kg)

```
co2_kg = co2_g / 1000
co2_kg = 7,600,000 / 1000 = 7,600 kg CO2
```

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
CO2 Feed Compressor	Burckhardt Compression	API 618 multistage reciprocating process compressor -- engineered package	×1	~£650,000	**£650,000**	— >2x

H2 Feed Compressor	Howden	API 618 hydrogen-service multistage compressor - engineered package	×1	~£550,000	**£550,000**	— -
CO2 Feed Dryer	Parker Hiross	**twin-tower regenerative molecular-sieve gas dryer - packaged skid**	×1	~£120,000	**£120,000**	— OK
H2 Buffer Storage Vessel	made-to-order fabrication	**fabricated hydrogen-service buffer receiver vessel - bespoke vessel**	×1	~£110,000	**£110,000**	— OK
Feed-Gas Blending Static Mixer	Sulzer	SMV	×1	~£4,200	**£4,200**	— OK
Feed-Gas Filter/coalescer	Pall	**gas filter coalescer assembly - configured**	×2	~£6,800	**£13,600**	— OK
Sub-total — Fluid transport					**£1,447,800**	

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 2× 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.

2.2 Fluid transport - chemical reaction

The feedstock receipt conditioning chemical reaction conditions 2 components. 2x made-to-order fabrication lead/lag guard-bed vessels operating at ~360 °C (the compressed feed is electrically heated to the ZnO chemisorption temperature upstream of the beds - compression precedes heating, so the compressors handle cool gas), ZnO + deoxo catalyst removing sulphur + oxygen traces that poison the FT catalyst sulphur + oxygen polishing guard bed, certified to PED 2014/68/EU.

A Johnson Matthey ZnO sulphur-polishing + precious-metal deoxo catalyst charge (replaceable line item) guard-bed zno/deoxo catalyst charge. ~1000 kg/h biogenic CO2 is dried and compressed to the 25 bar synthesis pressure, then heated and passed over ZnO/deoxo sulphur+oxygen guard beds (~360 °C chemisorption temperature); ~140 kg/h renewable H2 is received into buffer storage and compressed to the same pressure.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Sulphur/oxygen Guard Bed	made-to-order fabrication	**fabricated 316L lead/lag guard- -bed vessel pair - bespoke vessel**	×2	~£95,000	**£190,000**	— OK
Guard-Bed Adsorbent + Deoxo Charge	Johnson Matthey	**PURASPEC sulphur + oxygen polishing catalyst charge**	×1	~£85,000	**£85,000**	— >2x
Sub-total — Fluid transport - chemical reaction					**£275,000**	

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 2× 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 2 total — M1 Feedstock Receipt & Conditioning	**£1,722,800**

Validate this design with: A chartered senior rotating equipment engineer, A senior chemical process engineer — full questions in the Engagement Plan (Section 13).

MODULE 3

M3 Separation & Recycle

Cost **£889,800**

Module summary

PURPOSE

This module (M3 Separation & Recycle) the mass fluid transport process receives reactor effluent at 300 °C and 25 bar and routes it through the separation & recycle train. Within the train the stream first enters the hot 3-phase separator then the cold 3-phase separator, each vessel 0.573 m in diameter and 2.86 m long, where vapour velocity is limited to 0.336 m/s so that tail gas, process water and syncrude are cleanly divided.

HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 1 sub-module. The separation & recycle train — the reactor effluent is staged through 0.6 m x 2.9 m hot/cold 3-phase separators into tail gas, process water and syncrude; unconverted tail gas is recompressed (~4 kW) and recycled to near-extinction with a ~150 kg/h purge to the thermal oxidiser.

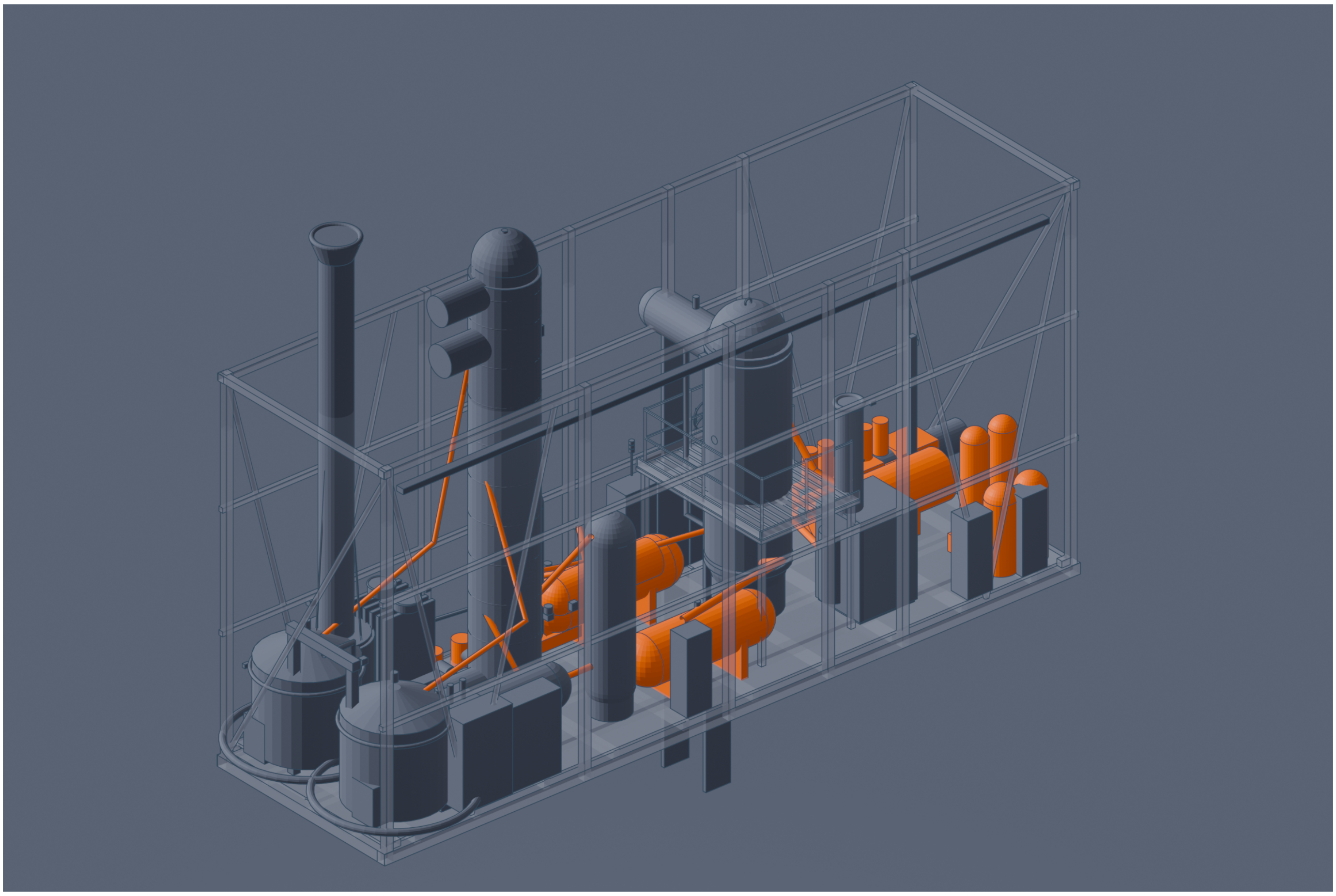


Illustration only — generic class render. Module 3 (M3 Separation & Recycle) shown in identity colour; other modules muted; enclosure ghosted.

The mass fluid transport process receives reactor effluent at 300 °C and 25 bar and routes it through the separation & recycle train. Within the train the stream first enters the hot 3-phase separator then the cold 3-phase separator, each vessel 0.6 m in diameter and 2.86 m long, where vapour velocity is limited to 0.34 m/s so that tail gas, process water and syncrude are cleanly divided.

The tail-gas recycle compressor returns the bulk of the unconverted gas while the purge control valve directs 150 kg/h to the thermal oxidiser; the effluent product cooler removes 782 kW before the recycle knock-out drum protects the compressor and the process-water transfer pump forwards the aqueous stream. These operations achieve 0.4 per-pass conversion and 0.65 carbon-to-liquids efficiency while the 3.57 kW recycle compressor maintains near-extinction recycle.

The separation & recycle train therefore isolates the three product phases and sustains gas recycle with minimal purge loss.

Sub-modules

3.1 Separation & recycle train

The separation & recycle train separates 7 components. A made-to-order fabrication horizontal hot high-pressure 3-phase separator (tail gas / process water / wax), boot + weir internals, NO mesh (wax fouling) hot 3-phase HP separator, certified to PED 2014/68/EU. A made-to-order fabrication horizontal cold high-pressure 3-phase separator downstream of the product cooler (tail gas / process water / syncrude) cold 3-phase HP separator, certified to PED 2014/68/EU.

An Atlas Copco Gas and Process single-stage centrifugal recycle compressor returning unconverted tail gas to the reactor feed, VSD-driven tail-gas recycle compressor, rated 4 kW, certified to API 617. An Alfa Laval shell-and-tube effluent cooler condensing syncrude + process water ahead of the cold separator, cooling-water served reactor-effluent product cooler. A made-to-order fabrication compressor-suction knock-out drum protecting the recycle compressor recycle-gas suction knock-out drum, certified to PED 2014/68/EU.

An Emerson Fisher control valve taking a small purge to the thermal oxidiser to prevent inert build-up tail-gas purge control valve. 2x Grundfos centrifugal process-water transfer pump, 1 duty + 1 standby, to water treatment/reuse FT process-water transfer pump. The reactor effluent is staged through 0.6 m x 2.9 m hot/cold 3-phase separators into tail gas, process water and syncrude; unconverted tail gas is recompressed (~4 kW) and recycled to near-extinction with a ~150 kg/h purge to the thermal oxidiser.

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.

Flash Separator (3-Phase) Sizing v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Souders-Brown maximum vapour velocity

```
v_max = K_eff x sqrt((rho_l - rho_v) / rho_v)
v_max = 0.049 x sqrt((720 - 15) / 15) = 0.3359 m/s
```

assumes: K_base = 0.07 m/s by pressure (22.0 bar; GPSA Section 7 bands); NO mesh pad -> x0.7 (gravity disengagement only); Souders & Brown (1934) terminal-velocity load factor

Vapour volumetric flow

```
Qv = vapour_flow / (rho_v x 3600)
Qv = 684 / (15 x 3600) = 0.0127 m3/s
```

assumes: actual volumetric vapour rate at operating P,T

Vapour-disengagement cross-section

```
A_vap = Qv / v_max
A_vap = 0.0127 / 0.3359 = 0.0377 m2
```

assumes: minimum vapour flow area to keep up-flow below the settling velocity

Liquid volumetric flow (HC + aqueous)

```
Ql = (hc_liq / rho_l + aqueous / rho_aq) / 3600
Ql = (208 / 720 + 819 / 1,000) / 3600 = 0.000308 m3/s
```

assumes: combined hydrocarbon + aqueous liquid drop-out rate

Liquid hold-up volume

```
holdup = Ql x (liq_residence_min x 60)
holdup = 0.000308 x (20 x 60) = 0.3693 m3
```

assumes: 20.0-min liquid residence (HC/water emulsion break, level-control surge)

Vessel diameter (horizontal, 50% liquid level)

```
D = sqrt(4 x (A_vap / 0.5) / pi)
D = sqrt(4 x (0.0377 / 0.5) / pi) = 0.5729 m
```

assumes: vapour space = upper 50% of bore so gross area A = A_vap / 0.5; horizontal: liquid in bottom 50% of bore; L from hold-up, 3D floor; D grown to satisfy hold-up at L/D=5.0 (above economic band)

Vessel tangent-to-tangent length

```
L = L_over_D x D
L = 5 x 0.5729 = 2.8647 m
```

assumes: L/D clamped to [2.5, 5.0] economic band (Svrcek & Monnery 2000)

Oil-water droplet settling velocity (Stokes)

```
v_settle = g x d^2 x (rho_aq - rho_l) / (18 x mu)
v_settle = 9.81 x 0.00015^2 x (1,000 - 720) / (18 x 0.0005) = 0.0069 m/s
```

assumes: aqueous droplet 150.0 um falling through the hydrocarbon layer; hydrocarbon-liquid viscosity 0.0005 Pa.s (~0.5 cP, light condensate); Stokes' law (laminar, Re < 1)

Gas Compressor (Multi-Stage Polytropic) Sizing v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Number of compression stages

```
n_stages = ceil(ln(Pout / Pin) / ln(max_stage_ratio))
n_stages = ceil(ln(25 / 22) / ln(3.5)) = 1
```

assumes: equal pressure ratio per stage (GPSA EDB §13); overall ratio Pout/Pin = 1.1364; at least 1 stage

Per-stage pressure ratio

```
r = (Pout / Pin)^(1 / n_stages)
r = (25 / 22)^(1 / 1) = 1.1364
```

assumes: equal-ratio staging keeps each stage discharge T within limits

Mixture molecular weight

```
MW = SUM x_i * MW_i
MW = SUM x_i * MW_i = 24.9151 g/mol
```

assumes: mole-fraction-weighted; component MW from critical-constant table

Mixture heat-capacity ratio k

```
k = Cp / (Cp - R)
k = 33.255 / (33.255 - 8.314) = 1.3333
```

assumes: ideal-gas Cp (mole-weighted from table); Cv = Cp - R

Real-gas Z (Peng-Robinson) - stage-1 inlet & discharge

```
Z_avg = (Z_in + Z_out) / 2
Z_avg = (0.9666 + 0.9679) / 2 = 0.9672
```

assumes: Peng-Robinson 1976 cubic, largest real positive (vapour) root; van-der-Waals one-fluid mixing, geometric-mean a_ij (k_ij=0); stage-1 inlet (313.15 K, 22.0 bar), discharge (326.97 K, 25.0 bar)

Polytropic exponent group (n-1)/n

```
(n-1)/n = (k - 1) / (k * eta_p)
(n-1)/n = (1.3333 - 1) / (1.3333 * 0.74) = 0.3378
```

assumes: polytropic compression (GPSA EDB §13)

Polytropic head per stage

```
H_poly = Z_avg * (R / M) * T_in * (n/(n-1)) * (r^((n-1)/n) - 1)
H_poly = 0.9672 * (8.314 / 0.0249) * 313.15 * (n/(n-1)) * (1.1364^(0.3378) - 1) = 13,203.5 J/kg
```

assumes: n/(n-1) = 1 / ((n-1)/n); stage inlet T = t_in_k after intercool

Compressor shaft (gas) power - all stages

```
P_shaft = n_stages * mdot * H_poly / eta_p / 1000
P_shaft = 1 * 0.19 * 13,203.5 / 0.74 / 1000 = 3.39 kW
```

assumes: identical stages summed; /1000 W->kW shown in formula so the printed arithmetic evaluates to the kW result (worked_calc_arithmetic_sound, 2026-06-06); per-stage Z recomputed; representative head shown

Driver (electric motor / turbine) power

```
P_driver = P_shaft / eta_mech
P_driver = 3.39 / 0.95 = 3.569 kW
```

assumes: mechanical/transmission losses (gearbox, bearings, seals)

Stage discharge temperature

```
T_disch = T_in * r^((n-1)/n)
T_disch = 313.15 * 1.1364^(0.3378) = 326.97 K
```

assumes: per-stage; intercooled back toward intercool_t_k between stages

Total intercooler heat-rejection duty

```
Q_ic = n_inter * mdot * Cp_spec * (T_disch - T_cool) / 1000
Q_ic = 1 * 0.19 * 1,334.73 * (326.97 - 313.15) / 1000 = 3.505 kW
```

assumes: sensible-heat cooling of each stage discharge; /1000 W->kW shown in formula so the printed arithmetic evaluates to the kW result (worked_calc_arithmetic_sound, 2026-06-06); Cp_spec = Cp_molar / MW (specific heat at constant pressure)

HT eps-NTU Heat Exchanger v1.2.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Conductance UA

```
UA = ntu x c_min
UA = 2.2 x 4 = 8.8 kW/K
```

Maximum heat duty

```
q_max = c_min x (t_hot_in - t_cold_in)
q_max = 4 x (250 - 30) = 880 kW
```

Actual heat transfer

```
q = effectiveness x q_max
q = 0.8892 x 880 = 782.493 kW
```

Hot-side outlet temperature

```
t_hot_out = t_hot_in - q / c_min
t_hot_out = 250 - 782.493 / 4 = 54.377 C
```

assumes: hot fluid taken as the C_min side (typical chiller/HVAC case)

Process Centrifugal Pump Sizing v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Pipe velocity

```
V = (Q_m3h / 3600) / (pi/4 x D^2)
V = (0.29 / 3600) / (pi/4 x 0.05^2) = 0.041 m/s
```

assumes: Q_m3h / 3600 converts m3/h to m3/s; keep 1-3 m/s for a process liquid line

Reynolds number

```
Re = rho x V x D / mu
Re = 720 x 0.041 x 0.05 / 0.0015 = 984.6
```

assumes: Newtonian fluid; pipe internal bore

Darcy friction factor (Swamee-Jain)

```
f = 0.25 / (log10(rel_rough/3.7 + 5.74/Re^0.9))^2
f = 0.25 / (log10(0.0003/3.7 + 5.74/984.6^0.9))^2 = 0.065
```

assumes: laminar f = 64/Re; rel_rough = roughness / D

Pipe friction head (Darcy-Weisbach)

```
H_friction = f x (L_eff / D) x V^2 / (2 x g)
H_friction = 0.065 x (35 / 0.05) x 0.041^2 / (2 x 9.8066) = 0.004 m
```

assumes: Darcy-Weisbach pipe friction (chemical-engineering standard); L_eff = straight run + fittings equivalent length

Process backpressure head

```
H_process = backpressure_kpa x 1000 / (rho x g)
H_process = 200 x 1000 / (720 x 9.8066) = 28.325 m
```

assumes: column packing + heat exchangers + filter pressure drop

Pump total dynamic head

```
H_total = static_head + H_friction + H_process
H_total = 15 + 0.004 + 28.325 = 43.329 m
```

assumes: static lift = delivery elevation - suction elevation

Pump hydraulic power

```
P_hyd = rho x g x (Q_m3h / 3600) x H_total
P_hyd = 720 x 9.8066 x (0.29 / 3600) x 43.329 = 24.6 W
```

assumes: P = rho g Q H; Q_m3h / 3600 converts m3/h to m3/s

Pump shaft power

```
P_shaft = P_hyd / pump_eff
P_shaft = 24.6 / 0.65 = 37.9 W
```

assumes: centrifugal pump efficiency 0.65 at duty point

Motor input power

```
P_motor = P_shaft / motor_eff
P_motor = 37.9 / 0.9 = 42.1 W
```

assumes: motor efficiency 0.9; recommended frame = 0.18 kW (next standard size with 15% margin)

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Hot 3-Phase Separator	made-to-order fabrication	**fabricated horizontal 3-phase HP separator vessel - bespoke vessel**	×1	~£150,000	**£150,000**	— **>2x**

Cold 3-Phase Separator	made-to-order fabrication	**fabricated horizontal 3-phase HP separator vessel - bespoke vessel**	×1	~£150,000	**£150,000**	— >2x
Tail-Gas Recycle Compressor	Atlas Copco Gas and Process	**centrifugal process gas compressor - engineered package**	×1	~£350,000	**£350,000**	— -
Effluent Product Cooler	Alfa Laval	**shell-and-tube process cooler - engineered**	×1	~£180,000	**£180,000**	— >2x
Recycle Knock-Out Drum	made-to-order fabrication	**fabricated compressor- - suction knock-out drum - bespoke vessel**	×1	~£45,000	**£45,000**	— OK
Purge Control Valve	Emerson Fisher	**easy-e GX control valve + DVC positioner**	×1	~£6,400	**£6,400**	— OK
Process-Water Transfer Pump	Grundfos	**CRNE 10-4**	×2	~£4,200	**£8,400**	— OK
Sub-total — separation & recycle train					**£889,800**	

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 2× 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 3 total — M3 Separation & Recycle **£889,800**

Validate this design with: Principal process engineer, Senior thermal systems engineer — full questions in the Engagement Plan (Section 13).

MODULE 4

M2 Fischer-Tropsch Synthesis

Cost **£1,724,000**

Module summary

PURPOSE

This module (M2 Fischer-Tropsch Synthesis) the energy conversion transduction module hydrogenates CO, directly to jet-range paraffins in a boiling-water-cooled multitubular Fischer-Tropsch reactor operated at 300 °C and 25 bar. Combined feed at 1000 kg/h CO, and 140 kg/h H, is first preheated by 133 kW in the thermal transfer sub-module, which also incorporates the catalyst reduction heater and reactor steam drum that recovers the 677 kW exotherm as 1290 kg/h of steam.

HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 2 sub-modules. The Energy conversion - chemical reaction — the combined feed is preheated (~133 kW) and reacted over a shaped iron catalyst in a 1.24 m x 5.0 m FT reactor at 300 °C / 25 bar ($CO_2 + 3 H_2 \rightarrow -CH_2- + 2 H_2O$); the ~677 kW exotherm is removed as ~1290 kg/h raised steam.

The Energy conversion - thermal transfer — the combined feed is preheated (~133 kW) and reacted over a shaped iron catalyst in a 1.24 m x 5.0 m FT reactor at 300 °C / 25 bar ($CO_2 + 3 H_2 \rightarrow -CH_2- + 2 H_2O$); the ~677 kW exotherm is removed as ~1290 kg/h raised steam.

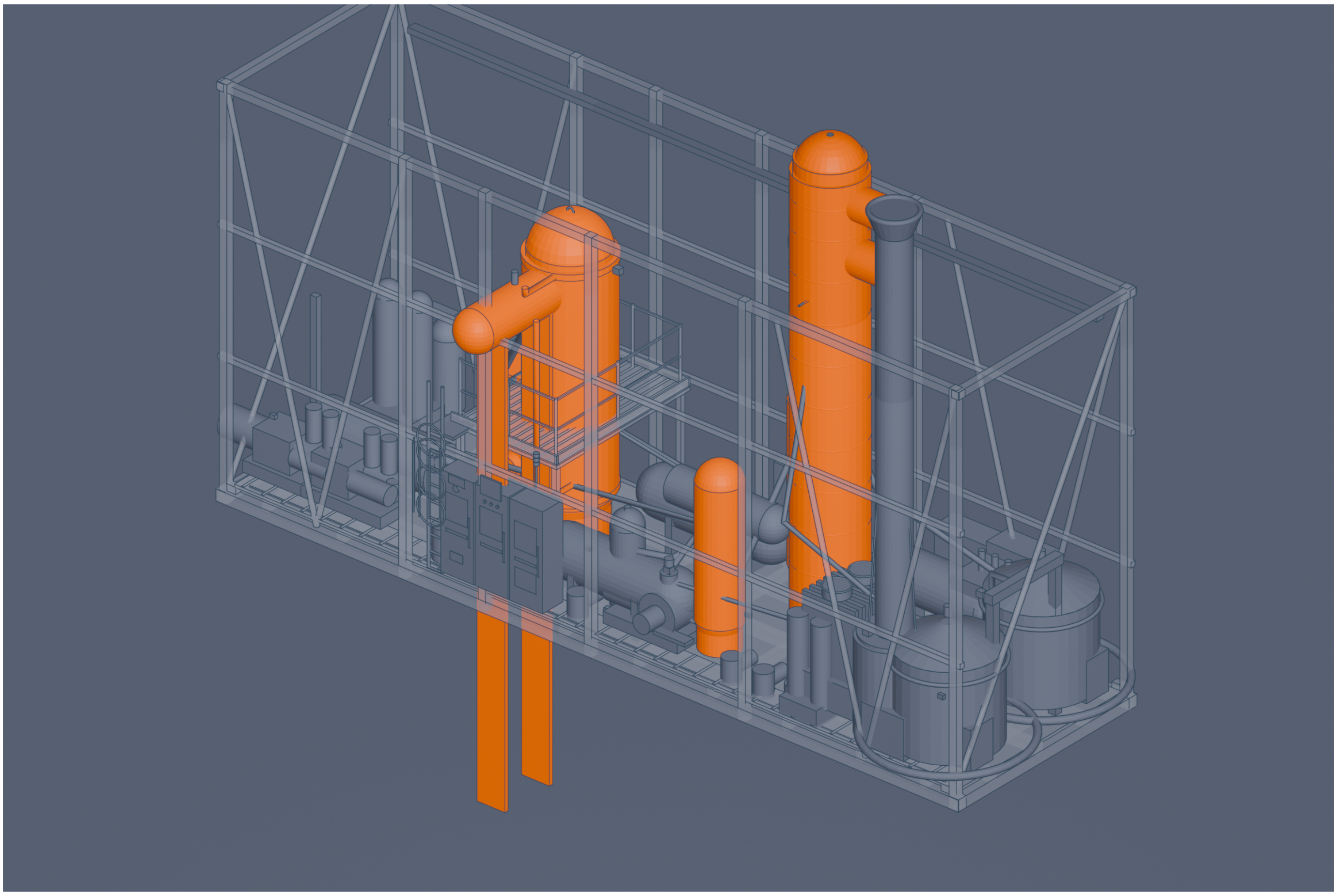


Illustration only — generic class render. Module 4 (M2 Fischer-Tropsch Synthesis) shown in identity colour; other modules muted; enclosure ghosted.

The energy conversion transduction module hydrogenates CO2 directly to jet-range paraffins in a boiling-water-cooled multitubular Fischer-Tropsch reactor operated at 300 °C and 25 bar. Combined feed at 1000 kg/h CO2 and 140 kg/h H2 is first preheated by 133 kW in the thermal transfer sub-module, which also incorporates the catalyst reduction heater and reactor steam drum that recovers the 677 kW exotherm as 1290 kg/h of steam.

The preheated gases then enter the chemical reaction chemical sensing etc sub-module, where they contact the shaped iron catalyst charge inside the 1.24 m diameter by 4.95 m high reactor of 5.07 m3 volume; temperature profiles are obtained via thermowells and over-pressure is relieved by dedicated valves. The two sub-modules therefore convert chemical energy while managing heat and ensuring safe operation at the design conditions.

Sub-modules

4.1 Energy conversion - chemical reaction

The ft synthesis train chemical reaction chemical sensing etc synthesises 4 components. A made-to-order fabrication cooled multitubular fixed-bed Fischer-Tropsch reactor, shaped iron catalyst, boiling-water-cooled tubes single-step CO2-hydrogenation FT reactor (part fabricated boiling-water-cooled multitubular Fischer-Tropsch reactor - bespoke vessel, 1.24 m dia x 5.0 m, 6683 kg), certified to PED 2014/68/EU. A proprietary catalyst supplier shaped/structured iron-based FT catalyst charge engineered for jet-range selectivity, low pressure-drop, long mechanical life (replaceable line item; pyrophoric when reduced) shaped iron fischer-tropsch catalyst charge.

4x Endress+Hauser multipoint Pt100 axial temperature-profile thermowell assembly tracking the exotherm hot-spot multipoint reactor temperature-profile assembly. 2x LESER spring-loaded PRV sized to PED on the synthesis loop FT reactor pressure-relief valve, certified to PED 2014/68/EU. The combined feed is preheated (~133 kW) and reacted over a shaped iron catalyst in a 1.24 m x 5.0 m FT reactor at 300 °C / 25 bar ($CO_2 + 3 H_2 \rightarrow -CH_2- + 2 H_2O$); the ~677 kW exotherm is removed as ~1290 kg/h raised steam.

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.

ASF Chain-Growth / FT Selectivity (PtL) v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Chain-growth probability alpha (user-supplied)

```
alpha = alpha_input
alpha = 0.92 = 0.92
```

assumes: alpha provided directly; no temperature correlation applied

ASF mass weight fraction formula (shown for C10 as example)

```
w_n = n x (1 - alpha)^2 x alpha^(n-1) / Z (Z = normalisation sum over
n=1..n_max)
w_n = 10 x (1 - 0.92)^2 x 0.92^(10-1) / Z (Z = 10ormalisatio10 sum over
10=1..50) = 0.0328 fraction
```

assumes: Anderson (1956) ASF polymerisation model - mass weight fraction formula; Normalisation Z ensures SUM(w_n, n=1..n_max) = 1 (closed finite sum); Shown for n=10 (C10, lightest jet-range carbon); actual cut sums over full range; Peak carbon number (mode of w_n): C12

Raw FT product cuts - straight ASF (before upgrading)

```
cut_frac = SUM(w_n, n=n_lo..n_hi)
cut_frac = SUM(w_n, n=n_lo..n_hi) = 1 fraction (sum of all cuts)
```

assumes: Cuts: C1=methane, C2-4=LPG, C5-9=naphtha, C10-16=jet/kerosene, C17-20=diesel, C21+=wax; Sum should be 1.000 ± 0.001 (n_max=50 truncation negligible above n=40 for alpha<0.93); Anderson-Schulz-Flory distribution; no olefin/paraffin ratio correction applied

Jet selectivity after selective wax hydrocracking

```
jet_selectivity = jet_raw + wax_to_jet_conversion x wax_raw + diesel_to_jet
x diesel_raw
jet_selectivity = 0.2293 + 0.83 x 0.4479 + 0 x 0.1192 = 0.6011 fraction
```

assumes: Process: wax (C21+) selectively hydro-cracked into the C10-C16 kerosene/jet boiling range; wax_to_jet_conversion = 0.83 (literature: 0.70-0.90 for selective Pt/SiO2 or Ni/W/Al2O3 hydrocracking; Steynberg & Dry 2004 ch.7); diesel_to_jet_fraction = 0.0 (default 0.0: the process targets wax primarily); Wax residue after upgrading = 0.07614 (fraction remaining); jet_selectivity_frac = 0.22931 + 0.83 x 0.44791 = 0.60108

Carbon-to-liquids fraction (C5+ liquid yield)

```
carbon_to_liquids = 1 - methane_frac - lpg_frac
carbon_to_liquids = 1 - 0.0069 - 0.052 = 0.9411 fraction
```

assumes: C5+ liquids = all carbon NOT lost as methane (C1) or LPG light gas (C2-C4); Methane + LPG are gaseous at ambient conditions and cannot be directly converted to liquid fuel without additional reforming; This is the fraction of converted carbon that reaches the liquid product stream

Reaction Feasibility (Gibbs Free Energy) v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Standard reaction Gibbs energy (298.15 K)

```
dG_rxn = sum_products - sum_reactants
dG_rxn = -7,256.312 - -6,307.906 = -948.406 kJ/mol
```

assumes: sum_products = sum of (coeff x dGf) over products: 1x(57.4268) + 32x(-228.554); sum_reactants = sum of (coeff x dGf) over reactants: 16x(-394.244) + 49x(0); lowest data confidence among species: high

Equilibrium constant at 298.1 K (ln K; then K = e^lnK = 1.424e+166)

```
ln_K = -(dG_rxn x 1000) / (R x T)
ln_K = -(-948.406 x 1000) / (8.3145 x 298.15) = 382.5825
```

assumes: x1000 converts kJ to J; ln K > 0 (K>1) => products favoured, ln K < 0 (K<1) => reactants favoured; K = exp(ln_K) = exp(382.5825) = 1.424e+166; standard (298.15 K)

Equilibrium constant at 573.1 K (ln K; then K = e^lnK = 3.485e+06)

```
ln_K = -(dG_rxn x 1000) / (R x T)
ln_K = -(-71.787 x 1000) / (8.3145 x 573.15) = 15.064
```

assumes: x1000 converts kJ to J; ln K > 0 (K>1) => products favoured, ln K < 0 (K<1) => reactants favoured; K = exp(ln_K) = exp(15.064) = 3.485e+06; approx (constant dH/dS from 298.15 K)

Reaction Stoichiometry Mass Balance v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Basis molar flow (CO2)

```
n_basis = (mass_basis x 1000) / MW_basis
n_basis = (0.2778 x 1000) / 44.0095 = 6.3118 mol/s
```

assumes: basis = 24.0 t/day of CO2; x1000 converts kg to g so g/s / g/mol = mol/s

Reactant mass flow: H2

```
mass = (coeff / coeff_basis) x n_basis x MW
mass = (3 / 1) x 6.3118 x 2.0159 = 38.1717 g/s
```

assumes: = 3.29803 t/day (g/s x 86.4 / 1000); atom conservation: product tonnages are exact, not estimated

Product mass flow: CH2

```
mass = (coeff / coeff_basis) x n_basis x MW
mass = (1 / 1) x 6.3118 x 14.0266 = 88.5327 g/s
```

assumes: = 7.64922 t/day (g/s x 86.4 / 1000); atom conservation: product tonnages are exact, not estimated

Product mass flow: H2O

```
mass = (coeff / coeff_basis) x n_basis x MW
mass = (2 / 1) x 6.3118 x 18.0153 = 227.4168 g/s
```

assumes: = 19.64881 t/day (g/s x 86.4 / 1000); atom conservation: product tonnages are exact, not estimated

Overall mass balance (conservation check)

```
closure = (mass_products - mass_reactants) / mass_reactants x 100
closure = (27.298 - 27.298) / 27.298 x 100 = 0 %
```

assumes: should be ~0% - mass in = mass out for a balanced reaction

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

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Reactor working volume (total)

```
V_working = Q x tau
V_working = 101.3333 x 0.05 = 5.0667 m3
```

assumes: throughput basis: mass 1824.0 kg/h / rho 18.0 kg/m3; working (liquid) volume = flow x residence time

Gross vessel volume (freeboard)

```
V_vessel = V_per / fill_fraction
V_vessel = 5.0667 / 0.85 = 5.9608 m3
```

assumes: fill fraction 0.85 leaves freeboard for disengagement/agitation

Vessel diameter from aspect ratio

```
D = (4 x V_vessel / (pi x L_over_D))^(1/3)
D = (4 x 5.9608 / (pi x 4))^(1/3) = 1.238 m
```

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

Vessel tangent-to-tangent height

```
L = L_over_D x D
L = 4 x 1.238 = 4.952 m
```

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

Shell minimum thickness (hoop stress, internal pressure)

```
t = P x D / (2 x S x E - 1.2 x P) + corr
t = 2.5 x 1,238 / (2 x 174 x 0.85 - 1.2 x 2.5) + 3 = 13.57 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 = 13.57 mm (>= 5 mm practical handling minimum)

Shell mass (wall + 2 heads) per reactor

```
m = (pi x (r_o^2 - r_i^2) x H + 2 x pi x r_o^2 x t) x rho / 1e9
m = (pi x (632.6^2 - 619^2) x 4,952 + 2 x pi x 632.6^2 x 13.57) x 8,000 /
1e9 = 2,386.72 kg
```

assumes: material steel_316L; flat-head approximation (conservative vs torispherical); 1e9 converts mm3 to m3

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Fischer-Tropsch Synthesis Reactor	made-to-order fabrication	**fabricated boiling-water- -cooled multitubular Fischer-Tropsch reactor - bespoke vessel**	×1	~£1,500,000	**£1,500,000**	— >2x
Shaped Iron FT Catalyst Charge	proprietary catalyst supplier	**shaped iron Fischer-Tropsch catalyst charge - proprietary**	×1	~£300,000	**£300,000**	— >2x
Reactor Thermowell + Temperature Profile	Endress+Hauser	**iTHERM TM411**	×4	~£2,400	**£9,600**	— <.5x
Reactor Pressure-Relief Valve	LESER	**Type 441**	×2	~£2,200	**£4,400**	— >2x
Sub-total — Energy conversion - chemical reaction					**£1,514,000**	

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 2× 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.

4.2 Energy conversion - thermal transfer

The ft synthesis train thermal transfer synthesises 3 components. A Kelvion feed/effluent + electric trim preheater raising the blended feed to reactor inlet temperature combined-feed electric/gas preheater (part feed/effluent shell-and-tube preheater - engineered, 1.8 m x 0.9 m x 1.2 m, 133 kW capacity).

A Watlow electric startup heater reducing/activating the iron catalyst in H2 before synthesis iron-catalyst reduction/activation electric heater. A made-to-order fabrication boiling-water steam drum disengaging the reactor cooling-circuit steam FT reactor steam drum, certified to PED 2014/68/EU.

The combined feed is preheated (~133 kW) and reacted over a shaped iron catalyst in a 1.24 m x 5.0 m FT reactor at 300 °C / 25 bar ($CO_2 + 3 H_2 \rightarrow -CH_2- + 2 H_2O$); the ~677 kW exotherm is removed as ~1290 kg/h raised steam.

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.

Fired / Electric Feed-Preheat + Catalyst-Activation Heater Sizing v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Process heat duty (sensible + latent)

```
Q_process = (mdot/3600) * (Cp * dT + vap_frac * latent)
Q_process = (0.3167) * (2 * 210 + 0 * 0) = 133 kW
```

assumes: steady-flow first-law energy balance; dT = t_out - t_in = 523.15 - 313.15 K; Cp in kJ/kg-K so kJ/s = kW directly; latent term zero unless a vaporised fraction is specified

Input (fuel/electrical) duty after efficiency

```
Q_input = Q_process / efficiency
Q_input = 133 / 0.98 = 135.714 kW
```

assumes: mode = electric; electric default 0.98 (element + losses); fired default 0.88 (burner)

Installed heating-element power

```
P_element = Q_input
P_element = 135.714 = 135.714 kW
```

assumes: electric resistance heater: installed element power = input duty

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Combined-Feed Preheater	Kelvion	**feed/effluent shell-and-tube preheater - engineered**	×1	~£90,000	**£90,000**	— OK
Catalyst Reduction/activation Heater	Watlow	**circulation process heater - made to order**	×1	~£60,000	**£60,000**	Est. >2x
Reactor Steam Drum	made-to-order fabrication	**fabricated steam drum with internals - bespoke vessel**	×1	~£120,000	**£120,000**	— OK
Sub-total — Energy conversion - thermal transfer					**£210,000**	

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 2× 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 4 total — M2 Fischer-Tropsch Synthesis £1,724,000

Validate this design with: Senior process engineer, chemical synthesis, Senior mechanical engineer, pressure vessels — full questions in the Engagement Plan (Section 13).

MODULE 5

M4 Upgrading & Fractionation

Cost **£2,728,200**

Module summary

PURPOSE

This module (M4 Upgrading & Fractionation) the energy conversion transduction module converts Fischer-Tropsch syncrude into on-specification sustainable aviation fuel by hydrocracking, isomerisation and dewaxing followed by fractionation. The energy conversion transduction chemical reaction thermal transfer first reheats the cold feed to 300 °C and 25 bar in a feed-effluent exchanger, drives the hydrocracker/hydrotreater and isomerisation/dewaxing reactors over the catalyst charge, and supplies heat via the fractionation reboiler while recovering duty in the overhead condenser.

HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 2 sub-modules. The Energy conversion - chemical reaction — the cold (~35 °C) syncrude/wax is first reheated to hydroprocessing temperature in a feed/effluent heat exchanger plus electric trim heater, then hydrocracked and isomerised/dewaxed (consuming an HP H2 slip-stream) and fractionated in a 0.8 m column into an on-spec SAF (jet) cut, a naphtha co-product (~667 t/yr) and a small recycle residue.

The Energy conversion - Fluid transport — the cold (~35 °C) syncrude/wax is first reheated to hydroprocessing temperature in a feed/effluent heat exchanger plus electric trim heater, then hydrocracked and isomerised/dewaxed (consuming an HP H2 slip-stream) and fractionated in a 0.8 m column into an on-spec SAF (jet) cut, a naphtha co-product (~667 t/yr) and a small recycle residue.

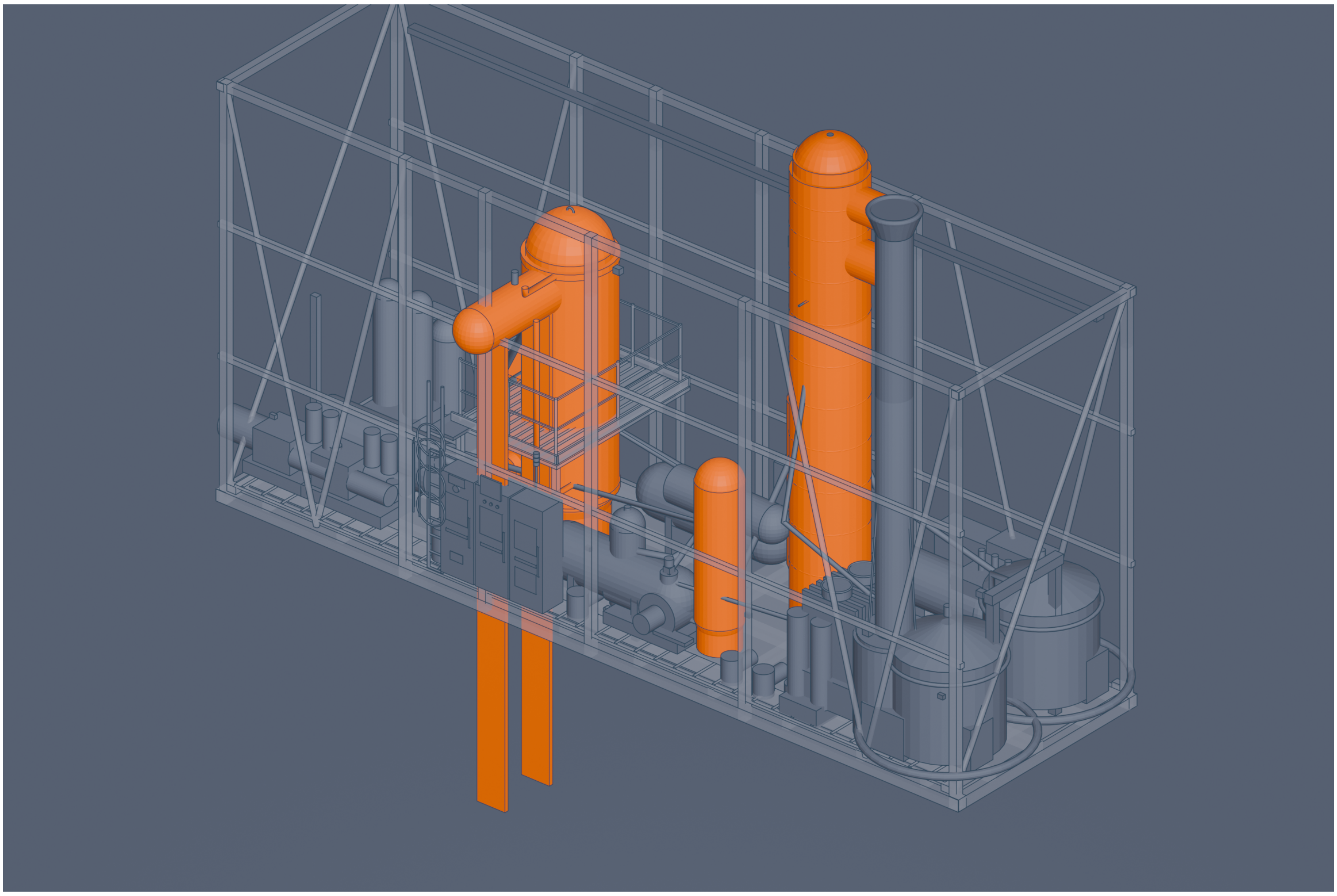


Illustration only — generic class render. Module 5 (M4 Upgrading & Fractionation) shown in identity colour; other modules muted; enclosure ghosted.

The energy conversion transduction module converts Fischer-Tropsch syncrude into on-specification sustainable aviation fuel by hydrocracking, isomerisation and dewaxing followed by fractionation. The energy conversion transduction chemical reaction thermal transfer first reheats the cold feed to 300 °C and 25 bar in a feed-effluent exchanger, drives the hydrocracker/hydrotreater and isomerisation/dewaxing reactors over the catalyst charge, and supplies heat via the fractionation reboiler while recovering duty in the overhead condenser.

The energy conversion transduction mass fluid transport process then routes the effluent through the product fractionation column fitted with internals, using the HP H2 make-up compressor and liquid product pump to maintain pressure and circulation. This arrangement yields 1000 t/yr of sustainable aviation fuel and 667 t/yr of naphtha co-product while the column is reboiled by Fischer-Tropsch steam.

The module therefore delivers the required jet-fuel cold-flow properties and co-product slate from the upstream synthesis step.

Sub-modules

5.1 Energy conversion - chemical reaction

The upgrading fractionation train chemical reaction thermal transfer upgrades 6 components. A Kelvion feed/effluent heat exchanger recovering heat from the hot hydrocracker effluent to reheat the cold (~35 °C) syncrude to hydroprocessing inlet temperature, with an electric trim heater to reach reactor temperature syncrude feed/effluent heat exchanger + electric trim heater (part syncrude feed/effluent shell-and-tube exchanger + electric trim heater - engineered, 210 kW capacity), certified to PED 2014/68/EU. A Kelvion thermosiphon reboiler on the column, fed by the FT raised steam fractionation column reboiler.

An Alfa Laval shell-and-tube overhead condenser + reflux drum on the column, cooling-water served column overhead condenser. A made-to-order fabrication trickle-bed hydrocracking/hydrotreating reactor breaking heavy chains + saturating olefins/oxygenates syncrude hydrocracker/hydrotreater reactor, certified to PED 2014/68/EU. A made-to-order fabrication catalytic isomerisation/dewaxing reactor meeting jet cold-flow (freeze-point) properties isomerisation/dewaxing reactor, certified to PED 2014/68/EU.

A Honeywell UOP hydrocracking + Pt/zeolite isomerisation catalyst charge (replaceable line item) hydrocracking + isomerisation catalyst charge. The cold (~35 °C) syncrude/wax is first reheated to hydroprocessing temperature in a feed/effluent heat exchanger plus electric trim heater, then hydrocracked and isomerised/dewaxed (consuming an HP H2 slip-stream) and fractionated in a 0.8 m column into an on-spec SAF (jet) cut, a naphtha co-product (~667 t/yr) and a small recycle residue.

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_design_mpa = p_design_barg x 0.1
p_design_mpa = 6 x 0.1 = 0.6 MPa
```

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

Shell minimum thickness (hoop stress, internal pressure)

```
t = p_design x D / (2 x S x E - 1.2 x p_design) + corr
t = 0.6 x 800 / (2 x 174 x 0.85 - 1.2 x 0.6) + 3 = 4.627 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_hoop = p_design x D / (2 x t)
sigma_hoop = 0.6 x 800 / (2 x 8) = 30 MPa
```

assumes: thin-wall cylinder under internal pressure

Yield safety factor (hoop-governing, internal pressure)

```
SF_yield = yield_mpa / sigma_hoop
SF_yield = 290 / 30 = 9.667
```

assumes: material steel_316L; yield from datasheet/standard; internal-pressure vessel - yield governs (no external-buckling check)

Cylinder wall mass

```
mass = pi x (r_outer^2 - r_inner^2) x length_mm x density / 1e9
mass = pi x (408^2 - 400^2) x 14,000 x 8,000 / 1e9 = 2,274.413 kg
```

assumes: material steel_316L; cylindrical shell only; heads computed separately; 1e9 converts mm3 to m3

Head mass (2 flat-plate heads)

```
mass = 2 x pi x r_outer^2 x t x density / 1e9
mass = 2 x pi x 408^2 x 8 x 8,000 / 1e9 = 66.939 kg
```

assumes: flat-head approximation (conservative vs torispherical); 2 heads; 1e9 converts mm3 to m3

Total vessel shell mass

```
total_mass = mass_cylinder + mass_heads
total_mass = 2,274.413 + 66.939 = 2,341.352 kg
```

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Syncrude Feed/effluent Preheater	Kelvion	**syncrude feed/effluent shell-and-tube exchanger + electric trim heater - engineered**	×1	~£95,000	**£95,000**	— **OK**
Fractionation Reboiler	Kelvion	**shell-and-tube thermosiphon reboiler - engineered**	×1	~£110,000	**£110,000**	— **OK**
Fractionation Overhead Condenser	Alfa Laval	**shell-and-tube overhead condenser - engineered**	×1	~£90,000	**£90,000**	— **OK**
Hydrocracker/hydrotreater Reactor	made-to-order fabrication	**fabricated trickle-bed hydroprocessing reactor - bespoke vessel**	×1	~£900,000	**£900,000**	— **>2x**
Isomerisation/dewaxing Reactor	made-to-order fabrication	**fabricated isomerisation/dewaxing reactor - bespoke vessel**	×1	~£500,000	**£500,000**	— **>2x**
Hydroprocessing Catalyst Charge	Honeywell UOP	**- licensed hydrocracking + isomerisation catalyst charge**	×1	~£100,000	**£100,000**	— **-**
Sub-total — Energy conversion - chemical reaction					**£1,695,000**	

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5.2 Energy conversion - Fluid transport

The upgrading fractionation train mass fluid transport process upgrades 4 components. A made-to-order fabrication packed/trayed fractionation column splitting the upgraded liquid into SAF (jet), naphtha + residue, field-erected on a plinth saf/naphtha fractionation column, certified to PED

2014/68/EU. A Koch-Glitsch structured packing + liquid distributors / valve trays for the jet/naphtha split fractionation trays/packing + distributors.

A Howden dedicated HP hydrogen make-up compressor feeding the hydrocracker/isomeriser slip-stream hydroprocessing HP H2 make-up compressor, rated 55 kW, certified to API 618. 3x Grundfos centrifugal product/reflux/residue pumps on the column draws fractionation product/reflux pump. The cold (~35 °C) syncrude/wax is first reheated to hydroprocessing temperature in a feed/effluent heat exchanger plus electric trim heater, then hydrocracked and isomerised/dewaxed (consuming an HP H2 slip-stream) and fractionated in a 0.8 m column into an on-spec SAF (jet) cut, a naphtha co-product (~667 t/yr) and a small recycle residue.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Product Fractionation Column	made-to-order fabrication	**fabricated 316L fractionation column shell - bespoke vessel**	×1	~£700,000	**£700,000**	— >2x
Fractionation Column Internals	Koch-Glitsch	**INTALOX structured packing + trays - engineered**	×1	~£120,000	**£120,000**	— >2x
HP H2 Make-Up Compressor	Howden	**hydrogen-service make-up compressor - engineered package**	×1	~£200,000	**£200,000**	— -
Liquid Product Pump	Grundfos	**CRNE 5-8**	×3	~£4,400	**£13,200**	— OK
Sub-total — Energy conversion - Fluid transport					**£1,033,200**	

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Module 5 total — M4 Upgrading & Fractionation **£2,728,200**

Validate this design with: Principal chemical process engineer, Senior pressure systems engineer — full questions in the Engagement Plan (Section 13).

MODULE 6

M8 Process Instrumentation & Control

Cost **£452,710**

Module summary

PURPOSE

This module (M8 Process Instrumentation & Control) the sensing instrumentation module acquires field measurements and executes control actions throughout the plant. Chemical sensing instruments monitor pressure, temperature, flow and level loops on all vessels, separators and tanks while also sampling process gas composition and detecting H,/CO leaks.

HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 4 sub-modules. The Sensing & instrumentation - chemical sensing — pressure, temperature, flow and level loops across all 7 vessels/separators/tanks, plus process gas analysers and modulating control valves.

The Sensing & instrumentation - electrical conduction — pressure, temperature, flow and level loops across all 7 vessels/separators/tanks, plus process gas analysers and modulating control valves. The electrical drives & power — variable-frequency drives for all 5 pumps/agitators and 3 compressors, a Form-4 motor control centre, and a UPS covering critical instrument and control loads.

The control network & marshalling — remote I/O stations at each process skid, 15-inch HMI at the local control panel, redundant PROFINET switches and marshalling cabinets — complementing the central DCS/SIS in the control_compute_communication module.

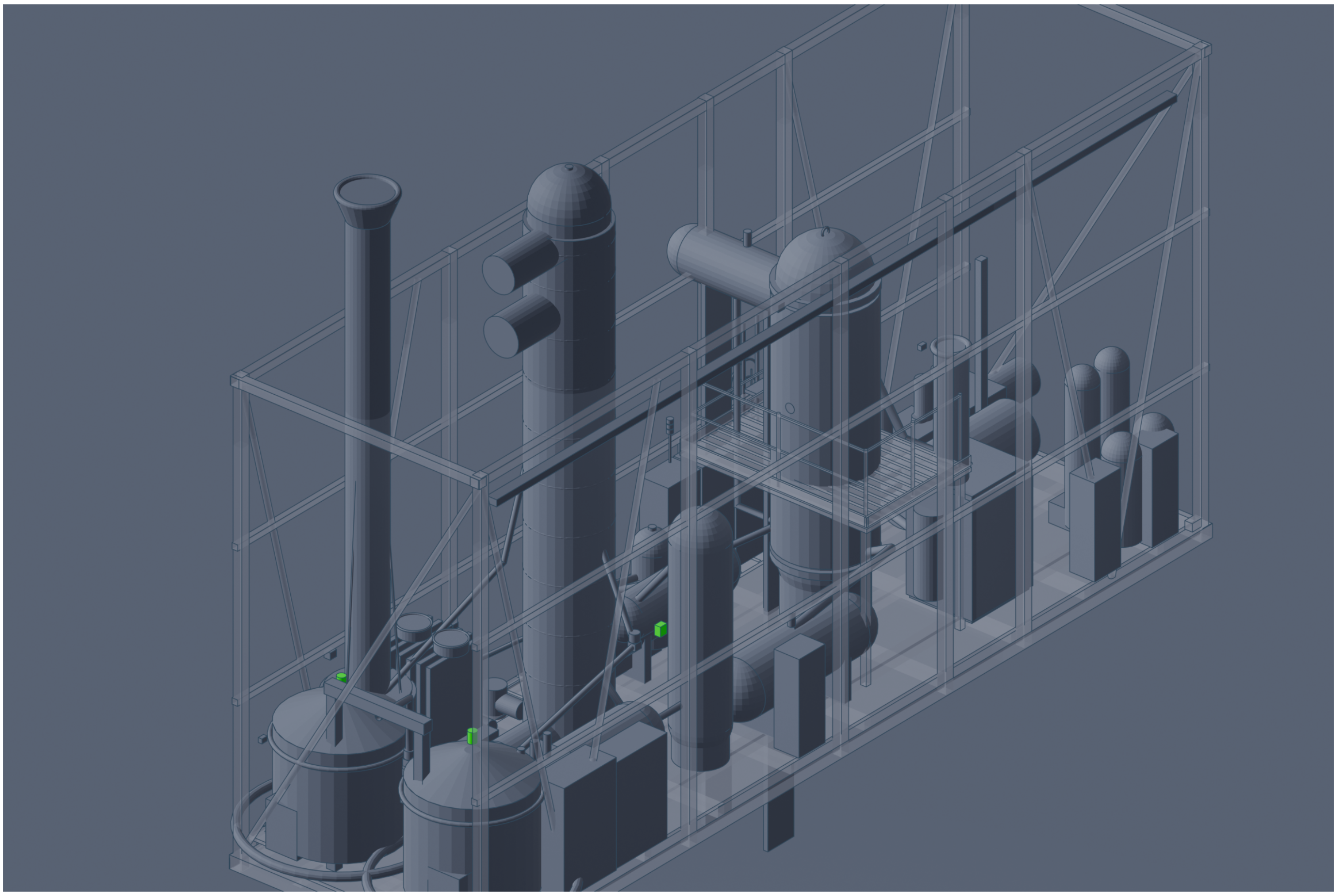

Illustration only — generic class render. Module 6 (M8 Process Instrumentation & Control) shown in identity colour; other modules muted; enclosure ghosted.

The sensing instrumentation module acquires field measurements and executes control actions throughout the plant. Chemical sensing instruments monitor pressure, temperature, flow and level loops on all vessels, separators and tanks while also sampling process gas composition and detecting H2/CO leaks. Sensing instrumentation electrical conduction mass fluid transport process positions control valves at the appropriate points in the pipework so that measured deviations can be corrected by modulating material flows.

Electrical drives & power deliver variable-frequency drives to the five pumps or agitators and three compressors, route power through a Form-4 motor control centre and maintain supply continuity via the uninterruptible power supply. Control network & marshalling concentrates signals at remote I/O stations, presents live data on the human-machine interface and transmits commands over redundant PROFINET switches housed in marshalling cabinets. The module thereby maintains regulatory compliance and stable plant operation.

Sub-modules

6.1 Sensing & instrumentation - chemical sensing

The field instrumentation chemical sensing measures 6 components. 25x Emerson coplanar gauge/differential, 4-20 mA HART, 316L wetted, -40 to +85 °C electronics, process range to 250 bar rosemount differential/gauge pressure transmitter, certified to ATEX II 2G, PED 2014/68/EU. 38x Endress+Hauser Pt100 resistance thermometer + thermowell + 4-20 mA HART head transmitter, -50 to +600 °C itherm pt100 thermowell + head transmitter, certified to ATEX II 2G Ex ia.

9x Endress+Hauser electromagnetic flow, Memosens digital, 4-20 mA HART + PROFIBUS PA, DN25-DN300, for aqueous/slurry streams promag W 400 electromagnetic flow transmitter, certified to ATEX II 2G, EN 10204 3.1, OIML R117. 7x Endress+Hauser 80 GHz free-space radar, 4-20 mA HART, range to 120 m, suitable for reactors + tanks + separators micropilot FMR62 80 ghz radar level transmitter, certified to ATEX II 1G Ex ia, SIL 2. 3x ABB extractive multi-component NDIR analyser for CO2, CO, CH4 + optional H2 - continuous on-line quality monitoring ABB EL3060 uras26 multi-component NDIR gas analyser, certified to ATEX II 2G, EN 15267-3 QAL1, BS EN 14181.

10x Dräger fixed catalytic bead/electrochemical transmitter, selectable for H2 / CO / flammable HC; 4-20 mA + relay output; IP66 dräger polytron 8700 electrochemical/catalytic gas detector, certified to ATEX II 1G Ex ia, EN 60079-29-1, DSEAR. Pressure, temperature, flow and level loops across all 7 vessels/separators/tanks, plus process gas analysers and modulating control valves.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Pressure Transmitters	Emerson	**Rosemount 3051CD**	×25	~£1,200	**£30,000**	— **>2x**
Temperature Transmitters	Endress+Hauser	**iTHERM TM411**	×38	~£650	**£24,700**	— -
Electromagnetic Flow Transmitters	Endress+Hauser	**Promag W 400**	×9	~£3,600	**£32,400**	— **>2x**
Radar Level Transmitters	Endress+Hauser	**Micropilot FMR62**	×7	~£2,400	**£16,800**	Est. **OK**
Process Gas Analysers	ABB	**EL3060 Uras26**	×3	~£9,500	**£28,500**	— **>2x**
Fixed Gas Detectors	Dräger	**Polytron 8700**	×10	~£2,400	**£24,000**	Est. **>2x**
Sub-total — Sensing & instrumentation - chemical sensing					**£156,400**	

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6.2 Sensing & instrumentation - electrical conduction

The field instrumentation electrical conduction mass fluid transport process measures 2 components. 32x Emerson Fisher rotary/globe control valve body, rated to process design pressure, with Fisher DVC6200 HART digital valve controller + feedback emerson fisher GX globe valve + dvc6200 digital positioner, certified to ATEX II 2G, IEC 60534 (ISA S75), PED 2014/68/EU.

23x Spelsberg GRP/polycarbonate IP65 field junction box, M20 gland entries, DIN rail + terminal strip inside spelsberg IP65 field junction box. Pressure, temperature, flow and level loops across all 7 vessels/separators/tanks, plus process gas analysers and modulating control valves.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Process Control Valves	Emerson Fisher	**GX + DVC6200**	×32	~£6,400	**£204,800**	Est. **>2x**
Field Junction Boxes	Spelsberg	**81040001**	×23	~£40	**£920**	— **<.5x**
Sub-total — Sensing & instrumentation - electrical conduction					**£205,720**	

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6.3 Electrical drives & power

The electrical drives & power drives 4 components. 5x ABB IP55 compact VFD, one per pump/agitator, built-in EMC filter, STO (Safe Torque Off) SIL 2, <=15 kW ABB ACS580 variable-frequency drive, <=15 kw, certified to IEC 61800-5-2 SIL 2, EN 61800-3 C2. 3x ABB wall/floor-mount VFD, DTC motor control, one per process compressor duty, 15-90 kW, IP55, integrated brake chopper ABB ACS880 variable-frequency drive, >15 kw, certified to IEC 61800-5-2 SIL 2, EN 61800-3 C2.

An ABB Form-4 withdrawable MCC, 3-MVA rated incoming, fully compartmentalised, busbar to 3750 kVA demand ABB MNS form-4 motor control centre, certified to BS EN 61439-2, IEC 61439-2, Form-4 compartmentalisation. An Eaton online double-conversion UPS, 10-30 kVA, 20-min autonomy at full critical instrument load, 3-phase in/out, hot-swappable VRLA batteries eaton 93pm online double-conversion UPS, certified to IEC 62040-3 Class 1, BS EN 62040-1. Variable-frequency drives for all 5 pumps/agitators and 3 compressors, a Form-4 motor control centre, and a UPS covering critical instrument and control loads.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Small Variable-Frequency Drives (Pumps/agitators)	ABB	**ACS580-01**	×5	~£1,700	**£8,500**	Est. **OK**
Medium Variable-Frequency Drives (Compressors)	ABB	**ACS880-07**	×3	~£8,500	**£25,500**	— **>2x**
Motor Control Centre	ABB	**ACS580-01**	×1	~£18,000	**£18,000**	— -
Uninterruptible Power Supply	Eaton	**93PM**	×1	~£8,500	**£8,500**	Est. **>2x**
Sub-total — electrical drives & power					**£60,500**	

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 2× 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.

6.4 Control network & marshalling

The control network & marshalling networks 6 components. 10x Siemens ET 200SP HA distributed I/O station + IM 155-6 PN/2 interface module, installed in field cabinets at each process skid siemens ET 200sp HA remote i/o station, certified to BS EN 61000-6-2 EMC. 10x Siemens DI 16x24 V DC + DQ 16x24 V DC modules for valve-position, pump-run, alarm and shutdown discrete signals siemens ET 200sp digital input/output cards.

10x Siemens AI 8x0/4-20 mA + AQ 4x0/4-20 mA modules for all transmitter loops + control valve outputs siemens ET 200sp analogue input/output cards. A Siemens 15-inch widescreen industrial HMI, multi-touch, PROFINET, IP65 front, 24 V DC supply, -20 to +60 °C siemens 15-inch industrial HMI panel, certified to CE, UKCA, cULus. 3x Siemens 8-port 100 Mbit/s managed industrial Ethernet switch, DIN-rail, PROFINET conformance Class C, ring redundancy (MRP), -40 to +70 °C siemens scalance XC208 managed profinet switch, certified to EN 61000-6-2, IEC 62439-2 (MRP).

3x Rittal floor-standing IP54 marshalling cabinet, 600 Wx2000 Hx600 D mm, DIN-rail terminal blocks + cable guides, screened cable entries rittal VX25 marshalling + terminal cabinet, certified to BS

EN 61439-1, IP54 IEC 60529. Remote I/O stations at each process skid, 15-inch HMI at the local control panel, redundant PROFINET switches and marshalling cabinets - complementing the central DCS/SIS in the control compute communication module.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Remote I/o Interface Stations	Siemens	**6ES7155-6AU01-0CN0**	×10	~£1,500	**£15,000**	— **<.5x**
Digital I/o Cards	Siemens	**6ES7131-6BH01-0BA0**	×10	~£95	**£950**	— **<.5x**
Analogue I/o Cards	Siemens	**6ES7134-6GF00-0AA1**	×10	~£180	**£1,800**	— **-**
HMI Panel	Siemens	**6AV2124-0QC02-0AX1**	×1	~£1,900	**£1,900**	— **OK**
PROFINET Industrial Switches	Siemens	**6ES7155-6AU01-0CN0**	×3	~£280	**£840**	Est. **-**
Marshalling Cabinets	Rittal	**VX25 8284.500**	×3	~£3,200	**£9,600**	— **>2x**
Sub-total — control network & marshalling					**£30,090**	

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Module 6 total — M8 Process Instrumentation & Control **£452,710**

Validate this design with: Senior instrumentation and control engineer, Lead automation and systems engineer — full questions in the Engagement Plan (Section 13).

MODULE 7

M7 Control & Safety

Cost **£280,960**

Module summary

PURPOSE

This module (M7 Control & Safety) the control compute communication silicon semiconductor houses the distributed control system that sequences synthesis, separation, recycle, upgrading, fractionation and loading together with the independent safety instrumented system, while the control compute communication chemical sensing mass fluid transport process supplies H,/CO/hydrocarbon gas detectors, optical flame detectors and emergency shutdown valves that initiate trips. SIL-rated isolation barriers and marshalling cabinets maintain signal integrity between the two sub-modules, ensuring that any detected hazard overrides the continuous sequencing logic.

HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 2 sub-modules. The Control & monitoring - electronics — a DCS sequences the synthesis, separation, recycle, upgrading, fractionation and loading; an independent SIL-rated SIS + fire-&-gas system with H2/CO/hydrocarbon detection trips the plant to a safe state.

The Control & monitoring - chemical sensing — a DCS sequences the synthesis, separation, recycle, upgrading, fractionation and loading; an independent SIL-rated SIS + fire-&-gas system with H2/CO/hydrocarbon detection trips the plant to a safe state.

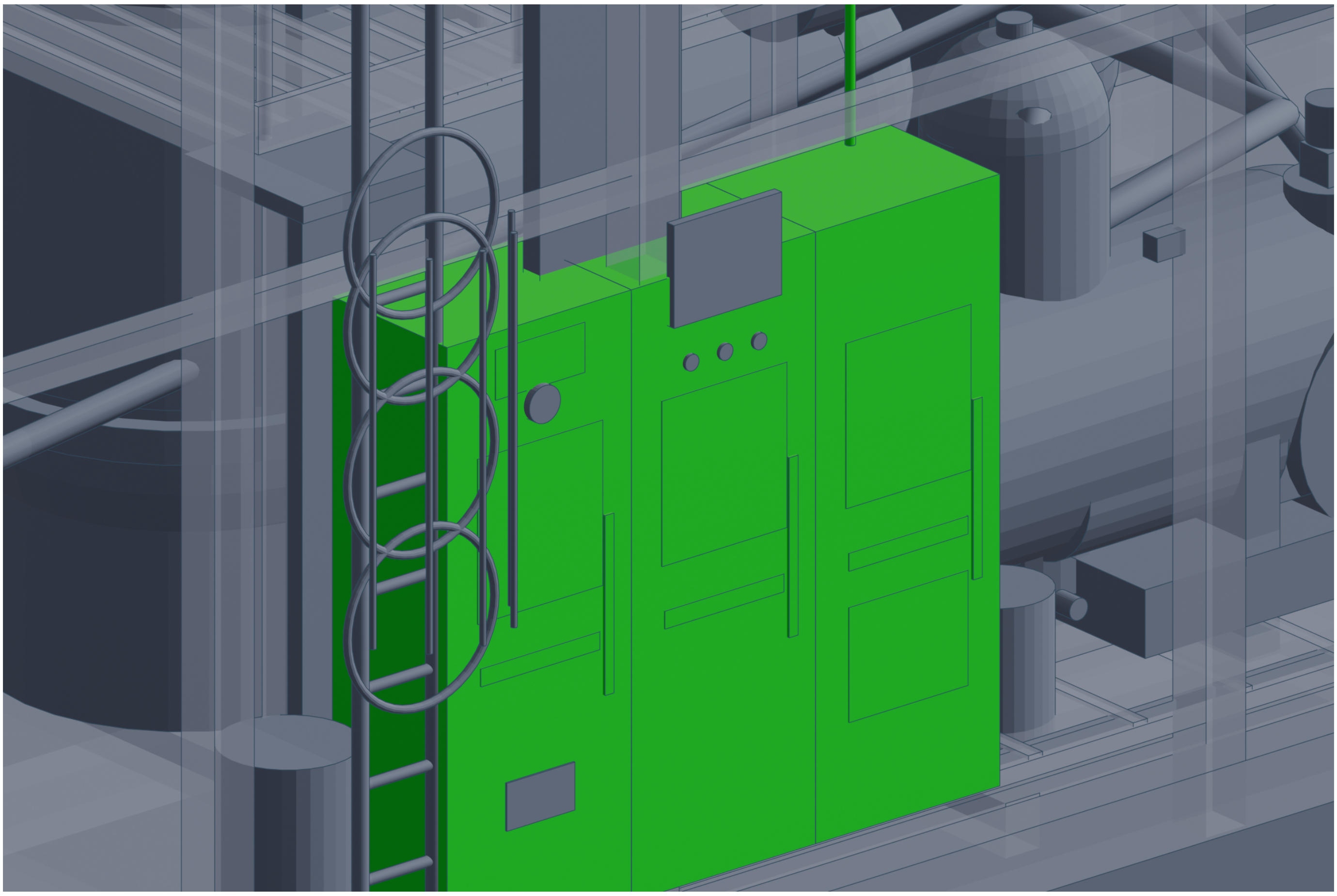

Illustration only — generic class render. Module 7 (M7 Control & Safety) shown in identity colour; other modules muted; enclosure ghosted.

The control compute communication silicon semiconductor houses the distributed control system that sequences synthesis, separation, recycle, upgrading, fractionation and loading together with the independent safety instrumented system, while the control compute communication chemical sensing mass fluid transport process supplies H2/CO/hydrocarbon gas detectors, optical flame detectors and emergency shutdown valves that initiate trips. SIL-rated isolation barriers and marshalling cabinets maintain signal integrity between the two sub-modules, ensuring that any detected hazard overrides the continuous sequencing logic.

All functions comply with COMAH, DSEAR/ATEX and IEC 61511 requirements for redundant, fail-safe operation. The module therefore maintains orderly plant control while guaranteeing automatic transition to a safe state on demand.

Sub-modules

7.1 Control & monitoring - electronics

The control safety system silicon semiconductor controls 6 components. A Siemens redundant DCS controller pair sequencing the continuous PtL process plant distributed control system (dcs).

A Siemens independent SIL-2/3 safety controller driving the emergency shutdown chain sil-rated safety instrumented system (sis/esd), certified to IEC 61511.

24x Siemens ET 200SP HA / fail-safe DI/DO + AI/AO modules for the process + safety loops dcs/sis distributed i/o cards. A Dräger multi-loop fire-&-gas control panel aggregating the gas + flame detectors and driving alarms/ESD addressable fire & gas controller, certified to IEC 61511. 16x Pepperl+Fuchs SIL-2 isolated signal barriers on the safety I/O sil-rated signal isolation barriers, certified to IEC 61511.

2x Rittal floor-standing IP54 control + marshalling cabinets for the DCS + SIS dcs/sis control + marshalling cabinet, certified to BS EN 61439. A DCS sequences the synthesis, separation, recycle, upgrading, fractionation and loading; an independent SIL-rated SIS + fire-&-gas system with H2/CO/hydrocarbon detection trips the plant to a safe state.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Distributed Control System	Siemens	**Siemens SIMATIC S7-1500 distributed control system controller - engineered**	×1	~£65,000	**£65,000**	— >2x
Safety Instrumented System	Siemens	**Siemens SIMATIC S7-1500F fail-safe safety-instrumented-system controller - engineered**	×1	~£85,000	**£85,000**	— >2x
Dcs/sis I/o Cards	Siemens	**Siemens SIMATIC ET 200SP HA fail-safe distributed I/O module - engineered**	×24	~£500	**£12,000**	Est. >2x
Fire & Gas Controller	Dräger	**REGARD 7000**	×1	~£6,800	**£6,800**	— >2x
SIL-Rated Isolation Barriers	Pepperl+Fuchs	**KFD2-STC4-Ex1**	×16	~£160	**£2,560**	— >2x
Control + Marshalling Cabinet	Rittal	**VX25 8284.500**	×2	~£3,400	**£6,800**	— OK
Sub-total — Control & monitoring - electronics					**£178,160**	

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 2× 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.

7.2 Control & monitoring - chemical sensing

The control safety system chemical sensing mass fluid transport process controls 3 components. 16x Dräger fixed catalytic/electrochemical H2 + CO + flammable-hydrocarbon detectors across the synthesis + separation areas H2 + CO + hydrocarbon gas detectors, certified to DSEAR.

6x Dräger IR3 optical flame detectors at the reactor, oxidiser and loading areas IR3 optical flame detectors, certified to BS EN 61511. 8x Emerson fail-safe actuated ESD valves isolating the feed, reactor, recycle and loading fail-safe emergency shutdown valves, certified to IEC 61511.

A DCS sequences the synthesis, separation, recycle, upgrading, fractionation and loading; an independent SIL-rated SIS + fire-&-gas system with H2/CO/hydrocarbon detection trips the plant to a safe state.

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.

Cantera Thermochemistry v3.2.0
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
H2/co/hydrocarbon Gas Detectors	Dräger	**Polytron 8700**	×16	~£2,400	**£38,400**	Est. **>2x**
Optical Flame Detectors	Dräger	**Flame 2700**	×6	~£3,800	**£22,800**	— **<.5x**
Emergency Shutdown Valves	Emerson	**Bettis actuated ESD ball valve - configured**	×8	~£5,200	**£41,600**	— -
Sub-total — Control & monitoring - chemical sensing					**£102,800**	

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 2× 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 — M7 Control & Safety **£280,960**

Validate this design with: Principal control systems engineer, Senior functional safety engineer — full questions in the Engagement Plan (Section 13).

MODULE 8

M6 Product Storage & Loading

Cost **£462,600**

Module summary

PURPOSE

This module (M6 Product Storage & Loading) the maintenance serviceability module receives finished sustainable aviation fuel at 125 kg/h and 3750 L/day. Within the mass fluid transport process the stream is additised to DEF STAN 91-091 specification, held under nitrogen blanketing in one product tank 5.37 m in diameter and 4.29 m high, and placed alongside the 667 t/yr naphtha co-product before being transferred by the product loading pump through the road-tanker loading gantry.

HOW ITS SUB-MODULES INTERACT

Internally this module is composed of 2 sub-modules. The Maintenance & serviceability - Fluid transport — finished SAF (~125 kg/h) is additised, certified and stored in 1 x 5.4 m dia x 4.3 m API 650 tank(s) alongside a naphtha tank, then loaded to road tanker at a metered loading gantry.

The Maintenance & serviceability - chemical sensing — finished SAF (~125 kg/h) is additised, certified and stored in 1 x 5.4 m dia x 4.3 m API 650 tank(s) alongside a naphtha tank, then loaded to road tanker at a metered loading gantry.

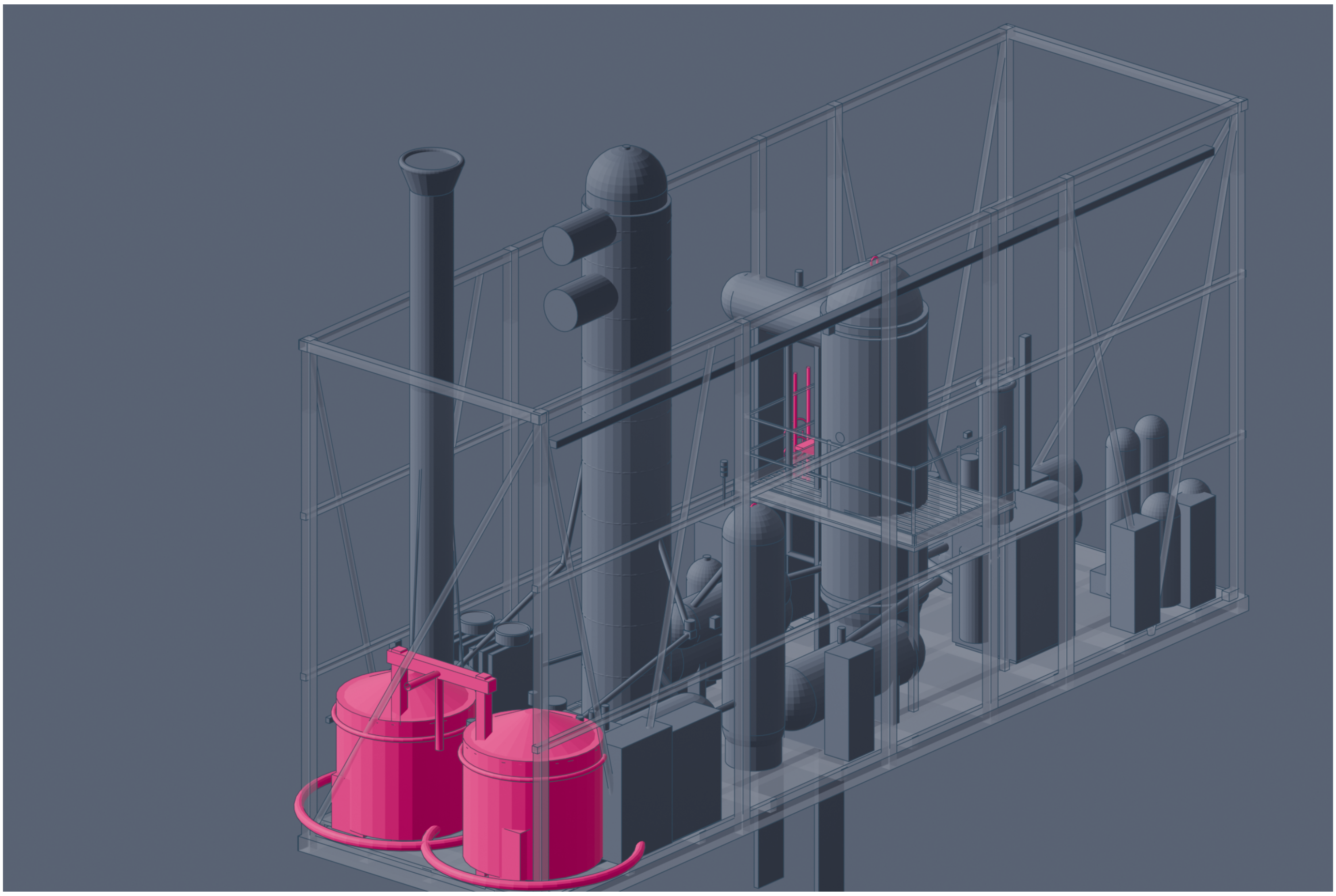

Illustration only — generic class render. Module 8 (M6 Product Storage & Loading) shown in identity colour; other modules muted; enclosure ghosted.

The maintenance serviceability module receives finished sustainable aviation fuel at 125 kg/h and 3750 L/day. Within the mass fluid transport process the stream is additised to DEF STAN 91-091 specification, held under nitrogen blanketing in one product tank 5.37 m in diameter and 4.29 m high, and placed alongside the 667 t/yr naphtha co-product before being transferred by the product loading pump through the road-tanker loading gantry.

The chemical sensing sub-module integrates the custody-transfer metering skid to certify every batch against EI 1530 requirements and to record volumes for fiscal transfer. These two sub-modules therefore complete the downstream handling chain by ensuring the fuel meets specification, remains protected during storage, and is accurately measured on dispatch.

Sub-modules

8.1 Maintenance & serviceability - Fluid transport

The product storage loading mass fluid transport process stores 6 components. A made-to-order fabrication API 650 atmospheric welded steel storage tank, >=14-day finished-SAF storage, bunded finished-saf storage tank, certified to API 650. A made-to-order fabrication API 650 atmospheric welded steel naphtha tank, N2-blanketed, bunded naphtha co-product storage tank, certified to API 650.

A Lewa metered additive-injection skid (static dissipator, antioxidant, lubricity) to DEF STAN 91-091 jet-fuel additive injection skid, certified to DEF STAN 91-091. An Emerson bottom-loading metered tanker loading arm + ground-verification + overfill protection metered road-tanker loading gantry, certified to EI 1530. 2x Grundfos centrifugal loading pump, 1 duty + 1 standby, tank to loading gantry tank-to-tanker loading pump.

2x Protego inert-gas blanketing regulator + breather valve set on the SAF + naphtha tanks storage-tank N2 blanketing valve set, certified to DSEAR. Finished SAF (~125 kg/h) is additised, certified and stored in 1 x 5.4 m dia x 4.3 m API 650 tank(s) alongside a naphtha tank, then loaded to road tanker at a metered loading gantry.

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.

ASF Chain-Growth / FT Selectivity (PtL) v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Chain-growth probability alpha (user-supplied)

```
alpha = alpha_input
alpha = 0.92 = 0.92
```

assumes: alpha provided directly; no temperature correlation applied

ASF mass weight fraction formula (shown for C10 as example)

```
w_n = n x (1 - alpha)^2 x alpha^(n-1) / Z (Z = normalisation sum over n=1..n_max)
w_n = 10 x (1 - 0.92)^2 x 0.92^(10-1) / Z (Z = 10ormalisatio10 sum over 10=1..50) = 0.0328 fraction
```

assumes: Anderson (1956) ASF polymerisation model - mass weight fraction formula; Normalisation Z ensures SUM(w_n, n=1..n_max) = 1 (closed finite sum); Shown for n=10 (C10, lightest jet-range carbon); actual cut sums over full range; Peak carbon number (mode of w_n): C12

Raw FT product cuts - straight ASF (before upgrading)

```
cut_frac = SUM(w_n, n=n_lo..n_hi)
cut_frac = SUM(w_n, n=n_lo..n_hi) = 1 fraction (sum of all cuts)
```

assumes: Cuts: C1=methane, C2-4=LPG, C5-9=naphtha, C10-16=jet/kerosene, C17-20=diesel, C21+=wax; Sum should be 1.000 ± 0.001 (n_max=50 truncation negligible above n=40 for alpha<0.93); Anderson-Schulz-Flory distribution; no olefin/paraffin ratio correction applied

Jet selectivity after selective wax hydrocracking

```
jet_selectivity = jet_raw + wax_to_jet_conversion x wax_raw + diesel_to_jet x diesel_raw
jet_selectivity = 0.2293 + 0.83 x 0.4479 + 0 x 0.1192 = 0.6011 fraction
```

assumes: Process: wax (C21+) selectively hydro-cracked into the C10-C16 kerosene/jet boiling range; wax_to_jet_conversion = 0.83 (literature: 0.70-0.90 for selective Pt/SiO2 or Ni/W/Al2O3 hydrocracking; Steynberg & Dry 2004 ch.7); diesel_to_jet_fraction = 0.0 (default 0.0: the process targets wax primarily); Wax residue after upgrading = 0.07614 (fraction remaining); jet_selectivity_frac = 0.22931 + 0.83 x 0.44791 = 0.60108

Carbon-to-liquids fraction (C5+ liquid yield)

```
carbon_to_liquids = 1 - methane_frac - lpg_frac
carbon_to_liquids = 1 - 0.0069 - 0.052 = 0.9411 fraction
```

assumes: C5+ liquids = all carbon NOT lost as methane (C1) or LPG light gas (C2-C4); Methane + LPG are gaseous at ambient conditions and cannot be directly converted to liquid fuel without additional reforming; This is the fraction of converted carbon that reaches the liquid product stream

Liquid-Fuel Storage Tank (API 650) Sizing v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Required gross storage volume

```
V_req = daily_production x days_storage / fill_fraction
V_req = 6.25 x 14 / 0.9 = 97.222 m3
```

assumes: 14.0 days of buffer storage; fill fraction 0.9 leaves ullage / overfill margin

Number of tanks (single-tank volume cap)

```
n_tanks = ceil(V_req / max_tank)
n_tanks = ceil(97.222 / 500) = 1
```

assumes: single-tank volume capped at 500.0 m3; minimum 1 tank

Volume per tank

```
V_each = V_req / n_tanks
V_each = 97.222 / 1 = 97.222 m3
```

assumes: required volume split evenly across the tank farm

Tank diameter from aspect ratio

```
D = (4 x V_each / (pi x H_over_D))^(1/3)
D = (4 x 97.222 / (pi x 0.8))^(1/3) = 5.3686 m
```

assumes: vertical cylinder V = (pi/4) D^2 H with H = (H/D) x D

Tank height

```
H = H_over_D x D
H = 0.8 x 5.3686 = 4.2949 m
```

assumes: H/D = 0.8 (squat atmospheric storage tank)

Shell-course thickness (API 650 1-foot method, floored at min plate)

```
t = max( 4.9 x D x (H - 0.3) x SG / (S x E) + corr , t_min )
t = max( 4.9 x 5.3686 x (4.2949 - 0.3) x 0.8 / (160 x 0.85) + 3 , 6 ) = 6 mm
```

assumes: API 650 clause 5.6.3 1-foot method (design condition, 0.3 m above course bottom); specific gravity SG = 0.8 (product / water); membrane thickness 3.6182 mm (= design 0.6182 mm + 3.0 mm corrosion); floored at API 650 Table 5.6a minimum plate 6.0 mm (squat low-SG tank is fabrication/weld/wind governed, not membrane-stress governed)

Dry tank mass per tank (shell + floor + roof + fittings)

```
m = (pi x D x H + (1 + 1.05)(pi/4)D^2) x (t/1000) x rho x 1.12
m = (pi x 5.3686 x 4.2949 + (1 + 1.05)(pi/4)5.3686^2) x (6/1000) x 7,850 x 1.12 = 6,269.2 kg
```

assumes: lateral shell 3411.81 kg + flat bottom plate 1066.19 kg + cone roof 1119.5 kg (roof 1.05x plan area for slope + rafters); x1.12 for nozzles / stairs / handrails / clips / wind girder; carbon-steel density 7850 kg/m3; (was lateral-shell-only before 2026-06-05 fix - understated dry mass ~2-3x and implied a sub-mm wall to the physics critic)

Yield + Economics NPV v1.0.0

WORKED CALCULATION — EVERY NUMBER CHECKABLE BY HAND

Annual gross revenue (year 1)

```
annual_revenue = annual_yield_kg x market_price
annual_revenue = 1,000,000 x 2.2 = 2,200,000 GBP/yr
```

assumes: year 1 price; subsequent years inflated at price_inflation_pct per annum

Gross margin year 1

```
gross_margin = (annual_revenue - opex_per_yr) / annual_revenue x 100
gross_margin = (2,200,000 - 7,367,115) / 2,200,000 x 100 = -234.87 %
```

assumes: gross margin before tax and depreciation; year-1 only

Energy intensity

```
energy_intensity = annual_energy_kwh / annual_yield_kg
energy_intensity = 500,000 / 1,000,000 = 0.5 kWh/kg
```

assumes: total site energy divided by total harvested yield; no allocation between crops

Operating cost per kg

```
cost_per_kg = opex_per_yr / annual_yield_kg
cost_per_kg = 7,367,115 / 1,000,000 = 7.3671 GBP/kg
```

assumes: year-1 opex only; subsequent years inflated

Amortised capital cost per kg

```
cap_amort = capex_gbp / (annual_yield_kg x project_years)
cap_amort = 2.5e+07 / (1,000,000 x 20) = 1.25 GBP/kg
```

assumes: straight-line amortisation over project life; matches straight-line depreciation assumption

All-in cost per kg (opex + amortised capex)

```
all_in_cost = cost_per_kg + cap_amort
all_in_cost = 7.3671 + 1.25 = 8.6171 GBP/kg
```

All-in margin per kg

```
all_in_margin = market_price - all_in_cost
all_in_margin = 2.2 - 8.6171 = -6.4171 GBP/kg
```

assumes: positive = profitable at year-1 volume and price

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
SAF Storage Tank	made-to-order fabrication	**API 650 welded steel atmospheric storage tank - bespoke**	×1	~£110,000	**£110,000**	— >2x

Naphtha Storage Tank	made-to-order fabrication	**API 650 welded steel atmospheric storage tank - bespoke**	×1	~£110,000	**£110,000**	— >2x
SAF Additisation Skid	Lewa	**metered additive-injection dosing skid - packaged**	×1	~£70,000	**£70,000**	— -
Road-Tanker Loading Gantry	Emerson	**metered loading gantry with batch preset controller - configured**	×1	~£100,000	**£100,000**	— >2x
Product Loading Pump	Grundfos	**NK 65-200**	×2	~£5,200	**£10,400**	— OK
Storage N2 Blanketing Valves	Protego	**DK/ES blanketing valve**	×2	~£3,600	**£7,200**	— >2x
Sub-total — Maintenance & serviceability - Fluid transport					**£407,600**	

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 2× 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.

8.2 Maintenance & serviceability - chemical sensing

The product storage loading chemical sensing stores 1 component. An Emerson Coriolis custody-transfer metering skid on the loading line custody-transfer flow-metering skid, certified to EI 1530.

Finished SAF (~125 kg/h) is additised, certified and stored in 1 x 5.4 m dia x 4.3 m API 650 tank(s) alongside a naphtha tank, then loaded to road tanker at a metered loading gantry.

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Custody-Transfer Metering Skid	Emerson	**Micro Motion custody- - transfer Coriolis metering skid**	×1	~£55,000	**£55,000**	— >2x
Sub-total — Maintenance & serviceability - chemical sensing					**£55,000**	

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 2× 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 8 total — M6 Product Storage & Loading **£462,600**

Validate this design with: Senior mechanical engineer, pressure vessel specialist, Senior terminal operations engineer — full questions in the Engagement Plan (Section 13).

Risk & Integration Analysis

TECHNICAL FEASIBILITY

Cost verdict. The priced bill of materials totals £10.30M across 73 priced lines; the fully-costed design reaches £17.17M ex-works (parts plus manufacturing, labour and margin). That is within the £45.00M brief cost ceiling (38% of ceiling). The order-of-magnitude check FAILS: the total diverges from comparable plants and should be re-estimated before procurement.

What is proven. The design is grounded in 82 engineering quantities computed by 22 validated analysis tools (stoichiometry balance, feasibility gibbs, fired heater, steam generator, flash separation, heat-exchanger heat exchanger, pump sizing, design, and 14 more), so the thermal duties, structural margins and energy demands below are calculated rather than assumed.

Cradle-to-grave plant CO2	**14426 t**
Road-envelope mass-budget utilisation	**0.00 %**
Total plant mass	**26011 kg**

Top technical risks (this design)

MEDIUM **The hydrogen compressor in M1 is rated at 140 kW, but the largest VFDs specified in M8 (ABB ACS880-07) are rated for '15-90 kW'**

The hydrogen compressor in M1 is rated at 140 kW, but the largest VFDs specified in M8 (ABB ACS880-07) are rated for '15-90 kW'. A 140 kW motor cannot be safely or effectively driven by a 90 kW rated VFD.

Mitigation: Increase the power rating of at least one VFD in the M8 instrumentation list to >= 160 kW to match the 140 kW H2 compressor.

MEDIUM **The recycle compressor is specified as a 'single-stage centrifugal recycle compressor' rated at 4 kW**

The recycle compressor is specified as a 'single-stage centrifugal recycle compressor' rated at 4 kW. At the low volumetric flow rate of this plant (~80 m3/h at 25 bar), a centrifugal compressor would operate at extremely low aerodynamic efficiency and high windage losses. Reciprocating or diaphragm compressors are standard for this low-flow, high-pressure recycle duty.

Mitigation: manual review against datasheet/CAD/test plan

LOW **The naphtha storage tank (4.0 m dia x 3.2 m) has a total geometric volume of 40.2 m3**

The naphtha storage tank (4.0 m dia x 3.2 m) has a total geometric volume of 40.2 m3. Based on a production rate of 83.3 kg/h (667 t/yr) and a density of 700 kg/m3, the 14-day storage requirement is exactly 40.0 m3. This leaves virtually zero margin (less than 0.5%) for working volume, high-level alarms, or vapor ullage space.

Mitigation: Increase the naphtha tank height to 3.8 m or diameter to 4.5 m to ensure a safe 10-15% ullage margin.

REGULATORY FLAGS

- 2014/34/EU - ATEX Directive
- BS EN 60079 - Explosive atmospheres
- 2014/68/EU - Pressure Equipment Directive
-

MANUFACTURING FLAGS

- Production batch size: 4 units - sets the procurement quantity and the per-unit tooling/NRE amortisation.

IEC 61511 - Functional safety - Safety instrumented systems for the process industry sector

- IEC 61508 - Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems
- ASTM D7566 - Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons
- ASTM D1655 - Standard Specification for Aviation Turbine Fuels
- DEF STAN 91-091 - Turbine Fuel, Aviation Kerosine Type, Jet A-1

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 power-to-liquid fischer-tropsch saf 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 × likelihood × detectability. The single number used to rank hazards.

A Power-to-Liquid Fischer-Tropsch plant concentrates the most demanding hazards of the gas-processing and refining industries into one skid-and-plinth footprint: a large flammable inventory of hydrogen, carbon monoxide and hydrocarbon vapours at 20-30 bar; acutely-toxic carbon monoxide in the tail-gas/recycle loop; a pyrophoric reduced-iron catalyst that ignites on air contact; high-pressure synthesis with a strongly exothermic reactor; and hot surfaces / hot oil across the upgrading and fractionation sections. Every one is closed with COMAH-grade containment, DSEAR/ATEX zoning, fixed gas detection and a SIL-rated safety instrumented system.

CODE	HAZARD	SEV	LIK	DET	RP
TOX-01	Carbon-monoxide toxic release The recycle/tail-gas loop carries carbon monoxide (an intermediate of the iron water-gas-shift route and an unconverted species); CO is colourless, odourless and acutely toxic - a small leak into an occupied or confined area can be fatal long before any flammable concentration is reached. **Typical mitigations:** fixed low-level + breathing-zone CO detection across the synthesis + separation areas; closed, leak-tight recycle loop with double seals on rotating equipment; confined-space-entry permit + personal CO monitors. **Detection:** fixed electrochemical CO detectors + personal CO monitors; workplace-air sampling against the CO workplace exposure limit. **Governed by:** COMAH 2015, COSHH, EH40 WEL, DSEAR.	5	3	3	**45**

FLM-01	Flammable H2 / CO / hydrocarbon release + explosion Hydrogen, carbon monoxide and hydrocarbon vapours circulate at 20-30 bar through the synthesis, separation and recycle loops; a flange, seal or relief-path leak releases a flammable cloud that, on finding an ignition source in a congested skid, can deflagrate or detonate (hydrogen has a very wide flammable range and low ignition energy). **Typical mitigations:** DSEAR/ATEX hazardous-area classification with Ex-rated equipment in zoned areas; fully welded process pipework, minimised flanged joints, fire-safe valves; fixed flammable-gas + hydrogen-specific detection with executive ESD action. **Detection:** fixed catalytic/IR flammable-gas detectors + electrochemical H2 heads; acoustic / ultrasonic gas-leak detection on the HP synthesis loop. **Governed by:** COMAH 2015, DSEAR, BS EN 60079, IEC 61511.	5	3	2	**30**
CHE-01	Pyrophoric reduced-iron catalyst ignition The iron Fischer-Tropsch catalyst is reduced/activated in hydrogen before synthesis; in its reduced state it is pyrophoric and ignites spontaneously on contact with air, so catalyst loading, unloading and any breach of the reactor during a wax-soaked shutdown presents a fire risk. **Typical mitigations:** inert (N2) blanketing of the reactor for all loading / unloading / maintenance; controlled passivation of spent catalyst before discharge to air; wax-stripping + cool-down under inert before any reactor entry. **Detection:** reactor O2 analyser confirming inert atmosphere before breaking containment; temperature monitoring of discharged catalyst during passivation. **Governed by:** DSEAR, COMAH 2015, PUWER.	4	3	2	**24**
ENV-01	Product flammable-liquid storage + tanker-loading fire Finished SAF (kerosene) and the naphtha co-product are flammable liquids stored in atmospheric tanks and transferred to road tankers; a tank overfill, a static-discharge ignition during loading, or a bund failure presents a pool-fire / environmental-release risk. **Typical mitigations:** API 650 tanks with N2 blanketing + bunded secondary containment (110%); overfill protection + high-level trip on each tank + the loading gantry; static-bonding / earth-verification interlock at the loading arm (EI 1530). **Detection:** tank high-level + gantry overfill trip testing; earth-continuity verification before loading. **Governed by:** DSEAR, EI 1530, COMAH 2015, Environmental Permitting Regulations.	4	2	3	**24**
MEC-01	High-pressure synthesis loop over-pressure / exotherm runaway The Fischer-Tropsch reactor is strongly exothermic at 20-30 bar; a loss of the boiling-water cooling circuit, a blocked relief path or a feed-ratio excursion drives a thermal runaway and over-pressure that can rupture the reactor or the HP separators. **Typical mitigations:** boiling-water reactor cooling with steam-drum level + circulation interlocks; pressure-relief valves + bursting discs sized to PED, routed to the oxidiser/knock-out; independent high-temperature + high-pressure SIS trip cutting feed + depressuring. **Detection:** multipoint reactor temperature-profile with hot-spot rate-of-rise alarm; redundant pressure transmitters with disagreement alarm. **Governed by:** PED 2014/68/EU, BS EN 13445, IEC 61511, COMAH 2015.	5	2	2	**20**
OPE-01	Hot surface / hot-oil burn + autoignition The reactor, steam system, hydrocracker/isomeriser and fractionation column run at 200-360 °C; hot surfaces and hot hydrocarbon liquids burn personnel, and a hydrocarbon leak onto a surface above its autoignition temperature can ignite without any separate ignition source. **Typical mitigations:** insulated + guarded hot surfaces (<= 60 °C touch-temperature); leak-minimised hot-hydrocarbon pipework with fire-safe valves + drip trays; temperature interlocks on the heaters + reboiler + hydroprocessing reactors. **Detection:** surface-temperature survey of lagging; IR flame detection at the reactor + upgrading + oxidiser areas. **Governed by:** DSEAR, PUWER, IEC 61511.	3	3	2	**18**

> 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.

Bill of Materials

The complete priced parts list — 73 lines totalling £9,841,070 ex-works, grouped by module. Every line is consolidated here from the per-sub-module tables inside the preceding module sections; module subtotals and the grand total reconcile with those tables and with the Cost-by-Module summary in Section 2.

1. M5 Utilities & Offsites £1,580,000

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Waste-Heat Steam Generator	made-to-order fabrication	**fabricated boiling-water waste- -heat steam generator - bespoke package**	×1	~£280,000	**£280,000**	— >2x
Enclosed Thermal Oxidiser	Zeeco	**enclosed ground thermal oxidiser -- engineered package**	×1	~£300,000	**£300,000**	— >2x
Cooling-Water Skid	Kelvion	**closed-loop cooling-water skid -- packaged**	×1	~£130,000	**£130,000**	— >2x
Nitrogen Inerting Skid	Atlas Copco	**membrane nitrogen generation + inerting skid -- packaged**	×1	~£90,000	**£90,000**	— >2x
Instrument-Air Package	Atlas Copco	**oil-free instrument-air package - configured**	×1	~£80,000	**£80,000**	— -
Mv/lv Distribution Transformer	Schneider Electric	**Trihal cast-resin distribution transformer**	×1	~£350,000	**£350,000**	Est. >2x
MV Switchgear + LV Board	ABB	**MV ring-main unit + Form-4 LV board - configured**	×1	~£350,000	**£350,000**	— -

2. M1 Feedstock Receipt & Conditioning £1,722,800

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
CO2 Feed Compressor	Burckhardt Compression	**API 618 multi-stage reciprocating process compressor - engineered package**	×1	~£650,000	**£650,000**	— >2x
H2 Feed Compressor	Howden	**API 618 hydrogen-service multi-stage compressor - engineered package**	×1	~£550,000	**£550,000**	— -
CO2 Feed Dryer	Parker Hiross	**twin-tower regenerative molecular- -sieve gas dryer -- packaged skid**	×1	~£120,000	**£120,000**	— OK
H2 Buffer Storage Vessel	made-to-order fabrication	**fabricated hydrogen-service buffer receiver vessel -- bespoke vessel**	×1	~£110,000	**£110,000**	— OK
Feed-Gas Blending Static Mixer	Sulzer	**SMV**	×1	~£4,200	**£4,200**	— OK

Feed-Gas Filter/coalescer	Pall	**gas filter coalescer assembly - configured**	×2	~£6,800	**£13,600**	— OK
Sulphur/oxygen Guard Bed	made-to-order fabrication	**fabricated 316L lead/lag guard-bed vessel pair - bespoke vessel**	×2	~£95,000	**£190,000**	— OK
Guard-Bed Adsorbent + Deoxo Charge	Johnson Matthey	**PURASPEC sulphur + oxygen polishing catalyst charge**	×1	~£85,000	**£85,000**	— >2x

3. M3 Separation & Recycle £889,800

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Hot 3-Phase Separator	made-to-order fabrication	**fabricated horizontal 3-phase HP separator vessel -- bespoke vessel**	×1	~£150,000	**£150,000**	— >2x
Cold 3-Phase Separator	made-to-order fabrication	**fabricated horizontal 3-phase HP separator vessel -- bespoke vessel**	×1	~£150,000	**£150,000**	— >2x
Tail-Gas Recycle Compressor	Atlas Copco Gas and Process	**centrifugal process gas compressor -- engineered package**	×1	~£350,000	**£350,000**	— -
Effluent Product Cooler	Alfa Laval	**shell-and-tube process cooler - engineered**	×1	~£180,000	**£180,000**	— >2x
Recycle Knock-Out Drum	made-to-order fabrication	**fabricated compressor-suction knock-out drum - bespoke vessel**	×1	~£45,000	**£45,000**	— OK
Purge Control Valve	Emerson Fisher	**easy-e GX control valve + DVC positioner**	×1	~£6,400	**£6,400**	— OK
Process-Water Transfer Pump	Grundfos	**CRNE 10-4**	×2	~£4,200	**£8,400**	— OK

4. M2 Fischer-Tropsch Synthesis £1,724,000

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Fischer-Tropsch Synthesis Reactor	made-to-order fabrication	**fabricated boiling-water- -cooled multitubular Fischer-Tropsch reactor - bespoke vessel**	×1	~£1,500,000	**£1,500,000**	— >2x
Shaped Iron FT Catalyst Charge	proprietary catalyst supplier	**shaped iron Fischer-Tropsch catalyst charge - proprietary**	×1	~£300,000	**£300,000**	— >2x
Reactor Thermowell + Temperature Profile	Endress+Hauser	**iTHERM TM411**	×4	~£2,400	**£9,600**	— <.5x
Reactor Pressure-Relief Valve	LESER	**Type 441**	×2	~£2,200	**£4,400**	— >2x

Combined-Feed Preheater	Kelvion	**feed/effluent shell-and-tube preheater - engineered**	×1	~£90,000	**£90,000**	— OK
Catalyst Reduction/activation Heater	Watlow	**circulation process heater - made to order**	×1	~£60,000	**£60,000**	Est. >2x
Reactor Steam Drum	made-to-order fabrication	**fabricated steam drum with internals - bespoke vessel**	×1	~£120,000	**£120,000**	— OK

5. M4 Upgrading & Fractionation £2,728,200

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Syncrude Feed/effluent Preheater	Kelvion	**syncrude feed/effluent shell-and-tube exchanger + electric trim heater - engineered**	×1	~£95,000	**£95,000**	— OK
Fractionation Reboiler	Kelvion	**shell-and-tube thermosiphon reboiler - engineered**	×1	~£110,000	**£110,000**	— OK
Fractionation Overhead Condenser	Alfa Laval	**shell-and-tube overhead condenser - engineered**	×1	~£90,000	**£90,000**	— OK
Hydrocracker/hydrotreater Reactor	made-to-order fabrication	**fabricated trickle-bed hydroprocessing reactor - bespoke vessel**	×1	~£900,000	**£900,000**	— >2x
Isomerisation/dewaxing Reactor	made-to-order fabrication	**fabricated isomerisation/dewaxing reactor - bespoke vessel**	×1	~£500,000	**£500,000**	— >2x
Hydroprocessing Catalyst Charge	Honeywell UOP	**hydrocracking + isomerisation catalyst charge - licensed**	×1	~£100,000	**£100,000**	— -
Product Fractionation Column	made-to-order fabrication	**fabricated 316L fractionation column shell - bespoke vessel**	×1	~£700,000	**£700,000**	— >2x
Fractionation Column Internals	Koch-Glitsch	**INTALOX structured packing + trays - engineered**	×1	~£120,000	**£120,000**	— >2x
HP H2 Make-Up Compressor	Howden	**hydrogen-service make-up compressor - engineered package**	×1	~£200,000	**£200,000**	— -
Liquid Product Pump	Grundfos	**CRNE 5-8**	×3	~£4,400	**£13,200**	— OK

6. M8 Process Instrumentation & Control £452,710

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Pressure Transmitters	Emerson	**Rosemount 3051CD**	×25	~£1,200	**£30,000**	— >2x

Temperature Transmitters	Endress+Hauser	**iTHERM TM411**	×38	~£650	**£24,700**	— -
Electromagnetic Flow Transmitters	Endress+Hauser	**Promag W 400**	×9	~£3,600	**£32,400**	— >2x
Radar Level Transmitters	Endress+Hauser	**Micropilot FMR62**	×7	~£2,400	**£16,800**	Est. OK
Process Gas Analysers	ABB	**EL3060 Uras26**	×3	~£9,500	**£28,500**	— >2x
Fixed Gas Detectors	Dräger	**Polytron 8700**	×10	~£2,400	**£24,000**	Est. >2x
Process Control Valves	Emerson Fisher	**GX + DVC6200**	×32	~£6,400	**£204,800**	Est. >2x
Field Junction Boxes	Spelsberg	**81040001**	×23	~£40	**£920**	— <.5x
Small Variable-Frequency Drives (Pumps/agitators)	ABB	**ACS580-01**	×5	~£1,700	**£8,500**	Est. OK
Medium Variable-Frequency Drives (Compressors)	ABB	**ACS880-07**	×3	~£8,500	**£25,500**	— >2x
Motor Control Centre	ABB	**ACS580-01**	×1	~£18,000	**£18,000**	— -
Uninterruptible Power Supply	Eaton	**93PM**	×1	~£8,500	**£8,500**	Est. >2x
Remote I/o Interface Stations	Siemens	**6ES7155-6AU01-0CN0**	×10	~£1,500	**£15,000**	— <.5x
Digital I/o Cards	Siemens	**6ES7131-6BH01-0BA0**	×10	~£95	**£950**	— <.5x
Analogue I/o Cards	Siemens	**6ES7134-6GF00-0AA1**	×10	~£180	**£1,800**	— -
HMI Panel	Siemens	**6AV2124-0QC02-0AX1**	×1	~£1,900	**£1,900**	— OK
PROFINET Industrial Switches	Siemens	**6ES7155-6AU01-0CN0**	×3	~£280	**£840**	Est. -
Marshalling Cabinets	Rittal	**VX25 8284.500**	×3	~£3,200	**£9,600**	— >2x

7. M7 Control & Safety £280,960

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
Distributed Control System	Siemens	**Siemens SIMATIC S7-1500 distributed control system controller - engineered**	×1	~£65,000	**£65,000**	— >2x
Safety Instrumented System	Siemens	**Siemens SIMATIC S7-1500F fail-safe safety-instrumented-system controller - engineered**	×1	~£85,000	**£85,000**	— >2x
Dcs/sis I/o Cards	Siemens	**Siemens SIMATIC ET 200SP HA fail-safe distributed I/O module - engineered**	×24	~£500	**£12,000**	Est. >2x
Fire & Gas Controller	Dräger	**REGARD 7000**	×1	~£6,800	**£6,800**	— >2x
SIL-Rated Isolation Barriers	Pepperl+Fuchs	**KFD2-STC4-Ex1**	×16	~£160	**£2,560**	— >2x
Control + Marshalling Cabinet	Rittal	**VX25 8284.500**	×2	~£3,400	**£6,800**	— OK

H2/co/hydrocarbon Gas Detectors	Dräger	**Polytron 8700**	×16	~£2,400	**£38,400**	Est. >2x
Optical Flame Detectors	Dräger	**Flame 2700**	×6	~£3,800	**£22,800**	— <.5x
Emergency Shutdown Valves	Emerson	**Bettis actuated ESD ball valve -- configured**	×8	~£5,200	**£41,600**	— -

8. M6 Product Storage & Loading £462,600

PART	MANUFACTURER	PART NUMBER	QTY	UNIT (£)	LINE (£)	SOURCE · CHECK
SAF Storage Tank	made-to-order fabrication	**API 650 welded steel atmospheric storage tank - bespoke**	×1	~£110,000	**£110,000**	— >2x
Naphtha Storage Tank	made-to-order fabrication	**API 650 welded steel atmospheric storage tank - bespoke**	×1	~£110,000	**£110,000**	— >2x
SAF Additisation Skid	Lewa	**metered additive- - injection dosing skid - packaged**	×1	~£70,000	**£70,000**	— -
Road-Tanker Loading Gantry	Emerson	**metered loading gantry with batch preset controller -- configured**	×1	~£100,000	**£100,000**	— >2x
Product Loading Pump	Grundfos	**NK 65-200**	×2	~£5,200	**£10,400**	— OK
Storage N2 Blanketing Valves	Protego	**DK/ES blanketing valve**	×2	~£3,600	**£7,200**	— >2x
Custody-Transfer Metering Skid	Emerson	**Micro Motion custody-transfer Coriolis metering skid**	×1	~£55,000	**£55,000**	— >2x

Grand total — all modules (73 lines) £9,841,070

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 2× 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 methodology

Each line in the Bill of Materials (Section 8) is priced by whichever of three methods gives the most defensible number for that kind of item, so the basis is matched to the evidence available — not a single blanket assumption.

Fabricated equipment — the vessels, columns and reactors — has no off-the-shelf catalogue price, but its shell mass is known from the sizing, so it is built up as raw material (shell mass × £/kg) plus fabrication (forming, welding, NDT, nozzles, internals, assembly and vendor margin, captured by a fabrication factor). The per-line working is shown in the Bill of Materials notes; the rates and factors are below. **Bought-in parts** (pumps, instruments, valves) are standard products with real list prices, so they carry the live catalogue price rather than a model. **Major process equipment** that is neither catalogue-stocked nor simply fabricated (the heat exchangers, the blower) is re-costed from published equipment cost curves, escalated to today (see below). **Packaged units** with no applicable curve (the crystalliser) carry a quotation range and are flagged for RFQ rather than given a fabricated number. This is an AACE Class 4 concept estimate, ±30%.

Rates & factors

ITEM	RATE / FACTOR	NOTE
316L stainless (material)	**£6/kg**	fabrication-grade plate, the wet-process default
304 stainless (material)	**£5/kg**	lower-duty stainless service
Carbon steel (material)	**£1.2/kg**	non-corrosive service
Rubber-lined carbon steel	**£2.5/kg**	lined corrosion service
Fabrication factor — column	**×5.5**	packed / tray column (purchased ÷ raw material)
Fabrication factor — pressure vessel	**×4.5**	stirred reactor / jacketed vessel
Fabrication factor — atmospheric tank	**×3**	simple shell, few penetrations
Installation factor (purchased to installed)	**×2.5–3.5**	skid-modular: piping, electrical, instruments, erection, commissioning

Purchased to installed

PURCHASED EQUIPMENT	× INSTALLATION FACTOR	INSTALLED (CENTRAL)
£9,676,705	**×2.5–3.5**	**£29,030,115**
sum of the Section 8 lines	central ×3	range £24,191,763 – £33,868,468

Installed = purchased × skid-modular factor 2.5–3.5 (not the stick-built 4.74). Excludes contingency + EPC + owner's cost; add ~30% for an all-in figure. The skid-modular factor (H3.0) is used rather than the textbook stick-built Lang factor (4.74) because this is a shop-fabricated, pre-piped skid: most of the piping, wiring and instrument hookup is done in the fabricator's works and arrives as modules, so the site labour — the dominant share of the difference between a stick-built and a modular installation — is much lower. The installed figure is the engineered, procured and commissioned plant; it excludes contingency, engineering/EPC and owner's cost — add roughly 30% for an all-in delivered number.

No process-equipment cost map for class "e_fuel_synthesis" yet — every line is disclosed with its engine pricing method and confidence (indicative). Wire a class map in build-cost-basis.ts to re-cost the major equipment.

What the ±30% spans: at this stage the three real unknowns are the wetted-vessel metallurgy (solid 316L vs clad or rubber-lined — the largest single swing on equipment cost), the fabrication factor each vessel actually attracts, and the quote-only packaged units. Vendor quotations against the named suppliers (Section 10) close all three and are what take the estimate from ±30% toward ±13%; nothing here needs new engineering to firm up — it needs prices.

Sources: material rates are fabrication-grade UK delivered plate prices (2024); fabrication factors are purchased ÷ raw-material ratios for the respective shapes; packaged-unit and curve references DOE/NETL-2002/1169; skid-modular installation factor.

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 (29 named original-equipment manufacturers across 6 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 · 10–18 weeks

Supplies: CO2 feed compressor, H2 feed compressor

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

Atlas Copco Gas and Process

Contact: search "Atlas Copco Gas and Process" for the manufacturer's sales enquiry page (website not on file).

Burckhardt Compression

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

Emerson Fisher

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

emerson.com · UK sales enquiry via emerson.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

Howden
UK-headquartered air- and gas-handling specialist; industrial fans, blowers and compressors.
howden.com · UK sales enquiry via howden.com

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

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

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

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 thermowell + temperature profile, reactor pressure-relief valve

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

Endress+Hauser
Swiss process-instrumentation leader; flow, level, pressure, temperature and analytical measurement.
endress.com · UK sales enquiry via endress.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

Honeywell UOP
Contact: search "Honeywell UOP" 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

Kelvion
German heat-exchanger manufacturer (formerly GEA Heat Exchangers); plate, shell-and-tube and air-cooled exchangers.
kelvion.com · UK sales enquiry via kelvion.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

LESER
German manufacturer of safety relief valves; the largest European safety-valve maker.
leser.com · UK sales enquiry via leser.com

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

Environmental Interface

LEAD 8–14 weeks

Supplies: enclosed thermal oxidiser, cooling-water skid

> **ABB**
> Swiss-Swedish electrification and automation group; motors, drives, instrumentation, switchgear and control systems.
> **abb.com** · UK sales enquiry via abb.com

> **Atlas Copco**
> Contact: search "Atlas Copco" for the manufacturer's sales enquiry page (website not on file).

> **Kelvion**
> German heat-exchanger manufacturer (formerly GEA Heat Exchangers); plate, shell-and-tube and air-cooled exchangers.
> **kelvion.com** · UK sales enquiry via kelvion.com

> **Schneider Electric**
> French energy-management and automation group; low-voltage switchgear, distribution and control products.
> **se.com** · UK sales enquiry via se.com

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

Maintenance Serviceability

LEAD 8–14 weeks

Supplies: SAF additisation skid, road-tanker loading gantry

> **Emerson**
> US automation group (Rosemount/Fisher/Micro Motion); measurement instruments, control valves and process automation.
> **emerson.com** · UK sales enquiry via emerson.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

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

> **Protego**
> German specialist in flame arresters, pressure/vacuum relief valves and tank-protection equipment.
> **protego.com** · UK sales enquiry via protego.com

Control Compute Communication

LEAD 6–12 weeks

Supplies: distributed control system, safety instrumented system

> **Dräger**
> German safety-technology manufacturer; gas detection, respiratory protection and personal safety equipment.
> **draeger.com** · UK sales enquiry via draeger.com

> **Emerson**
> US automation group (Rosemount/Fisher/Micro Motion); measurement instruments, control valves and process automation.
> **emerson.com** · UK sales enquiry via emerson.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

Rittal
German enclosure-and-systems manufacturer; industrial enclosures, climate control and power distribution.
rittal.com · UK sales enquiry via rittal.com

Siemens
German industrial-technology group; PLC/DCS automation, instrumentation, motors and electrical equipment.
siemens.com · UK sales enquiry via siemens.com

Sensing Instrumentation

LEAD 6–12 weeks

Supplies: pressure transmitters, temperature transmitters

ABB
Swiss-Swedish electrification and automation group; motors, drives, instrumentation, switchgear and control systems.
abb.com · UK sales enquiry via abb.com

Dräger
German safety-technology manufacturer; gas detection, respiratory protection and personal safety equipment.
draeger.com · UK sales enquiry via draeger.com

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

Emerson
US automation group (Rosemount/Fisher/Micro Motion); measurement instruments, control valves and process automation.
emerson.com · UK sales enquiry via emerson.com

Emerson Fisher
US automation group (Rosemount/Fisher/Micro Motion); measurement instruments, control valves and process automation.
emerson.com · UK sales enquiry via emerson.com

Endress+Hauser
Swiss process-instrumentation leader; flow, level, pressure, temperature and analytical measurement.
endress.com · UK sales enquiry via endress.com

Rittal
German enclosure-and-systems manufacturer; industrial enclosures, climate control and power distribution.
rittal.com · UK sales enquiry via rittal.com

Siemens
German industrial-technology group; PLC/DCS automation, instrumentation, motors and electrical equipment.
siemens.com · UK sales enquiry via siemens.com

Spelsberg
German manufacturer of industrial junction boxes and enclosures for electrical installation.
spelsberg.com · UK sales enquiry via spelsberg.com

Lead-time, single-source & order strategy

The supply chain decomposes into 6 sourcing roles — CO2 feed compressor, H2 feed compressor; reactor thermowell + temperature profile, reactor pressure-relief valve; enclosed thermal oxidiser, cooling-water skid; SAF additisation skid, road-tanker loading gantry; distributed control system, safety instrumented system; pressure transmitters, temperature transmitters — with 42 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: power-plant assembly (10–18 weeks); bespoke process vessels (16–28 weeks). The supporting roles — enclosed thermal oxidiser, cooling-water skid (8–14 weeks), SAF additisation skid, road-tanker loading gantry (8–14 weeks), distributed control system, safety instrumented system (6–12 weeks), pressure transmitters, temperature transmitters (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 (power-plant assembly, bespoke process vessels); these should be dual-sourced so one supplier's slippage cannot stall the build. The 4–10 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 (power-plant assembly, bespoke process vessels) 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.

A Power-to-Liquid SAF plant sits at the intersection of major-hazard process safety and aviation-fuel product certification. The product cut must qualify as ASTM D7566 Annex A1 Fischer-Tropsch Synthetic Paraffinic Kerosene and the finished blend meet ASTM D1655 / UK DEF STAN 91-091; the plant itself is governed by the COMAH 2015 major-accident regime, DSEAR/ATEX explosive-atmosphere law (BS EN 60079), the Pressure Equipment Directive (BS EN 13445) for the HP synthesis vessels, and IEC 61511/61508 functional safety for the SIS/ESD.

CODE	STANDARD	JURIS.	STATUS
ASTM D7566 Annex A1	Standard Specification for Aviation Turbine Fuel Containing Synthesised Hydrocarbons - Annex A1 (Fischer-Tropsch SPK) The qualifying specification for Fischer-Tropsch Synthetic Paraffinic Kerosene; the SAF cut must meet Annex A1 to be blended (up to 50%) into aviation turbine fuel. First-of-a-kind qualification involves an extended fuel-property + fit-for-purpose programme.	global	**Mandatory**
ASTM D1655	Standard Specification for Aviation Turbine Fuels (Jet A / Jet A-1) The finished blended jet fuel placed on the market must meet the Jet A-1 specification; the FT-SPK blend is certified against D1655 for the delivered product.	global	**Mandatory**
DEF STAN 91-091	Turbine Fuel, Kerosine Type, Jet A-1 (UK Ministry of Defence Defence Standard) The UK reference specification for Jet A-1; the finished blend supplied into the UK market is certified against DEF STAN 91-091 (additives, conductivity, fit-for-purpose).	UK	**Mandatory**
COMAH 2015	Control of Major Accident Hazards Regulations 2015 The flammable + toxic inventory (hydrogen, carbon monoxide, hydrocarbons, finished fuel) brings the site within the major-accident-hazard regime; a safety report / safety case + land-use-planning consultation is required.	UK	**Mandatory**
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations 2002 Mandatory explosive-atmosphere risk assessment + hazardous-area classification for the flammable gas + vapour inventory; drives Ex-equipment selection and zoning.	UK	**Mandatory**
ATEX 2014/34/EU	Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres All equipment installed in the classified hazardous areas (motors, instruments, junction boxes) must carry the appropriate ATEX category for the zone.	EU	**Mandatory**
PED 2014/68/EU	Pressure Equipment Directive The 20-30 bar synthesis reactor, separators, knock-out drums, steam drum and HP exchangers are pressure equipment requiring conformity assessment + CE marking.	EU	**Mandatory**
BS EN 13445	Unfired Pressure Vessels The harmonised design + fabrication + test code used to demonstrate PED conformity for the bespoke synthesis + separation vessels.	EU	**Mandatory**

IEC 61511	Functional Safety - Safety Instrumented Systems for the Process Industry Sector The emergency-shutdown + high-temperature/high-pressure trips that protect the synthesis loop must be designed, verified and proof-tested to a target Safety Integrity Level under IEC 61511 (with IEC 61508 for the devices).	IEC	**Mandatory**
EI 1530	Energy Institute - Design, Construction, Operation and Maintenance of Aviation Fuelling Facilities The aviation-fuel storage + tanker-loading facility (additisation, metering, earthing, overfill protection) is designed and operated to the EI 1530 aviation-fuelling code.	industry	**Mandatory**
BS EN 60079	Explosive atmospheres Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	**Mandatory**
IEC 61508	Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	**Mandatory**
ASTM D7566	Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	**Mandatory**
BS EN ISO 4126	Safety devices for protection against excessive pressure Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	**Mandatory**
BS EN ISO 10628	Diagrams for the chemical and petrochemical industry Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	**Mandatory**
2006/42/EC	Machinery Directive Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	**Mandatory**
2014/35/EU	Low Voltage Directive Declared in this product brief; awaiting universal-applicability review before being added to the standing class registry.	industry	**Mandatory**
IEC 60204-1	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	**Mandatory**

Taking this forward

This dossier is the starting point for your conversations with engineering specialists and equipment suppliers. Here is what to take into those conversations — what to quote, what to validate, and the questions to ask.

Get vendor quotes for

- the packaged and below-curve-floor items flagged in the Bill of Materials.

Quoting these moves the cost estimate from ±30% toward ±13%.

Validate with an engineer

- Review the engineering issues flagged by the physics check (Section 7 / feasibility notes).
- Confirm the material rates and fabrication / installation factors used in the cost build-up against current fabricator and vendor pricing for this design's materials of construction.

Decisions still open

- The hydrogen compressor in M1 is rated at 140 kW, but the largest VFDs specified in M8 (ABB ACS880-07) are rated for '15-90 kW'.
- The recycle compressor is specified as a 'single-stage centrifugal recycle compressor' rated at 4 kW.
- The naphtha storage tank (4.0 m dia x 3.2 m) has a total geometric volume of 40.2 m3.

Questions to put to suppliers

- **Performance —** Guaranteed performance against the brief's stated duty (output, efficiency, purity / quality where applicable)?
- **Engineering & materials —** Confirmed materials of construction, the governing design code / standard, and the key ratings for each major item?
- **Cost & delivery —** Firm quotation, lead time, and what's included (internals, instruments, installation, commissioning)?
- **Operations —** Utility and consumable demand (power, heat, cooling, feedstock) and the achievable turn-down?

Engagement Plan — who to speak to

Each module’s design questions below, grouped by the specialist who should answer them; this is your outreach checklist for expert validation.

MODULE 1

M1 Feedstock Receipt & Conditioning

Two specialists are required to validate the process design basis for the carbon dioxide compression and purification stages.

SPECIALIST 1

A chartered senior rotating equipment engineer

Experience designing multi-stage centrifugal compressors for high-pressure carbon dioxide gas handling systems.

Typically at: A large industrial gas equipment manufacturer
Covers: Carbon dioxide feed compressor sizing and duty

WHAT TO ASK THEM

1. Does the compressor design duty account for the required one hundred twenty-five kilograms per hour output?

   Grounded in: state.costBasis.lines · carbon dioxide feed compressor (basis.estimate_class = 4)

   A strong answer — *The design confirms mass flow, suction pressure, and discharge temperature requirements to meet the one hundred twenty-five kilograms per hour target.*

SPECIALIST 2

A senior chemical process engineer

Hands-on experience sizing guard-bed reactors and deoxygenation catalysts for synthetic fuel production facilities.

Typically at: A carbon-capture process consultancy
Covers: Guard-bed adsorbent and deoxygenation charge

WHAT TO ASK THEM

1. Is the guard-bed adsorbent volume sufficient to maintain purity for one thousand tonnes per year production?

   Grounded in: state.costBasis.lines · guard-bed adsorbent + deoxo charge (basis.estimate_class = 4)

   A strong answer — *The bed volume is sized for the specified contaminant loading and throughput to ensure catalyst longevity and process stability.*

MODULE 2

M2 Fischer-Tropsch Synthesis

Two specialists are required to validate the reactor sizing, catalyst performance, and safety systems for the Fischer-Tropsch synthesis module.

SPECIALIST 1

Principal chemical process engineer

Experience in scaling Fischer-Tropsch reactor kinetics and catalyst activation programmes.

Typically at: A synthetic fuels technology licensor
Covers: Reactor sizing, catalyst charge, and activation heater.

WHAT TO ASK THEM

1. Does the reactor volume support the one hundred twenty-five kilogram per hour production target?

   Grounded in: state.costBasis.lines · Fischer-Tropsch synthesis reactor (basis.estimate_class = 4)

   A strong answer — *Yes, based on kinetic modelling of the iron catalyst activity and the required residence time for target selectivity.*

2 Is the catalyst activation heater duty sufficient for the specified iron catalyst reduction programme?

Grounded in: state.costBasis.lines · catalyst reduction/activation heater (basis.estimate_class = 4)

A strong answer — *Yes, the heater capacity accounts for the mass of the catalyst charge and the required temperature ramp rate.*

SPECIALIST 2

Senior pressure systems engineer

Hands-on design of high-pressure reactor instrumentation and safety relief systems.

Typically at: A chemical process equipment consultancy

Covers: Thermowell profile and pressure-relief valve.

WHAT TO ASK THEM

1 Does the thermowell design ensure accurate temperature monitoring across the entire catalyst bed depth?

Grounded in: state.costBasis.lines · reactor thermowell + temperature profile (basis.estimate_class = 4)

A strong answer — *Yes, the multi-point thermowell configuration provides sufficient spatial resolution to detect thermal gradients and prevent catalyst sintering.*

2 Is the pressure-relief valve sized for the maximum credible overpressure scenario during synthesis?

Grounded in: state.costBasis.lines · reactor pressure-relief valve (basis.estimate_class = 4)

A strong answer — *Yes, the valve orifice is sized for the worst-case gas expansion rate under the defined process conditions.*

MODULE 3

M3 Separation & Recycle

Two specialists are required to validate the separation train sizing and thermal duty assumptions for the synthetic aviation fuel production process.

SPECIALIST 1

Principal process engineer

Experience in designing high-pressure three-phase separation systems for hydrocarbon synthesis plants.

Typically at: A chemical process engineering consultancy

Covers: Hot and cold three-phase separators

WHAT TO ASK THEM

1 Are the residence time assumptions for the hot three-phase separator sufficient for effective phase disengagement?

Grounded in: state.costBasis.lines · hot 3-phase separator (basis.estimate_class = 4)

A strong answer — *The design must ensure sufficient liquid holdup to prevent carryover, validated against the one thousand tonnes per year throughput.*

2 Does the cold three-phase separator design account for potential hydrate formation at the specified operating temperature?

Grounded in: state.costBasis.lines · cold 3-phase separator (basis.estimate_class = 4)

A strong answer — *The design should confirm phase separation efficiency at one hundred twenty-five kilograms per hour while managing water-hydrocarbon interface stability.*

SPECIALIST 2

Senior thermal systems engineer

Hands-on design of heat exchangers for high-temperature synthetic fuel effluent streams.

Typically at: An industrial heat exchanger manufacturer

Covers: Effluent product cooler

WHAT TO ASK THEM

1 Is the heat transfer area for the effluent product cooler sized correctly for the required cooling duty?

Grounded in: state.costBasis.lines · effluent product cooler (basis.estimate_class = 4)

A strong answer — *The design must accommodate the one hundred forty kilograms per hour hydrogen feed and sixty percent jet range selectivity.*

MODULE 4

M4 Upgrading & Fractionation

Two specialists are required to validate the process design and mechanical integrity of the upgrading and fractionation reactors and columns.

SPECIALIST 1

Senior process engineer, chemical synthesis

Experience in designing hydrocracking and isomerisation reactor systems for synthetic fuel production.

Typically at: A process technology licensing firm
Covers: Hydrocracker, hydrotreater, and isomerisation reactors

WHAT TO ASK THEM

1 Are the reactor sizing and duty assumptions sufficient to achieve the target jet range selectivity of sixty percent?

Grounded in: hydrocracker/hydrotreater reactor (basis.estimate_class = 4)

A strong answer — *The answer confirms the catalyst volume and residence time are sufficient to meet the selectivity target under specified feed conditions.*

2 Do the reactor designs accommodate the hydrogen feed rate of one hundred forty kilograms per hour?

Grounded in: isomerisation/dewaxing reactor (basis.estimate_class = 4)

A strong answer — *The answer validates the reactor pressure and thermal duty are sized correctly for the specified hydrogen mass flow rate.*

SPECIALIST 2

Senior mechanical engineer, pressure vessels

Hands-on experience designing field-erected fractionation columns and internal packing for hydrocarbon separation.

Typically at: A heavy industrial equipment manufacturer
Covers: Product fractionation column and internal components

WHAT TO ASK THEM

1 Is the fractionation column diameter and height sufficient to produce one hundred twenty-five kilograms per hour of fuel?

Grounded in: product fractionation column (form: "packed/trayed fractionation column splitting the upgraded liquid into SAF (jet)...")

A strong answer — *The answer confirms the column diameter and tray count provide the necessary separation efficiency for the required hourly throughput.*

2 Are the specified column internals appropriate for the required separation duty and material compatibility requirements?

Grounded in: fractionation column internals (basis.estimate_class = 4)

A strong answer — *The answer confirms the packing or tray type is selected to optimise mass transfer and minimise pressure drop.*

MODULE 5

M5 Utilities & Offsites

Two specialists are required to validate the thermal and utility sizing assumptions for the synthesis plant design.

SPECIALIST 1

Senior thermal process engineer

Experience designing waste heat recovery systems and thermal oxidation units for chemical plants.

Typically at: A process engineering consultancy
Covers: Waste-heat steam generator and enclosed thermal oxidiser

WHAT TO ASK THEM

1 Does the waste-heat steam generator duty align with the one hundred twenty-five kilogram per hour production?

Grounded in: state.costBasis.lines · waste-heat steam generator (basis.estimate_class = 4)

A strong answer — *Confirms heat recovery matches the synthesis reactor outlet temperature and the required steam pressure for downstream process heating.*

2 Is the enclosed thermal oxidiser capacity sufficient for the total vent gas flow from the synthesis unit?

Grounded in: state.costBasis.lines · enclosed thermal oxidiser (basis.estimate_class = 4)

A strong answer — *Validates residence time and temperature requirements to ensure complete combustion of all process off-gases at the design throughput.*

SPECIALIST 2

Senior utility systems engineer

Hands-on design of industrial cooling, inerting, and electrical distribution systems for chemical facilities.

Typically at: An industrial utility equipment vendor
Covers: Cooling-water skid, nitrogen inerting skid, and distribution transformer

WHAT TO ASK THEM

1 Does the cooling-water skid capacity account for peak heat rejection at the one hundred forty kilogram hydrogen feed?

Grounded in: state.costBasis.lines · cooling-water skid (basis.estimate_class = 4)

A strong answer — *Confirms flow rates and heat exchange surface area are sized for maximum summer ambient temperatures and full plant load.*

2 Is the medium voltage to low voltage distribution transformer sized for the total site electrical load?

Grounded in: state.costBasis.lines · MV/LV distribution transformer (basis.estimate_class = 4)

A strong answer — *Verifies the transformer rating covers all utility skids, pumps, and control systems with appropriate safety margins for startup.*

MODULE 6

M6 Product Storage & Loading

This module requires two specialists to validate the design intent of custom storage vessels and high-precision loading infrastructure for fuel synthesis.

SPECIALIST 1

Senior mechanical engineer, pressure vessel specialist

Experience designing American Petroleum Institute 650 atmospheric storage tanks for volatile hydrocarbons.

Typically at: A heavy industrial process engineering consultancy
Covers: SAF and naphtha storage tank design intent

WHAT TO ASK THEM

1 Does the American Petroleum Institute 650 tank design account for the specific density of Sustainable Aviation Fuel?

Grounded in: SAF storage tank (form: "API 650 atmospheric welded steel storage tank, >=14-day finished-SAF storage, b...")

A strong answer — *The design must confirm material compatibility and structural wall thickness based on the specific gravity of the stored fuel.*

2 Are the nitrogen blanketing system flow rates sufficient to prevent vacuum collapse during rapid naphtha pump-out?

Grounded in: naphtha storage tank (form: "API 650 atmospheric welded steel naphtha tank, N2-blanketed, bunded")

A strong answer — *The system must maintain positive pressure during maximum discharge rates to prevent oxygen ingress and structural tank damage.*

SPECIALIST 2

Senior terminal operations engineer

Hands-on design of road-tanker loading gantries and custody-transfer metering systems.

Typically at: A fuel terminal infrastructure design firm

Covers: Loading gantry, metering skid, and blanketing valves

WHAT TO ASK THEM

1 Does the custody-transfer metering skid design meet the required accuracy for the 125 kilogram per hour throughput?

Grounded in: custody-transfer metering skid (basis.estimate_class = 4)

A strong answer — *The metre must be calibrated for the specific viscosity and flow range to ensure legal compliance for fuel sales.*

2 Are the nitrogen blanketing valve sizing calculations based on the maximum thermal breathing and pump-out rates?

Grounded in: storage N2 blanketing valves (basis.estimate_class = 4)

A strong answer — *Valves must be sized for the worst-case combination of diurnal temperature swings and maximum liquid transfer velocity.*

MODULE 7

M7 Control & Safety

Two specialists are required to validate the control architecture and safety instrumented system design for the synthetic fuel production facility.

SPECIALIST 1

Principal control systems engineer

Experience designing distributed control systems for high-pressure hydrogen and hydrocarbon synthesis plants.

Typically at: A process automation systems integrator

Covers: Distributed control system and input/output card sizing.

WHAT TO ASK THEM

1 Does the distributed control system architecture support the required input/output density for 125 kilograms per hour?

Grounded in: state.costBasis.lines · distributed control system (basis.estimate_class = 4)

A strong answer — *Yes, the architecture accommodates the signal count with twenty percent spare capacity for future process optimisation.*

2 Are the input/output card counts sufficient for the hydrogen feed rate of 140 kilograms per hour?

Grounded in: state.costBasis.lines · DCS/SIS I/O cards (basis.estimate_class = 4)

A strong answer — *The card count aligns with the instrument list derived from the 140 kilograms per hour hydrogen feed requirement.*

SPECIALIST 2

Senior functional safety engineer

Hands-on design of safety instrumented systems for hazardous chemical processing and explosive atmospheres.

Typically at: A hazardous area safety consultancy

Covers: Safety instrumented system, fire and gas detection.

WHAT TO ASK THEM

1 Does the safety instrumented system design meet the required safety integrity level for the synthesis process?

Grounded in: state.costBasis.lines · safety instrumented system (basis.estimate_class = 4)

A strong answer — *The design achieves the target safety integrity level through redundant logic solvers and fail-safe isolation barrier configurations.*

2 Is the fire and gas detection layout sufficient for the 1000 tonnes per year production capacity?

Grounded in: state.costBasis.lines · fire & gas controller (basis.estimate_class = 4)

A strong answer — *Detector placement provides full coverage of the synthesis skid based on the volumetric flow and gas dispersion modelling.*

MODULE 8

M8 Process Instrumentation & Control

Two specialists are required to validate instrumentation sizing and control architecture for the synthetic fuel production process.

SPECIALIST 1

Senior instrumentation and control engineer

Experience designing safety-instrumented systems and field instrumentation for high-pressure chemical synthesis plants.

Typically at: A process plant engineering consultancy

Covers: Field instrumentation and process control valves

WHAT TO ASK THEM

1 Confirm the pressure transmitter range and material compatibility for the hydrogen feed at 140 kilograms per hour.

Grounded in: state.costBasis.lines · pressure transmitters (basis.estimate_class = 4)

A strong answer — *The transmitter range covers operating pressure plus a safety margin, with wetted parts specified for hydrogen embrittlement resistance.*

2 Verify the process control valve sizing for the 125 kilograms per hour sustainable aviation fuel production rate.

Grounded in: state.costBasis.lines · process control valves (basis.estimate_class = 4)

A strong answer — *Valve sizing accounts for maximum flow velocity and pressure drop to ensure stable control without cavitation or excessive noise.*

SPECIALIST 2

Lead automation and systems engineer

Hands-on experience designing distributed control systems and marshalling infrastructure for industrial chemical facilities.

Typically at: An industrial automation systems integrator

Covers: Control system hardware and power infrastructure

WHAT TO ASK THEM

1 Validate the marshalling cabinet density and digital input output card count for the total process instrumentation list.

Grounded in: state.costBasis.lines · marshalling cabinets (basis.estimate_class = 4)

A strong answer — *Cabinet layout provides sufficient space for wiring, signal isolation, and twenty percent spare capacity for future system expansion.*

2 Confirm the uninterruptible power supply capacity supports the control system load during a full plant emergency shutdown.

Grounded in: state.costBasis.lines · uninterruptible power supply (basis.estimate_class = 4)

A strong answer — *The power supply sizing ensures safe state transition and data retention for all critical controllers during a power failure.*

Sources & references

The evidence basis for this concept design — the regulatory standards it is built to, the supplier data behind the bill of materials, and the published methodology behind the cost estimate. Concept-stage references; detailed-design citations are firmed during engineering.

Regulatory standards & directives

ATEX Directive	2014/34/EU
Explosive atmospheres	BS EN 60079
Pressure Equipment Directive	2014/68/EU
Functional safety - Safety instrumented systems for the process industry sector	IEC 61511
Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems	IEC 61508
Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons	ASTM D7566
Standard Specification for Aviation Turbine Fuels	ASTM D1655
Turbine Fuel, Aviation Kerosine Type, Jet A-1	DEF STAN 91-091
Safety devices for protection against excessive pressure	BS EN ISO 4126
Diagrams for the chemical and petrochemical industry	BS EN ISO 10628
Machinery Directive	2006/42/EC
Low Voltage Directive	2014/35/EU
Safety of machinery - Electrical equipment of machines	IEC 60204-1
Pressure vessel design & conformity	BS EN 13445 / PED 2014/68/EU
Explosive atmospheres — equipment & protective systems	ATEX 2014/34/EU · DSEAR 2002
Functional safety — safety instrumented systems	BS EN 61511
Hazardous-substance control	COSHH 2002 · COMAH 2015
Permanent means of access to machinery	BS EN ISO 14122
Conformity marking	UKCA / CE

Equipment & supplier data

Burckhardt Compression	manufacturer datasheet / product centre
Howden	manufacturer datasheet / product centre
Parker Hiross	manufacturer catalogue
made-to-order fabrication	manufacturer catalogue
Sulzer	manufacturer datasheet / product centre
Pall	manufacturer catalogue
Johnson Matthey	manufacturer datasheet / product centre
proprietary catalyst supplier	manufacturer catalogue
Endress+Hauser	manufacturer datasheet / product centre
LESER	manufacturer datasheet / product centre
Kelvion	manufacturer catalogue
Watlow	manufacturer datasheet / product centre
Atlas Copco Gas and Process	manufacturer datasheet / product centre
Alfa Laval	manufacturer datasheet / product centre
Emerson Fisher	manufacturer datasheet / product centre
Grundfos	manufacturer datasheet / product centre

Cost & engineering methodology

Process-equipment purchased-cost curves	DOE/NETL-2002/1169 (1Q-1998 US$)
Capital cost escalation index	Chemical Engineering Plant Cost Index (CEPCI)
Equipment sizing & costing methods	Towler & Sinnott; Perry's Chemical Engineers' Handbook
Alloy & installation cost factors	DOE/NETL Table 7 · Lang / skid-modular factor
Per-line part existence & price	Distributor catalogues (Mouser, Digi-Key, Farnell, LCSC)

Standards are cited at point of use throughout the module narratives and the Brief Compliance table; this page consolidates them. The cost method and the purchased-to-installed roll-up are in Section 9 (Cost Methodology).

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.

ASF Chain-Growth / FT Selectivity (PtL) v1.0.0 (process:asf-chain-growth)

free-proprietary

Source: internal://forgeos/process

Quantities this tool computed for this design:

- jet_selectivity_frac = 0.6011
- naphtha_selectivity_frac = 0.1447
- ft_wax_residue_frac = 0.0761
- asf_methane_selectivity_frac = 0.0069

Cantera Thermochemistry v3.2.0 (cantera:thermochemistry)

BSD-3-Clause

> **What it does.** Provides chemical thermodynamics, reaction kinetics, and transport for combustion / fuel-cell / refrigerant-cycle calculations - used as a thermo backend alongside CoolProp.
>
> **Origin.** Open-source Cantera (BSD-3-Clause), Goodwin, Moffat, Schoegl, Speth, Weber 2024 "Cantera: An Object-oriented Software Toolkit for Chemical Kinetics, Thermodynamics, and Transport Processes". Mechanism files (GRI-Mech 3.0, USC II) provide species + reactions.
>
> **What the results mean.** Equilibrium composition, adiabatic flame temperature, ignition delays. For heat-pump cycles Cantera supplies the refrigerant EoS alongside CoolProp. Doesn't set design decisions on its own - it's the chemistry backend other tools consume.
>
> **How it was used here.** Currently used in the heat-pump refrigerant cycle and bioreactor metabolic-kinetics paths. Included for orchestrator breadth so domain-extensions (combustion, fuel cells) don't need a new wrapper.

Source: github.com/Cantera/cantera

Quantities this tool computed for this design:

- rwgs_equilibrium_co_mol_frac = 0.0881
- rwgs_equilibrium_h2o_mol_frac = 0.3297

Fired / Electric Feed-Preheat + Catalyst-Activation Heater Sizing- v1.0.0 (process:fired-heater)

free-proprietary

> **What it does.** Sizes a fired or electric process heater - heat duty (kW), heat-transfer area, and fuel/electrical demand - to raise a process stream to its reaction-inlet temperature, plus the separate transient catalyst-activation (reduction) duty.

Origin. In-tree implementation of the standard process heat balance Q = m·Cp·dT with a radiant/convective area split following API 560 fired-heater practice (electric-trim option for low duties); specific heats taken from the chemicals/thermo property layer.

What the results mean. duty_kw sets the fuel-gas or electrical load and the utility balance; heat_transfer_area_m2 drives the heater size and cost. The catalyst-activation duty is a start-up transient, sized separately so the steady-state electrical demand is not overstated.

How it was used here. Invoked wherever a stream must be preheated to reaction temperature - combined-feed preheat ahead of the synthesis reactor, guard-bed feed heating, catalyst reduction/activation. Sizes the preheater and its energy demand.

Source: internal://forgeos/process

Quantities this tool computed for this design:
- feed_preheater_duty_kw = 133 kW
- feed_preheater_input_kw = 135.714 kW

Flare / Thermal Oxidiser (purge destruction) Sizing v1.0.0 (flare:thermal-oxidiser)

free-proprietary

What it does. Sizes a thermal oxidiser / flare for purge-gas destruction - combustion-chamber duty, supplementary-fuel and combustion-air demand, and flare-tip size - to destroy a tail-gas purge to environmental-permit limits.

Origin. In-tree combustion heat balance (the purge lower heating value plus supplementary fuel raised to an adiabatic flame temperature meeting the 850 °C / 0.3 s destruction criterion), with API 521/537 flare-tip sizing for the exit velocity.

What the results mean. combustion_duty_kw and supplementary_fuel set the cost of destroying the purge; the chamber/residence sizing confirms the design meets the destruction-efficiency permit (>=850 °C, >=0.3 s). A large supplementary-fuel demand means a low-LHV purge (mostly inerts) - a signal to tighten the recycle.

How it was used here. Invoked for vent/purge destruction - the tail-gas purge that prevents inert build-up in the recycle loop, plus emergency relief. Sizes the thermal oxidiser / flare and its fuel and emissions basis.

Source: internal://forgeos/process

Quantities this tool computed for this design:
- thermal_oxidiser_heat_release_kw = 833.33 kW
- thermal_oxidiser_chamber_volume_m3 = 2.0209 m3
- thermal_oxidiser_stack_diameter_m = 0.4142 m

Flash Separator (3-Phase) Sizing v1.0.0 (process:flash-separation)

free-proprietary

What it does. Sizes a three-phase flash separator - vessel diameter and height - to disengage a reactor effluent into a tail-gas vapour, an aqueous process-water phase, and a liquid hydrocarbon/syncrude phase.

Origin. In-tree implementation of the Souders-Brown vapour-disengagement equation (K derated to ~0.07 m/s) for the gas-handling diameter, a 20-minute liquid-residence rule for the liquid section, and Stokes-law droplet settling for the water/oil split (GPSA separator practice).

What the results mean. vessel_diameter_m is set by the vapour load (Souders-Brown); vessel_height_m by liquid residence. A large diameter means the gas rate governs; a tall vessel means liquid holdup governs. The three-phase split confirms the design separates water from syncrude before downstream upgrading.

How it was used here. Invoked for any vapour-liquid(-liquid) separation duty - the hot and cold separators downstream of the synthesis reactor, knock-out drums. Sizes the separator vessels in the bill of materials.

Source: internal://forgeos/process

Quantities this tool computed for this design:
- separator_diameter_m = 0.5729 m
- separator_length_m = 2.8647 m
- separator_vapour_velocity_ms = 0.3359 m/s

Gas Compressor (Multi-Stage Polytropic) Sizing v1.0.0 (gas:compressor-sizing)

free-proprietary

What it does. Sizes a multi-stage gas compressor - polytropic head, shaft + driver power, per-stage discharge temperature, inter-stage cooling duty, and the number of stages - for raising a gas stream to a target delivery pressure.

Origin. In-tree implementation of the GPSA Engineering Data Book polytropic-compression method, with a Peng-Robinson real-gas compressibility factor (Z) recomputed per stage and the polytropic exponent n/(n-1) derived from the specific-heat ratio and polytropic efficiency.

What the results mean. shaft_power_kw / driver_power_kw size the motor and the plant electrical load; the per-stage discharge temperature must stay below the seal/material limit, which sets how many inter-stage coolers are needed; intercooler_duty_kw feeds the cooling-water balance. A high stage count or discharge temperature signals an aggressive pressure ratio that needs more inter-cooling.

How it was used here. Invoked for any gas-compression duty - feedstock compression to synthesis pressure, tail-gas recycle recompression, hydrogen make-up. Sizes the compressor package plus its electrical and cooling demand in the bill of materials.

Source: internal://forgeos/process

Quantities this tool computed for this design:

- co2_feed_compressor_stages = 3
- co2_feed_compressor_power_kw = 73.124 kW
- co2_feed_compressor_intercool_kw = 71.146 kW
- h2_feed_compressor_stages = 2
- h2_feed_compressor_power_kw = 139.992 kW
- h2_feed_compressor_intercool_kw = 132.49 kW
- recycle_gas_compressor_stages = 1
- recycle_gas_compressor_power_kw = 3.569 kW

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

Quantities this tool computed for this design:

- product_cooler_duty_kw = 782.493 kW (input: inputs from: process:flash-separation + brief)
- product_cooler_effectiveness = 0.8892 (input: inputs from: process:flash-separation + brief)
- product_cooler_ua_kw_k = 8.8 kW/K (input: inputs from: process:flash-separation + 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 = 14,425.84 t
- plant_annual_co2_t = 721.292 t
- plant_embodied_co2_t = 64.6 t
- saf_lifecycle_co2_per_kg = 0.721 kgCO2e/kg
- saf_avoided_co2_t_yr = 3,099 t/yr

Liquid-Fuel Storage Tank (API 650) Sizing v1.0.0 (storage-tank:liquid-fuel)

free-proprietary

What it does. Sizes atmospheric liquid-fuel storage tanks to API 650 - tank count, diameter, height, and shell mass - for finished-product (SAF, naphtha) buffer storage at the plant battery limit.

Origin. In-tree implementation of API 650 (Welded Tanks for Oil Storage): the one-foot-method shell-course thickness from hydrostatic head, plus roof, floor, and minimum-thickness plate, sized to a target days-of-storage at the production rate.

What the results mean. tank_count, diameter_m and height_m set the tank-farm footprint; shell_mass_kg drives the fabricated-steel cost. Days-of-storage trades tank size against road-tanker dispatch frequency - a smaller tank needs more frequent loading.

How it was used here. Invoked for finished-product and intermediate liquid storage - the SAF and naphtha product tanks. Sizes the storage tanks and the road-tanker loading basis.

Source: internal://forgeos/process

Quantities this tool computed for this design:

- product_tank_count = 1
- product_tank_diameter_m = 5.3686 m
- product_tank_height_m = 4.2949 m
- product_tank_shell_mass_kg = 6,269.2 kg

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 = 26,010.6 kg (input: inputs from: reaction:stoichiometry-balance, gas:compressor-sizing, reactor:cst...)
- mass_budget_utilisation_pct = 0 % (input: inputs from: reaction:stoichiometry-balance, gas:compressor-sizing, reactor:cst...)
- site_mass_kg = 26,010.6 kg (input: inputs from: reaction:stoichiometry-balance, gas:compressor-sizing, reactor:cst...)

Pressure Vessel Wall Design (hoop-stress sizing) v1.0.0 (pressure-vessel: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 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:
- fractionation_column_shell_mass_kg = 2,341.352 kg
- fractionation_column_wall_thickness_mm = 8 mm
- fractionation_column_yield_safety_factor = 9.667

Process Centrifugal Pump Sizing v1.0.0 (process:pump-sizing)

free-proprietary

Source: internal://forgeos/process

Quantities this tool computed for this design:
- product_pump_head_m = 43.329 m (input: inputs from: ht:ntu-heat-exchanger + brief)
- product_pump_motor_kw = 0.18 kW (input: inputs from: ht:ntu-heat-exchanger + brief)
- product_pump_hydraulic_power_w = 24.6 W (input: inputs from: ht:ntu-heat-exchanger + 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 - Tdelta 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

Quantities this tool computed for this design:

- ft_reaction_delta_g_kj_mol = -59.3 kJ/mol
- ft_reaction_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 CaCO3) into the required feed rates of every reactant (CO2, 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 CO2-in does not match the CaCO3-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

Quantities this tool computed for this design:

- ft_h2_consumed_t_day = 3.298 t/day
- ft_hydrocarbon_product_t_day = 7.6492 t/day
- ft_reaction_water_t_day = 19.6488 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:

- ft_reactor_volume_m3 = 5.0667 m3 (input: inputs from: reaction:stoichiometry-balance, gas:compressor-sizing, process:fir...)
- ft_reactor_diameter_m = 1.238 m (input: inputs from: reaction:stoichiometry-balance, gas:compressor-sizing, process:fir...)
- ft_reactor_height_m = 4.952 m (input: inputs from: reaction:stoichiometry-balance, gas:compressor-sizing, process:fir...)

- ft_reactor_shell_mass_kg = 2,386.72 kg (input: inputs from: reaction:stoichiometry-balance, gas:compressor-sizing, process:fir...)

Steam Generator (FT reactor heat recovery) Sizing v1.0.0-free-proprietary

(process:steam-generator)

What it does. Sizes a steam-raising heat-recovery system on an exothermic reactor - raised-steam flow (kg/h) and heat-transfer area - that converts the reaction exotherm into useful process steam.

Origin. In-tree heat-balance steam-raising calculation: the exotherm duty divided by the latent heat of vaporisation at the steam pressure (IAPWS-IF97 water properties) gives the steam flow; an LMTD area sizes the steam-generator surface.

What the results mean. steam_raised_kg_h is the credit to the site steam balance - when it exceeds the plant reboil + tracing demand the design is a net steam exporter (an operating-cost credit); heat_transfer_area_m2 sizes the steam drum / waste-heat boiler.

How it was used here. Invoked when an exothermic reactor heat is recovered as steam - the Fischer-Tropsch synthesis exotherm. Sizes the steam generator and feeds the utility steam balance and the net-steam-export claim.

Source: internal://forgeos/process

Quantities this tool computed for this design:

- steam_raised_kg_h = 1,289.52 kg/h (input: inputs from: reactor:cstr-pfr-sizing + brief)
- steam_generator_area_m2 = 15.448 m2 (input: inputs from: reactor:cstr-pfr-sizing + brief)
- steam_tsat_c = 212.35 degC (input: inputs from: reactor:cstr-pfr-sizing + brief)

Supply Chain Risk v1.0.0 (supply-chain-risk:scoring)

free-proprietary

What it does. Scores supply-chain risk for every BoM line - sole-source flag, geographic concentration, sanctions exposure, tariff cost.

Origin. In-tree compilation of EUC dual-use list + US BIS Entity List + UK ECJU + Companies House data on supplier ownership. Updated monthly.

What the results mean. risk_score per line item: green = multiple sources + low tariff, amber = single source OR sanctioned country, red = embargoed. The cumulative high-risk percentage tells the buyer whether to pursue dual sourcing.

How it was used here. Runs alongside Engine C supplier matching. Outputs feed the supply-chain section of the report.

Source: internal://forgeos/supply-chain

Quantities this tool computed for this design:

- supply_chain_risk_score = 73
- supply_chain_tariff_exposure_gbp = 88,500 GBP

Transport + Logistics Cost v1.0.0 (transport-logistics:routing)

free-proprietary

What it does. Routes a containerised or palletised shipment from manufacturer to deployment site, computing transit time, customs duty, freight class, and ground-transport restrictions.

Origin. In-tree implementation against the IMO IMDG code (sea), IATA DGR (air), ADR (road EU), and 49 CFR (road US). Freight rates from Freightos + Drewry indices.

What the results mean. door_to_door_days is the realistic transit time (~6-8 weeks China-EU sea; 3 days air). landed_cost_gbp includes freight + duty + handling. flagged_restrictions surfaces hazardous-goods classification (Li-ion -> UN 38.3 transport test required).

How it was used here. Runs once at the end. Outputs feed the deployment-logistics section.

Source: internal://forgeos/logistics

Quantities this tool computed for this design:

- transport_cost_per_unit_gbp = 0 GBP
- transport_door_to_door_days = 8 days

Yield + Economics NPV v1.0.0 (yield-economics:npv)

free-proprietary

What it does. Computes the financial NPV, IRR, and payback period of the design over a chosen holding period, given the cost stack, revenue model, and discount rate.

Origin. In-tree implementation of Brealey, Myers, Allen "Principles of Corporate Finance" 13th ed. + Damodaran "Investment Valuation" 3rd ed. The standard DCF methodology used across project finance.

What the results mean. npv_gbp is the discounted present value of the project's cash flows - positive means the investment beats the discount rate, negative means it doesn't. irr_pct is the discount rate that zeroes the NPV. payback_years is the time to recover CapEx; investors typically demand <5 for an industrial asset.

How it was used here. Runs at the end of the chain. Outputs feed the financial section + the cover-page cost stack.

Source: internal://forgeos/finance

Quantities this tool computed for this design:

- saf_levelised_cost_gbp_kg = 8.62 GBP/kg
- plant_npv_gbp = -75,322,752 GBP
- plant_payback_years = 0 yr

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.