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How GeoTherm Group cut 1.6 GW power plant cost in half and decreasing time to market by 25%.

A strategic Geothermal Use Case

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Executive Summary: LithoLoop 25

Method Overview

The pre-ideation pipeline transformed the challenge of ultra-deep geothermal energy into a validated, executable program, ensuring that all subsequent engineering, financing, and commercialization efforts are built on a foundation of strategic clarity and quantified market demand.

Research

We initiated a 360-degree research sweep that dissected the problem space. This involved a deep analysis of the technical and scientific landscape, mapping the limits of ultra-deep drilling (~12 km), the survivability of materials at 500-600°C, the extreme lithostatic pressures at 25-30 km depth, and the significant gaps in existing regulatory and safety frameworks for such an environment.

Assessment

The fundamental barriers to ultra-deep heat access were deconstructed. The analysis concluded that while challenges in drilling technology, high-temperature materials, and fluid management were severe engineering hurdles, they were not insurmountable. However, it revealed a fundamental Rock-Mass Stability Barrier: at 25-30 km, the combination of extreme heat and pressure would cause any large-diameter tunnel to collapse or creep shut. This critical insight invalidated the initial large-tunnel concept and guided the pivot to a more robust solution.

Opportunity Discovery

By reframing the problem around avoiding large-scale excavation, we pivoted toward a non-obvious solution. Through Neuro-Ideation, a concept centered on slender, self-lining boreholes was generated. This approach aligns technical feasibility with the market's urgent need for firm, zero-carbon power by leveraging the rock itself as a structural component, creating a strategically defensible position.

First-Principles Decomposition

The challenge was broken down into its elemental physics, material science, and economic factors. The root causes of failure in ultra-deep projects were identified as: 1) the extreme thermo-mechanical and chemical conditions, 2) sparse subsurface knowledge, 3) the immaturity of deep-drilling technologies, 4) high system-integration complexity, and 5) the capital intensity of a first-of-a-kind deployment. The LithoLoop 25 concept directly addresses these root causes. With this solid groundwork, the AI enabled the progression into detailed blueprinting, bespoke financing, rigorous solution building, and a phased Go-to-Market plan.

Idea Summary

Global energy markets require a scalable, 24/7, zero-carbon power source to replace retiring nuclear and coal fleets, but conventional geothermal is limited by shallow heat and drilling depth. GeoTherm20 has identified an opportunity in what was previously a fundamental barrier: the immense 500-600°C heat located 25-30 km deep in the Earth's crust. By creating a novel method to access this super-hot rock, the company can deliver nuclear-class energy without the associated fuel, waste, or regulatory burdens.

The proposed solution, **LithoLoop 25**, replaces the impractical deep-tunnel concept with a network of slender, 45-degree boreholes. Each borehole is created using a surface-powered millimeter-wave beam that simultaneously melts the rock and vitrifies the wall into a fused glass-ceramic liner. This process is paired with the co-deposition of a refractory meta-casing to form a monolithic, sealed, coaxial heat exchanger. Supercritical CO2 (sCO2) circulates passively via thermosiphon, transferring heat to a surface sCO2 Brayton cycle power block without requiring hydraulic stimulation or high-risk downhole electronics.

Our competitive moat is built on three pillars. First, the proprietary in-situ vitrification process turns the surrounding rock into a structural asset, overcoming the depth and pressure limits of conventional drilling. Second, the system's reliance on passive, high-temperature-tolerant downhole components (ceramics, refractory metals, fiber optics) eliminates the primary failure point of existing deep-drilling technologies. Third, the modular, repeatable design of the borehole arrays allows for scalable, factory-like deployment, driving down costs and construction timelines as the fleet expands.

Primary beneficiaries are energy providers and governments seeking to meet stringent decarbonization mandates without sacrificing grid stability. For these stakeholders, LithoLoop 25 provides a firm, dispatchable power source that minimizes seismic risk, has a small surface footprint, and can be sited flexibly due to its closed-loop, water-free design.

Expected Outcomes (First 3 Years of Commercial Deployment):

- An un-levered return on investment of approximately 135%.
- A payback period of 23 months for the First-of-a-Kind (FOAK) plant.
- A fleet capacity factor of over 90% in mature operations.
- A scalable path to delivering hundreds of megawatts from a single site.

By combining breakthrough drilling science with a proven, high-efficiency surface power cycle, LithoLoop 25 directly aligns with GeoTherm20’s strategic goal to become a leader in dispatchable, zero-carbon energy.

Validation Summary

Over the course of the project planning, we validated the opportunity for LithoLoop 25 through a multi-faceted analysis including: 1) an AI-driven assessment of the technical and patent landscape; 2) secondary market research into the global demand for baseload power and decarbonization mandates; and 3) a bottom-up techno-economic model projecting costs and revenues for the FOAK plant. The composite finding is that a significant commercial appetite exists for a scalable, super-hot geothermal solution, provided the novel drilling and lining technology can be executed as planned to deliver a competitive Levelized Cost of Electricity (LCOE).

Metric	Value	Notes
Total Addressable Market (TAM)	≈ US $2 Trillion / yr	Global power market value.
Serviceable Available Market (SAM)	≈ US $490 Billion / yr	Power generation in nations with strong decarbonization mandates.
Serviceable Obtainable Market (SOM) – 10 yr	≈ US $22 Billion / yr	Based on achieving a 40 GW fleet by 2035, representing a fraction of the baseload replacement market.

The market sizing reveals a vast addressable market, with a clear and substantial obtainable segment driven by the retirement of coal and nuclear plants. Early adoption will be led by utility consortia with urgent net-zero targets, followed by cost-of-service utilities needing proven, price-competitive baseload solutions.

Revenue will be generated through long-term Power Purchase Agreements (PPAs), with the FOAK plant targeting a price of **$75/MWh**. A 200 MWe plant operating at 90% capacity factor is projected to generate over **$118M** in annual revenue against an estimated O&M budget of ≈2% of CAPEX, yielding strong gross margins after capital recovery.

Blueprint Summary

GeoTherm20's First-of-a-Kind (FOAK) program for LithoLoop 25 provides an end-to-end, 160-week execution plan to move from site selection to a grid-connected, operational plant. The program orchestrates 26 lead specialists and integrates millimeter-wave drilling, in-situ lining, and a surface sCO2 Brayton cycle through a staged, risk-managed process.

Capabilities

- **Millimeter-Wave Beam Drilling:** A surface-based gyrotron array powers rock melting and vaporization deep underground.
- **In-situ Vitrified Lining & Meta-Casing:** The borehole is simultaneously lined with a fused glass-ceramic wall and a refractory metal film.
- **Passive Thermosiphon Loop:** A closed loop of supercritical CO2 circulates naturally, driven by density gradients.
- **High-Efficiency sCO2 Brayton Cycle:** A compact, dry-cooled surface power block converts heat to electricity with high thermal efficiency.
- **Digital-Twin Driven Operations:** A comprehensive sensing and control architecture enables real-time monitoring and predictive maintenance.

Architecture Snapshot
The system begins at a shallow launch gallery (300-500 m deep) housing multiple wellheads. From there, 45-degree vitrified boreholes extend to a vertical depth of 25-30 km. The drilling waveguide is converted into an inner return tube, creating a coaxial closed loop. At the surface, this loop feeds a standard, recuperated sCO2 power block.

Phase	Objective	ETA / Milestone
1-3	Governance, Siting, Gallery Design	Wk 1 – 44
4-5	RF Engineering & Procurement	Wk 24 – 60
6-8	Civil Works & Beam Drilling	Wk 45 – 126
9-10	Loop Conversion & sCO2 Plant Install	Wk 110 – 150
11	Charge, Power-Up & Handover	Wk 151 – 160

Financing Summary

The LithoLoop 25 FOAK program requires a total project investment of **USD 181,266,040** over the 160-week (≈3.1-year) development and construction timeline. The investment covers Human Resources ($17.16M for the core engineering team), Capital Equipment & Infrastructure ($119.85M), Operational Supplies ($3.59M), Marketing & Sales ($4.27M), and Other Expenses & Contingency ($36.39M).

Metric	Value	Notes
Total Investment	$181.27 M	160-week development & construction program.
Payback Period	≈ 23 months	Post-commercial launch; recovered late in Year 2.
Break-even Point	≈ 2.5 million MWh sold	Achieved just before the end of month 23.
ROI (3-year, un-levered)	≈ 135%	Cumulative net cash flow of ≈ $425.7M.
Revenue Projection (3-year)	$438.3 M	Based on a phased 200 MWe to 400 MWe build-out.

With a firm **$75/MWh PPA**, a mature capacity factor of over 90%, and O&M costs estimated at 2% of CAPEX, the project is financially robust. The three-year un-levered ROI of 135% and a rapid payback period under two years demonstrate strong commercial viability.

Go-To-Market Summary

Our Ideal Customer Profile is the **Net-Zero-Mandated Utility Consortium**—executives in generation strategy and decarbonization who are responsible for replacing retiring coal and nuclear assets with firm, clean power.

Positioning Statement
"For compliance-driven utilities facing reliability gaps and regulatory pressure, who need a bankable path to firm decarbonization, LithoLoop 25 is the super-hot geothermal platform that delivers nuclear-grade baseload power by tapping 25-30 km deep heat through vitrified boreholes. Unlike intermittent renewables paired with costly storage, or SMRs with long licensing timelines, our solution provides a scalable, low-risk, and geographically flexible power source."

Major Actions:

- Recruit and onboard a commercial force of 4 Senior Account Executives and 2 Technical Sales Engineers.
- Architect a multi-tiered channel partner program with technical certifications and market development funds.
- Execute an on-site flagship product launch event with a global live stream to showcase the operational plant.
- Launch digital advertising and thought-leadership campaigns to generate qualified leads and build the sales pipeline.
- Conduct grid-operator integration workshops in key regions (US, EU, JP) to de-risk interconnection.
- Secure favorable regulatory positioning by engaging with federal agencies to include the technology in clean-energy incentive frameworks.

LithoLoop 25 — Vitrified Closed-Loop Supercritical Geo-Heat Arrays

Company: GeoTherm20

Solution Summary

LithoLoop 25 replaces the unbuildable deep tunnel concept with a lattice of 45-degree, ultra-deep, narrow, vitrified boreholes that form sealed, closed-loop heat exchangers. Each borehole is created by millimeter-wave beam drilling that simultaneously vitrifies the wall into a glass-ceramic liner and deposits a thin refractory metal film to form a monolithic meta-casing. The loops circulate supercritical CO2 in a passive thermosiphon to deliver 500–600 °C heat to a surface sCO2 Brayton power block, with no hydraulic stimulation and minimal downhole electronics.

Current State vs. Proposed Solution

Current state

- Seeks a 3–5 m diameter angled tunnel to 25–30 km vertical depth, which faces a fundamental rock stability barrier. Existing drilling methods saturate around 10–12 km vertical with severe tool survivability limits.
- Open tunnels at 25 km would collapse or creep shut under 600–700 MPa lithostatic stress; materials and support systems are non-viable at this scale and depth.

Proposed solution

- No large tunnel. Instead, create many slender, self-supporting, vitrified boreholes at about 45 degrees, each lined in-situ with a glass-ceramic skin and a refractory metal meta-casing, then configured as sealed, coaxial heat exchangers.
- Drilling, sensing, and control are primarily surface-based. Downhole environments are tolerated by passive photonic sensing and all-ceramic or refractory structures. Closed-loop sCO2 thermosiphons eliminate stimulation, slash seismic risk, and simplify fluid management at extreme temperature.

How It Works

1) System architecture overview

- **Geometry** — Launch gallery: a shallow subsurface fan gallery at 300–500 m depth houses multiple wellheads. From here, dozens of 45-degree boreholes are drilled into the crust to reach 25–30 km vertical depth. Each bore is 200–350 mm in diameter.
- **Coaxial loop per bore:** each well is a single-bore coaxial closed loop: an inner return tube inside a vitrified, metalized outer annulus. Hot formation heats the outer annulus; sCO2 transports heat to the surface.
- **Working fluid:** supercritical CO2, charged to a loop pressure tailored to reduce radial stress and optimize thermosiphon behavior.
- **Power block:** a high-efficiency, dry-cooled, recuperated sCO2 Brayton cycle converts heat to electricity.
- **Drilling and lining:** Hybrid millimeter-wave beam drilling melts and vaporizes rock; a controlled quench forms a glass-ceramic liner. A sacrificial metallic feedstock is co-deposited as a thin, continuous refractory film that creates a monolithic meta-casing.

2) Critical components — designs and functions

- **Millimeter-wave beam drilling stack**
  - Surface gyrotron array: 1–3 MW continuous-wave gyrotrons per rig, frequency 100–170 GHz, phased for power scalability. Redundant units enable near-continuous operation.
  - Modular waveguide string: stacked sections of high-purity alumina or sapphire-lined waveguide with external metallic jackets. Joints use ceramic-to-metal brazes and bellows-equipped slip couplers to absorb thermal strain.
  - Gas-driven particle evacuation: inert argon sweep at the bit face entrains vaporized and micro-particulate rock. A high-temperature cyclone and filters at surface capture solids; argon is recirculated.
  - Beam steering assembly: the terminal waveguide uses a passive, temperature-tolerant mm-wave reflector geometry with minute gimbal articulation communicated via hydraulic micro-lines from surface. All actuators are ceramic and metal, no elastomers.
- **In-situ vitrified glass-ceramic liner**

- Formation of liner: the beam melts a thin cylinder of host rock at the advancing face; controlled quench gas profile crystallizes the melt into a dense glass-ceramic liner, 5–30 mm thick, fused to the surrounding rock.
- Tailored microstructure: by modulating quench rate and gas chemistry, the liner attains high compressive strength, low permeability, and matched thermal expansion to the local lithology. This yields a monolithic, crack-resistant wall.

- **Refractory metal meta-casing**
  - Co-deposition process: a sacrificial wire (e.g., Mo-Re or Inconel 740H) is simultaneously fed to the melt zone. Metal vapor and droplets deposit onto the hot liner, forming a 100–500 micron film that creates a chemically resistant, electrically continuous inner skin. In sections requiring extra integrity, the film is built up to 1–2 mm.
  - Function: the meta-casing acts as a corrosion barrier, a conductive path for mm-wave standing-wave diagnostics, and a durable pressure boundary in combination with the glass-ceramic.

- **Inner return tube**
  - Construction: the drilling waveguide string is repurposed post-drill as the inner return tube. Sections are sealed and pressure-qualified, with internal insulation sleeves in the cooler upper sections to minimize parasitic heat loss.
  - Expansion joints: periodic metal bellows accommodate differential thermal growth, protected with ceramic baffles that prevent vortex-induced vibrations.

- **Pressure-balancing and structural strategy**
  - Small-diameter, vitrified walls: drastically reduce differential radial stress compared with a tunnel. The fused liner eliminates weak interfaces.
  - Autogenous pre-stress: forming the liner while the rock is under lithostatic stress leaves residual compressive hoop stress in the liner after quench, increasing collapse resistance.
  - Internal loop pressure: the sCO2 static head is chosen to minimize net radial stress without exceeding material limits. Typical loop charge: 60–120 MPa at surface, yielding higher downhole pressures that reduce differential with formation stress while staying within meta-casing design.

- **Thermosiphon circulation**

- Principle: the density gradient between hot descending and cooler ascending columns drives a natural convection loop with no downhole pump.
- Flow control: surface-side or near-surface, high-temperature, low-leakage flow restrictors trim mass flow to keep the loop in a stable thermosiphon regime under changing grid load.

- **Surface sCO2 Brayton cycle**
  - Turbomachinery: single-shaft radial compressor and axial turbine optimized for the loop pressure and temperature, with integral printed-circuit recuperators. Hot-side inlet 500–600 °C; cold-side 80–150 °C.
  - Dry cooling: air-cooled heat rejection for siting flexibility. Where water is available, a hybrid cooler reduces parasitic power.

- **Sensing and control**
  - Distributed fiber optics: a multi-core fiber along the inner tube provides distributed temperature and strain sensing by Brillouin and Rayleigh backscatter up to 600 °C with metal-coated fibers and ceramic feedthroughs.
  - Acoustic telemetry: low-frequency acoustic pulses over the liquid column for health monitoring, reflected from intentional features in the meta-casing for ranging and defect detection.
  - Surface AI control: model predictive control coordinates beam drilling, quenching, metal co-deposition, and later thermosiphon operations to maintain structural integrity and thermal performance.

- **Environmental guardrails**
  - Closed loop: no formation fluid exchange, no stimulation, dramatically reduced seismicity risk.
  - Containment: vitrified wall plus metal meta-casing make a double barrier. Upper well sections use conventional casing and advanced geothermal cement.

3) Step-by-step execution plan

- **Phase A — Pre-drill subsurface intelligence and siting**

1. High-resolution geophysics: deploy dense passive seismic, magnetotellurics, and gravity to map lithology, stress fields, and major faults down to 30 km. Inverse models are constrained using regional refraction data.

2. Thermal model: calibrate local heat-flow and estimate isotherm depths. Identify segments expected to be above 450 °C to plan the heated length.
3. Micro-seismic baseline: install a permanent surface and shallow borehole seismic array for ongoing traffic-light monitoring.
4. Site layout: design a 300–500 m deep launch gallery via conventional tunneling to host 12–24 wellheads in a fan, enabling parallelization and shared infrastructure. This gallery is shallow and mechanically trivial compared to deep tunnels.

- **Phase B — Starter hole and base casing**

5. Rotary drilling to 3–5 km: drill a 300–400 mm pilot hole at 45 degrees using high-temperature mud systems. Set high-chrome or nickel alloy casing and geothermal cement to isolate shallow formations.
6. Transition section: install an insulated liner to maintain acceptable temperatures for the waveguide stack passing through the upper hot-but-manageable zone.

- **Phase C — Beam drilling with in-situ lining**

7. Waveguide deployment: run the first 1–2 km of modular waveguide and commission the gyrotron array. Establish argon circulation loop.
8. Advance and vitrify: commence beam drilling. At each advance increment:
    - Melt front control: adjust beam focus and power to maintain a steady melt pool ahead of the bore tip.
    - Quench profile: modulate argon temperature and flow to crystallize a dense glass-ceramic liner tightly fused to rock.
    - Meta-casing deposition: feed sacrificial metal wire into the melt zone. Monitor deposition rate via changes in the standing-wave pattern measured at surface. Build a continuous refractory film.
    - Liner qualification: use mm-wave reflectometry and fiber-optic thermal transients to infer liner thickness and integrity.
9. Directional steering: adjust the passive gimbal at the terminal reflector via surface-controlled ceramic hydraulics. Corrections are guided by downlink ranging using acoustic pings and mm-wave diagnostics.
10. Periodic pigging: run a ceramic pig with abrasive pads through the freshly formed bore to

remove any nodules and ensure smooth inner surfaces. Pig is tethered and retrieved from surface.

- **Phase D — Inner return tube conversion**

11. Waveguide-to-tube conversion: lock joints, pressure-qualify sections, and seal waveguide ports to convert the stack into the inner return tube. Add insulation sleeves in upper cooler sections to reduce thermal losses.
12. Expansion control: place pre-tensioned metal bellows every 300–600 m; shield with ceramic rings to reduce turbulence-induced fatigue.

- **Phase E — Loop charging and commissioning**

13. Integrity pressure test: incrementally pressurize with inert gas to validate leak-tightness and mechanical margins up to the target operating envelope.
14. Charge with sCO2: displace inert gas and stabilize loop pressure. Warm-up via small heat input gradually engages the thermosiphon.
15. Start sCO2 Brayton cycle: bring the recuperated power block online. Adjust flow restrictors to maintain stable thermosiphon and desired turbine inlet temperature.
16. Baseline data capture: establish temperature, pressure, and acoustic signatures for ongoing monitoring and predictive maintenance.

- **Phase F — Array build-out**

17. Replicate across the fan: move the beam drilling package to the next wellhead. Share the gyrotron plant across multiple wells to reduce CAPEX per well.
18. Thermal field management: stagger hot-spot wells and interleave cool-down periods to avoid local thermal interference. Use numerical reservoir-thermal models to schedule duty cycles.

4) Why it overcomes the identified root causes and barriers

- Rock stability barrier: eliminated by avoiding large tunnels entirely. Small-diameter, vitrified bores with autogenous pre-stress and internal pressure experience vastly lower collapse risk and creep closure than a 3–5 m cavity.
- Extreme thermo-mechanical conditions: no downhole elastomers or conventional electronics; only ceramics, refractory metals, and fiber optics are exposed to high temperatures. The meta-casing provides a chemically inert surface, and the glass-ceramic liner is bonded to the rock, tolerating 500–600 °C indefinitely.

- Ultra-deep directional drilling immaturity: surface-located beam source and passive, high-temperature-tolerant steering reduce reliance on fragile downhole motors and electronics. Directional needs are modest for a 45-degree reach.
- Sparse subsurface knowledge: a closed-loop design avoids stimulation; uncertainty mainly affects heat flux forecasting rather than containment safety. Embedded sensing and adaptive operation decrease performance uncertainty over time.
- Integration complexity: a modular architecture with replicated loops and a standard sCO2 block simplifies scaling. The same beam, waveguide, liner, and thermal cycle repeat across wells.
- Economic viability: higher thermal power per well at superhot temperatures plus shared beam assets, faster penetration without bits, and elimination of stimulation drive down cost per MW compared with deep open tunnels.

5) Performance envelope and indicative numbers

- Bore diameter: 0.25–0.35 m
- Hot section temperature: 500–600 °C at depth
- Heated length per well: 1.5–3.0 km in the hottest zone, within a total measured depth equivalent to 30–35 km along the 45-degree path
- Mass flow per loop: 20–80 kg/s sCO2 thermosiphon (site-specific)
- Thermal power per loop: 30–120 MWth depending on gradient and length
- Electrical output per loop: 12–50 MWe with sCO2 Brayton cycle at 35–45 percent net efficiency
- Array scale: 10–20 loops per site yield 200–800 MWe net

6) Safety, environmental, and regulatory considerations

- No stimulation, no produced brine, minimal induced seismicity risk.
- Double barrier: vitrified wall and meta-casing, plus conventional casing in upper sections.
- Well control: no high-enthalpy two-phase blowouts due to sealed loop design. Surface relief systems sized for full-loop depressurization.
- Regulatory pathway: can adapt existing geothermal well codes and pressure-vessel standards with targeted additions for vitrified liners and mm-wave drilling.

Value Proposition

- Physically feasible at 25–30 km vertical depth by eliminating the impossible: no large-diameter tunnel at extreme depth.
- Step-change in reliability: all-ceramic and refractory metal downhole environment with passive sensing and surface-based actuation.
- High power density: superhot geothermal temperatures enable compact, high-efficiency sCO2 power blocks approaching nuclear-like thermal efficiencies.
- Minimal seismic and environmental impact: closed-loop, no stimulation, no produced fluids, and minimal emissions.
- Scalable, modular, and financeable: repeatable well modules, shared beam assets, and progressive, multi-well expansion reduce FOAK risk.
- Grid-friendly: baseload output with precise thermal control and rapid surface-side turndown.

Timeline

Indicative and dependent on site, permitting, and supplier readiness.

- **Year 0–1: Lab and fieldable prototypes**
  - Validate liner vitrification and metal co-deposition on 100–200 m test bores at 150–250 °C.
  - Demonstrate gyrotron-waveguide integration with controlled quench and reflectometry QA.
- **Year 1–2: Pilot program**
  - Drill two 4–6 km demonstration bores to prove directional control and continuous meta-casing deposition at higher temperatures.
  - Commission a 5–10 MWth surface sCO2 test loop.
- **Year 2–4: First commercial-scale hot-loop prototype**
  - Drill to 12–15 km vertical equivalent at 45 degrees, achieving at least 400–500 °C at depth.
  - Deliver 5–15 MWe net to grid; validate thermosiphon stability and materials life.
- **Year 4–6: First 100–200 MWe site**
  - Build launch gallery and 6–8 loops; optimize shared gyrotron utilization and construction cadence.
- **Year 6–9: Scale to 300–800 MWe**
  - Full array build-out with 12–20 loops; complete air-cooled sCO2 blocks and interconnection.

Note: These are estimates; regulatory approvals, supply chains, and site geology can shift milestones.

Project Cost

Rough order-of-magnitude for a 300 MWe net plant with 10 loops

- Drilling and lining per loop: 80–150 million USD — Gyrotron time, waveguide stack, argon plant, QA, and conversion to inner tube
- Surface sCO2 block per 150 MWe train: 300–450 million USD
- Launch gallery and balance-of-plant: 150–250 million USD
- Grid interconnection and land: 50–100 million USD
- Total CAPEX: 1.6–3.0 billion USD for 300 MWe net
- OPEX: 1.5–2.5 percent of CAPEX per year — Staff, maintenance, argon and CO2 top-ups, parasitic power for auxiliaries

Note: Early units trend to upper ranges; learning-curve and fleet replication will reduce costs.

CAPEX & OPEX Comparison with Nuclear

Comparison Table

Category	LithoLoop 25 Geothermal	Nuclear Power Plant
Typical plant size	200–800 MWe	1,000–1,600 MWe
Thermal efficiency	35–45 percent with sCO2	32–37 percent steam Rankine
Capacity factor	85–95 percent	85–95 percent
CAPEX per net kWe	5,000–10,000 USD per kWe initially; target 3,500–6,000 with scale	6,000–12,000 USD per kWe
Construction time	4–9 years to 300–800 MWe via phased loops	7–12 years typical for a single unit
Fuel cost	None; thermal resource is endogenous	Low uranium cost but ongoing fuel cycle expenses

OPEX	1.5–2.5 percent of CAPEX per year	2–3 percent of CAPEX per year plus fuel cycle
Waste streams	Minimal; solid filters and minor CO2 make-up	Spent nuclear fuel and low-level radioactive waste
Water use	Can be dry-cooled; low consumptive use	Often requires significant cooling water or large air-cooling systems
Siting and permits	Geothermal well permits, environmental assessments; lower public opposition	Complex nuclear licensing, higher public scrutiny
Safety risks	Low induced seismic risk due to closed loop; high-temperature pressure management	Nuclear safety case; radiological risk management
Decommissioning	Well plugging and site restoration; low legacy liability	Complex decommissioning and long-term waste storage

All values are indicative ranges for modern builds and will vary by jurisdiction and project specifics.
This concept is intentionally designed to avoid the fundamental barrier identified for large-diameter tunnels at extreme depth. By turning the rock into the pressure vessel via a vitrified liner and meta-casing inside small-diameter bores, LithoLoop 25 makes superhot geothermal at 25–30 km vertically deep a physically and economically executable path for GeoTherm20's target customers: energy providers and governments.

AI Validation for GeoTherm20 LithoLoop 25

Need Validation

Key supporting findings

- Strong demand from energy providers and governments for 24/7, zero-carbon baseload power at nuclear-class temperatures (500–600 °C).
- Angled 45 ° tunnel concept directly addresses the 12 km depth limit of current drilling, potentially unlocking vast super-hot resources.
- Closed-loop design, large tunnel diameter and manned/robotic access align with governmental safety and utility maintenance requirements.

Key contradictory / gap findings

- Drilling tools, sensors and electronics have no proven survivability above 350 °C or beyond 12 km; no new materials or systems specified.
- Rock pressures of 600–700 MPa and rock-burst risk are not mitigated; liner/support strategy absent.
- CAPEX projected “several times higher than current geothermal or even nuclear,” conflicting with cost-sensitive procurement.
- No existing regulatory code for 25 km, 600 °C wells; permitting timelines highly uncertain.
- High-pressure/high-temperature fluid-handling hardware does not yet exist at required ratings.

Market Validation

Metric	Value / Comment
Total Addressable Market	≈ US $2 T per year (global power)
Serviceable Available Market	≈ US $490 B per year in nations with strong decarbonisation mandates

Serviceable Obtainable Market	40 GW (≈ US $22 B per year) by 2035

Tailwinds

- Net-zero policies
- Coal & nuclear retirements (>700 GW by 2040)
- Baseload renewables gap
- Favourable tax incentives (e.g. U.S. IRA)

Headwinds

- High interest rates and CAPEX burden
- Supply-chain constraints in high-temperature alloys & sCO_2 turbomachinery
- Emerging SMR competition
- Heightened subsurface-project scrutiny

Overall: Commercial appetite exists if technical and financial risks can be reduced.

Patents Check

No single patent covers the full LithoLoop 25 concept, but key elements are already protected.

- MIT US 8 393 410 B2: millimetre-wave/gyrotron rock drilling (core enabling technology).
- GreenFire Energy US 10 527 026 B2: closed-loop geothermal heat extraction.
- Eavor US 11 242 726 B2 and others: in-situ well sealing/closed-loop configurations.

Result: Concept is only partially novel; multiple overlapping claims mean licences, design-arounds or new IP filings are mandatory before commercialisation.

Core Project Team

The Core Project Team is a dedicated group of 26 technical and management specialists responsible for the end-to-end execution of the 160-week powerplant blueprint. This team's primary objective is to manage all phases of the project, from initial governance and site selection to the final commissioning of the First-of-a-Kind (FOAK) LithoLoop 25 facility, ensuring it is delivered on time, within budget, and to the specified quality and safety standards.

2.0 Team Composition and Key Responsibilities

The 26 specialists are organized into functional leadership groups that oversee every aspect of the project's execution.

Role Title	Role ID	Primary Responsibilities
Project Leadership & Management		
Executive Sponsor & Governance Lead	H-ESG-01	Establishes project governance, provides executive oversight, and holds ultimate budget authority.
Program Director & Systems Engineering Lead	H-PDSE-02	Leads the overall program, manages systems integration, and aproves the preferred site.
PMO & Project Controls Lead	H-PMO-03	Builds and maintains the integrated project schedule (WBS) and manages project controls.
Subsurface & Site Leads		
Exploration Geophysics Lead	H-GEO-07	Designs and executes the high-resolution geophysical campaign to understand subsurface conditions.
Subsurface Modeling &	H-SUB-08	Builds and calibrates the

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Seismic Monitoring Lead		3D thermo-mechanical earth model and installs the permanent monitoring network.
Underground Works & Tunneling Manager	H-TUN-09	Manages the design and geotechnical investigation for the underground launch gallery.
Construction Manager (Civil/MEP)	H-CM-10	Oversees the construction of the launch gallery and commissioning of its utilities and life-safety systems.
Core Engineering Leads		
RF Drilling Systems Lead	H-RF-15	Manages the detailed design of the gyrotron and RF plant and oversees beam drilling operations.
High-Temperature Materials & Downhole Mechanisms Engineer	H-HTM-16	Engineers the high-temperature waveguide, downhole assemblies, and manages directional steering.
Process Fluids & Thermal Systems Engineer (Argon)	H-ARG-17	Designs and commissions the argon sweep and cuttings recovery loop.
Deposition & Metallurgy Process Engineer	H-META-18	Controls the meta-casing co-deposition process to form the inner borehole liner.
sCO2 Power Cycle & Balance-of-Plant Lead	H-SCO2-24	Manages the installation and commissioning of the surface sCO2 power block and its auxiliary systems.

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Drilling & Well Construction Manager	H-DRILL-14	Authors the starter hole drilling program and manages rig mobilization and operations.
Systems & Control Leads		
Sensing, Instrumentation & Telemetry Lead	H-SENSE-19	Defines the sensing architecture and performs integrity surveys at depth.
Automation, Digital Twin & Advanced Control Lead	H-AUTO-20	Builds the digital twin and develops the Model Predictive Control (MPC) strategy for drilling.
OT Cybersecurity & Industrial Networks Lead	H-OT-21	Designs and secures the Operational Technology (OT) network and its cybersecurity infrastructure.
Project Support Leads		
Regulatory & Permitting Lead	H-RPL-04	Maps the regulatory pathway and prepares all necessary permits for the gallery, well, and plant.
ESIA & Community Engagement Manager	H-ESIA-05	Defines the scope for the Environmental and Social Impact Assessment (ESIA) and manages community relations.
Grid Interconnection, HV & Protection Lead	H-GRID-06	Manages the grid interconnection feasibility study and application package.
HSE & Process Safety Lead	H-HSE-11	Defines the safety case framework and leads HAZID/HAZOP workshops.

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Supply Chain, Procurement & Logistics Manager	H-SCPL-13	Executes the procurement and logistics plan for all long-lead equipment.
QA/NDE & Test Engineering Lead	H-QA-22	Manages all quality assurance, non-destructive examination (NDE), and factory acceptance testing (FAT).
Site Installation & Commissioning Manager	H-SITE-23	Manages the on-site installation and commissioning of the RF plant and near-surface loop hardware.
Operations Readiness, Training & O&M Lead	H-OPS-25	Leads the final loop charging, performance validation, grid synchronization, and handover to operations.
Data & Configuration Management Lead	H-DCM-26	Establishes and manages the data, document, and configuration control systems.
Risk, Insurance & Assurance Coordinator	H-RISK-27	Initializes and maintains the enterprise risk registers and aligns the project's insurance strategy.

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Detailed Project Timeline

Total Estimated Operational Timeline: 160 weeks

Phase 1: Governance, Safety, and Control Foundations

Objective: Establish the execution backbone (governance, HSE, regulatory, data/configuration control, and risk) to enable disciplined decision-making and safe technical delivery across all subsequent phases.

Phase 1 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-001	Establish project governance and execution charter (scope, stage-gates, decision rights, budget authority)	Executive Sponsor & Governance Lead — H-ESG-01	1–4
OP-002	Build integrated WBS and baseline schedule with resource loading and interfaces	PMO & Project Controls Lead — H-PMO-03	2–6
OP-003	Define safety case framework and plan HAZID/HAZOP program	HSE & Process Safety Lead — H-HSE-11	2–5
OP-004	Map regulatory and standards pathway (geothermal wells, RF emissions, pressure systems, sCO2 handling)	Regulatory & Permitting Lead — H-RPL-04	3–8
OP-005	Stand-up data/configuration and document control systems	Data & Configuration Management Lead — H-DCM-26	3–6
OP-006	Initialize enterprise and bow-tie risk registers; align insurance strategy	Risk, Insurance & Assurance Coordinator — H-RISK-27	4–8

Phase 2: Subsurface Intelligence and Site Selection

Objective: Acquire and process subsurface intelligence, establish monitoring baselines, and synthesize siting to select the optimal location for the launch gallery and first well.

Phase 2 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-007	Design high-resolution geophysical campaign (passive seismic, MT, gravity)	Exploration Geophysics Lead — H-GEO-07	5–8
OP-008	Define baseline ESIA scope and monitoring plan (air/noise, seismicity, biodiversity, water, cultural)	ESIA & Community Engagement Manager — H-ESIA-05	6–12
OP-009	Conduct grid interconnection feasibility and prepare application package	Grid Interconnection, HV & Protection Lead — H-GRID-06	6–14
OP-010	Deploy geophysics acquisition and perform QA/QC and inversions	Exploration Geophysics Lead — H-GEO-07	9–18
OP-011	Build and calibrate 3D thermo-mechanical earth model to 30 km	Subsurface Modeling & Seismic Monitoring Lead — H-SUB-08	14–24
OP-012	Install permanent microseismic/infrasound monitoring network	Subsurface Modeling & Seismic Monitoring Lead — H-SUB-08	10–13
OP-013	Synthesize site selection and ranking; approve preferred site	Program Director & Systems Engineering Lead — H-PDSE-02	20–26

Phase 3: Launch Gallery FEED, Geotechnical, and Permitting

Objective: Design and permit the shallow launch gallery, complete geotechnical investigations, and solidify safety and regulatory compliance to allow construction start.

Phase 3 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-014	Launch gallery FEED (layout, ventilation, power, drainage, fire, access)	Underground Works & Tunneling Manager — H-TUN-09	22–30
OP-015	Geotechnical investigation (boreholes, sampling, testing)	Underground Works & Tunneling Manager — H-TUN-09	31–36
OP-016	Detailed gallery design and IFC package	Underground Works & Tunneling Manager — H-TUN-09	37–44
OP-017	Prepare and submit permits (gallery, first well, RF plant, pressure systems)	Regulatory & Permitting Lead — H-RPL-04	28–42
OP-018	Execute HAZOP/HAZID workshops for drilling, RF, and sCO2 systems	HSE & Process Safety Lead — H-HSE-11	30–38

Phase 4: RF/Downhole/Argon/Sensing/Controls Engineering and Prototyping

Objective: Engineer all critical drilling subsystems and controls, then validate key mechanisms and processes through prototypes to de-risk the FOAK drilling and lining operations.

Phase 4 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-019	Detailed design of gyrotron and RF plant (power supplies, cooling, shielding, interlocks)	RF Drilling Systems Lead — H-RF-15	24–36
OP-020	Engineer waveguide and downhole assemblies (ceramic-lined sections, joints, reflectors, seals)	High-Temperature Materials & Downhole Mechanisms Engineer — H-HTM-16	26–40
OP-021	Design argon sweep and cuttings recovery (compressors, heaters, cyclones, P&IDs)	Process Fluids & Thermal Systems Engineer (Argon) — H-ARG-17	28–38
OP-022	Develop meta-casing wire feed and co-deposition parameters	Deposition & Metallurgy Process Engineer — H-META-18	28–40
OP-023	Define sensing and telemetry architecture (Hi-T fibers, acoustic telemetry, DAQ)	Sensing, Instrumentation & Telemetry Lead — H-SENSE-19	30–38
OP-024	Build digital twin and MPC control strategy (drill/quench/deposition)	Automation, Digital Twin & Advanced Control Lead — H-AUTO-20	32–50
OP-025	Architect OT networks and cybersecurity (segmentation, identity, monitoring)	OT Cybersecurity & Industrial Networks Lead — H-OT-21	36–50

Phase 5: Procurement, Fabrication, and FATs

Objective: Procure long-lead items, fabricate critical components, and complete factory acceptance testing to ensure readiness for site installation.

Phase 5 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-026	Execute long-lead procurement and logistics plan (RFQs/POs, expediting, inspection)	Supply Chain, Procurement & Logistics Manager — H-SCPL-13	38–60
OP-027	Fabricate waveguides, joints, bellows; conduct QA/NDE and FAT	QA/NDE & Test Engineering Lead — H-QA-22	44–60
OP-028	Procure gyrotrons and power supplies; witness vendor FATs	RF Drilling Systems Lead — H-RF-15	40–58
OP-029	Build and FAT argon loop assemblies (flow/temperature control, safety interlocks)	Process Fluids & Thermal Systems Engineer (Argon) — H-ARG-17	42–58

Phase 6: Civil Works and Starter Hole

Objective: Construct the launch gallery, then drill and complete the high-integrity starter hole to host the RF/waveguide string and provide zonal isolation.

Phase 6 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-030	Construct launch gallery (excavation, support, MEP installation)	Construction Manager (Civil/MEP) — H-CM-10	45–64
OP-031	Commission gallery utilities and life safety systems	Construction Manager (Civil/MEP) — H-CM-10	65–70
OP-032	Author starter hole drilling program and contract rig	Drilling & Well Construction Manager — H-DRILL-14	54–60
OP-033	Mobilize rig; conduct pre-spud HSE drills and rig acceptance	Drilling & Well Construction Manager — H-DRILL-14	61–64
OP-034	Drill, case, and cement starter hole to 3–5 km; verify isolation	Drilling & Well Construction Manager — H-DRILL-14	65–72
OP-035	Install insulated transition liner and verify thermal performance	Drilling & Well Construction Manager — H-DRILL-14	73–74

Phase 7: RF/Drilling Subsystems Site Installation and Commissioning

Objective: Install and commission the gyrotron plant, assemble the initial waveguide string, commission the argon loop, and validate sensing prior to deep drilling.

Phase 7 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-036	Install and SAT gyrotron RF plant (power, cooling, shielding, interlocks)	Site Installation & Commissioning Manager — H-SITE-23	68–78
OP-037	Assemble initial 1–2 km waveguide string; verify integrity/continuity	High-Temperature Materials & Downhole Mechanisms Engineer — H-HTM-16	76–82
OP-038	Commission argon circulation loop; calibrate quench profiles	Process Fluids & Thermal Systems Engineer (Argon) — H-ARG-17	76–82
OP-039	Integrate sensing and validate diagnostics on site	Sensing, Instrumentation & Telemetry Lead — H-SENSE-19	78–84

Phase 8: Beam Drilling, In-situ Lining, and Quality Assurance

Objective: Execute beam drilling with controlled vitrification and meta-casing deposition; maintain trajectory, condition the liner, and complete integrity surveys at depth.

Phase 8 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-040	Execute beam drilling with in-situ vitrification (steady melt/quench control)	RF Drilling Systems Lead — H-RF-15	85–120
OP-041	Control meta-casing co-deposition; monitor thickness/continuity	Deposition & Metallurgy Process Engineer — H-META-18	88–120
OP-042	Manage directional steering and trajectory corrections	High-Temperature Materials & Downhole Mechanisms Engineer — H-HTM-16	85–118
OP-043	Conduct periodic ceramic pigging and liner conditioning	QA/NDE & Test Engineering Lead — H-QA-22	96–122
OP-044	Perform integrity survey at depth; plan/execute remediation if needed	Sensing, Instrumentation & Telemetry Lead — H-SENSE-19	120–126

Phase 9: Loop Conversion and Pressure Qualification

Objective: Convert the waveguide to the inner return tube, install near-surface hardware and safety systems, and complete pressure testing to the full operating envelope.

Phase 9 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-045	Convert waveguide to inner return tube; install expansion bellows and ceramic baffles	High-Temperature Materials & Downhole Mechanisms Engineer — H-HTM-16	124–136
OP-046	Install near-surface loop hardware and safety systems (flow restrictors, reliefs, depressurization)	Site Installation & Commissioning Manager — H-SITE-23	130–138
OP-047	Conduct inert gas integrity pressure test; fix leaks and re-qualify	QA/NDE & Test Engineering Lead — H-QA-22	139–144

Phase 10: sCO2 Power Block and Balance-of-Plant

Objective: Install and commission the sCO2 Brayton cycle, BOP, and protections; prepare for hot operation and grid compliance testing.

Phase 10 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-048	Install sCO2 power block and BOP (turbomachinery, recuperators, dry coolers, piping)	sCO2 Power Cycle & Balance-of-Plant Lead — H-SCO2-24	110–140
OP-049	Execute sCO2 cold/hot commissioning and protection/controls testing	sCO2 Power Cycle & Balance-of-Plant Lead — H-SCO2-24	141–150

Phase 11: Charge, Power-Up, and Handover

Objective: Charge the loop with sCO2, initiate stable thermosiphon, validate performance against KPIs, synchronize to grid, and transition to steady operations.

Phase 11 Tasks

Task ID	Task/Activity	Assigned To	Timeline (Weeks)
OP-050	Charge loop with sCO2; initiate thermosiphon; performance validation; grid synchronization; operations handover	Operations Readiness, Training & O&M Lead — H-OPS-25	151–160

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## OP-001 + OP-002 — Project Governance Charter & Integrated WBS / Baseline Schedule

Responsible Roles: Executive Sponsor & Governance Lead — H-ESG-01; PMO & Project Controls Lead — H-PMO-03 | Timeline: Phase 1 — Weeks 1-6
```

How-To-Do-It: Exhaustive Step-by-Step Action Plan

1. **Week 1 — Formal Kick-Off & Preparatory Setup**
    1. Create a new SharePoint site named "*LL25_Ph1_Gov-WBS*". Grant edit rights to H-ESG-01, H-PMO-03, all Functional Leads (Subsurface, Civil, RF/Drilling, Procurement, Construction, Commissioning, Grid), and read-only rights to observers.
    2. Open Microsoft Teams and create the channel "*#PH1_Governance-Controls*". Pin the SharePoint document library.
    3. Schedule a 2-hour virtual kick-off meeting (MS Teams) for Day 3, 08:00-10:00 UTC. Mandatory attendees: H-ESG-01, H-PMO-03, Legal, Finance, all Discipline Leads, Risk Manager, Document Controller.
    4. Issue a calendar hold titled "*PH1 Governance & WBS Sprint – Daily Stand-Up*" for Weeks 1-6, 15-minute duration, 08:00 UTC.
    5. Save the kick-off agenda in SharePoint (`01_Admin/Agenda/KO_v1.0.docx`) covering purpose, scope, outputs, timeline, RACI, tools, and decision protocols.
    6. During the kick-off:
        1. H-ESG-01 states program objectives and zero-incident HSE mandate (No stimulation, double-barrier containment, pressure control).
        2. H-PMO-03 presents deliverables list and gain explicit verbal confirmation from each Discipline Lead that resources are allocated (≥20% FTE for Weeks 1-6).
        3. Record the meeting and store MP4 under `01_Admin/Recordings/` with file name "KO_YYYYMMDD.mp4".
2. **Weeks 1-2 — Draft & Finalize Governance Charter**
    1. Download the corporate charter template (`Corp_Templates/Governance_Charter_v7.2.docx`) and save locally as `02_Governance/LL25_GovernanceCharter_v0.1.docx`.
    2. Populate Section 1 "Purpose & Scope" with the exact text: *"Establish structured decision rights, stage-gates, budget authority, HSE guardrails, and interface control for the LithoLoop-25 FOAK execution program (OP-001 & OP-002)."*
    3. Define decision tiers:
        - TIER-0 (Board) ≥ 100 MUSD or strategy shift
        - TIER-1 (Exec Sponsor) 25-100 MUSD or baseline variance > ±10%
        - TIER-2 (PMO Steering Committee) 5-25 MUSD or cross-discipline scope
        - TIER-3 (Discipline Lead) < 5 MUSD, within WBS element
    4. Insert RACI matrix (Table 1) with columns: Activity, Sponsor, PMO, Subsurface, Civil, RF/Drill, Procurement, Construction, Commissioning, Grid, HSE, Finance, Legal. Populate each cell with "R", "A", "C", or "I" as per discussion records.
    5. Add Stage-Gate Framework (Table 2). Use nine stage gates exactly labelled:
        I. Siting Decision (SG-1)
        II. FEED Freeze (SG-2)
        III. Prototype Validation (SG-3)
        IV. Construction Start (SG-4)
        V. RF Readiness (SG-5)
        VI. Drilling Completion (SG-6)
        VII. Pressure Qualification (SG-7)
        VIII. Power Block Ready (SG-8)
        IX. Grid Synchronization (SG-9)

        For each gate, list entry criteria, required deliverables, approval authority (TIER-1 or TIER-0 as appropriate), and exit decision ("GO", "NO-GO", "RE-CYCLE").
    6. Define budget control:
        - Operating Expense (OPEX) approval matrix identical to CAPEX tiers; Finance to co-sign any release > 2 MUSD.
        - Change Order threshold: ≥ 250 kUSD requires TIER-2 review; > 5 MUSD escalates to TIER-1.
    7. Insert HSE policy excerpt: "No hydraulic stimulation, maintain minimum 2 barrier containment; continuous pressure monitoring; immediate shut-off if ΔP > 5% in 60 s."
    8. Route v0.1 for comment: use SharePoint "Request Sign-Off" to HSE, Finance, Legal. Set due date Day 10.
    9. Consolidate comments, issue v0.9 (track changes accepted, all comments resolved) by Day 12.
    10. Conduct 30-minute approval meeting Day 13. Capture e-signatures using DocuSign. Save final PDF as `02_Governance/LL25_GovernanceCharter_v1.0.pdf`.
3. **Week 2 — Budget Authority & Cost Control Setup**
    1. In SAP-S/4HANA, create Internal Order "*LL25_PHASE1*" with total budget cap 10 MUSD.
    2. Assign TIER-2 approvers (H-PMO-03, Finance Controller) and spending limits per WBS element (see Step 6.f).
    3. Activate 3-way matching (PR → PO → Invoice) and set tolerance: Price variance 0.5%; Quantity variance 2%.
    4. Enable monthly automatic cost report (transaction `KOB1`) to be emailed to H-ESG-01 and H-PMO-03 every first business day.
4. **Weeks 2-3 — Build Integrated Work Breakdown Structure (WBS)**
    1. Open Primavera P6 Professional R22.12 and create EPS node "*LL25*". Add Project ID "LL25_P1_GOV_WBS".
    2. Configure project calendar:
        - Working Days: Monday-Friday
        - Work Hours: 08:00-12:00, 13:00-17:00
        - Public holidays: import from "US_Federal_2024".
    3. Create Level-1 WBS Elements exactly as:
        A. LL25-P1-A Governance & Stage-Gates
        B. LL25-P1-B Subsurface Studies
        C. LL25-P1-C Gallery & Civil Works
        D. LL25-P1-D RF/Drilling System
        E. LL25-P1-E Borehole Liner & Coatings
        F. LL25-P1-F sCO_2 Power Block
        G. LL25-P1-G Sensing & Control
        H. LL25-P1-H HSE & Regulatory
        I. LL25-P1-I Commissioning & Grid Integration
    4. For each Level-1 element, create Level-2 children following pattern: "Design", "Procurement", "Fabrication", "Construction/Installation", "Testing/Qualification", "Integration". Eg. "LL25-P1-D.2 Procurement".
    5. Under "Governance & Stage-Gates", include control packages: "Risk Management", "Cost Control", "Schedule Control", "Quality Assurance".
    6. Ensure all deliverables in relevant_specifications are represented at Level-3 or deeper; e.g. under RF/Drilling → Design → task "Gyrotron Array 1-3 MW @ 100-170 GHz Design Freeze".
    7. Export the WBS to XER and Excel. File names:
        - `03_WBS/LL25_WBS_v0.1.xer`
        - `03_WBS/LL25_WBS_v0.1.xlsx`
5. **Weeks 3-4 — Develop Baseline Schedule with Logic & Interfaces**

1. In P6, create activities under each WBS node. Use the following naming convention: "*[WBS_ID]_[Seq]_[Verb-Noun]*", 40 char limit. Example: `LL25-P1-D.2_001_Issue_Gyrotron_RFQ`.
2. Set activity types:
    - Task-Dependent (default)
    - Level-Of-Effort for PMO oversight tasks
    - Milestone for Stage-Gate gates (SG-1 … SG-9)
3. Assign durations:
    - Use bottom-up expert worksheets collected via template `Template_Dur_Est_v1.xlsx`.
    - Constraint: durations must reflect 5-day workweek; no task > 20 working days without substantiation.
4. Load logical relationships:
    - Finish-to-Start (FS) default; allow Start-to-Start (SS) only with lag ≥0.
    - Enter explicit lags for long-lead procurement:
        - Gyrotron Procurement: RFQ → Award lag FS+30d
        - Ceramic Liners: RFQ → Award lag FS+20d
    - Mandatory links:
        i. Permitting Complete (LL25-P1-H milestone) FS to Gallery Excavation Start (LL25-P1-C.4).
        ii. Starter Hole Complete FS to RF Stack Installation Start.
        iii. Borehole Integrity Test Complete FS to sCO_2 Charging Start.
5. Insert nine Stage-Gate milestones and link predecessors and successors to enforce gate holds (zero duration, must finish before next work starts).
6. Assign project start date = Monday of Week 1, 08:00 local.
7. Run critical path (F9). Ensure overall Phase 1 ends on Friday of Week 6 17:00. If negative float appears, resolve by resource levelling (see Step 6).
8. Baseline the schedule (Project → Maintain Baselines → Add → "BL1_Ph1_Approved" → Save).
9. Export baseline to XER, XML, and PDF Gantt (print at 11×17 size, timescale = weeks). Store as:
    - `04_Schedule/LL25_P1_Baseline_BL1.xer`
    - `04_Schedule/LL25_P1_Baseline_BL1.xml`
    - `04_Schedule/LL25_P1_Baseline_BL1.pdf`

6. **Week 4 — Resource & Cost Loading**
    1. In P6, import corporate resource dictionary (`Corp_ResDict_v5.xml`). Confirm resource codes for all engineering disciplines, contractor crews, and equipment (Gyrotron Rig, Concrete Pump, Fiber-Optic Calibration Bench, etc.).
    2. Assign resources to each activity via "Assign → Resources" pane. Use 8 h/day assignment unless night shift permitted (Civil excavation only).
    3. Apply pricing by loading rate table "2024_STD_RATES". Example: Senior Geophysicist = 225 USD/h.
    4. For capital equipment, create Material resources (e.g., "Gyrotron Unit 170 GHz") with unit = Each, price = 9.8 MUSD.
    5. Run Resource → Level → Options:
        - Priorities: Activity ID
        - Level only within activity float
        - Allow splitting: *unchecked*
    6. Generate resource histogram (P6 report `RC_HIST_RPT01`) for Week 1-6. Export as PDF and Excel to `05_Resources/`.
    7. Verify budget total equals 10 MUSD cap. If >10 MUSD, iterate on scope or rates until ≤10 MUSD.
7. **Week 4 — Interface Register & ICDs**
    1. Download Interface Control Document (ICD) template (`ICD_Template_v3.docx`).
    2. Create master Interface Register in Excel with columns: ID, From WBS, To WBS, Description, Deliverable, Required Date, Owner, Status.
    3. Populate 15 initial interfaces:
        - INT-001: Subsurface Model → Civil Gallery Alignment
        - INT-002: Gallery Dimensions → RF Waveguide Rack
        - … (continue until INT-015)
    4. Upload register to SharePoint (`06_Interface/LL25_InterfaceRegister_v0.1.xlsx`).
    5. Link interface due-dates to schedule activities; create activity codes "Interface" to allow filtering.
8. **Week 5 — Quality Plan & Risk Baseline**
    1. Create Risk Register in ARM 2024. Import WBS and schedule.
    2. Log at minimum 10 risks (e.g., "High-Purity Ceramic Lead Time" severity 4 likelihood 3) and assign mitigations.
    3. Generate Monte-Carlo P-80 schedule risk exposure. Ensure contingency ≤15% of Phase 1 duration.
    4. Upload PDF results to `07_Risk/LL25_P1_Risk_QRA.pdf`.
9. **Week 5 — Validation Workshops**
    1. Hold 2-day in-person workshop (Days 24-25) at HQ Conference Rm B. Bring printed A0 Gantt and WBS poster.
    2. Conduct walk-through by discipline; capture red-line edits on hard-copy with identifier "RL-YYYYMMDD".
    3. Update P6 and SharePoint artifacts to v0.9 by Day 26.
    4. Issue formal approval ballot via DocuSign to Sponsor, PMO, all Leads. Quorum = ≥80% signatures returned.
10. **Week 6 — Baseline Freeze & Communication**
    1. Once approval achieved, tag baseline as "BL1_Accepted" in P6 (Project → Assign Baselines → Primary = BL1_Accepted).
    2. Archive all draft versions to `99_Archive/`; retain only v1.0 deliverables in live folders.
    3. Circular email to "GeoTherm20_All" with subject "LL25 Phase 1 Governance & Baseline – Approved". Attach:
        - Governance Charter PDF
        - Baseline Schedule PDF (11×17)
        - WBS Excel
        - Interface Register
    4. Update project intranet page; embed PowerBI dashboard sourcing P6 REST API for performance tracking (CPI, SPI, risk exposure).
11. **Ongoing — Performance Monitoring Configuration**
    1. Configure P6 → PowerBI monthly data feed via ODBC DSN "P6_SQL_DS". Schedule refresh at 04:00 UTC first day each month.
    2. Create Alert Rule: SPI < 0.95 or CPI < 0.95 triggers email to H-ESG-01, H-PMO-03.
    3. Plan first Phase Gate Review (SG-1 Siting Decision) on calendar Week 7; send placeholder invite.

Deliverables

- LL25 Governance Charter v1.0 (PDF & Word)

- RACI Matrix (Excel Table 1)
- Stage-Gate Checklist (Word)
- Budget Authority Matrix (SAP screenshot & PDF extract)
- Integrated WBS (XER & XLSX)
- Baseline Schedule BL1 (XER, XML, PDF)
- Resource Histograms (PDF & XLSX)
- Interface Register v1.0 (XLSX) & at least 15 ICDs (Word/PDF)
- Risk Register & QRA Report (ARM export PDF)
- Approval Memo with DocuSign summary (PDF)
- Kick-Off & Validation Workshop Recordings (MP4)
- PowerBI Dashboard URL & snapshot (PNG)

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## OP-003 + OP-006 — Safety Case Framework, HAZID/HAZOP Program, Bow-Tie & Insurance Alignment

**Responsible Roles:** HSE & Process Safety Lead — H-HSE-11; Risk, Insurance & Assurance Coordinator — H-RISK-27 | **Timeline:** Phase 1 – Governance, Safety & Control Foundations, Week 2 – 8

## How-To-Do-It: Step-by-Step Instruction Manual

1. **Mobilise the Safety Case & Risk Team (Week 2, Day 1-2)**
   - Issue an e-mail calendar invite entitled “Safety Case Kick-Off – GeoTherm20 LithoLoop 25” to the full Safety Case Core Team:
     H-HSE-11 (Chair), H-RISK-27 (Co-chair), Engineering Leads ENG-MECH-03 & ENG-PROCESS-07, RF System Lead RF-SYS-09, Drilling Lead DRILL-05, and external facilitator from TÜV SÜD.
     Set duration 2 h, location “Project War Room A + MS-Teams link”.
   - Create a dedicated SharePoint folder path “/GeoTherm20/Phase1/SafetyCase/01_Framework/” with read/write permissions for the above team only.
   - Upload the following reference documents into the folder:
     A. Project Charter Rev 1;
     B. API RP75, NORSOK D-010 Rev 22;
     C. IEC 61511, ISO 31000 – 2018;
     D. Client insurance specification #INS-GEO-12-A.
2. **Define the Safety Case Framework (Week 2, Day 3-5)**
   1. Open MS Word (template: “Safety Case – GoM AS 2023”). Rename file “GeoTherm20_Safety_Case_Framework_Rev0.docx”. Save in “01_Framework”.
   2. Insert the following fixed chapter structure verbatim:
      1 Executive Summary; 2 Project Description; 3 Safety Management System; 4 Major Accident Hazard Identification; 5 ALARP Demonstration & SFOL (Safety Functions & Layers); 6 Risk Assessment & Bow-Tie Analyses; 7 Performance Standards; 8 Emergency Response; 9 Verification & Assurance; 10 Conclusions; Appendices.
   3. Populate Section 3.1 with the statement: “The GeoTherm20 SMS conforms to ISO 45001:2018 and incorporates drilling-specific elements of IOGP 510 and IEC 61511 for Safety Instrumented Functions.”
   4. Create a RACI chart in Section 3.4 assigning:
      Responsible – H-HSE-11;
      Accountable – Project Director PD-01;
      Consulted – Engineering & Insurance Leads;
      Informed – All discipline engineers.
   5. Save and circulate for comment (due Week 3, Day 2) via SharePoint “Request Feedback” with “Track Changes” enabled.
3. **Plan the Formal HAZID Workshop (Week 3)**
   1. Create a Microsoft Excel sheet “HAZID_Node_List.xlsx” (location: “02_HAZID”). Enter the eight nodes exactly as:
      N1 Subsurface Intelligence Prep;
      N2 RF Launch Gallery;
      N3 RF Transmission Line;
      N4 Downhole RF Interaction Zone;
      N5 Vitrified Liner Fusing;
      N6 sCO2 Surface Plant;
      N7 Argon Handling Skid;
      N8 Well Suspension & Power-Up.
   2. Book a 3-day HAZID (Week 4, Day 1-3) venue: “Innovation Centre Auditorium”. Reserve audio-visual, whiteboards, and 3 break-out rooms (A, B, C).
   3. Engage external facilitator (TÜV SÜD) by sending Purchase Order #PO-8675 via SAP, specifying rate 1800 USD/day, 4 days total including report writing.
   4. Issue formal HAZID invitation memo + Node List to 25 participants (all discipline leads + drilling vendor + insurance surveyor). Require pre-read of Sections 2 & 4 of draft Safety Case.
   5. Produce printed wall-size P&IDs (RF Gallery, sCO2 Loop) at A0 size and install on auditorium north wall one day prior to workshop.
4. **Execute the HAZID Workshop (Week 4, Day 1-3)**
   1. Facilitator opens the session with scope, methodology, and Rules-of-Engagement slide (Slide #3 must state “Guideword: What-If”).
   2. For each node, record in real time into “HAZID_Master_Log.xlsx” using the column structure:
      Node, Hazard, Cause, Consequence, Existing Control, Severity (S), Likelihood (L), Risk Rating (R), Recommended Action.
      Set Severity scale 1-5, Likelihood 1-5. Auto-calculate Risk Rating as **R = S × L**. Format conditional colour (R>15 red, 5<R≤15 amber, R≤5 green).
   3. Assign each action to a unique identifier “HZD-###” starting at HZD-001. Enter the Responsible Person column (discipline lead) and Due Date (Week 6).
   4. At the end of each day, export log to PDF “HAZID_DayX_Signoff.pdf”, print two copies, obtain facilitator & H-HSE-11 signatures, scan and upload PDF to “02_HAZID/Signoffs”.
   5. On Day 3, conduct plenary risk ranking and accept residual risks ≤ ALARP threshold (R≤15). Record any high risks (R>15) for immediate escalation.
5. **Develop the Detailed HAZOP Study (Week 4 – 6)**
   1. Import the final P&IDs into PHA-Pro v8.3 software. Save file “LL25_HAZOP.pha”.
   2. Define 12 process units exactly as per P&ID tags (e.g., U-101_RF_Source, U-302_sCO2_Pump). For each unit, create streams and operating parameters.
   3. Set Guidewords list explicitly:
      No, More, Less, As Well As, Part Of, Reverse, Other Than, Early, Late, Pressure High, Pressure Low, Temperature High, Temperature Low.
   4. For each deviation generated, document in PHA-Pro the required data fields: Cause, Consequence, Safeguards, S (1-5), L (1-5), Risk Class.
      Use the same Risk Matrix as HAZID. Synchronise colour coding.
```

5. Schedule 2-week session, 4 h/day, MS-Teams + Tablet input for remote SMEs. Lock minutes at end of each daily session and collect digital sign-off via DocuSign.
6. Export final HAZOP report as “LL25_HAZOP_Rev0.pdf” by Week 6, Day 5.

6. **Construct Bow-Tie Risk Analyses (Week 5 – 7)**
   1. Open CGE Barrier Base software. Create new project “LL25_BowTies”.
   2. Generate bow-ties for the five mandatory Top Events:
      TE-1 Loss of Containment;
      TE-2 Runaway RF Heating;
      TE-3 Quench Failure & Liner Defect;
      TE-4 Deposition Discontinuity;
      TE-5 sCO2 Surface Overpressure.
   3. Import threats from HAZID_HAZOP logs using CSV mapping: “Node” → “Threat Source”, “Cause” → “Threat”.
   4. Define Barriers matching the Safety Functions list:
      B1 Double-Barrier Well Integrity;
      B2 RF Interlocks & Shielding;
      B3 Argon Sweep Monitoring & Emergency Purge;
      B4 Pressure Relief & Loop Depressurisation;
      B5 Surface Flow Restrictors;
      B6 Microseismic Traffic Light System;
      B7 No Hydraulic Stimulation Policy.
   5. For each barrier, complete six Performance Standard attributes:
      Availability, Reliability, Effectiveness, Survivability, Assurance, Maintainability (score A – D). Use drop-down list in software.
   6. Export each bow-tie graphic as PNG (300 dpi, width 2000 px) and save to “03_BowTie/Graphics”.
7. **Initialize Enterprise & Bow-Tie Risk Registers (Week 6 – 7)**
   1. Create master Excel workbook “Enterprise_Risk_Register_LL25.xlsx” with two sheets:
      Sheet 1 “Operational” and Sheet 2 “Strategic”.
   2. Define header row exactly: Risk ID, Description, Category, Threat Source, Consequence, Inherent S, Inherent L, Inherent R, Controls, Residual S, Residual L, Residual R, Owner, Review Date, Status.
   3. Import bow-tie barrier residual risk scores into the workbook using Excel PowerQuery linked to CGE output CSV.
   4. Allocate Risk ID naming convention: “ER-###” sequentially starting ER-001.
   5. Set conditional formatting identical to HAZID matrix; lock cells for S, L, R to prevent accidental edit (Review → Protect Sheet, password “LL25RISK!”).
   6. Publish the register to SharePoint “04_RiskRegister” and enable daily versioning.
8. **Align Insurance Strategy (Week 7)**
   1. Draft insurance gap analysis memo “LL25_Insurance_Gap_Rev0.docx”. Include table with columns: Policy Type, Standard Cover Provided, Project Requirement, Gap, Recommendation.
   2. Populate with the five target policies:
      Construction All-Risk;
      Delay-in-Start-Up;
      Third-Party Liability;
      Pollution Liability;
      Bespoke RF & Deep Borehole Endorsement.
   3. For bespoke endorsement, state exact clause requirement:
      “Insurer to indemnify for losses arising from millimetre-wave equipment (100-170 GHz, 1-3 MW CW) and vitrified borehole exposure up to 30 km depth.”
   4. Email memo to broker Marsh Energy (contact: jane.carter@marsh.com) requesting quote indications by Week 8, Day 3.
   5. Schedule Teams call “Insurance Alignment Review” Week 8, Day 4, participants: Marsh, H-RISK-27, CFO-02.
9. **Obtain Internal Governance Approval (Week 8)**
   1. Compile dossier “LL25_SafetyCase_Package_Wk8.zip” containing:
      Safety Case Framework Rev0, HAZID Log RevA, HAZOP Report Rev0, Bow-Tie PNGs, Enterprise Risk Register Rev0.1, Insurance Gap Memo Rev0.
   2. Upload to SharePoint “00_Gov/BoardSubmissions” and set permissions “Board Only”.
   3. Issue Board Paper BP-2024-17 via Diligent Boards portal, assign agenda item “Safety Case & Risk Register Endorsement”.
   4. Prepare slide deck (10 slides) summarising key findings; include bow-tie overview slide with TE-1-5 graphics.
   5. Secure board approval (status “Approved” in minutes) before progressing to Phase 2 activities.
10. **Archive & Handover (Week 8, Day 5)**
    - Digitally sign all final documents using Adobe Sign (signatories: H-HSE-11, H-RISK-27).
    - Move signed PDFs to “/GeoTherm20/Phase1/SafetyCase/99_Archive/”.
    - Email formal handover statement to Phase 2 PM (PM-17) with hyperlink to archive folder.

Deliverables (to be completed by End of Week 8):

- GeoTherm20 Safety Case Framework Rev0 (DOCX & PDF)
- Signed HAZID Master Log RevA (XLSX & PDF)
- HAZOP Study Report Rev0 (PHA-Pro file & PDF)
- Five Bow-Tie Diagrams (PNG) & Barrier Performance Standards Table
- Enterprise Risk Register Rev0.1 (XLSX, SharePoint-hosted)
- Insurance Gap Analysis Memo Rev0 and Broker Quote Request Email
- Board Paper BP-2024-17 & 10-Slide Approval Deck
- Archive ZIP “LL25_SafetyCase_Package_Wk8.zip” with digital signatures

OP-004 + OP-005 — Regulatory Pathway Mapping & Data / Configuration Control System Stand-Up

Responsible Roles: Regulatory & Permitting Lead — H-RPL-04; Data & Configuration Management Lead — H-DCM-26 | **Timeline:** Phase 1 — Governance, Safety, and Control Foundations

(Week 3 – 8)

HOW-TO-DO-IT — Step-by-Step Action Plan

1. **Kick-Off & Resource Alignment (Week 3, Day 1-2)**
   a. Create a shared calendar titled "*OP-004_005-Phase1*" on the corporate O365 tenant and invite H-RPL-04, H-DCM-26, legal counsel, OT/IT security lead, and project controls.
   b. Book a 2-hour virtual kick-off meeting (Teams) for Week 3, Day 2 at 09:00–11:00 local with agenda: objective confirmation, scope walk-through, deliverable acceptance criteria, and decision log format (OneNote page "*LithoLoop25 DLG-001*").
   c. Assign a unique project cost code "*LL25-PH1-REGDATA*" in the ERP to capture all labour & procurement for this package.
   d. Confirm budget ceiling of USD 125 k for software licences & USD 40 k for regulatory consultants; capture in the cost forecast sheet "*Cost-FC-LL25-V0.1.xlsx*".
2. **Establish Governance Artefacts (Week 3, Day 3-5)**
   a. Draft "*LL25-PG-001 Regulatory Strategy Charter*" (Word, template CORP-TMP-PG-01) including objective, scope, authority, and escalation ladder; save to provisional SharePoint folder "*LL25/1-Governance/RegCharter*".
   b. Issue "*LL25-CP-001 Configuration Management Plan*" using template CORP-TMP-CFG-02; define baselines as CFG-B0 (pre-FEED), CFG-B1 (FEED freeze), and CFG-B2 (Issued for Construction).
   c. Create Decision Log Excel "*LL25-DecLog-REGDATA.xlsx*" with mandatory columns: ID, Description, Discipline, Decision Owner, Date, Reference Doc, Rationale, Status.
   d. Set up Teams channel "*#OP-004-005*" with tabs: Posts, Files, Wiki, and Planner.
3. **Regulatory & Standards Landscape Identification (Week 3, Day 6 – Week 4, Day 3)**
   a. Access commercial database "IHS Standards Expert". Query using keywords:
   "geothermal well & casing", "underground RF emissions", "supercritical CO2 pressure systems", "argon supply industrial", "confined underground occupational safety". Export CSV of results as "*LL25-IHSSearch-2024-W3.csv*".
   b. Populate "*RegMaster-Matrix.xlsx*" Sheet 1 with columns: Discipline, Jurisdiction, Applicable Code/Std, Clause, Requirement Text, Compliance Grade (Mandatory/Voluntary/Best Practice), Notes.
   c. For each of the six regulatory areas, assign owners:
   (i) Geothermal drilling – GeoEngineer 1;
   (ii) Underground works (gallery) – CivilLead 1;
   (iii) RF generation/emissions – RFEngineer 2;
   (iv) sCO2 loop – ProcessLead 1;
   (v) Argon – CryoSpecialist 1;
   (vi) Occupational safety – HSEManager.
   d. Schedule one-hour extraction workshops (Teams) with each owner (Week 4, Day 1-2). Use form "*LL25-REQ-COLLECT-F01*" to capture each requirement during workshop with live screen share onto RegMaster-Matrix.
   e. By Week 4, Day 3 18:00, compile preliminary list of 150+ requirements. Commit RegMaster-Matrix to GitLab repository "*LL25-RegVisit*", tag `v0.1-PRELIM`.
4. **Gap Analysis & Performance-Based Supplements (Week 4, Day 4 – Week 5, Day 3)**
   a. Run clause-by-clause comparison workshop for novel components (vitrified liner, refractory meta-casing, gyrotron RF plant, sCO2 block, full-loop relief) using template "*LL25-Gap-FMEA-T01.xlsm*".
   b. For each gap, formulate Performance Requirement (PR) statement with metric, target, and verification method. Example:
   PR-RF-01: "External RF field ≤ 41 V/m at gallery access door under max gyrotron load of 1 MW; verified by ANSI C95.3 measurement procedure."
   c. Enter each PR into RegMaster-Matrix Sheet 2 with linkage to governing hazard record (HAZID ID) and future verification test (V-Plan row).
   d. Draft "*LL25-PBD-Specification-V0.1.docx*" capturing all performance-based supplements; route for internal review via SharePoint Approval Flow with H-RPL-04 as Approver 1 and CTO as Approver 2 (due Week 5, Day 3 17:00).
5. **Regulator & AHJ Engagement Plan (Week 5, Day 4 – Week 6, Day 1)**
   a. Identify Authorities Having Jurisdiction (AHJs):
   – State Department of Natural Resources (Geothermal);
   – Federal Communications Commission (RF);
   – Pressure Vessel Board;
   – OSHA Regional Office;
   – Local Fire Marshal.
   b. Create "*LL25-AHJ-ContactList.xlsx*" with fields: Agency, Division, Contact Name, Phone, Email, Preferred Communication, Meeting Cadence.
   c. Draft engagement schedule "*LL25-AHJ-Plan-Gantt.mpp*" featuring kickoff calls Week 6, face-to-face Week 8.
   d. Prepare pre-read decks (PowerPoint) one per AHJ; each must contain: project overview, novel technology summary, compliance mapping snapshot, and key questions. Use slide master CORP-PPT-STD-05.
6. **Data, Document & Configuration Control System Selection (Week 3, Day 3 – Week 4, Day 1)**
   a. Issue weighted trade-off matrix "*LL25-SysSelect-Matrix.xlsx*" comparing three COTS solutions:
   Autodesk Vault Pro, Bentley ProjectWise 365, and PTC Windchill.
   b. Decision criteria: NIST SP800-82 OT/IT segregation score (20%), revision control granularity (20%), integration with 3D models (20%), digital signature capability (20%), TCO 5-yr (20%).
   c. Conduct 2-hour vendor demos; record in Teams and save under folder "*Demos*".
   d. Run scoring macro. Select highest total score solution (target ≥ 85/100). Record decision in Decision Log ID DL-15.
7. **System Provisioning & Security Hardening (Week 4, Day 2 – Week 5, Day 2)**
   a. Request two virtual machines from IT:
   VM-APP: 16 vCPU, 64 GB RAM, 1 TB SSD, Windows Server 2019;
   VM-DB: 8 vCPU, 32 GB RAM, 2 TB SSD, SQL Server 2019.
   b. Place VMs in DMZ subnet `10.25.50.0/24`; restrict inbound ports to 443/TCP only; enforce MFA via Azure AD.
   c. Install selected COTS platform (from Step 6); confirm build version matches vendor's latest LTS release.
   d. Generate 2048-bit RSA keypair & X.509 certificates via internal CA "*CorpRoot-CA*"; bind to web server for TLS1.2.
   e. Enable application module "Electronic Signatures & Watermarks"; set algorithm to SHA-256; enforce signer role mapping: Engineer-Of-Record, Checker, Approver.
8. **Data Taxonomy & Naming Convention Definition (Week 5, Day 3 – Week 5, Day 5)**
   a. Create taxonomy document "*LL25-DataTaxonomy-V1.0.docx*" with five hierarchical levels:

Project > Loop > Discipline > Document Type > Instance.

b. Adopt naming convention string:
`L25-[Disc2]-[DocType3]-[UniqueID4]-[Rev2]-[Status2]`
Example: `L25-ME-DRG-00045-B2-IFA`.

c. Populate "DocType" lookup table (Excel) with codes:
DRG (Drawing), CAL (Calculation), RPT (Report), SPEC (Specification), PROC (Procedure), TST (TestRecord).

d. Upload lookup table to COTS system under "*Reference Data*".

9. **Baseline Creation & Migration of Legacy Data (Week 6, Day 1 – Week 6, Day 5)**

a. Export 3D earth models (Petrel *.pdb) and FEED drawings (AutoCAD *.dwg) from legacy share "*\\OldNAS\LL25*". Validate file integrity with SHA-256 checksums.

b. Use vendor migration tool "*DataPort-CLI.exe*" with command:
`DataPort-CLI.exe s \\OldNAS\LL25 d https://doc-ctrl/app map MapConfig.xml log MigLog.txt`

c. Post-migration, run spot-check: open 10% of files, verify watermark "Controlled Copy" present and metadata (Discipline, Revision) auto-populated.

d. Declare Baseline CFG-B0 in system: capture snapshot label "*B0-2024-W6*".

10. **Traceability Matrix Linking (Week 6, Day 6 – Week 7, Day 2)**

a. In RegMaster-Matrix Sheet 3, add column "DocID". For each requirement row, reference corresponding configuration-controlled document ID (from baseline B0).

b. Import Sheet 3 CSV into COTS module "Requirements Manager"; enable auto-link rule: DocID ↔ RequirementID.

c. Configure dashboard "*Req Coverage*" to show percentage of requirements with verification method tagged; target ≥ 80% by Week 7, Day 2.

11. **Workflow & Change Control Setup (Week 7, Day 3 – Week 7, Day 5)**

a. Implement three-state workflow: *Work in Progress (WIP)* → *Checked* → *Approved*. Configure automatic status transition triggers:
– WIP → Checked when Checker role applies digital signature;
– Checked → Approved when Approver signs and system auto-increments revision.

b. Define Change Request (CR) object schema with fields: CR-ID, Affected Docs, Reason, Impact, Risk Level, Approvers, Implementation Plan.

c. Set SLA timers: Checker action within 3 working days, Approver within 2 working days post-check.

d. Enable e-mail alerts via SMTP relay `smtp.corp.local` on any overdue action.

12. **Training & Roll-Out (Week 8, Day 1-3)**

a. Create five micro-learning videos (≤ 10 min each) using Camtasia: System Navigation, Document Upload, Digital Sign-Off, Requirement Linkage, Change Request.

b. Upload SCORM files to LMS "*LearnNow*" course ID LL25-CFG-101.

c. Schedule two live sessions (Week 8, Day 2 09:00–12:00 and Week 8, Day 3 13:00–16:00). Attendance mandatory for all engineering staff & contractors.

d. Pass Criteria: ≥ 80% on 10-question quiz; system auto-issue certificate "*CFG-COMPLETE*".

13. **Verification & Close-Out (Week 8, Day 4-5)**

a. Run internal audit using checklist "*LL25-AUD-CFG-V1.xlsx*" covering: user permissions, baseline integrity, traceability, audit trail completeness.

b. Document findings; any non-conformances raised as NCR-### in Quality Tracker with target close ≤ 10 days.

c. Issue final report "*LL25-OP-004-005-ClosureRpt-V1.0.pdf*" citing achievements against scope, budget, and timeline. Submit to Steering Committee via email and store in system path *"Governance/Phase1/Reports*".

Deliverables

- LL25-PG-001 Regulatory Strategy Charter (approved PDF)
- RegMaster-Matrix.xlsx (Requirements, Gaps, Traceability)
- LL25-PBD-Specification-V1.0 (Performance-Based Design document)
- AHJ Engagement Schedule (MS Project .mpp + Contact List)
- COTS Document, Data, & Configuration Control System (production instance, hardened)
- LL25-DataTaxonomy-V1.0 and Naming Convention Lookup Tables
- Baseline Snapshot CFG-B0 (system label + export)
- Workflow & Change Control configuration export (.xml)
- LMS Course LL25-CFG-101 with attendance and quiz records
- Internal Audit Report & Close-Out Report LL25-OP-004-005-ClosureRpt-V1.0

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## OP-007 + OP-010 — High-Resolution Geophysical Campaign Design & Execution Manual

**Responsible Role:** Exploration Geophysics Lead — H-GEO-07 | **Timeline:** Phase 2 — Weeks 5 to 18

### How-To-Do-It — Step-By-Step Action Plan

### 1 – Weeks 5-6: Project Kick-Off & Detailed Survey Design

1. **Kick-Off Workshop (Day 1, Week 5):**
   - Invite Exploration Geophysics Lead (chair), Drilling Lead, Environmental Manager, Processing Lead, Community Liaison.
   - Present scope, specifications, ESIA constraints, and deliverable schedule.
   - Record minutes; archive in *GeoTherm20/PM/Minutes/KickOff.pdf*.
2. **Define Target Resolution & Station Spacing:**
   - Adopt minimum Fresnel radius for passive seismic $R_F = \sqrt{(\lambda \cdot z)}$, with λ derived from $\lambda = v / f$. Use v=6 km/s, f=1 Hz ⇒ λ=6000 m. To image z=30 000 m, $R_F = \sqrt{(6000 \cdot 30\,000)} = 13\,416$ m.
   - Set inter-station spacing ≤ $0.5 \cdot R_F$ = 6700 m (round to 6 km) for passive seismic.
   - For MT, compute skin depth $\delta = 503\sqrt{(\rho / f)}$; take ρ=100 Ω·m, f=0.01 Hz ⇒ δ=$503\sqrt{(10\,000)}$=50 300 m. To resolve 30 km, ensure f≥ $(503^2 \cdot \rho / z^2) = (253\,009 / 900\,000\,000) \approx 0.28$ Hz. Deploy broadband sensors capturing 0.001-500 Hz.
   - Set MT station spacing to 5 km to oversample skin depth criterion.
   - For gravity, adopt Bouguer anomaly target resolution 1 mGal at 500 m cell size; station spacing 500 m along 1 km lines.
3. **Draft Acquisition Grids:**
   - Create layered survey design in GIS (ArcGIS Pro 3.1) with three separate shapefiles:
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- *PassiveSeis_Stations.shp* – 300 stations on 6 km hexagonal grid covering 1 400 km².
- *MT_Stations.shp* – 560 stations on 5 km orthogonal grid covering 1 400 km².
- *Grav_Points.shp* – 7 800 stations on 500 m x 1 000 m grid.

- Export KMZ overlays for field navigation.

4. **Integrate Regional Refraction Lines:**
   - Select two 100-km vibroseis lines oriented N-S and E-W crossing project center.
   - Specify source spacing 125 m, receiver spacing 25 m, 12-s records, sweep 8-96 Hz, 18 s linear.
5. **Finalize Survey Design Report (SDR-001):**
   - Compile all calculations, maps, ESIA mitigation measures, and station lists into a 30-page PDF.
   - Submit to Project Director for approval by end of Week 6.

2 – Weeks 6-8: Procurement, Permitting & Field Mobilisation

1. **Equipment Procurement:**
   - Issue purchase orders (PO-SEIS-07, PO-MT-04, PO-GRAV-01) via ERP.
   - Quantities:
     - Passive seismic nodes: 350 Galper G-32 three-component 2-Hz sensors.
     - MT systems: 60 Phoenix MTU-5C broadband kits with 200 m E-field wires.
     - Gravimeters: 2 Scintrex CG-6 AutoGrav units.
   - Mandate factory calibration certificates dated ≤ 30 days before shipping.
2. **Permitting & Land Access:**
   - Submit Form LA-21 to Land Office for 1 400 km² right-of-entry; attach ESIA baseline plan.
   - Schedule Community Town-Halls (4 villages, Week 7) — deliver 15-min presentation in local language and collect signed MoUs.
3. **Environmental & Wildlife Windows:**
   - Obtain bird-nesting calendar; restrict vibroseis lines to 10:00-16:00 and prohibit within 200 m of active nests.
   - Implement *"no-drive"* zones on GIS layers; load into Garmin GPS units.
4. **Field Crew Mobilisation:**
   - Hire 24 technicians and 8 observers locally; complete safety induction (HSE-SEIS-101) by Week 8.
   - Arrange 6 Land Cruisers, 1 water truck, 1 ATV-mounted auger.

3 – Weeks 9-12: Instrument Deployment & Acquisition

1. **Passive Seismic Node Installation (Weeks 9-10):**
   - At each station:
     1. Auger 20 cm-diameter, 50 cm-deep hole.
     2. Insert node inside PVC sleeve, orient North using Brunton compass (±1°), note tilt bubble < ±0.5°.
     3. Backfill with dry sand; tamp to ensure coupling.
     4. Record station ID, GPS (WGS-84) ±3 m, start time in FieldLog_Seis.csv.
   - Verify time-sync via GPS PPS pulse before burial; target drift < 200 µs per 24 h.
2. **Magnetotelluric Station Setup (Weeks 9-11):**
   - Deploy H-field coils oriented N-S and E-W on fiberglass sleds; level within ±1°.
   - Lay 100 m E-field copper wires in N-S, E-W directions; bury at 10 cm depth.
   - Connect non-polarizable Pb/$PbCl_2$ electrodes with contact resistance ≤ 1 kΩ (measure using Fluke 87).
   - Configure record schedule: continuous, sample rate 256 Hz, 32-bit, bandwidth 0.001-500 Hz.
3. **Gravity Survey (Weeks 10-12):**
   - Establish primary base station (concrete pier) with repeat reading every morning/evening.
   - For each measurement:
     1. Level CG-6 bubble to center, wait stabilization (reading variance < 5 µGal).
     2. Log temperature and pressure; enter in GravLog.csv.
     3. Take three repeat readings; accept if SD < 10 µGal; otherwise repeat.
4. **Vibroseis Refraction Lines (Weeks 11-12):**
   - Deploy 12-line spread with 8-vibrator fleet (Y-2400 trucks).
   - For each sweep:
     1. Load source parameter file: *Sweep: 8-96 Hz, 18 s*; check vib parameter group delay 100 ms.
     2. Record QC metric *Pilot correlation peak > 90%*.

4 – Weeks 9-12: Real-Time QA/QC Protocols (Ongoing)

1. Daily download 10% random seismic nodes; run *PS_NoiseScan.py* to compute Power Spectral Density (PSD). Flag nodes with median PSD > −120 dB re 1 $(m/s^2)^2$/Hz in 1-5 Hz band; schedule immediate visit.
2. Run MT remote-reference test each night: compute coherence > 0.8 between remote and local B-field at 0.01 Hz; if < 0.8, inspect electrodes.
3. Apply gravity loop closure: for every 20 stations, return to previous base; closure error ≤ 0.05 mGal; if exceeded, discard loop and repeat.
4. Maintain QC dashboard in Power BI connected to Dropbox/FieldData; update at 08:00 & 17:00 daily.

5 – Week 12: Demobilisation & Data Offload

1. Retrieve all nodes and MT systems; inspect for damage; log serial numbers.
2. Copy raw data to two encrypted SSDs (Samsung T7 2 TB) and one LTO-8 tape.
3. Verify SHA-256 checksum for every file; target zero mismatch.
4. Ship equipment back to vendors with RMA forms.

6 – Weeks 13-17: Data Processing, Inversion & Uncertainty Quantification

1. **Passive Seismic Ambient Noise Tomography:**
   1. Use ObsPy 1.4.0.

2. Detrend, demean, 1 Hz-50 Hz band-pass; slice into 1-hr windows; discard windows with RMS > 3 σ above median.
3. Compute cross-correlation; stack 60 days to form Green's functions.
4. Pick group velocity using FTAN; invert with FAST Marching Tomography (FMTOMO) to 30 km depth; target cell 1 km³.

2. **MT 3-D Inversion:**
    1. Convert raw time series to EDI using Phoenix SSMT2000; apply remote reference denoising.
    2. Run ModEM v3.0 with mesh 500 m horizontal, 250 m vertical until 10 km, then logarithmic increase factor 1.3.
    3. Set error floor: 5% apparent resistivity, 3° phase; fit target RMS ≤ 1.5.
3. **Gravity Inversion:**
    1. Apply free-air, Bouguer (ρ = 2 670 kg/m³), terrain corrections using Geosoft Oasis Montaj v9.
    2. Invert with UBC-GRAV3D; regularisation parameter λ chosen via L-curve; target misfit equal to data noise σ=0.1 mGal.
4. **Joint Inversion & Stress Indicators:**
    - Run joint inversion in GemPy 2.2 integrating seismic velocity, resistivity, density.
    - Derive maximum horizontal stress azimuth from fast S-wave polarisation; compute stress ratio $\Phi = (\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$.
    - Export 3-D model volumes as NetCDF v4 to directory */Models/Week17/*.
5. **Uncertainty Quantification:**
    - Implement 200 member Monte Carlo (perturb sensor noise ±2 σ, vary starting models).
    - Compute voxel-by-voxel coefficient of variation (CoV); map zones CoV > 30% for risk review.

7 – Week 18: Integration with Thermo-Mechanical Model & Final Reporting

1. Re-grid velocity, resistivity, and density volumes to 1 km resolution, 200 × 200 × 60 cells, align CRS to model (UTM Zone 33N, WGS-84).
2. Load into COMSOL Multiphysics 6.1 as property tables; execute verification run HT-CHECK-02 (simulate steady-state 350 °C at 30 km) and verify convergence.
3. Create drilling hazard map: compute gradient of velocity < −0.8 km/s per km as fracture zones; export raster GeoTIFF.
4. Generate launch gallery layout recommendation: place 12-24 wellheads where stress anisotropy angle ≤ 15° from planned 45° bore inclination.
5. Compile Final Campaign Report (FCR-007-010.pdf) sections:
    - Executive Summary (2 pages)
    - Methodology (10 pages)
    - Results (30 pages, with 12 figures, 4 tables)
    - Uncertainty & Risk (8 pages)
    - Recommendations (5 pages)
    - Appendices (raw logs, QC stats, processing scripts)
6. Hold close-out meeting; archive all material in SharePoint path */GeoTherm20/Subsurface/Campaign1/*.

Deliverables

- SDR-001 — Survey Design Report (Week 6)
- Field QC Dashboard (live Weeks 9-12; static export at Week 12)
- Raw & Processed Data Packages:
    - Passive Seismic SEG-Y Rev 1 (5.2 TB)
    - MT EDI files (420 GB)
    - Gravity ASCII + Oasis DB (2 GB)
- 3-D Inversion Models (Velocity, Conductivity, Density) — NetCDF v4 & VTK (Week 17)
- Uncertainty Volumes (CoV rasters)
- Drilling Hazard Map GeoTIFF (Week 18)
- Launch Gallery Layout Proposal CAD & PDF (Week 18)
- FCR-007-010 — Final Campaign Report (Week 18)
- Lessons-Learned Register LL-GEO-01 (Week 18)

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## OP-011 + OP-012 — Build & Calibrate 3D Thermo-Mechanical Earth Model to 30 km; Install Permanent Microseismic / Infrasound Monitoring Network

**Responsible Role:** Subsurface Modeling & Seismic Monitoring Lead — H-SUB-08 | **Timeline:** Phase 2 – Week 10 – 24

### Objective

Deliver a fully calibrated 30 km-deep, 3-dimensional thermo-mechanical earth model and a permanently-installed microseismic/infrasound monitoring network that together enable safe, optimized drilling and real-time operational decision-making for the LithoLoop 25 super-hot geothermal concept.

### Mandatory Pre-Execution Checks – Complete by Friday of Week 9

- Obtain written sign-off from HSE Manager confirming field-work risk-assessment (RA-SUB-021) and emergency-response plan (ERP-SUB-009) are approved.
- Verify procurement POs are fully executed for:
    - 12 × triaxial 4.5 Hz geophones (dynamic range ≥ 140 dB).
    - 4 × infrasound sensors, 0.01–100 Hz, noise floor < 0.3 Pa_rms.
    - 3 × edge-compute acquisition units (24-bit, ≥ 250 ksps aggregate).
    - 1 × OT-network enclave firewall (ISA/IEC 62443 compliant).
- Confirm GIS license (ArcGIS Pro 3.1) and geomechanics suite (PoroTect 2024) are activated on modeling workstation "GTH-WS-04".
- Create project directory `\\data-lake\GeoTherm20\Phase2\OP011_OP012` with sub-folders *raw_data*, *processed*, *models*, *reports*, *scripts*, and set permissions to the "SUB-TEAM" AD group.

### Step-by-Step Action Plan (Week 10 – 24)

1. **Week 10 – 12: Acquire & QA/QC All Input Data**
    1. Download regional heat-flow map (Global Heat Flow DB v5) in GeoTiff; re-project to UTM 33N (EPSG:32633) using `gdalwarp -t_srs EPSG:32633 input.tif output.tif`.
    2. Ingest oil & gas borehole logs:
        1. Locate LAS files *BH-101.las* to *BH-118.las* in vendor USB.
``````

    2. Run `las2txt.exe BH-*.las --mnemonic=DT,RHOB,GR,TEMP` and store in *raw_data\logs\csv*.
    3. Visually inspect curve headers; reject files missing > 10 % of DT or TEMP samples.
3. Pull inversion outputs (gravity, magnetotellurics) from `InversionServer@10.11.5.52:/mnt/inv_runs/final`; verify checksum with `sha256sum -c checksum.txt`.
4. Generate master data inventory spreadsheet (*processed\00_data_inventory.xlsx*) listing filename, vintage, CRS, units, quality-flags.

2. **Week 11 – 12: Field Survey for Sensor Deployment**
    1. Upload LiDAR-derived 1 m DEM into handheld GPS units (Trimble R8).
    2. Traverse planned gallery footprint; mark 12 geophone pads at 150 m radial spacing and 4 infrasound pads at 400 m spacing using flagging tape.
    3. Record precise coordinates (< 5 cm) and elevation; log in *survey.xlsx*.
    4. Conduct noise-level test for ≤ 30 min at each pad using portable seismometer; accept sites with RMS ground-noise < 10^{-8} m/s^2 for 1–50 Hz band.

3. **Week 12 – 16: Build Initial 3D Thermo-Mechanical Model**
    1. Launch PoroTect 2024. Create new project “LL25_TM_V1” with vertical extent 0–30 km, horizontal 35 km × 35 km.
    2. Import stratigraphic framework (faults.csv, horizons.grd); ensure lithocode mapping:
        - Basalt → Lithocode 11
        - Granite → Lithocode 22
        - Gneiss → Lithocode 33
    3. Assign petrophysical properties table (density, thermal conductivity, specific heat, Young’s modulus, Poisson’s ratio) located in *models\prop_table.xlsx*.
    4. Mesh Generation:
        1. Set X,Y,Z element size to 250 m; enable refinement to 50 m along major faults.
        2. Generate FE mesh; confirm total cell count ≤ 3 million.
    5. Apply Boundary Conditions:
        - Top (z = 0 m): constant temperature T_0 = 15 °C, σ_{hmin} = 0 MPa.
        - Base (z = −30 km): heat-flux q_b = 0.09 W m^{-2}, vertical displacement fixed.
        - Side walls: no-flux for heat, roller boundary for mechanics.
    6. Define Governing Equations:
        - Heat equation (conduction + advection):
          $\rho \cdot c_p \cdot (\partial T/\partial t + v \cdot \nabla T) = \nabla \cdot (k \cdot \nabla T) + Q$
        - Mechanical equilibrium (elastic/plastic rheology):
          $\nabla \cdot \sigma + \rho \cdot g = 0$
          $\sigma = D_e : (\varepsilon - \varepsilon^p)$ with Drucker–Prager yield (φ = 30°, c = 15 MPa)
    7. Iteratively solve to steady-state with `Δt = 1 kyr` time-steps until `|ΔT| and |Δσ| between iterations.`

4. **Week 16 – 20: Calibrate Model Against Observations**
    1. Insert borehole temperature logs BH-101, -104, -110, -118:
        1. For each depth point z_i, compute residual $r_i = T_{model}(z_i) - T_{obs}(z_i)$.
        2. Objective: minimize $\Sigma\, r_i^2$ using Levenberg–Marquardt on parameters $\{k_{granite}, q_b\}$.
    2. Stress Calibration:
        1. Load leak-off test data LOT-05 (depth 6.2 km, P_{frac} = 112 MPa).
        2. Adjust horizontal stress ratio $K = \sigma_{hmax}/\sigma_v$ until computed σ_{min} at 6.2 km equals 112 MPa within ±2 MPa.
    3. Generate updated model “LL25_TM_V2.cal”. Document calibration parameters in *models\cal_note.docx*.

5. **Week 18 – 21: Install Microseismic & Infrasound Network**
    1. Mobilize installation crew (3 technicians) and equipment truck on Monday 07:00 Week 18.
    2. For each geophone pad (G01-G12):
        1. Auger 80 cm-deep hole (Ø = 25 cm); pour dry quick-set grout level to 5 cm from rim.
        2. Lower sensor, align axes N-E-Z, tighten anchor screws; back-fill residual space with cuttings.
        3. Connect shielded-twisted-pair cable to junction box; verify resistance R = 37 ± 1 Ω.
    3. For each infrasound pad (IS01-IS04):
        1. Assemble porous-hose wind filter (4 m diameter).
        2. Mount sensor on concrete slab; route tubing through manifold to filter.
    4. Install edge-compute units in climate-controlled shed; patch fibre to OT firewall port G0/1.
    5. Configure acquisition software “SeisStream 6.2”:
        - Sample rate: 2 kHz geophones, 200 Hz infrasound.
        - Data format: miniSEED with 10 s packet length.
        - Time sync: GPS PPS (verify offset < 5 µs).
        - On-disk ring-buffer: 14 days (4 TB SSD).
    6. Run end-to-end test: tap each sensor with hammer; confirm arrival time difference matches inter-station distances within 10 ms.

6. **Week 21 – 22: Deploy Automated Event Detection & Traffic-Light System**
    1. On edge-compute unit, install Python 3.11, ObsPy 1.4.0, and machine-learning library ONNX-Runtime.
    2. Copy neural-network model *cnn_microeq.onnx* to `/opt/models`; verify SHA-256 hash equals `14d672…`.
    3. Create systemd service */etc/systemd/system/eeq_detect.service* with:

```
[Service]
ExecStart=/usr/bin/python3 /opt/scripts/run_detect.py --model /opt/models/cnn_microeq.onnx --threshold 0.95 --output http://10.9.1.80:8080/api/new_event
```

    4. Configure traffic-light logic in SCADA historian:
        - Green: Magnitude M_{lb} < −1.0.
        - Amber: −1.0 ≤ M_{lb} < 0.5, auto-notify drilling supervisor via SMS.
        - Red: M_{lb} ≥ 0.5 OR cumulative moment > 10^{11} Nm in 24 h → automatic well-control shutdown command issued to rig PLC.

7. **Week 22 – 24: Final Analysis & Delivery**
    1. Extract model outputs:
        - 1D temperature-depth profiles at 0°, 22.5°, 45° trajectory planes; export CSV.
        - 3D tensor volumes σ_1, σ_2, σ_3; export as VTK.
        - Fault proximity map: compute distance field to nearest mapped fault; output GeoTiff 10 m resolution.
        - Creep-closure index CCI = $(\sigma_\theta - P_{CO2})/E$; generate slice at 500 °C isotherm.
    2. Derive recommended heated-length intervals:
        1. Identify continuous 500–600 °C segment along 45° path; measure length L.
        2. If 1.5 km ≤ L ≤ 3.0 km → set interval L exactly; else select central 3.0 km within hottest zone.
        3. Record MD (measured depth) start/stop in *LL25_interval.xlsx*.
    3. Compile Final Report (*reports\OP011_OP012_Final.pdf*) structured:
        - Executive Summary – 2 pages.
        - Methodology – include equations, mesh parameters.
        - Results – figures 1-12, tables 1-4.
        - Monitoring Performance – sensor noise, detection latency histogram.
        - Recommendations – drilling trajectory, traffic-light thresholds.
    4. Hold stakeholder review meeting Friday Week 24 13:00–15:00. Capture MoM and obtain acceptance signatures from Project Director, HSE Manager, and Drilling Lead.

Deliverables

- 3D thermo-mechanical earth model file *LL25_TM_V2.cal* (native) + VTK export.
- Temperature-depth profile CSVs (0°, 22.5°, 45° trajectories).
- Stress tensor volumes and fault proximity GeoTiffs.
- Creep-closure risk map slices (500 °C isotherm).
- Recommended heated-length interval spreadsheet *LL25_interval.xlsx*.
- Installed microseismic & infrasound network (as-built drawings, sensor inventory, GPS coordinates).
- Operational traffic-light monitoring system fully integrated with OT network.
- Final PDF report “OP011_OP012_Final.pdf”.
- Meeting minutes & acceptance signatures (MoM-Week24-Final.docx).

```

## OP-008 — Define Baseline ESIA Scope & Monitoring Plan

**Responsible Role:** ESIA & Community Engagement Manager — H-ESIA-05 | **Task Timeline:** Phase 2 — Week 6 to Week 12

### HOW-TO-DO-IT — Step-by-Step Action Plan

1. **Week 6, Day 1 — Formal Kick-Off Meeting**
    - Send meeting invites to: ESIA team (all disciplines), Permitting Lead, HAZID/HAZOP Coordinator, Site Geoscience Lead, Community Liaison Officer, Procurement, and Data Management Lead.
    - Circulate agenda 48 h in advance: objectives, deliverables, timeline, role allocation.
    - During meeting, record minutes and confirm consensus on this action plan; publish minutes within 24 h in the project SharePoint folder “03_ESIA/OP-008/Minutes”.
2. **Week 6, Day 2-3 — Compile Regulatory & Standard Baseline**
    - Extract all applicable legal requirements and standards into “OP-008-RegMatrix.xlsx” with the following columns: Regulation_ID, Aspect, Requirement_Text, Source, Compliance_Metric, Reporting_Frequency.
    - Mandatory sources: Host-country ESIA decree §##, IFC PS 1-8, WHO Noise Guidelines (2018), ISO 4689-2 (vibration), Ramsar Convention for wetlands, UNESCO cultural heritage directives, FCC Part 18 (RF emissions), ASME PCC-2 for pressure systems.
3. **Week 6, Day 4 — Map LithoLoop-Specific Technical Attributes**
    - Create document “LL25_TechProfile.docx” summarising: closed-loop w/ no produced fluids, absence of stimulation, dry-cooling, shallow launch gallery (
    - Cross-reference each attribute against Regulation_ID in “OP-008-RegMatrix.xlsx”. Flag gaps in Column “Gap_Flag”.
4. **Week 6, Day 5 — Define ESIA Thematic Scope**
    - Populate “OP-008-ScopeRegister.xlsx”, Sheet 1 with rows for: Air Quality, Ambient Noise, Low-Frequency Noise, Ground Vibration/Micro-seismicity, Groundwater, Surface Water, Biodiversity, Cultural Heritage, Socio-Economic.
    - For each row add columns: Baseline-Parameter, Baseline-Method, Impact-Metric, Mitigation-Hierarchy, Monitoring-Frequency.
5. **Week 7 — Design Baseline Monitoring Campaigns**
    1. **Ambient & Low-Frequency Noise**
        - Instrument: Class 1 sound level meter, Brüel & Kjær 2250-L with outdoor kit.
        - Parameters: LAeq, L90, dB(C) for low frequency, and 1/3-octave band analysis 10 Hz – 20 kHz.
        - Measurement Formula: $\mathrm{LAeq} = 10 \times \log_{10}(1/T \int_0^{\wedge}T 10\wedge(\mathrm{L(t)}/10)\,\mathrm{dt})$
        - Sampling Plan: 4 off-site receptors (N,S,E,W) + plant boundary; continuous 7 days logging at 1 s intervals.
    2. **Air Quality**
        - Instrument: Aeroqual 500 series with $NO_2$, $SO_2$, $PM_{2.5}$, $PM_{10}$ sensors (accuracy ±2 µg/m³).
        - Sampling Duration: 14 days, 1 min average storage.
    3. **Ground Vibration/Micro-Seismicity**
        - Instrument: Nanometrics Trillium 120 PA broadband seismometer, 120 s corner.
        - Network: 5 stations on 1 km radius ring + 1 reference station 5 km away.
        - Trigger Threshold: 0.05 mm/s PPV at 4–90 Hz.
    4. **Groundwater Quality**
        - Identify 3 nearest boreholes ≤1 km down-gradient.
        - Parameters: pH, EC, TDS, As, Pb, Cl-, $SO_4^{2-}$, $sCO_2$ baseline.
        - Sampling Protocol: purge 3 well volumes, grab sample in 1 L HDPE bottles, chain-of-custody form COC-GW-01.
    5. **Biodiversity**
        - Survey Windows: Week 7 (spring), Week 10 (summer).
```

- Methods: Point-count for birds (radius 50 m, 10 min), live trapping for small mammals (20 Shermans/night), floristic transects (100 m × 2 m).

6. **Week 7, Day 5 — Procurement & Logistics**
   - Issue PRs in SAP for all listed instruments; include calibration certificates validity ≥12 months.
   - Book field vehicles and PPE; create Field HSE Plan “F-HSE-OP-008-V1.pdf”.
7. **Week 8 — Execute Field Campaigns**
   - Deploy sensors per GPS coordinates from “Sensor_Layout.kml”.
   - Check instrument levelling & orientation; log start-time in “FieldLog_OP-008.xlsx”.
   - Daily QA/QC: download data, run automated script “NoiseQA.py” — flag values where LAeq difference >3 dB between consecutive days.
   - For groundwater, ship samples on ice to ISO-17025 lab within 24 h.
8. **Week 9 — Data Validation & Storage**
   - Create PostgreSQL database “esia_baseline” with schema `public.air_noise_seis_bio`.
   - Use script “import_baseline.sql” to load CSV files; run duplicate check: `SELECT id, COUNT(*) FROM measurements GROUP BY id HAVING COUNT(*) > 1;`
   - Generate preliminary statistics (mean, 95th percentile) with R script “BaselineStats.R”. Output folder: “Analysis/Week9”.
9. **Week 9, Day 5 — Draft Mitigation Hierarchy**
   - Populate Sheet 2 in “OP-008-ScopeRegister.xlsx” with columns Avoidance, Minimisation, Restoration, Offset.
   - Example entry Air Quality-Dust: Avoidance = use paved access roads; Minimisation = water spray every 2 h; Restoration = wash vegetation quarterly; Offset = plant 100 trees/yr.
10. **Week 10 — Stakeholder & Community Engagement**
    1. Publish notice in local newspaper 7 days before meeting.
    2. Hold two public meetings (village hall & town council) — use presentation “LL25_ESIA_Baseline.pptx”.
    3. Capture all feedback in “Stakeholder_Log.xlsx” with unique ID, comment, response, follow-up action.
11. **Week 10, Day 5 — Define Incident Reporting & Roles**

Role	Responsibility	Form/Tool	Reporting Deadline
Field Lead	Immediate verbal alert to ESIA Mgr for any exceedance	Form INC-01	<1 h
ESIA Mgr	Root-cause analysis & corrective action plan	RCA Template RCA-02	72 h
Community Liaison	Notify affected stakeholders, record grievances	Grievance Log GL-01	24 h

12. **Week 11 — Interface Alignment**
    - Run joint workshop with Permitting & HAZID/HAZOP teams; map commitments using table “CommitmentRegister.xlsx”.
    - Ensure RF emission limits ≤ 27.5 dBm µV/m @3 m as per FCC Part 18; enter confirmation in Column “Permitting_Link”.
    - Cross-check pressure system controls vs ASME PCC-2 clause 5.2; attach evidence in register.
13. **Week 11, Day 4 — Draft Baseline ESIA Report**
    - Template: “Template_ESIA_Baseline.dotx”.
    - Structure: Exec Summary (2 pp) → Methodology → Results → Impact Screening → Mitigation & Monitoring → Stakeholder Engagement → Conclusion.
    - Embed maps exported from QGIS (CRS WGS84) at 300 dpi; caption style font-size:18px.
14. **Week 12, Day 1-2 — Internal Review**
    - Circulate draft to: Technical Director, VP HSSE, Legal Counsel. Use SharePoint “ESIA_Review” folder.
    - Collect track-changed comments; consolidate in “ReviewMatrix.xlsx”. Accept/reject within 48 h.
15. **Week 12, Day 3 — Third-Party Peer Review**
    - Send PDF to accredited ESIA consultant (EnviroCert Ltd); purchase order PO-3378.
    - Require responses matrix within 3 days; integrate changes immediately.
16. **Week 12, Day 5 — Final Approval & Handover**
    - Secure sign-off using DocuSign routing: ESIA Mgr → Project Director → CEO.
    - Upload final signed PDF “OP-008_ESIA_Baseline_V1-0_Signed.pdf” to EDMS; set status “Approved for Use”.
    - Issue transmittal note to all functional leads; close action items in Project Tracker.

Deliverables

- OP-008-RegMatrix.xlsx — comprehensive regulatory register
- OP-008-ScopeRegister.xlsx — ESIA scope & mitigation hierarchy
- Sensor_Layout.kml — geospatial coordinates for all monitoring stations
- Raw & validated datasets in PostgreSQL “esia_baseline” (export CSV backup)
- Stakeholder_Log.xlsx & GL-01 grievance records
- CommitmentRegister.xlsx — interface mapping to permitting & HAZID/HAZOP
- F-HSE-OP-008-V1.pdf — field HSE plan
- OP-008_ESIA_Baseline_V1-0_Signed.pdf — final baseline ESIA scope & monitoring plan

OP-009 + OP-013 — Grid Interconnection Feasibility, Site Synthesis & Preferred Site Approval

Responsible Roles: Grid Interconnection, HV & Protection Lead — H-GRID-06; Program Director & Systems Engineering Lead — H-PDSE-02 | **Timeline:** Phase 2 – Week 6 to 26

How-To-Do-It: Step-by-Step Execution Plan

1. **Week 6 (Initiation) — Formal Kick-off & Resource Allocation**
   a. Program Director sends a kick-off e-mail titled “OP-009 + OP-013 Launch” to *all grid, subsurface, ESIA, logistics, finance & legal stakeholders* by 12:00 UTC Monday Week 6.
   b. Attach this HTML manual and a RACI matrix (owner: H-GRID-06) and request e-signatures acknowledging responsibilities within 48 hours.
   c. Book a 2-hour virtual meeting on Wednesday Week 6 15:00-17:00 UTC. Agenda:
      - 10 min — Objectives & success metrics
      - 20 min — Grid feasibility methodology
      - 20 min — Site criteria weighting
      - 10 min — Governance gates & deliverables
      - 60 min — Q&A / role confirmation
   d. H-GRID-06 raises SAP purchase requests for:
      - Load-flow/licence upgrade for DIgSILENT PowerFactory v2024 SP1 — 1 floating licence
      - Short-circuit & protection module add-on
      - Two external PSCAD consultants (240 hours each)

e. Program Director loads Phase-2 Gantt in MS Project Online and shares read-only link within 24 hours after meeting.

2. **Week 6 to 10 — Consolidate All Input Data**
   a. Grid Team downloads latest transmission system data pack (node impedances, breaker ratings, existing protection settings) from TSO secure portal. Filename convention: `TSO_DATA_YYYYMMDD.zip`.
   b. Subsurface Team provides depth-to-isotherm rasters (`.tif`) at 250 m grid; naming: `TEMP500C_V03.tif` and `TEMP600C_V03.tif`.
   c. ESIA Lead supplies GIS shapefiles for environmental/heritage constraints: `ESA_BUFFER_3km.shp` etc.
   d. Logistics Lead uploads road, crane access, and water source layers to SharePoint folder `/GeoTherm20/SiteData/V2/`.
   e. H-GRID-06 verifies data completeness using checklist:

Dataset	Owner	Received?	Checksum MD5
Transmission Model	TSO	(y/n)	(hash)
Isotherm 500 °C Raster	Subsurface	(y/n)	(hash)
Environmental Buffers	ESIA	(y/n)	(hash)
Road & Crane Routes	Logistics	(y/n)	(hash)

   f. Any missing dataset triggers a RED status on the weekly dashboard and must be resolved within 72 hours.

3. **Week 8 to 16 — Detailed Grid Interconnection Feasibility Study**
   a. Create a dedicated directory `/GridStudy/FOAK_SiteNN/` for each candidate site. Standard sub-folders: `/01_Raw`, `/02_Models`, `/03_Results`, `/04_Reports`.
   b. For each site, perform the following sequential tasks:
      i. Model Integration:
         - Import TSO node data into DIgSILENT.
         - Insert sCO_2 Brayton generator equivalent using manufacturer test report `sCO2_GEN_V5.dgs` with the following electrical characteristics:
            - Rated apparent power S_{rated} = 1.05 × P_{max}
            - X''_d = 0.26 pu, X'_d = 0.33 pu, X_d = 1.85 pu (base MVA = generator MVA)
            - Short-circuit current contribution factor = 5.8 × I_{rated} for 100 ms.
      ii. Voltage Level Screening:
         - Run load-flow at 132 kV, 220 kV, 400 kV interconnection options.
         - Select lowest voltage with ≤ 2% bus voltage deviation under N-0 and < 15% branch loading under N-1.
      iii. Phased Capacity Ramp Simulation:
         - Create four scenarios: 12 MWe, 50 MWe, 200 MWe, 800 MWe.
         - Apply yearly commissioning years Y0, Y3, Y6, Y10 respectively.
         - Save scenario files as `SiteNN_SC##.dgs`.
      iv. Short-Circuit Analysis:
         - Run 3-phase bolted fault at POI and nearest HV bus using IEC 60909.
         - Document initial symmetrical fault current I_k'' and compare versus breaker duties:

```
Margin = BreakerRated_Ic - Ik"
```

           A positive margin ≥ 5 kA is required; otherwise flag for network upgrade.
      v. Protection Coordination:
         - Export relay settings file `RELSET_XXXX.set` from TSO.
         - Using PSCAD, inject time-domain fault signals to validate primary / back-up clearing times:

```
Δt = t_backup - t_primary ≥ 0.2 s
```

      vi. Dynamic Frequency & Voltage Ride-Through:
         - Implement sCO_2 governor model with droop = 4%, deadband = ±15 mHz.
         - Run a 1,000-MW system loss event and verify frequency nadir ≥ 49.4 Hz.
      vii. Curtailment Risk:
         - Import TSO 10-year congestion forecast (CSV).
         - Calculate annual curtailment percentage:

```
Curt_% = Σ(ForcedOffEnergy_MWh) / Σ(AvailableEnergy_MWh) × 100
```

         - Classify:
            - < 1% = Green
            - 1 – 5% = Amber
            - > 5% = Red
      viii. Export one-line diagram to AutoCAD DWG and PDF; naming: `SiteNN_OLI_V2.dwg`, `.pdf`.
      ix. Generate result dashboard (Excel) with macros locked, file name `SiteNN_RESULTS_V2.xlsm`.

4. **Week 14 to 20 — Site Selection & Ranking Synthesis**
   a. Compile multi-criteria decision matrix (`SiteRanking_V3.xlsx`) with the following weighted factors:

Criterion	Weight (%)	Scoring Function
Grid Capacity & Upgrades	25	Linear: 10 = No upgrade, 0 = > $50 M upgrade
Depth to 500 °C Isotherm	20	10 = < 22 km, 0 = > 28 km
Environmental Constraints	15	10 = Outside buffers, 0 = Inside exclusion zone
Community Acceptance Index	15	10 = > 80% support, 0 = < 50%
Water Availability (Hybrid Cooling)	10	10 = > 120 l/s within 3 km, 0 = < 40 l/s
Constructability of Launch Gallery	10	10 = > 50% flat rock, 0 = > 15° slope & weak soil
Logistics & Roads	5	10 = < 2 h heavy-haul, 0 = > 6 h

   b. Hold 4-hour workshop (Week 18 Wednesday) to assign individual criterion scores. Attendance mandatory: H-GRID-06, Subsurface Lead, ESIA Lead, Logistics Lead, Finance.
   c. Use formula to compute weighted score for each site:

```
TotalScore_site = Σ(Weight_i × Score_i) / 10
```

   d. Rank sites highest to lowest; highlight top 3 in green, bottom 3 in red.
   e. Export matrix as locked PDF `SiteRanking_V3.pdf`.

5. **Week 21 to 22 — Governance Review & Preferred Site Approval**
   a. Program Director schedules Gate 2 meeting (2 hours) with Executive Steering Committee (ESC).
   b. Distribute pre-read 5 business days in advance:
      - Grid feasibility summary (PDF ≤ 20 pages)
      - Site ranking matrix PDF
      - Decision memo draft (template `DEC_MEMO_V2.docx`)

c. During meeting, present slides with:
- Risk, schedule & cost differential between top 2 sites
- Recommendation: select site with highest TotalScore ≥ 7.5
- Seek formal motion: “Approve Preferred FOAK Site”

d. Record minutes and ESC vote. Requirement: ≥ 80% “Yes” to pass.
e. Upon approval, PD signs memo; file as `DEC_MEMO_Final.pdf` in SharePoint.

6. **Week 17 to 24 — Prepare Interconnection Application Package**
a. Populate TSO Form IC-2024 fields exactly:
- Section 3.1 “Proposed Maximum Net Power” = 800 MW
- Section 3.4 “Phased Commissioning Schedule” = see table below

b. Create Phasing Table (include in application):

Phase	Loop Count	Capacity (MWe)	Target COD
1	1	12	Y0 + 0
2	4	50	Y0 + 3 y
3	16	200	Y0 + 6 y
4	64	800	Y0 + 10 y

c. Attach the following compulsory documents:
- One-line diagram PDF
- DIgSILENT load-flow *.dgs model
- Short-circuit report PDF (auto-generated with revision 2)
- Protection philosophy note (`PROT_NOTE_V2.pdf`)
- sCO_2 generator data sheet (`sCO2_GEN_DS_V5.pdf`)

d. Use Adobe Acrobat to combine all PDFs into `IC_APP_SiteName_V2.pdf`; ensure file size ≤ 50 MB.
e. Upload to TSO portal before 17:00 local time Friday Week 24; capture submission ID and store in SharePoint.

7. **Week 24 to 26 — Post-Submission Follow-up & Close-out**
a. Create tracking log `IC_Query_Log.xlsx` with columns: Query#, DateRecv, Section, Owner, ResponseDue, Status.
b. Assign H-GRID-06 as primary contact; ensure 72-hour turn-around for TSO queries.
c. Update ESC weekly with 1-slide dashboard showing:
- Number of queries open/closed
- Any risks threatening target interconnection agreement date

d. Archive all final documents under SharePoint path `/Phase2/Completed/`. Lock folders (read-only) using compliance retention label “Phase2-Final + 7 Years”.
e. Issue Phase-2 Close-out memo with hyperlink to archive and circulate company-wide.

Deliverables:

- DIgSILENT load-flow & short-circuit models for each candidate site (`SiteNN_SCENARIOS_V2.dgs`)
- One-line diagrams (DWG & PDF)
- Grid feasibility technical report (`GRID_STUDY_V2.pdf`)
- Site ranking matrix (locked XLSX and PDF)
- Approved Decision Memo (`DEC_MEMO_Final.pdf`)
- Complete interconnection application package (`IC_APP_SiteName_V2.pdf`) with submission ID proof
- Query tracking log (`IC_Query_Log.xlsx`) and weekly dashboards
- Phase-2 Close-out memo with archive link

```html

## OP-014 + OP-015 — Launch Gallery Front-End Engineering Design (FEED) & Geotechnical Investigation

Responsible Role: Underground Works & Tunneling Manager — H-TUN-09 | Task Timeline: Phase 3 (Weeks 22 – 36)

### 1. Pre-Mobilisation & Kick-Off (Week 22)

1. Issue a formal **Notice-to-Proceed (NTP)** e-mail to all internal disciplines (Geotechnical, Civil, Mechanical, Electrical, Fire/Life-Safety, RF) and external drilling contractor (DRIL-SERV-03). Attach this instruction manual and require written acknowledgement within **24 h**.
2. Create Work Breakdown Structure (WBS) code **OP-014/015-P3** in Primavera P6 and allocate cost accounts.
3. Load all specifications referenced in this package to the project CDE (Asite) under folder *“03-Design > FEED > Launch Gallery P3”* and send read-access permissions.
4. Schedule a 2-hour virtual Kick-Off Meeting (Microsoft Teams) on **Week 22 Day 3 @ 09:00 local**. Agenda must include: scope review, HSE plan, data interfaces, and decision milestones. Record and archive the meeting video in CDE.

### 2. Design-Basis Re-confirmation (Week 22)

5. Download latest “LithoLoop25 System-Level Design Basis v2.4.pdf”. Verify that wellhead count (12–24) and incline angle (45°) are unchanged. If discrepancies exist, raise Design Change Request (DCR) form DCR-LL25-XX within 48 h.
6. Freeze the following numeric parameters in a dated Design-Basis Sheet (Excel) and store in CDE:
- Gallery invert depth: **350 m (±25 m)**
- Internal clear width: **8.0 m**
- Internal clear height crown-to-invert: **6.0 m**
- Maximum heat rejection from gyrotron & ancillaries: **$Q_{thermal}$ = 4.2 MW**
- Argon release credible worst case: **6 kg/s for 120 s**

7. Digitally sign the Sheet with Adobe Sign and mark “ISSUED FOR FEED”.

### 3. Detailed Geotechnical Investigation Plan (Weeks 22 – 23)
```

8. Select three borehole locations (BH-LG-01 to BH-LG-03) along the planned gallery centerline using GIS coordinates:
    - BH-LG-01: Easting 63,502.4 m; Northing 8,520,233.2 m
    - BH-LG-02: Easting 63,551.9 m; Northing 8,520,197.7 m
    - BH-LG-03: Easting 63,609.8 m; Northing 8,520,169.8 m
9. Set target borehole depth to **600 m TVD** with HQ-size oriented core.
10. Write “Field Instruction FI-GT-07” specifying:
    - Coring advance: ≤ 1.5 m/run
    - Core orientation tool: Reflex ACTIII
    - Downhole geophysics: Acoustic Televiewer, Optical Televiewer, Caliper, Natural Gamma
    - Water pressure test every 50 m (Lugeon method)
    - Hydraulic fracturing stress test at 300 m, 450 m, 580 m

    Export as PDF and issue to DRIL-SERV-03.
11. Submit Drilling Permit application to Regulator (GeoMin Dept.) with:
    - Form DR-A1 completed in blue ink
    - Site map scale 1:2 000
    - SAP Environmental Impact Screening ID EIS-2025-99

    Deadline: **Week 22 Day 5 17:00**.
12. Receive written permit approval before initiating mobilisation; log permit number in the Project Register.

4. Site Mobilisation & HSE (Week 23)

13. Verify contractor HSE documentation: Job Safety Analysis (JSA), MSDS files for drilling fluids, and Emergency Response Plan. Place hard copies in a weather-proof binder on site.
14. Install fencing (2 m chain-link) around each borehole pad; lockable gate, HSE signage “AUTHORIZED PERSONNEL ONLY” in 100 mm letters.
15. Conduct Site Induction for all personnel; record attendance on Form HSE-IND-04.
16. Deploy real-time gas monitor (Industrial Scientific Ventis Pro5) within 5 m of rig exhaust; configure alarm thresholds:
    - $O_2 < 19.5\ \%$
    - CO > 25 ppm
    - $H_2S > 10$ ppm

5. Borehole Drilling & Core Handling (Weeks 23 – 27)

17. Advance drilling in 12-hour shifts (07:00–19:00 / 19:00–07:00). Record penetration rate, mud weight, pump pressure on Daily Drilling Report (DDR) template.
18. Upon each core run, perform:
    a. Recover core into HQ split aluminium trays.
    b. Orient core using scribed line; mark Up/Down arrows every 1 m.
    c. Photograph every tray using DSLR camera at 300 dpi with scale bar and north arrow visible. File naming convention: *BH-LG-01_CoreBox-###.jpg*.
    d. Measure and log RQD to nearest 1 %. Record lithology, fracture frequency, infill type in Geospark® software; auto-sync to CDE nightly.
19. Seal sample sections for lab testing in heat-shrunk PVC sleeves, label with waterproof marker (black, 10 mm font).
20. At 600 m TVD, stop drilling, run full suite of geophysical logs while pulling out at 4 m/min; export LAS files.

6. Laboratory Testing (Weeks 24 – 29)

21. Ship core samples via tracked courier (Temp < 25 °C) to GeoLab Ltd. Include Chain-of-Custody form COC-GT-12.
22. Perform tests per table below and require ISO/IEC 17025 compliance:

Test	Standard	Specimen Qty	Output
Unconfined Compressive Strength (UCS)	ASTM D7012-14	45	σ_c (MPa)
Triaxial Compression	ISRM Suggested	18	σ_1, σ_3, E
Permeability (Pulse Decay)	BS EN ISO 17892-11	12	k (m/s)
Point Load Index	ASTM D5731-16	60	$I_{s(50)}$ (MPa)
Slake Durability	ASTM D4644-16	10	ID_2 (%)

23. Require GeoLab to deliver electronic PDF and CSV results within **10 working days** after sample receipt.
24. QC Check: Compare duplicate UCS results; if CoV > 8 %, issue Non-Conformance Report (NCR-GT-03).

7. Data Processing & Rock Mass Classification (Weeks 28 – 30)

25. Import LAS logs, lab CSV, and core logs into Leapfrog Geo 2023. Establish uniform datum = −50 m aMSL.
26. Compute RMR89 for each 1 m interval using formula:

    `RMR = RQD + Uniaxial Strength Rating + Discontinuity Spacing + Discontinuity Condition + Groundwater Rating`

    Use strength rating scale table in Bieniawski (1989) Appendix A.
27. Compute Q-System: $Q = (RQD/J_n) \times (J_r/J_a) \times (J_w/SRF)$
28. Populate 3-D block model; generate coloured iso-surfaces for RMR classes (I–V).
29. Export 3-D model as IFC and OBJ; store in CDE folder *“04-GeoModel”*.

8. Excavation & Ground Support Design (Weeks 30 – 32)

30. Using Rocscience RS2, set boundary conditions:
    - In-situ stress $\sigma_V = \rho g h = 0.027\ \text{MPa/m} \times 350\ \text{m} = 9.5\ \text{MPa}$
    - Horizontal stress ratio $k_H = 1.2$
31. Model gallery cross-section (horseshoe) 8 m W × 6 m H.
32. Select initial support pattern based on Q-System:
    - Shotcrete: 100 mm plain + 100 mm fibre-reinforced (steel 40 kg/m³) for Q < 4
    - Rock bolts: 25 mm dia. resin-grouted, 4 m L, triangular pattern 1.5 m × 1.5 m
    - Steel sets (HEB 200) every 1 m where Q < 1

    Digitally stamp rev “SUP-P3-01”.

33. Validate factor of safety > 2 for all cases; iterate until criteria met.

9. Ventilation & Gas Management Design (Weeks 31 – 33)

34. Calculate required airflow using heat load: $\dot{m} = Q / (\rho \times c_p \times \Delta T)$
    Input: Q = 4.2 MW; ρ (air) = 1.2 kg/m³; c_p = 1,005 J/kg·K; ΔT = 10 K → $\dot{m}$ = 350 kg/s.
35. Convert mass to volumetric flow: V = $\dot{m}$/ρ = 292 m³/s.
36. Select two identical axial fans (Howden AXR-2800) duty 150 m³/s @ 2.0 kPa; N+1 redundancy.
37. Design fresh-air duct Ø 3.0 m steel spiral; exhaust via raise Ø 5.0 m to surface.
38. Specify 12 fixed oxygen sensors (Teledyne MX-62) spaced every 25 m; trip setpoint 19.0 % O_2; hardwire to Allen-Bradley PLC in FLC.

10. Fire/Life-Safety & RF Shielding (Week 32)

39. Segment gallery into 30 m fire compartments using 150 mm FR concrete bulkheads with EI-120 rated doors.
40. Specify water-mist suppression (Fogtec Series 4000) with coverage density 0.25 L/min·m²; zoned valves every 30 m.
41. Emergency lighting: LED IP66 luminaires > 50 lx at floor for 90 min on UPS (UPS-900 kVA).
42. RF shielding: Install 6 mm carbon steel liner plate fully welded; continuity test ≤ 1 mΩ across joints; target attenuation ≥ 120 dB @ 170 GHz.
43. Integrate waveguide RF interlock; fail-safe open on O_2 deficiency or fire signal.

11. Equipment Foundations & Utilities (Week 33)

44. For each gyrotron (16 units assumed):
    - Design reinforced concrete plinth 2.0 m × 2.0 m × 1.2 m with 24 M20 anchor bolts.
    - Dynamic load case: 10 kN vertical @ 20 Hz; limit vibration < 50 µm peak-to-peak.
45. Pipe rack along north wall: 4 × OD 219 mm argon pipes + 2 × OD 273 mm CO_2 return; stainless 316L Schedule 40.
46. Cable trays Galv. steel 600 mm W with 38 mm rung spacing; install at 2.5 m elevation.

12. Construction Sequencing & Schedule (Week 33)

47. Adopt Top-Heading-and-Bench:
    - Heading advance: 3.0 m rounds, drill pattern 45 holes × 51 mm, charge 1.2 kg/m.
    - Apply initial shotcrete within 2 h of blast.
    - Bench removed 1 round lag (3 m).
48. Enter detailed sequence into MS Project sub-schedule “LG-CONST-SEQ” with logic links FS and lag = 1 day.

13. Cost Estimate & Risk Register (Week 34)

49. Compile BOQ in Excel (template COST-V11); include labour, material, plant, indirects. Contingency 15 %.
50. Create Risk Register (RR-LG-P3) with columns: ID, Description, Probability (1-5), Impact (1-5), Mitigation, Owner.

14. FEED Documentation & Internal Review (Weeks 34 – 35)

51. Draft FEED Report (max 200 pages) in Word using template DOC-STD-02. Sections: Executive Summary, Basis, Geotechnical, Excavation, Support, Ventilation, FLS, Utilities, Cost, Schedule.
52. Insert all drawings (PDF/A) produced in AutoCAD 2024, sheet size A1 landscape.
53. Run internal Inter-Discipline Check (IDC): circulate to Mech, Elec, Process, HSE; collect comments in Excel log.
54. Close all category A & B comments within 5 working days; attach evidence of closure.

15. Permitting Submission & Final Sign-Off (Week 36)

55. Package the following into ZIP “LaunchGallery-FEED-SUB-v1.0.zip”:
    - Signed FEED Report PDF
    - Geotechnical Factual & Interpretative Reports
    - IFC 3-D Models
    - Civil/MEP Drawings (DWG + PDF)
    - Risk Register
    - Cost Estimate (XLSX)
56. Upload ZIP to Regulator’s E-Permitting Portal; reference Project ID LL25-LG-P3.
57. Obtain electronic receipt; store in CDE. Update P6 milestone “SUB-FEED-LG” to **Complete**.
58. Issue “Completion Memo CM-LG-P3” to Project Director within 24 h.

Deliverables

- Design-Basis Sheet (Excel, signed)
- Geotechnical Factual Report (PDF)
- Geotechnical Interpretative Report (PDF)
- 3-D Geological Model (IFC & OBJ)
- Ground Support Drawings (DWG & PDF)
- Ventilation & FLS Calculations (Excel)
- RF Shielding Compliance Test Plan (PDF)
- FEED Report (PDF)
- Bill of Quantities & Class-3 Cost Estimate (Excel)
- Level-3 Schedule Extract (Primavera P6 XER)
- Risk Register (Excel)
- Permitting Submission Receipt (PDF)

- Completion Memo CM-LG-P3 (PDF)

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## OP-016 — Detailed Gallery Design & Issued-For-Construction (IFC) Package

**Responsible Role:** Underground Works & Tunneling Manager — H-TUN-09 | **Timeline:** Phase 3 – Week 37 to Week 44

### How-To-Do-It: Step-by-Step Execution Plan

1. **Week 37 — Kick-Off & Data Consolidation**
    1. Formally launch OP-016 in the project schedule management tool (Primavera P6 Activity ID: OP016-W37-KOF).
    2. Convene a 2-hour virtual kickoff meeting with: Geotechnical Lead, RF Systems Lead, Cryogenics Lead, Electrical/Power Lead, Fire Safety Engineer, BIM Manager, and Construction Superintendent. Record minutes and load to EDMS folder *"OP-016 \ 00-Meetings"* within 24 hours.
    3. Pull latest approved documents into the controlled workspace:
        - Geotechnical Investigation Report (GIR-V4 dated ≤ Week 36).
        - HAZOP & HAZID Registers (HAZ-RF-021 to HAZ-GEN-033).
        - Preliminary Gallery Design Model (REV P03).
        - Utility Interface Specs (PWR-IF-12, COOL-IF-07, ARG-IF-03).
    4. Create a single "Design-Freeze" change control log (xlsx) with columns: *Interface, Item, Baseline Rev, Proposed Rev, Impact, Approval Date*. Save as **OP016-IFC-DesignFreeze-Log.xlsx**.
2. **Week 38 — Interface Freezing & Criteria Definition**
    1. Update the 3D BIM model (Autodesk Revit 2024, central file: *LGallery_IFC_CEN.rvt*):
        - Import geotechnical strata surfaces *"GEO\Strata_IFC.dwg"* and lock to global coordinates (Lat: -23.388000°, Long: 132.235000°, Elev Datum = 0 mASL).
        - Apply recommended excavation support values from GIR Section 7: Shotcrete Fibre-Reinforced, 200 mm thickness, 4 m × Ø25 mm rock bolts @ 1.2 m grid.
    2. Define design freeze datum:
        - RF plant interface plane: X = -15.200 m.
        - Argon loop interface collar: Y = +9.050 m, Z = -4.000 m.
        - Power/Cooling manifold stub-outs: Embedded sleeves Ø150 mm, 12 mm wall, centreline at Z = +2.200 m.
    3. Circulate Interface Freeze Memo (**IFM-OP016-001**) for electronic signatures of all subsystem leads by Friday 17:00 local time.
3. **Week 39 — Detailed Arrangement & Equipment Placement**
    1. Model equipment pads: 40 MPa concrete, surface finish Ff45/Ff35, embed plates 300 mm × 150 mm × 20 mm, M20 ferrules @ 250 mm c/c. Reference Table 4.3 of Structural Spec STR-CIV-003.
    2. Add drainage system:
        - Sump 1 at KP 0+015, invert -6.300 m.
        - 150 mm HDPE PN10 piping, slope 1.0 % towards Sump 1.
        - Submersible pump: Grundfos SLV.65.80.40 D + Float Switch.
    3. Ventilation: Insert two axial fans (TLT-Turbo AFC 1180) at Gallery Portal, flow 14 m³/s each, configured push-pull with 1.2 kPa static pressure. Ducting: 1 000 mm dia × 3 mm spiral steel, joints gasketed EPDM.
    4. Create RF shielding tags:
        - Wall & ceiling: 6 mm thick Cu-Ni mesh @ 10 mm aperture, 97 % coverage.
        - Bond mesh to rebar using stainless steel clips every 300 mm.
        - Terminate to ground bus (99.9 % copper) at four equidistant nodes.
4. **Week 40 — Utilities & Monitoring System Integration**
    1. Power distribution: Route two 800 A / 480 V feeders in 150 mm cable tray (NEMA 12A) on west wall. Install 4-pole disconnect switch (Siemens SIVACON 8PS).
    2. Cooling: Detail 80 mm stainless steel chilled-water supply/return lines. Weld 304L pipe with TIG; perform 100 % radiographic inspection.
    3. Compressed gases: Provide dual manifold (Ar & $N_2$) in alcove at KP 0+027, with flashback arrestors (GENTEC model FA-100).
    4. Monitoring:
        - $O_2$ sensors: Teledyne MX16-O2 every 20 m.
        - Smoke detectors: Vesda VLF-500 aspirating pipeline at ceiling centreline.
        - Temperature RTDs: PT100 Class A, 5 m interval along east wall.
        - RF leakage probes: AR FieldSense FS-52, 4 points, integrate to SCADA tag block "RF-LG-###".
5. **Week 41 — Access, Egress & Rigging Provisions**
    1. Model longitudinal clear path 1 800 mm wide × 2 400 mm high for waveguide modules (200–350 mm bore). Add TURNING RADIUS study using Navisworks path simulation; maximum deflection ≤ 8° at KP 0+034.
    2. Insert embedded rigging rails: 200 mm × 100 mm I-beam (S355) at ceiling, 3 m spacing, SWL 1 500 kg. Weld 6 mm fillet, 150 mm continuous.
    3. Emergency egress: Provide two cross-passages to service tunnel at KP 0+012 and KP 0+045, finished floor elevation -4.500 m. Install FRP door (2-hr fire rating) opening towards egress flow.
6. **Week 42 — QA Checkpoints, Tolerances & Fire/Life Safety**
    1. Create QA tracker (OP016-QA-Matrix.xlsx) listing 28 inspection points:
        - Excavation over-break: Limit ≤ 150 mm.
        - Shotcrete thickness: Target 200 mm ± 10 mm (core test every 10 m).
        - Concrete pad levelness: ±3 mm over 3 m straightedge.
        - Cable tray sag: ≤ 10 mm per 3 m span.
    2. Document digital-twin capture:
        - Laser scan (Leica RTC360) each 5 m station.
        - Resolution: 6 mm @ 10 m, file format E57.
        - Upload to CDE folder "02-Design \ LaserScans \ Week42".
    3. Fire suppression: Specify mist system (Marioff HI-FOG) 120 bar, nozzle spacing 3 m. Water supply via 50 mm SS316 pipe, accumulator 1 000 L @ 150 bar.
    4. Fire separation: Build 2-hr fire wall at interface to Electrical room, 150 mm thick refractory panels (FiberFrax Isofrax 1400).
7. **Week 43 — IFC Documentation & Review**
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1. Generate IFC drawing set:
   - Civil (G-IFC-CIV-###) — 18 sheets, A1.
   - Structural (G-IFC-STR-###) — 12 sheets, A1.
   - MEP (G-IFC-MEP-###) — 25 sheets, A0.
   - Fire/Life Safety (G-IFC-FLS-###) — 6 sheets, A1.

   Export to PDF (300 dpi, PDF/A-2b) and native DWG.
2. Issue Design Report (OP016-DR-IFC-R01):
   - Executive summary (2 pp).
   - Basis of design (6 pp).
   - Geotech incorporation (4 pp).
   - Risk register & mitigations (3 pp).
3. Conduct 4-hour Formal Design Review DR-042 with external peer panel; capture 100 % comments in "IFC-PeerReview-Log.xlsx".

8. **Week 44 — Final Approvals & Package Release**
   1. Close out all peer review comments by 12:00 Wednesday. Update drawings to Rev IFC-B.
   2. Upload complete IFC package (ZIP, ≤ 2 GB) to CDE path *"04-IssuedForConstruction \ OP-016 \ Rev B"*.
   3. Issue Transmittal TR-OP016-IFC-B to Construction Superintendent and Quality Manager via EDMS; include checksum (SHA-256) of ZIP file.
   4. Update Primavera activity to "Completed" with actual finish date.
   5. Archive source models to cold storage bucket "\Archive\2024\OP016\Week44".

Deliverables:

- IFC Drawing Set (PDF + DWG) Rev IFC-B.
- Design Report OP016-DR-IFC-R01.
- Design-Freeze Log OP016-IFC-DesignFreeze-Log.xlsx.
- QA Matrix OP016-QA-Matrix.xlsx.
- Laser Scan Dataset (E57) with registration report.
- IFC Package Transmittal TR-OP016-IFC-B with checksum.
- BIM Model LGallery_IFC_CEN.rvt (Rev B).

OP-017 + OP-018 — Permit Preparation & HAZOP/HAZID Execution Manual

Responsible Roles : Regulatory & Permitting Lead — H-RPL-04; HSE & Process Safety Lead — H-HSE-11 | **Task Timeline :** Phase 3 — Week 28 to Week 42

HOW-TO-DO-IT — Step-by-Step Execution Plan

1. **Establish Project Governance (Week 28, Day 1)**
   - Create a dedicated Microsoft Teams channel named "P3-Permits-&-Hazard-Studies".
   - Upload the latest Issue-for-Design (IFD) package: *Gallery FEED Rev-C, Well Design Rev-B, RF Plant Rev-B, Pressure Systems Rev-B*.
   - Issue the "P3-RS-001 Responsibility Matrix" assigning document authors, reviewers, and approvers. Obtain electronic signatures in DocuSign within 24 hours.
   - Open SharePoint folder: `\\GeoTherm20\Phase3\Permits\` with subfolders: `01_Gallery`, `02_Well`, `03_RF_Plant`, `04_Pressure_Systems`, `05_HAZOP`, `06_HAZID`.
2. **Map Regulatory Requirements (Week 28, Days 1-3)**
   1. Download current statutes:
      - US 30 CFR 57, 30 CFR 250 (underground & offshore analogues)
      - ASME BPVC Section VIII, Div 3 (pressure systems)
      - FCC Part 18 (ISOLATED RF INDUSTRIAL, Scientific & Medical)
      - API Std 53 (well barriers)
      - ISO 17776 and IEC 61511 (hazard studies & SIFs)
   2. Populate "P3-REG-MAP.xlsx" with three columns:
      a. Regulation/Clause
      b. Applicability Note (Yes/No/Partial)
      c. Gap Handling Strategy (Code-Justified / Performance-Based)
   3. Highlight gaps for vitrified liners, meta-casing, and mm-wave drilling as light grey.
   4. Issue the mapping for approval by H-RPL-04 (deadline: Week 28, Day 3, 17:00 local).
3. **Freeze Permit Dossier Templates (Week 28, Day 4)**
   - Create Word templates "P3-PER-T001" to "P3-PER-T004" with the following fixed sections:
     1. Executive Summary
     2. Project Description
     3. Technical Design Basis
     4. Risk Assessment & Mitigations
     5. Environmental Management
     6. Monitoring & Reporting
     7. Appendices (drawings, calculations, test data)
   - Insert the following footer on every page: `GeoTherm20 — LithoLoop 25 | Document Class: Permit Application | Confidential — Regulator Use Only.`
4. **Compile Source Data (Week 28, Day 5 to Week 29, Day 2)**
   1. Gallery Geotechnical:
      - Import borehole logs LL25-GTH-017 to LL25-GTH-035 into "P3-DATA-GEO.accdb".
      - Export shear strength envelopes (Mohr-Coulomb) at 5 m increments (CSV).
   2. RF Plant:
      - Gather RF cavity design drawings DWG-RF-CAV-001-004.
      - Obtain shielding simulation results "MCNP6-RF-170GHz-Shielding.rpt".

3. Pressure Systems:
    - Export sCO2 loop P&IDs (PDF) and Relief Valve sizing spreadsheets RV-SIZ-SC02.xlsx.
    - Confirm pressure test certificates up to 120 MPa (scan originals to PDF, 300 dpi).
4. Well Design:
    - Collect meta-casing deposition validation report “VitrifTest-B316.pdf”.
    - Import CFD quench analysis “ANSYS-Quench-MeltStop.wbpz”.
5. Store all raw data in SharePoint “00_Source” and lock with read-only permissions.

5. **Draft Permit Dossiers (Week 29, Day 3 to Week 33, Day 5)**

Dossier	Primary Author	Page Limit	Key Attachments
Gallery Underground Works	Geotech Engineer G-ENG-07	85	Rock Stress Models, Excavation Sequencing
First Well & Double-Barrier Design	Drilling Lead D-LEAD-02	110	Meta-casing Test Data, Well Schematic IFC-WELL-01
RF Plant 100-170 GHz, 1-3 MW CW	RF Systems Engineer RF-SE-05	95	Shielding Calcs, Interlock Logic Diagrams
Pressure Systems (Argon & sCO2)	Pressure Lead P-LEAD-03	90	ASME VIII Div 3 Stress Reports, Relief Valve Certs

    a. Populate each Section 4 “Risk Assessment & Mitigations” using hazard registers from previous phases (CSV import path: `\\GeoTherm20\Phase2\HAZREG.csv`).
    b. For novel elements with no code coverage, insert a **Performance-Based Justification** subsection containing:
        1. Design Objective
        2. Functional Performance Criteria
        3. Validation Evidence (prototype test data, FEA, CFD)
        4. Monitoring Plan
    c. Use the following example statement for vitrified liners: “The vitrified liner provides an elastic modulus of 70 GPa and fracture toughness of 1.2 MPa√m, exceeding ISO 13679 Annex B leak rate criteria by a factor of 20.”
    d. Compile environmental control narrative for dry-cooling system: include annual water use = **0 m³/yr**, plume suppression height < 2 m above stack.

6. **Conduct Internal Review & QA (Week 34, Days 1-4)**
    1. Route each dossier via the GeoTherm20 e-QMS workflow “Permit Doc Review v3.2”.
    2. Assign reviewers:
        - Technical Accuracy: System Discipline Leads
        - HSE Compliance: H-HSE-11
        - Legal Consistency: Corporate Counsel LEG-01
    3. Reviewer comments to be returned in Word track-change mode by Day 4, 12:00.
    4. Authors to incorporate changes by Day 4, 18:00.
    5. Generate a single PDF file per dossier using Adobe Acrobat “PDF/X-4” preset.
7. **Hold Regulator Alignment Meetings (Week 34, Day 5)**
    - Schedule 2-hour virtual calls with:
        1. Mine Safety & Health Administration (gallery permit)
        2. Bureau of Safety & Environmental Enforcement (well)
        3. Federal Communications Commission (RF plant)
        4. Occupational Safety & Health Administration, PSM Unit (pressure systems)
    - Provide each agency with a 10-slide pre-read deck 48 h prior; slides to include high-level risk diagrams, mitigation summary, and schedule.
    - Record meetings in Teams, save MP4 files to `05_Regulator_Meetings` folder.
8. **Finalize & Submit Permit Dossiers (Week 35, Days 1-3)**
    1. Insert signed Form OP-PER-COV (agency-specific cover page) including Notary stamp where required.
    2. Create USB 3.2 Gen 2 sticks, label with laser etch: “GeoTherm20-Phase3-[Dossier Name]-Rev0”.
    3. Upload e-filing PDFs to each regulator’s portal; record submission ID.
    4. Email confirmation letters signed by H-RPL-04 within 1 hour of upload.
    5. Archive final PDFs and submission receipts in SharePoint “07_Submitted”.
9. **Plan HAZOP & HAZID Workshops (Week 35, Days 4-5)**
    1. Create spreadsheet “P3-HAZ-NODE-LIST.xlsx” with columns: Node ID, System Boundary, Design Intent, Guidewords.
    2. Define nodes:
        - DR-MELT-001 — MM-wave melt zone
        - DR-QUENCH-002 — Argon quench zone
        - WL-LINER-003 — Meta-casing deposition
        - RF-CAV-004 — RF cavity & beam waveguide
        - PS-SC02-005 — sCO2 high-pressure loop
        - EM-DEP-006 — Emergency depressurization train
    3. Invite participants:
        - Chair: Independent Facilitator (IF-01)
        - Scribe: Process Safety Engineer PSE-07
        - Discipline Experts: Drilling, RF, Mechanical, Electrical, Control Systems, HSE
        - Operations Rep: Shift Supervisor OPS-02
        - Regulator Observer Seats: 2 (optional)
    4. Schedule sessions:

System	Date	Duration	Location
Drilling & Well	Week 36 Mon-Wed	3 × 8 h	Room B201 / Teams Bridge
RF Plant	Week 37 Mon-Tue	2 × 8 h	Room B201 / Teams Bridge

Pressure & sCO2 Systems	Week 37 Wed-Thu	2 × 8 h	Room B201 / Teams Bridge

10. **Execute Workshops & Capture Actions (Week 36 to Week 37)**
    1. Facilitator opens each node with the phrase: “Design Intention: *[read verbatim]*; We will now apply guideword ‘No/More/Less/Reverse’.”
    2. Scribe enters deviations, causes, consequences, safeguards, and action items into *PHAST HAZOP Software* real-time.
    3. Assign unique Action IDs: format “P3-HZ-YYYY”, e.g., P3-HZ-0043.
    4. Define target risk ranking using ISO 31000 matrix:
        - Likelihood L (1-5)
        - Severity S (1-5)
        - Risk R = L × S (target ≤ 6)
    5. When risk > 6, mandate new safeguard. Record exactly one of the following safeguard types:
        1. Design Change
        2. SIF (Safety Instrumented Function)
        3. Procedural Control
        4. Administrative Control
    6. At session end, export “Action Log.xlsx” and circulate within 1 hour.
11. **Develop SIFs & Alarm Matrix (Week 38, Days 1-3)**
    1. Create “SIF-Index-P3.xlsx” with columns: SIF ID, Hazard Reference, Safe State, SIL Target, Trip Setpoint, Architecture.
    2. Calculate SIL using LOPA with the following formula:

       ```
       PFDavg = (1/β) × (λD × TI) / (2 × (1 − β))
       ```

       where:
        - `β` = Common cause factor (assume 0.05)
        - `λD` = Dangerous failure rate (from manufacturer data)
        - `TI` = Proof test interval (months)
    3. Select PLC platform: HIMA HIQuad-X with voting logic 2oo3.
    4. Populate Alarm/Severity Matrix using ISA-18.2; severity 4 alarms require dual audible & visual indicators with 90 dB A at 1 m.
12. **Run Focused HAZID for Novel Components (Week 38, Day 4)**
    1. Apply “What-If/Checklist” technique for meta-casing defects:
        - What if glass-metal bond delaminates?
        - What if quench fails mid-run?
        - What if liner inspection missed micro-crack > 0.2 mm?
    2. Record hazard scenarios in “HAZID-N-P3.xlsx”.
    3. Cross-link each scenario to respective permit sections.
13. **Close-Out Actions & Update Design (Week 39, Days 1-5)**
    1. Weekly Action Review Meeting chaired by H-HSE-11 every Wednesday 09:00.
    2. Design engineers to implement changes in IFC drawings; record Rev letter (e.g., IFC-WELL-01 Rev-D).
    3. Process Control team to upload PLC logic blocks to `DeltaV Sandbox Server 192.168.44.12` for FAT.
14. **Issue Final Hazard Study Reports (Week 40, Days 1-3)**
    1. Merge “Action Log.xlsx”, “SIF-Index-P3.xlsx”, and “Hazard Register” into single PDF “P3-HAZ-MASTER-Rev0”.
    2. Add executive summary stating total actions raised, closed, outstanding, and risk reduction achieved (quantify ΔΣR).
    3. Obtain facilitator sign-off, then H-RPL-04 approval.
15. **Submit Hazard Reports to Regulators (Week 40, Day 4)**
    - Email PDF to each agency focal point with subject: “GeoTherm20 — Hazard Study Package — Reference *[Permit Number]*”.
    - Attach cover letter referencing 49 CFR Part 190, Confidential Business Information marking.
16. **Manage Regulator RFIs (Week 40 to Week 42)**
    1. Create RFI log “P3-RFI-LOG.xlsx” with columns: ID, Regulator, Question, Owner, Due Date, Status.
    2. Assign each query within 2 working days.
    3. Issue formal responses using “RFI Response Template T-RFI-01”.
17. **Conduct Lessons Learned Session (Week 42, Day 5)**
    - Facilitated 3-h workshop capturing best practices and improvement areas.
    - Publish “LL-P3-Permits-HAZ-Rev0.docx” in SharePoint “08_Closure”.

Deliverables

- Four Permit Dossiers (Gallery, Well, RF Plant, Pressure Systems) — Rev 0, PDF & USB copies
- Regulator Submission Receipts & Meeting Minutes
- HAZOP Reports per System (Drilling, RF, sCO2) — Rev 0
- Master HAZID Register — Rev 0
- SIF Index & Alarm/Severity Matrix — Rev 0
- RFI Log with closed responses
- Lessons Learned Report “LL-P3-Permits-HAZ”

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## OP-019 + OP-025 — Detailed Design of Gyrotron & RF Plant; OT Network & Cybersecurity

**Responsible Roles:** RF Drilling Systems Lead — H-RF-15; OT Cybersecurity & Industrial Networks Lead — H-OT-21 | **Timeline:** Phase 4, Weeks 24 – 50

## How-To-Do-It: Step-by-Step Execution Plan

### 1. Project Mobilisation (Week 24)

- Issue formal kickoff meeting invite to all subsystem leads (RF Power, Cooling, Shielding, OT, Cybersecurity, QA) for Day 1 of Week 24 at 09:00 local time via Microsoft Teams.
- During kickoff, review the full scope in this manual, agree to weekly engineering checkpoints (Wed 13:00), and define document control on Confluence page “P4_RF-OT_Design”.
```

- Create a shared requirements matrix in Excel (file name: *P4_REQ_MATRIX_v1.xlsx*) with each row = requirement ID, parent spec clause, responsible owner, verification method.
- Establish internal Git repository *geoRF_OT_design*; push initial folder structure:
  `/PowerSupply /Cooling /Waveguide /Shielding /Interlocks /OT_Network /CyberSecurity /Diagnostics /Verification`.

2. Requirements Decomposition & Gap Analysis (Weeks 24-26)

- Parse relevant_specifications line-by-line; assign each requirement a unique ID "RF-REQ-###" or "OT-REQ-###".
- Validate power output requirement: **1 – 3 MW CW @ 100 – 170 GHz per rig**. Split into functional blocks: gyrotron, power supply, cooling, waveguide, shielding.
  Add derived requirement: "RF-REQ-034: Each gyrotron shall operate at > 90 % availability with N+1 redundancy."
- Confirm network determinism: <2 ms end-to-end latency for MPC loop; populate "OT-REQ-011".
- Log all unidentified spec gaps; raise a formal RFI via email to Systems Engineering (copy project manager) by Friday of Week 26.

3. Gyrotron & Power-Supply Design (Weeks 26-34)

a. **Electrical Design**
   - Define power supply topology: three-phase 13.8 kV utility → 3 MW 12-pulse thyristor rectifier → passive filter → IGBT chopper (soft-start ramp 0 → 60 kV in 5 s) → crowbar SCR for <5 µs fault shutdown.
   - Produce schematic in AutoCAD Electrical: file *PSU_SCH_WIP.dwg*, sheet size ANSI D.
   - Calculate conductor size with ampacity formula `A = I / (k × ΔT^0.44)`; set k = 0.24 (copper, enclosed). For 3 MW @ 0.98 pf, line current ≈ 125 A; cable selected: 3 × 4/0 AWG Cu, 90 °C insulation.

b. **Cooling System**
   - Use water as coolant, inlet 22 °C, outlet 30 °C (ΔT = 8 °C).
   - Compute flow rate per gyrotron with `Q̇ = ṁ c_p ΔT`, where Q̇ = 3,000,000 W, c_p = 4184 J/kg·K:
     ṁ = Q̇ / (c_p × ΔT) = 3e6 / (4184 × 8) = 89.6 kg/s. Set design margin +20 % → 108 kg/s.
   - Select dual redundant centrifugal pumps, each 60 L/s @ 6 bar, manufacturer: KSB ETAline.
   - Model pipe pressure drop with Darcy-Weisbach. Use 4" Sch.40 stainless; document results in Excel *Cooling_Calc_v2.xlsx*.

c. **RF Launch & Waveguide**
   - Specify HE11 corrugated circular waveguide, ID 31.75 mm, copper-plated, loss <0.05 dB/m.
   - Insert 10 dB directional coupler every 15 m for diagnostics. Vendor: Quinstar.
   - Draft 3-D routing in SolidWorks; maintain minimum bend radius 5 × ID.

d. **Shielding & Interlocks**
   - RF gallery walls: 6 mm steel plate backed by 150 mm concrete; target attenuation >100 dB @ 170 GHz. Verify using CST Microwave Studio simulation file *RFShield.cst*.
   - Design personnel access door with fail-safe shutter rated 55 dB isolation; integrate position switch (SICK IMS02) wired to SIL-3 safety PLC.
   - Create cause-and-effect matrix in Excel "RF_CE_Matrix.xlsx". Example:
     `Door_OPEN → Gyrotron_OFF in <10 ms`

4. Beam Diagnostics & Calibration (Weeks 30-38)

- Implement standing-wave ratio (SWR) measurement: install dual horn probes 300 mm apart on meta-casing; connect to Keysight PNA-X 67 GHz VNA + harmonic mixers.
- Develop Python (3.11) script *calibrate_SWR.py* to sweep 100-170 GHz, log S-parameters, and compute SWR = |(1+Γ)/(1-Γ)|.
- Program daily automated calibration at 02:00 via LAN-GPIB gateway.
- Store results in InfluxDB measurement "gyrotron_diag". Retention policy = 90 days.

5. OT Network Architecture (Weeks 24-40)

a. **Logical Segmentation**
   - Create VLAN 10 = Safety Interlocks (SIL 3), VLAN 20 = MPC Control, VLAN 30 = Historian/DAQ, VLAN 40 = Corporate DMZ.
   - Assign fixed /28 IPv4 blocks:
     VLAN 10 → 192.168.10.0/28, VLAN 20 → 192.168.20.0/28, VLAN 30 → 192.168.30.0/28, VLAN 40 → 192.168.40.0/28.

b. **Hardware Specification**
   - Core switch: Hirschmann DRAGON M4-10-4GSFP; enable IEC62443 compliance mode.
   - Edge switch (waveguide trench interrogator): Moxa EDS-G512E-8PoE.
   - Firewall between VLAN 30 & 40: PaloAlto PA-3220; rule set:
     ```
     Allow TCP 502 (Modbus/TCP) from 192.168.40.5 → 192.168.30.4 (read-only)
     Deny any any log
     ```

c. **Time Synchronisation**
   - Deploy Meinberg LANTIME M600 GPS PTP Grandmaster, PTP Profile: Power profile v2, announce interval = 1 logMsgInt.
   - Set all PLCs (Beckhoff CX2040) to slave-only; verify offset <250 ns using *ptp4l -m*.

d. **Determinism Validation**
   - Run Ostinato traffic generator: 1000 packets @ 1518 B, record latency on MPC network; ensure 99.9th percentile <2 ms.
   - If exceeded, enable QoS on switches: set CoS = 5 for MPC frames (Ethertype 0x88A4).

6. Cybersecurity Hardening (Weeks 28-44)

- Install Greylog SIEM server (Ubuntu 22.04 LTS) in VLAN 40; configure Syslog input on port 1514 TLS with Let's Encrypt cert.
- Enable anomaly detection: activate CrowdStrike Falcon Sensor on Windows HMI nodes; set policy "Industrial Baseline".
- Identity & Access Management:
  - Deploy FreeIPA; create roles "Operator", "Engineer", "Administrator".
  - Enforce MFA: TOTP token length 8 digits, validity 30 s.
  - Map user `H-RF-15` to group "Engineer", user `H-OT-21` to "Administrator".
- Monthly vulnerability scan with Tenable Nessus: schedule Day 1 every month 00:30.

7. System Integration & Testing (Weeks 40-48)

a. **Factory Acceptance Test (FAT)**
   - Develop test procedure doc ID "P4-FAT-RF-OT-01".
   - Run 8-hr CW operation @ 1.5 MW; record inlet/outlet temp every 1 s; cooling ΔT shall not exceed 8 °C.
   - Trigger simulated door-open event; gyrotron must shut down in ≤ 10 ms; log PLC timestamp.

b. **Cybersecurity Pen-Test**
- Contract external CREST-certified tester; scope limited to VLAN 40 DMZ; goal = zero critical findings.
- Execute MITRE ATT&CK ICS matrix; document results in PDF *P4_Pentest_Report.pdf*.

c. **Network Performance Test**
- Deploy iPerf3 between MPC PLC and SCADA; run `iperf3 -c 192.168.20.10 -u -b 50M -t 600`; verify packet loss <0.1 %.

8. ## Documentation & Handover (Weeks 48-50)
- Compile final As-Built drawing sets (PDF + DWG) and upload to SharePoint folder */P4_AsBuilt/*.
- Generate O&M manual: Word template “OM_Manual.dotx”, 250 pages including preventive maintenance schedule (quarterly PM with checklist).
- Deliver Training: 2-day session, 6 h/day, slides in PowerPoint “RF_OT_Training_v1.pptx”, attendance mandatory for operations staff.
- Obtain formal sign-off from QA Manager and Site Operations Director; file DocuSign form “P4_Closeout”.

Deliverables

- P4_REQ_MATRIX_v1.xlsx (requirements traceability matrix)
- PSU_SCH_WIP.dwg (detailed power-supply schematic)
- Cooling_Calc_v2.xlsx (pump and piping calculations)
- SolidWorks routing model: *Waveguide_Route_v3.sldasm*
- RFShield.cst (EM shielding simulation file)
- calibrate_SWR.py & automated cron job entry
- Cause-and-Effect Matrix: RF_CE_Matrix.xlsx
- Network Architecture Diagram: OT_Net_Topo.vsdx
- Firewall Rule-base export: *PaloAlto_cfg_2024-W40.xml*
- P4-FAT-RF-OT-01 (Factory Acceptance Test procedure)
- P4_Pentest_Report.pdf (external penetration test report)
- As-Built drawings (PDF & DWG) and O&M manual
- Training slide deck: RF_OT_Training_v1.pptx
- Project Closeout DocuSign: P4_Closeout

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# OP-020 + OP-021 — Engineering Waveguide & Downhole Assemblies; Design Argon Sweep & Cuttings Recovery

**Responsible Roles:** High-Temperature Materials & Downhole Mechanisms Engineer — H-HTM-16; Process Fluids & Thermal Systems Engineer (Argon) — H-ARG-17
**Task Timeline:** Phase 4 – Week 26 to Week 40

## Comprehensive Step-by-Step Instruction Manual

1. ### 1. Formal Project Kick-Off (Week 26, Day 1)
1. Create a shared project folder on the Engineering PDM vault named “P4_OP-020_021_Waveguide_Argon”. Grant read/write access to both responsible engineers and the following stakeholder groups: RF-Systems, Controls, Safety, Procurement.
2. Upload all existing reference documents:
   - GeoTherm20_Material_DB_v3.2.xlsx
   - LL25_RF_Interface_Control_Document_revB.pdf
   - Argon_Loop_Previous_Test_Reports.zip
3. Schedule a 90-minute virtual kick-off via MS Teams (meeting ID stored in the project calendar) involving: H-HTM-16, H-ARG-17, Systems Integration Lead, Safety Officer, RF Controls Lead.
4. During the meeting, confirm the scope, deliverables, timeline checkpoints at weeks 30, 34, 38, 40, and assign one-page MoMs (minutes of meeting) writer (H-ARG-17).

2. ### 2. Requirements Consolidation & Freeze (Week 26, Days 2-5)
1. Generate a single requirements document “OP020_021_REQ_v1.docx” with the following mandatory sections: Mechanical, Thermal, Chemical Compatibility, Interface, Control, Safety.
2. Populate each requirement with:
   - Unique ID (format: WG-REQ-### or AR-REQ-###)
   - Statement (≤ 30 words)
   - Verification Method (Analysis / Test / Inspection)
   - Acceptance Criteria (numerical or functional)
3. Key numerical requirements to include (copy exactly):
   - Bore Diameter Compatibility: 200 mm ≤ D ≤ 350 mm
   - Continuous Operating Temperature Downhole: 600 °C
   - Argon Sweep Mass Flow @ Bit Face: 0.85 kg·s$^{-1}$ ± 5%
   - Sweep Gas Oxygen Content at Exhaust Cyclone: < 5 ppm
   - Waveguide Internal Surface Roughness: ≤ 0.2 µm Ra
4. Route the document for e-signatory approval via the DocuSign workflow; freeze baseline after final approval.

3. ### 3. Material Selection & Compatibility Analysis (Week 27 to Week 28)
1. Open GeoTherm20_Material_DB_v3.2.xlsx; filter for:
   - Ceramics: $Al_2O_3$ ≥ 99.8 %; Sapphire single-crystal orientation C-axis < 0.5°
   - Metals: Inconel 625, Inconel 718, Haynes 282
   - Brazes: Ag–Cu–Ti alloy “Cusil-ABA”
2. For each candidate, populate “MaterialTradeStudy.xlsx” with the following columns: *ID | Composition | Tmax (°C) | CTE (µm/m·K) | $sCO_2$ Compatibility Rating | Embrittlement $\Delta\sigma/\sigma_o$ @ 600 °C → 25 °C | Cost USD/kg | Lead Time weeks*.
``````

3. Calculate the CTE mismatch between ceramic liner and metallic jacket: CTE_mismatch = |CTE_metal – CTE_ceramic| (µm/m·K). The target is CTE_mismatch ≤ 8 µm/m·K.
4. Select the final pair:
    - Liner: 99.8 % Alumina (CTE = 8.0 µm/m·K)
    - Jacket: Inconel 625 (CTE = 13.0 µm/m·K)
    - CTE_mismatch = 5.0 µm/m·K ≤ 8 → acceptable.
5. Document all selections in “MaterialSelectionReport_v1.pdf” and store in the project folder.

4. 4. Waveguide Mechanical Design (Week 29 to Week 32)

1. **4.1 CAD Modelling (Weeks 29-30)**
    1. Open Siemens NX 2206; create new assembly “WG_Modular_String.prt”.
    2. Model a single 2.0 m module:
        - Outer jacket OD = ♂ 190 mm, wall = 10 mm.
        - Liner ID = 150 mm; liner wall = 5 mm.
        - Include bellows at both ends: 8 convolutions, convolution pitch = 10 mm, thickness = 1.8 mm, material = Inconel 625.
        - Slip Coupler: telescoping overlap 100 mm, radial clearance 0.75 mm.
    3. Model the ceramic-to-metal braze joint:
        - Joint interface length = 40 mm.
        - Braze gap = 0.08 mm.
        - Braze fillet radius = 2 mm.
    4. Create assembly pattern to produce 50 modules (→ 100 m reference string) to validate cumulative thermal strain.
2. **4.2 Thermal & Stress Analysis (Week 31)**
    1. Export CAD to “.fem” for NX Nastran.
    2. Apply temperature profile: linear ramp from 25 °C @ surface node 0 to 600 °C @ downhole node end.
    3. Boundary conditions:
        - The uppermost flange fixed in all DOF.
        - Gravity: 9.81 m/s^2 in -Z.
    4. Run Static + Thermal load case; verify:
        - Max Von Mises stress ≤ 0.6 × yield (Inconel 625 yield = 460 MPa at 600 °C → allowable = 276 MPa).
        - Bellows axial stroke ≤ 80 % of design travel (travel = 30 mm; result ≤ 24 mm).
        - Liner compressive stress ≤ 150 MPa.
    5. Generate “WG_ThermoStress_Report_revA.pdf” containing: model screenshots, tables of max/min stress, displacement plots, compliance statement.
3. **4.3 Passive mm-Wave Reflector & Steering Assembly (Week 32)**
    1. Model 45° ellipsoidal reflector diameter = 150 mm, surface finish ≤ 0.15 µm Ra, material: polycrystalline diamond-coated sapphire.
    2. Include gimbal:
        - Outer spherical seat radius = 80 mm.
        - Articulation ±2° in both pitch and yaw via hydraulic micro-actuators (ceramic pistons, Inconel housings).
        - No elastomers; use metal-to-ceramic piston seals with lapped faces ≤ 0.1 µm flatness.
    3. Create “ReflectorSteering_Assembly.prt” and link to main string assembly via customer-defined interface (CDI-0302).

5. 5. Argon Sweep Loop Design (Week 29 to Week 33)

1. Create a new AutoCAD P&ID file “ArgonLoop_PID_A1.dwg”. Incorporate the following tagged components with IDs:
    - AR-COMP-001 — Compressor, Ingersoll-Rand Model C1100, flow = 1.2 $kg \cdot s^{-1}$.
    - AR-HEX-002 — Inline Electric Heater, Watlow Model HT600, capacity = 700 kW.
    - AR-VAL-003 — Control Valve, Fisher V500, Cv = 45, pneumatic actuator.
    - AR-PRV-004 — Pressure Relief Valve, set at 3.5 MPa.
    - AR-OXY-005 — O_2 Analyzer, Servomex 1100A, range 0 – 20 ppm.
    - AR-CYCL-006 — High-Temp Cyclone, 800 °C rating, efficiency ≥ 96 % at 1 µm.
    - AR-FIL-007 — Sintered Metal Filter, 0.5 µm cutoff, 700 °C.
2. Draw the process flow: *Compressor → Heater → Downhole Injection Line → Bit Face → Return Line → Cyclone → Filter → Compressor.*
3. Define control logic in “ArgonLoop_ControlNarrative.docx”:
    - Primary PID Loop (“AR-FLOW-MASTER”): maintains mass flow at 0.85 $kg \cdot s^{-1}$ by modulating AR-VAL-003.
    - Secondary PID Loop (“AR-TEMP-MASTER”): maintains injection temperature at 580 °C by cycling heater stages (Watlow HT600 has 10 × 70 kW elements, on/off controlled).
    - Safety Interlocks:
        - Over-Pressure: if P > 3.3 MPa, close AR-VAL-003 and trip compressor.
        - Over-Temperature: if T > 620 °C, open bypass AR-VAL-BYP-008 (Cv = 60) to surface quench loop.
        - O_2 > 5 ppm shuts down heater, closes injection line.
4. Export the P&ID as PDF “ArgonLoop_PID_revA.pdf” and add revision block (initial issue A0).

6. 6. Interface with RF Control & Model Predictive Control (Week 33)

1. Open “LL25_RF_Interface_Control_Document_revB.pdf”; append section 6.3 “Argon Loop Data Exchange”.
2. Add Modbus TCP mapping table:

Tag Name	Register	Format	Units
AR_Flow_PV	40001	Float32	kg/s
AR_Temp_PV	40003	Float32	°C
AR_Valve_Cmd	40005	UInt16 (0-100 %)	%

3. Save new file as “LL25_RF_Interface_Control_Document_revC.pdf” with change log entry.

7. 7. Prototype Fabrication & Assembly (Week 34 to Week 36)

1. Issue manufacturing drawings from Siemens NX drafting module:
    - DWG-WG-001 — Modular Waveguide Section, rev A.
    - DWG-WG-002 — Bellows Sub-Assembly, rev A.
    - DWG-REF-003 — Reflector Gimbal, rev A.
2. Create purchase orders in SAP:

- PO 4500097665 — Inconel 625 tubing, 200 m, delivery 3 weeks.
- PO 4500097666 — 99.8 % Alumina liners, 200 m, delivery 4 weeks.
- PO 4500097667 — Cusil-ABA braze foil 0.08 mm, 10 kg.

3. Send braze procedure spec (BPS-WG-01) and braze qualification record (BQR-WG-01) to vendor for NADCAP approval.
4. Upon receipt, assemble one 10 m prototype string:
   - Braze at 870 °C for 15 min in vacuum 5 × 10^{-5} mbar.
   - Pressure test with argon at 2.5 MPa for 30 min → no leak permitted (≤ 1 × 10^{-6} mbar·L/s).

8. **8. Thermal Cycling & Functional Test (Week 37 to Week 38)**
   1. Set up in Furnace FTX-900:
      - Cycle profile: 25 °C → 600 °C (ramp 5 °C/min) hold 3 h → 25 °C (natural cool) x 10 cycles.
      - Log internal temperature via K-type thermocouples every 10 cm.
   2. Post-cycle inspect with 5 MHz ultrasonic shear probe; reject if any delaminations > 2 mm detected.
   3. Mount prototype to Argon Loop skid; connect via 1″ Inconel pigtails.
   4. Flow argon at 0.85 kg·s^{-1} for 4 h; verify:
      - Pressure drop ≤ 55 kPa @ 600 °C.
      - O_2 at outlet < 5 ppm.
      - No particle count rise > 500 #/L > 0.5 µm.
   5. Record results in “Prototype_TestReport_v1.pdf”.

9. **9. Design Iteration & Final Freeze (Week 39)**
   1. Hold Design Review #DR-04 with cross-functional team; use checklist DR-04-Checklist.xlsx.
   2. Log all action items; close within 3 working days.
   3. Increment drawing revisions to “rev B”; update P&ID to “rev B”.
   4. Create “Design_Freeze_Memo.pdf” referencing baseline documents and obtaining signatures from Engineering Director, Safety Officer, QA.

10. **10. Project Close-Out & Handover (Week 40)**
    1. Compile full data pack “OP020_021_Package_Release.zip” containing: CAD, DWGs, PDFs, Materials Report, Stress Report, P&ID, Control Narrative, Test Report, Memo.
    2. Upload to PDM vault “Released” folder; set status = “Released For Field Trial”.
    3. Send formal e-mail (subject: “OP-020/021 Release”) to Program Manager and Field Operations with link and SHA-256 checksum.

Deliverables

- OP020_021_REQ_v1.docx (signed & frozen)
- MaterialSelectionReport_v1.pdf
- WG_ThermoStress_Report_revA.pdf
- Siemens NX CAD assemblies (WG_Modular_String.prt, ReflectorSteering_Assembly.prt)
- Manufacturing Drawings DWG-WG-001, DWG-WG-002, DWG-REF-003 (rev B)
- ArgonLoop_PID_revB.pdf
- ArgonLoop_ControlNarrative.docx
- LL25_RF_Interface_Control_Document_revC.pdf
- Prototype_TestReport_v1.pdf
- Design_Freeze_Memo.pdf
- OP020_021_Package_Release.zip (all compiled)

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# OP-022 + OP-023 — Meta-Casing Wire-Feed Co-Deposition & Sensing / Telemetry Architecture: Full Execution Manual

**Responsible Roles:** Deposition & Metallurgy Process Engineer — H-META-18; Sensing, Instrumentation & Telemetry Lead — H-SENSE-19 | **Timeline:** Phase 4 (Weeks 28 – 40)

## 1. Preliminary Set-Up (Wk 28, Days 1-3)

1. Secure the designated high-temperature metal-lab cell.
   - Verify cell ambient control > 950 °C capability via the Type-C thermocouple array (8 channels, ±0.5 °C accuracy).
   - Confirm Argon purge flow controller (0 – 20 SLPM, PID-ready) is calibrated within ±1 % full scale.
2. Install the RF/mm-wave bench:
   - Wave-guide assembly: WR-10, 88 – 100 GHz, stainless-steel jacket with water cooling jacket removed for 45 cm section.
   - Power source: 250 W CW gyro-klystron, frequency fixed at 94.0 GHz ± 150 kHz.
   - Directional coupler: 20 dB nominal, SMA-WR10 transition, connect forward port to power diode, reflected port to I/Q mixer.
3. Mount the 1.5 m sacrificial-wire spool on the motorized feed stand (closed-loop servo, 0.05–12 mm $s^{-1}$).
   - Spiral feed guide tube: 4.2 mm ID $Al_2O_3$, 1 m length; fix 20 cm downstream of melt zone centerline.
4. Prepare sensing harness mock-up:
   - 200 m metal-coated distributed fiber (Inconel-coated FBG chain, $\Delta\lambda_B$ = 0.01 nm).
   - Pair of ceramic feedthroughs rated 30 kpsi, 600 °C (OEM # CF-600-12P).
   - Acoustic transducer: 150 kHz piezoceramic ring, 38 mm OD, couple with high-temp silicone grease.
5. Create project directory structure:
   - \\srv-litholoop25\phase4\OP022-023\
   - Sub-folders: CAD, BOM, ProcParams, ControlCode, RawData, Reports.

## 2. Meta-Casing Co-Deposition Parameter Development (Wk 28 Day 4 – Wk 32)

1. **Establish Baseline Wire Feed Formula (Day 4):**
``````

Calculate target wire feed velocity (v_W) for a 250 µm/turn liner build on a 200 mm circumference tube rotating at 2 RPM.

• Deposition mass rate: $\dot{m} = \rho_W \cdot A_W \cdot v_W$

• Required cross-sectional build per revolution: 0.25 mm × 200 mm = 50 mm^2

Solve $v_W = 50\ mm^2 \cdot \omega / A_W$, where ω = 2 rev min^{-1} (0.033 rev s^{-1}), A_W (3 mm wire) = 7.07 mm^2.

→ $v_W = (50 \times 0.033) / 7.07 \simeq 0.233\ mm\ s^{-1}$. Program servo to 0.23 $mm\ s^{-1}$ initial set-point.

2. **Program PID on Wire Feed Servo (Day 5):**
   - Open Omron NX-I/O Studio → Axis 1 parameters.
     K_p = 1.8, K_i = 0.12 s^{-1}, K_d = 0.00.
   - Enable encoder feedback @ 1 kHz.
   - Activate "Position + Velocity Hold" mode.
3. **Establish Melt-Zone Thermal Window (Week 29):**
   a. Ramp mm-wave power from 0 → 160 W in 10 W increments; hold at each step 30 s.
   b. Record liner inner-wall temperature via IR pyrometer (Emissivity = 0.82, 2.2 µm). Log in `RawData\TempRamp_W29D2.csv`.
   c. Identify stable melt film regime: aim for 1450 ± 50 °C for Inconel 740H.
4. **Closed-Loop Deposition Rate Control Design (Week 30):**
   Implement stand-alone MPC (Model Predictive Control) in MATLAB/Simulink R2024a.
   • Inputs: mm-wave forward power P_{fwd}, reflected power P_{ref}, wire feed velocity v_W, IR-T.
   • State variable: Deposition thickness t.
   • Material balance state-space model: $dt/dt = k_{dep} \cdot \dot{m} / (\rho_{met} \cdot A_{tube})$. Use k_{dep} default = 0.63.
5. **Calibrate mm-Wave Reflectometry Thickness Function (Week 31):**
   a. Attach reference step coupons (100, 250, 500, 1000 µm) to inner wall.
   b. For each coupon:
      - Collect phase shift Δφ with I/Q mixer (sample at 20 kHz, 16-bit).
      - Compute thickness t using:
        $t = (c \cdot \Delta\varphi) / (4\pi f \sqrt{\varepsilon_r})$
        where c = 2.997 924 58×10^8 m s^{-1}, f = 94 GHz, $\varepsilon_r \approx 1$.
   c. Fit linear regression ($R^2 > 0.995$) to derive calibration constants A, B in $t = A \cdot \Delta\varphi + B$. Store JSON: `ProcParams\MMW_Cal.json`.
6. **Iterative Thermal & Wire Chemistry Sweep (Week 32):**
   - Matrix: {Wire Alloy ∈ [Mo-Re 47.5-52.5 wt %, Inconel 740H]} × {$P_{fwd} \in [120, 160, 200\ W]$} × {$v_W \in [0.2, 0.3, 0.4\ mm\ s^{-1}]$}.
   - Run each condition 180 s, log deposition uniformity via post-run ultrasonic C-scan (15 MHz transducer).
   - Populate parameter matrix Excel: `ProcParams\CoDep_Matrix.xlsx`.

3. Sensing & Telemetry Architecture Definition (Wk 33 – Wk 36)

1. **Distributed Fiber System Design (Week 33):**
   a. Cut 10 m test segment from 200 m spool; thermally cycle 25 → 600 °C (10 °C min^{-1}) three times.
   b. Measure Bragg shift; allowable drift ≤ 8 pm @ 600 °C. If exceeded, reject batch.
   c. Apply stainless-steel helix wrap spacing 15 mm pitch to accommodate strain transfer ≤ 1 % error.
2. **Acoustic Telemetry Chain (Week 34):**
   - Mount 150 kHz transducer 0.5 m above melt zone; orient normal to tube axis.
   - Configure Keysight PXIe-5122 digitizer: 100 MS s^{-1}, 14-bit, 1 Vpp range.
   - Generate 8-cycle Hanning-gated chirp; trigger every 250 ms; set transmit amplitude 1.2 Vpp.
   - Target SNR > 25 dB at 100 m column; confirm via time-gated RMS measurement.
3. **MM-Wave Reflectometry Integration (Week 35):**
   a. Split reflected signal (–10 dB coupler) to separate DAQ channel to avoid cross-talk.
   b. Synchronize sampler clocks across acoustic & mm-wave channels using NI XNET 10 MHz reference; jitter ≤ 5 ns.
4. **Health-Check & Calibration Routines (Week 36):**
   - Create LabVIEW VI `HealthCheck.vi` that:
     i. Executes 30 s self-test every 12 h (configurable).
     ii. Injects 50 °C step on FBG #1 via cartridge heater; compares expected $\Delta\lambda_B$ (50 °C × 10 pm $°C^{-1}$) to measured within ±1 pm.
     iii. Loops acoustic loopback with terminator 5 m away; verifies time-of-flight within ±2 µs.
   - Log outputs to `RawData\Health\YYYYMMDD_HHMM.json` using schema:
     { "timestamp":"ISO8601", "module":"string", "test_id":"string", "result":"PASS|FAIL", "metrics":{...} }

4. Integration & Validation (Wk 37 – Wk 39)

1. **Full-Stack Dry-Run (Week 37):**
   - Run mm-wave power at 120 W with dummy wire feed (feed paused).
   - Confirm no RF arcing; reflected power ≤ 5 % P_{fwd}.
   - Activate DAQ; ensure synchronized timestamp disparity < 1 sample across all channels.
2. **Hot-Wire Deposition Trial #1 (Week 38 Day 1-2):**
   a. Set conditions: Inconel 740H, 160 W, 0.30 mm s^{-1}, tube rotation 2 RPM.
   b. Run 600 s continuous; monitor live thickness t via reflectometry GUI.
   c. Abort if t deviates > +80 µm above set-point 250 µm.
3. **Cross-Section & NDT Validation (Week 38 Day 3-4):**
   - Section sample 100 mm length at mid-span; mount in epoxy; polish to 0.05 µm alumina.
   - Measure actual coating: optical microscope 100×; record 20 radial points.
   - Accept if 100 ≤ t ≤ 500 µm, σ ≤ ±10 %.
4. **Hot-Wire Deposition Trial #2 with Mo-Re (Week 39):**
   - Repeat steps 4.2–4.3 with Mo-Re wire, P_{fwd} = 200 W, v_W = 0.40 mm s^{-1}.
   - Compare layer adhesion via bend test 10 °; no flake or spall allowed.

5. Documentation & Handoff (Wk 40)

1. Update all parameter files; freeze versions in Git tag `v4.0-release`.
2. Export DAQ dataset to Parquet; compress with Zstandard, level 19.
   File path: `\\srv-litholoop25\phase4\OP022-023\RawData\Release\Phase4_dataset.parquet.zst`
3. Create 30-page PDF "Meta-Casing & Telemetry Stack Specification" containing:
   - Process flow diagrams (Visio),
   - Complete MPC tuning tables,
   - Sensing calibration graphs,
   - Error handling routine flowcharts.
4. Conduct 2-hour knowledge-transfer session; record Teams meeting; upload MP4 under `Reports`.
5. Submit formal sign-off form QF-123 to QA Manager no later than Friday 16:00.

Deliverables

- Co-Deposition Parameter Matrix — `ProcParams\CoDep_Matrix.xlsx`
- MPC Control Code & Calibration Constants — `ControlCode\MPC_Controller.mlx` & `MMW_Cal.json`
- Sensing & Telemetry Architecture Document — PDF
- Complete DAQ Dataset (Parquet + Zstd)
- Health-Check VI & Automated Test Logs
- Final 30-page Specification PDF & Knowledge-Transfer Recording
- QA Sign-Off Form QF-123

``````html

## OP-024 — Build Digital Twin and MPC Control Strategy (Drill / Quench / Deposition)

**Responsible Role:** Automation, Digital Twin & Advanced Control Lead — H-AUTO-20 | **Timeline:** Phase 4 – Week 32 to 50

### How-To-Do-It: Step-by-Step Execution Manual

1. **Week 32 – 33 | Confirm Requirements & Prepare Infrastructure**
   a. Conduct a 2-hour kick-off with RF, downhole, argon, sensing, and deposition SMEs. Record all objectives and constraints in the shared Confluence page "OP-024-Sys-Req-v1".
   b. Create a version-controlled directory structure on the central GitLab repository:
   `/OP-024/01_Models`, `/02_MPC`, `/03_HIL`, `/04_Interfaces`, `/05_Docs`.
   c. Spin-up an Azure D4s v5 VM named *"dtwin-sim-wk33"* (4 vCPU, 16 GB RAM, Ubuntu 22.04 LTS). Install required toolchain via:
   `sudo apt update && sudo apt install y python3.11 python3-pip git cmake g++`
   d. Inside the VM, create one Conda environment "op024" with:
   `conda create n op024 python=3.11 numpy=1.26 scipy=1.11 pandas=2.1 casadi=3.6 fenics-dolfin=2019.1`
   e. Reserve an OPC UA namespace index 7 on the OT test server *"ot-sim-01"* for digital-twin tags. Document mapping in `/04_Interfaces/tagmap.xlsx`.
2. **Week 33 – 37 | Develop Detailed Physics-Based Digital Twin**
   a. Create finite-element geometry of the downhole section (inner radius = 0 mm, liner target thickness = 5–30 mm, outer formation radius = 1500 mm, length = 5000 mm) in FEniCS. Mesh with maximum element edge length = 0.5 mm radially and 10 mm axially.
   b. Implement heat transfer PDE:
   `ρ(T)·c_p(T)·∂T/∂t = ·(k(T)T) + Q_rf(x,t) + Q_deposition(x,t)`
   where:
   ρ(T) = 2700 – 0.5·T [kg·m$^{-3}$],
   c_p(T) = 900 + 0.1·T [J·kg$^{-1}$·K$^{-1}$],
   k(T) = 1.8 + 0.002·T [W·m$^{-1}$·K$^{-1}$]
   c. Represent crystallization kinetics of the glass-ceramic liner using Johnson-Mehl-Avrami-Kolmogorov (JMAK):
   `X(t) = 1 - exp(-k0·exp(-E/R·1/T)·t^n)`
   Set `k0=1.2×10^7`, `E=185 kJ·mol-1`, `n=2.1`.
   d. Integrate refractory metal deposition using Langmuir adsorption kinetics:
   Deposition rate `R_dep = k_dep·P_metal·(1 - θ)`
   where coverage θ forecast is updated each 10 ms.
   e. Include mechanical stress evolution via thermo-elastic model:
   `σ_θ = E_liner/(1-ν)·(α_liner-α_rock)·ΔT`
   with liner Young's modulus = 95 GPa, ν = 0.23, α_liner = 6.5×10$^{-6}$ K$^{-1}$.
   f. Import real-time sensor feeds through OPC UA Index 7 tags:
   RF Power → *"7:RF_P"*, RF Phase → *"7:RF_Phase"*,
   Waveguide Temp → *"7:WG_T"*, Argon Flow → *"7:Ar_F"*, Argon Temp → *"7:Ar_T"*,
   Fiber DTS → *"7:DTS_Profile"*, FO DSS → *"7:DSS_Profile"*,
   mm-Wave Refl. → *"7:MMR"*, Acoustic → *"7:VSP"*.
   g. Validate model fidelity by replaying 12-hour dataset "trial-G1-w27.h5" and verify:
   • Mean absolute temp deviation < 12 °C.
   • Predicted liner thickness deviation < 0.8 mm.
3. **Week 37 – 39 | Reduce Model for Real-Time Execution**
   a. Apply Proper Orthogonal Decomposition (POD) with 150 snapshots. Retain the first 28 modes to keep > 98 % energy.
   b. Generate reduced basis matrices `A_r, B_r, C_r, D_r` and export to JSON (`/01_Models/Aug-ROM-v2.json`).
   c. Benchmark update rate on the VM. Confirm step = 5 ms, CPU utilization < 40 %.
4. **Week 39 – 44 | Design & Implement MPC**
   a. Define MPC horizon = 60 s (N = 12 with Δt = 5 s stages).
   Control vector `u = [RF_P, RF_Phase, Ar_F, Ar_T, Metal_Dep_Rate]`
   b. Objective function J:
``````

`min Σ_{k=1→N} [ w·(T_melt_k - T_set)^2 + w·(Thick_k - Thick_set)^2 + w·(σ_θ_k - σ_set)^2 + w·Ar_F_k ]`
Weights: $w_1 = 1.0$, $w_2 = 3.0$, $w_3 = 2.5$, $w_4 = 0.2$.

c. Constraints:
RF_P ∈ [0, 2.8 MW]; RF_Phase ∈ [0°, 360°];
Ar_F ∈ [0, 350 SLPM]; Ar_T ∈ [280 K, 450 K];
Metal_Dep_Rate ∈ [0, 0.9 kg·min^{-1}];
state stability margin: $\|\Delta u/\Delta t\|_2 \le 0.12$.

d. Use CasADi (IPOPT backend) with code:
`solver = nlpsol('s', 'ipopt', nlp, {'ipopt.max_iter':60, 'ipopt.tol':1e-4})`

e. Create Python class `OP024MPC()` in `/02_MPC/mpc.py`. Include methods:
`def initialize(self, rom_path, cfg_path)`
`def update(self, y_meas)`
`def get_controls(self)`

f. Simulate closed-loop control for 24-h synthetic drilling scenario "scenario-P45.json". Terminate if any violation occurs. Accept if:
liner thickness = 5–30 mm,
residual hoop stress < -15 MPa (compressive),
argon usage ≤ 1.8×10^6 SL.

5. **Week 44 – 48 | Hardware-in-the-Loop (HIL) Validation**

a. Connect the reduced digital twin to the NI-PXIe 1085 real-time chassis. Assign:
Analog Out AO0 → RF Power command,
AO1 → RF Phase command,
AO2 → Argon Flow setpoint,
AO3 → Argon Temp setpoint,
AO4 → Metal Rate.

b. Set HIL loop time base = 5 ms. Verify latency < 8 ms by logging `Δt = t_write - t_read` for 10,000 cycles.

c. Introduce sensor-loss fault injection at t = 3,600 s by zeroing *"7:DTS_Profile"*. MPC must trigger failover rule:
• Set RF_P → 0.3 MW;
• Set Ar_F → 300 SLPM;
• Set Metal_Dep_Rate → 0 kg·min^{-1}.

d. Confirm safe state: maximum temperature gradient in liner < 40 °C·m^{-1}.

e. Produce HIL report "OP024-HIL-R1.pdf" with plots: control commands, state evolution, fault response.

6. **Week 46 – 49 | Finalize Interfaces, Historian Tags & Failover Logic**

a. Publish interface control document "OP024-ICD-v3.docx" specifying:
• OPC UA node IDs,
• Data types,
• Refresh rates,
• Quality flags.
Example entry (table format in doc): NodeId = "ns=7;s=RF_P", Type = Double, Unit = MW, Scan = 100 ms.

b. Write PI Historian AF template *"LithoLoop-MPC-Drill"*. Include 38 attributes. Confirm data retrieval with PI-SQL:
`SELECT tag, time, value FROM piarchive..piinterp2 WHERE tag = 'RF_P' AND time BETWEEN '*-1h' AND '*'`

c. Embed watchdog process `wdg.py` that pings all sensors every 200 ms. If
• 3 consecutive bad quality, or
• timeout > 600 ms,
then execute `self.enter_safe_state()`.

7. **Week 49 – 50 | Deployment, Documentation & Handover**

a. Containerize twin and MPC inside Docker image "op024:1.0.0". Use Dockerfile:
```
FROM ubuntu:22.04
RUN apt update && apt install -y python3 python3-pip
COPY models /app/models
COPY mpc.py /app/
RUN pip3 install -r /app/requirements.txt
ENTRYPOINT ["python3", "/app/mpc_service.py"]
```

b. Push image to Harbor registry *harbor.geotherm20.local/op024/op024:1.0.0*.

c. Create 2-hour operator training module in Articulate 360 and export SCORM 1.2 package "OP024-Training-v1.zip".

d. Conduct formal handover with Operations team. Sign completion on SharePoint task "P4-OP-024-DONE".

Deliverables

- High-fidelity finite-element digital twin source code (`/01_Models`).
- Reduced-order model JSON file "Aug-ROM-v2.json".
- CasADi-based MPC Python package (`/02_MPC`).
- Hardware-in-the-Loop validation report "OP024-HIL-R1.pdf".
- Interface Control Document (ICD) "OP024-ICD-v3.docx".
- PI Historian AF template "LithoLoop-MPC-Drill".
- Safe-state watchdog script "wdg.py".
- Docker image "op024:1.0.0" pushed to Harbor registry.
- SCORM-compliant operator training package "OP024-Training-v1.zip".
- Signed handover record on SharePoint.

```

## OP-026 — Execute Long-Lead Procurement and Logistics Plan

**Responsible Role:** Supply Chain, Procurement & Logistics Manager — H-SCPL-13 | **Timeline:** Phase 5 (Week 38 – 60)
```

How-To-Do-It — Detailed Step-by-Step Action Plan

1. **Week 38 — Formalize Procurement Baseline.**
   - Open the project SharePoint folder *"Phase5/OP-026/Baseline"* and create file *"OP-026_LL_Matrix_V1.xlsx"*; load every long-lead item (#1-8) as individual rows with columns: Item ID, Spec Rev, Required-on-Site Date (ROS), Incoterms, Budget, Technical Owner.
   - Lock the sheet (Review → Protect Sheet, password: `LL2025!`) to prevent unauthorized edits.
   - Issue formal baseline via document control: email "DC-FRM-14-Baseline Issue Notice" to the CCB (`ccb-geotherm20@company.com`) with the XLSX attached.

2. **Week 38-40 — Vendor Pre-Qualification.**
   - Download approved vendor list template *"SCPL-TMP-07.xlsx"*; rename to *"OP-026_PreQual_Matrix.xlsx"*.
   - For each long-lead item insert minimum three candidate vendors. Populate ISO 9001 status, past performance score (1-5), financial health index (credit rating letter), and capacity (annual throughput in $USD).
   - Schedule & conduct 30-min compliance calls: book via Outlook with subject "OP-026 RFQ Eligibility Check – <Vendor >" for each vendor; record minutes in *"PreQual_Call_Minutes.docx"*.
   - Score using formula in column H: `Total Score = (ISO*0.25)+(Performance*0.35)+(Financial*0.15)+(Capacity*0.25)`. Accept vendors with Total Score ≥ 3.5.
   - Issue *"Approval Letter – Conditional"* (template SCPL-LTR-03) to qualified vendors via DocuSign for electronic signature.

3. **Week 39-42 — Prepare & Issue RFQs.**
   - Create eight RFQ packages (*RFQ-001 to RFQ-008*) correlating with items 1–8.
   - Each RFQ package must contain:
     1. Cover Letter (SCPL-LTR-05)
     2. Technical Specification PDF (engineering-controlled)
     3. Quality Requirements Annex (QA-REQ-11)
     4. FAT Checklist (QA-CHK-07)
     5. Draft Purchase Order T&Cs (SCPL-PO-STD-2025)
   - Compress each package into ZIP named "`OP-026_RFQ-00X_YYYYMMDD.zip`".
   - Upload ZIP to secure portal `https://vendorlink.geotherm20.com`; enable download tracking.
   - Email RFQ release notice to vendor primary contact & cc technical owner; set quotation deadline = ROS − (lead time+8 weeks logistics) with a minimum buffer of 14 calendar days.

4. **Week 42-45 — Evaluate Bids & Place Purchase Orders.**
   - Upon receipt, log quotation file into *"BidLog_OP-026.xlsx"* (columns: Date Received, Vendor Code, RFQ #, Price, Delivery, Exceptions).
   - Perform cost analysis: open *"CostEval_Template.xlsm"*; use macro "`Run_TotalCost()`" to compute `Total = Price + (Freight*1.07) + Import Duty`.
   - Perform technical compliance check with engineering using checklist QA-CHK-08; record pass/fail on every spec paragraph.
   - Hold CCM (Commercial Clarification Meeting) via Teams; capture MOM (Minutes of Meeting) signed by both parties within 24 h.
   - Create Purchase Order in Oracle ERP: Navigate Procurement → Purchase Orders → Create PO; enter:
     - PO Type: Standard
     - Supplier: <vendor name>
     - Ship-To: LithoLoop 25 Site Warehouse
     - Payment Terms: 30% advance / 50% at FAT pass / 20% DDP on-site
     - Incoterms: DDP, unless RF hardware = FCA (origin)
   - Attach final negotiated spec and QA plan to PO header; submit for three-level approval (Budget Owner, SCPL-13, CFO) in Oracle. SLA: 48 h.
   - Once approved, export PO PDF, stamp "CONFIRMED", and transmit via DocuSign to vendor for countersignature.

5. **Week 42-45 — Finalize QA/QC & Surveillance Plans.**
   - Open template *"Supplier_Quality_Plan_Template.docx"*; save as *"SQP_RFQ-00X_VendorName.docx"*.
   - Insert inspection points per spec: e.g., gyrotron vacuum integrity (`≤1×10 Torr` leak test), waveguide dielectric constant verification (`εr=9.4±0.1`), wire diameter tolerance (±0.5 %), recuperator channel etch test (visual + SEM), turbomachinery blade tip clearance (`0.15 mm ± 0.03 mm`), bellows cycle fatigue (≥10,000 cycles).
   - Add hold points: H1-Material Certs, H2-In-Process Weld Visual, H3-Pressure Test, H4-FAT.
   - Email draft SQP to vendor QA manager; set review deadline 5 working days.
   - FAT witness plan: book travel in Egencia for QA engineer; earliest FAT date = ROS − 8 weeks.

6. **Week 45-57 — Execute Manufacturing Surveillance & Expediting.**
   - Request weekly (or bi-weekly for Class II items) schedule update Gantt from vendor in MS Project format.
   - Update *"ExpeditingRegister_OP-026.xlsx"* every Monday by 12:00 UTC; compute `Schedule Variance = (Planned Finish − Forecast Finish)`. Flag any variance >3 days in red.
   - Hold progress calls every Thursday 09:00 UTC; record MOM with actions, owners, deadlines. Upload to SharePoint folder *"ProgressCalls"*.
   - For late activities, issue "SCPL-EXP-NCR-Form" to vendor within 24 h; require recovery plan with revised forecast not exceeding ROS.
   - Arrange in-process inspections per SQP: create site visit request in Safety App; attach HS-EHS-14 risk assessment; mandatory PPE list: safety glasses, class 00 electrical gloves, steel-toe boots.

7. **Week 48-58 — Perform & Witness FAT.**
   - Verify test rig calibration certificates (validity ≤ 12 months, traceable to NIST/ISO 17025).
   - Execute FAT checklist QA-CHK-07 item-by-item; for gyrotron, record CW output power with calibrated calorimeter; acceptance = ≥99 % of ordered rating.
   - Record all raw data in Excel sheet *"FAT_Data_ItemX.xlsx"*; lock sheet post-entry with password `FATpass!`.
   - Generate FAT report in PDF within 48 h using template QA-RPT-05; obtain vendor sign-off, then countersign by SCPL-13.
   - If failure occurs, raise NCR, require root-cause & corrective action within 5 working days; repeat failed test only after approval.

8. **Week 50-59 — Coordinate Packing, Shipping & Customs.**
   - Issue "Logistics Instruction Sheet" (LIS) per item:
     - Packaging Spec: ASTM D3951, add poly-urethane foam for ceramic components.
     - Shock Tracker: install SpotSee ShockWatch 2 (red, 25G) on each crate.
     - Humidity Indicator Cards for fiber reels (`RH limit = 30 %`).
   - Book freight in SAP-TM:
     - Mode: Air-ride truck for ceramics/fibers; Flat-rack sea freight for turbomachinery.
     - Carrier SLA: delivery within 5 days domestic / 21 days international.
   - Generate commercial invoice & packing list in SAP; HS Codes: gyrotron 8543.70.4600, ceramic waveguide 6914.90.8000, sCO2 turbine 8411.99.9090, etc.

- Apply for U.S. DOC export license (if applicable for RF hardware ≥170 GHz) via SNAP-R, commodity code ECCN 3B001.
- Email shipping documents to customs broker (`broker@logixcustoms.com`) 72 h before departure.

9. **Week 51-60 — Receive, Inspect & Store.**
   - At arrival, forklift operator to follow Rigging Plan RP-026; max fork spacing = 1.2 m; use nylon slings for waveguide crates.
   - Log receipt in Oracle: Inventory → Receipts → Enter Receipt; reference PO #. Generate Receiving Report (RR-####).
   - Perform incoming inspection using form QA-INSP-04:
     - Verify ShockWatch indicator: red = reject material.
     - Dimensional spot check: waveguide ID with bore gauge (tolerance 0/+0.03 mm).
     - Review certificate package (Mill Cert, FAT report, Export license).
   - Stamp accepted material "QC ACCEPTED", affix green label. For rejects, raise NCR in EtQ system within 2 h.
   - Store in climate-controlled warehouse A-2; set thermostat 20 ± 2 °C, RH ≤30 % for ceramics and fibers. Log storage location in Oracle: Inventory → Transfer to Sub-inventory = "CTL-STG-A2-RowB–Bin14".
   - Update *"LL_Inventory_Map.pdf"* with AutoCAD 2024, layer "Received WK51-60", color code #4CAF50.
10. **Week 38-60 — Reporting Obligations.**
    - Every Friday by 15:00 UTC, export dashboard from Power BI report "OP-026_Status" to PDF; email to PMO distribution list.
    - Month-end: conduct Earned Value analysis. Formula: `CPI = BCWP / ACWP`, `SPI = BCWP / BCWS`. Acceptable limits: 0.9 ≤ CPI, SPI ≤ 1.1.
    - At Week 60, compile Final Procurement Dossier: merge PDFs (POs, SQPs, FAT reports, Shipping Docs, Receiving Reports) into single 300-dpi PDF using Adobe Acrobat "Combine Files"; name *"OP-026_Closeout_WK60.pdf"*; store in SharePoint "Archive".

Deliverables

- Baseline Long-Lead Matrix (OP-026_LL_Matrix_V1.xlsx)
- Approved Vendor Pre-Qualification Matrix & Call Minutes
- Eight RFQ ZIP packages and corresponding Bid Evaluation files
- Executed Purchase Orders with attachments
- Supplier Quality Plans & Inspection Test Plans (ITPs)
- Weekly Expediting Registers & Progress MOMs
- Factory Acceptance Test Reports (signed PDFs)
- Logistics Instruction Sheets, Commercial Invoices, Packing Lists, Export Licenses
- Receiving Inspection Reports & NCR records
- Final Procurement Dossier (OP-026_Closeout_WK60.pdf)

OP-027 — Fabricate Waveguides, Joints, Bellows; Conduct QA/NDE and FAT

Responsible Role: QA/NDE & Test Engineering Lead — H-QA-22 | **Timeline:** Phase 5 — Week 44 to 60

1. Overview of Scope

This manual decomposes OP-027 into 8 fully-defined workstreams that collectively deliver fabricated, qualified, and factory-accepted waveguide modules, joints, and expansion bellows ready for site deployment for the first 1–2 km of LithoLoop 25.

2. Detailed Step-by-Step Plan (Weeks 44 – 60)

1. **Week 44 – 45 | Preparatory Engineering Release**
   1. Create a controlled document package (filename: *OP-027-ENG-PKG-v1.pdf*) containing: final drawings, GD&T callouts, brazing procedure qualification records (BPQRs), and material specifications (ceramic grade ≥ 99.5 % Al_2O_3; metal CTE-matched alloy Inconel 718).
   2. Issue internal Engineering Change Notice (ECN-027-F5) authorizing procurement and fabrication; route for electronic signature in PLM within 48 h.
   3. Lock down acceptance criteria in the *Master Inspection & Test Plan (MITP-027-R0)*. Include numeric limits:
      - Dimensional tolerance on ceramic bore straightness: ≤ 0.05 mm per 1 m span.
      - Joint helium leak rate: ≤ 1×10^{-10} std cm³/s at 1 atm ΔP.
      - Bellows axial compression range: 25 mm ± 1 mm.
2. **Week 45 – 48 | Raw Material Procurement**
   1. Raise purchase orders (PO-027-CER & PO-027-MET) in ERP for:
      - 5,000 kg high-purity ceramic tubes (ID = 150 mm, OD = 190 mm, length = 1.25 m).
      - 3,200 kg Inconel 718 bar stock Ø200 mm.
      - 2,000 kg AM Inconel 718 bellows blanks (laser-powder bed fusion).
   2. Specify lot traceability tags: alphanumeric code "LL25-WG-YYYY-LOT#" laser-etched every 0.5 m on ceramic blanks and engraved on metal billets.
   3. Receive, perform incoming dimensional sampling per ANSI Z1.4 Level-S2 (single sampling); quarantine any batch failing ≥ 1 sample.
3. **Week 46 – 52 | Fabrication of Waveguide Modules**
   1. Ceramic Liner Machining
      1. Mount tube on precision roller supports; employ diamond-tipped boring bar at 250 rpm, feed = 0.05 mm/rev to achieve ID roundness ≤ 0.03 mm.
      2. Finish grind OD to 190 mm ± 0.01 mm; verify with 3-point laser micrometer every 0.25 m.
   2. Metallization for Brazing
      1. Clean ceramic in ultrasonic bath (DI water + 2 % Alconox) 10 min, rinse, dry 120 °C × 1 h.
      2. Apply Mo-Mn paste layer 25 µm thick over 50 mm length on each end, sinter at 1,380 °C in wet H_2/N_2 for 3 h.
      3. Plate with 8 µm Ni barrier at 60 °C, pH = 4.1, current density = 2 A/dm².
   3. Protective Jacket Assembly
      1. Slip-fit 304 SS protective jacket (wall = 2 mm) over ceramic; TIG tack weld jacket seams (argon 99.99 %, 75 A, 3 mm/s).
      2. Leak-proof seam by continuous weld, water-quench, and polish Ra ≤ 0.8 µm.
4. **Week 49 – 54 | Fabrication of Joints & Expansion Bellows**
   1. Slip Coupler Machining
      1. Turn Inconel 718 on CNC lathe; maintain ID = 190.10 mm (for 0.05 mm diametral clearance).

2. Machine relief grooves (3 grooves, width = 6 mm, depth = 3 mm) to accommodate thermal growth.

2. Bellows Forming
    1. Heat AM blanks to 980 °C, hold = 30 min, solution-anneal; furnace cool to 400 °C.
    2. Hydroform to 14 convolutions (pitch = 12 mm) using internal mandrel pressure = 45 MPa.
3. Ceramic-to-Metal Brazing
    1. Place metallized ceramic end and Inconel stub flange in graphite fixture, add 125 µm BNi-2 braze foil.
    2. Vacuum furnace cycle: pump to 1 × 10^{-4} Torr, heat 20 °C/min to 1,050 °C, dwell = 15 min, cool ≤ 5 °C/min to 500 °C.
    3. Visual check for meniscus continuity 360°; reject if any void > 0.5 mm.

5. **Week 50 – 56 | Quality Assurance & Non-Destructive Examination (QA/NDE)**
    1. Dimensional Inspection:
        1. Use FARO Vantage laser tracker; capture 3D point cloud ≥ 50,000 pts per module.
        2. Pass criteria: max deviation ≤ 0.04 mm from model; auto-generate report (*WG-DIM-####.pdf*).
    2. Dye Penetrant (ASTM E1417):
        1. Apply penetrant D-100 *(dwell = 20 min)*, rinse, apply developer ZP-4B, inspect under UV 365 nm.
        2. Reject if linear indication > 1.5 mm or rounded > 2.0 mm.
    3. Ultrasonic Shear-Wave on Brazes:
        1. Calibrate probe 5 MHz, 70° wedge on IIW block; TCG curve within ±2 dB.
        2. Scan full circumference; record A-scans; reject if any reflector > 20 % screen height at 1 skip distance.
    4. Helium Leak Test (ASTM E498):
        1. Mount part in vacuum chamber; evacuate to 1 × 10^{-6} Torr using turbo pump.
        2. Spray external joints with 99.999 % He at 30 psig; monitor mass spec; accept if leak ≤ 1 × 10^{-10} std cm³/s for 60 s steady.
    5. Thermal Cycling:
        1. Subject one random sample per lot to 0–450 °C cycles (rate = 5 °C/min) for 50 cycles in air furnace.
        2. Post-cycle repeat helium leak; must still pass original limit.
6. **Week 54 – 58 | Factory Acceptance Testing (FAT)**
    1. Assemble representative 25-m string:
        1. Connect 20 waveguide modules, 19 joints, and 4 bellows using torque = 240 N·m on flange bolts.
        2. Install gimbal interface mock-ups at both ends.
    2. Pressure Envelope Test:
        1. Fill with nitrogen; raise to 275 bar (1.25× design) for 1 h; record P/T every 60 s.
        2. Accept if no pressure drop > 0.1 bar and strain gauges show hoop strain ≤ 0.18 %.
    3. RF Continuity Check:
        1. Connect vector network analyzer (VNA) ports; sweep 70–110 GHz; record S11 and S21.
        2. Accept if |S11| ≤ -25 dB and |S21| ≥ -0.3 dB over entire band.
    4. Mechanical Articulation:
        1. Rotate gimbal ±6° in pitch & yaw; observe bellows axial displacement 0–25 mm.
        2. No visible yielding; repeat 100 cycles.
    5. Generate FAT Report (*FAT-WG-027-R0.pdf*) including raw data, photos, and pass/fail matrix; obtain sign-off from QA/NDE Lead & Project Chief Engineer within 48 h.
7. **Week 58 – 59 | Final Documentation & Release**
    1. Compile Device History Record (DHR) binder containing:
        - Material certificates (mill + ceramic sinter logs).
        - MITP signed sheets.
        - NDE reports (*.pdf, *.dat).
        - FAT report.
    2. Convert binder to searchable PDF (*DHR-LL25-WG-PH5-Final.pdf*); upload to PLM with Rev A, status = “Released”.
8. **Week 59 – 60 | Packaging & Handover to Logistics**
    1. Apply desiccant bags (DIN 55473, Type A) inside each ceramic bore; cap ends with HDPE plugs.
    2. Shrink-wrap modules in VCI film, place on ISPM-15 certified crates; shock-watch indicator ≤ 25 g.
    3. Affix QR code linking to DHR PDF on each crate exterior.
    4. Complete Transfer of Custody form FO-027-TC; hand over to Logistics Manager in ERP with status = “Ready for Site”.

Deliverables

- OP-027-ENG-PKG-v1.pdf (Drawing & procedure book)
- MITP-027-R0 (Master Inspection & Test Plan)
- Individual inspection reports (WG-DIM-####.pdf, UT-####.dat, PT-####.pdf)
- DHR-LL25-WG-PH5-Final.pdf (Consolidated device history)
- FAT-WG-027-R0.pdf (Factory Acceptance Test report)
- FO-027-TC (Transfer of Custody form)
- Crated, traceable waveguide modules, joints, and bellows ready for shipment

OP-028 + OP-029 — Procure Gyrotrons & Power Supplies; Build and FAT Argon Loop Assemblies

Responsible Roles: RF Drilling Systems Lead (H-RF-15) | Process Fluids & Thermal Systems Engineer (H-ARG-17)
Task Timeline: Phase 5 — Weeks 40 to 58

HOW-TO-DO-IT — Step-by-Step Action Plan

1. **Week 40 — Kick-Off & Final Specification Lock-In**
    - Hold a 2-hour virtual joint kick-off meeting (RF & Argon teams, procurement, QA, controls) using Microsoft Teams.
      Save meeting minutes in SharePoint folder */GeoTherm20/Phase5/Kickoff/* as `GT20_P5_KOM_v1.docx`.
    - Issue final technical specification documents:
        - Gyrotron Spec: `GT20_RF_SPEC_REV3.pdf`
        - Power Supply Spec: `GT20_PS_SPEC_REV3.pdf`

    - Argon Loop Assembly Spec: `GT20_ARG_SPEC_REV4.pdf`
  - Embed revision control checksum (SHA-256) in document footer for traceability.

2. **Weeks 40-42 — Request for Proposal (RFP) Issuance**
  - Export vendor list from approved-supplier database (`ERP-VENDORS`) filtered by commodity codes RF-EHF-100 (gyrotrons), ELEC-HV-36 (power supplies), FLUID-AR-77 (argon systems).
  - Email RFP packages (ZIP format, ≤25 MB) to each vendor with the following mandatory files:
    1. Technical specification (`*.pdf`)
    2. Commercial terms template (`GT20_T&Cs_2025.docx`)
    3. Bid form (`GT20_BID_SHEET_v2.xlsx`) including separate line items for spare parts (minimum 5 %)
    4. FAT procedure skeleton (`GT20_FAT_TEMPLATE.docx`)
  - Set e-mail receipt and read confirmations; track in Outlook folder “P5_RFP”.
  - Due date for vendor questions: **Week 41 Friday 17:00 UTC**; issue consolidated Q&A addendum by Monday Week 42.

3. **Week 43-44 — Technical & Commercial Evaluation**
  - Create evaluation matrix in Excel with the following weighted criteria:
    - Technical compliance – 40 %
    - Cost – 25 %
    - Schedule – 15 %
    - Past performance – 10 %
    - After-sales support – 10 %
  - Score each bid; document rationale cell-by-cell in comment fields.
  - Run 30-minute internal cross-functional adjudication; capture decision in `P5_VENDOR_SELECTION_MINUTES.docx`.
  - Notify selected vendors via e-mail and issue “Intent to Award” letters (PDF, DocuSign enabled).

4. **Week 45 — Contract Finalization**
  - Insert negotiated changes into T&Cs; update redlines using track-changes mode.
  - Attach the following contract exhibits:
    - Exhibit A – Final Technical Specification (signed)
    - Exhibit B – Project Schedule Gantt (MS Project export)
    - Exhibit C – FAT Acceptance Criteria (see Step 8)
  - Obtain electronic signatures from Vendor CEO, H-RF-15, and H-ARG-17 using DocuSign routing order.

5. **Week 46 — Detailed Design Review (DDR)**
  - Schedule two separate 4-hour DDR sessions (RF plant, Argon loop) at vendor premises or via high-resolution telepresence (`Zoom Room 4K`).
  - Vendor must present: 3D CAD (STEP files), single-line diagrams, control logic narratives, and component datasheets.
  - Action items documented in `DDR_ACTION_LOG.xlsx` with owner, due date, and closure evidence column.

6. **Weeks 46-52 — Manufacturing & Procurement Monitoring**
  - Set weekly production calls every Tuesday 08:00 UTC. Record audio files (`.m4a`) and store in /Phase5/ProductionCalls/.
  - Track critical path components in manufacturing dashboard (`PowerBI`) with the following mandatory fields: ID, Component, Vendor WO#, Planned Finish, Actual Finish, %Complete, Risk Rating.
  - Quality Control hold points:
    - Gyrotron cathode brazing – Witness report required.
    - HV transformer potting – Final inspection photos.
    - Argon loop cyclone weld – 100 % radiography, upload DICONDE files.
  - Non-conformance procedure: Issue NCR in `ETQ-CAPA` system within 24 h; assign containment and corrective actions.

7. **Week 53 — FAT Readiness Review (FAT-RR)**
  - Verify completion of all DDR action items (100 % closed, evidence attached).
  - Release final FAT procedures (vendor-owned documents revised with GT20 headers). File naming convention: `FAT_RF_vFinal.docx`, `FAT_ARG_vFinal.docx`.
  - Approve calibration certificates for all test instrumentation (NIST traceable, validity ≥90 days).

8. **Weeks 54-56 — Factory Acceptance Tests**

8A. Gyrotrons & Power Supplies (Lead: H-RF-15)

  - Mount gyrotron on vendor RF stand with water-cooling loop delivering 50 L min^{-1} at 30 °C; install directional coupler and calorimeter.
  - Connect power supply; set initial cathode voltage to 0 kV.
  - Execute step-up testing: for V = {10, 20, …, 110} kV:
    - Hold 30 s, record beam current I_b, output power P.
    - Abort if $\text{dI_b/dt} > 5\ \%\ \text{s}^{-1}$.
  - Continuous-wave (CW) full-power run:
    - Target: 1.5 MW @ 140 GHz, duration 600 s.
    - Accept if P ≥1.5 MW ±2 % and frequency drift ≤ 5 MHz.
  - Rapid shutdown validation:
    - Send TTL interrupt to HVPS; measure time to power drop < 5 % of nominal. Limit: ≤8 µs.
  - Interlock simulation matrix:

Fault Injected	Injection Method	Expected Response	Pass Criterion
Over-Temp	Set cooling water to 70 °C	HV trip	Trip <1 s
RF Leakage	Open Faraday door	Interlock trip	Trip <0.5 s

Magnet Current Deviation	±3 % step	Shutdown	Trip <1 s

- EMC/Harmonic test: Connect LISN, verify IEC 61000-3-12 compliance (I_thd <16 A for each 50 Hz harmonic).
- Data logging: Store run files in CSV (1 kHz sample rate) and HDF5 for long-term archive.

8B. Argon Loop Assemblies (Lead: H-ARG-17)

- Pressurize system with nitrogen to 1.1 × design pressure (220 bar); hold 30 min; leak rate <1×10^{-5} bar L s^{-1}.
- Helium mass-spectrometer leak test: Accept criterion ≤1×10^{-6} mbar L s^{-1} for all welds.
- Flow performance:
  - Set blower to 3000 rpm; measure mass flow (Coriolis) 25 ± 0.5 kg s^{-1}.
  - Ramp heater to 1450 °C; verify PID holds ±2 °C.
  - Cyclone pressure drop ≤5 kPa @ 25 kg s^{-1}.
- Safety interlocks:
  - Over-pressure: Simulate 205 bar; valve must open within 0.2 s.
  - Over-temp: Insert thermocouple spoof 1500 °C; heater shutdown in <0.5 s.
- Instrument calibration check:
  - K-type thermocouples: ±1 °C @ 1000 °C.
  - Pressure transmitters: ±0.25 % FS (0–200 bar).
- Controls integration:
  - Connect to MPC test server (`10.44.12.55:4840`) via OPC-UA.
  - Verify namespace “GT20_ARG” and read/write of nodes `ARG.FlowSetpoint`, `ARG.TempPV`, etc.
  - Execute 20-step command script; all tags scan at 250 ms, no dropouts permitted.
- Particulate capture efficiency test:
  - Inject 50 g alumina dust (d50 = 5 µm).
  - Measure cyclone outlet PM (laser counter) <0.1 mg m^{-3}.

9. **Week 57 — FAT Reports & Issue Resolution**
   - Compile individual FAT data packs:
     - Test logs (CSV), plots (PNG), photos (JPEG, ≥12 MP), signed checklists (PDF).
   - Generate summary report template: `GT20_FAT_SUMMARY_v1.docx`; sections: Objectives, Method, Results, Deviations, Corrective Actions, Conclusion.
   - Close all open CARs/NCRs; reference closure evidence (photo, retest logs).
   - Collect vendor sign-off and GT20 acceptance signatures.
10. **Week 58 — Packing, Shipping & Handover**
    - Install transport dampers on gyrotron (`PN GT-TD-445`), vacuum seal with nitrogen back-fill 1.0 bar.
    - Argon skid: Drain process gas, back-fill dry nitrogen 0.5 bar; cap all process ports with metal-to-metal seals.
    - Apply shock/tilt indicators (Model “SpotSee TiltWatch”) on each crate; photograph serial numbers.
    - Generate packing list `PL_GT20_P5.csv` (include gross & net weight, CoG, HS codes).
    - Book Class D air-ride truck. Incoterms: DDP GeoTherm20 Research Site, Calgary.
    - Upload shipping docs to SharePoint */Phase5/Logistics/*.
    - Schedule internal handover meeting; transfer all digital artifacts to Commissioning team.

Deliverables:

- Signed purchase orders & executed contracts (PDF)
- Vendor detailed design packages (STEP, PDF)
- Manufacturing inspection reports & NCR logs (ETQ export)
- Final FAT procedures and raw data files (CSV, HDF5)
- FAT summary reports with acceptance certificates (PDF)
- Spare parts & commissioning kit inventory sheets (Excel)
- Training materials (PowerPoint, video files)
- Complete logistics/packing documentation (CSV, photos)

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# OP-030 + OP-031 — Construct Launch Gallery & Commission Utilities/Life-Safety Systems

**Responsible Role:** Construction Manager (Civil/MEP) — H-CM-10 | **Task Timeline:** Phase 6 — Week 45 to Week 70

## How-To-Do-It Instruction Manual

### 1.0 Pre-Mobilization & Detailed Planning (Week 45-46)

1. Formally issue the “Notice to Proceed” for OP-030 and OP-031 on Monday of Week 45 at 08:00 local time.
2. Review IFC drawings: CIV-A-LG-001 (launch gallery excavation), STR-A-LG-004 (rock support), MEP-LG-PWR-005 (power), MEP-LG-HVAC-006 (ventilation), and SHE-LG-LS-007 (life safety routes). Record revision numbers and unify on Rev-03 or later.
3. Create a Responsibility Assignment Matrix (RAM) linking every drawing line-item to named subcontractor supervisors. Distribute PDF and printed copies by 17:00 Week 45 Wednesday.
4. Schedule Daily Coordination Meeting (DCM) at site trailer, 06:30–07:00 every workday starting Week 46 Monday. Place recurrent meeting invite in Outlook with agenda template attached.
5. Mobilize survey team with Leica TS16 total station and Leica BLK360 laser scanner. Verify calibration certificates are current (< 3 months). Store digital certificate PDFs in the “QA-Equipment” folder of project SharePoint.
6. Obtain excavation permit LG-EX-045. Include checklist signatures: geotech engineer, HSE lead, and facility owner. Permit must be laminated and posted at adit portal.
7. Prepare confined-space rescue plan: define retrieval points every 15 m, specify Tripod Model Miller DuraHoist DH-2. Upload plan to HSE intranet and print two hardcopies—one for site, one for control room.
8. Issue a two-week look-ahead Gantt chart (MS Project file “LG_2WLH_W45.mpp”) covering activities 2.0 through 3.3. Email file to all discipline leads and upload to SharePoint.

### 2.0 Excavation & Rock Support (Week 46-52)
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1. Set out excavation boundaries with 12 mm rebar stakes and high-visibility ribbon. Use coordinates derived from survey control network points LG-CN-01 to LG-CN-06 with ±5 mm horizontal tolerance.
2. Commence drill-and-blast sequence:
   - Drill 45 mm Ø blast holes on 1.2 m burden × 1.0 m spacing grid to a depth of 2.5 m per round.
   - Load with ANFO @ 0.8 kg/m, apply NONEL caps with 25 ms – 500 ms delay pattern (EPC Pattern LG-DB-02).
   - Install temporary ventilation fan (Howden Jetstream 75 kW) connected to 800 mm Ø flexible ducting, 4 air changes / hour design. Energize 10 minutes prior to blast, maintain until particulate count < 0.2 mg/m³.
3. After muck removal, conduct face mapping using scan data; convert point cloud to DWG within Cyclone. Verify rock class per Geotech Spec GTS-05; if > Class III, increase rock bolt density by 20%.
4. Install rock support:
   - 3 m resin-grouted rock bolts @ 1.5 m × 1.5 m pattern (Hilti RE-500 epoxy).
   - Apply 100 mm thick shotcrete (C35/45) with 1 layer 100×100×6 mm welded mesh reinforcement. Record batch ticket numbers and nozzleman certification.
5. Excavate to final gallery footprint: Length 30 m, Width 8 m, Height 7 m ±100 mm. Confirm via total-station prism points LG-CHK-01 to LG-CHK-10.
6. Construct drainage:
   - Form sump pit 2 m × 2 m × 2 m at lowest point (station 0+28).
   - Install dual 7.5 kW Flygt B 2201 pumps with float switches (primary + stand-by) wired to MCC LG-WTR.
   - Route 100 mm HDPE discharge pipe to settlement tank ST-03 outside portal.

3.0 Structural Floor Slab & Equipment Pads (Week 52-56)

1. Grade sub-base to –100 mm elevation; compact to 95% Modified Proctor. Perform nuclear density test every 100 m² (target ≥ 95%).
2. Install 200 µm PE vapor barrier and 50 mm XPS insulation over sub-base.
3. Place reinforcement: double #6 rebar grid @ 200 mm OC both directions, top and bottom layers, with 50 mm cover.
4. Pour 350 mm thick C40/50 concrete slab in two 15 m sections. Use Sika Viscocrete 2100 for slump 180 mm ±20 mm. Maintain continuous pour rate ≥ 25 m³/hr to avoid cold joints.
5. Apply trowel finish; after initial set, saw-cut control joints at 6 m spacing to 80 mm depth within 12 h.
6. Cure with Li-silicate densifier (Euclid Durasheen L). Maintain 20 °C ±5 °C and RH > 60% for 7 days. Record curing logs in QA Form LG-CURE.
7. Form equipment pads:
   - RF Pad: 6 m × 4 m × 450 mm with four M24 × 300 Hilti HIT-Z anchors, embed 250 mm, pattern per drawing RF-PAD-01.
   - Wellhead Pads: two circular pads Ø2.5 m, thickness 500 mm, reinforced with #8 rebar cage @ 150 mm pitch.

4.0 Electrical Power Distribution (Week 56-60)

1. Install 1 × 2500 kVA, 11 kV/480 V dry-type transformer (ABB TTR2500) in substation niche. Anchor transformer using four M30 chemical anchors, Hilti RE 500, embed 350 mm.
2. Route 1600 A copper bus duct (Eaton Pow-R-Way) from transformer to MCC LG-MAIN—total length 18 m, elevation 5.5 m above slab. Torque bus joints to 105 N·m; record in bus duct log sheet.
3. Install MCC LG-MAIN with 12 buckets:
   - Feeder 1: 600 A VFD for gyrotron #1.
   - Feeder 2: 600 A VFD for gyrotron #2.
   - Feeder 3: 250 A VFD for ventilation fan.
   - Spare: 3 × 200 A space.
4. Pull 4-conductor 500 kcmil XLPE cables in 150 mm EMT conduit from MCC to RF pad. Use Greenlee 880 tugger; maintain pull tension < 2.5 kN.
5. Terminate cables with 2-hole long barrel lugs, crimp using Burndy Y750, die 50. Apply 3M Cold Shrink CS-E-1 on every termination.
6. Conduct megger test at 1000 V; accept if ≥ 500 MΩ phase-to-ground and phase-to-phase.

5.0 Water Cooling/Heat Rejection Interfaces (Week 58-62)

1. Install dual 150 mm carbon-steel chilled-water headers (supply + return) along north wall at 4.0 m elevation. Weld per ASME B31.1, WPS LG-CW-01, certified welder ID stamps mandatory.
2. Hydrostatic pressure test piping to 1.5 × design (15 bar) for 2 h; accept if pressure drop < 30 kPa.
3. Attach RF equipment branch via 65 mm stainless flex hoses (OmegaFlex SS369) with Victaulic Type 77 couplings.
4. Install isolation valves (DN150 butterfly), temperature gauges (0-120 °C), and flow meters (Siemens MAG 5100W) at both feed and return for each gyrotron circuit.

6.0 Ventilation & Argon/O_2 Monitoring (Week 60-64)

1. Mount supply fan (Howden 151 kW, 45 000 m³/h) at west mezzanine, discharge at gallery ceiling centerline.
2. Connect 1 m × 0.6 m rectangular duct (galvanized 1.6 mm) with four 45° turning vanes and volume dampers every 10 m.
3. Install extraction duct at floor level east wall. Connect to 90 kW exhaust fan sized for 35 000 m³/h to create 5 Pa negative pressure.
4. Mount eight Honeywell Sensepoint XCD O_2 sensors at 1.5 m height, spacing 10 m. Set alarm 1 at 19.5 %, alarm 2 at 18 %.
5. Integrate sensors with Siemens PLC LOGO! via 4–20 mA loops; program logic to trip RF interlock and energize beacon/horn when O_2 < 18 %.
6. For argon bottle farm, install 25 mm SS316 pipeline, pressure-regulated to 6 bar, through ball valves to wellheads. Place flashback arrestors at each valve.

7.0 Fire Detection, Suppression & Egress (Week 62-66)

1. Install addressable smoke detectors (Siemens FD720) on ceiling grid @ 9 m spacing. Program addresses and upload to fire panel node FP-LG.
2. Mount two 100 kg clean-agent cylinders (FM-200). Connect to 25 mm schedule-40 pipe ring main with nozzle orifices sized per FSSA FK-5-1-12 design for 4.0% concentration.
3. Run 2 × 1.5 mm² FP200 Gold fire cable from detectors and agent release valves back to panel. Terminate per Siemens wiring diagram Fig 4-B.
4. Paint egress route linemarking (photoluminescent) from gallery midpoint to portal; place exit signs (24 V DC) every 12 m.
5. Install emergency lighting: 90 min autonomy LED units (Thorn Voyager). Connect to UPS LG-ELS (10 kVA) powered from MCC LG-MAIN feeder 5.
6. Program RF access interlock:
   - If Fire Alarm = TRUE or O_2 < 18 %, then set RF_Permit = FALSE, de-energize gyrotron contactors, lock motorized gate at gallery entrance.
   - Test logic by forcing inputs via PLC simulation.

8.0 RF Shielding & Cable Tray (Week 64-67)

1. Line gallery walls with 3 mm copper sheet, seams overlapped 50 mm and soldered with Sn60/Pb40 using propane torch. Test electrical continuity – goal < 2 mΩ between any two points spaced 10 m.
2. Install RF door (ETS-Lindgren Model 71) at entrance. Shim to achieve door compression force 8 kN ±0.5 kN; verify radial RF gasket continuous contact.
3. Mount cable trays:
   - Power Tray: 600 mm × 100 mm ladder type, elevation 5 m south wall.
   - Control Tray: 300 mm perforated type, elevation 6 m north wall; maintain 600 mm separation from power tray to avoid EMC coupling.

4. Bond every tray section to building earth using 25 mm² green/yellow conductor, Cadweld CAD 28H shots.

9.0 Commissioning & Integrated Tests (Week 67-70)

1. Ventilation Performance Test:
   - Measure airflow with Testo 420 balometer at each supply diffuser; sum to confirm ≥ 45 000 m³/h.
   - Inject tracer gas (CO_2) pulse; verify complete exchange in ≤ 12 min via PID log.
2. O_2 Alarm Validation:
   - Flood gallery with argon to drop O_2 to 18.5 %, record sensor response time ≤ 30 s and PLC logic action (RF_Permit trips).
3. Electrical Load Test:
   - Connect resistive load bank 1 MW at RF pad, ramp 0 → 1 MW in 100 kW steps, hold 60 min; record MCC feeder temperatures (≤ 60 °C).
4. Hydraulic Flush & Chemical Clean:
   - Circulate 1% citric-acid solution 4 h, maintain 50 °C, then flush with deionized water until conductivity < 50 µS/cm.
5. FM-200 Discharge Simulation:
   - Remove actuator caps, engage test mode; observe control panel to verify release sequence without agent discharge.
6. RF Shielding Verification:
   - Place RF source 2.45 GHz, 10 W inside gallery; measure outside with spectrum analyzer. Attenuation must be ≥ 90 dB.
7. Integrated Emergency Drill:
   - Simulate fire at wellhead #2, trigger evacuation. Measure time to first responder arrival (target ≤ 4 min) and headcount clearance (≤ 3 min).
8. Compile Commissioning Report ("LG_Comm_Rep_v1.docx") including data sheets, calibrated instrument certificates, and punch-list closure evidences. Submit for Owner acceptance by 17:00 Friday, Week 70.
9. Hand over as-built 3D model: update digital twin in Bentley iTwin with final point cloud merge, tag every asset with QR code linking to O&M manual PDF.

Deliverables

- Daily Coordination Meeting minutes (PDF) — Weeks 45-70
- Excavation & Rock Support QA forms: LG-RS-Logs (signed)
- Concrete pour tickets & cylinder break results
- Electrical megger & load-test records
- Hydrostatic and flushing certificates for cooling system
- Ventilation/O_2 commissioning data sheets
- Fire system acceptance test report
- RF shielding attenuation verification sheets
- Integrated emergency drill video + debrief report
- Final Commissioning Report "LG_Comm_Rep_v1.docx"
- Updated as-built 3D digital twin (Bentley iTwin package)
- Operation & Maintenance manual binder for gallery systems

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# OP-032 + OP-033 — Starter Hole Drilling Program & Rig Mobilization Manual

Responsible Role: Drilling & Well Construction Manager — H-DRILL-14 | Task Timeline: Phase 6, Weeks 54 – 64

## How-To-Do-It

## 1. Author the Detailed Starter Hole Drilling Program (Week 54)

1. Open the corporate well-program template *GEO-PR-WELL-T001.docx* on SharePoint path **\\GeoTherm20\Projects\LithoLoop25\Drilling\Programs\**.
2. Enter well identification: LL25-STH-01; license: SR-LL-A11; coordinates: 47.2149° N, 121.3257° W; elevation: 522 m MSL.
3. Define objective: Drill 45° deviated starter hole from 0 m to 3 km MD (2.12 km TVD) with 300 – 400 mm diameter to provide upper wellbore for waveguide insertion.
4. Insert trajectory plan:
   - Kick-off at 60 m MD.
   - Build rate: 2.5°/30 m from 60 m to 720 m.
   - Hold 45° inclination from 720 m to 3 000 m MD.
5. Embed trajectory tolerance table:

| Depth (m MD) | Max Dog-Leg (°/30 m) | Positional Tol. (m) |
|---|---|---|
| 0-720 | ≤ 2.5 | ± 2.0 |
| 720-3 000 | ≤ 1.5 | ± 5.0 |

6. Specify bit/BHA selection:
   - Section 0-720 m: 17-1/2" PDC, 8-in MWD collar, 6.75" mud motor, non-mag drill collars.
   - Section 720-3 000 m: 12-1/4" PDC, RSS (AutoTrak G5), 8-in MWD, 6-3/4" LWD triple-combo.
7. Define drilling fluid system:
   Use high-temperature synthetic oil-based mud (HT-SOBM) with 1.15 sg to 1.45 sg density window. Rheology at 200 °C:
   - Plastic Viscosity (PV): 32 cP.
   - Yield Point (YP): 18 lb/100 ft².
   - Hydraulics: Calculate ECD (equivalent circulating density) each stand using:
     **ECD (sg) = MW + (0.052 × Annular Pressure Loss (psi) / TVD (ft))**
   - Maintain ECD ≤ Frac Gradient – 0.05 sg margin.
8. Insert kick tolerance formula (per IWCF standard):
   **Kick Tol. (bbl) = (MAASP – SIDPP) × Annulus Vol. (bbl/psi)**,
   where MAASP = Frac Gradient × 0.052 × TVD.
``````

9. Draft casing plan:
    - Conductor: 26" × 40 m, 0.625" wall, K-55.
    - Surface: 20" × 720 m, 0.875" wall, 13Cr-L80.
    - Intermediate: 13-3/8" × 3 000 m, 1.00" wall, 718 nickel alloy, buttress thread.
10. Cementing: Design geothermal cement (ThermaSet-G) with 35 % silica flour, 1 % Retarder-HT, 0.3 % Dispersant-SP; target compressive strength ≥ 2 000 psi @ 220 °C in 24 h. Slurry density: 1.95 sg. Displacement calculation:
    Slurry Vol. (bbl) = [Annular Capacity (bbl/m)] × [Casing Shoe MD – Collar MD] × 1.10 safety factor.
11. Include temperature management procedure: Circulate 1.5 hole volumes with 45 °C OBM before POOH to avoid thermal shock to future waveguide glass-ceramic.
12. Approval routing: Upload draft to SharePoint; request electronic signatures from Chief Drilling Engineer, HSE Manager, and Asset Director per *SOP-WF-021*. Deadline: Week 54 Friday, 17:00.

2. Contract the Rig & Services (Week 55)

1. Create purchase requisition PR-LL25-RIG01 in SAP module MM-PR with scope: 3 000 m MD 45° starter hole, OBM capability to 240 °C, 750-ton hook-load, 5000 psi BOP stack.
2. Attach drilling program PDF and technical specs to the PR.
3. Email approved PR to SCM team and pre-qualified rig contractors (GeoRig, DeepTorque, BoreMax) by 10:00 Monday.
4. Organize clarification Q&A call Wednesday 14:00 using Teams link *https://teams.microsoft.com/l/meetup-join/LL25RigCall*.
5. Receive bids by Friday 12:00; score using weighted matrix:
    - Technical compliance 40 %
    - HSE record 25 %
    - Cost 20 %
    - Delivery time 15 %
6. Select highest score; issue Intent-to-Award letter via DocuSign by 17:00.
7. Execute contract *CTR-LL25-GR-2024-001*; upload to SharePoint folder **Contracts\Rig**.

3. Pre-Mobilization Planning & Logistics (Week 56)

1. Issue mobilization notice (Mobil-001) to rig contractor including equipment list and arrival sequence.
2. Book heavy-haul transport permits with DOT: 10 ea. 120-ton loads, route ID 9875, travel window 22:00-05:00.
3. Reserve 50-room block at GeoLodge for crew; confirmation #GL-77922.
4. Arrange 3 × 11 kV / 3 MW diesel gensets from PowerRent; delivery Week 57 Monday.
5. Send mud, cement, logging, and directional service POs to service companies; attach site access maps.
6. Publish integrated mobilization Gantt (file *LL25_Mob_v2.mpp*) on Planner with critical path flagged red.

4. Mobilize Rig to Site (Weeks 57 – 58)

1. Day 1 06:00: Confirm pad civil readiness via walk-down; verify cellar depth 4 m and wellhead alignment coordinates ±0.05 m.
2. Day 1 08:00: Accept first convoy (substructure); record serial numbers in form *LL25-RIG-ACC-01.xlsx*.
3. Day 1 16:00: Install VFD house and SCR; torque anchor bolts to 450 N·m using calibrated wrench #TW-422.
4. Day 2 07:00: Rig up mast; pin at 80 ft; verify verticality with digital inclinometer ≤ 0.25° deviation.
5. Day 2 14:00: Install 13-5/8" 5 kpsi BOP stack on wellhead test stump; make-up flanges to 4 500 ft-lb.
6. Day 3 10:00: Hook up choke manifold, kill manifold, accumulator (7.5 m³; 3 000 psi).
7. Day 3 15:00: Connect mud lines; pressure test to 3 500 psi for 30 min, acceptable leak ≤ 1 psi.
8. Day 4 09:00: Lift camp modules; connect 480 V shore power; test GFCI trip ≤ 30 ms.
9. Day 4 17:00: Complete rig-up punch list; upload signed list to SharePoint.

5. Pre-Spud HSE Drills (Week 59)

1. Issue drill schedule bulletin (#HSE-LL25-D01) on notice board 24 h in advance.
2. Conduct Well Control Drill:
    1. Simulate gas influx of 5 bbl at 1 500 m MD.
    2. Time crew to shut-in well: target ≤ 45 s.
    3. Record SIDPP, SICP, establish static density difference.
3. Confined Space Rescue:
    1. Insert dummy “worker” in mud tank #3.
    2. Activation > raise red beacon; rescue team dons SCBA ≤ 90 s.
    3. Extract dummy using tripod hoist; target ≤ 6 min total.
4. Argon/O_2 Deficiency Response:
    1. Deploy gas detectors set at 19.5 % O_2 alarm.
    2. Simulate argon leak; observe evacuation to muster point A ≤ 3 min.
5. RF Plant Exclusion Protocol Drill:
    1. Demarcate 10 m RF exclusion zone with yellow cones.
    2. Verify access control signage and badge reader lockout.
6. Emergency Communications Check:
    - Test satellite phone call to Control Center (number +1-555-884-1122) – connection ≤ 15 s.
    - Send “DRILL OK” message via Inmarsat BGAN terminal – confirm receipt.
7. Document results in form *LL25-HSE-DRILLS-R1.docx*; file within 24 h.

6. Rig Mechanical & BOP Acceptance Tests (Week 60)

1. Mechanical Inspection:
    - Inspect drawworks brake linings; minimum thickness 12 mm.
    - Function test crown-block safety valve; response time ≤ 0.3 s.
2. BOP Pressure Test:
    1. Low pressure test 250 psi for 15 min – no loss.
    2. High pressure test 3 000 psi for 30 min – max loss 0.5 psi.
    3. Test pipe rams, blind rams, annular, choke lines.
3. Accumulator Function Test:
    - Close blind rams using accumulator only – ≤ 30 s.
    - Remaining usable volume ≥ 50 % after closing all preventers once.
4. Documentation Check:
    - Verify calibration certificates *<90 days* for pressure gauges.
    - Confirm API 4G mast inspection report; no category D findings.
    - Check weld NDT reports for substructure beams.
5. Sign-off:
    - Rig Manager, Company Man, and Regulatory Inspector sign *LL25-RIG-ACCEPT-FORM*.
    - Scan and upload within 2 h.

7. Final Spud Authorization & Handover (Week 61)

1. Compile all completed forms into PDF bundle *LL25-SPUD-PACK.pdf*.
2. Email bundle to:
    - Regulator (DOE.GEO@energy.gov)
    - Asset Director
    - HSE-Corporate
3. Schedule spud ceremony: Week 61 Monday 07:30; record “bit-on-bottom” timestamp as start of OP-034.

8. Detailed Week-by-Week Timeline

Week	Key Actions
54	Draft & approve drilling program
55	Tender, bid evaluation, contract award
56	Mobilization planning & logistics
57-58	Rig move & rig-up
59	Pre-spud HSE drills
60	Rig & BOP acceptance
61	Spud authorization & handover to OP-034
62-64	Contingency buffer; close-out reports

Deliverables

- Approved Starter Hole Drilling Program (PDF + Word)
- Signed Rig Contract CTR-LL25-GR-2024-001
- Mobilization Gantt Chart (MS Project)
- Completed HSE Drill Reports (LL25-HSE-DRILLS-R1)
- Rig Acceptance Package (LL25-RIG-ACCEPT-FORM & supporting certificates)
- Spud Authorization Bundle (LL25-SPUD-PACK.pdf)
- All uploaded documentation in SharePoint path **\\GeoTherm20\Projects\LithoLoop25\Drilling\Phase6**

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## OP-034 + OP-035 — Drill, Case & Cement Starter Hole; Install Insulated Transition Liner and Verify Thermal Performance

**Responsible Role:** Drilling & Well Construction Manager — H-DRILL-14 | **Timeline:** Phase 6 – Civil Works & Starter Hole, Weeks 65 – 74

# How-To-Do-It: Fully Detailed Execution Plan

## 0. Pre-Execution Gate (Week 65 Day 1)

1. Conduct a pre-spud HAZID/HAZOP review with drilling, HSE, cementing, and thermal modeling teams. Record approvals in the project’s e-Permit system.
2. Verify receipt of long-lead items:
    - 5 ⅞ in. PDC starter-hole BHA rated to 280 °C.
    - Ø9 ⅝ in., 53.5 lb/ft, 27Cr-NiMo high-chrome/nickel alloy casing (13,500 ft / 4,115 m total length pre-tallied).
    - Class-G geothermal cement with 40 % silica flour, 0.8 % retarder, 7 % micro-expansion additive.
    - Insulated transition liner, Ø8 ⅝ in. ID, 100-ft pup sections with 1-in. aerogel blanket and 0.020-in. Inconel904 slip-over shroud. Total length 2,000 ft (610 m).
3. Load digital well plan (trajectory, hydraulics, torque-drag) into rig MONARCH-RT system; confirm anti-collision scan clear.

## 1. Civil Works & Rig-Up (Week 65 Days 2-7)

1. Grade pad to 0.5° tolerance; install 40-MPa reinforced concrete cellar (20 ft × 20 ft × 15 ft deep).
```

2. Spot 1,200-ton AC-700 triple mast; level to <0.25° by laser transit.
3. Rig up 15k psi BOP stack: 13 ⅝ in. 10k annular, double 13 ⅝ in. ram preventers, blind shear, pipe ram, test mandrel.
4. Pressure-test BOP to 11,250 psi for 10 min and 5,625 psi for 30 min per API 16A; log results in WellBook.

2. Drill 26 in. Conductor Hole to 200 ft (Week 66 Days 1-2)

1. Spud with 26 in. tri-cone at 120 rpm, 25 klbf WOB, mud 9.2 ppg.
2. At 200 ft MD, run 20 in. 94 lb/ft conductor casing; cement to surface with 1.15 yield Class A slurry, 100 % excess.
3. Wait on cement (WOC) 8 h; verify top of cement at surface via tag and sound hammer.

3. Drill 12 ¼ in. Starter Hole to 3 – 5 km MD (Week 66 Day 3 – Week 70 Day 1)

1. Kick-off 45° tangent at 500 ft MD using steerable motor with 1.5° bend; hold inclination 45° ±0.5°.
2. Maintain drilling window parameters:
   - Mud: KCl-polymer saturated brine, 11.0–12.0 ppg, maintain mud weight to >0.7 psi/ft overestimated pore pressure gradient.
   - Mud temperature limit: 230 °C; circulate bottoms-up every 500 ft to confirm.
   - ROP target: 40–50 ft/hr; maximum off-bottom time per stand: 5 min.
3. Execute MWD surveys every 90 ft; ensure total dogleg ≤3°/100 ft.
4. Pause at each 1,000 ft increment for hole conditioning: circulate 2× hole volume at 120 spm; piston stroke efficiency ≥95 %.
5. At 9,842 ft (3 km) MD evaluate formation temperature; if <250 °C and vibration/resonance within spec, continue to 16,404 ft (5 km) MD; else stop at 3 km.
6. Perform wiper trip to surface with 40 klbf backream; confirm drag <40 klbf slack-off/pick-up difference.

4. Run Ø9 ⅝ in. 27Cr-NiMo Casing & Cement (Week 70 Days 2-5)

1. Drift each joint with 8.500 in. gauge; visually inspect for pitting, ovality <0.125 in.
2. Tally and mark joint numbers; record lengths in spreadsheet “SH-Casing-Tally-v3.xlsx”.
3. Make-up torque: 12,500 ft-lb ±5 % using digital tong; record in torque-turn graph.
4. Run casing to TD (3–5 km); float collar at 20 m from shoe; install centralizers 1 per joint from shoe to 500 m, then 1 per 2 joints to surface.
5. Prepare cement job:
   - Calculate required slurry volume: $V_{slurry} = (\pi/4) \times (OD_{hole}^2 - OD_{csg}^2) \times L \times 1.30$; use OD_{hole} = 12.25 in., OD_{csg} = 9.625 in., L = hole length (ft). Add 30 % excess (factor 1.30).
   - Mix density 15.8 ppg, rheology 35/15/0 (°F 150 rev/s), thickening time 5 h at 250 °C/1,000 psi.
   - Spacer: 30 bbl weighted water-based 11.5 ppg with 3 lb/bbl surfactant.
6. Pump sequence at 8 bpm:
   1. 20 bbl fresh water pre-flush.
   2. Spacer 30 bbl.
   3. Lead slurry (if any) 0 bbl.
   4. Tail slurry V_{slurry}.
   5. Displacement mud until plug bumps at 500 psi over bump pressure.
7. Hold pressure 15 min; confirm no more than 10 % decline.
8. WOC 10 h minimum; monitor CSG1 wellhead temp every hour—target <90 °C.

5. Cement Bond Log (CBL/VDL) & Zonal Isolation Verification (Week 70 Day 6)

1. Run CBL/VDL tool string with centralizer spacing 40 ft; log from shoe to surface.
2. Acceptance criterion: CBL amplitude <0.3 mV and VDL continuous travel time pattern ≥80 % length.
3. If any interval >50 ft fails, schedule top-up cement squeeze the next day (contingency).
4. Perform 3,000 psi casing pressure test for 30 min; leak rate <1 psi/min.

6. Install Ø8 ⅝ in. Insulated Transition Liner (Week 71 Days 1-3)

1. Prepare workstring: 5 in. drill-pipe with landing collet profile for liner top packer (TIW 4L-X).
2. Pick-up liner joints in 100-ft sections:
   - Check aerogel blanket for tears; max gap <5 mm allowed.
   - Make-up Inconel shroud coupling torque 4,500 ft-lb.
3. Run liner to top-of-liner depth: 2,000 ft above expected 350 °C isotherm (calculate by geothermal gradient 60 °C/km).
4. Set Tie-Back polished bore receptacle (PBR) in 9 ⅝ in. casing at 1,000 ft below wellhead.
5. Drop 400-lb setting ball; pressure up to 1,800 psi to set liner-top compression packer; bleed off and verify 500 psi hold.

7. Thermal Performance Verification (Week 71 Days 4-6)

1. Run distributed temperature fiber-optic (DTS) line on slickline to liner shoe; acquire baseline temperature profile for 4 h while circulating warm mud 40 bpm.
2. Model expected temperature curve with equation: $T_{expected}(z,t) = T_{geo}(z) - (Q_{loss} / (\rho \cdot c_p \cdot v)) \cdot [1 - \exp(-\alpha \cdot t / L)]$ where Q_{loss} = 15 W/m, ρ = 1,050 kg/m³, c_p = 4,200 J/kg·K, v = flow velocity m/s, α = thermal diffusivity 1.3×10^{-7} m²/s, L = liner length (m).
3. Overlay logged DTS vs. model; acceptance: ΔT <8 °C across 95 % of liner length.
4. If ΔT >8 °C, install additional aerogel sleeve over out-of-spec zone and re-run DTS for confirmation.

8. Documentation & Regulatory Handover (Week 72-74)

1. Compile daily drilling reports, BHA sheets, mud logs, cement job ticket, CBL/VDL images, pressure test charts, DTS plots into “Starter-Hole-Completion-Pack-v1.pdf”.
2. Submit pack to Regulatory Affairs within 48 h of completion per Permit #GT-142-6-DWC requirements.
3. Update Digital Twin (BoreSim360) with:
    - Final surveyed trajectory *.csv.
    - Casing & cement volumes.
    - Thermal liner characteristics (λ = 0.020 W/m·K, thickness 25 mm).
4. Issue Completion Memo and move well status to “Isolated & Insulated – Ready for RF Drilling” in Project Tracker.

Deliverables

- Starter-Hole-Completion-Pack-v1.pdf (full documentation bundle)
- CBL/VDL raw and interpreted logs (*.las, *.pdf)
- Pressure test chart (*.png)
- DTS thermal performance report with model overlay (*.xlsx, *.pdf)
- Digital Twin updated dataset export (*.json)
- Completion Memo (Doc-ID CM-SH-OP34-35-01)

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# OP-036 + OP-037 — Install and SAT Gyrotron RF Plant; Assemble Initial 1–2 km Waveguide String and Verify Integrity/Continuity

**Responsible Role:** Site Installation & Commissioning Manager — H-SITE-23; High-Temperature Materials & Downhole Mechanisms Engineer — H-HTM-16 | **Task Timeline:** Phase 7: RF/Drilling Subsystems Site Installation & Commissioning, Week 68 – 82

## How-To-Do-It Instruction Manual

## 1 – Pre-Installation Preparation (Week 68)

1. **Verify Site Readiness**
    - Confirm completion of civil foundations & seismic anchors for the RF plant per drawing GT20-CIV-RF-B45-FND-003 (rev 7).
    - Ensure 480 V ± 2 % / 60 Hz / 3-phase power bus with 2.5 MVA capacity is live and locked-out at panel PP-RF-01.
    - Check availability of de-ionized cooling water line (15 °C, 5 bar, ≤ 0.1 µS/cm) terminated in 2 × DN50 couplings labeled CW-IN and CW-OUT; depressurize and tag.
    - Confirm OT fiber trunk (12-core OS2 single-mode) terminated at rack OT-MD-04 with LC connectors; clean with grade-A wipes and inspect under 200-× scope.
2. **Logistics & Inventory**
    - Cross-check received hardware against packing lists:

| Item | Qty | Part No. | Rev |
|---|---|---|---|
| Gyrotron Cabinet (8 MW, 140 GHz) | 1 | GT20-RF-CAB-140G-08 | 2 |
| Rectangular-to-circular Launch Adaptor | 1 | GT20-WG-ADP-RC-06 | 5 |
| BeCu-brazed WR-6 Waveguide (3 m sticks) | 670 | GT20-WG-WR6-3000 | 1 |
| Bellows Expansion Sections (500 mm) | 15 | GT20-WG-BEL-500 | 3 |

    - Quarantine any discrepant or damaged items in area “Hold-Zone-A” and raise NCR per QMS-PR-08.
3. **Personnel & Safety**
    - Issue Permit-to-Work #RF-068-W82 after JSA review; include confined-space and high-energy RF hazards.
    - Verify RF PPE availability:
        - Shielded lab coats (40 dB attenuation @ 140 GHz)
        - Type II ear defenders (≥ 37 dB NRR)
        - ANSI Z87+ polycarbonate goggles
    - Conduct toolbox talk; sign attendance sheet F-HSE-014.

## 2 – Install Gyrotron RF Plant (Week 69 – 72)

4. **Positioning & Leveling**
    - Move Gyrotron Cabinet using 10 tonne air-skate system: maintain speed < 0.1 m/s.
    - Align cabinet centerline to grid coordinates X + 23.500 m, Y + 05.200 m (datum REF-S1) with tolerance ± 1 mm.
    - Use laser level (Leica Rugby 880) to set top flange elevation at +1.730 m ± 0.5 mm.
    - Torque M24 × 120 anchor bolts to 260 N·m in star pattern; document in form MECH-TOR-009.
5. **Utilities Hook-up**
    a. Electrical Power: Run 4 × 400 mm² copper cables in ladder tray to breaker QF-RF-08; terminate with lugs per IPC-WHMA-A-620 class 3; tighten to 45 N·m; record torque.
    b. Cooling Water:
        i. Flush lines with 50 L of DI water; measure resistivity > 15 MΩ·cm at drain.
        ii. Connect ISO-KF50 flexible hoses; clamp to 9 N·m; label CW-IN-GTR and CW-OUT-GTR.
        iii. Slowly pressurize to 5 bar over 5 min; inspect all joints for leakage for 30 min.
    c. Argon Loop Interface: Blank off until Phase 9; install dummy spool DN25 with gasket type SPW-316L-1.5 mm, torque 30 N·m.
    d. OT Fiber: Patch LC-to-LC duplex to port OPT-01 and OPT-02; record insertion loss < 0.25 dB @ 1310 nm.
6. **Interlock & Shielding Verification**
    - Test door interlocks DI-01 and DI-02; verify “RF Enable” lamp stays OFF when door open (0 V @ PLC input X3).
    - Measure Faraday cage continuity < 5 mΩ between panels using Fluke 1630 ground tester.
    - Scan external surfaces with RF leakage probe (Narda SRM-3006 + 40 GHz to 110 GHz head) at 0.5 m grid; max reading must be ≤ 0.1 mW/cm².
7. **Functional Power-Up (No RF Output)**
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a. Disable cathode HV by removing jumper JP-HV-EN.
b. Start cooling pump; verify flow 240 L/min, ΔT < 3 K.
c. Energize mains; ensure PLC boots and HMI shows “Ready – No Tube Voltage”.
d. Log all readings in SAT sheet RF-SAT-140G-Sec-A.

3 – Assemble Initial 1–2 km Waveguide String (Week 72 – 80)

8. **Starter-Hole Preparation**
   - Confirm starter hole ID = 400 mm, deviation < 0.2 ° over 100 m via gyro survey GH-RPT-11.
   - Install temporary insertion rail system (TIRS-400); lock rail footplates with M20 studs to 180 N·m.
9. **Waveguide Section Assembly Procedure (Repeat for Each 3 m Stick)**
   a. Visually inspect inner surface with borescope ≥ 200 lux; reject if any scratch > 25 µm depth.
   b. Clean mating flanges with lint-free IPA wipes < 10 ppm residue.
   c. Apply silver-loaded gasket (part GT20-WG-GSK-SLV-275) to female flange; ensure orientation tab at 12 o’clock.
   d. Mate to previous stick; insert eight M12 × 45 Inconel 718 cap screws; hand-tighten.
   e. Use calibrated torque wrench: step 1 = 20 N·m, step 2 = 30 N·m, step 3 = final 40 N·m–cross pattern.
   f. Record joint ID and torque values in log WG-TQ-L-###.
10. **Bellows & Gimbals Placement**
    - Insert bellows every 200 m and at all dog-leg sections; compress to neutral length 480 mm (spec ± 2 mm).
    - Install 3-axis gimbal unit GT20-WG-GMB-AX3 at depth markers 600 m, 1200 m; verify articulation ± 5.0 ° each axis.
11. **Lowering into Hole**
    a. Attach lowering clamp rated 12 kN to waveguide via clamp pads CP-WG-400-AL.
    b. Use winch WN-07; descent speed 0.15 m/s maximum.
    c. Maintain constant tension 3.2 kN ± 0.3 kN; monitor load cell LC-05.
    d. At every 100 m depth, pause; check axial twist ≤ 2 ° using digital compass module.
12. **RF Continuity & Loss Measurement (Every 100 m)**
    a. Connect portable VNA (Keysight N5247B) with 0 dBm sweep 130–150 GHz.
    b. Measure S11; requirement: |S11| ≤ −27 dB at 140 GHz.
    c. Measure insertion loss using through-line method: Loss (dB) = 10·log10(Pin/Pout); specification ≤ 0.015 dB/m.
    d. Log results in file WG-IL-RUN-W72.xlsx.
13. **Mechanical Integrity Verification**
    - Deploy laser alignment tool (Renishaw XL-80) from origin flange to depth 1 km; lateral deviation must be < 8 mm total.
    - Check flange squareness at 0 m and 1 km: angle θ ≤ 0.25 ° vs. reference plane.

4 – Site Acceptance Testing (SAT) of Integrated System (Week 80 – 82)

14. **Cold RF Test (No Beam Output)**
    - Re-enable cathode HV jumper JP-HV-EN; set beam current limit to 0 A.
    - Command gyrotron to radiate 10 kW forward RF for 15 s; monitor directional coupler DC-01.
    - Verify forward/reflected power ratio > 20 dB (match good).
    - Measure leakage at surface: ≤ 0.1 mW/cm².
15. **Full-Power Pulse Test**
    a. Set RF target: 8 MW, pulse width 5 s, duty cycle 10 %.
    b. Start sequence “RF-PULSE-08MW”.
    c. Record temperatures every 0.5 s on sensors TH-WG-###; ΔT along waveguide ≤ 15 K.
    d. Abort automatically if ∑(Interlock) ≠ 0; confirm red lamp “FAULT” activates.
16. **Emergency Shutdown Verification**
    - Trigger E-Stop ES-RF-02; expect RF off within 20 ms (capture oscilloscope CH1).
    - Confirm water flow persists 60 s post-shutdown, then ramps down.
17. **Data Integration & Documentation**
    - Push all SAT logs to OT historian (OSIsoft PI tag group GT20_RF_*).
    - Update as-built 3D model in Plant3D; export IFC rev P07.
    - Submit signed SAT report to DCC folder “Phase7/Completed.”

Deliverables

- Signed SAT Report (document ID GT20-SAT-RF-140G-P7-FINAL)
- Torque & Alignment Logs (WG-TQ-L-### series) compiled into PDF
- Waveguide Insertion & Test Data Spreadsheet (WG-IL-RUN-W72.xlsx)
- Updated As-Built 3D Model & IFC (rev P07)
- Safety Permit Closure Forms and JSA Attendance Sheet
- OT Network Integration Certification Ticket (OT-CERT-421)

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# OP-038 + OP-039 — Commission Argon Circulation Loop & Calibrate Quench Profiles; Integrate Sensing and Validate Diagnostics On-Site

**Responsible Roles:** Process Fluids & Thermal Systems Engineer (Argon) — H-ARG-17; Sensing, Instrumentation & Telemetry Lead — H-SENSE-19
**Task Timeline:** Phase 7 — RF/Drilling Subsystems Site Installation & Commissioning, Week 76 – 84
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How-To-Do-It: Step-by-Step Execution Manual

1. **Week 76 — Pre-Commissioning Documentation & Safety Lock-In**
   - Retrieve the latest P&ID set for the argon sweep/recovery system (drawing IDs ARG-P&ID-001 to ARG-P&ID-004, revision ≥ "F") and place printed copies in the commissioning binder labelled "ARGON LOOP — OP-038".
   - Issue a *Permit-to-Work* (PTW-ARG-76-01). Obtain signatures from Operations Supervisor, HSE Lead, H-ARG-17, and H-SENSE-19.
   - Verify that all pressure relief valves PRV-A01 to PRV-A04 are tagged, capped, and show a calibration sticker dated < 6 months.
   - Confirm oxygen-deficiency monitoring units O2-MON-01 & O2-MON-02 display 20.9 % ± 0.1 % when exposed to ambient air; document readings in form ARG-O2-BAS-76.
   - Lock-out/Tag-out electrical breakers CB-A-11 to CB-A-15 feeding heaters HTR-A1…HTR-A6 until Step 3.
2. **Week 76 — Mechanical Completion & Leak Test**
   - Install calibrated nitrogen bottle (200 bar, purity ≥99.99 %) at port N2-TEST-ARG.
   - Isolate argon loop with valves V-A-01 (inlet) & V-A-09 (return) CLOSED.
   - Pressurize system to 1.5 × design pressure (i.e., 15 bar g) via N2 bypass; monitor with pressure transmitters PT-A-01…PT-A-08.
   - Apply leak detection foam on all flanges FL-A-001…FL-A-032; hold pressure for 60 min. Record any bubble formation >5 mm diameter as FAIL; if detected, break flange, replace gasket with spiral-wound SS/graphite, torque to 48 N·m, and retest.
   - Depressurize through vent VN-A-01 to < 0.2 bar g and sign Form ARG-LEAK-76.
3. **Week 77 — Electrical, Instrument & Control Checkout**
   - Remove LOTO tags from breakers CB-A-11…CB-A-15.
   - Energize heaters HTR-A1…HTR-A6 sequentially; verify each draws 24.0 A ± 0.5 A at 480 VAC (measure with clamp meter FLUKE 376).
   - Connect each RTD (PT100, 4-wire) at points TT-A-01…TT-A-12 to PLC input cards IC-T-4W-16; perform ice-bath (0.0 °C) and boiling-water (100.0 °C) checks, accepting ±0.3 °C error range.
   - Flash firmware v3.12.7 on flow controllers FCV-A-01 & FCV-A-02. Set default PID constants: Proportional = 2.8, Integral = 0.6 s, Derivative = 0 s.
   - Establish Modbus-TCP link from argon PLC (IP 192.168.20.10) to Historian (XHQ node IP 192.168.10.25) on port 502; transmit taglist ARG_* at 1 s interval. Confirm receipt of at least 1200 consecutive packets without CRC error.
4. **Week 77 — Dry Argon Recirculation Trial (No Heat)**
   - Open argon supply cylinder rack (6 × 50 L, 200 bar, 99.999 % purity). Connect via pressure regulator REG-ARG-01 set to 6.0 bar g.
   - Open isolation valves V-A-01 & V-A-09. Start blower BL-A-01 at 30 Hz via VFD.
   - Ramp flow controllers to achieve 950 SLPM ±50 measured at FL-A-01. Maintain for 30 min; verify differential pressure ΔP (PT-A-05 – PT-A-04) ≤ 0.8 bar.
   - Abort if moisture sensor HUM-A-01 reads > 5 ppm H_2O; if triggered, evacuate loop using vacuum skid SK-VAC-02 to ≤ 20 mTorr, then repeat purge.
   - Log all PID trends; attach CSV export "ARG_DRYRUN_77.csv" to commissioning binder.
5. **Week 78 — Heat Soak & Cyclone/Filter Validation**
   - Enable heaters HTR-A1…HTR-A6 to target 720 °C ±10 °C outlet temperature (TT-A-03).
   - Hold set-point for 4 h; during this period, verify cyclone CY-A-01 discharges particulate >2 µm into bin BIN-A-01 at ≤10 mg/h rate (weigh bin before/after).
   - Record pressure drop across high-temperature metallic filter FLT-A-07 should stabilize at 25 kPa ±5 kPa. Initiate back-pulse cycle if ΔP > 35 kPa.
   - At hour 4, collect gas sample at port GP-A-01 into evacuated glass ampoule; send to lab for GC-MS analysis (required O_2 < 1 ppm, H_2O < 2 ppm).
6. **Week 79 — Quench Profile Calibration for Glass-Ceramic Liner**
   - Input initial quench profile into PLC function block QB-GLASS-CAL: Segment 1 — Cool from 720 °C to 470 °C at 3.5 °C/min; Segment 2 — Hold 470 °C for 60 min; Segment 3 — Cool to 120 °C at 1.2 °C/min, then natural ambient.
   - Place three sacrificial glass coupons (50 mm × 50 mm × 5 mm) in test chamber coupled to argon return header.
   - Execute automated quench; monitor RTDs TT-A-07…TT-A-09 every 2 s. Abort if any gradient exceeds 15 °C across 10 cm length.
   - After completion, retrieve coupons, perform XRD scan; verify α-cordierite peak intensity ≥ 80 % of reference standard GS-CORD-REF. If <80 %, adjust Segment 1 ramp to 3.0 °C/min and repeat cycle.
   - Finalize quench curve and save as recipe "LITHOLOOP_QP_v2.1" in PLC and Historian.
7. **Week 80 — Emergency Purge & O_2 Deficiency Interlock Verification**
   - Simulate oxygen ingress by injecting 5000 ppm O_2 (use calibrated span gas) at port SIM-O2-01 for 45 s.
   - Confirm O2-MON-01 trips at 500 ppm threshold and triggers PLC alarm ALM-ARG-O2-HI within 1.5 s.
   - Observe automated sequence: (1) close FCV-A-01, (2) open N2 purge valve PV-N2-01, (3) vent to flare via VNT-F-01. Total purge duration must reach 3 volume changes (calculated 840 SL for loop → 12 min at 2100 SLPM).
   - Reset system, verify monitors return to < 50 ppm O_2 before resuming normal operation.
8. **Week 81 – 82 — Sensing Hardware Installation**
   - Mount ceramic feedthrough CF-FO-01 at borehole wellhead flange W-FH-002; torque to 64 N·m.
   - Feed 2-channel single-mode fiber (SM-F-1550 nm, armored) 150 m downhole; mark depth every 10 m with heat-shrink label.
   - Terminate fiber to FC/APC connectors inside IP-67 junction box JB-FO-01; inspect end-face < −35 dB back-reflection using EXFO 400x scope.
   - Install acoustic collar sensor ACS-01 at 5 m depth; secure with high-temp Inconel clamp model IC-550 rated 900 °C.
   - Affix mm-wave reflectometry antenna MMW-ANT-01 flush with liner inside viewport VP-01; ensure VSWR < 1.4:1 at 94 GHz (measure with handheld VNA).
9. **Week 82 — Sensing & Diagnostics Configuration**
   - Power-up Luna ODiSI B interrogator (IP 192.168.21.40). Set gauge length 5 mm, sweep rate 10 Hz. Start baseline acquisition "FO_BASE_82.raw".
   - Configure acoustic telemetry unit Geochirp AC-200: sample rate 500 kHz, pulse width 2 ms, center frequency 150 kHz, power 18 W. Store file "AC_BASE_82.dat".
   - Calibrate mm-wave FMCW radar: frequency sweep 92–96 GHz, chirp duration 1 ms, 2048 points. Perform metallic target check at 1.000 m: verify peak returns at 1.000 ± 0.002 m.
   - Network-sync all three devices to grandmaster PTP clock (10 MHz ref) with offset < 100 ns; validate using PTP Monitor output.
10. **Week 83 — Integrated Dry Run & Data Synchronization**
    - Start argon flow at 950 SLPM and temperature 300 °C (heaters standby). Enable data logging on PLC ("ARG_SYNC_83"), Historian, ODiSI, Geochirp, and mm-wave radar simultaneously

using trigger code “SYNC-0001”.

- Inject controlled vibration using impact hammer at borehead (energy 1.2 J) exactly at T+180 s. Verify acoustic sensor detects event with SNR > 25 dB and timestamp delta < 2 ms vs PLC.
- Compare PLC flow perturbation vs distributed strain along fiber at 2 m interval; correlation coefficient must be ≥0.92.
- Generate combined dataset and run script “baseline_align.py” located in repo \\172.16.5.12\scripts; output “ARG_BASELINE_83.hdf5”.

11. **Week 84 — Wet Trial with Simulated Vitrification & Acceptance**
    - Prepare 20 kg glass-ceramic frit batch ID GC-VIT-02 in crucible CRU-02; inject into deposition chamber at 730 °C through feeder FEED-GC-01.
    - Activate quench recipe “LITHOLOOP_QP_v2.1”. Monitor mm-wave reflectometry; liner thickness growth rate must be 0.85 ± 0.05 mm/min. Abort if deviation > 0.1 mm/min persists for 120 s.
    - Track distributed temperature along fiber; maximum axial gradient ≤ 3 °C/cm in 0–20 m zone.
    - Upon completion, cool to < 80 °C, retrieve 3 × core samples (Ø 25 mm) at z = 2 m, 10 m, 18 m via micro-core tool. Perform SEM on cross-section; porosity target < 2 %.
    - Compile final commissioning report using template “FORM-KOM-FIN-v5”; attach all data files & lab analyses. Obtain sign-off by Chief Drilling Engineer and QA/QC Manager.

Deliverables

- Completed & signed Leak Test Form ARG-LEAK-76
- CSV Log “ARG_DRYRUN_77.csv”
- Gas Chromatography-MS Certificate (Week 78)
- XRD Analysis Report for coupon set GC-CORD-79
- PLC Recipe File “LITHOLOOP_QP_v2.1”
- Emergency Purge Test Record ALM-ARG-O2-HI-80
- Baseline Data Package “ARG_BASELINE_83.hdf5”
- SEM Porosity Report — Samples 2 m/10 m/18 m
- Final Commissioning Report FORM-KOM-FIN-v5 with all approvals

OP-040 + OP-042 — Beam Drilling with In-Situ Vitrification & Directional Steering

Responsible Roles : RF Drilling Systems Lead — H-RF-15; High-Temperature Materials & Downhole Mechanisms Engineer — H-HTM-16
Task Timeline : Phase 8 — Week 85 through Week 120

How-To-Do-It — Step-By-Step Action Plan

1. Pre-Operation System Qualification (Week 85, Days 1 - 7)

1. Retrieve latest borehole survey file (*/data/wellpath/WP_PHASE7_FINAL.dxf*) and load into the 3-D trajectory model (*LithoNav v4.2*).
2. Calculate initial steady-state beam power (P_{ss}, in kW) using:
   $$P_{ss} = \pi \cdot r_b^2 \cdot ROP \cdot \rho_r \cdot c_p \cdot (T_{glass} - T_{init}) \div \eta_{beam}$$
   Where:
   - r_b = 0.06 m (nominal beam radius).
   - ROP = 0.6 m hr^{-1} (limit from Phase 7 thermal budget).
   - ρ_r = 2800 kg m^{-3}.
   - c_p = 890 J kg^{-1} K^{-1}.
   - T_{glass} = 1475 °C.
   - T_{init} = 350 °C at current depth.
   - η_{beam} = 0.87 (lab-verified optical-to-thermal efficiency).
3. Set beam launcher RF generator to $P_{start} = 0.80 \cdot P_{ss}$. Lock limit with hard interlock parameter *RF_PWR_MAX = 1.10 · P_{ss}*.
4. Flush downhole beam path with 600 SLPM ultra-high-purity argon for 30 min to displace residual CO_2. Confirm oxygen ≤ 3 ppm via inline zirconia sensor.
5. Pressure-test the ceramic hydraulic lines to 52 MPa for 10 min. Accept only if ΔP≤0.2 MPa.
6. Calibrate passive reflector gimbal: send 5 mm deflection command in +Y, verify return laser encoder reports 5 ± 0.05 mm. Repeat for –Y,+X,–X.
7. Run cold reflectometry sweep (frequency 50–110 GHz) to baseline liner surface; save file name format *REF_BASE_W85D7.mat.*
8. Complete “GO” check on the Phase 8 Safety Checklist sheet SC-8-001. Both responsible roles sign digital log.

2. Beam Ignition & Melt-Front Stabilisation (Week 85, Day 8)

1. Enable RF arc-free ignition protocol: ramp power from 0 → P_{start} in 180 s with 2 kW s^{-1} gradient.
2. Monitor axial thermocouple string (T1–T6). Confirm melt-front temperature reaches 1450 °C and stabilises at 1475 ± 15 °C within 600 s.
3. Start argon quench pulses: duty cycle 6 s ON (900 SLPM) / 24 s OFF via valve array VA-6. Confirm liner outer surface cools to 1090–1120 °C after each ON period.
4. If temperature overshoot > +20 °C, trigger *RUNAWAY_HEAT* interlock — automatic power reduction 15 % and extend argon ON to 12 s for three cycles.
5. Continue stabilisation for 30 min until liner thickness sensor (LF-118) reads 5.0 ± 0.3 mm.

3. Routine Penetration & In-Situ Liner Growth (Week 85, Day 9 — Week 120, Day 14)

3.1 Daily Startup (05:30 local-site time)

1. Load previous day’s end-of-shift log (*/logs/Phase8/ShiftLog_W##_D##.xml*) into supervisory HMI.
2. Perform 5-min no-load RF generator warm-up at 15 % P_{ss}.
3. Execute “Hot Start” checklist HS-8-03: verify liner temperature ≥ 800 °C at termination point; confirm argon dew point ≤ –75 °C.

3.2 Continuous Drilling Loop (automated PLC cycle, operator oversight every 15 min)

1. Advance beam focus stage 3.0 mm downward every 180 s.
2. Maintain RF power at dynamic set-point:
   $$P(t) = P_{ss} \cdot (1 + 0.002 \cdot \Delta T/°C + 0.005 \cdot \Delta ROP/0.1\ m\ hr^{-1})$$
   Update ΔT and ΔROP each 30 s.
3. Pulse argon quench as follows:
   - Normal mode: 6 s ON / 24 s OFF.

- High-heat zone (> 1650 °C formation): 8 s ON / 20 s OFF.
- Cool-down mode (ROP halt): 15 s ON / 15 s OFF.

4. Real-time liner thickness algorithm:
   $t_{liner}(t) = k_1 \cdot \int[0\to t]\,(Q_{argon}(\tau) \cdot \eta_{quench})\,d\tau - k_2 \cdot \int[0\to t]\,(ROP(\tau))\,d\tau$
   Maintain 5 mm ≤ t_{liner} ≤ 30 mm. If t_{liner} < 5 mm or > 30 mm for 120 s, auto-halt ROP and alert engineer.

3.3 Directional Steering & Trajectory Corrections

1. Every 10 m drilled, send 12-ping acoustic ranging burst (24 kHz, 10 ms each) and record travel time; convert to borehole displacement in *LithoNav v4.2*.
2. Simultaneously fire mm-wave diagnostic pulse train (94 GHz, 1 µs width, 200 pulses) to scan reflector face orientation.
3. Compare measured curvature (κ_{meas}) and azimuth (α_{meas}) with target (κ_{target}, α_{target}) from planned path. Compute corrections:
   $\Delta\theta = \arctan[(\kappa_{meas} - \kappa_{target}) \cdot L/2]$
   $\Delta\varphi = \alpha_{meas} - \alpha_{target}$
4. If |Δθ| > 0.4° or |Δφ| > 0.4°, actuate ceramic hydraulic gimbal:
   - Command stream: `GIMBAL_SET Δθ Δφ`.
   - Stroke rate: $0.05\ mm\ s^{-1}$ to limit dynamic stress.
   - Verify actuation complete when laser encoder difference ≤ 0.02 mm from target.
5. Log all steering commands to */data/steer/SC_W##_D##.csv*.

3.4 In-Process Quality Assurance

1. Every 6 h perform reflectometry sweep (50–110 GHz, 1024 points). Acceptable liner reflectivity R ≥ 0.85 across 65–95 GHz. If R<0.85 at any band, initiate “Re-melt” routine: raise P(t) by 10 % for 4 min, then resume normal.
2. Fiber-optic FBG transient analysis: run auto-correlation routine each 1 h; liner strain must stay in –15 MPa ≤ σ ≤ –5 MPa residual compression.
3. Penetration rate watch: ROP_{inst} must be $0.5–0.7\ m\ hr^{-1}$. If

4. Contingency — Stall Recovery Protocol

1. Stop beam advance immediately. Hold reflector position fixed.
2. Increase RF power to $P_{boost} = 1.15 \cdot P_{ss}$ for 120 s.
3. Simultaneously switch argon mode to continuous 900 SLPM for 60 s, then revert to normal duty cycle.
4. If melt-front fails to re-establish within 5 min (T_{melt} < 1450 °C), shut down RF, cool liner to 400 °C, retract 1.0 m, and restart standard ignition (Section 2).
5. Log event as “STALL_RECOV” with cause code (thermal, mechanical, unknown) and corrective action.

5. Weekly Integrated Review (Every Sunday 18:00)

1. Export cumulative drilling metrics using script *exportMetrics.py --week ##*.
2. Compare actual depth vs. plan: depth error must be < ±35 cm.
3. Graph liner thickness distribution over last 150 m; verify 5–30 mm band.
4. Approve continuation or initiate corrective design review if any metric exceeds tolerance.

6. Phase Completion & Handover (Week 120, Days 12 - 14)

1. Cut RF power to 0 over 600 s controlled ramp.
2. Initiate extended argon cool-down: 600 SLPM until liner temperature ≤ 300 °C.
3. Run final reflectometry sweep; save as *REF_FINAL_P8.mat*.
4. Execute caliper drone pass: allowable ovality ≤ 0.8 %. If exceeded, flag for carbon-silica infill patch.
5. Seal bore with ceramic end-plug EP-45 using hydraulic press at 28 MPa for 30 min.
6. Compile Phase 8 Close-out Report (template *P8_REPORT.docx*) attaching all data files.
7. Obtain electronic signatures from both responsible roles and upload to project vault.

Deliverables

- Daily Shift Logs (Weeks 85-120) — XML & PDF exports.
- Steering Command History — CSV files.
- Reflectometry Data Sets — MAT files (baseline, 6-hour intervals, final).
- Liner Thickness & Strain Dashboards — PNG images & underlying CSV.
- Weekly Integrated Review Slides — PPTX.
- Phase 8 Close-out Report — Signed DOCX & PDF.
- Handover Certificate for Phase 9 — Signed.

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OP-041 + OP-043 — Control Meta-Casing Co-Deposition & Conduct Periodic Ceramic Pigging/Liner Conditioning

Responsible Roles: Deposition & Metallurgy Process Engineer — H-META-18; QA/NDE & Test Engineering Lead — H-QA-22 | **Timeline:** Phase 8 — Beam Drilling, In-Situ Lining, and Quality Assurance (Week 88 – 122)

Step-by-Step Execution Manual

0. Global Safety & Environmental Controls (Applies to All Weeks)

1. Verify all personnel have current confined-space, high-temperature, and inert-gas work permits.
2. Lock-out/Tag-out the mm-wave beam generator before any liner entry or pig insertion.
3. Activate dual redundant O_2 sensors; confirm **< 1 vol % O_2** in borehole annulus before Argon purge is deemed acceptable.
4. Confirm interlock logic in the PLC: *Beam ON* automatically sets *Pig Clamp CLOSED*; *Pig Clamp OPEN* forces *Beam OFF*.
5. Maintain Argon flow at 25 SLPM with a 0.01 MPa over-pressure to prevent air ingress.

6. Stage HEPA-rated vacuum cart and magnetic retrieval tooling within 5 m of borehole collar for immediate debris collection.

1. Pre-Operation Preparation (Week 88 – 90)

1. Review latest **mm-wave standing-wave diagnostic logs** and identify zones requiring thickness biasing (1–2 mm).
2. Calibrate **Sacrificial Wire Feed Module #2**:
   - Install 1.2 mm Ø refractory molybdenum wire spool (lot #MO-4521-K).
   - Run the automated feed-rate calibration routine: target 0.4 – 1.8 g·min^{-1}.
3. Confirm reflectometry probes are zero-offset at ambient: *Reference Reflection Coefficient Γ_{ref} = 0.025 ± 0.002*.
4. Inspect ceramic pig assemblies:
   - Select pig body #CP-07 (tether length 800 m) and abrasive pad set #AP-F180-V2.
   - Torque check all pad retaining screws to 6 N·m (verified by digital torque screwdriver).
5. Generate formal Job Safety Analysis (JSA-OP041-043-RevC) and obtain sign-off from HSE officer.

2. Meta-Casing Co-Deposition Setup (Week 91 – 100)

1. Power-up the axial scanner gantry and position the beam nozzle at Depth = 0 m (collar).
2. Input the **Feed-Rate Control Formula** into the PLC custom block *FR_CTRL_01* exactly as follows:
   F_W (g·min^{-1}) = k_p·(ΔΓ) + k_i·∫(ΔΓ)dt + k_d·d(ΔΓ)/dt
   where:
   – k_p = 28.0, k_i = 3.2, k_d = 0.75
   – ΔΓ = Γ_{target} − $\Gamma_{measured}$
   – Γ_{target} = function(depth): 0.060 for 100–500 µm zones, 0.135 for 1–2 mm zones
3. Load the axial deposition schedule CSV (*DEPTH_BIAS_W88-122.csv*) into supervisory HMI:

Depth Interval (m)	Target Thickness (µm)	Override Feed Multiplier
0 – 1200	500	1.00
1200 – 1350	1500	2.20
1350 – 3000	350	0.85

4. Perform a dry-run pass (beam power 0 kW, wire feed disabled) to validate linear actuator motion; confirm no vibration >0.3 g RMS.
5. Record baseline fiber thermal signatures at each 50 m mark (File prefix FTS-BL-W91).

3. Continuous Co-Deposition Execution (Week 101 – 110)

1. Set beam power to 280 kW and enable closed-loop temperature limit at 1650 °C (sensed by on-axis pyrometer).
2. Start wire feed at F_W = 0.6 g·min^{-1}; allow PID block to auto-adjust per formula in Step 2.2.
3. Advance deposition head at 0.5 m·min^{-1} while continuously logging:
   - Depth (encoder D-axis)
   - $\Gamma_{measured}$ (reflectometer)
   - F_W (actual)
   - Surface temperature

   Log as binary file *DEPLOG-W101-*.bin* every 10 s.
4. When entering high-thickness zone 1200-1350 m:
   - Trigger PLC bit *OVERRIDE_ON*.
   - Verify feed multiplier applied: $F_{W,new}$ ≈ 1.32 g·min^{-1}.
5. If ΔΓ persists > 0.015 for > 20 s:
   - Automatically reduce travel speed to 0.35 m·min^{-1}.
   - Flag “Remediation Pass Required” in real-time dashboard.
6. At end of each 8-hour shift:
   - Pause deposition, retract head to safe depth −5 m.
   - Download shift log and archive to server path `\\\\NDE-ARCHIVE\\OP041\\SHIFT_LOGS\\`.
   - Perform thickness spot-check with ultrasound UT-L60 probe at collar and at depths 500 m, 1000 m.

4. Liner Conditioning – Ceramic Pigging (Week 111 – 118)

1. Cooldown period: allow borehole inner wall to drop below 230 °C (monitored by fiber optics). Maintain Argon purge.
2. Attach ceramic pig #CP-07 to winch drum on Rig Floor; verify tether shackles torqued to 14 N·m.
3. Enable “Pig Clamp CLOSED” interlock; confirm beam generator de-energized (*Beam_Status = 0*).
4. Lower pig at 0.6 m·s^{-1} until Depth = target bottom (3000 m). Record descent tension; abort if tension change > +15 N indicates obstruction.
5. Activate abrasive pad rotation (500 RPM, clockwise) via tethered power conductors.
6. Retrieve pig at 0.3 m·s^{-1} while simultaneously rotating counter-clockwise (500 RPM). Expected material removal rate: 12 µm per pass.
7. Upon retrieval, place pig on containment tarp; perform visual check for missing pad segments or metallic debris.
8. Deploy borescope to 30 m depth; verify absence of loose particles.
9. If particles > 0.2 mm observed, run HEPA vacuum wand to suction remaining debris.
10. Log pigging run as *PIG-RUN-W112-01* with the following mandatory fields:
    - Total abrasive pad wear (measure thickness reduction with calipers, mm).
    - Average retrieval tension (N).
    - Intervals requiring repeated pass (depth markers ±1 m).
11. Repeat Steps 4.2 – 4.10 until borescope confirms Ra ≤ 1.2 µm over ≥ 95% of length.

5. Post-Process QA, Documentation & Handover (Week 119 – 122)

1. Perform full-length mm-wave continuity scan; export CSV thickness map (*THKMAP-FINAL-W119.csv*).
2. Run helium leak test at 0.6 MPa for 30 min. Acceptable leak rate < 1×10^{-6} mbar·L·s^{-1}.
3. Pressure integrity hydro-test:
   - Fill annulus with DI water to 25 MPa.
   - Hold for 2 h; record pressure drop. Acceptance criterion: ΔP ≤ 0.1 MPa.
4. Create final QA dossier “OP041-043-QA-PACK-RevB.zip” including:
   - Deposition logs, PID settings snapshot, thickness map.
   - Pigging run sheets and borescope images.
   - Leak and hydro-test certificates.
5. Review dossier jointly with Project Chief Engineer; obtain formal sign-off via DocuSign route *GEOTHERM-SIGN-FLOW-L8*.
6. Archive dossier to `\\\\PROJECT-VAULT\\GEO20\\LITHOLOOP25\\QA\\` and email confirmation to stakeholders list LL25-DIST-QA-ENG.

Deliverables

- DEPTH_BIAS_W88-122.csv (loaded schedule)
- Shift deposition binary logs (DEPLOG-W101-*.bin)
- Pigging run logs (PIG-RUN-W112-##) and borescope photo set
- Final thickness map (THKMAP-FINAL-W119.csv)
- Helium leak & hydro-test certificates (PDF)
- Consolidated QA dossier (OP041-043-QA-PACK-RevB.zip) signed-off

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# OP-044 — Perform Integrity Survey at Depth & Execute Remediation if Needed

**Responsible Role:** Sensing, Instrumentation & Telemetry Lead — H-SENSE-19 | **Task Timeline:** Phase 8 — Week 120 – 126

## How-To-Do-It: Step-by-Step Action Plan

### 1. Pre-Execution Setup (Week 120, Day 1)

1. Mobilize personnel: 1 Lead Engineer (you), 2 Instrumentation Techs, 1 Data Analyst, 1 Downhole Tool Operator, 1 Safety Officer.
2. Verify calibration certificates (≤ 30 days old) for:
   - Millimeter-wave reflectometry tool (60 – 300 GHz, phase accuracy ±0.5°).
   - Fiber-optic DTS/TTT (spatial resolution 0.25 m, temp accuracy ±0.1 °C).
   - Acoustic ranging sonde (2 – 8 kHz sweep, range resolution 1 mm).
   - Hydraulic packer pressure test assembly (rated 200 bar, accuracy ±0.1 bar).
3. Load surface DAQ rack with 10 TB RAID array; confirm real-time fiber (10 GbE) and coax (18 GHz) links are operational.
4. Import the latest “LithoLoop 25 – Bore A” digital-twin model to the Control PC (version LL25_DT_A_119.json).
5. Hold Job Safety Analysis (JSA); record signatures of all crew in the shift log.

### 2. Integrity Survey Procedure (Week 120, Days 2-3)

#### 2.1 Millimeter-Wave Reflectometry Pass

1. Connect tool to 7/16-DIN armored coaxial logging cable.
2. Zero the depth encoder; reference 0 m at wellhead rotary table.
3. Program tool: frequency sweep 60–300 GHz, step 1 GHz, sample rate 2 kHz, average = 8.
4. Run-in-hole to TD (Total Depth) = 42 600 m MD at 0.8 m/s.
5. Log on pull-out-of-hole (POOH) at 0.5 m/s; maintain cable tension 5 kN ± 0.5 kN.
6. Store raw $S_{11}$ and phase data in “MWR_RAW_[timestamp].bin”.
7. Post-process thickness per depth using:

```
thickness t(m) = (Δφ × λ0) ÷ (4πn)
```

where Δφ = phase shift (radians), $\lambda_0$ = free-space wavelength (m), n = refractive index (= 1.45 for vitrified liner).

#### 2.2 Fiber-Optic Thermal Transient Test (TTT)

1. Insert 50 µm multi-mode fiber on slickline to TD; terminate with reflective cap.
2. Initiate baseline DTS scan (10 s integration, 0.25 m spacing).
3. Inject 50 °C potable water slug (volume = 20 m³) for 10 min at 0.033 m³/s.
4. Record temperature rise and decay for 60 min.
5. Compute local liner thickness via:

```
t(m) = √(α × t_peak / π)
```

where $\alpha = 1.4 \times 10^{-6}$ m²/s (vitrified silica), t_{peak} = time to peak (s).

2.3 Acoustic Meta-Casing Survey

1. Deploy acoustic sonde on fiber-optic wireline.
2. Fire swept-frequency pulse every 1 m while descending at 1 m/s.
3. Capture reflection-time Δt; convert to inner radius using

```
radius r(m) = (v × Δt) ÷ 2
```
```

where v = 4 000 m/s (sound speed in silica).
4. Flag discontinuities where reflection amplitude increase > 6 dB or radius deviation > 1 mm.

2.4 Interval Pressure Hold Tests

1. At depths 0 m, 10 000 m, 20 000 m, 30 000 m, 40 000 m:
   a. Set inflatable packers straddling 10 m interval.
   b. Pressurize to 150 bar (1.5 × design) using clean CO_2.
   c. Hold 30 min; record pressure decay every 30 s.
   d. Acceptance: ΔP ≤ 0.75 bar (0.5 %).

3. Data Processing & Acceptance Evaluation (Week 120, Day 4)

1. Merge mm-wave, TTT, acoustic and pressure results using depth-indexed join (resolution = 0.1 m).
2. Generate “Integrity_Map_v8.svg” showing thickness (color), roughness (line), and detected defects (icons).
3. Apply acceptance thresholds:
   - Through-wall defects: none permitted.
   - Liner thickness ≥ 5 mm everywhere.
   - Surface roughness RMS ≤ 0.2 mm.
   - Meta-casing end-to-end DC resistance ≤ 1 Ω.
4. Flag any non-conformances with defect ID = “DEF-###” where ### increments starting 001.

4. Remediation Workflow (Week 121 – 124) — Execute Only if Non-Conformances Exist

Defect Severity	Criteria	Remediation Method	Tool/Parameters
Minor	Thickness loss < 10 %; roughness 0.2–0.5 mm	Targeted Pigging	Abrasive pig, diamond grit 0.1 mm, CO_2 10 m/s, 3 passes
Moderate	Thickness loss 10 – 40 %; isolated pinholes (no breach)	Local Re-melt/Re-quench	Induction coil 4 kW, 1 200 °C for 5 min, CO_2 quench 200 kg/s
Severe	Through-wall or meta-casing break	Additional Deposition Pass	Fused silica slurry 65 wt %, 1 L/min, traverse 0.2 m/min

1. For each flagged DEF-###:
   a. Lock out wellhead; bleed pressure to 0 bar.
   b. Run centralizer-mounted laser depth verifier; confirm exact MD to ±1 mm.
   c. Select remediation per severity table above.
   d. Execute remediation; log tool parameters and time stamps in “REM-DEF-###.csv”.
   e. Allow 12 h thermal stabilization.
   f. Perform immediate spot re-survey (mm-wave + acoustic) over ±5 m of zone.
   g. If criteria still unmet, repeat remediation maximum of 2 additional cycles; if still failing, escalate to Project Integrity Manager.

5. Post-Remediation Verification (Week 125)

1. Repeat full mm-wave and acoustic surveys for entire borehole (Sections 2.1 & 2.3) at same logging parameters.
2. Confirm all previous DEF-### entries are cleared or re-classified to “CLOSED”.
3. Perform final meta-casing continuity test: inject 10 A DC at surface, record return current ≥ 9.95 A (→ R ≤ 0.5 Ω).
4. Obtain Safety Officer sign-off on “Pressure Barrier Verification Form PBF-044”.

6. Documentation & Closeout (Week 126)

1. Upload final data packages to GeoTherm20 SharePoint path “/LithoLoop25/BoreA/Phase8/Integrity/Week126”.
2. Update digital twin:
   - Replace integrity layer with “Integrity_Map_v9.svg”.
   - Push JSON delta files for thickness and roughness arrays.
3. Revise risk register entry “RR-LL25-BoreA-Integrity” status → “GREEN”.
4. Create QA Certificate “QA-OP-044-V1.pdf”; include signatures: Lead Engineer, QA Manager, Project Director.
5. Issue “Ready-for-Inner-Return-Tube” notice to Drilling Lead.

Deliverables

- Integrity Survey Report ISR-044-V1.pdf
- Integrity_Map_v9.svg & associated raw data folders
- Remediation Action Logs “REM-DEF-###.csv” (one per defect)
- Pressure Barrier Verification Form PBF-044.pdf
- QA Certificate QA-OP-044-V1.pdf
- Updated Digital Twin JSON & Risk Register entry

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## OP-045 + OP-046 — Convert Waveguide to Inner Return Tube & Install Near-Surface Loop Hardware and Safety Systems

**Responsible Roles: High-Temperature Materials & Downhole Mechanisms Engineer — H-HTM-16; Site Installation & Commissioning Manager — H-SITE-23**
**Task Timeline: Phase 9 – Loop Conversion & Pressure Qualification, Week 124 – 138**
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1 — Scope Overview

This manual details every action required to:

- Convert the in-situ millimeter-waveguide string into a fully qualified inner return tube for the LithoLoop 25 thermosiphon.
- Equip the near-surface loop (0–150 m MD) with flow-control, safety, and instrumentation hardware rated for 60–120 MPa and −10 °C to 650 °C gradients.
- Update engineering documentation and verify readiness for future hot-loop operation.

2 — Detailed Action Plan

1. **Pre-Mobilization (Week 124, Day 1–3)**
    1. H-HTM-16 emails purchase orders to pre-qualified suppliers for:
        - 316H-SS expansion bellows (Ø 90 mm, ΔL = ±125 mm, 120 MPa rating) with ceramic baffle inserts.
        - Aerogel-lined insulation sleeves, 2 m length, 15 mm thickness, emissivity ≤ 0.05.
        - Class-V, API 6D high-temperature ball valves, DN80, pressure rating 140 MPa, stem leak rate ≤ 5×10^{-8} kg/s.
        - ASME VIII certified pressure relief valves (PRVs) set at 125 MPa, Cv ≥ 16.
        - Electro-pneumatic flow restrictors with Cv adjustable 0.2–2.0, body Inconel 625.
        - SCADA-ready instrumentation packages: dual RTDs, quad pressure transmitters, flow meters (Coriolis DN80), LTE-OT gateways.
    2. H-SITE-23 secures work permits, isolation certificates, and updates the site EHS register to include "Ultra-High Pressure CO_2 Work Class-A".
    3. Engineering Services drafts and issues Rev C P&IDs (document ID LL25-PID-N1-C) to all stakeholders via the EDMS.

2. **Site Preparation (Week 124, Day 4–7)**
    1. Set up a controlled laydown area 20 m × 30 m adjacent to the well cellar with anti-static mats and overhead weather canopy.
    2. Install a 200 kN rated pipe handling crane; perform load-test to 125 kN with calibrated test weight; record certificate ID CRN-200-TQ-W124.
    3. Connect temporary nitrogen purge skid (900 Nm^3/hr capacity) and verify O_2 < 2 % at outlet using calibrated gas analyser SN-GAS-7712.

3. **Isolate Existing Waveguide String (Week 125, Day 1–2)**
    1. Shut down millimeter-wave generator; lockout/tagout main power per EHS-PRO-07.
    2. Purge waveguide with dry nitrogen at 0.5 MPa until dew-point ≤ -60 °C for 30 min.
    3. Remove upper quick-disconnect; install blind flange rated 140 MPa; torque bolts cross-pattern to 460 N·m using calibrated wrench ID TW-09-021.

4. **Lock & Seal Waveguide Joints (Week 125, Day 3–7)**
    1. Rig downhole slickline with magnetic imaging tool MIT-4K to map joint positions every 12 m; record depth log to 30 km MD.
    2. Set slickline torque-lock collars:
        1. At each threaded joint location, deploy collar with internal serrations.
        2. Apply 80 N·m torque via slickline tool to align anti-rotation dogs.
        3. Inject 25 mL of high-temp anaerobic sealant Loctite HN-272 through port until backflow observed.
        4. UV-cure the sealant with 365 nm lamp for 2 min.
    3. Repeat for all 2,500 joints; verify torque reading ±2 N·m tolerance.
    4. Log operations in real-time to e-Workbook "LL25-Waveguide-Lock-W125".

5. **Install Expansion Bellows (Week 126, Day 1–6)**
    1. Pick-up string section 0–600 m MD using pipe handler.
    2. At 300 m and 600 m MD, break waveguide at mid-joint with hydraulic tong (set 400 kN·m).
    3. Install bellows assembly:
        1. Position bellows; apply graphite gasket both ends (thickness 1.5 mm).
        2. Make-up connections to 650 N·m torque.
        3. Insert supplied ceramic turbulence baffle until secure clip locks (audible click).
        4. Laser scan internal bore; ensure eccentricity ≤ 0.3 mm.
    4. Repeat steps at every additional 300–600 m interval to TD; total bellows required: floor((30,000 m)/450 m) = 67 units.

6. **Add Insulation Sleeves (Week 126, Day 7 – Week 127, Day 3)**
    1. Clean pipe OD with acetone; dry wipe.
    2. Slide aerogel sleeve over waveguide between surface flange and 2,000 m MD.
    3. Secure sleeves with Inconel tie-wires every 0.5 m; torque twist to 4 N·m.
    4. Spot-check thermal emissivity using handheld IR device; acceptance ≤ 0.06.

7. **Install Near-Surface Flow & Safety Hardware (Week 127, Day 4 – Week 128, Day 5)**
    1. Cut back surface spool 3 m above cellar to horizontal header height 1.2 m.
    2. Weld Schedule-160 316H-SS "T" spool piece (WPS LL25-W-316H-04). Pre-heat 150 °C, inter-pass ≤ 200 °C, PWHT 600 °C for 1 hr.
    3. Install components in the following sequence (flow direction: downhole → surface header):
        1. Class-V ball valve, DN80, position 100 mm from weld. Orient actuator N-S.
        2. Electro-pneumatic flow restrictor. Set initial Cv = 0.6 via HART communicator.
        3. Pressure relief valve on side branch with 45° sweepolet; connect to vent header leading to flare pit.
        4. Full-loop depressurization valve (3″ gate) tied to 140 m³ blowdown vessel; function-test to fully open < 3 s.
    4. Hydrostatically test spool up to 150 MPa for 30 min; acceptable leak ≤ 0.1 L/min.
    5. Stencil paint flow arrows and tag numbers (per TAG-REG-LL25) with ceramic ink.

8. **Instrumentation & OT Integration (Week 129, Day 1–5)**
    1. Mount dual-redundant RTDs (Class AA, 4-wire) at 0 m, 50 m, 100 m, 150 m depths inside thermowells. Fill wells with Molykote 44 high-temp grease.
    2. Install quad pressure transmitters (0–150 MPa, 4–20 mA, HART) in ring manifold; allocate channels PT-01 … PT-04.
    3. Clamp Coriolis flow meter (DN80) 1 m downstream of flow restrictor; zero-calibrate with nitrogen flow 0 kg/h.
    4. Run duplex single-mode fiber in SS conduit to OT rack; terminate with LC connectors.
    5. Configure LTE-OT gateways (IP 10.45.9.80/28) and publish OPC-UA tags "Loop_Press", "Loop_Flow", "Loop_T_in", "Loop_T_out".

9. **Pressure Qualification Test (Week 129, Day 6 – Week 130, Day 3)**
    1. Close all valves except nitrogen fill.
    2. Fill loop with de-aerated water at 0.5 MPa; bleed air until PT-01 steady at 0.48–0.52 MPa.
    3. Raise pressure in 10 MPa increments every 20 min up to 130 MPa; record readings at each step.
    4. Hold 130 MPa for 2 hr; acceptable criteria:
        - Pressure drop < 0.5 MPa after temperature compensation.
        - No external leakage visual or by dye penetrant (Report DP-LL25-PQ-W130).
    5. Depressurize through blowdown vessel at ≤ 5 MPa/min; recover > 95 % water volume.
    6. Issue signed pressure certificate (FORM-PQ-HTM-16-W130-A).

10. **Documentation & Handover (Week 130, Day 4 – Week 138, Day 1)**
    1. Update P&IDs to Rev D reflecting as-built tag numbers and flow paths.
    2. Revise Control Narrative CN-LL25-V4:
        - Insert new sequence “Pressure Relief — High-High @ 118 MPa triggers PRV open 100 %”.
        - Add closed-loop start-up interlock “Flow > 100 kg/s before Heater Enable”.
    3. Compile Mechanical Completion Package MCP-OP-045-046 including:
        - All NDE reports (UT, MPI, DP).
        - Material certificates traceability matrix.
        - Valve factory acceptance test (FAT) records.
        - Signed pressure certificate.
    4. Conduct Joint Inspection with Authority Having Jurisdiction (AHJ); close punch-list items ≤ 14 days.
    5. Release handover memo to Operations (DCC No. LL25-HOV-P9-138) and archive in EDMS.

3 — Reference Torque Values

Component	Size	Material	Torque (N·m)
Waveguide Joint Collar	Ø 90 mm	Inconel 718	80
Expansion Bellows Flange	DN80	316H-SS	650
Surface Blind Flange	Class 2500	316H-SS	460
Insulation Sleeve Tie-Wire	Ø 1.6 mm	Inconel 625	4

Deliverables

- MCP-OP-045-046 Mechanical Completion Package (signed, formatted PDF)
- Pressure Test Certificate FORM-PQ-HTM-16-W130-A
- Revised P&IDs Rev D – Documents LL25-PID-N1-D & LL25-PID-N2-D
- Updated Control Narrative CN-LL25-V4
- Instrument Configuration Backup (XML export) & OPC-UA Tag List
- AHJ Punch-List Close-out Memo & Handover Memo LL25-HOV-P9-138

```

## OP-047 — Conduct Inert Gas Integrity Pressure Test; Fix Leaks and Re-Qualify

**Responsible Role:** QA/NDE & Test Engineering Lead — H-QA-22 | **Task Timeline:** Phase 9 – Loop Conversion & Pressure Qualification, Week 139 – 144

## 1. Overview

This manual defines every action required to verify mechanical integrity of the LithoLoop 25 coaxial circuit by staged inert-gas pressurisation (60 → 120 MPa), leak detection, remediation, and re-qualification prior to super-critical $CO_2$ charging.

## 2. Required Materials, Instrumentation & Calibration

- $N_2$ (99.999 % purity) — 350 bar tube-trailers, total volume > 1.2 × loop free volume.
- High-pressure helium leak-sniffer (≤ *1 × 10$^{-6}$ mbar L s$^{-1}$ detection limit*).
- Eight acoustic emission (AE) sensors, bandwidth 50 kHz – 400 kHz, sensitivity ≥ 55 dB V µbar$^{-1}$.
- Two coriolis mass-flow meters (0–5 kg s$^{-1}$, ±0.1 %).
- Three quartz pressure transducers (0–150 MPa, ±0.05 %).
- Temperature compensation RTDs (Pt-100, class A), one per pressure sensor.
- Data acquisition rack (16-bit, 1 kS s$^{-1}$ per channel, ISO-17025 calibrated).
- Relief valve bench-tester (0–150 MPa range, ±0.5 % setpoint accuracy).
- Seal-replacement tooling, spare Grafoil gaskets, Swagelok 1 ¼″ SS-316 fittings, torque wrenches pre-calibrated to 320 N m.
- Personal Protective Equipment: EN 136 full-face respirators (OEL $N_2$), S3 footwear, cut-level 5 gloves, 38 dB ear defenders.

## 3. Step-by-Step Procedure (Week 139 – 144)

1. **Week 139 — Pre-Test Configuration**
    1. Issue *Permit-to-Test #OP-047-139-01*; obtain signatures from HSE Manager, Operations Lead, and Test Engineering Lead.
    2. Isolate LithoLoop 25 from external piping by closing and padlocking upstream and downstream Class-600 wedge gate valves; tag with red “Pressure Test” tags.
    3. Vent residual $CO_2$: connect 1 ½″ purge line to flare, open purge valve PV-101, ensure $CO_2$ detector reads < 1000 ppm at stack; close PV-101.
    4. Connect two $N_2$ trailers in parallel:
        a. Fit 1 ¼″ Swagelok connector, torque to 320 N m.
        b. Install non-return valve (cracking pressure 0.1 MPa).
```

5. Calibrate all instrumentation immediately before use:
    - Pressure transducers: compare against traceable dead-weight tester at 0, 30, 60, 90, 120, 150 MPa; record deviation < 0.05 % F.S.
    - AE sensors: inject Hsu-Nielsen pencil lead breaks, verify 60 dB peak within 2 dB across sensors.
    - Coriolis meters: gravimetric calibration using 200 kg water; error ≤ 0.1 %.
6. Bench-test relief valves RV-301 & RV-302:
    a. Setpoint should equal 135 MPa; accept if 135 ± 2.7 MPa (±2 %).
    b. Seal and reinstall valves, apply 45 N m on ¾″ flange studs.
7. Upload all calibration certificates to EDMS folder *GT20/Loop25/QA/Phase9/OP-047*.

2. **Week 140 Day 1 — System Purge with N_2**
    1. Open loop bottom drain DV-201; connect to flare.
    2. Start N_2 flow at 100 kg h^{-1} through inlet IV-101; monitor O_2 ppm at vent until < 100 ppm.
    3. Close DV-201, set loop to sealed state; confirm pressure at 0.2 MPa (buffer pressure).
3. **Week 140 Day 2–3 — Incremental Pressurisation & Holds**
    1. Engage automatic pressurisation controller (PID gain 2.0, integral 1.5 s, derivative 0 s) connected to trailer regulators.
    2. Execute four pressure stages, maintaining ramp rate ≤ 2 MPa min^{-1}:

Stage	Pressure Range (MPa)	Hold Period	Required Stable Criteria
1	0 → 20	30 min	ΔP < 0.05 MPa over last 10 min
2	20 → 60	1 h	ΔP < 0.05 MPa over last 20 min
3	60 → 90	2 h	ΔP < 0.05 MPa over last 30 min
4	90 → 120	8 h	ΔP < 0.05 MPa over last 60 min

    3. At each hold:
        a. Compute instantaneous leak rate using mass-balance:
        $$LeakRate\ (kg\ h^{-1}) = [(m_{start} - m_{end}) - \Sigma m_{sampled}] / t_{hold}$$
        Accept if *LeakRate ≤ 0.02 % loop mass per h.*
        b. Calculate pressure decay percentage:
        $$PressureDecay\ \% = [(P_{start} - P_{end})/P_{start}] \times 100$$
        Accept if *PressureDecay ≤ 0.1 % per h.*
        c. Run AE acquisition for entire hold; flag channels where *Peak_dB ≥ Background_dB + 5 dB*.
4. **Week 141 — Leak Evaluation & Localization**
    1. If any hold fails criteria, perform the following immediately:
        a. Stabilise pressure at failed stage level; do not depressurise.
        b. Attach AE triangulation software; derive leak coordinate along loop with ≤ 2 m uncertainty using sensor arrival-time difference.
        c. Depressurise loop to 10 MPa at controlled rate 1 MPa min^{-1}.
        d. Apply helium sniffer at identified surface joint(s); accept leak if helium reading ≥ 1 × 10^{-5} mbar L s^{-1}.
5. **Week 142 — Leak Remediation**
    1. For gasket leaks:
        a. Remove bolts; replace Grafoil gasket; re-install with cross-pattern torque: 100 N m → 200 N m → 320 N m.
        b. Verify with helium sniff: reading must be < 1 × 10^{-7} mbar L s^{-1}.
    2. For cracked pipe section:
        a. Cold-cut 200 mm either side; install replacement 2 m SS-316L spool piece; weld per WPS-TL-316-12; passivated surface finish ≤ 0.8 µm.
        b. Radiographic test (RT) 100 % of weld; accept if no indications exceeding ASME B31.3 severity level 2.
    3. Update piping & instrumentation diagram, revision C3.
6. **Week 143 — Re-Test to Full Envelope**
    1. Repeat Section 3.2 stages without alteration.
    2. Confirm all acceptance criteria pass.
    3. Seal QA acceptance record *OP-047-143-Pass* with digital signature (DocuSign) by QA/NDE Lead.
7. **Week 144 — Post-Test Documentation & Handover**
    1. Vent N_2 to 0.2 MPa buffer; close all valves; install blind flanges on test ports.
    2. Generate final report including:
        - Calibration certificates.
        - Pressure & AE plots (PNG, 300 dpi).
        - Leak logs and remediation records.
        - Pass/fail matrix.
    3. Archive report to EDMS path *GT20/Loop25/QA/Final/OP-047*; assign “Released for Operations” status.
    4. Conduct Operations Readiness Review meeting; present results; obtain Operations Director sign-off.

4. Safety & Compliance Requirements

- Maintain exclusion zone 10 m radius during any pressure > 20 MPa; access limited to authorised personnel with RFID badges.
- Install blast shields on all viewports.
- Continuous gas detection: trip alarm at O_2 < 19 % v/v or N_2 > 1 % v/v; evacuate immediately.
- Regulatory references: ASME B31.3, ISO 15649 pressure testing, OSHA 1910.169, IEC Ex 60079-10.

Deliverables

- Signed *Permit-to-Test #OP-047-139-01*.
- Instrumentation calibration certificates (pressure, AE, flow).
- Pressurisation log file *OP-047-Pressure.csv* (1 Hz resolution).
- Acoustic emission raw data & processed triangulation plots.
- Leak remediation work orders & NDT reports.
- Relief valve test certificates.
- Final QA acceptance report *OP-047-Final.pdf*.
- Updated P&ID revision C3.
- Operations Readiness Review sign-off minutes.

OP-048 — Install sCO_2 Power Block and Balance-of-Plant (BOP)

Responsible Role: sCO_2 Power Cycle & Balance-of-Plant Lead — H-SCO2-24 | **Timeline:** Phase 10 (Week 110 – 140)

How-To-Do-It: Detailed, Sequential Action Plan

1. **Pre-Installation Kick-off & Documentation Control (Week 110)**
    1. Collect and store the latest IFC (Issued-For-Construction) drawings, vendor manuals, QA/QC plans, and specifications in the project DMS folder "/Phase10/OP-048/Controlled Docs". Verify revision numbers match those listed in document register REG-DOC-P10-V04.
    2. Conduct a technical review meeting with turbine OEM, recuperator vendor, dry-cooler vendor, piping contractor, electrical contractor, and I&C team. Minuted action items must be logged in Minutes-Mtg-OP-048-KO-RevA.docx within 24 h.
    3. Freeze the installation schedule Gantt (file OP-048-Schedule-Rev1.mpp) and assign task owners using RACI matrix stored in OP-048-RACI-RevB.xlsx.
2. **Site Preparation & Layout Verification (Week 110-112)**
    1. Mark the exact equipment centerlines on the turbine hall floor using a laser tracker (Leica AT960) referenced to plant survey control points P-10-CP-01 to P-10-CP-06. Tolerance: ±1 mm in X/Y.
    2. Verify anchor-bolt pattern locations for:
        - Compressor-turbine skid (Foundation drawing TUR-FDN-SHT-02-Rev3)
        - Generator skid (GEN-FDN-SHT-01-Rev2)
        - Recuperator racks 1 & 2 (REC-FDN-SHT-05-Rev1)

       Any deviation >±2 mm must trigger epoxy grout sleeve adjustment per procedure PROC-EPOXY-ADJ-P10.
    3. Lay down protective mats around piping corridors to prevent floor damage; mats spec: 20 mm thick HDPE, 1 000 kg/m² rating.
3. **Receive & Inspect Major Equipment (Week 111-113)**
    1. Uncrate compressor-turbine skid (OEM crate no. CT-SKID-3708). Perform inbound inspection using checklist INSP-CT-01. Key checks:
        - Rotor lock in place; no visible shipping damage.
        - Shipment shock-loggers <2 g on all axes.
        - Desiccant indicators <10 % RH.

       Log results in CMMS asset entry ID CT-3708.
    2. Uncrate printed-circuit recuperators (PCR) pallet IDs REC-PCR-A & REC-PCR-B. Measure plate fin channel flatness with feeler gauge: max gap 0.05 mm across 600 mm length.
    3. Receive dry air-cooler modules (ACM-01…ACM-08). Verify fan blade pitch set to 18 °. Record serials in AssetRegister-P10.xlsx.
4. **Foundation Grouting & Anchor Bolt Tensioning (Week 112-115)**
    1. Pressure-wash foundations; dry for 24 h to <3 % moisture content (measure with Protimeter MMS2).
    2. Mix non-shrink grout (BASF MasterFlow 648) at 21 °C ±2 °C, water ratio 0.135 l/kg.
    3. Pour grout to foundation plates to target thickness 40 mm; cure 48 h.
    4. Tension 1"-UNC anchor bolts to 28 kN using calibrated hydraulic wrench (Hytorc AVT-7). Record torque chart in Grout&Torque-Log-OP-048.xlsx.
5. **Install Compressor-Turbine-Generator Train (Week 115-118)**
    1. Position skid onto foundation using 200 t gantry crane. Lower at 5 mm/s until baseplate sits flush on grout pads (gap ≤0.5 mm each corner).
    2. Align turbine shaft to generator shaft:
        - Install dial indicators on coupling perimeter; rotate shafts 360 °.
        - Cold alignment targets: axial offset ≤0.02 mm; angular misalignment ≤0.03 mm/100 mm.
        - Shim with 0.1 mm stainless packs as necessary.
    3. Install high-speed flexible coupling (KOP-FLEX size KF-1580) torqued to 420 N·m per bolt (M20, property class 10.9) using torque wrench calibrated within last 30 days.
    4. Connect lube-oil skid (LOS-42) to bearing housings with 1" NPS stainless tubing, Swagelok fittings torqued to 110 N·m.
    5. Run temporary 4 bar nitrogen purge through casing to hold O_2 <50 ppm until first CO_2 fill.
6. **Install Printed-Circuit Recuperators (Week 118-120)**
    1. Hoist recuperator modules onto rack steel structure. Use spreader beam SB-4 m to prevent bending.
    2. Bolt modules with M24 × 80 mm A193-B7 bolts; torque to 280 N·m, sequence: star pattern, double pass.
    3. Weld 4" Sch160 sCO_2 inlet/outlet nozzles to loop headers using GTAW; WPS: WPS-SCO2-P11-05, 100 % RT per ASME IX.
    4. Hydrostatic test recuperator circuits to 320 bar with demin water at 30 °C. Hold 30 min, pressure drop ≤0.5 bar.
7. **Erect Dry-Cooling Air-Cooler Bank (Week 119-122)**
    1. Assemble support steel per drawing ACM-SUP-SHT-07-Rev2. Verify column plumbness ≤0.2 % by laser level.
    2. Install 8 fan modules using 60 t crane, positioning fans 6 m above grade. Secure with M20 galvanized bolts, 180 N·m torque.
    3. Connect 6" Sch160 CO_2 gas lines to air-cooler headers with 300-lb flanges, spiral wound gaskets type 316L/graphite. Bolt torque 540 N·m in cross-pattern.
    4. Pull 480 V power cables (Type TC-ER 3C 4/0 AWG) from MCC-04 to VFD panels on each fan. Megger test at 1 kV: Insulation resistance ≥200 MΩ.
    5. Program VFDs: accel ramp 20 s, decel 30 s, max speed 60 Hz, Modbus address 30-37 for fans 1-8 respectively.
8. **High-Pressure sCO_2 Piping Fabrication & Installation (Week 120-126)**
    1. Cut A790-UNS S31254 (6Mo) pipe to spool lengths per isometric ISO-SCO2-P10-800-SHT01-Rev4. Tolerances: cut length ±2 mm, bevel angle 37.5° ±1°.
    2. Perform GTAW root + SMAW fill/cap welds. Interpass temp ≤150 °C. PWHT: 725 °C × 1 h/in thickness in electric furnace ID PWHT-FCE-02.
    3. Document each weld in weld log WeldLog-OP-048.csv with welder ID, WPS, PQR, heat number, RT result.
    4. Install spools onto supports with PTFE slide plates; cold spring offset set per drawing notes (2 mm toward heat source).
    5. Install sCO_2 service valves: 4" Class 2500 ball valves (Velan SB4). Orient stem vertical ±5°. Torque packing follower to 60 N·m.
    6. Fit piping insulation: 100 mm calcium silicate + aluminum cladding, joints sealed with 3 mm butyl tape. Verify insulation continuity via IR camera: target outer surface ≤55 °C at 600 °C process temp.
9. **Instrumentation & Controls Integration (Week 122-128)**
    1. Mount transmitters:
        - Pressure: Rosemount 3051S-HT, range 0-350 bar, HART address per tag list TAG-P10-PRESS-Rev3.
        - Temperature: WIKA TC80 type K, 8 mm sheath, insertion 150 mm.
        - Vibration: Bently Nevada 3300 XL prox probes, tip-gap 0.8 mm.
    2. Terminate all 4-20 mA loops in DCS IO cabinet DCS-IO-P10-03. Use ferruled wires, 1.5 mm² Cu, blue for signal (+), white (-).
    3. Upload tag mapping spreadsheet DCS-Mapping-OP-048-RevC.xlsx to AVEVA System Platform; cross-reference 100 % of tags.
    4. Program protective relay settings (SEL-700GT for generator): Over-freq trip 63 Hz / 0.1 s, Over-speed trip 110 % N_{nom} / 0 s, Reverse power 5 % P_{nom} / 5 s.
10. **Electrical Power-Side Works (Week 124-130)**
    1. Install 11 kV generator breaker (ABB VD4-12) in switchgear lineup. Bolt busbar joints with 50 N·m; apply Dow Corning 4 compound.

2. Pull single-core 3×400 mm² XLPE cables from generator to breaker. Phasing: R-Y-B verified via phase rotation meter (must read R-Y-B clockwise).
3. Megger test 5 kV/1 min: insulation ≥5 GΩ. Record in Elec-Test-OP-048.pdf.
4. Connect neutral grounding resistor 10 Ω, 10 s rating, per drawing NGR-SHT-01-Rev1.

11. **Auxiliary Systems Commissioning (Week 126-132)**
    1. Flush lube-oil system with ISO VG32 oil at 60 °C, flow 120 l/min for 4 h. Target cleanliness NAS class ≤4.
    2. Seal gas system: Fill seal buffer with 99.999 % N_2 at 6 bar. Verify leakage <0.01 bar/24 h.
    3. Start-up vibration monitoring: connect BN 3500 rack to Condition Monitoring Network. Baseline vibration <0.7 mm/s overall.
12. **System Pressure & Leak Testing (Week 130-134)**
    1. Conduct pneumatic pressure test on entire sCO_2 circuit:
        - Pressurize with N_2 to 1.1 × design pressure = 330 bar.
        - Stabilize 30 min; allowable pressure drop ≤1 bar.
        - Apply soap-film solution to all welds, flanges, valve stems. Zero bubble criterion.
    2. Complete Pneumatic-Test-Certificate-OP-048-RevA.docx; sign by QA Lead, Client Rep, and Authorized Inspector.
13. **Thermal Insulation & Labeling (Week 132-135)**
    1. Install high-temp insulation blankets on turbine casing: 50 mm needlemat silica, SS mesh outer; tie-wire spacing 150 mm.
    2. Apply equipment labels: 304 SS tags, laser-engraved 25 mm text, fixed with SS zip ties. Color code per site standard: yellow for high-pressure CO_2.
    3. Stencil flow arrows with heat-resistant yellow paint (DECO-HT600).
14. **Pre-Start-up Safety Review (PSSR) (Week 135-136)**
    1. Hold PSSR walk-down using checklist PSSR-P10-OP-048-RevB. Minimum attendees: HSE Manager, Commissioning Lead, OEM reps, Ops Supervisor.
    2. Close all action items, sign master punch-list. Category A punches (safety-critical) must be zero before first CO_2 fill.
15. **Initial CO_2 Charge & Loop Integration (Week 136-137)**
    1. Evacuate sCO_2 circuit to 1 mbar using dry scroll vacuum pump (Edwards nXDS15i) for 4 h; record pressure log.
    2. Charge with industrial-grade CO_2 (≥99.995 %) from trailer at 23 °C until system reaches 110 bar cold fill.
    3. Equalize with LithoLoop header via flow restrictor LR-02; ramp flow 2 kg/s per min to design 220 kg/s.
16. **Cold Spin & Bump Test (Week 137-138)**
    1. Engage starter motor; spin rotor to 3 000 rpm under N_2 seal gas. Observe vibration ≤1.5 mm/s, bearing temps <40 °C.
    2. Perform "bump" overspeed trip test: inject 5 % speed increment, verify trip at 110 % N_{nom} <100 ms.
    3. Calibrate proximity probe scale factors in BN 3500 software.
17. **Hot Commissioning & Performance Verification (Week 138-140)**
    1. Ramp turbine inlet temp from 200 °C to 500 °C in 50 °C steps, dwell 20 min each. Confirm metal temps lag <150 °C.
    2. Reach rated speed 13 500 rpm, load generator to 100 % P_{nom}. Log parameters every 1 min for 4 h stability test: Heat-to-power efficiency ≥48 %, compressor surge margin ≥10 %.
    3. Trip test scenarios: Loss of grid, high CO_2 pressure, lube oil failure. Verify automatic shutdown within 2 s.
    4. Sign final Acceptance Certificate (FAC-OP-048-Rev0) with client.

Deliverables:

- Minutes-Mtg-OP-048-KO-RevA.docx
- OP-048-Schedule-Rev1.mpp
- OP-048-RACI-RevB.xlsx
- Grout&Torque-Log-OP-048.xlsx
- WeldLog-OP-048.csv with 100 % NDE records
- DCS-Mapping-OP-048-RevC.xlsx
- Pneumatic-Test-Certificate-OP-048-RevA.docx
- PSSR-P10-OP-048-RevB signed checklist and closed punch-list
- Hot Commissioning Performance Report (HCPR-OP-048-Rev0.pdf)
- Final Acceptance Certificate (FAC-OP-048-Rev0)
- As-Built Drawings package (PDF & native CAD)
- Updated CMMS asset registry entries for all equipment

OP-049 — Execute sCO2 Cold/Hot Commissioning & Protection/Controls Testing

Responsible Role: sCO2 Power Cycle & Balance-of-Plant Lead — H-SCO2-24 | **Timeline:** Phase 10 — Week 141 – 150

How-To-Do-It: Step-by-Step Execution Manual

1. **Week 141 — Pre-Commissioning Preparation (Day 1 – Day 7)**
    1. Review all finalized Process & Instrumentation Diagrams (P&IDs), loop sheets, control logic narratives, mechanical/electrical datasheets, and Safety Integrity Level (SIL) verifications. Confirm that each document bears a "REV FINAL" stamp and is stored in *GeoTherm20\Project\Docs\Controlled\POWERBLOCK*.
    2. Access the master punch-list spreadsheet (*POWERBLOCK_PUNCHLIST_v5.xlsx*) and confirm that all items in tabs "Mechanical," "Electrical," and "I&C" show status "CLEARED." If any item is marked "OPEN," assign a red-tag lockout on the relevant component and halt further commissioning until resolved.
    3. Obtain a signed, site-specific Permit-to-Work (PtW) for "sCO2 System Commissioning." Attach the following risk assessments as annexes: *RA-171_Supercritical_CO2_Hazards.pdf*, *RA-188_High_Temperature_Surfaces.pdf*. Ensure PtW is posted at the control room and field entry gate.
    4. For every instrument listed in *INSTR_CAL_LOG_W141.csv*, verify the "Cal Date" is within 30 days. If any device exceeds 30 days, perform immediate recalibration using manufacturer-supplied calibrators:
        - Pressure Transmitters (PT-###): Use *Fluke 721-3601*, set reference gas to N_2, span 0 – 30 MPa, achieve ±0.025% accuracy.
        - Temperature RTDs (TT-###): Use *Isotech Dry-Block Model FastCal*, temperature sweep 20 °C – 650 °C, validation ±0.1 °C.
        - Vibration Sensors (VS-###): Use *PCB 356A15* calibrator, 10 Hz – 1 kHz sweep, accuracy ±2% of reading.
    5. Log in to the Distributed Control System (DCS) server *GT20-DCS-01* with admin credentials (*u: H-SCO2-Lead / p: !G3o20P@ss*), navigate to *C:\DeltaV\Projects\LithoLoop25*, and run the script *backup_config.bat*. Confirm creation of ZIP file *DeltaV_Backup_W141.zip* in *E:\Backups\Weekly*.
2. **Week 142 – 143 — Cold Commissioning (Day 8 – Day 21)**
    1. Perform hard-wired loopback for every I/O channel:
        1. Open DeltaV Diagnostics; select node tree "PowerBlock/SCO2_Rack A/B."
        2. For each AI tag, short terminal + and – in the marshalling cabinet; verify DCS reads 20 mA ± 0.02 mA.

3. For each AO tag, force output 12 mA from DCS; confirm handheld ammeter reads 11.98 mA – 12.02 mA.
4. Document pass/fail in sheet “LOOPBACK_RESULTS_W142.xlsx.”

2. Sequentially stroke every control valve (CV-###):
    1. Place valve in “Manual” via DCS faceplate.
    2. Command 0 % – 100 % – 0 % travel at 10 % increments; dwell 5 sec at each point.
    3. Capture position feedback using Fisher DVC 6200 diagnostics log; acceptable deviation ≤ 1 % of commanded.
    4. Flag any valve outside tolerance; enter work order in CMMS (Maximo work order type “URGENT CALIB”).
3. Pressurize the entire CO_2 loop to 20 MPa using high-purity Nitrogen (99.999%):
    1. Isolate vents, connect N_2 skid (*Model AirLiquide N2-45MPa*) to fill port PF-001.
    2. Ramp pressure at ≤ 1 MPa/min while monitoring PT-101 & PT-102.
    3. Stabilize at 20 MPa for minimum 4 hours.
    4. Using Flir GF343 camera, inspect every flange, weld, and instrument thread; record leak rate. Criteria: 0 ppm-v visual detection.
    5. If leak is found, tag joint and depressurize segment; repair via rated spiral-wound gasket or TIG weld per *WPS-SCO2-12*. Repeat test until zero leaks.
4. Execute automated logic test script:
    1. Open DeltaV batch file *COLD_TEST_SEQ.sq*.
    2. Initiate test; script will simulate 50 process scenarios by toggling Soft I/O “SIM*” tags.
    3. Pass criterion: every SIS interlock (IL-###) must transition from “READY” to “TRIP” within 150 ms of fault injection and automatically reset upon clear.
    4. Generate auto-report *LogicTest_W143.pdf*; save to controlled drive.

3. **Week 144 – 147 — Hot Commissioning (Day 22 – Day 49)**
    1. Initiate pre-heat using electrical resistance heaters (HX-PRE-001):
        - Set heater controller to ramp 5 °C/min from 25 °C to 120 °C.
        - Monitor TT-201 through TT-209; ensure ΔT between any two sensors < 10 °C.
        - Hold temperature at 120 °C for 2 hours to remove moisture.
    2. Displace N_2 with CO_2:
        1. Connect CO_2 truck to port PF-001; purge with 50 kg/min flow.
        2. Maintain vent valve VV-101 slightly open; continue until N_2 concentration < 1 % (Verify with gas chromatograph GC-01 reading).
    3. Using compressor CP-101 in recycle mode:
        1. Ramp pressure from 7.5 MPa (critical point) to 25 MPa at 0.5 MPa/min.
        2. Simultaneously ramp turbine inlet temperature (TIT) via primary heater HX-PH-001 from 120 °C to 550 °C at 5 °C/min.
        3. Parameter acceptance:
            - Surge margin ≥ 15 % (verify on CP-101 map).
            - Recuperator ΔT_lmtd = 85 °C ± 5 °C (calculate in DCS: tag RECUP_DT).
            - Dry cooler outlet temperature ≤ 45 °C at 100% fan speed.
    4. Start turbine TB-101 with bypass valve BV-301 closed:
        1. When turbine speed reaches 3000 rpm, verify vibration VS-101 ≤ 3.5 mm/s RMS.
        2. Continue acceleration to 12 500 rpm (synchronous speed for 60 Hz grid via gearbox).
        3. At 12 000 rpm, execute overspeed test by forcing speed loop +10 % for 5 sec; observe mechanical trip at 13 250 rpm (≤ 4 % deviation).
        4. Reset trip, restart machine, stabilize at 12 500 rpm.
    5. Tune primary control loops using Ziegler-Nichols closed-loop method:

Loop Tag	Critical Gain (Kc)	Oscillation Period (Pc)	Final PID (P, I, D)
FC-101 (sCO2 Mass Flow)	1.8	40 s	(0.9, 20 s, 5 s)
TIC-201 (Turbine Inlet Temp)	3.2	60 s	(1.6, 30 s, 7.5 s)
PC-301 (System Pressure)	2.5	50 s	(1.25, 25 s, 6.25 s)

    Enter final PID values in DeltaV:
        1. Navigate to control module, e.g., FC-101.
        2. Input P, I, D parameters; click “Download to Controller.”
        3. Repeat for TIC-201 and PC-301; log adjustments in *PID_TUNE_LOG_W145.docx*.

4. **Week 148 — Protection & Controls Testing (Day 50 – Day 56)**
    1. Execute black-start & ESD sequence test:
        1. With system at 50 % load, press ESD pushbutton PB-ESD-01.
        2. Verify:
            - Trip valves TV-101/102 close within 200 ms.
            - Turbine coast-down to < 1 000 rpm in ≤ 30 s.
            - Generator circuit breaker opens within 4 cycles (< 80 ms).
            - All heaters de-energize.
        3. Record sequence via high-speed historian (1 ms scan rate).
    2. Simulate overpressure by inserting 10 % pressure bias on PT-301 (using HART communicator, write D/A offset = +2.5 MPa):
        - Expected Action: Relief valve RV-201 should pop at setpoint 30 MPa ± 0.5 MPa; DCS should issue “PRESSURE_TRIP” and close isolation valves.
        - After test, remove bias; inspect RV-201 seat for damage; re-torque bolts to 120 N·m.
    3. Engage plant in grid simulator (Siemens *SICAM PAS v9*):
        1. Run low-voltage ride-through profile: 0.15 p.u. voltage for 625 ms.
        2. Ensure generator stays synchronized and returns to 100 % active power within 1 s of voltage recovery.
        3. Frequency response test: Step load ±10 % and verify governor droop of 4 %.
    4. Inject vibration fault via shaker device on bearing 2:
        - Increase vibration to 7.1 mm/s; confirm trip at setpoint 7.0 mm/s.

    Overspeed test already completed during Week 145; log both results in *PROT_TEST_SUMMARY_W148.xlsx*.

5. **Week 149 – 150 — Documentation & Readiness Approval (Day 57 – Day 70)**
    1. Re-export updated punch list; ensure “Status” column shows 100 % “CLEARED.” Obtain signatures from Mechanical Lead, Electrical Lead, and QA/QC Manager on tab “Sign-off.” Upload PDF to EDMS with code *LL25-PB-PLC-FINAL*.

2. Compile all historian data (tags list in Appendix A) for 24-h steady-state run at 100 % load:
    - Calculate Net Plant Efficiency (η_{net}) via formula: $\eta_{net} = (P_{gross} - P_{aux}) / (Q_{thermal,in})$
    - Target: ≥ 50 %.
    - Publish report *GT20_LL25_SCO2_Perf_W149.pdf*.
3. Conduct 2-day operator training:
    1. Day 1 (Theory): Classroom presentation slides *OPR_TRAIN_MOD1.pptx*.
    2. Day 2 (Practical): Hands-on in DCS; trainees must complete checklist "OPR_SKILL_MATRIX_v3.xlsx" with ≥ 90 % score.
4. Assemble "Readiness Dossier" containing:
    - Signed punch list
    - Logic & Protections test certificates
    - Performance test report
    - Operator training certificates

Submit dossier to Project Director for signature on Form *F-GT20-RS-02*. Once signed, issue "Ready for Grid Synchronization" notice to Transmission Operator.

Deliverables

- LOOPBACK_RESULTS_W142.xlsx
- LogicTest_W143.pdf
- PID_TUNE_LOG_W145.docx
- PROT_TEST_SUMMARY_W148.xlsx
- GT20_LL25_SCO2_Perf_W149.pdf
- OPR_SKILL_MATRIX_v3.xlsx (completed)
- Readiness Dossier (Form F-GT20-RS-02 signed)
- "Ready for Grid Synchronization" official notice

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# OP-050 — Charge Loop With $sCO_2$; Initiate Thermosiphon; Performance Validation; Grid Synchronization; Operations Handover

**Responsible Role:** Operations Readiness, Training & O&M Lead — H-OPS-25 | **Timeline:** Phase 11 – Week 151 to 160

## 1 Pre-Execution Gate

1. Review and sign the "Phase-11 Readiness Checklist" (Document ID : GT20-P11-CHK-001). All 23 line items must read "GREEN".
2. Verify that the surface piping, separators, heat exchangers, and all Class 15000 pressure vessels have an active "In-Service Certificate" issued within the last 30 days.
3. Confirm full calibration (≤ ±0.25 % F.S.) for the following sensors:
    - Pressure: PT-1001 to PT-1012 (0-150 MPa)
    - Temperature: TT-2001 to TT-2018 (0-800 °C)
    - Mass-flow Coriolis meters: FT-3001 / FT-3002 (0-120 kg $s^{-1}$)
4. Lock-out/tag-out (LOTO) non-essential systems (e.g., auxiliary glycol loop) per LOTO procedure GT20-SAFE-05.
5. Hold a "GO/NO-GO" meeting. Required quorum: O&M Lead, Commissioning Director, Grid Code Compliance Officer, HS&E Supervisor. Document minutes in GT20-MOM-P11-001.

## 2 Loop Evacuation & Inert Gas Displacement (Week 151, Day 1)

1. Close valves V-001 to V-006 isolating the loop from the power block.
2. Activate the vacuum skid VS-25. Set target pressure to ≤ 20 kPa(abs). Record pressure every 60 s until stable for 30 min.
3. Back-fill the loop with 99.999 % pure $N_2$ to 0.5 MPa(g) via port P-B01. Maintain temperature ≤ 50 °C (monitor TT-2004).
4. Isolate and hold for 1 hour. Perform helium mass-spectrometer leak test – acceptance criterion ≤ $1 \times 10^{-8}$ mbar L $s^{-1}$.
5. Vent $N_2$ to flare stack; depressurize to 0.1 MPa(g).

## 3 $sCO_2$ Charging (Week 151, Day 2-3)

1. Connect liquid $CO_2$ ISO-container to charge manifold CM-01 using ANSI Class 2500 flexible hose.
2. Purge charge manifold with $CO_2$ for 120 s at 5 kg $s^{-1}$; vent to flare.
3. Open valve V-C01 at 2 rpm motorized speed to avoid pressure shock.
4. Increase loop pressure in 10 MPa increments up to 60 MPa while ensuring temperature ΔT across any component < 25 °C:
    - Hold 15 min soak at 20 MPa, 40 MPa, 60 MPa.
    - Check stress monitor SM-10 < 90 % of ASME Section VIII limit.
5. Continue charging to design pressure (target 100 MPa, allowable 60-120 MPa site-specific). Final ramp : 1 MPa $min^{-1}$.
6. When P ≥ design pressure ±1 MPa and Tavg ≥ 35 °C, close V-C01, isolate charge manifold, bleed off connection to 0 MPa, disconnect ISO-container.
7. Record total $CO_2$ mass injected: integrate Coriolis FT-3001. Expected ≥ 73,500 kg for 25 km loop of 10-cm ID annulus.

## 4 Thermosiphon Initiation (Week 152, Day 1-2)

1. Ensure surface heat-addition skid (Electric Heater EH-01) is ready. Verify SSR duty cycle limiter set to 80 %.
2. Calculate required density differential (Δρ) to achieve target mass flow:
    - Formula: $\dot{m}_{target} = C_D \times A_{loop} \times \sqrt{(2 \times g \times \Delta h \times (\Delta\rho\bar{\rho}))}$
    - Where $C_D$ = 0.82, $A_{loop} = 7.85 \times 10^{-3}$ $m^2$, Δh = 25,000 m
    - Re-arrange to find Δρ. Document in spreadsheet GT20-CALC-TS-01.
3. Start EH-01 at 200 kW, ramp +200 kW every 30 min until TT-2012 (downhole annulus) reaches 180 °C.
4. Confirm circulation inception by verifying ΔP across flow restrictor FR-01 ≥ 0.15 MPa and positive FT-3001 flow ≥ 10 kg $s^{-1}$ for 10 min.
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5. Continue heat ramp to achieve inlet turbine temperature 500 °C:
   - Raise EH-01 to 3 MW in 500 kW steps every 15 min.
   - Monitor thermal stress: SM-10 ≤ 95 % limit.
6. Lock EH-01 at 3 MW when continuous mass flow 20-80 kg s^{-1} stabilizes. Record ΔT (annulus vs inner pipe) ≤ 80 °C.

5 Performance Validation (Week 152 – Week 155)

1. Configure data historian PI-AF template “P11-Perf” with 1 s sample rate for 48 tags (pressure, temperature, flow, power).
2. Run three power-block load profiles:
   a. Base Load : 100 % for 8 h
   b. Step Test : 100 % → 50 % → 75 % → 100 %, each level 2 h
   c. Ramp Test : 0 % → 100 % at 10 % min^{-1}, hold 4 h
3. During each profile, measure:
   - Mass flow (FT-3001) — acceptance 20-80 kg s^{-1}, ±2 % stability
   - Turbine inlet temperature (TT-2015) — 500-600 °C
   - Net electrical output (WT-E01) — 12-50 MWe
   - Thermal-to-electric efficiency η = P_{net}/(ṁ × c_p × ΔT). Target 35-45 %
4. Tune flow restrictor FR-01:
   - Adjust orifice plate cam from 20 mm to 30 mm in 2 mm increments.
   - Select setting with Σ|ΔP fluctuations| over 30 min ≤ 0.05 MPa.
5. Compile results in “FOAK KPI Validation Report” (GT20-REP-P11-KPI-001). Sign-off required by CTO.

6 Grid Synchronization (Week 156)

1. Conduct protective relay self-tests (ANSI 25, 27, 32, 59, 81U/O):
   - Over-frequency 81O setpoint : 51.5 Hz (trip 0.2 s)
   - Under-frequency 81U setpoint : 48.5 Hz (trip 0.2 s)
   - Rate-of-change 81R setpoint : 2 Hz s^{-1}
2. Verify sync phasing lights: ΔV ≤ 5 %, Δf ≤ 0.1 Hz, Δφ ≤ 10°.
3. Close breaker CB-G01 when sync criteria met for 5 continuous cycles.
4. Run dynamic response tests per Grid Code G-GEO-2022:
   - 10 % load drop in 0.5 s; frequency deviation ≤ 0.4 Hz, recovery ≤ 5 s
   - Fault Ride-Through: 150 ms zero-voltage, maintain synchronism
5. Submit “Grid Compliance Certificate Request” to ISO via portal. Upload raw PQ data (.COMTRADE).

7 Operations Handover (Week 157-160)

1. Finalize Operations Manual (GT20-OM-LL25-RevA). Include:
   - Operating envelope table (pressure, temperature, flow)
   - Traffic-light system linked to microseismic thresholds:

Color	Peak Ground Velocity (mm s^{-1})	Action
Green	< 4	Normal operation
Yellow	4 – 8	Reduce load by 25 %
Red	> 8	Immediate shutdown

2. Complete operator training:
   - Modules TR-OP-01 to TR-OP-06 (classroom) — 24 h
   - Hands-on console simulation (SIMOPS-LL25) — score ≥ 85 %
3. Issue “Training Completion Certificates” via LMS.
4. Create spare-parts list SP-LL25-01; place initial purchase orders for long-lead items (turbine bearings, seal-land kits).
5. Commission predictive maintenance baseline:
   - Run 72 h data capture of vibration, lube-oil particulates, CO_2 purity.
   - Upload to APM cloud, tag Asset ID: LL25-01.
6. Sign Handover Certificate (GT20-HC-P11-001) jointly by Commissioning Manager and Plant Manager.

Deliverables

- Phase-11 Readiness Checklist (GT20-P11-CHK-001) — signed
- CO_2 Charge Log & Mass Balance Spreadsheet (GT20-LOG-CO2-P11)
- Thermosiphon Calculation Sheet (GT20-CALC-TS-01)
- FOAK KPI Validation Report (GT20-REP-P11-KPI-001)
- Grid Compliance Certificate (ISO-DOC-GCC-LL25-001)
- Final Operations Manual (GT20-OM-LL25-RevA)
- Training Completion Certificates batch (LMS export)
- Handover Certificate (GT20-HC-P11-001)

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Introduction to the Financial Plan

Solution Concept

LithoLoop 25 replaces the impractical deep-tunnel vision with a network of slender, 45-degree vitrified boreholes that reach the 25–30 km super-hot zone. Each bore is simultaneously drilled and glass-ceramic lined by a surface-powered millimeter-wave beam, then clad with a refractory meta-casing to form a sealed coaxial heat exchanger. Supercritical CO_2 circulates passively in the closed loop, delivering 500–600 °C heat to a surface sCO_2 Brayton cycle and producing round-the-clock zero-carbon electricity without hydraulic stimulation, formation fluid handling, or high-risk down-hole electronics.

Financial Summary

A comprehensive aggregation of five cost domains—Human Resources, Capital Equipment & Infrastructure, Operational Supplies & Materials, Marketing & Sales, and Other Expenses & Contingency—yields a total project investment of USD 181,266,040. Under the validated three-year revenue forecast, this investment generates an un-levered return on investment of approximately 135 % and is expected to reach break-even in just 23 months.

Method of Innovation

The concept was crafted with the BlueCallom Innovation Framework, beginning with a 360-degree research sweep that dissected the problem space, market forces and technological boundaries. Through first-principle deconstruction and Neuro-Ideation, a non-obvious solution was generated, then rigorously validated by AI analytics and optional customer feedback to ensure feasibility, desirability and economic soundness before blueprinting.

Strategic Importance

For GeoTherm20 and its energy-provider and government customers, LithoLoop 25 opens a path to nuclear-class baseload power without fuel, emissions or radiological liabilities. It diversifies the company’s portfolio beyond

wind, solar and hydro, positions the brand at the forefront of deep-geothermal innovation, and supplies a scalable, modular asset that can satisfy tightening decarbonisation mandates while insulating stakeholders from commodity-price and policy volatility.

Report Overview

The detailed financial plan that follows is organised sequentially: a consolidated cost table, granular breakdowns for each expense category, revenue projections, sensitivity analyses, and milestone-linked cash-flow models.

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Human Resources Cost

Sourcing Strategy & Savings Summary

The 160-week (≈3.1-year) programme requires 26 specialist positions. A role-by-role feasibility screen shows that activities demanding continuous site interaction with heavy equipment, regulatory officials, or physical prototypes must remain in Houston, Texas (primary project location). Digital or analytics-dominant roles can be delivered just as effectively from a lower-cost engineering hub in Bengaluru, India. The resulting blended team (20 Houston on-site + 6 Bengaluru remote) delivers identical head-count coverage while cutting total HR spend by roughly 12 %. All figures below are expressed in U.S. dollars (USD).

Sourcing Location	Number of Roles	Total Cost for Group (USD, 3.1 yrs, fully-burdened + recruitment)
Houston, Texas (on-site)	20	$15.26 M
Bengaluru, India (remote)	6	$1.90 M
Programme Total	26	$17.16 M
Estimated Savings vs. All-Houston Staffing	–	≈ $2.2 M (-11.5 %)

Detailed Cost Breakdown

Role	Head-count	Sourcing Location	Benchmark Annual Salary	Total Cost for Timeline (Fully Burdened)	One-Time Recruitment Cost
Executive Sponsor & Governance Lead	1	Houston	$250 000	$1 007 500	$37 500

Program Director & Systems Engineering Lead	1	Houston	$220 000	$886 600	$33 000
Total	26	—	—	$16 547 000	$606 000

Footnotes

- Salary benchmarks: Houston figures taken from 2024 Aon & SPE Energy-Sector compensation survey (P50 for equivalent role seniority). Bengaluru benchmarks sourced from NASSCOM 2024 “Engineering-R&D Salary Guide” (upper quartile for multinational captives).
- Burden rates: 30 % for U.S. employees (medical, FICA, FUTA/SUTA, 401k match, workers comp) and 20 % for Indian employees (EPF, gratuity, statutory bonus, social security, local office overhead).
- Recruitment costs: 15 % of first-year salary for U.S. placements via retained search; 12 % for Indian hires via regional engineering staffing partners.
- Duration conversion: 160 weeks ÷ 52 = 3.08 years, rounded to 3.1 years for costing.
- All-local comparison assumes Houston salary levels and burden rates for the six roles sourced remotely in the blended model.

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Capital Equipment & Infrastructure Costs

1. Team Hardware & Core IT

Item	Quantity	Est. Cost per Unit (USD)	Total Cost (USD)	Justification
High-spec engineering laptops (CAD / FEA capable)	26	3,000	78,000	Needed for all new hires across 26 roles (Action-Plans OP-001 … OP-050)
GPU workstations for HPC simulation cluster	4	15,000	60,000	Runs digital-twin, CFD & FEM workloads (OP-024)
Central file / compute server + 40 TB NAS	1	25,000	25,000	On-prem vault for large design files, model versions & historian back-ups
Office networking gear & peripherals set	1 lot	10,000	10,000	Switches, docking stations, ergonomic monitors for new project office
Category Sub-total			173,000	

2. Specialized Lab & Test Equipment

Item	Qty	Est. Cost / Unit	Total Cost	Justification
High-vacuum 1 600 °C furnace	1	350,000	350,000	Materials qualification for vitrified liner & meta-casing coupons (OP-022)

200 MPa / 600 °C autoclave test cell	1	400,000	400,000	Pressure / corrosion tests for sCO_2 & argon loops (OP-038, OP-047)
mm-Wave VNA w/ 50–110 GHz extenders	1	500,000	500,000	Reflectometry calibration & on-site SAT (OP-036, OP-044)
Distributed-fiber DTS interrogators	2	60,000	120,000	Permanent temperature / strain monitoring, bench & field (OP-011, OP-039)
Acoustic sensing & AE toolkit	1	80,000	80,000	Downhole ranging & integrity surveys (OP-044, OP-047)
Robotic wire-feed deposition test cell	1	600,000	600,000	PID tuning & metallurgical trials for meta-casing (OP-041)
250 kW pilot gyrotron module @ 94 GHz	1	2,500,000	2,500,000	Lab-scale drilling / vitrification R&D prior to FOAK field unit
Portable UT / shear-wave NDE sets	2	40,000	80,000	QA of joints, bellows & liner sections (OP-027, OP-041)
IR pyrometers & thermal-imaging package	1 lot	50,000	50,000	Real-time melt-front & quench-profile validation (OP-040, OP-042)
Category Sub-total			4,680,000	

3. Drilling & Downhole Equipment Assets

Item	Qty	Est. Cost / Unit	Total Cost	Justification
8 MW, 140 GHz field gyrotron + HVPS	1	25,000,000	25,000,000	Primary beam-drilling power-plant shared across wells (OP-040)
Fabrication of first 2 km modular waveguide string	1 lot	7,000,000	7,000,000	Initial closed-loop inner/outer tubing (OP-036, OP-045)
1 200-t AC-700 triple-mast drilling rig (upgrade & purchase)	1	15,000,000	15,000,000	Required hook-load & high-temp spec for starter hole & deep sections (OP-032)
15 k psi ultra-HT BOP stack	1	4,000,000	4,000,000	Safety barrier for high-pressure, high-temp starter hole (OP-033)
High-capacity argon circulation / filtration skid	1	2,000,000	2,000,000	Supplies quench & sweep gas during drilling & vitrification (OP-038)
Ceramic pigging system incl. 10 pigs	1 lot	1,000,000	1,000,000	Liner conditioning & debris removal (OP-041)
Hydraulic gimbal fabrication & setting tools	1 lot	3,000,000	3,000,000	Directional steering & reflector actuation at 25–30 km depth (OP-042)
Category Sub-total			57,000,000	

4. Facility & Site Infrastructure Setup

Item	Qty	Est. Cost / Unit	Total Cost (USD)	Justification

Launch-gallery excavation TBM procurement & civil works	1	30,000,000	30,000,000	Shallow 300–500 m fan gallery for multiple wells (OP-014, OP-030)
Rock support (shotcrete, bolts, liners)	1 lot	8,000,000	8,000,000	Long-term ground support of gallery & adits
Ventilation fans, ducting & air-quality systems	1 lot	3,000,000	3,000,000	45 000 $m^3\ h^{-1}$ gallery airflow & O_2-deficiency protection (OP-030)
Cooling-water plant & heat-rejection piping	1 lot	4,000,000	4,000,000	Services gyrotron, sCO_2 cycle & drilling equipment
Dry-cooler air-cooling bank (8 modules)	1	5,000,000	5,000,000	Closed-loop heat rejection for sCO_2 power block (OP-048)
2 500 kVA transformer & 11 kV switchgear	1	4,000,000	4,000,000	Dedicated power feed to RF plant & auxiliaries
MCCs, cabling & power distribution	1 lot	2,000,000	2,000,000	Motor control for fans, pumps, heaters (OP-030, OP-048)
Fire & life-safety systems (FM-200, detection, RF doors)	1 lot	1,000,000	1,000,000	Code-compliant life-safety package for gallery & RF room
OT / SCADA servers, switches & secure racks	1 lot	1,000,000	1,000,000	Real-time controls, historian & cyber-secure OT network (OP-024, OP-048)
Category Sub-total			58,000,000	

Total Estimated Capital Expenditure: USD $119,853,000

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Operational Supplies & Materials Costs

Recurring Operational Costs

Service/License	Monthly Cost (USD)	Total Cost for 38-Month Timeline (USD)
OSIsoft PI System Cloud Connect – licence + 24 × 7 support	3,000	114,000
AVEVA / GE APM Cloud (predictive maintenance)	4,000	152,000
Microsoft Azure Digital-Twin VM + storage (D4s v5, 4 vCPU / 16 GB RAM)	330	12,540
GitLab Premium (50 users × 29 USD)	1,450	55,100
Atlassian Confluence/Jira Cloud (50 users × 10 USD)	500	19,000
Power BI Pro (40 seats × 20 USD)	800	30,400

DeltaV DCS software maintenance & cyber-patch subscription	2,500	95,000
Bently Nevada “System 1” remote vibration-monitoring SaaS	2,000	76,000
Subtotal (Recurring)		554,040

Project duration taken as 160 weeks ≈ 38 months.

Consumable Supplies & Materials

Item/Material	Justification	Total Estimated Cost (USD)
Bulk liquid argon (≈ 132 t @ 3 USD kg^{-1})	Continuous quench / sweep gas during beam-drilling & commissioning	396,000
Contingency argon (10 % over-run)	Duty-cycle fluctuation, purges	39,600
High-purity nitrogen (≈ 25 000 Nm^3 @ 0.50 USD Nm^3)	Inerting, pressure testing, loop purges	12,500
Refractory metal wire – Mo-Re / Inconel (≈ 79 t @ 30 USD kg^{-1})	Continuous co-deposition of 250–500 µm meta-casing film over 30 km bore	2,370,000
Glass-ceramic frit & repair slurry (500 kg @ 15 USD kg^{-1})	Local re-melt & liner remediation	7,500
Ceramic pigs (10 units @ 10 000 USD) and abrasive pad sets (100 pads @ 500 USD)	Periodic liner conditioning & debris removal	70,000
Grafoil gaskets, high-temp sealants, Loctite HN-272 (lump-sum)	Joint locking, high-pressure flanges	30,000
Cement additives (silica flour, retarders, micro-expansion)	High-temp geothermal cement jobs	50,000
High-purity CO_2 for pressure tests / commissioning (80 t @ 0.20 USD kg^{-1})	Loop pressure tests, charge displacement	16,000
Helium leak-test gas (100 cyl @ 150 USD)	All integrity and flange leak tests	15,000
High-temp lubricants & greases	Expansion bellows, valve stems, pig drive	20,000

Subtotal (Consumables)		3,036,600

Total Estimated Operational Supplies & Materials Cost

USD 3,590,640

All monetary values expressed in United States Dollars – USD.

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Marketing & Sales Costs

Proposed Go-to-Market Activities

- Brand & Core Messaging Development
- Corporate Website Overhaul and Technical SEO Programme
- Thought-Leadership Content Marketing (white papers, peer-reviewed papers, infographics, videos)
- Multi-Platform Digital Advertising Campaign – LinkedIn Sponsored Content – Google Search/Display Ads – Energy-sector portal display & retargeting
- Public-Relations & Media Outreach (specialised energy-tech PR agency)
- Analyst & Investor Relations (briefings with Wood Mac, Gartner, BloombergNEF, etc.)
- Flagship On-Site Product Launch Event (commissioning ceremony & live-stream)
- Trade-Show & Conference Exhibitions (World Geothermal Congress, CERAWeek, Power-Gen, etc.)
- Webinar & Virtual Road-Show Series (technical deep-dives for utilities, EPCs, regulators)
- Pilot-Site Customer Visit Programme (guided tours, safety briefings, hospitality)
- Client Workshops & Solution Demos at Prospect Headquarters
- Sales-Enablement Collateral Production (print/digital datasheets, 3-D animations, VR demo, video documentary)
- CRM & Marketing-Automation Stack Implementation (HubSpot Enterprise + integrations)
- Government Affairs & Regulatory Liaison (policy consultancy & lobbying compliance)
- Channel/Partner Programme Design & Enablement (contracts, portal, training, incentive fund)
- Sales-Force Build-out (4 Sr Account Execs + 2 Technical Sales Engineers, first-year only)
- Grid-Operator Integration Workshops & Training (pre-interconnection curriculum)
- 10 % Contingency Reserve for un-scoped marketing & sales needs

Detailed Estimated Cost Breakdown

Activity	Cost Breakdown / Justification	Estimated Cost (USD)
Brand & Core Messaging Development	External brand agency (80 k) + market positioning research (40 k)	120,000
Website Overhaul & SEO	UI/UX redesign (50 k); headless CMS build (30 k); technical SEO sprints (25 k); copy/graphics (25 k); 24-mo maintenance & hosting @ 5 k mo (120 k)	200,000
Thought-Leadership Content	10 white papers @ 5 k (50 k); 2 case-studies (15 k); 2 motion-graphics/animation packs (40 k)	105,000
Digital Advertising Campaign	LinkedIn Ads 12 mo × 10 k (120 k); Google SEM 12 mo × 12 k (144 k); energy portals & retargeting 12 mo × 8 k (96 k)	360,000
PR Agency & Media Outreach	Energy-tech PR retainer 18 mo × 15 k (270 k); press-kit creation (15 k)	285,000
Analyst & Investor Relations	Subscription packages (60 k); briefing tour travel & collateral (20 k)	80,000
Flagship Product-Launch Event	Venue/production (150 k); travel & lodging for 100 VIPs (100 k); live-stream & media services (50 k)	300,000
Trade-Show & Conference Exhibitions	Custom booth design/build (80 k); floor-space 2 shows (100 k); staff travel (48 k); freight/drayage (12 k)	240,000
Webinar & Virtual Road-Shows	Platform 18 mo × 1.2 k (21.6 k); 8 webinars – production 5 k ea (40 k); promotion 5 k ea (40 k)	101,600
Pilot-Site Customer Visit Programme	PPE & safety gear (10 k); 20 visits × 3 k catering (60 k); travel subsidy for 50 orgs × 2 k (100 k)	170,000
Client Workshops & Demos	Sales-engineer travel 7 trips × 5 k (35 k); workshop materials (20 k)	55,000

Sales-Enablement Collateral	Datasheets (10 k); 3-D interactive/VR model (35 k); 8-min documentary video (50 k)	95,000
CRM & Marketing-Automation Stack	HubSpot Enterprise 24 mo × 3.2 k (76.8 k); implementation (25 k); ERP/SCADA integration middleware (15 k)	116,800
Government Affairs & Regulatory Liaison	Specialist consultancy 18 mo × 12 k (216 k); lobbying registration/compliance (15 k); policy brief creation (20 k)	251,000
Channel/Partner Programme	Legal & contract drafting (20 k); partner portal dev (30 k); training sessions/materials (25 k); initial incentive fund (100 k)	175,000
Sales-Force Build-out (Year 1)	Salaries/benefits: 4 AEs @ 160 k ea (640 k) + 2 Tech Sales @ 140 k ea (280 k); recruitment fees 20 % (184 k); onboarding & training (30 k)	1,134,000
Grid-Operator Integration Workshops	Curriculum development (20 k); 3 regional workshops @ 25 k ea (75 k)	95,000
Contingency (≈10 %)	Reserve for unforeseen GTM costs	388,400
Total		4,272,400

Total Estimated Marketing & Sales Cost: USD 4,272,400

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Other Expenses & Contingency

Expense Item	Justification	Estimated Cost (USD)
Bank Transaction & FX Fees	>1 400 supplier payments over 38 months will incur wire, SWIFT and currency-conversion charges (≈0.15 % of expected cash-outflow).	250,000
Specialized Consulting & Expert Peer Reviews	Independent rock-mechanics panel, sCO_2 turbine peer review, and cyber-security red-team exercises not covered in base engineering budget.	1,100,000

Builder's Risk & General Liability Insurance	Covers all on-site construction, drilling, RF equipment and third-party liability during 160-week build (≈2 % of insured CapEx).	2,500,000
Legal & IP Counsel	Contract drafting, IP filings for proprietary vitrification process, and ongoing regulatory advice.	650,000
Land Acquisition & Surface-Rights Easements	Purchase of 150 ac for plant, launch gallery, dry coolers and grid tie-in, plus utility easements.	1,500,000
Permitting & Regulatory Filing Fees	State geothermal well permits, RF emission licences, pressure-vessel certification, environmental impact filing charges.	750,000
Travel, Lodging & Field Per-Diem	Rotational travel for Bengaluru staff, vendor FAT witness trips and 30+ site-based workshops over 3.1 years.	900,000
Training & Operator Certification	OSHA HAZMAT, confined-space, RF safety, High-Pressure sCO_2 operations and emergency-response drills for 40 personnel.	300,000
External Audit & Quality Accreditation	ISO 9001, ISO 45001 certifications and annual third-party QA/NDE audits of liner integrity.	400,000
Site Security & Access Control	Fencing, CCTV network, badge system, 24 × 7 guard service during construction and early operations.	600,000
Project Office Rent & Utilities	Houston project office lease, utilities and janitorial services for the 160-week programme.	240,000
Corporate Shared-Services Overhead Allocation	Finance, HR, IT help-desk and executive support not captured in direct HR cost model.	800,000
Initial Critical Spare-Parts Inventory	Long-lead spares for gyrotron tubes, waveguide sections, high-temp seals and sCO_2 turbomachinery.	1,200,000

Interest During Construction (IDC)	Financing cost on average outstanding draw of USD 60 M at 5 % p.a. over 3 years.	9,000,000
Decommissioning Reserve (Net-Present)	Future obligation for well plugging, gallery closure and site restoration (≈1 % of CapEx).	1,200,000
Project Contingency Fund	12 % of uncovered cost categories to buffer schedule slips, supply shocks & scope growth for this high-complexity FOAK project.	15,000,000

Total Other Expenses & Contingency: USD 36,390,000

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Total Project Cost Summary

181,266,040 USD

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3-Year Post-Launch Revenue Projection

Key Assumptions

- Product sold: firm, zero-carbon electricity generated by the first LithoLoop 25 site owned and operated by GeoTherm20.
- Local currency: U.S. Dollars (USD) – selected because capital equipment, PPAs and competitor benchmarks are all normally quoted in USD.
- Plant build-out plan:
    - FOAK module = 200 MWe net (≈10 closed loops).
    - Additional 200 MWe of loops added during Year 2, commissioned at the start of Year 3.
- Capacity factors:
    - Year 1: 60 % (commissioning & learning curve).
    - Year 2: 90 % (steady-state for first 200 MWe).
    - Year 3: 92 % (mature operations across 400 MWe).
- PPA price locked at 75 USD/MWh (no escalation in real terms over the three-year window).
- No production-tax-credit or carbon-credit upside has been included – revenues reflect power sales only.

- Downtime for planned maintenance is already embedded in the capacity-factor figures.
- Average wholesale inflation is assumed to match the PPA indexation clause, keeping the real price flat.

Pricing Justification

1. Value to buyer: LithoLoop 25 delivers nuclear-class, 24/7 power without radiological risk. Utilities now routinely contract new nuclear or SMR output in the 90–120 USD/MWh range (e.g., Vogtle, Ontario SMR PPAs).
2. Competing renewables + storage: firmed wind/solar bids are clearing at 65–85 USD/MWh once four-hour batteries or long-duration storage are incorporated.
3. Strategic positioning: setting the price at 75 USD/MWh places GeoTherm20 below new-build nuclear and roughly on par with "firmed renewables," while comfortably above the 55–60 USD/MWh long-run levelized cost required for site-level IRR ≥12 %. The figure therefore balances competitiveness with early-stage risk and FOAK capital recovery needs.

Projection Table

Year	Average Net Capacity (MWe)	Capacity Factor	Energy Sold (MWh)	Price (USD/MWh)	Revenue (USD million)
1	200 MWe nameplate, ramping → 60 % utilisation → 120 MWe average	60 %	1,051,200	75	78.8
2	200	90 %	1,576,800	75	118.3
3	400	92 %	3,216,000	75	241.2

Final Justification

The forecast reflects a conservative FOAK learning curve followed by rapid duplication of proven well modules. Year 1 revenue is deliberately muted: only 60 % utilisation is assumed while drilling completes, controls are tuned and the O&M team climbs the reliability curve. By the start of Year 2 the initial 200 MWe block operates at a steady 90 % capacity factor, matching today's mature geothermal and nuclear fleets. Continuous drilling in parallel with operations allows the site to double to 400 MWe by Year 3, driving a two-fold jump in sales. No price escalation is projected because the 75 USD/MWh PPA already embeds indexation to general inflation, leaving real revenues flat while volumetric growth dominates the top line.

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ROI & Viability Analysis

Key Financial Metrics

1. Post-Launch Costs over 3 Years (all amounts in USD, rounded)

   - Year 1 (months 1–12) – O&M budget ≈ $3.6 M / yr → $0.30 M / mo
   - Year 2 (months 13–24) – O&M budget ≈ $4.0 M / yr → $0.33 M / mo
   - Year 3 (months 25–36) – O&M budget ≈ $5.0 M / yr → $0.42 M / mo

   Assumptions: Post-launch operating costs are estimated at 2 % of pre-launch CAPEX for the first 200 MWe block (Years 1–2). An additional 0.8 % of CAPEX is added in Year 3 when the plant doubles to 400 MWe, reflecting extra wells, staff and maintenance while preserving scale efficiencies.

2. Return on Investment (ROI) over 3 Years: ≈ 135 %

   Cumulative net cash-in (Revenue – O&M) Years 1-3 = (78.8 – 3.6) + (118.3 – 4.0) + (241.2 – 5.0) = $425.7 M
   Total pre-launch investment = $181.3 M
   ROI = (425.7 – 181.3) / 181.3 ≈ 1.35 → 135 %.

3. Estimated Payback Period: ≈ 23 months

   After Year 1 the project has recovered $75.2 M.
   Required balance $106.1 M is earned in ≈ 11.1 months of Year 2 (monthly net ≈ $9.5 M).
   Break-even cash date therefore falls late in month 23 after COD.

4. Break-Even Point Analysis
   At an all-in net margin of ≈ $71.5 per MWh (75 $ price – 3.5 $/MWh fixed O&M), the plant must sell roughly 2.5 million MWh to recover the initial $181 M outlay—equivalent to the forecast generation achieved just before the end of month 23.

Viability Statement

The three-year outlook indicates a highly attractive financial profile: the project repays its entire $181 M capital spend in under two years, then delivers a 135 % un-levered ROI by the close of Year 3. These results are driven by (a) a firm $75 /MWh power-purchase agreement that positions LithoLoop output below new-build nuclear while capturing a premium to bulk renewable prices, and (b) comparatively low operating costs (≈2 % of CAPEX annually) made possible by a closed-loop geothermal design with no fuel cost and minimal consumables.

Key dependencies and risks:

- Drilling & scale-up execution – timetable slippage or lower-than-planned capacity factors would defer payback.
- O&M cost containment – if post-launch costs trend toward the industry high end (≈3 % of CAPEX) the ROI would fall to ~110 %.
- Commodity price exposure – argon and refractory metals prices are volatile; future make-up requirements could raise long-run OPEX.
- Financing assumptions – analysis is un-levered. Debt service would lengthen the payback unless offset by tax shields or incentives.
- Policy / PPA stability – the 75 $/MWh tariff must hold in real terms; downward repricing would erode margins.

Subject to these considerations, the project is financially sound and appears well worth pursuing, with rapid capital recovery, strong cash generation and manageable operating risk provided execution milestones are met.

Go-To-Market Plan for LithoLoop 25

LithoLoop 25 is GeoTherm20's breakthrough closed-loop super-hot geothermal platform that taps 500-600 °C heat at unprecedented 25–30 km depths through vitrified, ultra-slender boreholes. By eliminating hydraulic stimulation, large tunnels and high-risk downhole electronics, LithoLoop 25 delivers nuclear-grade baseload power with minimal seismic or environmental footprint—setting a new benchmark for firm, zero-carbon energy.

Why the Market Needs LithoLoop 25

Utilities across OECD and advanced Asian markets face binding net-zero mandates, coal & nuclear retirements, and escalating grid-stability costs from variable renewables. LithoLoop 25 offers:

- 24/7 carbon-free baseload at projected LCOE < US $65/MWh.
- Modular 50-200 MW deployment blocks that integrate into existing generation portfolios.
- Closed-loop architecture that avoids induced seismicity and water consumption concerns.
- Rapid phased build-out—replicable wells sharing surface infrastructure drive down CAPEX.

Primary & Secondary Markets

Segment	Key Drivers
Early Adopters: Net-Zero-Mandated Utility Consortia	Urgent need for firm clean power to meet 2035-2045 targets; willing to co-invest in FOAK projects to showcase innovation leadership.
Early Majority: Compliance-Driven Cost-of-Service Utilities	Mandated coal phase-outs 2028-2032; demand proven, price-competitive baseload solutions with minimal public-perception risk.
Secondary: 24/7 Clean-Energy Buyers & High-Temp Industrial Hubs	Hyperscale data centres and green-hydrogen clusters seek geographically matched, round-the-clock clean power and 500-600 °C process heat.

Market Opportunity at a Glance

GeoTherm20 targets **10 GW** net capacity online by 2031—capturing **US $5.5 billion** in annual revenue (1.1 % of the SAM). Scaling to a 40 GW fleet by 2035 unlocks a **US $22 billion** revenue stream while

displacing ~240 million tCO_2/yr from coal and gas generation.

Strategic Path to Market

1. **Position & Prepare (Weeks 120-134):** craft brand narrative, launch SEO-optimised site, and deploy CRM foundation.
2. **Educate & Engage (Weeks 135-150):** release technical white-papers, 3-D explainer assets, and secure thought-leader channels.
3. **Seed Demand (Weeks 151-165):** brief analysts, lock trade-show slots, and curate pilot-site visits ahead of sales activation.
4. **Activate Revenue (Weeks 166-180):** recruit sales force, launch partner programme, and run multi-channel lead-gen campaigns.
5. **Launch & Accelerate (Weeks 181-195):** headline commissioning event, global media blitz, and pipeline conversion sprint.

This phased strategy aligns commercial momentum with engineering milestones, ensuring GeoTherm20 enters the market with validated technology, resonant messaging, and a surgically targeted customer pipeline—positioning LithoLoop 25 to redefine the baseload paradigm for a decarbonised world.

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Define brand narrative & positioning framework

This action plan equips the Chief Marketing Officer (CMO) with an unambiguous, day-by-day blueprint for building GeoTherm20's master brand narrative and positioning framework during Phase 1 (Weeks 120-124). Follow each step sequentially; do not skip, reorder, or compress tasks. All completion dates assume a standard Monday start for Week 120. Adjust only if executive leadership changes program-wide timelines.

Week	Primary Objective	Key Deliverables Due
Week 120	Kick-off, research commissioning, narrative skeleton	Discovery brief, research plan
Week 121	Competitive analysis, persona validation, narrative drafting	Competitive matrix, target-persona insight sheet
Week 122	Refine messaging pillars, create proof-point repository	Proof-point repository v1.0

Week 123	Build deck & elevator pitch, draft messaging matrix	6-slide deck v0.9, 1-page pitch v0.9, matrix v0.9
Week 124	Stakeholder reviews, iterate, obtain formal sign-off	Final deck, pitch, matrix, sign-off checklist

Step-by-Step Execution Plan

1. **Week 120 – Monday (Day 1): Kick-Off Alignment**
   1.1 Schedule a 90-minute project kick-off with CEO, CTO, VP Engineering, VP Sales, and Communications Director.
   1.2 Present task context and success criteria; secure consensus on deliverables, review budget (US$120 k) and allocate agency funds (US$90 k execution / US$30 k research).
   1.3 Appoint an internal “Messaging SWAT” (3-person squad: CMO, Senior Product Marketer, Market Research Lead) and define authority levels (CMO final sign-off).
   1.4 Open a dedicated workspace in Notion titled “Brand Narrative v1.0”; create folders: /Research, /Drafts, /Proof-Points, /Approvals.
   1.5 Publish a Slack #brand-positioning channel; post meeting notes and timeline.

2. **Week 120 – Tuesday (Day 2): Commission External Research**
   2.1 Draft a two-page research brief covering: *objective*, *target persona hypotheses*, *competitive frame*, *information gaps* (regulatory drivers, utility decision triggers), required outputs (10 interviews & secondary data).
   2.2 Issue the brief to pre-vetted energy market research agencies; request 24-hour proposals.
   2.3 Evaluate proposals same day; select agency with geothermal/utility expertise. Confirm NDA execution.
   2.4 Negotiate timeline: all raw interview transcripts delivered by Day 10 (Week 121 – Wednesday).
   2.5 Upload signed SOW and PO to /Research folder.

3. **Week 120 – Wednesday (Day 3): Narrative Skeleton Draft**
   3.1 Conduct a 2-hour whiteboard session with CTO & Lead Reservoir Engineer to map technology differentiators to four messaging pillars (feasible depth, nuclear-class output, low seismicity, modularity).
   3.2 Extract quantitative proof points (depth reached in pilot well, CAPEX per MW, seismicity studies). Document in /Proof-Points spreadsheet (columns: Pillar, Claim, Data Source, Verification Status).

3.3 Write a 300-word narrative skeleton including: *tension* (retiring baseload), *insight* (superhot geothermal unlock), *resolution* (GeoTherm20 offering). Save as "Narrative_Skeleton_v0.1".

3.4 Share skeleton link in Slack channel for async feedback.

4. **Week 120 – Thursday (Day 4): Discovery Brief Consolidation**

4.1 Merge kick-off notes, research brief, and skeleton into a master "Discovery Brief" (max 8 pages).

4.2 Circulate Discovery Brief to leadership for 24-hour review; request tracked comments only.

4.3 Log all incoming comments in Notion's "Feedback Log" table (fields: Commenter, Section, Severity, Resolution Owner, Deadline).

5. **Week 120 – Friday (Day 5): Feedback Integration & Lock-In**

5.1 Address critical comments; mark each as *Resolved* or *Deferred* in Feedback Log.

5.2 Publish Discovery Brief v1.0 (PDF) to /Drafts and lock editing permissions.

5.3 Email confirmation to executive team: Discovery Brief is now baseline; any scope changes require C-suite approval.

6. **Week 121 – Monday (Day 6): Competitive Landscape Deep-Dive**

6.1 Assign Senior Product Marketer to build a competitive matrix comparing GeoTherm20 vs SMRs, long-duration storage, hydraulic-stimulation geothermal across 10 criteria (CAPEX, OPEX, regulatory risk, scalability, etc.).

6.2 Populate data sources; cite DOE, IEA, vendor datasheets. Complete first draft by EOD.

6.3 Upload "Competitive_Matrix_v0.8.xlsx" to /Research.

7. **Week 121 – Tuesday (Day 7): Persona Validation Interviews Begin**

7.1 Send agency interview guide for CMO approval; ensure questions capture adoption criteria, budget triggers, and decarbonization mandates.

7.2 Receive and review first two interview transcripts; extract verbatims relevant to each messaging pillar and tag in Proof-Points sheet.

7.3 Schedule daily 30-minute check-ins with agency until Day 10 delivery complete.

8. **Week 121 – Wednesday (Day 8): Narrative Drafting Session**

8.1 Based on competitive matrix and early persona insights, expand skeleton to full 1-page elevator pitch draft v0.5 (headers: Challenge, Solution, Evidence, Call to Action).

8.2 Share draft in Slack; request inline comments by next morning.

8.3 Update Proof-Points repository with any new quantitative claims used in the pitch.

9. **Week 121 – Thursday (Day 9): Competitive Matrix Finalization**

9.1 Apply leadership feedback; freeze Competitive Matrix v1.0.
9.2 Designate objectively weakest competitor claim areas; highlight for later slide visuals.
9.3 Export high-resolution PNG of the matrix for deck insertion; store in /Assets.

10. **Week 121 – Friday (Day 10): Research Package Delivery & Analysis**
    10.1 Receive remaining interview transcripts and agency summary report.
    10.2 Run a 3-hour insights workshop: *Read-out → Affinity Mapping → Key Themes*.
    10.3 Distill top five utility purchasing drivers; update Messaging Matrix "Pain/Benefit" columns.
    10.4 Archive raw transcripts securely (GDPR & CCPA compliant) in /Research/Raw.
    10.5 Approve agency invoice for payment processing.

11. **Week 122 – Monday (Day 11): Messaging Pillar Refinement**
    11.1 Cross-reference interview findings with existing four pillars; revise language for engineering pragmatism (e.g., swap "Nuclear-class output" → ">95% CF baseload output, nuclear-class scale").
    11.2 Add a "Risk Mitigation" sub-pillar if data shows high concern about induced seismicity.
    11.3 Update Messaging Matrix v0.7, including column for *Proof Point ID*.

12. **Week 122 – Tuesday (Day 12): Proof-Point Repository v1.0**
    12.1 Gather all quant and qualitative evidence (pilot bore logs, third-party studies, customer quotes).
    12.2 For each proof point, fill metadata: Source, Date, Pillar, Confidence Score (1-5).
    12.3 Perform a two-person data verification spot-check on 20% of entries; mark Verified/Unverified.
    12.4 Publish repository v1.0; lock editing except for Research Lead.

13. **Week 122 – Wednesday (Day 13): Story Arc Workshop**
    13.1 Facilitate 2-hour virtual workshop using Miro: map *Beginning (Urgency) → Middle (GeoTherm20 Breakthrough) → End (Zero-Carbon Baseload Future)*.
    13.2 Vote with leadership on 3 alternative thematic angles; select winning arc by majority vote.
    13.3 Document final story arc storyboard (6 frames) in PDF for deck use.

14. **Week 122 – Thursday (Day 14): Visual Language Brief**
    14.1 Write a one-page visual brief: color usage (dark blue primary), imagery (engineer-centric), infographic style (technical line art).
    14.2 Deliver brief to brand agency; set turnaround for deck templates by Day 18.
    14.3 Confirm the brief aligns with global brand guidelines.

15. **Week 122 – Friday (Day 15): Progress Review Checkpoint**

15.1 Hold 30-minute C-suite status meeting; demonstrate repository, matrix, narrative progress.

15.2 Capture any directional feedback; log in Feedback Log with Day 17 resolution deadline.

16. **Week 123 – Monday (Day 16): Deck Outline Construction**

16.1 Define slide titles: 1) Context, 2) Problem, 3) GeoTherm20 Solution, 4) Proof, 5) Competitive Advantage, 6) Call to Action.

16.2 Draft bullet hierarchy for each slide directly in Google Slides template placeholder.

16.3 Insert Competitive Matrix PNG on Slide 5; add caption citing sources.

17. **Week 123 – Tuesday (Day 17): Elevator Pitch & Deck Copy v0.9**

17.1 Finalize 250-word elevator pitch; apply engineer-to-engineer tone, avoid adjectives lacking data.

17.2 Drop pitch text onto Slide 3 “Solution” and in standalone 1-pager (A4, PDF).

17.3 Send both assets to legal for compliance wording check (24-hour SLA).

17.4 Close feedback items flagged in Day 15 status meeting.

18. **Week 123 – Wednesday (Day 18): Design Integration**

18.1 Receive brand agency slide template; apply to deck, ensuring font (Montserrat or system fallback), primary color #003359.

18.2 Review contrast ratios for accessibility; tweak colors if contrast <4.5:1.

18.3 Export Deck v0.9 PDF; upload to /Drafts.

19. **Week 123 – Thursday (Day 19): Messaging Matrix v0.9**

19.1 Complete remaining columns: *Persona Pain*, *Message*, *Proof Point ID*, *Asset Examples*.

19.2 Run consistency check: every pillar must map to at least two proof points and one slide.

19.3 Circulate to Sales Enablement Lead for review; collect redlines by next day.

20. **Week 123 – Friday (Day 20): Dry-Run & Pre-Review**

20.1 Conduct a 45-minute internal pitch rehearsal (CMO presenting) with Sales, Engineering, and CEO observers.

20.2 Capture live feedback (clarity, data sufficiency, flow). Record session.

20.3 Summarize feedback and tag as Critical/Major/Minor; set fix deadline Day 22.

21. **Week 124 – Monday (Day 21): Final Iterations**

21.1 Address all Critical and Major feedback in deck, pitch, matrix.

21.2 Verify legal-approved wording is integrated; obtain written clearance email.

21.3 Update Proof-Points repository references where wording changed.

22. **Week 124 – Tuesday (Day 22): Formal Stakeholder Review**
    22.1 Distribute “Sign-Off Packet” (Deck v1.0, Pitch v1.0, Matrix v1.0) via DocuSign PowerForms.
    22.2 Include Sign-Off Checklist: Accuracy, Compliance, Brand, Strategic Fit, Executive Approval.
    22.3 Require electronic signatures from CEO, CTO, VP Sales, VP Engineering, General Counsel within 48 hours.

23. **Week 124 – Wednesday (Day 23): Contingency Buffer**
    23.1 If any stakeholder rejects an item, schedule a 30-minute conflict-resolution call same day.
    23.2 Document agreed fixes and implement within 24 hours.
    23.3 Issue revised asset version numbers (v1.1, v1.2 as needed).

24. **Week 124 – Thursday (Day 24): Archive & Disseminate**
    24.1 Move final signed assets into corporate SharePoint “Master Messaging” directory.
    24.2 Tag assets with metadata: Version, Owner, Validity Period (12 months), Next Review Date (Week 172).
    24.3 Notify entire company via email & Slack with link to assets; emphasize “single source of truth”.

25. **Week 124 – Friday (Day 25): Post-Mortem & KPI Logging**
    25.1 Hold 1-hour retrospective with Messaging SWAT to document lessons learned: What Worked, What Didn’t, Improvement Ideas.
    25.2 Record metrics: budget consumed, # stakeholder revisions, on-time % milestones.
    25.3 Publish retrospective summary; schedule six-month health check (Week 150) to validate narrative efficacy.

Upon successful completion of Step 25.3, the “Define brand narrative & positioning framework” task is officially closed, and the Phase 1 Strategic Positioning milestone is achieved.
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# Create visual identity & brand guidelines

Responsible Role: **Brand & Creative Director – P-BCD-02**

# 1. Executive Summary
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This manual decomposes the 8-week mandate (Phase 1, Weeks 120–128) into an explicit, sequential work plan. Follow every action exactly; do not skip, merge, or reorder steps unless CMO provides written approval.

2. Objectives

- Create a distinctive visual identity that passes WCAG 2.1 AA, scales from hard-hat decals to 4 m trade-show backdrops, and reads clearly against thermal-imagery.
- Produce a fully codified brand-guideline portal and downloadable asset kit.
- Deliver templates for white papers, datasheets, social posts, and CAD overlays.
- Stay within US$120 k budget envelope.

3. Final Deliverables

1. Primary & secondary logo files (SVG, EPS, PNG, DWG)
2. Color palette swatches with HEX, RGB, CMYK, Pantone values
3. Typography stack (web & print) with license documentation
4. Icon library: vitrified bore, closed loop, sCO_2 cycle
5. WCAG 2.1 AA compliance report
6. Templates: white paper (Word/InDesign), datasheet (Illustrator), social post (Figma 1:1 & 16:9), CAD overlay (DXF layer set)
7. Brand-guideline portal (Notion or Frontify) with modular sections & downloadable asset kit

4. Budget Guardrails (US$120 k)

Category	Allocation	Notes
Design Sprints (external agency)	$60 k	2×three-week sprints
Asset Production & Testing	$25 k	Prototyping, user tests
WCAG Audit	$5 k	External accessibility partner
Portal Development	$15 k	Frontify annual license
Contingency (10%)	$15 k	Reserve – CMO sign-off required to draw

5. Weekly Action Plan (Weeks 120-128)

Week 120 – Kick-off & Discovery

1. Hold 90-min internal briefing (Brand & Creative Director + CMO) to reaffirm scope, success metrics, decision gates.
2. Issue RFP to three pre-vetted design agencies; include technical requirements (thermal-imagery legibility, hard-hat decal scaling, WCAG compliance).
3. Book exploratory interviews with:
    - Utility consortium reps (2)
    - Investor relations lead (1)
    - Field operations supervisor (hard-hat decal test)
4. Compile competitive visual audit (10 geothermal/energy tech firms) inside shared Figma board.
5. Create Notion project workspace; load timeline, budget tracker, & stakeholder directory.

Week 121 – Agency Selection & Research Synthesis

1. Review agency proposals against criteria matrix (expertise, process, budget, timeline fit).
2. Select agency; draft & sign SOW and NDA by EOD Friday.
3. Deliver compiled research pack to agency: competitive audit, technology diagrams, stakeholder interview transcripts.
4. Set up shared Slack channel & Figma permissions for agency team.

Week 122 – Sprint 1 / Concept Ideation

1. Day 1: Run remote design sprint kickoff (4 hrs) – define “How might we” statements.
2. Day 2-3: Agency produces 3 distinct visual territories (mood boards, color preliminaries, type pairings).
3. Day 4: Internal review with Brand & Creative Director; consolidate feedback.
4. Day 5: Utility representative feedback session (1 hr) focusing on industrial application legibility.
5. End-of-week deliverable: PDF deck of 3 territories + feedback log uploaded to Notion.

Week 123 – Sprint 1 / Logo & Icon Prototype

1. Agency refines preferred territory into 5 logo directions (monochrome only).
2. Create initial icon sketches for vitrified bore, closed loop, sCO_2 cycle; ensure geometric consistency.
3. Conduct WCAG contrast pre-check using WebAIM tool; log values in spreadsheet.
4. Print 3” hard-hat decals & mock 4 m booth banner; perform distance-legibility test at 10 m & 30

m.

5. Internal decision gate: select top 2 logo directions; approve continued refinement.

Week 124 – Sprint 2 / Color, Typography, Accessibility

1. Develop full color palette (primary, secondary, neutrals, alert states). Test against thermal-imagery backgrounds (5 sample frames).
2. Select typography stack:
    - Web: Google Fonts (e.g., Inter) – Open license
    - Print: Commercial font (e.g., Neue Haas Grotesk) – procure 10-user license
3. Run full WCAG 2.1 AA audit on color & type combinations; record any failures & iterate.
4. Establish numerical naming convention for colors & typography styles.
5. Prepare interim presentation deck for CMO checkpoint on Friday; document decisions.

Week 125 – Sprint 2 / Final Logo & Icon Lock-in

1. Agency finalises single logo master: horizontal & stacked variants, positive & reversed.
2. Create full icon set (stroke & filled) with 24 px, 48 px, 96 px grid-fit exports.
3. Generate master artwork files (AI, SVG) and version control in Git repository.
4. Legal clearance: run trademark search via legal counsel; flag conflicts.
5. CMO approval meeting; obtain sign-off signature in Notion.

Week 126 – Asset Production & Template Engineering

1. Design templates:
    - White paper (Word & InDesign): 12-page base
    - Datasheet (Illustrator): 2-page front/back
    - Social post (Figma): 1080×1080 & 1920×1080 components
    - CAD overlay: DXF layer styles + color keys
2. Populate each template with placeholder content for fit tests.
3. Run print proofs for white paper & datasheet at in-house printer; verify color accuracy (Pantone swatches).
4. Handoff files to engineering for CAD overlay integration test; collect any layer/line-weight feedback.

Week 127 – Guideline Portal Build & QA

1. Configure Frontify:
    - Sections: Brand Story, Logos, Color, Typography, Iconography, Templates, Do/Don't, Downloads
    - Enable SSO with corporate Azure AD
2. Upload final assets; embed WCAG audit report.
3. Set permission tiers: Viewer (all staff), Editor (Marketing), Admin (Brand & Creative Director).
4. QA checklist:
    - All downloads function
    - Color HEX codes match spec
    - Auto-resize scales images without blurring
5. Send 10-user beta invite; collect bug reports in Notion kanban.

Week 128 – Final Review, Training & Launch

1. Conduct 60-min live training webinar (recorded) for Marketing & Sales teams; cover logo misuse scenarios, template instructions.
2. Publish brand-guideline portal URL on internal intranet.
3. Distribute asset kit ZIP via secured SharePoint link.
4. Close project: archive Figma files, lock Git repo, finalise budget report (actual vs. forecast).
5. Post-mortem meeting: document lessons learned; log in continuous-improvement register.

6. Risk Management & Contingencies

Risk	Mitigation	Owner
Agency over-run on scope	Hard cap hours in SOW; weekly burndown review	Brand & Creative Director
WCAG audit fails	Allocate 5% schedule buffer for color tweaks	Accessibility partner
Trademark conflict	Early legal screening (Week 125) before asset production	Legal Counsel

7. Approval Workflow

1. Each weekly deliverable uploaded to Notion within 2 hrs of completion.
2. Brand & Creative Director signs first; then routes to CMO for final approval within 48 hrs.
3. No asset may enter production without recorded CMO sign-off.

8. Success Metrics

- 100% of visual assets meet WCAG 2.1 AA.
- Stakeholder satisfaction ≥8/10 in post-project survey.
- Portal adoption: ≥90% of Marketing & Sales log in within first month.
- Project delivered ≤120 k budget and ≤8-week timeline.

```

## Re-engineer corporate website with technical SEO

# 1. Executive Summary

This manual provides an exhaustive, week-by-week action plan for the SEO & Web Manager (Role ID: P-SWM-05) to re-engineer GeoTherm20's corporate website on a headless architecture, fully optimised for Core Web Vitals and deep technical SEO. All steps align with Phase 1 (Weeks 121-132) of the go-to-market programme.

# 2. Objectives

- Create a performance-optimised, headless React/Next.js site served via CDN with LCP <2.5 s and CLS <0.1.
- Rank Top 3 for 50 mapped technical-intent keywords (e.g., "superhot geothermal baseload").
- Generate qualified leads by integrating gated assets through HubSpot, feeding contact intelligence into CRM and sales workflows.
- Deliver 25 conversion-focused landing pages, full sitemap, structured data, analytics dashboard and hand-off documentation within the US$200 k budget.
```

- Achieve GDPR, CCPA and WCAG 2.1 AA compliance.

3. High-Level Milestones

Week	Milestone	Acceptance Criteria
121	Kick-off, full legacy audit, tech stack confirmed	Audit doc approved by CMO & CTO
122-123	IA, keyword map, UX wireframes, tech spec	Signed-off sitemap, 50-keyword matrix, annotated wireframes
124-129	Build sprint, component library, CMS, integrations	All pages reachable in staging; automated deploy pipeline green
130	Accessibility & compliance audits	WCAG 2.1 AA, GDPR, CCPA test reports pass
131	Performance & SEO QA	Lab & field CWV pass; Lighthouse SEO >95
132	Production launch & hyper-care	Zero-error deploy; analytics dashboard live; first leads captured

4. Detailed Step-by-Step Plan

Week 121 – Kick-Off & Legacy Audit

1. Schedule cross-functional kick-off meeting (SEO & Web, Engineering, Content, Legal, Sales Ops) and circulate agenda.
2. Export full URL inventory of current geotherm20.com using Screaming Frog. Include meta data, traffic, backlinks.
3. Benchmark current Core Web Vitals via PageSpeed Insights API and compile baseline report.
4. Audit existing CMS, hosting, security posture; flag migration blockers.
5. Hold budget alignment session with Finance; lock US$200 k line items by category (UX, build, SEO, hosting).
6. Publish shared project tracker in Jira; create epics and 2-week sprints.

Week 122 – Information Architecture & Keyword Mapping

1. Cluster 50 target keywords into awareness, consideration, decision groups using Ahrefs KD, SERP intent.
2. Create sitemap v1: 25 planned landing pages + core institutional pages.
3. Map each keyword to a specific page, URL slug, H1, meta title (≤60 chars) and meta description (155-160 chars).
4. Validate sitemap with Sales Director to confirm alignment with buyer journey.
5. Document internal linking plan (anchor text, parent/child relationships).

Week 123 – UX Wireframes & Technical Specification

1. Produce low-fidelity wireframes for homepage, product, resources, gated landing page, newsroom using Figma.
2. Run 2 utility-sector stakeholder interviews to confirm information priorities.
3. Draft high-level technical spec covering:
    - Next.js v14, React 18, ISR strategy.
    - CDN provider (e.g., Vercel Edge Network) + fallback to global PoPs.
    - WCAG 2.1 AA compliance requirements.
    - CI/CD pipeline (GitHub Actions).
4. Confirm spec with CTO; capture change requests.
5. Freeze IA & wireframes after sign-off.

Week 124 – CMS & Content Modelling

1. Create Contentful space; set up environments (master, staging, prod).
2. Define content types:
    - Page (with SEO fields, OpenGraph, JSON-LD slot).
    - Post, Event, Whitepaper, FAQ, Case Study.
3. Configure role-based permissions (Marketing Editors, Legal Review, DevOps).
4. Establish webhooks to trigger Vercel builds on publish.
5. Import existing blog posts and assets; map redirects in `/redirects.json`.

Week 125 – Design System & Component Library

1. Translate approved wireframes into high-fidelity designs adhering to GeoTherm20 brand palette.
2. Build reusable Next.js components (Header, Footer, Hero, Accordion, Data-Table, Form, CTA).
3. Implement global CSS with Tailwind or CSS-in-JS; ensure critical CSS inlined.
4. Set up Storybook; document props and variant guidelines.
5. Peer-review component performance with Lighthouse CI in PR workflow.

Week 126 – Performance Engineering & Core Web Vitals

1. Enable Next.js Image component with AVIF/WebP, smart cropping.
2. Implement script & font optimisation:
    - Defer non-critical scripts; use `<link rel="preload">`.
    - Self-host critical fonts; use `font-display: swap`.
3. Set up automated CWV monitoring (Calibre or SpeedCurve) for staging URLs.
4. Configure edge caching rules: HTML 0 s stale-while-revalidate, assets 365 d.
5. Run stress test (k6) to validate TTFB <200 ms at 1k RPS.

Week 127 – Structured Data & Schema Implementation

1. Create schema templates (JSON-LD) for:
    - FAQPage, TechArticle, Whitepaper (CreativeWork), Event.
2. Embed dynamic schema injection via Next.js `<Script type="application/ld+json">`.
3. Validate in Google Rich Results Test; fix warnings.
4. Generate automated tests to flag schema drift on deploy.

Week 128 – On-Page SEO & Content Migration

1. Populate 25 landing pages with optimised copy, H1-H3 tags, internal links.
2. Apply rel=canonical, hreflang (en-US, en-GB, ja-JP) tags as required.
3. Compress images ≤100 KB, ensure descriptive alt text.
4. Create robots.txt and XML sitemap auto-publish hook.
5. Bulk-upload redirects to Vercel `vercel.json` for legacy URLs.

Week 129 – CRM & Marketing Automation Integration

1. Embed HubSpot forms on gated assets; enable invisible reCAPTCHA v3.
2. Map form fields to CRM objects: Company, Contact, Deal.
3. Configure progressive profiling: second-visit requests “Utility capacity planning horizon”.
4. Set up webhook to Sales Ops Slack channel for high-value downloads.
5. Test end-to-end journey: form submission CRM lead score sales notification.

Week 130 – Accessibility & Compliance

1. Run axe-core, WAVE and Lighthouse accessibility audits; remediate errors until WCAG 2.1 AA score ≥ 95 %.
2. Implement cookie consent banner (IAB TFC v2.2 compliant) with opt-in categories.
3. Update privacy policy page to reflect data processing, retention, DSR procedures.
4. Conduct GDPR/CCPA legal review with counsel—capture sign-off document.

Week 131 – Pre-Launch QA

1. Execute full regression test suite (Cypress) across Chrome, Firefox, Safari, Edge, mobile.
2. Validate CWV in field (CrUX) – confirm LCP <2.5 s, CLS <0.1, FID <100 ms.
3. Run screaming-frog crawl; ensure no 4xx/5xx, duplicate titles.
4. Perform security scan (OWASP ZAP) – close critical findings.
5. Hold go-no-go meeting; secure sign-offs from CMO, CTO, Legal.

Week 132 – Launch & Hyper-Care

1. Switch DNS A records to Vercel production target at low-traffic window (02:00 UTC).
2. Verify SSL certificates propagate; confirm 200 response via curl.
3. Submit updated sitemap in Google Search Console & Bing Webmaster.
4. Activate real-time dashboards (GA4, HubSpot, Calibre) and monitor for anomalies for 72 h.
5. Issue press release linking to newsroom URL to accelerate indexing.
6. Document post-launch report and schedule lessons-learned workshop.

5. Resource Allocation

Role	FTE Weeks	Key Responsibilities
SEO & Web Manager (P-SWM-05)	12	Owns project, coordinates vendors, ensures KPIs.
UX Designer	3	Wireframes & high-fidelity designs.
Front-End Engineer (2)	10 each	Build components, performance tuning.
SEO Specialist	6	Keyword research, on-page, schema.
QA & Accessibility Engineer	3	Testing & compliance.

6. Risks & Mitigation

- **Scope creep:** Freeze requirements by Week 123; any additions require written change request and impact analysis.
- **Performance regressions:** CI pipeline blocks merge if CWV metrics exceed thresholds.
- **Compliance failure:** Conduct dual legal review (internal & external) Week 130.
- **DNS propagation delays:** Use low-TTL settings (300 s) 48 h pre-launch.

7. Final Acceptance Criteria

1. All live pages load with LCP <2.5 s, CLS <0.1 on 3G simulated network.
2. Index coverage in GSC shows zero errors within first 7 days.
3. HubSpot captures ≥5 qualified leads in first 30 days.
4. Top 10 ranking for ≥15 target keywords within 60 days post-launch.
5. Signed hand-off package (code, documentation, analytics credentials) stored in Confluence.

```html
## Deploy CRM (HubSpot) & marketing-automation stack
```

1. Purpose

Establish a fully operational HubSpot Enterprise environment—including data schema, integrations, automations, security, and reporting—during Phase 1 (Week 126-134) of the GeoTherm20 GTM program. The CRM will capture, score, and route every prospect touchpoint, benchmarking baseline engagement before major campaigns and ensuring clean revenue attribution.

2. Scope & Deliverables

- HubSpot Enterprise license activated and assigned.
- Custom objects: Utility Consortium, Pilot Site, Regulatory Body.
- Integrations: website forms, ZoomInfo enrichment, PowerBI, ERP “deal-value handshake.”
- MQL Scoring Model live (firmographic + engagement signals).
- Role-based access with MFA enforced.
- Baseline dashboards (engagement, pipeline velocity, attribution) published to PowerBI.
- Admin & user training complete; playbooks documented.

3. Week-by-Week Action Plan (Week 126-134)

Week	Primary Objectives	Responsible	Key Deliverables
126	• Kick-off; align with Marketing Ops & IT. • Purchase/assign HubSpot Enterprise licences. • Define data-governance charter (naming, field usage, deduplication rules). • Draft high-level data architecture incl. custom objects.	CRM Admin Marketing Ops Lead IT Security	Kick-off minutes; licence receipt; data charter v1; architecture diagram.
127	• Build standard objects (Companies, Contacts, Deals) field map. • Create custom objects (Utility Consortium, Pilot Site, Regulatory Body). • Configure unique IDs & associations. • Establish staging sandbox; import *no live data* yet.	CRM Admin	Custom objects active; staging instance URL.
128	• Integrate website forms (HubSpot tracking script, hidden UTM capture). • Connect ZoomInfo: set enrichment cadence & overwrite rules. • Authenticate ERP API; map “Deal Value (validated)” field	CRM Admin Web Dev ERP Analyst	Integrations live in sandbox; MQL scoring draft.

	(validated)" field. • Draft MQL scorecard logic.		
129	• Configure MFA; set role-based permissions matrix. • Implement GDPR & CCPA consent mechanisms. • Finalise MQL scoring model (firmographic: portfolio >500 MW, net-zero ≤2045; engagement: ≥3 high-intent activities). • Build automated lead routing workflows to SDR queue.	CRM Admin IT Security	Security audit report; Scoring model live (sandbox); routing workflows v1.
130	• Connect PowerBI via HubSpot API; build baseline dashboard templates. • Stress-test data flows with synthetic records. • Validate ERP "deal-value handshake" accuracy ±0.5%. • Prepare migration scripts for historical data (if any).	Data Analyst CRM Admin	PowerBI connection string; dashboard templates; stress-test log.
131	• User Acceptance Testing (UAT) with 5 SDRs & 2 AEs. • Capture defects; iterate workflows & permissions. • Lock final data schema; enable deduplication rules. • Freeze sandbox for prod push.	CRM Admin Sales Ops	UAT sign-off sheet; defect log resolved.
132	• Promote configuration to production instance. • Run historical data migration (if approved). • Activate live integrations; monitor error logs 24 h. • Trigger initial PowerBI refresh; validate metrics parity.	CRM Admin Data Analyst	Production environment live; migration report; error-free sync.
133	• Conduct role-based training (Admin, SDR, AE, Marketing). • Distribute quick-reference playbooks (PDF & LMS upload). • Launch "soft open" live capture with marketing test offers. • Collect first-week baseline engagement data.	CRM Admin L&D Specialist	Training attendance log; playbooks; baseline dataset.
134	• Review baseline metrics; confirm data integrity (no leakage). • Hold go/no-go with Marketing & Sales leadership. • Finalise Phase 1 budget reconciliation (US$116.8 k vs. actual). • Archive documentation; handover to Campaign Ops for Phase 2.	CRM Admin Finance Ops	Sign-off memo; budget variance report; complete documentation set.

4. Detailed Daily Checklist – Week 126

1. **Day 1:** Kick-off call (60 min). Confirm objectives, success metrics, and stakeholders. Record decisions.
2. **Day 2:** Purchase HubSpot licences; provision admin accounts; enable MFA immediately.
3. **Day 3:** Draft data-governance charter; circulate for comments.
4. **Day 4:** Map required fields & naming conventions; review with Marketing Ops.
5. **Day 5:** Finalise high-level data architecture; secure IT approval to proceed.

5. Governance & Security Controls

- MFA mandatory for all user tiers.
- Least-privilege access: SDRs (read/write Contacts), AEs (read/write Deals), Marketing (workflow edits), Finance (read-only deal values).
- Quarterly permission audit scheduled.
- GDPR/CCPA compliance: double-opt-in, data-deletion SLA = 30 days.

6. Budget Control (US$)

Item	Allocated	Actual	Variance
HubSpot Enterprise (24 mo)	76,800	TBD	—
Implementation & Middleware	40,000	TBD	—

7. Risk Register & Mitigation

- **Data Leakage:** Mitigate via MFA, role-based permissions, audit logs.
- **Integration Failure:** Stage in sandbox; parallel run 48 h; rollback plan ready.
- **Scope Creep:** Lock data schema by Week 131; any change requires Change Request form.
- **Budget Overrun:** Weekly burn-rate review with Finance Ops.

8. Approval Matrix

Deliverable	Approver	Approval Deadline

Data-Governance Charter	VP Marketing	End Week 126
MQL Scoring Model	Sales Director	End Week 129
Production Go-Live	CTO	End Week 132

9. Post-Deployment Metrics (to be captured Week 133-134)

- Form-fill to CRM latency <3 sec (P95).
- Data-enrichment success rate ≥90%.
- MQL conversion accuracy (manual audit) ≥95%.
- Dashboard refresh latency <15 min.

10. Primary Contacts

- **CRM Administrator (P-CRM-21):** crm.admin@geotherm20.com
- **IT Security Lead:** itsec@geotherm20.com
- **Marketing Ops:** mops@geotherm20.com

```

## Author flagship technical white-paper series (10)

The following is a **single, exhaustive, and unambiguous action plan** for the Content Strategist – P-CS-06 to deliver ten peer-reviewed technical white papers (WP01-WP10) during Phase 2, Weeks 135-145. Execute each action in the exact order listed. No deviations, additions, or omissions are permitted.

| # | Week | Action | Deliverable | Dependencies / Notes |
|---|---|---|---|---|
| 1 | 134 (T-7 days) | Secure US$50 k budget line item in NetSuite, assign cost centre “Thought-Leadership → White Papers”. | Budget code and PO# issued. | Approval from CFO required before Week 135. |
```

2	135 Mon 08:00	Create master “LithoLoop 25 White-Paper Series Plan” in Asana with ten separate tasks WP01-WP10 and attached this action plan.	Asana project URL.	Link to GTM master schedule.
3	135 Tue 10:00	Download IEEE template; customise with GeoTherm20 branding (logo top-left, accent colour #003359) and fixed sections: Executive Summary, Body (6-8 headings), LCOE Model Appendix, References, Author Bios.	“GT20_IEEE_WP_Template_v1.docx”.	Save on SharePoint & link in Asana.
4	135 Tue 15:00	Recruit 3-member Technical Review Board (TRB): CTO, External Professor (petrophysics), External Analyst (Lazard). Obtain NDAs and availability for two review rounds per paper.	Signed NDAs + calendar holds Weeks 137 & 140.	Legal to countersign NDAs.
5	135 Wed 09:00	Schedule 60-min series kickoff call with SME leads (drilling, materials, thermodynamics, finance, regulatory, ESG). Distribute outline and deliverables.	Kickoff agenda & Zoom recording.	Ensure all SMEs receive template.
6	135 Thu-Fri	Gather and catalogue existing lab data, LCOE models, CAD diagrams, and field-test photos in SharePoint	Curated, tagged source library.	No gaps >10% tolerated; escalate missing data.

		“WhitePaper_Source”. Tag per WP.		
7	136 Mon-Wed	Draft detailed 1-page abstract for each WP01-WP10; include 5 SEO keywords and proposed DOI slug.	10 abstract docs (.docx) + keywords sheet (.xlsx).	Send to SEO manager for keyword validation within 24 h.
8	136 Thu	Register provisional DOIs via CrossRef for each abstract; store confirmation emails.	10 DOI registration receipts.	List DOIs in metadata sheet.
9	136 Fri EOD	Lock chapter outlines for all papers; assign lead author & two co-authors per WP in Asana.	Approved outlines PDF.	TRB sign-off required before drafting.
10	137 Mon-Fri	Author full first drafts (12-15 pp each) following IEEE style; embed figures, equations, and LCOE sensitivity graphs. Daily check-ins 09:00.	10 draft manuscripts v0.1.	Use Overleaf to enforce citation style.
11	138 Mon-Tue	Run Grammarly and iThenticate plagiarism checks; target	Compliance reports attached to each manuscript.	Flag >3% to legal immediately.
12	138 Wed-Fri	Send drafts to TRB round 1; supply review form (clarity, technical accuracy, commercial coherence). Collect comments by Friday 17:00.	TRB comment matrix (.xlsx).	No extensions; escalate late reviews.
13	139 Mon-Thu	Incorporate TRB feedback; refine figures to 300 dpi; verify all references (minimum 25 per paper) are in IEEE style.	Manuscripts v0.8.	Attach change-log.

14	139 Fri 09:00	Send refined drafts to Marketing Design for PDF layout (fonts, colour scheme, header/footer, alt-text).	InDesign package folder.	Follow brand guidelines v3.2.
15	140 Mon	Receive formatted PDFs; perform final QA checklist (TOC links, figure numbering, DOI on cover).	QA checklist signed.	Fix defects within 24 h.
16	140 Tue-Wed	Send PDFs to TRB round 2 for final approval; require sign-off by Wed 17:00.	TRB approval emails.	No technical changes allowed post-approval.
17	140 Thu	Publish final PDFs to HubSpot file manager; set gated form requiring email, company, role, project timeline.	Live gated landing pages (10 URLs).	Integrate with Salesforce lead workflow “WhitePaper_Download”.
18	140 Fri	Upload PDFs and metadata (title, authors, abstract, DOI) to Zenodo; enable Creative Commons BY-NC-ND license.	10 Zenodo records.	Link Zenodo DOI to CrossRef.
19	141 Mon-Wed	Draft promotional assets: 10 LinkedIn posts, 10 tweet threads, 10 analyst-pitch emails. Include UTM parameters.	Promo copy deck (.pptx).	Get CMO approval.
20	141 Thu	Schedule HubSpot email blast to existing early-adopter utility list (2 k contacts) with A/B subject lines.	Email campaign set live for 08:00 Friday.	Set KPI: 25% open, 8% CTR.
21	142 Fri-Sun	Monitor campaign performance; adjust CTA copy if CTR	Performance dashboard screenshot.	Escalate to CMO if KPIs missed.

22	143 Mon-Tue	Export new leads from HubSpot daily; push to Salesforce campaign “WP_Series_Q3”. Assign SDR owner in territory.	Synced lead list.	Verify sync logs error-free.
23	143 Wed-Fri	Conduct 30-min enablement session with SDR team: positioning, top objections, follow-up cadence.	Enablement deck & recording.	Attendance >90% mandatory.
24	144 Mon-Thu	Compile post-launch analytics: downloads, leads generated, top geo markets, analyst citations (Google Scholar alerts).	White-Paper KPI Report v1.0.	Submit to exec staff meeting Week 145.
25	145 Mon	Archive final source files, TRB approvals, and analytics report in SharePoint “WP_Series_Archive”. Set retention 7 years.	Signed completion checklist.	Notify Compliance & Knowledge Mgmt.
26	145 Tue 09:00	Conduct 30-min retrospective with TRB, SMEs, Marketing; document lessons learned and optimisation proposals for next content cycle.	Retrospective minutes.	Log in Confluence.

Mandatory Success Criteria

- All ten papers published by 17:00 Week 140 Friday.
- Each paper length 12-15 pages; ≥25 IEEE references; DOI registered and displayed.
- Lead-generation target: ≥750 net-new utility/analyst leads by end of Week 144.
- Peer-review cycle completed with zero outstanding technical objections.
- Total spend ≤US$50 000 (track in NetSuite).

Escalation Path

If any action is blocked for >24 h, immediately notify (1) CMO, (2) CTO, and (3) Programme Director via Slack #wp-series-alerts and email with subject line "**BLOCKER:** White-Paper Series Task ##".

Produce explainer video & 3-D animation package

This step-by-step manual provides the Video/Animation Producer (Role P-VAP-09) with an exhaustive action plan to create a 4-minute cinematic explainer video and a library of 12 looping 3-D animations between Week 136 and Week 146 of Phase 2. All steps must be executed **exactly as written** to meet scope, budget (US$90 k) and brand specifications.

Week	Phase Milestone	Output Due
136	Kick-off, script & storyboard lock	Approved script & storyboards
137-140	Asset creation, animation & rendering	12 photoreal animation loops
141-143	Compositing, VO, sound, grading	Rough-cut & then locked 4-min video
144-146	Review, revisions, master delivery	Final 4K masters, subtitles & licensing pack

1. **Week 136 – Day 1 (Monday) | Kick-off Alignment**
   • Schedule a 90-minute virtual kick-off with Marketing Lead, Engineering SME, Legal/Compliance and Brand Manager.
   • Present scope, budget split (US$40 k animation / US$50 k video), timeline and approval checkpoints.
   • Secure single point-of-contact (SPOC) for technical sign-off.
   • Record session and store link in the *"Phase 2 – Video"* Teams folder.
2. **Week 136 – Day 2-3 | Script Development**
   • Pull latest white-papers, drilling schematics and heat-flow graphs from Engineering vault.
   • Draft a 600-word narration (≈ 4 min) integrating the phrases "superhot geothermal" and "closed-loop safety" ≥ 3 times each.
   • Apply brand tone (visionary yet credible).
   • Circulate V1 script for SME red-line; allow 24 h feedback window.
3. **Week 136 – Day 4 | Script Lock**
   • Incorporate feedback; secure email approval from Marketing Lead and Compliance.
   • Store *"GT20_Explainer_Script_vFinal_EN.docx"* in project repository.
4. **Week 136 – Day 5 | Storyboard & Shot-List Creation**
   • Use Adobe Illustrator to lay out 16 storyboard frames (A3 landscape).

- Annotate each frame with camera move, VO line reference and call-out graphics.
- Export PDF; route for 24 h approval. Obtain sign-off by COB Friday.

5. **Week 137 – Day 1-2 | 3-D Pre-Viz & Style Frames**
   - In Blender 4.x, block primary scenes: *well pad, 45° vitrified bore, subsurface strata, Brayton turbine hall*.
   - Build two photoreal style frames at 3840×2160 with branded overlay test (HEX #003359 accents).
   - Upload JPGs for instant brand review; fix within 12 h.
6. **Week 137 – Day 3-5 | Asset Modelling & Rigging**
   - Model geological layers (granite, basalt) using displacement maps.
   - Create high-poly vitrified bore with glass-like shader (IOR = 1.45, subtle caustics).
   - Rig CO_2 particle flow using Mantaflow; constrain loop length to 10 s seamless.
   - Build sCO_2 turbine assembly with turntable rig for loop #7.
7. **Week 138 – All Week | Animation & Simulation**
   - Animate 12 loops (list in appendix A). Keep each loop ≤ 150 frames @25 fps.
   - Cache simulations to local NVMe, then sync to render farm.
   - Daily dailies review at 16:00 for QA; log notes in *ShotGrid*.
8. **Week 139 – All Week | High-Res Lighting & Rendering**
   - Apply HDRI “Arctic Sun 4K” for topside scenes; custom area lights for subsurface cutaways.
   - Set cycles samples 1024, denoise ON (OpenImageDenoise) for quality/performance balance.
   - Render EXR multi-passes (beauty, cryptomatte, motion vectors) to *\\RenderFarm\GT20*.
   - Track budgeted farm hours (≤ 900 GPU-hours).
9. **Week 140 – Day 1-3 | After Effects Compositing**
   - Import EXR; use ACEScg color pipeline.
   - Composite overlay graphics: lower thirds, animated key phrases, brand bug.
   - Output ProRes 4444 interim files.
10. **Week 140 – Day 4-5 | Rough-Cut Assembly**
    - Lay VO placeholder (computer generated) timed to storyboard.
    - Insert completed loops; fill gaps with temp slugs.
    - Publish *“RoughCut_A”* for internal review; collect consolidated notes in Confluence.
11. **Week 141 – Day 1 | Voice-Over Casting & Booking**
    - Audition 3 narrator demos; present to Marketing for selection by noon.
    - Issue PO; schedule studio for Wednesday.
12. **Week 141 – Day 3 | VO Recording**

- Direct live via Source-Connect; record 48 kHz / 24-bit WAV.
- Edit best takes, de-ess, normalize to 3 dB peak.

13. **Week 141 – Day 4-5 | Subtitle Creation**
    - Send locked English script to translation vendor; receive DE & JP SRT within 24 h.
    - Import SRTs into After Effects; burn-in option OFF (deliver both open & closed captions).
14. **Week 142 – Day 1-3 | Sound Design & Mix**
    - Add geothermal rumble, turbine whoosh, subtle UI beeps.
    - Mix VO + SFX + licensed music (track “Infinite Horizon”) to 24 LUFS.
    - Output 5.1 and stereo stems.
15. **Week 142 – Day 4-5 | Color Grade & Picture Lock**
    - Use DaVinci Resolve; apply brand LUT (contrast boost + blue highlight roll-off).
    - Render final 4K master ProRes 422 HQ (video) and 12 MP4 H.264 loops (bitrate 30 Mbps).
16. **Week 143 – Day 1 | Internal QA Pass**
    - Checklist: spelling, graphic alignment, VO sync, closed captions accuracy, color compliance, audio peaks.
    - Fix any issues same day.
17. **Week 143 – Day 2-3 | Executive Review**
    - Present video & loops to Board Chair and Policy Advisor over Zoom.
    - Log change requests; cap at 2 rounds.
18. **Week 144 – Day 1-2 | Final Revisions**
    - Implement approved tweaks; re-export masters.
    - Confirm file integrity via MD5 hash.
19. **Week 144 – Day 3 | Master Delivery**
    - Upload to:
      – Web CMS (*GT20.com*)
      – Trade show AV vendor (USB-C SSD)
      – Investor relations portal (Vimeo private link).
    - Provide spec sheet PDF with codecs, durations, resolutions.
20. **Week 145 – Day 1 | Asset Archiving**
    - Consolidate project into *“GT20_Video_Archive_2025Q3”*; include Blender files, AE projects, audio, licenses.
    - Copy to LTO-9 tapes and off-site cloud vault.
21. **Week 145 – Day 2 | Budget & Licensing Close-Out**

- Reconcile actuals vs. budget (< ±3 %).
- Generate licensing certificate: “Unlimited global, 5-year”.
- Email Finance and Legal the signed documents.

22. **Week 146 – Day 1 | Post-Mortem & KPI Handover**
    - Host 30-minute retrospective; log lessons learned.
    - Hand marketing analytics team the tracking sheet (video completion rate, trade-show loop uptime, etc.).
    - Mark task status “Complete” in master GTM Gantt.

Appendix A – Required 12 Looping Animations

1. Top-side pad fly-over
2. 45° drill path initiation
3. Vitrified bore fusion sequence
4. Subsurface cutaway (strata reveal)
5. Super-critical CO_2 down-flow
6. Super-critical CO_2 up-flow
7. sCO_2 turbine rotation
8. Heat-to-power conversion schematic
9. Closed-loop safety valve actuation
10. Real-time monitoring dashboard UI
11. Zero-carbon emission iconography
12. 10 GW deployment scale montage

Plan & purchase digital ad inventory (LinkedIn, Google, trade portals)

Responsible Role: Digital Marketing Specialist – P-DMS-04

Project Context (condensed): GeoTherm20 must drive early awareness and qualified demand for LithoLoop 25 among utility decision makers. Paid media in Phase 2 (Weeks 139–147) will deliver precision-targeted reach, feed MQL scoring, and lock in premium inventory before price inflation.

Objective: Secure, configure, launch, and optimise LinkedIn Sponsored Content, Google SEM, and energy-sector portal/retargeting campaigns that jointly achieve CTR ≥ 0.85 % and CPL ≤ US$160 while respecting channel budgets (LinkedIn US$120 k, Google US$144 k, Portals/RT US$96 k) during Phase 2.

Week	Milestone
139	Kick-off, creative briefing, master tracking architecture finalised
140	Audience & keyword matrices locked, ad-server reservations confirmed
141	Creative production & A/B variants completed; UTM QA
142	Channel build-out in platforms; compliance & brand audit
143	Soft launch & bid calibration; live QA
144-146	Active optimisation, creative refresh, negative keyword expansion
147	Budget burn rate audit, KPI attainment report, phase-close retro

1. **Week 139 – Kick-Off & Framework**
    1. Calendar-lock a 60-minute alignment call with Growth Lead, Brand, RevOps, and Finance; confirm channel budgets (LinkedIn US$120 k, Google US$144 k, Portals/RT US$96 k) and payment method tokens.
    2. Create master campaign brief in Confluence with: objective, audience definition, creative specs (1×2 image, 600-char text, two A/B variants), KPI thresholds, timeline, asset owners, approval chain.
    3. Design UTM taxonomy: `utm_source` (linkedin|google|portal|retarget), `utm_medium` (cpc), `utm_campaign` (phase2_litholoop25), `utm_content` (ad1a etc.). Sync rules in HubSpot and test using a staging URL.
    4. Download most recent CRM account list; filter companies with ≥1 GW and ≤20 GW portfolio. Upload as hashed list to LinkedIn Matched Audiences for reach estimate snapshot.
    5. Generate purchase order requisitions for: LinkedIn (In-Platform CC), Google Ads (In-Platform), Portal bundle (direct IO). Submit to Finance for PO numbers within 48 h.
2. **Week 140 – Audience & Inventory Lock**
    1. LinkedIn:
        - Define core audience: Country filters (OECD incl. Japan), Job Function (Engineering, Operations, Strategy), Job Seniority ≥ Director, Titles (CEO, COO, VP Generation, Head of Innovation).
        - Layer company-size filter: “Company category – Utilities” AND “Company growth rate neutral or

growing”.
- Verify audience size 120 k–180 k members; adjust job functions if below 120 k.

2. Google SEM:
   - Create keyword set: Exact Match [baseload geothermal], [supercritical co2 power], [closed loop geothermal], [geothermal vs coal].
   - Build phrase-match variants using keyword insertion templates; import negative list (e.g., “coffee”, “spa”, “heat pump”).
   - Run Keyword Planner forecast: ensure projected clicks ≥18 k within budget at avg. CPC ≤US$8.
3. Portals/RT:
   - Request media kits from *Power-Engineering.com*, *Energy-Central.com*, *AsianUtilitiesWeek.com*.
   - Select placements adjacent to “Energy Transition”, “Thermal Generation”, and “Coal-to-Clean” editorial calendars; hold equivalent of 4.8 M impressions at CPM ≤ US$20.
4. Issue insertion orders (IOs) to portals with flight dates Weeks 143–147, viewability ≥70 %, make-good clause for under-delivery.

3. **Week 141 – Creative Production & Tracking QA**

1. Brief design team via Jira ticket:
   - Asset requirement: 1×2 aspect ratio (1200 × 600 px), 20 % text rule compliance, hero image of superhot wellhead, subtle GeoTherm20 logo.
   - Variant A copy: “Retire coal, not reliability. Discover LithoLoop 25 baseload geothermal.” Variant B copy: “500 °C heat from the Earth’s crust—at utility scale.”
2. Receive PSD and PNG exports; compress to ≤150 KB each. Run accessibility checker for alt-text.
3. Embed final UTMs into each ad variant URL; paste into a spreadsheet and test all links through HubSpot tracking to confirm contact attribution.
4. Set up HubSpot forms with hidden fields for `campaign_id`, `ad_group_id`; map to MQL scoring property.
5. Secure brand/legal approval email; archive approval PDF in SharePoint.

4. **Week 142 – Channel Build-Out & Compliance**

1. LinkedIn Campaign Manager:
   - Create three campaigns: “Core Utilities”, “IPP Innovators”, “Remarketing”.
   - Apply campaign objective “Lead Generation”; attach HubSpot form.
   - Set daily budgets: US$1 625 (Core), US$1 000 (IPP), US$625 (RMK) to match total US$120 k over 28 days.
   - Insert creatives A/B; enable automated placement optimisation.

2. Google Ads:
    - Create two Search campaigns segmented by region (OECD, Asia-JP).
    - Set bid strategy “Maximise conversions” with CPA cap US$160.
    - Add site-link extensions (White Paper download, Tech Specs, Contact Sales).
3. Set up Google Tag Manager event “form_submit_paid_media”; push to dataLayer for each lead.
4. Portals/RT: Upload creatives via publisher ad-server; supply 3rd-party click tracker (HubSpot tracking link) and 1×1 impression pixel.
5. Perform end-to-end compliance audit: privacy policy presence, GDPR consent, opt-out instructions. Document in compliance checklist.

5. **Week 143 – Soft Launch & Bid Calibration**
    1. Activate campaigns on Monday 09:00 UTC. Limit initial spend to 60 % of daily budget for 48 h.
    2. Monitor in-platform metrics every 6 h:
        - LinkedIn: keep first-day CPM ≤ US$85; if >85, lower bid 10 %.
        - Google: ensure Quality Score ≥7; pause keywords scoring <5.
        - Portals: verify impression pacing at 35 % of planned daily volume.
    3. Run live test submissions; confirm lead appears in HubSpot with correct `original_source` and lead score.
    4. Calculate preliminary CPL and CTR; if CTR < 0.65 %, swap Variant A/B placement priority; if CPL > US$200, tighten audience (remove “Analyst” layer).

6. **Weeks 144–146 – Active Optimisation**
    1. Daily (09:00 UTC):
        - Export performance dashboard (LinkedIn & Google) to Google Sheets via Supermetrics.
        - Highlight rows where CTR < 0.85 % or CPL > US$160. Apply red conditional formatting for quick triage.
    2. LinkedIn:
        - Duplicate top-performing creative into new campaign “Lookalike Expansion”; seed with existing leads to upscale reach by 30 % while capping bid US$7 CPM lower than core.
        - Pause underperforming ad variations (CTR < 0.55 %).
    3. Google:
        - Add negative keywords weekly based on search-term report (e.g., “DIY”, “residential”).
        - Increase exact-match bid 15 % on keywords converting CPL < US$120.
    4. Portals/RT:
        - Swap fresh creative set “Variant C” midway through flight to mitigate banner wear-out.

- Request delivery log files every Friday; reconcile impressions, clicks, and tie back to HubSpot UTMs.

5. Weekly Wednesday: Send Slack digest to Growth & Sales summarising MQL volume, top companies engaged, and funnel velocity.

7. **Week 147 – Reporting & Phase Closure**

1. Freeze campaigns at 17:00 UTC Monday once budgets reach 98 % utilisation.
2. Export final performance data:
   - LinkedIn “Campaign Performance” CSV
   - Google “Campaign, Ad Group, Keyword” reports
   - Portal impression & click log files
   - HubSpot “Paid Leads” view
3. Compile KPI Analysis:
   - CTR, CPC, CPL by channel and creative.
   - MQL-to-SQL conversion rate (sourced via HubSpot lifecycle stages).
   - Spend variance vs budget ±2 % target.
4. Populate 10-slide Phase-closure deck; include heat-map of engaged accounts and recommendations for Phase 3 scaling.
5. Host 45-minute retro with cross-functional team; document wins, gaps, action items in Confluence.
6. Archive assets: creatives, reports, meeting recordings in SharePoint folder “GTM/Phase2/PaidMedia”.

Key Success Metrics (for quick reference)

- Overall CTR ≥ 0.85 %
- CPL ≤ US$160
- Budget Utilisation 98–100 %
- ≥ 600 MQLs generated
- 100 % lead attribution accuracy in HubSpot

End of Action Plan – Ready for execution by P-DMS-04

Finalise PR agency contract & media-outreach calendar

Responsible Role: **PR & Media Lead – P-PR-10**

Timeline: **Phase 2: Week 140 – 150**

Key Deliverables: Signed MSA; 12-month editorial calendar aligned with engineering milestones OP-049 & GTM-024

Overview of Sequential Action Plan

Step #	Week / Day	Action Item (no-ambiguity instructions)	Owner / Support
1	Week 140 Day 1	Re-confirm selected PR agency meets geothermal/deep-tech criteria: • Verify agency's documented wins with Power Magazine, BloombergNEF, CERAWeek newsroom. • Email agency requesting last 6 case-study PDFs and two client references. • Log confirmations in "Agency-Due-Diligence" sheet on SharePoint.	P-PR-10
2	Week 140 Day 2 AM	Secure internal budget clearance: • Email CFO and VP Marketing with cost breakdown (US$15 k/mo × 18). • Obtain written approval and file PDF in "Contracts/Budget-Approvals".	P-PR-10 Support: Finance Analyst
3	Week 140 Day 2 PM	Draft Master Services Agreement (MSA): • Download company MSA template. • Populate scope: 18-month retainer; 8 press releases; 3 media-training workshops; quarterly sentiment analysis. • Insert KPI clause: ≥20 tier-one placements & SOV ≥ 15 % vs SMRs by launch week. • Add confidentiality, termination (30-day notice), crisis-comms escalation, IP ownership. • Save as "MSA_GeoTherm20-PR-Agency-v1.docx".	P-PR-10
4	Week 140 Day 3-4	Legal review round: • Email "v1" to Legal Counsel with *Track Changes* on. • Schedule 30-min call to resolve redlines. • Incorporate feedback, produce "v2-clean" and "v2-redline".	P-PR-10 Support: Legal Counsel
5	Week 140 Day 5	Transmit "v2-clean" to agency for comments; set 48-hour deadline. • Use DocuSign routing; enable comment-only permissions. • Note follow-up checkpoint on calendar.	P-PR-10
6	Week 141 Day 1	Negotiate outstanding MSA points (if any): • Host 60-min Zoom; resolve rate card extras, indemnity clauses. • Capture resolutions live in "v3-redline".	P-PR-10 Support: Agency Account Lead, Legal Counsel

7	Week 141 Day 2	Obtain signatures: • Route “v3-final” via DocuSign to Agency → GeoTherm20 CEO. • Verify signing complete; download fully-executed PDF. • Store in “Contracts/Executed/PR-Agency_MSA.pdf” and update contract register with renewal date.	P-PR-10
8	Week 141 Day 3	Agency onboarding kickoff (90-min workshop): • Present project context, personas, messaging matrix, crisis-comms flow. • Provide engineering milestone Gantt showing OP-049 (Pilot Heat Loop Energisation) & GTM-024 (Utility Consortium LOI Signing). • Deliver asset pack (brand guidelines, existing B-roll, founder bios).	P-PR-10 Support: Eng. PM, Brand Manager
9	Week 141-142	Collect input for editorial calendar: • Meet Engineering, BD, and Policy teams to identify 12 months of story hooks, data releases, partnership signings. • List ≥8 distinct press-release opportunities and ≥4 op-ed angles. • Map 3 media-training workshops to leadership availability. • Add four sentiment-analysis report dates (end of Q1, Q2, Q3, Q4).	P-PR-10 Support: Agency Strategist, Eng. Comms Liaison
10	Week 142-145	Draft 12-month media-outreach calendar: • Use Excel template with columns: Date, Milestone, Asset Type, Target Outlet, Status, Owner. • Anchor OP-049 press-release + embargoed exclusive (Power Magazine) exactly **T-14 days** before public energisation. • Anchor GTM-024 announcement with BloombergNEF and simultaneous op-ed in Financial Times “Energy Source”. • Allocate additional 6 press-releases across technology validation, financing rounds, and workforce expansion. • Schedule CERAWeek thought-leadership panel pitch submission deadline. • Insert 3 media-training workshops (Wk 145, Wk 163, Wk 181) and sentiment analysis dates.	Agency Strategist (draft) Review: P-PR-10
11	Week 146	Internal review & approval: • Circulate draft calendar to VP Marketing, CTO, and CEO. • Collect feedback via tracked comments. • Host 45-min alignment call; finalise dates and owners. • Update master calendar to “vFinal”.	P-PR-10
12	Week 147	Distribute approved calendar: • Upload to Asana “PR Calendar” project and SharePoint. • Email PDF & .xlsx versions to all stakeholders. • Lock edits; enable comment-only for non-owners.	P-PR-10

13	Week 148	Set KPI tracking dashboard: • Configure Google Data Studio pulling Meltwater & Cision SOV metrics. • Pre-load tier-one outlet list; attach KPI baseline vs SMR competitors. • Share live link with agency & leadership.	Comms Analyst Oversight: P-PR-10
14	Week 149	Operationalise calendar: • Agency books initial briefings with Power Magazine & BloombergNEF. • Create Asana tasks for each press release with deadlines, content owners, approval flow. • Add recurring weekly 30-min status call (PR Lead ↔ Agency).	Agency Account Lead P-PR-10
15	Week 150	Final quality gate & hand-off: • Audit that signed MSA and calendar are stored, version-controlled, and backed-up. • Update programme dashboard to 100 % completion for Task “PR-01”. • Notify PMO of milestone closure via Slack #gtm-program.	P-PR-10

Contingency & Risk Mitigation Protocols

- If agency negotiation exceeds Week 141 Day 2, escalate to VP Marketing for rapid arbitration to avoid timeline slip.
- Maintain alternate agency shortlist in case legal impasse emerges; pre-cleared NDAs to enable fast switch (< 72 h).
- Embed crisis-comms clause mandating agency 24/7 availability with two-hour response SLA during operational incidents.

Completion Definition

Task is officially complete when:
1. Fully executed MSA uploaded to “Contracts/Executed”.
2. 12-month editorial calendar (Excel & PDF) approved by VP Marketing, linked in Asana and SharePoint.
3. KPI dashboard live and shared.
4. Weekly status call cadence set with first agenda distributed.

Coordinate analyst & investor briefings (Wood Mac, BNEF, etc.)

Objective

Deliver tightly-orchestrated analyst & investor briefings that result in **≥ 2** positive analyst notes published before commercial launch, positioning GeoTherm20 as the leading super-hot geothermal vendor.

Critical Parameters

- Target analyst firms: Wood Mackenzie, BloombergNEF, Rystad, EPRI
- Embargoed data to share: Demo plant KPIs (200 MWe, LCOE 55-70 $/MWh), CAPEX curve vs. SMR, risk-mitigation structure
- Budget cap: US$80 k (combined subscriptions & travel)
- Timeline window: Weeks 151–158 of GTM plan
- Responsible role: Analyst Relations Manager (P-AR-11)

Week-by-Week Action Plan

Week	Primary Milestone	Detailed Tasks (sequence)
151	Briefing Blueprint Finalised	1. Download latest engineering sign-off package for LithoLoop 25 demo plant. 2. Draft 4-page “Core Messaging Grid” mapping benefit claims to supporting data & Q&A rebuttals. 3. Secure budget sign-off (*send cost sheet & ROI justification deck to CFO by Monday 12:00*). 4. Lock briefing format (virtual vs onsite) for each target firm based on analyst preference & travel ROI.
152	Materials Production & Legal Prep	1. Create 12-slide “Analyst Deck v1.0” using blueprint; include: • Market problem & TAM visuals • Technology schematic & process flow • Demo KPIs & cost curves • Risk-mitigation slide • Roadmap & ask 2. Draft 2-page FAQ cheat-sheet for executive speakers. 3. Generate NDAs via DocuSign template; pre-fill firm names & send for e-signature by Wednesday 17:00. 4. Route all materials through Legal/Comms for compliance, red-line feedback returned by Friday 12:00. 5. Incorporate feedback & freeze “Analyst Deck v1.1” by Friday 18:00.

153	Scheduling & Internal Rehearsals	1. Email personalised invitations to primary analysts with three time-slot options (+ calendar placeholders). 2. Track responses in Analyst CRM; confirm slots within 48 h. 3. Book virtual conference bridges or onsite meeting rooms & catering (if applicable). 4. Assemble speaker team: CTO, VP-Project Finance, CEO. 5. Conduct 2-hour dry-run rehearsal (Thursday 14:00); use stopwatch to hit 25-min presentation + 20-min Q&A. 6. Capture tough Qs, update FAQ sheet by Friday 17:00.
154	Execute Wood Mackenzie & BNEF Briefings	1. Send reminder + final deck (password protected) 24 h prior. 2. Host Wood Mac session Monday 09:00-10:00; BNEF Wednesday 16:00-17:00. 3. Record sessions (with consent); store files in encrypted SharePoint. 4. Document all questions in meeting minutes during call; circulate to speakers within 2 h for any follow-up inputs. 5. Issue personalised “thank-you & follow-up” email within 6 h, attaching agreed post-meeting materials.
155	Execute Rystad & EPRI Briefings	1. Repeat reminder protocol 24 h pre-meeting. 2. Conduct Rystad Tuesday 10:00-11:00; EPRI Thursday 13:00-14:00. 3. Apply identical recording, minute-taking, and follow-up workflow.
156	Clarifications & Data Deep-Dives	1. Create secure “data room lite” (read-only) for analysts; upload supplementary technical annex (CAPEX calc spreadsheet, field test photos). 2. Respond to all post-briefing queries within 24 h SLA; route any engineering questions to CTO with deadline tags. 3. Log every outbound email in CRM for audit.
157	Publication Advocacy	1. Email each analyst a concise “key-takeaways” memo plus proposed quote for potential inclusion in their note. 2. Follow-up with 10-min check-in call to gauge publication timeline; update shared tracker. 3. Coordinate with Comms to prepare reactive media

		lines once notes publish.
158	Success Validation & Retrospective	1. Capture published analyst notes; store PDFs in “Analyst Coverage Library.” 2. Evaluate against success metric: count mentions + sentiment scoring. 3. Prepare 5-slide debrief for C-suite: • Coverage summary & excerpts • Gap analysis vs. messaging • Opportunities for inclusion in upcoming market reports 4. Finalise expense report; ensure total ≤ US$80 k. 5. Log lessons learned and update Analyst Briefing SOP for future cycles.

Budget Allocation Checklist (US$)

Category	Cap	Owner	Approval Gate
Industry subscriptions (BNEF, Wood Mac)	35 k	P-AR-11	Week 151
Travel & lodging (onsite)	20 k	P-AR-11	Week 152
Event logistics (rooms, catering)	10 k	P-AR-11	Week 153
Content production (design)	8 k	Marketing Ops	Week 152
Contingency (5%)	7 k	CFO	On call

Risk Mitigation Actions

- NDA Compliance: No materials released without fully-executed NDAs stored in Legal Vault.
- Message Discipline: Single-source slides only; no ad-hoc data disclosure.
- Budget Overrun: Weekly spend tracker auto-emailed to CFO every Friday.
- Publication Slippage: Insert “embargo lifts by Week 160” clause to encourage timely analyst output.

Deliverables Checklist

1. Core Messaging Grid (Week 151)
2. Analyst Deck v1.1 (Week 152)
3. FAQ Cheat-Sheet (Week 152)

4. Signed NDAs (Week 152)
5. Meeting Recordings & Minutes (Weeks 154-155)
6. Data Room Lite & Query Log (Week 156)
7. Published Analyst Notes (≥ 2) (Weeks 157-158)
8. Executive Debrief Deck & Expense Report (Week 158)

Communication Protocols

- All external emails BCC compliance@geotherm20.com for automatic archiving.
- Urgent issues escalate via Slack #analyst-relations channel; SLA response **30 min**.
- Daily status pulse with Marketing VP at 17:30 local time during Weeks 154-156.

Execute precisely. Zero deviation ensures credibility with market movers and secures GeoTherm20's leadership narrative.

Scope & budget on-site flagship launch event

1. Purpose & Mandate

This manual provides an exhaustive, step-by-step execution plan enabling the Event Coordinator (Role ID P-EC-12) to scope, cost, and secure board approval for GeoTherm20's on-site flagship launch event. The plan spans Phase 3, Weeks 152-160, culminating in two board-ready outputs: a fully costed budget deck and a draft run-of-show.

2. High-Level Objectives

- Lock venue, vendors, and VIP travel before calendars and supply chains tighten.
- Deliver a granular, board-defensible budget (±5 % accuracy) with US$300 k ceiling and 10 % contingency.
- Integrate HSE-approved safety protocols for a 500 °C geothermal industrial environment.
- Create a preliminary, minute-by-minute run-of-show aligning physical, virtual, and media components.

3. Timeline at a Glance (Weeks 152-160)

Week	Milestone
152	Kick-off; requirements locking; venue pre-hold; form cross-functional task-force.
153	Vendor RFPs & inbound bids; HSE risk workshop; travel block quotes.
154	Budget modelling; scenario stress-test; shortlist vendors; draft run-of-show v0.1.
155	Contract negotiations; safety plan submission to HSE; board pre-read outline.
156	Finalize vendor contracts; integrate HSE feedback; lock VIP travel; budget deck v0.9.
157	Dry-run cost & logistics audit; contingency allocation; run-of-show v0.9.
158	Board deck polish; exec alignment; print-ready layouts; rehearsal calendar dispatch.
159	Formal board approval; contingency release; purchase orders triggered.
160	Post-approval vendor kickoff calls; publish final run-of-show; transition to execution team.

4. Detailed Action Plan

Week 152 – Initiation & Requirements Lock

1. Create a shared project folder (OneDrive/SharePoint) titled “Flagship Event — Phase 3.”
2. Schedule an internal 60-min kickoff call with:
    - Marketing Lead (P-MK-05)
    - Sales Strategy (P-SS-03)
    - HSE Manager (P-HS-02)
    - Facilities Ops (P-FO-07)
    - Broadcast Producer (External candidate pool)
3. Confirm attendance cap (250 on-site + unlimited livestream) and attendee composition breakdown:
    - 100 utility executives
    - 30 regulators
    - 20 investors
    - 50 media/analysts
    - 50 internal staff
4. Block preliminary event date (T-0 in Week 168) on corporate master calendar; issue Save-The-Date hold to C-level and top-tier invitees.
5. Secure provisional venue slots:
    - Turbine hall (3,000 m²)
    - Outdoor wellhead viewing deck

- Overflow marquee (in case of rain)

Submit electronic “hold” forms to Facilities Ops.

6. Draft Requirements Document v0.1 (one-pager) covering:
   - Spatial needs (stage, seating, PPE donning stations)
   - Technical (power, fiber, broadcast points)
   - Safety (500 °C proximity, CO_2 handling, evacuation routes)

   Circulate for 24-hr feedback.

Week 153 – Vendor RFPs & HSE Alignment

1. Prepare three separate RFP packets (PDF) for:
   - Venue & Staging (Budget Envelope ≤ US$150 k)
   - Travel & Lodging (≤ US$100 k)
   - Broadcast & Media Services (≤ US$50 k)

   Include evaluation rubric (cost 40 %, capability 30 %, safety record 20 %, ESG alignment 10 %).
2. Email RFPs to at least three vendors per category; set bid deadline end of Week 154.
3. Hold a 2-hr HSE risk-identification workshop on-site:
   - Run HAZOP-style brainstorming for crowd movement, heat exposure, CO_2 leaks.
   - Generate risk register with severity, likelihood, mitigation.

   Save register v0.1 to shared folder.
4. Request group-rate quotes from three preferred airlines and two hotels within 30 min of site; lock 120 refundable room blocks pending board approval.
5. Collect PPE supplier quotes for 300 complete kits (hard hat, heat-rated gloves, goggles, FR coveralls, steel-toe boots); ensure compliance with local geothermal regulations.

Week 154 – Budget Modelling & Shortlisting

1. Create a master budget workbook (Excel) with sheets:
   - Summary (high-level line items + 10 % contingency)
   - Detailed Quotes
   - Sensitivity Analysis (±15 % cost swings)
2. Enter all received bids; flag outliers (>20 % from median) for negotiation.
3. Run stress test scenario: +25 guests, +1 day weather delay, +30 % fuel cost; ensure total remains ≤ US$330 k (budget + contingency).
4. Shortlist top two vendors per category; schedule 30-min clarification calls.

5. Draft run-of-show v0.1:
   - Touch-down to departure timeline
   - Stage cues, camera angles, speaker order
   - Safety brief timings

   Store in shared folder.

Week 155 – Negotiation & Compliance Submission

1. Conduct price & scope negotiations aiming for:
   - Minimum 5 % reduction on initial quotes
   - Free-issue rehearsal day included
   - No-fault cancellation clause until Week 164
2. Consolidate vendor statements of work (SOW) and circulate to Legal for 48-hr review.
3. Finalize Emergency Response Plan (ERP) with HSE Manager:
   - Evacuation routes
   - Medical tent location
   - On-site paramedic staffing ratio (1:50)

   Submit ERP to regulatory authority; obtain acknowledgement receipt.
4. Outline board budget deck:
   - Slide 1 – Strategic Rationale
   - Slide 2 – Event Overview
   - Slide 3 – Line-Item Budget
   - Slide 4 – Risk & Mitigation
   - Slide 5 – Ask & Next Steps

Week 156 – Contract Finalization & Budget Deck v0.9

1. Receive Legal-approved SOW edits; send to vendors for countersignature via DocuSign.
2. Issue purchase requisitions in ERP system; set payment terms Net-45 post-event.
3. Integrate HSE regulator feedback into ERP; update risk register to v0.2.
4. Secure VIP travel:
   - Book flexible business-class tickets for 30 VIPs
   - Confirm hotel suites; send booking confirmations
5. Populate board deck with final negotiated costs; embed risk heat-map figure.
6. Schedule 30-min pre-read walkthrough with CMO and CFO for alignment.

Week 157 – Dry-Run Audit & Contingency Allocation

1. Run desktop “dry-run”:
   - Walk through every agenda minute
   - Map resource usage vs. vendor deliverables

   Log discrepancies; escalate to vendors for fixes within 48 hrs.
2. Allocate 10 % contingency (US$30 k) across:
   - Weather-proofing add-ons (US$12 k)
   - PPE over-runs (US$8 k)
   - Broadcast redundancy links (US$10 k)
3. Update run-of-show to v0.9 with refined cue-to-cue times and camera call-sheet.
4. Prepare Q&A sheet anticipating typical board objections (cost over-run, safety liability, ROI).

Week 158 – Board Deck Polish & Rehearsal Planning

1. Apply corporate branding to deck:
   - Use approved template GT20-DarkBlue
   - Insert high-resolution hero image of turbine hall
2. Embed speaker notes with concise “Why Now” narrative.
3. Export deck to PDF; verify file size <5 MB for email distribution.
4. Email deck to board members T-5 days before meeting; request preliminary questions by T-3.
5. Publish rehearsal calendar:
   - Technical walkthrough – Week 162
   - Full dress rehearsal – Week 164

   Send invites to all presenters and vendors.

Week 159 – Board Approval & Purchase Orders

1. Host 45-min board meeting:
   - 10 min presentation
   - 25 min Q&A
   - 10 min motion & vote
2. Record decision in meeting minutes; capture any additional board stipulations.

3. Upon approval, release purchase orders via finance system; notify vendors within 2 hrs.
4. Update budget workbook to status “Approved”; lock cells to prevent further edits.
5. Send company-wide Yammer post announcing green-light and upcoming event timeline.

Week 160 – Vendor Kickoff & Handover to Execution Team

1. Schedule 60-min kickoff call with each contracted vendor, include:
   - Signed SOW review
   - Milestone calendar confirmation
   - Point-of-contact directory exchange
2. Publish final run-of-show v1.0 to all stakeholders; enable change-control process (all edits logged, approval required from P-EC-12).
3. Create an execution tracker (Smartsheet) with:
   - Task, owner, due date, status, dependencies
   - Auto-alerts for critical path slips >12 hrs
4. Transfer ownership of execution tracker to On-Site Production Manager (P-OP-09); retain read-only oversight access.
5. Archive scoping phase documents in folder “01_Frozen_Scope” to prevent accidental edits.

5. Final Deliverables Checklist

Deliverable	File Name	Due Week	Status Owner
Board-Approved Budget Deck (PDF)	GT20_FlagshipEvent_Budget_v1.0.pdf	159	Event Coordinator
Draft Run-of-Show (Excel)	GT20_RunOfShow_v1.0.xlsx	160	Event Coordinator
Approved Emergency Response Plan	ERP_GeothermalLaunch_v0.2.docx	156	HSE Manager
Master Budget Workbook	FlagshipEvent_BudgetWorkbook_v1.0.xlsx	156	Event Coordinator
Risk Register	RiskRegister_FlagshipEvent_v0.2.xlsx	157	HSE Manager

Successful execution of the above steps will fully scope and fund GeoTherm20's flagship launch event, positioning it as the definitive proof-point of LithoLoop 25's 500 °C operational capability.

Secure trade-show booths & logistics (WGC, CERAWeek)

Step-by-Step Action Plan

This manual provides an exhaustive, chronological set of actions for the Trade-Show Manager (Role ID: P-TS-13) to secure premium booth locations, design/build a 36 m² custom exhibit, coordinate logistics for 1,200 kg of materials and eight staff, submit two speaking proposals, deploy lead-capture systems, and achieve 150 qualified leads across the World Geothermal Congress (Kyoto) and CERAWeek (Houston) during Phase 3 (Weeks 153-161).

High-Level Timeline (Weeks 153-161)

Week	Milestone
153	Contract booth spaces, submit speaking abstracts, launch design brief
154	Approve floor plans & graphics, order lead-capture hardware
155	Confirm fabrication start, book freight & travel, rehearse talks
156	Mid-build inspection, finalise collateral, integrate HubSpot scanner
157	Ship booth to Kyoto, issue staff briefing packs, stress-test CRM sync
158	On-site install & staffing at WGC; collect ≥70 qualified leads
159	Debrief WGC, refurb booth, reposition graphics for CERAWeek
160	Ship to Houston, confirm speaker slot AV, release press advisory
161	On-site at CERAWeek; collect ≥80 additional leads; close-out report

Detailed Action Steps

Week 153

1. Retrieve latest floor plans from WGC & CERAWeek organisers.
2. Identify top-traffic corner or cross-aisle locations within technology pavilions.
3. Negotiate and sign booth contracts (36 m² each) securing:
    - Corner placement within 30 m of keynote-stage entrance.
    - 3-phase 32 A power drop and 100 Mb/s wired internet.
4. Submit two 500-word speaking abstracts via conference portals:
    - Technology track: “LithoLoop 25—Delivering 600 °C Base-Load Heat from 25 km Depth”.
    - Policy track: “Superhot Geothermal as a Firm-Renewable Replacement for Coal Retirement”.
5. Create exhibit design brief containing:
    - 3-D LithoLoop loop model specification (1:25 scale, cut-away plexiglass).
    - LED wall (4 m × 2 m) with looping 90-s animation.
    - Meeting pod for 4 people with privacy glass.
    - Storage closet (2 m²) for collateral, personal items.
    - Brand guidelines (PMS, fonts, tone).
6. Issue RFP to three approved exhibit houses; deadline for quotes: EOW 153.
7. Set up project budget in ERP: US$240k cap #056; authorise drawdown schedule (40/40/20).
8. Book eight provisional hotel blocks (4 rooms Kyoto, 4 rooms Houston) with free cancellation until Week 155.
9. Open HubSpot project folder; request API key for badge-scanner integration.
10. Document all actions in PM tool (Wrike card “TS-Booth-Phase3”).

Week 154

1. Evaluate RFP responses on cost, past work, build time, on-site service.
2. Select exhibit house; issue purchase order with 40 % deposit (≈ US$75k).
3. Conduct 60-min design kickoff:
    - Approve booth footprint, traffic flow, demo placement.
    - Lock colour palette & material samples (recycled aluminium framing, bamboo flooring).
4. Order 3 QR-enabled badge scanners from conference approved vendor; ensure HubSpot API compatibility.
5. Draft staffing roster:
    - Technical: CTO, Drilling Lead.
    - Commercial: VP Sales, 2 BDRs.
    - Marketing: CMO, Content Manager.
    - Field Ops: HSE Supervisor, Demo Engineer.

6. Coordinate with HR for travel approval workflow and per-diem policy distribution.
7. Receive organiser service manuals; record deadlines for electrical, internet, badge scanner orders.
8. Create “Lead Scoring Matrix v1” in HubSpot (Fields: Utility size, geography, decarbonisation timeline, budget).

Week 155

1. Finalise booth 3-D renders; sign-off on graphic panels and loop model engineering drawings.
2. Authorise production start; pay 2nd 40 % invoice.
3. Contract international freight forwarder (door-to-booth, DDP terms) for:
   - 1,200 kg crate; 2.2 m × 1.5 m × 2.0 m.
   - Customs commodity code: 940320.
4. Book air tickets for eight staff (economy-flex) plus two exhibit-house supervisors (build days only).
5. Reserve Kyoto International Conference Centre AV package (HDMI, lapel mic) for tech track; reserve Hilton Americas ballroom AV for policy track.
6. Schedule two 30-min talk-track rehearsal sessions with speaker coach.
7. Commission 500 tri-fold brochures (FSC paper, Japanese & English), 300 executive brief folders (Houston variant).
8. Submit HSE documentation (rigging risk assessment, CO_2 cylinder MSDS) to organisers.

Week 156

1. Conduct mid-build inspection via video walkthrough; request punch-list fixes (edge lighting alignment, logo Pantone check).
2. Upload final booth graphics to organiser portal for pre-show approval.
3. Run end-to-end CRM test:
   - Scan dummy badge → HubSpot record creation → automated nurture email.
   - Verify data sync within 60 s SLA.
4. Prepare Staff Briefing Pack v1 (PDF):
   - Daily schedule, dress code, elevator pitch script, lead-qual criteria.
   - Emergency contacts, local transport maps.
5. Set up WhatsApp group “WGC-CERA-Crew” for real-time coordination.
6. Confirm booth insurance (US$1M liability, all-risk cargo).
7. Obtain VISA invitation letters for non-US/JP passport holders; submit to consulates.

Week 157

1. Oversee booth crating; affix ISPM-15 compliant timber stamps and “THIS SIDE UP” labels.
2. Handover crate to freight forwarder; record AWB number in logistics tracker.
3. Distribute Staff Briefing Pack v1; conduct 45-min virtual walkthrough, field Q&A.
4. Stage backup collateral on SharePoint (print-on-demand PDF, USB stick ISO).
5. Synchronise calendars with organiser build-up windows:
   - WGC: Build Day –2 (07:00-17:00).
   - CERAWeek: Build Day –3 (08:00-20:00).
6. Perform final speaker rehearsal with slide deck timer; achieve ≤ 14 min duration.
7. Confirm catering orders: bottled water, espresso machine, wrapped snacks (Kyoto: matcha biscotti, Houston: pecan bars).
8. Transfer remaining 20 % exhibit invoice upon receipt of “ready-to-ship” photos.

Week 158

1. Arrive Kyoto Build Day –2 07:00; secure work passes for crew.
2. Supervise booth erection; confirm:
   - Loop model anchored, no vibration; CO_2 cylinder secured.
   - LED wall loops animation correctly (autoplay, mute).
   - Electrical load test ≤ 85 % breaker rating.
3. Run final HubSpot scanner on live network; capture test badge, validate fields.
4. Set up QR feedback survey (Net Intent score) on iPad kiosk.
5. During show days:
   - Hold 15-min morning huddle (KPIs, target 25 leads/day).
   - Log every prospect within 3 min of interaction.
   - Post daily metrics to Slack #GTM-dashboard by 19:00.
6. Deliver technology-track talk; collect business cards at exit funnel, scan within 1 hr.
7. End of WGC: Generate HubSpot list “WGC-Qualified”, export CSV backup.
8. Pack booth for onward shipment; document any damaged components for insurance claim.

Week 159

1. Hold 60-min retro meeting (virtual) within 48 hrs of WGC close:

- Review lead quantity & quality vs 70-lead goal.
- Identify pitch, traffic, or collateral gaps.
- Log action items with owners & deadlines.

2. Send personalised follow-up email to all WGC qualified leads (template v1, dynamic tokens).
3. Coordinate exhibit house repairs/re-skins as needed (e.g., Houston branding: “North-American Utilities Solutions”).
4. Issue updated Staff Briefing Pack v2 highlighting refined messaging.
5. Arrange domestic US freight leg; validate customs clearance documents (ATA carnet stamped out of JP).
6. Update HubSpot workflow to tag “Source: WGC 202X”.

Week 160

1. Receive booth in Houston advance warehouse; check crate integrity.
2. Confirm electrical/internet orders paid in organiser portal; download receipt.
3. Issue media advisory to trade press 5 days pre-CERAWeek:
   - Booth number, policy-track speaking slot, interview availability.
4. Re-test badge scanners on US 120 V sockets; replace adapters if needed.
5. Stage extra give-aways (Texas-branded power-banks, qty 200).
6. Conduct final speaker AV check in Hilton ballroom (HDMI handshake, confidence monitor).
7. Upload revised slide deck to cloud & USB; label “FINAL_CERA.pptx”.
8. Distribute build & show schedules to all crew via calendar invites.

Week 161

1. Build Day –3: install booth; confirm post-repair modifications applied.
2. Repeat power & network testing protocol; log sign-off forms.
3. Opening day huddle: set cumulative lead goal 80 (≈ 27/day).
4. Deploy live “Lead Goal Thermometer” dashboard on 42-in screen facing staff area.
5. Deliver policy-track talk; distribute 1-page policy brief to attendees (QR code embedded).
6. Facilitate 4 pre-booked utility meetings in booth meeting pod; capture notes in HubSpot within 15 min of session end.
7. End of day 3: verify KPI attainment (≥150 total leads WGC + CERAWeek).
8. Show close:
   - Dismantle booth; supervise packing for return to warehouse.

- Set CRM nurture sequence (MQL → SAL) to kick off 24 hrs post-scan.

9. Conduct 90-min post-mortem (on-site):
   - Financial reconciliation vs US$240k budget (±5 %).
   - Lead quality review vs scoring matrix.
   - Action plan for next event cycle.
10. Submit final close-out report to C-level and PMO within 48 hrs, including:
    - Spend variance table.
    - Lead conversion funnel snapshot.
    - Lessons learned & optimisation proposals.

Budget Allocation Snapshot

Category	Amount (US$)	Payment Trigger
Booth space (WGC + CERAWeek)	60,000	Week 153 on contract signature
Design & Fabrication	180,000	40 % Wk 154, 40 % Wk 155, 20 % Wk 157
Freight & Drayage	18,000	Week 157 upon AWB issue
Travel & Accommodation	45,000	Split across Weeks 155-161 per policy
Contingency (5 %)	12,000	Only with CFO approval

Key Performance Indicators

- Qualified leads: ≥150 (WGC≥70, CERAWeek≥80).
- Booth traffic dwell time: ≥4 min average (track via overhead sensor).
- Cost per qualified lead: ≤ US$1,600.
- Talk session attendance: ≥85 % room capacity.
- CRM data integrity: 0 duplicate records, 100 % mandatory fields.

Top Risks & Mitigation Measures

Risk	Likelihood	Mitigation Action
Freight delay in customs	Medium	Use ATA carnet; ship one week earlier than minimum; pre-clear docs.

HubSpot scanner failure	Low	Carry two backup handheld scanners; offline CSV import procedure ready.
Staff illness	Medium	Maintain on-call reserve BDR; provide PPE & health insurance.

Strict adherence to the above sequence will ensure secure booth acquisition, flawless logistics, and achievement of lead-generation KPIs within budget.

Build webinar curriculum & annual schedule

Objective: Produce an 8-part, buyer-journey-aligned webinar curriculum and a 12-month broadcast calendar that launches Month 4 of Phase 3 (Week 175), meets a US$101.6 k budget, and delivers ≥500 registrants and ≥50 % MQL conversion per session.

Key Deliverables

1. Curriculum Brief (topic rationale, learning objectives, buyer-stage mapping).
2. Session Design Sheets (run-of-show, speaker list, interactive elements).
3. Broadcast Calendar & Production Gantt (Weeks 155-175 planning + monthly cadence).
4. ON24 Channel set-up & HubSpot integration map.
5. Budget Tracker & KPI Dashboard template.
6. Speaker Contracts & Production Playbook.

Curriculum Overview

#	Session Title	Buyer-Journey Stage	Primary Outcome
1	Intro to Superhot Geothermal	Awareness	Generate intrigue & list growth
2	Drilling Physics Deep-Dive	Consideration	Validate technical feasibility
3	Plant Economics & LCOE Modeling	Consideration	Equip finance teams with ROI data
4	Regulatory & Permitting Pathway	Consideration	De-risk compliance concerns
5	Financing Structures & Offtake	Preference	Show path to bankability
6	Grid Integration & Stability Impacts	Preference	Assure system planners
7	Global Case-Study Panel	Decision	Demonstrate peer validation

8	Live Executive Q&A	Decision	Move prospects to pilot discussion

Granular Action Plan (Weeks 155 – 163)

1. **Week 155 – Kick-off & Framework Alignment**
    1. Create a detailed project Gantt referencing this action plan; circulate to Marketing VP & Sales Ops.
    2. Host 60-min alignment meeting with Product Marketing, Sales Enablement, and Engineering leads to validate curriculum topics against buyer-journey gaps.
    3. Confirm success metrics: 500 registrants, 50 % MQL, budget cap US$101.6 k.
    4. Open ON24 project in procurement system; lock enterprise license allocation.
2. **Week 156 – Curriculum Deep-Draft**
    1. For each of the 8 sessions:
        1. Define 3 SMART learning objectives.
        2. Draft 5 key talking points mapped to objections uncovered by Sales.
        3. List ideal speaker profiles (internal SME, external validator, customer).
    2. Compile into a *Curriculum Brief* (8-page deck); route for feedback via Slack channel #webinar-gtm.
3. **Week 157 – Speaker Sourcing & Contracts**
    1. Issue speaker invitations with briefing sheets & honorarium terms (US$750/session external).
    2. Create DocuSign templates; track status daily until 100 % signed.
    3. Log bios, headshots, and availability into Master Speaker Sheet (Google Sheets).
4. **Week 158 – Session Design & Interaction Mapping**
    1. Build ON24 console template:
        1. Branding palette #003359 + GeoTherm20 logo.
        2. Widgets: Q&A, Resources, Polling, CTA “Request Pilot”.
    2. Create *Session Design Sheets* with run-of-show timelines (min-by-min, max 45 min content + 15 min Q&A).
    3. Review with Production Engineer for technical feasibility.
5. **Week 159 – Calendar Engineering**
    1. Using corporate holiday calendars (OECD + Asia), propose monthly Wednesday 16:00 UTC slots starting Week 175; assign each session to Month 1-8.

2. Enter schedule into ON24 and HubSpot Events; ensure bi-directional sync tags (Campaign ID: GT20-WEB2024).
3. Publish internal *Broadcast Calendar & Production Gantt*; attach dependency milestones (dry-runs T-14 days, asset final T-7 days).

6. **Week 160 – Asset Production Pipeline**
    1. Commission design of:
        1. Master Keynote template.
        2. Social banners (LinkedIn 1.91:1, Twitter 16:9).
        3. Email headers & footer graphics.
    2. Draft copy for:
        1. Registration landing pages.
        2. Three-touch promotional email series.
        3. Reminder & post-event nurture emails (include dynamic CTA to next session).
    3. Route assets through Brand Compliance; implement edits within 48 h.

7. **Week 161 – Tech Stack Integration & QA**
    1. Configure ON24 → HubSpot field mapping:
        1. Registrant → Lifecycle Stage.
        2. Poll response → Custom Property “Pain_Point”.
        3. CTA click → MQL score +30.
    2. Run end-to-end registration test; confirm data writes within 5 min.
    3. Create KPI Dashboard in HubSpot reporting library; schedule weekly auto-emails to stakeholders.

8. **Week 162 – Dry-Run Protocol & Playbook Finalisation**
    1. Document 20-step Production Playbook (tech check, greenroom, emergency plan).
    2. Host mock webinar with internal staff; measure audio, video, latency, poll trigger timings.
    3. Incorporate feedback; version-lock playbook v1.0.

9. **Week 163 – Executive Sign-off & Public Launch**
    1. Present full package (curriculum, calendar, assets, dashboard) to CMO for approval.
    2. Post approval, switch ON24 registration pages from “private” to “public”.
    3. Activate first email blast (Audience: Tier-1 & Tier-2 utility personas, 52 k records).
    4. Publish LinkedIn organic + paid campaigns; allocate US$2k PPC starter budget.

5. Archive all planning docs to SharePoint > Marketing > Webinars > 2024 Plan.

Post-Plan Ongoing Responsibilities (Weeks 164 →)

1. Hold fortnightly sprint reviews; update Gantt & risk log.
2. Track registration velocity; trigger paid-media booster if <250 registrations T-10 days.
3. Conduct T-14 day and T-1 day dry-runs for each session.
4. Within 24 h post-broadcast, publish On-Demand link, transcribe via Rev.com, and load caption file to ON24 for accessibility compliance.
5. Enrich all poll & Q&A data to HubSpot; trigger personalized nurture streams.
6. Quarterly budget vs. actual reconciliation; adjust allocations to stay ≤ US$101.6 k annual.

KPI Tracking & Reporting Cadence

- Weekly: Registration count, cost per registrant.
- Fortnightly: Attendance rate, poll engagement, Q&A volume.
- Monthly: MQL conversion %, pipeline $ influenced, content syndication downloads.
- Quarterly: ROI analysis (revenue attributed ÷ spend), curriculum refresh recommendations.

Risk Register & Mitigation Actions

Risk	Likelihood	Impact	Mitigation
Speaker cancellation	Medium	High	Secure alternates in Week 157; maintain evergreen backup slides.
Platform outage	Low	High	Simul-record via Zoom; auto-push recording if live fails.
Budget overrun	Medium	Medium	Monthly reconciliation; freeze discretionary ad spend if variance >10 %.

By executing the above step-by-step plan, the Webinar Producer (P-WP-14) will deliver a fully-operational, metrics-driven webinar program that scales GeoTherm20’s market education and accelerates pilot commitment from target utilities.

```html
# Design pilot-site customer-visit program (safety, logistics)
```

1. Objectives & KPI Alignment

Create a turnkey, repeatable site-visit program that:

- Delivers **20** tours (up to **10** guests each) during Phase 3.
- Achieves post-visit **NPS ≥ 70** and **50 %** RFP conversion within 6 months.
- Maintains zero safety incidents and zero interference with site commissioning.
- Operates within the US$ 170 k budget (PPE, catering, travel subsidies).

2. End-to-End Action Plan (Week 157 – 165)

#	Week / Day	Action	Deliverable / Decision Gate
1	W157 D1	Kick-off with Site Ops, HSE, Legal, Sales. Confirm tour dates that do not overlap with turbine commissioning milestones.	Signed cross-functional charter & locked calendar (20 slots).
2	W157 D2-D3	Draft visitor workflow diagram (invite → NDA → pre-brief → arrival → tour → debrief → follow-up).	Process map v1.0 approved by VP Marketing.
3	W157 D4-D5	Issue RFPs for the following suppliers: PPE kits, catering, coach transport, VR demo equipment rental.	3 vendor quotes/category uploaded to procurement portal.
4	W158 D1	Select vendors via scoring matrix (cost, availability, safety certs).	Signed purchase orders; budget burn-down sheet updated.
5	W158 D2-D3	Script 25-minute guided tour covering drill rig, wellhead, turbine hall, control room, flare stack & safety muster points.	Tour script v1.0; slide deck for guides.
6	W158 D4-D5	Record 7-min HSE induction video with captions; upload to secure portal.	Video link embedded in confirmation emails.
7	W159 D1	Create digital NDA package (DocuSign) pre-filled with visitor data fields.	Automated NDA workflow live.
8	W159 D2-D3	Order PPE (flame-resistant coveralls, helmets, gloves) in S-XXL; print visitor names on helmets.	Inventory log & sizing matrix confirmed.
9	W159 D4-D5	Design visitor badge & lanyard; incorporate RFID for zone access.	100 badges printed & tested.
10	W160 D1	Draft personalised invitation emails for priority utilities, embed calendar booking link.	Email templates approved by Sales SVP.
11	W160 D2-D5	Launch invitation wave 1 (120 recipients). Track RSVPs; trigger NDA & HSE video auto-send upon registration.	50 % slot fill target reached.

12	W161 D1-D2	Set up hospitality lounge: furniture, branding banners, 75-inch screen for VR drill-path demo.	Lounge checklist signed off by Facilities.
13	W161 D3-D4	Integrate VR demo (Unity build) with visitor headsets; conduct UI walkthrough.	VR latency < 40 ms verified; guide cheat-sheet printed.
14	W161 D5	Create emergency-response quick-card (laminated) for all staff & guests.	40 cards distributed.
15	W162 D1	Conduct full walkthrough with Site Ops & HSE to validate visitor routing and muster points.	Sign-off on route & risk register (rev C).
16	W162 D2-D3	Train 6 tour guides (2 primary, 4 backup) on script, radios, crowd management.	Competency checklist 100 % passed.
17	W162 D4-D5	Prepare visitor welcome packs (agenda, fact-sheet, safety card, branded notebook, pen).	200 packs sealed, stored in lounge.
18	W163 D1	Dry-run with internal staff acting as visitors; time each segment, capture friction points.	Action log (≥ 10 improvements) implemented.
19	W163 D2	Finalize contingency plan (bad weather, equipment trip, medical event).	Contingency SOP uploaded to SharePoint.
20	W163 D3-D5	Send reminder emails to week-164 visitors (agenda PDF, gate map, PPE size confirmation).	Zero open issues on visitor tracker.
21	W164 D1-D5	Execute first 3 customer visits (Mon/Wed/Fri). Log safety observations, visitor questions, dwell times.	Daily debrief report & NPS survey distribution.
22	W165 D1	Analyse first-week data: NPS, dwell, VR feedback, safety deviations, budget variance.	Performance dashboard v1.0.
23	W165 D2	Present findings to Marketing & Site Ops; agree top 5 improvements.	Change-log v1.1 signed; implement immediately.
24	W165 D3-D5	Roll out improvements and continue weekly cadence of 3 visits until capacity met; maintain continuous feedback loop.	Program moves to steady-state; hand-off SOP to Successor Coordinator.

3. Control Mechanisms

- **Budget Tracker:** Update every Friday; flag ≥ 10 % variance to VP Finance.
- **Safety Audits:** HSE officer completes form GT20-HSE-VIS v2 after each visit.
- **NPS Dashboard:** Qualtrics automation feeds Tableau; alert if score < 70.
- **RFP Conversion Tracker:** CRM pipeline tagged “Pilot Visit”; review M+6.

4. Escalation Matrix

Issue	Threshold	Escalate To	Action Window
Safety incident (recordable)	Any	VP HSE + Site Manager	1 hour
NPS < 70	Weekly Avg.	VP Marketing	24 hours
Budget over-run > 10 %	Cumulative	CFO	48 hours
Commissioning conflict	Any date clash	Site Operations Lead	2 hours

5. Post-Visit Follow-Up (Standard for Every Group)

1. Send thank-you email + NPS survey within 2 hours of departure.
2. Upload attendee list & notes to CRM within 24 hours.
3. Assign technical Q&A to Engineering Liaison; respond within 72 hours.
4. Schedule commercial follow-up call with Sales Executive (≤ 7 days).
5. Tag opportunity “Post-Visit” and start 6-month RFP countdown timer.

6. Documentation & Version Control

All templates, SOPs, logs and dashboards reside in **SharePoint Customer Visit Program v1**; controlled by Event Coordinator P-EC-12. Change requests follow Doc ID GT20-DOC-076.

Prepared for: Event Coordinator – P-EC-12 | Approved by: VP Marketing & VP HSE

``

Produce sales-enablement collateral (datasheets, VR demo)

Objective

Create a comprehensive collateral suite that enables the sales force to accelerate deal velocity with technical buyers by Week 165, within the US $95 k budget and in full compliance with brand guidelines GTM-002. Deliverables include:
1) 4-page plant datasheet, 2) financing options one-pager, 3) risk-mitigation brief, and 4) an immersive Meta Quest VR demo of a 25 km LithoLoop 25 bore and surface power block. All assets must be uploaded to the HubSpot File Manager with buyer-stage tags for automated nurture workflows.

Responsible Role & Authority

Graphic Designer – P-GD-08

• Full design authority over collateral layout, typography, imagery, and interactive experience flow.

• Operational authority to requisition copywriters, illustrators, 3D modelers, Unity developer(s), and QA testers within the US $95 k budget.

• Required to route all drafts through Brand, Legal, and Engineering for formal sign-off before release.

Granular Week-by-Week Action Plan (Phase 3 – Weeks 158-165)

Week	Sequential, Non-Negotiable Actions	Owner(s)	Budget Check-point
158	1. Download and review GTM-002 brand guideline PDF to lock typography, colour codes (#003359 primary / #FFFFFF secondary) and logo-use rules. 2. Book 90-min kickoff call with Sales Lead (S-SL-03), Product Manager (P-PM-05), and Engineering Liaison (E-EL-02) to confirm: target persona pain-points, mandatory KPIs, CAPEX ranges, financing mechanisms, and risk mitigations. 3. Request most recent engineering spec sheets, 3D CAD models, and project finance term-sheet via Confluence. 4. Break total US $95 k budget into preliminary work-packages: US$25 k print collateral, US$60 k VR development, US$10 k QA & contingency. 5. Log task in Asana with eight milestones, assign cross-functional reviewers, and sync due dates to company calendar (GMT-0). 6. Create HubSpot folder tree: /Collateral/Phase3/Week158-165 with sub-folders “Datasheet”, “Financing-OnePager”, “Risk-Brief”, “VR-Demo”.	P-GD-08	Budget baseline published to CFO
159	1. Draft 4-page datasheet wireframe in Adobe InDesign: Page-1 Hero, Page-2 KPIs, Page-3 Footprint & Brayton-cycle diagram, Page-4 CAPEX & OPEX table. 2. Commission illustrator to convert engineering CAD STL files into brand-compliant isometric SVGs (max spend US$4 k). 3. Write initial copy (≤120 words per section) and paste into InDesign placeholders. 4. Simultaneously storyboard VR demo in Figma; define five waypoints: Surface Pad, Vertical Kick-off, Mid-Bore vitrified wall, Reservoir 30 km, Power Block.	P-GD-08 + Illustrator + Unity Dev	Spend to-date ≤ US$15 k

	5. Engage Unity developer via existing vendor frame agreement; issue SoW with deliverables, pay-ment milestones, and Meta Quest build settings (Unity 2022 LTS, URP). 6. Upload v0.1 datasheet PDF and VR storyboard PNGs to HubSpot; tag “Buyer-Stage: Awareness”.		
160	1. Route datasheet v0.1 to Engineering for technical accuracy; capture red-lines in InDesign comments. 2. Design custom CAPEX bar-chart and LCOE waterfall graphic in Adobe Illustrator; embed as linked EPS. 3. Apply colour-blind-safe palette check (WCAG 2.1 AA). 4. Produce datasheet v0.2; submit to Legal for disclaimers and IP statements. 5. Receive initial 3D mesh decimation from Unity developer; verify polygon count ≤ 450 k total for Quest. 6. Create VR-demo UI style-guide (font: Poppins Medium 24 pt, button radius 8 px, ARIA labels for all interactables). 7. Document all changes in Asana and update HubSpot “version-notes.txt”.	P-GD-08	Spend to-date ≤ US$30 k
161	1. Build Financing Options one-pager layout: half-page infographic (IPP vs utility PPAs), half-page bullet list of debt-equity mix. 2. Conduct 30-min finance validation call with CFO (F-CFO-01) to ensure IRR, WACC, tenor figures are accurate. 3. Draft Risk-Mitigation brief (2 pages): headings “Geological Risk”, “Drilling Risk”, “CO_2 Loop Integrity”, “Construction Schedule”. 4. Insert third-party insurance partner logo per brand co-branding rules; secure written permission email. 5. Complete datasheet v1.0 incorporating all feedback; export PDF/X-1a:2003 with 300 dpi images. 6. Upload finalized datasheet to HubSpot; apply tags “Buyer-Stage: Consideration”, “Asset-Type: Datasheet”.	P-GD-08 + CFO	Spend to-date ≤ US$40 k
162	1. Iterate Financing one-pager and Risk brief with design polish: use 12-column grid, 0.7 in margins, kerning -10 for headings. 2. Run readability test (Flesch-Kincaid ≤ Grade 12). 3. Send both assets to Legal for regulatory disclaimer language (SEC Reg D reference) and to Brand for final design approval. 4. Commission professional voice-over (English neutral, 90 seconds) for VR demo intro; budget ≤ US$2 k, deliver 48 kHz WAV. 5. Receive Unity demo alpha build (v0.5) via GitHub; install on Meta Quest test headset; execute QA checklist: • Frame rate ≥ 72 FPS • Controller ray-cast alignment ≤ 2° error • Audio-lip-sync ±50 ms 6. Document all defects in Jira and assign to Unity developer.	P-GD-08 + Legal + Unity Dev	Spend to-date ≤ US$60 k

163	1. Receive defect-fixed Unity build (v0.7); perform second QA pass; confirm all critical issues resolved. 2. Localize Financing one-pager and Risk brief into Spanish, French, Japanese; employ approved translation vendor, budget ≤ US$4 k. 3. Package print-ready files: collect all fonts, linked images; compress to ZIP named GeoTherm20_Collateral_163.zip; upload to HubSpot with “print-ready” tag. 4. Create HubSpot CTA buttons linking to each asset; schedule nurture emails #7–#9 in Awareness & Consideration sequence. 5. Draft Meta Quest store private release notes, privacy policy, and icon 1024 × 1024 px.	P-GD-08 + Translation Vendor	Spend to-date ≤ US$70 k
164	1. Conduct cross-functional sign-off meeting (Sales, Engineering, Legal, Brand) for all collateral PDFs – obtain electronic approvals via DocuSign. 2. Receive VR demo Release Candidate (v0.9); run full-length user-journey test with three sales reps; capture usability SUS score (target ≥ 85). 3. Optimize texture compression (ASTC 6×6) and rebuild; retest load time ≤ 20 seconds. 4. Submit RC build and assets to Meta for App Lab private listing; set access by invite-only email group “prospect-vr-demo@geotherm20.com”. 5. Update HubSpot property “VR Demo Access Granted” and connect webhook to send invite automatically upon MQL stage change. 6. Lock final project ledger; forecast final spend ≤ US$90 k (≤ 5 % contingency remaining).	P-GD-08 + Unity Dev	Spend to-date ≤ US$90 k
165	1. Receive Meta approval; download App Lab URL; shorten via branded Bitly link. 2. Embed VR demo link within Financing one-pager QR code; regenerate PDF (v2.0). Upload and overwrite previous file in HubSpot. 3. Execute final QA sweep: open each HubSpot CTA, PDF, and VR link from external network; capture screen-record for audit evidence. 4. Archive all source files on internal NAS path “/Marketing/Archive/Phase3_Collateral_W165”. 5. Email project-completion memo to CMO, CFO, Sales Lead with: budget summary (actual vs planned), asset list, and analytic dashboards URLs. 6. Close Asana project, marking 100 % completion.	P-GD-08	Final spend ≈ US$92 k (3 % under budget)

Mandatory Quality-Control Checklist

- Brand colours, fonts, logo spacing exactly as GTM-002.
- All PDFs pass pre-flight (PDF/X-1a), CMYK profiles embedded.

- Legal disclaimer footer appears on every collateral page.
- HubSpot tags: “Buyer-Stage” + “Asset-Type” populated.
- VR demo export setting: Target Device = Quest 2/3/Pro, API Level ≥ 26, Hand Tracking OFF.
- Meta privacy policy URL functional.

Risk Log & Mitigations

Risk	Mitigation Action
Meta store approval delay	Submit by Week 164; maintain sideload APK fallback distribution.
Budget overrun > 5 %	Hold 5 % contingency; defer multi-language audio to later tranche if needed.
Engineering spec changes after datasheet finalization	Freeze KPI inputs at Week 160; any post-freeze change requires VP Engineering written approval.

NON-NEGOTIABLE: No asset may reach prospects until Legal, Engineering, and Brand have signed-off, and HubSpot tags are correctly applied. Failure to comply will trigger automatic rollback and corrective action plan.

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### Recruit & onboard 4 Sr. Account Executives + 2 TSEs

# Objective

Staff the Commercial Force with four senior Account Executives (AEs) and two Technical Sales Engineers (TSEs) by Week 172, ensuring 100 % completion of all learning-management system (LMS) modules and readiness to pursue ≥US$50 M utility deals for LithoLoop 25.

## Summary Timeline (Phase 4: Weeks 166–172)

| Week | Milestone |
|---|---|
| 166 | Finalize job briefs, engage agency, launch requisitions |
| 167 | Source, screen & shortlist |
| 168 | Panel interviews & technical assessments |
```

169	Reference checks & offer negotiation
170	Contracts signed, hardware ordered, IT profiles created
171	4-week onboarding kicks off (Day 1 orientation)
172	Onboarding Week 1 complete; LMS 25 % checkpoint

Step-by-Step Action Plan

1. **Pre-Launch Preparation (Week 165, 2 days before Phase start)**
    - Review *GeoTherm20 Talent Policy* and confirm budget code “US$1.134 M – Commercial Force Deployment”.
    - Block 30-minute daily stand-up from Week 166-172 with HRBP and recruiting agency lead.
    - Load competency matrix (utility sales, RFP navigation, geothermal domain) into ATS scoring template.
2. **Week 166 – Requisition & Sourcing Kick-off**
    - Day 1 (Mon): Approve and post two job descriptions:
        1. Sr. Account Executive – Utility Vertical (4 headcount)
        2. Technical Sales Engineer – Superhot Geothermal (2 headcount)
    - Day 1: Send signed master-service agreement to chosen recruitment agency; confirm 20 % fee on first-year comp.
    - Day 2: Provide agency with screening questions and “must-have” thresholds (10+ yrs utility, ≥US$50 M deal close, technical acumen).
    - Day 3: Publish requisitions on LinkedIn, UtilityDive Jobs, EnergyCentral, and internal referral portal.
    - Day 4: Upload compensation bands (AEs 160k + 80k, TSEs 140k) to HRIS and set auto-reject filter for candidates outside range.
    - Day 5: HRBP exports initial résumé batch; Sales Director tags 20 high-priority profiles for recruiter outreach.
3. **Week 167 – Screening & Shortlisting**
    - Day 6: Recruiter conducts 30-min phone screens for 30 candidates; logs scores in ATS.
    - Day 7: Sales Director reviews screened list; selects top 12 AEs & 6 TSEs for first-round panel.
    - Day 8: Schedule video interviews (Zoom, 60 min) with panel:
        - Panel A: Sales Director, VP Marketing, Utility Solutions Architect (for AEs).
        - Panel B: CTO, Principal Drilling Engineer, Sales Director (for TSEs).
    - Day 9: Dispatch pre-work case study (“Structure $75 M PPA for 500 MW e Baseload Plant”).
    - Day 10: Confirm all NDAs signed via DocuSign.

4. **Week 168 – Technical & Cultural Assessment**
    - Day 11-12: Conduct 18 video interviews; score rubric: Deal Size (25 %), Utility Network (20 %), Technical Fluency (25 %), Culture Fit (15 %), Case Study (15 %).
    - Day 13: Run 2-hour debrief to rank candidates; select 6 finalists (4 AEs, 2 TSEs + 2 alternates).
    - Day 14: Begin reference checks (3 per candidate) and background screenings (Sterling).
5. **Week 169 – Offer Generation & Negotiation**
    - Day 15: Draft offer letters with Finance; attach variable-comp plan & KPI sheet.
    - Day 16: Obtain CEO signature on offers ≥$300 k total comp.
    - Day 17: Email offers; set 48-hour acceptance window.
    - Day 18-19: Negotiate minor clauses (start date, relocation) within approved band.
6. **Week 170 – Contract Finalization & Logistics**
    - Day 20: All six contracts countersigned; forward to Payroll.
    - Day 20: Initiate recruitment-agency invoice (20 % of $1.134 M = $226.8 k) – route to Accounts Payable.
    - Day 21: IT orders laptops, CRM seats (Salesforce Enterprise), Gong licenses, and 5G travel hotspots.
    - Day 22: Facilities books site-visit travel (HQ + pilot plant) for first onboarding week.
    - Day 23: HR loads employees in LMS; assigns 30 modules (product, compliance, ESG policy).
7. **Week 171 – Onboarding Week 1 (Immersion Kick-off)**
    - Day 24: Day 1 orientation
        - CEO welcome (30 min); safety briefing (15 min); IT hand-off (30 min).
    - Day 24: Distribute 4-week immersion schedule:
        1. Product Deep-Dive (Week 1)
        2. Shadow Webinars & Analyst Briefings (Week 2)
        3. Site Visit & Drilling Rig Walk-through (Week 3)
        4. Compliance & Deal Desk Simulation (Week 4)
    - Day 25-27: Live sessions with Engineering (geology, heat-loop thermodynamics, Brayton cycle).
    - Day 28: LMS Progress Review: target 25 % completion.
8. **Week 172 – Onboarding Week 2 Launch & KPI Checkpoint**
    - Day 29: Shadow utility-consortium webinar; each AE drafts question list for follow-up.
    - Day 30: Sales Director conducts 1-on-1s; log learning gaps & assign mentors.
    - Day 30: Submit status memo to COO confirming “Team fully staffed” milestone achieved.

Success Metrics & Reporting

- Headcount: 4 AEs + 2 TSEs active in HRIS by Week 170.
- Onboarding: 100 % LMS completion by Day 52 (end of Week 174, tracked automatically).
- Shadow Hours: ≥16 hrs of webinar/briefing attendance per hire logged in Gong.
- Cost Control: Keep total first-year cost ≤US$1.134 M; variance report in Month-End 8.
- Time-to-Fill: ≤30 calendar days from requisition to acceptance.

Risk Mitigation

- **Candidate Shortfall** – Activate referral bonus (US$5 k) if Week 167 pipeline <25 qualified leads.
- **Offer Decline** – Maintain two alternates; send “warm-standby” emails by Day 17.
- **Onboarding Slippage** – Escalate to HRBP if LMS completion <50 % by Day 35; schedule catch-up sprint.

Hand-off & Next Steps Post-Week 172

Upon completing Week 2 onboarding, responsibility transitions to Regional VPs for territory assignment and quota planning in Phase 5 (Pipeline Acceleration). Sales Director retains oversight of performance ramp until each hire closes first $10 M in bookings.

```

## Technical product boot-camp for AEs & TSEs

This action plan provides the Sales Director (P-SD-17) and Tech Sales Engineer 1 (P-TSE1-22) with a granular, unambiguous sequence of tasks required to design, deliver, assess and certify the technical boot-camp between Week 170 and Week 174 (Phase 4: Commercial Force Deployment) for Account Executives (AEs) and Technical Sales Engineers (TSEs). Strict adherence to the schedule, success metrics and deliverables is mandatory to ensure the sales force can independently handle deep-tech enquiries and compress deal cycles.

| Role | Initials | Primary Responsibilities |
|---|---|---|
```

Sales Director	SD	Programme owner, budget & resource approval, certification sign-off.
Tech Sales Engineer 1	TSE1	Curriculum architect, instructor coordination, assessment administration.

Master Timeline (Weeks 170 – 174)

Week	Focus	Hours
170	Pre-work, orientation, drilling physics classroom	8 hrs
171	sCO_2 thermodynamics classroom + lab	10 hrs
172	Regulatory codes & compliance classroom	8 hrs
173	Financial modelling classroom + case study	14 hrs
174	Field immersion (pilot site), certification exam & graduation	16 hrs

Step-by-Step Action Plan

1. **T-4 Weeks (Week 166):** SD emails formal mandate to TSE1 confirming budget (within onboarding cost line-item) and scope; copy HR L&D.
2. TSE1 drafts detailed agenda mapping 40 hrs classroom + 16 hrs field to curriculum modules; submits to SD within 48 hrs for approval.
3. TSE1 secures instructor slots: 2 × 2-hr guest sessions with CTO; allocates personal lead for remaining modules.
4. TSE1 books HQ training rooms (capacity 24, AV, whiteboard) and pilot-site access (Week 174); confirms logistics with Facilities.
5. SD circulates calendar invitations to all AEs & TSEs (mandatory) and partner programme observers (optional).
6. **Week 170, Day 1 (Mon, 09:00-10:00):** SD hosts orientation, reiterates learning objectives and ≥ 85 % pass criterion.
7. Day 1 (10:00-12:00): TSE1 issues pre-work: 30-page primer on drilling physics and 15-min safety video; sets overnight quiz in LMS (pass ≥ 70 %).
8. Day 2-3: TSE1 delivers 6-hr classroom on drilling physics (slide deck GTM-018-DP-v1); integrates live Q&A every 20 min.

9. **Week 171, Day 1:** CTO conducts 2-hr deep dive on sCO_2 Brayton cycle, includes turbine-material selection discussion.
10. Day 1 afternoon: Lab demo using digital twin; participants complete worksheet calculating thermal-gradient profiles.
11. Day 2: TSE1 facilitates 6-hr thermodynamics workshop; assigns group micro-teach (5 min each) captured on video for feedback.
12. **Week 172, Day 1-2:** TSE1 lectures 8 hrs on OECD/Asian regulatory codes; provides downloadable code-matrix tool.
13. Participants perform compliance mapping exercise for target utility in assigned territory, submit by Day 2 17:00.
14. **Week 173, Day 1-2:** TSE1 instructs 10-hr financial modelling using LithoLoop LCOE template (Excel GTM-018-FM-v2).
15. Day 2 evening: Teams build model for 500 MW plant, produce one-page investment memo.
16. Day 3 morning: Panel (SD, CFO, TSE1) critiques memos; scores contribute 15 % of final grade.
17. **Week 174, Day 1:** Field immersion at pilot site; safety briefing 07:30; split into 4 groups rotating through drilling rig, heat-exchanger skid, control room and environmental monitoring station (4 × 90 min).
18. Day 2 (HQ): 3-hr review session; distribute exam blueprint (80 MCQs, 2 case-based simulations).
19. Day 2 13:00-16:00: Proctored certification exam in LMS; auto-scoring immediately shows pass/fail. SD countersigns certificates for ≥ 85 % scorers.
20. TSE1 logs scores, identifies remediation list; schedules 1-on-1 coaching for anyone < 85 % within 7 days.
21. SD issues internal press release announcing certified cohort; updates CRM skill matrix.
22. TSE1 uploads all training assets to Partner Programme folder to fulfil GTM-018 reuse requirement.
23. SD surveys participants (NPS > 60 target) and submits ROI analysis to Executive Committee by Week 176.

Success Metrics & Acceptance Criteria

- Certification exam pass rate ≥ 90 % overall; individual minimum 85 %.
- Participant self-reported confidence to answer deep-tech questions ≥ 4/5.
- Time-to-technical-validation in sales cycle reduced by 20 % within 90 days (SD tracks).
- All materials uploaded and version-controlled for partner reuse (audit by PMO).

Key Risks & Mitigation

Risk	Mitigation Owner	Action
Instructor availability clash	TSE1	Secure alternates & pre-record fallback videos by Week 168.
Pilot site access restricted (weather/regulation)	SD	Arrange virtual reality site tour alternative; decision gate Week 172.
Exam tech failure	TSE1	Backup paper exam copies + manual scoring sheets prepared Week 173.

Execution of the above steps without deviation is mandatory to uphold GeoTherm20's commercial timelines and to establish deep-tech credibility with utility stakeholders. SD and TSE1 are accountable for on-time, on-quality delivery.

Architect channel/partner programme (T&Cs, tiers, MDF)

1. Executive Overview

This manual provides the Partner Programme Manager (P-PPM-24) with a precise, week-by-week roadmap—covering Phase 4, Weeks 168-176—to architect GeoTherm20's global EPC/Drilling Channel Programme. Follow every step in sequence; deviation risks budget overrun, legal exposure, or partner confusion.

2. Pre-Work & Mandatory Dependencies (Complete before Week 168 Day 1)

1. Secure written confirmation of **US $175 k** budget line from CFO.
2. Book 30-minute kick-off slot on calendars of CRO, CLO, VP Engineering, and PMO.
3. Request latest HSE/TRIR data sheet template from QHSE lead.
4. Collect sales pipeline data for prospective partners (CRM export).
5. Create shared project workspace in GeoTherm20 SharePoint with permissions for Legal, Finance, and Marketing.

3. Detailed Week-by-Week Action Plan

Week	Mandatory Actions (Execute in Listed Order)
168	1. Conduct 60-min programme kick-off with core team; confirm objectives, timeline, and deliverables. 2. Finalise partner qualification criteria: ≥3 geothermal/O&G EPC projects, HSE TRIR < 0.5, regional reach, balance-sheet review. 3. Draft “Desired Partner Persona” one-pager; circulate for CRO sign-off within 24 h. 4. Build master partner candidate list from CRM + industry databases; tag by region & capability. 5. Engage Finance to obtain margin thresholds for discount modelling; deadline: Friday EOD.
169	1. Architect tier framework: Silver, Gold, Platinum—define quantitative thresholds for revenue, certifications, HSE, and pipeline contribution. 2. Financial model: calculate discount bands and MDF allocation per tier; ensure aggregate discount ≤ planned margin erosion (secure CFO validation). 3. Draft Governance model: quarterly business review cadence, scorecard metrics, escalation path. 4. Schedule 90-min cross-functional workshop (Legal, Finance, Marketing, Sales Ops) for Week 170 Day 2 to ratify framework.
170	1. Facilitate workshop; log all decisions in meeting minutes within 2 h post-session. 2. Engage Legal to begin drafting Master Channel Agreement (MCA): scope, IP protection, branding rules, indemnities, termination clauses. 3. Draft Joint Marketing Service-Level Agreement (SLA) including response times, content approvals, and co-branding guidelines. 4. Define MDF operational process: request form, approval SLA 48 h, reimbursement timeline 30 days. 5. Upload version-1 documents to SharePoint; request line-by-line feedback by Week 171 Day 3.
171	1. Consolidate feedback; resolve conflicts via 30-min huddles with each function. 2. Secure preliminary legal sign-off on IP, warranty, and liability sections. 3. Build Partner Tier Matrix slide: visual table with criteria, benefits, discounts, MDF caps. 4. Draft internal FAQ (≥25 Q&A) covering pricing, exclusivity, certifications, HSE compliance. 5. Distribute revised pack (v2) to CRO & Legal for green-light by Week 172 Day 1.
172	1. Design Partner Scorecard template: KPIs—pipeline generated, certifications completed, HSE incidents, deal conversion, MDF ROI. 2. Build automated dashboard link to CRM for real-time metric pull; coordinate with Sales Ops. 3. Draft Partner Onboarding Playbook (step-by-step tasks, contacts, SLAs, training modules). 4. Review MDF budget utilisation projection; adjust tier caps to maintain initial US$100 k pool. 5. Arrange exec review meeting (C-Suite) for Week 173 Day 3; circulate pre-read 48 h prior.
173	1. Conduct 60-min C-Suite review; capture approval or action items live. 2. Finalise legal documents; obtain signatures from CLO and CRO. 3. Freeze discount & MDF schedule; upload to ERP pricing module. 4. Issue change-control notice to Finance and PMO confirming locked framework. 5. Launch design request for branded Partner Programme collateral (brief to Marketing).
174	1. Produce partner-facing PDF kit: overview, tier benefits, T&Cs summary, application form. 2. Develop 30-slide internal enablement deck; include objection handling & pricing calculator walkthrough. 3. Record 15-min Loom video summarising key changes for global sales teams. 4. Schedule two global time-zone training webinars for Week 175 Day 2 and Day 3. 5. Publish collateral to Partner Portal (behind NDA gate).

175	1. Deliver live sales enablement webinars; answer questions in real time; log unanswered Qs. 2. Email post-webinar survey; target 80 % completion within 24 h. 3. Iterate FAQ based on webinar queries; republish v1.1. 4. Draft partner outreach email sequence (3 touches) for launch. 5. Load sequence into marketing automation platform; QA links & tracking pixels.
176	1. Soft-launch programme: send outreach email to top-20 target partners; track open & response rates. 2. Activate application intake workflow; monitor submissions daily; triage qualification within 48 h. 3. Set first Quarterly Business Review (QBR) calendar placeholders for future partners. 4. Close project with lessons-learned session; document improvement actions. 5. Transfer ownership of ongoing operations to Partner Success Lead; sign hand-off checklist.

4. Deliverable Completion Criteria (Non-Negotiable)

- Approved Partner Tier Matrix (Silver/Gold/Platinum) uploaded to SharePoint.
- Signed Master Channel Agreement & Joint Marketing SLA stored in Contract Repository.
- Discount & MDF Schedule configured in ERP pricing module.
- MDF initial pool of US$100 k reflected in Finance ledger with GL code.
- Partner Scorecard dashboard live and connected to CRM.
- Partner-facing collateral published to Portal; internal teams trained (attendance ≥90%).

5. Budget & Resource Allocation

Line Item	Cap (US $)
Legal Drafting & Review	60,000
Marketing Collateral & Design	35,000
Sales Enablement & Training	15,000
Partner Portal Enhancements	20,000
Contingency (10%)	17,500
Total	**175,500**

6. Top Risks & Mitigation Actions

Risk	Mitigation
Legal review delays	Set SLA 3-day turnaround; escalate to CLO if breached.

Discounts erode margin	Finance validates model; PPM enforced cap via ERP controls.
MDF misuse	Reimbursement only on pre-approved activities with receipts; quarterly audit.
Partner brand dilution	Strict co-branding guidelines in SLA; revoke usage rights on breach.

7. Final Sign-Off Authority

Completion of this action plan requires written approval (email or DocuSign) from: CRO, CLO, CFO, VP Marketing, and PMO Lead. Store signed confirmation in project workspace.

Build partner portal & training modules

Executive Summary

The following step-by-step instruction manual enables the Channel Enablement Specialist (Role ID: P-CES-25) to design, develop, deploy, and optimise a secure self-service partner portal integrated with TalentLMS and HubSpot during Week 170–178 of GeoTherm20's GTM programme. Completion will certify a minimum of ten partners to Silver tier, lighten direct Sales Engineering workload, and accelerate joint deal execution.

Objectives

- Ship a branded, tier-controlled partner portal (TalentLMS) seamlessly integrated with HubSpot partner object & SSO.
- Publish six micro-learning courses (≤7 min each) covering product, HSE, proposal estimator, and go-to-market skills.
- Launch downloadable co-branding kit (logos, boilerplates, slide decks, imagery, messaging guardrails).
- Achieve ≥10 Silver-tier partner certifications by Week 178.
- Stay within the allocated US$205 000 budget (US$175 000 programme + US$30 000 development).

Timeline Overview (Week 170 – 178)

Week	Milestone
170	Kick-off, requirement finalisation, portal architecture & brand kit outline
171	TalentLMS instance provisioned, HubSpot OAuth & SSO configured, wireframes approved
172	Micro-course scripts finalised, UX front-end build complete, QA round 1
173	Video/audio production, SCORM packaging, certification logic coded
174	Beta launch to 3 pilot partners, bug fixing, content localisation checks
175	Iterate portal, final asset upload, co-marketing kit approved by Legal/Brand
176	Global partner roll-out, enablement webinars, KPI tracking dashboard live
177	Certification push campaign, help-desk triage, satisfaction survey collection
178	Target ≥10 Silver certificates issued, project close-out & handover to Partner Ops

Detailed Weekly Action Plan

Week 170 – Project Initiation & Scope Lock

1. Book 90-minute kick-off with Product, Sales Engineering, Legal, Brand, and IT Security.
2. Confirm functional requirements: LMS features, HubSpot data sync, tiered access rules (Silver, Gold, Platinum).
3. Collect existing training collateral, HSE manuals, proposal estimator documentation.
4. Draft portal IA (Information Architecture) including dashboards, course catalog, certification pathways.
5. Create first version of co-branding kit outline (asset list, brand usage policy, template needs).
6. Lock success metrics & reporting cadence (daily Slack digest, weekly KPI sheet).
7. Submit purchase orders against US$30 000 dev budget for UX agency & SCORM freelancer.

Week 171 – Platform Provisioning & Wireframing

1. Provision dedicated TalentLMS tenant (geo-redundant EU & US servers).
2. Implement SSO (SAML 2.0) using GeoTherm20 Okta; map HubSpot partner IDs to TalentLMS user fields via API.
3. Create user roles: Partner-Standard, Partner-Silver, Partner-Gold, Partner-Platinum, GT20-Admin.
4. Design responsive wireframes (Figma) for:
    1. Landing & login
    2. Learning dashboard

    3. Certification progress tracker
    4. Resource library (co-marketing assets)
5. Submit wireframes to Brand & IT for approval (SLA: 48 h).
6. Compile micro-learning outline (6 courses × ≤7 min) with specific objectives, formats, and SME owners.

Week 172 – Content Scripting & Front-End Build

1. Finalize course scripts/storyboards:
    - Course 1: LithoLoop 25 Overview & Value Prop
    - Course 2: Technical Architecture Deep-Dive
    - Course 3: HSE Compliance & Risk Mitigation
    - Course 4: Proposal Estimator Walk-through
    - Course 5: Competitive Positioning vs. Coal/Nuclear
    - Course 6: Deal Registration & Joint Selling Process
2. Hand scripts to multimedia vendor; secure voice-over talent.
3. Convert approved wireframes into HTML/CSS within TalentLMS theme editor; enforce dark-blue palette.
4. Integrate Google Analytics & HubSpot tracking pixels.
5. QA front-end (desktop, tablet, mobile); log defects in Jira board “Partner-Portal” project.
6. Secure sign-off from Brand and Accessibility leads (WCAG 2.1 AA).

Week 173 – Media Production & Certification Logic

1. Record screen-casts & VO; generate subtitles (SRT) for localisation.
2. Package each module as SCORM 1.2; embed interactive quizzes (4 questions each; 80 % pass threshold).
3. Create certification rule: Complete all six courses + score ≥80 % average → Silver certificate auto-issued.
4. Connect TalentLMS webhook to HubSpot to update partner tier field on certification event.
5. Draft automated nurture emails (HubSpot): “Course Reminder”, “Congrats Certified” templates.
6. Conduct internal UAT with 5 GT20 employees representing partner personas; complete feedback form.

Week 174 – Closed Beta & Localisation

1. Select 3 pilot partners (EU, US, JP); create ten test accounts each with Partner-Standard role.
2. Execute 5-day beta program:
    - Day 1: Onboarding email & SSO instructions
    - Day 3: Mid-beta check-in via Slack/Teams
    - Day 5: Exit survey (NPS, content clarity, UX)
3. Log issues, prioritise P0/P1 bugs, fix within 48 h.
4. Run automated translation for subtitles (FR, JP, DE) and validate via native speakers.
5. Refine co-branding kit (add sample press release, social tiles, webinar-in-a-box deck).

Week 175 – Stabilisation & Asset Finalisation

1. Implement beta feedback fixes; rerun regression QA.
2. Upload final SCORM packages, subtitle files, resource PDFs, proposal estimator spreadsheet v2.3.
3. Obtain Legal approval for co-marketing kit usage terms (click-wrap agreement in portal).
4. Generate printable PDF certificate with hologram watermark & unique ID.
5. Configure daily data sync (HubSpot → Snowflake) for live KPI dashboard.
6. Publish portal user guide (FAQ, support process, SLAs).

Week 176 – Global Launch & Enablement Push

1. Send official launch email to all existing partners (HubSpot list “Active Partners”).
2. Host two live enablement webinars (EMEA/APAC & AMER) demonstrating portal navigation and benefits.
3. Activate automated email cadence: Day0 launch → Day3 reminder → Day7 nudge.
4. Monitor real-time adoption via KPI dashboard; flag low-engagers to Partner Managers.
5. Open 24/7 help-desk using Zendesk; train CSRs with runbook.

Week 177 – Certification Drive & Support

1. Launch “Race to Silver” campaign: leaderboard email + prizes (swag kits).
2. Schedule 1-on-1 office hours for partners scoring <80 % on quizzes.
3. Handle ticket backlog ≤4 h response SLA.

4. Collect satisfaction surveys; aim for ≥8.0/10 average rating.
5. Prepare weekly progress report for GT20 leadership.

Week 178 – Milestone Completion & Handover

1. Verify at least 10 unique partners have Silver certificate status in HubSpot.
2. Run final portal performance test (load, uptime, security scan).
3. Compile project close-out deck:
    - Budget vs. actuals
    - Adoption metrics
    - Lessons learned
4. Transfer admin credentials, runbooks, and documentation to Partner Operations team.
5. Archive project Jira board; schedule 30-day post-launch review meeting.

Resource Allocation & Budget

Item	Estimated Cost (US$)	Owner
TalentLMS Licensing (1 yr)	45 000	Channel Enablement
UX/UI Agency	25 000	Marketing Ops
SCORM & Multimedia Production	30 000	Learning Design Lead
HubSpot Integration Dev	20 000	RevOps
Translations & Subtitles	15 000	Localization PM
Contingency (10%)	20 000	Finance
Total	**155 000**	

Remaining US$50 000 of the programme budget (plus US$30 000 development buffer) reserved for future Gold/Platinum course expansion and ongoing maintenance.

Risk Management & Mitigation

- **Delay in content production** – Set daily stand-ups with multimedia vendor; maintain backup narration talent.
- **Integration failure** – Stage integration in sandbox; schedule pen-test; keep manual CSV fallback import.
- **Low partner adoption** – Trigger automated reminders; escalate to Partner Managers for personal

outreach.
- **Budget overrun** – Track weekly spend; freeze contingency if variance >5 %.
- **Compliance breach** – Conduct security review, enforce MFA, annual penetration test.

KPIs & Reporting Cadence

Metric	Target	Frequency
# Partners certified Silver	≥10 by Week 178	Weekly
Course completion rate	≥70 % within 2 weeks of launch	Daily
Average quiz score	≥85 %	Weekly
NPS of portal	≥50	At Week 177

Communication & Stakeholder Management

- **Daily** – #partner-portal Slack channel auto-posts adoption stats.
- **Weekly** – Email summary to GT20 leadership (CRO, CMO, CTO).
- **Bi-weekly** – 30-min steering committee call (Enablement, RevOps, Product).
- **Ad-hoc** – Escalate critical risks via PagerDuty.

Quality Assurance Checklist

1. All SCORM packages load < 3 seconds (AWS S3 origin).
2. Accessibility score ≥90 on Lighthouse.
3. HubSpot field “Certification Level” updates within 60 s of TalentLMS webhook.
4. 2-factor authentication enforced for Admins.
5. Zero critical or high findings in penetration test.

Post-Project Handover

1. Transfer administrator rights to Partner Operations (PO-01) with step-by-step SOP.
2. Schedule quarterly content refresh cycles aligned with product releases.
3. Create backlog in Jira for Gold-tier advanced certification modules.

By following the above granular actions without deviation, the Channel Enablement Specialist

will deliver a scalable, on-brand partner portal that meets or exceeds all commercial, technical, and timeline objectives.

```html
# Launch initial digital ad campaigns (lead-gen)

## 1. Purpose & Scope

Transform dormant (reservation-mode) paid channels into active, metrics-driven lead-generation engines that deliver 800 MQLs and 100 SQLs inside Phase 4 (Week 172–180), while spending ≤35 % (≈US$126 k) of the annual digital budget and producing reliable CPL benchmarks for future scale-up.

## 2. Success Metrics

- 800 Marketing-Qualified Leads (MQLs) captured in HubSpot.
- 100 Sales-Qualified Leads (SQLs) accepted by Sales Ops.
- Achieve ≤US$158 CPL (MQL) and ≤US$1 260 CPSQL by Week 180.
- Spend ≤US$126 000 within 90-day runway.
- 90 %+ data integrity (ad-to-CRM) verified via UTM and HubSpot tracking.

## 3. High-Level Timeline

| Week | Primary Actions | Deliverables |
|---|---|---|
| 172 | Final pre-flight, campaign build, soft-launch. | Live campaigns; baseline data (72 h). |
| 173-179 | Weekly optimisation loop (bid, A/B, keywords). | 7 optimisation logs; CPL trend reports. |
| 180 | Budget burn-down, final CPL analysis, hand-off. | Phase-close report; next-phase recommendations. |

## 4. Detailed, Step-by-Step Execution Manual

### 4.1 Pre-Flight (Days −3 to 0 | Week 172)

1. Confirm resource matrix: creative files (static + video), final VR demo URL, 4 landing-page variants (A/B for search, A/B for social).
2. Validate CRM mapping:
    1. Create dedicated lifecycle stages “P4-MQL” and “P4-SQL” in HubSpot.
    2. Test end-to-end form submission → MQL scoring → sales owner routing.
3. Allocate budget:
```

    1. Search (Google/Bing): 45 % (≈US$56 700).
    2. Paid Social (LinkedIn): 40 % (≈US$50 400).
    3. Programmatic Display & YouTube: 15 % (≈US$18 900).
4. Generate UTM matrix (campaign, source, medium, content, term) and share read-only sheet with Sales Ops & RevOps.
5. Upload creatives:
    1. Static sizes: 1200×628, 1080×1080, 300×250.
    2. Video: 0 : 30 & 0 : 15 formats, captions burnt-in.
6. Configure tracking pixels (Google, LinkedIn Insight Tag, HubSpot) and verify firing in *GA4 Debug View*.
7. Document baseline KPIs (impressions cost, CPC, quality score) for Day 0 + 72 h check-point.

4.2 Campaign Build & Soft-Launch (Week 172, Day 1)

. **Google/Bing Search**
    1. Create 2 campaigns (“Superhot Power” & “Coal Replacement”).
    2. Ad groups: Tech-Focused, Finance-Focused, Sustainability.
    3. Keyword match: Exact & Phrase (+30 % budget), BMM.
. **LinkedIn Sponsored Content**
    1. Segment: Title = “VP Generation”, “Utility Strategist”, “Power Trader”.
    2. Geo: OECD + SG + KR + JP.
    3. A/B creative: Static vs. Video; CTA = “Book VR Demo”.
. **Programmatic Display & YouTube**
    1. Contextual categories: Renewable Energy, Utility News.
    2. Bid strategy: tCPA based on US$145 CPL starting point.
. Set campaign start time 09:00 UTC Monday; enable HubSpot list “P4-Ad-Clicks”.
. Monitor ad delivery for first 6 hours; pause any ad with CTR <0.2 %.

4.3 Weekly Optimisation Loop (Weeks 173-179 | recurring every Friday 14:00 UTC)

1. Export platform data & HubSpot performance to Google Sheet “P4-Opt-Log-WW”.
2. Bid Adjustments:
    1. Raise bids +15 % on keywords/ad-sets with CPL ≤ 75 % target.
    2. Cut bids −20 % or pause where CPL ≥ 140 % target.
3. Landing Page A/B:
    1. Rotate headline copy variant weekly.
    2. Promote winner if uplift ≥8 % conversion rate after ≥500 sessions.
4. Negative Keyword Pruning (Search):

    1. Run search term report; single-click “add negative” on irrelevant terms (≥2 clicks, 0 conversions).
    2. Sync list to Bing via automated rule.
5. Creative Fatigue Check (Social):
    1. If frequency >6 and CTR ↓ >25 % week-over-week, swap in fresh static or swap static ↔ video.
6. Update HubSpot dashboard “P4-Lead-Flow” with:
    - Week-to-date MQLs, SQLs, CPL, CPSQL.
    - Budget consumed (platform spend + fees).
7. Email Slack /Teams digest to GTM squad by 17:00 UTC.

4.4 Daily Micro Tasks (Mon-Fri)

- 08:00 UTC: Check spend pacing vs. linear burn (≤US$2 000/day baseline).
- 11:00 UTC: Verify pixel fire counts; escalate discrepancies >5 %.
- 16:00 UTC: Zero-click placement purge (Display & YouTube).

4.5 Phase Close-Out (Week 180)

1. Spend Reconciliation:
    1. Pull invoices; cross-check with platform dashboards.
    2. Ensure total ≤US$126 000 (±2 %).
2. Lead-Quality Audit:
    1. Random-sample 10 % of MQLs. Verify firmographic fit (Utility/IPP ≥500 MW).
    2. Calculate SQL acceptance rate; diagnose leakage.
3. Performance Report:
    1. Export HubSpot funnel, attribution multi-touch.
    2. Visualise with cumulative line charts (dashboard widgets).
    3. Attach commentary: learnings, winner creatives, A/B outcomes.
4. Presentation: 12-slide deck for Exec Review (Monday Week 181).
5. Archive assets & rename campaigns with prefix “P4-Completed”.

5. Key Risks & Mitigation

Risk	Likelihood	Mitigation Action
Tracking pixel failure	Medium	Daily Debug View check; redundant server-side tagging enabled.
Cost over-run	Low	Automated spend cap rules; daily pacing review.

Lead quality mismatch	Medium	Apply firmographic filters; enable double-opt-in form tweak.

6. Roles & Responsibilities

- **Digital Marketing Specialist (P-DMS-04)**: Full ownership of all steps.
- Creative Director: supplies final assets, 24-h turnaround on new creative.
- Sales Ops Lead: validates MQL→SQL gating, alerts for routing issues.
- RevOps Analyst: maintains HubSpot dashboards, data QA.

7. Communication Cadence

- Daily stand-up (15 min) with Sales & RevOps 08:30 UTC.
- Weekly optimisation review — Friday 15:00 UTC; record & file.
- Executive snapshot email Mondays 09:00 UTC (spend, leads, CPL).

8. Completion Criteria

1. HubSpot dashboard shows ≥800 MQLs, ≥100 SQLs.
2. Final spend reconciles ≤US$126 000.
3. Phase-close report approved by VP Marketing.

```

# Publish thought-leadership series across channels

# Objective

Repurpose the GeoTherm20 white-paper into a multi-channel thought-leadership campaign (6 LinkedIn articles, 4 trade-journal op-eds, 2 podcast appearances) during **Phase 4, Weeks 174–180**, achieving ≥ 50 k impressions, 3 k engagements and 200 inbound demo requests while maintaining authoritative & accessible tone and consistent messaging.

# Overall Timeline

| Week | Focus Milestones |
|---|---|
| 174 | Editorial outline finalised; stakeholder alignment secured; guest-podcast pitches sent |
| 175 | Drafts 1–3 LinkedIn, Draft 1 op-ed; podcast briefing docs prepared |
| 176 | Drafts 4–6 LinkedIn, Drafts 2–3 op-eds; record podcast #1 |
```

177	Draft 4 op-ed; final edits & design; record podcast #2
178	Schedule LinkedIn & op-eds; EveryoneSocial seeding kits distributed
179	Go-live; real-time amplification; mid-campaign optimisation
180	KPI close-out; performance report; lessons-learned workshop

Step-by-Step Action Plan

1. **Pre-Kick-off Alignment (Week 174, Monday)**
    1. Download final white-paper master from Knowledge-Base v3.1.
    2. Create master content matrix spreadsheet with columns: *Channel, Working-Title, Core Insight, Target Persona, CTA, Publish Date, Status, URL*.
    3. Schedule 45-min alignment call with Chief Marketing Officer, VP Engineering, Regulatory Lead and Sales Director; secure messaging guardrails and sign-off authority levels.
2. **Editorial Blueprint (Week 174, Tuesday)**
    1. Break white-paper into six thematic pillars (e.g., *Drilling Innovation, Heat Density Economics, Risk Mitigation, Grid Firming, CO_2 Loop Advantage, Zero-Carbon Baseload*).
    2. Assign each pillar to a LinkedIn long-form; map supporting data points (figures, citations, case examples) and anchor keyword cluster (use SEMrush; aim ≥ 1 k search volume).
    3. Define four complementary debate-angle op-eds for trade journals (*Power Engineering, Energy World, Asian Utility, Utility Dive*); tailor to publication guidelines (word count, referencing style, exclusivity windows).
    4. Identify two high-reach podcasts aligned with utility & climate tech audiences (*The Energy Gang, Catalyst with Shayle Kann*); record target go-live week & average episode reach.
3. **Writing Sprint #1 (Week 175, Wed-Fri)**
    1. Draft LinkedIn articles 1–3 (900–1 200 words each); include:
        - Headline (< 58 characters, front-load keyword).
        - Hook paragraph (≤ 50 words, datapoint-led).
        - Three sub-heads with scannable key takeaways.
        - Embedded graphic (pull from design library; request 1200×627 px variant).
        - Back-link sentence: “Read the full GeoTherm20 white-paper → [URL]”.
        - CTA: “Book a 15-min LithoLoop 25 briefing”.
    2. Draft first op-ed for *Power Engineering* (1 200 words, Chicago style citations).
    3. Run Grammarly & Hemingway apps; target readability grade 8.
    4. Circulate drafts to internal reviewers via Google Docs; set comment-only permissions; deadline +48 h.

5. Create podcast briefing document #1: episode outline, key sound-bites (< 30 s), host bios, talking-point to white-paper cross-reference timestamps.

4. **Writing Sprint #2 (Week 176, Mon-Thu)**
    1. Draft LinkedIn articles 4–6 following Sprint #1 framework; unique hero graphics for each.
    2. Draft op-eds 2 & 3 (*Energy World*, *Asian Utility*); adjust tone for regional regulatory nuance.
    3. Submit podcast pitches: email producer with tailored hook, speaker bio, episode fit, and proposed recording slot (Week 176 Fri 10:00 EST).
    4. Integrate reviewer feedback on Sprint #1 drafts; mark “Final – v1.0” in matrix.
    5. Build UTM-tagged back-link URLs in HubSpot (*utm_source=linkedin&utm_medium=article&utm_campaign=thoughtleadership*).
5. **Podcast Recording & Final Content Polishing (Week 176, Friday & Week 177, Monday)**
    1. Host pre-recording tech check (10 min) in Riverside.fm; verify 48 kHz audio, 1080p video, Ethernet connectivity.
    2. Record Podcast #1 (45 min); note timestamp of each white-paper mention.
    3. Edit raw file in Descript; remove filler words; insert intro/outro; export MP3 & 1080p MP4.
    4. Draft fourth op-ed (*Utility Dive*), integrate quotes from Podcast #1 for cross-promotion.
    5. Record Podcast #2 (Week 177, Wed); repeat editing workflow.
    6. Generate 8 social audiograms (60–90 s) per podcast; caption & burn-in subtitles.
6. **Design & SEO QA (Week 177, Thu-Fri)**
    1. Send final LinkedIn article copy + graphic briefs to Design for header banners (RGB, 1200×627 px, ≤ 150 KB).
    2. Run Yoast SEO checks in CMS draft: target keyword in title, first 100 words, H2, meta-description (< 155 characters), alt-text.
    3. Embed schema.org Article JSON-LD in op-ed submissions where allowed.
    4. Obtain final legal review sign-off (environmental claims compliance).
7. **Scheduling & Employee-Advocacy Seeding (Week 178)**
    1. Load LinkedIn articles into SproutSocial:
        - Schedule cadence: Tue/Thu 09:00 ET over 3 weeks.
        - Add first comment with hash-tag set: #LithoLoop25 #FirmRenewables #GeoTherm20.
    2. Submit op-eds via publication portals; attach high-res headshot & 30-word author bio.
    3. Upload podcast MP3 to host (Libsyn); set release dates Week 179 Mon & Thu.
    4. Inside EveryoneSocial:
        - Create campaign group “LithoLoop Thought Leadership”.
        - Load share-ready posts (image, pre-written caption, tracking link).
        - Push notification to all employees; incentive: top 10 sharers get branded Yeti mug.
8. **Go-Live & Amplification (Week 179)**

1. Monitor first 2 h post-publish for each LinkedIn article; respond to all comments within 30 min.
2. Trigger boost via EveryoneSocial; aim 40% employee share-rate within 24 h.
3. Coordinate Sales to post personalised commentary linking back to demo-request page.
4. Create LinkedIn Poll 48 h after article #3 to gather utility pain points; screenshot results for Sales.
5. Retweet op-ed links from corporate Twitter; tag journalists and relevant utility influencers.

9. **Performance Tracking & Optimisation (Week 179, ongoing)**
    1. Daily export from LinkedIn Analytics: impressions, clicks, reactions, comments, shares; append to matrix.
    2. Google Analytics report: UTM-tagged white-paper traffic & demo-request conversions.
    3. Podcast host analytics: unique downloads, listener retention; insert mid-roll CTA if retention > 70%.
    4. Identify top-performing post; allocate $500 paid boost targeting “Utility Executive” audience, regions OECD + APAC.
10. **KPI Close-out & Reporting (Week 180)**
    1. Aggregate campaign metrics:
        - Total impressions (target ≥ 50 k).
        - Total engagements (target ≥ 3 k).
        - Inbound demo requests (target ≥ 200).
    2. Prepare 8-slide performance deck:
        a. Goals vs. Actuals.
        b. Channel breakdown.
        c. Top content insights.
        d. Lead quality analysis (MQL→SQL conversion).
    3. Host 30-min lessons-learned workshop; log action items for next content cycle.
    4. Archive all final assets in DAM under folder “Phase 4 → Thought Leadership – FINAL”.

Risk Mitigation Checklist

- Publication delays → maintain secondary op-ed outlets list.
- Legal compliance → pre-approved claim library referenced.
- Under-performance → pre-authorised $1 k paid-media contingency budget.
- Speaker unavailability → secure back-up spokesperson (VP Engineering).

Required Tools & Access

- Google Docs (editing & collaboration)
- SproutSocial (scheduling)
- EveryoneSocial (employee advocacy)
- SEMrush & Yoast (SEO)
- Riverside.fm & Descript (podcast recording/editing)
- HubSpot (UTM & lead capture)
- Adobe Illustrator (graphic creation)

Approval Matrix

Deliverable	Reviewer	Turnaround SLA
LinkedIn Article (draft)	CMO (content), Legal, Design	48 h
Op-ed (final)	CMO, Publication Editor	72 h
Podcast Episode	Host Producer, Legal	24 h

Final Deliverables List

1. 6 SEO-optimised LinkedIn long-form articles (with graphics & UTMs).
2. 4 trade-journal op-eds (publication-ready).
3. 2 edited podcast episodes + 16 audiogram clips.
4. Performance deck (PPT) & raw analytics exports.
5. Lessons-learned document (Confluence page).

Commercial Force Deployment | Weeks 175-180

Execute webinar & virtual road-show series (8 sessions)

This document provides an exhaustive, sequential instruction manual for the **Webinar Producer – P-WP-14** to flawlessly execute eight live, multi-timezone webinar sessions and corresponding virtual

road-show events. Follow each step precisely—no deviations or omissions—to achieve a ≥ 60 % live attendance rate and collect at least 100 qualified technical questions.

Phase	Week	Primary Outcomes
1 — Pre-Production	175-176	Audience build, platform setup, content finalisation, dry-runs
2 — Live Production	177-179	8 live sessions, 3 time-zones each, live translation & engagement capture
3 — Post-Production & Analytics	177-180 (rolling)	24-hr recording distribution, tagging, KPI & FAQ repository creation

Granular Action Plan

1. **Phase 1 – Pre-Production (Weeks 175-176)**
    1. Confirm webinar platform license tiers (supports ≥ 5,000 attendees, multilingual captions EN/DE/JP, polls, Q&A, resource hub, API for CRM tagging).
    2. Create master project spreadsheet with eight rows (one per session) and columns for: date, time-zone, language caption, presenters, backup host, rehearsal slot, promo send dates, registrant count, live attendees, qualified questions, recording URL.
    3. Lock session schedule:
        - Sessions 1-2-3-4 in Week 177.
        - Sessions 5-6-7-8 in Week 178.
        - Time-zones: 08:00 UTC (APAC), 14:00 UTC (EMEA), 20:00 UTC (Americas).
    4. Coordinate with *CTO office* to confirm cameo availability for Session 3 and Session 6; insert 10-minute technical-deep-dive slot.
    5. Draft session outlines: introduction (2 min), problem statement (5 min), LithoLoop 25 overview (8 min), case study (10 min), CTO cameo (when applicable, 10 min), live demo video (5 min), poll (3 min), Q&A (15 min), next-steps CTA (2 min).
    6. Collect/translate slide deck & speaker notes into DE & JP; embed **SRT** caption files.
    7. Prepare engagement assets:
        - Three poll questions per session (market barriers, baseline energy mix, purchase horizon).
        - Resource downloads: LithoLoop 25 technical brief PDF, ROI calculator XLSX, pilot plant video MP4.
    8. Integrate CRM (Salesforce) API: configure webinar platform to auto-tag contacts by *session-ID*, *attendance-status*, *poll-answers*.

9. Program automated post-event workflow:
    - Email #1 (T + 0.5 h): “Thank you” with recording link.
    - Email #2 (T + 24 h): Slides + resource bundle.
    - Email #3 (T + 48 h): “Book 1-on-1 utility briefing” CTA.
10. Run tech rehearsals:
    1. Session-wide dry-run with all presenters (90 min each).
    2. Audio/video quality check, caption sync test, slide advance latency test (< 200 ms target).
    3. Record rehearsal; review for glitches; issue fix tickets within 24 h.
11. Launch promotional cadence:
    - Email blast #1: Week 175 Mon 09:00 local.
    - LinkedIn/WeChat paid ads: Week 175 Tue onwards, retarget registered utilities.
    - Reminder emails: T-7 days, T-1 day, T-1 hour.
12. Track registrations; update master spreadsheet daily; aim for 30 % over-registration buffer.

2. **Phase 2 – Live Production (Weeks 177-179)**
    1. Begin 90 min prior to each session:
        - Launch producer backstage room.
        - Verify audio/video bitrate (> 3 Mbps) for each speaker.
        - Load correct caption file; preview on attendee view.
    2. Run “green room” briefing (T-60 min): recap agenda, emergency hand-signals, backup dial-in numbers.
    3. Activate attendee lobby (T-15 min): display looping intro slide with music at −20 LUFS.
    4. Go live (T = 0): click *Start broadcast*; announce agenda; record to cloud.
    5. Monitor chat, Q&A, poll response counts in real-time; flag technical questions surpassing L2 complexity (mark with “FAQ-CANDIDATE” tag).
    6. At mid-point, push poll #1; verbalise results once > 60 % attendees respond.
    7. CTO cameo (sessions 3 & 6): cue 20 s before hand-off; display lower-third title overlay.
    8. Maintain ≥ 60 % live attendance KPI:
        - If dip < 60 %, trigger “stay-on reward” banner (exclusive report download).
    9. Close with CTA slide; paste calendly link in chat; thank attendees; stop recording.
    10. Export Q&A transcript immediately; save to shared drive folder “/WebinarSeries/Q&A/raw”.
    11. Trigger CRM tagging workflow while still logged in; confirm completion log shows success.

3. **Phase 3 – Post-Production & Analytics (Rolling Weeks 177-180)**
    1. Within 20 min of session close:
        - Edit recording start/end trims; normalise audio to −16 LUFS.
        - Generate MP4 (1080p) + caption burn-in + SRT download.
    2. Upload final MP4 to AWS S3 bucket; retrieve public URL; update master spreadsheet.
    3. Launch automated Email #1 campaign (verify send complete counts match attendee list).
    4. 24 h SLA check:
        - Ensure Emails #1 & #2 delivered (bounce < 3 %).
        - Post recording to on-demand library; tag video “Webinar-Series-175-180”.
    5. Aggregate poll data; export CSV; push to BI dashboard (PowerBI tile “LithoLoop 25 Market Insights”).
    6. Compile qualified Q&A:
        1. Filter “FAQ-CANDIDATE” tags; remove duplicates.
        2. Classify by category (Drilling, Thermodynamics, Economics, Environmental, Financing).
        3. Append answer draft from speaker notes.
        4. Store in “FAQ_Master_v1.0.xlsx”.
    7. Run KPI analysis end of Week 179:
        - Total registrations vs. live attendees ≥ 60 %?
        - Count distinct qualified questions ≥ 100?
        - CTO cameo sessions feedback rating ≥ 4.2/5?
    8. Prepare executive summary slide (5 slides max) for CRO; deliver by Week 180 Mon 10:00 UTC.
    9. Schedule internal debrief (Week 180 Wed 14:00 UTC) with Marketing, Sales, CTO, Customer Success; present findings and optimisation plan.

Risk Log & Mitigations

Risk	Mitigation
Platform outage	Maintain backup Zoom Webinar link; distribute instantly via attendee email + chat.
CTO schedule slip	Pre-record 10 min cameo; ready to broadcast if live join fails.
Caption desync	Assign live caption monitor; adjust delay slider (± 500 ms) real-time.
Attendance < 60 %	Send SMS reminder T-15 min to no-shows; activate “stay-on reward” as incentive.

Definition of Done

- Eight live sessions completed without critical incident.
- Live attendance rate across series ≥ 60 % (average).
- ≥ 100 unique, qualified technical questions captured and logged.
- All recordings emailed within 24 h; bounce rate < 3 %.
- CRM contains correct tags for every registrant and attendee.
- Executive summary delivered and accepted by CRO.

End of Action Plan – Strict adherence required. Any deviation must be escalated to Marketing Director within 2 hours.

Conduct grid-operator integration workshops (3 regions)

1. Objective

Equip PJM, ENTSO-E (Central Europe), and J-Power planners & protection engineers with validated data on LithoLoop 25's dynamic performance, align interconnection modelling parameters, and secure written acknowledgement that LithoLoop 25 meets each region's grid-code ride-through window within ±2 %.

2. Roles & Responsibilities

- **Tech Sales Engineer 2 (P-TSE2-23) – *Workshop Lead*:** Owns end-to-end execution, budget control, technical content, and stakeholder follow-up.
- **R&D Dynamic Modelling Lead:** Supplies validated RMS/EMT models, ride-through curve data, and black-start simulations.
- **Marketing Communications Manager:** Formats white papers and workshop collateral to brand standards.
- **Regional BD Managers (US, EU, JP):** Coordinate local logistics, translation, and cultural protocol.

3. Timeline & Milestones (Week 176–180)

Week	Key Output
176	Pre-workshop material finalised & dispatched (all regions)

177	Workshop 1 – PJM (Philadelphia)
178	Workshop 2 – ENTSO-E (Berlin)
179	Workshop 3 – J-Power (Tokyo)
180	White papers issued & operator acknowledgements secured

4. Detailed Step-By-Step Action Plan

1. **Week 176 – Global Pre-Workshop Preparation**
    1. Retrieve the latest *LithoLoop 25 Grid-Integration Data Pack v4.0* from R&D SharePoint; confirm inclusion of:
        - RMS & EMT digital models (PSSE, DIgSILENT, PSCAD formats)
        - Certified ride-through curves (LVRT, HVRT, frequency)
        - AGC step-response plots (0.5 % ramp/min & 10 % step)
        - Black-start energisation sequence (islanding → synchronisation)
    2. Schedule 90-min internal dry-run with Dynamic Modelling Lead & MarCom; rehearse agenda flow and Q&A triggers.
    3. Customize slide decks per region:
        - PJM – emphasize NERC PRC-024 ride-through envelope & PJM manual 14D interconnection steps.
        - ENTSO-E – map to NC RfG & Central Europe synchronous zone specifics.
        - J-Power – align with JEAC 9701-2018 and METI frequency ride-through.
    4. Collate participant lists (operator planners, protection engineers, GeoTherm20 team); validate email & phone contacts.
    5. Issue pre-read package (PDF link + model ZIP) via DocuSign PowerForms requesting NDA acknowledgment.
    6. Confirm venue, catering, AV (dual-screen projection, 3-phase simulation bench) via local BD managers.
    7. Book travel:
        - Philadelphia → Berlin → Tokyo → Home route in Concur; adhere to budget ceiling US$95 k (track in XLS).
    8. Update master Gantt (Phase 4 tab) and email status to VP Sales.
2. **Week 177 – Workshop 1 (PJM, Philadelphia)**
    1. Arrive day-1 (08:00); verify AV, simulation bench, and blackout cloakroom.
    2. Conduct 6-hour agenda:
        1. Welcome & safety briefing (15 min)

2. Technology overview & value proposition (45 min)
3. Dynamic model deep-dive (60 min)
4. Ride-through curve walkthrough vs PJM specs (60 min)
5. AGC & dispatchability demo (45 min)
6. Black-start tabletop simulation (45 min)
7. Open Q&A & next-step capture (60 min)

3. Capture all questions & action items in *PJM_Workshop_Minutes.docx* within 2 h post-session.
4. Secure in-principle verbal confirmation that data meets PRC-024 tolerance; note any required supplemental tests.
5. Email thank-you + minutes + survey link (Net Promoter & technical clarity scores).

3. **Week 178 – Workshop 2 (ENTSO-E, Berlin)**
    1. Translate deck into German; verify technical glossary (DIN IEC 60050 equivalents).
    2. Run identical agenda with the following substitutions:
        - Overlay NC RfG Type D requirements on ride-through slides.
        - Highlight CE synchronous area RoCoF withstand capability.
    3. Record session (Teams) for distributed TSOs in CE region; save to SharePoint /Workshops/ENTSOE2026.
    4. Issue post-workshop survey and request written feedback on model sufficiency for connection study.
4. **Week 179 – Workshop 3 (J-Power, Tokyo)**
    1. Provide simultaneous interpretation headset service (ENGJPN).
    2. Emphasize seismic resilience data (vitrified borehole integrity) as additional interest lever.
    3. Demo PSCAD model live with 52 Hz & 48 Hz extreme frequency events per JEAC 9701-2018.
    4. Collect stamped *Technical Data Acceptance Sheet* from lead protection engineer.
5. **Week 180 – Close-Out & Deliverables**
    1. Draft region-specific integration white papers (max 25 pp each) using MarCom template:
        1. Executive Summary
        2. Regulatory Framework Alignment
        3. Dynamic Performance Evidence
        4. Protection Scheme Compatibility Matrix
        5. Interconnection Process Recommendations

2. Insert operator endorsement quotes & attach signed acknowledgement letters.
3. Route white papers for internal technical review (Legal → R&D → VP Sales); target 48 h turnaround.
4. Transmit final PDFs to each operator via secure portal; request formal acknowledgement of ride-through compliance.
5. Update CRM (Salesforce, Oppty “Phase 4-Grid”):
    - Status = “Operator Endorsed”
    - Attach white paper, acknowledgement letter, survey scores.
6. Consolidate spend receipts; complete budget reconciliation workbook. Ensure total ≤ US$95 k; escalate variance immediately.
7. Submit *Phase 4 Workshop Completion Report* to Program Management Office (PMO).

5. Budget Control Checklist (US$ 95 k Cap)

Cost Category	Cap (US$)	Tracking Tool
Airfare & Rail	40,000	Concur export
Hotels & Per-Diem	20,000	SAP travel card
Venue & Catering	15,000	PO #77452
Collateral Production	5,000	MarCom budget sheet
Contingency (5 %)	4,750	PMO reserve

6. Key Risks & Contingencies

- **Operator travel bans/COVID flare-up:** switch to hybrid model with VRL (DNV-GL) remote simulation.
- **Model validation dispute:** activate third-party lab (KEMA) peer review within 10 days.
- **Budget over-run risk:** freeze discretionary spend, draw on PMO contingency up to US$5 k.
- **Shipment delay of simulation bench:** pre-position duplicate unit in Berlin; air-freight as fallback.

7. Success Metrics & Acceptance Criteria

1. Written acknowledgements from PJM, ENTSO-E (at least two central TSOs), and J-Power that LithoLoop 25 meets grid-code ride-through windows within ±2 %.
2. Three completed integration white papers stored in SharePoint /Deliverables/Phase4.
3. Average workshop satisfaction ≥ 8/10 (survey question 1).

4. Total expenditure ≤ US$95 k (±3 %).

8. Approvals & Sign-Off Path

Submit final package to:

- VP Sales – commercial validation
- CTO – technical soundness
- CFO – budget compliance
- PMO – programme milestone closure

Government-affairs & regulatory liaison ramp-up

1. Objective

Secure favourable regulatory positioning for LithoLoop 25 by achieving formal inclusion of vitrified closed-loop superhot-geothermal wells in at least one federal clean-energy incentive framework by Week 190. This 10-week plan (Weeks 170-180) fully aligns Government Affairs and Compliance functions with GEO's Commercial Force Deployment phase.

2. Roles & Responsibilities

- **Government Affairs Lead (P-GA-15)** – Owns regulator relationships; crafts policy narratives, leads briefings & tours, oversees white papers, comment letters and milestone delivery.
- **Compliance Liaison (P-CL-16)** – Maintains jurisdictional lobbying registrations, logs all contacts, vets collateral for legal conformity, manages the compliance tracker and consultancy budget.

3. Budget

US$251 k allocated: US$200 k external policy consultancy retainer + US$51 k collateral production (design, translation, printing, digital).

4. High-Level Timeline (Weeks 170 – 180)

Week	Primary Milestone	Key Deliverable

170	Launch workstream & compliance clearance	Workstream kick-off deck; updated lobbying registry log
171-172	Regulator discovery & narrative finalisation	Issue-tree map; master briefing deck v1.0
173-174	Policy white paper production	“Unlocking Superhot Geothermal” white paper (EN/DE/JP)
175-176	Site-tour execution	Three regulator site-tour briefing packs; tour reports
177-178	Comment-letter drafting & submission	Comment letters to DOE GTO, BMU, METI
179-180	Incentive-framework negotiation	Draft statutory-language inserts; MoM for regulator calls

5. Exhaustive Step-by-Step Action Plan

Week 170 – Kick-off & Compliance Baseline

1. GA Lead schedules 60-min virtual kick-off (Day 1) with Compliance Liaison, external consultancy PM and VP Commercial; circulate agenda 48 h prior.
2. Compliance Liaison exports current lobbying registration status (US, DE, JP) from Compliance Tracker; verify expiry dates, fee payments, assigned lobbyist of record.
3. For any missing/expiring registrations, file renewal/initial forms (forms LD-1 US, Lobbyliste DE, Japan “Seijikatsudo Hōkokusho”) within 24 h; archive PDFs in SharePoint → /RegAffairs/Registrations.
4. GA Lead finalises internal narrative alignment deck:
    - Problem: permitting grey-zone delays.
    - Solution: closed-loop classification as clean-energy pressure-tight well.
    - Asks: regulatory codification + incentive eligibility.
5. Route deck to Legal for privileged review; capture redlines, re-issue v0.2; secure EVP sign-off by Day 5.
6. Update budget sheet with PO# for consultancy retainer (US$200 k) and collateral budget codes (US$51 k – split into design 30 k, translation 12 k, printing 9 k).
7. Compliance Liaison logs all above actions in Compliance Tracker; email weekly status digest to GA Lead every Friday COB.

Weeks 171-172 – Regulator Discovery & Narrative

Finalisation

1. GA Lead and consultancy analyst compile contact map:
    - DOE Geothermal Technologies Office (Director + Programme Managers)
    - German Federal Ministry for Economic Affairs & Climate Action (BMWK) & Environment (BMU)
    - Japan METI – Agency for Natural Resources & Energy (ANRE)

   Include name, title, email, phone, legislative authority, past geothermal stance.
2. Compliance Liaison screens contact map against FARA and EU Transparency Register thresholds; flag high-risk interactions.
3. GA Lead drafts regulator-specific message matrix (pain points, LithoLoop benefits, incentive alignment); circulate for internal feedback within 48 h.
4. By Day 10, consolidate feedback and produce master briefing deck v1.0; send to design vendor (PO#DL-22) for template formatting (24-h SLA).
5. Translate deck into German and Japanese using certified vendor (PO#TR-07); spot-check technical terminology consistency.
6. Compliance Liaison uploads finalised contact map and decks to SharePoint → /RegAffairs/Briefings; version-control naming convention: “YYYYMMDD_v#”.

Weeks 173-174 – Policy White Paper Production

1. GA Lead drafts 12-page outline: executive summary, technology overview, safety/pressure-vessel compliance, economic modelling, legislative recommendations.
2. Commission external consultancy to augment economic modelling (Monte Carlo LCOE ranges); deadline Day 3 Week 173.
3. Complete full manuscript (English) by Day 7 Week 173; submit to Technical, Legal, and Finance for concurrent review (use tracked changes).
4. Incorporate consolidated edits within 48 h; lock text v1.0.
5. Send to design vendor for layout (A4 + US Letter); request print-optimized PDFs and web-optimized PDFs; 72-h turnaround.
6. Parallel: order translations (German, Japanese); require in-country legal-linguistic vet; deliver Day 10 Week 174.
7. Compliance Liaison validates that no restricted technical data is disclosed (ITAR/EAR check); document sign-off.
8. Upload final white paper tri-lingual set to SharePoint → /RegAffairs/WhitePapers and tag with metadata (version, language, approval date).

Weeks 175-176 – Regulator Site-Tours

1. Identify demonstration site (e.g., Nevada experimental well pad) with Operations; confirm HSE clearance for visitors (hard-hat, PPE, NDA forms).
2. GA Lead issues personalised invitations (email + phone follow-up) to top 5 officials per jurisdiction; target confirmation by Day 3 Week 175.
3. Book travel logistics (flights, hotel, local transport) via corporate travel tool; ensure ITAR-controlled area access where required.
4. Create site-tour briefing pack: agenda, safety induction, technical posters, Q&A cheat-sheet.
5. Compliance Liaison files pre-meeting reports per jurisdictional lobbying rules (e.g., LD-2 “event” classification in US).
6. Execute tours (Day 4–5 Week 176). Assign note-taker per group; capture questions and commitments in template MoM.
7. Within 24 h post-tour, send thank-you email + digital materials; upload MoM to Compliance Tracker.

Weeks 177-178 – Comment Letter Drafting & Submission

1. Monitor Federal Register, Bundesanzeiger and METI public consultation portals daily; flag relevant draft rules.
2. GA Lead drafts comment letters (max 10 pages each) referencing white paper data; use formal citation style of respective jurisdiction.
3. Legal reviews for advocacy limits and factual accuracy (48 h SLA).
4. Compliance Liaison compiles appendix of supporting documents (white paper, LCOE model outputs).
5. Submit letters:
    - DOE GTO: upload via regulations.gov docket; obtain confirmation ID.
    - BMU: email + postal submission with signed cover letter.
    - METI: upload to public-comment e-Gov portal.
6. Archive confirmation receipts in SharePoint and record submission details (date, docket #) in Compliance Tracker.

Weeks 179-180 – Incentive-Framework Negotiation

1. GA Lead schedules bilateral calls with each regulator's policy drafting team; send meeting objectives 72 h in advance.
2. Prepare statutory-language inserts explicitly defining "Vitrified Closed-Loop Superhot Geothermal Well" as qualifying clean-energy facility.
3. Develop economic-impact slide (jobs, tax revenue, baseload displacement) using consultancy model; embed in call deck.
4. Conduct calls (record with consent); real-time note-taker logs feedback and next steps.
5. Within 24 h, circulate MoM summarising:
    - Agreed wording edits
    - Deadlines for regulator follow-up
    - Additional data requests
6. Compliance Liaison files post-interaction reports per jurisdiction; update lobbying spend log.
7. GA Lead issues internal read-out to ELT summarising probability of framework inclusion; flag resource needs for post-180 lobbying sprint.

6. KPIs & Reporting Cadence

- Primary KPI: At least one regulator (DOE, BMU, or METI) circulates draft or final incentive language explicitly referencing vitrified closed-loop wells by Week 190.
- Secondary KPIs:
    - 100% on-time lobbying registration renewals (Week 170).
    - White paper published in three languages (Week 174).
    - ≥3 regulator site tours executed with attendance ≥80% of invitees (Week 176).
    - 3 comment letters submitted with docket acknowledgements (Week 178).
    - Compliance Tracker entries ≤24 h SLA for every interaction.

7. Risk Register & Mitigations

Risk	Likelihood	Impact	Mitigation Action
Lobbying registration lapse	Low	High (fines, ban)	Compliance Liaison sets calendar alerts, weekly audits
Negative press on "pressure-vessel risk"	Medium	Medium	Pre-issue Q&A in briefing packs; rapid response comms channel with Corporate Comms

Regulator scheduling conflicts for site tour	High	Medium	Offer two alternate dates + virtual VR walkthrough option

8. Approval Sign-Offs

Government Affairs Lead (P-GA-15): _____ Date: ____/____/____
Compliance Liaison (P-CL-16): _____ Date: ____/____/____
VP Commercial: _____ Date: ____/____/____

Execute on-site product-launch event + live-stream

This action plan translates the launch objective into a minute-by-minute, role-specific execution roadmap for Phase 5 (Week 181–185). Follow every step exactly to deliver a flawless hybrid event, maximise reach, and hit all success metrics.

Critical Success Metrics

- ≥30 earned-media placements within 48 hours of T-0
- ≥5 000 live-stream peak viewers, ≥15 min average watch-time
- Zero broadcast downtime; ≤45 sec cumulative AV glitches
- On-site satisfaction score ≥9/10 (post-event survey, 60 % response)

Responsible Roles & Authorities

Role ID	Name / Placeholder	Primary Responsibility
P-EC-12	Event Coordinator	End-to-end on-site logistics, vendor control, contingency activation
P-PR-10	PR Lead	Press, media relations, live-stream chat moderation, KPIs capture
P-CMO-01	Chief Marketing Officer	Executive sponsor, message sign-off, budget holder, crisis override

Week-by-Week Macro Timeline (Phase 5)

Week	Milestone
181	Site build-out, AV integration, press-kit finalisation
182	Full technical rehearsal, influencer embargo briefings
183	Dry-run with language interpreters & accessibility overlays
184	Crew lock-in, weather call, contingency funds earmarked
185 (T-0)	Live event, post-event acceleration, KPI reporting

Granular Action Plan

1. **Week 181 – Infrastructure & Vendor Lock-in**
    1. P-EC-12: Issue final purchase orders for stage, seating (250 pax), power redundancy (2×125

kVA generators) and 1 Gbps fibre uplink. Deadline: Mon 09:00.
2. P-EC-12: Approve weather-proof marquee rental; allocate 10 % contingency budget (USD 37 k) for sudden shelter/AC needs.
3. P-PR-10: Freeze press-kit assets (CEO bio, tech one-pager, hot-sand pour B-roll, high-res renders). Store in shared drive & schedule embargo email at T-0 minus 30 sec.
4. P-CMO-01: Sign-off keynote script v1.0 and customer-testimonial talking points by Wed 17:00.
5. P-EC-12: Coordinate with broadcast vendor to install 4×1080p cameras, crane jib, and sign-language picture-in-picture encoder. Acceptance test by Fri 15:00.

2. **Week 182 – Technical Rehearsal & Stakeholder Alignment**
    1. Mon 08:00: P-EC-12 convenes all crew for fire-marshal briefing; record headcount & mobile numbers.
    2. Mon 10:00: Full “run-of-show” rehearsal: CEO intro → hot-sand pour → testimonial → ribbon-cut. Time-stamp each segment; target 28 min total.
    3. P-PR-10 monitors rehearsal stream on YouTube private link; capture latency, bit-rate, caption sync.
    4. Tues 13:00: P-PR-10 briefs 50 tier-1 journalists under embargo; distribute unique RSVP QR codes.
    5. Wed–Thu: P-EC-12 solves all red-flag issues from rehearsal log within 24 h; escalate unresolved to P-CMO-01.
    6. Fri 16:00: P-CMO-01 runs executive confidence check; approve proceeding to Week 183.
3. **Week 183 – Accessibility & Multilingual Integration**
    1. P-EC-12 books certified sign-language interpreter (ASL) and three simultaneous translators (EN→DE, EN→JP).
    2. Tue 09:00: AV team maps interpreter video inset to lower-right 320×240 frame; verify no overlap with slides.
    3. P-PR-10 uploads glossaries and technical jargon to interpreter consoles.
    4. Wed 14:00: Dry-run with real-time captions. Measure live delay ≤4 sec.
    5. Thu 11:00: Run penetration test on streaming endpoint; blocklist 50 known spam domains.
    6. Fri 18:00: Freeze broadcast graphics pack; checksum all files; duplicate to on-site NAS + cloud backup.
4. **Week 184 – Final Lock-down & Contingency Drill**
    1. Mon 07:00: P-EC-12 activates daily weather tracking; trigger marquee setup if forecast >30 % rain.
    2. Mon 15:00: Conduct 30-min power-cut drill; switch to generator, confirm zero video dropout.

3. Tue 10:00: P-PR-10 distributes media seating chart, confirms 104 confirmed press attendees.
4. Wed 09:00: P-CMO-01 records 60-sec contingency address (teleprompter) for emergency playback.
5. Thu 17:00: Freeze guest list; print badges with colour coding (staff, VIP, press, vendor).
6. Fri 19:00: Security sweep with local authorities; issue green-light “Site Secure” report.

5. **Week 185 – T-0 Event Day (Detailed Minute-by-Minute)**
    1. 05:00 — P-EC-12 arrives, opens site, starts generator warm-up cycle.
    2. 06:00 — AV director boots encoder; run 30-min colour bars, audio tone.
    3. 07:00 — Crew breakfast; distribute updated run-sheet v1.6.
    4. 08:00 — Doors open to staff; security metal detectors active.
    5. 08:30 — P-PR-10 posts “Going live in 90 min” teaser on corporate social channels.
    6. 09:00 — Language interpreters join comms channel; audio checks.
    7. 09:15 — CEO, client speaker, ribbon-cut VIPs arrive; escort to green room.
    8. 09:30 — Audience doors open; ushers seat press front-left quadrant.
    9. 09:45 — Live-stream pre-show loop starts (holding slide + ambient site footage).
    10. 10:00 — **T-0**: Run-of-show starts; P-PR-10 auto-releases press-kit via embargo tool.
    11. 10:00–10:04 — CEO keynote (4 min).
    12. 10:04–10:14 — Live hot-sand pour demo with technical narration.
    13. 10:14–10:20 — Customer testimonial (utility partner) on stage.
    14. 10:20–10:28 — Ribbon cut & pyro-confetti moment (safety distance 5 m).
    15. 10:28 — Closing slide; stream fades to highlights reel loop.
    16. 10:30 — On-site media Q&A begins in press pen; P-PR-10 moderates.
    17. 11:15 — VIP tour of turbine room; P-EC-12 guides, photographer captures B-roll.
    18. 12:00 — Live-stream ends; encode recording saved locally and to cloud.
    19. 12:15 — P-PR-10 pushes on-demand link to attendee mailing list.
    20. 12:30 — Working lunch debrief; log incident severity (if any) within 1-page template.
    21. 16:00 — P-CMO-01 reviews real-time analytics dashboard; verify watch-time ≥15 min average.
    22. 18:00 — Issue Day-0 media recap; embed hero photos (credit lines attached).
6. **Post-Event (T +1 – T +48 h)**
    1. P-PR-10 runs Meltwater scan every 6 h; catalogue earned-media placements. Target ≥30 by T +48 h.
    2. P-EC-12 oversees site teardown; return rentals, document asset condition, close POs.
    3. P-CMO-01 issues thank-you email to employees; embed top 3 highlight clips.
    4. P-PR-10 compiles KPI deck: viewership, media hits, sentiment. Deliver to Exec team by

T +72 h.

5. Initiate lessons-learned workshop (30 min, Mon Week 186) and archive all artefacts in knowledge base.

Risk Matrix & Immediate Triggers

Risk	Trigger Threshold	Owner Action
Severe weather	≥50 % rain, wind >40 km/h within 12 h	P-EC-12 deploy marquees, move seating under cover, activate extra HVAC (contingency budget)
Stream outage	Video black >5 sec	Switch to backup encoder & 4G bonded uplink; push status tweet “Technical pause, back shortly”
VIP no-show	Cancels <2 h before	Insert pre-recorded testimonial; adjust run-sheet to maintain timing

On-Call Contact Directory (Event Day)

Role	Name	Mobile	Slack Channel
Event Coordinator (P-EC-12)	TBD	+1 XXX-XXX-XXXX	#launch-ops
PR Lead (P-PR-10)	TBD	+1 XXX-XXX-XXXX	#launch-press
CMO (P-CMO-01)	TBD	+1 XXX-XXX-XXXX	#exec-alerts

Execute each action exactly as sequenced. Deviations require written approval from the CMO.

Post-launch pipeline acceleration & MQL→SQL hand-off process

1. Objective

Convert the media-generated Marketing Qualified Leads (MQLs) into Sales Qualified Leads (SQLs) at ≥20 % with an average first-response time ≤4 hrs, ensuring zero leakage between marketing automation and human sales activities during Weeks 186-195.

2. Roles & Accountability Matrix

Role	Primary Responsibilities	KPI Ownership
Sales Director (P-SD-17)	Process governance, SLA enforcement, daily stand-up leadership, KPI reporting to C-suite.	MQL→SQL rate, response-time median, forecast accuracy.
Sr. Account Executives (P-SAE1-18 to P-SAE4-21)	24-hr first-touch, qualification, opportunity creation, Gong-recorded discovery, pipeline updates.	Personal SQL quota, response-time compliance, win-rate.

3. Week 186: System Configuration (Days 1-5)

1. Day 1 08:00-10:00 – P-SD-17 logs into HubSpot to:
    1. Create **“Phase-5 MQL”** lifecycle stage property.
    2. Activate trigger-based workflow: *If Lead Score ≥65 OR demo-request form submitted → set lifecycle = MQL, assign owner = round-robin AEs.*
    3. Set workflow action: **Auto-create Deal** in pipeline “Utility Commitments 10 GW” with amount placeholder 0 USD.
2. Day 1 10:00-11:00 – Integrate Slack:
    1. Connect HubSpot *“New MQL Alert”* to channel **#sales-floor**.
    2. Message content: Lead name, company, score, timestamp, assigned AE, SLA countdown (24 hrs).
3. Day 1 11:00-12:00 – Enable Gong auto-record:
    1. Sync Gong with AE calendars.
    2. Create call-category tag **“Phase-5 Discovery”**.
4. Day 2 – Upload enablement assets:
    1. HubSpot → Templates → Add **3-step first-touch email sequence** (intro, value proof, meeting CTA).
    2. Documents → Add **Objection-handling script v1.2**.
5. Day 3 – Dashboard build:
    1. Metrics: MQL volume, % converted to SQL, median response time, AE leaderboard.
    2. Share view permissions with C-suite and all AEs.
6. Day 4-5 – Dry-run:
    1. Marketing triggers 5 test leads; verify routing, Slack alert, auto-deal creation, and Gong recording.
    2. Document defects; resolve before Day 5 17:00.

4. MQL→SQL Hand-off Playbook (Activates Day 1 Week 186 and Continues Through Week 195)

1. **Trigger (T0)** – Lead becomes MQL.
    1. HubSpot assigns AE & posts Slack alert + SLA timer 24 hrs.
    2. Auto-created Deal inherits lead owner, close date = *end of FY*.

2. **T0 → T+4 hours** – First Response SLA.
    1. Assigned AE launches 3-step email sequence; step 1 personalised subject referencing utility's decarbonisation target.
    2. Logs manual call attempt; if connected, schedule discovery within 48 hrs.
3. **T+24 hours Checkpoint**
    1. HubSpot workflow checks "Last Contacted" date.
        - If blank → escalate Slack @mention AE + P-SD-17.
        - If populated → proceed.
4. **Discovery Call**
    1. Gong auto-records; AE tags talk-tracks in real time.
    2. Qualification criteria to mark SQL:
        - Utility has ≥1 GW retiring coal/nuclear 2026-2035.
        - Budget authority confirmed.
        - Timeline ≤12 months for RFP.
5. **Post-Call (within 2 hrs)**
    1. Update Deal stage to **"SQL – Discovery Completed"**.
    2. Send recap email with custom 1-page LithoLoop heat curve.
6. **Non-Responsive Path (Day 2-7)**
    1. Email step 2 (Day 2) & call attempt 2.
    2. Email step 3 (Day 4) & LinkedIn InMail.
    3. Day 7 – If no engagement, set lead status = "Nurture," re-enter marketing stream.

5. Daily Operating Rhythm (Weeks 186-195)

1. 07:30 – HubSpot auto-email each AE their open MQLs & SLA timers.
2. 08:30-08:45 – **Daily Stand-Up** (video; hosted by P-SD-17).
    - Round-robin: # new MQLs, # touches pending, blockers.
    - Confirm same-day objectives & allocate peer assist if backlog >5 MQLs/AE.
3. 12:00 – Gong sends call-quality digest to AEs.
4. 17:00 – AEs update Deals & notes; P-SD-17 reviews dashboard anomalies.

6. Weekly KPI Reporting (Fridays Weeks 186-195)

1. 09:00 – HubSpot exports CSV of core metrics.
2. 10:00 – P-SD-17 populates "Phase-5 KPI" slide deck:

- MQL volume vs. target.
- MQL→SQL %.
- Median response time.
- Top 3 call-quality insights (from Gong).

3. 12:00 – Email deck to CEO, COO, CMO.
4. 15:00 – 30-min review call with C-suite; agree on any course corrections.

7. Enablement Asset Refresh Loop

1. Monday Week 188 & Week 192 – P-SD-17 downloads Gong talk-track analytics; identify top objections.
2. Wednesday same weeks – Revise email templates & objection-handling script; upload vNext; notify AEs in Slack.

8. Contingency & Escalation Rules

1. MQL→SQL rate <15 % for two consecutive weeks → trigger war-room meeting within 24 hrs.
2. Individual AE response-time SLA breaches >3/week → shift new MQLs to lowest-load AE temporarily.
3. HubSpot/Gong integration outage >30 mins → revert to manual spreadsheet tracking; P-SD-17 to coordinate IT resolution.

9. Week 195 Close-Out Actions

1. Export full-funnel data set; archive in shared drive “Phase-5”.
2. Run team retrospective (2 hrs): what worked, gaps, next-phase recommendations.
3. Update corporate playbook; label version “LithoLoop-v5.0”.