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Seamless Integration of Deep Geothermal Heat into 3rd and 4th Generation District Heating Networks – The Durham (UK) Cogeneration Demonstrator

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Abstract

The Durham Geothermal Cogeneration Project targets the radiogenic Weardale Granite and overlying sediments along the Sharnberry–Deerness fault in northeast England. A geothermal gradient of ~32–38 °C/km yields production temperatures of ~210–250°C at ~6.5 km (and ~180–210°C at 5.5 km), well above the 85°C required for current third-generation district heating and technically suitable for fourth-generation operation as customer-side return temperatures are reduced.

A four-gate phased development strategy mitigates resource and delivery risk while maximising flexibility. Gate 1 drills a ~2.5 km slim-hole to evaluate fault transmissivity and temperature for comparison with the extremely high artesian flowrates observed in the offset Eastgate #1 well. If artesian behaviour, high fault transmissivity and/or sufficient geothermal gradient are confirmed, Gate 2 advances to a ~6.5 km deep full-scale well with a ~500 m lateral. A successful outcome (≥210°C, ~75 kg/s) enables a seven-lateral fault-flow development (four producers, three injectors) yielding ~39 MW_t and up to ~40 MW_e via an Organic Rankine Cycle (ORC). If transmissivity is lower than this, trial stimulation for an Enhanced Geothermal System (EGS) is undertaken. If that is unsuccessful, Gate 3 investigates natural transmissivity and EGS fallbacks at 5.5 km vertical depth, and if not successful, Gate 4 investigates natural transmissivity and EGS in 4.5 km sedimentary rock, which still yields sufficient power generation to meet for parasitic losses but requires higher heat tariffs. Gates 2-4 reuse the existing wellbore, mitigating risk while preserving delivery of the ~39 MW_t base case.

Surface infrastructure comprises a 16.9 km city-wide heat network delivering 101 GW_t·h/year to anchor loads including Durham University, the hospital, and civic buildings (achieving ~5.95 MW_t·h /m linear heat density). A central energy centre incorporates twin heat exchangers, 900 m^3 of thermal storage, SCADA controls, and variable-speed pumps. The high-enthalpy resource enables flexible operation between cogeneration and heat-only modes, with electricity revenues cross-subsidising near-zero heat input prices (£0.01/kW_t·h), supporting affordable network expansion into lower-density zones. Built-in geothermal redundancy—single-well direct-heat fallback and sustained production under temporary injector outages via siphon effects—avoids reliance on fossil backup or high-cost alternatives, ensuring a resilient, low-carbon supply. A dedicated high-temperature branch (≈100°C) can also meet specialist institutional loads such as hospital sterilisation.

1. Introduction

Urban heat is the “last big load” to decarbonise in the UK. In Durham City, >85% of buildings presently rely on natural gas, yet zoning, anchor loads, and a favourable subsurface make a city-scale district heat network (DHN) technically and economically attractive. A feasibility study for Durham identified a deep-geothermal, city-wide network with a river crossing as the preferred pathway, supplying 101 GW_t·h/y with a diversified peak of 39 MW_t and 16.9 km of mains.

This paper expands on two themes critical to the demonstrator's bankability and scalability:

- Cross-subsidy: high-temperature cogeneration produces power and heat; power sales pay for the capital-intensive subsurface, allowing near-free heat input (£0.01/kW_t·h) to the DHN.

- Inherent redundancy: the development and temperature headroom allow direct-heat fallback (≥85°C) from a single production well, and days of continued production under injection-pump outages due to siphon effects—reducing or eliminating the need for fossil or other backup typically specified for UK networks.

We use the Durham City techno-economic results for the network and the geothermal development plan to show how a high-enthalpy, near-city resource re-writes district heat network economics and reliability.

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2. Geological Concept and Geothermal Development Plan

The objective is to provide 39 MW_t, 100,000 GW_t.h/y of thermal heat at 85°C to Durham City for at least 30 years, as cheaply as possible. Depending on the geothermal gradient encountered at depth, the transmissivity of the fault system, and the geomechanical properties of the granite, up to 41 MW_e of electric power over 15 years could be available for sale to a microgrid of public sector buildings and to the Northern Power Grid. Power revenues are intended to cross-subsidise heat into the Durham City network, lowering consumer costs while maintaining long-term security of supply.

The Sharnberry-Deerness fault system, whose north-easterly terminus is understood to be located west of Durham City (Fig. 1), is a promising target for geothermal development. Situated on the eastern edge of the heat-producing North Pennine Batholith (commonly known as the Weardale Granite), the fault potentially offers dual advantages: a structural pathway for fluid movement and access to deep, radiogenic granite ideal for a next generation Enhanced Geothermal System development (Fig. 2),. The area benefits from good mapping by magnetic, gravimetric, radiometric, seismic, and latterly Magneto-Telluric surveys as well as a number of drilled wells.

The regional geothermal gradient used in this assessment (32–38°C/km) is derived from the British Geological Survey (BGS) and other legacy datasets.

A Magneto-Telluric Array (MTA) survey was undertaken to increase understanding of the nature and depth of the fracture system along this pathway. It identified a well-developed, predominantly northeast–southwest fault system beneath the survey area and supports the mapping of deeper, laterally continuous structures; these features may be deep offset expressions of the nearer-surface BGS lineaments Extensive mineralisation events give very high confidence that the fault does extend to the granite itself – i.e. that fracture conditions encountered at shallower depths should be repeated to and into the granite itself, reinforcing the rationale for testing a deep intercept where feasible.

The plan is to drill a full-sized first development well (an injector) and undertake scientific measurements during its drilling, stimulation, and testing. The well will investigate the attractiveness of the full field development at 6.5km, 5.5km and 4.5 km vertical depths, both for fault-based flow and EGS, and a hybrid of both.

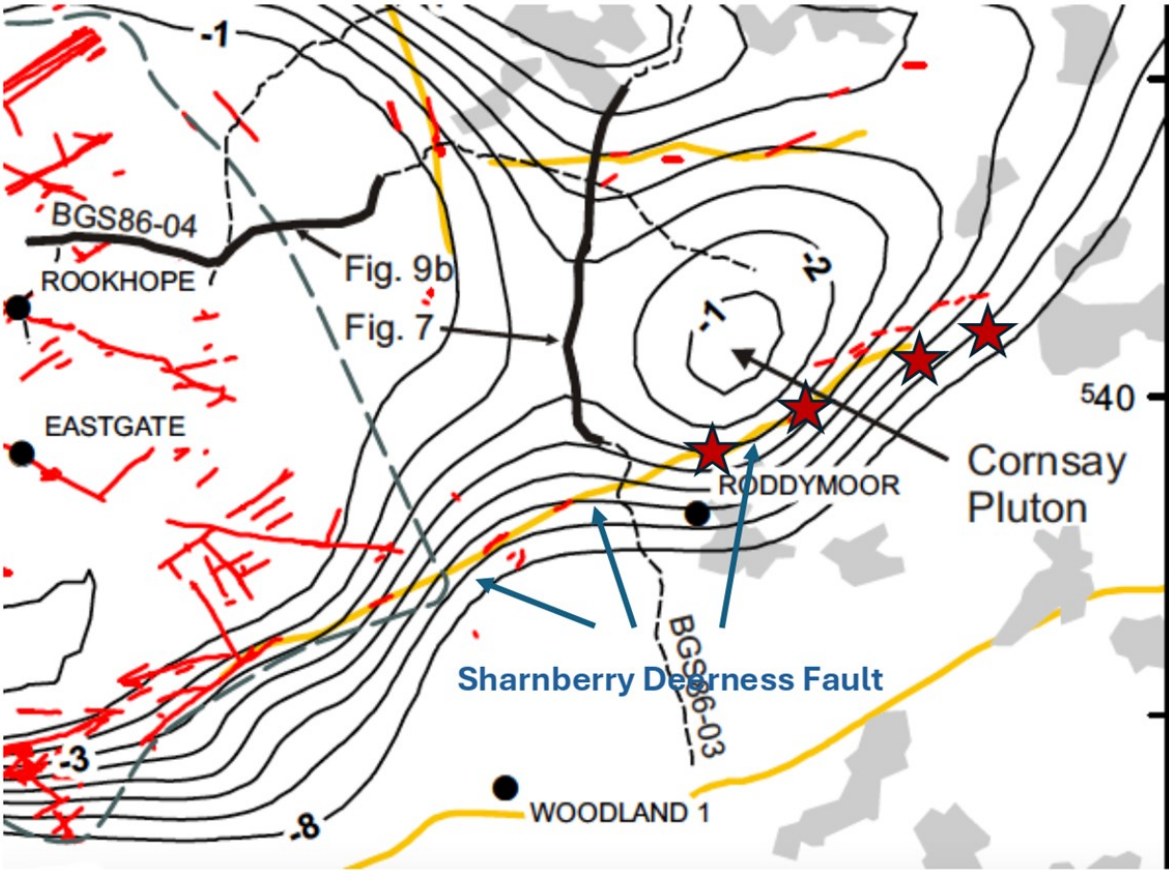
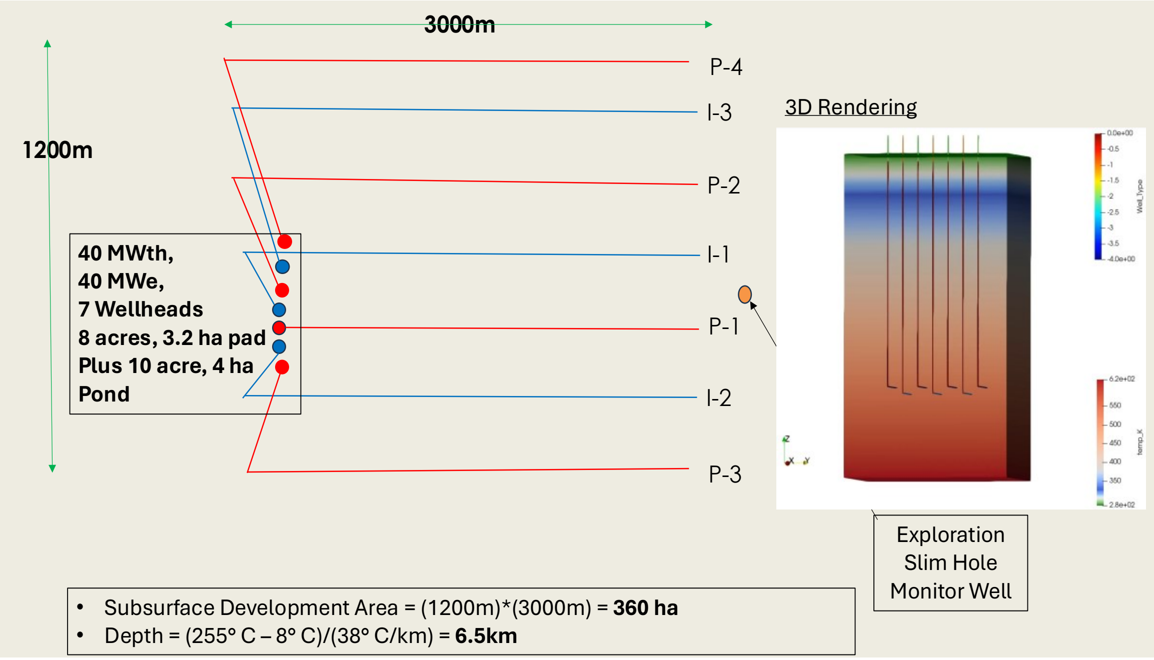


Fig. 1 Sharnberry-Deerness fault and contour depth of granite. Stars represent Magnetotelluric Array sites. Red lines represent Mineralisation Events. Source: Kimbell etal 2010



40 MWth,
40 MWe,
7 Wellheads
8 acres, 3.2 ha pad
Plus 10 acre, 4 ha
Pond

- Subsurface Development Area = (1200m)*(3000m) = **360 ha**
- Depth = (255° C – 8° C)/(38° C/km) = **6.5km**

Fig. 2 Illustration of a 7-well EGS Development

3. Heat Network Integration and Economics

3.1 Scope and performance

- Annual heat: 101,000 MW$_t$.h/y
- Peak: 39.1 MW$_t$
- Length: 16.9 km; Linear Heat Density (LHD): ~5.95 MW$_t$.h/m
- Operating temperatures (initial): 85/65 °C primary; steel mains
- Storage: 900 m^3 (30 min of peak)
- Pumping: two intermediate stations to keep pressures <16 bar across 100 m elevation range
- KPIs (40 y): LCOH ~8.55 p/kW$_t$.hr; environmental carbon intensity 0.252 gCO2/kW$_t$.hr; strong social IRR and NPV.

Implications for expansion. Because the heat input price is near-zero, tariff setting is driven largely by distribution capex, losses, and O&M—not by fuel. The Durham modelling shows that when heat supply is priced competitively below heat-pump alternatives, the network can rationally extend into mixed-density districts and still meet KPIs, provided route optimisation and staged connections maintain LHD in the 6 MW$_t$.h/m range or better (compared with the pilot England baseline of 4 MW$_t$.h/m). This is precisely what the design achieves by including a river crossing to capture additional city-centre anchors in one integrated scheme rather than two smaller systems (Fig. 3).

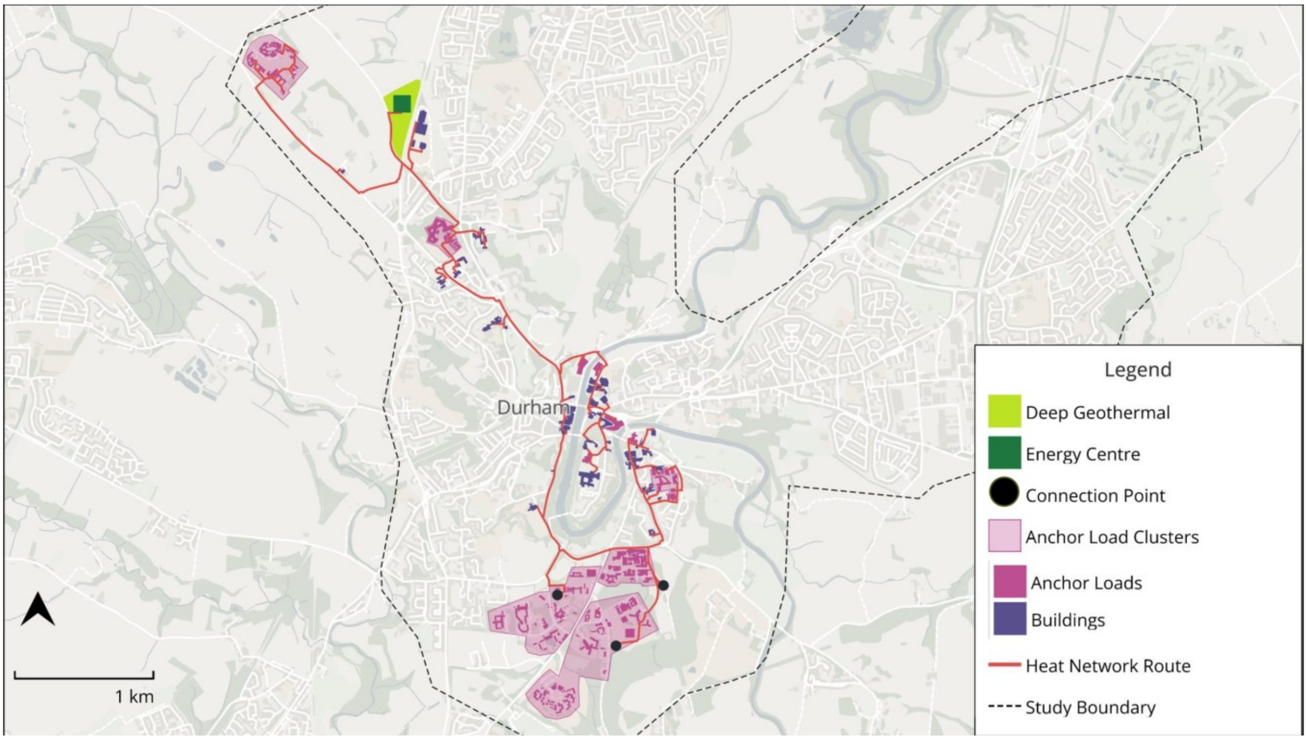


Fig. 3 Planned Durham Heat Network, 39 MWth ramping from 2029 to 2033 to 101 GWth.hr pa

3.2 Connections, anchors, and routing

Eighty-nine connections are envisaged, with eleven anchor loads accounting for ~76% of demand (e.g., University Hospital of North Durham; Durham University clusters; prisons; hotels; retail). Routing avoids bridge pipework (unsuitable clearances/structures) and instead tunnels under the river to reach high-density clusters. Indirect substations with N+1 (or N+2 at the hospital) exchangers are specified, with return-temperature management improving over time as buildings are optimised.

3.3 Temperatures and losses

Initial operation at 85/65°C matches today's emitters; as retrofit progresses, return temperatures can fall—improving ΔT, pipe sizing, and pumping energy. Heat losses for the integrated city-wide design are consistent with Series-2 insulation assumptions and are small relative to delivered heat at this scale. Raising geothermal delivery to 95°C is technically feasible and may improve hydraulics at a small increase in boundary heat price—pragmatic given the near-zero baseline.

3.4 Dedicated High-Temperature Branches (e.g., 100 °C Hospital Service)

A signature capability of this project is supplying dedicated ≥100°C service (e.g., steam/hot-water sterilisation and humidification at the University Hospital of North Durham) from the 250°C resource. This enables partial or full "de-steaming" and rationalisation of on-site plant without forcing the city-wide DHN to run at higher temperatures. A parallel, insulated branch (or a local booster loop) can meet process specifications while the main network continues its glidepath to lower temperatures over time.

3.5 Inherent Redundancy

Because production temperatures are 180–250°C, the ORC extracts power first, then residual heat feeds the DHN at 85°C. In a contingency, one or more production wells can be valved out of the ORC and switched to direct heat to cover the network's 39 MW_t peak (or a large fraction thereof, depending on instantaneous well enthalpy and flow). This obviates dedicated gas/CHP backup typically required when the primary source is a heat pump.

3.6 Hydraulic tolerance

If injection pumps stop working, the system's siphon and artesian qualities keep flow going for days, allowing maintenance without thermal shutdowns. Multiple injectors and a multi-lateral geometry further distribute risk. At the surface, N+1 pumps and twin heat exchangers at the energy centre add conventional redundancy to subsurface robustness.

4 Regional Economic, Carbon, Social and System-Wide Benefits

Beyond end-user economics, the quantified 40-year metrics include:

- 330-500 construction jobs for six years
- 25-70 operations and maintenance jobs for over 40 years
- 15 billion cubic feet (0.4bcm, 0.8 million tonnes CO_2) natural gas consumption avoided vs Business As Usual (gas) for the heat network and the declining carbon intensity for the electricity network
- High social IRR and NPV metrics using the HM Treasury methodology (Fig. 4)

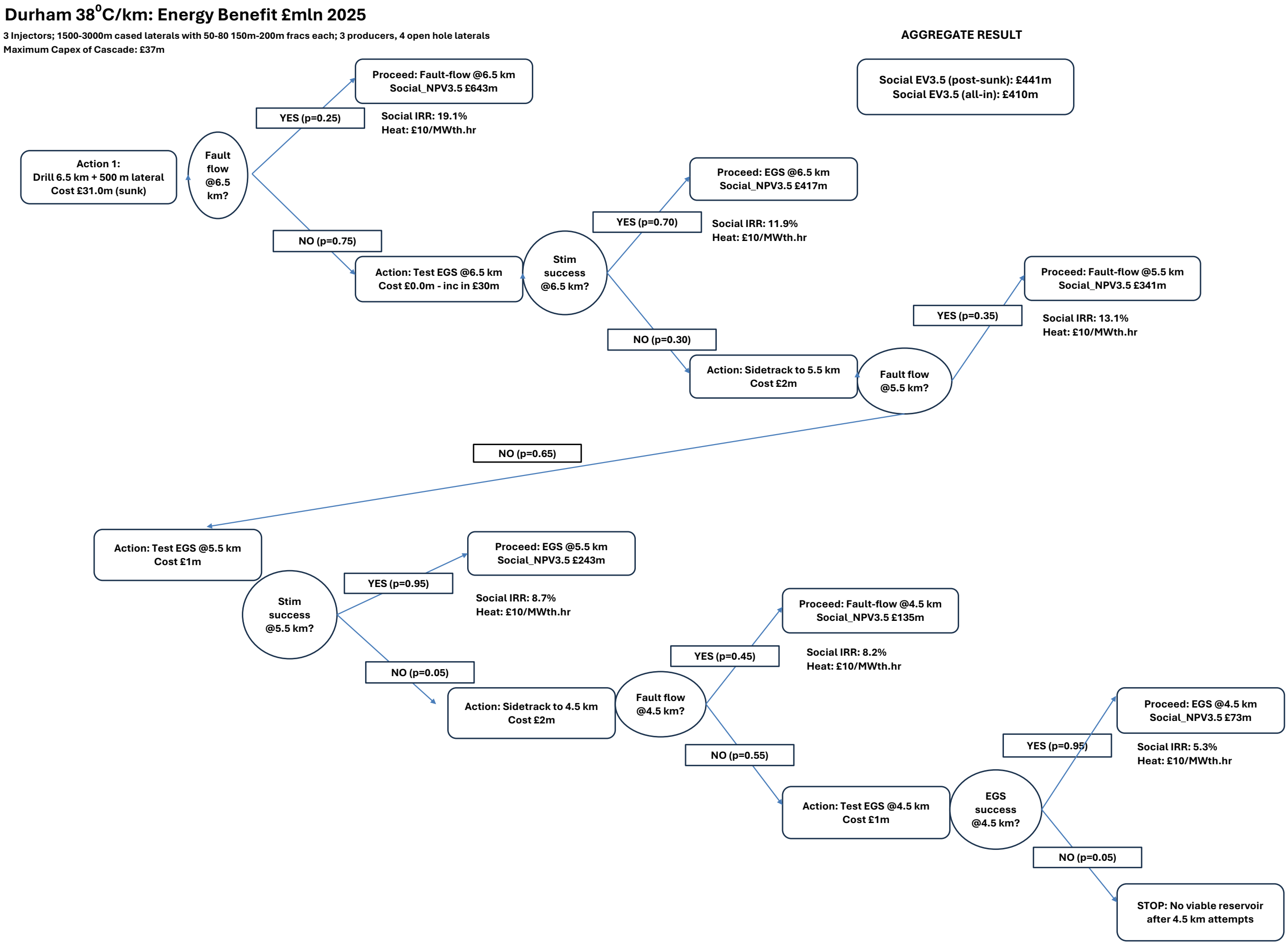


Fig. 4 Social NPV Decision Tree of HM Treasury Green Book Methodology: 38º C/km Geothermal Gradient

Additional system benefits include:

- Avoided electricity grid reinforcement: Direct thermal supply prevents large winter coincident electric loads from building-scale heat pumps, reducing reinforcement needs at distribution and transmission levels across Durham's profile.
- Reduced constraint payments: Firm, near-load ORC capacity helps on net to reduce instances where UK system operators pay to curtail remote generation when transmission is saturated—Durham's local generation contributes diversity and flexibility.
- Lower distribution losses: Moderate-temperature, high-density trunking with optimised ΔT, storage, and pumping strategy keeps losses low even at 3rd-gen start conditions, with further improvement as returns fall.

5. Tariffing, Finance, and Delivery

5.1 Tariff architecture

Durham's modelling applies standard UK heat-tariff structures (connection fee, fixed charge, variable energy charge) with discounts to the counterfactual, so customers always pay less than a like-for-like heat-pump alternative. With nearly free boundary heat, the network operator can keep tariffs competitive and maintain returns while pursuing city-centre and medium-density infill.

5.2 Capital structure

A staged structure is advised:

1. Equity-at-risk for Gates 1-4: resource and development plan proving;
2. Blend of concessional/debt for full field after heat and power offtake frameworks are executed;
3. DHN financing via utility/PPP structures, potentially with government grant support for distribution capex.

Because subsurface capex is recovered primarily from electricity, the DHN is not exposed to fuel risk and can negotiate long-tenor, infrastructure-style debt.

5.3 Delivery plan and risks

Key near-term actions include: confirm river-crossing method and cost; secure Distribution Network Operator (DNO) positions for ORC export and station supplies; confirm boundary conditions and water-quality protocols; continue planning and EA/HSE engagement on wells and surface plant; sequence anchor connections to sustain LHD during build-out (Fig. 5). Risks (geology/transmissivity, permitting timelines, distribution CAPEX) are mitigated by the gated plan, alternative horizons (6.5/5.5/4.5 km), and the strong KPI headroom.

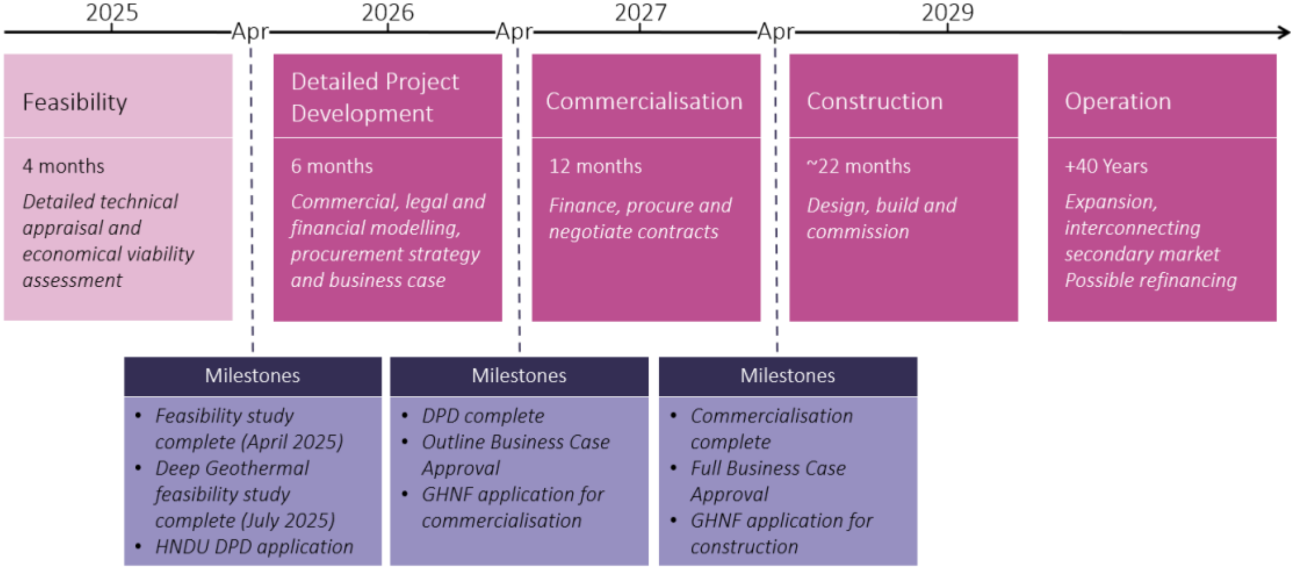


Fig. 5 Indicative Heat Network Delivery Plan for Durham City

6. Implementation Architecture and Operating Model

- **Interface:** Geothermal delivers at a boundary valve pit at agreed T/P/flow; the DHN operator takes custody and commercial risk from that point.
- **Operations:** ORC dispatch optimises between power and heat value; storage buffers the network, smoothing transients; pump Variable Speed drive (VSD) control maintains pressures <16 bar across the elevation profile.
- **Resilience:** Redundant exchangers and pumps; well-level bypass to direct-heat mode; multi-injector circulation.
- **Evolution:** Progressive reduction of return temperatures and emitter upgrades transition the network toward 4th-gen operation without disrupting legacy buildings.

7. Conclusions

Durham City's deep geothermal cogeneration demonstrator shows how very-high-temperature, near-load geothermal can change the fundamentals of DHN development:

1. Cross-subsidy works: power sales fund the subsurface, making heat nearly free at the boundary and enabling economically rational expansion into areas that would otherwise fail LHD or tariff tests.
2. Redundancy is intrinsic: wellfield geometry and temperature headroom provide built-in backup, reducing reliance on fossil fuel backup.
3. High-grade use-cases are enabled: dedicated 100°C branches (e.g., hospital sterilisation) coexist with an 85/65°C primary—future-proof toward 4th-gen operation.
4. Societal value is high: strong LCOH, carbon, and social returns; avoided grid and gas costs

Durham offers a replicable blueprint for UK cities with viable deep-geothermal prospects and strong anchor loads.

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