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Geothermal For Mega-projects: A Use case Strategy for Scalable, Low-Risk Deployment

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ABSTRACT

Mega infrastructure projects demand energy systems that are not only sustainable, but also rapidly deployable and low-risk. This presentation explores how geothermal energy can meet that challenge, using NEOM's pioneering geothermal program in the Kingdom of Saudi Arabia as a case study. As the geothermal Owner's Engineering firm for NEOM, Steam S.r.l., in collaboration with NEOM's geothermal office, is implementing a geothermal development strategy grounded in a comprehensive assessment of the project's long-term energy needs. These are mapped to the geothermal use cases of power, cooling, desalination, industrial heat, and agriculture/aquaculture, and then vetted against available subsurface data and alternative energy options to assess feasibility. The process can define optimal exploration methods and helps balance CAPEX and OPEX against the expected impact and timeline of each use case. Strategic recommendations prioritize limited-scope, high-impact pilot projects that offer scalability, serve as proof-of-concept, and unlock further investment. The session will outline how this structured, use case driven approach not only supports NEOM's sustainability goals but also offers a replicable model for applying geothermal in other large-scale developments worldwide.

1 INTRODUCTION – GEOTHERMAL AS THE STRUCTURAL ENERGY PILLAR FOR MEGA-PROJECTS

Mega-projects, including planned cities, industrial corridors, logistics hubs, tourism districts, and integrated urban zones, are developments that benefit greatly from a comprehensive approach population, infrastructure, water production, industry, and mobility planning and management. This creates continuous energy demand, dominated by cooling, desalination, industrial heat, and uninterrupted power for data systems and transport electrification. Intermittent renewables struggle in this environment: cooling peaks when solar declines, industrial processes cannot cycle with the wind, and large-scale storage remains costly, land-intensive, and slow to deploy. Energy in these settings is no longer a utility input; it is a structural requirement of the master plan.

Geothermal directly addresses these constraints. It provides weather-independent baseload electricity and continuous thermal output that can be applied to absorption cooling, desalination, industrial processing, greenhouse agriculture, aquaculture, and tourism infrastructure. Its small surface footprint allows deployment within dense or high-value development zones without visual or land-use conflict. When incorporated from the beginning of project planning, geothermal flattens peak electrical load, reduces grid-expansion requirements, stabilizes system operations, and enables development forms that would otherwise depend on oversized or volatile energy supply.

What remains missing is not geological potential, but methodology. Conventional geothermal development begins with exploration and only later seeks end uses. Mega-projects require the reverse: energy planning that starts with defined demand, aligns resources with specific use cases, and phases development so that uncertainty is progressively converted into proven capacity. This paper presents the structured, use-case-driven model applied in the Kingdom of Saudi Arabia, demonstrating how geothermal can function as a foundational design element for large-scale developments rather than a niche renewable technology.

2 GLOBAL PRECEDENTS FOR INTEGRATED GEOTHERMAL SYSTEMS

Several national and regional developments already demonstrate that geothermal can serve as a foundational energy asset when coupled with infrastructure, industry, and municipal planning. These examples show how cascading utilization, phased de-risking, and sector coupling allow geothermal to function as an energy platform.

2.1 Iceland: A National Thermal Architecture

Iceland's transition from fossil-fuel dependency to renewable self-sufficiency illustrates how geothermal can underpin urban, industrial, and environmental systems at national scale. Geothermal now provides roughly 90 percent of heating demand and around 30 percent of electricity (Cariaga 2024). Its role expanded not through a single flagship installation, but through integration across municipal heating networks, industrial clusters, and downstream applications.

High-temperature resources at Hellisheiði and Reykjanes supply steam for power production, while residual heat feeds Reykjavík's district network, serving more than 260,000 residents (Registers Iceland, n.d.). The same cascading principle supports agricultural greenhouses and industrial activity, including three aluminum smelters: Rio Tinto's ISAL, Alcoa's in Fjarðaál, and Norðurál (a subsidiary of Century Aluminum Company) in Grundartangi (Þórðardóttir 2018). Carbon capture and mineralization at CarbFix (World Economic Forum 2019), the Climeworks Orca direct air capture facility, and the Blue Lagoon tourism complex further demonstrate how geothermal can anchor multi-sector infrastructure within a single geographic node (CarbFix 2024).

Critically, Iceland's development was phased and risk-managed. Public investment and a national drilling-loss insurance mechanism through Orkusjóður unlocked private capital participation (Bochove 2023). The result is a system where geothermal serves as both a utility backbone and an innovation platform.

2.2 Kenya's Menengai Field: Industrial and Agricultural Coupling

Kenya's Menengai development provides a continental analogue, demonstrating how geothermal can drive industrialization and agricultural productivity. With a planned 465 MW electrical capacity (Geothermal Development Company 2025), 105 MW already drilled, 35 MW already installed, and 70 MW under construction, Menengai follows an explicitly phased model: exploration by the state-owned GDC, followed by private build-own-operate units.

Beyond electricity, medium-temperature brine at 87–100 °C supports milk pasteurization, grain drying, fish farming, and greenhouse heating (Kori 2020). Financing blends public and multilateral capital from the African Development Bank and the European Investment Bank with private equity supported by government-backed steam-supply agreements (AfDB 2019; EIB 2020). Resulting power costs of $0.06–0.08 per kWh (Africa Energy Portal 2023; POWER Magazine 2024) demonstrate how geothermal can anchor economically viable industrial hubs in arid climates.

The development also shows adaptive flexibility. Lower-than-expected temperatures in early wells shifted investment toward direct use rather than abandonment, illustrating how phased planning can convert geological uncertainty into diversified opportunity (Payton 2024).

2.3 Other Large-Scale Precedents

Additional high-capacity examples reinforce geothermal's scalability and multi-sector function:

- Olkaria Complex (Kenya): 963 MW supporting Nairobi's industrial corridor, with cascading heat use for greenhouses and spas (Kori 2020).
- Sarulla (Indonesia): 330 MW baseload system serving a 5,000-hectare agro-industrial zone, financed through MIGA guarantees and ADB/JBIC loans (Asian Development Bank 2024).
- Mak-Ban (Philippines): 458 MW across six plants, where Binary and ORC systems enable dense, low-impact deployment (Ramos 2024).
- Miravalles (Costa Rica): ~165 MW integrated with agricultural processing and eco-tourism (Berg 2022).

2.4 Synthesis of Global Patterns

Across these cases, three consistent dynamics emerge:

1. Cascading use multiplies economic value: power, heat, cooling, agriculture, and tourism reinforce each other rather than operating independently.
2. Phased development reduces financial risk: pilot data help attract capital for expansion.
3. Sector coupling turns geothermal into planning infrastructure: energy, water, agriculture, and industry co-develop.

These precedents show that geothermal's value does not derive from a single application, but from intentional multi-use application. The next section examines how the Kingdom of Saudi Arabia can apply these principles

at the scale of a planned mega-project, where energy, land use, zoning, and infrastructure are designed simultaneously.

3 NEOM AS A PURPOSE-DESIGNED GEOTHERMAL TESTBED

NEOM provides a development context where geothermal can be integrated from the outset, with energy planning advancing in parallel with land use, infrastructure, and construction. Unlike retrofit environments, the project's synchronized design process allows geothermal to be deployed where it delivers the highest functional value, shaping district cooling needs, desalination systems, industrial activity, and urban density.

3.1 A Landscape of Distinct Energy Demands

The project area spans the Kingdom of Saudi Arabia's coastal plains along the Red Sea, mountain ranges, inland plateaus, and island environments. These contrasting terrains form development zones with differentiated energy profiles:

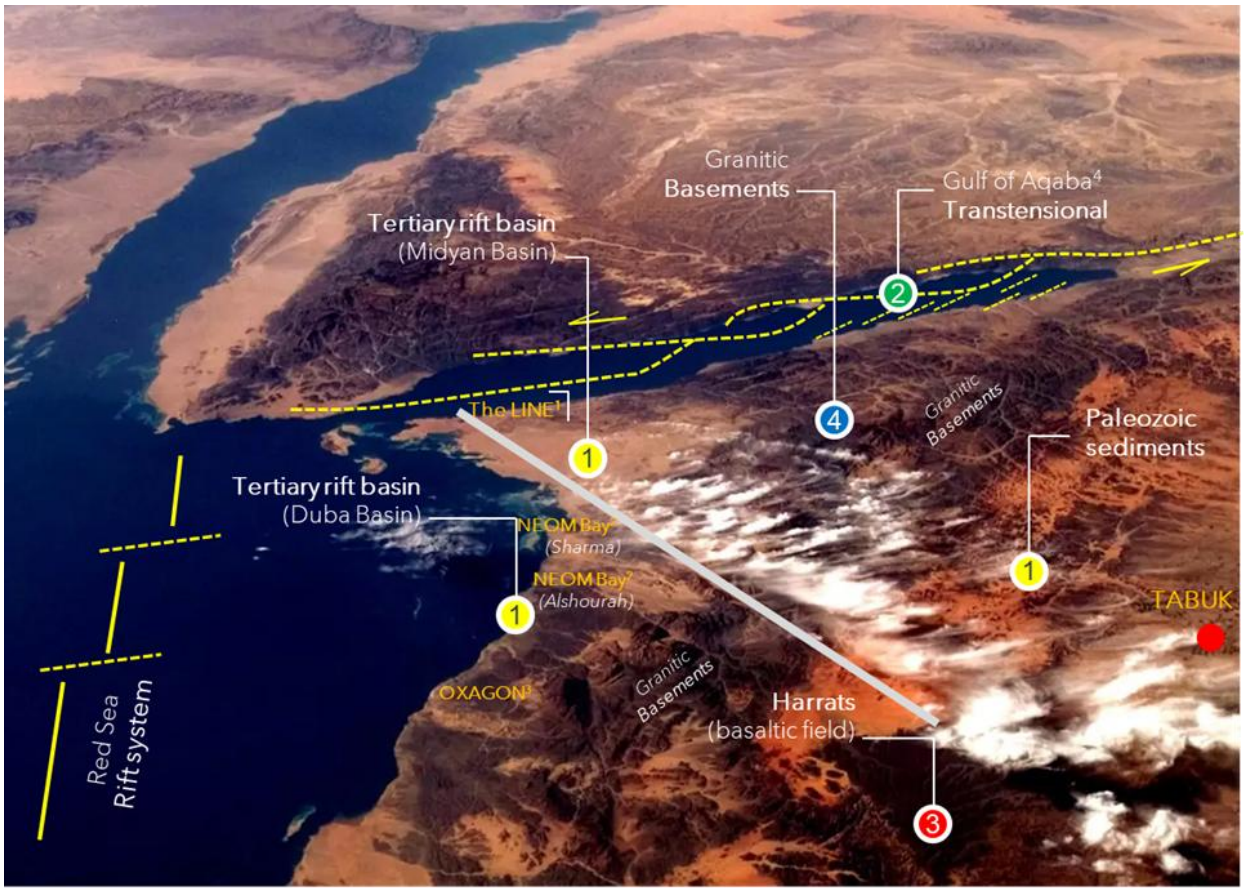


Image credit: http://city.jsc.nasa.gov/scripts/sseop/photo.pl?mission=ISS016&roll=E&frame=8810

Image 1. NEOM Working Area, Image credit: NEOM. This image provides a contextual references for system design based on the NEOM projected construction plan and the surrounding geological context.

- Coastal Industrial Hub: Requires baseload electricity, process heat, and large-scale desalination capacity.
- Mountain Recreation Zone: Experiences seasonal variation in heating and cooling, compatible with ground-source heat exchange.
- Linear Urban Corridor: Demands low-visual-impact, high-reliability energy in a dense urban plan.
- Marine Hospitality Enclave: Prioritizes cooling and water production, suited to hybrid geothermal-desalination systems.
- Inland Agricultural Region: Favors shallow and medium-temperature geothermal for greenhouse heating and absorption cooling for aquaculture.

Together, these zones reflect the multi-sector, multi-load characteristics seen in global precedents, but within a single planned geography.

3.2 Subsurface Variations as Functional Advantage

Geological characterization across NEOM identifies three resource tiers aligned to different energy uses:

- A shallow aquifer suitable for GSHP
- an intermediate-depth reservoir for thermal uses and absorption cooling
- a deep reservoir for power generation

Rather than forcing a single solution, this enables resource–use matching that avoids stranded assets and tailors investment to actual demand.

3.3 A Zonal Deployment Model

The result is a distributed thermal architecture in which each zone hosts a geothermal system matched to its dominant load, while collectively contributing to system resilience and reduced peak electrical demand. Geothermal becomes not a standalone plant, but an organizing layer influencing infrastructure phasing, cooling network design, desalination strategy, and industrial siting.

3.4 Why NEOM Advances the Geothermal Development Model

NEOM brings together the characteristics found in global precedents:

- defined multi-sector thermal demand
- high cooling dependence
- synchronized construction timelines
- policy alignment and capital planning
- ability to phase and scale based on operating data

These factors allow geothermal development to begin with use cases rather than resource speculation, providing the setting in which the use-case-driven model is applied and tested.

4 THE USE CASE DRIVEN DEVELOPMENT MODEL

Large-scale geothermal deployment succeeds when energy production is matched to specific and measurable demand. Rather than beginning with exploration and later searching for end uses, NEOM's geothermal strategy starts by defining how energy will be used and then matching those requirements to the most suitable subsurface systems. Identified use cases include power, cooling, desalination, industrial heat, and agricultural applications. This approach reframes geothermal from a resource-first activity into a planning methodology grounded in functional design.

4.1 Step 1: Define the Energy Use Cases and Match to Resource Types

The first stage evaluates the distinct energy demands within the development:

- Baseload electricity for critical infrastructure.
- Absorption cooling for large building clusters and industrial processes where electric chillers would impose peak load stress.
- Desalination through direct-boil and hybrid membrane systems.
- Industrial and district heat for manufacturing, chemical processes, and potential hydrogen production.
- Agricultural and aquacultural applications, including greenhouse heating, fish farming, and post-harvest drying.

Each use case is characterized by temperature range, load profile, spatial adjacency, and cascade potential, allowing development to be sized according to verified demand rather than speculative capacity.

Once demand is defined, resource matching to resource type (see 3.2 Subsurface Variations as Functional Advantage), prevents stranded assets and ensures that resource conditions and demand profiles reinforce one another.

4.2 Step 2: Preliminary subsurface screening and data integration

With energy use cases and preferred resource types established, the second stage performs a rapid, multi-source subsurface screening to identify geothermal systems capable of supporting the matched demands.

Existing geological, geophysical, and geothermal datasets are compiled and reviewed for consistency and relevance. Public-domain data, prior studies, and remote-sensing information are integrated to establish a first-order understanding of basin architecture, fault systems, and likely fluid circulation pathways.

These inputs support a preliminary static subsurface framework capturing lithology, major structural elements, and expected temperature ranges. At this stage, the objective is not detailed reservoir characterization, but early differentiation between potentially viable and non-viable areas relative to the defined use cases.

Prospective zones are screened against each matched use case using a qualitative three-tier screening (high / medium / low suitability) based on four practical criteria:

- Expected temperature range and depth to resource
- Indicative permeability and reservoir thickness appropriate to the intended application
- Structural setting, including the presence of faults or fractures that may support fluid flow
- Spatial alignment and proximity to identified demand centers

Areas advancing beyond this stage demonstrate sufficient confidence in temperature, deliverability potential, and spatial fit to justify targeted data acquisition and techno-economic evaluation in the subsequent stage. The outputs include a spatially explicit shortlist of candidate geothermal systems, an integrated data inventory, and a clear articulation of the key uncertainties to be addressed.

4.3 Step 3: Evaluate Technical and Economic Feasibility

Each paired use case undergoes a multi-criteria evaluation including:

- thermal productivity
- proximity to demand centers
- CAPEX/OPEX performance
- environmental compatibility

This evaluation determines whether the project progresses to pilot-scale implementation, where operational data replaces modeled assumptions and establishes the economic signals that guide subsequent development phases. It is at this point that feasibility shifts from theoretical modeling to evidence-based decision-making, defining configuration, risk posture, and investment sequencing.

4.4 Step 4: Pilot, Validate, and Scale

Following feasibility assessment, development proceeds through staged scaling:

- pilots small enough to manage risk
- large enough to generate bankable data
- data feeds both engineering optimization and investor confidence
- scaling occurs through replication rather than redesign

This converts uncertainty into measurable performance evidence.

5 PHASED DEVELOPMENT ECONOMICS AND THE IMPACT OF USE CASE ALLOCATION MODELS

Economic feasibility in large-scale geothermal development can shifts significantly according to how capital costs are allocated across electricity and cooling. In this section, we will use three CAPEX allocation models for exploration costs:

- 100% electrical
- 50% electrical and 50% cooling
- 100% cooling

These models are then applied to each of the three planned development phases to illustrate how cost signals can evolve as geothermal systems scale.

5.1 Phase 1: Pilot and Validation

The initial phase includes a minimal two-well configuration yielding 1.5 MWe and 8.2 MW of cooling capacity. At this scale, cost allocation determines whether the project appears exploratory or prematurely judged.

- Full electricity allocation places all drilling cost on the electrical output, resulting in an LCOE of 72.0 $/MWh, an unfavorable early signal if interpreted through utility power benchmarks—especially when compared to solar PV and onshore wind LCOE often below $40/MWh in optimal regions, risking dismissal of geothermal despite its baseload advantages.
- Proportional allocation reflects both services, reducing LCOE to 51.7 $/MWh and producing a cooling cost of 19.9 $/MWh-c, supporting continued development by yielding more competitive power economics while delivering thermal services that solar and wind cannot provide directly, avoiding the need for separate electric chilling infrastructure.
- Full cooling allocation produces a cooling cost of 21.6 $/MWh-c, while the resulting power LCOE drops sharply to 44.9 $/MWh, demonstrating that even pilots can generate competitive electricity when cooling anchors the value proposition.

Phase 1 shows that if early-stage geothermal is judged solely on power economics, viable resources may be dismissed. When cooling needs are considered, pilots become rational risk-reduction investments.

Table 1. Phase 1: Configuration and Outputs

Attribute	Value
Primary purpose	Resource confirmation and flow validation
Wells drilled	1 production + 1 reinjection
Electrical output	1.5 MWe
Cooling output	8.2 MW
Scale characteristics	Minimal surface system, proof-of-concept
Decision leverage	Determines whether development proceeds
Scenario insight	Power seems marginal unless cooling value is recognized

Table 2. Phase 1: Cost Allocation Effects

Scenario Allocation Method	Resulting Cost Signal
Full CAPEX on electricity	High LCOE (72.0 $/MWh)
Proportional CAPEX allocation (50%-50%)	Balanced economics (LCOE 51.7 / LCOC 19.9)
Full CAPEX on cooling	Competitive LCOE (44.9 $/MWh)

Once resource performance is confirmed, the development question shifts from viability to scalability and offtake needs.

5.2 Phase 2: Demonstration and Expansion

Phase 2 introduces multiple wells, shared infrastructure, and meaningful energy delivery, with 10.1 MW of electricity and 16.4 MW of cooling, respectively. At this stage, anchor users and investors enter the decision process, and cost signaling shapes the preferred approach to development.

- Full electricity allocation results in an LCOE of 125.6 $/MWh, a distorted signal caused by assigning all drilling and gathering costs to electricity alone, and excluding completely the geothermal option.
- Proportional allocation lowers the LCOE to 68.9 $/MWh and produces a cooling cost of 25.2 $/MWh-c, demonstrating viable hybrid economics, which positions geothermal closer to competitive power benchmarks while delivering thermal services (e.g., absorption cooling) that solar and wind cannot supply directly, avoiding separate infrastructure or high-cost electric chilling with battery backup.
- Full cooling allocation yields a cooling cost of 55.2 $/MWh-c, while the resulting power LCOE falls to 33.4 $/MWh, reflecting that electricity appears low-cost when cooling anchors the value proposition.

Phase 2 marks the transition from resource confirmation to commercial optionality. At this stage, the project can credibly pursue electricity-led, cooling-led, or hybrid deployment paths depending on broader system priorities.

Table 3. Phase 2: Configuration and Outputs

Attribute	Value
Primary purpose	Reproducibility and early commercial operation
Wells drilled	4 production + 4 reinjection
Electrical output	10.1 MWe
Cooling output	16.4 MW
Scale characteristics	Shared gathering, modular surface system
Decision leverage	Determines investor entry and anchor use case
Scenario insight	Economics hinge on whether cooling or power dominates

Table 4. Phase 2: Cost Allocation Effects

Scenario Allocation Method	Resulting Cost Signal
Full CAPEX on electricity	Very high LCOE (125.6 $/MWh)
Proportional CAPEX allocation (50%-50%)	Viable hybrid economics (LCOE 68.9 / LCOC 25.2)
Full CAPEX on cooling	Strong LCOE (33.4 $/MWh) but higher LCOC (55.2)

With modular reproducibility established, development shifts toward district-scale applications and load shaping.

5.3 Phase 3: System Integration and Expansion

With twelve production and twelve reinjection wells delivering 31.5 MWe and 49.1 MW of cooling, Phase 3 reflects a district-scale system operating as core infrastructure.

- 100% electricity allocation produces an LCOE of 100.8 $/MWh, which reflects the same issue addressed in Phase 2.
- Proportional allocation drops LCOE to 59.2 $/MWh and cooling cost to 23.1 $/MWh-c, demonstrating competitive economics while simultaneously providing thermal output for absorption cooling or process heat, services that solar and wind cannot deliver directly and which would otherwise require additional electric infrastructure and peak-shaving costs.
- 100% cooling allocation results in a cooling cost of 46.0 $/MWh-c and a power LCOE of 33.1 $/MWh, confirming that cooling-anchored planning yields highly competitive baseload electricity.

Phase 3 illustrates how geothermal can transition from a marginal renewable to a core infrastructure layer, supporting district cooling, reducing peak electrical demand, and lowering system-wide emissions.

Table 5. Phase 3: Configuration and Outputs

Attribute	Value
Primary purpose	District-scale energy services and system optimization
Wells drilled	12 production + 12 reinjection

Electrical output	31.5 MWe
Cooling output	49.1 MW
Scale characteristics	Integrated surface network, baseload operation
Decision leverage	Establishes geothermal as core infrastructure
Scenario insight	Strategic cost allocation unlocks competitive project economics

Table 6. Phase 3: Cost Allocation Effects

Scenario Allocation Method	Resulting Cost Signal
Full CAPEX on electricity	High LCOE (100.8 $/MWh)
Proportional CAPEX allocation (50%-50%)	Competitive hybrid economics (LCOE 59.2 / LCOC 23.1)
Full CAPEX on cooling	Very strong LCOE (33.1 $/MWh) with moderate LCOC (46.0)

5.4 Implications Across the Three Phases

Across all phases, the same wells can appear uneconomic or highly competitive depending solely on allocation method. Scale creates value only when multiple services are stacked, and single-vector metrics such as LCOE fail to account for avoided peak load, reduced grid sizing, and displacement of electric cooling. For mega-projects, cost evaluation must therefore reflect multi-vector performance rather than electricity alone.

Table 7. Comparison Table, All Phases: Projected LCOE and LCOC for the Three Exploration CAPEX Allocation Scenarios

Development Phase	Scenario Basis	Electrical Output (MWe)	Cooling Output (MW)	LCOE ($/MWh)	LCOC ($/MWh-c)	Interpretation
Phase 1 – Pilot & Validation	Full wells CAPEX on electricity	1.5	8.2	72.0	18.1	Power appears marginal; cooling remains attractive
	Proportional CAPEX allocation (50%-50%)	1.5	8.2	51.7	19.9	Shared-use framing supports continued development
	Full wells CAPEX on cooling	1.5	8.2	44.9	21.6	Cooling primary value; electricity generation costs reduced to near zero
Phase 2 – Demonstration & Expansion	Full wells CAPEX on electricity	10.1	16.4	125.6	16.3	Power appears unviable if assessed alone
	Proportional CAPEX allocation (50%-50%)	10.1	16.4	68.9	25.2	Hybrid economics viable; diversification justified

	Full wells CAPEX on cooling	10.1	16.4	33.4	55.2	Cooling primary path if load dominance assumed
Phase 3 – System Integration & Scale	Full wells CAPEX on electricity	31.5	49.1	100.8	16.3	Power still appears costly under single-vector framing
	Proportional CAPEX allocation (50%-50%)	31.5	49.1	59.2	23.1	System achieves competitive economics
	Full wells CAPEX on cooling	31.5	49.1	33.1	46.0	Cooling-led planning viable in high-cooling climates

5.5 Considerations for Mega-project Planning

For developments with synchronized construction, dense cooling demand, and multi-sector district infrastructure, geothermal becomes a planning tool. When cooling is recognized as the primary load and electricity treated as a co-product, geothermal delivers:

- competitive baseload electricity
- low-cost absorption cooling
- reduced grid expansion requirements
- reduced intermittency management
- improved CAPEX efficiency

Phased development combined with use case-aligned cost allocation proves geothermal can act as a scalable, risk-managed, infrastructure-anchoring energy system for large integrated developments.

6 FINANCING AND POLICY CONSIDERATIONS

Large-scale developments benefit from energy systems that combine capital intensity with long-term price stability. Geothermal fits this profile: once built, operating expenditures are minimal and unaffected by fuel markets, allowing predictable pricing for cooling, desalination, industrial processes, and baseload electricity. When thermal services are valued alongside electricity, cost signals fall well below electric chilling and compare competitively with conventional thermal supply in high-cooling environments.

Phased development strengthens the financial case by replacing geological uncertainty with operating data. Pilot results sharpen cost estimates for subsequent phases, increase confidence in reservoir performance, and support higher debt ratios with lower premiums. This mirrors proven approaches: Iceland reduced early-stage risk through drilling-loss insurance, and Kenya enabled private operators through government steam guarantees. The mechanism varies, but the principle is constant: early institutional support unlocks infrastructure-grade capital once uncertainty is reduced.

Policy alignment further accelerates deployment where sustainability mandates intersect with water security, industrial development, and resilient power systems. In the Kingdom of Saudi Arabia, geothermal can directly support national energy and climate objectives while fitting within permitting, land-use, and design frameworks. Internationally, continuous-output renewables increasingly qualify for green bonds, blended capital, and ESG-linked financing, positioning geothermal as an institutional asset rather than a niche technology. The combination of stable economics, phased risk reduction, and policy compatibility enables geothermal to function as a reliable infrastructure backbone for mega-projects rather than an experimental alternative.

7 CONCLUSIONS

The development model being applied at the Kingdom of Saudi Arabia's NEOM working area is transferable because it is based on a vision-led, holistic development approach rather than just geology. Starting from

defined energy demand ensures that projects are sized to measurable value rather than speculative output. Phased deployment converts uncertainty into operating data, improving economics and enabling investors to enter on progressively stronger terms. Cascading utilization distributes capital across cooling, desalination, industrial heat, and electricity, turning each unit of resource into multiple revenue-supporting services. Where early-stage support bridges the risk gap and later-stage capital scales proven configurations, geothermal becomes an infrastructure asset rather than a resource gamble.

7.1 Core Principles of Transferability

The following principles guide this geothermal-first development processes:

- Start from demand: Size pilots and scale phases according to concrete use cases (i.e. new cities, ports, industrial clusters, logistics hubs, or any development with defined thermal loads).
- De-risk through measurable pilot phases: Operational data shrinks the financial gap between uncertainty and bankability, as demonstrated in Menengai and Iceland's early district heating expansion.
- Use cascading and multi-sector integration as multipliers: Repurposing residual heat for cooling, desalination, agriculture, or processing yields multiple economic outputs from the same resource across climates and development models.
- Inform master planning through subsurface potential: Resource variation becomes a design advantage when planners, infrastructure strategists, and urban designers participate alongside geoscientists and engineers.
- Blend public and private capital: Early-stage institutional support (insurance, guarantees, policy backing) enables private investment once technical risk has been reduced.

These core principles are universally transferable: logical sequencing, empirical de-risking, value multiplication through integration, interdisciplinary planning, and staged capital mobilization apply wherever large continuous thermal loads concentrate—coastal industrial hubs, highland resorts, dense urban corridors, or agricultural belts.

Certain enabling conditions amplify the model's effectiveness in contexts like NEOM: centralized governance that reduces veto points, synchronized planning across energy, land use, infrastructure, and water, sovereign-backed capital depth, and long-horizon coordination unconstrained by short-term electoral cycles.

Where these conditions are weaker—municipal-scale projects, fragmented regulatory environments, or private-market-driven developments—the model remains viable but requires adaptation. Decentralized governance calls for stronger multi-stakeholder coalitions or third-party facilitation; capital constraints shift emphasis toward modular pilots funded incrementally through utilities, cooperatives, or development finance; planning synchronization relies more on regulatory incentives or demonstration projects. These adjustments increase coordination overhead, but the demand-led, pilot-de-risked, cascade-oriented logic continues to provide a robust pathway, shifting geothermal from opportunistic add-on to integrated infrastructure foundation.

NEOM demonstrates that when geothermal is planned alongside land use, cooling networks, industrial systems, and water infrastructure, it shifts from a renewable option to a structural component of territorial design. For mega-projects, the question is no longer whether geothermal can contribute, but how early it can be embedded to shape layout, investment sequencing, and long-term performance. Energy no longer follows construction—energy shapes it.

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