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Unlocking The Potential Of Hot Sedimentary Aquifers In Indonesia: A Technical Framework Integrating Geomechanical Perspectives For Future Development

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ABSTRACT

Hot Sedimentary Aquifers (HSAs) represent a promising yet underexplored geothermal resource in Indonesia, offering an opportunity to diversify national geothermal development beyond high-temperature volcanic/magmatic-associated heat-source systems. While international projects have demonstrated the viability of HSA systems in non-volcanic regions, the potential of HSA in Indonesia remains at the conceptual stage, with no commercial operations yet established. This paper provides a forward-looking technical framework for integrating geomechanical considerations into Indonesia's emerging HSA exploration and development strategies. Using a literature-based approach, we examine key challenges, including caprock integrity, in-situ stress state characterization, fracture behavior, and mechanical responses under long-term fluid extraction or injection. Although current Indonesian HSA studies primarily focus on geological and hydrogeological assessments, incorporating rock mechanics and geomechanics into development planning will be crucial to ensure wellbore stability, reservoir sustainability, and long-term performance. We highlight the importance of targeted laboratory testing, stress modeling, and adaptive well design, drawing lessons from global HSA development while focusing on Indonesia's geological context. Additionally, the framework supports assessing the feasibility of repurposing existing oil and gas wells for geothermal use, offering potential synergies between Indonesia's hydrocarbon and geothermal sectors. This contribution provides a structured foundation for future research, pilot projects, and cross-disciplinary collaboration, offering technical insights to guide Indonesia's geothermal sector as it prepares to unlock HSA resources. Integrating geomechanical perspectives into planning and development will help transform Indonesian HSA systems from theoretical potential into practical, scalable energy solutions, supporting the country's broader goals for geothermal diversification and resilience.

1 INTRODUCTION

The development of Hot Sedimentary Aquifers (HSAs) has gained global attention as an alternative geothermal pathway beyond volcanic regions. HSAs utilize thermal energy stored in porous sedimentary formations at depths of 1.5 to 4 km. Examples in France, Germany, and the Netherlands demonstrate their viability for district heating and pilot power generation (Brémaud et al., 2025; see Figure 1).

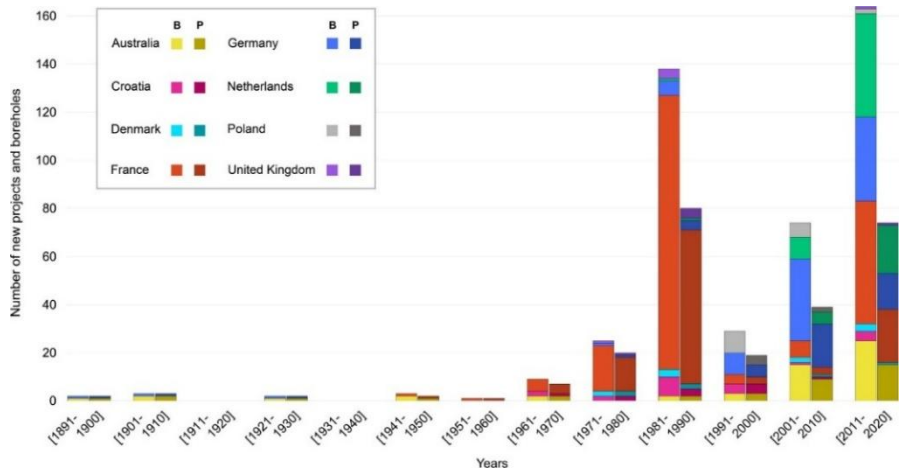


Figure 1. Global trends in Hot Sedimentary Aquifer (HSA) projects. Adapted from Brémaud et al. (2025).

Indonesia's geothermal program has focused on volcanic/magmatic-associated heat source geothermal systems (hereafter referred to as volcanic/magmatic systems), yet large sedimentary basins such as Central and South Sumatra and East Java remain underexplored for HSA potential (Figure 2; Putriyana et al., 2022).

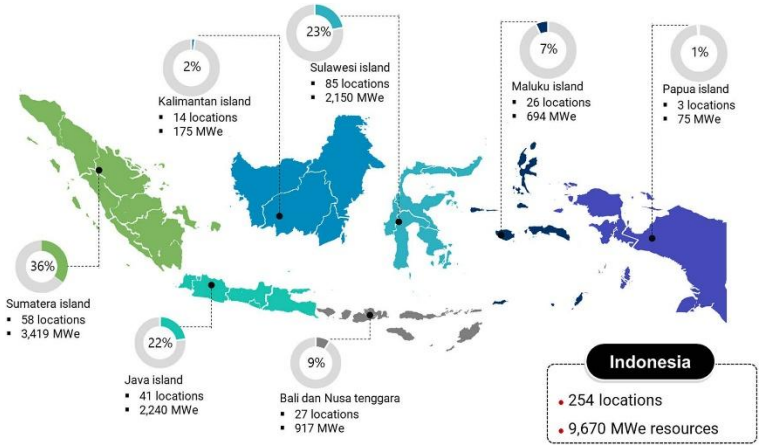


Figure 2. Distribution of low- to medium-temperature geothermal systems in Indonesia and potential HSA targets. Adapted from Putriyana et al. (2022).

Recent studies have identified favorable thermal gradients, thick aquifer packages, and potential caprock layers within these basins (Nurhuda et al., 2023; Nurul et al., 2023). However, no pilot or commercial projects have been implemented to date. Multiple technical gaps, such as limited integration of geomechanical and rock-mechanical insights during early-stage evaluation, hinder the pathway from theoretical potential to practical deployment. These issues, along with their cross-sector relevance, are summarized in Table 1.

Table 1. Key technical challenges for Hot Sedimentary Aquifer (HSA) development in Indonesia and their geomechanical relevance. Adapted from White et al., 2014; Trujillo et al., 2021; Zoback, 2007; Kruszewski et al., 2023; Kivi et al., 2022; Szklarz et al., 2024; Feng et al., 2020; Nagel, 2001.

Challenge	Typical Indonesian Context	Geomechanical / Rock-Mechanical Relevance
Caprock integrity	Shale–mudstone seals of variable thickness in Central & South Sumatra basins; leakage may reduce confinement.	Requires tensile & fracture tests and seal-failure modeling; analogs from CCS emphasize caprock evaluation.
In-situ stress state	Sparse orientation/magnitude data; tectonic variability affects wellbore stability.	Stress profiling is essential for well path, stimulation feasibility, and fault-slip analysis.
Fault reactivation	Pre-existing faults may slip during injection or cooling.	Slip-tendency and coupled THM analyses define safe pressure limits.
Fracture & permeability evolution	Matrix-dominated aquifers, but fracture zones control flow.	Changes in aperture–stiffness–conductivity under thermal cycling govern injectivity.
Compaction / subsidence	Long-term drawdown may deform overburden and infrastructure.	Reservoir compaction modeling and stress redistribution analyses are required.
Well integrity	Reuse of idle O&G wells; uncertain casing/cement behavior under thermal stress.	Assess casing–cement–rock interaction, expansion mismatch, and stress alignment.
THM coupling	Few Indonesian studies integrate coupled effects.	THM modeling captures pressure–temperature–stress evolution during operation.

This paper proposes a technical framework for the development of Indonesian HSA, grounded in geomechanical principles. It focuses on key challenges, including caprock integrity, in-situ stress state, reservoir mechanical

behavior, and potential fault reactivation. Although much of the existing work in Indonesia focuses on hydrogeological or petrophysical analysis, geomechanical considerations will be crucial for ensuring safe and sustainable long-term operation (Mustika et al., 2023).

The framework also considers the reuse of existing oil and gas wells as an accelerated pathway for HSA deployment. By anchoring HSA exploration and planning in a robust geomechanical framework, this paper aims to strengthen the credibility of early feasibility studies and align Indonesia's geothermal strategy with international best practices.

2 BACKGROUND AND CURRENT KNOWLEDGE

Hot Sedimentary Aquifers (HSAs) are geothermal reservoirs hosted in deep sedimentary basins, where naturally porous and permeable formations contain thermally active fluids. Unlike conventional high-temperature volcanic systems, HSAs are typically found in tectonically stable regions and are dominated by conduction-driven heat transfer from the surrounding formations (Moeck, 2014). Reservoir depths commonly range from 1.5 to 4.0 km, with formation temperatures between 60°C and 150°C, depending on the geothermal gradient and burial history. These systems are increasingly being developed in Europe, North America, and Australia, primarily for direct-use heating and — in some pilot projects — for low-enthalpy power generation.

In Indonesia, geothermal development has historically focused on volcanic/magmatic systems. However, national mapping and resource reviews have recently identified several sedimentary basins with potential for HSA development — notably the Central Sumatra, South Sumatra, and East Java Basins. Their distribution and key parameters are presented in Figure 2 and Table 2.

Table 2. Geothermal and hydrogeological characteristics of key Indonesian sedimentary basins with potential for Hot Sedimentary Aquifer (HSA) development. Adapted from Putriyana et al., 2022; Nurhuda et al., 2023; Nurul et al., 2023.

Basin / Region	Dominant Lithology / Reservoir Type	Depth (km)	Gradient (°C/km)	Est. Temp (°C)	Hydrogeological Remarks
Central Sumatra	Sandstone aquifers (Menggala Fm.)	1.5 – 3.0	30 – 40	60 – 120	Moderate porosity; reasonable well control; regionally continuous shale seals.
South Sumatra	Deltaic sandstones (Talang Akar Fm.)	2.0 – 3.5	25 – 35	84 – 116	Large aquifer volume; suitable for doublet design; locally faulted caprock.
East Java	Carbonate–clastic mix (Ngimbang Fm.)	2.5 – 3.5	25 – 30	70 – 100	Moderate gradient; existing oilfield infrastructure supports repurposing.

*) Other basins, such as Barito and Kutai in Kalimantan, show comparable thermal gradients and lithologies but lack systematic temperature and pressure data, requiring further validation.

For example, Nurhuda et al. (2023) estimated heat-in-place resources in the Central Sumatra Basin using volumetric methods, identifying 60–120°C intervals at depths of 1.5–3 km and aquifer packages exceeding 500 m in thickness. Similarly, Nurul et al. (2023) applied ordinary kriging to interpolate heat-in-place potential in the South Sumatra Basin, identifying prospect zones where formation temperatures could support binary-cycle or direct-use applications. These Indonesian case studies highlight significant theoretical potential but remain limited to preliminary assessments with no commercial deployment to date.

While promising, current Indonesian assessments remain limited to heat-in-place estimation, geothermal gradient mapping, and sedimentary thicknesses — useful for preliminary screening, but insufficient for comprehensive de-risking. These studies lack detailed evaluations of permeability architecture, caprock integrity, stress regime, and faulting patterns. These geomechanical aspects are crucial for assessing reservoir continuity, pressure containment, and long-term stability under fluid circulation or stimulation. In more mature geothermal environments, such as Germany and the Netherlands, geomechanical evaluation is already integrated into pre-feasibility workflows — particularly for projects involving pressure perturbation or the repurposing of oil and gas infrastructure (Marelis et al., 2024).

The potential for repurposing abandoned or idle oil and gas wells adds further momentum to the development of HSA. In Indonesian basins, such as Arun (Aceh), Rokan (Riau), and South Sumatra, thousands of inactive wells are found across mature petroleum fields. Previous studies (e.g., Syarifudin et al., 2016; Febrianto et al., 2019) have demonstrated the technical plausibility of converting these wells into geothermal assets, particularly for low-enthalpy applications. These cross-sector opportunities are likely to become more attractive as national energy transition plans mature and carbon-reduction strategies intensify.

By integrating both Indonesian and international experiences, the groundwork is now in place to develop a more rigorous, geomechanically informed framework — detailed in the following chapters.

3 GEOMECHANICAL AND ROCK MECHANICAL CHALLENGES IN HSA DEVELOPMENT

Although Hot Sedimentary Aquifers (HSAs) are typically located in more predictable sedimentary environments than volcanic geothermal systems, their development involves a suite of mechanical risks that must be understood and managed. These challenges arise from stress changes, pore-pressure variations, fracture propagation, caprock integrity, and the long-term mechanical evolution of the reservoir during injection and production.

The main geomechanical challenges in HSA development include:

- Caprock integrity — ensuring pressure and thermal confinement within the reservoir;
- In-situ stress uncertainty — influencing wellbore stability and fault-slip risk;
- Fracture behavior — controlling injectivity and fluid pathways;
- Thermal and pressure effects — governing reservoir deformation and permeability evolution;
- Well integrity and THM coupling — key to long-term stability.

These factors govern injectivity, containment, and long-term stability (Sections 3.1–3.4).

3.1 Caprock Integrity and Seal Performance

HSAs, particularly those developed using open-loop doublet configurations, require a competent, laterally continuous caprock to prevent vertical leakage and to preserve pressure and heat within the target formation. Caprock integrity is therefore critical not only for fluid containment but also for ensuring thermal confinement and long-term system sustainability. As shown schematically in Figure 3, a typical HSA system comprises a permeable target formation bounded above and below by low-permeability sealing units, commonly shale or mudstone. Some Indonesian reservoir–seal pairs may exhibit low pressure-dependent permeability (low stress sensitivity), but this should be confirmed from laboratory or log-based data before injection design.

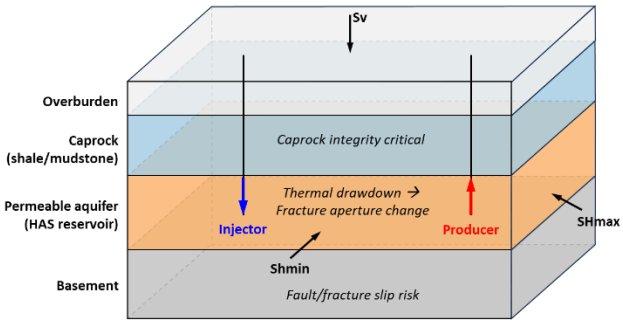


Figure 3. Conceptual schematic of an HSA system showing aquifer–caprock geometry, wells, and principal stresses (Sv, SHmax, Shmin). Adapted from geothermal and CCS analogs.

Long-term injection and extraction can impose thermal and mechanical perturbations that may induce tensile failure, shear slip, or progressive damage within the caprock. To evaluate such risks, key rock-mechanical parameters — including tensile strength, elastic modulus, fracture toughness, and failure envelope characteristics — should be determined through laboratory testing of representative core samples (e.g., Brazilian, triaxial, and fracture-toughness tests) or inferred from analogues where direct data are unavailable (White et al., 2014; Trujillo et al., 2021). These parameters provide the foundation for assessing the caprock's susceptibility to stress-induced fracturing or fault reactivation during HSA operation.

3.2 In-Situ Stress State and Fault Reactivation Risk

The in-situ stress regime controls wellbore stability, fault-slip potential, and the mechanical response of both the reservoir and the overburden. In tectonically varied basins, such as those in Central and South Sumatra, stress orientations can vary significantly across compartments, reflecting strike-slip and transpressional regimes (Heidbach et al., 2018). Misaligned injection wells relative to the minimum principal stress direction may induce hydraulic fracture or fault slippage depending on the local stress field, pre-existing structural weakness, and perturbations in pore pressure or temperature (Kruszewski et al., 2023; Kivi et al., 2022). Modeling studies have shown that thermal stresses can propagate beyond cooled regions and potentially reactivate faults located distant from the injection zone (Kivi et al., 2022).

The absence of observed fault slip or leakage does not eliminate risk, as monitoring has been limited. Documented subsidence and well-integrity issues in Indonesian fields justify routine stress and fault-stability modeling.

As shown in Figure 4, faults with a high slip tendency under prevailing stress conditions may reactivate in response to changes in pressure or temperature. Therefore, stress modeling and fault stability analysis (e.g., Mohr–Coulomb and slip-tendency plots) should be integrated into early feasibility studies, even in low-enthalpy settings.

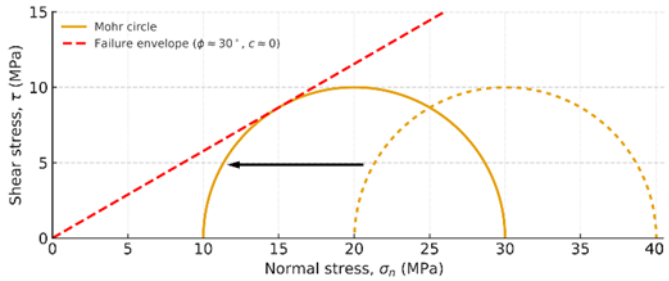


Figure 4. Example fault slip tendency diagram showing Mohr circle and failure envelope (ϕ ≈ 30°) for Indonesian strike-slip regimes. Adapted from Zoback (2007); Kruszewski et al. (2023); Kivi et al. (2022).

Recent work by Szklarz et al. (2024) emphasized the importance of integrating geomechanical constraints and geological uncertainty in field development planning, particularly in sedimentary reservoirs with stacked formations. Their modeling approach demonstrates how stress path evolution and fault stability can inform well placement, thereby reducing the risk of fault reactivation in geothermal systems.

3.3 Fracture Behavior and Permeability Evolution

While HSAs are typically matrix-dominated systems, natural fractures and fault damage zones can significantly enhance or short-circuit flow. Under pressure cycling, fractures may open, close, or propagate depending on the stress path and stiffness of the surrounding rock. When injectivity is insufficient, hydraulic stimulation or acid fracturing may be considered. These require an understanding of fracture-aperture evolution, normal and shear stiffness, and fracture-conductivity decay under thermal stress.

The key rock and fracture mechanical parameters that control HSA injectivity and containment can be summarized as follows:

- Strength and deformation properties — uniaxial/triaxial strength, tensile strength, and elastic moduli govern wellbore stability, compaction, and casing design.
- Fracture behavior and aperture evolution — fracture toughness and normal/shear stiffness determine injectivity, leak-off, and thermal-stress response during pressure cycling.
- Stress state and failure envelope — principal stresses (SHmax, Shmin, Sv), friction angle (ϕ), and cohesion (c) define safe injection-pressure windows and fault-slip potential.
- Thermo-hydro-mechanical (THM) coupling — temperature-dependent stress, pore pressure, and deformation control long-term stress redistribution and cooling effects.
- Caprock integrity — tensile strength, fracture-propagation resistance, and permeability change determine containment capacity and leakage risk.

Open fractures may facilitate early breakthrough or thermal short-circuiting, particularly in systems with high flow contrast. Closed-loop designs reduce this risk but remain susceptible to thermal contraction and potential casing deformation due to rock–steel interaction. Where natural matrix permeability or fracture connectivity is insufficient to support binary-cycle flow requirements, selective stimulation — hydraulic, thermal, or chemical — may be considered to enhance reservoir deliverability. However, such interventions introduce additional geomechanical and operational risks that must be rigorously evaluated.

3.4 Long-Term Stability and Coupled THM Effects

Extended HSA operations involve years of heat extraction and fluid reinjection, which modify the reservoir's thermal and pore-pressure conditions. These changes may cause subsidence, compaction, or even fault activation. Thermal contraction, especially near injection wells, may reduce fracture aperture and reservoir permeability over time. Alternatively, injection-induced pressurization may cause dilation or the creation of new fractures. These interactions are best addressed using coupled THM (Thermal–Hydraulic–Mechanical) models, though such simulations remain rare in Indonesian geothermal studies.

Long-term geomechanical monitoring—through microseismicity, surface deformation, and pressure-temperature tracking—can improve predictive models and guide mitigation strategies.

4 COMPARATIVE PERSPECTIVE: HSA VS. OTHER SUBSURFACE ENERGY SYSTEMS

Although Hot Sedimentary Aquifers (HSAs) share several geomechanical challenges with other subsurface energy systems, their risk profile is moderate and well constrained. Compared with oil and gas operations, HSAs experience smaller pressure and stress changes but stronger thermal–mechanical coupling. Relative to CCS/CCUS projects, they operate under lower injection pressures and shorter timescales, thereby reducing long-term concerns about seal integrity. Unlike volcanic/magmatic geothermal or Enhanced Geothermal Systems (EGS), HSAs occur in shallower sedimentary reservoirs with more predictable stratigraphy and mechanical behavior. Their primary geomechanical focus lies on caprock integrity, stress orientation, and fracture evolution during thermal cycling. These insights suggest that Indonesia’s HSA prospects fall within a manageable operational window, where lessons from oil and gas and CCS projects can be directly applied to inform design and monitoring practices (see Table 3 for a comparative summary).

Table 3. Comparative overview of geomechanical risks and focus areas across subsurface energy systems. Adapted from Kivi et al., 2022; Marelis et al., 2024; Nagel, 2001; Zoback, 2007; White et al., 2014; Trujillo et al., 2021; Febrianto et al., 2019; Kruszewski et al., 2023.

System	Key Geomechanical Risks	Primary Focus Areas / Required Studies
Hot Sedimentary Aquifer (HSA)	Fault slip, seal failure, thermal contraction, casing stress	Stress and seal mapping; injection-induced stress modeling; monitoring of pressure / temperature / deformation
Oil & Gas	Reservoir compaction, subsidence, and fault reactivation from depletion	3-D stress modeling, compaction prediction, and wellbore stability analysis
CCS / CCUS	Caprock failure, fracture propagation, induced seismicity	Coupled THM modeling, containment verification, and pressure-limit definition
Volcanic Geothermal	Thermal fracturing, casing deformation, and scaling-related stress	Fracture-network monitoring, thermal-stress analysis, high-T well design
Enhanced Geothermal System (EGS)	Induced seismicity, fracture over-propagation, thermal drawdown	Seismic hazard modeling, stimulation-pressure optimization, and microseismic monitoring

5 CONCEPTUAL FRAMEWORK AND ROADMAP FOR INDONESIA

The development of Hot Sedimentary Aquifers (HSAs) in Indonesia remains in its infancy. Despite promising resource assessments in basins such as Central Sumatra and South Sumatra, no field has advanced beyond preliminary mapping. A clear technical framework is necessary to guide exploration, mitigate risk in reservoir development, and align investment decisions with project viability, whether for direct-use heating or low-

enthalpy power generation. This chapter outlines a conceptual roadmap tailored to Indonesia's sedimentary context, integrating geomechanical, geological, and operational considerations. A visual summary of the proposed framework is shown in Figure 5.

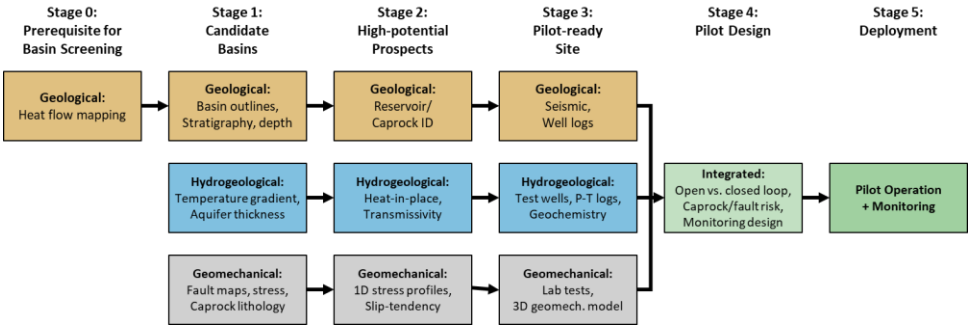


Figure 5. Workflow for HSA development in Indonesia, integrating geological, hydrogeological, and geomechanical screening, with terrestrial heat-flow mapping emphasized as the foundational step prior to basin screening and pilot design. Adapted conceptually from Moeck (2014) and Putriyana et al. (2022).

5.1 Foundation: Basin Screening and Resource Mapping

The first step involves screening sedimentary basins using regional datasets such as well logs, temperature gradients, formation thickness, and known aquifer intervals. Resource estimates should go beyond volumetric heat-in-place calculations to incorporate reservoir quality, caprock presence, and structural configuration. Candidate formations must exhibit adequate porosity-permeability at depths between 1.5 and 4 km and be overlain by competent sealing units.

Geomechanical screening should be introduced at this early stage to flag:

- Areas with known active faulting or overpressured zones,
- Caprock lithologies susceptible to thermal or hydraulic failure,
- Unfavorable stress regimes for injection or stimulation.

5.2 Integration of Geomechanical Models

Once a target formation is identified, a 1D-to-3D geomechanical model should be constructed using available well logs, seismic interpretations, and regional stress-orientation data. This model supports:

- Wellbore stability analysis for new or repurposed wells,
- Caprock integrity simulations under varying injection/production pressures,
- Fault slip tendency mapping using available structural data.

While many of these methods are mature in the oil & gas industry, their application in geothermal — especially HSAs — is still emerging in Indonesia.

5.3 Pilot Design: Open vs. Closed Loop Feasibility

A key decision in HSA projects—in Indonesia and comparable sedimentary settings worldwide— is whether to pursue open-loop or closed-loop circulation systems. Open-loop systems extract and reinject formation fluids, necessitating the management of permeability and injectivity. Closed-loop systems (e.g., coaxial wells, U-tube, or multilateral designs) isolate the working fluid from the formation, thereby avoiding contamination and reinjection issues, but introduce design complexity. Stimulation is not assumed as a default; it is a contingency only if step-testing confirms insufficient injectivity.

A decision matrix should consider:

- Reservoir permeability and heterogeneity,
- Thermal drawdown behavior,
- Caprock competency and induced seismicity (IS) risks,

- Availability of existing wellbores and surface infrastructure.

These criteria are compared in Table 4, which outlines key technical and operational considerations for evaluating open- and closed-loop HSA designs in Indonesian and comparable sedimentary basins worldwide.

Table 4. Comparison of open- and closed-loop Hot Sedimentary Aquifer (HSA) systems in Indonesian and comparable sedimentary basins worldwide.

Aspect	Open-Loop System	Closed-Loop System	Relevance to Indonesian Context
Fluid & heat transfer	Extracts and reinjects formation water; direct thermal exchange	Circulates working fluid in a sealed loop; conductive heat transfer	Open-loop, where water chemistry is manageable; closed-loop for saline or scaling aquifers
Permeability dependence	Requires sufficient natural permeability	Independent of formation permeability	Open-loop limited by low-k layers
Reservoir & environmental impact	Alters pressure and chemistry; potential fracture reactivation	Minimal reservoir disturbance	Closed-loop preferred in faulted or low-seal areas
Monitoring & operation	P–T–chemistry and microseismic surveillance; higher O&M (scaling, corrosion)	Thermal/mechanical performance monitoring; lower O&M but higher CAPEX	Both require geomechanical and thermal tracking; the trade-off depends on existing wells
Application examples	Aquifer-based doublets (Netherlands, Germany)	Coaxial / U-tube loops (Alberta, China)	Both are relevant for Central & South Sumatra pilots

5.4 Repurposing Existing Oil & Gas Wells

Indonesia possesses a significant inventory of suspended and abandoned wells — particularly in Sumatra and Java — that may intersect potential HSA reservoirs. These wells offer an opportunity to reduce drilling costs and environmental impact if both thermal suitability and mechanical integrity can be ensured.

Initial site selection should prioritize areas with elevated terrestrial heat flow or existing wells with high bottom-hole temperatures (BHT), as these provide the most promising starting points for repurposing.

Key screening criteria for well repurposing include:

- Proximity to mapped geothermal gradients or aquifers,
- Known cement bond logs and casing integrity,
- Orientation relative to in-situ stress (for injectivity/stability),
- History of corrosive or reactive fluids.

In most repurposed oil wells, scaling and corrosion are minor issues; however, residual hydrocarbons may cause fouling in binary-plant heat exchangers and should be removed or isolated before circulation testing. Pilot testing may involve pressure injection, temperature profiling, and tracer tests to evaluate reservoir connectivity and response. An example checklist for repurposing is shown in Figure 6.

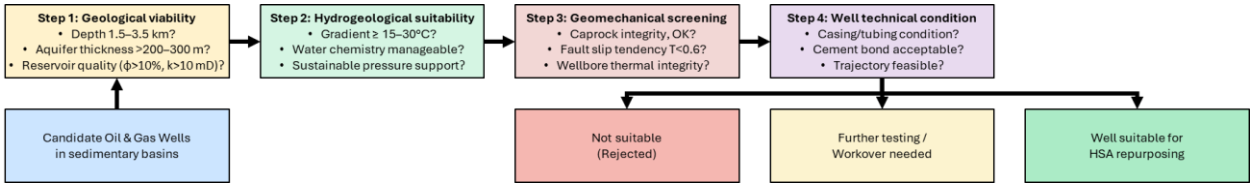


Figure 6. Screening workflow for repurposing oil and gas wells into Hot Sedimentary Aquifer (HSA) systems.

5.5 Recommendations and Strategic Priorities

A staged implementation roadmap is summarized through three practical priorities below. While broader geothermal development priorities typically begin with demand assessment, surface-facility planning, and fluid characterization, this paper explicitly emphasizes geomechanical readiness as the technical foundation for safe and sustainable Hot Sedimentary Aquifer (HSA) development in Indonesia. The following priorities are proposed to accelerate safe and viable HSA deployment in Indonesia:

- Integrate geomechanical workflows early. Incorporate stress, fault-stability, and caprock analyses from basin screening through pilot design (Figure 7).
- Leverage existing oil and gas assets. Use legacy wells and datasets to reduce costs and shorten development time; promote joint pilot programs under MEMR coordination.
- Develop pilot demonstration wells. Compare open- and closed-loop concepts in Central or South Sumatra, using complete THM monitoring to validate models and guide scaling, with techno-economic screening (heat first, power where viable) handled in parallel.

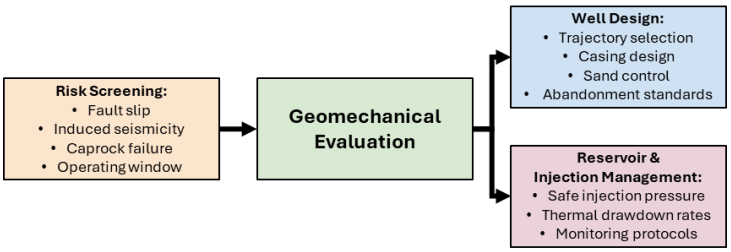


Figure 7. Geomechanical evaluation in HSA projects: supporting risk screening, well design, and injection management.

Table 5 summarizes the primary technical, regulatory, and financial considerations for such pilot initiatives, highlighting the actions required to ensure early-stage success.

Table 5. Strategic checklist for Indonesian HSA pilot projects covering technical, regulatory, and financial dimensions.

Dimension	Key Focus / Checklist Items	Intended Outcome
Technical & Geomechanical	Select representative basin (Central/South Sumatra); verify gradient, aquifer thickness, seal integrity; integrate THM/stress modeling; instrument wells for P–T–IS monitoring.	Ensures safe pressure & containment limits.
Regulatory & Institutional	Coordinate with MEMR/EBTKE/KLHK; clarify non-volcanic permitting; establish baseline & data-sharing.	Enables timely approval & capacity building.
Financial & Investment	Estimate CAPEX/OPEX; identify incentives; evaluate PPP / cost-sharing models.	Demonstrates economic viability & attracts early investors.

HSA projects—particularly those using closed-loop or hybrid systems—offer co-benefits for industrial decarbonization, low-carbon heating, and regional energy access. These systems can deliver direct-use heat to agro-industrial clusters or aquaculture, support just transition strategies in post-oil provinces, and reduce reliance on diesel- or coal-based heating in remote areas. Integrating HSA into national energy planning documents (RUEN, RUPTL) and green financing mechanisms (e.g., climate bonds, carbon pricing) will be essential to attract sustained investment.

6 CONCLUSION

Indonesia has the subsurface assets, technical talent, and policy momentum to become a leader in Hot Sedimentary Aquifer development in Southeast Asia. However, realizing this vision requires a shift in exploration mindset — from purely geological appraisal to an integrated framework that includes rock mechanics, geomechanics, and cross-sector synergy. The time to build that foundation is now.

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