India Advances Geothermal Energy with New Policy and First Wells at Ladakh's Puga Valley for Clean Energy Transition

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Recent Developments:

- **India has moved from geothermal resource assessment towards field-level implementation**, following the notification of the **National Policy on Geothermal Energy** in September 2025 and the commissioning of the country's first 2 geothermal wells at **Puga Valley, Ladakh**, in July 2026.
- The 2 wells, commissioned by the **ONGC Energy Centre**, are located at an altitude of more than **14,000 feet** and are approximately **1,000 metres deep**, supporting geothermal reservoir assessment and laying the foundation for India's proposed **1 MW demonstration geothermal power project**.
- The **Ministry of New and Renewable Energy** is the nodal ministry for implementing the National Policy on Geothermal Energy, which seeks to create a systematic framework for exploration, technology development, resource utilisation and private-sector participation.
- India possesses an estimated **theoretical geothermal resource potential of approximately 10,600 MW**, while the Geological Survey of India has documented **381 hot springs** and identified **42 geothermal manifestations** as promising for electricity generation and direct-heat applications.

Understanding Geothermal Energy:

Meaning and Characteristics:

- **Geothermal energy** is renewable energy obtained from the **natural heat present inside the Earth**, which can be used for electricity generation as well as direct heating and cooling.
- It is a **steady, low-carbon and weather-independent energy source**, making it different from variable renewable sources such as solar and wind.
- Geothermal resources can therefore provide **round-the-clock energy**, improve renewable-energy reliability and reduce dependence on fossil fuels.
- The resource is particularly significant in regions where geological structures allow underground heat to accumulate near the surface in the form of **hot water, steam or heated rocks**.

Origin of Earth's Internal Heat:

- Earth's internal heat originates mainly from **radioactive decay of elements such as uranium, thorium and potassium**, along with residual heat retained from the planet's formation.
- This internal heat drives **mantle convection**, which contributes to major geological processes including tectonic activity, volcanism, earthquakes and mountain building.
- In tectonically active regions, **faults and fractures** can provide pathways through which underground heat and fluids move towards the surface, creating exploitable geothermal reservoirs.

How Geothermal Energy is Harnessed:

Electricity Generation:

- Geothermal power plants use **deep wells to access hot water and steam**, which can be used to drive turbines connected to electricity generators.
- After heat extraction, the cooled geothermal fluid can be **reinjected into underground reservoirs**, helping maintain reservoir pressure and supporting long-term resource utilisation.
- Depending on resource temperature and geological conditions, geothermal systems can employ different technologies, including **dry-steam, flash-steam and binary-cycle systems**.

Direct-Heat Applications:

- Geothermal heat can be directly used for **district heating, agriculture, aquaculture, space heating and cooling**, thereby reducing the need to convert thermal energy into electricity.
- **Ground Source Heat Pumps** can use relatively shallow geothermal heat for efficient heating and cooling of buildings.
- Such applications can be particularly useful in cold regions and for agricultural activities requiring controlled temperatures.

India's Geothermal Energy Potential:

Resource Base:

- India has considerable geothermal potential because of its **diverse geological and tectonic characteristics**, although commercial exploitation remains at an early stage.
- The **Geological Survey of India** has mapped and studied **381 geothermal or thermally anomalous areas**, forming an important scientific basis for future exploration.
- The estimated theoretical potential of approximately **10,600 MW** indicates a substantial resource base, although theoretical potential should not be equated with immediately commercially exploitable capacity.
- Among the identified resources, **42 geothermal manifestations** have been considered promising for further development of power generation and direct-heat applications.

Major Geothermal Regions:

- Important geothermal provinces include the **Himalayan Geothermal Province, Naga-Lusai Province, Andaman and Nicobar Islands, Son-Narmada-Tapi Province, West Coast, Cambay Graben, Aravalli, Mahanadi, Godavari and South Indian Cratonic regions**.
- These regions differ in geological structure, reservoir temperature, accessibility and resource quality, requiring **location-specific exploration and technology selection**.

Puga Valley, Ladakh:

- **Puga Valley** is among India's most promising geothermal locations because of its abundant hot springs and favourable underground thermal conditions.
- The commissioning of the first 2 geothermal wells represents a shift from **resource identification to experimental utilisation** and provides an opportunity to evaluate reservoir characteristics under Indian high-altitude conditions.
- The proposed **1 MW demonstration project** can provide valuable information regarding drilling, reservoir management, operating costs and the technical feasibility of geothermal power generation in India.

National Policy Framework for Geothermal Energy:

National Policy on Geothermal Energy, 2025:

- The Government notified the **National Policy on Geothermal Energy on 15 September 2025** to establish a framework for the exploration, development and utilisation of geothermal resources.
- The policy promotes **systematic exploration, drilling, technology development, reservoir management, direct-use applications, pilot projects, Ground Source Heat Pumps, Centres of Excellence and a national geothermal data repository**.
- It also seeks to create conditions for **public and private-sector participation**, thereby enabling geothermal development beyond government-funded exploration.
- The policy explicitly recognises the possibility of **repurposing abandoned oil and gas wells** for geothermal energy recovery, subject to technical and economic feasibility.

Research and Technology Development:

- The **Renewable Energy Research and Technology Development Programme** of the Ministry of New and Renewable Energy supports research institutions and industry in developing **indigenous and cost-effective renewable-energy technologies**, including geothermal applications.
- Advanced technologies such as **Enhanced Geothermal Systems** and other engineered geothermal approaches can potentially expand geothermal utilisation beyond naturally occurring high-temperature reservoirs.
- Repurposing existing oil and gas wells can reduce some exploration and drilling requirements by utilising **existing well data, drilling expertise and infrastructure**, although reservoir conditions must first be technically assessed.

Importance of Geothermal Energy for India:

Energy Security and Clean Energy Transition:

- Geothermal energy can diversify India's renewable-energy portfolio by adding a **firm and continuously available renewable source** alongside variable solar and wind power.
- Its domestic availability can strengthen **energy security**, reduce dependence on imported fossil fuels and support India's transition towards a low-carbon economy.
- Geothermal power can also complement variable renewable energy by providing **stable electricity generation**, potentially reducing pressure on energy-storage systems.

Regional and Socio-Economic Benefits:

- Geothermal resources can support **heating, agriculture, aquaculture and tourism**, creating opportunities beyond electricity generation.
- Remote and geographically isolated regions can potentially benefit from locally available geothermal resources, particularly where conventional fuel supply is costly or difficult.
- Development of geothermal projects can promote **local employment, specialised skills, scientific research and clean-energy infrastructure**.

Challenges in Geothermal Development:

High Exploration and Drilling Risk:

- Geothermal development requires substantial **upfront exploration and drilling expenditure**, while the quality and quantity of underground resources may remain uncertain until wells are drilled.
- Unsuccessful drilling can therefore create significant financial risk during the early stages of a project.

Technological and Geological Constraints:

- India requires greater domestic capability in **deep drilling, reservoir characterisation, geothermal modelling, corrosion control and reinjection technologies**.

- Different geological conditions across geothermal provinces make standardised deployment difficult and require location-specific technological solutions.

Environmental and Social Considerations:

- Geothermal projects can involve **land-use requirements, induced seismicity, mineral-rich fluid management and possible contamination risks** if geothermal fluids are not properly handled.
- Sustainable development therefore requires appropriate environmental assessment, reservoir monitoring and responsible reinjection practices.

Economic Competitiveness:

- Geothermal projects may face higher initial costs than mature solar and wind technologies because India has limited commercial-scale geothermal deployment experience.
- Achieving cost competitiveness will require **demonstration projects, technology learning, domestic manufacturing, concessional finance and risk-sharing mechanisms**.

Way Forward:

Building a Geothermal Ecosystem:

- India should strengthen **resource mapping, exploratory drilling and geothermal data sharing** to reduce uncertainty and improve investor confidence.
- Demonstration projects such as Puga Valley should be used to generate domestic knowledge on **reservoir behaviour, drilling economics, plant performance and environmental management**.
- Public funding can initially absorb part of the exploration risk, while successful projects can progressively attract **private investment and technology partnerships**.
- International cooperation with countries having advanced geothermal capabilities, including **Australia, Iceland, Saudi Arabia and the United States**, can accelerate technology transfer, knowledge sharing and joint research.
- India should integrate geothermal development with its broader **Net Zero 2070 strategy**, particularly in regions where geothermal resources can provide firm renewable power or direct thermal applications.

Value Addition for UPSC:

Key Analytical Takeaway:

- **Geothermal energy represents a firm renewable-energy source that can complement variable solar and wind power**, thereby strengthening the reliability and diversity of India’s clean-energy system.
- The Indian case illustrates the transition from **resource assessment ? policy support ? demonstration projects ? commercial-scale deployment**.
- **Puga Valley** is strategically important because it provides India with an opportunity to develop indigenous expertise in high-altitude geothermal exploration and reservoir management.
- The central policy challenge is to convert India’s **theoretical geothermal potential into commercially viable and environmentally sustainable capacity** through risk-sharing, technological development, accurate resource assessment and private-sector participation.