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GEOTHERMAL ENERGY: HARNESSING EARTH'S HEAT FOR SUSTAINABLE POWER

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INTRODUCTION

After successfully hosting the G20 Summit in 2023, India positioned itself as a top destination for energy transition investments. That year, India added 17 GW of new capacity, with 13.8 GW from non-fossil sources. Financial support was increased for green hydrogen and green ammonia initiatives, alongside preparations for domestic carbon markets. In 2024, India aims to surpass 1 billion metric tons in domestic coal production, reducing reliance on imports. New gas pricing reforms are set to boost domestic production. Renewables remain pivotal in India's climate strategy, with over 20 GW of new capacity expected, supported by falling global module costs and a backlog of tenders. Hybrid renewable tenders are gaining traction, and standalone storage tenders are rising to manage grid stability amid increasing renewable integration.

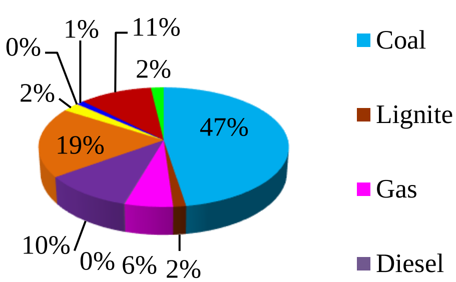

Figure 1. Generation capacity (444.76 GW) distribution of India (As on May 2024)

Geothermal energy, originating from the Greek words "geo" (meaning Earth) and "thermos" (meaning heat), is the thermal energy stored beneath the Earth's crust. It constitutes a renewable energy source arising from the natural decomposition of radioactive substances in the Earth's core and residual heat from the planet's formation.

The transmission of heat from the Earth's core to its surface involves conduction, convection, and radiation. Heat moves through conduction from the core to the mantle, where it drives convection currents. These currents gradually transport the heat towards the Earth's surface, where it can be utilized for generating energy.

GEOTHERMAL ENERGY IN INDIA

The Geological Survey of India has identified approximately 340 geothermal hot springs nationwide. Most of these springs have low surface temperatures ranging from 37°C to 90°C, making them suitable for direct heating. These springs are categorized into seven geothermal regions: the Himalayan region (including Puga and Chhumathang), Sahara Valley, Cambay basin, Son-Narmada-Tapi (SONATA) lineament belt, West Coast, Godavari basin, and Mahanadi basin. Notable geothermal sites include Puga Valley and Chhumathang in Jammu and Kashmir, Manikaran in Himachal Pradesh, Jalgaon in

Maharashtra, Tapovan in Uttarakhand, and Tattapani in Chhattisgarh.

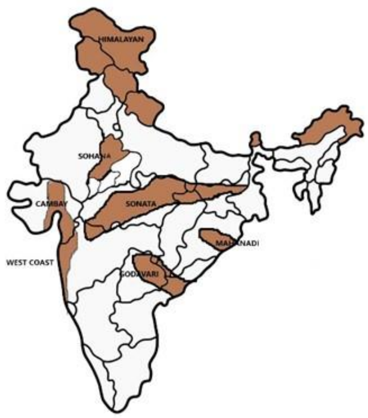

Figure 2. Geothermal sites of India

VARIATION IN GEOTHERMAL ENERGY

Geothermal energy varies in their technological requirements based on depth, temperature, and intended energy output. The main categories include:

1. **Very Low Temperature:** Located between 10–200 m underground, with temperatures below 30°C, suitable for heating individual homes or small commercial buildings.
2. **Low Temperature:** Found at depths of 200–2,500 m, with temperatures ranging from 30–90°C can be used for heating entire neighbourhoods or industrial zones.
3. **Medium Temperature:** Operates with temperatures of 90–150°C, found at depths up to 4,000 m which is ideal for electricity generation in geothermal power plants.
4. **Very High Temperature:** Utilizes temperatures above 150°C, typically found in plate boundaries and regions of high tectonic activity is used extensively in geothermal power plants.
5. **Supercritical/Ultra-Deep Geothermal:** Depths up to 10,000 m, accessing temperatures of 300–350°C. This emerging technology offers potential for large- scale, heat-intensive processes and is being developed globally for future renewable energy supply.

Current geothermal power plants typically access depths up to 4,000 meters. However, ongoing advancements and new initiatives are focusing on ultra-deep geothermal technologies, aiming to establish a reliable base-load supply of renewable energy for the electricity grid.

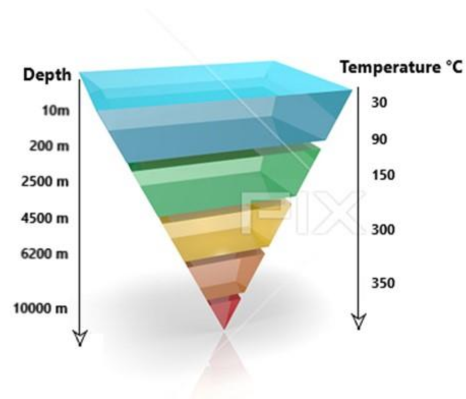

Figure 3. Temperature gradient of Earth

GEOTHERMAL POWER PLANTS

Geothermal power plants utilize heat from the Earth's interior to produce electricity, employing three primary types: flash steam, binary cycle, and dry steam.

a) Flash steam plants, the most prevalent type, harness high-pressure hot water from subsurface reservoirs. Extracted through wells, the hot water undergoes separation to isolate steam from liquid. The steam propels a turbine, converting heat into mechanical energy, which a generator subsequently transforms into electrical power.

b) Binary cycle plants focus on lower temperature geothermal sources. These facilities use a heat exchanger to transfer heat from the geothermal fluid to a secondary fluid, typically an organic Rankine cycle (ORC) fluid. The ORC fluid, with a lower boiling point, vaporizes and drives a turbine for electricity generation, enabling efficient use of lower temperature geothermal resources.

c) Dry steam plants are situated near natural steam reservoirs underground. Steam directly powers turbines, generating electricity before being condensed back into water for reinjection into the reservoir. This type relies on abundant high-temperature steam for its operational effectiveness and is one of the earliest forms of geothermal power generation.

Table 1. Geothermal distribution in Global scale

Country	Generation (TWh)	Capacity (GW)
United States	16.24	2.60
Indonesia	15.90	2.28
Philippines	10.89	1.93
Turkey	10.77	1.68
New Zealand	7.82	1.27
Iceland	5.68	0.76
Italy	5.53	0.77
Kenya	5.12	0.86
Mexico	4.28	1.03
Japan	3.02	0.48
China	0.13	0.03

BENEFITS

Geothermal energy is a sustainable and clean energy source that emits minimal greenhouse gases, making it environmentally friendly. Unlike fossil fuels, geothermal energy does not release substantial amounts of carbon dioxide, sulphur dioxide, or nitrogen oxides into the atmosphere. Geothermal power plants offer reliable baseload capacity, ensuring a stable electricity supply around the clock. This reliability contrasts with other renewable energy sources like wind and solar, which depend on variable weather conditions.

Beyond its environmental and reliability benefits, geothermal energy contributes positively to the economy. The establishment and operation of geothermal power plants create jobs and foster local economic growth. Additionally, by reducing reliance on imported fuels, geothermal energy enhances energy independence for countries with significant geothermal resources.

Geothermal energy extends far beyond electricity generation, finding diverse applications such as geothermal heating and cooling systems. These systems leverage the Earth's consistent temperature to efficiently regulate indoor climates. During winter, geothermal heat pumps extract warmth from the ground for heating, while in summer, they transfer heat back into the ground for cooling. This approach significantly cuts down on energy consumption and associated costs compared to conventional methods of heating and cooling.

INDIA'S POTENTIAL TOWARDS GEOTHERMAL

India is actively progressing towards achieving energy independence by 2047, with renewable sources such as solar, wind, biomass, and hydro increasingly dominating its energy mix. Geothermal Energy (GTE) presents a versatile addition to this mix, known for its cleanliness, safety, and sustainability. It involves extracting hot water from the earth, which is then returned to the geothermal reservoir after utilizing its heat. Unlike solar and wind, GTE is available consistently, unaffected by sunlight, local weather conditions, or seasonal changes. This reliability makes it ideal for baseload power generation, as well as heating and cooling applications in the low to medium temperature range.

Geothermal energy harnesses heat stored in the Earth's crust, often found in hydrothermal systems like geysers and hot springs. Drilling in these areas yields hot fluids under high temperature and pressure, containing steam which is utilized for energy extraction. Successful GTE projects require wells for both fluid extraction and reinjection to ensure sustainable resource use. Implementing a comprehensive GTE project also involves practices like water conservation, watershed management, and forest cover preservation.

In India, geothermal resources primarily consist of medium enthalpy types, necessitating pilot projects to confirm technical viability. Modular geothermal plants can be incrementally installed, catering to remote populations' energy needs. Globally, the installed geothermal power capacity is expected to grow significantly by 2025, potentially reaching 23.74 GW by the end of the decade, driven by advancements in technology and project feasibility.

Table 2. Geothermal Potential of India

S.No.	Province	Surface T °C	Reservoir T °C
1	Himalaya	> 90	260
2	Cambay	90-150	175-80
3	West coast	72-102	137-75
4	SONATA	95 -105	217-120
5	Godavari	60-175	215-93

The Geological Survey of India has identified approximately 350 high-potential geothermal sites, particularly in regions like the Himalayas, Western Coastal areas, SONATA basin, and Godavari basin. Besides electricity generation, direct heat applications such as Ground Source Heat Pumps (GSHP) could substantially reduce fossil fuel usage for heating in residential and small to medium industrial sectors. Overall, India's pursuit of geothermal energy underscores its commitment to diversifying its energy portfolio sustainably, leveraging technological advancements and regional geothermal potential to meet future energy demands.

CONCLUSION

India's strides in energy transition, exemplified by its ambitious renewable energy objectives and growing emphasis on geothermal resources, demonstrate its steadfast commitment to sustainable development. By diversifying its energy sources and expanding geothermal capacity, India not only strengthens energy security but also reduces carbon emissions and promotes economic growth through job creation and technological advancement. Following the G20 Summit in 2023, India showcased leadership in global energy transition by achieving milestones such as adding 17 GW of renewable capacity and prioritizing non-fossil fuel sources. Concurrent efforts to boost coal production and reform gas pricing align with ambitious renewable targets, further enhancing energy security and sustainability. Geothermal energy, identified across numerous high-potential sites in India, offers a sustainable pathway to diversify the energy mix, supporting economic growth and advancing climate objectives. Its reliability and minimal environmental impact position geothermal energy to play a pivotal role in India's future energy landscape, benefiting local communities and contributing significantly to global efforts to mitigate climate change.