Chapter 3

Direct-Use Geothermal for Manufacturing and Industrial Processes

Namrata Bist, Pandit Deendayal Energy University

Industry drives India's economy—and its pollution and emissions. India's geothermal resources include approximately 11,000 gigawatts of direct-use industrial technical potential, and its resources are particularly well suited for food processing and chemical, pharmaceutical, pulp, paper, and textile manufacturing. Unlocking its geothermal resources can enable India to increase competitiveness, reduce expenditures, improve air quality (and public health), and create jobs.

Heat makes up nearly half of all global energy consumption. In India, heat runs boilers and process equipment used for many industries, including chemical, cement, textile, and paper manufacturing and food processing. It is also used for low- to medium-temperature processes for agriculture, aquaculture, and community needs.[1] And much of this heat is still produced by burning coal and other fossil fuels.

Delivering useful heat is more difficult than moving electrons: Heat must arrive at the right temperature exactly where the process needs it. That's where direct-use geothermal heat stands out, as it supplies steady, on-site thermal energy without the need to convert to electricity and back or to have major grid build-outs. On an already constrained grid, the use of geothermal to provide heat improves reliability, lowers operating risks, and helps control energy costs.

India's economy is growing rapidly, with demand for energy surging across the industrial and residential sectors. The nation relies heavily on coal, which accounts for roughly 1,500 terawatt-hours of India's energy usage (doubled from 2012).[2]

From high-enthalpy heat in Himalayan provinces to low- and medium-temperature systems in Gujarat, Maharashtra, and the Northeast, India has vast untapped geothermal potential. Taken together, these regions contain 11,000 gigawatts of technical potential for geothermal industrial direct-use heat (with a 100°C cutoff temperature down to 3,500 metres). By using these resources, India can

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improve air quality, create skilled local jobs that leverage drilling and engineering capabilities, strengthen resilience with 24/7 local energy, and position itself as a global leader in geothermal services and standards—all while supporting national development objectives.

As outlined in this chapter and Chapter 4, "Geothermal Cooling Opportunities," direct-use heat, industrial steam, and cooling are among the biggest near-term opportunities for the nation to use its geothermal resources. This chapter focuses on heat use for industry and agriculture, while Chapter 4 focuses on geothermal applications for building cooling.

Process steam generation accounts for about 38% of India's total industrial energy consumption— comparable to the energy consumption of India's transportation sector.[3] In addition, key Indian industries such as food processing and chemicals and textile manufacturing run on steam generated by process boilers, producing 1.26 billion tonnes of steam each year. This process releases 182 million tonnes of carbon dioxide emissions, more than one-quarter of all industrial greenhouse gas emissions.[4] The decarbonisation of steam and high-temperature heat is critical to reducing India's industrial energy use and emissions.

Geothermal can deliver the same steam quality—pressure and temperature—that plants use today, slotting into existing networks while eliminating fuel purchases, reducing price volatility, and removing stack emissions. These advantages, coupled with the nation's significant subsurface potential, means India could achieve a goal of producing 10 gigawatts of geothermal process heat by 2035, 20 gigawatts by 2040, and 50 gigawatts by 2050, as suggested in Chapter 8, "Policy and Regulatory Pathways to Catalyse Geothermal in India."

How Direct-Use Geothermal Heat Systems Work

- Hot geothermal fluids from a subsurface reservoir pass through a boiler, a device that transfers heat from one fluid to another without the two fluids mixing. (The fluids are kept separate by solid walls—usually metal tubes, plates, or coils—that conduct heat efficiently.) The geothermal fluid is hotter and gives up its heat; the other fluid is water, which transforms into steam when it absorbs the heat.
- Steam is delivered via a network of pipelines to different facilities or customers.
- The high-grade heat produced can then be used as process steam for industrial purposes. The residual heat can be routed to drying, cold storage, or other processes to cascade the heat.
- After the heat dissipates from the geothermal fluids, the liquid is reinjected into the reservoir to close the loop and sustain the reservoir.

Benefits of Direct-Use Geothermal Heat to Industry and Community

- Cuts fuel costs and reduces reliance on coal or gas-powered boilers, minimising emissions.
- Improves air quality in locations with industrial clusters.
- Creates skilled local jobs in drilling, construction, and operations and maintenance while building Indian geothermal supply chains.
- Makes industry and residential heating more efficient when combined with thermal networks for residential areas.
- Unlocks cascading value by using the same geothermal resource at multiple temperature levels (for example, high-temperature steam for industrial processes, followed by lower-temperature heat for food drying, and finally absorption cooling for cold storage).
- Diversifies the energy mix with a reliable, domestic resource.

How Geothermal Compares with Other Clean Heat Options

When comparing geothermal to other clean heat options, it's important to consider project needs. Solar thermal is attractive in locations where land is available and process temperature is modest and needed during the day. Biomass can work in situations where sustainable feedstock is available but air quality and logistics constraints present potential barriers. Electric heat pumps excel at low- to mid-range temperatures when secure, affordable electricity and capacity are available.

Geothermal heat is most competitive when thermal energy is needed 24/7 year-round, land is constrained, necessary temperatures are between 150°C and 250°C, and fuel price or availability is risky. In these conditions, geothermal can provide the lowest life cycle cost, highest reliability, and largest air-quality gains.

ADVANCING DIRECT-USE HEAT IN INDIA

Thanks to India's geothermal resources,[5] direct-use systems are already at work today (**Figure 3.1**). But development remains limited because of policy gaps, high up-front costs, and a lack of technical capacity.[6] Advancing geothermal heat in the nation requires coordinated investment, resource mapping, and cross-sector collaboration.

Existing and Expandable Direct-Use Geothermal Heat Applications in India

Industrial Processes

Industrial steam offers an immediate opportunity for direct-use geothermal in India. It requires the lowest operational change while reducing fuel costs, particularly for sectors such as food processing and chemical, pharmaceutical, pulp and paper, and textile manufacturing in which most on-site fuel goes into boilers that make steam at defined pressures and temperatures. Geothermal heat can be transferred via

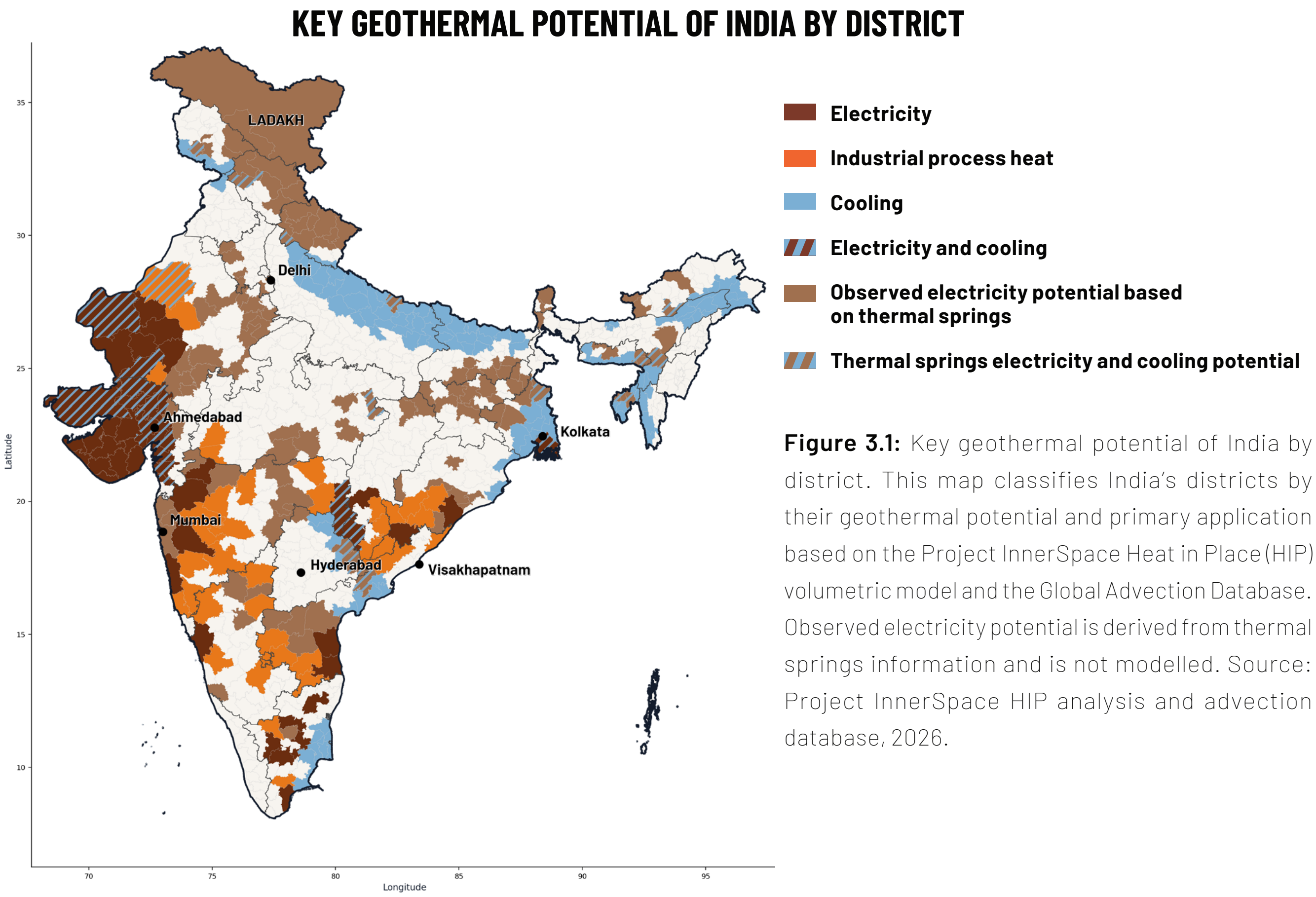

Figure 3.1: Key geothermal potential of India by district. This map classifies India's districts by their geothermal potential and primary application based on the Project InnerSpace Heat in Place (HIP) volumetric model and the Global Advection Database. Observed electricity potential is derived from thermal springs information and is not modelled. Source: Project InnerSpace HIP analysis and advection database, 2026.

GEOTHERMAL APPLICATIONS AND TEMPERATURE REQUIREMENTS

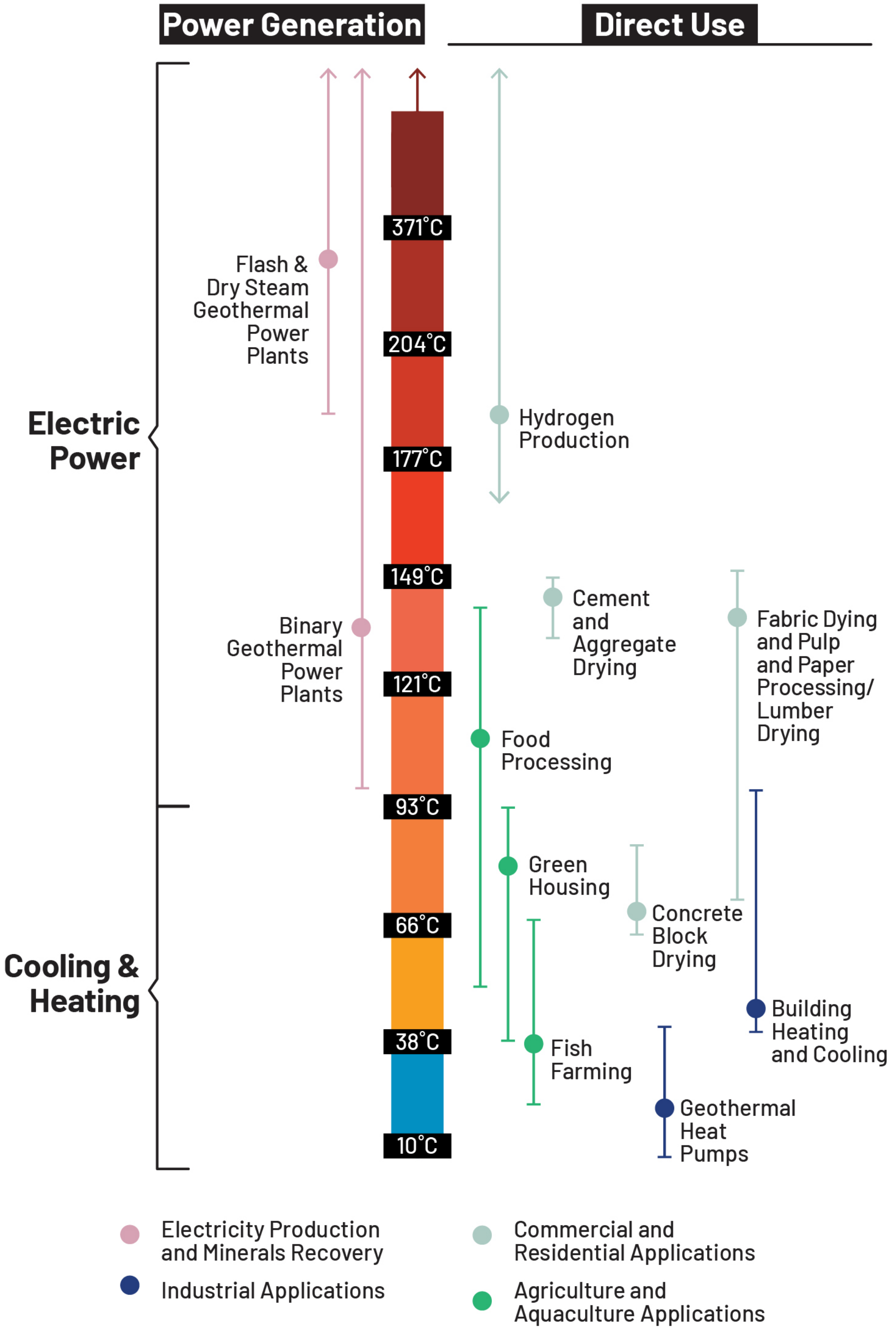

Figure 3.2: This Lindal diagram shows potential applications based on variation of temperature range. Source: Adapted from Porse, S. (2021). *Geothermal energy overview and opportunities for collaboration*. Energy Exchange.

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closed heat exchangers to generate matched-quality steam (in other words, steam at the same specs the plant uses today), slotting into existing steam networks with minimal retrofit needed. What's more, because geothermal delivers 24/7 heat without fuel purchases, it cuts operating costs, eliminates stack emissions, and stabilises production against fuel-price shocks.

For example, in Kenya, a cement manufacturer has partnered with a geothermal development company to use geothermal steam rather than fossil fuels for drying pozzolanic ash.[7] Implementing similar geothermal drying processes in India's construction industry could enhance energy efficiency and sustainability.

Geothermal will fit best in sites that require year-round demand; sites that use heat at temperatures between 150°C and 250°C; regions that experience fuel-price volatility; places that aren't meeting air-quality standards; and sites with the potential to cascade residual heat to drying, cold storage, and district cooling.

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UNLOCKING INDIA'S INDUSTRIAL DECARBONISATION

Project InnerSpace conducted a case study on Aarti Industries' plant in Jhagadia, Gujarat, to determine how a geothermal industrial heat project would work in the region.

By Dani Merino-Garcia, Project InnerSpace

In India, a significant amount of fossil fuels are used to create steam for chemical, steel, and cement manufacturing; food processing; pharmaceuticals; and paper factories. Replacing fossil-fuel-fired steam with low-carbon energy is critical for both emissions reduction and long-term energy security. Project InnerSpace has studied India's geothermal potential using GeoMap, the organisation's open-access prospecting tool, and has found that Gujarat is a prime candidate for direct-use geothermal networks.

In partnership with Aarti Industries, a leading Indian chemical manufacturing company (**Figure 3.4**), Project InnerSpace conducted a feasibility study for Aarti's industrial site in Jhagadia, Gujarat, to evaluate whether coal use could be replaced in a cost-effective way with direct-use steam generation. The region has rich geothermal resources and is currently heavily dependent on coal-fired power for industry. The analysis considered a cascade process in which the residual heat from Aarti would be sent to three additional nearby facilities to produce mid- and low-pressure steam at different temperature grades (see **Figure 3.5**).

Gujarat's industrial facilities sit in a geothermal zone with a temperature gradient of more than 50°C per kilometre—twice the global average, which indicates excellent geothermal potential. To provide the high-grade steam needed in these facilities (250°C), engineers need to drill to 4 kilometres depth. At that

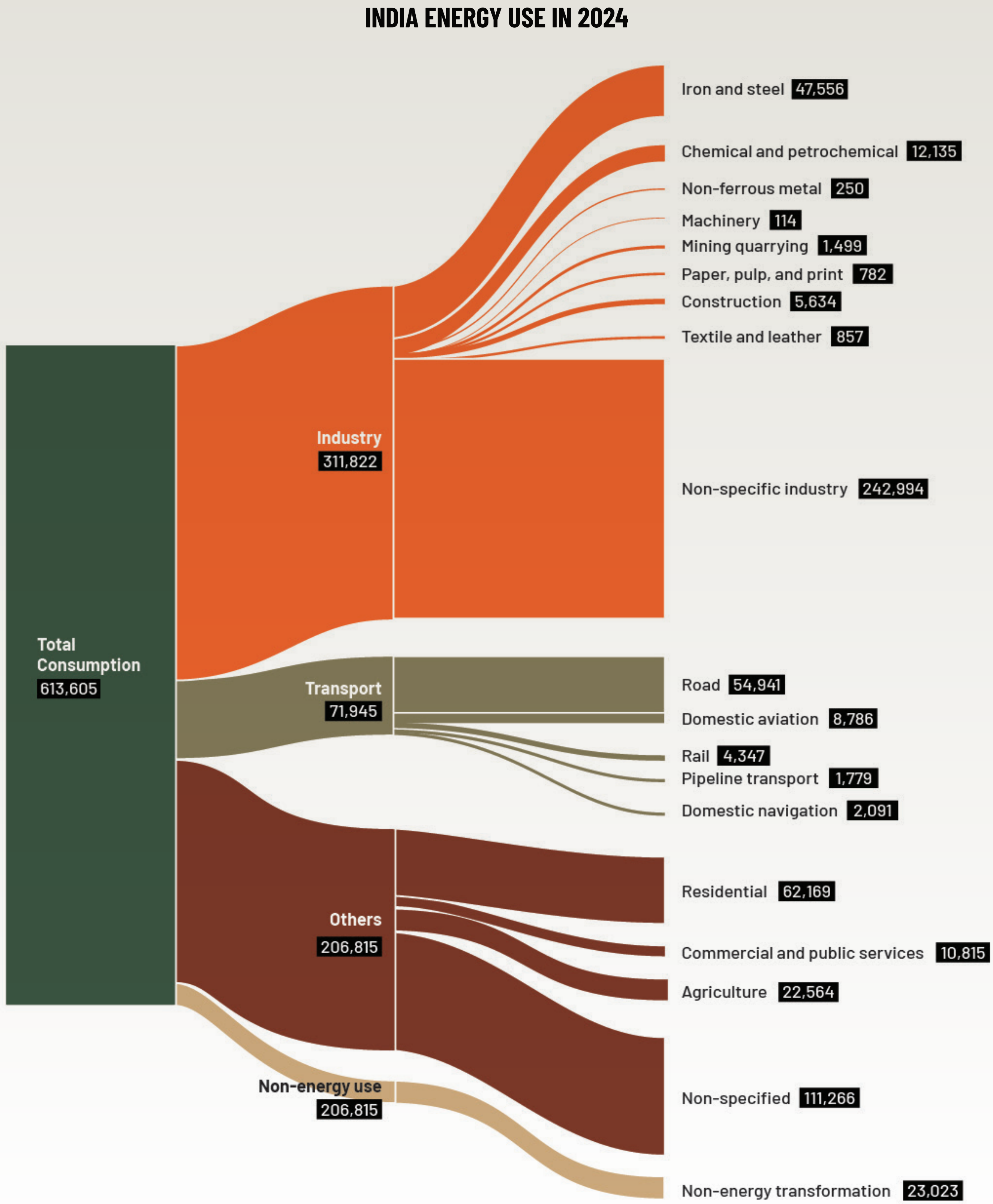

Figure 3.3: Sankey diagram of India energy use in 2024 (kilotonnes of oil equivalent). Source: Ministry of Statistics and Programme Implementation, National Statistics Office. (2025). *Energy statistics India 2025*. Government of India.

AARTI INDUSTRIES INDUSTRIAL FACILITY

Figure 3.4: Aarti Industries industrial facility in Jhagadia, Gujarat. Source: Aarti Industries.

DIRECT-USE GEOTHERMAL FOR INDUSTRIAL STEAM PROCESSES

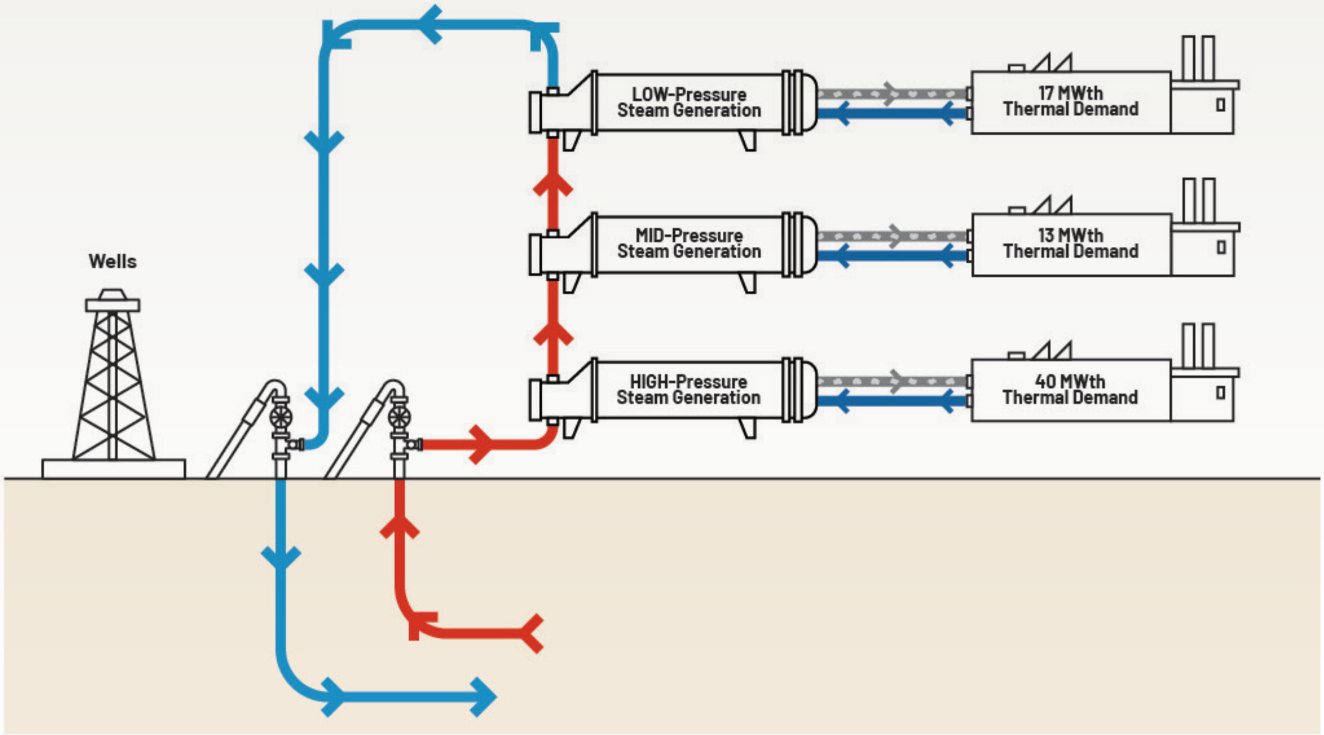

Figure 3.5: Direct use of geothermal energy to provide steam of different qualities to three facilities. MWth = megawatts-thermal. Source: Project InnerSpace.

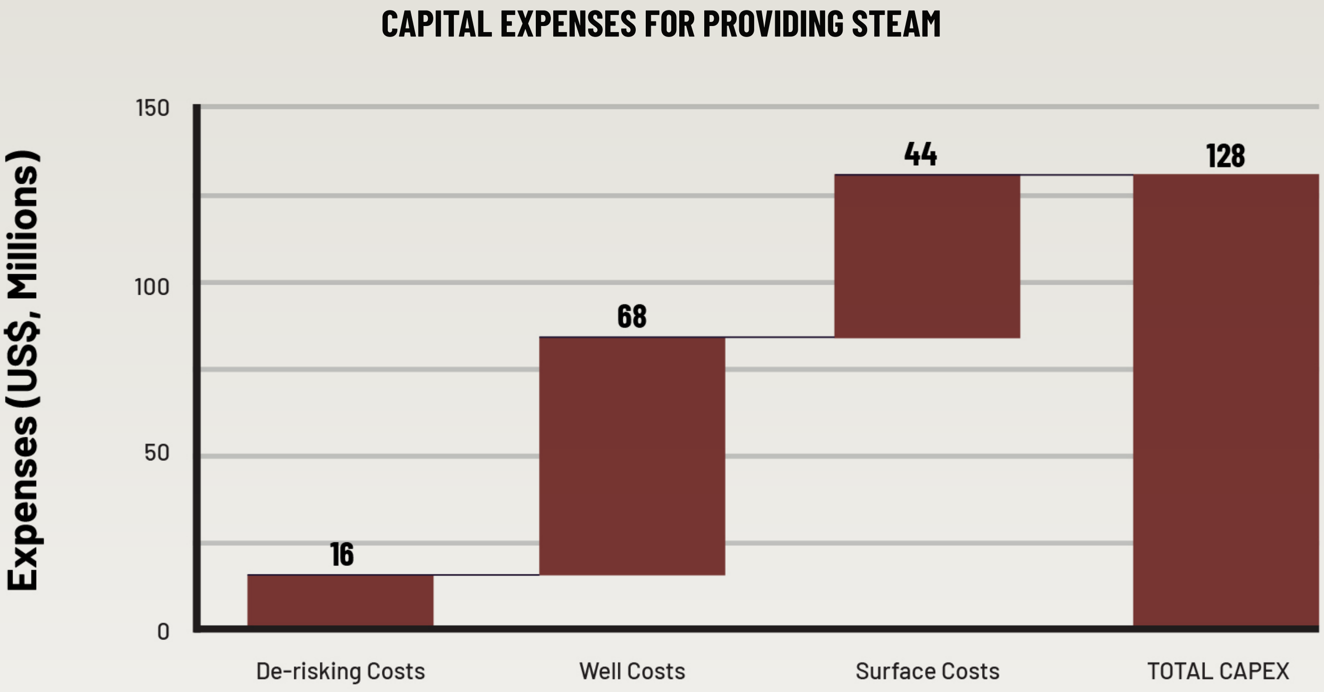

Figure 3.6: Capital expenses (CAPEX) split (US$, millions) in Gujarat case study to provide steam to four facilities. Source: Project InnerSpace.

point, the subsurface is expected to be made of fractured basement formations.

To meet all of the steam demand, the Gujarat facilities need about 200 kilograms per second of geothermal fluid at 250°C. A typical geothermal well is expected to deliver between 60 kilograms and 100 kilograms per second. Therefore, provided sufficient fracture connectivity, the study suggests drilling three production wells to sustain this output for more than 30 years.

To reduce corrosion risks and minimise operating costs in the industrial cluster, the companies prefer to work with steam and liquid water. Because geothermal fluids are prone to solid formation and tend to be corrosive, companies also want to eliminate exposure and locate boilers as close to the geothermal wells as possible so that the corrosive geothermal fluids stay out of the facilities.

Industrial processes tend to have well-optimised steam networks in which multiple processes share a steam supply. To keep costs low and make sure the system fits smoothly into existing facilities, the geothermal fluid is used to generate the same steam quality as the current boilers that use coal. This way, the facilities only receive the same clean, high-quality steam they are already accustomed to using.

In this scenario, steam production at four facilities has a potential break-even cost of between US$30 and US$35 per megawatt-thermal-hour, making it competitive with the cost of steam with coal (US$35–US$40 per megawatt-thermal-hour). These figures take into consideration the cost of a de-risking phase to unlock a project's full investment potential by properly characterising the resource via geophysics work and drilling exploration wells, the cost of drilling of three producers and three injector wells, and the cost of the fluid circulation pipeline network and the boilers for heat exchange. This cost comparison does not include any climate and air pollution benefits in switching from coal to carbon-free geothermal.

India's recently published National Policy on Geothermal Energy may further improve the economics of such a project. The policy highlights various financial support mechanisms to offset capital costs to geothermal development, including concessional loans, viability gap funding, tax incentives, and import duty exemptions. (For more on the National Policy on Geothermal Energy and recommendations for expanding a geothermal industry in India, see Chapter 8, "Policy and Regulatory Pathways to Catalyse Geothermal in India.")

The following steps are necessary for building an industrial direct-use system:

1. Carry out a feasibility study (as has been done for the cluster detailed above industrial buildings).
2. Conduct studies that can de-risk projects, including a geophysics campaign and the drilling of exploratory wells to characterise the resource.
3. Drill the production wells for the heat.
4. Install the equipment to transport fluid from the wells to the industrial buildings (the end users).
5. Develop an asset management system to optimise heat distribution among facilities in a cluster with variable loads and heat demands.

The Way Forward

The Gujarat industrial cluster is a microcosm of India's broader boiler-driven process heat economy—a system heavily reliant on coal, which is expensive, emission-intensive, and increasingly unsustainable. A geothermal direct-use network offers a low-carbon, reliable, and cost-effective substitute, delivering steam without fuel combustion.

Geothermal systems also offer long-term cost savings by replacing fossil fuels—with their operational expenditures and emissions—with a stable, renewable heat source. They also cut a "fuel purchase" line from a company's budget, as once a system is in place, there's no need to purchase more fuel (which is often subject to price volatility). In other words, a direct-use system improves a company's or industrial centre's global competitiveness—especially in energy-intensive sectors. Local geothermal projects also create skilled jobs in drilling, engineering, and system maintenance, contributing to regional economic development. (See Chapter 5, "Leveraging Oil, Gas and Mining Technologies and Workforce to Advance Geothermal in India.")

These are important projects to explore: Over a 30-year period, there is potential to reduce carbon dioxide by up to 7 million metric tonnes when compared to coal for this one project. A direct-use system can also reduce local air pollutants such as particulate matter and nitrogen oxides. These benefits are particularly relevant in industrial zones such as Gujarat, where air quality is affected by combustion-related emissions. At a national level, geothermal deployment would support India's climate goals by cutting industrial greenhouse gas emissions, a key step for achieving its net-zero target by 2070.

What's more, according to Project InnerSpace analysis, the footprint for such a geothermal system would be only 0.8 hectares, or 2 acres. Additionally, after steam is generated for an industrial plant, the residual energy above 90°C can be used for direct thermal applications in a residential district heating or cooling network. When integrated into thermal networks, geothermal systems enhance energy efficiency across entire clusters.

Together, these economic and environmental advantages make geothermal direct-use applications a compelling tool for industrial decarbonisation and sustainable growth.

With supportive policies—including licencing reform, fiscal incentives, and capacity building, as outlined in Chapter 7, "Who Owns the Heat? Navigating Subsurface Rights in Indian Law"—India could accelerate industrial decarbonisation, positioning geothermal heat as a strategic lever in its clean energy transition.

GEOTHERMAL WATER-BASED FOOD DRYER

Figure 3.7: Outlet of India's first-ever geothermal water-based food dryer developed by the Centre of Excellence for Geothermal Energy. Source: Bist, N., Yadav, K., & Sircar, A. (2023). Water for food drying: Geothermal energy-based food dryer. In S. Saxena, S. Shukla, & P. K. S. Mural (Eds.), *Emerging materials and technologies in water remediation and sensing: Proceedings of ICWT 2022*. Springer.

Agricultural Drying Processes

Geothermal energy is a highly promising and viable solution for food drying in India given its strong agricultural base, diverse crop production, and significant post-harvest losses. India is a leading producer of perishable crops such as mangoes, bananas, chilies, turmeric, paddy, and tea—many of which require efficient and hygienic drying processes to retain quality and reduce spoilage. Traditional sun-drying methods are often unreliable and weather-dependent, leading to microbial contamination and value loss.

Today, geothermal provides agricultural facilities with the capability to dry fruits and vegetables in various regions across India. Using geothermal energy for food drying can reduce food waste, lower energy costs, and provide a sustainable solution for rural communities. India's first geothermal-based food drying unit—at the Centre of Excellence for Geothermal Energy at Pandit Deendayal Energy University in Gandhinagar, Gujarat (see **Figure 3.7**)—harnesses geothermal heat from wells in Gujarat to power a hot air generator, which dries apples, turmeric, and other local produce.[8]

Low-enthalpy geothermal resources found in regions like Gujarat and Himachal Pradesh are ideal for direct-use applications, offering a resilient, efficient alternative to diesel or electric dryers. In the Dholera region of Gujarat, a geothermal energy–based food dryer has been developed to dry Tulsi leaves, an herb used in many Indian and Thai dishes. This drying method preserves the leaves' phytochemical properties.

Such applications can be extended to other crops, enhancing shelf life and reducing post-harvest losses. Globally, successful examples such as the geothermal fruit drying plant in Alasehir, Turkey, and the industrial-grade food dehydrator in Nayarit, Mexico, demonstrate how geothermal systems can reduce operational costs, improve product shelf life, and support sustainable agro-processing.[9,10] In India, integrating such systems in agricultural zones can enhance farmer incomes, reduce post-harvest losses, and promote energy access in rural areas.

HARNESSING EARTH'S HEAT FOR SUSTAINABLE AGRICULTURE: GEOTHERMAL COLD STORAGE IN HIMACHAL PRADESH

By Smita Satiani, Project InnerSpace

Around the world, many croplands are near untapped geothermal resources, which presents an opportunity to leverage the Earth's heat for sustainable agriculture. In Himachal Pradesh, a new project funded by Project InnerSpace aims to use that resource to enhance food security, boost rural incomes, and cut environmental footprints.

Nestled in the scenic Kinnaur district of Himachal Pradesh, Tapri is a high-altitude village known for its premium apple orchards and other produce. The region's cool climate and fertile slopes make it ideal for fruit cultivation. But the absence of reliable cold storage for these goods forces farmers to sell during peak harvest periods, when prices can be at their lowest.

Tapri, however, is also home to a naturally occurring hot spring. In other words, near these orchards is a valuable geothermal resource that has the potential to power sustainable infrastructure. This unique combination of

APPLE ORCHARDS IN KINNAUR, HIMACHAL PRADESH, INDIA

Figure 3.8: Apple orchards in Kinnaur, Himachal Pradesh, India, the location of the GeoFund pilot project. Source: Shutterstock.

GEOTHERMAL DRILLING IN HIMACHAL PRADESH

Figure 3.9: Geothermal drilling in Himachal Pradesh. Source: Geotropy.

agricultural abundance and geothermal energy makes Tapri the perfect location for a pioneering secure cold storage and crop-drying project.

Built by the company Geotropy, a geothermal project developer and consultancy, the Tapri Geothermal Cold Storage Project is designed to be a model for agricultural infrastructure in India's mountainous regions. When completed in 2026, the facility will feature a 500 tonne controlled atmosphere storage system to preserve apples and other produce for extended periods and a geothermal system for drying fruits and vegetables to minimise losses, with a capacity up to 2 tonnes per day. At the heart of the facility is a vapor refrigeration system powered by geothermal water from an existing borewell. Hot water pumped through the well from 100 metres below the surface—at approximately 96°C— will drive the absorption chiller (a heat-powered cooler that produces chilled water) to maintain optimal storage temperatures, while the residual heat will be recovered through a heat exchanger to operate the drying unit. This system maximises energy efficiency, reduces operational costs, and operates entirely on a secure and renewable heat source.

The Tapri Geothermal Cold Storage Project is also tailored to Tapri's steep terrain. The wellbore and pump housing will be located along National Highway 5; the storage building will sit on the river side of the road. The three-story structure will have equipment space; storage chambers; and areas for loading, unloading, and pre-grading activities such as inspection and cleaning. Farmers will be able to store produce for up to eight months, which lets them avoid distress sales during peak harvest periods and earn better prices.

Geothermal direct-use projects like this facility address one of India's most pressing agricultural challenges: post-harvest losses due to lack of proper storage. At the same time, they reduce reliance on diesel-powered cold chains (such as transportation and storage warehouses) that drive up costs and emissions. In horticulture-dependent regions such as Himachal Pradesh, the year-round stability of geothermal energy

FRUIT AND VEGETABLES DEHYDRATED USING GEOTHERMAL HEAT

Figure 3.10: Fruit and vegetables dehydrated using geothermal heat. Source: Geotropy.

ensures uninterrupted operation. In other words, it can relieve farmers from seasonal variability and improve the resilience of farming communities. India's cold chain and refrigerated logistics market—valued at roughly US$4 billion to US$5 billion in 2024—is projected to nearly triple to around US$12 billion by 2030.[11] This rapid expansion reflects both chronic underinvestment in storage infrastructure and rising demand for temperature-controlled supply chains. As the country scales its cold storage capacity over the next decade, the key question is not whether growth will occur, but how it will be powered.

Direct-use agriculture applications are considered the "low-hanging fruit" of geothermal development in India because they operate efficiently with moderate-temperature resources, require lower capital investment, and deliver immediate economic benefits.

Furthermore, as India seeks to scale its cold storage, geothermal offers an excellent opportunity to do so with minimal impact. Cold storage could be undertaken using methods such as those implemented in Tapri or through ground source heat pumps (described in more detail in Chapter 4, "Geothermal Cooling Opportunities").

The Tapri model is both scalable and replicable. Other geothermal-rich areas in India—such as parts of the Himalayas, Western Ghats, and Northeast—can adopt similar systems. Matching cropland to low- to moderate-temperature geothermal resources offers opportunities to deploy low-carbon cold storage solutions while also limiting post-harvest losses for nutrient-dense crops. Today, approximately 14% of food is lost between harvest and retail worldwide, contributing to between roughly 8% and 10% of global greenhouse gas emissions. Local geothermal cold storage projects such as the Tapri facility can help improve food security, stabilise rural incomes, and reduce environmental footprints.

The Tapri project is designed for community impact. It will prioritise training and hiring local workers to build community expertise, offer equitable access to storage for all village households, and extend services to nearby villages if capacity allows. Operations will follow transparent rental-based pricing, and revenues will be reinvested in the upkeep of the facilities. By uniting secure energy, efficient post-harvest handling, and local participation, Tapri's geothermal project offers a blueprint for sustainable rural transformation.

GEOTROPY TEAM MEMBERS

Figure 3.11: Vijay Chauhan with the Geotropy team. Source: Geotropy.

Vijay Chauhan: Bringing Geothermal Innovation Home

For Vijay Chauhan, the CEO of Geotropy, the journey with geothermal energy is as much personal as it is professional. A native son of an apple-growing community, he sees in the Earth's heat not only power but also a way to give back to the land that raised him. Chauhan earned his doctorate in mechanical engineering at Háskólinn í Reykjavík and worked in the geothermal fields in Iceland. At the Iceland Deep Drilling Project, he researched the frontier of superheated steam, devising new techniques for its use in power generation.

Today, Vijay straddles the worlds of innovation and education as an adjunct faculty member at Reykjavik University. Through his leadership at Geotropy, he comes full circle—channeling the lessons of Iceland into sustainable energy solutions for his own community in Himachal Pradesh.[12]

Greenhouse Cultivation

Geothermal greenhouse farming is a viable direct-use application in India, enabling year-round cultivation of fruits and vegetables in cold or arid regions such as Ladakh, Himachal Pradesh, and parts of Gujarat, where traditional farming is limited. By using geothermal heat for temperature control, crops such as tomatoes and leafy greens can thrive, improving food security and farmer income.

There are some global examples of this use: In Türkiye, the Sultan Sera facility in Aydın uses geothermal energy for soil-less tomato farming on once-unusable land, while Sandıklı exports geothermal-grown tomatoes to Europe, proving its commercial success.[13,14]

India's pioneering efforts in geothermal greenhouse cultivation, led by Kunzes Dolma (the author of Chapter 6 in this report, "India's Stakeholders: Opportunities and Implications for Geothermal Growth and Development"), have taken root in the high-altitude region of Chumathang, Ladakh, where a pilot greenhouse project has successfully demonstrated the use of geothermal heat for year-round vegetable farming.[15] Using training in Iceland, the

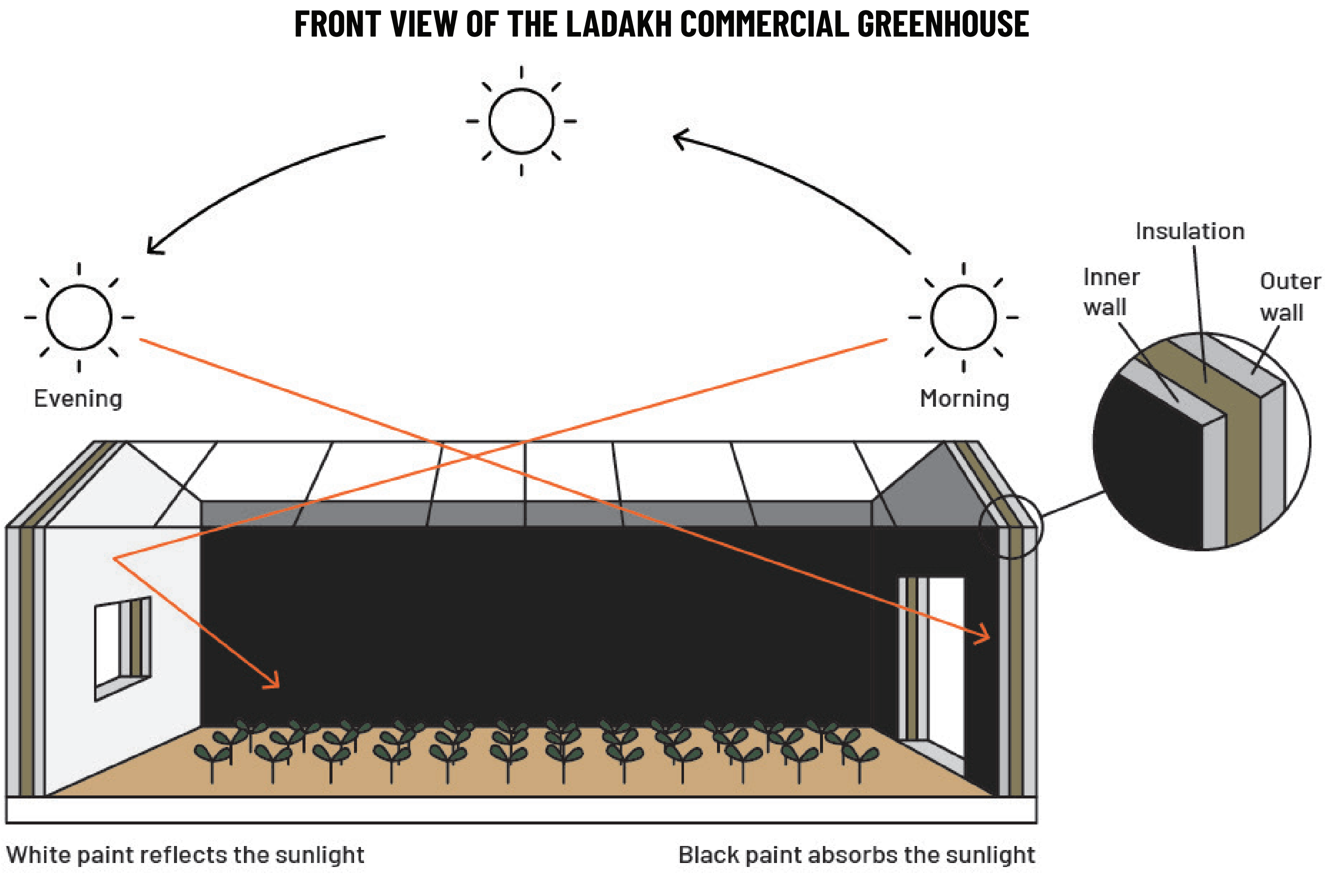

Figure 3.12: Schematic of a front view of the Ladakh commercial greenhouse. Source: Dolma, K. (2020). *Energy and food security using geothermal energy: A case study of Chumathang, Union Territory of Ladakh, India*. Master of science thesis, GRÓ Geothermal Training Programme. Re-created by Project InnerSpace.

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project brought a sustainable solution to the harsh winter conditions of Ladakh, where temperatures often plummet below -20°C. The greenhouse taps into naturally heated groundwater, maintaining optimal growing temperatures without the need for fossil fuels. (See **Figure 3.12**.) This innovative approach has significantly improved local food security, reduced dependence on imported vegetables, and empowered rural women through active participation in agricultural operations.

Aquaculture

Geothermal energy offers a sustainable solution for aquaculture, especially in maintaining optimal water temperatures. In the Philippines, for instance, geothermal resources are used to heat aquaculture ponds, enhancing the growth rates of species such as tilapia and shrimp. This use reduces fuel costs by up to 80% and minimises the need for antibiotics due to the presence of beneficial minerals in geothermal water. In India, the Directorate of Coldwater Fisheries Research has developed polyculture techniques for exotic carp species in mid-altitude regions, which could benefit from geothermal heating to maintain optimal growth temperatures. In India, regions with geothermal potential, such as parts of Gujarat and Andhra Pradesh, can leverage this energy source to boost aquaculture, particularly for species like carp, which thrive in warmer waters.

Honey Processing

The Centre of Excellence for Geothermal Energy has also pioneered the direct use of geothermal energy for honey processing. The centre developed an integrated system at Dholera, where geothermal water between the temperatures of 45°C and 75°C is used for honey pasteurisation and enzyme deactivation, reducing energy consumption.[16] The system includes plate-type heat exchangers and supports other applications such as milk pasteurisation, space heating, and food drying, making a significant step towards sustainable agro-processing in India.

Thermal Baths

India's geothermal hot springs are an important part of the nation's history and culture. They include prominent sites in Gujarat, such as Tuwa, Unai Dholera, Lasundra, and Tulsishyam, where thermal waters are rich in sulphur and other minerals. These springs have surface temperatures ranging from 60°C to 90°C and are known for their anti-inflammatory and antimicrobial properties that makes them effective for the treatment of arthritis, skin disorders (psoriasis and eczema), and muscular pain.[17]

In Manikaran and Tattapani (Himachal Pradesh), Surajkund (Jharkhand), and Puga Valley (Ladakh), people frequent thermal baths for religious and medicinal purposes. In Uttarakhand, the Badrinath hot springs near the Alaknanda River are famous for postpilgrimage rejuvenation. Ganeshpuri and Akaloli (Maharashtra) are major sulphur spring sites near Mumbai. Across India's more than 400 geothermal spring locations, the natural presence of sulphur compounds has made these sites essential for traditional healing, naturopathy, and wellness tourism. (See **Figure 3.13**.)

Traditional hot springs in Manikaran, Tattapani, and Bakreshwar show the potential for India to develop more hot springs for bathing purposes. Iceland's Blue Lagoon serves as a model for boosting tourism through luxury spa and medical facilities.[18]

Cloth Drying

Geothermal energy holds significant potential for India's textile industry, particularly in cloth drying, an energy-

GEOTHERMAL HOT SPRING NEAR MANIKARAN TEMPLE

Figure 3.13: Geothermal hot spring near the Manikaran temple in Himachal Pradesh, India. Source: Shutterstock.

intensive process. Although currently underutilised in India, geothermal heat is being used for drying in the Wayang Windu geothermal field in Indonesia. Hot geothermal fluids are piped to heat exchangers and create the hot air used in tea-drying units.[19] This approach replaces conventional fossil fuels, reducing both energy costs and emissions. In India, textile hubs such as Gujarat and West Bengal could benefit by leveraging nearby geothermal sources, such as those in Unai or Bakreshwar, for fabric drying. Implementing such systems would require feasibility studies, pilot projects, and supportive policy frameworks to promote resilient and efficient industrial practices.

Direct geothermal applications should be prioritised in regions with low- to moderate-temperature uses that align with the socioeconomic conditions of rural and semi-urban areas. Applications such as food drying, community bathing, and greenhouse farming should be high on the list because of resource availability and daily applicability. These uses appeal to large populations whose access to a resilient and stable source of energy is limited. Emphasis should also be placed on decentralised, low-cost solutions that improve quality of life and reduce fuel dependency. Development should balance economic aspects with social impact—in favour of inclusive and sustainable development.

DELAYED, ABANDONED, OR STALLED GEOTHERMAL PROJECTS AND ASSOCIATED CHALLENGES

Despite the many successful projects, a number of geothermal projects in India have been delayed, abandoned, or underdeveloped. Understanding why projects experienced setbacks can help inform future projects. Common challenges include environmental and permitting risks, insufficient subsurface data, design and equipment shortfalls, financing gaps, lack of an offtaker, and higher-than-expected costs (all of which are discussed in more detail in the following sections).

Dholera Geothermal Project, Gujarat

A small-scale geothermal plant was installed in the Dholera region in Gujarat, via the Centre of Excellence for Geothermal Energy, for heating and cooling. Future plans for the plant included electricity generation through Organic Rankine Cycle technology. Project installation was successful, yet it faced financial challenges. The project started at ₹1 crore, but operating expenses were between 20% and 25% higher than typical conventional methods.[20] Based on the author's assessment, indications for cost recovery in three years failed to overcome the initial investment barriers, which slowed widescale duplication.

Understanding why projects experienced setbacks can help inform future projects. Common challenges include environmental and permitting risks, insufficient subsurface data, design and equipment shortfalls, financing gaps, lack of an offtaker, and higher-than-expected costs

Tapovan Geothermal Prospect, Uttarakhand

In Tapovan, Uttarakhand, the Wadia Institute of Himalayan Geology identified hot springs with surface temperatures between 89°C and 93°C, suitable for low-enthalpy applications. A memorandum of understanding was signed with Jaydevm Energies Private Limited to develop a 5 megawatt geothermal power plant at the site.[21] However, scientists have raised concerns about the environmental sensitivity of the area, particularly due to the proximity of the subsidence-prone town of Joshimath. Potential issues include noise and vibrations from drilling activities, which could exacerbate land instability. As a result, while geothermal potential exists, the project faces environmental and logistical challenges that have delayed its implementation.[22]

Bakreswar Geothermal Area, West Bengal

Medium-enthalpy geothermal systems exist in the Bakreswar region of West Bengal, which has significant potential. An analysis of magnetotelluric studies exposed conductive areas below the surface that indicate the presence of geothermal reservoirs. But development in the area remains slow because there is not enough investment or quality local infrastructure and advanced geophysical methods are not used.

SCALING DIRECT-USE GEOTHERMAL

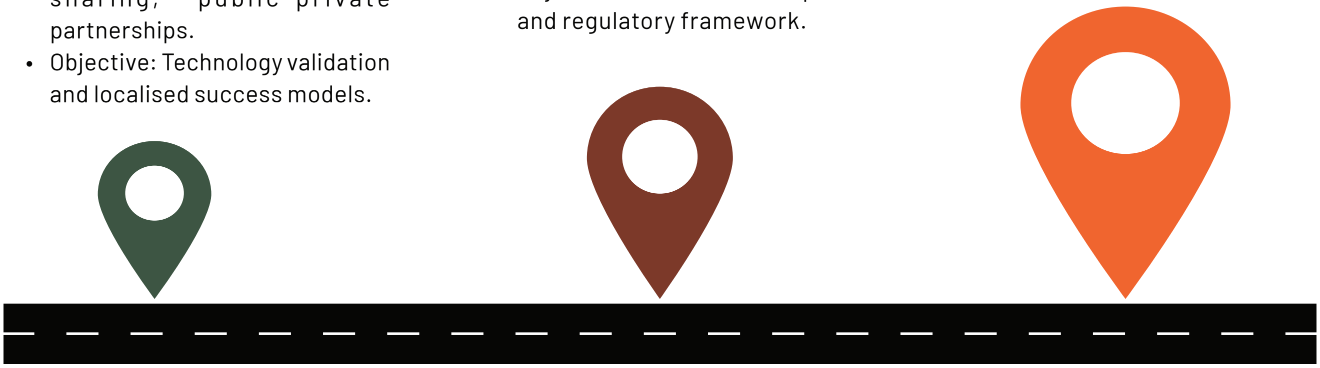
In India, scaling direct-use geothermal will hinge on a few essentials: building talent and research and development capacity; streamlining permitting and land access with early community engagement; and taking the risk out of capital. As mentioned, Chapter 8, "Policy and Regulatory Pathways to Catalyse Geothermal in India," provides specific, actionable recommendations for expanding direct-use geothermal in India. Hitting these marks would deliver enormous benefits: lower energy costs and import dependence; cleaner air in industrial corridors; stronger grid resilience through 24/7 local heat; globally competitive manufacturing; and the potential creation of between 350,000 and 700,000 skilled jobs across drilling, fabrication, and operations and maintenance.

To integrate direct-use geothermal into India's industrial and commercial heating infrastructure, a structured plan is essential. The roadmap starts at pilot deployments, then moves to broader market scale-up and finally, as costs fall, to district-wide systems. This map is complementary to the policy solutions outlined in Chapter 8.

The roadmap has three steps:

1. **2025–2030:** Pilot direct-use projects in industrial clusters, funding exploration, wells, and heat-exchange equipment.
2. **2030–2040:** Scale projects to commercial and residential markets with standards, technician training, and tighter operating cost management.
3. **2040–2050:** Deploy district networks and grid-integrated systems at scale as technology matures, targeting payback timelines of six to eight years.

POTENTIAL ROADMAP FOR DIRECT-USE IMPLEMENTATION



Phase 1: Pilot Demonstration (2025–2030)

- Target industrial clusters (e.g., food processing, textiles).
- Focus on direct-use systems for thermal applications.
- High CAPEX: drilling, exploration, reservoir evaluation.
- Deploy in high-enthalpy zones.
- Require R&D support, risk-sharing, public-private partnerships.
- Objective: Technology validation and localised success models.

Phase 2: Expansion and Standardisation (2030–2040)

- Scale to commercial and residential sectors.
- Develop standard building codes and safety guidelines.
- Roll out training and workforce development programs.
- Focus on OPEX management: heat pumps, system monitoring.
- Policy integration and urban utility planning.
- Objective: Mainstream adoption and regulatory framework.

Phase 3: Full Deployment and Grid Integration

- Establish direct heating networks.
- Optimize OPEX with automation and predictive maintenance.
- Encourage private sector investment through policy certainty.
- Aim for carbon offset benefits and long-term energy cost savings.
- Objective: Sustainable, large-scale geothermal heating transition.

Figure 3.14: Roadmap for implementing direct-use geothermal in India based on capital and operating expenditures (CAPEX and OPEX, respectively). Source: Adapted from author by Project InnerSpace.

CONCLUSION

India has substantial resources for geothermal energy, particularly for direct-use heat. Using geothermal energy for industrial steam boilers, food and crop drying, food processing, greenhouse cultivation, balneotherapy, and other direct-use processes has proven successful and can be an important part of India's economy going forward. The programs carried out at Indian School of Business Mohali, the Centre of Excellence for Geothermal Energy project in Gujarat, and the Geotropy project in Himachal Pradesh saw energy use fall by 55%, making them beneficial to local communities. Still, the lack of a national policy, insufficient technical experience, and lengthy approval processes for environmentally important areas such as Puga Valley and Tapovan represent ongoing challenges to direct-use geothermal heat.

The case studies and experiences outlined in this chapter provide a roadmap for how to achieve the suggested geothermal goals for industrial direct-use heat: 10 gigawatts by 2035, 20 or more gigawatts by 2040, and 50 or more by 2050. A successful scaling of geothermal requires exploring ideas at the pilot level and getting support from policymakers, standardising geothermal's industrial use from 2030 to 2040, and increasing use in industrial clusters with heat cascaded to agricultural drying and cold storage between 2040 and 2050. In rural areas, food drying and greenhouse farming should be prioritised, as geothermal energy can prevent food spoilage and increase sufficiency of food resources. Using viability gap funding, forming public-private groups, and working with countries such as Iceland can help reduce risks and boost the adoption of these solutions. By building expertise, creating a streamlined approach to development, and engaging the community, India can use geothermal energy as a vital part of sustainable and responsible growth. Prioritising industrial steam first—while expanding high-impact uses like drying and greenhouses—will deliver cleaner air, stronger energy security, competitive industry, and skilled jobs at scale.

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