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Unlocking Next-Generation Geothermal Heat for Industry

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Table of Contents

Executive Summary **3**

1. Unlocking Geothermal Heat **4**

2. Advantages of Geothermal Heat for Industry **7**

2.1 Clean, Around-the-Clock Heat 8

2.2 On-Site, Off-Grid Heat 8

2.3 Low & Predictable Operating Costs 8

2.4 Community & Environmental Benefits 9

3. Using Geothermal Heat for Industry **10**

3.1 Using Geothermal for Steam, Hot Water, and Hot Air 10

3.1.1 Heating Water 10

3.1.2 Generating Steam 10

3.1.3 Heating Air 11

3.1.4 Implementation Considerations 11

3.2 Which Sectors are Good Candidates for Geothermal? 13

3.2.1 Timber, Pulp, and Paper 14

3.2.2 Food and Beverages 16

3.2.3 Chemicals and Minerals 18

3.3 Case Studies 19

3.3.1 Pulp and Paper Processing in Kawerau, New Zealand 19

3.3.2 Onion & Garlic Drying in Fernley, Nevada 20

3.3.3 Milk Pasteurization in Klamath Falls, Oregon 21

4. Strategies to Scale Geothermal Heat for Industry **23**

4.1 Heat-as-a-Service Models 24

4.2 Co-Locate Industrial Parks 25

4.3 Expand Demonstration Projects 26

4.4 Targeted Policy Support 27

4.4.1 Expand Incentives for Direct Heat Projects 27

4.4.2 Streamline Permitting and Environmental Reviews 27

4.4.3 Mitigate Risk with Public Cost-Sharing and Insurance 28

5. Induced Seismicity & Environmental Considerations **29**

5.1 Seismicity 29

5.2 Particulate Emissions 29

5.3 Water Use 30

5.4 Responsible Geothermal Development 30

6. Next Steps: Mapping Geothermal Heat for Industry **31**

Acknowledgements **32**

EXECUTIVE SUMMARY

Industrial facilities produce the goods and materials that underpin modern life. But the sector is also a major polluter, accounting for 23% of all U.S. greenhouse gas emissions. Most of these emissions come from burning fossil fuels to generate heat, an essential input for many manufacturing processes. Yet, there is an abundant, zero-emissions source of heat right beneath our feet: geothermal energy. This report explores how next-generation geothermal technologies can provide clean, reliable heat to slash emissions across the industrial sector.

Conventional geothermal systems rely on rare hydrothermal reservoirs, but emerging next-generation geothermal technologies can harness heat from hot rock almost anywhere. With recent advances in deep drilling, directional boring, and wellfield design, these systems are increasingly cost-competitive and ready to deploy. Next-generation geothermal systems offer several advantages for industry: around-the-clock heat, near-zero emissions, low and predictable operating costs, and heat that does not rely on natural gas or large amounts of electricity. This lowers exposure to commodity price fluctuations, reduces load on the grid (removing the need for costly grid upgrades), and improves energy resilience.

We examine how geothermal systems can produce steam and hot water for process heat, with a focus on three industrial sectors: pulp and paper, food and beverages, and chemicals. For each sector, we explore how specific unit operations can be converted to geothermal heat and present case studies of facilities that already use geothermal.

Then, we outline several key strategies to realize geothermal's potential for the industrial sector:

- **Heat-as-a-service** business models to overcome up-front investment barriers
- **Co-located industrial parks** to share infrastructure and reduce costs
- **Lower drilling costs** through technological innovation
- **Demonstration projects** to build technical confidence
- **Targeted policy**, including financial incentives and public risk-sharing

This report is intended as a primer on direct-use geothermal heat. In *The 2035 Initiative's* upcoming work, we will provide a national, plant-level suitability analysis for geothermal heat using engineering archetypes for the food, pulp and paper, and chemicals sectors. This analysis will map geothermal resource availability, facility location, and estimated process-level heat needs to generate actionable insights for policymakers, developers, and industrial stakeholders.

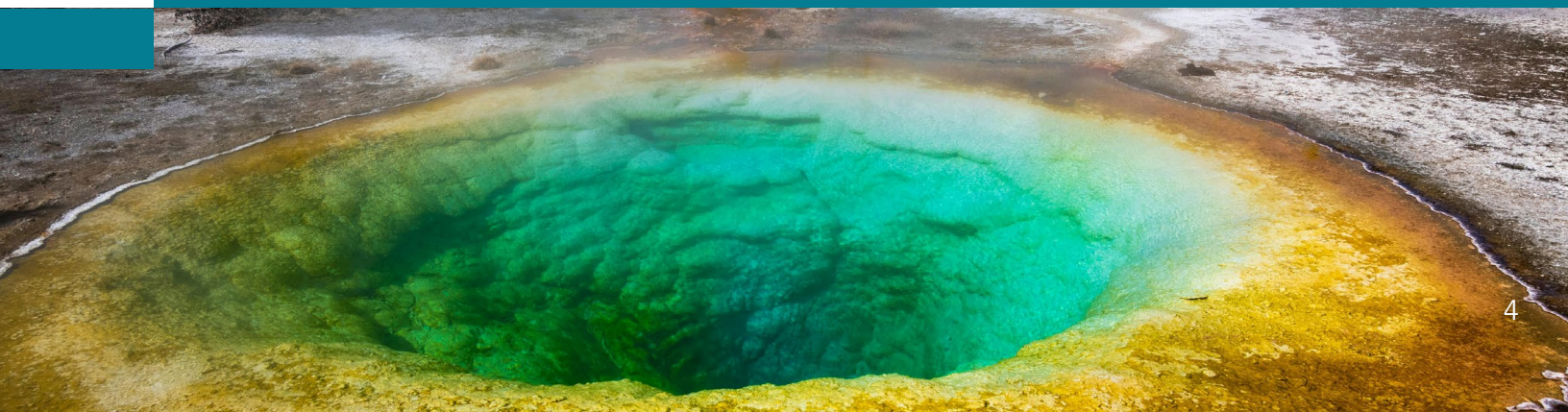
1. UNLOCKING GEOTHERMAL HEAT

Geothermal energy is naturally occurring heat stored in the ground. It comes primarily from the radioactive decay of elements in the earth's core, which produces heat that continuously radiates towards the surface. The intensity of this heat varies by location, but it exists everywhere and does not vary by weather conditions. This makes geothermal a uniquely abundant and stable energy resource.

Geothermal heat can be accessed using a range of technologies that vary based on the local geology. These can be broadly grouped into two categories:

- **Conventional systems,** which rely on naturally occurring reservoirs of hot fluids.
- **Next-generation systems,** which use advanced engineering to unlock geothermal heat in regions without naturally occurring fluids or reservoirs.

Conventional geothermal systems work where subsurface rock: (1) is hot; (2) has naturally occurring fluids; and (3) is porous and permeable enough for fluid flow. These systems are concentrated in geologically active regions, such as the Western U.S., Iceland, and New Zealand. These areas also tend to be marked by "surface signs" like hot springs and geysers. Currently, around 40 countries use some form of conventional geothermal energy. While proven and mature, conventional geothermal systems are geographically constrained to areas with these unique natural conditions. As a result, there is limited potential for large-scale conventional geothermal deployment.

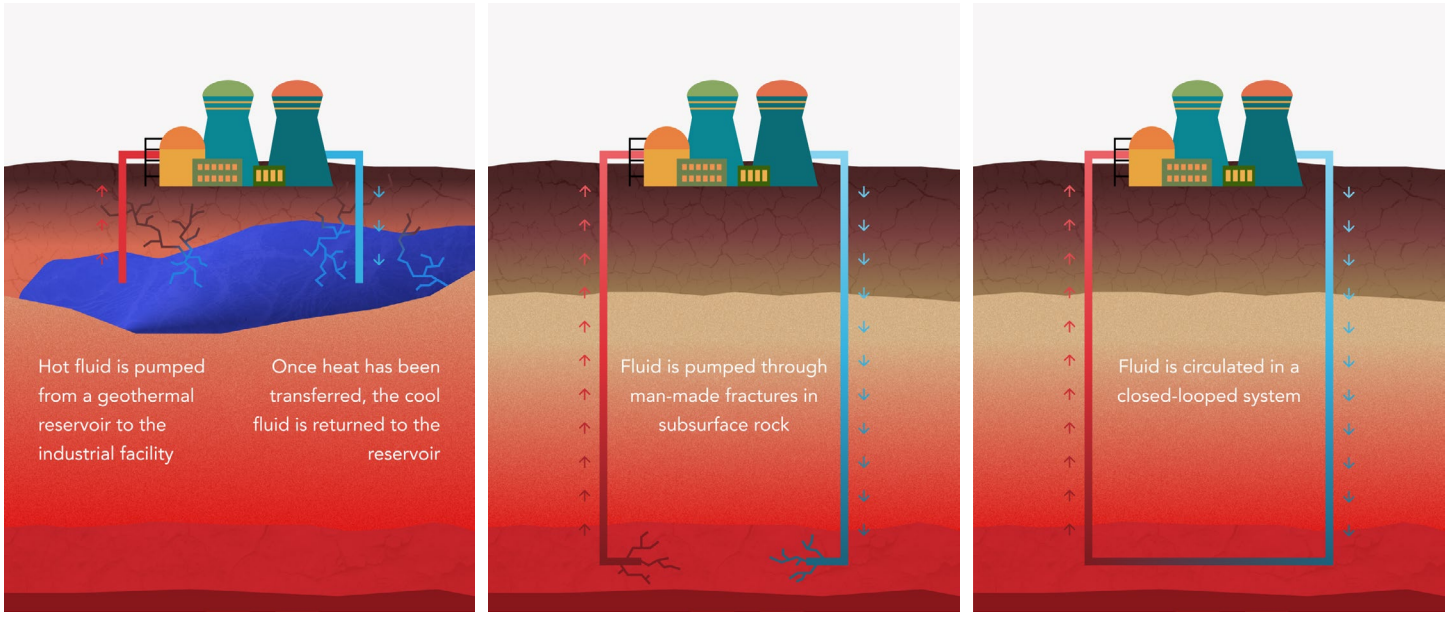


However, **next-generation geothermal systems** can access geothermal heat virtually anywhere, dramatically expanding the range of locations where geothermal is viable. These systems involve drilling long boreholes into the earth to circulate fluid through the subsurface. Geothermal heat transfers to the fluid as it passes underground and is pumped back to the surface, where the heat then can be used.

There are two types of next-generation systems:

Enhanced Geothermal Systems (EGS): Many subsurface areas are hot, but lack the natural permeability or fluid content for a geothermal reservoir to form naturally. EGS addresses this using hydraulic fracturing techniques from the oil and gas industry. Fluids are pumped underground through boreholes at high pressures, causing new cracks to open in the rock and widening existing ones. Once this happens, fluid can circulate through the "enhanced" network of fractures and absorb heat, mimicking the function of a natural reservoir. Horizontal drilling increases the surface area of the underground network, boosting thermal output.

Advanced Geothermal Systems (AGS): These systems circulate fluid through a sealed pipe loop embedded in hot rock. Unlike open-loop systems, the working fluid does not interact with the surrounding geology, minimizing risks from corrosion or mineral scaling. However, closed-loop systems require longer boreholes and more surface area for heat transfer, which can raise costs and space requirements.



Conventional Geothermal System | Enhanced Geothermal System (EGS) | Advanced Geothermal System (AGS)

Figure 1. Illustrating conventional and next-generation geothermal systems

Next-generation geothermal systems can unlock an abundant source of clean, renewable energy. In its recent Future of Geothermal report, the IEA found that there is enough geothermal energy to power the world 140 times over. Altogether, there is an estimated 5,157 GWe of geothermal resource potential at depths less than 7 km and temperatures more than 150°C, with 800 million TWh available at lower temperatures.

As a result, next-generation geothermal is attracting growing interest and investment. In 2018, the Department of Energy created the Frontier Observatory for Research in Geothermal Energy (FORGE) in Utah, a flagship test site for EGS development. In 2024, the Bipartisan Infrastructure Law allocated an additional $74 million to pilot demonstrations of next-generation geothermal power plants. The success of these technologies has led to several start-ups attempting to commercialize next-generation geothermal energy.

Historically, technological risks and drilling costs have been the main barriers to next-generation geothermal. The boreholes often need to be several kilometers deep to access high enough temperatures. Drilling for next-generation geothermal also means penetrating rock that is hotter, harder, and deeper than for conventional systems and fossil fuels. It is usually necessary to drill more wells for next-generation systems, which also increases costs. And, these systems use hydraulic fracturing and horizontal drilling procedures that increase the complexity of the operation.

But drilling technology is progressing rapidly. Fervo Energy (a next-generation geothermal company) has reported that improvements to drilling processes have yielded a 70% reduction in drilling time. Fervo has also reported improvements to drill bit durability, reducing the number of bits broken when drilling a horizontal well from 13 to just 1. Altogether, Fervo's drilling costs dropped from $1,000 per foot in its first project to $400 per foot in its second.

The market for next-generation geothermal should only continue to improve. The IEA projects that by 2035, geothermal will be cheaper than nuclear and competitive with solar photovoltaics (PV) and wind when each is paired with battery storage. Meanwhile, a recent economic analysis put the cost of next-generation geothermal electricity at $64 per MWh, which would be competitive with other renewables before accounting for the cost of battery storage associated with intermittent power sources. Additional analysis from the IEA shows that a low-cost scenario for next-generation technologies would make switching to geothermal economical for 35% of global industrial heat demand below 200°C. This would save about 750 Mt of CO_2 emissions (equivalent to the annual emissions of Canada, the world's 12th largest emitter).

Unlike some other clean technologies, next-generation geothermal projects appear poised to receive continued policy support in 2025 and beyond. Multiple recent Executive Orders include geothermal as a solution to improving U.S. energy security, while Secretary Wright has trumpeted geothermal's benefits. Given these technological advances and political tailwinds, next-generation geothermal is ready to scale in the coming years.

2. ADVANTAGES OF GEOTHERMAL HEAT FOR INDUSTRY

Today, geothermal energy is primarily used in two ways: electricity generation and space or water heating. District heat networks and ground-source heat pumps[1] are the most common applications, accounting for around three-quarters of all geothermal energy consumption. These systems circulate fluid through an underground pipe network to provide space heating, air conditioning, and/or hot water for buildings. In electricity generation, high-pressure geothermal steam spins a turbine to create power.

Right now, industrial applications constitute just 1% of all direct geothermal heat use.[2] But next-generation geothermal systems carry enormous potential for supplying heat to industrial processes. Many facilities use fuel-combustion boilers to make steam and heat water.[3] There are nearly 40,000 of these boilers across the U.S., and they are a major source of pollution. According to Greenhouse Gas Reporting Program (GHGRP) data that surveys emissions at large industrial facilities, fuel-combustion boilers at just this subset of facilities are responsible for over 70 million metric tons of CO_2 emissions and 6% of all industrial NO_x pollution every year. Particulate emissions from boilers can cause a variety of problems for human health, including cardiovascular and pulmonary illnesses.

[1] Though a common and fairly mature technology, ground-source heat pumps (also known as "geothermal heat pumps") operate at temperatures well below 100°C and are generally not suitable for industrial process heat.
[2] When geothermal energy is used for heat without first being converted to electricity, it is often referred to as "direct heat" or "direct use."
[3] A significant portion of facilities have combined heat and power (CHP) systems, which use combustion to provide both heat and electricity. This makes these systems more efficient than separated fuel-combustion boilers and grid generation. Compared to replacing a stand-alone boiler, it also makes replacing a CHP system more complex and less beneficial in terms of emissions reductions. Forthcoming analysis by *The 2035 Initiative* will analyze CHP decarbonization.



Geothermal systems can make steam and hot water without pollution, since they don't rely on combustion to generate heat. Next-generation geothermal has several advantages that make it a particularly useful technology for decarbonizing industry, outlined here.

2.1 Clean, Around-the-Clock Heat

Once built, **geothermal systems do not produce emissions**, making them ideal replacements for fossil fuel boilers and complementary to intermittent renewable electricity. And unlike other zero-emissions energy sources, **geothermal heat is readily available 24 hours a day, 7 days a week**. This is a major advantage given that many large industrial facilities must run 24/7 to maximize profits. Even for facilities that operate during normal business hours, a reliable and predictable energy supply is paramount.

2.2 On-Site, Off-Grid Heat

Geothermal heat can be generated at or near the point of use. This reduces the need for expensive grid upgrades, new substations, or transformer installations, which are common barriers to electrification. It also improves resilience by lowering dependence on the grid. And with proper drilling and siting, next-generation geothermal systems can be deployed almost anywhere.

This has broader system-level benefits. While electrification remains important to industrial decarbonization, it also places additional demand on an already-constrained grid. Next-generation geothermal offers a complementary pathway that meets thermal energy needs without increasing electricity load. In doing so, it helps avoid grid congestion and delays while allowing clean electricity to service demand from other sectors. Geothermal heat is not only a replacement for fossil fuels – it can also reduce the amount of infrastructure needed to meet growing energy demand.

2.3 Low & Predictable Operating Costs

Geothermal resources have no fuel costs. This means that facilities that use geothermal would be less vulnerable to price volatility in electricity or gas markets. The cost of electricity remains a barrier to widespread industrial electrification. Geothermal heat is a zero-emissions solution that mitigates this issue.

There are some operating and maintenance costs associated with geothermal, such as managing reservoir pressure, maintaining pumps and wells, and addressing corrosion. These constitute about 25% of the lifetime cost of a geothermal power plant. Yet, studies show that geothermal heat can reach cost parity or better when measured on a levelized cost of heat basis.

Importantly, ownership structure impacts operating costs. A facility can own and operate a geothermal system directly, or purchase geothermal heat through a "heat-as-a-service" model, which we discuss in Section 4.1.

2.4 Community & Environmental Benefits

Geothermal is a low-impact energy source. Next-generation geothermal carries significantly lower environmental risks than fossil fuel extraction, including hydraulic fracturing for oil and gas. It produces negligible air and water pollution and relies less on critical minerals than other clean technologies.

Additionally, most geothermal infrastructure is located underground and can be developed with minimal surface disruption, reducing visual impact on landscapes that could lead to local opposition. Direct geothermal heat may constitute an appealing industrial decarbonization solution in contexts where electrification in conjunction with renewables meets land use challenges.

Next-generation geothermal can also support a just transition by offering high-quality jobs for oil and gas workers, since geothermal drilling requires many of the same skills.



3. USING GEOTHERMAL HEAT FOR INDUSTRY

This section explores the use of geothermal heat for industry in practice. We explain how geothermal heat can replace combustion-fired units, discuss sectors that are good candidates for geothermal, and highlight case studies of direct use geothermal heat.

3.1 Using Geothermal for Steam, Hot Water, and Hot Air

Many industrial processes use heat in the form of steam, hot water, or hot air. Steam and hot water is usually supplied by a fuel-combustion boiler with a piping system that moves the hot fluid around a plant. Around 75% of all heat demand from industrial boilers is for heat below 200°C. Combustion-fired units such as dryers and evaporators that provide hot air operate in similar temperature ranges. Meanwhile, the most recent EGS systems operate at temperatures in excess of 500°C, which makes them more than suitable for many thermal processes that rely on these heat mediums.



3.1.1 Heating Water

To produce hot water (40-90°C), a geothermal system can use a heat exchanger to transfer thermal energy from the fluid that has been heated by circulating underground (the "geothermal fluid") to the facility's water loop (Figure 2-2). This hot water can then be used for pasteurizing, cleaning, washing, and other processes. In select instances, it is also possible to use geothermal liquid at a facility without a heat exchanger (Figure 2-1).

Some facilities might be able to further improve energy efficiency by "de-steaming" – replacing steam-based heat with lower-temperature hot water, where possible. Geothermal systems can also preheat boiler feedwater, reducing fuel demand for conventional steam generation.

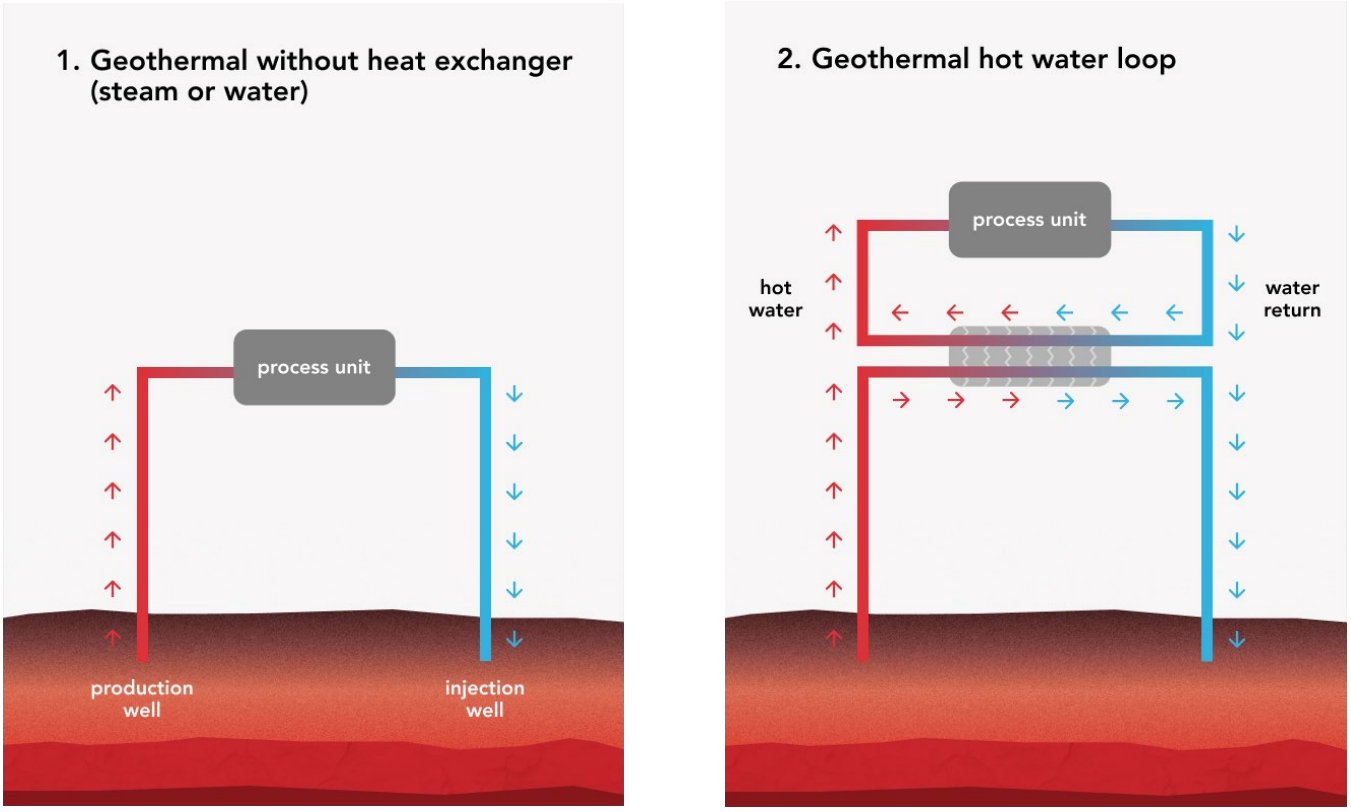
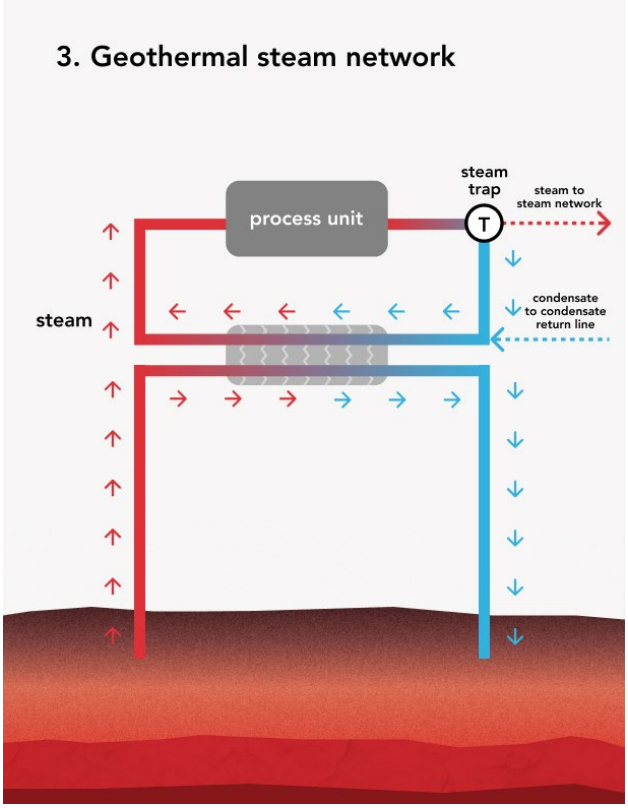
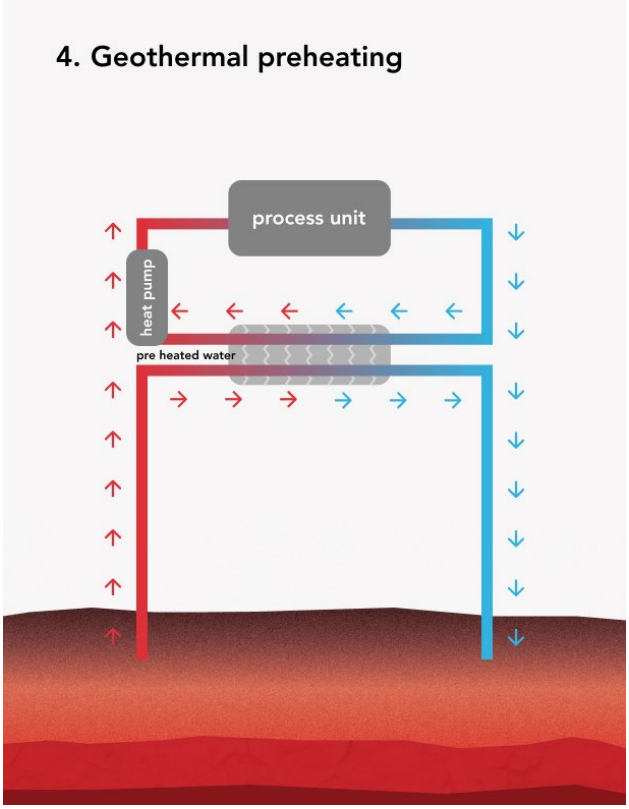


Figure 2. Representation of different ways of utilizing geothermal heat for industrial processes.

3.1.2 Generating Steam

Geothermal systems with sufficiently hot fluids can produce steam (90-200°C, but potentially higher) through a heat exchanger, without the use of a traditional boiler (Figure 2-3). If geothermal fluid temperatures are not high enough, an industrial heat pump could raise the temperature to generate steam, provided the heat pump has sufficient lift and can accommodate changes in the temperature of the geothermal fluid (Figure 2-4).



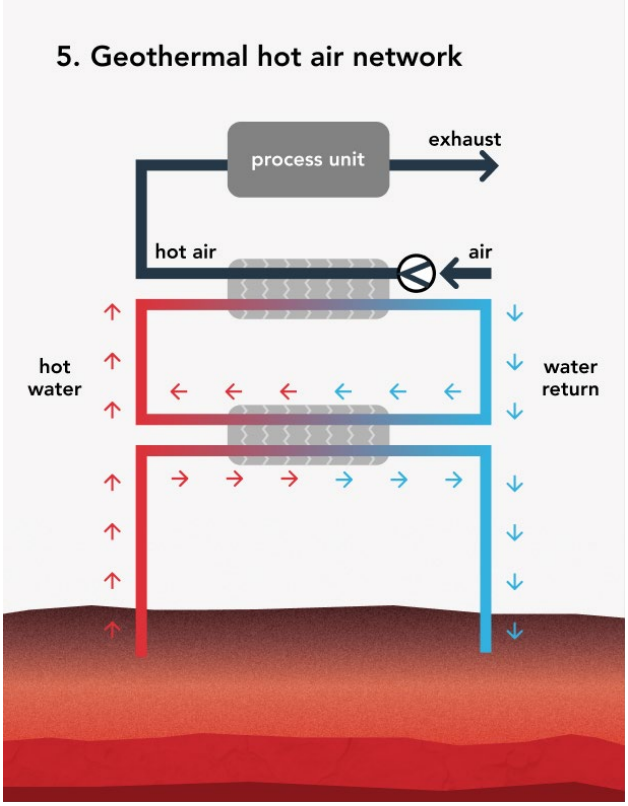




3.1.3 Heating Air

Heating air with geothermal energy is more complex due to the fact that most facilities use local combustion at each step that requires hot air, rather than a central air heating system. As a result, retrofitting a facility for geothermally heated air may require multiple heat exchange systems: one to transfer geothermal heat to steam or water for distribution around the facility, and others to transfer the heat to air at each step in the manufacturing process (Figure 2-5). While technically feasible, this option is generally more suited to new installations, facilities with centralized air heating systems, or facilities with a small number of hot air processes.

Some geothermal applications use steam piping systems to control the air temperature and humidity, such as timber drying in a kiln. In such cases, geothermal steam can also be used to heat air.



3.1.4 Implementation Considerations

Depending on the characteristics of geothermal fluid at a site, other equipment may be necessary to leverage geothermal for industrial process heat. When geothermal fluid is a mix of steam and hot water (known as "two-phase"), separation equipment for two-phase flow or specific piping for condensate recovery may be required. Geothermal fluids pumped from the ground can also contain impurities or minerals that would interfere with manufacturing processes if used directly. Therefore, most geothermal systems rely on heat exchangers to separate geothermal fluids from process loops, avoiding contamination or equipment corrosion. Equipment such as fluid scrubbers can help remove pollutants from the geothermal fluid before it enters a heat exchanger.

3.2 Which Sectors are Good Candidates for Geothermal?

The chemicals, pulp and paper, and food and beverage sectors have the highest installed fuel-combustion boiler capacity across U.S. facilities (Figure 3). Together, these three sectors account for ~58% of total boiler capacity[4] and over half of industrial-energy-related emissions. This makes them priority targets for process heat decarbonization with geothermal energy. But more broadly, any facility with a fuel-combustion boiler is a potential candidate for geothermal heat.

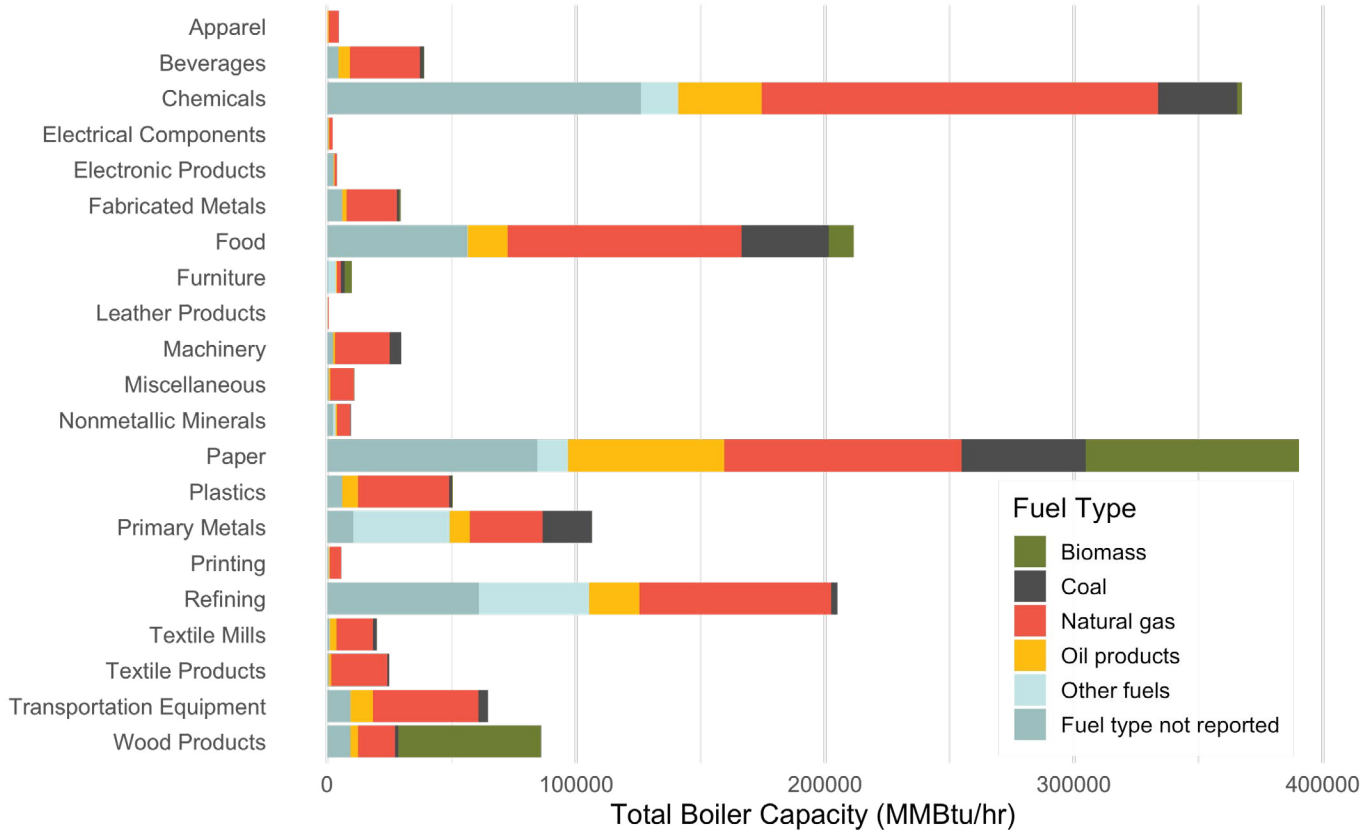


Figure 3. Installed boiler capacity by manufacturing sector in U.S., 2022 (Adapted from Schoeneberger et al., 2022)

[4] Authors' calculation using data from Schoeneberger et al., 2022.

Application	Category	Country
Food dehydration, drying	Low-medium temperature industrial heat	Guatemala, Kenya, Turkiye, Iceland, U.S.A.
Milk and dairy processing	Low-medium temperature industrial heat	Romania, New Zealand
Wood and timber drying	Low-medium temperature industrial heat	New Zealand, Romania
Pulp, paper, tissue	Low-medium temperature industrial heat	Germany, New Zealand, Italy
Breweries, distilleries, restaurants	Low-medium temperature industrial heat	Iceland, Italy, Spain, United Kingdom
Cement and concrete curing	Low-medium temperature industrial heat	Guatemala, Kenya
Greenhouse & fish farming	Agriculture	Iceland, Kenya, Netherlands, Turkiye, U.S.A.
Lithium extraction / hydroxide refining	Minerals	Germany, U.S.A.
Silica extraction	Minerals	Iceland, New Zealand
Captured CO2 re-injection	Non-heat industrial application	Iceland, Turkiye
Data center cooling	Non-heat industrial application	France, Italy

Table 2. Industrial Facilities Using Geothermal as of 2025

3.2.1 Timber, Pulp, and Paper

The use of heat to control and remove the moisture in wood is central to timber and paper product manufacturing. Many of these processes are steam-based, with temperatures lower than 160°C (pulping, bleaching, evaporating, drying, etc.). Other units in wood product manufacturing, such as digesters, require higher pressure steam (160-180°C).

The pulp and paper sector stands out for its share of biogenic emissions, which largely come from burning natural byproducts such as black liquor and hog fuel. Because these byproducts are derived from biomass whose carbon content came from the atmosphere, their combustion is often considered carbon-neutral. As Figure 4 shows, however, the pulp and paper sector's emissions from fossil fuel combustion are still comparable to those of the food and beverages sector. This means that pulp and paper remains a prime candidate for geothermal heat.

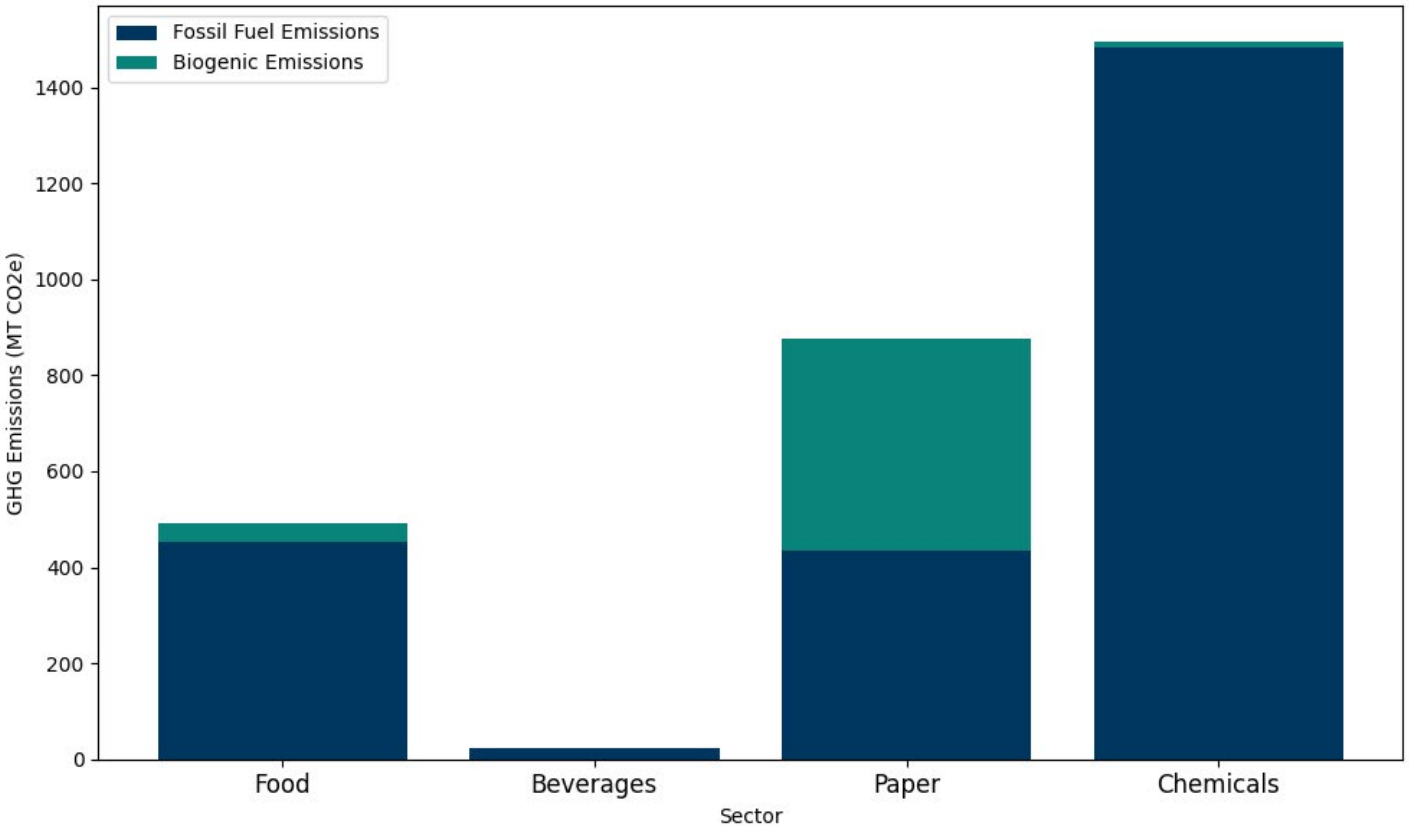


Figure 4. Combustion emissions in 2023 by sector and emissions type. (Environmental Protection Agency GHGRP)

There are several active wood processing facilities that use conventional geothermal energy. In Section 3.3.1, we investigate New Zealand's Kawerau wood processing cluster in an extended case study, which is the largest site of this type in the world. Beyond Kawerau, Nature's Flame pellet facility in Taupō, New Zealand uses a multi-loop heat exchange system where geothermal water at ~180°C is piped over 1.2 km to the factory. There, the heat is transferred via a secondary loop to produce hot air for drying waste wood. Another operational pulp and paper facility using geothermal heat is the wood chip drying plant in Tuscany, Italy, which uses fluid at 85°C from a nearby geothermal power plant.



3.2.2 Food and Beverages

Most food and beverage manufacturing processes involve steam or hot water at temperatures within the range of geothermal, as shown in Figure 5.

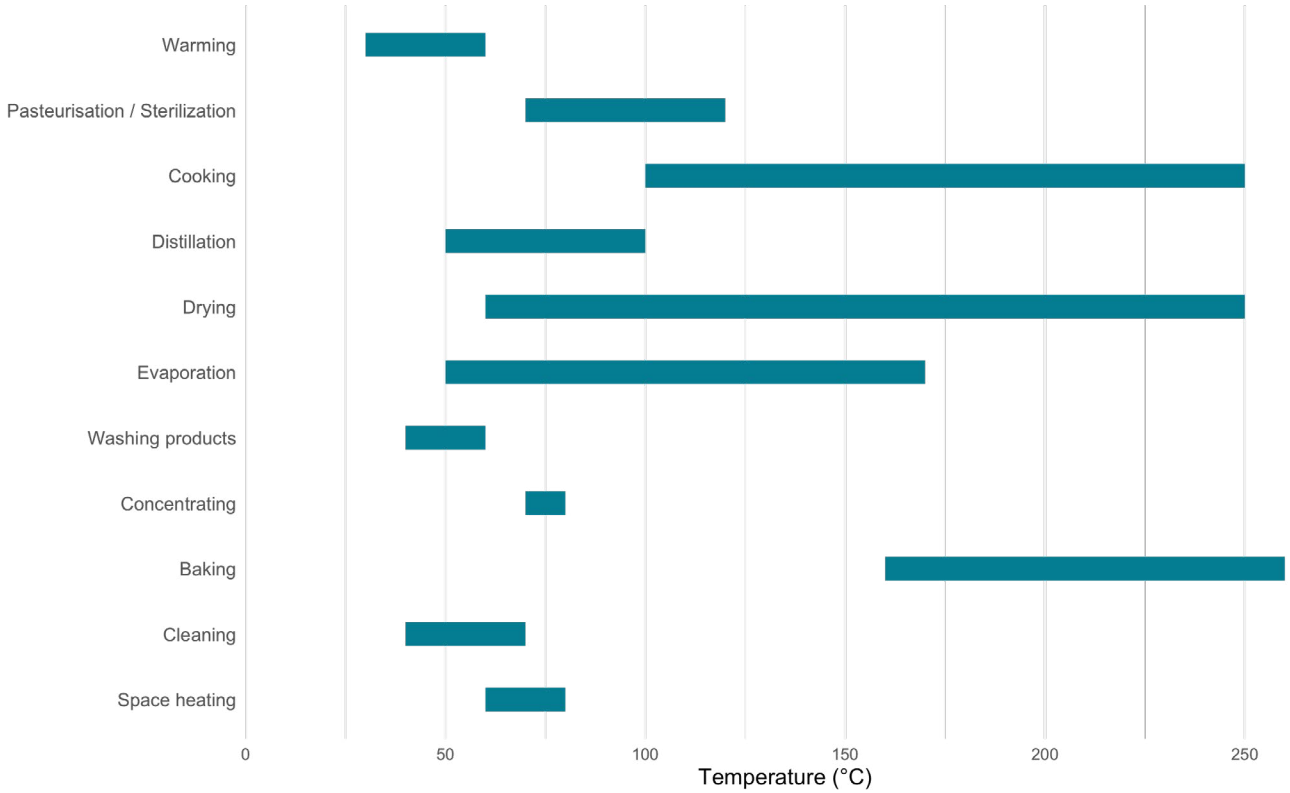


Figure 5. Unit processes in the food and beverages sector and their temperature ranges.

For example, a common step in beverage manufacturing is heating a liquid. Milk pasteurization requires bringing the milk to ~63°C to kill harmful bacteria and extend shelf life. When making beer or liquor, the "mash" (a mixture of grain, water, and yeast) also needs to be raised to around 63°C to convert starches into sugars. Coffee and tea drinks need to be steeped at warm temperatures to extract the flavors.

Geothermal systems are well-suited to supplying energy for heating liquids. There are multiple operational facilities that use conventional geothermal heat for milk pasteurization, including one in Kenya and another in New Zealand. One milk processing plant in Klamath Falls, Oregon ran on geothermal heat for over 50 years, which we investigate in Section 3.3.2. There are also a number of U.S. breweries using geothermal-heated water for beer making:

- Riff Raff Brewing in Colorado uses 60°C geothermal water in a heat exchanger to warm brewing water.
- Superior Bathhouse Brewery in Arkansas brews directly with geothermally heated spring water.
- Klamath Basin Brewing in Oregon and Prairie Street Brewing in Illinois also use geothermal heat for brewing operations.

Drying food products, which entails raising air temperature to evaporate moisture content, also uses low-to-medium temperature heat. Drying is used to manufacture foods such as pantry spices, dried fruits, cereals, meat jerky, and others. These applications are energy-intensive due to the high moisture content of agricultural products.

Several food manufacturing facilities have taken advantage of geothermal heat for their drying needs. One example is a Mexican plant that uses geothermal to make dehydrated pineapples. The facility uses two heat exchangers: one to transfer heat from geothermal fluid to intake water, and another to produce hot air for drying ovens up to 90°C. In Section 3.3.3, we dive into another example of geothermal heat for food drying.

Yet, the potential of geothermal for food and beverage manufacturing extends well beyond existing applications. In the United States, wet corn milling, beet sugar manufacturing, and cane sugar manufacturing are the highest-emitting food and beverage subsectors.[5] As with milk pasteurization and brewing, a large amount of heat demand in these sectors comes from heating liquids. Wet corn milling involves steeping corn at ~50°C to soften the kernels prior to grinding. In sugar production, hot water is used to "leach" the sugar from the sugar beets as well as from cane. Geothermal systems can supply the heat for such processes.

Finally, one prevalent use of direct geothermal heat is temperature control in farming. There are fish farms ("aquaculture") that use geothermally heated water to keep pools at the right temperature. In cold climates, the hot water can warm greenhouses to create a suitable environment for farming crops, fruits, and vegetables. One innovative project uses geothermal to cultivate algae for commercial sale. While "industrial decarbonization" typically refers to non-agricultural sectors, we highlight these applications as additional uses for geothermal, with potential for synergies between farms and food processing facilities at geothermal sites.

[5] Authors' calculation using data from GHGRP.



3.2.3 Chemicals and Minerals

In the chemicals sector, typical unit operations that use heat from steam and hot water include:

- Reactors
- Distillation columns
- Evaporators
- Concentration
- Sterilization & cleaning
- Mixture separation
- Polymerization
- Crystallization

In addition, there are other processes in the chemicals sector that require direct-fire units to reach sufficiently high temperatures, but make use of steam as a feedstock. This includes steam methane reforming for hydrogen (which is used to make ammonia) and steam cracking for light olefins and other chemicals. While geothermal could not fully replace the energy demands for these sectors, it could decarbonize the boiler or CHP unit that supplies steam for the process.

One notable application of geothermal in the chemical sector is the Belgian campus of Janssen Pharmaceutica (a subsidiary of Johnson & Johnson). Whereas most facilities we discuss make use of existing geothermal well fields from nearby power plants, this chemical manufacturer did its own drilling onsite. Now, the geothermal system pumps water at 85°C over a 3.5-kilometer heat network. In addition to space heating, the water is used to make vaccines and pharmaceuticals. It is estimated that the project will reduce the company's emissions in Belgium by 30%.

Manufacturers can also use the geothermal fluid itself for mineral extraction. Geothermal brine often contains valuable dissolved minerals such as lithium, boron, and iodine. Historically, Italy's Larderello site produced boric acid from geothermal fluid before electricity production began. Today, BASF is exploring geothermal brine as a source of lithium in Germany, combining geothermal energy and resource recovery into a single business model.



3.3 Case Studies

The following examples of conventional geothermal use in these three sectors provide additional insight into the mechanics and benefits of using geothermal heat for industry.

3.3.1 Pulp and Paper Processing in Kawerau, New Zealand



Geothermal power plant in Kawerau, New Zealand. Photo Credit: "100 MW Geothermal Power Plant at Kawerau NZ" by Rjglewis is licensed under CC BY-SA 3.0.

Kawerau, located in New Zealand's Bay of Plenty region, is home to an industrial cluster for wood and paper processing powered by geothermal energy. This highly integrated cluster includes several major facilities:

- Log yard (~1 million cubic meters of logs per year)
- Industrial sawmill (~54,000 oven-dry tonnes per year)
- Structural sawmill (~134,000 oven-dry tonnes per year)
- Kraft pulp mill (~243,000 oven-dry tonnes/year)
- Newsprint mill (~121,000 oven-dry tonnes/year
- Tissue paper mill (~44,000 oven-dry tonnes/year)

Additionally, the site hosts a number of geothermal power plants with a combined capacity of approximately 122 MW.

The cluster is characterized by a high level of industrial symbiosis in material and energy exchanges. Wood chips from the sawmills feed into the two pulp mills, supplemented by chips from imported pulp logs. The pulp mills share a CHP system that utilizes both geothermal steam and biomass-fueled boilers to produce clean steam for processing. Electricity from both the CHP system and standalone geothermal plants supplies power to the cluster.

Geothermal energy enabled one of the sites in the cluster, the Oji Fibre Solutions Tasman Mill, to switch from a coal boiler to geothermal steam in 2021. This shift saves the company $4 million in energy costs and avoids 10,000 to 28,000 tonnes of CO2-equivalent emissions each year (depending on whether indirect emissions are included).

The Essity tissue paper plant also uses direct geothermal heat at the Kawerau site. This facility recently began operating the first tissue machine that uses 100% geothermal steam drying. The conversion was done iteratively, as the company started by converting its paper machine hoods in 2009, which allowed two gas boilers to be replaced. In 2024, it expanded geothermal use further by converting the drum dryer to geothermal steam. In total, Essity invested $20 million into its paper machine upgrades, leading to a 66% reduction in the mill's carbon emissions.

Last, the Sequal timber mill at Kawerau has used geothermal heat in its kiln drying process since 2014. The kilns use geothermal steam and hot air to dry timber at temperatures up to 150°C. Using geothermal steam instead of burning sawdust waste allows the byproduct to be used for other renewable products, like wood pellets.

3.3.2 Onion & Garlic Drying in Fernley, Nevada



Brady's Hot Springs Power Plant provides direct geothermal energy to Olam Spices and Vegetables, Inc. Photo Credit: "Brady's Hot Springs Power Plant (Brady's Hot Springs, Nevada, USA)" by James St. John is licensed under CC BY 2.0.

Olam's Fernley plant is a standout example of full geothermal integration into a heat-intensive food processing line. The facility processes garlic and onions, both of which require drying from high moisture contents (~85% for onions, ~65% for garlic) to ~5% in powdered form. Per ton of dried product, this represents around 2 to 5 tons of water that need to be vaporized using industrial heat.

While typical drying operations rely either on a natural gas boiler or a direct-fired dryer, the Ferney plant relies exclusively on geothermal heat. The drying process uses geothermal steam at 130°C in conjunction with indirect heat exchangers (Figure 2-III). The plant produces 216,982 MMBTU annually (equivalent to ~63,591 MWh) while avoiding ~11,500 tons of CO_2 emissions. While the cost savings were not reported, 216,982 MMBTU corresponds to 209,039 thousand cubic feet of natural gas. Using the 2019 industrial price average for natural gas of $3.90 per thousand cubic feet, **this amounts to an estimated fuel savings of $815,250 per year.**

Fruit and vegetable processing consumes around 92 trillion BTU of natural gas for steam per year. Switching this process to geothermal heat would theoretically save about 88 billion cubic feet of gas and 4.2 million metric tons (MMT) of CO_2 annually.

3.3.3 Milk Pasteurization in Klamath Falls, Oregon



A milk processing plant in Klamath Falls, Oregon used a shallow (233 m) geothermal well with a temperature profile between 80 and 98°C. The geothermal system replaced a natural gas boiler and was able to pump 6.3 L/s of geothermal fluid through a heat exchanger (Figure 2-II), maintaining pasteurization tank temperatures of ~78°C. The facility processed approximately 0.84 L/s of milk, or 225,000 kg/month.

As a result of the fuel savings from replacing natural gas with geothermal, the plant saved ~$12,000/year in 1974, equivalent to ~$76,800/year in today's dollars. The geothermal water was also used for space heating and as hot feedwater for efficiently producing steam in the plant's remaining natural gas boilers.

Meanwhile, the effect on electricity consumption at the site was likely negligible. The pumps that moved the geothermal fluid from the ground to the rest of the facility were rated at 5.6 kW, or 7.5 HP. Comparatively, industrial gas boilers have a blower requirement between 2 and 75 HP, meaning the electricity usage of the geothermal system was in the lower range of the power draw of natural gas boilers.[6]

If scaled, direct use of geothermal heat for milk processing could generate significant emissions reductions. Nationwide, the U.S. dairy industry consumes 122 trillion BTU of energy annually, 79 trillion of which comes from natural gas for steam. Replacing all of this steam with geothermal would theoretically save 76 billion cubic feet of natural gas, avoiding up to 4.2 MMT of CO_2 emissions each year).

[6] In the case of a small-scale facility such as this milk plant, the lower figure of 2 HP can be assumed, as this falls within the specifications of a smaller boiler. According to Brown (1996), 1 kg of fluid milk requires 0.281 kg of steam. With 225,000 kg of milk produced per month, this translates to 376 kg of steam used per hour, assuming 21 days of operation each month and 8 hours of operation each day. This quantity of steam falls in the range of smaller industrial boilers such the CleaverBrooks M5M, which has a rated maximum hourly steam flow of 751 kg/hr and a blower electric draw of 2 HP (1.47 kW). Therefore, a geothermal pump would slightly increase the power draw due to the added requirement of pumping water over a large circuit length and height differential, but this effect on energy consumption would be offset by fuel savings.

4. STRATEGIES TO SCALE GEOTHERMAL HEAT FOR INDUSTRY

While geothermal heat offers unique advantages, scaling it will require a different approach than other industrial heat technologies. Developing a new geothermal site entails resource exploration, underground drilling, and wellfield management – a very different proposition than installing a new piece of factory equipment.

There are two key challenges that distinguish geothermal development from other means of generating process heat:

High capital investment: Drilling for geothermal is expensive, as it is time-intensive and requires specialized skills and equipment. The most recent estimates show the cost of EGS drilling at around $4.8 million per well, with at least two wells necessary for operation. This is a larger investment than other zero-emissions technologies such as industrial heat pumps, which studies estimate at around $5 million or less in total capital cost (sometimes much less). More demonstration projects are needed to accurately assess the levelized cost of next-generation geothermal heat for industry on a per-MMBtu basis, as the up-front investment is offset by lower operating and maintenance costs. But even accounting for this, high capital costs mean that geothermal projects can be difficult to finance and carry a long payback period.

Geothermal resource risk: Accessing underground thermal resources comes with uncertainty. Subsurface conditions such as temperature, rock permeability, and fluid content can be difficult to predict before drilling, and unexpected conditions can impact project timelines and costs. In open-loop systems like EGS, successful heat delivery depends on sustained fluid circulation between injection and production wells, a process that is not always guaranteed. Once a site is operational, performance can change if reservoir heat, pressure, and flow rates shift over time. Ensuring stable output over decades requires active management and specialized expertise in wellfield monitoring and maintenance.

Manufacturers may not be willing to shoulder the technical, operational, and financial complexities of developing geothermal heat on their own. Unlocking geothermal's full potential for industrial decarbonization will require tailored strategies to make the technology viable and attractive to both heat users and solutions providers.

4.1 Heat-as-a-Service Models

Instead of owning and operating geothermal systems, industrial facilities can buy geothermal heat as a service from a solutions provider. In this model, a third-party developer installs and manages the geothermal system, selling hot water or steam to the facility at a fixed price per unit of heat.

Heat-as-a-service is used at the Kawerau Geothermal Industrial Park, where an energy company owns and operates the geothermal equipment and sells steam to industrial users on the site. Heat-as-a-service contracts have also facilitated an industrial heat pump conversion at a dairy plant in California and thermal energy storage at a food processing plant in Finland, both of which are examples of decarbonization projects with high up-front capital investments.

Heat-as-a-service-models could help scale geothermal for a few reasons:

- **Capital investment and risk for the project is borne by the solutions provider**. A geothermal developer is more likely to shoulder the risks and long payback period of the up-front investment. A geothermal developer can also bring expertise that reduces overall risks and costs associated with project siting, resource risk, permitting, and project financing. Developers could even securitize the future revenue streams from selling heat, facilitating access to project financing.
- **Heat-as-a-service reduces operational risk.** Since the developer is selling the heat to the facility on a per-unit basis, service interruptions affect the provider's revenue stream, incentivizing a quick response. This also allows a facility to delegate the responsibility and technical expertise for managing a geothermal wellfield to a dedicated entity.
- **Redundant heat supply guarantees reliability and reduces cost risk.** Geothermal heat-as-a-service arrangements can include a redundant heat supply which improves resilience in the event of a service disruption. Additionally, in the event that the geothermal heat is more expensive than the backup source, the facility can switch, ensuring the lowest possible costs to the facility and incentivizing minimal operational costs for the developer. It also incentivizes performance from the provider, since their revenue depends on delivering reliable heat.

4.2 Co-Locate Industrial Parks

Strategically locating multiple industrial facilities near a geothermal site can improve project economics and reduce risk across the board. Shared infrastructure allows for economies of scale, while industrial users benefit from a reliable, clean heat source. This model is especially effective because a productive geothermal wellfield often generates more thermal energy than a single facility can use. By distributing that output across multiple users, projects can maximize utilization of the resource and improve return on investment.

Locating an industrial park near a planned or existing geothermal power plant allows direct heat to be efficiently integrated with electricity production. After geothermal high-pressure steam spins a turbine to generate electricity, the remaining lower-pressure steam and/or condensate can be used for industrial processes. Usually, this energy would be wasted. The Resource Park in Svartsengi, Iceland is an example of this "cascading" use of geothermal energy. After geothermal steam is used to make electricity, the remaining energy is captured for a district heating network. This heat supplies a fish drying facility, an aquaculture farm, a cosmetics company, and a green methanol facility recycling captured CO_2 from the flue gas at the power plant.

Co-locating industry and power generation also means that the geothermal power company can operate as the service provider in a heat-as-a-service arrangement. This yields all of the benefits outlined in Section 4.1. And, if an industrial park can be sited next to an existing geothermal power plant, this significantly reduces risks associated with project development. For the power company, an industrial park can improve project economics through additional revenue from selling geothermal steam and/or power to industrial facilities. The Kawerau Industrial Park is another example of this arrangement, where timber, dairy, and pulp and paper processing plants have co-located next to an existing geothermal power plant. The wellfield supplies the facilities on site with around 6 PJ of geothermal heat per year.

Manufacturers, geothermal developers, and policymakers can work together to create similar geothermal industrial hubs. Compared to a factory retrofit, a new facility is a significant investment with many operational considerations beyond generating process heat. Developing an industrial park would be a complex undertaking and would require strong community, business, and government partnerships.



4.3 Expand Demonstration Projects

Demonstration projects are essential to scaling direct-use geothermal heat for industry. They reduce technical and financial risk, build stakeholder confidence, and generate sector-specific knowledge to guide replication. In particular, pilot projects using next-generation geothermal for heat, not just power generation, can provide proof-of-concept for this newer application.

As of the date of publication, all next-generation geothermal projects we identified are used exclusively for electricity. Yet the same systems can deliver steam at temperatures suitable for industrial processes.

Demonstration projects would help scale next-generation geothermal heat in the following ways:

- **Clarify required retrofits.** Adapting a plant for geothermal often requires more than swapping a boiler, as components like heat exchangers, control systems, and process equipment may also need to be replaced. Facilities must also be prepared to manage site-specific conditions such as chemical impurities in geothermal brine or fluctuations in fluid temperature and flow rate. For example, the Essity factory in Kawerau, New Zealand converted both its hood systems and drum dryers to run on geothermal steam, replacing components that interacted directly with process heat delivery.
- **Help developers understand industrial customers.** Most developers are experienced in electricity generation, not in supplying process steam to industrial users. Sites like the Kawerau Industrial Park highlight challenges such as meeting varying steam pressures and flow rates across facilities. Demonstration projects can help clarify service needs and standardize heat-as-a-service offerings.
- **Prove long-term performance.** Maintaining steady heat output over time requires active wellfield management. Circulating fluid underground can change reservoir heat, pressure, and flow rates. While conventional geothermal sites use techniques like reinjection, flow balancing, and drilling "make-up wells" to sustain operations for decades, these practices still need to be tested and adapted for next-generation systems which have only recently cleared their first year of operation.

Early demonstration projects could begin with industrial retrofits near existing conventional geothermal wells, such as breweries, dairies, or food dehydrators, where resource risk is lower. Demonstration projects could also help assess the feasibility of cost-saving measures such as leveraging abandoned oil and gas wells for next-generation geothermal.

Projects should be paired with robust documentation of best practices and technical lessons — resources that are currently lacking for geothermal heat. Over time, this real-world data will be essential for de-risking investments, informing project finance models, and providing a foundation for policy and permitting reform. For geothermal heat to scale, demonstration projects must become the bridge between technical feasibility and commercial deployment.

4.4 Targeted Policy Support

The following policy interventions can help accelerate development and deployment of geothermal heat for industry:

4.4.1 Expand Incentives for Direct Heat Projects

Grants and tax credits can improve the financial outlook for geothermal developers and industrial users alike. The Infrastructure Investment and Jobs Act allocated $84 million for next-generation geothermal demonstration projects, helping advance enhanced geothermal drilling and reservoir engineering. With commercial pilot projects now underway, the next step could be public loan programs or milestone-based funding tied to project delivery targets.[7]

In the electricity sector, tax credits have been critical in accelerating clean technology deployment. Thermal energy could use similar mechanisms. A clean heat investment tax credit (ITC) would help cover the upfront cost of building new projects, while a clean heat production tax credit (PTC) would provide an incentive for every unit of clean heat the facility produces. These credits would help lower barriers to entry, attract investment, and accelerate deployment of geothermal for direct heat applications.

4.4.2 Streamline Permitting and Environmental Reviews

Geothermal projects can face significant delays due to permitting hurdles. In some cases, a single geothermal project may trigger multiple National Environmental Policy Act (NEPA) reviews. In 2019, the DOE GeoVision report estimated project timelines at 8 to 10 years for geothermal systems.

In contrast, oil and gas developers often receive categorical exclusions that exempt them from certain reviews, despite having much more severe environmental impacts than geothermal projects. Granting the same exclusions to geothermal could accelerate timelines by 2–6 years. The Bureau of Land Management has already finalized exclusions for geothermal resource confirmation and is considering further streamlining for indirect evidence of geothermal resources.

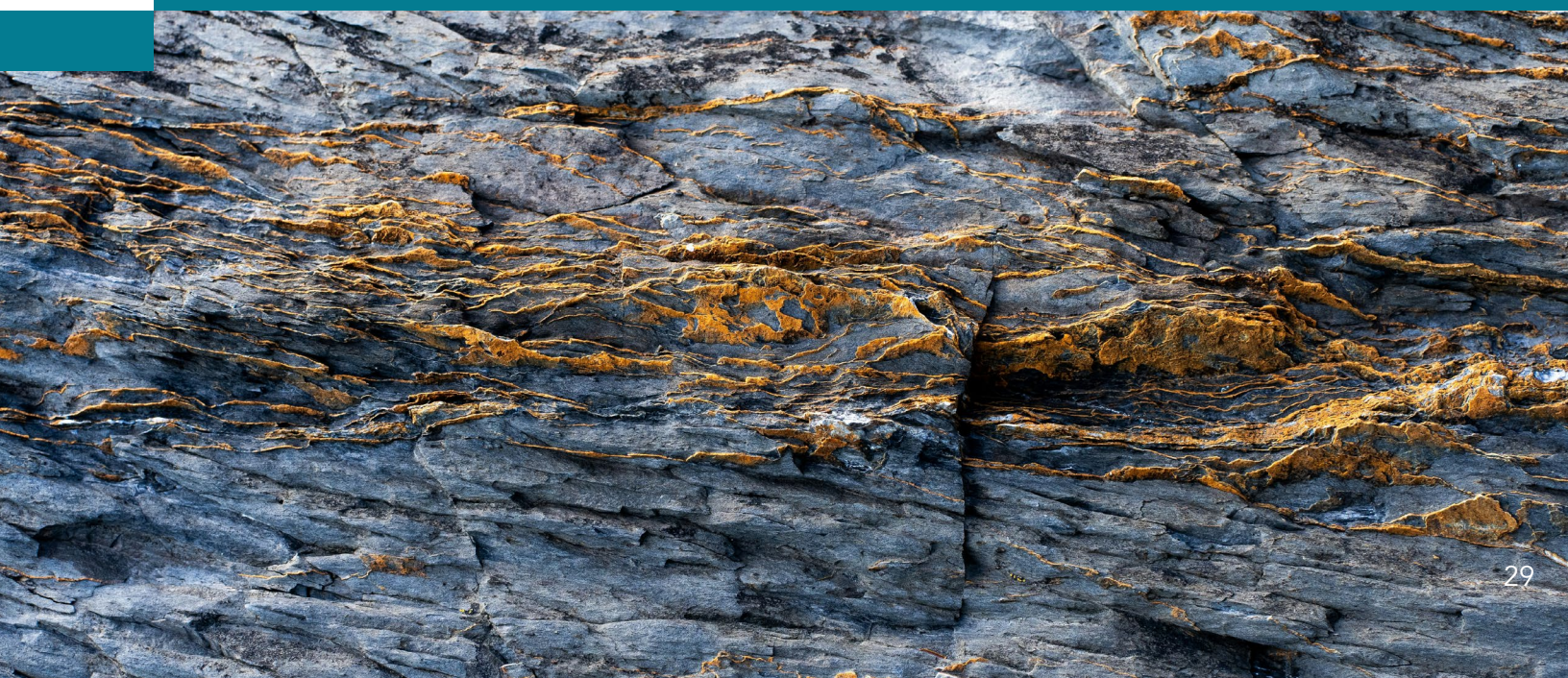
On non-federal lands, such as state, local, or privately owned properties, permits may be inconsistent or unclear. Questions about reusing spent oil wells or subsurface rights vary widely across jurisdictions. Federal guidance could help harmonize practices and provide a clearer regulatory roadmap.

[7] Milestone-based funding means that funding is delivered in stages when a project meets certain pre-specified targets. This reduces the government's exposure to costs if a project fails. It was used to support the development of private rocket technology and COVID-19 vaccines. See Datta and George (2023) for more explanation.

4.4.3 Mitigate Risk with Public Cost-Sharing and Insurance

Exploration risk remains one of the largest barriers to geothermal development. Public programs that co-fund exploration or insure against well underperformance can encourage investment and reduce capital constraints.

Countries like Kenya and France offer models: Kenya's public utility co-finances exploration, while France subsidizes first-well drilling and provides long-term reservoir performance insurance. The European Union's GEORISK initiative also provides risk coverage through public insurance. Adapting these programs for next-generation geothermal in the U.S. could unlock more private capital.



5. INDUCED SEISMICITY & ENVIRONMENTAL CONSIDERATIONS

While geothermal energy has one of the lowest environmental footprints of any energy source, some localized impacts require careful attention. The most frequently cited concern is induced seismicity, along with site-specific considerations related to fluid chemistry, emissions, and water use.

5.1 Seismicity

Induced seismicity can occur when fluids are injected underground at high pressure to create or expand fractures in hot rock. This is a necessary part of many next-generation geothermal systems, which rely on hydraulic stimulation to access deep, low-permeability heat resources. In some international projects, fluid injection has led to measurable seismic events at the surface, prompting concerns around fault activation and operational safety.

To mitigate this risk, the DOE developed a Protocol for Addressing Induced Seismicity. The protocol includes pre-drilling site mapping, ongoing seismic monitoring, community engagement, and a "traffic light" system that guides injection activity in response to observed seismicity. These best practices have been widely adopted for U.S. geothermal projects on federal land and have successfully prevented significant seismic incidents for over a decade. Continued improvements in real-time reservoir monitoring, coupled with better fault modeling tools, would further reduce risk. Expanding regulation so that all geothermal projects must abide by this protocol – not just federally funded ones – would also help to reduce seismicity risk.

5.2 Particulate Emissions

Open-loop geothermal systems may bring dissolved minerals and gases to the surface, depending on site geology and fluid composition. While this can include substances like silica or hydrogen sulfide, most geothermal plants are equipped with separators, steam scrubbers, or reinjection systems that prevent these compounds from entering the environment or interfering with equipment. Similar measures can be used in conjunction with heat exchangers at industrial heat sites to ensure that particulates stay underground and do not interfere with industrial processes.

5.3 Water Use

Next-generation geothermal systems – EGS specifically – use water during reservoir stimulation to create hydraulic fractures underground. Some water is also used during drilling to cool the equipment.

Once a well is operational, the circulating geothermal fluid is re-injected into the ground. This means that after drilling, the geothermal system does not actually consume groundwater. Additionally, geothermal doesn't require freshwater – these systems can make use of "degraded" water sources such as brackish water, treated wastewater, or saline aquifers. Within the facility itself, a geothermal system would not increase water use unless other changes were made in tandem, such as swapping out a direct combustion process with steam.

In fact, geothermal conversions could save water on net. This is because hydraulic fracturing for natural gas uses similar amounts of water as EGS. But looking at energy yield per well, Fervo Energy estimates that it has much lower water use per MWh at its geothermal power sites than coal- and natural gas-fired power plants. Furthermore, unlike oil and gas drilling projects which typically use chemical additives in fracking fluids, geothermal drilling uses low-toxicity stimulation fluids. To date, there are no known instances of groundwater contamination from geothermal development in the United States.

5.4 Responsible Geothermal Development

Ensuring strong environmental outcomes will require clear permitting guidance, robust monitoring frameworks, and consistent use of best practices. As deployment grows, regulators may consider codifying DOE's seismicity protocol or issuing standards for site characterization and fluid management—steps that would help safeguard communities while supporting responsible geothermal development.

6. NEXT STEPS: MAPPING GEOTHERMAL HEAT FOR INDUSTRY

This report highlights the potential of geothermal energy to decarbonize steam and hot water generation for industrial heat. With a constant, zero-emissions heat supply and a growing set of commercial technologies, next-generation geothermal can play a role in providing clean heat for industry. In this report we have identified solutions to overcome deployment barriers, including high capital costs, development risk, and equipment integration. Targeted policy support can accelerate adoption.

However, we also must understand which areas and facilities are best suited for geothermal deployment. To address this gap, *The 2035 Initiative* is conducting a national, facility-level assessment to evaluate geothermal's role in industrial decarbonization. This work is part of a broader project to model decarbonization pathways for industrial process heat using **plant- and unit-level engineering archetypes,** beginning with three major sectors: chemicals, food and beverages, and pulp and paper.

As part of this analysis, we are developing a **geothermal suitability layer** that integrates:

- Spatial data on subsurface temperatures and geothermal resource quality, drawn from GeoMap by Project InnerSpace
- Locations of active industrial facilities, drawn from national manufacturing datasets
- Estimated energy and mass balances at the unit process level
- Technical requirements for integrating geothermal with in-plant systems (e.g. heat exchangers, steam loops, process retrofits)

This modeling framework will identify which facilities have both the **geologic potential** and **process compatibility** to adopt geothermal heat. By pairing facility archetypes with subsurface and siting data, we can evaluate what it would take, technically and economically, for each site to switch to geothermal for their process heating needs.

The result will be a **geothermal decarbonization roadmap** that pinpoints:

- Where geothermal systems are most viable for industrial heat
- Sector-specific infrastructure upgrades needed
- Financial, policy, and deployment recommendations to unlock geothermal

This work will help policymakers, advocates, and geothermal developers prioritize opportunities that deliver the greatest benefits per dollar invested. It will also support targeted demonstration projects in high-potential geographies. Expected in late 2025, this analysis will serve as a **decision-support tool** for scaling geothermal industrial heat across the United States, aligned with the broader goal of decarbonizing the industrial sector.

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