

# Geothermal Energy

## Geothermal Resource and Potential

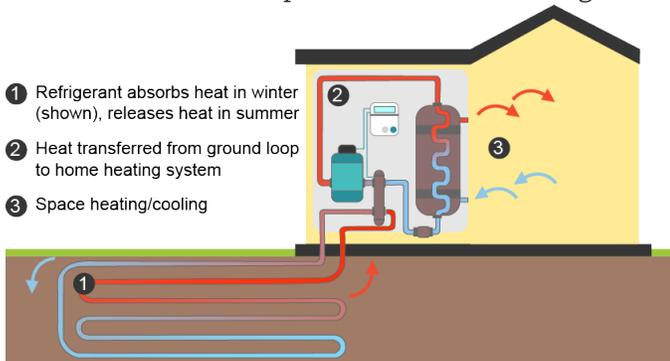
- Geothermal energy derives from Earth’s natural heat.<sup>1</sup> It exists in high enthalpy (volcanoes, geysers) and low enthalpy forms (heat stored in rocks in the Earth’s crust). Most heating and cooling applications utilize low enthalpy heat.<sup>2</sup>
- Geothermal energy has two primary applications: heating/cooling and electricity generation.<sup>1</sup> Ground source heat pumps (GSHPs) use 75% less energy than traditional heating and cooling systems.<sup>3</sup>
- The U.S. has tapped less than 1% of its geothermal electricity resources; the majority is accessible through Enhanced Geothermal System technology.<sup>4,5</sup>
- Improving exploration and management technology could reduce development costs and risks, potentially increasing geothermal power generation 26-fold to 90 GW of always-on, flexible electricity generation capacity by 2050.<sup>18,37</sup>
- The U.S., Indonesia, Turkey, Philippines, and New Zealand accounted for over 67% of global installed geothermal capacity in 2023.<sup>6</sup> The U.S. leads with 4 GW of capacity installed in 2022 and generation growing at 3% annually.<sup>7</sup> 95% of U.S. capacity is in California and Nevada.<sup>7</sup>
- Geothermal electricity generation is projected to increase from 15.7B kWh in 2024 to 55.9B kWh by 2050.<sup>8,9</sup>

## Geothermal Technology and Use

### Direct Use and Heating/Cooling

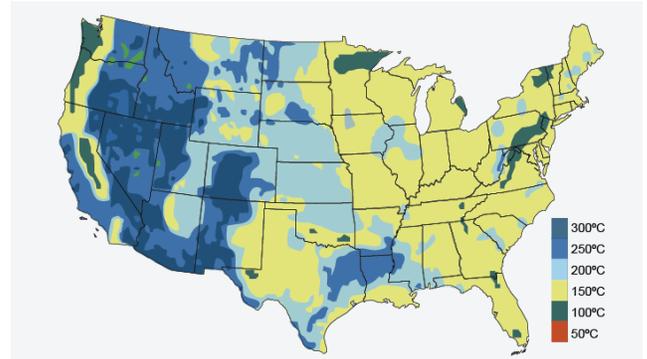
- GSHPs are the primary method for direct geothermal use, utilizing shallow ground as an energy reservoir that maintains nearly constant temperature.<sup>10</sup>
- GSHPs transfer heat from buildings to the ground during cooling season and from the ground to buildings during heating season.<sup>10</sup>
- The U.S. installed capacity of geothermal heating and cooling represents less than 10% of market potential.<sup>18</sup>

### Geothermal Heat Pump for Residential Heating<sup>11,21</sup>



- Direct-use applications include space and district heating, greenhouses, aquaculture, and commercial and industrial processes.<sup>12</sup>

### U.S. Geothermal Resources at 10 km Depth<sup>13</sup>



## Electricity Generation

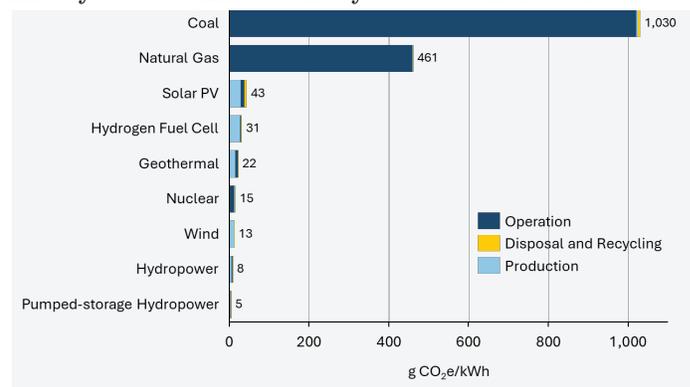
- In 2024, the U.S. had the most installed geothermal capacity in the world at 19,499 GWh, representing 0.4% of U.S. electricity generation.<sup>8,6</sup>
- Hydrothermal energy from underground water reservoirs is the main thermal source for electricity generation. Water is pumped as steam to the surface to spin electricity-generating turbines.<sup>14</sup>
- Dry steam plants route steam directly from geothermal reservoirs through turbines to drive generators.<sup>14</sup>
- Flash steam plants pump high-pressure hot water into low-pressure surface tanks, causing rapid “flashing” to steam that spins turbine generators. These are the most common type of geothermal plants.<sup>14</sup>
- Binary cycle plants use separate closed-loop systems for geothermal water and working fluid. Heat exchangers transfer heat to the working fluid, causing it to flash to steam to power turbine generators.<sup>14</sup>
- Enhanced Geothermal Systems (EGS) technology under development could expand geothermal use to new geographic areas. EGS creates subsurface fracture systems to increase rock permeability, allowing injection of heat transfer fluid (typically water) that is heated by the rock and returned to the surface for electricity generation.<sup>15</sup>
- The technical potential of new geothermal systems is second only to solar PV among renewable technologies and sufficient to meet global electricity demand 140 times over.<sup>34</sup>
- The U.S. DOE estimates over 100 GW of potential geothermal electric capacity in the continental U.S.—nearly 10% of current electricity capacity and 40 times current installed geothermal capacity.<sup>15</sup>

## Installation, Manufacturing, and Cost

- The main stages of geothermal power development are resource exploration, drilling, reservoir/plant development, and power generation.<sup>16</sup>

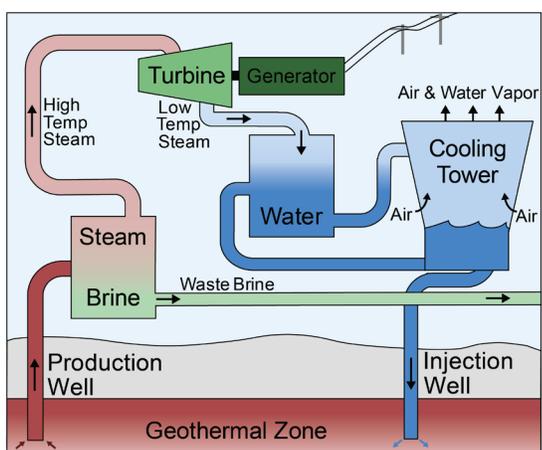
- Geothermal power projects have higher capital costs (\$3,000-\$6,000/kW) compared to onshore wind or utility-scale solar (\$1,700-\$2,100/kW).<sup>18</sup> However, geothermal offers low operating costs and high capacity factors of >90% (ratio of actual power production to production potential).<sup>16,18</sup>
- In 2025, geothermal electricity cost \$88/MWh, nearly half the price of coal or gas but about \$10-\$20 more than onshore wind and solar.<sup>39</sup>
- Geothermal plants qualified for the federal Production Tax Credit (PTC) as of May 2020. The 2023 Inflation Reduction Act renewed and expanded the PTC, providing up to 2.75¢/kWh for geothermal electricity generation.<sup>19</sup>
- If deep cost reductions for next-generation geothermal can be achieved, total investment could reach \$1T cumulatively by 2035 and \$2.5T by 2050.<sup>34</sup>

Life Cycle GHG Emissions by Power Generation<sup>27</sup>



- Some geothermal facilities produce solid waste that must be disposed of in approved sites, though some by-products can be recovered and recycled.<sup>26</sup>

Flash Steam Geothermal Power Plant<sup>20</sup>



## Environmental Impacts

- Geothermal power plants do not burn fuel but may release small amounts of SO<sub>2</sub> and CO<sub>2</sub>. They emit 97% less acid rain-causing sulfur compounds and 99% less CO<sub>2</sub> than similarly sized fossil fuel plants.<sup>35</sup>
- Most geothermal plants inject used geothermal steam and water back into the earth, helping renew the resource and reduce emissions.<sup>35</sup>
- Binary cycle plants consume 0.24-4.21 gal of water/kWh while flash plants use 1.59-2.84 gal/kWh, compared to 15 gal/kWh for thermoelectric plants in 2015.<sup>22,23</sup>
- Each year, U.S. geothermal electricity offsets emissions of 22 Mt of CO<sub>2</sub>, 200,000 Mt of nitrogen oxides, and 110 kt of particulate matter from coal plants.<sup>18</sup>
- The U.S. DOE is actively funding research into combining carbon capture and storage with geothermal energy production, although the risks of long-term and high-volume geologic carbon sequestration are uncertain.<sup>24,25</sup>

## Solutions and Sustainable Actions

### Funding Opportunities

- With a capacity factor over 90%, geothermal electricity generation could offset coal, natural gas, or nuclear power as baseload supply in the electricity market.<sup>17</sup>
- The IRA provides federal tax credits covering up to 30% of qualifying residential GSHP system costs (depending on construction date) from 2006 through 2034.<sup>30,36</sup>
- Renewable Portfolio Standards (RPS) require electricity providers to obtain a minimum fraction of energy from renewable resources.<sup>28</sup>
- Renewable Energy Certificates (RECs) are sold by renewable energy producers in addition to the electricity they produce; for a few cents per kWh, consumers can purchase RECs to “offset” their usage and help renewable energy become more competitive.<sup>29</sup>
- Around 850 utilities in the U.S. offer customers the option to purchase renewable energy, or “green power.”<sup>31</sup>
- Many companies purchase renewable energy as part of their environmental programs. Microsoft, Google, T-Mobile, Walmart, and AT&T were the top five users of renewable energy as of July 2024.<sup>32</sup>

Steamboat Hills Geothermal Power Plant, Nevada<sup>33</sup>

