Chapter 3

Geothermal Direct-Use Opportunities: Meeting Heating and Cooling Demand Across the Commonwealth

J. Wen, R. Madsen (Contributing Author)

Geothermal energy offers a key opportunity for Pennsylvania's industrial and agricultural sectors. Lancaster, Montgomery, and several other counties with high thermal energy demand are well-positioned to harness geothermal resources and promote sustainable growth, thereby increasing energy resilience and reducing the state's emissions.

INTRODUCTION

As described in *Chapter 2: Where to Develop Geothermal*, many areas of Pennsylvania have a subsurface that can provide low to medium levels of heat—temperatures that could support a broad range of direct geothermal uses in industry and agriculture. This chapter outlines the opportunities for those sectors; capitalizing on them could help Pennsylvania continue its energy leadership and expand jobs for its existing energy workforce while providing abundant heat to vital economic sectors in the Commonwealth.

GEOTHERMAL DIRECT-USE IN INDUSTRY AND AGRICULTURE AROUND THE WORLD

In regions that have conventional hydrothermal resources, geothermal direct-use is already a fairly common solution for meeting industrial and agricultural thermal demands. In the United States, direct-use geothermal energy is mostly used in the food and beverage sector, for agricultural purposes, and for district heating. An onion dehydration plant in Nevada uses heat from the nearby Brady Hot Springs

geothermal power plant;[1] potatoes in Oregon are dried via geothermal energy; Utah has one of the nation's largest geothermally heated greenhouses, growing poinsettias and other flowers. Many places in the U.S. use geothermal energy to melt snow and ice on roads and sidewalks. (See Lund, 2020 for more examples.)

Around the world, engineers have developed more complex geothermal direct-use applications. Iceland is perhaps the most well-known user of geothermal power and heat—harnessing it for power generation, district heating, and direct-use industrial and agricultural applications via a cascading combination of heat and power (see Figure 3.1). That said, the largest direct-use geothermal facility in the world is in New Zealand: the Norske Skog Tasman pulp and paper mill uses geothermal fluids to generate steam at 340°F (171°C) for paper drying, evaporators, and electricity generation.[2] There's also a Māori-owned dairy in New Zealand that uses geothermal to dehydrate milk powder.[3] In the Netherlands, the large greenhouse industry—which historically used as much as 8 percent of the nation's natural gas—began converting many of its operations to geothermal around 2010, and recent geopolitical conflict has accelerated its use.[4]

THERMAL ENERGY DEMAND IN PENNSYLVANIA

Overview of State Thermal Demand

Pennsylvania is one of the largest energy-consuming states in the country (see Table 3.1). In fact, the Commonwealth ranks in the top ten for energy use across the residential, commercial, industrial, and transportation sectors. Its industrial sector—manufacturing, mining, construction, and agriculture—

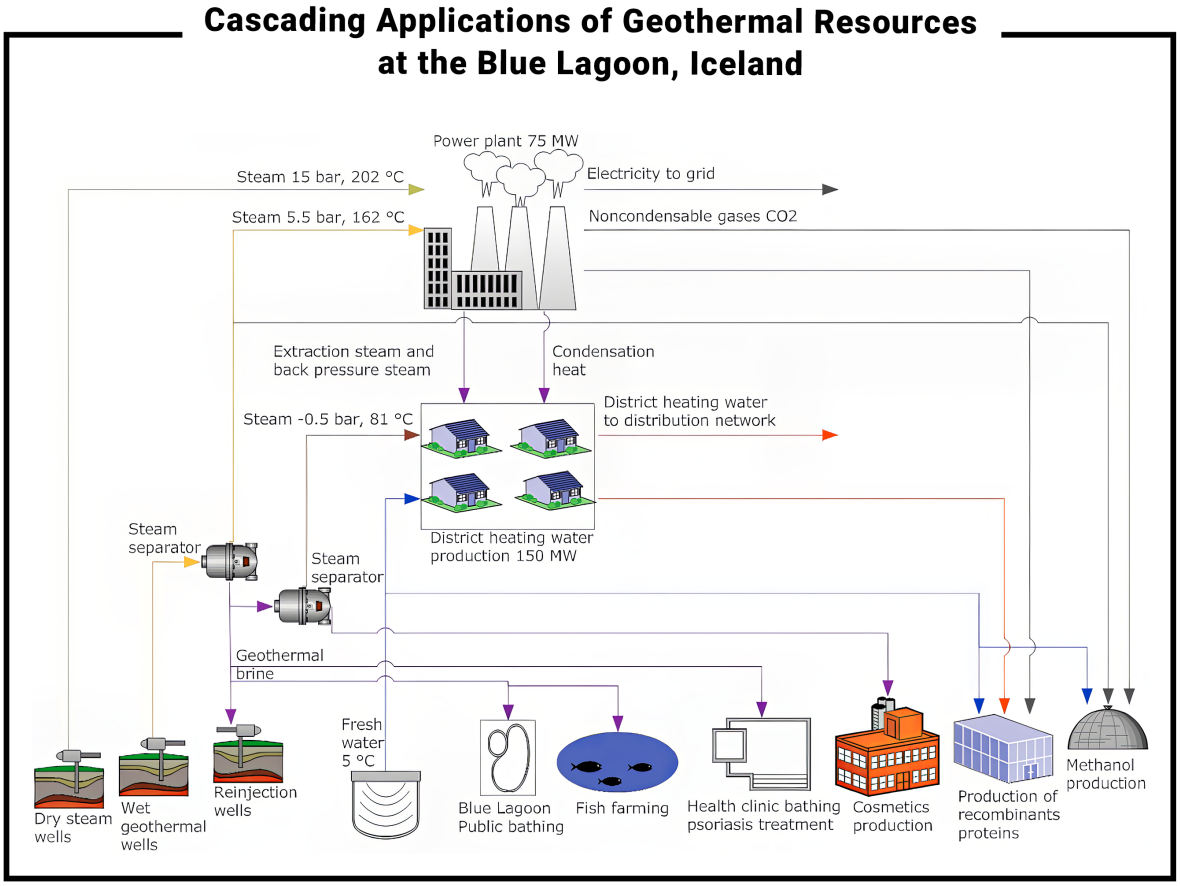

Figure 3.1: Source: Moya, D., Aldas, C., & Kaparaju, P. (2018). Geothermal energy: Power plant technology and direct heat applications. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2018.06.047

is the largest source of energy consumption in the Commonwealth (as shown in Figure 3.2) and ranks 4th for energy use in the nation. The independent research organization Rhodium Group estimates Pennsylvania's industrial energy consumption produces 45.05 million metric tons of carbon dioxide equivalent (CO_2e) per year. That amounts to as much as is produced by 11 coal-fired power plants.[5]

Much of Pennsylvania's industrial energy is used for generating heat for manufacturing. According to the Manufacturing Energy Consumption Survey (MECS) for the Northeast Census Region, fuel for manufacturing in the Northeast consumed 813 TBtu of energy in 2018, of which thermal energy (boiler use and direct-use process heating) accounted for 39.9 percent or 324 TBtu, as shown in the excerpt of MECS data in Table 3.2. Including combined heat and power (CHP) increases the amount to 448 TBtu (55.1 percent), however it is challenging to separate out how much of CHP is attributed to heat for processes as opposed to generating electricity.

Unfortunately, MECS data is not released on a state-by-state basis, so no exact figures for Pennsylvania exist. However, in 2018, the National Renewable Energy Laboratory (NREL) estimated Pennsylvania-specific manufacturing fuel consumption by combining the 2014 MECS with Census Bureau data.[6] The dataset provides thermal energy use estimates, broken down by industry and end use (boilers, CHP / cogeneration, and process heating). NREL's dataset indicates that thermal fuel consumption for Pennsylvania manufacturing accounted for 270.14 TBtu of energy in 2014.[7]

Along with manufacturing, agriculture also uses a significant amount of heat, both to keep greenhouses warm and to dry products before they are sent to market. As described in more detail later in this chapter, some of the counties that use the most heat for agriculture in the nation are in Pennsylvania.

2022 Total Energy Consumption Estimates by End-Use Sector, Ranked by State

Rank	Residential		Commercial		Industrial		Transportation		Total	
	State	Trillion Btu	State	Trillion Btu	State	Trillion Btu	State	Trillion Btu	State	Trillion Btu
1	Texas	1,633.4	Texas	1,546.1	Texas	7,338.5	Texas	3,268.8	Texas	13,760.6
2	California	1,203.7	California	1,193.1	Louisiana	2,950.5	California	2,915.8	California	6,882.4
3	Florida	1,182.6	Florida	969.8	California	1,539.3	Florida	1,738.8	Florida	4,325.0
4	New York	1,024.8	New York	930.4	**Pennsylvania**	**1,445.3**	New York	1,128.1	Louisiana	4,246.0
5	Illinois	925,5	Illinois	743.9	Indiana	1,180.0	Illinois	892.8	**Pennsylvania**	**3,736.9**
6	**Pennsylvania**	**880.7**	Virginia	734.1	Ohio	1,136.8	Georgia	875.4	Illinois	3,675.6
7	Ohio	844.5	Ohio	651.4	Illinois	1,109.0	Ohio	871.8	Ohio	3,503.2
8	Michigan	753.9	Michigan	579.0	Alabama	774.3	**Pennsylvania**	**852.5**	New York	3,452.7
9	Georgia	697.2	**Pennsylvania**	**559.4**	Iowa	771.3	N. Carolina	806.5	Georgia	2,836.2
10	N. Carolina	672.6	N. Carolina	558.3	Georgia	738.9	Louisiana	755.9	Michigan	2,706.8

Table 3.1: Source: U.S. Energy Information Administration (EIA), Table C11, eia.gov

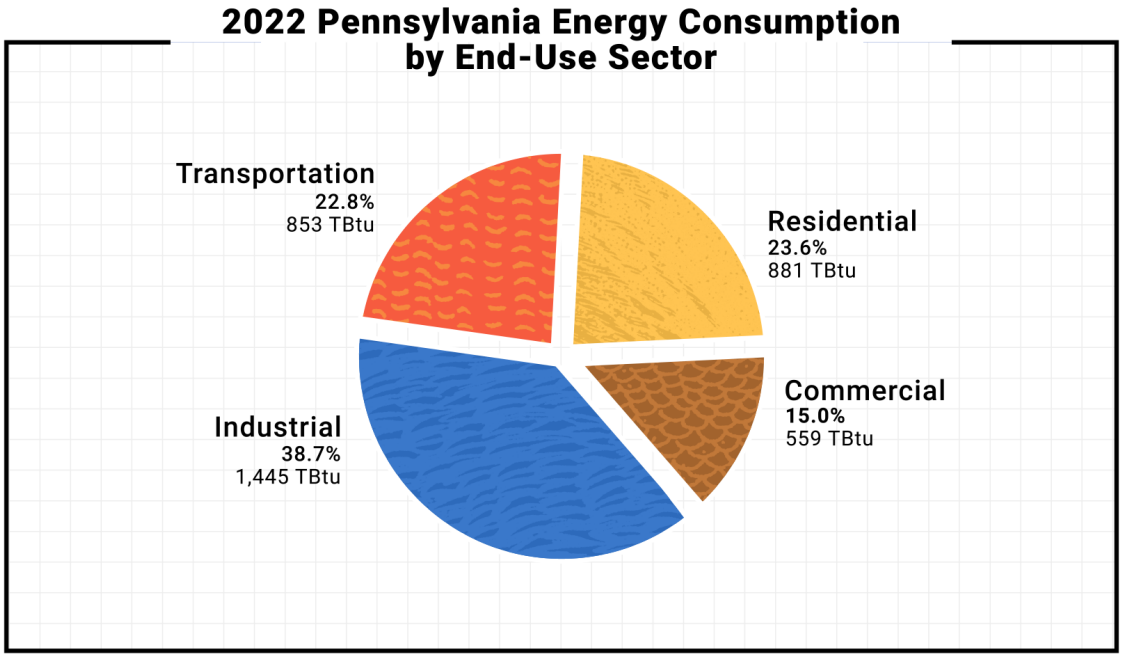

Figure 3.2: Source: EIA, State Energy Data System, eia.gov

Selected Manufacturing End Uses of Fuel Consumption

End Use	Electricity	Fuel Oil	Distillate & Diesel	Natural Gas	Gas Liquids	Coal	Total	Percentage of Total
Indirect Uses Boiler Fuel	6	2	1	177	1	13	200	24.6%
Conventional Boiler Use	6	1	*	67	1	1	76	9.3%
CHP and/or Co-generation	-	1	1	110	*	12	124	15.3%
Direct Uses - Total Process	200	1	10	242	2	6	461	56.7%
Process Heating	31	1	0	209	2	5	248	30.5%
Other End Use	70	1	4	71	6	0	152	18.7%
Total - All Uses	**276**	**4**	**15**	**490**	**9**	**19**	**813**	**100.0%**
Total - Thermal End Uses	37	2	0	276	3	6	324	39.9%

Table 3.2: Table shows subset of 2018 Manufacturing End Uses for the Northeast Census Region. Blank cells indicate total consumption of less than 0.5 Tbtu. "Q" cells indicate a standard error of greater than 50%. "Other End Use" combines all other end uses not explicitly detailed. Source: Adapted from EIA's Manufacturing Energy Consumption Survey (MECS), Table 5.8, eia.gov

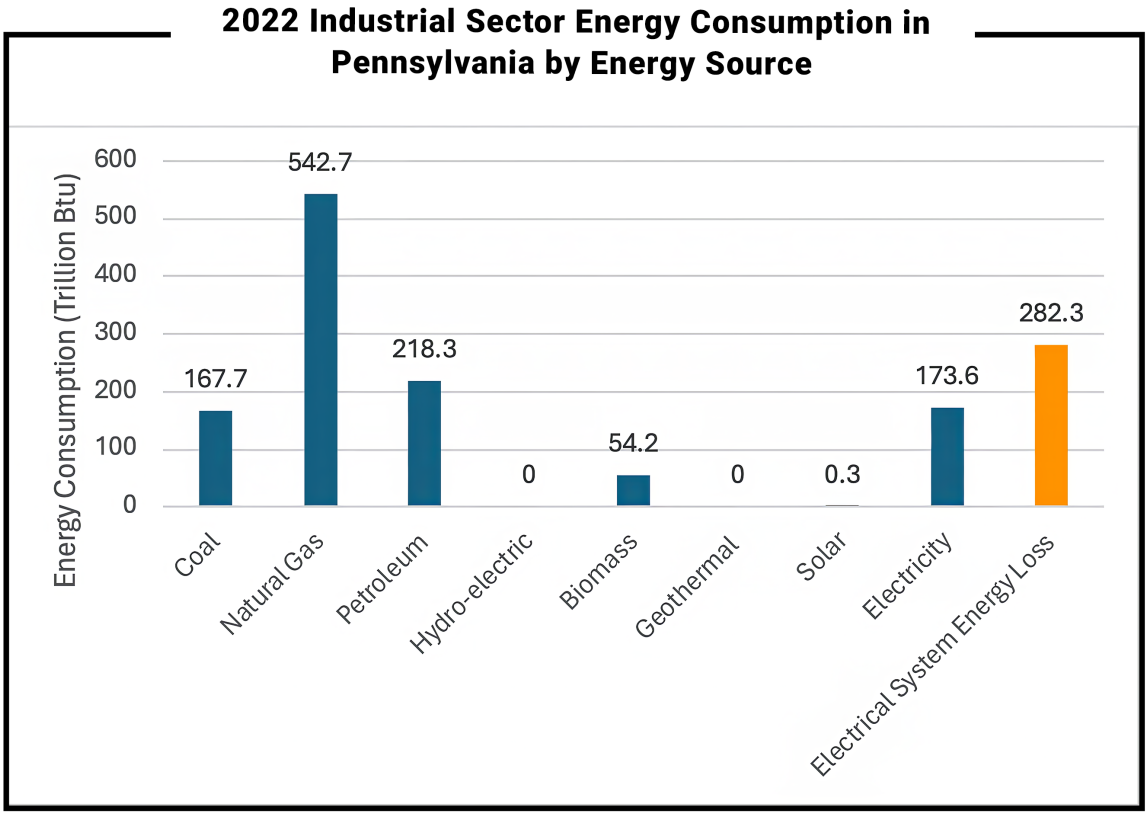

Figure 3.3: All units in Trillion Btu. Source: Based on EIA Table C7, 2022. eia.gov

Currently, almost all Pennsylvania industrial heat, whether for manufacturing or agriculture, is generated by burning fossil fuels. Figure 3.3 provides a detailed breakdown of Pennsylvania's 2022 industrial sector consumption by energy source. As shown, natural gas is the predominant energy source, powering nearly 40 percent of Pennsylvania's industry (542.7 TBtu), followed by petroleum (15 percent), electricity (12 percent), and coal (11.6 percent). Demand growth from AI and data centers is expected to substantially drive up industrial sector electricity consumption.[8] Notably, Pennsylvania's industrial sector currently uses no geothermal.

Manufacturing Process Heating and Cooling by Temperature Range, Industry, and County

Countless different manufacturing processes consume thermal energy, and their temperature needs can vary widely, from milk pasteurization on the low end to cement manufacturing on the high end.

The NREL dataset includes some process temperatures, but it is primarily a breakdown of fuel consumption by county. The authors of this chapter combined that dataset with a more granular breakdown of process temperatures from Brown, et. al (1985)—which collected hyper-granular temperatures for 108 different manufacturing processes, including industrial cooling.[9] This chapter therefore goes beyond the NREL analysis to identify the temperatures of manufacturing process demand in each of Pennsylvania's counties.[10] Reviewing data on temperatures and energy consumption for process heating and cooling across Pennsylvania's industrial landscape reveals distinct temperature needs in different manufacturing sectors across the Commonwealth (see Figure 3.4). The highest demand is seen at temperatures above 450°C, but there is also significant demand below 250°C. As of 2014, Pennsylvania had about 36 TBtu of industrial thermal energy consumption in the 100-149°C range, 14 TBtu in the 150-199°C range, and 29 TBtu in the 200-249°C range.

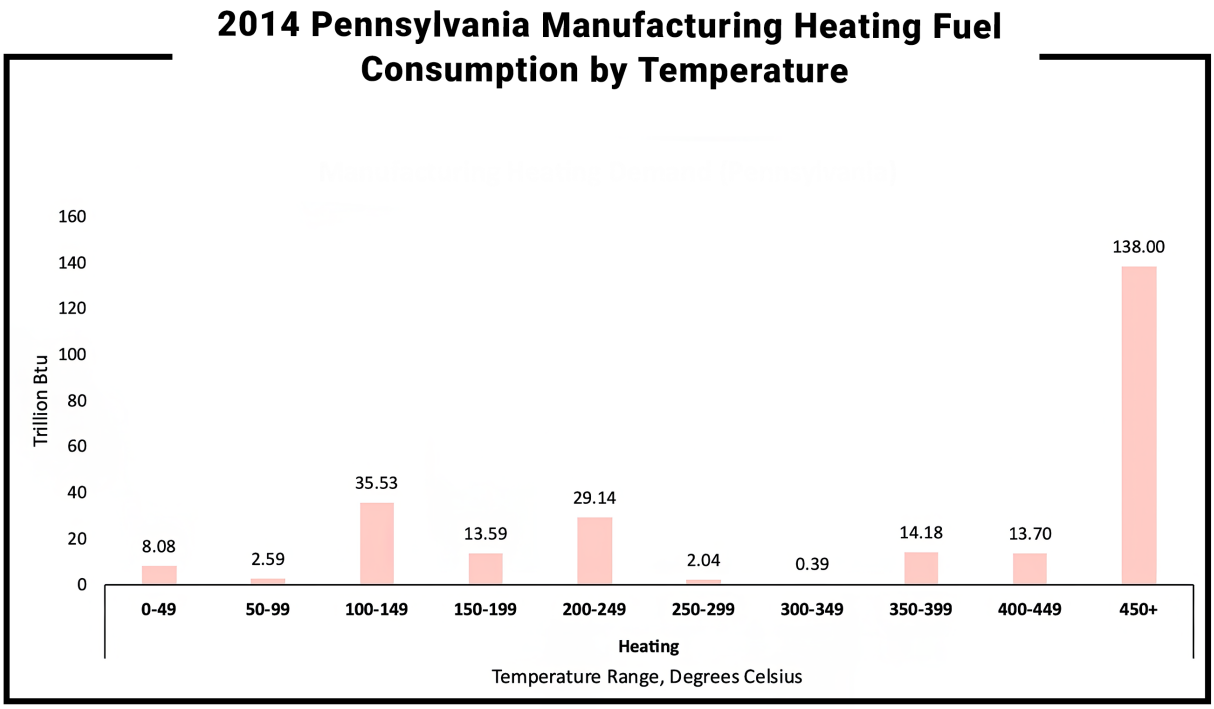

Figure 3.4: Authors' analysis of NREL dataset combined with process temperature data.

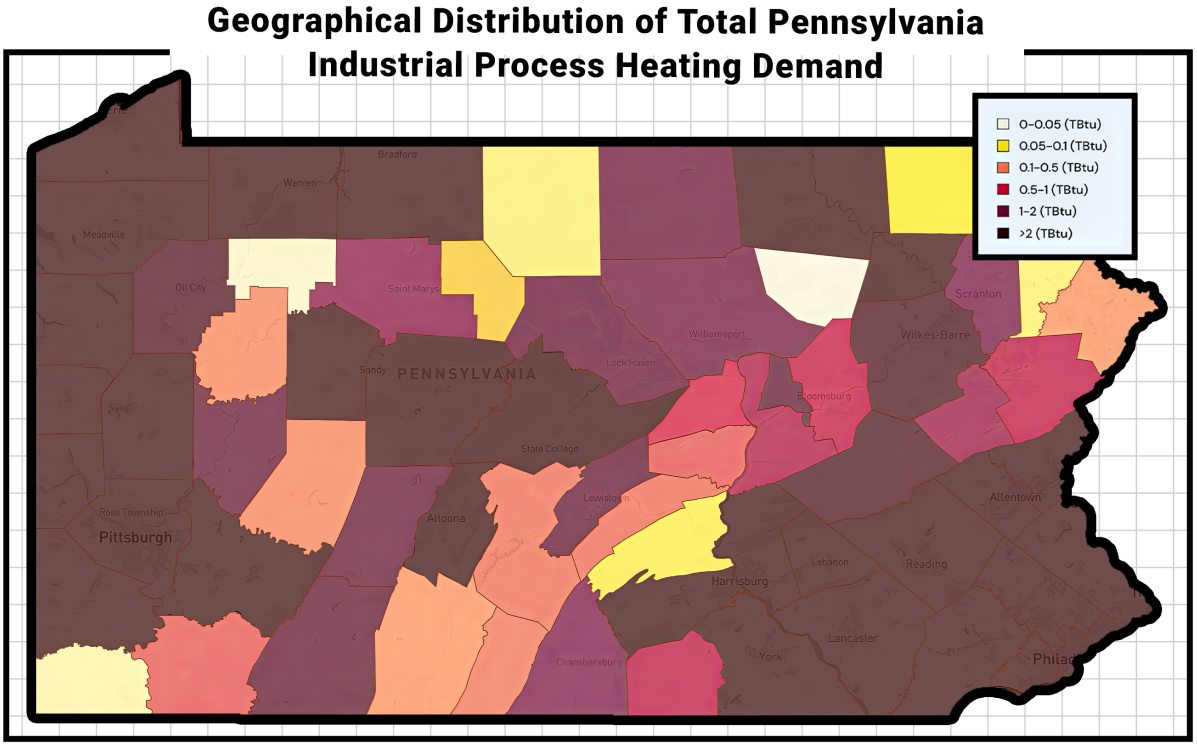

Figure 3.5: Authors' analysis of NREL dataset combined with process temperature data. Source: GeoMap

Aggregate demand is relatively distributed across Pennsylvania, with concentrations in the southeast, the central part of the Commonwealth, and along the western and northern border counties (see Figure 3.5).

While geothermal may be used for processes with higher temperatures, current technology and Pennsylvania's subsurface make geothermal especially suitable for use in lower-temperature applications, from 0 to 150°C. In Pennsylvania, industrial processes in these temperature ranges are concentrated in Wyoming, Montgomery, Philadelphia, Dauphin, Delaware, Lancaster, and York counties, all of which have 2 TBtu or more of demand in that range (see Table 3.3).

At these lower temperatures, Pennsylvania's manufacturing sector heating demand is dominated by several industries (see Table 3.4). In the 100-149°C range, the greatest demand comes from paper mills, which use steam and hot water in manufacturing. This demand is primarily located in Wyoming County.[11] Another significant source of demand in this range is the pharmaceutical and medicine sector concentrated in Montgomery County, which requires precision heating to maintain product integrity. There is also a fair amount of food manufacturing that occurs in this temperature range and the lower range of 50-99°C. In addition, while most processes in petroleum refineries need temperatures above 250°C, more than 35 percent of processes operate below that level, with 10 percent of consumption attributable to processes operating from 0 to 49°C. These low-temperature petroleum processes make up the majority of the process heating in Pennsylvania that occurs below 50°C.

Table 3.5 marries the data from the previous two tables (3.3 and 3.4) to show counties with high concentrations of demand in the 0 to 150°C range, broken down by industry. Doing so reveals clear concentrations. For example, in Wyoming County, pulp and paper mills appear to be the only meaningful source of 0 to 150°C demand. Philadelphia and Delaware counties show concentrations in petroleum and coal, followed by small fractions in pulp and paper mills. However, in Montgomery and Dauphin counties, the primary demand engines are pharmaceuticals and sugar and confectionary, respectively.

Counties with Highest Manufacturing Sector Heating Demand (0-150°C), TBtu

County	Demand (0-150°C)
Wyoming	5.64
Montgomery	4.65
Philadelphia	4.10
Dauphin	2.85
Delaware	2.52
Lancaster	2.26
York	2.07
McKean	1.61
Berks	1.44
Allegheny	1.40

Table 3.3: Authors' analysis of NREL dataset combined with process temperature data.

Online Data Exploration with GeoMap

*Much of the data presented in this analysis is available online through **GeoMap**, an interactive, open-source, and free platform on which individual users can explore and manipulate a variety of geothermal maps and relevant data, including temperature, depth, sources of energy demand, power plants, and more.*

Top 5 Pennsylvania Industries with Process Heating Demand (TBtu) in Selected Temperature Ranges (°C)

Industry	0-49	50-99	100-149
Paper (except Newsprint) Mills			8.71
Petroleum Refineries	6.74		
Dried and Dehydrated Food Manufacturing		0.85	2.59
Pharmaceutical Preparation Manufacturing			3.43
Reconstituted Wood Product Manufacturing			1.31
Other Snack Food Manufacturing		0.27	0.94
Toilet Preparation Manufacturing	0.21		
Adhesive Manufacturing	0.15		
Photographic Film, Paper, Plate, and Chemical Manufacturing		0.15	
Primary Aluminum Production	0.14		
Nonchocolate Confectionery Manufacturing		0.13	
Frozen Specialty Food Manufacturing	0.10		
Breweries		0.10	

Table 3.4: Authors' analysis of NREL dataset combined with process temperature data.

Agricultural Heating and Cooling by Temperature Range and County

The low heating and cooling temperature requirements of the agriculture sector in Pennsylvania make it an ideal candidate for ground-source heat pumps and geothermal direct-use. Heating demand in the sector is concentrated in the 0 to 99°C range, with 1.50 TBtu in the 0 to 49°C range and 5.89 TBtu in the 50 to 99°C range. Cooling requirements—for things such as food storage—are concentrated in the 0 to 24°C range, with a demand of 0.22 TBtu (see Figure 3.6).

As shown in Figure 3.7, thermal demand for Pennsylvania agriculture is geographically concentrated, with more than 1.1 TBtu of consumption in Lancaster County and another 1 TBtu in surrounding counties (York, Dauphin, Lebanon, Berks, Chester). These are some of the most heating-intensive counties for agriculture in the entire United States—in the top 1 percent—and are far and away the biggest counties for agricultural heat demand in the Northeast.

PROMISING COUNTIES AND INDUSTRIES FOR DIRECT-USE GEOTHERMAL DEVELOPMENT IN PENNSYLVANIA

The solutions to reduce emissions from industrial sector heat are still being developed, and include hydrogen, carbon capture and storage, and nuclear energy. In Pennsylvania, geothermal should also be part of the mix.

Process Heating Demand (0-150°C) for Selected Industries by Selected Counties (TBtu)

	Paper Mills	Petroleum & Coal	Pharma	Sugar & Confectionary	Other Food	Fruit & Veg.	Foundries	Soap & Cleaning
Wyoming	5.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Montgomery	0.00	0.00	3.19	0.06	0.05	0.03	0.01	0.02
Philadelphia	0.25	2.74	0.14	0.00	0.07	0.05	0.00	0.00
Dauphin	0.00	0.00	0.00	2.66	0.05	0.00	0.00	0.00
Delaware	0.31	1.60	0.01	0.02	0.00	0.01	0.00	0.00
Lancaster	0.00	0.00	0.01	0.32	0.14	0.04	0.07	0.02
York	0.29	0.00	0.02	0.00	0.82	0.23	0.07	0.00
McKean	0.00	0.96	0.00	0.00	0.00	0.00	0.00	0.00
Berks	0.28	0.00	0.02	0.32	0.05	0.12	0.09	0.01
Allegheny	0.00	0.01	0.07	0.04	0.05	0.65	0.08	0.01

Table 3.5: Authors' analysis of NREL dataset combined with process temperature data.

In *Chapter 2: Where to Develop Geothermal*, the authors provide insights into the easiest and most likely locations and depths necessary to develop geothermal resources. Overlaps between geothermal potential and low- to moderate-temperature industrial thermal demand may indicate which counties, and which industries, in Pennsylvania are likely best suited to take advantage of the Commonwealth's geothermal resources.

As noted, given current technology, it will be most economical in Pennsylvania to drill for geothermal at temperatures at or below 300°F (150°C). Combining the underlying data presented in this chapter and the information in Chapter 2, the maps in figures 3.8 through 3.10 illustrate the geographic distribution of industrial demand from 0 to 49°C, 50 to 99°C, and 100 to 149°C, overlaid with the most promising areas of geothermal potential in the Commonwealth.

As shown in Figure 3.8, thermal demand in the 0 to 49°C range and relatively favorable geothermal potential overlap in Delaware, Philadelphia, McKean, Butler, and Warren counties. As shown in Figure 3.9, there is only modest overlap of geothermal favorability and thermal demand in the 50 to 99°C range, though aggregate demand in this band is minimal. As shown in Figure

3.10, the 100 to 149°C band sees high concentrations of industrial heat overlapping with geothermal potential in Wyoming, Montgomery, and Lancaster counties.

Merging the aggregate geothermal favorability maps and the assessment of the industries within each county with thermal operating needs between 0 and 149°C can illuminate which industries in which counties might be best positioned to take advantage of geothermal energy. For example, petroleum and coal refineries in Philadelphia, Delaware, and McKean counties should look into using direct-use geothermal.[12] Low-temperature petroleum and coal processes might be suitable for geothermal energy use in Butler and Warren counties. Pharmaceutical manufacturing in Montgomery County may be especially suitable for direct-use geothermal, and the same is true for some greenhouses and other agricultural processes in York, Lancaster, and Chester counties.

Even outside the most geothermally favorable areas, ground-source heat pumps could be used across almost all of Pennsylvania for heating and cooling buildings, water heating, and refrigeration across industries.

CONCLUSION

Pennsylvania's thermal energy demand across the industrial and agricultural sectors presents a significant opportunity to diversify the Commonwealth's energy mix by taking advantage of geothermal. By leveraging low- to medium-temperature geothermal resources in the most favorable locations, Pennsylvania's manufacturers can meet their thermal energy needs while reducing emissions. The integration of geothermal energy into Pennsylvania's energy mix would not only support the Commonwealth's long-standing energy leadership but also promote sustainable economic growth. Pennsylvania's agriculture and manufacturing sectors are well-positioned to capitalize on this renewable energy resource for a more resilient future.

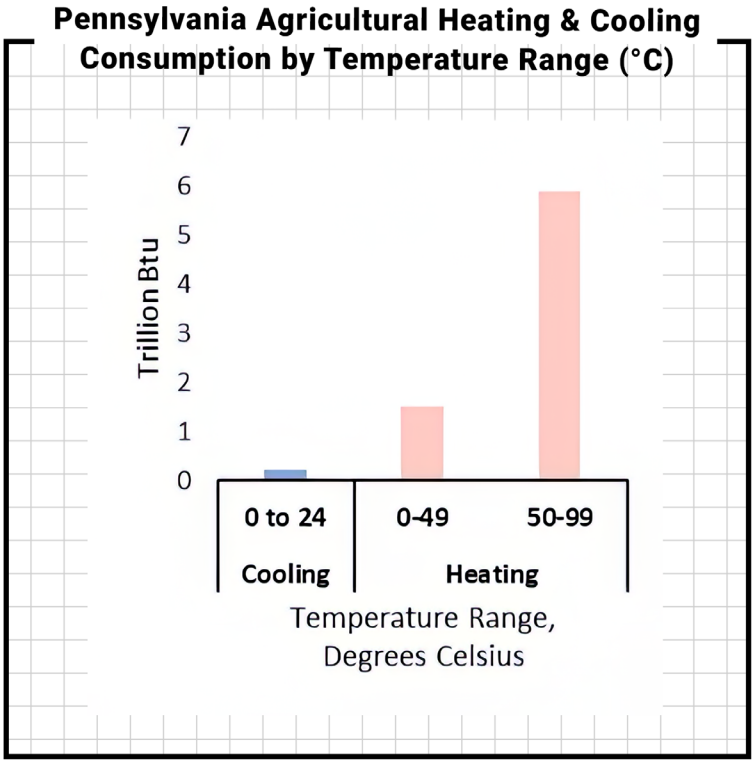

Figure 3.6: Authors' analysis utilizing NREL dataset combined with process temperature data.

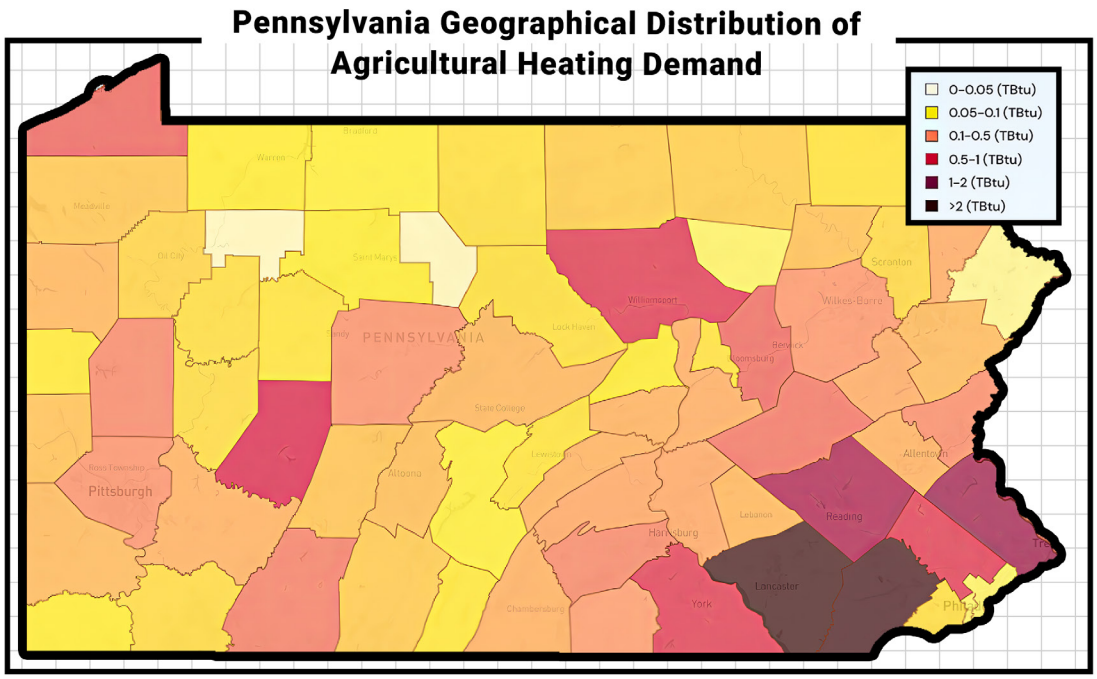

Figure 3.7: Source: GeoMap using NREL's Updated U.S. Low-Temperature Heating & Cooling Demand by County and Sector

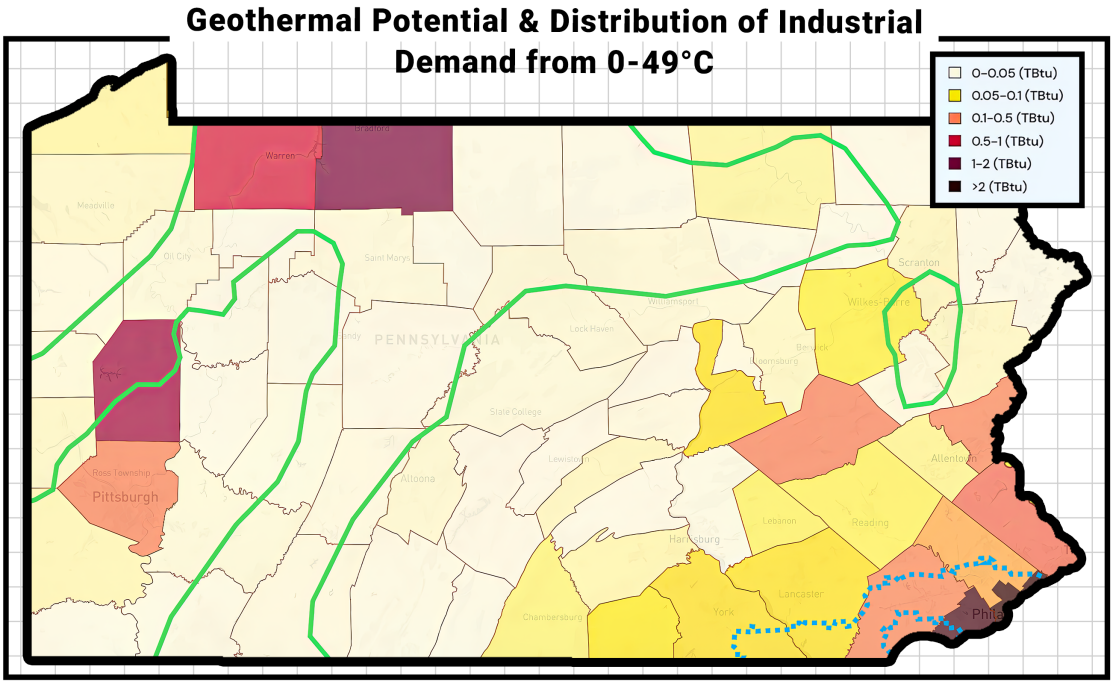

Figure 3.8: Pennsylvania's most favorable geothermal potential lies within the boundaries of the green lines, with additional exploration needed to confirm the favorability of areas within the blue line. Source: GeoMap and authors' analysis of NREL and process temperature data

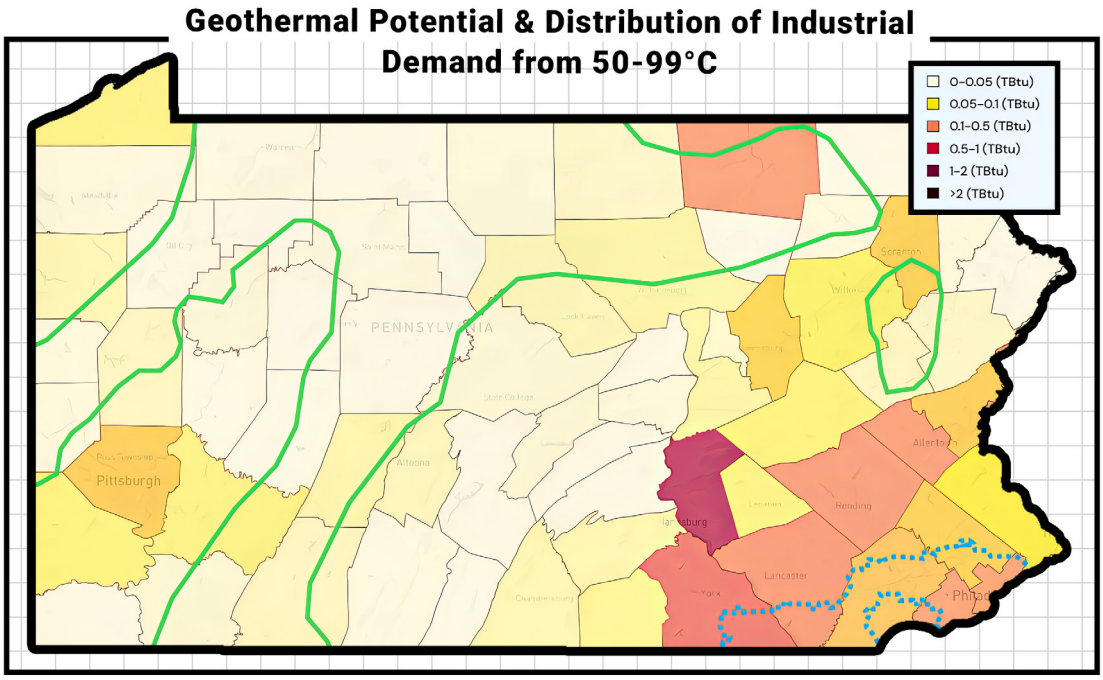

Figure 3.9: Pennsylvania's most favorable geothermal potential lies within the boundaries of the green lines, with additional exploration needed to confirm the favorability of areas within the blue line. Source: GeoMap and authors' analysis of NREL & process temperature data

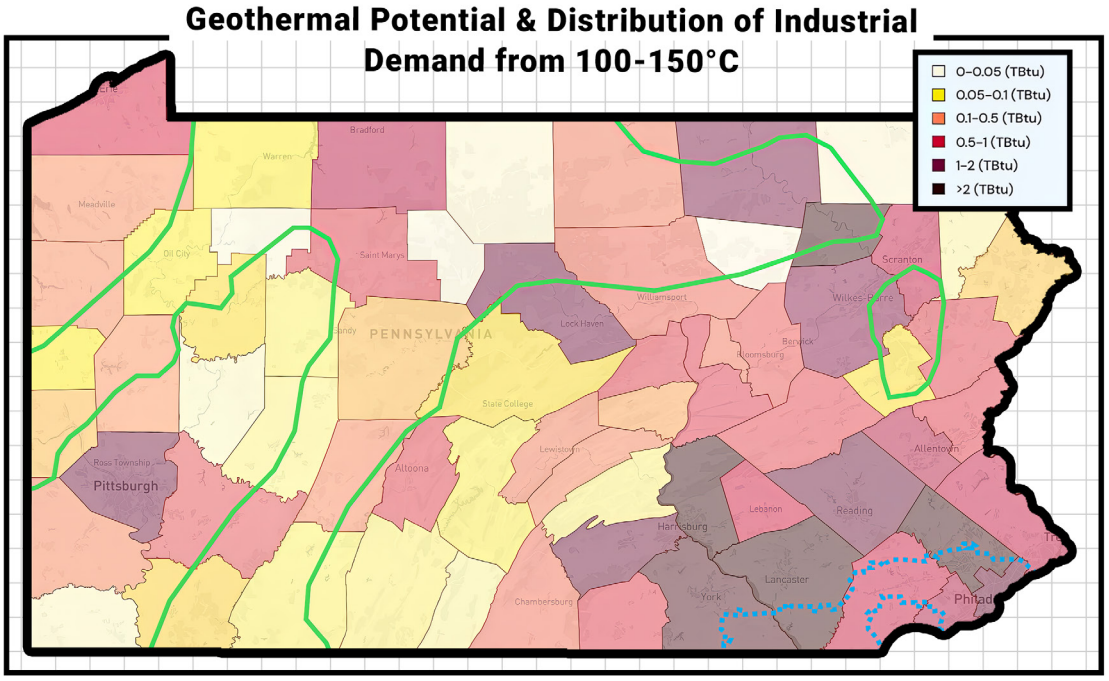

Figure 3.10: Pennsylvania's most favorable geothermal potential lies within the boundaries of the green lines, with additional exploration needed to confirm the favorability of areas within the blue line. Source: GeoMap and authors' analysis of NREL & process temperature data

CHAPTER REFERENCES

1 J. W. Lund, A. Sifford, S. G. Hamm, and A. Anderson, "The United States of America Direct Utilization Update 2019," in Proceedings World Geothermal Congress 2020, Reykjavik, Iceland, 2020.

2 Lund, J. W., Freeston, D. H., & Boyd, T. L. (2017). Direct utilization of geothermal energy 2015 worldwide review. National Renewable Energy Laboratory. Retrieved from https://www.nrel.gov/docs/fy17osti/66763.pdf

3 Wannan, O. (2022, April 26). The dairy company using geothermal steam instead of coal to dry milk. Stuff. https://www.stuff.co.nz/environment/climate-news/128494831/the-dairy-company-using-geothermal-steam-instead-of-coal-to-dry-milk

4 Brasnett, J. (2024). Geothermal energy: Advancements and future prospects. Stanford University. Retrieved from https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2024/Brasnett.pdf

5 King, B., Gaffney, M., & Rivera, A. (2024). Preliminary US greenhouse gas emissions estimates for 2023. Rhodium Group. Retrieved from https://rhg.com/research/us-greenhouse-gas-emissions-2023/

6 C. McMillan, "Manufacturing Thermal Energy Use in 2014," National Renewable Energy Laboratory-Data (NREL-DATA), Golden, CO, 2019, https://data.nrel.gov/submissions/118

7 Again, energy consumed for CHP is omitted from this figure.

8 Aljbour, J., Wilson, T., & Patel, P. (2024, May). Powering intelligence: Analyzing artificial intelligence and data center energy consumption. Electric Power Research Institute. Retrieved from https://www.epri.com/research/products/000000003002028905

9 Brown, H., Hamel, B., and Hedman, B.: Energy Analysis of 108 Industrial Processes, The Fairmont Press, Inc., (1985).

10 Although the NREL data is a decade old, it is the most recent county-by-county breakdown of thermal energy consumption available. Further, over the past decade Pennsylvania's total industrial energy consumption has remained relatively flat. Brown is even older, but remains one of the more comprehensive aggregations of process temperature data. Future research might look to update these values, as industrial processes have likely changed since 1985. Nevertheless, the data is still useful for analysis.

11 Note that much of the energy consumed in pulp and paper manufacturing comes from byproducts of the manufacturing process itself—black liquor and "hog fuel"—which are considered biofuels (Lund, 2017).

12 As discussed in *Chapter 2: Where to Develop Geothermal?*, favorability in Philadelphia and Delaware counties is modeled rather than observed and would benefit from confirmatory exploration.