ANALYSIS OF WASTE HEAT AND GEOTHERMAL HEAT POTENTIALS FOR DISTRICT HEATING IN UKRAINE

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Introduction

This report of "*Analysis of waste heat and geothermal heat potentials for district heating in Ukraine*" was made by the Ukrainian NGO Renewable Energy Agency (REA), as part of the Project "*Change Agents for a Green Society with Focus on Renewable Energy for District Heating, Ukraine*" in December 2022.

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The analysis concerns the situation before of the full-scale invasion of the Russian Federation into Ukraine on February 24, 2022. The territory of the Republic of Crimea, parts of the Donetsk and Luhansk regions occupied by the Russian Federation in 2014 does not include in the report.

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REA: https://rea.org.ua/projects/878/;

INFORSE-Europe: https://www.inforse.org/europe/ChangeAgents_Ukraine.htm

Summary

The purpose of this report is to analyze the potential of using waste heat resources of the industry of Ukraine and geothermal energy in district heating (DH) in terms of their volumes, availability and temperature levels, as well as researching a number of issues affecting the feasibility of such use.

The following areas were reviewed:

- general development and spread of DH in Ukraine;
- basic information on the gradation of waste energy resources;
- the main branches of industry that have a significant potential for waste heat;
- the main technological processes of industries that produce waste heat, its temperature levels and the main ways of waste heat recycling;
- general assessment of the available potential and volumes of waste heat resources in the industrial sectors of Ukraine;
- geographic localization of enterprises in industries with the greatest potential for waste heat and assessment of their location relative to potential consumers of waste heat resources for DH supply;
- existing examples of using waste heat of industrial enterprises for DH;
- the main types of geothermal resources in Ukraine, their geographical localization;
- different assessments of the potential of geothermal resources in Ukraine;
- thermal potential of existing geothermal wells;
- location maps of promising places for the use of geothermal energy in Ukraine;
- a more detailed review of the main artesian basins, where it is possible to organize the extraction of thermal waters on an industrial scale (Zakarpatskyi, Peredkarpatskyi, Dniprovsko-Donetskyi and Prychornomorskyi artesian basins);
- the level of development of geothermal energy in Ukraine - implementation of projects from 1978 to the present;
- geothermal projects currently existing in Ukraine, their main characteristics;
- existing assessments of the applicability of geothermal energy sources for city heating, potential geothermal energy facilities in Ukraine, potential geothermal energy resources near cities in western part of Ukraine; an example of assessing the possibilities of locating geothermal fields for heat supply of multi-apartment buildings in the cities of Pereyaslav and Balaklia (low-potential geothermal resources at a shallow depth);
- the results of a survey among territorial communities and heat energy suppliers in Ukraine regarding the possibilities and available examples of the use of industrial waste energy potential for DH;
- analysis of plans for the use of waste heat of industrial enterprises and geothermal energy in the energy strategies of Ukrainian cities and national level documents (in particular, in the Energy Strategy of Ukraine for the period until 2035, the National Action Plan for Energy Efficiency for the period until 2030, the draft National Action Plan for Development of renewable energy for the period until 2030 and the National action plan for the development of renewable energy for the period until 2020).

As a result of conducting this analysis, it was determined that Ukraine still has a sufficiently developed system of DH supply, which exists not only in large, but also in medium and sometimes small cities and covers about 35-40% (according to some estimates - up to 50%) of heating service for the population. The amount of thermal energy production for the needs of DH is estimated to be about 6.2 million toe. However, there is a constant decrease in the use of thermal energy in DH supply, including due to the transition of some consumers to autonomous and individual heating. The cities of Zakarpatska Oblast have completely switched to autonomous and individual heating.

The most developed DH supply is in the industrial areas of the center, east and south-east of Ukraine. In total, there are 5 regions that provide about 60% of the total volume of DH supply services in Ukraine. These are Kyiv, Kharkiv, Dnipropetrovsk, Donetsk and Zaporizhzhia regions. These regions also have the highest concentration of industrial enterprises, which can potentially be sources of waste heat resources for heat supply needs, which in general contributes to the possibility of using industrial waste heat for DH supply.

It should be taken into account that any alternative solutions in DH, when determining their feasibility, will be compared with the base situation, when the cost component of energy sources in the heat tariff is reduced (subsidized).

According to one of the estimates, the output of industrial waste energy resources in Ukraine in 2010 was 20.1 million Gcal/year, of which **11.1-12.4 million Gcal/year** could be used, which is equivalent to **annual saving 1.8- 2.0 million tons of coal equivalent (1.3-1.44 million toe)**. Ferrous metallurgy has the greatest potential of waste heat (about 58% of total potential in the industry of Ukraine), the chemical and petrochemical industry (28% of total potential), the building materials industry (4%), the fuel industry without coke plants, and metalworking + mechanical engineering (2% of the total potential), non-ferrous metallurgy (up to 1% of the potential). The rest of the industries have a total share about 4-5% of total waste heat potential. Unfortunately, no later estimates were found that would take into account the existing level of industrial production and recovery of waste heat in the industry of Ukraine.

In open sources, there is extremely little information regarding the estimated volumes and temperature levels of waste heat resources of specific industrial enterprises, as well as examples of utilization of waste heat. Only 2 active projects can be attributed to the use of waste heat of industrial enterprises in heat supply - this is an example of providing hot water to consumers in several districts of Zaporizhzhia city from the industrial site of PJSC "Zaporizhstal" and providing hot water to the part of Avdiyivka city from the Avdiyivka Coke Chemical Plant (“Avdiyivskyi koksokhimichnyi zavod”).

The conducted study of the location of more than 500 enterprises of various industries in relation to possible heat consumers showed that, although the enterprises of the metallurgical industry are located mainly in medium and large cities of the southeast and east of Ukraine, where there is a DH supply and dense urban development, they are relatively far away (as a rule, more than 1 km in a straight line) from a multi-storey building, where DH networks may run. Enterprises of the chemical and petrochemical industry (2-3 km distance), as well as cement factories are even more distant from potential consumers (mainly, further than 2 km). A little closer (on average about 1.7 km) to potential heat consumers are brick factories, and about 1 km - glass factories, factories for the production of paper, plywood, MDF. Food industry enterprises are relatively closer to potential consumers of waste heat, although the average distance for them is about 1 km. As a rule, bakeries and breweries, food factories (up to 1 km), oil industry enterprises (1 km) can be located closer to multi-storey buildings, and a little further away - milk processing plants, cheese and butter production, meat processing plants, tobacco factories (on average 1-1.5 km). Thus, when evaluating the potential of using waste heat of industrial enterprises, one should take into account the peculiarities of their location relative to potential consumers. Often, these enterprises are located in industrial zones of cities, where next to them, as well as between them and potential consumers of heat, there are production facilities and industrial sites of other enterprises, railway tracks and other objects. The length of potential heat lines in the vast majority of cases will exceed 1 km. Therefore, the possibility of using waste heat resources of industrial enterprises is the subject of a technical and economic assessment in each specific case, which should include both a detailed assessment of technical capabilities, temperature levels, and the potential amount of waste energy that can be released from the enterprise, as well as the potential consumption of such heat energy and distance to possible consumers.

When evaluating the possibility of using waste energy of certain industrial enterprises for the heating needs of settlements, it is worth focusing on obtaining preliminary information according to the following list:

- the interest of the management of the industrial enterprise in finding and evaluating the amount of waste heat resources for possible useful use;
- the interest of the company's management in using waste heat resources specifically for heat supply, since the organization of heat supply to third-party consumers is a licensed activity and requires, in addition to technical, also certain organizational measures;
- heat level and volumes of waste heat resources, type of heat transfer medium, daily and annual irregularity of obtaining heat;
- presence and proximity of potential DH consumers or large individual consumers;
- the presence and proximity of heat networks of heat supply companies to the potential point of heat output from the industrial enterprise, the thermal schedule of the DH supply network or individual consumers, the possibility of laying heat networks from the industrial enterprise in view of possible obstacles.

The most promising in terms of the potential geothermal sources are the areas in the east of Ukraine (bordering the Kharkiv, Donetsk, Luhansk and Dnipropetrovsk regions), as well as the Zakarpattia region, the north and east of the Crimean peninsula. Estimates of the potential of geothermal energy by different researchers in Ukraine can differ significantly. According to a more conservative estimate of the IET of the National Academy of Sciences of Ukraine, the potential of replacing natural gas due to the use of technically available potential of geothermal energy in the most promising areas is **15.8 thousand GWh** per year, which is equivalent to replacing **2.2 billion m^3 of natural gas**. The specified amount is only 4% of the total geothermal potential of Ukraine. The temperature range of geothermal resources in the most promising regions is from 65 to 130 °C, which makes them applicable for DH for at least part of the heating period.

There is (but not publicly available) an electronic database of 655 geothermal points. According to the results of the research, several geothermal artesian basins are distinguished: the Zakarpatskyi (Transcarpathian) internal depression (probably the most studied, especially the Berehovo deposit), the Carpathian (Peredkarpatskyi) foothill depression, the Dnieper-Donetsk (Dniprovsko-Donetskyi) artesian basin, the Black Sea (Prychornomorskyi) artesian basin.

From 1978 to 2002, 9 geothermal energy facilities were built in Ukraine, including 5 facilities on the Crimean Peninsula, 3 facilities in Zakarpattia and 1 facility in the Kherson region. The total thermal capacity of these facilities was 11.2 MW, electric capacity was 0.17 MW. As of 2020, 2 of them were operating in Zakarpattia Oblast (0.25 MW each) and one with a capacity of 1 MW in Crimea. **Since 2002, no new installations have been put into operation, and in general geothermal energy has not developed significantly**.

Geothermal heat energy resources of Ukraine, the most ready for development (with water temperature of 60–80 °C), amount to **more than 1 GW** of thermal power. The most promising regions are Zakarpattia, Sumy, Chernihiv, Kherson and Poltava regions. The thermal potential of the existing 34 geothermal wells of Ukraine when used in geothermal heat supply and hot water systems (temperature of thermal water - 60-70 ˚C) is 240.7 thousand MWh/year, which is equivalent to 23 million m^3 of natural gas per year.

One of the studies (dated 2016) outlined promising geothermal facilities - 15 geothermal stations in 6 regions of Ukraine, including 5 electric and cogeneration stations with a capacity of 5 to 14.2 MW, and 10 thermal stations with a capacity of 1 to 11 MW.

According to another assessment, the existence of promising geothermal deposits near such large cities in the west of Ukraine as Lviv, Ivano-Frankivsk, Chernivtsi, Uzhhorod, as well as smaller cities Mostyske and Berehove is noted. However, the potential heat capacities of geothermal energy for the cities of Uzhgorod (120.4 MW), Mostyske (27.3 MW) and Berehove (21.5 MW) are more or less determined. A negative circumstance that may affect the possibilities of such implementation is that the cities of Zakarpattia region, including Uzhgorod, practically abandoned DH supply, switching to autonomous and individual heating.

That is, despite the considerable amount of accumulated data on geothermal resources of Ukraine, specialists in the field expect not so many promising objects, which do not foresee the large-scale involvement of geothermal resources in heat supply and their replacement of a significant share of fossil fuels.

Examples of assessing the possibilities of using geothermal fields for heat supply of apartment buildings in the cities of Balaklia and Pereyaslav considered the drilling depth up to 100 m, for heat extraction the use of a ground heat pump was considered. According to the calculation, the investment in the installation with a thermal capacity of 108 kW should amount to 198,370 Euros (ie, 1,837 Euros/kW of thermal capacity). The estimated payback period of the well and the probe was 50 years, 20 years for the heat pump. The study also noted that the cost of drilling geothermal wells in Ukraine is approximately 200-300 Euros per meter of depth. A heat pump together with auxiliaries costs about 20-25% of the cost of drilling. Modern heat pumps of European manufacturers cost as much in Ukraine as in Western European countries. It is noted that despite the relatively high cost, this technology is still worth considering as a thermal energy source in relatively large new buildings.

According to experts [25], geothermal energy projects, in contrast to most RES, have a specificity, which consists in high risks and the duration of the first development period. The full implementation of such a project usually lasts from 5 to 10 years with significant investments without a guarantee of a positive result. This circumstance causes problems of attracting private capital. Therefore, for the successful development of geothermal energy, an important condition is the participation in it of both the public and private sectors. It is noted that relying only on commercial capital, even in the most economically developed countries, is rarely successful.

The Energy Strategy of Ukraine until 2035 directly states the need to use the heat of technological processes of industrial enterprises for heat supply. The use of geothermal resources is not directly mentioned, however, in the forecast structure of the total primary energy supply there is such a component as "thermal energy", which is understood as "thermal energy of the environment and waste resources of man-made origin". The planned share of thermal energy in the structure of Ukraine's total primary energy supply in 2035 should be **about 2%.**

The draft National action plan for the development of renewable energy for the period until 2030 forecasts the total share of geothermal energy in the total RES use in heating and cooling systems as **about 2%**, or 210 thousand toe in 2030. In addition, the installation of about **20 MW** of electric capacity based on geothermal sources is forecast starting from 2025 (4 MW), which will allow the production of **100 GWh of electricity** in 2030. In total, in 2030, it is planned to obtain 44,230 GWh of electric energy from RES, that is, production based on geothermal energy will make up **about 0.23%** of the total electricity production from renewable energy sources.

Analysis of energy efficiency programs for sustainable energy development and the use of RES in a number of cities and regions showed that state-level plans regarding the use of waste heat of industrial enterprises and geothermal energy, including for heat supply, remain at this level, not being reflected in plans at the level of individual communities, i.e. at the level of direct implementation. This can be explained by the fact that communities, when developing their plans, are guided by the existing experience of implementing energy efficiency plans and the traditional list of relevant measures, which, in turn, reflect the most effective, from the community's point of view, methods of achieving the set goals. As a rule, those measures are selected that guarantee a greater economic effect with lower capital costs.

The potential implementation in Ukraine of the national system of trading quotas for greenhouse gas emissions (GHG), external and internal energy management systems with an assessment of specific energy consumption per unit of finished products, the growth of the carbon tax, the targeted use of the tax on carbon dioxide emissions to stimulate industrial enterprises to energy efficiency, as well as the Carbon Border Adjustment Mechanism (CBAM) will promote the use of waste energy resources at industrial enterprises to increase the energy efficiency of these enterprises.

Thus, based on the results of the analysis, it can be stated that the considered areas of replacing fossil fuels in DH supply should of course be considered when forming, for example, municipal energy efficiency plans, action plans for sustainable energy development, regional programs for increasing energy efficiency and the use of renewable energy sources, etc. But the search for potential projects in these directions may find a lack of information about the potential of waste energy of specific industrial enterprises or the prospects of a given territory for the use of geothermal resources. For a more effective consideration of the possibilities of using waste energy of industrial enterprises for heat supply, it is worth starting with a survey of the management of these enterprises regarding their possibilities and interest in such cooperation. When evaluating the prospects for the use of geothermal resources, it is worth studying information on relevant existing research on the territory of Ukraine. In particular, establish cooperation with scientific institutions of NASU of Ukraine, that have relevant information (Institute of Renewable Energy, Institute of General Energy, Institute of Geophysics, Institute of Engineering Thermophysics). In addition, given the insufficient distribution and lack of relevant experience in both planning and practical implementation of such projects in Ukraine, it is worth studying foreign experience, especially those countries that have achieved significant success in developing these areas.

1. General overview of district heating in Ukraine, heat energy consumption, localization of main consumers by regions.

The analysis is based on State Statistics Service data on the number of people, the number of apartments in settlements that connected to district heating system (DH), as well as data from DH companies, developed heat supply schemes, National Action Plans for sustainable energy development of individual settlements.

In Ukraine, in more than 300 settlements with a population of more than 10,000 people, there are heat supply enterprises, that is, those that have the appropriate license and sell heat energy to consumers. Small settlements often do not have an extensive heat network, and heat supply enterprises operate boiler houses, which serves one building (school, hospital, kindergarten, etc.). Most heat supply organizations belong to municipalities, that is, they use the relevant infrastructure of municipalities and are subject to their management in their activities. There is also a certain small part of heat supply organizations, which are divisions of industrial enterprises that have their own heating boiler houses and supply heat for at least part of the settlement where they are located. This system has been used since Soviet times, when large industrial enterprises heated the adjacent part of the city, where the employees of these enterprises lived. Currently, these enterprises are mostly privatized and can be considered independent heat suppliers, since they are not directly subordinated to the municipal authorities. There are also independent heat producers, that is, private enterprises for which heat supply is the main type of activity. In total, 350-400 utilities and 50-60 private heat supply organizations operate in Ukraine.

Natural gas is the main fuel for the heat production in DH in Ukraine. Small part of the heat is supplied from small coal-fired boiler houses or from coal-fired CHPs. There is also a small part of boiler houses on electric energy. Firewood, pellets, wood chips are also used, especially in new boiler houses built in the last 10 years. In recent years, state programs for the transition of schools, kindergartens, hospitals in small towns and rural areas from natural gas to biomass have been implemented. A significant part of them has already been converted to biomass heating. As a rule, these are autonomous boiler houses that heat separate budget institution. The share of biomass in the production of heat in heat supply in Ukraine as a whole is about 10%.

The heat supply for DH is carried out from boiler houses and from electric power stations. In general, the share of thermal energy supply from CHP can be estimated at 25-27% of the total heat supply for DH in Ukraine. Another 3% is supplied to the nearest cities from TPPs and NPPs. The rest of heat supply for DH is provided by heating boiler houses.

Information on the total amount of DH services by regions of Ukraine is presented below (**Table 1, Fig. 1**). This data include heat supply for the population, public institutions (schools, hospitals, kindergartens, other public buildings) and other consumers. All data separated by regions are ranked by the estimated level of heat production in the DH.

According to our estimates, about 35-40% of the population is provided with district heating services (space heating and hot water supply (DHW) during the heating season, or year-round DHW in large cities, or only space heating in most cities).

The level of coverage of DH services are different in the by region. This is the result of several factors. First, there is a different level of concentration of large and medium-sized cities, where DH is most common. Secondly, even in cities of the same size, the level of distribution of DH can be different. Thirdly, regional politics contribute to the creation of such unevenness.

Table 1. Heat production for DH in the regions of Ukraine.

Region	Numbers of cities with DH	Share of the residential	Share of total heat	Heat production for DH, ktoe

		area connected to DH, %	production, %	
Kyiv region and Kyiv city	35	67%	23%	1,446
Kharkiv	15	71%	13%	809
Dnipro (Dnipropetrovska)	25	63%	10%	628
Zaporizhzhia	12	54%	7%	423
Donetsk	28	60%	6%	398
Odesa	11	45%	5%	289
Lviv	26	33%	4%	257
Sumy	12	46%	3%	196
Vinnytsia	9	26%	3%	174
Poltava	13	37%	3%	173
Khmelnytsky	15	32%	2%	155
Chernihiv	20	32%	2%	142
Cherkasy	14	28%	2%	138
Mykolayiv	5	47%	2%	137
Ivano-Frankivsk	11	23%	2%	107
Zhytomyr	10	27%	2%	107
Rivne	12	29%	2%	106
Kherson	8	39%	2%	106
Kropyvnytskyi (Kirovohradska)	10	35%	2%	105
Ternopil	7	26%	2%	99
Lutsk (Volynska)	7	29%	1%	93
Luhansk	11	40%	1%	84
Chernivtsi	6	19%	1%	47
Ushgorod (Zakarpatska)	0	0%	0%	0
Totall	**322**		**100%**	**6,220**

For example, the transition to individual heating was easier in certain regions and cities. A few years ago, the authorities of Uzhgorod, the regional center of Zakarpatska Oblast, decided to abandon DH in favor of individual heat supply. There are also a number of examples of the refusal of the DH in the cities of the south and south-east of Ukraine. In total, about twenty cities in Ukraine have already given up DH, including Uzhgorod, Nikopol, Marganets, Pokrov, and Truskavets. The local authorities in Ivano-Frankivsk announced their intention to abandon DH services.

The most developed DH is in the industrial areas of the center, east and south-east of Ukraine. This is due to the existence of large cities in these regions, which actively grew during the period of industrialization (beginning and middle of the 20th century), and from the very beginning had large areas of multi-flat buildings, which allowed them to efficiently heat large areas with the help of powerful heating boiler houses or CHPs.

As a result, there are 5 regions that provide about 60% of the total amount of DH services in Ukraine. These are the Kyiv, Kharkiv, Dnipropetrovsk, Donetsk, and Zaporizhia regions **(see Fig. 2**).

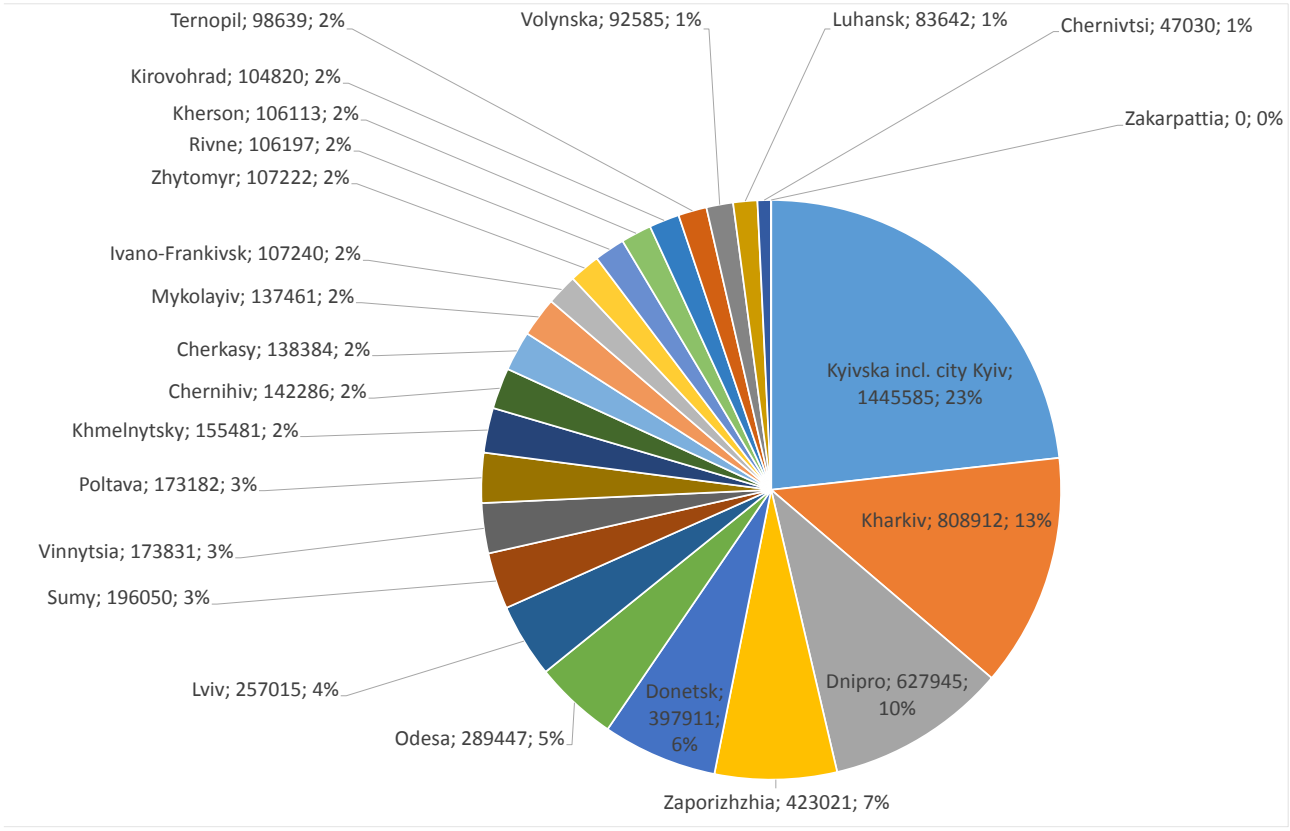

Fig. 1. Amounts (thousand toe) and the share (%) of regions of Ukraine in the total heat production for DH

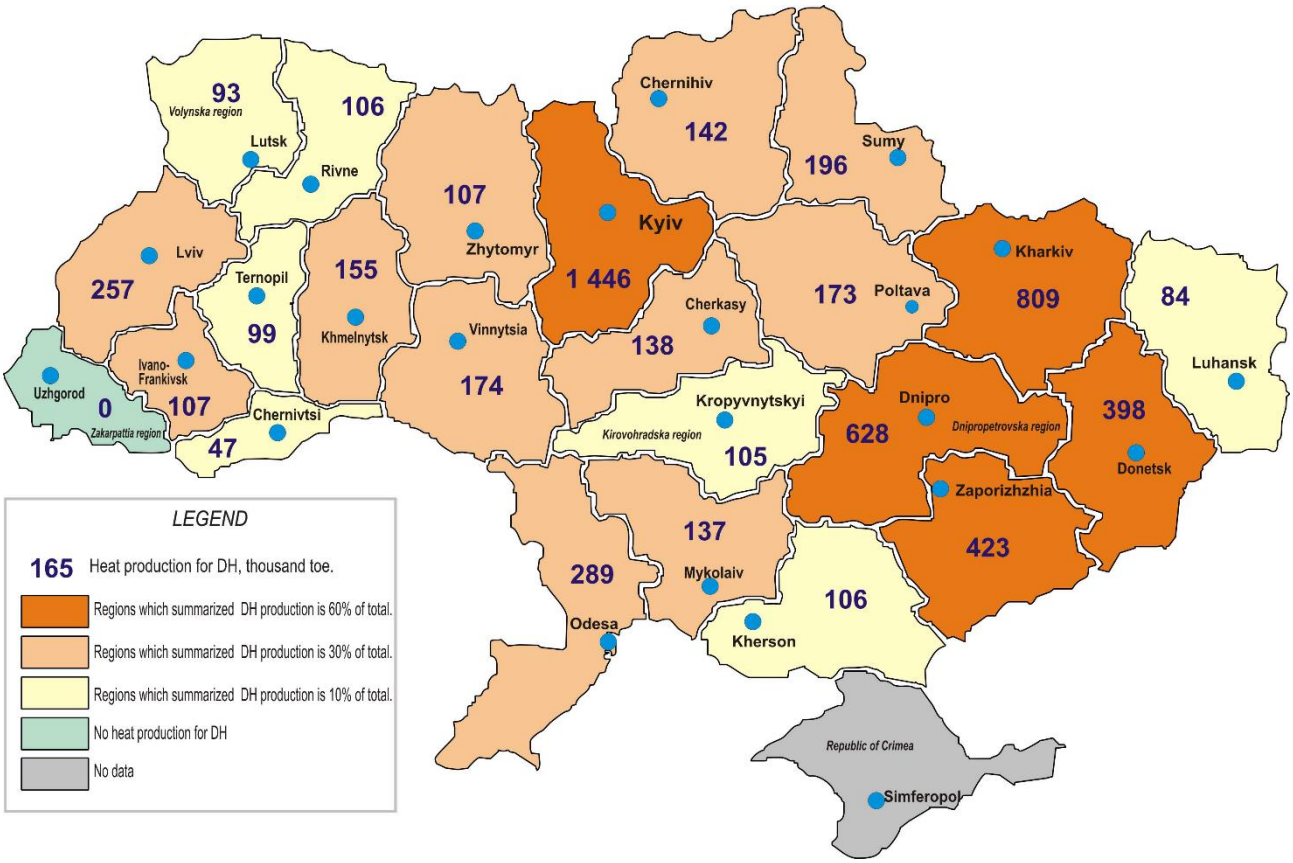

Fig. 2. Geographical distribution of heat production for DH by the regions (thousand toe)

The next group of regions with a lower concentration of DH service, providing about 30% of the total DH, includes such regions as Odesa, Lviv, Sumy, Vinnytsia, Poltava, Khmelnytskyi, Chernihiv, Cherkasy, Mykolaiv, Ivano-Frankivsk and Zhytomyr regions. The other seven regions provide only about 10% of total heat production for DH. **And also there is one region – Zakarpattia, where there is practically no DH.**

It should be noted that regional centers, as a rule, are the largest cities that provide a significant part of the region's DH. Only the two largest cities - Kyiv and Kharkiv - provide about 28% of the total heat production for DH in Ukraine. The top 50 largest cities, which total share in the Ukrainian DH is 78%, are presented in **Fig. 3.**

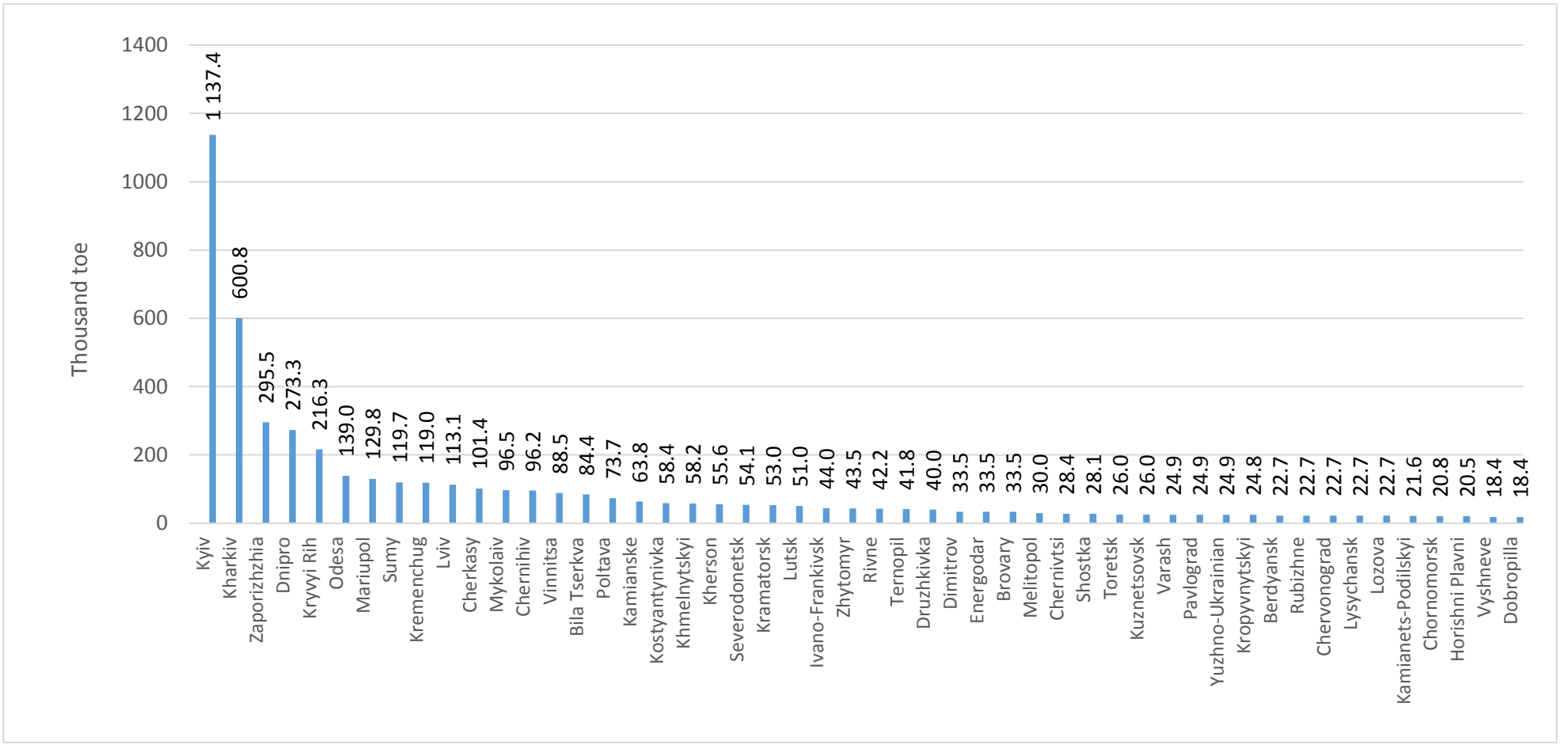

Fig. 3. Cities with the biggest heat production for DH in Ukraine

Prospects for implementation of alternative heating in the Ukrainian DH may significantly depend on the tariff policy and energy prices. Heat tariffs for DH are formed according to the "cost plus" principle. At the same time, there are three prices for natural gas. As of September-October 2022, the price of natural gas for population was about UAH 8,000, for budget institutions - UAH 16,500/thousand m^3 incl. VAT, and for industrial consumers - about 30,000 UAH/thousand m^3 incl. VAT. The price of natural gas for the first two specified categories is subsidized (not market-based). At the same time, the population makes up more than 80% of all DH consumers by amount of service. Also, preferential prices for electricity have been established for the privet households (1.68 UAH per kWh compared to 5.5-6.5 UAH per kWh for other consumers).

Fig. 4 shows the cost of energy in the fuel according to the prices of energy carriers in the heating season of 2021-2022.

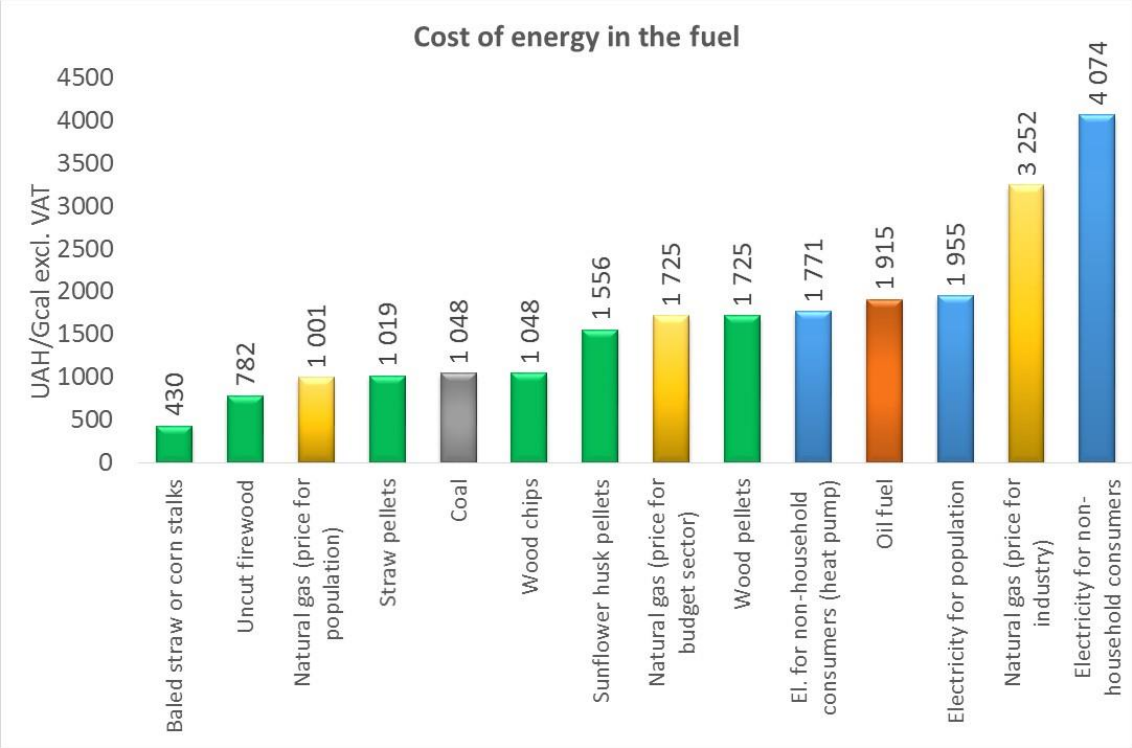

Fig. 4 Cost of energy in the fuel (of heating season 2021-2022)

As can be seen from the above data, not all types of fuel biomass are competitive with cheap gas for private households. Therefore, any alternative solutions in DH will compete with the baseline situation of reduced (subsidized) energy component in the DH heat tariff.

Conclusions on chapter 1

1. There is still a developed DH supply in Ukraine, which exists in large, medium and sometimes small cities and covers about 35-40% (according to some estimates - up to 50%) of the total heat supply for population. According to our estimate, the amount of heat production in DH is about 6.2 Mtoe.
2. In recent years, there has been a decrease of heat generation for DH, which is the result of energy efficiency measures, the limitation of heat supply due to the economic problems of heat supply companies, as well as the disconnection of some customers. There are cases when whole cities stop functioning of DH and switch to autonomous or individual heating systems of consumers. There are already about twenty cities in Ukraine, including Uzhgorod,

Nikopol, Marganets, Pokrov, and Truskavets. The local authorities in Ivano-Frankivsk announced their intention to abandon DH.

3. The most developed DH in the industrial areas of the center, east and south-east of Ukraine. There are 5 regions that provide about 60% of the total DH supply services in Ukraine. These are Kyiv, Kharkiv, Dnipropetrovsk, Donetsk and Zaporizhzhia regions.
4. Regions that have the most developed and large-scale DH also have the largest concentration of industrial enterprises, which can potentially be sources of waste heat resources for heat supply. This generally contributes to the possibility of using waste energy (WE) of industrial enterprises for DH.
5. Prospects for the implementation of new projects using waste heat of industrial enterprises or geothermal heat may depend on competetion with the baseline situation of reduced (subsidized) energy component in the DH heat tariff.

2. Overview of the main industries and industrial enterprises of Ukraine, which can be sources of wate heat for heating

2.1. Main industries and volumes of waste heat sources

All functioned industrial enterprises and TPP use only part of the energy in technological processes. About half of all fuel energy is lost. Waste energy potential of waste materials, by-products and intermediate products can be used for energy supply of other installations, objects, aggregates and is defined as the secondary energy sources or thereafter, waste energy (WE) [1].

According to the classical definition [2], **waste energy resources** are the energy potential (energy reserve in the form of physical heat, potential energy of excess pressure, chemical energy, etc.) of products, waste, by-products and intermediate products that cannot be used in the production unit itself, but can partially or fully used for energy supply to other consumers (**Fig. 5**).

In other words**, waste energy resources** are energy contained in the main or by-products of a technological process, which cannot be used in a given technological process, but can be partially or completely used in another technological process [3].

WE can be used directly or due to the production of a higher energy potential or other type of energy carrier in the special energy (recovery) equipment.

Waste heat recovery equipment is a equipment for producing energy carriers (steam, hot or chilled water, electricity, mechanical work) due to the reduction of the energy potential of the WE carrier.

WE sources are divided into the following groups:

1. ***Combustible or fuel WE*** – resources that have chemical energy that can be used as fuel. Blast furnace, ferroalloy, and converter gases, as well as coke gas, are classified as fuel WE. All these gases are used as fuel in furnaces and boiler houses.
2. ***Thermal WE*** – resources that have physical heat (exhaust gases of technological units; heated main, secondary and intermediate products; working coolants of cooling systems; hot water and steam spent in technological and power plants).

[1]https://elearn.nubip.edu.ua/pluginfile.php/634892/mod_resource/content/1/%D0%9B%D0%B5%D0%BA%D1%86%D1%96%D1%8F%205.pdf

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[3] Гічов Ю.О. Вторинні енергоресурси промислових підприємств. Частина І: Конспект лекцій: Дніпропетровськ: НМетАУ, 2012. – 56 с. https://nmetau.edu.ua/file/17._gichov_yu.o._vtorinni_energoresursi_promislovih_pidpriemstv._chastina_i.pdf

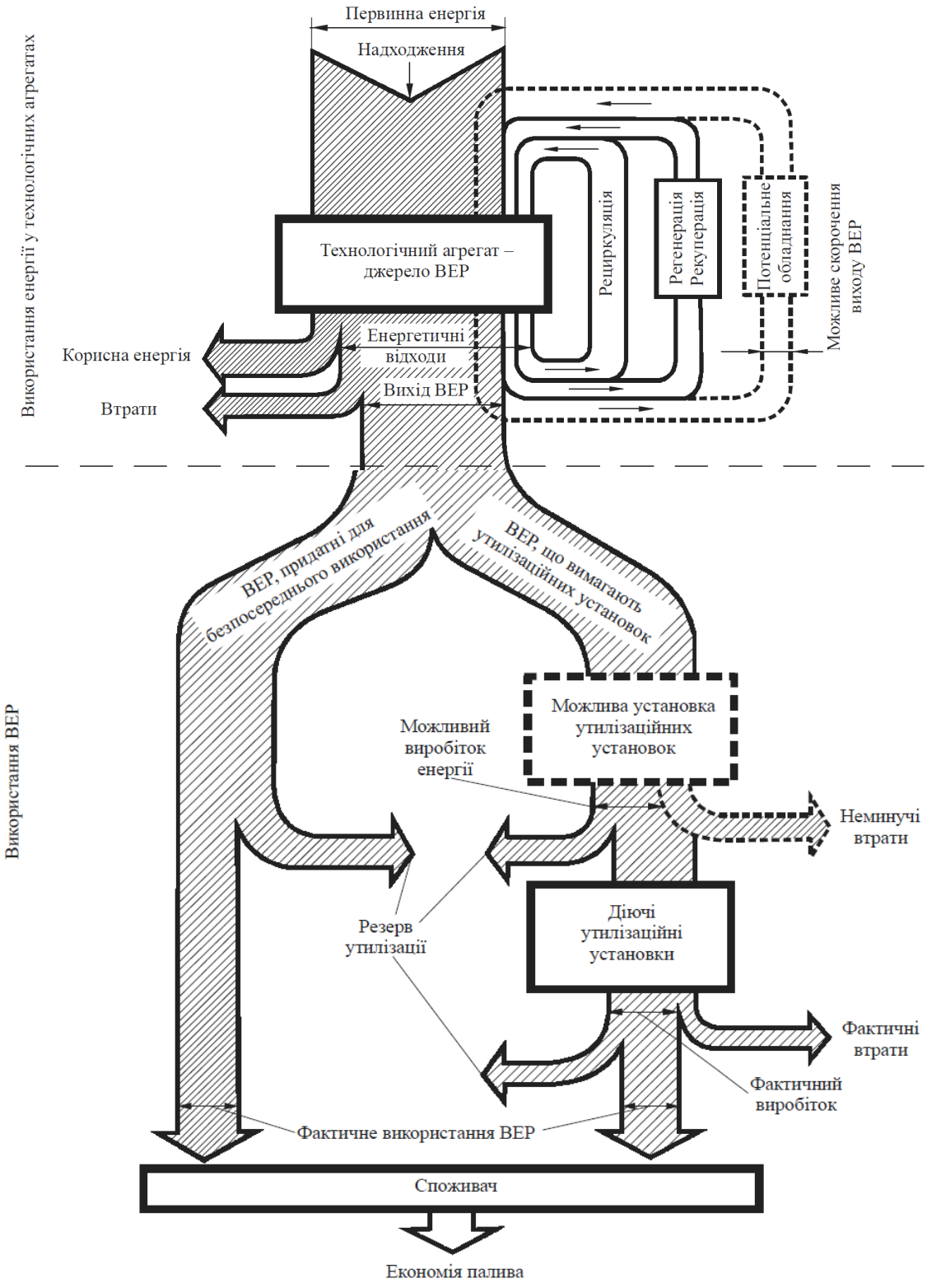


Fig. 5. Energy use flow diagram with WE recovery [4].

The waste heat energy that comes out of the technological unit and is used to heat the flows of substances entering the same unit (regeneration and recuperation processes) does not belong to WE.

[4] Ратушняк І.О., Семенов М.М., Ратушняк Л.П. "Вторинні енергетичні ресурси та енергозбереження": Методичні вказівки для студентів заочної форми навчання. – Миколаїв: НУК, 2007. – 48 с. https://core.ac.uk/download/161603806.pdf

Up to 10% of primary fuel is saved annually due to the use of WE. Not all heat losses in technological units can be used economically. The most valuable for heat utilization are heat carriers characterized by continuity of supply, high temperature potential and quantitative concentration. These include: heat of the finished product; waste gas heat; heat given off during cooling of furnace elements.

3. ***Excess pressure WE*** – resources with potential energy (as a rule, gases and liquids leaving technological units under pressure). The main utilization method is the generation of electrical or mechanical energy [4, 5, 6].

Ferrous metallurgy, chemical and petrochemical industry, non-ferrous metallurgy, production of non-metallic mineral products, mining, and food and the tobacco industry is the most energy consumption industries, which can be considered as the main sources of WE according to the data of the energy balance of Ukraine for 2020 [7] **(Fig. 6).** The transportation industry, especially road and pipeline transportation, and agriculture are energy intensive. These industries can hardly be considered as significant sources of WE due to the peculiarities of their functioning and remoteness from potential consumers. Residential sector, trade and services can be waste heat consumers. As can be seen from the presented data on **Fig. 6**, even the total consumption of energy resources of the above industries is significantly less than the consumption of residential sector and trade and services.

WE sources in the ferrous metallurgy are:

- processes of preparation of iron ore raw materials (sintering and coagulation of iron ore concentrate), coking of coal, calcination of limestone, production of refractories and ferroalloys;
- cast iron production processes in the blast furnace and off-blast iron production processes (**Fig. 7**);
- steelmaking processes (Marten, oxygen-converter, electric steelmaking);
- processes of pouring, crystallization, heating and rolling of metal.

In ferrous metallurgy, the WE sources include:

- physical heat of the main products of technological processes (sinter, slag after firing, lime, coke, cast iron, steel, rolled steel);
- physical heat of metallurgical slags (blast, Marten, converter, electric steel smelting);

[5] Вторичные энергетические ресурсы. Нетрадиционные и возобновляемые источники энергии : учеб.-метод. пособие для студентов специальности 1-43 01 06 «Энергоэффективные технологии и энергетический менеджмент» / А. Б. Сухоцкий. – Минск : БГТУ, 2012. – 92 с https://core.ac.uk/download/pdf/143994125.pdf
[6] Конспект лекцій з дисципліни «Теплоенергетика» для студентів заочної форми навчання напряму 6.050401 – «Металургія» / Укл. І.Є. Соколовська.- Дніпродзержинськ, ДДТУ, 2013. - 56с. https://www.dstu.dp.ua/Portal/Data/6/29/6-29-kl26.pdf
[7] https://www.ukrstat.gov.ua/operativ/operativ2021/energ/En_bal/Bal_2020_ue.xls

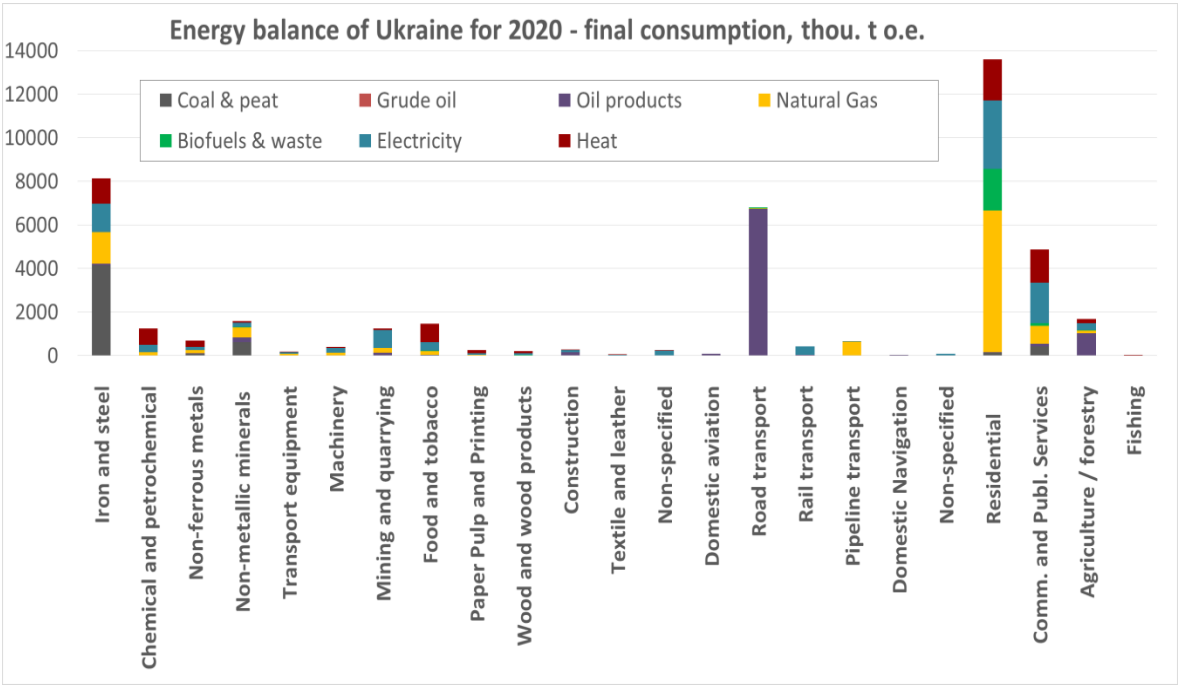


Fig.6. Energy balance of Ukraine. Final energy consumption in 2020, ktoe

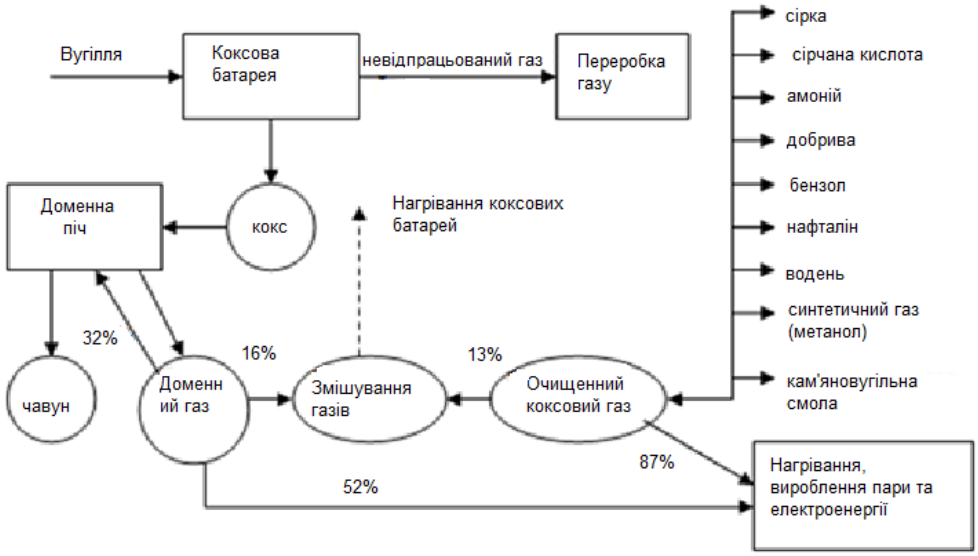
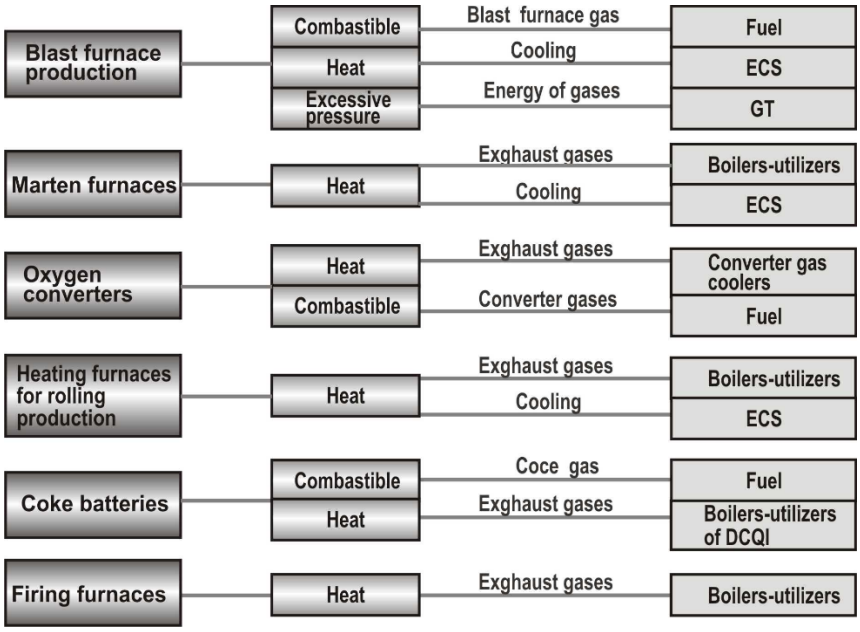


Fig. 7. The scheme of coke production, integrated to the metallurgical enterprise [8]

- physical heat of waste gases of technological furnaces and aggregates (sintering, gases of firing furnaces, coke, blast furnace, Marten, converter, electric steel smelting, ferroalloy, waste gases of heating devices of rolling shops);
- • the heat of the coolant of the structural elements of technological furnaces and units operating at high temperatures: heated water during water cooling, steam during evaporative cooling, heated air during air cooling [3].

[8] Черноусов П.И. Аналитический обзор - ВЭР черной металлургии https://metalspace.ru/production-science/ecology/811-ver-chernoj-metallurgii.html

Regarding a metallurgical enterprise with a full cycle, the following structure of WE formation and use can be given. (**Fig. 8**).



ECS - evaporative cooling systems, DCQI - dry coke quenching installation, GT - gas turbine

Fig. 8. The structure of production and disposal of WE in ferrous metallurgy [8].

Dry quenching of coke with the supply of heat to boiler plants for steam generation (pressure in the superheated state up to 39 MPa, temperature 440°C) has become the most common in coke chemical production. The gas, cooled to 150–170°C, is cleaned of dust in cyclones and returned to the extinguishing chamber.

The dry method of extinguishing allows to utilize of more than 80% of heat of the hot coke. After cooling in the heat utilization system, the coke gas undergoes a complex system of purification from resins, ammonia and benzene. After that, it is sent to the gas holder, and from there to the fuel consumer - directly or through a gas mixing station.

As can be seen from the figure, blast furnace gas is a combined WE, that is, thermal, fuel and excess pressure.

The blast furnace process is the source of:

- thermal WE, which make up 19% of the total heat consumption (heat of liquid iron ~ 6%, heat of slag ~ 5%, physical heat of blast furnace gas ~ 4% and heat of cooling blast furnace structural elements ~ 4%);
- fuel WE, which is 44% of the total heat consumption (chemical energy of blast furnace gas).

The heat of waste gases of blast furnace air heaters is also included to the WE, that is about 20% of the heat consumption for heating the air blast. The physical heat of blast furnace gas, due to the temperature on the furnace of 150-350°C, is not used for the following reasons:

- gas heat loss during wet cleaning, which dominates in blast furnaces;
- low temperature of blast furnace gas, which makes it impractical to use traditional surface heat exchangers.

The physical heat of blast furnace gas is used in the following directions:

- application of dry gas cleaning with subsequent use of gas in gas turbines;
- use of blast furnace gas for heating purified gas with subsequent use in gas turbines;
- use of blast furnace gas for heating of water in heat supply systems;

- application of contact heat exchangers [9].

In order to increase the service life, some parts of the high-temperature furnaces are subject to forced cooling. Heat losses in some cases amount to 10–20%. This heat can be used in evaporative cooling systems (ECS), by which blast furnaces are equipped, Marten furnaces, heating furnaces, and other furnaces. Saturated steam with a pressure up to 4 MPa produced in ECS [6].

For example, most of the Marten furnaces are equipped with ECS, which provides cooling of about 25 elements of the furnace: caissons of gas spans, heel beams of the main vault of the furnace, columns of the front walls, frames of loading windows, nozzles, reversing valves, and others.

The use of the physical heat of the converter steel depends on the method of pouring the steel: in a foundry or on machines for continuous casting of blanks (CCB). About 50% of the heat of the steel can be used by means of hot stamping. The difficulty of implementing a hot position lies in the difficulty of coordinating the work of the converter and rolling shops. When pouring steel at the CCB, the heat of the steel can be used for steam or hot water production.

There are mainly two directions in the use of converter gas: for the steam production and as a fuel.

The main waste heat sources in rolling production is thermal and heating furnaces, among which methodical heating furnaces are the most powerful. The main amount of heat when cooling the structures of methodical furnaces falls on the bottom pipes (longitudinal, transverse, support). The use of cooling heat is achieved by using ECS. The use of waste gas heat by heat recovery for heating the air used for gas combustion in heating furnaces. The residual heat of waste gases after recuperation requires utilization, which is usually achieved by the production of energy products: hot water, steam or electricity [9].

Heat recovery in metalworking

The physical heat of hot products can be used in one of the following directions: regeneration of heat with its return to this process, technological use of heat in a further process, direct heat use.

The following technological use of heat is typical for metallurgical production: liquid cast iron obtained in a blast furnace enters the Marten furnaces or converters. In this case, the physical heat of liquid cast iron is included in the heat balance of further processing as one of its profitable items.

The use of the heat of liquid steel is possible in furnaces of a rolling shop (hot position of ingots) or in continuous casting machines.

Utilization of waste gas heat and furnace cooling heat

Furnace waste gases are the most valuable heat carrier, which has all the main characteristics that make their use technologically possible and economically expedient. Heat losses with flue gases make up 30–40% (sometimes 60–70%) of all heat released during fuel combustion.

The heat of waste gases can be used according to three main schemes: closed or technological, open (energy) and combined.

In a closed circuit (**Fig. 9**), due to the heat of exhaust gases in regenerative or recuperative heat exchangers, the exhaust air is heated, sometimes the gas is burned. At the same time, part of the heat of the waste gases is returned to the unit. Thus, in a closed circuit, fuel consumption in the

[9] Гічов Ю.О. Вторинні енергоресурси промислових підприємств. Частина ІІ: Конспект лекцій - Дніпропетровськ: НМетАУ, 2012. – 54 с. https://nmetau.edu.ua/file/18._gichov_yu.o._vtorinni_energoresursi_promislovih_pidpriemstv._chastina_ii.pdf

technological process is reduced. At the same time, the output of WE resources that can be used outside the unit is reduced.

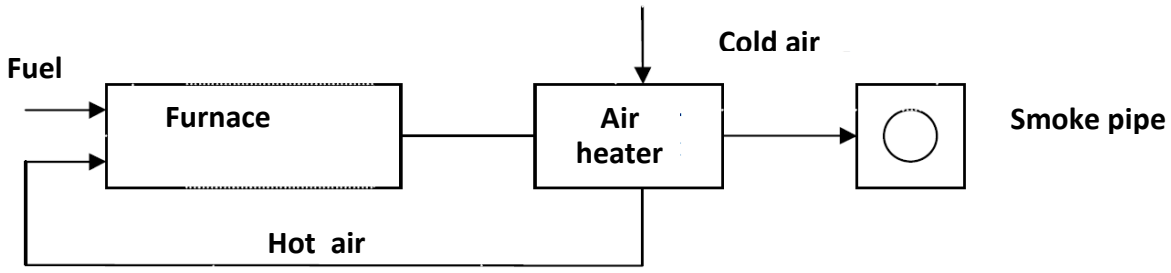


Fig. 9. Closed diagram for heat recovery of waste gases

Exhaust gases het is used for the production of steam, hot water, and electricity generation in the open or energy scheme (**Fig. 10**). Recovered heat save primary fuel outside of main technological unit or process. The most common in the open scheme are utilizing boilers for the steam production.

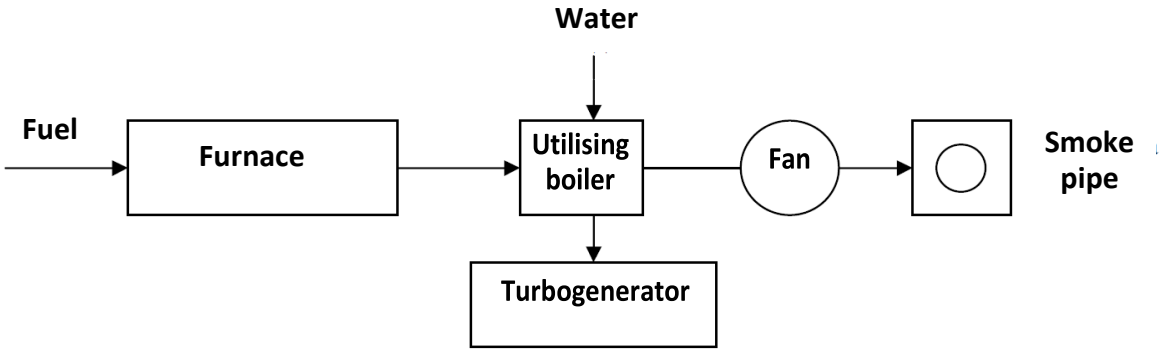


Fig. 10. Open diagram of heat recovery of waste gases

Installation of waste heat boilers allows for much deeper cooling of gases than in recuperators or regenerators. Typical exhaust gas temperature aprox. 180–200ºC.

The greatest energy effect is achievable by heat recovery process in the combined scheme (**Fig. 11**). Installation of air heaters and heat recovery boilers is common practice.

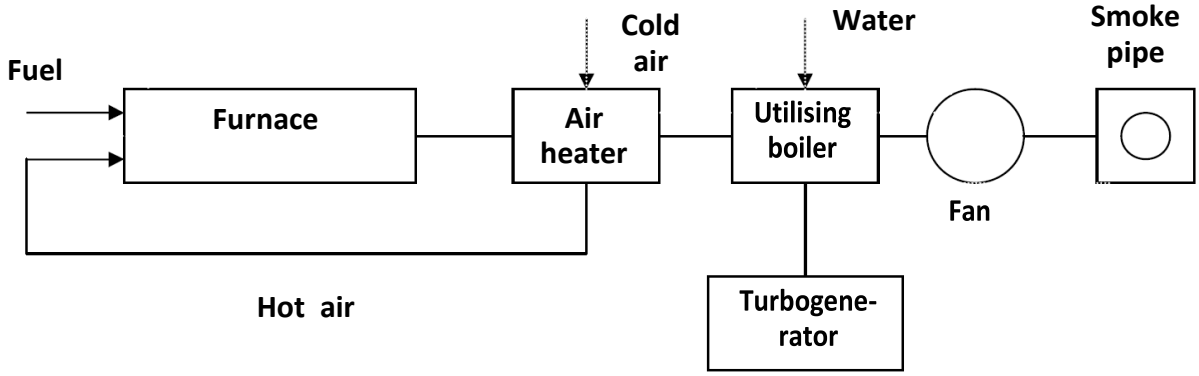


Fig. 11. Diagram of combined heat recovery of waste gases

Heat recovery (utilizing) boilers

Utilising boilers are designed to obtain steam due to the use of heat from waste gases of technological units. There are radiation, radiation-convective and convective boilers.

Boilers of the first two types are used in converter production, where the gas temperature is above 1000 ºC. The most widespread in ferrous metallurgy were use convective type heat revery boilers. They are installed after furnaces. These boilers are designed for the use of gases with a temperature of 600-850ºC [6].

Currently, the following main design types of heat recovery boilers are used:

- gas tube boilers, used in low-power installations with low steam pressure $p \leq 15$ atm and for the initial temperature of waste gases $t \leq 700 – 800°C$;
- water-tube heat recovery with natural circulation, operating on gases with a high initial temperature of about 1000°C and above.

In general, the main sources of thermal WE in various industries are technological units, which are usually not sufficiently perfect from the energy point of view. Heating and thermal furnaces (their thermal efficiency is 12–18%), cupolas of iron foundries (heat losses with gases exceed 50–60%), low-pressure steam boilers (efficiency about 50%), steam hammers of blacksmith shops (efficiency no more than 2–5%) and others [10].

The food industry includes the following main industries: sugar, alcohol, brewing, canned vegetables. In these industries, the level of heat utilization is relatively high and amounts to 88-93% [11].

In the building materials industry, WE resources are formed during the firing of cement clinker and ceramic products, glass production, and melting of heat-insulating materials. So far, insufficient attention has been paid to their use. With the total output of thermal WE equivalent to hundreds of thousands of tons of coal equivalent per year, their utilization with heat generation does not exceed 15-17%. At present, large glass furnaces are mainly equipped with utilising boilers at sheet glass factories.

In the chemical industry, the most energy-intensive are the production of ammonia, chemical fiber, synthetic resin, soda ash, phosphorus, and methanol, which consumes more than 70% of electricity and more than half of the heat consumed by the entire industry. The output of WE in the industry as a whole is quite large and amounts to more than 1.0 million tons of coal equivalent per year. Thermal WE largely cover the heat needs of individual industries. Thus, in the nitrogen industry, more than 26% of the heat needs are met due to WE, in the soda industry - more than 11%. The main reason for the relatively low level of their use is that the technological units are not fully equipped with already mastered disposal equipment, in addition, in a number of cases disposal is impossible due to the lack of necessary technical means [12].

One of the options for estimating the amount of use of thermal WE in Ukraine is given in **Table. 2**.

A significant amount of thermal waste is classified as low-potential. One of the significant sources of low-potential heat (LPH) is spent production steam. The largest amount of this steam is from the operation of forging and press equipment of machine-building enterprises.

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[10] Утилизация вторичных энергетических ресурсов, д.т.н., проф. Лотош В.Е. http://lotosh.1gb.ru/fopp/txt/secondenerg.pdf

[11] Вторичные энергоресурсы и энерготехнологическое комбинирование в промышленности: Учебник для вузов / Н.А. Семененко, Л.И. Куперман, С.А. Романовский и др. – К.: Вища школа. 1979. – 296 с.

[12] Традиційні та нетрадиційні системи енергозабезпечення урбанізованих і промислових територій України: моногр. / Г.Г. Півняк, О.С. Бешта, М.М. Табаченко та ін.; під заг. ред. Г.Г. Півняка. – Д.: Національний гірничий університет, 2013. – 333 с.

Heat pumps (HP) are very effective for using LPH. They are designed to increase the potential (temperature) of the heat carrier from values unsuitable for use in this process to sufficient. With the help of heat pump units, 3-6 kWh of thermal energy with a higher potential are obtained, spending 1 kWh of external electricity to drive them. Three types of heat pumps are known: compression, sorption and thermoelectric.

As a source of LPH in heat pumps, exhaust air, waste water of the hot water supply system, industrial and domestic water can be used. The received heat is transferred to water (water-water HP) or air (air HP) [10].

Table 2. Assessment of waste heat recovery in Ukraine [13].

	Year			
	2010		2015	
	kGcal			
	Amount of waste heat	Amount of possible use	Amount of waste heat	Amount of possible use
Ferrous metallurgy, including coke plants	11,700	5,500–6,150	12,900	6,200–7,400
Non-ferrous metallurgy	170	81–85	180	85–95
Fuel industry without coke plants	470	330–360	560	390–470
Chemical and petrochemical industry	5,700	3,900–4,400	6,800	4,100–4,800
Construction materials industry	840	670–740	1,310	1,050–1,250
Metalworking and mechanical engineering	420	200–230	460	220–265
Other activities	875	420–460	1200	580–700
In total	**20,175**	**11,100–12,425**	**23,410**	**1,262–14,980**
Fuel economy, k tce (coal equivalent)		1,845–2,060		2,070–2,450

2.2. Waste heat temperature ranges

Methods of using thermal WE resources are determined by the temperature level.

High Temperature Heat Recovery uses temperatures of waste gases from industrial process equipmentin of the high temperature range. All of these sources are from direct fuel fired processes.

Medium Temperature Heat Recovery uses the temperatures of waste gases from process equipment in the medium temperature range. Most of the waste heat in this temperature range comes from the exhaust of directly fired process units.

Low Temperature Heat Recovery uses heat sources in the low temperature range. In this range it is usually not practical to extract work from the source, though steam production may not be completely excluded if there is a need for low-pressure steam. Low temperature waste heat may be useful in a supplementary way for preheating purposes.

Table. 3a Typical waste heat temperature at high temperature range

[13] Куц Г.О. Використання теплових вторинних енергоресурсів у системах теплопостачання міст // Проблеми загальної енергетики, 2010, вип. 1(21), с. 47-53
http://pge.org.ua/index.php?option=com_docman&task=doc_download&gid=133&lang=ua

Type of device	Temperature, ˚C
Nickel refining furnace	1,370-1,650
Aluminium refining furnace	650-760
Zinc refining furnace	760-1,100
Copper refining furnace	760-815
Steel heating furnace	925-1,050
Copper reverberator furnace	900-1,100
Open hearth furnace	650-700
Cement kiln (dry process)	620-730
Glass melting furnace	1,000-1,550
Hydrogen plants	650-1,000
Solid waste incinerations	650-1,000
Fume incinerators	650-1,450

Table 3b. Typical waste heat temperature at medium temperature range

Type of device	Temperature, ˚C
Steam boilers exhausts	230-480
Gas turbine exhausts	370-540
Reciprocating engine exhausts	315-600
Reciprocating engine exhausts (turbo charged)	230-370
Heat treating furnaces	425-650
Drying and baking ovens	230-600
Catalytic crackers	425-650
Annealing furnace cooling systems	425-650

Ferrous metallurgy

Finished products of processing of ferrous metallurgy (coke, cast iron, steel, rolled products), as well as slags of blast furnace and steelmaking processes have a high temperature (1,200–1,700°C) and the share of waste physical heat in the balance of aggregates is from 5 to 50%.

The waste gases of metallurgical furnaces are the most valuable waste energy resource (**Table 3**).

Table 3. Parameters of waste heat sources at the metallurgical enterprise [14]

Parameters	Blast furnaces	Marten furnaces and oxygen converters	Heating furnaces	Coke batteries	Burning furnaces
Temperature, °C	150–300	≈ 250	110–200	300–400	120–200
Average volume of waste gases, thousand m^3/h	80	37	3	1,000	35

Exhausts gases of heating, Marten, firing, thermal furnaces, as well as converter gases have a temperature of 700–1,800 °C. The heat of the outgoing gases can be used to heat the charge, air, fuel,

[14] Утилизация сбросной теплоты технологических процессов промышленного предприятия с целью выработки электроэнергии /А. Л. Шубенко, Н. Ю. Бабак, А. В. Сенецкий, В.А. Маляренко.// Энергосбережение • Энергетика• Энергоаудит. – 2012. – № 7 (101). – С. 23–28.

to obtain steam and electricity. Most furnaces are equipped with heat recovery units: recuperators, heat recovery boilers and other equipments [6].

Coke gas has great WE potential. It leaves the furnace with a temperature of 700-800 °C and its heat content is about 1,000 MJ/t of coke or up to 30% of heat consumption.

The heat of coke gas is taken at different stages of cooling: in the risers of coke chambers – from 700–800 to 400 °C; in gas tanks - from 400 to 82 °C; in primary refrigerators - from 82 to 30 °C. The heat of the first and third stages is used.

The risers are equipped with heat exchangers through which the heat carrier circulates in a closed circuit to dispose of the heat of the first stage. Such heat can be directed to obtain steam, hot water, heating of organic coolants. The heat of the third stage of cooling is used to heat the coke gas desulfurization solutions.

The physical heat of the coke discharged from the chamber is about 50% of the heat spent on coking. It is disposed of during dry quenching of coke, i.e. cooling of coke in the chamber with an inert circulating gas (nitrogen). Having heated up to 750-800°C, the gas enters the heat exchanger of the secondary heat carrier (steam boiler, air heater or gas heater, coal charge heater or a combination of various devices that use heat, and power plants).

The heat of exhausts gases of air heaters of blast furnace production has a high energy potential. Waste heat makes up about 15-20% of heat consumption for blast furnace blowing. Their temperature ranges from 150–600 °C (or 150–350 °C according to [9, 10]).

The heat of exhaust gases of blast furnace air heaters can be used in the following directions:

- in heat supply systems (heat utilization);
- for heat the air for more effective combustion (heat recovery).
- steam generation or to heat blast furnace gas before entering the gas turbine.

The specific yield of blast furnace slag is 0.6-0.8 t/ton of cast iron, with a blast furnace outlet temperature of 1,450-1,550 °C, which makes the heat of the slag a rather significant thermal WE. The use of slag heat depends on the method of its granulation, which can be water or air. Granulated slag is widely used as a building material. In water granulation, the heat of the slag is used to produce steam or heated water in heat supply systems. In air granulation, the heat of heated air as a result of slag granulation is used to produce steam in a recovery boiler.

The heat from the waste gases of the Marten furnaces is largely used to heat the air in the regenerators. After the regenerators, the temperature of the waste gases is 500-900 °C. The heat of the gases leaving after the regenerators is used in heat recovery boilers. Installation of boilers behind the Marten furnaces lowers the temperature of waste gases to 150-200 °C, which allows to install a smoke fan, provide forced draft and increase the productivity of the furnace.

The heat potential of slag of oxygen-converter steel production is connected to the outlet temperature of 1,450–1,550 ºC. The specific yield of slag is 0.1 t of slag/t of steel. Several industrial installations for the use of slag heat are known, which differ in design, but include two similar technological operations:

- Air granulation of slag, which is accompanied by air heating during granulation to a temperature of ~ 900 ºC.
- Use of heated air to generate steam in heat recovery boilers.

When using converter gas to produce steam, air from the blower is passed through the nozzles of the regenerator in turn. The air is heated to 800–900 ºC and sent to the recovery boiler, where its heat is used to generate steam. In this way, a constant and uninterrupted steam productivity of the boiler-utilizer is achieved.

In rolling mill production, about 90% of the heat is removed through the cooling system using ECS. The value of ECS steam is increased by superheating the steam in central superheaters. Table

4 shows data on central superheaters ЦП-60-С-1,9 and ЦП-60-С-4,5 (where the marking mean the following: СР - central superheater; 60 - steam productivity, t/h; С - serial; 1,9 and 4,5 - steam pressure, MPa.)

Table 4. Technical characteristics of central superheaters

Indicators	ЦП-60-С-1,9	ЦП-60-С-4,5
Inlet steam temperature, ºС	206	256
Outlet steam temperature, ºС	370	450
Blast furnace gas consumption, m^3/h	4600	6270
Outlet air temperature, ºС	285	330
Outlet gas temperature, ºС	170	190

In addition to the largest thermal WE considered above, a number of other sources exist. These are gases of agglomeration, calcination of limestone and coils, copper furnaces, wells for rolling production, etc. Their temperature varies from 800–900 °C in furnaces with regenerators to 900–1200 °C in thermal, rolling and forging devices (without regeneration).

The heat of the high-temperature waste gases of such powerful industrial units can be used by gas turbine units built into the gas tract to produce electricity and supply gas and air to the furnace. For a more complete utilization of the heat of waste gases, a recovery boiler is usually installed after the heat exchangers of gas turbine plants, since the temperature of the combustion products is still significant (~450–500 °C). It allows to produce a steam of high parameters for technological or energy needs.

Since the temperature of the gases after the waste heat boiler is high (about 200–250 °C), it is advisable to use their heat for space heating or DHW.

Non-ferrous metallurgy

The usual temperature of waste gases of the largest furnaces of copper smelters is: mine 100–600 °C, in the fluidized bed 800–900 °C, chop and oxygen-suspended smelting 1,200–1,400 °C. These heat sources are characterized by a large output and concentration of energy, they are often stable in supply. At the same time, they are of high dustiness and aggressiveness, which creates difficulties during disposal.

Traditionally, the use of heat from the waste gases of smelting is widely used for melting on the matte. Here, two-stage utilization is the most effective: a recovery boiler followed by an air heater.

Other industries

Waste gases from cement clinker kilns with a temperature of 1,000–1,100 °C are among the most powerful sources of WE in the building materials industry. The main part of them is used for preheating the raw material mixture in the dry method of clinker production. Heating can be carried out in several ways, including in a cyclone heat exchanger with waste gases of furnaces up to 800–850 °C with decarbonization of the charge by 30–40%; or on conveyor machines (Lepole furnaces).

Gases from limestone kilns are the second most powerful source of WE in the production of building materials. They consist mainly of fuel combustion products and gases formed during the decomposition of limestone. Their yield when using rotary kilns is 2,500–3,000 m^3/t (temperature 750–800 °C). To reduce fuel consumption and utilize the heat of waste gases, heaters (shaft, step, cyclone, and others) are installed behind the rotating furnaces, into which lump materials intended for firing are sent. From here, with a temperature of 500–700 °C, they enter the furnace, from which they enter a drum-type cooler. With this option, the heat consumption for firing is reduced from 5,900–7,300 to 4,600–5,000 kJ/kg of lime.

Stocks of WE in the chemical, petrochemical, oil refining and gas industries are also large. For example, pyre furnaces have exhaust gas temperatures of about 650–900 °C, process gas generators - 250–1,100 °C, tubular furnaces for oil and fuel oil processing - 400–600 °C. These and

other gases, as a rule, are sent to recovery boilers for the production of process and energy steam. Gases are significantly cooled in waste boilers. For example, intermediate products of ammonia production - from 900-1,500 °C to 180 °C, sulfur gas in the production of sulfuric acid - from 850-950 °C to 400-450 °C, nitrous gases in nitric acid technology - from 800-850 ° C to 160–170 °C, etc.

More than 70% of the heat is dissipated with exhaust gases (temperature 270–400 °C) of gas turbine units at compressor stations of main gas pipelines. When cooling to 160 °C in recycling devices, it is possible to obtain up to 2.2-3.8 GJ/h per 1 MW of the working capacity of gas turbine plants.

A large amount of WE have relatively low temperatures (**Table 5**). These include gases from technological and power plants with temperatures below 300 °C, ventilation emissions (15–25 °C), heat from exhaust steam, ambient air, condensed heated and circulating water (25–40 °C), and others [10].

Temperature and other parameters of waste heat in industry strongly depend on the specific industry. For example, thermal emissions in the petrochemical and oil refining industry can be in the form of polluted steam at a temperature of about 150 °C or cooling water at about 30–55 °C, in the food and beverage industry, the temperature level can be about 80 °C. The greatest potential for heat savings exists in the metallurgical, cement, chemical, and petrochemical industries [15].

Table 1. Typical waste heat temperature at low temperature range from various sources

Source	Temperature, °C
Process steam condensate	55 – 88
Cooling water from:	
Furnace doors	30-55
Bearing machines	30-90
Welding machines	30-90
Injections molding machines	30-90
Annealing furnaces	65-230
Forming dies	27-88
Air compressor	25-50
Pumps	25-90
Internal combustion engines	65-120
Air condition and refrigeration condensers	30-45
Liquid still condensers	32-88
Drying, baking and curing ovens	90-230
Hot processed liquids	30-230
Hot processed solids	90-230
Ventilation air from buildings	20-25

At coal industry enterprises, the following sources of low-potential heat at the temperature level of 30–70 °C are:

- Water from circulating water supply systems (35 – 45 °C).
- Compressed air of compressor stations (50 – 80 °C).
- The heat of the Tericon breed (25 – 75 °C) [16].

[15] Кусаков С.К. Джерела тепла низького потенціалу і вимоги до теплообмінного обладнання для енергетично ефективної утилізації такого тепла // Інтегровані технології та енергозбереження 4’2019, с 79-90, doi: 10.20998/2078-5364.2019.4.10 http://repository.kpi.kharkov.ua/bitstream/KhPI-Press/43813/1/ITE_2019_4_Kusakov_Dzherela.pdf

[16] Альтернативні джерела енергії на підприємствах вугільної промисловості Красник В.Г., Уланов М.М. ДП «Науково-технічний центр «Вуглеінновація» https://dtek.com/content/files/vyacheslav-krasnik.pdf

2.3. Geographical localization of industrial waste heat and the correlation with location of potential DH consumers.

More than 500 enterprises of various industries in different settlements of Ukraine were investigated regarding the proximity to potential consumers of waste heat of these enterprises for heating. Enterprises of those industries where high- and medium-temperature processes are used in technological operations were selected: metallurgical, chemical, oil refining, production of rubber products, production of building materials, glass, refractories (glass factories, brick factories, production of cement, refractories, mineral wool), production of paper, plywood, MDF, food and processing industry (bakeries, production of alcohol, beer, dairy products, food factories, meat processing plants), enterprises of the tobacco industry, enterprises of edible oils industry. In general, the selected enterprises belong to large industrial enterprises. Some enterprises provide the main employment of the population in the settlement where they are located. A complete list of enterprises see in **Appendix 1.**

The linear distance from the industrial enterprises was chosen to the nearest residential multistorey building. In other cases, the distance was determined to consumers of the budget sector (schools, gymnasiums, kindergartens, polyclinics, hospitals). Below are the characteristic features of the location of enterprises of various industries.

Metallurgical industry

Totally 69 enterprises were considered. Most of them are located in large cities in the eastern part of Ukraine (the average number of inhabitants of settlements is about 340 thousand people). Only three enterprises are located in villages with a population of up to 9,000 people. The majority of enterprises are located at a distance of more than 1 km from a multistorey residential building (the average distance for all considered enterprises is 2 km), while some enterprises are located at a distance of 4-6 km. As a rule, enterprises are located in industrial zones of cities, where other enterprises are also located nearby, so the potential route of laying the heat pipelines will pass through the territories of other enterprises, and it will often be necessary to cross railway tracks. Only some relatively small foundries are located up to 1 km from residential buildings. Thus, despite the great expected potential for the use of WE, there is a need to lay long heat pipelines. On the other hand, the location in large cities with fairly dense multi-storey buildings creates prerequisites for the use of WE in DH.

Chemical industry

We considered 17 enterprises located in different regions of Ukraine. Among the settlements there are large and medium-sized cities (the average number of inhabitants of the settlements is about 150 thousand people). Only two enterprises are located in the towns with a population of up to 10,000 people. All enterprises are located at a distance of more than 1 km from a multistorey residential building (the average distance for all considered enterprises is 3 km), while 10 enterprises are located at a distance of more than 2 km, there are also those that are at a distance of 5-8 km. As a rule, enterprises are located in industrial zones of cities, closer to the outskirts, or even outside the city. Thus, it may be necessary to lay long heating pipelines, although the location in or near large and medium-sized cities makes it possible to use waste heat in DH with appropriate reasoning.

Oil refining industry

We considered 6 enterprises located in Lviv, Poltava, Luhansk, Ivano-Frankivsk, Odesa, and Kherson regions, while among the settlements there are large and medium-sized cities (the average number of inhabitants of the settlements is about 280,000 people). All enterprises are located at a distance of more than 2 km from multistorey residential buildings (the average distance for all considered enterprises is 4 km). As a rule, enterprises are located in industrial zones of cities or outside the city. Thus, there may be a need to lay very long heat pipelines (more than 2 km), although the use of waste heat of these enterprises in the DH still seems possible with considerable approval.

Rubber production

We considered 6 enterprises located in 4 regions, in large cities (the average number of inhabitants of settlements - about 800 thousand people). All enterprises are located at a distance of up to 3 km from multistorey residential buildings (the average distance for all considered enterprises is 1.1 km). As a rule, enterprises are located in industrial zones of cities or even separately, but generally not as far from multistorey buildings as metallurgical or chemical enterprises. Only 2 enterprises are within 0.5 km from potential heat consumers. Thus, in most cases, it may be necessary to lay rather long heat pipelines, although the location in large and medium-sized cities makes it possible to use waste heat in DH, if there are sufficient amounts of such heat.

Glass factories

There were considered 14 enterprises, located quite evenly in different regions of Ukraine, while among settlements there are both large and medium-sized cities and villages with a population of several thousand people (the average number of inhabitants of settlements is about 100,000 people). Two or three enterprises are located in small towns with a population of up to 10,000 people. and lack of DH. All other enterprises are located at a distance of 0.3–2.0 km from multi-storey residential buildings (the average distance for all considered enterprises is 1 km). As a rule, enterprises are located in industrial zones of cities or even separately, while only 2 enterprises are located at a distance of up to 0.5 km from a multistorey building. Thus, the length of the possible heat pipelines should be at least 0.5 km, although the location in large and medium-sized cities makes it possible to use waste heat in DH, if there are sufficient amounts of such heat.

Brick factories

We considered 31 enterprises located mainly in the central and western regions of Ukraine, mostly in medium-sized cities, as well as in villages with a population of several thousand people (the average number of inhabitants of settlements - about 90 thousand people). Up to 6 enterprises are located in small towns with a population of up to 10,000 people and lack of DH. The rest of the enterprises are located at a distance of 0.2-3.0 km from multistorey residential buildings (the average distance for all considered enterprises is 1.7 km). As a rule, enterprises are located in industrial zones of cities or closer to the outskirts, only one enterprise is located at a distance of up to 0.5 km from a multistorey building. Thus, the length of the possible heat pipelines should be at least 0.5 km, although the location in large and medium-sized cities makes it possible to use waste heat in DH, if there are sufficient amounts of such heat.

Refractory plants

We considered 7 enterprises, located mainly in the eastern regions of Ukraine, in cities of different sizes (the average number of inhabitants of settlements is about 200,000 people). In the three considered cities in the Donetsk region, there is a high probability that there is no DH. All enterprises are located at a distance of 0.4-1.2 km from multistorey residential buildings (the average distance for all considered enterprises is 0.7 km, although the distance to multistorey buildings is shorter in cities where there is no DH). As a rule, enterprises are located in industrial zones of cities or separately, at a distance of about 1 km from multistorey buildings. Thus, the length of possible heat pipelines for connection to DH system will be more than 1 km.

Production of mineral wool

Only 2 enterprises located in the cities Odesa and Zhytomyr were considered. The enterprises are located at a distance of about 2 km from the multi-storey building. Thus, the length of possible heating pipelines for connection to the DH system will be more than 2 km, which still seems possible with appropriate approval.

Cement plants

We considerd 12 enterprises, located fairly evenly in different regions of Ukraine, while large cities predominate among settlements (the average number of inhabitants of settlements is about

560,000 people). Only 1 enterprise is located in a settlement with a population of up to 10,000 people. Almost all enterprises are located at a distance of more than 1 km from multistorey residential buildings (the average distance for all considered enterprises is 3 km). As a rule, enterprises are located in industrial zones of cities or separately, on the outskirts of cities. Thus, the length of possible heat pipelines can be quite significant, at least more than 1 km.

Production of paper, plywood, MDF

There were considered 24 enterprises located in the central and western regions of Ukraine, while the settlements include both large and medium-sized cities and small villages (the average population of the settlements is about 300,000 people). Seven enterprises are located in settlements with a population of up to 10,000 people, where there is practically no possibility of using waste heat in DH, except for, perhaps, separate buildings of budget institutions that are far enough away. Almost all other enterprises are located at a distance of 0.4-4.0 km from multistorey residential buildings (the average distance for all considered enterprises is 1.2 km). As a rule, enterprises are located in industrial zones of cities or separately, on the outskirts of cities. Therefore, the length of the possible heat pipelines can be quite significant, at least more than 1 km. Although in several cases the distance can be shorter - up to 0.6 km.

Bakeries

We considered 71 enterprises in different regions of Ukraine, while large and medium-sized cities predominate among the considered settlements (the average number of inhabitants of the settlements is about 260,000 people). As a rule, enterprises are located in cities relatively close to multistorey buildings (0.1–1.8 km, while the average distance for all considered enterprises is 0.4 km). Relatively short distances to enterprises, together with the presence of fairly dense urban development, facilitates the possible use of waste heat resources of such enterprises for DH, of course, provided that such resources are sufficiently available.

Distilleries

We considered 35 enterprises in different regions of Ukraine. The average number of residents of the considered localities is about 10,000 people, while 30 enterprises are located in localities with a population of less than 10,000 people, of which less than 1,000 people live in 6 localities. There is no DH in 30 settlements. The only possible consumers of waste heat in such settlements may be individual buildings of the budgetary sphere - schools, kindergartens, clubs, premises of village councils, although in 8 settlements even such consumers were not found. The average distance to potential heat consumers for all considered enterprises is 0.7 km. Thus, the use of waste heat of distilleries for heating consumers seems to be quite problematic, with the exception of 1-2 larger settlements (Lutsk, Haysyn).

Breweries

There were considered 35 enterprises in different regions of Ukraine. Among the considered settlements, in contrast to the location of distilleries, large and medium-sized cities prevail (the average number of inhabitants of the settlements is about 380 thousand people). As a rule, enterprises are located in cities relatively close to multistorey buildings (0.2–4.5 km, while the average distance for all considered enterprises is 0.8 km). Relatively small distances to enterprises, together with the presence of a fairly dense urban development, contribute to the possible use of waste heat resources of such enterprises for DH, of course, provided that such resources are sufficiently available.

Dairies

We considered 74 enterprises in different regions of Ukraine. Among the considered settlements there are both large and medium-sized cities and small settlements with a population of up to 10,000 people. The average number of residents of the considered settlements is about 250,000 people. At least in 24 considered settlements there is no DH. A number of enterprises are located directly in cities relatively close to multistorey buildings, others are located on the outskirts of cities or outside the city. The range of distances is 0.1-4.0 km, while the average distance across all

considered enterprises is 0.9 km. At least 31 enterprises are located at a relatively short distance from potential consumers (up to 0.5 km in a straight line), which, together with the fairly dense urban development, contributes to the possible use of waste heat resources of such enterprises for DH, of course, provided that such resources are sufficiently available.

Food factories

We considered 31 enterprises in different regions of Ukraine. Among the considered settlements there are both large and medium-sized cities and small settlements with a population of up to 10 thousand people, which make up about 40% of all settlements. The average number of residents of the considered settlements is about 130,000 people. At least in 6 considered settlements there is no DH. The vast majority of enterprises are located directly in cities relatively close to multistorey buildings. The range of distances is 0.1–1.6 km, while the average distance across all considered enterprises is 0.6 km. At least 13 enterprises are located in large and medium-sized cities at a relatively short distance from potential consumers (up to 0.5 km in a straight line), which, together with the urban development, contributes to the possible use of waste heat resources of such enterprises for DH, provided that such resources are sufficiently available.

Tobacco factories

We considered 9 enterprises in 8 oblasts of Ukraine, while large cities predominate among the considered settlements (the average number of inhabitants of the settlements is about 640,000 people). Five enterprises are located at a distance of up to 1 km from potential heat consumers, others - at a distance of up to 4 km. The average distance to potential consumers for the considered enterprises is 1.4 km. Therefore, at least for a few such enterprises, it seems possible to use waste heat resources for district heating, provided that such resources are sufficiently available.

Meat processing plants

We considered 41 enterprises in different regions of Ukraine. Among the considered settlements there are both large and medium-sized cities and small settlements with a population of up to 10,000 people. The average number of residents of the considered settlements is about 260,000 people. There is no DH in at least 10 considered settlements. A few enterprises are located directly in cities relatively close to multistorey buildings, but there are a number of enterprises located on the outskirts of cities or outside the city. The range of distances is 0.25–4.2 km, while the average distance across all considered enterprises is 1.2 km. At least 7 enterprises are located in large and medium-sized cities at a relatively short distance from potential consumers (up to 0.5 km in a straight line), which, together with the urban development, contributes to the possible use of waste heat resources of such enterprises for DH, provided that such resources are sufficiently available.

Edible oils industry

We considered 30 enterprises in different regions of Ukraine. Among the considered settlements there are both large and medium-sized cities and small settlements with a population of up to 10,000 people, which make up to 45% of the total number of settlements. The average number of residents of the considered settlements is about 290,000 people. At least in 9 considered settlements there is no DH. A few enterprises are located directly in cities relatively close to multistorey buildings, but there are a number of enterprises located on the outskirts of cities or outside the city. The range of distances is 0.25–2.3 km, while the average distance across all considered enterprises is 1.0 km. At least 5 enterprises are located in large and medium-sized cities at a relatively short distance from potential consumers (up to 0.5 km in a straight line), which, together with the urban development, contributes to the possible use of waste heat resources of such enterprises for DH, provided that such resources are sufficiently available.

In Table 6 listed cities with the largest number of enterprises included in the above list. These are mainly large cities with a dense urban structure and DH utilities, which potentially have the greatest opportunities for using waste heat resources of industrial enterprises for DH supply.

Table 6. Cities with the largest number of large industrial enterprises

City	Numberr of large industrial enterprises
Zaporizhzhia	21
Kyiv	18
Kharkiv	17
Dnipro	16
Odesa	13
Lutsk	11
Zhytomyr	10
Lviv	9
Kramatorsk, Kremenchuk	7
Bila Tserkva, Kamianske, Poltava, Kherson	6
Kryvyi Rih, Kropyvnytskyi, Melitopol, Nikopol, Cherkasy	5
Vinnytsia, Haysyn, Sumy, Chernivtsi	4

Thus, it can be noted that despite the presence of a sufficiently large number of industrial enterprises in the vicinity of large cities or directly in the cities, which are related to industries with a large consumption of thermal energy and fuel, not all such enterprises can foresee the expediency of using waste heat resources for heat supply. First of all, the location of the largest enterprises far enough away from the multi-storey building, which will require the laying of heating pipelines with a length of 1 km. Therefore, the possibility of using such waste heat resources is the subject of a feasibility study in each specific case, which should include both a detailed assessment of technical capabilities, temperature levels and the potential amount of waste heat that can be supplied from the enterprise, as well as the potential consumption of such heat and distance to possible consumers.

It should be noted that currently there is no assessment of the potential of waste heat resources for each industrial enterprise in open information sources. Obviously, such estimates can be obtained as a result of an energy audit of the enterprise, which will take into account the current level of use of waste heat resources by the enterprises themselves.

Below (**Table 7–Table 11**) are data on the largest enterprises, for some of them it was possible to find an estimate of the waste heat output.

Table 7. Coke chemical enterprises

	Name of the enterprise	Address of the enterprise	Output volume of waste heat, k Gcal **2004** [17]
1	PrJSC "Avdiiv Coke Chemical Plant"	Avdiivka https://akhz.metinvestholding.com/ua/development/energy_saving	
2	JSC "Zaporizhkoks"	Zaporizhzhia https://www.zaporozhcoke.com/kontakty/	
3	OJSC Kharkiv Coke Plant	Kharkiv http://www.hkz.com.ua/index.php/ekologiya/obshchaya-informatsiya	
4	PJSC "Dniprovsky KHZ"	Kamianske	2,537

[17] Куц Г.О., Літинська Л.О.Аналіз стану утилізації теплових і горючих вторинних енергоресурсів та їх використання у комунальній теплоенергетиці промислових вузлів // Проблеми загальної енергети ки. — 2006. — № 4. — С. 69—80.

		https://dkhz.com.ua	
5	PJSC "Dniprovsky Metallurgical Plant"	Dnipro https://dmz-petrovka.dp.ua/	849
6	Yuzhkox PJSC	Kamianske https://www.bkoks.dp.ua/	
7	Arcelormittal Kryvyi Rih JSC	Kryvyi Rih https://ukraine.arcelormittal.com	7,054

Enterprises liquidated or not controlled by Ukraine: CJSC "Makiivkoks", Yasiniv Coke Chemical Plant, Alchevsk Coke Chemical Plant, Yenakiev Koksokhimprom, OJSC "Donetskkoks", Azovstal.

Table 8. Metallurgical enterprises

	Name of the enterprise	**Address of the enterprise**	**Output volume of waste heat, k Gcal, 2004**
1.	LLC "ELEKTROSTAL-KURAHOVE"	Kurakhove	
2.	PJSC "Druzhkiv Metal Products Plant"	Druzhkivka	
3.	Non-ferrous Metals Plant LLC	Bakhmut	
4.	Kramatorsk Ferroalloy Plant LLC	Kramatorsk	24
5.	LLC "Kramatorsk Plant of Metal Structures"	Kramatorsk	
6.	PrJSC "Avdiivsky Plant of Metal Structures"	Avdiivka	
7.	JSC "Zaporizhstal"	Zaporizhzhia https://zaporizhstal.com/	3,167
8.	OJSC "Nikopol Ferroalloy Plant"	Nikopol https://www.nzf.com.ua/main.aspx	
9.	OJSC "Zaporizhsky Plant of Ferroalloys"	Zaporizhzhia http://zfz.com.ua/	
10.	OJSC "Zaporizhsky Industrial Aluminum Combine"	Zaporizhzhia	
11.	Zaporizhzhya titanium-magnesium plant	Zaporizhzhia http://ztmc.zp.ua/uk/	

Enterprises that are liquidated/bankrupt or not controlled by Ukraine: Nikopolsky Zavod Truboprovidnoi Armaturu, JSC Stakhanovsky Ferroalloy Plant, JSC "MMK IlIicha", JSC "Alchevskyi MK", JSC "Yenakiivskyi MZ", CJSC "Donetskstal-MZ"", Donetsk Electrometallurgical Plant (DEMZ) (JSC "MMZ "Istil Ukraine"), PJSC "Dniprovsky Metkombinat", PJSC "DMK".

Table 9. Glass and construction materials production

	Name of the enterprise	**Address of the enterprise**
1.	PJSC "Rokytnivsky Glass Plant"	Village Rokytne http://rsz.com.ua/
2.	Kostopil glass factory	Kostopil http://kostopilglass.com.ua/
3.	PrJSC "Zaporizhskloflus"	Zaporizhzhia https://www.steklo-flus.com/
4.	LLC "Vilnohorske Sklo"	Vilnogirsk

		http://www.steklotara.com.ua/
5.	Poltava Medical Glass Plant Joint-Stock Company	Poltava http://www.medicalglass.com.ua/
6.	"VETROPAK GOSTOMELSKY SKLOZAVOD" PRIVATE LIMITED	city of Irpin, village Gostomel
7.	CJSC "Consumers-Sklo-Zorya"	Zorya village

Enterprises that have been liquidated/bankrupt/ceased/are in a state of termination or are not controlled by Ukraine: Kyiv art glass factory, PJSC "Lysychansky Glazing Proletariy", Kostyantyniv glass factory and plant "Avtosklo", JSC "Lvivsky Mehsklozavod", JSC " Berezhanskyi Glass Factory"

Table 10. Enterprises of the chemical industry

	Name of the enterprise	**Address of the enterprise**
1.	JSC "Dniproazot"	Kamianske
2.	Odesa Port Plant	Yushne https://opz.odessa.net/
3.	"Rivneazot"	willage Horodok https://www.azot.rv.ua/
4.	OJSC "Sumikhimprom"	Sumy http://sumykhimprom.com.ua/
5.	PJSC "AZOT"	Cherkasy http://www.azot.ck.ua/

Table 11. Rubber productions

	Name of the enterprise	**Address of the enterprise**
1.	LLC "RUBBER PRODUCTS FACTORY"	Lviv
2.	OJSC "Polymer Plant"	Lutsk
3.	PRAT "ROSAVA"	Bila Tserkva https://rosava.com/
4.	"KYIVGUMA" LLC	Brovary https://kievguma.ua/
5.	Zaporizhzhia Plant of Rubber Products Ltd.	Zaporizhzhia
6.	PJSC "BERTY"	Berdiansk https://berti.com.ua/

2.4. Ukrainian practice of waste heat use for DH

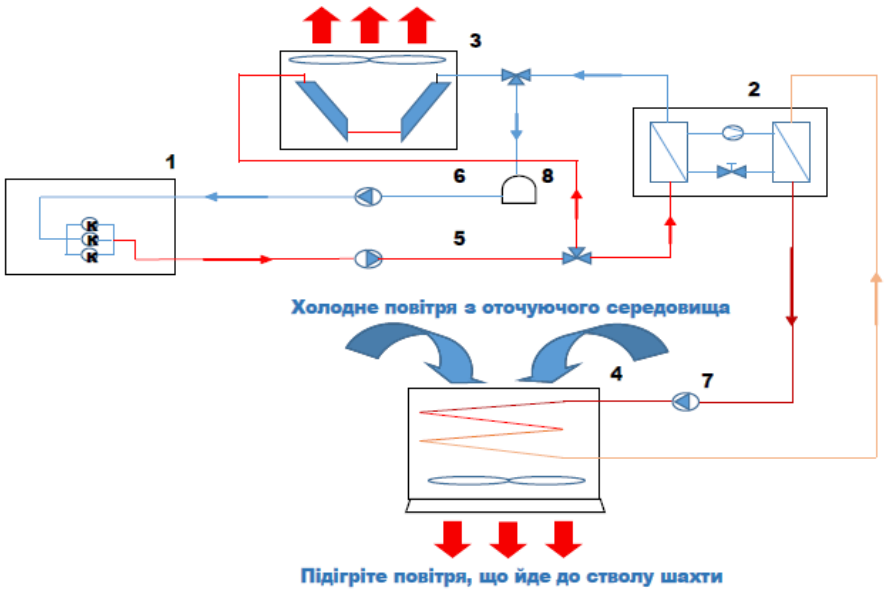
At coal industry enterprises, the sources of low-potential heat include water from circulating water supply systems with a temperature level of 35-45 °C.

Fig. 12 shows the technological scheme of heat pump unit, which utilizes heat of the circulating water of the compressor station at the mine "SkhidGZK" SE for heating the shafts of the mine.

Terykons are large massifs of empty rock that accumulate a fairly significant amount of low-potential energy. At the same time, due to the chemical reactions that take place in the middle of the tericons, the phenomenon of self-heating of the rock is constantly observed, in some cases this leads to the self-ignition of the tericons. With the help of horizontal or vertical collectors, it is possible to extract the accumulated thermal energy from the tericon rock. It should be noted the advantages and disadvantages of the utilization of this heat:

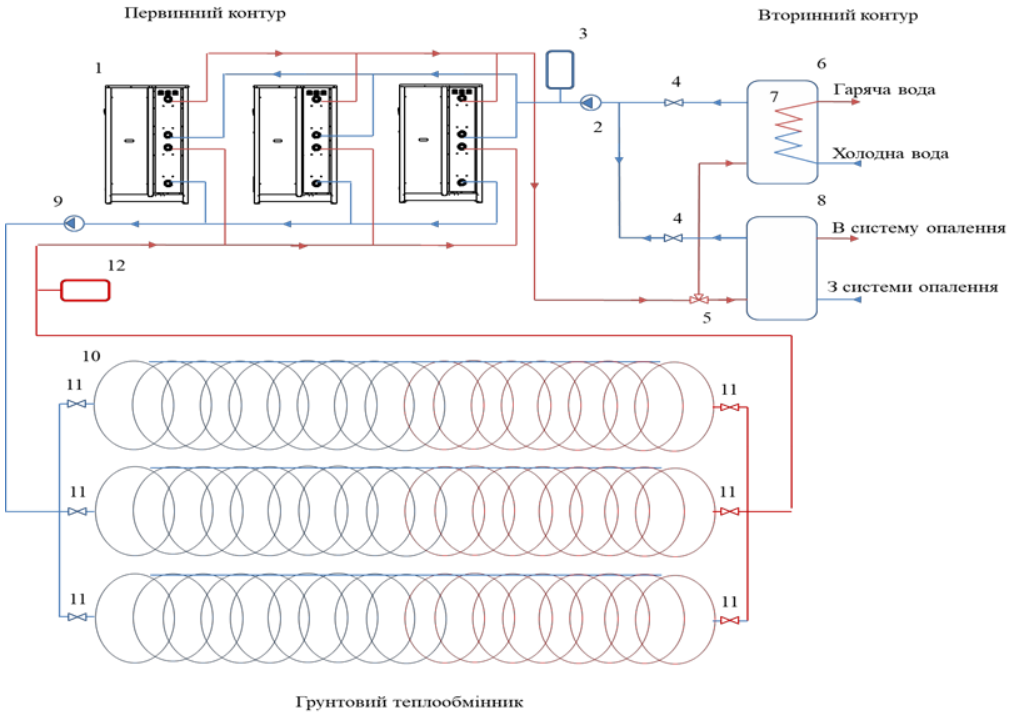
- Advantages – high heat removal.
- Disadvantages – the high cost of work is associated with the installation of a soil heat exchanger, a decrease in the temperature of the rock over a period of time.

We can cite an example of using the heat of terrycones with a temperature level of 25-75 °C. **Fig. 13** shows the technological diagram of the heat pump unit that utilizes the waste heat of the rock/tericon of the Lviv Coal Mine. Unfortunately, it is not specified where exactly the recycled heat is delivered.



1 – compressor station, 2 – heat pump station, 3 – cooling tower, 4 – heat exchanger for heating the air supplied to the shaft of the mine, 5, 6, 7 – circulation pumps, 8 – hydromodule.

Fig. 12. Technological scheme of the heat pump unit that utilizes the heat of the circulating water of the mine compressor station of the SE "ShidGZK".



1 – high-temperature heat pumps of the “water-water” type, 2 – coolant circulation pump, 3 – expansion tank, 4 – two-way valves, 5 – three-way valve, 6 – heat storage tank of the hot water supply system, 7 – heat exchanger heater for hot water, 8 – heat storage tank of the heating system, 9 – circulation pump of the intermediate coolant, 10 – ground heat exchanger, 11 – two-way valve of the ground heat exchanger, 12 – expansion tank.

Fig. 13. Technological scheme of the heat pump installation that utilizes the heat of the waste rock/tericon of the mine of the SE "Lvivvugilya" [18]

It is also known that due to the reconstruction of the equipment of the Zaporizhstal Metallurgical Plant OJSC and the construction of a new heating pipeline, residents of Ordzhonikidzevsky district and the sixth village of Leninsky district of Zaporizhzhia have been supplied by hot water since 2005 during the nonheating season. This enable to reduce the natural gas consumption for communal needs up to 10 million cubic meters per year [19]. It is emphasized that this is the "waste" heat of the industrial site of the "Zaporizhstal", although the specific source of waste heat is not indicated [20].

Coke gas is used as the main energy carrier in the production of products at PrJSC "Avdiivsky Coke Chemical Plant" [21]. By burning coke gas in the furnaces of steam boilers, the factory CHP plant produces technological steam for production needs, as well as electricity. In addition, coke gas is used as a fuel for heat exchange processes in the chemical workshops of the plant, for drying coal flotation concentrate at the coal beneficiation plant, heating garages, defrosting coal in winter, heating water in water-heating boilers of the thermal power plant **to provide hot water supply to the plant and to the city of Avdiivka.**

Conclusions on chapter 2

1. Many studies mention a potentially significant amount of WE in the Ukrainian industry, although the definition of its amount varies in different estimates, which is obviously due

[18] Альтернативні джерела енергії на підприємствах вугільної промисловості Красник В.Г., Уланов М.М. ДП «Науково-технічний центр «Вуглеінновація» https://dtek.com/content/files/vyacheslav-krasnik.pdf
[19] http://www.golos.com.ua/article/172910
[20] https://www.ukrinform.ua/rubric-regions/2425512-u-mizopaluvalnij-period-zaporizci-matimut-garacu-vodu-za-rahunok-vtorinnogo-tepla-zaporizstali.html
[21] https://akhz.metinvestholding.com/ua/development/energy_saving

to the fact that the production volumes of the main industries are changing, part of the WE already being utilized for the production needs of the same enterprises, at the same time, there are no exact statistics on the amount of utilized heat. Also, different assessments are possible when using different methods.

2. According to one of the estimates, the output of WE in the industry of Ukraine in 2010 was 20.1 million Gcal/year, of which 11.1-12.4 million Gcal/year could be used, which is equivalent to savings 1.8-2.0 million tce (1.3-1.44 million toe). Ferrous metallurgy has the greatest potential of WE (about 58% of the total potential in the industry of Ukraine), the chemical and petrochemical industry (28% of total), the building materials industry (4%), the fuel industry without coke plants, and metalworking + mechanical engineering (2% of the total potential), non-ferrous metallurgy (up to 1% of the potential). The rest of the industries have a total of about 4-5% of the total potential of WE.
3. The experience of using waste heat at industrial enterprises of Ukraine is very little mentioned in open sources.
4. Among the main difficulties in using the waste heat, high capital investments are often noted, which are related to the fact that waste heat is "inside" the technological process and needs to be removed with the help of appropriate heat exchange equipment, utilization plants, intermediate coolants, etc. Often, the physical streams containing the waste heat are dirty, dusty, and may require pre-cleaning or periodic cleaning of equipment using waste heat. In some cases, it is noted that effective methods of extraction and utilization of waste heat of certain processes have not yet been developed. Also important is the mode of operation of the equipment and the regularity of waste heat obtaining, which can affect the expediency of their use, in particular, for the needs of heat supply.
5. For some processes and intermediate products, physical flows are a source of both heat and fuel WE (for example, blast furnace gas, coke gas). The highest temperature levels are marked by the thermal WE of ferrous and non-ferrous metallurgy, as well as building materials (gases from furnaces for burning cement clinker and limestone). A significant amount of waste heat is classified as low-potential. The greatest potential for heat saving exists in the metallurgical, cement, chemical and petrochemical industries.
6. A study of the location of more than 500 enterprises of various industries relative to possible consumers of heat for heating showed that enterprises of the metallurgical industry, although they are located mainly in medium and large cities of the southeast and east of Ukraine, where there is a DH and dense urban development, are located relatively far (as a rule, more than 1 km in a straight line) from a multi-storey building, where DH networks may run. Enterprises of the chemical and petrochemical industry, as well as cement factories (2-3 km) are even more distant from potential consumers (mainly, further than 2 km). A little closer (on average about 1.7 km) to potential heat consumers are brick factories, and about 1 km - glass factories, factories for the production of paper, plywood, MDF. Food industry enterprises are relatively closer to potential consumers of waste heat, although the average distance for them is about 1 km. As a rule, bakeries and breweries, food factories (up to 1 km), edible oils industry enterprises (1 km) can be located closer to multi-storey buildings, and a little further away - milk processing plants, cheese and butter production, meat processing plants, tobacco factories (on average 1-1.5 km). Thus, when evaluating the potential of using waste heat of industrial enterprises, one should take into account the peculiarities of their location relative to potential consumers. Enterprises with, according to the assessment, the greatest potential, are not too close to potential consumers. It should also be taken into account that these enterprises are located, as a rule, in industrial zones of cities, where next to them, as well as between them and potential consumers of heat, there are production facilities and industrial sites of other enterprises, railway tracks and other objects that will have to be passed by to lay heating pipelines to

consumers. The length of such heat pipelines in the vast majority of cases will exceed 1 km.

7. The greatest concentration of enterprises of various types of industry, which are potential sources of WE, is observed in the same cities and regions where there is the largest production of heat for DH (Kyiv, Zaporizhzhia, Kharkiv, Dnipro, Odesa). This generally promotes the use of waste heat for DH.
8. Thus, the possibility of using such waste heat resources is the subject of a technical and economic assessment in each specific case, which should include both a detailed assessment of technical capabilities, temperature levels and the potential amount of waste heat that can be supplied from the enterprise, as well as potential consumption opportunities of such heat and the distance to possible consumers. Estimates of the amounts of waste heat available for use can be obtained as result of energy audit of the enterprise (in case the enterprise is interested in such an activity as heat supply to third-party consumers), which will take into account the current level of use of waste heat by the enterprises for their own needs.
9. The only currently documented examples of industrial waste heat use for DH are the following:
    - use of hot water from the industrial site of the "Zaporizhstal" in some areas of the city of Zaporizhzhia;
    - provision of hot water supply to part of the city of Avdiyivka from the Avdiyivsky coke-chemical plant, although this is the result of using coke gas as fuel, i.e. it is not a purely waste heat.

3. Overview of geothermal energy potential in Ukraine (depth over 500 m). Application of deep geothermal potential for district heating in Ukraine with gradation by temperature levels (40-80°C, 80-110°C and above 110°C)

Ukraine has a sufficient resource base and developed geothermal technologies for extracting and developing the following types of geothermal energy sources:

- sub-geothermal - the heat of the upper layers of the Earth up to a depth of 500 m, which is used with the help of heat pump installations;
- hydrothermal - the heat of deep underground thermal waters and parahydrotherms, which is used with the help of heat and electricity generating units;
- petrothermal - the heat of superheated "dry" rocks, which is used with the help of borehole heat exchangers or by creating artificial underground permeable collectors.

The distribution of geothermal energy potential by regions of Ukraine is shown in **Fig. 14, Fig. 15** and in **Tab. 12.**

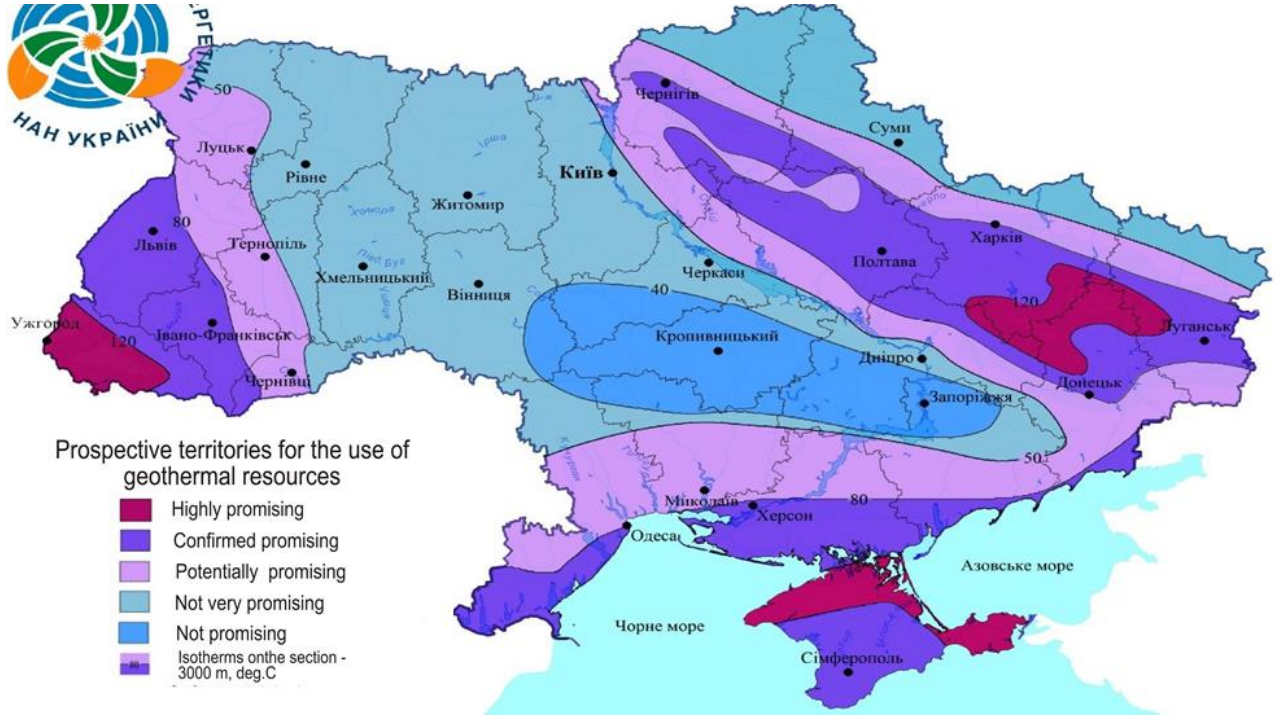


Fig. 14. Prospective territories for the use of geothermal resources [22]

Hydrothermal resources are the most widespread and currently suitable for technical use as a source of geothermal energy in Ukraine. Potential geothermal resources of thermal waters amount to 27.3 million m^3/day, and their thermal energy potential is about 84 million Gcal/year.

According to the calculations of the Institute of Renewable Energy of National Academy of Sciences of Ukraine (NASU) the annual technically achievable heat energy potential of geothermal energy in Ukraine is equivalent to 6.9 million toe, and its use will save about 5.6 billion m^3 of natural gas [22].

[22] Атлас енергетичного потенціалу відновлюваних джерел енергії України / за заг. ред. С.О. Кудрі. – Київ: Інститут відновлюваної енергетики НАН України, 2020. – 82 с

Table 12. Predicted heat energy potential of geothermal energy deposits in perspective areas [23]

Region	The expected outlet heat carrier flow temperature, °C	The equivalent of technically available natural gas saving, billion m^3
1. Zakarpattia	85–90	0.4
2. Ivano-Frankivsk	65–90	0.3
3. Lviv	90–130	0.4
4. Poltava	120–130	0.3
5. Sumy	80–100	0.2
6. Kharkiv	85	0.3
7. Chernivtsi	77	0.1
8. Chernihivska	70–100	0.2
TOTAL	-	2.2 (4 % of total Ukrainian geothermal potential)

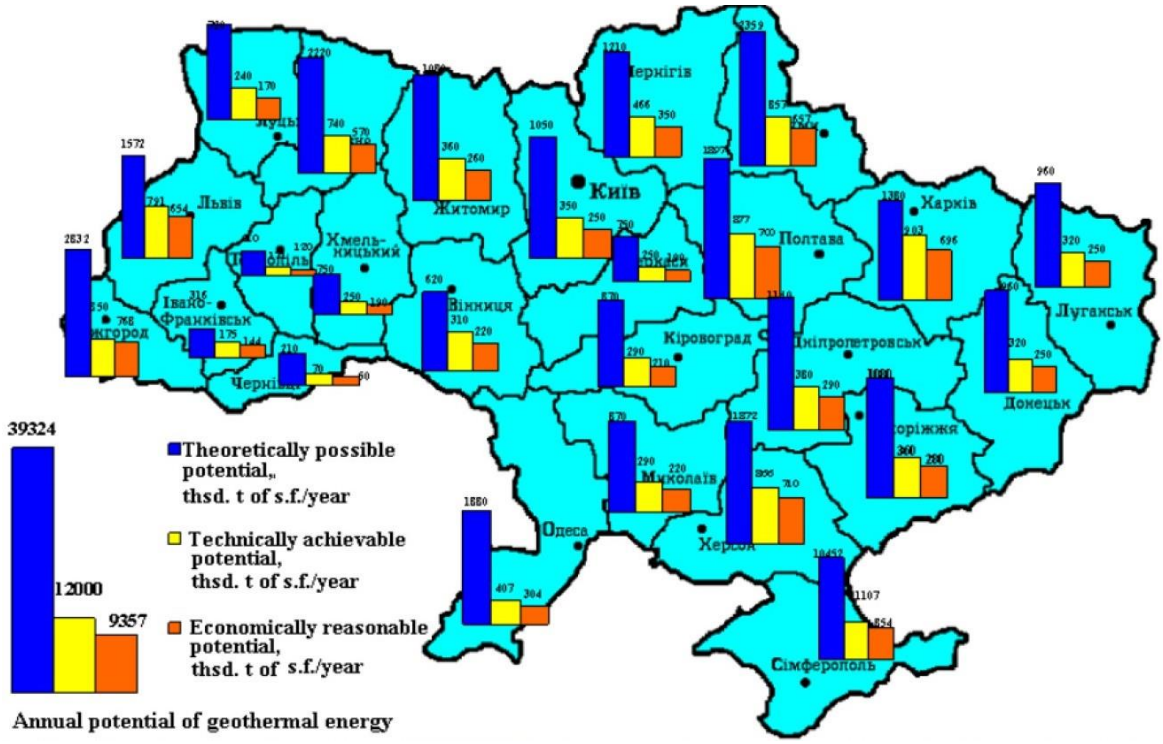


Fig. 1. Distribution of geothermal energy potential in Ukraine [24]

According to the predictive assessment of the Institute of Engineering Thermophysics of NAS of Ukraine, the technically available for implementation energy potential of geothermal waters in the 8 most promising regions of Ukraine is almost 15.8 thousand GWh for a year. This will provide an opportunity to produce about 13.5 thousand GWh per year of heat and 2.3 thousand GWh per year of electricity, which is equivalent to a reduction in natural gas consumption by 2.2 billion m^3 per year [23].

[23] А.А. Долінський. Перспективи геотермальної енергетики в Україні, 2016, http://engecology.com/wp-content/uploads/2015/08/8-dolinskij-odessa-21.09.16.pdf
[24] «Геотермальна стратегія: Можливості та інструменти для України», 2016, https://orkustofnun.is/gogn/Skyrslur/OS-2016/OS-2016-01.pdf

The author [25] made attempts to summarize and analyze the data of various authors regarding the assessment of resources and energy potential of geothermal energy in Ukraine. As a result, it was concluded that it was not possible to bring the data to the common denominator - sometimes the data differ by several times, but it is impossible to check their correctness due to the lack of data on calculation methods.

According to geological and geophysical data, at depths of up to 6 km, the temperature of rocks in the Transcarpathian region reaches 230–275 ºC (**Fig. 16**). Geothermal wells with a depth of 550 m - 1.5 km, where the water temperature at their crater is 40–60 ºC, are considered easily accessible here. At depths of up to 2 km, the temperature rises to 90–100 ºC. It should be noted the economic expediency of using thermal waters of such deposits as Berehivske, Kosynske, Zaluzske, Tereblianske, Velyatynske, Velikopaladske, Velikobaktyanske and Uzhgorodske.

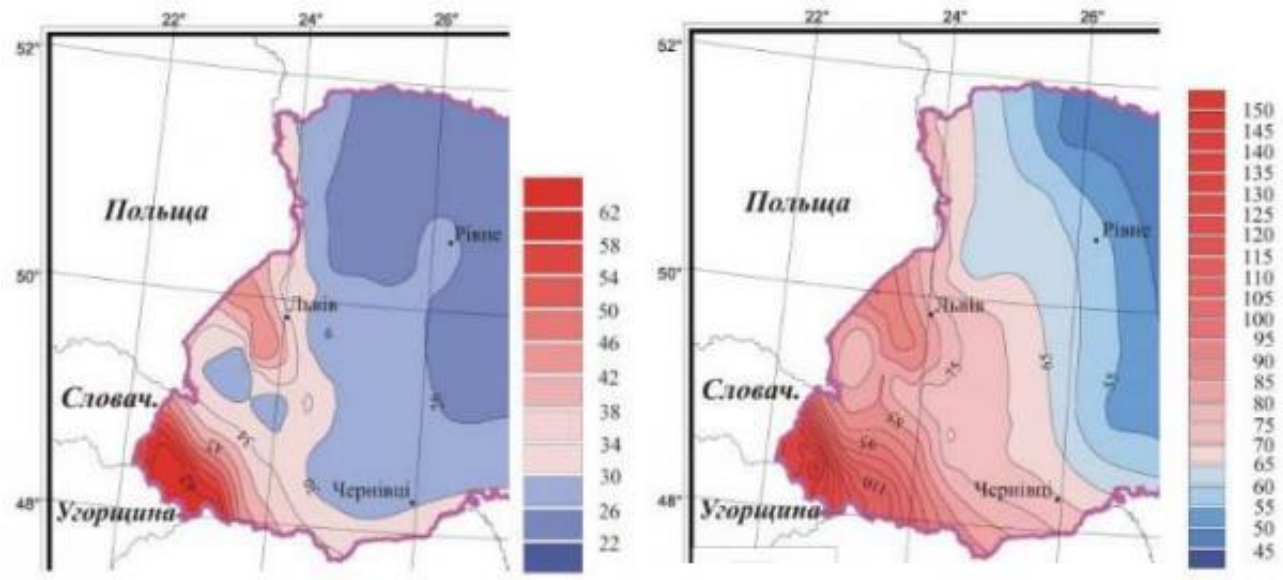


Fig. 16. Temperature map at 1,000 m (left) and 3,000 m (right) depth [26]

Some characteristics of promising areas for geothermal heat plant are presented in **Table. 13.**

Table 13. Potential of geothermal energy in Ukraine [27].

№	Region	Depth, km	Average temperature, ºC	Deposit area, km^2	Geological reserves of thermal energy	Possible capacity, thousands of MW
1	Transcarpathia	3–6	210–250	50–130	8.5	5.8
2	Carpathian region	4–7	200	600	6.7	4.6
3	Crimea	4–7	200–220	300–500	15.3	10.5

[25] Ю.О. Шурчкова. Стартові умови для розвитку геотермальної енергетики в україні // Проблеми загальної енергетики, № 2(57), 2019, с 35–40, https://doi.org/10.15407/pge2019.02.035, http://pge.org.ua/index.php?option=com_docman&task=art_details&mid=20192&gid=544&lang=ua

[26] Oleksandr Burachok, Oleksandr Kondrat Geothermal Energy Production Potential from Oil and Gas Fields in Western Ukraine // Journal of Geological Resource and Engineering 7 (2019), p. 123-131, doi:10.17265/2328-2193/2019.04.002 https://www.davidpublisher.com/Public/uploads/Contribute/5dd72ca72ef7e.pdf

[27] Ольга ФОМИНА АЛЬТЕРНАТИВА ИЗ ГЛУБИНЫ НЕДР// ЭНЕРГОСБЕРЕЖЕНИЕ И ЭНЕРГОЭФФЕКТИВНОСТЬ, № 12, 2005, http://www.tek-ua.com/article0$pa!481$a!306091.htm

4	Territories in the east of Ukraine	5–7	185–217	660–2,800	70	48.0
Total					100	70

Geothermal heat energy resources of Ukraine are prepared for development (with water temperature of 60–80°C). It is amount to more than 1 GW of thermal power. The most promising regions are Zakarpattia, Sumy, Chernihiv, Kherson and Poltava.

In geothermal heat energy it is possible to use thermal water with mineralization up to 35 mg/l; in hot water supply - up to 10 mg/l; in boiler houses and when using heat pumps - up to 5 mg/l. In the case of water mineralization of more than 35 mg/l, purification systems are required. The wide range of hardness, acidity and gas saturation of thermal water requires the use of special materials in the design of elements on geothermal thermal power plant (TPP). According to the opinion of the authors, the direction of construction of small geothermal TPP with a unit capacity of 0.05–5 MW and with a temperature of 90–120°C is perspective in Ukraine [28].

3.1. Geographical localization of geothermal energy sources by regions, temperature levels and correlation of their location with placement of consumers of district heating.

There are four large artesian basins in Ukraine, where it is possible to organize extraction of thermal waters on an industrial scale. These are Transcarpathian, Transcarpathian, Dnipro-Donetsk and Black Sea artesian basins..

The largest number of wells is located in 8 regions of Ukraine (**Table 14**).

Table 14. Heat potential of existing geothermal wells in Ukraine for use in geothermal district heating and hot water supply (temperature of thermal water - 60–70˚C) [23]

№	Region	Number of wells	Heat potential	
			MWh/year	million m^3 of gas/year
1	Dnipropetrovsk	2	14,710	1.6
2	Zakarpattia	4	25,000	2.7
3	Ivano-Frankivsk	4	29,500	3.2
4	Lviv	10	73,550	7.9
5	Poltava	4	29,500	3.2
7	Kharkivska	5	34,500	3.7
8	Khersonsk	5	34,500	3.7
	TOTAL	34	240,760	26.0

The depth of aquifers varies from 430 m (Velika Bakta No. 22-T, Transcarpathian region) to 7,005 m (Shevchenkove-1, Ivano-Frankivsk region). It was established by based of the analysis the actual data of the existing fund of wells. In geothermal wells formation temperatures from 50 to 90ºC are recorded most often. According to the amount of mineralization, thermal waters can be divided into two groups: the first - mineralization does not exceed 50 g/l and the second - the amount of mineralization ranges from 100 to 200 g/l.

Methods of geothermal resources extraction which using thermal waters are divided into

[28] Геотермальна енергетика: виробництво електричної і теплової енергії / А.А. Долінський, А.А. Халатов // Вісник Національної академії наук України. — 2016. — № 11. — С. 76-86, http://dspace.nbuv.gov.ua/bitstream/handle/123456789/109877/10-Dolinskiy.pdf?sequence=1

fountain (with forced pumping) and with reverse pumping. The most common and environmentally safe are geothermal circulation systems (GCS).These are systems for extracting the deep heat of the Earth from permeable underground layers by forced movement of the geothermal heat carrier flow along a closed circuit. The GCS consists from one or more lifting wells, an intermediate heat exchanger and one or more injection wells which ensure the injection of spent geothermal heat carrier flow into the same permeable underground collector of thermal water [29].

In studies [23, 24] the maps were developed. The most promising places for locating geothermal facilities in Ukraine are shown in **Fig. 17 and Fig. 18.**

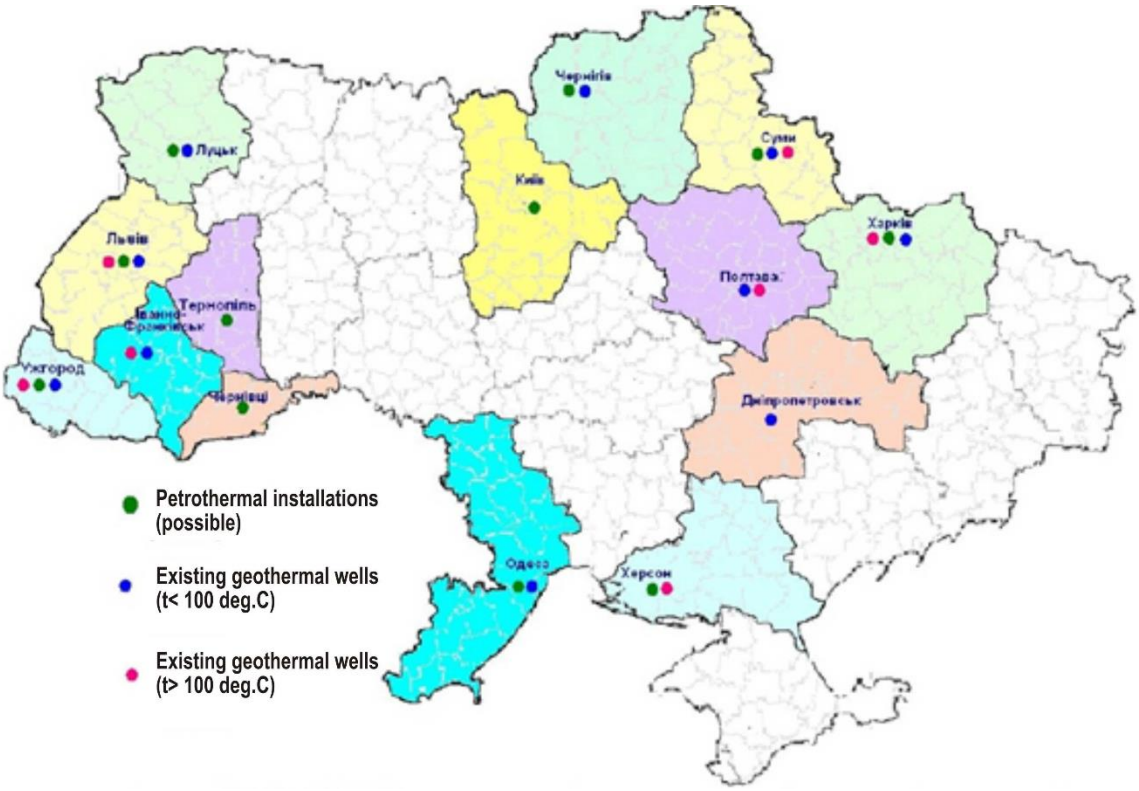


Fig. 17. Promising regions of Ukraine for the development of geothermal energy [23]

[29] Ю.П. Морозов, А.А. Барило. Обгрунтування методики визначення теплового потенціалу геотермічних пластових покладів // Відновлювана енергетика. 2021. No 1, с 81-86, https://ve.org.ua/index.php/journal/article/view/293/214

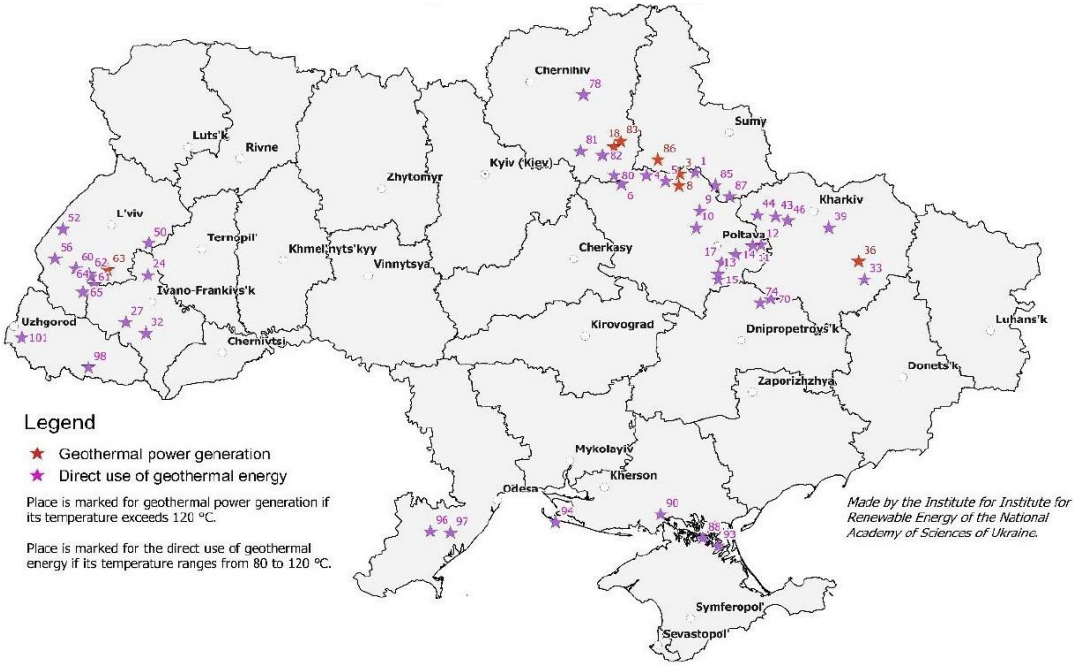


Fig. 18. The location of some promising places for the use of geothermal energy in Ukraine [24]

The electronic database of prospective geothermal objects of Ukraine was created. The database was collected from data of the stock materials of the "State Geological Information Fund of Ukraine. Currently the database includes 655 geothermal objects. The administrative regions of Ukraine are represented by the database (**Fig. 19**). As can be seen from the diagram, the information is collected in 12 regions. The largest amount is in Poltava, Lviv, Ivano-Frankivsk and Kherson regions. Note that currently about 54% of the existing hydrocarbon deposits are included in the database.

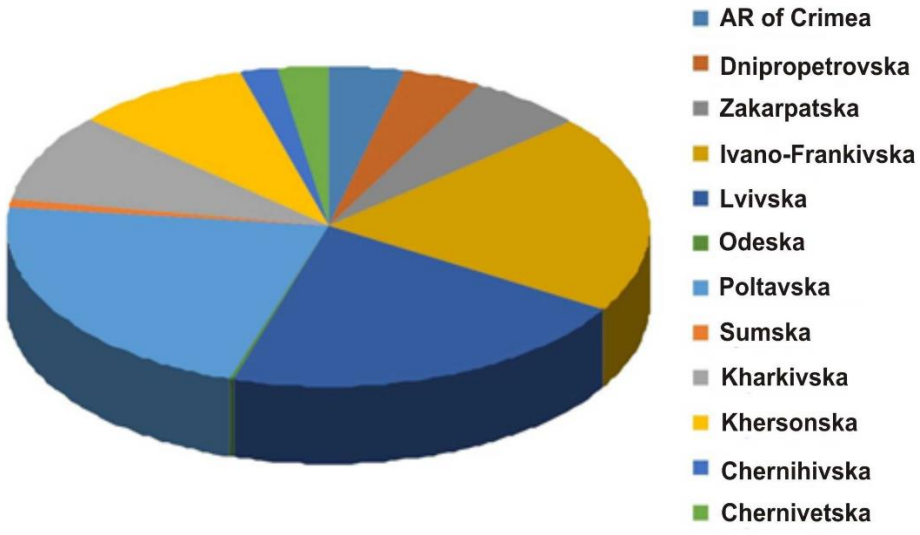


Fig. 19. Geothermal objects distribution of electronic database by administrative regions of Ukraine.

Transcarpathian internal bend. There are 38 geothermal objects within the structure. The average geothermal gradient is 5ºC/100 m (for some deposits it is equal to 7–8ºC/100 m) despite the high geothermal background of this area (the deep heat flow of the Transcarpathian internal bend

reaches 120 mW/m^2 (**Fig. 20**), The prevailing formation temperature of geothermal objects varies in the range from 40 to 70°C (**Fig. 21**).

First of all, this can be explained by the low depth of well drilling. As can be seen from **Fig. 22**, the depth of geothermal objects, which are included in the database, does not exceed 3 km and is 1,000-2,000 m on average.

In addition, the high location of the crystalline basement is the cause of limits of the thermal aquifers creation. For example, the absolute foundation marks within the Berehiv block are only 400–1000 m. The regional area of deep aquifers feeding is the zone of the Folded Carpathians. The cold atmospheric waters through the mountain faults cools of aquifers. Therefore, large thermal water deposits are not observed on the territory of the Folded Carpathians.

As can be seen from **Fig. 23**, two types of groundwater are clearly distinguished by the amount of mineralization: relatively weakly mineralized groundwater with a mineralization of up to 50 g/l and brines with a mineralization from 100 to 140 g/l. The origin of brines is most often associated with the presence of rock salt deposits in the section.

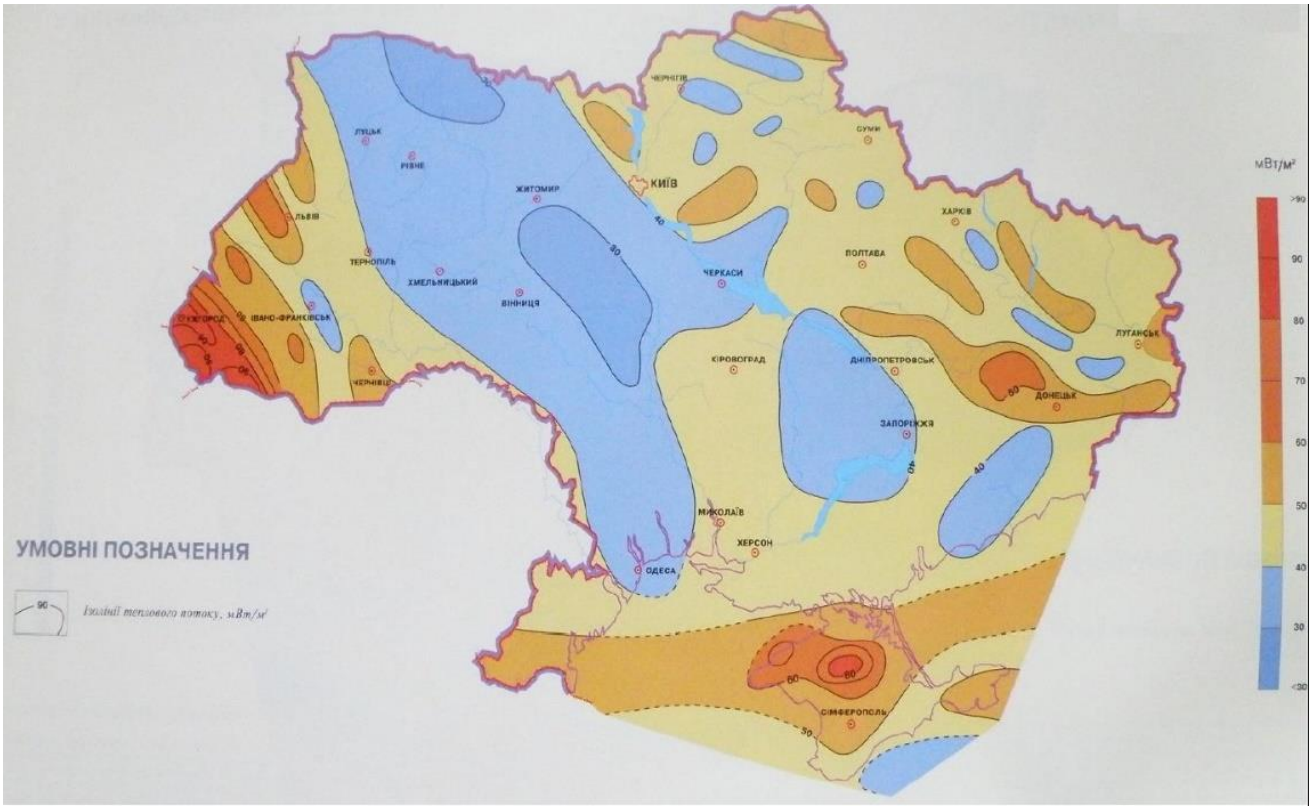


Fig. 20. Distribution of deep heat flux values on the territory of Ukraine, mW/m^2

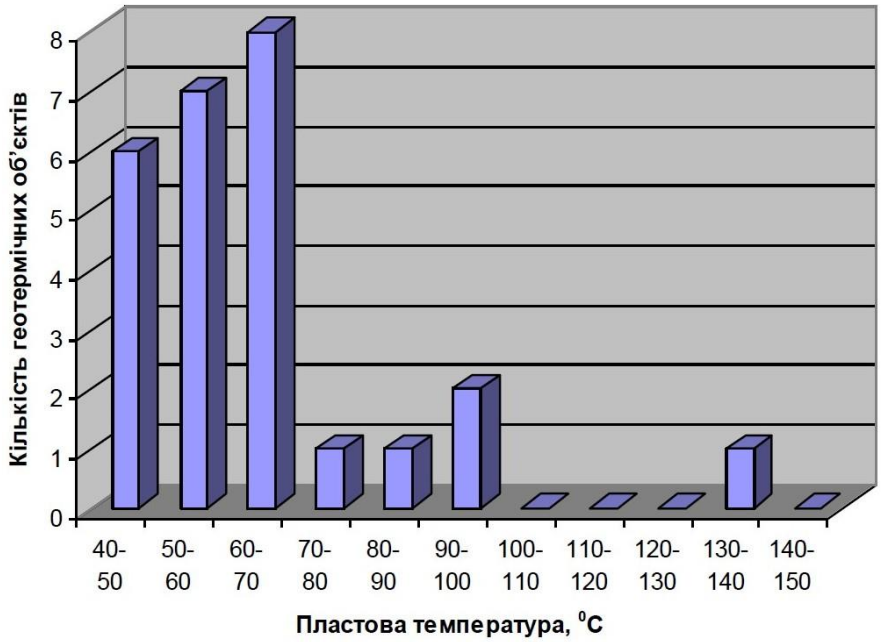


Fig. 21. Aquifer temperature distribution in the geothermal objects of Transcarpathian bend.

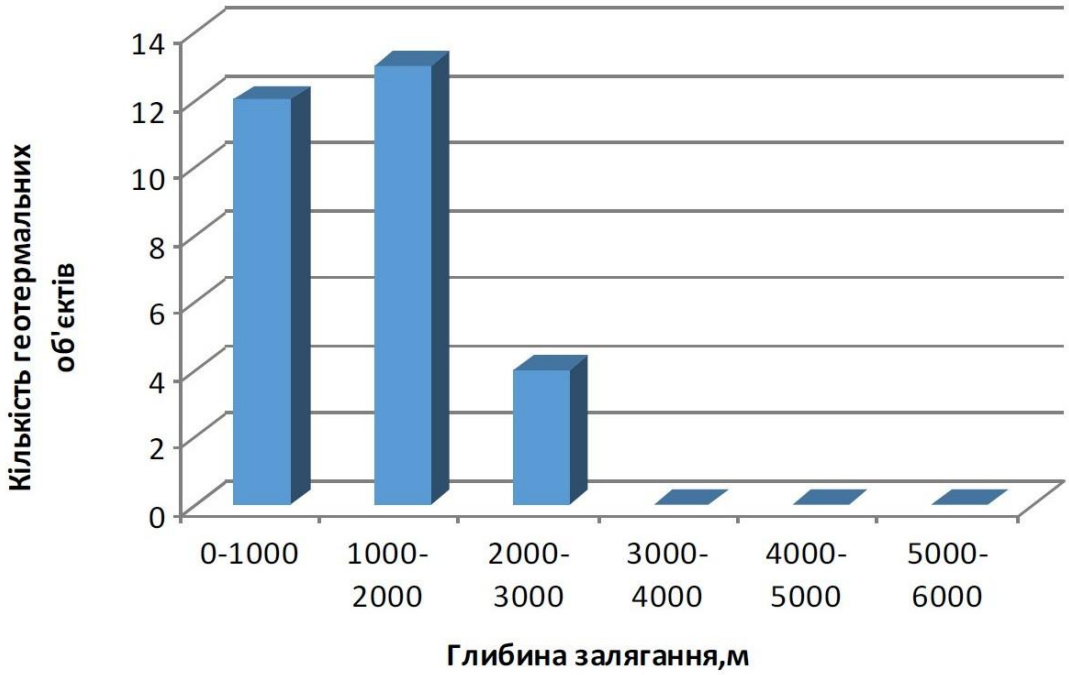


Fig. 22. Aquifer depth distribution in the geothermal objects of Transcarpathian bend.

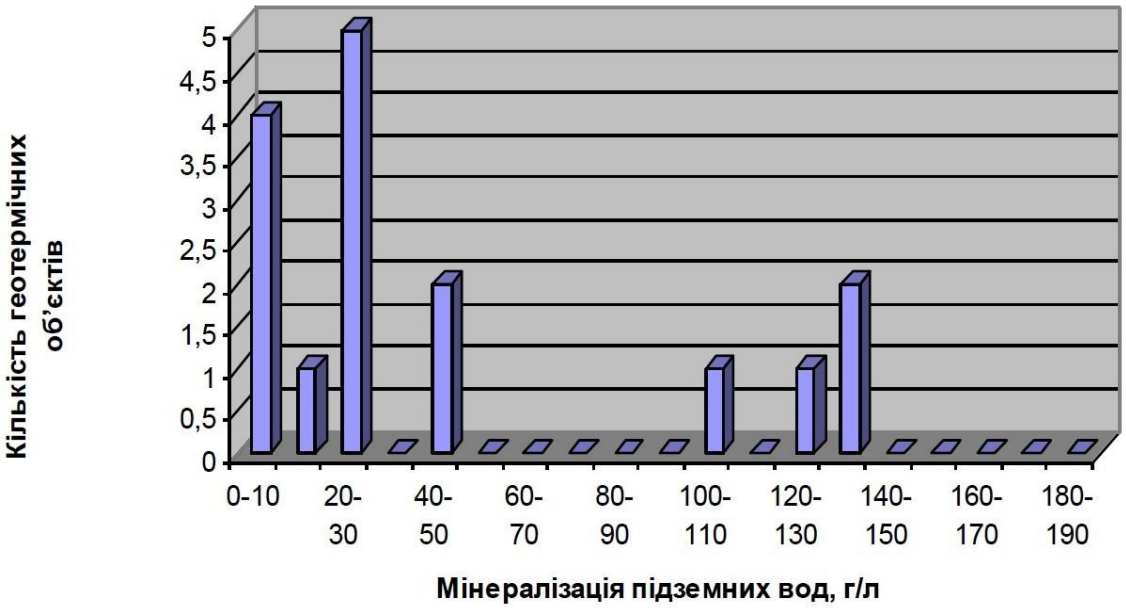


Fig. 23. Aquifer mineralization distribution in the geothermal objects of Transcarpathian bend.

Carpathian submountain bend (Fig. 24 - Fig. 26). On the territory of this structure there are 129 geothermal objects in Ivano-Frankivsk region, 138 objects in Lviv region and 16 objects in Chernivtsi region.

The southwestern slope of the Volyn-Podilsky plate is the main feeding area of the Carpathian bend due to the infiltration of atmospheric precipitation. On this area the sedimentary layer increases becauce aquifers practically come to the surface and sink in the direction of the Carpathians. Accordingly, the depth of the foundation varies from 1-2 km in the lateral part to 10 km in the axial part of the bend.

The sedimentary cover of the bend is structurally very heterogeneous. From bottom to top, three layers are distinguished in it: Precambrian-Paleozoic, Mesozoic-Paleogene and Neogene. The first is represented by little metamorphosed clay shales and quartzite sandstones. The second is represented by terrigenous flysch rocks. The third is represented by sand-clay formations.

Therefore, the geothermal objects are represented by the Carpathian bend are very diverse.

The most represented in the database is the third, uppermost structural layer of the sedimentary cover. The majority of geothermal objects and deposits are associated with this structural layer.

The inner part of the bend, which is directly adjacent to the Folded Carpathians, is the warmest. Average geothermal gradients are changed from 2.3 to 3.5ºC/100 m.

The distribution of groundwater mineralization in the objects of the database is varied. This indicates a very diverse origin of their chemical composition, which depends primarily on the composition of water-bearing rocks, the depth of occurrence and the openness of the horizon to water exchange. Note that the thickness of the salt-bearing formation in the inner zone of the Carpathian bend varies from 2,250 to 6,500 m. The terrigenous carbonate formation with a thickness of up to 2,000 to 3,000 m is widespread mainly in the outer zone of the bend. The largest number of objects are included in the range of 90 - 100 g/l.

Collectors are also very diverse in type, but mostly have porous-stratum and fractured- stratum types. Pressure horizons, static levels are set at depths from 150 m below to 100 m above the wellhead.

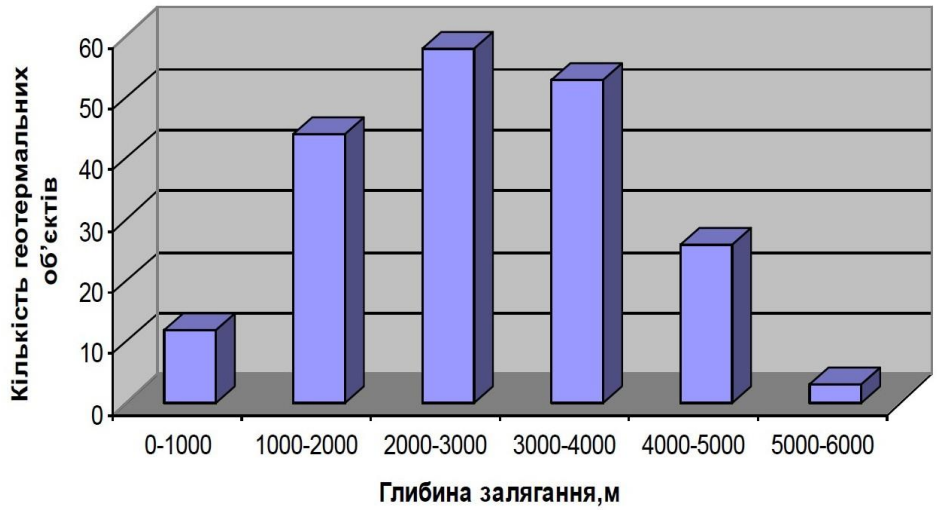


Fig. 2. Aquifer depth distributions in the geothermal objects of the Carpathian bend**.**

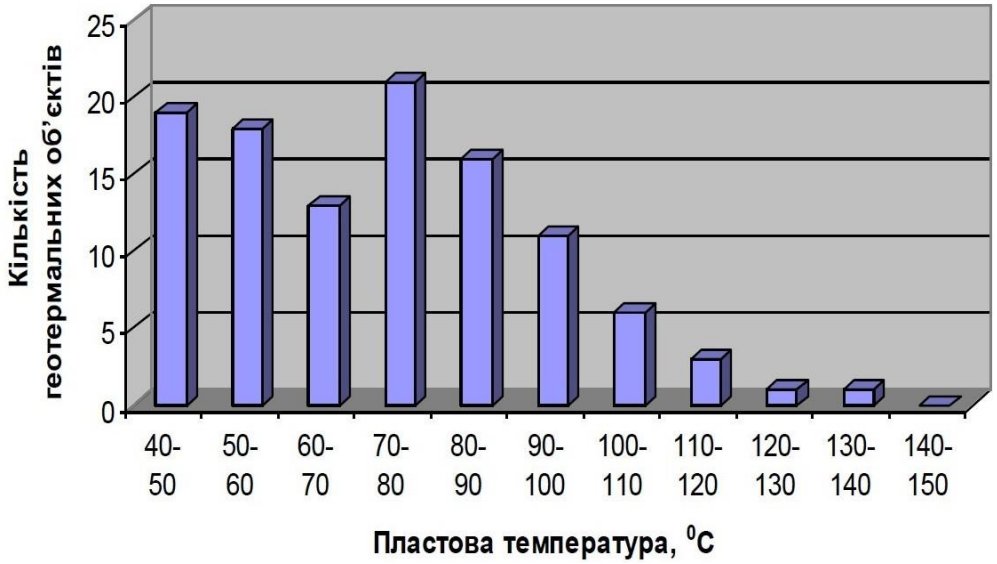


Fig. 25. Aquifer reservoir temperatures distribution in the geothermal objects of the Carpathian bend.

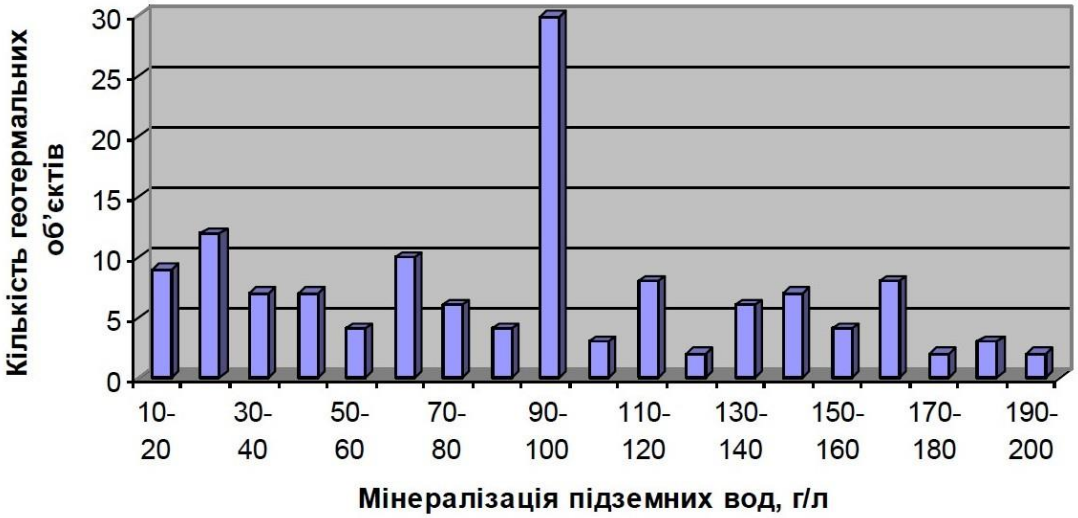


Fig. 26. Underground mineralization distribution in the geothermal objects of the Carpathian bend.

Dnipro-Donetsk artesian basin (Fig. 27 - Fig. 29). On the territory of this structure there are 143 geothermal objects of Poltava region, 6 objects of Sumy region, 13 objects of Chernihiv region and 58 objects of Kharkiv region. The Dnipro-Donetsk bend is a complex graben was made by the Paleozoic and Mesocenezoic sedimentary rocks with a total thickness from 2 to 12 km.

The general thermal background of its deposit is low (up to 3ºC/100 m). However, the deep immersion of the crystalline foundation and the presence of powerful sedimentary deposits at a considerable depth with good filtration properties which alternate with water-resistant clay horizons creates generally favorable conditions for the formation of thermal water deposits . The temperature directly depends on the depth of the horizon. Therefore, the predominant depth of geothermal objects varies from 1,500 to 5,000 m and above. The stratum temperature varies from 60 to 110ºC.

The horizons of stratum type with relatively high reservoir properties are observed in the central part of the Dnieper-Donetsk basin, up to a depth of 5-5.5 km. It is widely allocation over the area.

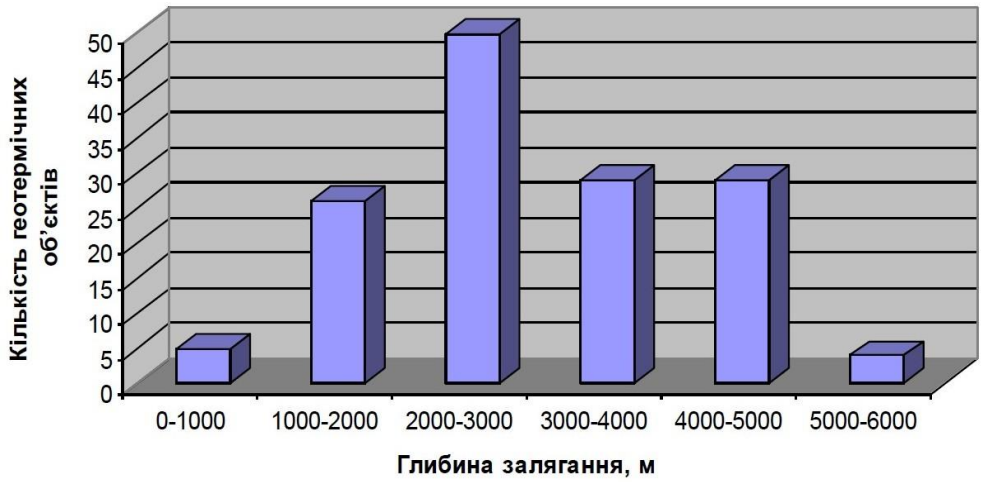


Fig. 27. Aquifer depth distributions in geothermal the objects of the Dnieper-Donetsk artesian basin.

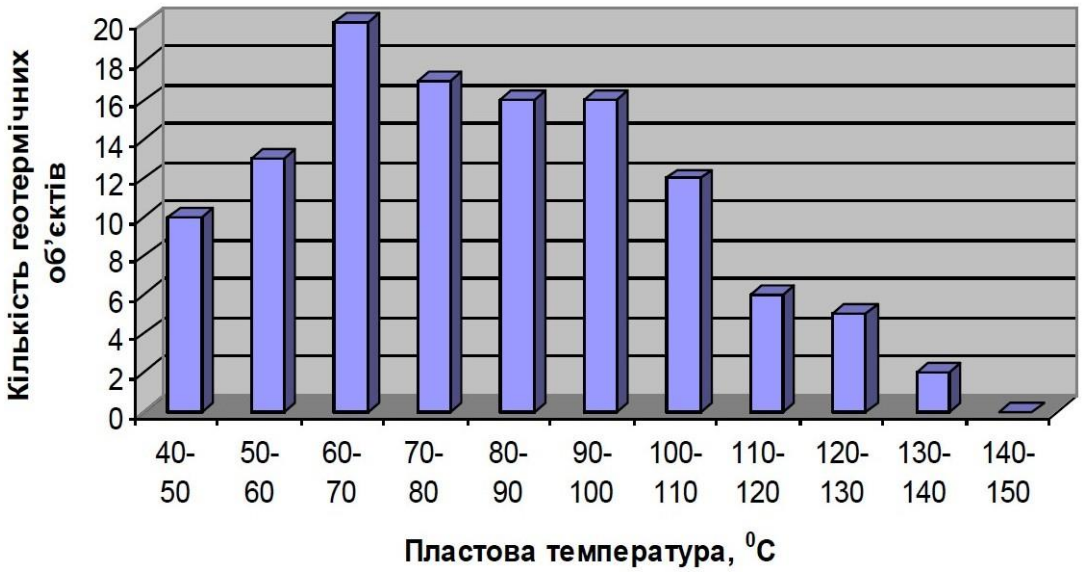


Fig. 28. Aquifer reservoir temperatures distribution in the geothermal objects of the Dnieper-Donetsk artesian basin.

Fig. 29. Underground mineralization distribution in the geothermal objects of the Dnieper-Donetsk artesian basin.

Black Sea artesian basin (Fig. 30 - Fig. 32).

On the territory of this structure, there are 59 geothermal objects in the Kherson region, 3 objects in the Odesa region, and 25 objects in the Autonomous Republic of Crimea. The main area of aquifer feeding is the southern slope of the Ukrainian Crystalline Massif. The surface of the crystalline foundation is inclined from north to south from the Ukrainian Shield towards the Black Sea. In the Odesa and Kherson regions, the foundation is immersioned to a depth of up to 2,000 m. Therefore, geothermal objects have a relatively small depth of occurrence and aquifer reservoir temperatures temperatures. The average geothermal gradient is 2.5ºC/100 m. The southern part of the Kherson region is the warmest.

The main thermal aquifers are limited to sedimentary formations of the Cretaceous, Paleogene and Neogene ages are represented by sandstones, limestones and argillites. The productive horizons are mainly stratum type. High-pressure horizons, static levels are formed at depths of ± 50 m from the wellhead.

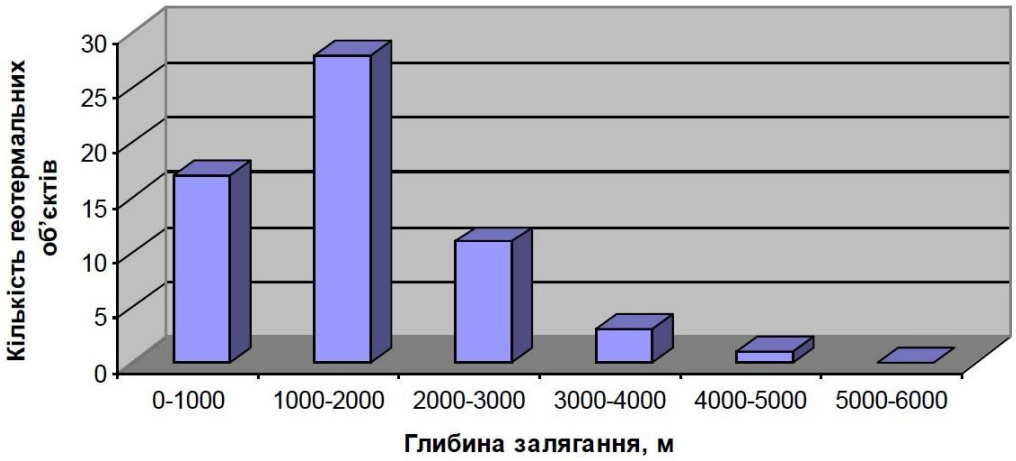


Fig. 30. Aquifer depth distributions in the geothermal objects of the Black Sea artesian basin.

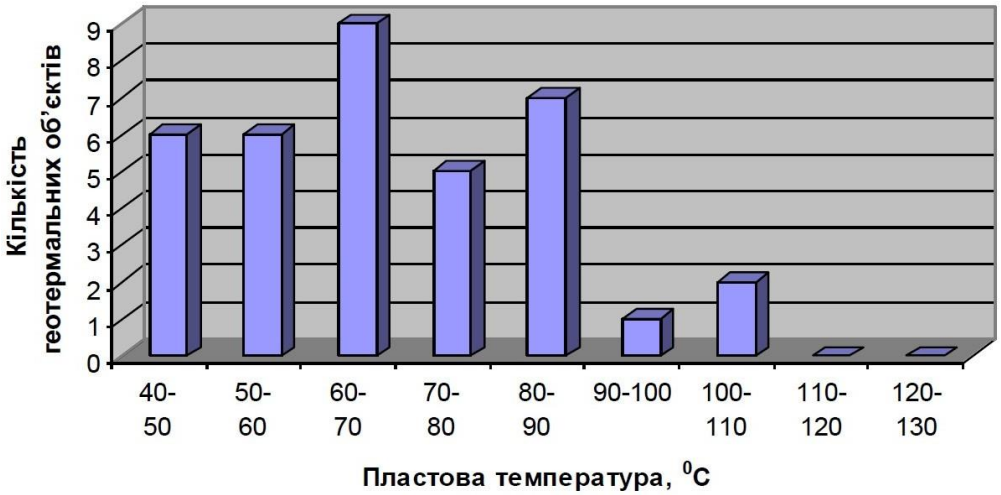


Fig. 31. Aquifer reservoir temperatures distribution in the geothermal objects of the Black Sea artesian basin.

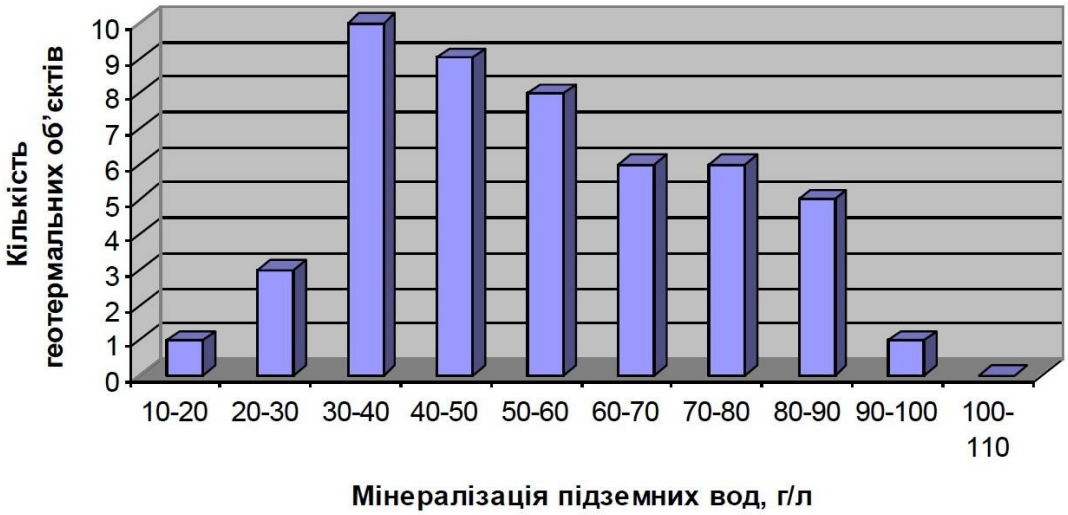


Fig. 32. Underground mineralization distribution in the geothermal objects of the the Black Sea artesian basin [30].

[30] А.А. Барило. Аналіз гідрогеологічних і геотермічних характеристик геотермальних об'єктів України// Відновлювана енергетика. 2020. No 1, с 74-85, https://doi.org/10.36296/1819-8058.2020.1(60).74-85, https://ve.org.ua/index.php/journal/article/view/246/175

3.2. Examples of the use of geothermal energy for heating (appropriate operated heating plants).

According to research data [23], energy supply systems were built in Ukraine, which are shown in **Table. 15.**

Table 15. The geothermal energy plants in Ukraine which were built and were operated.

Object name		Location	Year of commissioning	Heat / power capacity, MW	Fuel saving, tce/year
1.	The heat supply system of the Beecnfrehiv sports complex	Transcarpathian region Berehiv district	1978	2.1	1,520
2.	The heat supply system of the Kosino sanatorium	Transcarpathian region Berehiv district	1999	1.2	860
3.	The heat supply system of the Latoritsa health complex	Transcarpathian region Mukachevo district	1985	0.5	310
4.	Chongar village energy supply system	Kherson region	1991	3.6	2,700
5.	Heat supply system of Yantarne village	Crimea	1998	1.0 (0.1)	900
6.	Energy supply system of Medvedivka village	Crimea	2000 (heat) 2002 (power)	0.8 (0.07)	650
7.	The heat supply system of social and cultural life facilities in the village of Zernovo	Crimea	1997	0.4	335
8.	The system of heat supply of communal facilities in the village of Pyatikhatky	Crimea	1996	0.3	300
9.	The system of heat supply of communal facilities in the village of Nizynne	Crimea	1998	0.03	300
	Total in Ukraine			**11.2 (0.17)**	**7,375**

The three plants are operated according to the data of the authors [22] on 2020 year (**Table. 16).**

Table 16. Operating geothermal energy facilities in Ukraine

№	Object name, location	Capacity, MW
1	Geothermal heat station, Dzhankoy district, village Medvedivka, Autonomous Republic of Crimea	1.00
2	Geothermal heat station, Berehiv district, village Kosyno, Transcarpathian region	0.25
3	Geothermal heat station, Berehiv district, Berehove city, Zakarpattia region	0.25

The authors of the article from 2017 [31] claimed that the Berehiv deposit is one of the most studied in Ukraine. The thermal waters of this deposit have been used for more than forty years for the functioning of the swimming pool of the "Zakarpattia" sports base.

The Berehove geothermal field is located in the northeastern part of the city of Berehove, Transcarpathian region. The deposit is located on the left bank of the Verke River in the immediate vicinity of the "Zakarpattia" sanatorium (**Fig. 33**).

Thermal waters in this area were discovered during exploration for oil and gas. It was decided to carry out targeted geological exploration in search of thermal waters for the needs of the Zakarpattia sports base. The main requirements that were set by the customer of the works to the geologists were as follows: to provide the wellhead temperature at least 50ºC (conditions for a swimming pool), in addition, operational wells should be located at a minimum distance from the sanatorium.

It should be noted that the geothermal research in this area was narrowed by proposed requirements. So, for example, the depth of the drilling did not exceed the depth of the isotherm of 60ºC with an adjustment for the loss temperature in the wellbore to 10ºC. The location of wells was attached to the building of the sports base.

According to the results of research in nearby deposits the horizon with high filtration parameters and a temperature of more than 65ºC is situated on below the productive horizon at a depth of up to 1400 m. Therefore, the addition exploration of this horizon is recommended in further. The wells must be located closer to the feeding area, i.e. in the southwest direction from the Berehiv geothermal field.

The system of thermal water withdrawal was created for the pool operation. Two operational wells (well No. 2-T and well No. 8-T) are constructed the system. In addition, two observation wells (No. 15-T and No. 19-T) were drilled in area of the water withdrawal influence. The scheme of the water withdrawal is shown in **Fig. 33**. The construction of operational and observation wells is given in **Table. 17.**

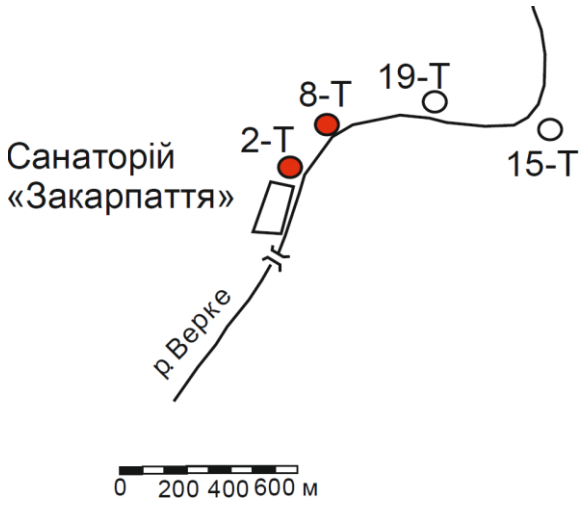


Fig. 33. Location of Beregovo area wells.

Table 17. Structures of operational and observational wells of the Beregovo geothermal field

№ of wells	**Depth, m**	**Drilling diameter, mm**	**Casing diameter, mm**
2-T	0.0–45	394	325
	45–351	295	219

[31] А.А.Барило. Дослідження свердловинних термограмм Берегівського гідротермального родовища // Відновлювана енергетика. 2017. № 4, с 75 – 83, https://ve.org.ua/index.php/journal/article/download/27/18

	351–930.4	190	146
	930.4–1,049.1	112	without casing
8-T	0.0–55	394	325
	55–331.1	295	219
	331.1–790	190	146
	790–1,050	112	89 (to depth 1,000 m)
15-T	0.0–34	394	325
	34–345	295	219
	345–844	190	146
	844–1,127	112	without casing
19-T	0.0–46	394	325
	465–354	295	219
	354–957.8	190	146
	957.8–1,160.1	112	without casing

The aquifer reservoir temperatures at a depth of 900 m for a number of wells which are drilled within the study area or in its immediate vicinity are presented in **Tab.18**.

The values of heat flows vary by the area of the deposit from 82 to 90 mW/m^2 (**Fig. 34**).

Table 18. Aquifer reservoir temperatures at a depth of 900 m

№ of wells	Berehove2-T	Berehove8-T	Berehove19-T	Berehove12-T	Ivanivka 3-T	V.Harasdivka 50c	Borzhava 4-T
Temperature, ºC	56.9	59.0	55.9	54.1	58.0	60.9	46.4

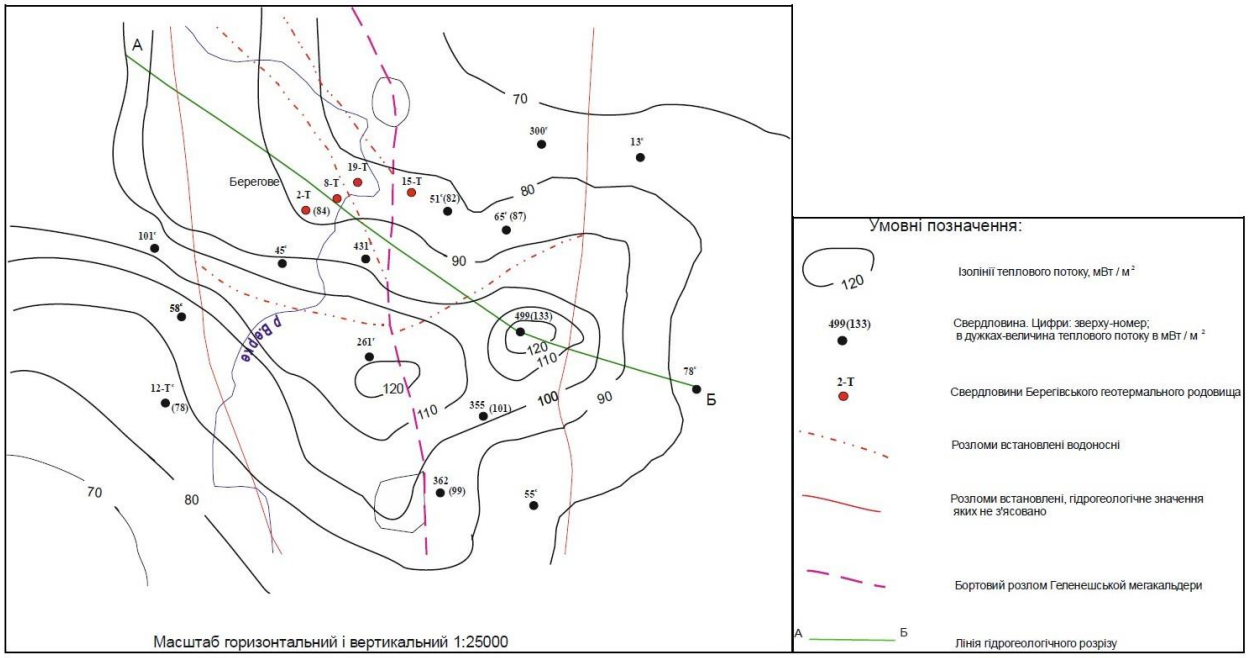


Fig. 34. Map diagram of heat flows and basic geological structures.

The results of temperature measurements in the boreholes of the Berehiv thermal water withdrawal are presented on **Fig. 35 – Fig. 37**.

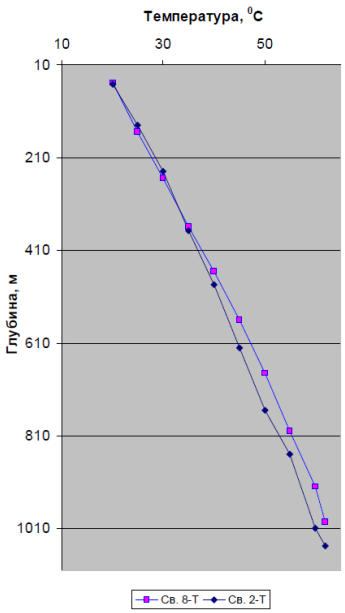


Fig. 35. Distribution of temperature in operational wells after drilling.

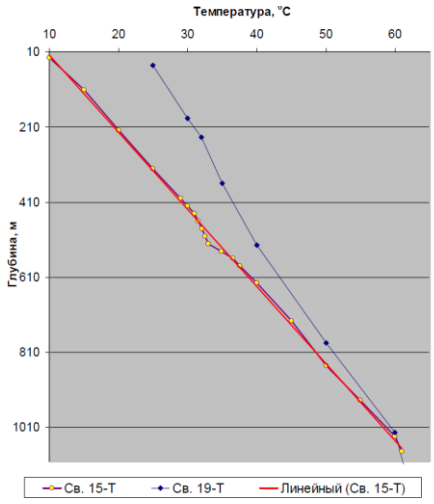


Fig. 36. Distribution of temperature in observation wells after their drilling.

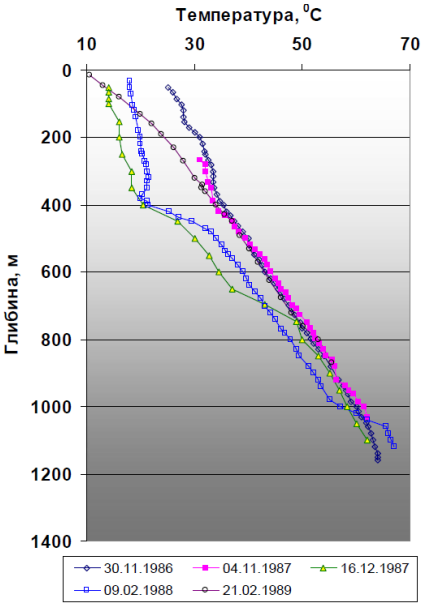


Fig. 37. Temperature distribution in well № 19-T during experimental filtering works.

As can be seen from the graphs, the natural temperature distribution in the massif is almost linear and increases uniformly with depth. The average geothermal gradients for wells No. 2-T, No. 8-T, No. 15-T, and No. 19-T are 0.042, 0.04, 0.044, and 0.028ºC/m, respectively.

During the entire period of operation, the temperature in the observation wells did not change, that is, the temperature front did not reach them. The temperature at the end of operation exceeded the initial temperature by 2–4ºC. It may indicate the arrival of warmer groundwater from remote areas of the deposit.

Analysis of wells thermograms showed that the thermal field of the Berehiv geothermal deposit in an undisturbed state is formed mainly by the conductive component. The filtration of groundwater is on the second place. There are no significant feeding area in the area of wells location. According to the map of heat flows, the main feeding area is located in the southeast direction from the contour of the deposit at a distance of 1.5-2 km [31].

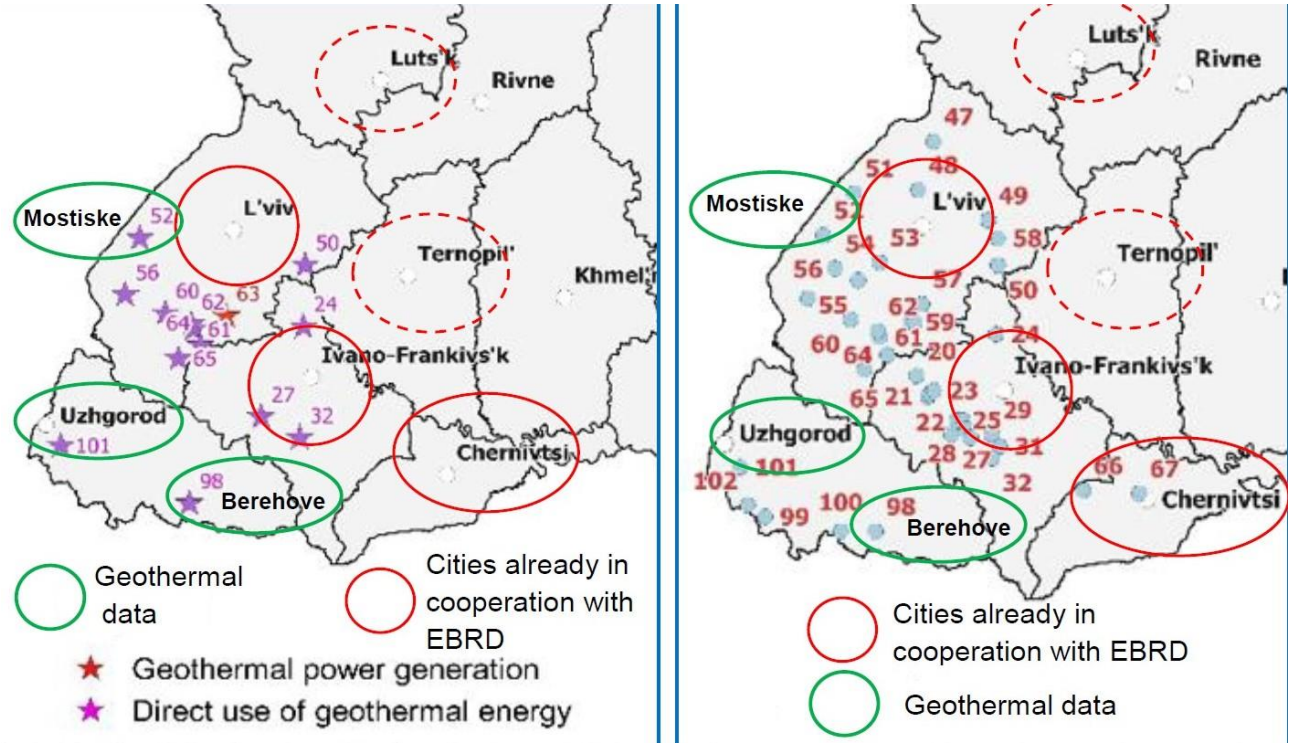
3.3. Assessment of the applicability of geothermal energy sources for heating the city, in which part of the centralized heating is 40-80% of the total heating demand.

Table 19. Potential objects of geothermal energy in Ukraine [22]

№	Location	Potential capacity, MW
Kherson region		
1	Geothermal heat station, Henichesky district, Henichesk	1.3
2	Geothermal heat station, Henichesky district, village. Chongar	1.5
Transcarpathian region		
3	Geothermal heat station, Mukachivsky district, village Kosino	1.0
4	Geothermal cogeneration station, Tyachevsky district, with. Tereblya	5.0

5	Geothermal heat station, Khustsky district, village Velatino	6.0
6	Geothermal heat station, Vynogradivsky district, with. Great Paladia	3.0
7	Geothermal heat station, Berehiv district, with. Great Bacta	2.0
8	Geothermal heat station, Uzhgorod district, Uzhgorod city	5.0
9	Geothermal heat station, Berehove	4.7
10	Geothermal power station, Uzhgorod district, with. Komarivtsi	6.0
Lviv region		
11	Geothermal heat station, Sambir district, village Pinyani	3.0
12	Geothermal power station, Mostysky district, Mostyska city	12.5
Poltava region		
13	Geothermal cogeneration station, Gadyatsky district, Gadyach	14.2
Chernihiv region		
14	Geothermal heat station, Ichnyansky district, village. Monastery	11.0
Kharkiv region		
15	Geothermal power station, Izyum district, Izyum city	10.0

Some promising geothermal energy resources in Ukraine are identified in the research [32] The results are shown in **Fig. 38** and in **Tab. 20**.



Place is marked for geothermal power generation if its temperature exceeds 120°C

Place is marked for the direct use of geothermal energy if its temperature ranges from 80 to 120°C

[32] «Геотермальна стратегія: Можливості та інструменти для України», 2016, https://orkustofnun.is/media/banners/OS-2016-01-ukraina.pdf

Fig. 38. Location of some promising geothermal energy resources

Table 20. Some perspective geothermal energy resources in Ukraine

Location	Population, thousand people	Expected consumption m^3/day	Temperature, °C	Geotherm. energy. MW	Fuel economy, k tce/year*	Recommendations
Lviv	730	Data needed	Data needed	Data needed	Data needed	Large district heating – exploration of geothermal potential is needed in the area
Ivano-Frankivsk	229	Data needed	Data needed	Data needed	Data needed	
Chernivtsi	263	Data needed	Data needed	Data needed	Data needed	
Uzhgorod	115	65,300	60	120.4	117.707	Heat supply of communal and industrial facilities in Uzhgorod
Mostyske	11	7,800	107	27.3	15.783	Heat supply of industrial premises, railway station, depot, residential buildings of Mostyske village
Berehove	24.5	10,300	58	21.5	21.152	Heat supply of Berehove village, balneological complex

* (tce - tons coal equivalent).

The authors of the study [33] assessed the possibility of using geothermal energy for heating houses in the cities of Balaklia and Pereyaslav (**Table 21**).

Table 21. Assessment of the location possibilities of geothermal fields for heat supply of multi-apartment buildings

Balaklia	Pereyaslav
There are necessary areas near 7 boiler houses. The amount of potential heat is 907 MWh/year. It corresponds to approximately 1.6% of the heat networks base load. There are no such areas near 2 boiler houses - on the street Partizanska, 1 and st. Zhovtneva.	Only near one boiler house - on the street. Khmelnytskogo, 1 - the appropriate area was found. The amount of potential heat of 199 MWh/year can cover 100% of the existing base load. It is about 149 MWh/year. No such areas were found near other boiler houses.
Heat network on 2,706 m2 of useful area of geothermal fields near the boiler house on the street. Partyzanska, 3 (Balakliya) requires about 198,370 euros of investments for 108 kW of thermal energy production and 195 MWh/year of total production. The payback period of the well and the probe is 50 years. The	

[33] Трансформація системи теплопостачання, Частина Б, Каталог заходів із інтеграції відновлюваних джерел енергії, модернізації централізованого теплопостачання та громадських будівель, dena 2021 https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2021/Handbuch_Kommunale_Waermewende_in_der_Ukraine_Teil_B.pdf

payback period of the heat pump is 20 years. Taking into account the costs of electricity, the cost of thermal energy will be about 3.15 Eurocents/kWh (0.95 UAH/kWh)	

Table 22. The variable component of the energy production cost in comparison (natural gas, wood, pellets, geothermal heat pump). The normalized efficiency losses and losses due to conversion are took into account.

Heat source	Cost of energy	Energy density	Heat production cost, UAH / kWh
Natural gas boiler (NES, 2019)	8.55 UAH /m^3	8.37 kWh /m^3	1.02
Boiler on wood	1.4 UAH /kg	2.34 kWh /kg	0.59
Boiler on pellets	4.2 UAH /kg	3.29 kWh /kg	1.27
Geothermal heat pump	0.9 UAH / kWh_{el}	Cumulative annual efficiency indicator: 4.2	0.23

In combination with a heat pump, geothermal energy is an effective technology option for relatively small buildings (**Fig. 39 - Fig. 40**).

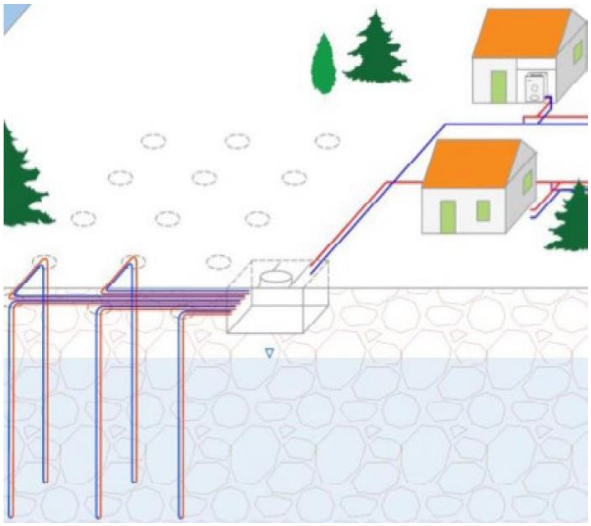


Fig. 39. System location of wells and connecting pipelines

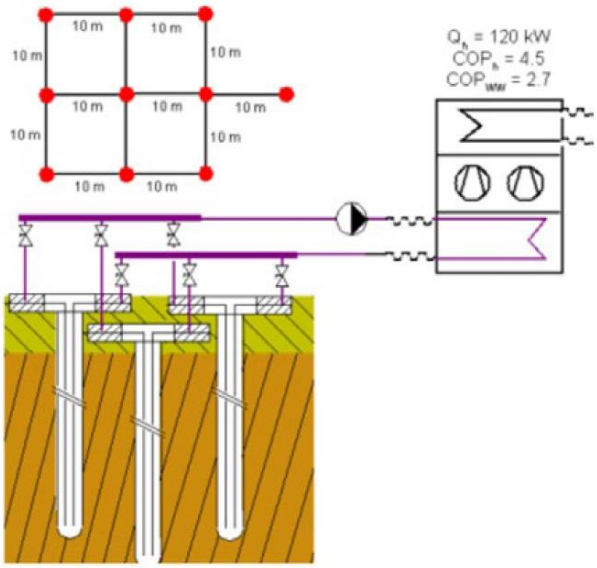


Fig. 40. Recommended location of 10 probes on a geothermal field for heat supply of an apartment building

The cost of drilling geothermal wells in Ukraine is approximately 200-300 euros per meter of depth. The heat pump together with the peripherals costs approx. 20-25% of the cost of drilling. Modern heat pumps of European manufacturers cost as much in Ukraine as in Western European countries.

A geothermal probe is inserted into a vertically drilled well. The most common variant of a geothermal probe is a (double) U-shaped probe. It is formed by parallel polyethylene pipes are connected at the bottom in the form of the letter "U". Water with a non-freezing liquid (brine) circulates in the ring collector. In water-poor areas, carbon dioxide is also used as an alternative type of heat carrier. The geothermal energy is not used to support centralized networks or directly in buildings in any of two presented cities Balaklia and Pereyaslav.

A 100 meters drilling depth was determined as the typical for near-surface probes. At a depth of more than 100 m, the legal regulations come into force in field of mineral deposits development. In addition, the probability of hard rocks appearance in one of the wells is increased at depth of more than 100 m. As result there is a possibility of drilling method changing (from wet to submersible hammer). It requires more funds. The potential ground heat that can be extracted by 100-meter probes is usually calculated at 50 watts per linear meter of drilling. Taking into account the possible unfavorable distribution of soft and hard rocks underground, it is better to take the potential of 40 W/m as the basis of the assessment.

The distance between the wells is 5-10 m, as a rule. The distance between the probes should be 10 m to prevent mutual damage of the probes on a long time. The efficiency (efficiency coefficient at the optimal operating regime) of the heat pump is 5.13. Total annual efficiency index (average efficiency, including start-up, shutdown, partial load/ adverse operating regime): 4.2 (81% of efficiency). Own electricity consumption is 2%.

If the above indicators are taken as a basis, the potential of integrating geothermal energy into the heat network of Balaklia will look like at **Table 23**:

Table 23. Geothermal potential for separate networks in the city of Balaklia by streets

Characteristics	Unit	Rostovtseva	Soborna	Gazovykiv	Pokrovska	Peremogy	Partyzanska	Novoselivka	Khmelnitskogo	**Total (average)**
Heat production, 2018	MWh	10,895	31,734	9,480	355	698	1,020	2,282	154	**56,518**
Amount of heat, basic load per year	MWh	10,157	30,640	9,159	334	675	989	2,184	149	**54,287**
The area of the site of the boiler house	m^2	1,300	1,590	1,524	2,900	1,001	2,706	1,573	2,769	**15,363**
Possible heat production by the geothermal probe and a pump per year	MWh	94	114	110	209	72	195	113	199	**1,106**
The share of coverage of the base load of the heating network	%	1	0.4	1	63	11	20	5	134	**(29.425)**

The thermal energy of water from wells with a depth of approximately 50 meters is used for heating buildings through the use of water-to-water heat pumps. The three-story kindergarten for 250 children in the Transcarpathian village of Pidvynogradiv is an example of the practice project implementation. The kindergarten has been heated by geothermal energy since 2015. Before that, the kindergarten burned 4-5 thousand cubic meters of gas per month. On average, 20-25 thousand cubic meters of gas were used during the heating season [34].

In the opinion of experts [25], geothermal energy projects, in contrast to most RES projects, have a specificity which consists in high risks and the duration of the first development period. Usually a duration of such project in its entirety is 5 - 10 years. The project needs significant

[34] https://heatpumpjournal.com.ua/arhiv/806/zhurnal-teplovye-nasosy-3-2017

investments and is implemented without a guarantee of a positive result. This circumstance is a problem for attracting of private capital. Therefore, the participation in projects state and private sectors is important condition for the successful development of geothermal energy. It is noted that orientation only on commercial capital is rarely successful even in developed countries. In international practice it is accepted that the government or international donors finance part of the costs. It is costs for initial development of the project, including exploratory drilling. Now in open sources there is no information about state financing of geothermal energy projects in Ukraine.

Conclusions of chapter 3

1. The areas in the east of Ukraine (bordering the Kharkiv, Donetsk, Luhansk and Dnipropetrovsk regions), as well as the Zakarpattia region, the north and east of the Crimean peninsula are most promising as the potential of geothermal sources.
2. Large parts of Poltava and Kharkiv regions, parts of Chernihiv, Sumy, Kyiv, Cherkasy, Dnipropetrovsk, Donetsk, Luhansk, Odesa, Mykolaiv, Kherson, and Zaporizhia regions, as well as parts of Lviv, Ivano-Frankivsk, Ternopil, and Chernivtsi regions, central and the southern parts of the Crimean Peninsula are also perspective. There are also a number of potentially promising territories adjacent to those mentioned above (see **Fig. 14**).
3. The temperature range of geothermal resources in the most promising regions is from 65 to 130°C, which makes them applicable for DH supply for at least part of the heating period. The potential of replacing natural gas due to the use of the technically available potential of geothermal energy in the most promising areas is 15.8 thousand GWh per year. It is equivalent to replacing 2.2 billion m^3 of natural gas. The specified amount or volume is only 4% of the total geothermal potential of Ukraine.
4. In general, the data on the assessment of the geothermal energy potential of different authors significantly differ, perhaps due to the use of various assessment methods.
5. Hydrothermal resources are the most widespread and currently suitable for technical use as a source of geothermal energy in Ukraine. Potential geothermal resources of thermal waters amount to 27.3 million m^3/day, and their thermal energy potential is about 84 million Gcal/year.
6. Geothermal heat energy resources of Ukraine, the most ready for development (with water temperature of 60–80°C), amount to more than 1 GW of thermal power. The most promising regions are Zakarpattia, Sumy, Chernihiv, Kherson and Poltava regions.
7. The possible capacity of Geothermal Power Plant in the most promising regions is estimated by some experts at 70 GW. The 48 GW of which are situated in the east of Ukraine. According to the some authors opinion [28], the direction of construction of small geothermal TPP with a unit capacity of 0.05–5 MW and with a temperature of 90–120°C is perspective in Ukraine.
8. The electronic database of researched geothermal objects of Ukraine was created by a team of researchers. The database was collected from data of the stock materials of the "State Geological Information Fund of Ukraine". Currently the database includes 655 geothermal objects. According to the results of the research, several geothermal artesian basins are selected: the Transcarpathian internal bend (probably the most studied, especially the Berehiv deposit), the Carpathian piedmont bend, the Dnieper-Donetsk artesian basin, the Black Sea artesian basin. This database is not publicly available.
9. The heat potential of the existing 34 geothermal Ukrainian wells is 240.7 thousand MWh/year for heat supply and hot water systems (temperature of thermal water - 60-70˚C). It is equivalent to 26 million m^3 of natural gas per year.

10. From 1978 to 2002 the 9 geothermal energy objects were built in Ukraine, including 5 objects on the Crimean Peninsula, 3 objects in Zakarpattia and 1 object in the Kherson region. The total thermal capacity of these objects was 11.2 MW, electric capacity was 0.17 MW. As of 2020, 2 objects are operated in Zakarpattia Oblast (0.25 MW every object) and one with a capacity of 1 MW is worked in Crimea. Since 2002, no new installations have been put into operation, and in general geothermal energy has not developed significantly.

11. The 15 geothermal plants in 6 regions of Ukraine, including 5 electric and cogeneration plants with a capacity of 5 to 14.2 MW, and 10 thermal plants with a capacity of 1 to 11 MW are selected as promising geothermal objects in more recent study (2016). In particular, the experts in the sector have not identified so many promising objects, despite the considerable volume of accumulated data on the geothermal resources of Ukraine. In any case, we are not talking about the prospect of large-scale involvement of these resources in heat supply and replacement at their expense of any significant share of fossil fuels.

12. The presence of promising geothermal deposits near such large cities in the west of Ukraine as Lviv, Ivano-Frankivsk, Chernivtsi, Uzhgorod, as well as smaller cities Mostyske and Berehove is noted. However, the potential of heat capacities of geothermal energy for the cities of Uzhgorod (120.4 MW), Mostyske (27.3 MW) and Berehove (21.5 MW) are more or less determined. The cities of the Transcarpathian region, including Uzhgorod, practically refused DH supply. The autonomous and individual heating are operated. It is a negative circumstance that may affect to the possibilities of geothermal energy implementation.

13. More practical assessments of the possibilities of using geothermal fields for heat supply of an apartment buildings in the cities of Balaklia and Pereyaslav are considered a drilling wells of depth up to 100 m. It is because at a depth of more than 100 m, the legal regulations come into force in field of mineral deposits development. In addition, the probability of hard rocks appearance is increased. It is needed of use more expensive drilling methods. The use of a ground heat pump was considered for heat extraction. It was found that not every existing boiler house has enough area to build an additional geothermal plant on it. According to the calculation, the investment in the installation with a thermal capacity of 108 kW should amount to 198,370 Euros (ie, 1,837 Euros/kW of thermal capacity). The estimated payback period of the well and the probe is 50 years. The payback period of the heat pump is 20 years. However, the given comparison of the variable component of the heat energy cost is showed lower values for geothermal energy than for other possible options (natural gas, wood, pellets), the volume of needed capital investments increases the estimated payback period. The cost of drilling geothermal wells in Ukraine is approximately 200-300 Euros per meter of depth is noted in the study. The heat pump together with the peripherals costs approx. 20-25% of the cost of drilling. Modern heat pumps of European manufacturers cost as much in Ukraine as in Western European countries. Despite the relatively high cost, this type of technology is still worth considering as a source of thermal energy in relatively large new buildings.

14. In the opinion of experts [25], geothermal energy projects, in contrast to most RES projects, have a specificity which consists in high risks and the duration of the first development period. Usually a duration of such project in its entirety is 5 - 10 years. The project needs significant investments and is implemented without a guarantee of a positive result. This circumstance is a problem for attracting of private capital. Therefore, the participation in projects state and private sectors is important condition for the successful development of geothermal energy. It is noted that orientation only on commercial capital is rarely successful even in developed countries.

4. A survey among territorial communities and heat energy suppliers in Ukraine regarding the possibilities and existing examples of the use of waste heat of industrial enterprises for DH.

In order to assess the possibilities of using waste heat of industrial enterprises for DH, a survey was conducted among municipalities. The Questionnaire is given in Appendix 2.

There were 14 responses received, among which 6 responses stated that there are industrial enterprises in or near their cities that could potentially be a source of waste heat resources. The main content of the received positive answers is shown in the table below (**Table 24**).

Table 24. List of positive responses regarding the availability of waste heat resources of industrial enterprises in municipalities.

	Zaporizhzha	Ladyzhyn	Lviv	Rivne	Nadvirna
City/Town	Zaporizhzha	Haysyn	Lviv	Rivne	Nadvirnyanskyy
Region	Zaporizhzha	Vinnytsya	Lviv	Rivne	Ivano-Frankivska
Are there sources of DH (boiler plants, heating networks) in the settlement?	Yes	Yes	Yes	Yes	Yes
What is their number and thermal power?	100 MW	1	200 MW	more than 10 DH boiler houses	2
Specify, if known, the number of consumers of DH	750,000	20,000		more than 180 thousand people	
Indicate, if known, the total connected heat loads for heating, Gcal/hour or MW				more than 60 Gcal/h	
Indicate, if known, the annual costs of energy resources for DH (thousand m3 of gas, tons of coal, firewood, etc.)	10,000			60 million м^3 of nat.gas	
Are there industrial enterprises with waste heat sources that are not used or not fully used (hot waste gases, hot air, hot water, steam) in the settlement or near it?	Yes	Yes	Yes	Yes	Yes
Specify what are the sources of waste heat	Steam, sewage	Hot water, steam	CHP, boiler-houses	Hot water	Hot air, hot water, steam
Estimated distance (km) from the industrial enterprise with waste heat resources to the heat network lines	5	2 km	2	60 km	2
Estimated distance (km) from an industrial enterprise with waste heat resources to existing sources of heat supply (boiler plants)	5	5 km	2	60 km	3
Estimated distance (km) from an industrial enterprise with waste heat	5	2 km	2	60 km	2

resources to potential heat consumers for heating					
Are there active examples of heating due to waste heat sources of industrial or other enterprises in your locality?	Yes	No	No	No	No
What exactly is heated and at the expense of which sources of waste heat?	DH system				-

It should be noted that all cities listed in the table are included in the list of Annex 1, that is, industrial enterprises that could potentially be sources of waste heat resources for heating have been identified in these cities. The indicated distances (2-5 km) are fairly typical distances from industrial facilities to potential heat consumers, as was shown in section 2. In the case of Rivne, where the indicated distance is 60 km, it is probably Rivne NPP meant as a source of waste heat resources.

Conclusion on chapter 4

1. Despite the large number of questionnaire letters sent out, only 14 responses were received. In our experience, this is generally a fairly typical survey result, reflecting the fact that respondents can only be expected to respond if they have a significant interest in the results of such a survey.
2. In terms of effectiveness, the search for potential industrial enterprises as sources of waste heat is clearly inferior to the search for such enterprises using open sources.
3. In the future, when evaluating the possibility of using WE of certain industrial enterprises for the heating needs, it is worth focusing on obtaining preliminary information according to the following list:
    - the interest of the management of the industrial enterprise in finding and evaluating the amount of waste heat resources for possible useful use;
    - the interest of the company's management in using waste heat resources specifically for heat supply, since the organization of heat supply to third-party consumers is a licensed activity and requires, in addition to technical, also certain organizational measures;
    - heat level and volumes of waste heat resources, type of heat transfer medium, daily and annual irregularity of waste heat production;
    - presence and proximity of potential consumers of DH or large individual consumers;
    - the presence and proximity of heat networks of heat supply enterprises to the potential point of heat output from the industrial enterprise, the thermal schedule of the DH network or individual consumers, the possibility of laying heat networks from the industrial enterprise in view of possible obstacles.

5. Analysis of plans for the use of waste heat of industrial enterprises and geothermal energy in the energy strategies of Ukrainian cities and documents of the national level.

5.1. Energy Strategy of Ukraine (ESU) for the period until 2035

"Energy strategy of Ukraine for the period until 2035 "Security, energy efficiency, competitiveness" (hereinafter- ESU) [35] was approved by Decree of the CMU No. 605-r dated August 18, 2017.

This is a document that outlines the strategic guidelines for the development of the fuel and energy complex of Ukraine for the period up to 2035. The forecast indicators contained in the document demonstrate the trajectory of the development of energy and related industries. In the future, the tasks and indicators of the ESU should be detailed and reflected in the relevant development programs of the sub-sectors. According to the results of the implementation of the ESU tasks, it is planned to achieve a reduction in the energy intensity of GDP by more than two times by 2035.

A key quantitative and qualitative characteristic of the ESU is the structure of the total primary energy supply (TPES), which reflects the indicators that Ukraine must achieve, including in accordance with its international obligations in the areas of RES development and climate change.

Regarding the use of waste heat of industrial enterprises and geothermal energy, the ESU states that one of the measures to reduce energy consumption in DH systems **should be the use of heat from the technological processes of industrial enterprises**.

It is also stated that the realization of energy saving potential in industry will be ensured through the implementation of energy management and energy service systems, stimulating state economic policy and gradual increase in energy efficiency requirements by revising energy consumption standards.

Local energy systems should be formed on the basis of cost-effective consideration of the potential of local fuels, supply logistics, regional and national energy infrastructure, and optimization of local heat supply systems should be carried out on the basis of **economic efficiency**, coordination of centralization and decentralization of heat supply.

Also, by 2025, it was planned to reassess the technical and economic indicators of long-distance heat transport projects from large energy facilities (TPP and NPP) and make a decision on the feasibility of their implementation.

Thus, in the ESU there is a direct indication of the need to use the heat of technological processes of industrial enterprises for heat supply. The use of geothermal resources is not directly mentioned, however, in the forecast structure of the TPES there is such a component as "thermal energy", which is understood as *"thermal energy of the environment and waste resources of man-made origin"*. The forecast structure of the TPES is shown in **Table. 25** and illustrated in **Fig. 41.**

Table 25. The structure of Ukraine's TPES, Mtoe

Names of sources of primary energy supply	2010	2015	2020 (forecast)	2025 (forecast)	2030 (forecast)	2035 (forecast)
Coal	38.3	27.3	18	14	13	12
Natural gas	55.2	26.1	24.3	27	28	29
Oil products	13.2	10.5	9.5	8	7.5	7

[35] https://zakon.rada.gov.ua/laws/show/605-2017-%D1%80#Text

Nuclear energy	23.4	23.0	24	28	27	24
Biomass, biofuel and waste	1.5	2.1	4	6	8	11
Solar and wind energy	0.0	0.1	1	2	5	10
HPP	1.1	0.5	1	1	1	1
Thermal energy*		0.5	0.5	1	1.5	2
In total	132.3	90.1	82.3	87	91	96

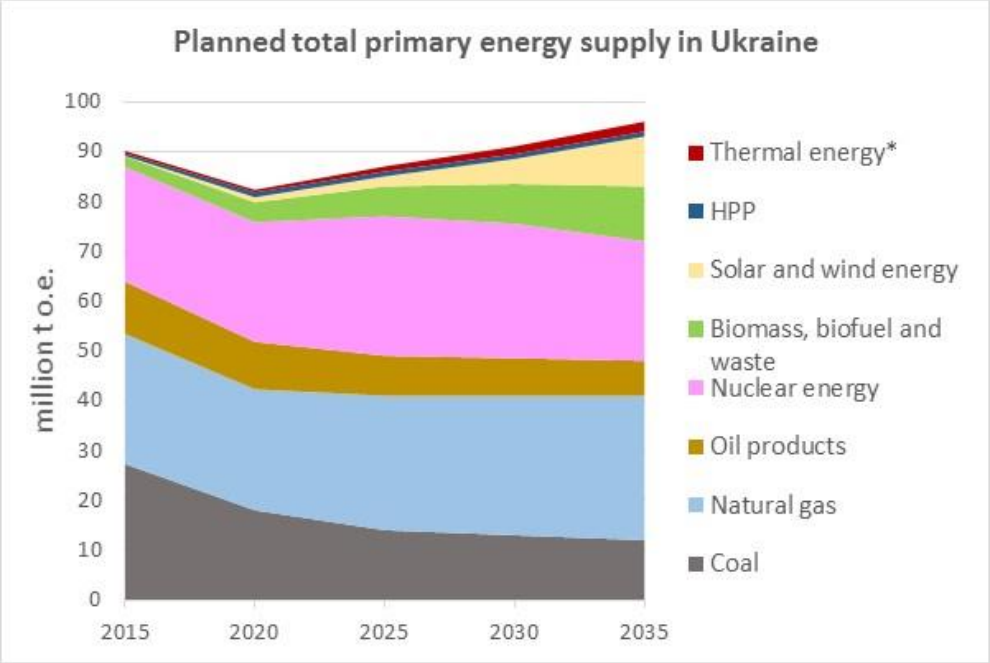


Fig. 41. The structure of Ukraine's TPES (Energy Strategy of Ukraine until 2035)

Thus, in 2035, the share of thermal energy in the structure of Ukraine's TPES should be 2% (**Fig. 42**)

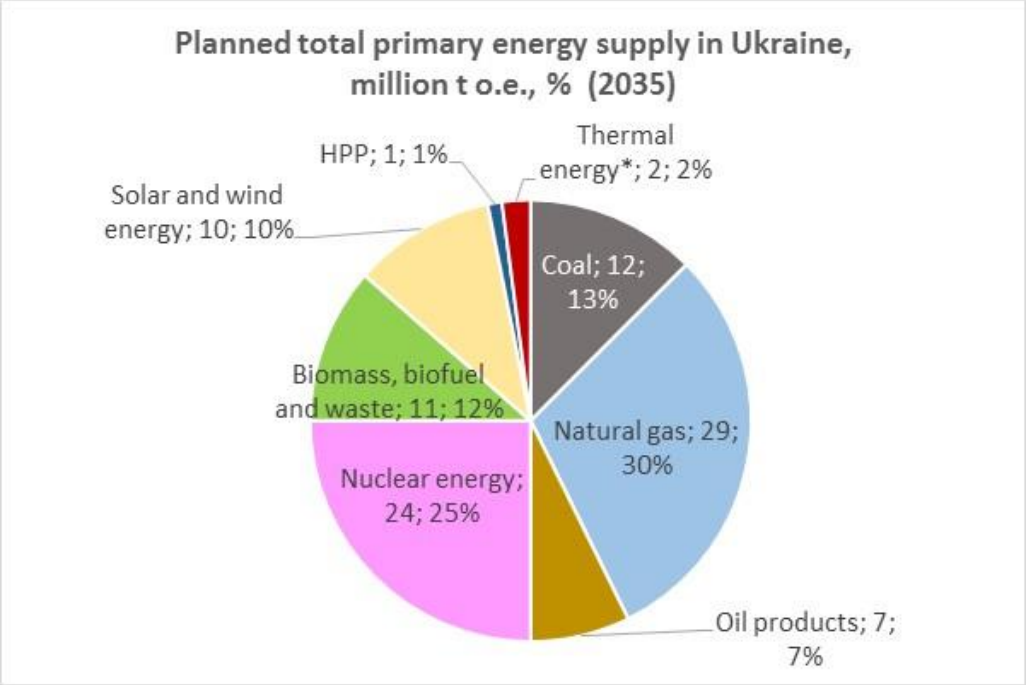


Fig. 42. Forecsat structure of TPES of Ukraine's in 2035, Mtoe, %.

5.2. National Energy Efficiency Action Plan for the period until 2030

The National Energy Efficiency Action Plan for the period up to 2030 [36] was approved by CMU Order No. 1803 dated December 29, 2021, and the Action Plan for the implementation of the National Energy Efficiency Action Plan for the period up to 2030 in 2021-2023 was also approved.

With regard to the use of waste heat of industrial enterprises and geothermal energy, the National Energy Efficiency Action Plan for the period until 2030 (hereinafter - NAP) envisages a number of measures that will have an indirect effect, in particular:

- Functioning of the Energy Efficiency Fund.
- Introduction of a mechanism to stimulate industrial enterprises to implement energy-efficient measures, state support of such measures at the expense of stable sources of funding, which implies the energy audits performed by enterprises with the consistent creation of an effective monitoring and verification system or the introduction of an energy management system, which provides for a monitoring and verification system as a component.
- Energy taxes/greenhouse gas emissions taxes (environmental taxes), including an increase in the carbon tax, the introduction of taxation of environmental externalities through a special excise tax on relevant goods.
- Implementation of energy efficiency measures under the energy service mechanism.
- Implementation of energy audit and energy management systems at industrial enterprises.
- Measures to support the improvement of the efficiency of heat supply systems, in particular, the actualization of measures of the Concept of implementation of state policy in the field of heat supply.
- Support of highly efficient combined production of heat and electricity (cogeneration) and **use of waste energy potential**. The measure will include support for investment in high-efficiency cogeneration plants, but additional legislation must be adopted to comply with the Energy Efficiency Directive 2012/27/EU.

Regarding energy efficiency measures in industry, it is noted that in 2017 and 2019, the share of industry in the structure of final energy consumption was 31.9% and 34.6%, respectively. More than half of the energy is used in ferrous metallurgy, the food and mining industries, as well as the production of non-metallic mineral products, are also large energy consumers.

The **Concept of the mechanism for the targeted use of the tax on carbon dioxide emissions** to stimulate industrial enterprises to energy efficiency and the use of renewable energy sources as part of the transition to low-carbon development has already been developed. Currently, the Verkhovna Rada of Ukraine has registered a draft law on the creation of the Decarbonization Fund, which will finance energy-efficient projects. In accordance with the obligations of the Association Agreement between Ukraine, on the one hand, and the European Union, the European Nuclear Energy Community and their member states, and the requirements of Directive 2003/87/EU, it is expected that Ukraine will introduce a **national quota trading system for emissions of greenhouse gases (ETS)**.

Increasing energy efficiency in industry should be considered in the context of reducing the energy intensity of the economy and strengthening its competitiveness both in general and for individual goods and groups of goods. The future **Carbon Border Adjustment Mechanism (CBAM)** will also be a factor in the formation and implementation of Ukraine's state policy in the field of industry, regarding which the EU is currently conducting consultations and will be held in the future regarding the inclusion of Ukraine in the mechanism.

Thanks to energy efficiency measures, by 2030 (compared to the baseline scenario), it is planned to achieve a reduction in primary energy consumption in the amount of:

[36] https://zakon.rada.gov.ua/laws/show/1803-2021-%D1%80#Text

- in industry - 4.25 million toe;
- in heat supply - 3.33 million toe;
- due to the development of highly efficient combined production of thermal and electrical energy (cogeneration) and the use of waste energy potential - 7.9 million toe.

The Plan of measures for the implementation in 2021-2023 of the National Energy Efficiency Action Plan for the period until 2030 provides, in particular:

- introduction of a mechanism to encourage business entities to implement energy-efficient measures and implementation of energy-efficient measures in at least 180 enterprises;
- increasing the number of introduced energy management systems and energy monitoring systems in industry and other areas of energy-intensive production;
- development and implementation of an updated plan of measures for the implementation of the Concept of implementation of state policy in the field of heat supply for the period until 2025, creation of conditions for assessing the potential of using renewable energy sources in heat supply, highly efficient combined production of thermal energy (cogeneration) and waste energy potential (IV quarter of 2021);
- spread of the use of technologies of highly efficient combined production of heat and electricity (cogeneration) and the use of waste energy potential in accordance with the principles and provisions of EU legislation, creation of a legislative basis for the development of highly efficient cogeneration.

Thus, the NAP does not directly mention and does not single out a separate direction for the use of waste heat of industrial enterprises or geothermal energy for heat supply needs, but it contains a number of provisions that can potentially contribute to the development of such projects.

At the same time, it should be noted that in case of the introduction of the aforementioned Carbon Border Adjustment Mechanism (CBAM), some industrial enterprises may find it more profitable to use their own waste heat resources to reduce the energy intensity of their own products than to supply this heat to other consumers.

5.3. The draft National action plan for the development of renewable energy for the period until 2030 [37].

This document has not yet been approved, but it was published on the official website of the State Energy Efficiency Agency and public consultations were held in October 2022.

The document states that Ukraine has a certain potential for the development of geothermal energy. This is due to the thermogeological features of the terrain and features of the country's geothermal resources. However, in contrast to other renewable energy sources, the growth of geothermal energy production capacity in Ukraine is much slower. This is due to additional initial capital costs, which include not only the costs of energy equipment for the conversion of geothermal energy sources, but also the costs of drilling operations.

The most widespread and currently suitable source of geothermal energy for technical use in Ukraine are hydrothermal resources (heat of deep underground thermal waters and parahydrotherms, which is used by the heat and electricity generating units). The most favorable geothermal conditions for the development of hydrothermal resources are characterized the Pre-Carpathian (Lviv, Ivano-Frankivsk, partly Chernivtsi oblasts) and Transcarpathian (Transcarpathian oblasts) depressions, the

[37] https://saee.gov.ua/sites/default/files/blocks/6_%D0%9F%D1%80%D0%BE%D0%B5%D0%BA%D1%82_%D0%9D%D0%9F%D0%94%D0%92%D0%95-21.09.2022%20%28%D0%B4%D0%BE%D0%BE%D0%BF%D1%80%D0%B0%D1%86%D1%8C%D0%BE%D0%B2-%D0%B7%D0%B0-%D0%B7%D0%B0%D1%83%D0%B2%D0%B0%D0%B6%29.pdf

Dnieper-Donetsk depression (Chernihiv, Poltava, Sumy, Kharkiv, Dnipropetrovska oblasts), Steppe Crimea and the coast of the Black Sea (Kherson and Odesa regions).

Currently, the using of heat of the upper layers of the Earth by heat pump installations has gained the greatest development in Ukraine. The country has enough geothermal deposits with a high temperature potential (120-180°C), which makes it possible to use geothermal heat also for electricity production. But it is necessary to maintain such a level of use of geothermal energy, which would allow the exploitation of the energy source without harming the natural environment. For each region of Ukraine, there is a certain maximum intensity of geothermal energy extraction, which can be maintained for a long time.

Taking into account the current situation, conditions and the available potential, the production of electricity by geothermal installations in Ukraine is possible by implementation of the new capacities in the amount of 100 GWh in 2030 (with a total capacity of 20 MW).

In addition, it is considered possible to use the potential of geothermal energy for use in heating and cooling systems (**Table 26**).

Table 26. Estimate of the total contribution (final energy consumption) expected by each source of renewable energy to achieve the mandatory indicative goals for 2030 and the indicative intermediate trajectory for achieving the share of energy from renewable sources in heating and cooling systems for 2021-2030

Thermal energy production by types of sources	ktoe										
	year 2020	year 2021	year 2022	year 2023	year 2024	year 2025	year 2026	year 2027	year 2028	year 2029	year 2030
Geothermal (except low-temperature geothermal heat for use in heat pumps)				6	13	19	25	31	38	44	50
Solar	1	20	62	104	147	189	231	273	316	358	400
Biomass, including:	2,816	3,340	4,116	4,893	5,669	6,446	7,222	7,999	8,775	9,552	10,328
solid	2,797	3,300	3,970	4,640	5,309	5,979	6,649	7,319	7,988	8,658	9,328
biogas	19	40	147	253	360	467	573	680	787	893	1,000
Energy from heat pumps, including:	52	86	154	222	291	359	427	495	564	632	700
aerothermal	36	46	92	138	184	230	276	322	368	414	460
geothermal	10	24	39	54	69	84	100	115	130	145	160
hydrothermal	6	16	23	30	37	44	52	59	66	73	80
TOTAL	2,869	3,446	4,333	5,226	6,119	7,012	7,905	8,799	9,692	10,585	11,478

The data of **Table. 26** is illustrated in **Fig. 43 and Fig. 44.**

Thus, the total share of geothermal energy in the total renewable energy use in heating and cooling systems is forecast at the level of about 2%, or 210 thousand toe per annum in 2030.

In addition, the implementation of about 20 MW of electric power based on geothermal sources is forecast starting from 2025 (4 MW), which will allow the production of 100 GWh of electric energy in 2030. In total, in 2030, it is planned to obtain 44,230 GWh of electric energy from renewable energy sources, that is, production based on geothermal energy will make up about 0.23% of the total volume of electricity production from renewable energy sources.

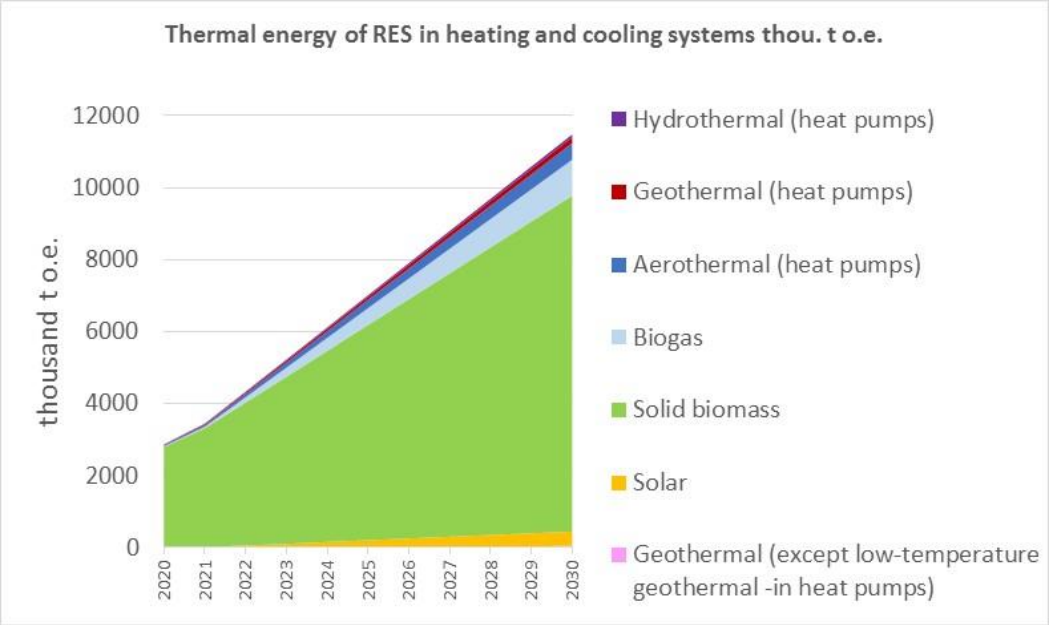


Fig. 43. Forecast of RES implementation in the heating and cooling systems.

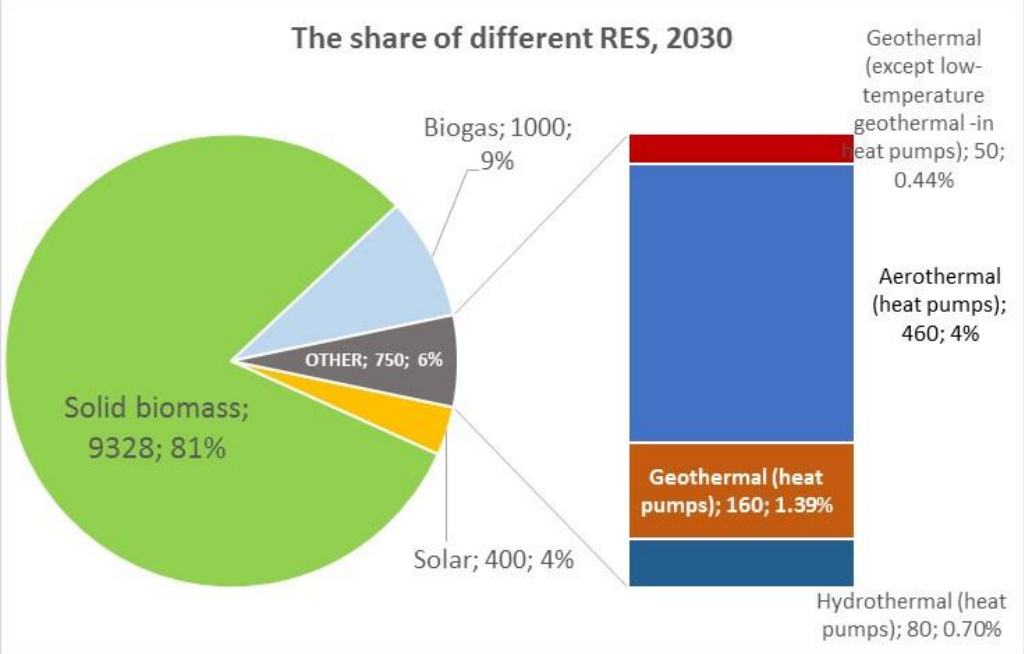


Fig. 44. Forecasted share of different types of renewable energy sources in heating and cooling systems in 2030, thousand toe per year, %.

In the previous **National action plan for the development of renewable energy for the period until 2020 [38]**, which was adopted in 2014, it was noted that currently scientific, geological exploration and practical work in Ukraine is focused only on geothermal resources, represented by thermal waters. According to various estimates, the economically feasible energy resource of Ukraine's thermal waters is up to 8.4 million toe per year. The practical development of thermal waters in Ukraine is carried out in the Autonomous Republic of Crimea (which was occupied by the Russian Federation in 2014), where 11 geothermal circulation systems have been built that

[38] https://zakon.rada.gov.ua/laws/show/902-2014-%D1%80#Text

correspond to modern technologies for extracting geothermal heat from the earth. All geothermal installations are at the research and industrial stage.

Large reserves of thermal waters were discovered in the territory of Chernihiv, Poltava, Kharkiv, Luhansk and Sumy regions. Hundreds of wells that have discovered thermal water and are in conservation **can be restored for their further exploitation as a geothermal heat extraction systems.** Taking into account the experience of European countries regarding the introduction of geothermal power stations, the possible production of electricity by geothermal installations in Ukraine can be 44 GWh in 2015 (provided a total capacity of 8 MW) and **120 GWh in 2020 (with a total capacity 20 MW)**.

With regard to thermal energy, the prospect of obtaining 50,000 toe of geothermal energy in 2020 (except for low-temperature geothermal heat for use in heat pumps) and another 120,000 toe of geothermal energy using heat pumps.

Thus, since none of the plans for geothermal energy specified in the National RES Action Plan until 2020 were implemented, these plans were simply transferred to the new National RES Action Plan until 2030, while the forecast for electricity production was slightly reduced, but the forecast for thermal energy increased slightly.

5.4. The Concept of implementation of state policy in the field of heat supply [39]

Currently, this document is actually the only document of the national level, which refers to energy efficiency directly in the heat supply sector and defines certain stages of its improvement.

An increase in the technological level of heat supply systems is expected in the following areas:

- **development and promotion of the transition of thermal energy production for alternative energy sources**, which will reduce the consumption of natural gas;
- increase in the share of combined production of electricity and thermal energy (cogeneration), which will make it possible to use energy resources more efficiently;
- reduction of the specific fuel and energy consumption per unit of supplied heat through reconstruction and modernization of generating equipment;
- reduction of electrical energy consumption by technological equipment in stages of the technological process;
- optimization due to energy saving measures of the amount of thermal energy produced and consumed;
- implementation of software and hardware complexes that ensure monitoring, management and automation of the processes of production, transportation and supply of thermal energy.

The share of use of alternative energy sources in the production of thermal energy is expected to increase to 30% in 2025 and to 40% in 2035. In order to increase the share of the use of alternative energy sources in the production of thermal energy and to support and develop heat supply facilities that use alternative energy sources, it was proposed to improve the payment system for supplied thermal energy, for the production of which alternative energy sources were used, and to develop a tariff forming system for heat produced by units using alternative energy sources, as well as to develop and submit to the Cabinet of Ministers of Ukraine proposals regarding sustainable heat supply systems based on low-potential energy sources.

At the same time, specific plans for the implementation of use of industrial waste heat or geothermal energy were not mentioned.

[39] https://zakon.rada.gov.ua/laws/show/569-2017-%D1%80#Text

5.5. Analysis of regional energy efficiency programs

In order to find out the importance of the plans for use of industrial waste energy and geothermal energy in heat supply, the regional programs for increasing energy efficiency and the use of renewable energy sources of the following regions were analyzed (years of implementation): Zaporizhzhia (2016-2020); Zaporizhzhia (2010-2015); Vinnytsia (2017-2022); Dnipropetrovska (2018-2035); Dnipropetrovska (2010-2015); Zakarpattia (2016-2020); Kyiv (2022-2027); Kirovohradska (2017-2020); Luhansk (2011-2015); Lviv (2021-2025); Mykolayiv (until 2025); Odesa (2020-2022); Rivne (2018-2025); Sumy (2010-2015); Ternopil (2021-2024); Kharkiv (2016-2022); Cherkasy (2011-2015); Chernihiv (2011-2015).

The developed Action Plans for sustainable energy development within the framework of the Agreement of Mayors of the following cities were also analyzed: Khmelnytskyi (until 2025); Cherkasy (until 2020); Bila Tserkva (2017-2030); Kramatorsk (2015-2030); Kreminna (2019-2030); Pavlograd (2015-2030) Baranivka (until 2030); Bakhmut (until 2020); Bashtanka (until 2030); Vinnytsia (until 2020); Zhytomyr (2021-2030); Zaporizhzhia (2021-2030); Ivano-Frankivsk (until 2020); Kropyvnytskyi (until 2030); Lutsk (until 2025); Lviv (until 2030); Poltava (until 2020); Rivne (until 2020); Sumy (up to 2025); Ternopil (until 2020); Kharkiv (until 2030); Chernivtsi (until 2020); Chernihiv (2015-2023), as well as of other (smaller) cities.

As a result, it can be noted that the mentioned documents in most regions indicate the need to use the waste heat of industrial enterprises. However, only a few programs propose specific projects for such use, for example:

- ***Zaporizhzhia region (2010-2015):***
  - "Switch of heat supply of microdistricts No. 1, No. 2 and a quarter of dormitories to heat supply from the Zaporizhzhya NPP. Central heating point". Zaporizhzhia region, Energodar, str. Kurchatova, 1.
  - Reconstruction of the heat supply system of social objects by installing heat pumps using the heat of the soil. Veselivsky district. Educational institutions of the district.
  - Zaporizhzhia boiler houses - modernization with installation of heat utilizers for PTVM-30 boilers.
  - Installation of dry coke quenching. Installation of turbogenerator-3, PJSC "Zaporizhkoks", Zaporizhzhia, str. Diagonalna, 4.
- ***Sumy region (2010-2015):***
  - implementation of an energy-saving project at OJSC "Sumikhimprom", which involves the construction of a power plant for the utilization of thermal energy of chemical reactions for electricity production; Reconstruction of the existing and construction of new sulfuric acid production facilities with the construction of a power unit for the production of up to 183 million kWh of electricity per year due to utilization of the heat of chemical reactions.
  - Utilization of heat from pneumatic transport and aspiration systems (Krolevetskyi bread products factory JSC "Hlib Ukrainy").
- ***Chernihiv Region (2010-2015):***
  - Use of steam after gas drying units for further production process - Hnidyn gas processing plant, Varvynskyi district
  - Utilization of waste heat of vacuum evaporators - CJSC "Ichnia Dry Milk and Butter Plant" in Ichnia
  - Installation of recuperative heat exchangers for waste water - Branch "Mensky Syr" PE KF "Prometey" in Mena
  - Installation of heat exchangers-utilizers - OJSC "Nizhynsky Hlib" in Nizhyn
- ***Action Plan for sustainable energy development of Zaporizhzhia, 2021-2030:***

- ❖ Switch of hot water supply of the Komunarskyi district to waste heat from the Central sewage treatment plants No.1 (Construction of heat pump station at the Central sewage treatment plants No.1).

Therefore, only a few projects involve the use of waste heat for heat supply:

1. The use for heat supply of thermal energy of steam, which obtained by cooling of the PT-50/60-130/7PR1 turbogenerator No. 2 - "Chernihivska CHP" LLC of the firm "TechNova", Chernihiv (Chernihiv region, 2010-2015).
2. Zaporizhzhia boiler houses - modernization with the installation of heat utilizers for PTVM-30 boilers (Zaporizhia region, 2010-2015).
3. "Switch of heat supply of microdistricts No. 1, No. 2 and a quarter of dormitories to heat supply from the Zaporizhzhya NPP. Central heating point". Zaporizhzhia region, Energodar, str. Kurchatova, 1. (Zaporizhia region, 2010-2015).
4. Switch of hot water supply of the Komunarskyi district to waste heat from the Central sewage treatment plants No.1 (Construction of heat pump station at the Central sewage treatment plants No.1) (Action Plan for sustainable energy development of Zaporizhzhia, 2021-2030).

But as for the proposal number 1, it is rather a project to increase the energy efficiency of the heat supply source, since "Chernihivska CHP" LLC of the "TechNova" company is already DH heat supplier in the city of Chernihiv. In the same way, proposal number 2 relates to improving the energy efficiency of boiler houses in the city of Zaporizhzhya, which are also heat suppliers for DH.

Proposal number 3 is also an extension of the already existing heat supply activity, which was already carried out by the Zaporizhzhya NPP to supply heat to the consumers of Energodar, where the NPP employees live. In addition, it is not known whether this energy is exactly waste heat.

Thus, only 1 planned measure (number 4) was found, which imply the new project for the utilization of waste heat of the enterprise and supply of this heat for DH. This heat can be used not directly, but by increasing its potential by heat pumps. It should also be noted that this is the supply of heat energy from one utility company (KP Vodokanal Zaporizhzhia) to another (heat supply) utility company (that is, it is not a plan of a private industrial company with an appropriate assessment of costs and benefits).

As for heat pumps, there are quite a few projects of their use, where the heat of both the ambient and ventilation air in buildings, as well as the heat of the soil, is offered as a source of low-potential heat.

Quite interesting is the conclusion made in the energy efficiency program of the Dnipropetrovsky region (2010-2015), where it is stated that the coefficient of use of waste heat resources of the region's enterprises has already reached 91.6%. This, of course, leaves few opportunities for their additional use.

It is also interesting to quote the energy efficiency program of the Luhansk region: *"Implementation of the first stage of the regional energy efficiency program of the Luhansk region for 2011-2015 consists in determining the sources of utilization with an assessment of their economically feasible potential, followed by the identification of potential consumers of the utilized energy, then - the installation of heat recovery units and the use of the obtained heat. A wide range of utilization sources in the Luhansk region, from the metallurgical and coke-chemical industries to the utilization of heat in ventilation systems and sewage drains, determines a wide range of equipment from industrial recyclers and cogeneration to heat pumps."* That is, although without specifying specific projects or industrial enterprises, there were plans to implement heat utilization at the industrial enterprises in the region. Unfortunately, a large part of the region was occupied by the Russian Federation in 2014, just in time for the possible implementation of the mentioned plans.

Regarding geothermal energy, some plans mentioned the present potential in one or another area. So, for example, in the energy efficiency program of the Zakarpattia region (2016-2020) it is

noted that *"In the structure of renewable energy sources of the region, 60.0% is accounted for possible use of small hydropower and geothermal energy, 22.0% for biomass energy, 9.0% for wind energy, 5.0% for environmental energy, 4.0% for solar energy."* The programs of several other regions also mention the potential of geothermal energy, but its estimated level is much lower than the potential of using biomass, solar or wind energy. No project of practical use of geothermal energy was found.

Most of the proposed measures in the considered plans relate to the reduction of energy needs of consumers (thermomodernization of buildings, installation of individual heat substations), implementation of biomass boilers, energy-efficient lighting, reconstruction of internal heat supply systems of consumers, replacement of boiler equipment with more efficient ones, replacement of existing heating pipelines with pre-insulated pipes, implementation of solar collectors for hot water heating, solar and wind power generation, heat pumps, biogas plants, there are also several projects for the construction of waste incineration plants and cogeneration based on them. Also, as mentioned above, there are several projects for the utilization of waste heat of industrial enterprises, but for use at the enterprises themselves. The same applies to heat recovery projects behind the boilers of powerful boiler houses - the received heat is used to increase the efficiency of heat production of the boiler houses themselves.

Conclusions on chapter 5

1. The documents on energy conservation and implementation of RES at the national level indicate the need to utilize waste heat resources of industrial enterprises and the need to develop measures to stimulate such use. There is also a vision for the share of thermal energy in future energy balances.
2. With regard to geothermal energy, at the national level there are plans to use it for the production of both thermal and electrical energy. However, the beginning of the implementation of these plans has been postponed for the past decade.
3. At the level of plans of individual regions/cities/communities, there is a very limited vision regarding the possibilities of using waste heat of industrial enterprises even in regions with great industrial potential. In the best case, projects for the use of waste heat resources of enterprises at the same enterprises are proposed.
4. There is no any project that would involve the utilization of heat at a privately owned industrial enterprise with subsequent use in DH. There is also no plan to use geothermal energy even in those areas where its potential is greater than the national average.

Therefore, it is possible to draw a general conclusion that the national level plans regarding the use of waste heat of industrial enterprises and geothermal energy, including for heat supply, remain at this level, not being reflected in plans at the level of individual communities, that is, at the level of direct implementation. This can be explained by the fact that communities, when developing their plans, are guided by the existing experience of implementing energy efficiency plans and the traditional list of relevant measures, which, in turn, reflect the most effective, from the community's point of view, methods of achieving the set goals. As a rule, those measures are selected that guarantee a greater economic effect with lower capital costs. If we take into account that the potential of implementing measures with a better ratio of costs and benefits is far from exhausted, it can be expected that such measures as the use of WE of industrial enterprises for heat supply or the use of deep geothermal energy will not be implemented as a priority. In addition, in the case of the introduction in Ukraine of the national system of trading quotas for greenhouse gas emissions (ETS), systems of external and internal energy management with the assessment of specific energy consumption per unit of finished products, the growth of the carbon tax, the targeted use of the tax on carbon dioxide emissions to stimulate industrial enterprises to energy efficiency, as well as the

Carbon Border Adjustment Mechanism (CBAM), the more likely way to use waste heat resources at industrial enterprises is to increase the energy efficiency of these enterprises themselves.

GENERAL CONCLUSIONS

1. There is still a developed DH supply in Ukraine, which exists in large, medium and sometimes small cities and covers about 35-40% (according to some estimates - up to 50%) of the total heat supply for population. According to our estimate, the amount of heat production in DH is about 6.2 Mtoe.
2. In recent years, there has been a constant decrease of heat production in DH. About two dozen cities have already switched to autonomous and individual heating for consumers. The cities of Zakarpattia region have completely switched to autonomous and individual heating.
3. The most developed DH in the industrial areas of the center, east and south-east of Ukraine. In total, there are 5 regions that provide about 60% of the amount of DH services in Ukraine. These are Kyiv, Kharkiv, Dnipropetrovska, Donetsk and Zaporizhzhia regions. These regions also have the highest concentration of industrial enterprises, which can potentially be sources of waste heat resources for heat supply, which in general contributes to the possibility of using WE of industrial enterprises for DH.
4. It should be taken into account that any alternative solutions in DH, when determining the feasibility of their implementation, will be compared with the baseline situation of reduced (subsidized) energy component in the DH heat tariff.
5. According to one of the estimates, the output of WE in the Ukrainian industry in 2010 was 20.1 million Gcal/year, of which 1.1-12.4 million Gcal/year could be used, which is equivalent to saving 1.8-2.0 million t c.e. (1.3-1.44 million toe). Ferrous metallurgy has the greatest potential of WE (about 58% of the total potential in the industry of Ukraine), the chemical and petrochemical industry (28% of total), the building materials industry (4%), the fuel industry without coke plants, and metalworking + mechanical engineering (2% of the total potential), non-ferrous metallurgy (up to 1% of the potential). The rest of the industries have a total of about 4-5% of the total potential of WE. Unfortunately, no later estimates were found that would take into account the existing level of industrial production and the level of WE utilization in the industry of Ukraine.
6. In open sources, there is extremely little information regarding both the estimated amounts and temperature levels of waste heat resources of specific industrial enterprises, and examples of utilization of WE in Ukraine. Only 2 active projects can be attributed to the use of thermal WE of industrial enterprises in heat supply - this is an example of providing hot water to consumers in several districts in the city of Zaporizhzhia from the industrial site of PJSC "Zaporizhstal" and providing hot water supply to part of the city of Avdiyivka from the Avdiyivsky Coke Chemical Plant, although this is the result of fuel use of the coke gas, that is, it is not a purely thermal WE.
7. Our study of the location of more than 500 enterprises of various industries in relation to possible consumers of WE for heating showed that enterprises of the metallurgical industry, although they are located mainly in medium and large cities of the southeast and east of Ukraine, where there is a DH and dense urban development, are located relatively far (as a rule, more than 1 km in a straight line) from a multi-storey building, where networks of DH may run. Enterprises of the chemical and petrochemical industry, as well as cement factories (2-3 km) are even more distant from potential consumers (mainly, further than 2 km). A little closer (on average about 1.7 km) to potential heat consumers are brick factories, and about 1 km - glass factories, factories for the production of paper, plywood, MDF. Food industry enterprises are relatively closer to potential consumers of waste heat, although the average distance for them is about 1 km. As a rule, bakeries and breweries, food factories (up to 1 km), edible oils industry enterprises (1 km) can be located closer to multi-storey buildings, and a little further away - milk processing plants, cheese and butter production, meat processing

plants, tobacco factories (on average 1-1.5 km). Thus, when evaluating the potential of using thermal WE of industrial enterprises, one should take into account the peculiarities of their location relative to potential consumers. Enterprises with, according to the assessment, the greatest potential, are not too close to potential consumers. It should also be taken into account that these enterprises are located, as a rule, in industrial zones of cities, where next to them, as well as between them and potential consumers of heat, there are production facilities and industrial sites of other enterprises, railway tracks and other objects that will have to be passed by to lay heating pipelines to consumers. The length of such pipelines in the vast majority of cases will exceed 1 km.

8. The given data show that the possibility of using waste heat resources of industrial enterprises is the subject of a technical and economic assessment in each specific case, which should include both a detailed assessment of technical capabilities, temperature levels and the potential amount of waste heat that can be supplied from the enterprise, as well and the potential consumption of such thermal energy and the distance to possible consumers. Estimates of WE available for use can be obtained as the result of energy audit of the enterprise (in case the enterprise is interested in such activity as heat supply to third-party consumers), which will take into account the current level of use of waste heat resources by the enterprises themselves.

9. The most promising potential sources of geothermal energy are in the areas of the east of Ukraine (bordering the Kharkiv, Donetsk, Luhansk and Dnipropetrovsk regions), as well as the Zakarpattia region, the north and east of the Crimean peninsula. Large parts of Poltava and Kharkiv regions, parts of Chernihiv, Sumy, Kyiv, Cherkasy, Dnipropetrovsk, Donetsk, Luhansk, Odesa, Mykolaiv, Kherson and Zaporizhia regions, as well as parts of Lviv, Ivano-Frankivsk, Ternopil and Chernivtsi regions, central and southern parts of the Crimean Peninsula are also promising regions.

10. Estimates of the potential of geothermal energy of different researchers in Ukraine can differ significantly and, as a rule, these estimates are not brought to some generally accepted basis of comparison and methodology. According to a more conservative estimate of the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine, the potential of replacing natural gas due to the use of technically available potential of geothermal energy in the most promising areas is 15.8 thousand GWh per year, which is equivalent to substitute 2.2 billion m^3 of natural gas. The specified amount is only 4% of the total geothermal potential of Ukraine. The temperature range of geothermal resources in the most promising regions is from 65 to 130 °C, which makes them applicable for DH for at least part of the heating period.

11. Based on the stock materials of the "State Information Geological Fund of Ukraine", a team of researchers collected data and created an electronic database of investigated geothermal objects of Ukraine. Currently, the database includes 655 geothermal objects. According to the results of the research, several geothermal artesian basins are distinguished: the Transcarpathian internal depression (probably the most studied, especially the Berehiv deposit), the Carpathian foothill depression, the Dnieper-Donetsk artesian basin, the Black Sea artesian basin. This database is not publicly available.

12. Geothermal heat energy resources of Ukraine, the most ready for development (with water temperature of 60–80 °C), amount to more than 1 GW of thermal capacity. The most promising regions are Zakarpattia, Sumy, Chernihiv, Kherson and Poltava regions. The thermal potential of the existing 34 geothermal wells of Ukraine when used in geothermal heat supply and hot water systems (temperature of thermal water - 60-70 ˚C) is 240.7 thousand MWh/year, which is equivalent to 23 million m^3 of natural gas per year.

13. From 1978 to 2002, 9 geothermal energy facilities were built in Ukraine, including 5 facilities on the Crimean Peninsula, 3 facilities in Zakarpattia and 1 facility in the Kherson region. The total thermal capacity of these facilities was 11.2 MW, electric capacity was 0.17 MW. As of

2020, 2 of them were operating in Zakarpattia Oblast (0.25 MW each) and one with a capacity of 1 MW in Crimea. Since 2002, no new installations have been put into operation, and in general geothermal energy has not developed significantly.

14. More recent studies (2016) singled out 15 geothermal facilities promising for implementation in 6 regions of Ukraine, including 5 electric and cogeneration stations with a capacity from 5 to 14.2 MW, and 10 thermal stations with a capacity from 1 to 11 MW. That is, despite the considerable amount of accumulated data on the geothermal resources of Ukraine, specialists in the field have not identified so many promising objects, which does not mean the large-scale involvement of geothermal resources in heat supply and appropriate substitution of significant share of fossil fuels.
15. The promising geothermal fields near such large cities in the west of Ukraine as Lviv, Ivano-Frankivsk, Chernivtsi, Uzhgorod, as well as smaller cities Mostyske and Berehove are noted. However, the potential heat capacities of geothermal energy for the cities of Uzhgorod (120.4 MW), Mostyske (27.3 MW) and Berehove (21.5 MW) are more or less determined. A negative circumstance that may affect the possibilities of such implementation is that the cities of Zakarpattia region, including Uzhgorod, practically abandoned DH, switching to autonomous and individual heating.
16. We found estimates of the possibilities of using geothermal fields for heat supply of multi-apartment buildings in the cities of Balaklia and Pereyaslav considered a drilling depth of up to 100 m, the use of a ground heat pumps for extracting heat was considered. According to the calculation, the investment in the installed thermal capacity of 108 kW should amount to 198,370 EUR (ie, 1,837 EUR/kW of thermal capacity). The estimated payback period of the well and the probe was 50 years, and 20 years of the heat pump. The study also noted that the cost of drilling geothermal wells in Ukraine is approximately 200-300 EUR per meter of depth. The heat pump together with the peripherals costs approx. 20-25% of the cost of drilling. Modern heat pumps of European manufacturers cost as much in Ukraine as in Western European countries. It is noted that despite the relatively high cost, this type of technology is still worth considering as a source of thermal energy in relatively large new buildings.
17. According to experts [25], geothermal energy projects, in contrast to most RES, have a specificity, which consists in high risks and the duration of the first development period. The implementation of such a project in its entirety usually lasts from 5 to 10 years with significant investments without a guarantee of a positive result. This circumstance causes problems of attracting private capital. Therefore, for the successful development of geothermal energy, an important condition is the participation in it of both the public and private sectors. It is noted that the hope only on commercial capital, even in the most economically developed countries, is rarely successful.
18. Based on the results of the survey conducted by us among territorial communities and heat energy suppliers in Ukraine regarding the possibilities and existing examples of the use of the waste heat potential of industrial enterprises for DH, this method of searching for potential industrial enterprises as sources of waste heat is clearly inferior to the search using open sources.
19. In the future, when evaluating the possibility of using WE resources of certain industrial enterprises for the heating needs of settlements, it is worth focusing on obtaining preliminary information according to the following list:

    - the interest of the management of industrial enterprises in finding and evaluating the amount of waste heat resources for possible useful application;

- the interest of the company's management in using waste heat specifically for heat supply, since the organization of heat supply to third-party consumers is a licensed activity and requires, in addition to technical, also certain organizational measures;
- the temperature levels and amounts of waste heat resources, type of heat transfer medium, daily and annual irregularity of waste heat availability;
- presence and proximity of potential consumers of DH or large individual consumers;
- the presence and proximity of DH networks to the potential point of heat output from the industrial enterprise, the thermal schedule of the DH network or individual consumers, the possibility of laying heat networks from the industrial enterprise in view of possible obstacles.

20. The Energy Strategy of Ukraine until 2035 directly states the need to use the heat of technological processes of industrial enterprises for heat supply. The use of geothermal resources is not directly mentioned, however, in the forecasted structure of TPES there is such a component as "thermal energy", which is understood as "thermal energy of the environment and waste resources of man-made origin".

21. The draft National Action Plan for the Development of Renewable Energy for the period until 2030 forecasted the total share of geothermal energy in the total renewable energy in heating and cooling systems as about 2%, or 210 thousand toe in 2030. In addition, the implementation of about 20 MW of electric power based on geothermal sources is forecast starting from 2025 (4 MW), which will allow to generate 100 GWh of electric energy in 2030. In total, in 2030, it is planned to obtain 44,230 GWh of electric energy from renewable energy sources, that is, geothermal-based energy generation will make up about 0.23% of the total electricity production from renewable energy sources.

22. Analysis of energy efficiency programs for sustainable energy development and the use of RES in a number of cities and regions showed that state-level plans for the use of waste heat of industrial enterprises and geothermal energy, including for heat supply, remain at this level, not being reflected in the plans for the level of individual communities, that is, at the level of direct implementation. This can be explained by the fact that communities, when developing their plans, are guided by the existing experience of implementing energy efficiency plans and the traditional list of relevant measures, which, in turn, reflect the most effective, from the community's point of view, methods of achieving the set goals. As a rule, those measures are selected to achieve greater economic effect with lower capital costs. If we take into account that the potential of implementing measures with a better ratio of costs and benefits is far from exhausted, it can be expected that such measures as the use of waste energy of industrial enterprises for heat supply or the use of deep geothermal energy will not be implemented as a priority.

23. In addition, in case of the introduction in Ukraine of the national system of trading quotas for greenhouse gas emissions (ETS), systems of external and internal energy management with the assessment of specific energy consumption per unit of finished products, the growth of the carbon tax, the targeted use of the tax on carbon dioxide emissions to stimulate industrial enterprises to energy efficiency, as well as the Carbon Border Adjustment Mechanism (CBAM), the more likely way to use waste heat resources at industrial enterprises is to increase the energy efficiency of these enterprises themselves.

24. Thus, based on the results of the conducted research, it can be stated that the abovementioned areas of replacing fossil fuels in DH should of course be considered when forming, for example, municipal energy efficiency plans, action plans for sustainable energy development, regional programs for increasing energy efficiency and the use of renewable energy sources, etc. But the search for potential projects in these directions may find a lack of information about the potential of WE of specific industrial enterprises or the prospects of certain areas

for the use of geothermal resources. For a more effective consideration of the possibilities of using of industrial WE for heat supply, it is worth starting with a survey of the management of these enterprises regarding their possibilities and interest in such cooperation. When evaluating the prospects for the use of geothermal resources, it is worth studying information on relevant existing research on the territory of Ukraine. In particular, establish cooperation with scientific institutions of NASU of Ukraine, that have relevant information (Institute of Renewable Energy, Institute of General Energy, Institute of Geophysics, Institute of Engineering Thermophysics). Given the insufficient experience of such projects in Ukraine in both planning and practical implementation of such projects, it is worth studying foreign experience, especially those countries that have achieved significant success in this field. We hope that the research conducted by us will be one of the stages alloing us to see both possible problems and "white spots" regarding the use of industrial WE and geothermal energy in DH, as well as to outline the ways of approaching to the practical implementation of these directions.

APPENDIX 1

The location of enterprises that can be potentiall sources of waste heat for DH

Industry, company name	Region	City, settlement	Number of population, thousands of people	Local DH supply company	Aprox distance, km	Notes
METALLURGICAL						
Avdiyivskyi koksokhimichnyi zavod	Donetska	Avdiyivka	32.4	CHP Avdiyivskoho koksokhimichnoho zavodu. KP «SLUZHBA YEDYNOHO ZAMOVNYKA»	4-5 km	On the front line
Avdiyivskyi zavod metalichnykh konstruktsiy	Donetska	Avdiyivka	32.4	CHP Avdiyivskoho koksokhimichnoho zavodu. KP «SLUZHBA YEDYNOHO ZAMOVNYKA»	1.4 km	On the front line
Azovstal	Donetska	Mariupol	446.1	MARIUPOLTEPLOMEREZHA. METALURHIYNYI KOMBINAT «AZOVSTAL.	2-3 km	In okkupation
Alchevskyi koksokhimichnyi zavod	Donetska	Alchevsk	108.7	ALCHEVSKTEPLOKOMUNENERHO.	2-3 km	In okkupation
Alchevskyi metalurhiynyi kombinat	Donetska	Alchevsk	108.7	ALCHEVSKTEPLOKOMUNENERHO.	2-3 km	In okkupation
ArselorMittal Kryvyi Rih	Dnipropetrovska	Kryvyi Rih	634.7	KRYVORIZKA TEPLOTSENTRAL	1.5-4.0 km	
Verkhnodniprovskyi hirnycho-metalurhiynyi kombinat	Dnipropetrovska	Verkhnodniprovsk	16.7	Verkhnodniprovsk-teploenerho	1-2 km	
Vorskla Stal (unfinished electrometallurgical plant)	Poltavska	Horishni Plavni	50.8	Teploenerho Horishni Plavni	?	
Vilnohirskyi hirnycho-metalurhiynyi kombinat»	Dnipropetrovska	Vilnohirsk	22.6	no DH	1.2 km	
Dniprovskyi koksokhimichnyi zavod	Dnipropetrovska	Kamyanske	236.7	KMR Pivdenni teplomerezhi	2-3 km	
Dniprovskyi metalurhiynyi kombinat	Dnipropetrovska	Kamyanske	236.7	KMR Pivdenni teplomerezhi	1-2 km	
Dniprodzerzhynskyi stalelyvarnyi zavod	Dnipropetrovska	Kamyanske	236.7	KMR Pivdenni teplomerezhi	2-3 km	
Dniprospetsstal	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	2.5-3 km	
Donetskyi metaloprokatnyi zavod (not functioning from 2017)	Donetska	Donetsk	1560	Donetski miski teplovi merezhi	2 km	In okkupation
Donetskyi metalurhiynyi zavod ta Donetskyi elektrometalurhiynyi zavod	Donetska	Donetsk	1560	Donetski miski teplovi merezhi	1 km	In okkupation
Enerhomashspetsstal	Donetska	Kramatorsk	157.1	Kramatorskteploenerho	3-4 km	
Yerystivskyi hirnycho-zbahachuvalnyi kombinat	Poltavska	Horishni Plavni	50.8	Teploenerho Horishni Plavni	3-4 km	
Elektrostal-Kurakhove, LLC	Donetska	Kurakhove	18.7	Kurakhivska TES	3-3.5 km	
Zavod kolorovykh metaliv, LLC	Donetska	Bakhmut	73.2	LLC Bakhmut-Enerhiya	2 km	On the front line
Zaporizhstal	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	4.5 km	
Zaporizhkoks	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	2 km	
Zaporizkyi tytano-mahniyevyi kombinat	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	1-2 km	
Zaporizkyi zavod ferosplaviv	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	1.5-2.5 km	

Zaporizkyi lyvarno-mekhanichnyi zavod	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	4.5-5.5 km	
Zaporizkyi staleprokatnyi zavod	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	1.5-2.0 km	
Zaporizkyi vyrobnychyi alyuminiyevyi kombinat	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	1.5 km	
Zaporizkyi zavod kolorovykh splaviv	Zaporizka	Zaporizhzhya	747.7	Miski Teplovi Merezhi	0.7 km	
Instrumentalnyi zavod poroshkovoyi metalurhiyi	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	0.2 km	
Novomoskovskyi trubnyi zavod Interpayp	Dnipropetrovska	Novomoskovsk	70.3	Novomoskovskteploenerho	4-5 km	
Nyzhnodniprovskyi truboprokatnyi zavod Interpayp	Dnipropetrovska	Dnipro	966.4	Several suppliers	1.5 km	
Nikopolskyi zavod stalevykh trub	Dnipropetrovska	Nikopol	115.9	Komunservis teplo Nikopol	1 km	
Niko Tyub Interpayp	Dnipropetrovska	Nikopol	115.9	Komunservis teplo Nikopol	2 km	
Nikopolskyi zavod ferosplaviv	Dnipropetrovska	Nikopol	115.9	Komunservis teplo Nikopol	6 km	
Dniprovskyi metalurhiynyi zavod	Dnipropetrovska	Dnipro	966.4	Several suppliers	1 km	
Dniprostal	Dnipropetrovska	Dnipro	966.4	Several suppliers	1.5 km	
PJSC «Druzhkivskyi zavod metalevykh vyrobiv»	Donetska	Druzhkivka	58.4	OKP Donetskteplokommunenerho	0.4-1 km	
Kostyantynivskyi metalurhiynyi zavod	Donetska	Kostyantynivka	69.8	OKP Donetskteplokomunenerho	1.5 km	
Kramatorskyi metaloprokatnyi zavod	Donetska	Kramatorsk	157.1	Kramatorskteploenerho	1.5-2.0 km	
LLC Kramatorskyi zavod metalevykh konstruktsiy	Donetska	Kramatorsk	157.1	Kramatorskteploenerho	3 km	
Novokramatorskyi mashynobudivnyi zavod	Donetska	Kramatorsk	157.1	Kramatorskteploenerho	1.6 km	
Kramatorskyi metalurhiynyi zavod	Donetska	Kramatorsk	157.1	Kramatorskteploenerho	1.5-2.0 km	
Kramatorskyi ferosplavnyi zavod	Donetska	Kramatorsk	157.1	Kramatorskteploenerho	1.5-2.0 km	
Kremenetskyi zavod poroshkovoyi metalurhiyi	Ternopilska	Kremenets	20.8	Kremenetskyi teplorayon OKP "Ternopilteplokomunenerho"	1.5 km	
Kremenchutskyi stalelyvarnyi zavod	Poltavska	Kremenchuk	219	KP Teploenerho. LLC Kremenchutska CHP	1.5 km	
Makiyivkoks	Donetska	Makiyivka	345.6	?	0.5-1 km	In okkupation
Makiyivskyi metalurhiynyi zavod	Donetska	Makiyivka	345.6	?	0.5-1 km	In okkupation
Mariupolskyi metalurhiynyi kombinat imeni Illicha	Donetska	Mariupol	446.1	MARIUPOLTEPLOMEREZHA. METALURHIYNYI KOMBINAT "AZOVSTAL".	2-3 km	In okkupation
Markokhim (belongs to Azovstal)	Donetska	Mariupol	446.1	MARIUPOLTEPLOMEREZHA. METALURHIYNYI KOMBINAT "AZOVSTAL".	2.5-3 km	In okkupation
Pobuzkyi feronikelevyi kombinat	Kirovohradska	Pobuzke	6	Avkubi, only budgetary consumers	1.5 km	
Poltavskyi lyvarno-mekhanichnyi zavod	Poltavska	Poltava	284.9	Poltavateploenerho	2.5-3 km	
Toreztverdosplav	Donetska	Torez (Chyctyakove)	53.9	?	2-2.5 km	In okkupation
Ukrhrafit	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	2.5 km	
Ukrsplav	Dnipropetrovska	Dnipro	966.4	Several suppliers	1.0 km	
Kharkivskyi koksovyi zavod	Kharkivska	Kharkiv	1419	Several suppliers	1.5-3 km	
Khartsyzkyi trubnyi zavod	Donetska	Khartsyzk	56.5	Khartsyzkteplomerezha	2 km	In okkupation
Khersonskyi lyvarnyi zavod	Khersonska	Kherson	279.1	Khersonska CHP. KHERSONTEPLOENERHO	0.5-1 km	
Yuzhkoks	Dnipropetrovska	Kamyanske	236.7	KMR Pivdenni teplomerezhi	2.5-3 km	

Yasynivskyi koksokhimichnyi zavod	Donetska	Makiyivka	345.6	?	2-2.5 km	In okkupation
LLC «Zavod Horstal»	Volynska	Horokhiv	9	no DH	1.5 km	
Novovolynskyi lyvarnyi zavod	Volynska	Novovolynsk	51	Novovolynskteplokomunenerho	0.8 km	
LLC Mekhanichno-Lyvarnyi zavod	Volynska	village Shakhtarske	0.1	no DH	2.5 km	
LLC «Krasylivskyi lyvarnyi zavod»	Khmelnytska	Krasyliv	18.7	Krasylivske pidpr-vo teplovykh merezh	0.7 km	
Lyvarnyi zavod "Stolychnyi"	Kyiivska	Kyiiv	2884	Several suppliers	0.6 km	
PJSC "Kharkivskyi doslidnyi lyvarnyi zavod"	Kharkivska	Kharkiv	1419	Several suppliers	0.35 km	
SE "Lyvarnyi zavod"	Mykolayivska	Pervomaysk	64.1	PKP "Teplomerezhi"	0.2 km	
PJSC Luhanskyi Lyvarno-Mekhanichnyi Zavod	Luhanska	Luhansk	409.8	LLC "LUHANSK-TEPLOPOSTACH"	0.3 km	In okkupation
Zaporizkyi lyvarno-mekhanichnyi zavod	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	1.4 km	
LLC Zaporizkyi tytanomahniyevyi kombinat (ZTMK)	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	2.5 km	
MLZ Foundry / MLZ (Melitopolskyi lyvarnyi zavod)	Zaporizka	Melitopol	154.8	Melitopolski teplovi merezhi	1.3 km	In okkupation
CHEMICAL						
PJSC Azot	Cherkaska	Cherkasy	279	Cherkasyteplokomunenerho	3-4.5 km	
«Inkor i Ko» KKHP Fenolnyi zavod	Donetska	smt Nyu-York	10	?	0.5-1.5 km	
DniproAzot	Dnipropetrovska	Kamyanske	236.7	KMR Pivdenni teplomerezhi	1 km	
Poliplast	Kyiivska	Brovary	108.3	Brovaryteploenerhomerezha. Brovaryteplovodenerhiya	1 km	
Kontsern Styrol	Donetska	Horlovka	245.7	DH exists	1.5-2 km	In okkupation
Arselor Mittal Kryvorizkyi koksokhimichnyi zavod	Dnipropetrovska	Kryvyi Rih	634.7	KRYVORIZKA TEPLOTSENTRAL	2 km	
Kryvorizkyi surykovyi zavod	Dnipropetrovska	Kryvyi Rih	634.7	KRYVORIZKA TEPLOTSENTRAL	3.5-4 km	
Krymskyi sodovyi zavod	AR Krym	Krasnoperekopsk	26.2	DH exists	до 2 km	In okkupation
OJSC Skloplastyk	Luhanska	Syevyerodonetsk	106.5	KP "Syevyerodonetskteplokomunenerho"	2.5 km	In okkupation
Syevyerodonetske obyednannya «Azot»	Luhanska	Syevyerodonetsk	106.5	KP "Syevyerodonetskteplokomunenerho"	1 km	In okkupation
Odeskyi pryportovyi zavod	Odeska	Yuzhne (Hryhorivka)	32.7	KPTM «Yuzhteplokomunenerho»	6.5 km від Григорівки до м. Южне	
Pavlohradskyi khimichnyi zavod	Dnipropetrovska	Pavlohrad	108.6	Pavlohradteploenerho	2-2.2 km	
Rivneazot	Rivnenska	village Horodok	2.7	no DH	8.5 km до м. Рівне	
LLC Barvnyk	Luhanska	Rubizhne	56.7	Rubizhneteplokomunenerho	1.6-2 km	In okkupation
Sumykhimprom	Sumska	Sumy	264.7	Sumyteploenerho	3.2 km	
Karpatnaftokhim	Ivano-Frankivska	Kalush	66.1	Kaluska enerhetychna kompaniya	5 km	
LLC "KARPAT·SMOLY"	Ivano-Frankivska	Kalush	66.1	Kaluska enerhetychna kompaniya	5 km	
Oil refinery						
Naftopererobnyi kompleks «Halychyna»	Lviviska	Drohobych	75.3	KP “Drohobychteploenerho”	2 km	
Kremenchutskyi naftopererobnyi zavod	Poltavska	Kremenchuk	219	KP Teploenerho. LLC Kremenchutska CHP	3.5 km	
Lysychanskyi naftopererobnyi zavod	Luhanska	Lysychansk	99.5	KP "Lysychanskteplomerezha"	11 km	In okkupation

Naftokhimik Prykarpattya	Ivano-Frankivska	Nadvirna	22.5	TeploHarant	2.5-3 km	
Odeskyi naftopererobnyi zavod	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	3-3.5 km	
PJSC «Khersonskyi NPZ»	Khersonska	Kherson	279.1	Khersonska CHP. KHERSONTEPLOENERHO	2 km	
RUBBER PRODUCTS MANUFACTURING						
LLC "Zavod Humovykh Vyrobiv"	Lvivska	Lviv	721.3	Lvivteploenerho	0.3-0.4 km	
OJSC «Zavod «POLIMER»	Volynska	Lutsk	213.9	Lutskteplo	0.4-1 km	
PJSC "ROSAVA"	Kyiivska	Bila Tserkva	203.8	KP BMR Bilotserkivteplomerezha	1.5 km	
LLC «Kyiivhuma»	Kyiivska	Kyiiv	2884	Several suppliers	1 km	
LLC «Zaporizkyi zavod humotekhnichnykh vyrobiv»	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	2.8 km	
Berdyanskyi zavod humotekhnichnykh vyrobiv PJSC «BERTI»	Zaporizka	Berdyansk	113.3	Berdyanske pidpryiemstvo teplovykh merezh	0.2 km	In okkupation
BUILDING, GLASS, FIREPROOFING						
Glass factories						
Poltavskyi zavod medychnoho skla	Poltavska	Poltava	284.9	Poltavateploenerho	0.8-1 km	
Rokytnivskyi sklyanyi zavod	Rivnenska	smt Rokytne	6.7	Rokytnekomunenerhiya	0.4-1.1 km	
Kostopilskyi zavod sklovyrobiv	Rivnenska	Kostopil	31.3	Kostopilkomunenerhiya	0.6 km	
Veralliya Ukrayina (Konsyumers Sklo Zorya), PJSC	Rivnenska	villageZorya	5.5	no DH	немає	
Vilnohirske sklo	Dnipropetrovska	Vilnohirsk	22.6	no DH	0.7 km	
Berezhanskyi sklozavod	Ternopilska	Berezhany	17.4	Berezhanskyi teplorayon OKP "Ternopilteplokomunenerho"	1 km	
Romanivskyi sklozavod	Zhytomyrska	smt Romaniv	7.8	no DH	0.3 km	
Lysychanskyi sklozavod	Luhanska	Lysychansk	99.5	KP "Lysychanskteplomerezha"	1 km	In okkupation
Khersonskyi zavod sklovyrobiv	Khersonska	Kherson	279.1	Khersonska CHP. KHERSONTEPLOENERHO	1.5 km	
Kostyantynivskyi sklyanyi zavod	Donetska	Kostyantynivka	69.8	OKP Donetskteplokomunenerho	0.5 km	
Zaporizhskloflyus	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	1.5 km	
Popasnyanskyi sklozavod	Luhanska	Popasna	19.9	Filiya "Teploenerho" Popasnyanskoho ZHKO	0.7 km	In okkupation
Buchanskyi zavod sklotary	Kyiivska	Bucha	28.5	KPP "Teploenerhopostach"	2 km	
Hostomelskyi sklozavod	Kyiivska	Hostomel	16.9	KPP "Teploenerhopostach"	0.5 km	
Brick factories						
Tsehelnyi zavod	Khmelnytska	Khmelnytskyi	265.6	MKP Khmelnytskteplokomunenerho	2 km	
Vinnytskyi tsehelnyi zavod	Vinnytska	Vinnytsya	370.8	Vinnytsyamiskteploenerho	1.4 km	
Lutskyi tsehelnyi zavod №2	Volynska	Lutsk	213.9	Lutskteplo	1.5 km	
Ostrozkyi tsehelnyi zavod	Rivnenska	Ostroh	14.8	KP Teploenerhiya	1.5-2 km	
Tsehelnyi zavod	Khmelnytska	Volochysk	19.5	Volochyske KPTM "Teplovyk"	0.5 km	
Zhydachivskyi tsehelnyi zavod	Lviviska	Zhydachiv	10.6	Zhydachivteplokomunenerho	1.7 km	
Tsehelnyi zavod	Lviviska	Drohobych	75.3	KP “Drohobychteploenerho”	2 km	

Tsehelnyi zavod	Zhytomyrska	Korostyshiv	24.8	KP «Teploservis»	1.3 km	
Tsehelnyi zavod "Promin"	Lviviska	Mostyska	9.3	no DH	1 km	
JSC Tsehelnyi Zavod	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	1.5 km	
Tsehelnyi zavod	Ivano-Frankivska	Horodenka	9	Teploenerho	2 km	
Hold Keramika, tsehelnyi zavod	Ivano-Frankivska	villageZahvizdya	3.9	no DH	2.5 km (Івано-Франківськ)	
Litynskyi tsehelnyi zavod	Vinnytska	smt Lityn	6.6	no DH	2.5 km	
JSC Skvyrskyi Tsehelnyi zavod "Promin"	Kyiivska	Skvyra	15.6	Teplo Plyus	0.8 km	
Keramik	Ternopilska	Berezhany	17.4	Berezhanskyi teplorayon OKP "Ternopilteplokomunenerho"	1.4 km	
Tsehelnyi zavod	ZakarPJSC·ska	Khust	28.3	KP «Khustteplo»	2 km	
PE Illinetskyi tsehelnyi zavod	Vinnytska	Illintsi	11.2	no DH	2.5 km	
KERAMBUD LLC	Lviviska	Horodok	15.8	no DH	2.5 km	
Chernivetskyi tsehelnyi zavod №1, PJSC	Chernivetska	Chernivtsi	262.2	Chernivtsiteplokomunenerho	0.6 km	
Snyatynskyi tsehelnyi zavod JSC	Ivano-Frankivska	Snyatyn	9.9	Zakhidteploenerhoinvest-Snyatyn	1.8-2.5 km	
PJSC Chernihivskyi Tsehelnyi Zavod N 3"	Chernihivska	Chernihiv	285.8	Chernihiv teplopostach	1-2 km	
LLC Tsehelnyi Zavod №1	ZakarPJSC·ska	Uzhgorod	112.4	no DH	0.2 km	
Bilotserkivskyi tsehelnyi zavod	Kyiivska	Bila Tserkva	203.8	KP BMR Bilotserkivteplomerezha	1 km	
PJSC "Nizhynskyi tsehlyanyi zavod"	Chernihivska	Nizhyn	68	NizhynTeploMerezhi	2 km	
Tsehelnyi zavod	Poltavska	Lubny	45	Lubnyteploenerho	1.5-2 km	
PJSC Zavod Tsehla Trypillya	Kyiivska	Obukhiv, Ukrayinka	33.4	Obukhivrayteplomerezha	2 km	
Sambirskyi zavod budkeramiky	Lviviska	Sambir	34.6	Sambirteplokomunenerho	0.7 km	
Zhytomyrskyi kombinat sylikatnykh vyrobiv	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	2 km	
FP-KLINKER ™	Zhytomyrska	Korostyshiv	24.8	KP «Teploservis»	4 km	
Slobozhanska budivelna keramika	Sumska	Romny	38.9	Romnykomunteplo	3 km	
Korsun-Shevchenkivskyi tsehelnyi zavod	Cherkaska	Korsun-Shevchenkivskyi	17.5	KP “Teplomerezha”	1 km	
Refractjry plants						
Dniprovskyi futerovochnyi zavod	Dnipropetrovska	Nikopol	115.9	Komunservis teplo Nikopol	0.4 km	
OJSCutinskyi kombinat vohnetryviv	Cherkaska	Vatutine	16.6	Komunalne pidpryiemstvo teplovykh merezh	1.2 km	
PJSC Zaporizhvohnetryv	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	0.9 km	
Chasivoyarskyi vohnetryvkyi kombinat	Donetska	Chasiv Yar	12.7	?	0.4 km	
Krasnohorivskyi vohnetryvkyi kombinat	Donetska	Krasnohorivka	16.7	no DH	0.6 km	
Velykoanadolskyi vohnetryvkyi kombinat	Donetska	village Volodymyrivka	1.2	no DH	0.5 km	
PJSC «KDZ» (kolyshniy Krasnoarmiyskyi dynasovyi zavod)	Donetska	Pokrovsk	617.7	Pokrovskteplomerezha	1 km	
Production of mineral wool						
Izovat	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	2 km	
LLC IPH "Mayster"	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	1.7 km	
Cement plants						
OJSC Kombinat budindustriyi	Kyiivska	Kyiiv	2884	Several suppliers	2 km	
PJSC «Dikerhoff Tsement Ukrayina»	Kyiivska	Kyiiv	2884	Several suppliers	1-1.5 km	
Podilskyi Tsement	Khmelnytska	Kamyanets-Podilskyi	99.7	Miskvodteploenerhiya	5.5 km	

Kamyanskyi tsementnyi zavod	Dnipropetrovska	Kamyanske	236.7	KMR Pivdenni teplomerezhi	1 km	
PJSC "Kryvyi Rih Tsement"	Dnipropetrovska	Kryvyi Rih	634.7	KRYVORIZKA TEPLOTSENTRAL	3.5 km	
PJSC "Mykolayivtsement"	Lvivska	Mykolayiv	14.7	LLC«Halpek-Mykolayiv»	2 km	
Dnipropetrovskyi tsementnyi zavod	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.9 km	
Odeskyi tsementnyi z-d LLC	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	3-3.5 km	
PJSC "BALTSEM"	Kharkivska	Balakliya	27.2	Balakliyski teplovi merezhi	8 km	
PJSC "Ivano-Frankivsktsement"	Ivano-Frankivska	Ivano-Frankivsk	230.5	Ivano-Frankivskteplokomunenerho	3-3.5 km	
Volyn-tsement	Rivnenska	Kvasyliv	8.1	KP Kvasyliv teploenerho	2 km	
Kramatorskyi tsementnyi zavod Pushka	Donetska	Kramatorsk	157.1	Kramatorskteploenerho	2.5 km	
Pulp plants, MDF, PLYWOOD						
Kyiivskyi kartonno-paperovyi kombinat	Kyiivska	Obukhiv, Ukrayinka	33.4	Obukhivrayteplomerezha	0.85 km	
Korostyshivska paperova fabryka	Zhytomyrska	Korostyshiv	24.8	KP «Teploservis»	0.5 km	
Malynska paperova fabryka Vaydmann	Zhytomyrska	Malyn	25.8	Malyn Enerhoinvest	0.35-0.5 km	
Kartonno-paperova kompaniya	Lvivska	Lviv	721.3	Lvivteploenerho	1 km	
PJSC "Zhydachivskyi tselyulozno-paperovyi kombinat"	Lvivska	Zhydachiv	10.6	Zhydachivteplokomunenerho	0.6-0.8 km	
PJSC "Kokhavynska paperova fabryka"	Lvivska	village Hnizdychiv	4.1	no DH	2.6 km (?)	
Lutska kartonno-paperova fabryka	Volynska	Lutsk	213.9	Lutskteplo	1-1.4 km	
LLC "Poninkivska paperova fabryka"	Khmelnytska	village Poninka	7.1	KP Poninka-Teplomerezhi	0.55-0.6 km	
Chyzhivska paperova fabryka OJSC	Zhytomyrska	village Chyzhivka	1.5	no DH	0.2 km (?)	
Izmayilskyi tselyulozno-kartonnyi kombinat	Odeska	Izmayil	71.2	KP «TM Izmayilteplokomunenerho»	4 km	
Korostenskyi zavod MDF	Zhytomyrska	Korosten	62.8	Komunalne pidpryiemstvo teplozabezpechennya	2-2.5 km	
PJSC “Fanplyt”	Kyiivska	Kyiiv	2884	Several suppliers	0.6-0.9 km	
PJSC Tsuman	Volynska	smt Tsuman	6.5	no DH	0.45 km	
LLC "Krono-Ukrayina"	Ivano-Frankivska	smt Broshniv-Osada	5.5	LLC «Yevropeyska enerhetychna kompaniya»	0.5-1.3 km	
LLC "Svispan Limited"	Rivnenska	Kostopil	31.3	Kostopilkomunenerhiya	0.5 km	
LLC "LK "InterplytNadvirna"	Ivano-Frankivska	Nadvirna	22.5	TeploHarant	1.5-2 km	
PJSC Avers	Kyiivska	Kyiiv	2884	Several suppliers	1.2 km through railway	
Cherkaskyi zavod plytnykh materialiv	Cherkaska	Cherkasy	279	Cherkasyteplokomunenerho	0.4-0.45 km	
Swiss Krono LLC	Lvivska	Kamyanka-Buzka	10.6	Teplopostachannya Kamyanky-Buzkoyi	1.2 km	
Solonytsivskyi kombinat meblevykh detaley JSC	Kharkivska	smt Pisochyn	23.2	KP "Kharkivski teplovi merezhi"	0.4-0.5 km through railway	
SVISS KRONO, LLC	Kharkivska	smt Pisochyn	23.2	Kp "Kharkivski teplovi merezhi"	0.9 km	
LLC Uniplyt	Ivano-Frankivska	village Vyhoda	2.2	no DH	0.5 km	
Kronospan UA	Volynska	Novovolynsk	51	Novovolynskteplokomunenerho	1 km	
LLC Kronospan Rivne	Rivnenska	village Horodok	2.7	no DH	4 km до м. Рівне	
FOOD AND PROCESSING INDUSTRY						
Bakeries						

Berdychivskyi khlibozavod	Zhytomyrska	Berdychiv	74.8	Berdychivteploenerho	0.35 km	
Berdyanskyi khlibokombinat	Zaporizka	Berdyansk	113.3	Berdyanske pidpryiemstvo teplovykh merezh	0.3 km	In okkupation
Bilotserkivskyi khlibokombinat	Kyiivska	Bila Tserkva	203.8	KP BMR Bilotserkivteplomerezha	0.6-0.75 km	
OJSCutinskyi Khlibokombinat	Cherkaska	Vatutine	16.6	Komunalne pidpryiemstvo teplovykh merezh	0.7 km	
Vinnytskyi khlibokombinat №2	Vinnytska	Vinnytsya	370.8	Vinnytsyamiskteploenerho	0.1 km	
Khlibzavod №10	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.85 km	
Dniprovskyi khlibokombinat №5,LLC	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.6 km	
Khlibzavod №9	Dnipropetrovska	Dnipro	966.4	Several suppliers	1.2-1.4 km	
Pavlohrad Khlibzavod	Dnipropetrovska	Pavlohrad	108.6	Pavlohradteploenerho	1.22 km	
Dunayevetskyi khlibzavod Laslava	Khmelnytska	Dunayivtsi	15.9	KP TEPLOVYKH MEREZH DMR	0.15 km	
Yemilchynskyi khlibozavod	Zhytomyrska	Yemilchyne	6.6	no DH	0.5 km	
JSC Khlibozavod №3 "Zolotoy Karavay"	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	1.5 km	
Zaporizkyi khlibzavod №3	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	0.4 km	
Zaporizkyi khlibozavod №5 "Khlibodar"	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	0.26-0.75 km	
Khlibokombinat №1, OJSC	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	0.6 km	
Ivano-Frankivskyi khlibokombinat	Ivano-Frankivska	Ivano-Frankivsk	230.5	Ivano-Frankivskteplokomunenerho	0.4 km	
Khlibokombinat №10	Kyiivska	Kyiiv	2884	Several suppliers	0.4 km	
Khlibokombinat (Kyiivskyi BKK)	Kyiivska	Kyiiv	2884	Several suppliers	0.2 km	
Doslidnyi Khlibzavod	Kyiivska	Kyiiv	2884	Several suppliers	0.2 km	
Khlibokombinat №11	Kyiivska	Kyiiv	2884	Several suppliers	0.2 km	
SE "Khlibokombinat №9"	Kyiivska	Kyiiv	2884	Several suppliers	0.2-0.4 km	
Kremenchutskyi khlibokombinat	Poltavska	Kremenchuk	219	KP Teploenerho. LLC Kremenchutska CHP	0.4 km	
Kirovohradskyi khlibozavod	Kirovohradska	Kropyvnytskyi	226.4	KP "Teploenerhetyk"	0.5 km	
Khlibozavod	Kirovohradska	Kropyvnytskyi	226.4	KP "Teploenerhetyk"	0.1 km	
Kichkarivka	Volynska	Lutsk	213.9	Lutskteplo	1.8 km	
Teremno Khlib	Volynska	Lutsk	213.9	Lutskteplo	0.35 km	
Volynskyi pekar	Volynska	Lutsk	213.9	Lutskteplo	0.7 km	
Lvivskyi khlibozavod №1	Lvivska	Lviv	721.3	Lvivteploenerho	0.3 km	
Zavod khlibobulochnykh napivfabrykativ	Lvivska	Lviv	721.3	Lvivteploenerho	0.3 km	
Lvivskyi khlibzavod №5	Lvivska	Lviv	721.3	Lvivteploenerho	0.2-0.3 km	
Khlibozavod	Kharkivska	Lyubotyn	20.6	no DH	0.5 km	
Balakliyskyi khlibozavod	Kharkivska	Balakliya	27.2	Balakliyski teplovi merezhi	0.1 km	
Melitopolskyi Khlibokombinat OJSC	Zaporizka	Melitopol	154.8	Melitopolski teplovi merezhi	0.5 km	In okkupation
Mykolayivskyi khlibzavod №1	Mykolayivska	Mykolayiv	486.2	Mykolayivoblteploenerho. Mykolayivska CHP	0.1 km	
Myrhorodskyi khlibozavod	Poltavska	Myrhorod	38.4	Myrhorodteploenerho	0.1-0.7 km	
PJSC "Nikopolskyi Khlibokombinat"	Dnipropetrovska	Nikopol	115.9	Komunservis teplo Nikopol	0.15 km	
LLC «Beryslav-khlibzavod»	Khersonska	Nova Kakhovka	45.4	KP «Teplovi merezhi»	0.4-0.7 km	In okkupation
Pershyi stolychnyi khlibozavod	Kyiivska	Novi Petrivtsi	7.7	KP `Petrivskyi Kombinat komunalnykh posluh	0.3 km	
Novohrad-Volynskyi khlibozavod	Zhytomyrska	Novohrad-Volynskyi (Zvyahel)	55.7	Novohrad-Volynskteplokomunenerho	0.15 km	
Odeskyi Karavay	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	0.2 km	
Khlibzavod №3	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	0.2 km	

Odeskyi khlibozavod №2	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	0.2 km	
Odeskyi Kombinat Khliboproduktiv	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	0.2 km	
Khlibozavod N 1 OJSC "Poltavskyi Khlibokombinat"	Poltavska	Poltava	284.9	Poltavateploenerho	0.2 km	
LLC POLTAVAKHLIB-3	Poltavska	Poltava	284.9	Poltavateploenerho	0.9 km	
Podilskyi khlibozavod	Odeska	Podilsk	40	DH exists	0.15 km	
Khlibozavod	Chernihivska	Pryluky	53.3	Prylukyteploaodopostachannya	0.25 km	
FRM Rivnenskoho khlibozavodu - TM Rumyanets	Rivnenska	Rivne	243.9	LLC "Rivneteploenerho"	0.65 km	
Polissyakhlib	Rivnenska	Rivne	244.9	LLC "Rivneteploenerho"	1 km	
Sarnenskyi khlibozavod	Rivnenska	Sarny	29	Sarnyteploservis	0.5 km	
SE PJSC "Kyiivkhlib" - Skvyrskyi Khlibozavod	Kyiivska	Skvyra	15.6	Teplo Plyus	0.2-0.5 km	
Slavut·skyi khlibozavod	Khmelnytska	Slavuta	35.2	KP Slavut·ske ZHKO	0.15 km	
Khlibzavod "Nadzbruchchya khlib "	Ternopilska	smt Pidvolochysk	7.7	Pidvolochyska teplodilnytsya OKP Ternopilteplokomunenerho	0.8 km	
Romanivskyi khlibozavod LLC "Strit Fud"	Zhytomyrska	smt Romaniv	7.8	no DH	0.6 km	
Sumskyi khlibokombinat	Sumska	Sumy	264.7	Sumyteploenerho	0.2 km	
Sumskyi kombinat khliboproduktiv	Sumska	Sumy	264.7	Sumyteploenerho	0.35 km	
Khlibozavod	Lebedyn	Sumska	24.6	Lebedynteploenerho	0.2-0.5 km	
Ternopilkhlibprom	Ternopilska	Ternopil	216.3	Ternopilmiskteplokomunenerho	0.3 km	
Fastivskyi khlibokombinat PJSC "Kyiivkhlib"	Kyiivska	Fastiv	45.3	KP «Fastivteplomerezha»	0.1 km	
LLC Khlibozavod "Novo-Bavarskyi"	Kharkivska	Kharkiv	1419	Several suppliers	0.6 km	
LLC "Kulynichivskyi Khlibzavod"	Kharkivska	Kharkiv	1419	Several suppliers	0.5 km	
PJSC Kharkivskyi khlibokombinat Slobozhanskyi	Kharkivska	Kharkiv	1419	Several suppliers	0.3 km	
Khersonskyi Khlibokombinat	Khersonska	Kherson	279.1	Khersonska CHP. KHERSONTEPLOENERHO	0.1 km	
Khlibozavod №3	Khersonska	Kherson	279.1	Khersonska CHP. KHERSONTEPLOENERHO	0.75 km	
Khmelnytskyi khlibokombinat	Khmelnytska	Khmelnytskyi	265.6	MKP Khmelnytskteplokomunenerho	0.2 km	
Khlibozavod "Krystynopil Khlib"	Lvivska	Chervonohrad	65.8	Chervonohradteplokomunenerho	0.6 km	
Cherkaskyi Khlibokombinat	Cherkaska	Cherkasy	279	Cherkasyteplokomunenerho	0.5 km	
PJSC "Chernivetskyi khlibokombinat"	Chernivetska	Chernivtsi	262.2	Chernivtsiteplokomunenerho	0.2 km	
Chernihivskyi khlibozavod №2	Chernihivska	Chernihiv	285.8	Chernihiv teplopostach	0.36 km	
Chortkivskyi khlibozavod	Ternopilska	Chortkiv	28.6	Chortkivskyi teplorayon OKP Ternopilteplokomunenerho	0.2 km	
Novoushytskyi khlibokombinat	Khmelnytska	village Nova Ushytsya	4	no DH	0.45 km	
Distilleries						
Tryliskyi spyrLLCyi zavod SE	Kyiivska	s Trylisy	2.3	nemaye	?	
Chervonoslobidskyi spyrLLCyi zavod	Kyiivska	village Chervona Sloboda	1	no DH	0.32 km	
SE "Vuzlivskyi spyrLLCyi zavod"	Lvivska	village Vuzlove	1	no DH	0.7 km	
SE Chemerskyi spyrLLCyi zavod	Chernihivska	village Chemer	1.3	no DH	0.35 km	

SE Dublyanskyi spyrLLCyi zavod	Kharkivska	village Dublyanka	0.6	no DH	0.3 km	
Ovechatskyi spyrLLCyi zavod SE	Vinnytska	village Druzhne	0.8	no DH	?	
SE Ivankivskyi spyrLLCyi zavod	Cherkaska	village Ivanky	2.8	no DH	2.3 km	
Lutskyi spyrtohorilchanyi kombinat	Volynska	Lutsk	213.9	Lutskteplo	0.5-1.7 km	
SE Nemyrivskyi spyrLLCyi zavod	Vinnytska	Nemyriv	11.5	no DH	0.7 km	
LLC "Luzhanskyi spyrLLCyi zavod"	Chernivetska	village Luzhany	4.7	no DH	0.5 km	
Spyrtzavod	Ternopilska	village Zarubyntsi	1.5	no DH	?	
SE “Karapchivskyi spyrLLCyi zavod”	Chernivetska	village Karpachiv	2	no DH	0.9	
Zalozetskyi Spyrt Zavod	Ternopilska	village Hayi Za Rudoyu	0.8	no DH	?	
SE "Dovzhotskyi spyrLLCyi zavod"	Khmelnytska	village Dovzhok	4.2	no DH	0.52 km	
SE "Uherskyi spyrLLCyi zavod"	Lvivska	village Uhersko	1.6	no DH	0.4 km	
Rava-Ruskyi spyrLLCyi zavod	Lvivska	Rava Ruska	8.6	LLC «RAVA-RUSKA TEPLOSTANTSIYA»	1.2-2 km	
Kozlivskyi spyrLLCyi zavod	Ternopilska	village Kozliv	1.8	no DH	0.75 km	
Spyrt-zavod	Lvivska	village LoPJSCyn	3.3	no DH	0.4 km	
SE Haysynskyi spyrLLCyi zavod (bioetanol)	Vinnytska	Haysyn	25.8	KP "Vinnytsyaoblteploenerho"	0.7-1 km	
Velykolyubinskyi spyrLLCyi zavod	Lvivska	village Velykyi Lyubin	4.5	no DH	0.77	
SE Borshchivskyi spyrLLCyi zavod	Ternopilska	Borshchiv	10.8	Borshchivskyi teplorayon OKP "Ternopilteplokomunenerho"	0.4 km	
Haysynskyi spyrLLCyi zavod	Vinnytska	Haysyn	25.8	KP "Vinnytsyaoblteploenerho"	0.5 km	
Zirnenskyi spyrLLCyi zavod SE	Rivnenska	village Zirne	2.8	no DH	0.7 km	
LLC "SpyrLLCyi zavod "Sukhodoly"	Lvivska	village Sukhodoly	0.5	no DH	?	
Artemivskyi spyrtzavod	Kharkivska	village Artemivka	1.3	no DH	0.2 km	
SE Malovyskivskyi SpyrLLCyi Zavod	Kirovohradska	Mala Vyska	13.1	no DH	0.2 km	
Derzhavne pidpryiemstvo «Zarubynskyi spyrLLCyi zavod	Ternopilska	village Zarubyntsi	1.5	no DH	?	
Marylivskyi spyrLLCyi zavod	Ternopilska	village Nahirnyanka	2.1	no DH	1.5 km	
Spyrtzavod.	Ternopilska	village Nahirnyanka	2	no DH	1 km	
Hosprozrakhunkovyi Vidosoblenyi Pidrozdil Podillya SE Bdzhilnyanskyi SpyrLLCyi Zavod	Vinnytska	village Bdzhilna	1.1	no DH	2.2 km до с Теплик	
Zaluchanskyi spyrLLCyi zavod SE	Ivano-Frankivska	village Dolishnye Zaluchchya	1.8	no DH	?	
SE novosukhanivskyi spyrLLCyi zavod	Sumska	Novosukhanivka	0.7	no DH	0.37 km	
Kholmynskyi spyrLLCyi zavod SE	Chernihivska	village Kholmy	2.5	no DH	?	
Martynivskyi spyrLLCyi zavod SE	Vinnytska	village Martynivka	0.7	no DH	0.25 km	
Spyrtzavod	Khmelnytska	village Dovzhok	4.2	no DH	0.25-0.5 km	
Breweries						
Berdychivskyi pyvovarnyi zavod	Zhytomyrska	Berdychiv	74.8	Berdychivteploenerho	0.15 km	
First Dnipro Brewery	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.1 km	
Donetskyi Pyvovarennyi Zavod Ukrayiny	Donetska	Donetsk	1560	Donetski miski teplovi merezhi	1 km	In okkupation
OJSC Pyvzavod «Zhytomyrpyvo»	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	0.5 km	

Carlsberg Ukraine	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	2.5-3 km	
Yzyumskyi pyvzavod	Kharkivska	Izyum	46.6	Izyumske KP TM	0.32 km	
Kyiivskyi pyvovarnyi zavod	Kyiivska	Kyiiv	2884	Several suppliers	4.5 km	
Obolon	Kyiivska	Kyiiv	2884	Several suppliers	0.5 km	
Pyvzavod Zeman	Volynska	Lutsk	213.9	Lutskteplo	0.17 km	
Lvivska pyvovarnya	Lvivska	Lviv	721.3	Lvivteploenerho	0.3 km	
Melitopolskyi pyvovarnyi zavod	Zaporizka	Melitopol	154.8	Melitopolski teplovi merezhi	0.15 km	In okkupation
Brovarnya LLC "Mykulynetskyi brovar"	Ternopilska	Mykulyntsi	3.7	Terebovlyanskyi teplorayon OKP Ternopilteplokomunenerho	0.5 km	
Mukachivskyi pyvovarnyi zavod, OJSC	ZakarPJSC·ska	Mukachevo	85.7	no DH	1.2 km	
PJSC Okhtyrskyi pyvovarnyi zavod	Sumska	Okhtyrka	47.6	Okhtyrska CHP	0.1 km	
Poltavpyvo	Poltavska	Poltava	284.9	Poltavateploenerho	0.35 km	
PBK «Radomyshl»	Zhytomyrska	Radomyshl	14.1	no DH	0.9 km	
Rivnenskyi pyvzavod	Rivnenska	Rivne	243.9	LLC "Rivneteploenerho"	0.1 km	
Rovenkivskyi pyvovarnyi zavod, PJSC	Luhanska	Rovenky	45.7	Rovenkyteplo	0.15-1.0 km	In okkupation
SvaLLCskyi pyvzavod	Luhanska	SvaLLCe	14.1	KP SvaLLCe - teplo	1.3 km	In okkupation
Pyvobezalkoholnyi kombinat«Krym»	AR Krym	Simferopol	331.9	?	0.3 km	In okkupation
Slavut·skyi Pyvzavod	Khmelnytska	Slavuta	35.2	KP Slavut·ske ZHKO	0.3 km	
Opillya	Ternopilska	Ternopil	216.3	Ternopilmiskteplokomunenerho	0.25 km	
Umanpyvo	Cherkaska	Uman	82.6	UKP "Umanteplokomunenerho"	0.4 km	
Pyvovarnya Ziberta	Kyiivska	Fastiv	45.3	KP «Fastivteplomerezha»	0.7 km	
LLC "Nova Bavariya"	Kharkivska	Kharkiv	1419	Several suppliers	0.4-0.5 km	
Kharkivska brovarnya AB InBev Efes Ukrayina	Kharkivska	Kharkiv	1419	Several suppliers	1.4 km	
Kharkivski Drizhdzhi	Kharkivska	Kharkiv	1419	Several suppliers	0.3 km	
Khmelpyvo	Khmelnytska	Khmelnytskyi	265.6	MKP Khmelnytskteplokomunenerho	0.2 km	
Radoy	Vinnytska	Khmilnyk	27.3	KP "Vinnytsyaoblteploenerho"	0.55 km	
Cherkaske pyvo, PJSC	Cherkaska	Cherkasy	279	Cherkasyteplokomunenerho	0.2 km	
Chernihivska brovarnya AB InBev Efes Ukrayina	Chernihivska	Chernihiv	285.8	Chernihiv teplopostach	1.5 km	
Mykolayivska brovarnya AB InBev Efes Ukrayina	Mykolayivska	Mykolayiv	486.2	Mykolayivoblteploenerho. Mykolayivska CHP	3.5 km	
Persha pryOJSCna brovarnya	Lvivska	Lviv	721.3	Lvivteploenerho	0.4 km	
"Pinta" - Kreminskyi pyvovarnyi zavod	Luhanska	Kreminna	18.6	KP «Kreminnatelokomunenerho» ?	1.8 km	In okkupation
Kaluskyi pyvzavod	Ivano-Frankivska	Kalush	66.1	Kaluska enerhetychna kompaniya	0.2 km	
Dairy factory						
Andrushivskyi maslosyrzavod LLC	Zhytomyrska	Andrushivka	8.5	nemaye	0.85 km	
JSC "Zhytomyrskyi maslozavod"	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	0.5 km	
Bilotserkivskyi molochnyi kombinat, PJSC	Kyiivska	Bila Tserkva	203.8	KP BMR Bilotserkivteplomerezha	4.2 km	
Berdychivskyi molokozavod	Zhytomyrska	Berdychiv	74.8	Berdychivteploenerho	0.2 km (?)	
Bohodukhivskyi molokozavod	Kharkivska	Kharkiv	1419	Several suppliers	0.2 km	

Burynskyi molokozavod SvitMilk SvytMylk	Sumska	Buryn	8.4	KP Burynteplo	3.6 km	
Valkivskyi molokozavod	Kharkivska	Valky	10.3	Teplovi Merezhi	0.8 km	
Vapnyarskyi molokozavod OJSC	Vinnytsya	village Vapnyarka	7.4	no DH	0.52 km	
OJSC "Zarichnenskyi molokozavod"	Rivnenska	village Zarichne	7.3	no DH	0.7 km	
Vinkovetskyi Syrzavod	Khmelnytska	Vinkivtsi	6	Vinkivtsi teploenerho	0.55 km	
Volnyanskyi molokozavod	Zaporizka	Vilnyansk	14.8	OVUZHK·H m. Vilnyanska	1.3 km	
Halychyna Radekhiv	Lvivska	Radekhiv	9.7	no DH	0.7 km	
LLC "Molochna kompaniya "Halychyna" Lviv	Lvivska	Lviv	721.3	Lvivteploenerho	0.35 km	
Haliyivskyi Maslozavod Im.V.F.Mazurkevycha OJSC	Zhytomyrska	village Haliivka	0.5	no DH	?	
Dubnomoloko	Rivnenska	Dubno	37.4	Dubnokomunenerhiya	0.4-0.6 km	
Ekolat, Chernivetskyi molochnyi zavod	Chernivetska	Chernivtsi	262.2	Chernivtsiteplokomunenerho	1.5 km through railway	
Zhytomyrskyi molochnyi zavod	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	0.3 km	
Ichnyanskyi zavod sukhoho moloka ta masla OJSC	Chernihivska	Ichnya	10.7	no DH	2 km	
Kahma	Kyiivska	Kaharlyk	13.4	Kaharlykteplomerezha	0.1 km	
Kalanchatskyi maslozavod OJSC	Khersonska	Kalanchak	9.2	Kalanchak teplokomunenerho	0.65 km	In okkupation
Kanivskyi maslosyrzavod	Cherkaska	Kaniv	23.7	Kanivske komunalne pidpryiemstvo teplovykh merezh	0.2-2.5 km	
Kyiivsskyi molokozavod №1	Kyiivska	Kyiiv	2884	Several suppliers	0.4 km	
Kyiivskyi molochnyi zavod №3, PJSC "Vimm-Bill-Dann Ukrayina"	Kyiivska	Vyshneve	41.8	Vyshnivskteploenerho	1.5 km	
Kovelmoloko	Volynska	Kovel	68.2	PTM "Kovelteplo"	0.35 km	
Kozivskyi maslozavod	Ternopilska	village Kozova	8.9	LLC «Zelena enerhiya - 2012»	1.4 km	
Kombinat Prydniprovskyi (Zlahoda)	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.36 km	
Kompaniya «Rud» — Zhytomyrskyi maslozavod	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	0.5 km	
CE "Mahdalynovskyi maslozavod"	Dnipropetrovska	village Mahdalynivka	6.4	KP «Komunalnyk»	0.6 km	
Krasylivskyi molochnyi zavod	Khmelnytska	Krasyliv	18.7	Krasylivske pidpr-vo teplovykh merezh	0.3-0.4 km	
Kremenchutskyi miskmolokozavod	Poltavska	Kremenchuk	219	KP Teploenerho. LLC Kremenchutska CHP	0.3 km	
Kryvorizkyi molokozavod №1	Dnipropetrovska	Kryvyi Rih	634.7	KRYVORIZKA TEPLOTSENTRAL	2.3 km	
Letychivskyi maslozavod PE	Khmelnytska	Letychiv	10.2	no DH	0.41 km	
Litynskyi molochnyi zavod - Biloz·har™	Vinnytska	village Lityn	6.6	no DH	0.75 km	
Lubenskyi molochnyi zavod	Poltavska	Lubny	45	Lubnyteploenerho	2-2.5 km	
Malorohanskyi molochnyi zavod	Kharkivska	Kharkiv	1419	Several suppliers	0.55 km	
Molochnyi zavod «Roshen»	Vinnytska	Vinnytsya	370.8	Vinnytsyamiskteploenerho	1.55 km	
Novovodolazhskyi molokozavod, Zorka Mylk | Zor`ka Milk	Kharkivska	Nova Vodolaha	10.7	LLC "N-V TM"	0.5-1 km	
Novonykolaevskyi molokozavod	Zaporizka	village Novomykolayivka	5.2	no DH	0.3 km	
Novoushytskyi Maslozavod	Khmelnytska	village Nova Ushytsya	4	no DH	0.25 km	

Obukhivskyi molokozavod "Lukavytsya"	Kyiivska	Obukhiv, Ukrayinka	33.4	Obukhivrayteplomerezha	0.1 km	
Olkom (Kyiivskyi marharynovyi zavod)	Kyiivska	Kyiiv	2884	Several suppliers	0.4 km	
LLC Kehychivskyi molokozavod	Kharkivska	village Kehychivka	5.8	no DH	0.15 km	
Pyryatynskyi syrzavod	Poltavska	Pyryatyn	15.2	Pyryatynteplopostachannya	0.55 km	
Radyvylivmoloko	Rivnenska	village Krupets	1.3	no DH	?	
Radomilk SE	Zhytomyrska	Radomyshl	14.1	no DH	1 km	
Ratnivskyi Molokozavod	Volynska	village Ratne	10	no DH	0.6 km	
Rykhalskyi zavod sukhoho moloka	Zhytomyrska	village Rykhalske	1.3	no DH	0.27 km	
Rozhyshchenskyi syrzavod	Volynska	Rozhyshche	12.7	Pidpr-vo ZHK·H	0.35 km	
Romanivskyi maslozavod "Eney"	Zhytomyrska	smt Romaniv	7.8	no DH	0.6-0.7 km	
Snyhyrevskyi maslozavod	Mykolayivska	Snihurivka	12.4	no DH	0.6-0.8 km	
Starokostyantynivskyi molochnyi zavod	Khmelnytska	Starokostyantyniv	34.4	KP Teplovyk	0.7 km	
Sumskoy molochnyi zavod TM "DOBRYANA"	Sumska	Sumy	264.7	Sumyteploenerho	2 km	
TDV "Veselivskyi molokozavod"	Zaporizka	Vesele	9.6	no DH	0.35 km	In okkupation
TDV "Yahotynskyi maslozavod"	Kyiivska	Yahotyn	19.4	Yahotynteplomerezha	0.4 km	
LLC "Molokozavod "Sambirskyi "	Lvivska	Sambir	34.6	Sambirteplokomunenerho	0.2 km	
LLC "Hlobynskyi maslosyrzavod"	Poltavska	Hlobyne	9.2	Hlobyneteploservis	0.4 km	
LLC "Ichnyanskyi maslozavod"	Chernihivska	Ichnya	10.7	no DH	2 km	
LLC "Khmilnytskyi Zavod SZM "Molochnyi Vizyt"	Vinnytska	Khmilnyk	27.3	KP "Vinnytsyaoblteploenerho"	0.35 km	
LLC “Derazhnyanskyi molochnyi zavod”	Khmelnytska	Derazhnya	10.5	no DH	0.2 km	
LLC «Vinkovetskyi Syrzavod»	Khmelnytska	Vinkivtsi	6	Vinkivtsi teploenerho	0.55 km	
LLC Bilotserkivskyi molochnyi kombinat	Kyiivska	Bila Tserkva	203.8	KP BMR Bilotserkivteplomerezha	4 km	
LLC Haliyivskyi maslozavod	Zhytomyrska	village Haliyivka	0.5	no DH	?	
LLC Dunayevetskyi maslozavod	Khmelnytska	Dunayivtsi	15.9	KP TEPLOVYKH MEREZH DMR	1.1 km	
LLC Hadyachsyr	Poltavska	Halyach	23.3	KPTH "Hadyachteploenerho	1 km	
LLC Losynivskyi maslosyrzavod	Chernihivska	village Losynivka	3.7	no DH	0.2 km	
LLC Mohyliv-Podilskyi molokozavod	Vinnytska	Mohyliv-Podilskyi	30.3	KP "Teploenerhetyk	1 km	
LLC Orhanik Milk	Zhytomyrska	Baranivka	11.4	no DH	1 km	
LLC FUD DEVELOPMENT Tulchynskyi maslosyrzavod	Vinnytska	Tulchyn	14.8	no DH	0.6 km	
LLC Kharkivskyi miskyi molochnyi zavod №1	Kharkivska	Kharkiv	1419	Several suppliers	0.15 km	
Filiya "Kyiiv-moloko" Kompaniya "Molokiya"	Kyiivska	Kyiiv	2884	Several suppliers	2.5 km	
KHERSONSKYI MASLOZAVOD	Khersonska	Kherson	279.1	Khersonska CHP. KHERSONTEPLOENERHO	0.1 km	
KHRYSTYNIVSKYI MOLOKOZAVOD PJSC	Cherkaska	Khrystynivka	10.2	MBP-TEPLOMEREZHA	0.5 km	
TSYURUPYNSKYI MASLOZAVOD OJSC	Khersonska	Oleshky	24.5	KP "Oleshky-servis"	1 km	In okkupation
Chechelnytskyi molochnyi zavod	Vinnytska	village Chechelnyk	4.9	no DH	0.7 km	

Food factories						
PJSC Shchorskyi zavod prodovolchykh LLCariv	Chernihivska	Snovsk	10.9	“OBLTEPLOKOMUNENERHO” m.Chernihiv	0.25 km	
PJSC Kamyanskyi zavod Prodtovariv	Cherkaska	Kamyanka	11.3	Kamyanske komunalne pidpryiemstvo teplovykh merezh	0.25 km	
Bohuslavskyi zavod Prodtovariv OJSC	Kyiivska	Bohuslav	16.1	Bohuslavteplovodenerhiya	0.5-0.6 km	
PJSC "Sumskyi zavod Prodtovariv"	Sumska	village Bezdryk	1.7	no DH	0.2-0.25 km	
Shpolyanskyi zavod Prodtovariv, LLC	Cherkaska	Shpola	16.6	Shpolyanske pidpr-vo teplovykh merezh	0.6-0.8 km	
Rzhyshchivskyi zavod Prodtovariv	Kyiivska	Rzhyshchiv	7.3	KPTM RZHYSHCHIVTEPLOMEREZHA	0.6 km	
PJSC "Kobelyatskyi zavod prodovolchykh tovariv "Mriya"	Poltavska	Kobelyaky	9.7	Teplopostach KP	0.45 km	
Haysynskyi zavod prodtovariv	Vinnytska	Haysyn	25.8	KP "Vinnytsyaoblteploenerho"	0.2 km	
Hoshchanskyi Zavod Prodtovariv, TM Pryhoshchaysya	Rivnenska	village Hoshcha	5.1	no DH	0.6 km	
Kolektyvne pidpryiemstvo "ProdLLCary"	Odeska	Bilhorod-Dnistrovskyi	48.6	KP "Bilhorod-Dnistrovskteploenerho"	0.4-0.8 km	
TM "Dobryi Smak"	Kharkivska	Kharkiv	1419	Several suppliers	0.5 km	
BON KHERSON plodoovochevyi kombinat	Khersonska	village Zelenivka	5.8	no DH	0.4 km	
Odeskyi konservnyi zavod dytyachoho kharchuvannya	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	0.4 km	
Odeskyi konservnyi zavod IA PJSC	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	0.15-0.5 km	
PJSC "Hospodarochka"	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	0.8 km	
Konservnyi zavod	Vinnytska	Haysyn	25.8	KP "Vinnytsyaoblteploenerho"	0.42 km	
Bilotserkivskyi konservnyi zavod OJSC	Kyiivska	Bila Tserkva	203.8	KP BMR Bilotserkivteplomerezha	0.5-0.6 km	
Mohyliv-Podilskyi konservnyi zavod	Vinnytska	Mohyliv-Podilskyi	30.3	KP "Teploenerhetyk	0.3-0.6 km	
Novoushytskyi konservnyi zavod	Khmelnytska	village Nova Ushytsya	4	no DH	0.45 km	
Zhytomyrskyi konservnyi zavod	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	0.4 km	
SE Cherkaskyi konservnyi kombinat	Cherkaska	Cherkasy	279	Cherkasyteplokomunenerho	0.15 km	
LLC Hora Ukrayina	Zaporizka	Tokmak	32.9	TOKMAK TEPLOENERHIYA	0.5-0.6 km	In okkupation
DCHP Storozhynetskyi konservnyi zavod	Cherniveka	Storozhynets	14.1	SDKMP MISKA TEPLOMEREZHA	0.6 km	
JSC Nizhynskyi konservnyi zavod	Chernihivska	Nizhyn	68	NizhynTeploMerezhi	0.2 km	
Konservnyi zavod	Ivano-Frankivska	Kolomyia	61.2	Kolomyiateploservis	1.6 km	
LLC «Chyhyrynskyi konservnyi zavod»	Cherkaska	Chyhyryn	8.6	HP «Chyhyrynski teplovi merezhi»	0.1 km	
LLC Yarmolynetskyi konservnyi zavod	Khmelnytska	village Yarmolyntsi	7.3	TEPLOKOMUNENERHO YARMOLYNETSKOYI SR	1 km	
LLC Moshurivskyi konservnyi zavod	Cherkaska	village Moshuriv	2	no DH	0.3 km	
Buskyi konservnyi zavod	Lvivska	Busk	8.6	no DH	0.3 km	
LLC konservnyi zavod DAR BESARABIYI	Odeska	village Starokozache	5.2	no DH	3 km	
Lutsk fudz	Volynska	Lutsk	213.9	Lutskteplo	0.8 km	
Tobacco factories						
Imperial Tobacco Ukraine	Kyiivska	Kyiiv	2884	Several suppliers	2.5 km	

Prylutska tyutyunova fabryka "British American Tobacco Ukraine"	Chernihivska	Pryluky	53.3	Prylukyteplovodopostachannya	1.5 km	
Lviv Tobacco Factory	Lvivska	Vynnyky	18	Lvivteploenerho	1.2 km	
Filip Morris Ukrayina	Kharkivska	Kharkiv (Dokuchayevske)	1419	Several suppliers	4 km	
Kremenchutska tyutyunova fabryka	Poltavska	Kremenchuk	219	KP Teploenerho. LLC Kremenchutska CHP	0.4 km	
LLC Dana-AS	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.5 km	
Monastyryska tyutyunova fabryka	Ternopilska	Monastyryska	5.5	no DH	0.15 km	
LLC Global Tobacco International	Volynska	Lutsk	213.9	Lutskteplo	1 km	
LLC "United Tobacco"	Dnipropetrovska	Zhovti Vody	43.5	KP ZhovLLCodskteplomerezha	0.85-1 km	
Meat processing plants						
Myaso-Polissya	Zhytomyrska	Zhytomyr	266.1	Zhytomyrteplokomunenerho	1.3 km through railway	
Kyiivskyi m″yasokombinat	Kyiivska	Bila Tserkva	203.8	KP BMR Bilotserkivteplomerezha	0.4-1 km (0.7 km through railway)	
PJSC Kozyatynskyi myasokombinat	Vinnytska	Kozyatyn	22.9	LLC Vinnytsyaoblteploenerho	0.65-1 km	
LLC Antonivskyi myasokombinat	Kyiivska	village Mala Antonivka	0.6	no DH	0.44 km	
SE "Myasokombinat "Zorya"	Rivnenska	village Klevan	7.4	no DH	2 km	
Korostenskyi myasokombinat	Zhytomyrska	Korosten	62.8	Komunalne pidpryiemstvo teplozabezpechennya	0.35 km (?)	
Ternopilskyi myasokombinat	Ternopilska	Ternopil	216.3	Ternopilmiskteplokomunenerho	2.5 km	
Hlobynskyi myasokombinat	Poltavska	Hlobyne	9.2	Hlobyneteploservis	1.6 km through railway	
Myasokombinat	Poltavska	Myrhorod	38.4	Myrhorodteploenerho	1.7 km	
Lutskyi myasokombinat №1	Volynska	Lutsk	213.9	Lutskteplo	0.5 km	
M`yasokombinat	Poltavska	Kremenchuk	219	KP Teploenerho. LLC Kremenchutska CHP	0.25 km	
Chortkivskyi myasokombinat	Ternopilska	Chortkiv	28.6	Chortkivskyi teplorayon OKP Ternopilteplokomunenerho	3 km	
LLC "Khodorivskyi myasokombinat"	Lvivska	Khodoriv	9.2	Khodorivvodokanal	0.7 km	
Dubenskyi myasokombinat	Rivnenska	Dubno	37.4	Dubnokomunenerhiya	1.3 km	
LLC Myasokombinat Yuvileynyi	Dnipropetrovska	Dnipro	966.4	Several suppliers	4.2 km	
LLC Myasna fabryka "Favoryt plyus"	Dnipropetrovska	Dnipro	966.4	Several suppliers	1 km	
PE “Starytskyi m″yasokombinat”	Lvivska	village Volya-Starytska	0.3	no DH	3.3 km	
Oleksandrivskyi myasokombinat. LLC Oleksiyivskyi myasokombinat	Kharkivska	Kharkiv	1419	Several suppliers	0.8-1.5 km	
TM Farro	Poltavska	Kremenchuk	219	KP Teploenerho. LLC Kremenchutska CHP	0.4 km	
Novovolynskyi myasokombinat	Volynska	Novovolynsk	51	Novovolynskteplokomunenerho	1 km	
LLC "VP Rohanskyi Myasokombinat"	Kharkivska	Kharkiv	1419	Several suppliers	1 km	
Odeskyi Myasopererobnyi zavod	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	1.5 km	
LLC "Sokolivskyi myasokombinat"	Kirovohradska	village Sokolivske	0.25	no DH	0.9 km	
Chernyakhivski Kovbasy	Kirovohradska	village Sokolivske	0.25	no DH	0.95 km	
OJSC Myasokombinat Yatran	Kirovohradska	Kropyvnytskyi	226.4	KP "Teploenerhetyk"	0.5-1.3 km	
MK Myasnyi	Kharkivska	Kharkiv	1419	Several suppliers	0.9-1.3 km	

Melitopolskyi myasokombinat	Zaporizka	Melitopol	154.8	Melitopolski teplovi merezhi	1 km	In okkupation
LLC Ukrayinskyi myasokombinat	Kharkivska	Kharkiv	1419	Several suppliers	1-1.5 km	
Saltivskyi myasokombinat	Kharkivska	Kharkiv	1419	Several suppliers	0.15 km	
Drohobytskyi myasokombinat	Lviviska	Drohobych	75.3	KP “Drohobychteploenerho”	0.7 km	
Derhachivskyi myasokombinat - Persha stolytsya	Kharkivska	Kharkiv (Podvirky)	1419	Several suppliers	0.15 km	
LLC Bohodukhivskyi m″yasokombinat	Kharkivska	Bohodukhiv	15	no DH	1 km through railway	
Hoshchanski kovbasy	Rivnenska	village Hoshcha	5.1	no DH	0.7 km	
M″yasopererobnyi kompleks LLC «Verest»	Khmelnytska	village Hirchychna	0.6	no DH	?	
Chernyakhivski kovbasy	Kirovohradska	village Chernyakhivka	0.6	no DH	3 km	
Lebedynski Kovbasy	Sumska	Lebedyn	26.9	KP "Lebedynteploenerho"	2 km	
Mykhodi™	Rivnenska	Zdolbuniv	24.8	KP “Zdolbunivkomunenerhiya”	0.15 km	
Myasopererobna fabryka "Alan"	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.4-0.95 km	
Kupyanskyi myasokombinat TD LLC	Kharkivska	Kupyansk	27.5	KUPYANSKTEPLOENERHO	2-2.5 km	
TM "Myasnyi dar"	Volynska	village Boratyn	1	no DH	0.2 km	
Vovchanskyi myasokombinat	Kharkivska	Vovchansk	17.9	Vovchanske PTM	1 km	
Food Oil industry						
PJSC «Vinnytskyi OZHK ViOyl	Vinnytska	Vinnytsya	370.8	Vinnytsyamiskteploenerho	0.55 km	
Vovchanskyi oliynoekstraktsiynyi zavod	Kharkivska	Vovchansk	17.9	Vovchanske PTM	0.7-0.8 km	
LLC Hlobynskyi pererobnyi zavod	Poltavska	Hlobyne	9.2	Hlobyneteploservis	1.5 km	
Ukroliya	Poltavska	Dykanka	7.7	Dykanskyi KKP	2 km	
OEZ «Potoky»	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.8 km	
Dniprovskyi masloekstraktsiynyi zavod	Dnipropetrovska	Dnipro	966.4	Several suppliers	0.5 km	
Zaporizkyi oliyazhyrkombinat	Zaporizka	Zaporizhzhya	746.7	Miski Teplovi Merezhi	0.7 km	
Kyiivskyi marharynovyi zavod	Kyiivska	Kyiiv	2884	Several suppliers	0.35 km	
Kirovohradoliya, PJSC	Kirovohradska	Kropyvnytskyi	226.4	KP "Teploenerhetyk"	0.6 km	
LLC "Prydniprovskyi OEZ"	Kirovohradska	Kropyvnytskyi	226.4	KP "Teploenerhetyk"	2-2.3 km	
Hurtivnya "Mayola"	Lvivska	Lviv	721.3	Lvivteploenerho	0.25 km	
Melitopolskyi oliynoekstraktsiynyi zavod	Zaporizka	Melitopol	154.8	Melitopolski teplovi merezhi	0.3 km	In okkupation
Odeskyi oliynoekstratsiynyi zavod	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	1 km	
Odeskyi oliynozhyrovyi kombinat OJSC	Odeska	Odesa	993.1	KP Teplopostachannya mista Odesy	0.9 km	
PJSC Polohivskyi OEZ	Zaporizka	Polohy	18.6	KPTM "Temp-Tsentr"	0.65 km	In okkupation
Poltavskyi oliynoekstraktsiynyi zavod - KERNEL GROUP	Poltavska	Poltava	284.9	Poltavateploenerho	0.6-0.7 km	
Ahrarna tekhnolohichna kompaniya	Khmelnytska	village Adampil	1	no DH	?	
LLC "Krasnohirskyi oliynyi zavod"	Cherkaska	village Antypivka	0.8	no DH	1.6 km	
Bandurskyi oliynoekstraktsiynyi zavod	Mykolayivska	village Bandurka	0.3	no DH	?	
LLC Vasyshchevskyi zavod roslynnykh oliy	Kharkivska	village Vasyshcheve	5.8	no DH	1 km	
LLC "Hidrosend"	Kirovohradska	village Vlasivka	7.6	Vlasivski TM	2 km	
Olsidz Blek Si LLC	Odeska	village Voronivka	0.1	no DH	?	

LLC «Katerynopilskyi Elevator»	Cherkaska	village Yerky	4.3	no DH	0.8 km	
Lan-Oil Tade	Ternopilska	village Oryshkivtsi	1.6	no DH	?	
LLC Prykolotnyanskyi oliynoekstraktsiynyi zavod	Kharkivska	village Prykolotne	2	no DH	1.4 km	
Oliyar	Lvivska	village Stavchany	1.7	no DH	?	
LLC "SVATIVSKA OLIYA"	Luhanska	SvaLLCe	14.1	KP SvaLLCe - teplo	0.2-0.3 km	In okkupation
Chernivetskyi oliyno-zhyrovyi kombinat, PJSC	Chernivetska	Chernivtsi	262.2	Chernivtsiteplokomunenerho	0.85 km	
Ukrayinska Chornomorska Industriya, LLC	Odeska	Chornomorsk	58.9	KP "Chornomorskteploenerho"	2 km	
Delta Vilmar Ukrayina	Odeska	Yuzhne (Novi Bilyari)	32.7	KPTM «Yuzhteplokomunenerho»	?	

APPENDIX 2.

QUESTIONNAIRE
on the assessment of the possibilities of using waste heat of industrial enterprises for district heating.

1. Name of the settlement, district and region.

2. Are there sources of centralized heat supply (boiler plants, heating networks) in the settlement? What is their number and thermal capacity?

3. Specify, if known:
- The number of consumers of district heating,
- Total connected heat loads for heating, Gcal/hour or MW
- Annual consumption of energy resources for district heating (thousand m^3 of gas, tons of coal, firewood, etc.)

4. Are there industrial enterprises in the settlement or near it that have sources of waste heat that are not used or not fully used (hot waste gases, hot air, hot water, steam)? Specify what are the sources of waste heat

5. What volumes (t/hour or m^3/hour) and temperature of waste heat resources, if known

6. Estimated distance (km) from an industrial enterprise with waste heat resources to
- heat network lines:
- existing sources of heat supply (boiler):
- potential heat consumers for heating:

7. Are there existing examples of heating using waste heat sources of industrial or other enterprises in your locality? What exactly is heated and from which sources of waste heat?

8. Are there plans to implement the use of waste heat of industrial enterprises for heating? What is needed for their implementation?