PROCEEDINGS, 48th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 6-8, 2023
SGP-TR-224

Another Way to Alleviate Europe's Energy Crisis

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Keywords: Energy crisis, vulnerability, geothermal energy, abandoned mines, mine waste, mine tailings, dump, heat.

ABSTRACT

The world is experiencing the first truly global energy crisis in history, and the situation is especially perilous in Hungary. Hungary, like the rest of Europe, is at the epicenter of the energy market turmoil. Hungary has never been energy-independent: it has always imported the energy it needed. Currently, however, the country's overall energy consumption has dropped to levels not seen since the 1970s. Hungary's primary energy consumption was 1119.7 PJ in 2010, for example, but only 1004.9 PJ in 2022.This might seem like a positive development at first glance, but is in fact the consequence of something far less cheerful: more and more energy-intensive industries have shut down, unable to compete in the post-communist world. Up until the Ukrainian war, Hungary imported more than 55% of its energy -- mostly from Russia -- with natural gas making up the larger part of the imported energy. The war highlighted our vulnerability even more.

The Hungarian government was/is feverishly searching for some source of independently produced energy. This article investigates an unusual geothermal source - that of abandoned mines, slag pits and other mine waste. In the '60s and '70s northern Hungary had many coal mines. Beginning in the early 2000s these were gradually shut down, until by 2004 Hungary's only operational mine was the open-pit mine in Būkkábrány. All the shaft mines were abandoned. For the most part, those mines and mine-waste sites underwent minimal or no mitigation. In some of these abandoned mine-waste dumps low-temperature ignition occurred, and was allowed to continue smoldering. In this article, we present an example of how energy can be harvested from these smoldering dumps, and calculate the potential energy yield.

1. EUROPEAN ENERGY VULNERABILITY

Hungary, like most European countries, was never energy independent and always imported the energy it required. The European Union imported 57.5% of the energy it consumed in 2022, as its own production and reserves satisfied only 42.5% of its needs. Russia is the leading supplier of natural gas, oil and coal to the EU, and has been for a long time. Russian gas was always attractive to Europe because it was easy to transport, at first relatively cheap and almost always available for more than half a century. In 1964, the Druzhba pipeline began supplying Hungary and other Eastern Bloc allies of the USSR , and has been operating continuously since then. Its importance grew after the fall of the Berlin Wall in 1989, especially in Western Europe, as more and more European countries moved to end coal and nuclear power generation, as production from their own gas fields declined.

Because of the Russia-Ukraine war, Europe's energy system faced an unprecedented crisis in 2022. Supplies of Russian gas critical for heating, industrial processes, and power were cut by more than 80 percent last year. Europe is experiencing its first winter without Russian gas, resulting in higher prices, gas shortages, and what may become a major recession. Despite the significant drop in Russian energy supplies – from 45% of the EU's gas imports in 2021 to less than 30% in 2022-- much of Europe has managed to find alternative supplies, reducing its demand so as to compensate for the shortfall and allow for more rapid deployment of renewables IEA(2022).

Although EU energy-import sources have varied over recent years, Russia is still the leading EU supplier of all the main energy commodities: natural gas, crude oil and hard coal. The countries' varying import dependencies create vastly different country-specific energy dependencies on Russia. Along with its regional neighbors, the EU has reviewed its options for reducing this dependency on pipeline imports from Russia, diversifying its oil-import sources, and – most importantly - finding independently owned and preferably renewable sources of energy within the EU itself. Fig. 1 shows the EU27 countries' energy imports from Russia as a percentage of total energy used (marked in green), vs. those countries' renewable energy use (marked in purple) again as a percentage of total energy used. There is a significant difference in dependence between the individual countries. Hungary, for example, is far above the European average for Russian gas imports, and at the same time below the EU27 average in the percentage of its energy derived from renewables. Perhaps not coincidentally, Hungary has spent most of 2022 as the EU27 country suffering from the highest rate of inflation.

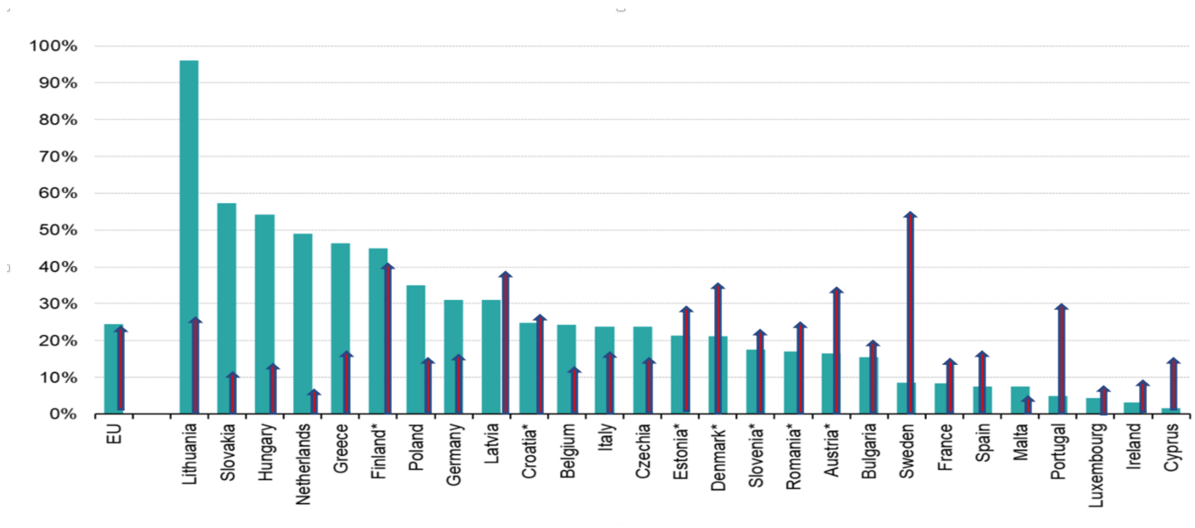
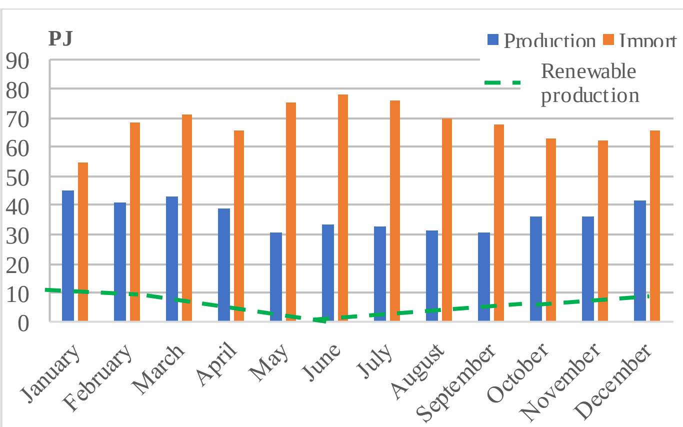


Figure 1: In gross energy imports from Russia to EU and the renewable energy shares 2020 (Eurostat, 2022)

2. HUNGARIAN ENERGY SITUATION

In 2021, Hungary's overall energy consumption was 761 PJ and its import dependency stood at 87%. Hungary is heavily dependent on the southern branch of the Druzhba pipeline for its crude oil imports. Russia accounted for 64% of crude oil imports and 95% of gas imports. Natural gas is the most significant source in Total Energy Supply (TES), accounting for 34% in 2020 and almost 60% of residential heating. With its latest emergency legislation, the Hungary government is seeking to increase gas production (to 2 bcm/y), secure additional gas imports from Russia, potentially ban exports of anything that qualifies as an 'energy carrier' (including firewood), increase coal production, increase power output at Hungary's lignite-fired power plant, and extend the lifetime of the Paks Nuclear Power Plant (2022). But these stopgap measures cannot solve the problem.



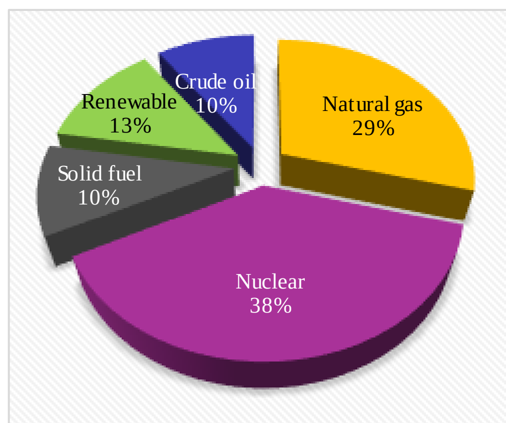


Figure 2: Primary energy balance in Hungary in 2021 (MEKH, 2022) **Figure 3: Primary energy production (Eurostat, 2021)**

Renewable-energy sources are steadily increasing their share, and are now at 13% of gross final energy production. Despite Hungary's favorable natural conditions for geothermal energy production, its utilization has been stuck for years at around 1000 MWth, Tóth (2020). Renewable-based heating and cooling, which is basically a geothermal source, has only 18.9% of that share. Geothermal district-heating and thermal-water heating cascade systems represent a major part of direct use, available in 26 towns, which altogether represent an installed capacity of 235,29 MWth and 641,37 GWhth/yr production. Individual space heating (mostly associated with spas) is available at nearly 50 locations. These represent altogether an installed capacity of 94,11 MWth and 163,39 GWhth/yr production. The agriculture sector is still a key player in direct use, accounting for about 402 MWth installed capacity and about 880 GWhth/yr production. Balneology (spas) has a long historical tradition in Hungary, and represents a total installed capacity of about 263 MWth with an annual use of about 778,5 GWhth/yr. There is still one operating geothermal power plant in Tura, with a gross electric capacity of 2.3 Mwe, Nador et al (2022).

3. HARVESTING ENERGY FROM ABANDONED COAL MINES

As elsewhere throughout the world, many of Europe's coal mines – still a significant energy source for EU27 - were closed or due to be closed before the Ukrainian war began. These mine closure created negative social, economic, urban and environmental effects in the affected areas. Many of these mines have great potential for the geothermal utilization of low-temperature water, which could be used for heating and cooling purposes. Where this potential geothermal energy from underground mines has been actually detected and used, such cases have been reported on in the US, Canada and Europe: in the Netherlands, Verhoeven et al (2014); Germany, Ramos (2015), Oppelta et al (2022)); Poland, Chudy (2022); United Kingdom, Banks et al (2004), Batchelor (2021), Monaghan et al (2021); Spain, Menéndeza (2019); Canada, Wainer et al (2019); and the USA, Watzlaf and Ackman (2006). The power obtained from mine water could be as little as a few kilowatts thermal (kWt) from small installations as in Freiberg, Germany, and Shettleston and Lumphinnans in the UK (Toth, (2011). At the other end of the scale, there are large installations which extract several megawatts thermal (MWt) from mine waters like those in Heerlen (The Netherlands), Mszczonow (Poland), and Mieres (Spain). Those projects were usually based on mine water, or a flooded mine's water thermal potential. This article takes a different approach, instead investigating an abandoned mine's slag pit to see how energy can be harvested from a smoldering dump, and top see what advantages can be obtained from developing this kind of energy resource in an abandoned, neglected and historically poor locality.

3.1 The story of the Lyukóbánya coal mine

Coal mining has a long tradition in Hungary, and in the Borsod region goes back more than 200 years, with abundant available data relating to the area's coal-mining history. More than 600 coal-prospecting holes have been drilled there, usually to a depth of 200-400 m in Miocene formations, Bertalan et al, (1986). The Lyukó coal mine is located in the eastern Bükk range, a geological remnant of the Inner Carpathian arc of extinct volcanoes. In the last century, detailed geological and geophysical surveys yielded much data regarding the area's surface and subsurface geology.

The Lyukóbánya coal mine started production in 1942. The Lyukó coal beneath the ground was found among soft, sedimentary rocks. Accompanying rocks containing mostly sand, sandy clay, siltstone tufa rocks, marls, and slates frequently contained significant amounts of water. The area of the Lyukó mine is 29.6 km^2 and is 200-250 m deep on average. The length of the shafts was about 50 km, and 3.5-4 m in diameter. The heyday of the mine was in the 1980's and 1990's, when it produced more than a million tons of coal per year and the production was fully mechanized.

Since it began operation, a significant amount of Lyukóbánya's waste was created during coal production. The waste was then separated, transported to the open air and stored in appropriate places, depending on the terrain surrounding the mines. Since the separation of coal and waste was carried out with rather simple methods, the waste often contained 5-10% coal. The waste's coal content has been and still is oxidizing as a result of precipitation, sunlight, and summer heat. The clay and the argillaceous marl rocks are especially suitable for sustaining such oxidation, as the small amounts of infiltrating precipitation and minimal amounts of oxygen in the loose sediment are just enough to enable low intensity oxidation, which generates heat. Lyukóbánya happens to have a particularly large reclaimed waste dump, which smolders to a significant depth, and even shows surface manifestations of that smoldering.

In the 1990's and 2010's, the families and settlements that made their living in the mining industry of Northeast Hungary were impoverished by the sudden mine closures. Their standard of living is still far below average, even by Hungarian standards. Because no gas pipes were installed near the Lyukó mine, the people who remain in this region have to generate heat by burning wood and other low-grade combustibles, significantly degrading air quality and contributing to the worldwide greenhouse effect. If harvesting the Lyukóbánya's coal waste could provide them some employment or the heat that they need, it would help them, the country, and the world at large.

3.2 Physical characteristics of the Lyukóbánya smoldering slag dump

The mine was closed in 2004, having produced more than 38 million tons of coal in its lifetime, and leaving approximately 10 million tons of coal underground. Over time, the shafts filled up with water. The dump at the Lyukó mine was placed at a low area of the Lyukó creek water catchment zone. The precipitation flowing into this low area is fed in by a tunnel underneath the dump. The water catchment zone is about 5.5 km^2, and groundwater flows into the coal-waste dump at an average rate of 690 l/s Nádasi, (2005). The waste dump was recultivated after the mine closed, with trees and other vegetation being planted to make blend it into the surrounding landscape Szepessy, 2002). The recultivation is at least partly successful, as it is now woody, bushy area once again populated by wildlife. Fig. 4 shows the now vegetated Lyukóbánya coal-waste hill.

Figure 4: Lyukóbánya slag dump

The dump has a roughly elliptical shape, the shorter diagonal 105-140 m long, the longest diagonal 200 m, the maximum height 36m, the angle of inclination about 36^o (Fig 5). The surface area is 76,000 m^2. Its volume is 1.5 million m^3. The dump's partially burnt-out contents have been compacted for more than 60 years, and consist of coal, oxidized coal shale, argillaceous marl, siltstone tufa rocks, marls, slates, and brecciated and fragmented clay.

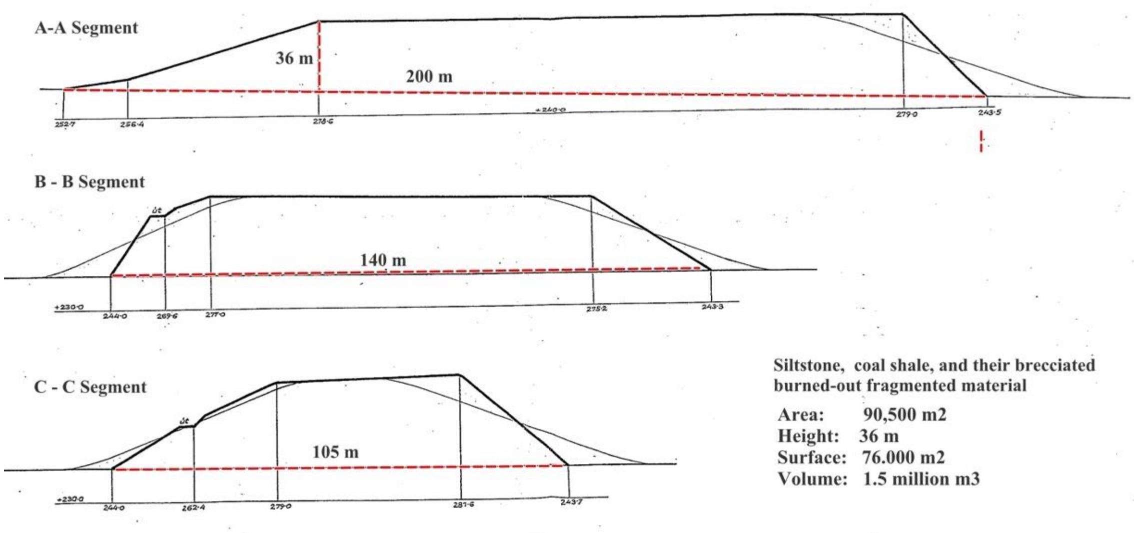


Figure 5: Lyukóbánya slag dump's size and segments

The temperature data have been obtained in exploratory boreholes. The temperature of the dump was measured twice. First in 2013, when 10 vertical probe holes were drilled by Techmo TM105 drilling equipment at the dump's surface. Rock samples were taken from every hole and where it was thought worthwhile. The second measurement was carried out in 2022. Data were measured by MAXWELL MX25 500 digital mercury thermometers. The temperature data were made nearly ten years apart, but did not show any significant variations. In both cases a deeper hole did not necessarily yield a higher temperature. (The #10 hole's temperature could not be assessed.) The bore-hole sites were selected based on the surface manifestations - where the lack of the vegetation was obvious (Fig. 6 - 8). In particular, the temperature results of holes 1#, 6#, 8# and #9 were and are promising (Fig. 9).

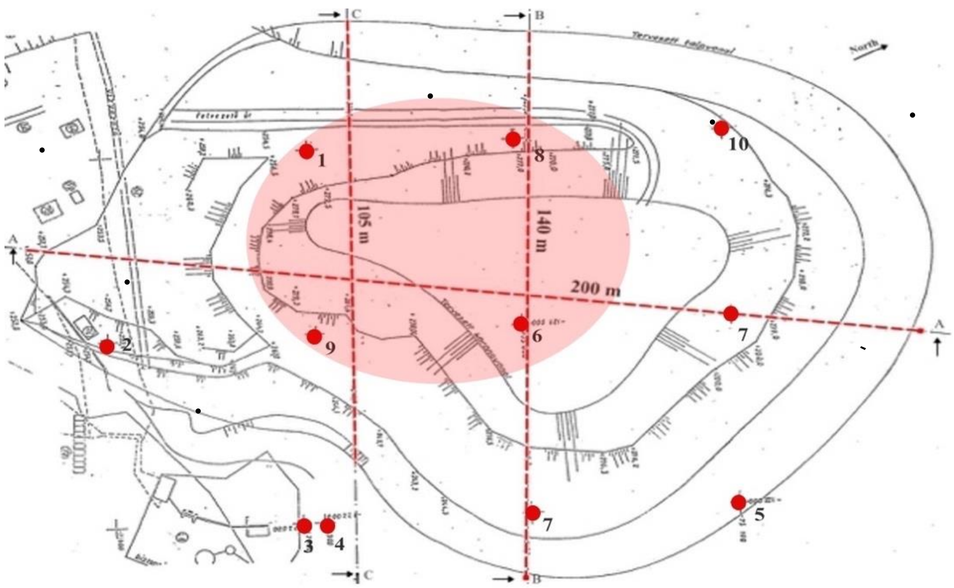


Figure 6: Lyukóbánya waste dump's site plan and its temperature holes

Figure 7: Smoldering part of the waste dump

Figure 8: Drilling a hole for measurement

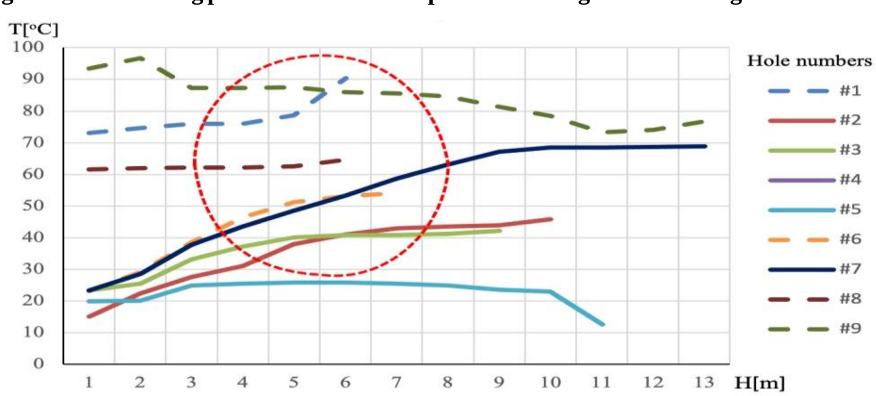


Figure 9: Lyukóbánya waste dump's holes and their measured temperatures in 2022

4. CALCULATED RESOURCE HEAT AND ITS HARVESTING

Lyukóbánya waste dump has a large volume - 1.5 million m^3. The compacted rocks' physical parameters were specified based on core sampling The average weight density is 19 kN/m^3, the porosity is 10 - 35%, the permeability is 0.4 - 60 mD and the heat capacity is 0.91 – 1.1 kJ/kg°C. At the surface of the dump, the temperature depends on the season, varying from -5 to + 25°C. The mean annual temperature in this part of Hungary is about 10.5 °C.

4.1 Theoretical heat content

The dump's rock mass was calculated based on the nine evaluable core samples. Based on the nine samples taken, the heat capacity difference was negligible. At a conservative estimate, assuming a difference between the rock and the surface temperature ΔT = 40°C, the theoretical energy content can be calculated as

$$E = \sum_1^n (Vi * \rho i) * c * \Delta T \tag{1}$$

where: V_i = volume [m^3]

ρi =density [kg/m^3]

c = rock heat capacity [J/kg °C]

ΔT = 40 [°C]

The calculated theoretical energy content is 1.2 PJ, which seems very considerable. This energy content could qualify as a Hypothetical Resource in the McKelvey diagram (Fig 10), since Hypothetical resources are those where mining/drilling (or other extraction) took place, wasn't yet discovered, yet are anticipated to exist It might even be realistic to move it into Conditional Resources category, as these these data sets were twice measured ten years apart and didn't show significant differences. Another favorable factor is the generally recognized need for a local, independently owned energy source – something which would also fundamentally affects the region's economic conditions.

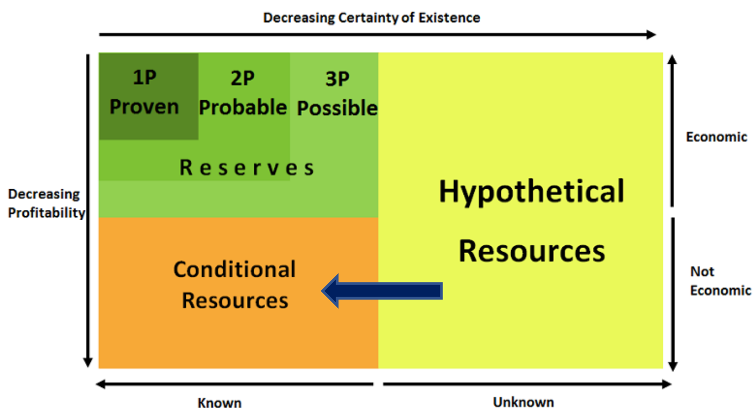


Figure 10: McKelvey diagram for the heat harvesting

It has to be noted that although coal-waste is not a renewable source, and not even geothermal energy, the methods used to determine the coal-waste's energy content and to harvest its energy are the same as are used for the usual \ geothermal-based energy sources.

The heat-extraction operation's duration and intensity could vary based on demand. The extractable energy is also strongly technology-dependent. At the same time it should be emphasized that this is a real energy resource which was before regarded as only refuse, which does not contribute greenhouse gases and which could be locally owned, and could stimulate an otherwise moribund regional economy.

4.2 Possible way to extract its heat energy and its utilization

Lyukóbánya's coal dump is very favorably located for energy harvesting, with water as a working fluid, since it's situated on the lower part of the Lyukó stream catchment basin, in a fairly wet part of Hungary. There, the water catchment area extends to about 5.5 km^2, and quite a lot of groundwater flows down through the waste dump – about 690 l/s on average onto the lower vertical cross-section of the waste dump. In 1980, a half m diameter tunnel was formed to gather and drain the water. It runs lengthwise along the base of the dump, open on top inside the hill, so as to collect the water, and closed at either end where it exits the hill. The existence and the amount of the outflowing water from the water-collection tunnel proves that the dump's rock material (Fig. 11) has very good permeability. In January, 2022,. the measured outflowing water temperature was 13°C. A good way to extract heat from the gathering-tunnel's outflow would be to use a water-source heat pump.

Figure 11: Water gathering tunnel through the dump

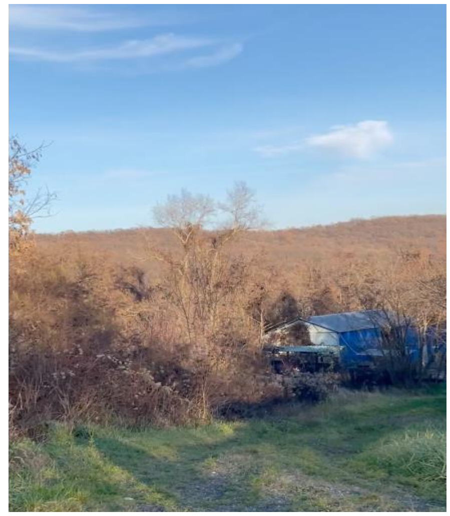


Figure 12: The existing timber dryer nearby

Another way to extract heat would be to ignore the existing gathering tunnel, and instead install heat exchanger bore-holes in the warmest places -- around 1#, 6#, 8# and #9 holes. The indicated area is shown in red on Fig 6. The bore-hole heat exchangers employ a heat pump. It would probably be necessary to build in suitable heat pumps to increase the temperature. The number of bore-holes used and the size of the heat pump would depend on the heat demand.

The HPWH systems using carbon dioxide (CO_2, R744) as a working fluid can typically achieve COP 20% higher than the most energy-efficient HPWH systems on the market. Those systems use HFC or propane as a working fluid (Toth, 2011). In terms of energy efficiency and utilization of renewable heat, CO_2 systems even outperform state-of-the-art solar heating systems. Air-to-water and water-to-water CO_2 HPWHs in the capacity range from about 5 to 60 kW have now become commercially available in Japan and Europe, available from a number of Japanese manufacturers. So that might be another solution that could work in Lyukóbánya and similar sites.

Or both methods could be used, since the utilization primarily heating small family houses and one office buildings nearby and their heat demand are about 7-10kW/house. There is an existing timber dryer heated by wood burn about 150m far, the owner interested this new way heating also.

5. CONCLUSION

There are several potential advantages in using abandoned coal waste dumps. The most important is that a locally owned, economical and renewable energy source, especially welcome in one of the poorest regions of Hungary, could attract investment to the coalfield communities still devastated by the mine closures. Another benefit is that this energy source can be used intermittently as needed, stopped and restarted later - its continuous operation is not required. The use of waste-dump heat is also versatile in how it could be applied, for residential, agricultural or industrial applications.

If successful, harvesting Lyukóbánya's coal-waste heat could provide an example which could be repeated in many similar waste- dump locations throughout Hungary, Poland, Ukraine and elsewhere in eastern Europe, providing independently-owned sources of energy while creating employment and stimulating depressed regional economies.

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