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Technological Considerations and Medium-Term Projection Related to Underground Thermal Energy Storage

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ABSTRACT

Underground Thermal Energy Storage (UTES) technologies have not been widely utilized so far as it should be optimal. An important cause of this backlog is that UTES usually is not yet an independent technologic challenge or project, we regard it as part of the heat production and/or energy management. Therefore it is well worth

- seeing the technology linking between UTES and the fairly developed geothermal technologies with wide experience, and also
- reviewing the latest results in innovation and development opportunities.

This process can generate a new way of thinking in field management and we can recommend new opportunities to enlarge the utilization of this type of energy storage. The paper follows this process and sets up middle-term UTES projection in Hungary.

The first approach in the status review of UTES is the development of the evaluation of geological background. Geological exploration has developed significantly in the latest decade and it provides better opportunities for underground heat storage than before. The national and international databases, as well as new geological concepts, help to evaluate precisely the heat storage potential of the different formations.

The second approach is the systematization of the available technological solutions of producing and reinjecting fluids, as well as the creation of underground heat exchangers. The shallow (with maximum 300 meter deep wells) and deep storage (with over 300 meter deep wells) are to be evaluated separately, because of the different technologic challenges. Shallow utilization has experience with ground source heat pumps, but deep UTES needs a lot of research and further deep demonstration projects are to be planned.

The third approach is focusing on the heat market on the surface. Different technology and energy solutions are needed in every project. UTES projects wish to exploit synergies of the energy and geothermal industry, as well as make renewable energy projects more competitive. Moreover, hybrid solutions increase the renewable energy capacities efficiently and improve the flexibility of the utilization of renewable energies. The geothermal energy industry already has more and more experiences so UTES has to find long term positions.

The paper reviews all the three approaches (geological exploration, available technologies and heat market issues), makes a distinction between shallow and deep UTES opportunities and provides recommendation to widen the utilization of UTES in the geothermal sector. A middle term projection is presented with taking into consideration the real Hungarian geological, legal, economic and technological background.

1. INTRODUCTION

The following reflections and calculations are illustrated by Hungarian data. Hungary is situated in the moderate climatic zone in Central-Eastern Europe, where both winter space heating and summer space cooling is necessary. However, the methodology suggested in this paper can be used in all countries as well, where the rate of heating and cooling is different.

The enhancement of UTES strongly depends on the development of shallow and deep geothermal energy sectors. UTES prospective areas generally cover the prospective areas of geothermal energy production. The utilized techniques are similar to the conventional geothermal ones, and UTES can emerge as a complementing technology in traditional geothermal regions, or can make competitive geothermal technologies in new areas.

The Country Update of Hungary (Nádor et al. 2019) includes the latest figures of the Hungarian geothermal sector and provides some background to UTES projection calculations (Table 1). The operational and 2025 projected data are calculated from the Country Update 2019.

Effective utilization could be increased with the widening cascade technologies. Meanwhile the spread of zero heat emission buildings will decrease the effective utilization as well as the necessary heat capacity. There will be changes in the building construction sector in the following decade, which will reduce the required heat capacity and utilization. The cooling demand will be increasing onwards, and similarly, the demand for underground thermal energy storage will surely increase. UTES will emerge and spread in those regions, where the hydrocarbon or/and geothermal sectors have strong industrial culture and the heat market demand makes UTES technologies competitive.

Table 1: Shallow and deep geothermal capacity and production data in Hungary.

	Shallow geothermal		Deep geothermal	
	Capacity (MW_{th})	**Production (GWh_{th}/year)**	**Capacity (MW_{th})**	**Production (GWh_{th}/year)**
In operation at the end of 2017	72	144	908,18	2267,36
Projected by 2025	104	198	938	2372
Expected by 2030	128	230	978	2470

2. STATUS REVIEW OF UTES BY THE GEOLOGICAL BACKGROUND

UTES technologies are to be approached as advanced geothermal energy technologies, which depend on the geological environment. The advanced technology requires advanced geo-science basis. In the past decade significant development has been achieved in the geo-science knowledge. There are numerous geothermal atlases, interactive maps, showing the best areas for geothermal energy production.

However, the best areas for underground heat storage are not equal to the areas with the best geothermal potential. Therefore updated geological and geophysical methods are needed to determine the underground stores. Figure 1 illustrates the determination method of the basement of the sedimentary rocks during the development of an UTES Project.

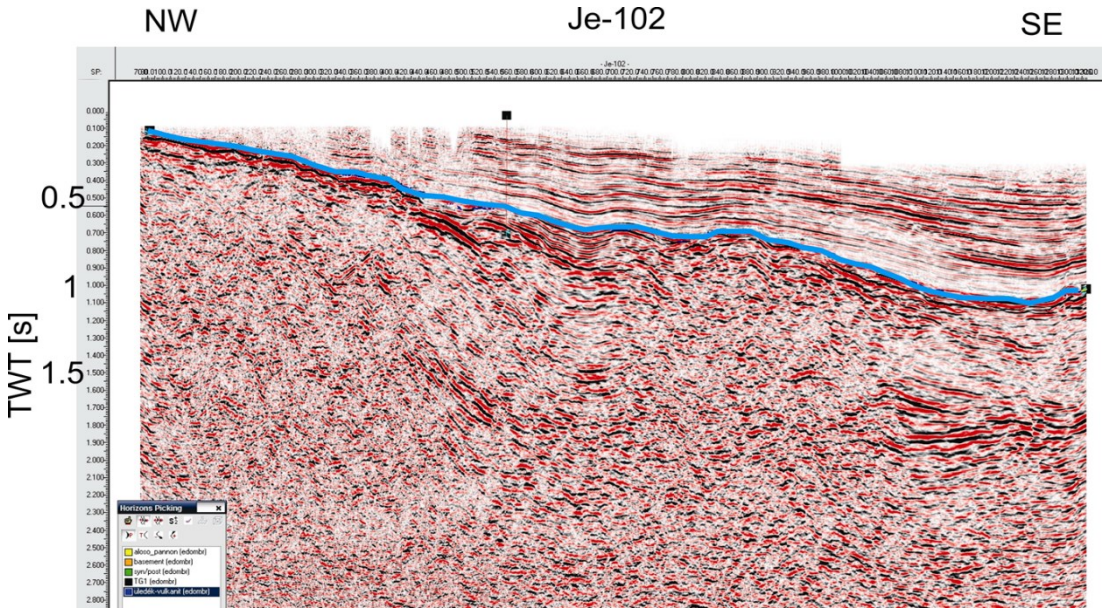


Figure 1: Basement of sedimentary rocks in an UTES Project (after ELTE University).

After the determination of the heat storing strata, further techniques are required to calculate the storage size and evaluate the petrophysical parameters. Figure 2 provides an example how to determine the size of a potential underground heat storage.

Reviewing the widespread literature, we have to state that geo-science methods provide enough knowledge and information to spread underground heat and cold storage. There have been more than 8000 hydrocarbon wells and more than 1400 geothermal wells been drilled in Hungary, thus this country has well-explored regions. The geo-science knowledge and methodologies will support the spreading of UTES sites. Thermal models can be used to predict seasonal temperature in the ground. Stable temperature regime can be established, which is achieved by matching the inputs and outputs of heat over one or more annual cycles.

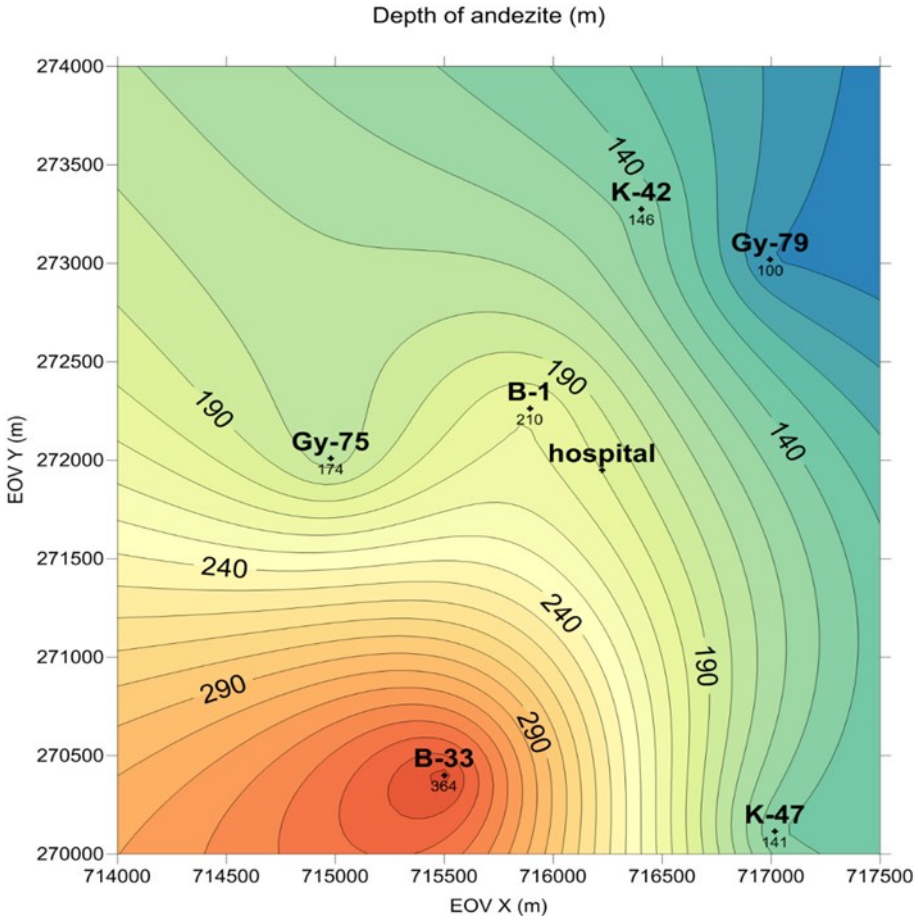


Figure 2: Analysis of the distribution of existing wells and bottom of sediments (after ELTE University).

3. UTES TECHNOLOGIES

In underground thermal energy storage, the storage medium may be geological strata ranging from earth or sand to solid bedrock, or aquifers.

3.1 ATES, Aquifer Thermal Energy Storage

ATES storage is composed of thermal water production and reinjection well or wells and an underground aquifer, which is settled between impermeable geological layers above and below. The heat or cold storage medium is the water and the rock of the aquifer.

There is a variety of ATES systems in developed geothermal countries, which do not require the highest geothermal potential if the objective is thermal heating-cooling. ATES generally has a lower installation cost than BTES because usually fewer holes are drilled, however, ATES has a higher operating cost. ATES requires the presence of an appropriate aquifer.

The Heatstore Project (Kornneef et al. 2019) summarises the best European cases of this technology as below:

- The deepest ATES site has an over 5 MW thermal energy capacity with a maximum of 90°C rock temperature. The volume of produced heat is 20 GWh/year.
- A deep ATES site of over 50°C rock temperature in porous limestone is able to provide 4 MW thermal capacity.
- Surplus heat storage underground (200 – 500 m, max 120˚C) in existing district heating system fed with combined-cycle, waste-to-energy and wood fired plants. Maximum heat capacity is 1.7 MW.
- Mine Thermal Energy Storage pilot plant for the energetic reuse of summer surplus heat from Concentrated Solar Thermal for heating buildings in winter. Maximum heat capacity is yet 45 kW.
- Solar thermal heat production combined with BTES with lateral heat recovery boreholes. The rock temperature is about 40°C, the maximum storage volume is 100 MWh/year.
- Demand side management (DSM) of a geothermal heating network, including assessment of adding thermal storage. Maximum heat capacity is 9.5 MW, and storage volume is 3.5 GWh/year.

These are demonstration or pilot projects, but their volume or capacity can show the range of this technology in the following decades (Bloemendal et al. 2019). Figure 3 presents an example for the increasingly widespread ATES sites in the shallow geothermal sector.



Figure 3: ATES sourced heat pumps.

3.2 BTES, Borehole Thermal Energy Storage

BTES stores can be constructed wherever a lot of vertical boreholes are drilled, and a few °C temperature difference can be achieved between the wellhead and well bottom. All sizes of systems can be built, including large, over 3 – 5 MW_t units. The largest Hungarian BTES type heat-pump system is over 2.25 MW_t.

The strata can be anything from sand to crystalline hard rock, and the depth can be from 50 to 500 meters. Spacing has ranged from 3 to 8 meters.

3.3 MTES, Mine Thermal Energy Storage and Other Special Solutions

These types of storing technology are feasible in old mines, constructed chambers, or abandoned underground hydrocarbon reservoirs if they are close enough to a heat or cold market. During the construction of buildings, borehole heat exchangers much like those used for BTES stores have been spiraled inside the cages of reinforcement bars for pilings, with concrete then poured in place. The pilings and surrounding strata then become the storage medium; this is the energy piling technology. Interseasonal Insulated Thermal Storage is created when constructing any building with a primary slab floor, an area approximately the footprint of the building to be heated, and is insulated on all 6 sides, typically with HDPE closed cell insulation.

Figure 4 shows the wide range of UTES technology opportunities depending on depth and rock temperature. A wide range of technological solutions can be developed which include:

- Ground source heat pumps (< 300 m, ATES or BTES),
- deeper ground source heat pumps (300 m – 1000 m, ATES or BTES),
- one borehole heat exchanger,
- deep geothermal doublet (>300 m.), and
- their mixtures, and also
- their mixtures with other renewable energy resources (solar or bioenergy, etc.).

This inter-technological approach ensures a good chance to find the optimal geothermal solution in the project generation process when the geothermal resources are located below 1000 meters.

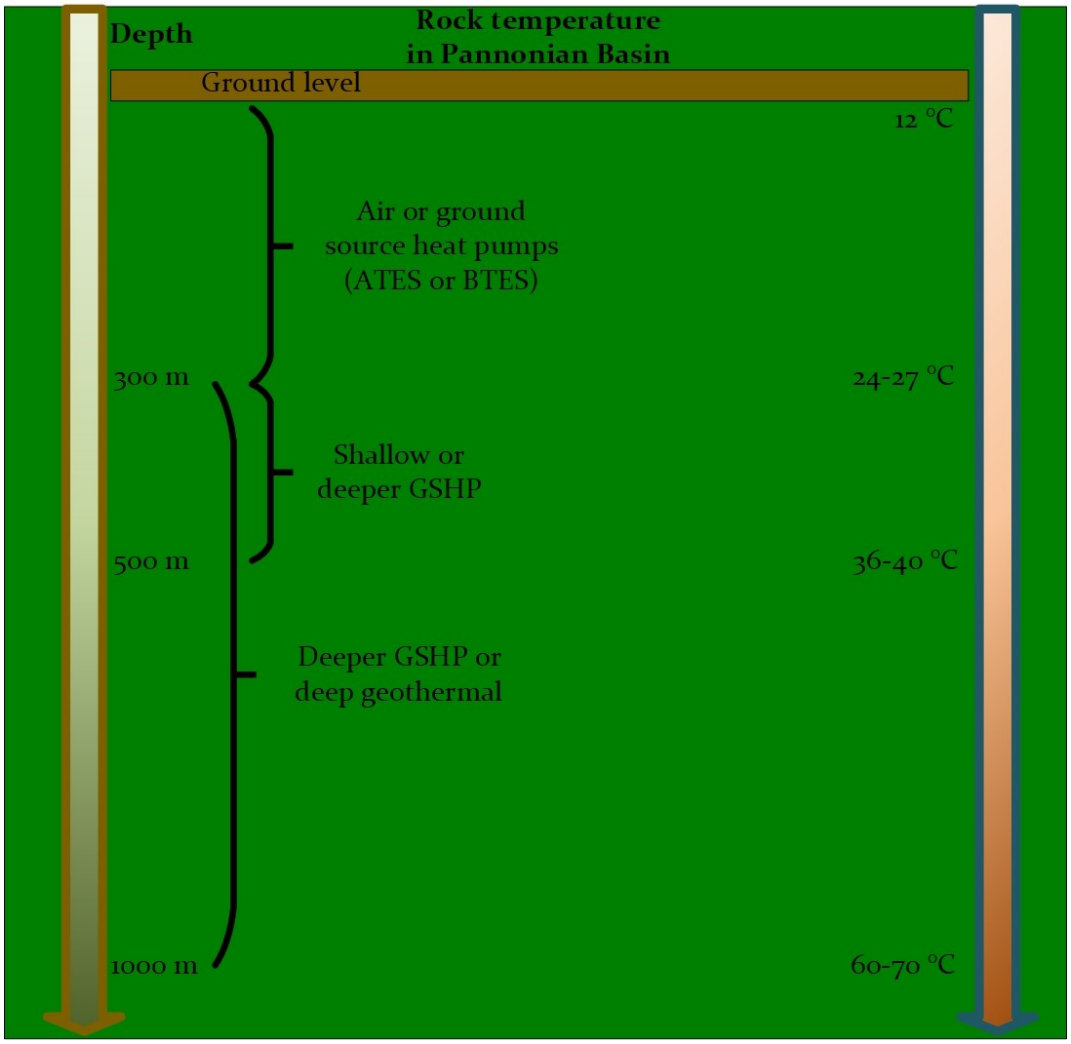


Figure 4: Different technologies by depth and rock temperature.

4. COMPLEX AND HYBRID TECHNOLOGIES

It is rare nowadays that a project simply utilizes geothermal heat. The engineering activity involves updated solutions, from cascade systems to combined heat and power. It has already become an ordinary practice to create complex or hybrid solutions. These engineering practices open the door to underground heat storage, which can be utilized in the following technologies:

- GSHP utilization parallel heating-cooling,
- waste heat exploitation combined with GSHP,
- large heat pumps, larger heating systems (> 2 MW_{th}),
- GSHP in district heating systems,
- Hybrid ATES or BTES systems with solar, PV, bio technologies (Schulte et. al, 2019), and
- combined GSHP and deep geothermal technology.

Figure 5 provides the simplest way of cascade utilization, from which UTES solutions can emerge. The figure shows the utilization ranges. However, in summer time often there is no market for one or two sorts of these ranges. 30 – 110°C waste heat (in hot water or in steam) can be a perfect basis in summer for storing it and extracting in winter.

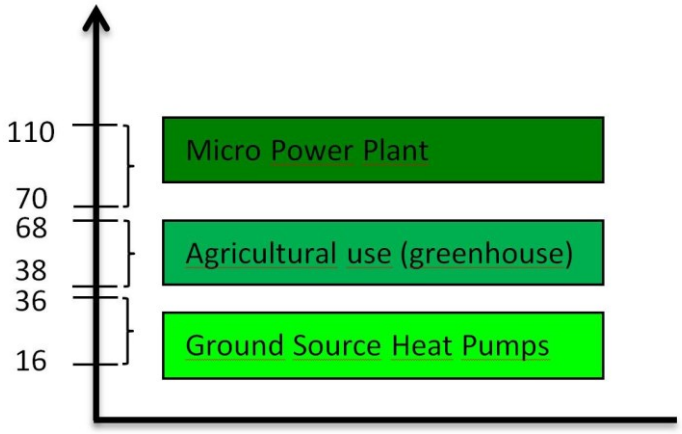


Figure 5: Cascade system opportunities by temperature [°C].

5. HEAT MARKET ISSUES

As the list of the technological solutions has existed for a long time, the main barrier of spreading UTES is the market existence in prospective areas. The three main prospective areas where UTES can be utilized are listed as below:

- combine heat and power stations (geo-, PV solar and bioenergy),
- waste heat utilization, and
- spas supplied by thermal water.

The thermal spas in Europe have traditions of thousand years, but the conscious energetic utilization of the produced thermal heat started only a few decades ago, moreover it has not been started everywhere. Merely partial solutions have emerged so far. Only unique, practical solutions are implemented in the spas and they regularly do not achieve the energetic optimum. Figure 6 shows an analysis how the thermal heat of the brine of spas can be utilized. The task in this case is to set the heat range to the heat market inside the spa building or nearby. The surplus heat can be stored.

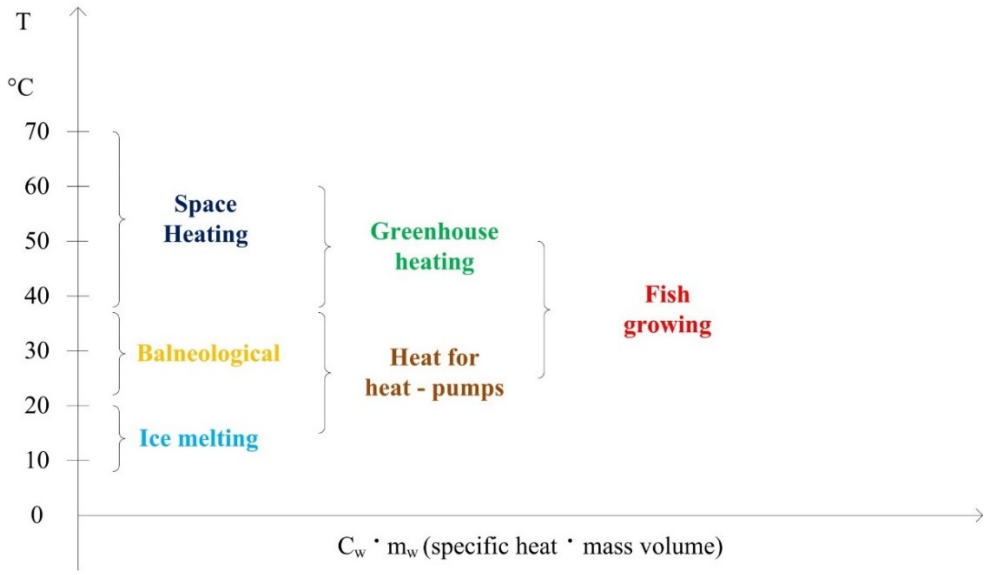


Figure 6: Opportunities of cascade heat utilization.

The 37/22°C temperature range of the thermal water temperature is utilized for balneology purposes in the spas. Meanwhile, in the majority of the spas the produced temperature has far higher temperature than 37°C. Average (Hungarian) 52°C thermal water loses more than 60% of its heat energy without energetic utilization. In this case the spa implies an operational and energetic expense. To optimize the heat energy utilization in the almost 300 Hungarian spas is a significant energy efficiency task.

Figure 7 is a developed utilization of the energy optimization, because the C_w and m_w product can be utilized directly for the calculations. Accordingly, the exact energy utilization of the half dozen utilization types can be calculated from their area. The last and most specific part of the energy optimization is the determination of the surplus heat and its involvement into the seasonal energy management by storing it under the ground.

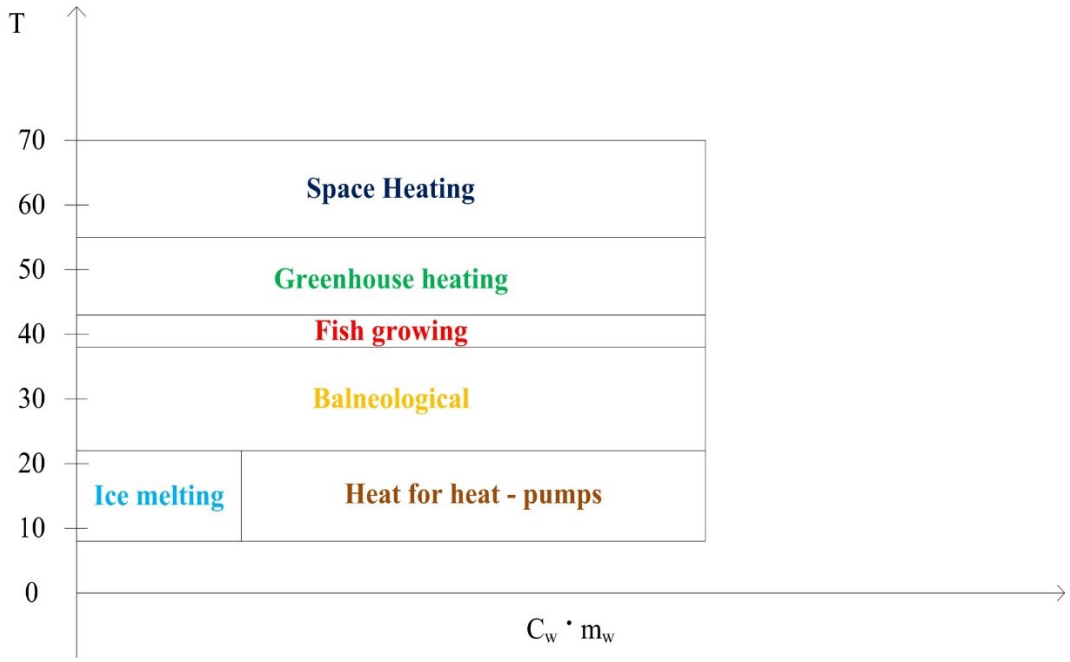


Figure 7: Heat energy calculation in a cascade system.

6. MEDIUM-TERM PROJECTIONS FOR UTES IN HUNGARY

The medium-term projections relate to the next five years, 2020 – 2030. During this time the following factors will influence the Hungarian geothermal sector:

- Financially: European Union and also national renewable energy support schemes will be issued.
- Technologically: Further demonstration and pilot UTES projects will be launched and finished. They will provide new technological models.
- Market: decentralization, energy communities, local decisions, local investment.

6.1 Shallow Heat Storage (< 300 m)

Table 2: Shallow heat storage projection till 2030.

Technology	Number of projects, size and type	Total capacity, MW_t	Stored heat, GWh/year
'Classical' ground source heat pump	10,000 units~10 kW houses, 26 units ~500 kW comm.	113	205
Solar thermal heat production combined with BTES with lateral heat recovery boreholes	1,000 units ~10 kW houses, 50 units ~ 50 kW communal	12.5	25
Mine Thermal Energy Storage	50 units ~ 50 kW communal	2.5	5

6.2 Medium Deep Heat Storage (300 – 1000 m)

Table 3: Medium-deep heat storage projection till 2030.

Technology	Number of projects, size and type	Total capacity, MWt	Stored heat/year
Deeper ground source heat pumps (ATES, BTES, MTES)	30 units ~500 kW communal	15	25
Surplus heat storage, in existing district heating system fed with combined-cycle, waste-to-energy and natural gas fired plants	10 units ~1 MW, district heating	10	20
One borehole heat exchanger	5 units ~100 kW communal	0.5	1

6.3 Deep Heat Storage (> 1000 m)

Table 4: Deep heat storage projection till 2030.

Technology	Number of projects, size and type	Total capacity, MW_t	Stored heat GWh/year
Surplus heat storage, in existing bio energy power plant, into deep ATES sites over 50°C rock temperature in carbonate or sandstone reservoir	5 units ~2 MW communal	10	20
Demand side management (DSM) of a geothermal heating network, adding thermal storage	5 units ~2 MW district heating	10	20
Surplus heat storage, in existing PV power plant into deep ATES sites over 50°C rock temperature in carbonate or sandstone reservoir	5 units ~2 MW communal	10	20

7. SUMMARY

As Hungary has an excellent geothermal potential and also demands a large amount of energy for heating and cooling, the development of both shallow and deep geothermal heating-cooling sectors is expected to be continuous, possibly progressive.

The geo-science knowledge, geological and geophysical data exist. Technological models are also available, and technologies are under research, by demonstration and pilot projects. A calculation was performed concerning the heat storage opportunities in the next decade. Table 5 shows the results of the calculation. The expected Hungarian geothermal heat production in 2030 is over 1100 MW. The calculated underground heat storage can provide plus 16.6%, 183.5 MW_t. There are a lot of technology opportunities available and a well-planned project, as well as field management, can ensure a significant enhancement in underground thermal energy storage.

Table 5: Hungarian heat storage projection till 2030.

Technology	Number of projects and size	Total capacity, MWt	Stored heat GWh/year
Altogether shallow, medium deep and deep technologies	between 2 kW and 10 MW	183.5	341

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