Underground Thermal Energy Storage Opportunities in the Pannonian Basin

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ABSTRACT

Geothermal technologies are fairly developed and have gained wide experience in the Pannonian Basin in Central-Eastern Europe. However, Underground Thermal Energy Storage (UTES) technologies have not been widely utilized so far.

There are two directions of this Borehole Thermal Energy Storage development; shallow and deep storage, with over 300 – 500 meter deep wells.

The key idea in both cases includes underground heat storage of the summer surplus or waste heat production, as well as producing and selling the stored heat in winter, during the heating season. This technology will lead to higher flexibility and financial competitiveness concerning the heat service aspect.

The main characteristics of UTES in the Pannonian Basin are the following:

- There are regions with excellent, good and poor geothermal potential in the Pannonian Basin therefore professionals have to be prepared for different geological challenges.
- Complex hybrid renewable energy technologies are becoming more and more significant in CEE countries. As storage itself does not create energy, UTES is a service in a renewable energy hybrid system; e.g. part of the integration of bio- and geo-energy technologies.
- Accession to the traditional heating systems is a key question in all sites.
- In CEE countries the climate is continental. There is a large difference between summer and winter heat demand. UTES basically serves the inter-seasonal energy management as heat storage facility.
- As regards energy producers and consumers, it is a new approach to create a more competitive complex renewable energy technology.

A group of companies, institutions and universities started to investigate the opportunities in CEE countries to demonstrate the feasibility of underground heat storage under different conditions, and to prove its competitiveness.

Shallow and deep UTES face different challenges concerning different heat producers, heat markets and geological conditions. Therefore different technological and energetic solutions are needed. While shallow utilization has gathered experience with ground source heat pumps and it is under positioning in energy statistics and policies, deep UTES needs a lot of research, and deep demonstration projects are to be planned.

This document reviews the differences between shallow and deep UTES opportunities in the Pannonian Basin and provides the latest results of the research group.

1. INTRODUCTION

The European Union has an ambitious common objective concerning the fulfilment of the 28 National Renewable Energy Action Plans (NREAPs) of the Member States. In order to achieve the overall EU objective, all possible renewable energy resources are to be exploited in an optimal way. There are well developed professional strategies, with regard to the main renewable resources, including geothermal energy as well. The scope of geothermal utilization can be widened by underground thermal energy storage by boreholes (Nordell, 2012).

Although the utilization of UTES-BTES is an existing technology and the practice of the ground source heat pumps is well known, UTES is rather undeveloped, and the installations are mainly focusing on shallow utilization (Björn, 2013).

In UTES technology only a low number of professional solutions have been completed (Homuth et al, 2013). Few projects are operating; system efficiencies are not always the highest possible. Currently, most of the operating technologies are customised combinations of single components assembled by the installer. The efficiency of the overall system strongly depends on the installer's

skills, technical knowledge and choice of the right components.

Complex innovative solutions are needed that strongly improve the competitiveness of the technology.

2. TECHNOLOGICAL BACKGROUND IN THE PANNONIAN BASIN

The average surface temperature in Central Europe is 12°C. The geothermal potential is fairly prospective for UTES-BTES in the Pannonian Basin, because of two main characteristics

- the geothermal gradient is high; 4.5 – 5.5 °C/100m, and
- there are a lot of different sedimental formations; sandstone and clay layers are changing each other.

Therefore we can choose storing formation on the requested original temperature, in a range between 20 – 100 °C.

An appropriate cover and a bottom rock formation is needed, in this case we can exactly calculate the heat transfer process in the storing formation.

As regards the heat storing rock, there are several geological concept approaches in the Pannonian Basin:

- Storage only in sedimental sandstones
- Storage in sedimental sandstone, as well as in clay layers
- Storage both in sediments and top fractured crystalline structures.

The underground heat storage units provide interseasonal energy management with warm water circulation and include

- Shallow wells, 30 – 300 m. or
- Deep wells, 300 – 1200 m. and
- Combined with buffer tanks, which allows smooth operation.

Naturally, 300 m is not a strict border; it is only a depth, which generally separates shallow and deep geothermal projects. The future will show if it is a useful border between shallow and deep UTES as well.

Figure 1 presents the basic technical solutions for deep as well as shallow UTES-BTES utilization. In summer operation hot water is injected into the wells and the hot water heats the rocks around the wells. In winter cold water is injected into the wells and the warm rocks heat the water that extracts the heat to the surface technology.

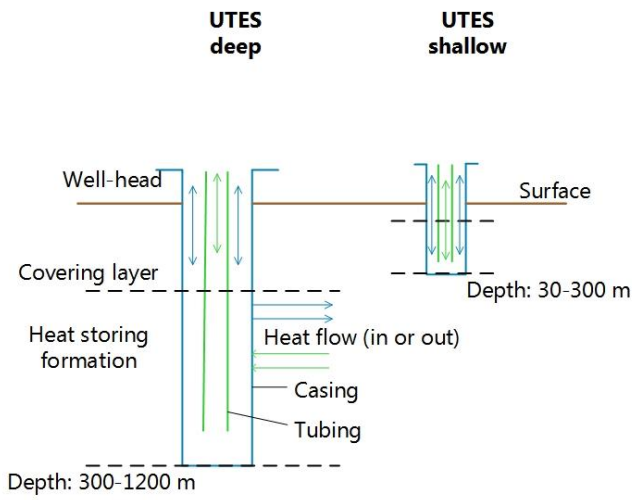

Figure 1: Technological solution of a simple deep and shallow well.

It is an exciting task for the geothermal professionals to create a complex engineering professional advisory service package related to the interseasonal energy management through underground thermal energy storage.

The specific objectives of this service package include

- analysis of the technological opportunities of UTES,
- review of other renewable energy (biomass, biogas, waste heat, solar) markets and find the technical opportunities where UTES can be applied,
- finding an optimal solution to create an UTES site, and
- evaluation of its technical and financial competitiveness.

3. TECHNOLOGY MODELS

3.1 Shallow heat storage

Shallow UTES offers the advantage of easy geological database building and low cost of wells. However, it is not easy to create large heat storage capacity. Moreover, higher temperatures (>40 – 50 °C) cannot be stored with high efficiency.

Shallow underground heat storage units consist of numerous boreholes. All boreholes are composed of a casing and coaxial tubing inside the casing. The heat-conveying hot water is pumped into the wells within an annular space between the casing and tubing during the summertime, and the cooler water is produced from the well by the annular space. The closed casing transmits heat to the rocks near the well. The rocks store the heat, which is produced in wintertime, by

cold water being pumped into the annular space and producing warmer water from the tubing.

A simple heat energy model can be set up based on the following geological and technological inputs.

Geological inputs

- Surface average temperature is 12 ^{o}C
- Average geothermal gradient is ~ 5°C/100 m.
- Between 100 – 500 meters the temperature is 17 – 37 ^{o}C, on average 27 ^{o}C.
- The depth of the heat storing formation is 100 – 500 m. There are mainly sandstone and clay layers varying in the sediment. On top of the storing formation is a covering layer, with low heat transmission capacity. There is a closing bottom formation under the sediment.

Technical inputs

- Average specific heat power between well and rock is ~80 – 85 W/m
- Average effective well depth is 400 m
- Input temperature of the water in summer is 70 – 90 ^{o}C
- Well heat storing capacity is 33 kW_t

The capacity of 15 shallow wells is 0.5 MW_t, and that of 30 wells is 1 MW_t.

The distribution of wells is to be analysed by heat-flow modelling. In order to prepare a professional model, a complete database building is needed as follows:

- collection of all geological and hydrogeological data of the site,
- collection of the existing well data (stratigraphy, hydraulic heads, well test data) to estimate the regional groundwater flux,
- measurements in the site: geoelectrical sections, well logs, hydraulic (interference) well tests, optional: thermal (interference) well test.

This data building process is followed by thermal modelling to optimize the geometry of the grid of the wells (distance and shape of the grid) in order to maximize the heat storage power.

Figure 2 presents a modelling system.

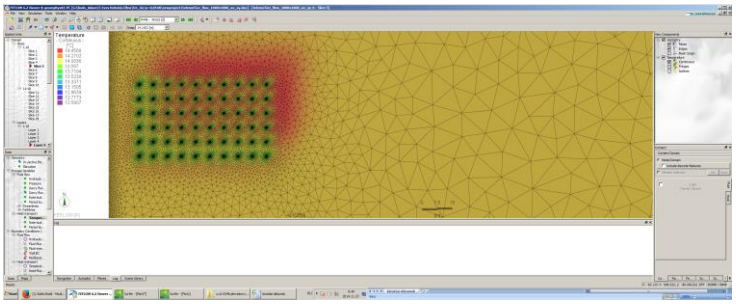

Figure 2: Temperature modelling of a borehole heat exchanger field (Source: Eötvös Lórand University, 2015)

3.2 Deep heat storage

In case of deeper (>300 – 500 m.) heat storage the initial temperature of the storage formation is higher (40 – 80 ^{o}C).

A simple heat energy model can be set up based on the following geological and technological inputs.

In case of geological inputs there are similar parameters to the shallow case, but

- Between 800 – 1200 meters the temperature is 52 – 72 ^{o}C, on average 62 ^{o}C.
- The depth of the heat storing formation is 800 – 1200 m. There are mainly sandstone and clay layers varying in the sediment. On top of the storing formation is a covering layer, with low heat transmission capacity. Under the sediment is a closing bottom formation.

Technical inputs which differ from the shallow case

- Input temperature of the water in summer is 90 – 110 ^{o}C
- Well diameters and water flow rates can be higher than in the shallow case.

As a deep storage project generates more difficult challenges, the selection of UTES site has a lot of criteria:

- Sustainable bioenergy power technology and fuel supply
- Both heat and power production and sale (CHP)
- Environmentally sound CHP system
- Remaining waste heat in summer time, further heat necessity in winter time
- Existing abandoned hydrocarbon, thermal or water well nearby can be advantageous

- Local earth science exploration data are advantageous
- High geothermal potential is not needed
- Existence of geological formations and layers for heat storage
- Positive approach from local municipalities

This list of criteria shows that site selection is a complex process.

4. CRITICAL RISKS AND THEIR MITIGATION

As a new technology, UTES has numerous risks. Their mitigation can arise from earlier hydrocarbon or geothermal experience.

The first projects must face a lot of complex technical, financial and environmental challenges that arise. The technical planning and permitting process is a challenge, not only for the planning experts, but also the related authorities as well. Therefore direct connection is needed to all related authorities, and they are to be invited to all discussions and related workshops in order to present and discuss the project scope.

The underground thermal heat conditions generally are well calculable, but underground water flows can strongly influence them. Exploratory well drilling and well testing in every site are to be implemented in order to determine an exact storage volume, in which the heat will not escape.

Special well tubing insulation is needed, which is not typical in the geothermal or hydrocarbon practice. Therefore exploratory wells installed tubing insulation and heat transfer measurement are needed in each site. Taking into consideration the experience of pilot sites, widespread experience will emerge, in view of this challenge.

A critical point of an UTES project is the exact determination of the storage formation. Professional underground exploration is needed to be implemented prior to locating the storage (Lenkei et al, 2015).

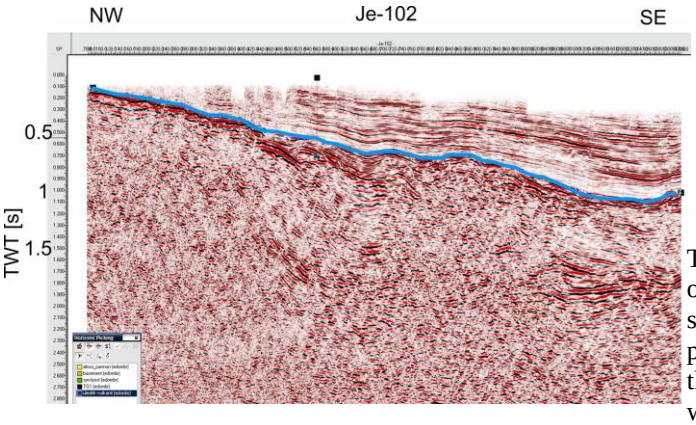

Figure 3: Locating the storage, basement of sediments (Source: Eötvös Lórand University, 2015)

Figure 3 is a processed two-dimensional seismic acquisition. The basement of the sediment rocks shows the lower border of the storage. The deepest closing thick clay layer of the sediment formation can be the bottom of the storage formation.

Figure 4 presents a map, which includes the top of volcanic rocks and helps to determine the storage structures in the sediments.

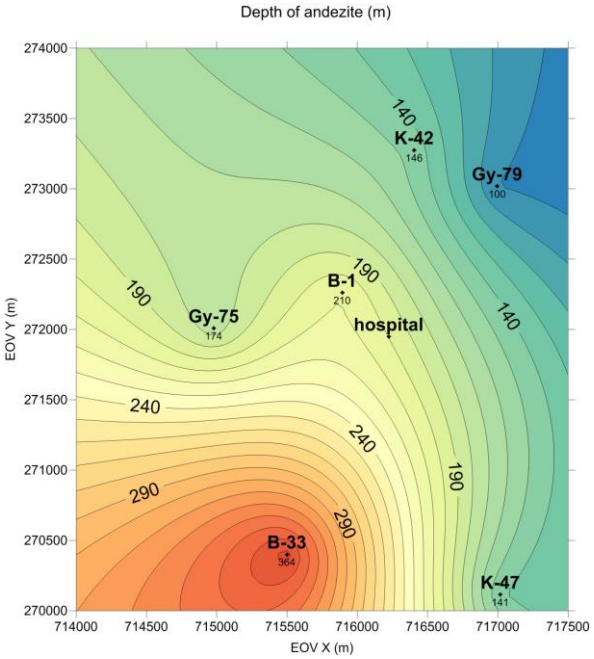

Figure 4: Locating the storage, map of basement (Source: Eötvös Lórand University, 2015)

5. MARKET OPPORTUNITIES

UTES projects wish to exploit synergies of energy and geothermal industry, as well as make renewable energy projects more competitive.

This type of hybrid solutions

- increase the renewable energy capacities efficiently,
- increase the competitiveness of renewable technologies, and
- improve the flexibility of the utilization of renewable energies.

The key idea is to store the produced heat from a bio-, or other type of energy plants in an underground heat storage unit during the summer; this creates the potential to provide power in a flexible way and to use the produced and stored heat during the winter cycle when it is needed.

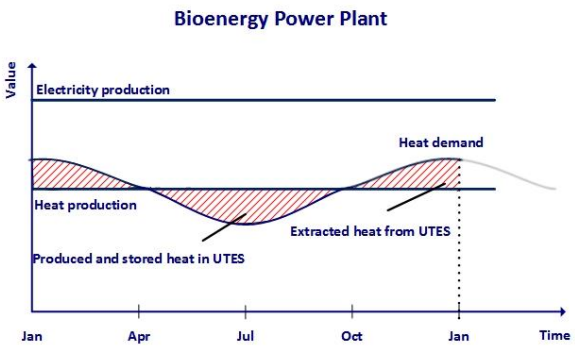

Figure 5: Interseasonal utilization of the underground thermal energy storage

Figure 5 presents the key elements of UTES technology: in summer time the produced, but unnecessary heat is stored in an underground geological structure through wells and hot water, and this heat energy can be extracted in winter time, when there is shortage of heat for the consumers.

The operation of biomass/biogas or other type of power plants depends on their fuel supply and on appropriate heat utilization during the whole year. During the heating period, from October to April, the heat of CHP-units can be sold to local consumers. However, during summer this heat most often is considered as "waste heat". This waste heavily decreases the overall cost-efficiency of bio-power plants. The innovative solution to this problem includes storing the summer`s waste heat by geothermal wells and utilizing this heat during wintertime. Moreover, bio-based CHP-plants gain flexibility regarding the power supply since they can supply power on demand and store the heat in an underground heat storage unit. Thus biomass-based CHP-units will become an even more powerful balancing option for distribution and transmission grids.

This hybrid-technology allows utilizing "waste heat" by using seasonal underground storage and simultaneously provides flexibility for electric distribution grids since excess heat from CHP-units is storable at any time. The combination of two existing technologies in a new innovative hybrid-technology approach serves as a solution for both for the electricity and the heat sector.

The most relevant market segment of UTES is the CHP sector. They all can use UTES to save the heat produced in summer. The next relevant market segment is the family housing. Just like underground heat pump technology is able to heat and cool the same house, shallow UTES also can manage the interseasonal heat management.

The most important market barriers are the financial resources for demonstration projects. A complex professional advisory system is needed to create technical and business models. There are only minor opportunities to receive financial resources to create a European level concept for UTES technologies.

Potential stakeholders are the owners of CHP plants. Important stakeholders are the municipalities as well, because their buildings, institutes and their relationship with the industrial, agricultural and service sectors can contribute to meeting new energy development challenges.

The following draft model presents the created values of an UTES:

Created values are developed both for heat/electricity producers and energy consumers.

<u>For heat producers</u>

- Summer heat production of a bioenergy plant, stored and sold in winter

1 MW_t capacity heat storage works ~ 3000 hours/year, ~ 3000MWh =10 800 GJ

1 GJ heat energy ~ 10 – 12 € therefore 1 MW_t heat storing capacity saves 100,000 – 130,000 €/year.

<u>For heat consumers</u>

- Competitive renewable energy heat instead of natural gas. The gap between natural gas and renewable energy can achieve 3 – 5 €/GJ heat energy.

The market is huge, from CHP plants to housing estates, as thousands of megawatt heat capacity is needed in the European energy industry.

<u>Draft operating model:</u>

- Storing time is 4000 hours per year in the summertime. Heat production time is 3000 hours in the winter heating time.

There are several concrete hybrid renewable project concepts including UTES.

<u>Draft concepts of shallow UTES utilization:</u>

- heating a greenhouse in a farm,
  1 MW_{th}/hectare. The source of the heat is the summer waste heat from the bioenergy plant.
- 0.5 – 1 MW_t heating support of a district heating system The heat source is the excess summer heat of the DH System
- 0.5 – 1 MW_t heating support of a communal heating system. The heat source is the excess summer heat from the new solar system.

Figure 6 shows a greenhouse, which is to be heated from underground heat storage.



Figure 6: Greenhouse to be heated by UTES

6. MAJOR ADVANTAGES OF UTES TECHNOLOGY

As UTES is a complex technology, widespread technological, financial, legal and management competences are needed to develop it. Overall complex planning is necessary, which includes all geological, technological, financial and legal aspects of the UTES solutions.

The main innovation modules of the presently planned UTES sites

- Flexibilisation of combined heat and power (biomass/biogas based) by the decoupling of the heat and electricity supply
- Interseasonal Energy Management
- ICT remote control applied to all of the technology
- Renewable energy hybrid technology; integration of bio- and geoenergy technologies
- Underground heat storage with efficient heat transfer
- Multifuel supply of heating systems with increasing renewable energy utilization
- Bioenergy operation system that assists the optimal electricity and heat production

UTES projects have the following impacts:

- Advance the modernity of heat storing technologies
- Provide enhanced understanding of integration between energy production and accumulation systems
- Develop suitable methods for comparing energy storing practices across Europe
- Create demand-based tools for improving efficiency of energy transformation processes involved in heat and electricity production from renewable resources
- Increase knowledge of how technology maturity, efficiency and accessibility affect the costs of renewable energy hybrid systems
- Lead people to better information and communication technology-based services for interseasonal energy management
- Enhance the cooperation between researchers of different scientific backgrounds in one research network

The key values of UTES projects are listed below:

- Less heat loss from Bioenergy Plants
- Increase CHP electricity production
- Produce heat from solar technology
- Winter market supply from summer heat
- Less fluctuation and more flexibility of electricity production.

The key impact of the Project on the European energy system is its applicability almost everywhere in Europe, where summer heat surplus and winter heat shortage occurs together.

The development of UTES technology will have the following impacts

- Advance the modernity of heat storing technologies
- Provide enhanced understanding of integration between energy production and accumulation systems
- Develop suitable methods for comparing energy storing practices across Europe
- Create demand-based tools for improving efficiency of energy transformation processes involved in heat and electricity production from renewable resources
- Increase knowledge of how technology maturity, efficiency and accessibility will

affect the costs of renewable energy hybrid systems

- Lead people to better information and communication technology-based services for interseasonal energy management
- Enhance the cooperation between researchers of different scientific backgrounds in one research network.

7. CONCLUSIONS

UTES is a prospective geothermal technology to be developed. There are a few shallow systems, but no deep site operation has been developed so far. Both systems need significant research work.

UTES offers a lot of advantages, therefore a large underground heat storage market will appear in the near future. This technology will ensure synergy in renewable energy hybrid technologies.

Both shallow and deep UTES can be used in the Pannonian Basin. There are appropriate geological structures for both technologies and the first geological and technological concepts have already been formulated. The professionals are prepared to implement the first Central Eastern European research and later commercial UTES projects.

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