"BLUE MINING" – THE FUTURE OF MINING
INITIAL CONSIDERATIONS FOR UNDERGROUND PUMPED STORAGE PLANTS

*M. Kellner, A. Agasty, E. Clausen, O. Langefeld and J.-G. Swanson
Clausthal University of Technology
Institute of Mining
Clausthal-Zellerfeld, Germany
*(*Corresponding author: moritz.kellner@tu-clausthal.de)*

ABSTRACT

Due to continuously growing resource demands and increasing requirements for sustainability, safety and environmental protection on the other hand, the mining industry is being subjected to these additional requirements. Over the past few decades progress has been made in all topics. In 1987, the United Nations published the following in the Brundtland Report: "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*."[5]

The term "Blue Mining" means to work sustainably, economically, ecologically, and efficiently while also improving ergonomics, for example by increasing automation.

An example of how mining can actively be involved in energy management will be shown. Initial evaluations of underground cavitites were done for purpose of energy storage. The planning and construction of underground pump storage plants both in active and inactive mining operations was also investigated.

INTRODUCTION

The mining for energy and mineral resources has been ongoing for over two millennia. The extraction of resources has increased the prosperity of Europeans but has also lead to conflicts and a negative impact on the mining regions. Environmental issues were completely ignored, resources were often needlessly wasted, and the people were exposed to hazardous and unhealthy work environments. The negative effects of mining can still be seen in the subsidence of swaths of land, waste heaps with poisonous residue or unknown underground openings that can lead to sudden surface depressions. In addition, the underground workplace is a workplace that does not comply with the work environment above ground.

It seems evident that through an intergenerational contract, in which the current generation is committed to a conservational and diligent handling of resources for future generations, fundamental changes with regards in the mindset and actions of mining companies are required.

BLUE MINING – A Definition

The mining of primary resources is a keystone of economic strength and the prosperity. At the same time today, more than ever, attention must be given to the fact that mineral deposits are limited and resources need to be mined in a gentle and effective manner by the mining industry.

As a result of the mining-related breaches against humanity and nature in Germany, it is necessary to learn from these mistakes. The statement "leave no trace behind" has been proposed decades and means to preserve the environment now and for the future. By adhering to this approach, the long-standing goal of sustainability can truly be realized.

Besides sustainable handling of resources, the issue of "energy" must be introduced. Considering the current political conditions in Germany, which plans on implementing an energy turnabout this coming decade, "energy" concerns can no longer be ignored. All aspects linked to energy, be it energy production, energy efficiency, or energy storage and distribution, should be regarded as essential components of sustainability. The third point, which leads to concept of "Blue Mining", includes the consideration of ergonomic workplaces in underground mining. To summarize, the term "Blue Mining" has the following core elements:

1) Sustainability

Limited deposits and resources should be mined out in their entirety, while limiting the effect on nature and human beings. The term describes the concept of the use of regenerative systems in a way that this system remains intact in its core characteristics and its supply can be regenerated through natural processes. Relating to mining, Germany has developed sustainability indicators in the recent past that account for the guidelines of a sustainable development concept [3]. For this, the core statement goes back to the conclusions of Brundtland Commission in 1987. The term for sustainable development was precisely defined for the first time as:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[4]

Transferred to the mining industry this statement stands for the careful extraction of resources so that the current demand is met while avoiding the squandering of resources to guarantee the current standard of living for future generations. This means that precisely those limited resources that have an integral role in our current prosperity cannot be wasted or neglectfully handled [3][4].

2) Energy

a) *Energy efficiency:*

The extraction of any resources should be conducted with the minimum possible energy consumption. This can be defined be the term "Low-Energy-Mine". It should be understood that for the entire life-cycle of a deposit the energy expenditure for the extraction of the resource should be kept as low as possible. Already starting with the development, the energy consumption in form of fuel or electrical energy should be kept to a minimum. Extraction, conveying and processing should also be done in an energy saving manner.

b) *Energy production*:

Mining can be viewed as an energy supplier. The first approaches can be seen in deep geothermal projects to make use of the available thermal energy in abandoned or active mining operations or in abandoned coal mines with the extraction of methane gas.

Consideration is being given to the use of geothermal energy in existing mining operations, such as the deep German potash deposits. Here, the relatively high geothermal gradient in central Europe of 3 K / 100 m can be viewed as an advantage. Considering the mining company information, K+S Kali GmbH, a deep drill hole from the deepest level, which is currently at a depth of 1500 m with a rock temperature of up to 70° C, is conceivable.

Another possibility for energy production is the use of existing and often developed bituminous coal deposits in western Germany. The use of underground coal seams as unconventional methane deposits is shifting more into focus as a result of the discontinuation of subsidized coal mining in Germany in 2018. For mines still in production, the danger of uncontrolled gas bursts can be contained. Extensive work on the fundamentals already examines the three possibilities for the utilization of methane. For this purpose the terms Abandoned Coal Mine Methane (AMM), Coal Mine Methane (CMM, gas production in an active mine) and Coal Bed Methane (CBM, gas production from undeveloped coal deposits) have been defined [6].

c) *Energy storage and distribution:*

Active or abandoned mines can be used for the distribution and storage of energy. As a result of the current political situation and the so-called energy turnabout in Germany, underground pump storage plants are gaining in relevance. These serve to temporarily store energy from energy sources irregular in time and amount, such as wind and solar power, and then distribute this energy to the consumer.

An increased focus is being put on this topic because of the current political goals of the federal government. The energy turnabout is understood as the realization of an energy supply, in the sectors electricity, heat and mobility, with renewable energy sources. Germany's interim goal for the year 2020 is to produce 40% of its electricity from alternative energy sources. The debate for an increase in renewable energy has special consideration as the expansion of the renewable energy supply is imperative as a result of Germany's decision to phase out nuclear energy production by 2022. The geographic situation for the production of renewable energy is partially explained by the fact that wind energy can primarily be produced at the North Sea, while many large consumers are located in southern Germany. Additionally, wind and solar energy cannot be controlled in production rates and are dependent upon the respective climate conditions. In order to absorb electricity spikes when consumers have a lower demand, the Institute of Mining sees underground pump storage plants as a viable option to counteract these problems.

3) Ergonomics

With increased automation and simultaneous improvement of environmental conditions underground, we may provide miners with more favorable working environment.

To begin with, increasing automation, with the long-term goal of a fully automated mine, provides more and more possibilities to shift the workforce away from non-ergonomic work places. As an example, the fully automated longwall is consequently being further developed in Germany in order to move workers away from relatively thin seams during regular production [8].

In other mining operations, such as salt and ore, on the other hand a major concern is the continuous improvement of the working environment through air-conditioned equipment in warm working areas or increased use of electrically powered equipment to minimize particulate and noxious gases (NOX, CO, SO_2, etc.).

"Blue Mining" will describe with a holistic term mines that operate both in an energy efficient and ergonomic manner on the way to full automation. Furthermore, this new concept encompasses the continued use above and beyond the actual extraction as a possible energy supplier. This concept must be viewed for the entire mine, especially energy consumption during mine construction or deposit life-cycle. The defined areas of "sustainability – energy – ergonomics" shift into focus once they are applicable for the respective deposit cycle. This means that from the beginning of exploration until mine closure of the specified areas "sustainability – energy – ergonomics" within the context of the deposit's life-cycle will respectively shift into focus.

In the combination of the three terms "sustainability – energy – ergonomics", multifaceted scopes for the designing of resource mining can be realized today and in the future.

The Planning and Construction of Underground Pumped Storage Plants (UPSP) in underground cavities is part of current research and development projects at Department of Underground Mining Methods and Machinery at Institute of Mining of Clausthal University of Technology, Germany.

Ambition of constructing Underground Pumped Storage Plants

Regarding the first developments in planning and construction of UPSP, one can clearly see, that this topic is strictly related to the task of "Blue Mining". First of all, the installation of UPSP offers the advantage of very low land use and hence minimalizes impact on the environment. Therefore, UPSP can be considered as a unique but sustainable ambition. Furthermore, the UPSP does clearly fit into the blue aspect of "Energy" as they are supposed to store energy from regenerative sources and deliver power to the customer as and when required.

The feed-in of power from intermittent and variable sources as wind or solar energy will constantly rise over the upcoming years. This is as a result of the political decisions made to move Germany into a country to be delivered by power just from green sources. Therefore, nuclear power is supposed to phase out in 2022 for example. A basic requirement for the upcoming success of the development strategy for usage of renewable energies is the technical and economic integration into the energy system. The energy system of the future needs to react flexibly to the variations of power produced and power required. Therefore, following technologies for energy storage need to be considered (besides others):

- to store the surplus of power produced and to deliver it to the customer his request
- provide flexible energy to stabilize the power network

Besides the storage of energy, impacts on the environment need to be kept as low as possible. Furthermore, the storage devices must be located in the northern part of Germany, as most of the wind energy will be produced in the North Sea and needs to be provided to the customers in southern Germany.

The most important advantage of the construction of UPSP is the very low land use. Another advantage will be, that existing cavities, i.e. underground mines, can be considered as location for UPSP.

The working principle of UPSP is shown on image 1.

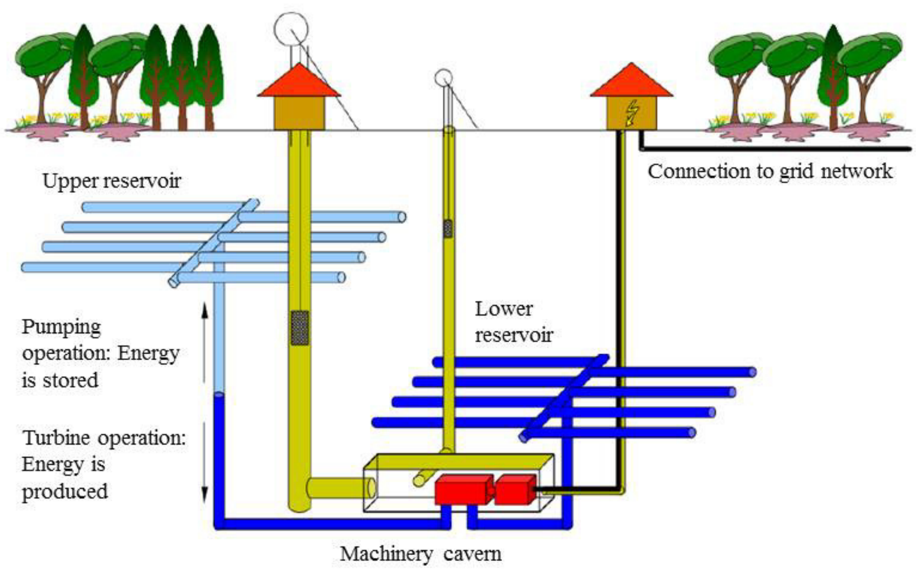

Figure 1: Principle working method of an Underground Pump Storage Plant

<u>Facilities of planning and construction of UPSP</u>

The basic question to alternate usage or re-usage of underground cavities is related to the location of the UPSP. Basically, following three options are provided:

- Planning and Construction of UPSP in virgin strata
- Planning and Construction of UPSP in an active mine
- Planning and Construction of UPSP in an abandoned mine

Following overview will give an introduction onto development and research results regarding the planning of UPSP.

a) Planning and Construction of UPSP in virgin strata

The idea of constructing UPSP into unworked rock leads to severe efforts and challenges as no cavities do exist so far in Germany. As economic and environmental investments are much higher compared to the other chances, this will not be part of the "Blue Mining" progress and is not part of current research and development at the Institute of Mining.

b) Planning and Construction of UPSP in an active mine[2][5][7]

The planning and construction of an UPSP in an active mine, leads to the point, that the mine will need to serve two functions in the future. On one side, the mineral excavation of the deposit will continue and on the other the excavated districts of the underground mine will be used as reservoirs for the UPSP. One very special challenge for the mining engineers is to provide solutions, that the mineral extraction and the UPSP would work independently without having any adverse impact on each other.

The mine where the realisation is planned at the moment is an active iron-ore and limestone mine located west of Hanover and east of Dortmund. The location is well regarding the task of a location within northern Germany, but with well grid supply to the south of the Republic. Ore and limestone are mined since 1883 from an ore seam of25 m thickness and is dipped northbound with an angle of 18°. Mining takes place in depths between 70 m and 400 m. The deposit strikes from the west to the east about 10 km. The opening to the surface is realized by a dipped adit with a length of 675. Annual production is about 500.000 t. The mining method is a dipped room-and-pillar operation with room dimensions of about 9 m width, 15-17 m heights and up to 600 m length. [5]

As excavation is currently active in the western field of the mine, a pilot project of an UPSP is supposed to be located in the center of the mine field as a first step. One special point about that will be, that the connecting pressure adit between the upper and the lower reservoir will cross the main haulage road that connects the western mine fields to the dipped adit to the surface. Lining will be managed by usage of steel pipes with a diameter of about 1m [2]. Figure 2 below gives an overview of the dimensions of the demonstration building, that is supposed to provide a installed rating of 10 MW of energy. It also gives an overview how the layout of the pilot project shall look like.

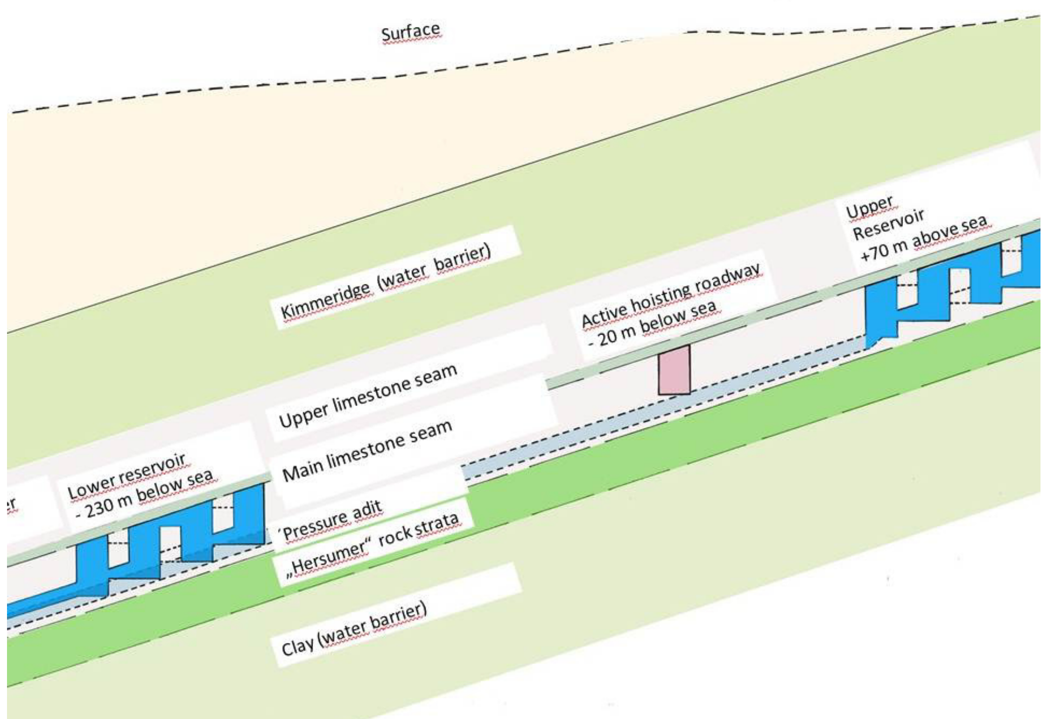

Figure 2: Location of the Pilot Project within the seam

If the pilot project, i.e. a pilot demonstration UPSP, will be successful, it is planned to start planning large scale UPSP in the same mine afterwards with each a capacity of larger than 100 MW. Following tasks need to be considered at the moment for planning the demonstration building:

- Location
- Rock Mechanics
- Environmental impacts
- Safety concepts
- Ventilation concepts
- Permissions
- Powerplant technology
- Economic appraisal
- Technical design and economic rating of the demonstration building

Regarding the pilot project, hardly any new cavities need to be excavated in the underground. Only special caverns like the machinery chamber will have to be extracted or the lining, i.e. pipes for the water flow will have to be put in.

The safety concepts within the feasibility-study consist basically in developing of emergency scenarios for the operation of the pilot project. Plannings consider the amount of water totals up in 100.000 m³ for the demonstration plant. The work regarding this issue will finish up with the exemplary creation of an operation plan that could be offered to the responsible authorities.

A basic requirement for the safe construction and operation of the underground pump storage plant is the ventilation that mining and operation of the underground pump storage plant will happen simultaneous. Classic tasks of ventilation always are:

- continuous supply of fresh air to all working places
- dilution of noxious gases resulting from operating combustion engines and blasting
- removal of heat from rock and machinery [7]

Regarding this special research project, one unique task needs to be considered regarding ventilation. As to the feed-in and dynamic dump of the water into or out of each reservoir, air is displaced or taken in. This may lead to a cyclic inversion of the air flow in certain mine areas. Furthermore, it is required to deal with three operational types with each special requirements on ventilation, which are construction of the underground pump storage plant, the operation and maintenance. Therefore, CAD-simulations will be used to give prognoses how the ventilation flow will behave during each feed in or dump of water in the reservoirs. Further on, CAD gives the opportunity to show up what will happen with noxious gases of fires in the machinery chamber.

Provided that construction and operation of the pilot project bring successful results, next step will be to start planning the large scale underground pump storage plant. Besides the points already figured out above, two more points will become important. On the one side, roadway drive-age and additional underground excavation will be required to provide enough space for reservoirs and machinery, on the other side new concepts are required how to deal with the additional amount of mineral, that will be mined out during the excavation process.

c) Planning and construction of underground pump storage plants in abandoned mines [1]

The usage of abandoned mines provides large potential especially in Germany. The most obvious advantage is that underground cavities already exist. Furthermore, the mine would not get into trouble regarding a parallel active mining process. Research results on two possible locations in abandoned German mines already exist in the Harz Mountains in Central Germany and in the Erzgebirge close to the border to the Czech Republic. At the Institute of Mining, research began on creating a digital overview of the underground cavities with the help of MAPTEK Vulcan software. One can see on the following figures, how the chambers and reservoirs had been created digital from historic mine maps.

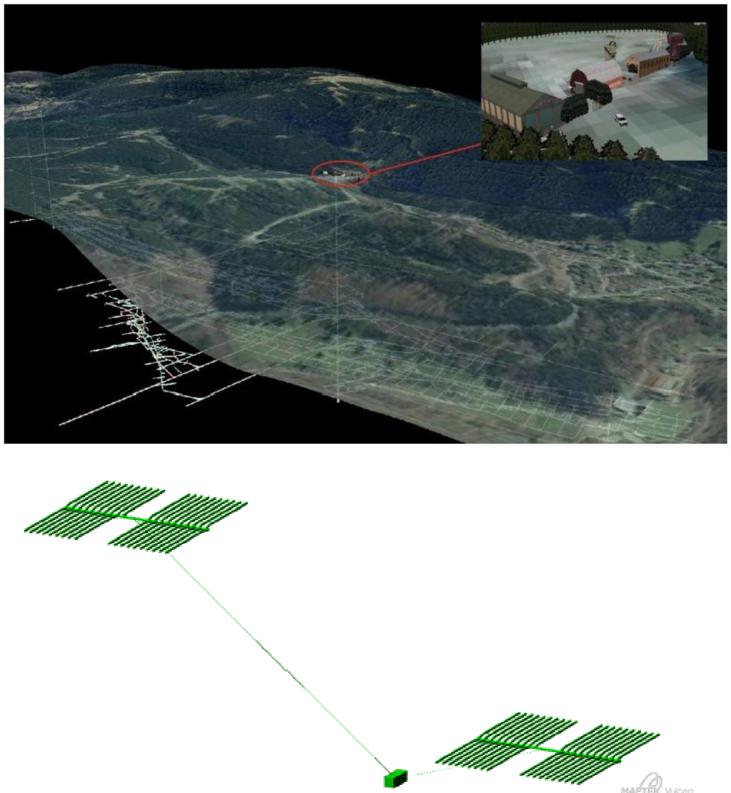

Figure 3: "Grund" ore mine above and upper and lower reservoir below

After visual works, the Institute of Mining started it’s studies regarding the drivage technology of the reservoirs. Conventional drivage on drilling and blasting was supposed to be the better method regarding rock mechanical issues and the length of each drive. For prediction of the ventilation flows, the analytic system NETZCAD was used to visualize the total overview of the ventilation model. Afterwards, CAD simulation was used to visualize the ventilation processes during dumping and fueling-up of the reservoirs. So it was possible to show up each velocity of air and water as well the volume flows, which is shown as an example in following figure 4.

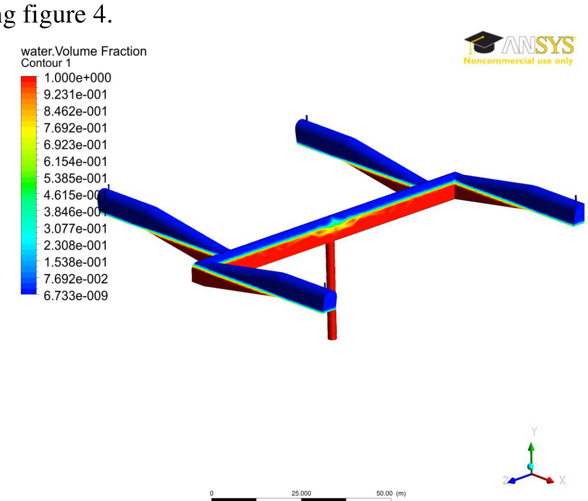

Figure 4: Demonstration of the two-phase-simulation during fuel-up of the reservoirs with water

CONCLUSIONS

Rising demand for commodities and constantly challenging surrounding conditions provides the chance to introduce the term of "Blue Mining". Therefore, the challenge is to combine the task of sustainability to the terms of energy and ergonomics. To each point, measures were defined which could give the opportunity to operate a mine in a sustainable way, efficient and as comfortable as possible for each men and machinery.

The overview of alterative use or subsequent use of active or abandoned mines as location for an underground energy reservoir demonstrated, that the usage of underground cavities as underground pump storage plants is possible. Especially regarding the current situation in Germany, mining can get the chance to become an important component in constructing and operating energy reservoirs area-wide to store the possibly anti-cyclical energy from wind and sun in an energy-neutral way.

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