Options of post-mine utilization of hard coal deposits

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A number of countries abandoned mining with the upcoming substitution by readily available and cheap oil and gas. However, in recent years there are chances seen in utilizing the remaining coal resources and even the old mine workings. Several options can also provide environmentally friendly sources of energy or mitigate greenhouse gas emissions. However, some still lack the ultimate proof of technical and/or economic feasibility. The most widely used or investigated technologies involve

- Abandoned Mine Methane,
- Coalbed Methane,
- CO_2-Sequestration with Enhanced Coalbed Methane,
- Natural Gas Storage,
- Underground Coal Gasification, and
- Thermal Use of Mine Water.

One commonly applied technology is the use of **methane** released in **abandoned mines** (AMM) for the production of thermal and electric energy or as a fuel in burners. Using AMM provides two major advantages: the conversion of a waste product into a clean fuel for energy production and the reduction of greenhouse gases. Most projects used degasification pipes already installed in shaft fillings for an easily accessible gas supply. Drilling production wells was required to access additional resources. Normally, AMM contains 40–80% methane. Improvement of technology allowed the utilization of gas with reduced methane contents down to 25%. Due to the *Methane to Markets* database only five countries (USA, United Kingdom, France, Czech Republic, and Germany) run commercial projects on abandoned mine methane. Several other countries (Australia, Italy, South Africa, and Ukraine) have pilot projects or are seriously considering implementation.

Coalbed methane (CBM) normally contains more than 90% methane and can substitute natural gas in most applications. Starting in 1981, the promotion of CBM as an independent source of energy by tax credits initiated the development of a CBM industry in the United States. Coalbed methane production increased rapidly within just a decade, with thousands of wells contributing considerably to the country's energy mix. Therefore, many hard coal deposits with higher methane contents became the target of exploration in various countries. The main problem remained the low permeability which made it difficult to reduce the pressure around the well to stimulate desorption. Generally, American deposits show favourable conditions for CBM production, including higher permeabilities, seam thickness, shallower depth, and less structural complexity. In the meantime, countries like Australia have established a CBM industry. Today, commercial CBM production is also reported from Canada and, at a smaller scale, China and Kazakhstan. Even in Europe, new technologies like directional drilling and advanced fraccing methods initiated new exploration.

One disputed methodology is the **storage** or – as it is often called – sequestration **of** the greenhouse gas **carbon dioxide** in deep unminable coal seams or in abandoned coal mines, which, in the system of carbon capture and storage (CCS), may represent interesting options for some regions without geological alternatives. It presents a number of advantages like adsorption to the inner surface of the coal considerably reducing the risk of leakages, high theoretical capacities, claystone sealing, and correspondence of industrial point sources and coal deposits as potential CO_2 sinks.

Several R&D projects were initiated to investigate the actual potential. In Europe, the only pilot project for CO_2 storage in coal is the RECOPOL project in Poland. The low injectivity of CO_2 due to the low permeability of the coal could substantially be increased by frac stimulation. Nevertheless, the total amount injected is considered to be too low at comparably high costs. Similar projects have also been implemented in Canada, China, and Japan. In fact, CO_2 storage in coal seams may be a viable option for countries with deposits with more permeable coals. From the San Juan Basin it is reported that CO_2 injection significantly improved methane recovery to 95% of the original coalbed methane in place (CO_2-ECBM). It was also concluded that injectivity was substantially reduced due to matrix swelling. It does not seem likely that CO_2 storage in deep coal seams will be a viable option in Europe in the near future.

The vast amount of coal remaining after the seizure of mining activities could provide a more easily accessible micro-porosity potential. However, due to the fracturing of roof rocks including potential claystone cap rocks, CO_2 may ultimately diffuse through the overburden into the atmosphere or towards drinking water aquifers. A current German conceptual study involves storage of CO_2 as well as the "geological filtering" of flue gas. Storage potential in coal mines seems to be limited compared to other options but may provide interesting potential in countries with growing coal production.

Storage of natural gas in abandoned coal mines could provide an alternative for conventional storage sites for the increasing storage volume required to meet peak demands. The oldest and still successfully working application is the Leyden mine near Denver, Colorado. The geological sealing is assured by the hydrostatic pressure in the aquifer underlying the coal and more than 20 m of impermeable claystone at the top. A technical challenge was the gastight sealing of four shafts. The facility can store more than the potential calculated from the cavity volume and gas compression showing the importance of adsorption. Two locations in Belgium in the Carboniferous coal deposits have considerably different geological settings but have also been operated successfully for several years. The partly flooded upper part of the Carboniferous strata and a major watertight thrust fault provided the sealing. The actual gas storage volume is the dry workings below the thrust fault. It is estimated that 8 times more CH_4 is adsorbed to coal than stored in the actual cavities. Analyses show that storing gas in abandoned mines can be a feasible alternative for conventional storage sites, particularly in conjunction with AMM or CBM production sites.

In the former Soviet Union, the technique of **Underground Coal Gasification** (UCG) was applied at an industrial scale with one project being still in operation in Uzbekistan after almost 50 years. Today, the state-of-the art technology uses two wells (vertical or directional) drilled into the coal. One well serves for the injection of oxidants and one for gas extraction. By injecting hot air or oxygen with the presence of water, a controlled partial combustion is stimulated. At high pressures and temperatures, the combustion produces town gas and other commercially valuable chemicals and water as by-products. A large number of tests have been performed at a pilot scale in the United States but also in countries like Belgium, France, Spain, and New Zealand, covering a wide range of depths and seam thicknesses. A current development is the connection of UCG with CO_2 storage into the newly generated cavities.

The projects making use of abandoned mines in the **thermal use of mine water** are mostly at a small local scale. Maybe the most spectacular due to its setting is the Design School Zollverein. The 27 °C warm mine water is used as an "active insulation" rather than for actual heating. Via a heat exchanger, the water is pumped through a system of meandering tubes encased in the concrete of the walls. Most of the projects, however, work with production and injection sites, which are either drillholes or shafts. A closed circuit can be maintained: warm water is produced, thermal energy is obtained via heat pumps, and cooler water is injected and heated up again along its flow path through the rocks and/or old mine workings. In a museum mine in Saxony, the heat pump is actually located within the partly flooded tin mine on the lowermost accessible level. Another project is located in the small town of Springhill in Nova Scotia, Canada. Due to the specific set-up of the coal mines, the natural convection delivered warm water almost to the surface. The Heerlen Minewater Project in the Netherlands is aimed at distributing heat from mine water to buildings in the local communities by means of a large heat pump to feed a district heat network. The set-up of the mine-water system for both areas involves drilling into the mine at different levels.

This overview shows the variety of options to use coal deposits and abandoned coal mines beyond actual coal production. Many problems have to be solved not only on a technical or economic basis but also with regard to legal regulations and acquiring public acceptance. In any case, timely consideration of the potential use during the ongoing mining activities can considerably improve technical and economic feasibility of the projects as well as the comprehensive use of available resources.