Moving Coal Up the Value Chain

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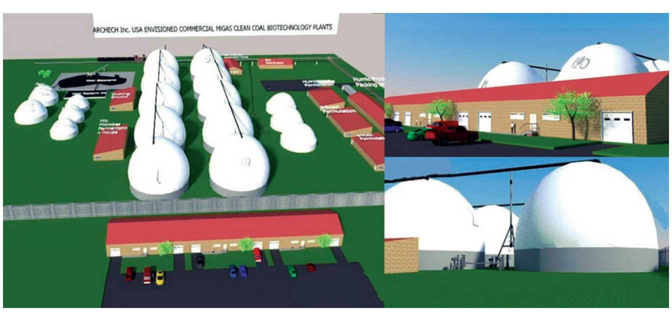
Energy projections have shown that coal will be needed to meet today's and tomorrow's energy demand.[1] However, overcoming the challenges facing the coal industry, whether legislative, technical, or from activist opposition, will require a shift in traditional thinking around coal conversion; options beyond combustion and liquefaction should become a larger component of the coal conversion industry. Specifically, we believe that employing biotechnology overcomes these challenges by creating clean energy while producing higher-value products that meet the needs of the large agriculture and environmental protection and remediation markets.

HUMAXX MICGAS™ BIOREFINERY

One example of such biotechnology is the HUMAXX MicGAS™ biorefinery, which uses termite-derived microbes to convert mined coal in anaerobic bioreactors to hydrogen-rich methane biogas, carbon-rich organic humic liquid for agriculture use, and a solid coproduct that can be used to adsorb (i.e., remove) toxic contaminants from wastes and waters. For unmineable coal seams, bioconversion can occur in the seam itself and the biogas can be recovered gradually.

This biotechnology utilizes every component that makes up coal. Even heavy metals, such as mercury (Hg) and arsenic, which must be captured in other coal conversion processes, become part of the solid coproduct; these metals remain permanently bound and are not released. One of the main products, methane, can be used to generate electricity or converted to other low-carbon liquid fuels or chemicals.



ARCTECH's envisioned biotechnology plants could convert coal into several useful products.

Another major product, organic humic acid, is sold to the agricultural industry for use as a soil amendment, a practice that is gaining recognition globally. For example, in the U.S., organic humic products have received approvals from the Environmental Protection Agency and the Department of Agriculture and are also supported by various trade organizations. In China, the Bureau of Agriculture recently set standards for the agricultural use of humic acid. Humic acid for this purpose is under the trademark Actosol® (a liquid organic humic fertilizer).

"This technology allows the coal industry to follow the successful business model employed by petroleum companies for decades…"

In addition to being a soil additive, humic acid can also be converted into products that adsorb toxins, such as heavy metals, as well as products that facilitate waste recycling. Such products are currently in use under the trademarks HUMASORB® (a multipurpose contaminant adsorber) and Actodemil® (for waste recycling). These products are being proven in real-world applications (visit www.arctech.com for additional details). For example, it has recently been demonstrated that HUMASORB® can remove CO_2, SO_x, NO_x, Hg, and other trace metals from coal combustion and gas streams; spent HUMASORB® can also be converted into a water filter.

Through conversion to the various products, the patented MicGAS™ biotechnology can lead to zero-waste coal conversion. An integrated flow schematic for both mined coals and unmineable coals is shown in Figure 1. There are several options for carrying out this biotechnology, including using only mined coal, using only unmineable coal in the seam, or a combination of both in an integrated process. For mined coal, Steps 1–3 are carried out in bioreactors. For unmineable coal seams, coal is converted in situ into methane-rich gas, which is then extracted from the seam. In an integrated version of the process, the methane-rich gas from the unmineable coal seam is sent to above-ground bioreactors containing mined coal and then all the gas can proceed through Steps 1–3.

During Step 1, microbes convert solid coal into soluble organic liquids, such as acetate. In Step 2 the liquid, along with gases that are produced, are contacted with methane-producing

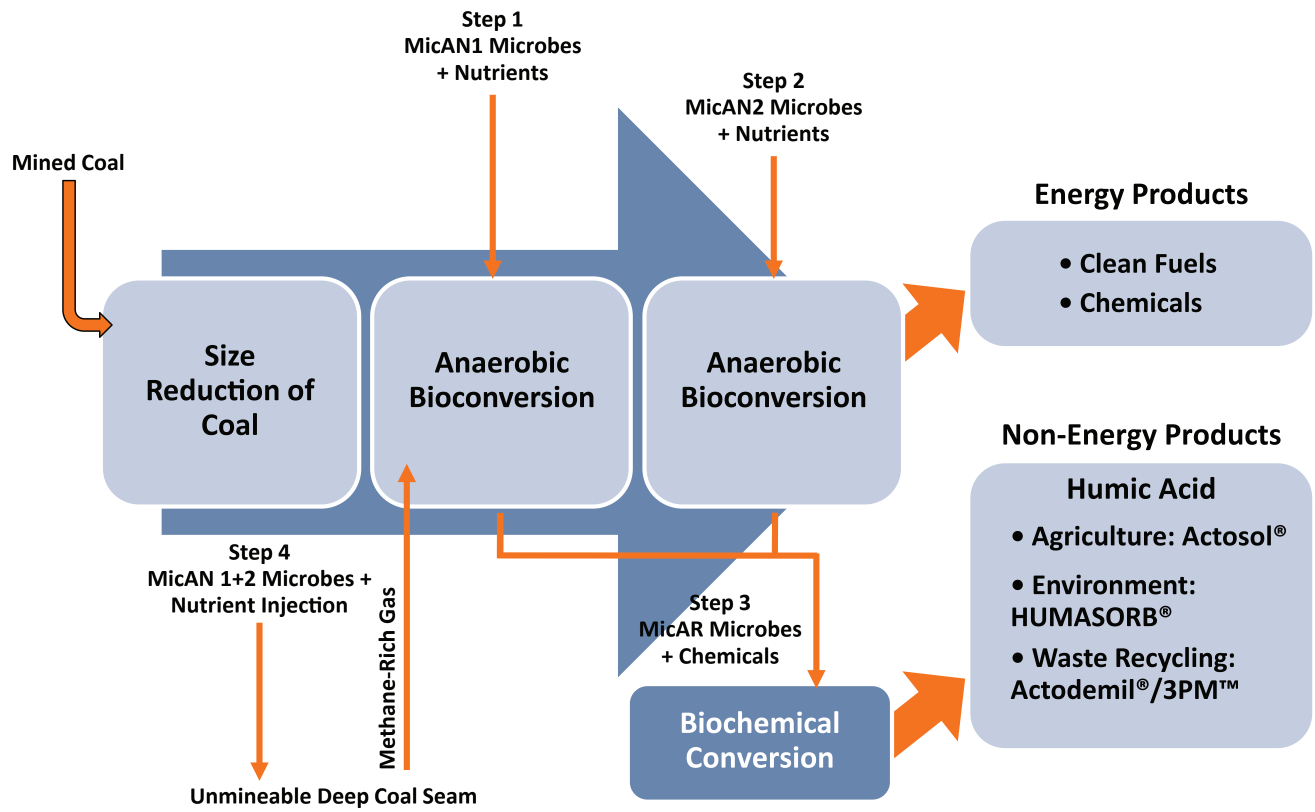


FIGURE 1. Integrated MicGAS™ biotechnology process flow scheme

microbes that hydrogenate the acetate and CO_2 into methane-rich gas. In Step 3 the methane-rich gas is then separated from the humic-rich coal residue; this coal residue is then subjected to digestion by aerobic microbes followed by chemical extraction and separation into liquid and solid humic acid. The liquid and the solid humic acid are then formulated into agricultural and environmentally useful products. Step 4, which is only applied to unmineable coal seams, includes injection of Mic microbial inoculants and nutrients directly into the coal seam. Step 4 has been termed MicGAS™ in situ.

Depending on the characteristics of the unmineable coal seam, injection and multiwall recovery wells or directional wells can be utilized to increase proliferation of the microbes and nutrients, taking advantage of new drilling techniques developed and currently employed for coal bed methane and shale gas extraction. Once sufficient microbes are established in the target coal seam, only nutrients must be added to maintain long-term methane-rich gas production. As is shown in Figure 1, no humic acid products are produced in Step 4, but in the integrated process the methane-rich biogas containing CO_2 can be sent through the above-ground bioreactors to further convert CO_2 to methane and increase the amount of gas, if desired. Current estimates indicate that about 10–25% of the carbon in mined coal can be converted to methane-rich gas while the remaining carbon is converted into organic humic acid products.

When the in situ biotechnology is applied to unmineable coal seams, the production of the methane-rich gas occurs over time. However, this approach takes advantage of the coal seam as a large, natural anaerobic geobioreactor. Large volumes of coal can be treated without incurring the capital costs of the bioreactors; there is a much lower cost associated with drilling.

As noted, the in situ approach can be deployed as a standalone process for producing only methane-rich gas. However, the integrated approach, wherein methane-rich gas from the unmineable coal seam is sent to above-ground bioreactors, provides increased production of economical methane-rich gas, while also producing higher value humic acid products. It also provides the flexibility to use both mined and unmineable coal, ensuring a reliable fuel source. Water usage in above ground reactors is about one cubic meter for every ton of coal, and it is completely utilized in the process without producing any wastewater. All the process water and the water contained in the coal become part of the organic humic products, which provides moisture when the humic products are added to soil.

PRODUCT VALUE

As is shown in Figure 1, the two primary yields from the HUMAXX™ biorefinery are methane and humic acid products. This technology allows the coal industry to follow the successful business model employed by petroleum companies for decades: Produce large volumes of low-value energy products and lesser volumes of (comparatively) high-value non-energy products. The overall economics are based on the sum total of the value generated from both products: low-carbon fuel and humic-acid derivative products.

The value of the products is of even greater interest when considering that the raw material could be coal that is otherwise unmineable, and therefore of little value. This represents a major opportunity in some areas. For example, the U.S. Geological Survey estimates that there are about 9.5 trillion tons of coal resources in the U.S. (including Alaska), but the vast majority of these resources are not economically and/or technically recoverable.[2,3]

Low-Carbon Fuel

The methane from the process can be used directly for clean energy production or can be converted to other clean fuels using techniques practiced commercially today. The energy security value and economic benefits of producing clean, low-carbon fuels from coal are already well known, so they are not explored further in this article. It is worth noting, however, that there are many regions where coal is abundant and natural gas prices are high; in such cases there may be a particularly strong incentive to employ biotechnology-based coal conversion.

Humic Acid Product: Agricultural Use

The usefulness of humic acid for increasing soil fertility has been recognized for centuries. In recent years there has been an upsurge in scientific research on humic acid as well as a general increase in interest in improving soil for agricultural uses and environmental protection. Because coal originates from plant matter, it is a rich source of humic acid and the MicGAS™ biotechnology offers a means to take advantage of it through the production of Actosol®, which is currently being used at farms in the U.S., Egypt, and China.

Humic Acid Product: Environmental Remediation

The helix-like structure in humic acid gives it versatile characteristics, including the ability to adsorb toxic compounds during environmental remediation applications. Examples of applications include cost-effective removal of metal and organic toxins from contaminated waters, recycling of industrial wastes, and even the safe disposition of dangerous chemical agents and explosives.

HUMASORB®, a multipurpose adsorber made from lignite-derived humic acid, is currently being demonstrated for removing contaminants from acidic mine drainage, industrial wastewater discharges, and municipal sewage wastewaters as well as radioactive contaminants from nuclear power plants. Based on market analysis of these two sectors in the U.S., it is estimated that almost 500 million tons of coal per year would be required to produce enough HUMASORB® to be used for this amount of environmental remediation.

Humic Acid Product: Carbon Storage

Experts have determined that the soil organic matter is the fourth-largest storehouse of carbon after sedimentary rocks, fossil fuels, and oceans.[4] In the MicGAS™ process, most of the carbon is converted into humic products, meaning that it does not enter the atmosphere. (In addition, it should be noted that the clean fuels produced offer a low-carbon intensity energy source.) However, there is an added benefit: When added to soil, carbon-rich humic acid increases growth in plant matter, which effectively removes carbon from the atmosphere.[4] In this way, when applied to mined coal the process can actually be considered carbon negative, which will enable it to be readily applied in a carbon-constrained world.

CASE STUDY: APPLICATION ON TURKISH LIGNITE

Turkish lignite is generally high in ash and moisture content and thus is very low in calorific value. Ash content ranges from 20–50+% and moisture can be as high as 50%. Lignite accounts for almost 90% of Turkey's coal resources and is primarily used for power generation. Turkey imports almost 90% of its natural gas and oil, incurring high costs and reducing energy security. For this reason Turkey has a national interest in supporting technology development and deployment that will allow the country to utilize its vast lignite resources to improve energy security and reduce overall energy costs.

The application of a HUMAXX MicGAS™ coal biorefinery is a natural fit. In collaboration with Turkish Coal Enterprises, the largest coal mining company in Turkey, the technology was demonstrated on mined lignite from the Bursa and Mugla-Husamlar mines and also lignite from a deep unmineable lignite coal seam in Mugla-Husamlar.

For the demonstration test the coal samples were ground until they were a typical size for pulverized coal. The samples were

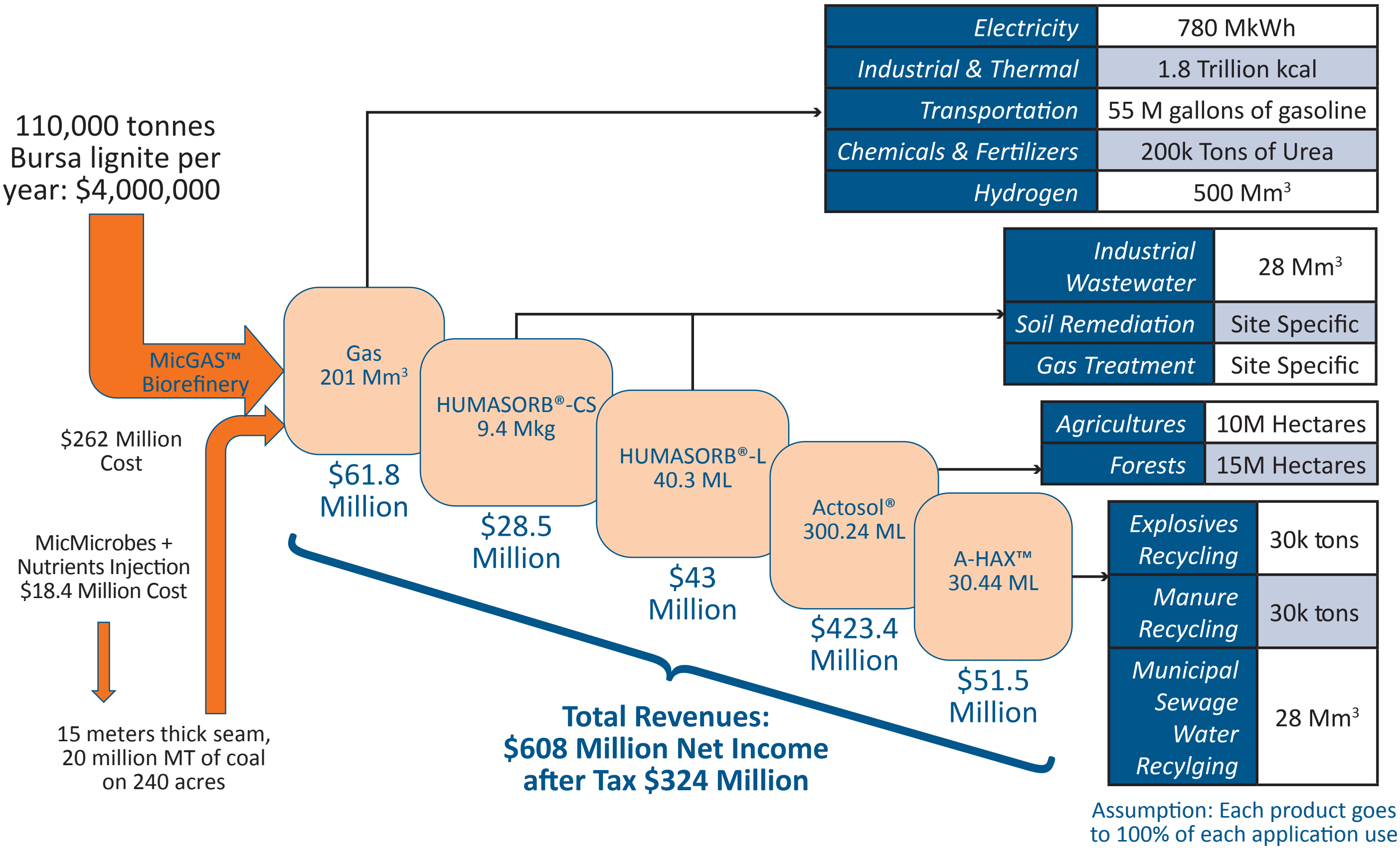


FIGURE 2. Total value chain of HUMAXX MicGAS™ coal biorefinery for Turkish lignite

Notes: 1 m³ of gas = 4.44 kWh (www.eia.gov), 1 m³ gas = 0.28 gal gasoline (www.nist.gov), 1000 m³ gas = 1.1 ton urea (wiki.answers.com), 1 m³ gas = 1.5 m³ H_2 (www.nrel.gov), Wastewater: 1.67 m³/kg HUMASORB®-CS, 0.2 m³/L HUMASORB®-L, Agriculture: 30 L Actosol®/hectacre, Forests: 20 L Actosol®/hectacre, Wastes: 1000 L A-HAX™/1.1 ton wastes

then subjected to digesting with anaerobic microbes and proprietary nutrients in anaerobic bioreactors for approximately 35 days. About 250 gallons (i.e., 0.95 m³) of water per ton of coal was utilized. This water requirement is similar to some estimates for coal-based thermal generation,[5] but much lower than traditional coal-to-liquids conversion.[6] However, this water is not actually consumed in the HUMAXX™ process; water in the coal as well as the process water is retained in the organic humic products. When the humic products are eventually added to soil, the retained water replaces some of the water that would otherwise be provided during agricultural production.

Almost 60 m³ of methane-rich biogas was produced per ton of lignite during the demonstration. The undigested residue coal, now enriched in humic acid, was subjected to digestion by aerobic microbes, followed by chemical extraction to obtain organic humic acid. Water-soluble liquid humic acid was formulated into three products: Actosol®, an organic humic fertilizer; HUMASORB®-L, a liquid adsorbent; and A-HAX, a reagent for the Actodemil® process of waste recycling. The solid residue was chemically cross-linked into a water-insoluble HUMASORB®, a multipurpose water filter. All of the coal was used in the various products, resulting in zero waste.

In addition to the mined samples, the HUMAXX MicGAS™ coal biorefinery technology was also tested on unmineable Turkish lignite. Feasibility tests were conducted with Mugla-Husamlar lignite in a simulated deep seam geobioreactor. The demonstration resulted in the production of about 10 m³ of methane-rich gas per ton of coal on a yearly basis. This in situ approach of bioconverting coals into gas results in a slower conversion rate, and thus lower volumes of methane-rich gas in the short term, but it can continue over several years.

All the organic humic products produced during the demonstration tests were then evaluated for their applicability for agriculture, water treatment, and wastes recycling needs in Turkey.

Feasibility tests were conducted in which HUMASORB®-CS made from the Turkish lignite was compared with the HUMASORB®-CS made from U.S. lignite for its stability under highly acidic and alkaline pH conditions, as well as for removal of metals from spiked waste waters (important characteristics for use of this product as a water filter). Table 1 presents select test results in which the HUMASORB products were able to remove metals from wastewater. An important implication of the demonstration results is that the biotechnology process can be applied to coal from very different geographies and a similar product can be yielded.

A-HAX™, a product of the Actodemil® technology, was demonstrated to officials of MKEM, the Turkish Armed Forces explosive manufacturing enterprise, as a reagent for safe destruction and recycling of manufacturing wastes of a propellant as well as highly explosive TNT. These tests resulted in complete chemical destruction of both compounds, and in the production of nitrogen-rich organic humic fertilizer. The resulting fertilizer was proven to be free any residue of explosives or toxins and was used for seed germination and plant growth.

Based on the demonstration results, a detailed design for a HUMAXX MicGAS™ coal biorefinery processing 110,000 tons of coal per year was developed, including the capital and O&M costs. The estimates were made for Turkey-based operations. Recognizing the retention time requirement of 35 days for the anaerobic bioconversions in Step 1 and 2, low-cost bioreactors were designed based on dome tanks often used in other industries to store large volumes of liquids. For the full design, these reactors had a footprint of about 25–40 acres, depending up on the existing coal handling infrastructure. Although the footprint of biotechnology-based gasification is large compared to thermal gasification, the overall footprint of the biorefinery is smaller because it does not require front-end air separation, back-end gas cleanup, conversion to syngas, and large wastewater treatment equipment—all of which are required for thermal coal conversion.

TABLE 1. Metal removal effectiveness for HUMASORB® produced from Turkish or U.S. lignite

Metal	Metal Removal (%)	
	Turkish HUMASORB®	U.S. HUMASORB®
B	97.14	96.09
Cd	100.00	100.00
Cr	100.00	100.00
Cu	99.87	100.00
Fe	98.43	98.89
Se	93.65	95.00
Zn	100.00	100.00

A total value chain analysis for conversion of Turkish lignite was completed (see Figure 2), which included the mass balance from coal to products and costs and values derived from experience in selling these products from ARCTECH's prototype production plant in Virginia, U.S. Market analysis of use of the MicGAS™ coal biorefinery products for the energy, agriculture, and environmental market sectors of Turkey revealed that the large, growing needs for the various end products means that a biorefinery processing 110,000 tons of coal per year would meet less than 20% of Turkey's market demand.

THE FUTURE OF CLEAN COAL CONVERSION

The HUMAXX MicGAS™ coal biorefinery approach offers an approach of moving the coals up the value chain, meeting the growing needs for clean energy, food, and water, while eliminating pollution and climate impact concerns from coal use. We believe it is the future of clean coal conversion and provides a comprehensive solution for meeting the basic requirements of rapidly increasing population and the burgeoning economies. In our opinion, it offers an approach for propelling the second industrial revolution with coal use, just as steam production from coal combustion helped to propel the first industrial revolution two centuries ago.

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