

Assessing coal conversion processes

Monitoring and control technologies need to be developed to assure that environmental and occupational health problems associated with the commercialization of this technology are prevented

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The increasing energy demands in the U.S. have forced energy planners to take a fresh look at the nation's energy sources and uses. A useful estimate of U.S. energy resources and an indication of where priorities should be placed to supply the demand now and in the future are shown. The term "recoverable" refers to the expectation that recovery can be accomplished by current techniques, under present economic conditions. Coal represents a large percentage of our energy re-

sources and should be heavily depended on to meet near-term energy needs.

The transportation sector of the U.S. economy depends heavily on liquid fuels. The domestic and commercial sectors depend almost entirely on liquid and gaseous fuels. And the industrial sector depends on liquid and gaseous fuels for 75% of its energy needs. As access to petroleum resources becomes less certain, conversion of coal to gaseous and liquid fuels will become necessary in the near-term to ensure the availability of fuel in conventional form for the above major uses.

Considerable work has already gone into the development of the technology

necessary to convert coal to synthetic gaseous and liquid fuels. However, it is important, from an engineering viewpoint, to determine in advance of commercialization of such technology, the potential environmental and occupational health problems associated with the technology. This technical information, in turn, needs to be factored into the design of commercial-scale coal-conversion processes (CCP) and facilities.

Coal-conversion processes

Coal-conversion technology dates back to 1670 when Rev. John Clayton of Yorkshire, England, reported generation of a luminous gas when coal was burned in a chemical retort.

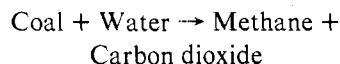
Large-scale production of synthetic fuels began around 1930. The Fischer-Tropsch process was developed in Germany, and is still used in South Africa to produce fuel. The Lurgi process was also developed in Germany in the 1930's to gasify non-coking coal with oxygen and steam to produce a gas with a heating value (HV) of around 400 Btu/scf (standard cubic foot, 14 800 kJ/m³).

The current level of technology development for CCP in the U.S. is at the process development unit to pilot-plant level. U.S. industry, however, is currently using low-Btu gasification to a limited extent. The time span to commercial-scale operating plants, which must also provide for a demonstration plant phase, is lengthy—ranging from 10-15 y.

Low-Btu and high-Btu gas are the products of prime interest in coal gasification. Low-Btu gas (HV = 100-500 Btu/scf or 3700-18 500 kJ/m³) is usable as fuel feedstock or for power generation in combined gas-steam turbine power cycles. High-Btu gas (HV = 900-1000 Btu/scf or 33 300-37 000 kJ/m³) can be a substitute for natural gas and would find wide use for heating fuel and industrial feedstock.

The conversion of coal to high-Btu gas requires major chemical and physical changes in solid coal to produce a pipeline-quality substitute for natural gas. Both gaseous and liquid fuels are produced as a result of decreasing the carbon to hydrogen ratios (C/H) of solid coal. Coal has a C/H weight ratio, ranging from 12 for lignite to 20 for bituminous grade coal. By the addition of hydrogen or the rejection of carbon, the C/H weight ratio can be lowered to 10 to produce synthetic crude liquids. This is the general objective of coal liquefaction. By increasing the hydrogen content further, methane gas can be formed as the C/H weight ratio approaches 3. This is the general objective of coal gasification.

The general chemical reaction for coal gasification is very simple:



However, in practice it is not feasible to convert coal directly to methane by reaction with water. Instead, the conversion is done in steps.

The basic difference between low-Btu and high-Btu processes is that air is used instead of oxygen in the gasifier to produce low-Btu gas. Also, the shift conversion and methanation operations are not used in low-Btu gas production. Most gasification technologies

under development today incorporate the concept of hydrogasification in which the incoming coal is initially reacted with a hydrogen-rich gas to form directly substantial amounts of methane.

The rates and degrees of conversion of the various reactions that take place in gasification are functions of temperature, pressure, gas composition, and the nature of the coal being gasified. Aside from the various operating configurations used, most gasification systems can be categorized according

Coal conversion processes at a glance

- There will be an increasing demand for liquid and gaseous fuels produced from coal conversion.
- The current level of development of CCP in the U.S. is at the process development unit/pilot-plant stage.
- Very limited information is available on the health effects of CCP effluents. Such data must be obtained without delay.
- Definitive CCP effluent characterization data are required that are traceable to specific process technology and can be related to health-effects studies.
- Monitoring and control technology has not advanced commensurate with process technology.
- Monitoring data are a foundation for technical judgments regarding the engineering control of effluents.
- Coal-conversion plants will require a monitoring system engineered for each facility.
- Air emission clean-up technology has not been adequately developed.
- Wastewater-treatment processes are available, but their effectiveness has not been determined.
- Land disposal of solid waste is the likely disposal approach, but leaching problems need attention.
- Trace elements have not been adequately evaluated from a control standpoint.
- Major R&D on CCP effluents is needed and must be undertaken in parallel with process technology development work. Such work must be given high priority in order to prevent serious health problems that can originate from such major facilities in the future.

to the following methods of contacting gas and liquid streams: suspension—or entrained-bed reactor; fixed—or moving-bed reactor; fluidized-bed reactor; and molten-bath reactor.

Although it is difficult to predict the degree of commercial-scale development of coal gasification processes in the U.S., the U.S. government is proceeding with plans to demonstrate full-scale, new or improved technology to provide incentives to industry to advance the state-of-the-art.

Synthetic liquid fuels have a prime potential use in the firing of industrial and electric boilers and gas turbines. Advantages of coal liquefaction are that the entire range of possible products—including fuel oil, gasoline, jet fuel, and diesel oil—can be produced from coal by varying the type of catalysts and other operating conditions. This flexibility is very desirable from a process standpoint. In contrast to gasification, liquefaction appears to have very good potential in that fewer chemical changes are involved and the energy conversion efficiency is somewhat higher.

As noted earlier, the objective in liquefaction is to process coal to lower the C/H weight ratio to 10 to produce synthetic liquid fuel. Four principal processes have been developed to the pilot-plant level in the U.S. Most of the work under way is directed to improving technology originally developed in Germany.

Although considerable process development and pilot-plant work has been undertaken, full-scale plants have not been built in the U.S. The processes developed to date appear to offer considerable potential.

Health effects

Unfortunately, the environmental and occupational health effects of human exposure to the primary effluent streams of air, water and solid waste from CCP have not been well defined. Pertinent literature is not generally available. For example, a literature search for this paper, using the CHEMCON literature search system of the American Chemical Society, which used the key words "Health Aspects of Coal Gasification," resulted in one citation.

A national conference was recently held that addressed the health effects of energy use. Although a chapter of the proceedings dealt with health effects, no technical data were presented. However, it is encouraging to note that substantial effort is being undertaken to obtain such data. The report issued by Battelle in 1975 provides a useful overview of the potential carcinogenic

U.S. recoverable energy resources, 1975

Resource	Minimum resources (Quadrillion Btu)	Maximum resources (Quadrillion Btu)
Coal	5200	10 400
Uranium	3360	not available
Geothermal	70	130
Natural gas	1441	2597
Petroleum	1584	2860
Shale oil	460	1160

Note: 1 Btu = 1.05 kilojoules

Source: ERDA (now DOE)

Coal gasification unit operations

Unit operation	Primary purpose
Gasification	To convert coal to gases, liquids and tars by use of air or oxygen and steam.
Gas cooling and cleaning	To separate particulates, tar, oil and water from gasifier off-gases.
Shift conversion	To provide proper CO/H ₂ ratio to form methane.
Gas purification	To separate undesirable constituents to form synthesis gas stream.
Methanation	To convert CO and H ₂ to methane.

Coal liquefaction processes

Process	Description
A. Direct catalytic hydrogenation	Hydrogenation of slurry of heavy oil and coal with a catalyst. Main product is liquid oils.
B. Solvent extraction	Coal partially dissolved in hydrogen-rich solvent. Solvent is recycled and hydrogenated separately or in-situ.
C. Pyrolysis and carbonization	Heat applied without addition of hydrogen. Most of carbon is rejected as solid, with significant quantities of by-product gas and char produced.
D. Liquid hydrocarbon catalytic synthesis	Coal is gasified with oxygen and steam producing medium-Btu gas. Carbon monoxide and hydrogen are converted to liquid hydrocarbons through a catalyst.

Gas liquor treatment techniques

Contaminants of concern	Treatment process
Phenolic compounds	Extraction by organic solvent or oil
Hydrogen sulfide, ammonia, light hydrocarbons	Sour water stripper
Suspended solids	Filtration
Fluoride ions	Lime
Organics, nitrogen, phosphorus and sulfur compounds	Biological oxidation
Refractory compounds—alkylated benzene and naphthalene	Activated carbon

exposure associated with coal conversion. It is evident that the health effects of CCP effluents must be determined and evaluated in advance of commercial-scale development of the various technologies in order to prevent major acute or chronic health hazards that may be associated with such operations.

The chemical nature of coal—which is very complex—and the reaction conditions under which conversion of coal to gas and liquid hydrocarbons occurs, results in the production of a wide range of products that are potentially hazardous to health. What is needed is definitive effluent characterization data that are traceable to specific technologies for coal conversion. In turn these data must be related to both short-term and long-term health-effects studies to establish the presence or absence of health hazards. This work is no small undertaking, but it needs to be performed without delay if coal conversion is to proceed to commercial scale in a manner that will not result in major health hazards.

In summary, the potential health effects of CCP effluents are numerous. However, factual data to document the scope of the problem are very hard to find. This information gap needs to be filled.

The EPA has undertaken a program to assess the health effects of conversion processes. Technical reports have been prepared by Exxon covering five gasification and two liquefaction processes. EPA also plans to propose national emission standards for the control of gaseous sulfur and hydrocarbon emissions from coal gasification plants. NIOSH has also recently initiated a number of research projects to specifically address the occupational health aspects of coal-conversion processes.

Monitoring, control technology

The state-of-the-art of environmental monitoring and engineering control technology that is directly applicable to CCP effluents is not well documented. This is, in part, the result of the relatively recent impetus to advance coal-conversion technology and the lag, that must be reduced, in developing, validating and applying monitoring and control technology.

There are varying opinions as to when is the optimum time to perform environmental and occupational health monitoring and develop engineering controls. Some argue that the only time this can be done with confidence is when full-scale plants are constructed and operated on a continuous basis. Although this is true to a certain extent, it does not obviate the value of

monitoring and control efforts at the pilot-plant stage. In the opinion of the author, the earlier such potential problems are addressed during technology development, the more likely the problems will be solved efficiently in the final plant operation.

Engineering controls are and should not be limited to "black boxes attached to the end of pipelines." A very logical approach to engineering controls for CCP may well be process modifications at the pilot-plant stage that could be instrumental in eliminating the generation of pollutants at the source. Source control of such pollutants is the best approach if it is technically feasible to do so.

Environmental and occupational health monitoring is defined as the collection and analysis (physical, chemical and biological) of samples of the following nature: environmental samples (air, water, solid waste); workplace area samples (air); and worker breathing-zone samples (air).

The collection and analysis of such samples is a complex topic in itself. Air, water, solid waste and industrial hygiene chemistry have become distinct fields of expertise, and this paper is not intended to deal with these topics in depth. However, it must be emphasized that such monitoring technology is an integral component of any project designed to evaluate or develop engineering control technology. The measurements made, whether by sophisticated instrumentation or the more conventional field sampling and laboratory analysis, are the foundation for technical judgments that must be made to determine the effectiveness of controls.

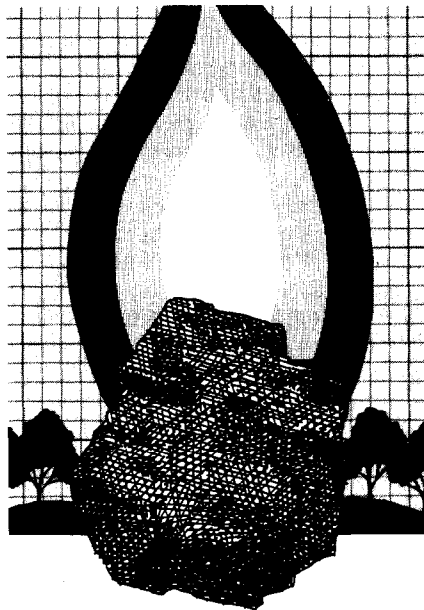
The following approach to monitoring is recommended to efficiently accomplish measurement objectives at coal-conversion plants. Gross identification of pollution potential should be based on short-term sampling. Accurate identification of pollutants should be based on long-term integrated sampling.

Workplace air monitoring is a special concern that requires attention. Both direct-reading instruments and conventional sampling and analytical methods are presently used to monitor for chemical substances of traditional concern. Research work is under way to develop improved techniques for measuring contaminants in the workplace that will, hopefully, also enable accurate determinations to be made for CCP effluents to which workers may be exposed. Ultraviolet light monitoring techniques are in use to detect the characteristic fluorescence of materials such as polynuclear aro-

matics, which may be potential skin contaminants.

In June 1976, ERDA (now DOE) sponsored a symposium entitled "Sampling Strategy and Characterization of Potential Emissions from Synfuel Production." Discussion at the symposium emphasized the need for immediate monitoring program objectives with the following being suggested:

- determine exactly what kind of data are required
- obtain an understanding of the behavior of substances that are potential pollutants



- obtain data that will be transferable from pilot to full-scale plants. It was also noted that, in the long term, individual coal-conversion plants will require the development of monitoring systems that are specifically designed for each such facility.

Engineering controls are defined broadly in this paper. The following approaches are included: process modification to prevent effluents at the source; built-in, engineer-designed equipment to control effluents; and add-on, engineer-designed equipment to control effluents.

The basic areas of concern with regard to engineering controls at coal gasification plants include air effluents: in-plant and to ambient air, including those from furnaces and coal dryers, sulfur plant tail gas, cooling towers, and CO₂ from acid gas removal; water effluents: gas liquor (phenols, sulfur and nitrogen compounds, oil, cresols); solid waste effluents, including ash or slag from gasification and sludge from water cleanup (refuse from coal cleaning is significant also, but beyond the scope

of this paper); and trace metals: volatiles from gas clean-up systems, from leaching of ash, and from oil products.

Unfortunately all of these areas have not been adequately addressed from a comprehensive engineering control standpoint. Various control techniques have been developed and have application, but numerous control technology gaps do exist, both with regard to coal gasification and liquefaction.

A basic objective in control technology for CCP is the removal of sulfur and other pollutants from gas streams at high temperatures and pressures. It has been estimated that thermal efficiency of a gasification process could be increased by 5-9% by cleaning gas streams at high temperatures, rather than cooling before clean-up.

The condensed wastewater known as gas liquor contains a large number of contaminants. Several treatment techniques are applicable and are considered effective.

Solid waste streams will include ash or slag from gasification and wastewater sludge. Land disposal of such materials is the likely approach, although the subject has not been addressed in the literature to a significant degree. Leaching of salts and trace metals into groundwater is a potential problem that must be evaluated in connection with specific land-disposal techniques.

The problem of trace elements that may be found in air, water or solid waste-effluent streams has not been given sufficient attention. Large amounts of volatile toxic trace elements may be found in raw gas streams and must be recovered for further use, or disposed of in a safe manner.

A recent review of EPA programs dealing with control technology identified three major areas of emphasis: bench-scale studies of generic raw and acid gas clean-up systems; bench-scale studies of wastewater treatment; and bench-scale studies of high-temperature/pressure particulate control.

A good example of a positive approach to building engineering controls into the coal gasification process development effort is the work performed at the Dept. of Energy's Pittsburgh Energy Research Center.

R&D needs

The identification of R&D needs is not an easy task, regardless of the technical subject. This is the case with regard to health effects, and monitoring and control technology for CCP effluents.

The need for health-effects data with regard to CCP effluents is so broad that it is very difficult to know where to begin. What is needed is systematic laboratory studies that can be translated to humans to determine the health effects of exposure to chemical agents likely to be found in CCP effluents.

The list of chemical compounds to be tested is long and complex, but the task must be undertaken systematically if the problems are to be defined and solved. The only logical option to identifying "safe levels" of exposure for workers and the public and proceeding to monitor and control to such levels is to design, construct and operate totally closed systems that will prevent discharge of effluents. This approach may become technically feasible in the future, but until then the "safe level" approach must be pursued.

Notwithstanding the above, there is need to initiate employee health surveillance and recordkeeping at all CCP. Such information is essential for the tracking of morbidity and mortality patterns.

Some specific monitoring R&D data gaps have been identified that require significant research follow-up effort; these include:

- the determination of the fate of trace elements entering coal-conversion plants from a qualitative and quantitative standpoint
- a quantitative determination of volatiles that are picked up in cooling water through leakage
- development of analytical techniques to accurately measure chemicals in water, such as certain aromatics that do not show up in the conventional biochemical oxygen demand determination
- the determination of the composition of miscellaneous purge streams is needed
- the determination of the leachability of inorganic materials from coal ash and other solids.

An analytical test plan was recently developed for EPA to aid in determining the scope of the measurement problem that must be faced to assess CCP effluents. It was determined that a typical coal gasification plant would have 72 pollutant streams that may require monitoring. A typical coal liquefaction plant would have 74 streams. The scope of analyses that would be required to properly monitor the above pollutant streams amount to a major challenge; all streams must be covered and all potentially hazardous constituents evaluated.

Chemical and biochemical screen-

Coal gasification plant monitoring requirements

Materials requiring monitoring	Number of distinct analyses required
Metals	17
Gases	16
Polynuclear aromatics	14
Other organics	9
Inorganic ions	7
Coal, ash and char	11
Water contaminants	12

ing tests need to be fully developed and should become very useful monitoring techniques in the future. The microbial Ames test is an example of a test that could be used to screen CCP effluents.

Given the general lack of health-effects data and the broad scope and challenge of monitoring effluents, it is difficult to envision efficient engineering control techniques. Nevertheless such solutions must be developed and some specific immediate research needs have been identified.

It is necessary to develop an improved system for acid gas removal. For the best results, the system should: remove all forms of sulfur to low levels; provide a concentrate H₂S stream to sulfur plant; assure that the CO₂ reject stream is clean; and generate no chemical waste residues. Improved techniques for methanation need to be developed that would accomplish the process in a shift reactor upstream of acid gas removal. Because of the complex array of potential wastewater contaminants, selected treatment systems need to be demonstrated to verify predictions.

Improved techniques are needed to reliably and safely feed coal to CCP. The development of such injection systems is necessary to prevent potentially harmful emissions at that process point.

In summary

Coal is a logical source material for the nation's short-term energy demands. The conversion of coal to gaseous and liquid fuels is necessary to meet conventional energy demands, since we will not be able to continue to rely on traditional petroleum resources. However, the state-of-the-art of coal conversion in the U.S. is generally at the process-development unit to pilot-plant stage.

The health effects of coal-conversion plant (CCP) effluents have not

been well defined. However, the complex composition of coal and the reaction conditions prevalent in conversion results in a wide range of products that can be hazardous to health. The air emissions, water discharges and solid waste streams produced are the prime targets of concern both within plants (worker health) and outside (public health). Monitoring and control technologies are needed; at present, these technologies have not been developed commensurate with process technology. Monitoring and control technology is needed to assure the prevention of serious health problems that may be attendant to major CCP development.

Additional reading

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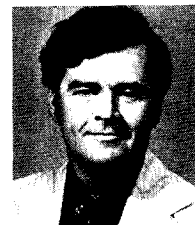
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