Joint ICTP-IAEA Workshop on Vulnerability of Energy Systems to Climate Change and Extreme Events

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Climate Impacts on the Coal System from Resource Assessments through Environmental Remediation

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Prepared for the ICTP/IAEA Workshop on the Vulnerability of Energy Systems to Climate Change and Extreme Events
Approach to presentation

- We will discuss the coal cycle from exploration through environmental remediation before focusing on climate effects.
- The coal system operates as it does based on the current economics of coal compared to those of competing energy resources and industrial feed stocks.
- As currently deployed, this system experiences impacts from the weather including:
  - Costs for developing coal resources into operating mines;
  - Costs for transporting coal from production to end use;
  - Economics of coal as a fuel or feedstock;
  - Operation of environmental clean-up technologies and site remediation.
- Once each of the subsystems has been explored, particular, additional impacts of climate change on the economics of coal use will be discussed.
Conceptual view of the coal cycle

- Exploration: Assessing resources, Evaluating commercial reserves
- Development and Extraction: Open pit or deep mining, UCQ (U)
- Coal preparation: Mine-mouth, At site of final use
- Power production: Coal burning, Cement manufacturing, Other industrial uses
- Environmental controls: GHG emissions, Ozone depletion, Trace metals
- By-product Uses: Coke, Coal Ash
- Impoundments or disposal
- CO2 to enhance or sequestrate

Coal stockpiles provide local storage; coal plant management systems cost, available to meet projected demand.

Coal-based power, industrial applications: withdrawal large volumes of water but consume much less.

LTI
Characteristics of the coal cycle - Introduction

- Coal resource base not completely understood.
  - Known resources could become accessible due to economic trends;
  - New mining technology or underground coal gasification could expand reserves.
- Coal primarily destined for use in large batches at power stations, in steel making, and for cement manufacture.
  - Coal a valuable feedstock in industry
- Coal used by chemical, fertilizer, and pharmaceutical industries, and as feedstock for synthetic liquid fuels, and for carbon fibers.
- Producing and transporting coal is classic bulk solids handling; costs are directly related to the economies of scale in material handling.
- Coal is hauled considerable distances particularly by rail, barge, or ocean-going vessel.
- At larger sizes and when not dried, coal can withstand open storage.
Projected changes that impact the coal cycle
The coal cycle begins with finding coal deposits.

Considerable work is needed to determine whether a deposit – an estimated resource – can be defined as a proven resource.

More work is required to evaluate whether a proven resource contains areas that can be mined cost-effectively.

Brazil – see map at left – produces coal only in the 3 southern-most states.

Brazil stopped active exploration for coal in 1982.

Coal Classification

- Coal has been classified in numerous ways over the history of interest in coal.
- Current methods focus on the chemical content of the coal, primarily the carbon, inherent moisture and mineral matter.
- Other indicators could include petrography, volatile content, and free swelling index.
Coal statistics: Reserves vs. Resources

Table 1: Sampling of world coal statistics

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Africa</th>
<th>United States of America</th>
<th>Total North America</th>
<th>Brazil</th>
<th>Total South America</th>
<th>India</th>
<th>Pakistan</th>
<th>Total Asia</th>
<th>Germany</th>
<th>Russian Federation</th>
<th>United Kingdom</th>
<th>Total Europe</th>
<th>Total Middle East</th>
<th>Australia</th>
<th>TOTAL WORLD</th>
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<td>Proven amount in place</td>
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<td>Estimated additional amount in place and estimated additional amount of all types (bituminous, anthracite, sub-bituminous, and lignite)</td>
<td>4. Proved amount in place and estimated additional amount of all types (bituminous, anthracite, sub-bituminous, and lignite)</td>
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</tbody>
</table>
What is not discussed in the WEC statistics?

- There are regions that appear to contain large resources of coal that have not been adequately characterized.
- We will mention three: Alaska, Mozambique, and Pakistan.
- The state of Alaska may contain between 1 and 5 trillion tons of coal. Resource estimates suggest that the value lies somewhere between these two numbers.
  - These deposits are not commercial as many are on the North Slope.
- Mozambique has recently drawn the attention of coal buyers from India and Brazil in search of metallurgical coal.
  - Development of open cast mines in Tete is slowed by periodic heavy rains.
- Pakistan has begun to develop the Tharparkar region where a poorly characterized coal deposit may extend under approximately 9000 square kilometers of the Thar desert in Sindh.
  - The harsh climate has made exploration and development difficult.
There are a number of different mining methods that may be employed based on the location of the deposit, how close it is to the surface and whether it is relatively “flat” or sloping.

This figure combines the basic options on a single figure. Slope mines and shaft mines can often extend miles underground.

Real deposits are not so uniformly horizontal.
Geologic formations often slope steeply— including the coal deposits

Mining down slope increases cost. Down slope deposits can “dip” effective making further mining uneconomical.
Mining methods

• The various types of mines and mining equipment are shown.
• Open cast or strip mines are depicted in the photo, in the drag line, mountain top removal, open pit and contour mine photos.
• At the bottom right are a room and pillar mine, a continuous mining machine and a long-wall miner.
The coal transportation system within the United States

- Coal moves within the United States primarily by rail (red lines) and by barge. (left-hand image).
- Several transport corridors out of the Power River Basin are the most heavily used in the country.

(Graphics courtesy of Lloyd Kelly, LTI and Greenmount Energy)
- The Joint Line railroad, shown as a red dashed line, serves eight large strip mines.
- In 2003, as an example, the line operated at 88% of capacity.
- In May of 2009, the Union Pacific railroad celebrated the dispatch of its 200,000th coal train along this line between August of 1984 and May of 2009.
Coal transportation within China

Coal deposits and Rail lines

• The main coal routes move coal from three primary regions – Shanxi, Shaanxi, and the western portion of Inner Mongolia – along three main rail corridors to coal consumers and coal export ports.

• In general, these lines move coals from northwest to southeast, along and across two of the three main river systems in China – the Chang Jiang and the Huang He.

• China plans to increase the capacity of the existing network to move more coal - upwards of 1 billion tons.

Map taken from: http://globalpublicmedia.com/museletter_coal_in_china

Map: Coal deposits and rail lines in China.
International Coal Trade

- Japan and South Korea are the leading coal importers.
- They import both metallurgical coal and steam coal.
- India and Brazil are both increasing their imports; Brazil for steel making and India for both. Several of the new Ultra-mega Power Projects in India (UPP’s) will use imported coal often from Indonesia.)
Richards Bay, South Africa

Port Limitations: The port of Richards Bay entrance channel is dredged to a permissible draught of 17.5 meters with a -19.5m depth in the entrance channel. Berthing varies between 8m (small craft berth) and 19m (coal berths). The largest ship handled in the port so far was the 372,201DWT Brazilian Pride, which had a length of 363.7m, a beam of 63.4m and a maximum draught of 21.8m. The largest shipment of coal was lifted onto the 206,258DWT bulk carrier Ocean Vanguard.
Newcastle, New South Wales, Australia
Rotterdam
Coal Value Chain

• Headwaters Technologies presents the value generating elements of the coal cycle relevant to that company as shown below.
• Although coal-fired power plants are not typically optimized to generate revenue from a number of products, that potential does exist.
• Integrated gasification combined cycle power systems are more readily understood in this context as the syngas can be readily used in liquid fuels production, and for producing chemicals.
During gasification, the syngas (H₂ and CO) can be used to make liquid fuels and hydrocarbons, leaving some of the carbon in the product.

Alternatively, the syngas can be undergo a water/gas shift reaction producing hydrogen and a more concentrated stream of carbon dioxide.

The path that optimizes hydrogen leads to easier carbon dioxide capture. The other path, particularly when biomass is co-processed, can make liquid fuels with low net carbon emissions compared to conventional fuels.

With 30% biomass/ 70% coal and employing carbon capture and storage, the life cycle emissions would be 33% below that for the manufacture of diesel fuel¹.

The ultimate end uses for coal will have major impacts on the other commodities tied to the coal cycle.

Water issues

- Water is used throughout the coal cycle.
- Water is essential for mining, coal cleaning, and, often, for transportation from mines to end users.
- Many places in the world are already water-short. Additional, large-scale industrial development can strain resources further.
- Impacts to the climate that alter the precipitation patterns can further exacerbate this problem.
# Water consumption and cooling duty factors for thermoelectric power plants

<table>
<thead>
<tr>
<th></th>
<th>Without CO₂ Capture</th>
<th>With CO₂ Capture</th>
<th>% change with CO₂ capture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Consumption Factors (gallons per MWh net power)</strong>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear²</td>
<td>720</td>
<td>--</td>
<td>+90%</td>
</tr>
<tr>
<td>Subcritical PC</td>
<td>520</td>
<td>990</td>
<td>+90%</td>
</tr>
<tr>
<td>Supercritical PC</td>
<td>450</td>
<td>840</td>
<td>+90%</td>
</tr>
<tr>
<td>IGCC, slurry-fed</td>
<td>310</td>
<td>450</td>
<td>+50%</td>
</tr>
<tr>
<td>NGCC</td>
<td>190</td>
<td>340</td>
<td>+80%</td>
</tr>
</tbody>
</table>

|                      |                      |                  |                          |
| **Cooling duty factors (MMBtu per MWh net power)** |
| Subcritical PC       | 4.7                  | 11               | +130%                    |
| Supercritical PC     | 4.1                  | 9.3              | +130%                    |
| IGCC, slurry-fed     | 3.0                  | 3.7              | +20%                     |
| NGCC                 | 2.0                  | 4.2              | +110%                    |
Coal has a long history of use; environmental concerns are almost as old.

- Coal was probably first used in China approximately 3000 years ago.
- ‘The first person recorded to have suffered from medieval pollution was a Queen of England, Eleanor, who was driven from Nottingham Castle in 1257 by the unpleasant fumes of the sea coal burned in the industrial city below.’

‘By the last decades of the thirteenth century, London had the sad privilege of becoming the first city in the world to suffer man-made atmospheric pollution. In 1285 and 1288 complaints were recorded concerning the infection and corruption of the city's air by coal fumes from the limekilns. Commissioners of Inquiry were appointed, and in 1307 a royal proclamation was made in Southwark, Wapping, and Easth Smithfield forbidding the use of sea coal in kilns under pain of heavy forfeiture.’ (Gimpel 1976)
Coal Combustion By-product production and utilization

<table>
<thead>
<tr>
<th>CCB Type</th>
<th>Production</th>
<th>Utilization</th>
<th>Percent Utilized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly Ash</td>
<td>57,113,000</td>
<td>19,147,000</td>
<td>33.5%</td>
</tr>
<tr>
<td>BOTTOM ASH</td>
<td>15,204,000</td>
<td>4,753,000</td>
<td>31.3</td>
</tr>
<tr>
<td>Boiler slag</td>
<td>2,704,000</td>
<td>2,166,000</td>
<td>80.1</td>
</tr>
<tr>
<td>FGD by-products</td>
<td>22,682,000</td>
<td>2,263,000</td>
<td>10.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>97,703,000</td>
<td>28,263,000</td>
<td>29.0</td>
</tr>
</tbody>
</table>

- The EU 25, produces 93 million metric tonnes of coal combustion by-products annually
- India currently produces over 70 million tons/yr of fly ash but current utilization rate is ~10%; U.S. rate is 35%
- Ash haul-back demonstration project evaluated using fly ash from NTPC’s Singrauli power station for backfill at Coal India’s Gorbi Mine

Numbers in metric tonnes, Data from the American Coal Ash Association
Carbon dioxide Capture and Storage (CCS) can raise consumption of water.

- Water withdrawals by thermal plants represent a significant impact on streams. Although most of the water is not consumed, it may be changed. Limitations on the use of water have restricted plant siting.
- New EPA rules seek to move thermal plants toward alternative types of cooling that have little impact on surface waters (free flowing, natural sources).
- Adding CCS, primarily due to the parasitic losses due to reduced efficiency and for cooling the compressors, increases water consumption.
- If the “storage” aspect of CCS generates produced water, that can either be an additional impact or it can be a benefit.
- This issue will be discussed later in the presentation…
Existing and emerging carbon dioxide pipeline infrastructure

- To meet an atmospheric stabilization goal of 450ppm, 22,000 miles of CO2 pipeline would be needed by 2030 and 28,000 miles by 2050.
- The average rate of growth to achieve this capacity would be slightly less than 900 miles per year.

Each stage removes ~98% of total dissolved solids (TDS). Process reduces TDS from in brine from 233,000 ppm (by mass) to 21 ppm mass (potable) in water exhaust stream.

Total output of potable water from the system is a maximum rating of 23.6 million gallons per day from a IGCC plant with nominal 386MW output without CO2 capture (330MW w/HDS)

Adding the HDS to the plant minimizes some of the impact seen from addition of the sequestration and condenser cooling packages
  - Cost of water used by the IGCC plant is now zero due to supply from the HDS.
  - A second credit is added to the by-product section of the O&M costs, with the sale of potable water.
  - Using the HDS covers its specific capital costs due to water sales.
  - HDS is less capital intensive (than the RO) though higher in operating costs due to power consumption.

The lower net operating cost allows the COE to decrease.
What sort of changes would affect the coal cycle significantly?

- Identifying and developing coal resources into coal reserves is subject to the local climatic conditions.
- Mining technology favors economy of scale – open pit or strip mining is often preferred. Open pits more susceptible to weather upsets than are deep shaft mines.
- Rail transportation involves moving tens of thousands of tons. Wet coal, coal with a high percentage of mineral matter (or dirt), is less valuable than lower mineral matter, lower moisture coal. All transport modes except pipelines are impacted by weather.
- Although the coal cycle is not “just in time”, modern practice is based on lower inventories throughout the system.
- End use technologies typically require large volumes of cooling water concentrating these operations near rivers. Thermal processes are more efficient rejected heat to colder thermal sinks.
- Environmental controls need the same high reliability as do power stations or steel mills.
Impacts of climate change on the coal cycle

- Aside from concerns about coal as a source of CO₂, increases in average temperatures, changes in precipitation, sea level rise, and declining sea ice will impact flow of coal and other bulk materials that determine a large share of the cost of using coal.

- Changing river flows can impact the lock and dam system that manages the flow of rivers important to the coal trade. The rate at which barges can clear locks determines the rate of supply.

- Extreme weather events, such as flooding, can inundate key parts of many of the processing, storage, and end use facilities in the coal cycle.

- Sea level rise can threaten the port infrastructure.

- Hotter, dryer or wetter conditions complicate coal mining and development of resources. Higher operating temperatures reduce efficiencies across the cycle including for CO₂ pipelining.

- But there may also be circumstances that favor the coal trade.
The National Intelligence Council in the United States publishes a periodic assessment of global trends. Their 2008 publication focused on global trends in 2025. One of the key elements was climate change and in that section they focused in particular on the impact that opening the Arctic ocean to trade would mean.

The report argues that the opening of the Arctic is of great strategic importance. The authors believe that the most important implications of an opening Arctic are improved access to likely vast energy and mineral resources and potentially shorter maritime shipping routes. A trade route across the Arctic Ocean could trim about 5,000 nautical miles off when transiting between the North Atlantic and the North Pacific and some 4,000 nautical miles off of a trip between Europe and Asia compared to sailing through the Panama Canal.

This access could also open the waters off the northern Alaskan coast to shipping and allow consideration of exploiting the vast coal resources on the North Slope.
Is this truly “coals to Newcastle”

Russia is the largest supplier of imported coal to the UK.
Alaska North Slope coal resources

- The photograph is of a ~7 meter thick coal bed in the Nanushuk Group.
- The single black line on the map of coal thickness defines the cross-section on the figure in slide 11.