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

James Ekmann

Leonardo Technologies, Inc.
Pittsburgh
USA

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

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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.

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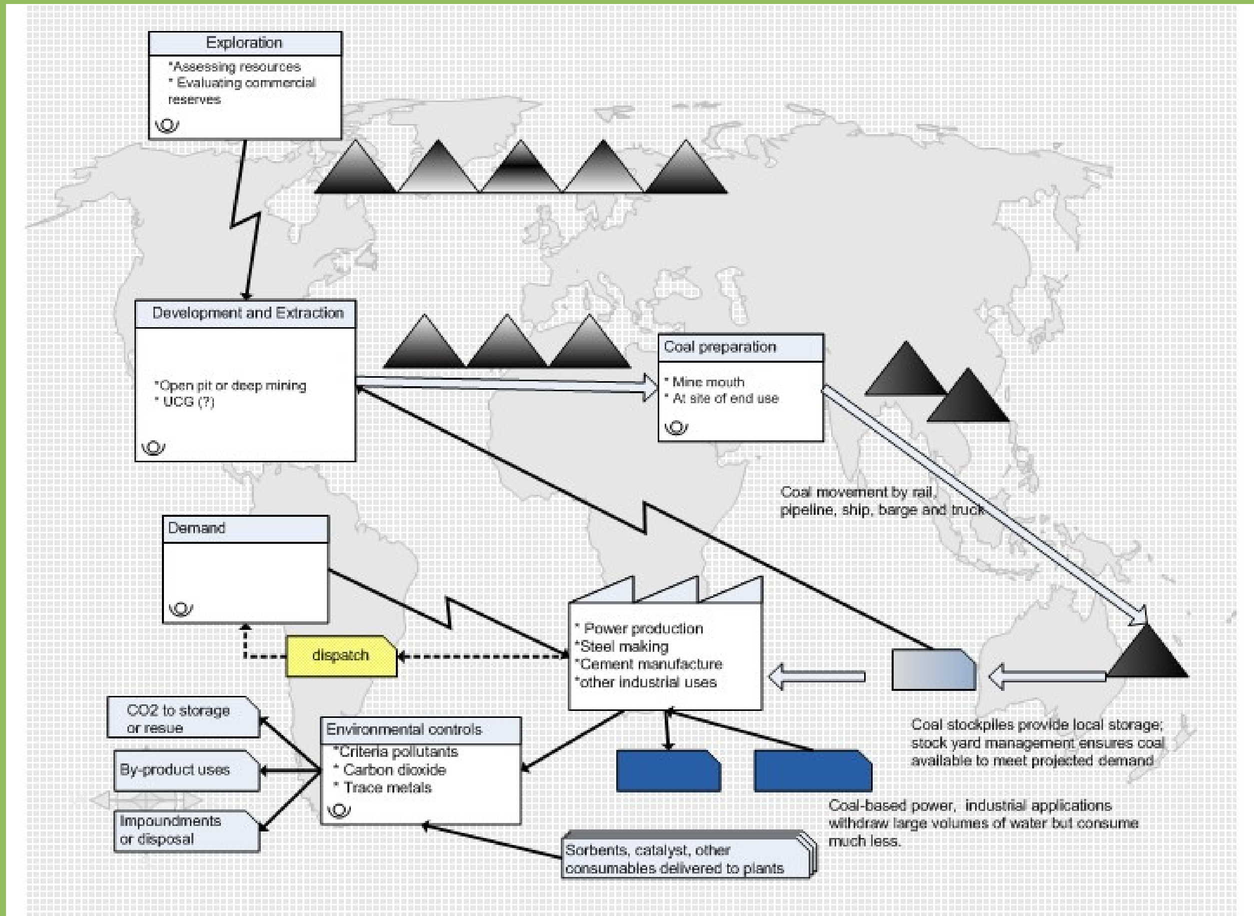
Conceptual view of the coal cycle



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 under ground 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.

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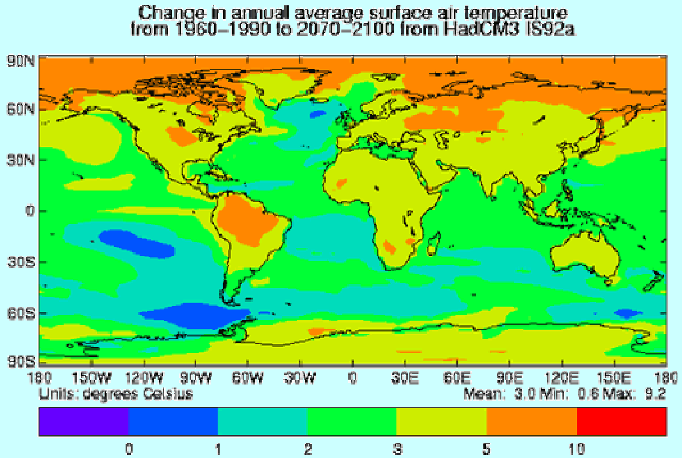
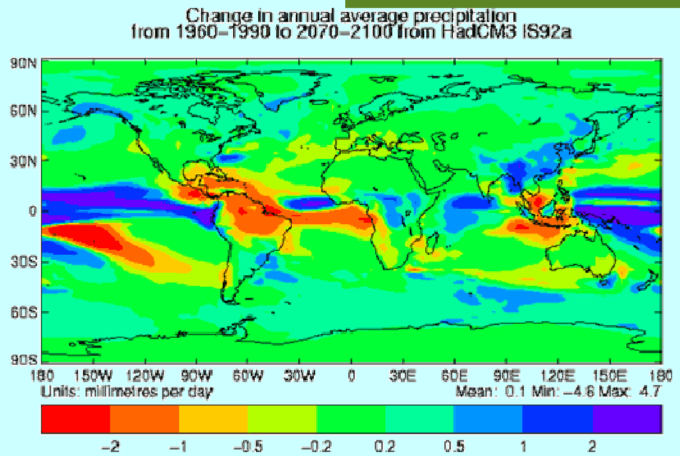
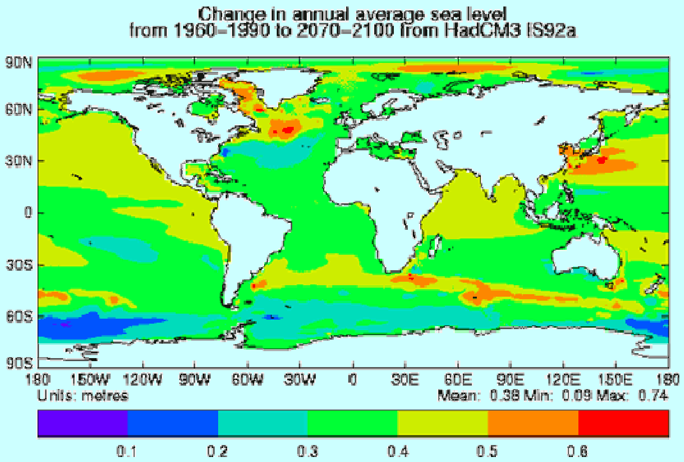
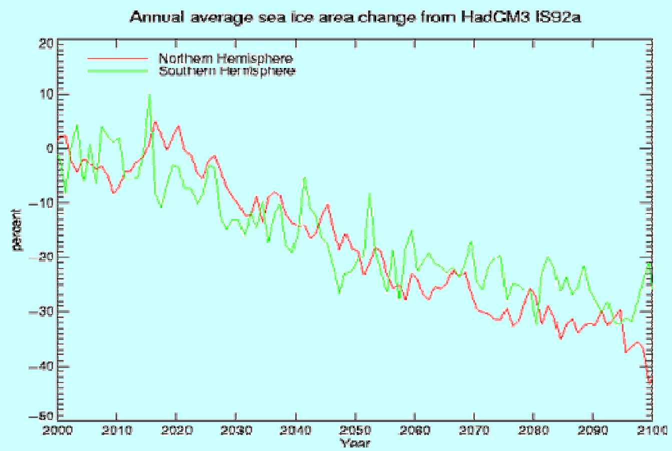
Projected changes that impact the coal cycle

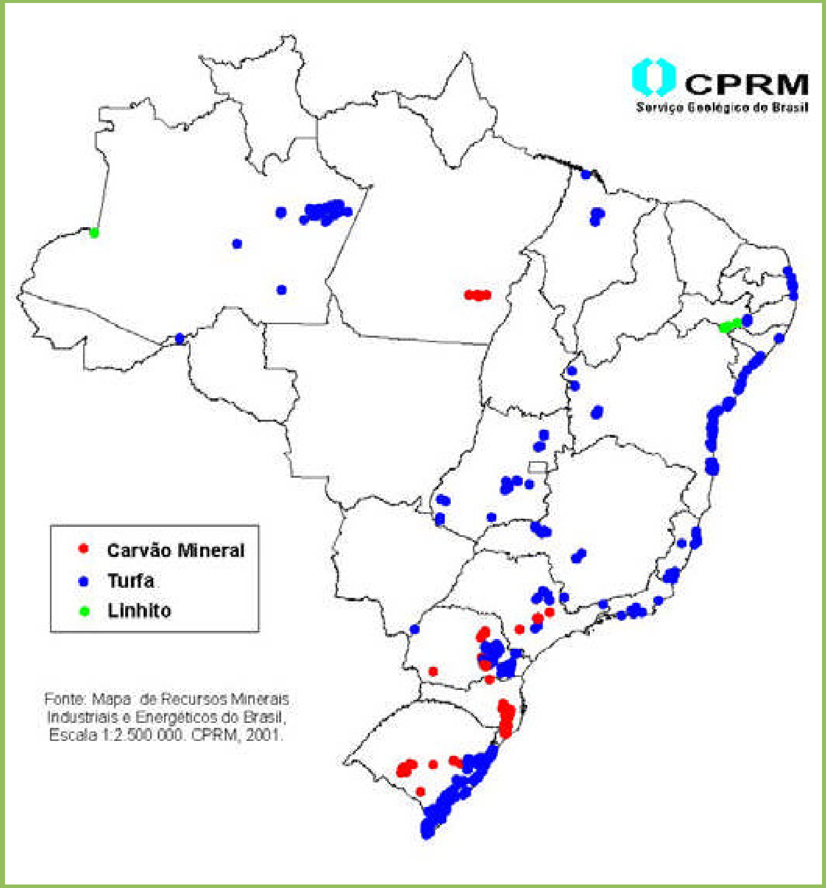








Exploration and production

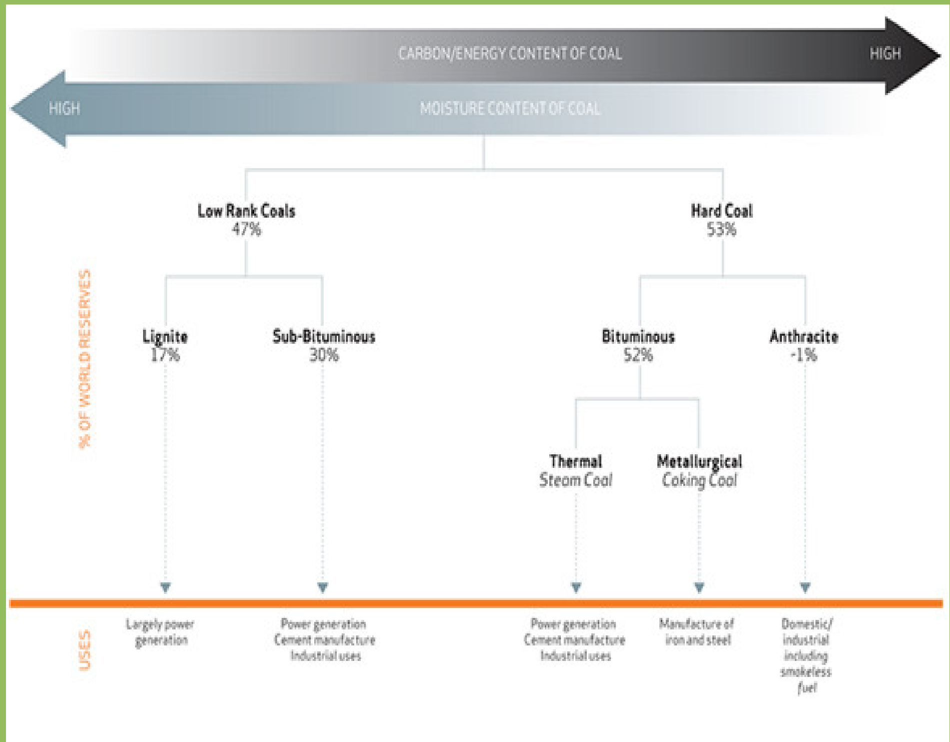


From: CHARACTERIZATION AND POSSIBLE UTILIZATION OF BRAZILIAN COALS, Zuleika Correa Da Silva, Cleber J.B. Gomes, presented at Petrobras/ ABCM workshop (2007)

- 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

	Coal: proved recoverable reserves at end-2005 (million tonnes)				Recoverable reserves	Proved amount in place Tonnage (million tonnes)	Estimated additional amount in place (million tonnes)
	Bituminous including anthracite	Subbituminous	Lignite	TOTAL (2005)	TOTAL (2007)	TOTAL All Types	TOTAL All types
Country							
Mozambique	212			212			
Nigeria	21	169		190			
South Africa	48000			48000	30408	115000	
Total Africa	49431	171	3	49605			
United States of America	112261	100086	30374	242721	238308	800739	1111761
Total North America	**116592**	**101440**	**32661**	**250693**			
Brazil		7068		7068			
Total South America	**7229**	**9023**	**24**	**16276**			
India	52240		4258	56498	58600	117141	195647
Pakistan	1	167	1814	1982		3304	38073
Total Asia	**146251**	**36282**	**34685**	**217218**			
Germany	152		6556	6708		7455	42165
Russian Federation	49088	97472	10450	157010			
United Kingdom	155			155		194000	>200000
Total Europe	**72872**	**117616**	**44649**	**235137**			
Total Middle East	**1386**			**1386**			
Australia	37100	2100	37400	76600	76200		
TOTAL WORLD	**430896**	**266837**	**149755**	**847488**	826001		

Notes:

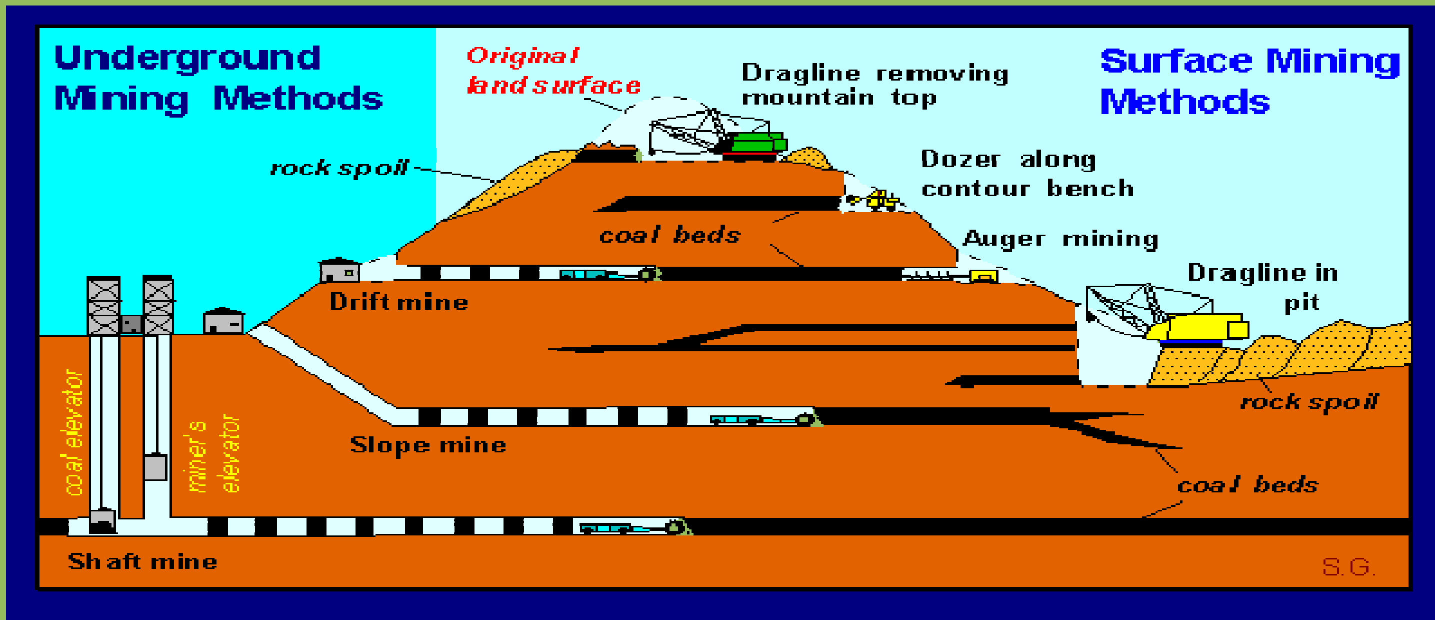
1. Sources: WEC Member Committees, 2006/7; data reported for previous WEC Surveys of Energy Resources; national and international published sources.
2. The 2007 WEC report is the last one with global data. There is a 2009 update, based on 2007 data, is available. Selected figures are taken from that document.
3. The data on resources are those reported by WEC Member Committees. They thus constitute a sample, reflecting the information available in particular countries: they should not be considered as complete, or necessarily representative of the situation in each region. For this reason, regional and global aggregates have not been computed
4. Proved amount in place and estimated additional amount sum of all types (bituminous, anthracite, sub-bituminous, and lignite)

What is not discussed in the WEC statistics?

- There are regions that are 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

Mining methods – conceptual depiction

- 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

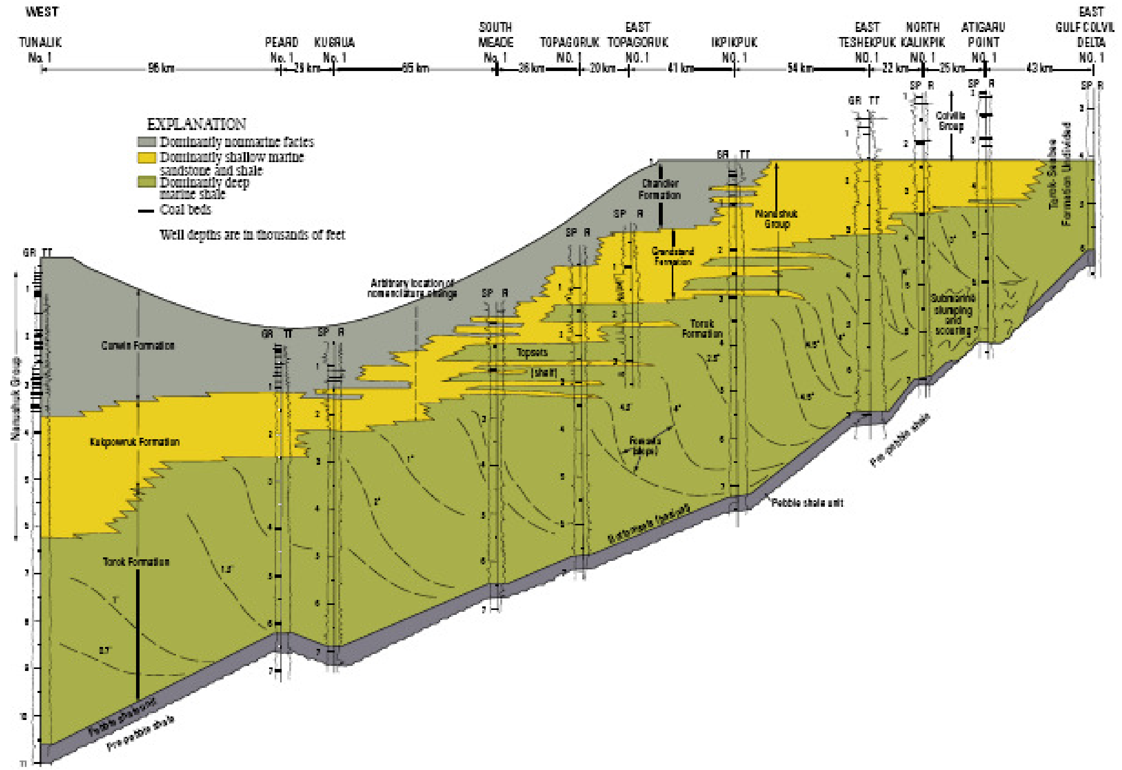
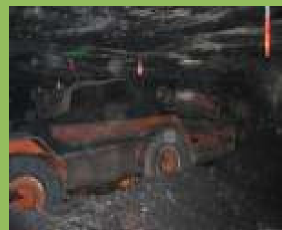


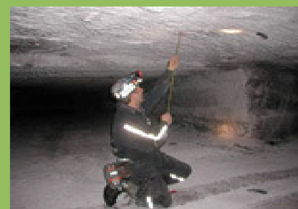
Figure 9. Cross section showing the Nanushuk progradation sequences. Modified from Molenaar, (1985). See figure 8 for location of the cross section.

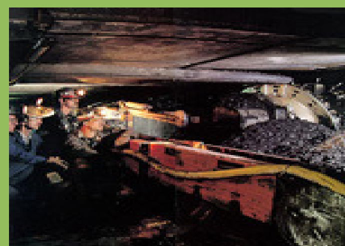
Mining down slope increases cost. Down slope deposits can "dip" effective making further mining uneconomical.

Mining methods

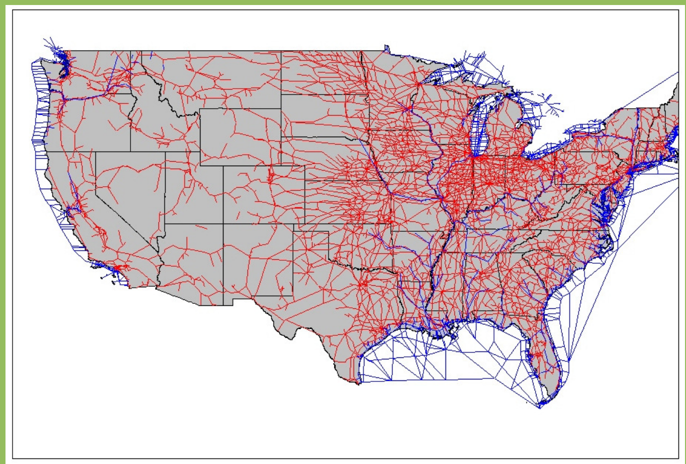
- The various types of mines and mining equipment are shown.
- Open cast or strip mines are depicted in the photo, in the drag line, mountain top removal, open pit and contour mine photos.
- At the bottom right are a room and pillar mine, a continuous mining machine and a long-wall miner.

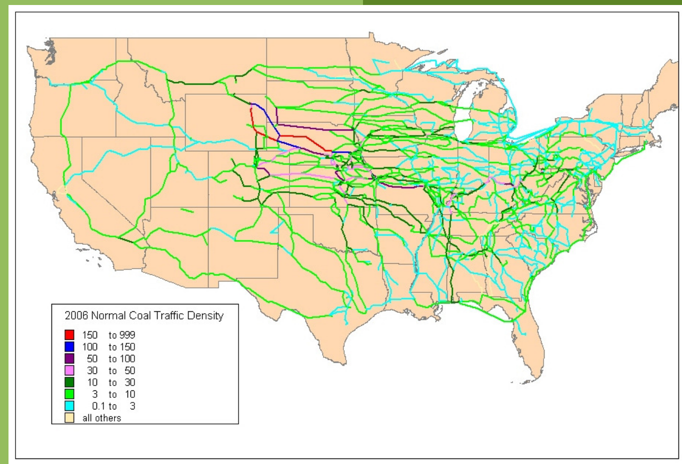






The coal transportation system within the United States

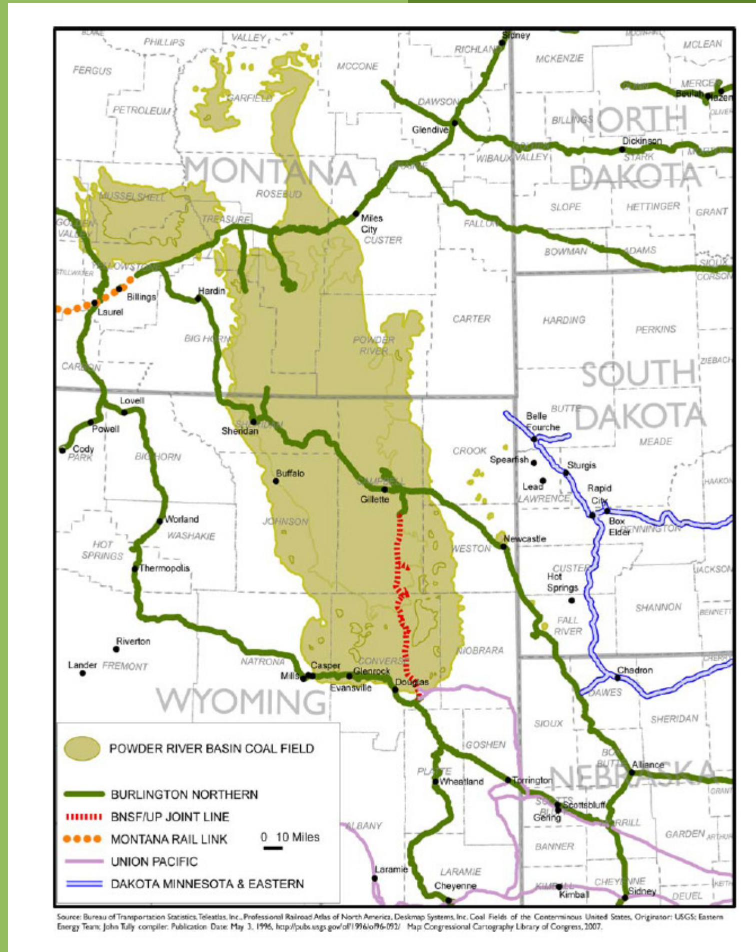




- Coal moves within the United States primarily by rail (red lines) and by barge. (left-hand image).
- Several transport corridors out of the Power River Basin are the most heavily used in the country.

(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.



Powder River Basin Coal Field and Railroads
from CRS RL34186

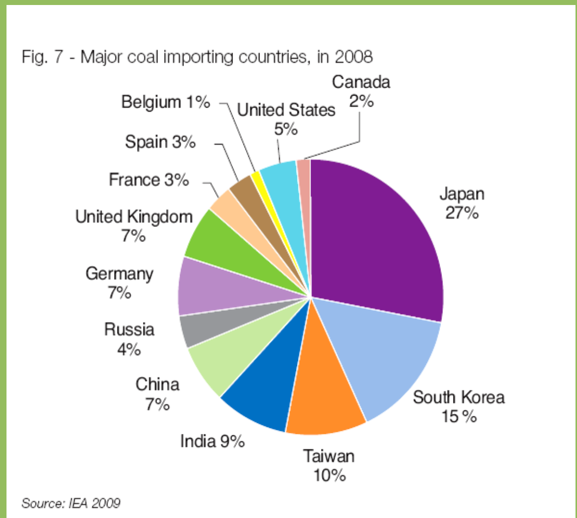
Coal transportation within China

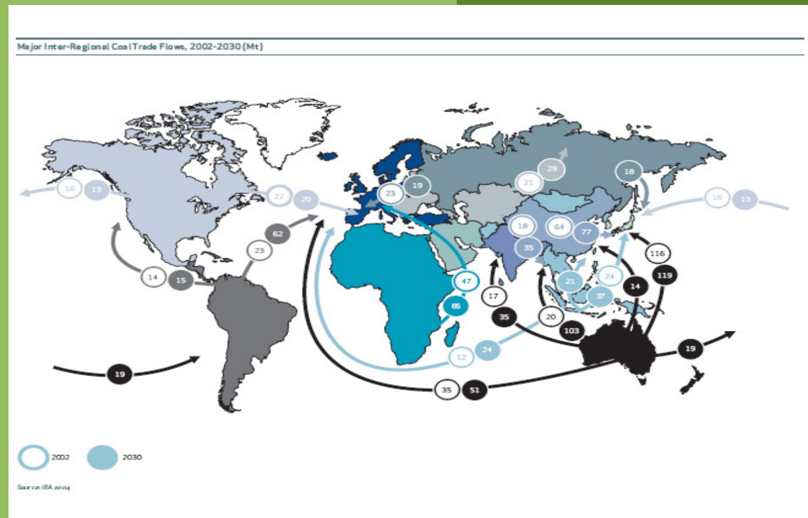
Coal deposits and Rail lines

- 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 south-east, 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

International Coal Trade



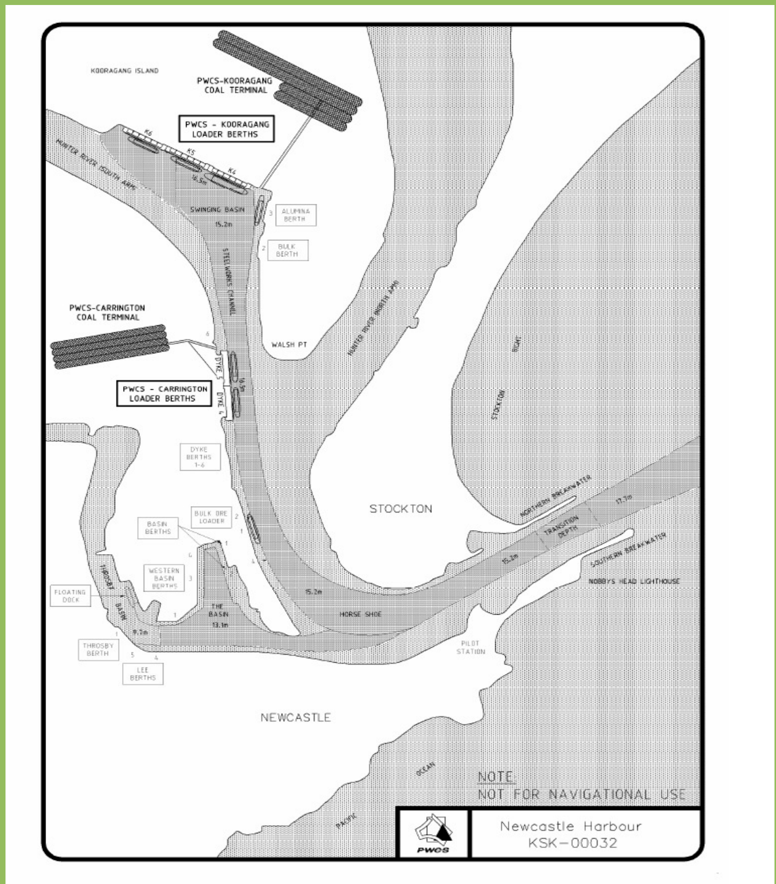


- Japan and South Korea are the leading coal importers.
- They import both metallurgical coal and steam coal.
- India and Brazil are both increasing their imports; Brazil for steel making and India for both. Several of the new Ultra-mega Power Projects in India (UPP's) will use imported coal often from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

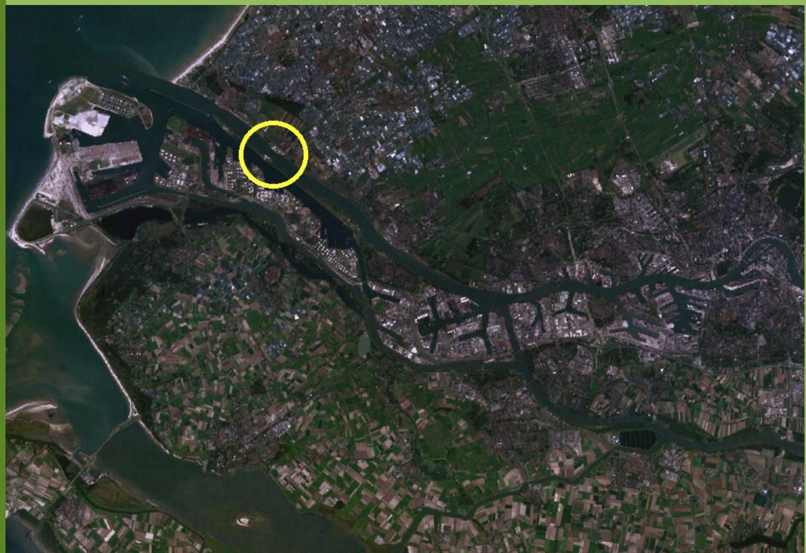
Richards Bay, South Africa

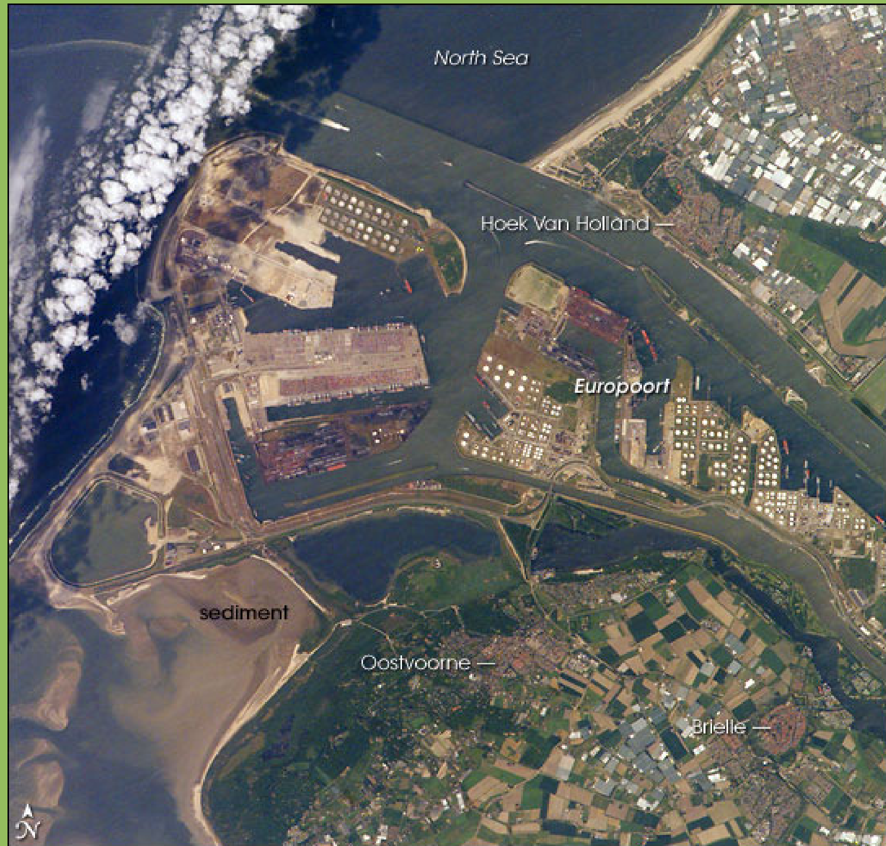
Port Limitations: The port of Richards Bay entrance channel is dredged to a permissible draught of 17.5 meters with a -19.5m depth in the entrance channel. Berthing varies between 8m (small craft berth) and 19m (coal berths). The largest ship handled in the port so far was the 372,201DWT Brazilian Pride, 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



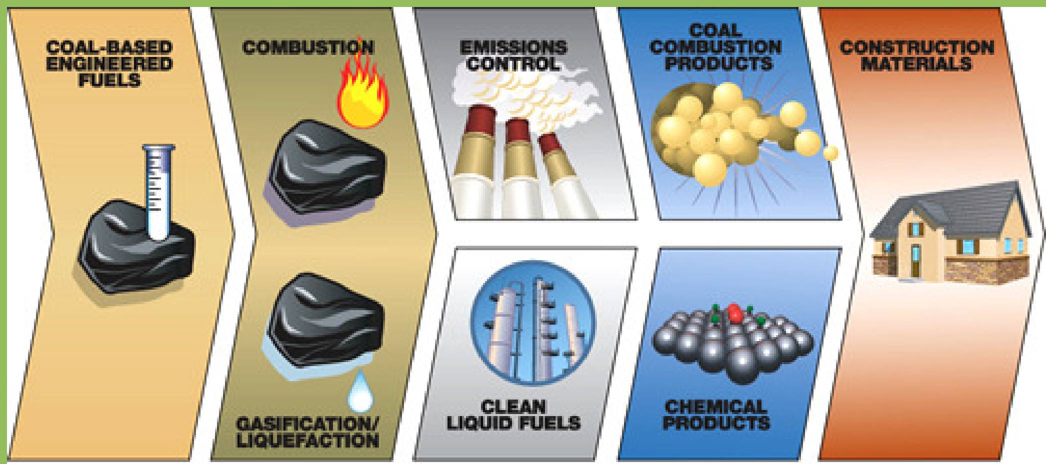
Rotterdam




North Sea
Hoek Van Holland
Europoort
sediment
Oostvoorne
Brielle
N

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.



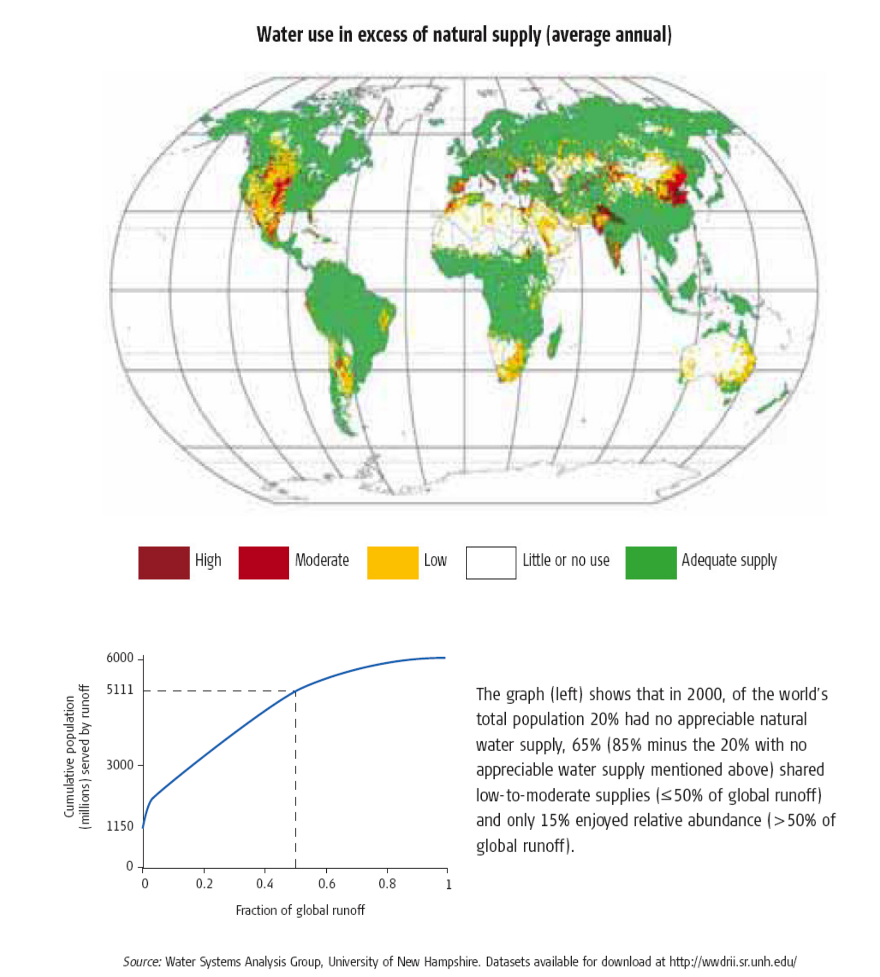
Coal Value Chain – trade-offs

- During gasification, the syngas (H_2 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 fuel[1].
- The ultimate end uses for coal will have major impacts on the other commodities tied to the coal cycle.

1. See: **Affordable, Low-Carbon Diesel Fuel from Domestic Coal and Biomass**, **DOE/NETL-2009/1349 (2009)**

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

	Without CO_2 Capture	With CO_2 Capture	% change with CO_2 capture
*Water Consumption Factors (gallons per MWh net power)**			
Nuclear[8]	720	--	
Subcritical PC	520	990	+90%
Supercritical PC	450	840	+90%
IGCC, slurry-fed	310	450	+50%
NGCC	190	340	+80%
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

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

- 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

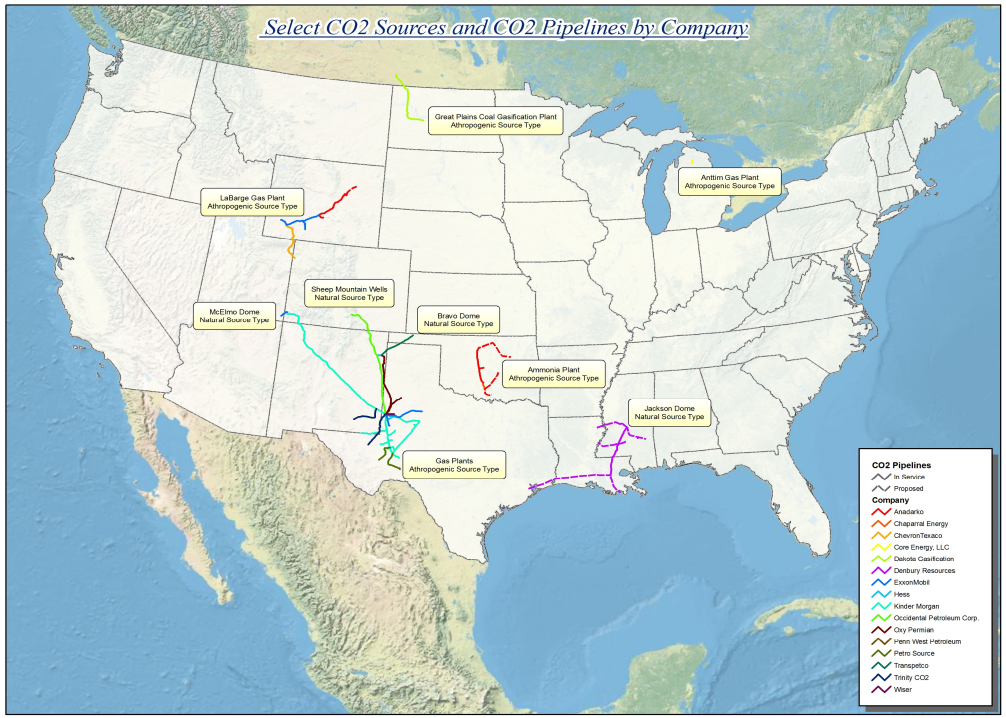
Numbers in metric tonnes, Data from the American Coal Ash Association

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.



Modeled Hydrate desalination process

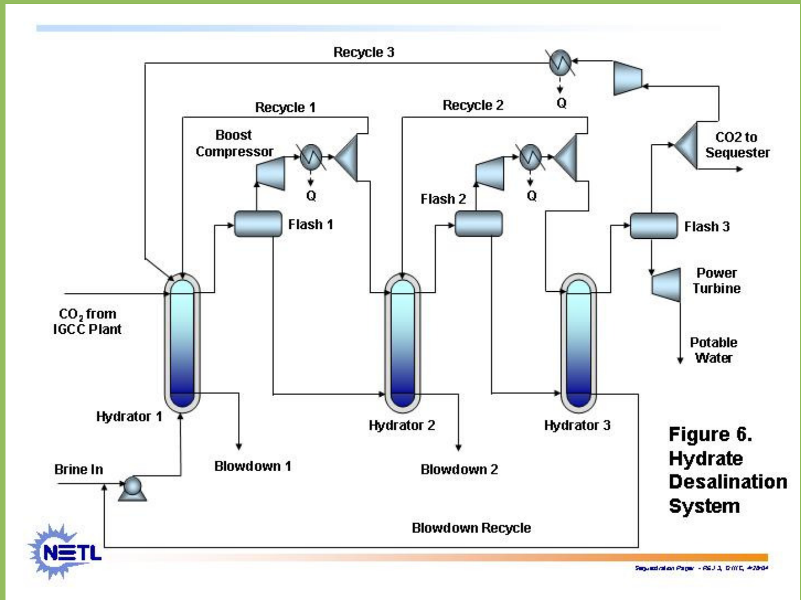


Figure 6. Hydrate Desalination System

- Three-stage process uses saline water and captured CO2. Process modeled after patent by McCormack & Andersen, 1995.
- 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 CO_2 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 CO_2, 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 CO_2 pipelining.
- But there may also be circumstances that favor the coal trade.

Opening of the Arctic Ocean

- 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

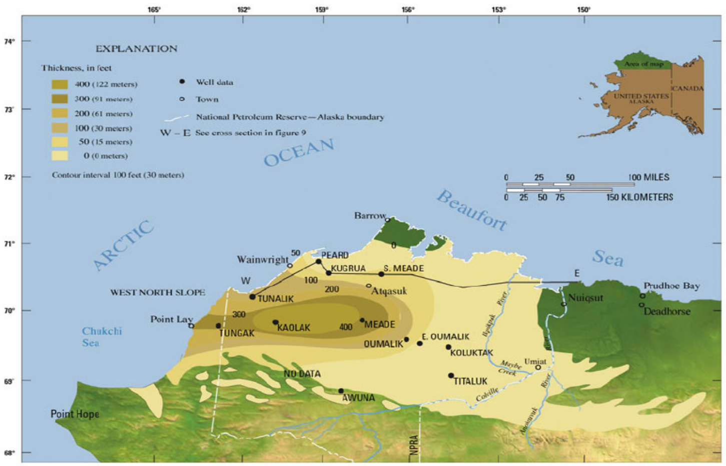


Figure 8. Net coal thickness map of the Nanushuk Group in the western part of the Northern Alaska-Slope coal province. See figure 9 for line of cross section. Modified from Sable and Stricker (1987).

- 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.