Resources – Coal

Outline

- Coal types
- Mining Methods
- Reserves
- Prices
- Emissions
- Coal Bed Methane
- Oil from Coal or Gas

Based on

- The Coal Resource by World Coal Institute 2005.
Fossil Fuels: Coal

- Coal, like oil and gas, forms from organic materials. Coal formation started during the Carboniferous Period (360-290 million years ago).
- Coal contains much less hydrogen than oil or gas, but it still is a hydrocarbon.

<table>
<thead>
<tr>
<th></th>
<th>Carbon molecule ratio</th>
<th>Vitrinite reflectance ratio</th>
<th>BTU per pound</th>
<th>kCal per kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat</td>
<td>●&lt;40</td>
<td>●&lt;0.20</td>
<td>●&lt;6300</td>
<td>●&lt;3503</td>
</tr>
<tr>
<td>Lignite</td>
<td>40&lt;●&lt;50</td>
<td>0.20&lt;●&lt;0.35</td>
<td>6300&lt;●8300</td>
<td>3503&lt;●4615</td>
</tr>
<tr>
<td>Bituminous</td>
<td>50&lt;●&lt;85</td>
<td>0.35&lt;●&lt;2.00</td>
<td>8300&lt;●14000</td>
<td>4615&lt;●7784</td>
</tr>
<tr>
<td>Anthracite</td>
<td>85&lt;●98</td>
<td>2.00&lt;●&lt;4.10</td>
<td>14000●</td>
<td>14000●</td>
</tr>
<tr>
<td>Graphite</td>
<td>98●</td>
<td>4.10●</td>
<td>14000●</td>
<td>14000●</td>
</tr>
</tbody>
</table>

- Vitrinite reflectance is ability to reflect light (rises with the temperature the rock is exposed to).
- 1 BTU (British Thermal Unit) raises the temperature of 1 pound of water by 1 °F.
  - This is increasing temperature of 453.6 grams of water by 0.556 °C.
- 1 Calorie increases the temperature of 1 gram water by 1°C.
  - 1 BTU = 453.6 * 0.556 = 252.2 calories. Compare with the calories in your food.
Energy in Terms of Joule

1 Joule is the potential energy spent to lift 1 kg by 0.1 meter (=1/9.8).
- 1 BTU = 1055 joules
- 1 BTU = 252 calories
- 238 calories = 1000 joules = 1 kilo joule = 0.001 mega joule
- To burn 238 Calories lift 1 kg package by 0.1 meter approximately 1000 times.
- A serving of Hershey chocolate bar has 220 calories, lift 1 kg package by 0.1 meter approximately 925 times.

6300 BTU = 6.6465 Mega Joule. 6300 BTU is 6,646,500 (=6,300*1055) joules

If 1 pound peat gives 6300 BTU, it gives 6.6465 Mega Joule. Then 1 kilogram peat gives 6.6465/0.4536 = 14.653 Mega Joule. Rest of the table below is computed similarly.

<table>
<thead>
<tr>
<th></th>
<th>BTU per pound</th>
<th>Mega Joules per kilogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat</td>
<td>&lt;6300</td>
<td>&lt;14.7</td>
</tr>
<tr>
<td>Lignite</td>
<td>6300&lt;●&lt;8300</td>
<td>14.7&lt;●&lt;19.3</td>
</tr>
<tr>
<td>Bituminous</td>
<td>8300&lt;●&lt;14000</td>
<td>19.3&lt;●&lt;32.6</td>
</tr>
<tr>
<td>Anthracite</td>
<td>14000&lt;●</td>
<td>32.6&lt;●</td>
</tr>
<tr>
<td>Graphite</td>
<td>14000&lt;●</td>
<td>32.6&lt;●</td>
</tr>
</tbody>
</table>
Coal Supplies and Uses

- Significant amount of coal is used for power generation. In 2002, 39% of global electricity is generated from coal. This percentage is expected to drop slightly to 38% in 2030.
- Use of coal depends on country
  - US: 91% of coal for electric generation
  - China: 55% of coal for electric generation
Mining

- Mining Methods
Production: Coal Mining

Room-Pillar Mining:
- Pillars support the rocks/soil (overburden) above the mine.
- Pillars can consume up to 40% of coal, so 60% coal recovery.
- To improve recovery, use retreat mining: remove coal from pillars as exiting the mine. Dangerous but possible.

Longwall Mining:
- Coal shearer has roof supports.
- After the shearer is done with a panel, roof supports move away and the panel collapses.
- 75% of the coal can be extracted.

Both Retreat and Longwall mining cause a collapse underground; effects over the ground?
Surface Effects of Underground Mine Collapse

Mine Drainage
Mine drainage occurs when old underground mine workings gradually fill up with water and the water breaks out onto the ground surface usually near a coal outcropping or near a hillside. Sometimes heavy rains or melting snows can raise the water level in a mine and trigger a mine water breakout. If such a breakout occurs suddenly and unexpectedly near a building, substantial damage can occur. Although this is not considered mine subsidence, under certain circumstances, building damage from such a mine water breakout would be covered by Mine Subsidence Insurance.

Sinkhole Subsidence
Sinkhole subsidence occurs in areas overlaying underground mines which are relatively close to the ground surface. This type of subsidence is fairly localized in extent and is usually recognized by an abrupt depression evident at the ground surface as overburden material collapses into the mine void. Sinkhole subsidence is perhaps the most common type of mine subsidence and has been responsible for extensive damage to many structures throughout the years.

Trough Subsidence
Subsidence troughs occur when the overburden that supported the mine roof collapses due to the removal of all or part of the overburden. This results in a trough or depression in the ground which is usually elliptical or circular in shape.

Subsidence is usually greatest at the center of the trough and it progressively decreases until the limit of the impacted surface area is reached. Horizontal ground movements also occur within a trough. Structures near the center of the trough can experience damage caused by the compression of the ground surface, and structures near the edges can be damaged by tension or stretching of the surface. Ground movement within a subsidence trough can result in damage to buildings, roads, bridges, pipelines, and utilities, and practically any other structure or surface feature that may be present. In addition, the flow of streams may be altered or disrupted, and surface cracks may occur, particularly near the edges of the trough.

Source: www.pamsi.org
Surface Mining: 5 steps

1. Graded and level invert tv action baffle  to limit erosion and drift
2. Top soil- and sub soil - stripped by heavy scrapers and carefully stored
3. Overburden from benches dug by shovels and hauled by dumper trucks
4. Overburden being excavated by drag line
5. Gravel and trees

Surface mining is safer and can be used when coal is closer to the surface. But it can change the mountain contours.

Water stream(s) can be polluted by dumped waste. Army Corp of Engineers issues permits to dump rock, soil and waste into streams. It did for Spruce 1 mine of Arch Coal in Appalachia in 2007. In 2009, EPA revoked the permit saying “dumping waste would impose unacceptable harms on water quality and wildlife. Arch Coal attempted to take the matter to the Supreme Court which declined to review it in 2014.

Economics and Environment

- Reserves: Coal is plenty and shippable
- Prices: Coal is cheap
- Emissions: Coal is dirty
Reserves and Production: Coal is Plenty

Sufficient coal reserves for 190 years and most are in the USA.

### Reserves and Production

<table>
<thead>
<tr>
<th>Reserves</th>
<th>% of Global</th>
<th>% Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>27.1</td>
<td>17.0</td>
</tr>
<tr>
<td>Russia</td>
<td>17.3</td>
<td>5.0</td>
</tr>
<tr>
<td>China</td>
<td>12.6</td>
<td>38.4</td>
</tr>
<tr>
<td>India</td>
<td>10.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Australia</td>
<td>8.6</td>
<td>6.0</td>
</tr>
<tr>
<td>South Africa</td>
<td>5.4</td>
<td>4.1</td>
</tr>
<tr>
<td>Ukraine</td>
<td>3.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>3.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Top 8 countries</td>
<td>88.4</td>
<td>80.6</td>
</tr>
</tbody>
</table>

### Reserves in MM tons and Production in MM tons

<table>
<thead>
<tr>
<th>Country</th>
<th>Reserves in MM tons</th>
<th>Production in MM tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montana</td>
<td>74,900</td>
<td>40</td>
</tr>
<tr>
<td>Wyoming</td>
<td>40,600</td>
<td>404</td>
</tr>
<tr>
<td>Illinois</td>
<td>38,000</td>
<td>32</td>
</tr>
<tr>
<td>W. Virginia</td>
<td>18,000</td>
<td>154</td>
</tr>
<tr>
<td>Kentucky</td>
<td>14,900</td>
<td>120</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>11,800</td>
<td>67</td>
</tr>
<tr>
<td>Ohio</td>
<td>11,500</td>
<td>25</td>
</tr>
<tr>
<td>Colorado</td>
<td>9,800</td>
<td>39</td>
</tr>
<tr>
<td>Texas</td>
<td>9,500</td>
<td>46</td>
</tr>
<tr>
<td>US Total</td>
<td>267,000</td>
<td>1,131</td>
</tr>
</tbody>
</table>

Coal reserves are more uniformly distributed than Oil/Gas: Geographically large countries have large reserves.

2006 coal production is 6.2 billion tons = 125*10^{15} Btu = 80% of annual oil production.

Source: Producing Liquid Fuels from Coal.
Who are the Producers and Consumers?

From left to right, producers, exporters, importers and consumers. Amounts are in million tons.
Source: The Coal Resource.

<table>
<thead>
<tr>
<th>Importing Country</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>162</td>
</tr>
<tr>
<td>Korea</td>
<td>72</td>
</tr>
<tr>
<td>Taiwan</td>
<td>54</td>
</tr>
<tr>
<td>Germany</td>
<td>35</td>
</tr>
<tr>
<td>UK</td>
<td>32</td>
</tr>
<tr>
<td>Russia</td>
<td>24</td>
</tr>
<tr>
<td>India</td>
<td>24</td>
</tr>
<tr>
<td>USA</td>
<td>23</td>
</tr>
<tr>
<td>Holland</td>
<td>22</td>
</tr>
<tr>
<td>Spain</td>
<td>22</td>
</tr>
</tbody>
</table>

- Over 4 Billion ton of coal is produced in 2005.
- Consumption increased to 6.3 Billion tons in 2010.
- Production is expected to reach 7 Billion ton in 2030.
Global Coal Trade: Coal is shippable

Largest exporter Australia sells to Pacific Market (Japan, Korea, Taiwan, India).
Atlantic Market (UK, Germany, Spain) buys from Africa, Australia, North America, Russia, Indonesia. Atlantic market is expected to get smaller.
Global Coal Market

- Coal demand is uncertain as the recovery from global financial crisis is questionable.
- Chinese domestic coal market > 3 the international coal trade. An imbalance in Chinese market strongly affects the global market.
- Demand growth continues but slows down. China in absolute growth and India in relative growth lead the market.
- US is a swing coal producer. It is capable of ramping-up exports quickly and nearly doubling from 2010 to 2012.
- Mongolia and Mozambique are joining the list of major coal exporters.
- Investments into mining fields and transportation infrastructure is solid.


**Mining costs $ per ton**

**Costs at destination $ per ton**

Mining costs increased from 2007 to 2009 but freight costs dropped.

Coal is Cheap
Coal Prices $ per ton

Price is $ per ton for Mid-range Bituminous coal that gives about 6400 kCal per kg.
Or 11500 Btu=0.0115 MMBtu per pound.
Or about 0.025 MMBtu per kilogram.
Or 25 MMBtu by paying about $120/ton.
Or 1 MMBtu bt paying $4.80.

Source: D. Houssin presentation on Jan 11, 2012
Based on Medium-term Coal Market report 2011.

For 1 MMBtu,
Pay $35 for gasoline;
Pay $3-16 for natural gas;
Pay $4-5 for coal.
- Gas is now the cheapest!!
- Gasoline is the most expensive.

Richards Bay, South Africa
Quinhuangdao, China
North West Europe Steam Coal

Steam coal for power generation,
Coking coal for iron & steel manuf.
Steam coal is appreciating faster
than coking coal. Steam and coking
coal prices are decoupling!
A cheap substitute for steam coal?
Coal is Dirty
Who Emits More now and in the future?

Coal combustion (burning coal) generates carbon dioxide, a greenhouse gas. According to 2006 estimates on p.7 of The Future of Coal by MITEI.

<table>
<thead>
<tr>
<th></th>
<th>TOTAL EMISSIONS (BILLION METRIC TONS CO₂)</th>
<th>EMISSIONS FROM COAL (BILLION METRIC TONS CO₂)</th>
<th>COAL % OF TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>11.4 (4.98)</td>
<td>9.84</td>
<td>21.2</td>
</tr>
<tr>
<td>2003</td>
<td>13.1 (5.80)</td>
<td>11.9</td>
<td>25.0</td>
</tr>
<tr>
<td>2006</td>
<td>14.2 (6.37)</td>
<td>16.1</td>
<td>30.3</td>
</tr>
<tr>
<td>2010</td>
<td>15.0 (6.72)</td>
<td>18.6</td>
<td>33.6</td>
</tr>
<tr>
<td>2015</td>
<td>15.7 (7.12)</td>
<td>21.0</td>
<td>36.7</td>
</tr>
<tr>
<td>2020</td>
<td>16.5 (7.59)</td>
<td>23.5</td>
<td>40.0</td>
</tr>
<tr>
<td>2025</td>
<td>17.5 (8.12)</td>
<td>26.2</td>
<td>43.7</td>
</tr>
</tbody>
</table>

- Carbon Dioxide emission of non-OECD countries is expected to surpass OECD countries.
- Non-OECD coal-based emission was more than that of OECD in 1990.
  - There are more non-OECD (Russia, China, India) countries than OECD countries, is this grouping sensible?
- Coal’s contribution to Carbon Dioxide emissions is increasing to 41%.
  » Penalties for Coal consumption? See appendix.
Unconventional Coal

- Unconventional reserve: Coal bed methane
- Unconventional use: Fischer Tropsch Process
Coal Bed Methane (CBM)
Coal or Methane, or both?

- Recall Oil and Gas have H along with C; while coal has mostly C.
- **Coal Bed Methane:** H remains as methane gas CH\(_4\) in a coal reserve.
- CBM is natural, common and causes explosion in coal mines.
- Coal has more surface area than other reservoir rocks.

![Surface Area Comparison](image)

- More surface area per unit volume
- Less surface area per unit volume

- With its more surface area, coal can hold a lot of methane:
  - 6-7 times more gas than conventional gas reservoir.
- CBM exists in three forms:
  - Free methane gas
  - Gas dissolved in the water in coal reserve
  - Gas absorbed on the solid coal surface
- Think of water as the prison guard of the gas around coal.
  - If the guard is removed, gas wants to escape provided that coal permits;
  - The coal seam (reserve) should have high permeability.
- In summary, commercial and profitable CBM reserves should have
  - **More gas:** Saturated with gas. 500-600 cubicfeet per ton of coal is very favorable for commercial production. Amount of gas is more in mature coal such as anthracite and bituminous coal, less in lignite or peat.
  - **Permeable coal:** Peat and lignite are more permeable than bituminous coal.
  - Tradeoff between amount of gas and ease of extraction.

CBM Reserves and Production

- CBM production in Western US is from bituminous coals; that in Eastern US is from higher rank coals.
- Production is by pumping the water out to reduce the pressure in the reserve. This releases gas which goes up to the surface.
  - Initially in overwatering stage, more water is pumped than gas
  - Water declines fast later and more gas is extracted.
- The water has higher salinity with metals and salts dissolved within. It may not be released to agricultural fields without processing.
Is This an Oil Well, Gas Well or CBM Well?

This well is named CZ Fee A No. 114. It is in Winn Parish, Louisiana; about 100 kms southeast of Shreveport. It is drilled by Vintage Petroleum to 3114 feet in January 2004. Perforated about 2,730 to 2,734 feet in a Paleocene-Eocene coal bed. Average monthly production is 450,000 cubic feet.

Fossil fuels require drilling. Know-how obtained in Oil & Gas drilling can be used in CBM drilling; or vice versa. An integrated understanding of Oil, Gas, Coal and CBM is useful.
Fischer-Tropsch Process

Empirical formulas such as
\[ \text{C}_{137}\text{H}_{97}\text{O}_9\text{NS} \] for bituminous coal,
\[ \text{C}_{240}\text{H}_{90}\text{O}_4\text{NS} \] for high-grade anthracite.

- Fischer-Tropsch technology is an **assembly** operation. It assembles \( \text{H}_2 \) to \( \text{CO} \) to obtain \( \text{CH}_2 \) groups, long-chain HCs.
- The first two steps involve the **manufacture of synthesis gas** (\( \text{CO} \) and \( \text{H}_2 \)) from coal.
- In 1925, Franz Fischer and Hans Tropsch developed a catalyst to convert \( \text{CO} \) and \( \text{H}_2 \) at 1 atm, 300 °C to liquid HCs.
- By 1941, Fischer-Tropsch plants produced ~ 700,000 tons of petroleum per year in Germany. Total of 9 plants, the largest in Ruhland-Schwarzheide with capacity of 180,000 tons per year.
- Post WW II, Fischer-Tropsch technology was under study in most industrial nations. The low cost and high availability of crude oil, led to a decline in interest in liquid fuels made from coal. The technology leader is Sasol, South Africa.
- 2015, Sasol has a Lake Charles, LA plant project to turn natural gas into ethylene. A bigger project to turn natural gas to diesel fuel cancelled in 2015 due to low oil prices.
Coal Gasification

Separated vertical rooms for external heating gasification.

Some systems are required to decrease the sulfur amount. Sulfur causes

\[
\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 \quad \text{acid corrosion}
\]

In order to reduce the sulfur: Wash of coal in advance with some chemicals, use some additives during the burning and sulfur traps (shower systems).

**Hydrogen insufficiency:** Generally gasification system results in 0.7 mol of hydrogen out of 1 mol CO. Theoretically, that ratio must be 2.

**Mitigation of Hydrogen Insufficiency:** Gas Water Shift reaction (next page) may be used to compensate for the hydrogen insufficiency and provide some hydrogen for cracking process.
Water Gas Shift (WGS) Reaction

Reaction temperature depends on catalysts. Generally, high temp 150-600°C, 3MPa or more. This is an exothermic (-41.2 kJ/mol) reaction so it releases heat.

![Diagram showing the WGS reaction]

To obtain the WGS reaction, highly selective catalysts and supports are necessary. Otherwise side reactions below are likely.

<table>
<thead>
<tr>
<th>Possible Side Reactions of the Water Gas Shift Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2CO ↔ C + CO₂</td>
</tr>
<tr>
<td>CO + H₂ ↔ C + H₂O</td>
</tr>
<tr>
<td>CO₂ + 2H₂ ↔ C + 2H₂O</td>
</tr>
<tr>
<td>2CO + 2H₂ ↔ CO₂ + CH₄</td>
</tr>
<tr>
<td>CO + 3H₂ ↔ CH₄ + H₂O</td>
</tr>
</tbody>
</table>
Putting Them Together: Coal to Oil

**COAL**

COAL + O₂ + H₂O → CO + H₂ (Coal Gasification)

**AIR**

O₂ → Air Compressor → Gas Turbine (Electric Energy)

**Gas Separator**

**Distillation Column**

CₙH₂ₙ₊₂ → Heavy Hydrocarbon → Cracking → Tall Gas → Fischer-Tropsch Process

**Gas Seperator**

(2n+1)H₂ + nCO → CO + H₂O

H₂O → Tall Gas → Fischer-Tropsch Process

Liquid Fuel

**CO₂**

Nitrogen: N₂

**Oxygen Generator**

**Water Gas Shift**

H₂ + CO₂ → (2n+1)H₂ + nCO

**Coal Gasification**

CO + H₂ → CO + H₂O
Putting Them Together: Gas to Oil

Natural Gas

Gas, $O_2$ → CO$_2$, $H_2$

Heat

$H_2$ $CO_2$

Air Compressor

Gas Separator

Electric Energy

Gas Turbine

Oxygen Generator

Air

Putting Them Together: Gas to Oil

Electric Energy

Gas Compressor

O$_2$

Gas Turbine

Oxygen Generator

Cracking

Fischer Tropsch Process

Distillation Colon

$C_nH_{2n+2}$

H$_2$ + nCO$_2$

C$_n$H$_{2n+2}$

Tall Gas

Heavy Hydrocarbon

Licenses by Haldor Topsoe, Denmark

Licensed by Sasol, South Africa

Sasol, Lake Charles, LA?

Oryx Plant, Qatar.


Some Gas-to-Oil plants in Malaysia and Russia. Methanol to Oil in New Zealand.

Licensed by Sasol, South Africa

Nitrogen: $N_2$

5% Liquid Petroleum Gas

20% Nafta

15-35% Kerosin

15-35% Diesel

H$_2$O
Summary – Coal

- Coal types
- Mining Methods
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- Coal Bed Methane
- Oil from Coal or Gas

Oil, Gas, Coal are similar molecules and are fossil fuels. They all have to be pumped, drilled and mined. They all emit greenhouse gasses in combustion. Their combustion can be used to create pressurred water vapor to turn turbines at power plants.
Appendix: Carbon Dioxide Penalty and Emissions

- **Penalty for emitting Carbon Dioxide** can be
  - Low penalty: Starting in 2010, $7 per ton, increasing at 5% per year, and reaching about $50 per ton in 2050.
  - High penalty: Starting in 2015, $25 per ton, increasing at 4% per year, and reaching about $100 per ton in 2050.

- **Nuclear reactor capacity expansion**
  - Limited capacity: 261 GW in 1997 and 327 GW in 2050. 1 GW = $10^9$ W = 3.4 $10^9$ Btu/hr
  - Expanded capacity: 261 GW in 1997 and 1000 GW in 2050.

Results of Emissions Predictions and Policy Analysis (EPPA) model: [http://globalchange.mit.edu/igsm/eppa.html](http://globalchange.mit.edu/igsm/eppa.html)

Business as usual and emissions continue to rise.

Low Penalty: Emissions stabilize ~ 2040 at ~ 42 Billion tons per year (2 x the level in 2000).

High Penalty: Emissions stabilize about 2015 at about 28 Billion tons per year.

These are all scenarios which have not happened!

No penalty in 2012 or in the near future. Nuclear capacity is 375 GW (= $10^9$ W) in 2010. Countries do not participate in these penalties such as carbon-cap and trade.
Appendix: Penalty and Emissions with Carbon Capture and Storage (CCS)

- High penalty becoming effective in 2015 can **reduce energy consumption** with respect to no penalty.

- High penalty can change the composition of energy sources:
  - Coal consumption without CCS drops
  - Coal consumption with CCS increases in the Limited Nuclear Capacity case. Decreases in the Expanded Nuclear Capacity case – Nuclear can substitute coal!
  - Oil consumption is stable and Gas consumption is increasing
  - Renewables increase

CCS is more important under high penalty and limited nuclear capacity when coal is expensive and needed. Limited nuclear capacity in the USA but expansions abroad; neither limited nor expanded capacity.