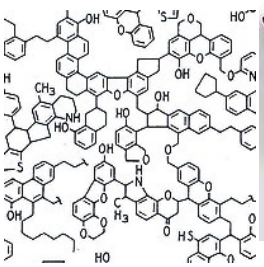
Coal

Coal

A readily combustable black or brownish-black sedimentary rock normally occurring in rock strata in layers of veins know as coal beds.

Formed from annual plant remains protected from biodegradation by acidic waters then later mud deposits mainly during the carboniferous period

Coal seam



Vein bituminous coal

Types of coal

Coal

Peat – a precursor of coal used in Ireland, Finland, Russia

Lignite (brown coal) – lowest rank of coal used for electric power generation

Sub-bituminous coal – properties range from lignite to bituminous coal used for
- Electric power generation
- Source of light aromatic hydrocarbons for the chemical synthesis industry

Bituminous coal – dense and black used
- Primarily electric power generation
- Heat and power in manufacturing
- Making coke

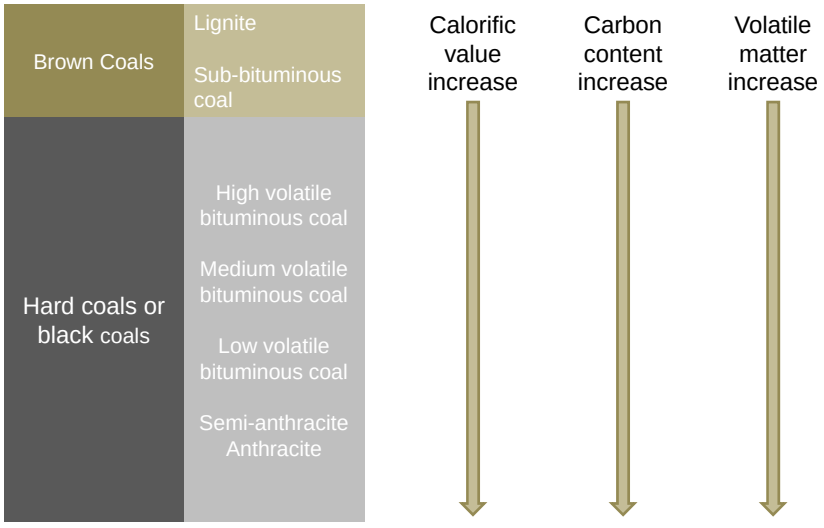
Steam coal – used for steam locomotives & domestic heating

Anthracite – highest rank used for residential and commercial space heating

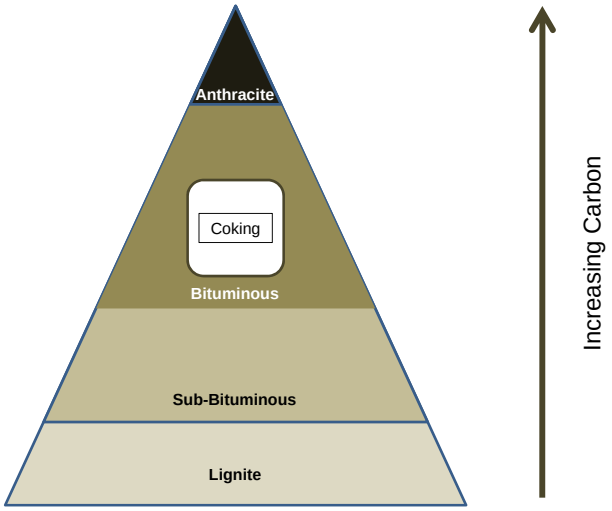
Graphite – highest rank but not used for fuel but pencils and, when powdered as a lubricant

Coal Classification

Coal



Ranks of Coal



Coal

Characteristics

Type	Volatiles (%)	C %	H%	O%	S%	Energy Content (GJ/t)
Lignite	45-65	60-75	6.0-5.8	34-17	0.5-3	28.47
Anthracite	7 - 12	>91.5	<3.75	<2.5	~1	35.3

History **Coal**

Outcrop coal used in Britain during Bronze Age (2000-3000 years BC)

Carved in Neolithic times in China (4000 C)

Used as fuel in Han Dynasty 206-220 AD

Romans exploiting coal from all major coalfields in E&W by 2nd Century

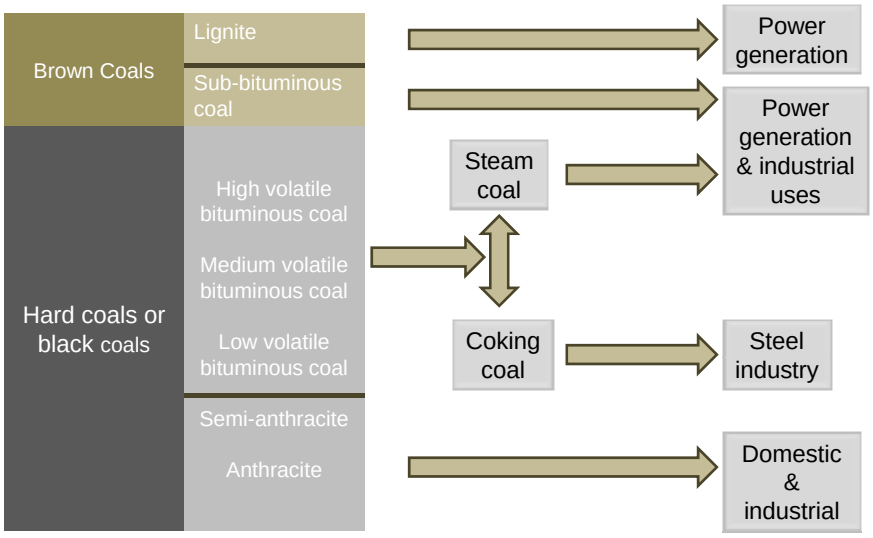
Not developed on large scale until industrial revolution

Coal Combustion **Coal**

300 BC	Greeks record use of coal combustion
1700s	First steam engines
1820s	Stoker boiler
1881	First steam electric plant
1920s	Pulverised coal boiler
1920-present	Atmospheric fluidized bed combustor
	Pulverised coal boiler to 38% efficiency
	Supercritical boilers
	Cyclone combustors (1950s)
	Pressurised fluidised bed combustor (1980s)
	Environmental controls for No_x and SO_2

Coal uses, by coal type

Coal



Uses

Coal

- Two major uses for coal:
  - Electricity generation (7100 Mtce in 2010)
  - Steel production (721 Mtce in 2010)
- Coal provided in 2010:
  - 23% of total global primary energy demand
  - 40% of the world's electricity production
  - 70% of the world steel production
- Five largest users: China, USA, India, Russia, Japan account for 77% of global consumption

Coal

Importance of Coal in Electricity Generation

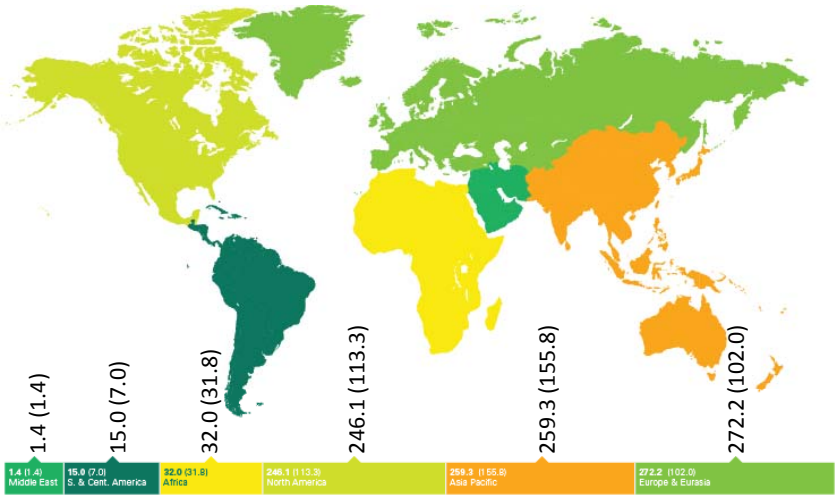
Country	%	Country	%	Country	%
S Africa	93	Poland	92	China	79
Australia	77	Kazakstan	70	India	69
Israel	63	Czech Republic	60	Morocco	55
Greece	52	USA	49	Germany	46

Coal

Reserves - Production

	World coal reserves (745,000 mtce in 2000)	World coal production (3210 mtce in 2000)
North America	25%	29%
Europe	11%	11%
Former Soviet Union	22%	9%
Australasia	9%	7%
Africa	8%	6%
S & Central America	2%	2%
Asia	23%	36%

Proved coal reserves 2008



Source: BP Statistical Review of World Energy June 2009

Thousand million tonnes (anthracite & bituminous coal in brackets)

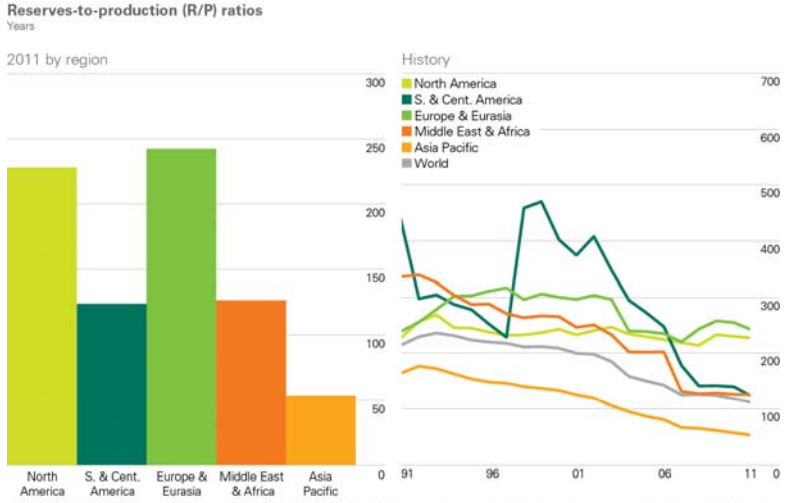
Coal

Coal Reserves Mtonnes

Region	Anthracite and Bituminous	Sub-Bituminous & Lignite	Total	Share (%)	R/P (y)
N America	112835	132253	245088	28.5	228
S&C America	6890	5618	12508	1.5	124
Europe & Eurasia	92990	211614	304604	35.4	242
Middle East & Asia	159326	106517	265843	30.9	53
World	404762	456176	860938		112

Source: BP 2012

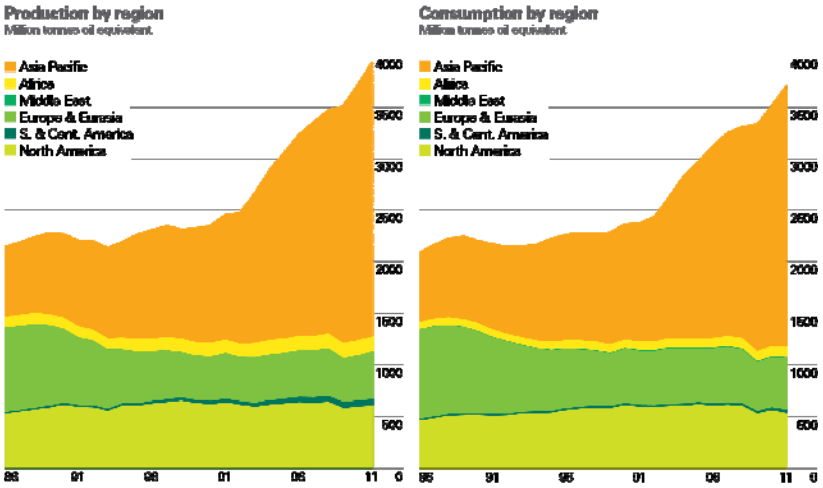
Coal reserves-to-production ratios 2011



World proved reserves of coal in 2011 were sufficient to meet 112 years of global production, by far the largest R/P ratio for any fossil fuel. Europe & Eurasia holds the largest regional reserves and has the highest R/P ratio. The Asia Pacific region holds the second-largest reserves, while North America has the second-highest R/P ratio.

BP Statistical Review of World Energy 2012

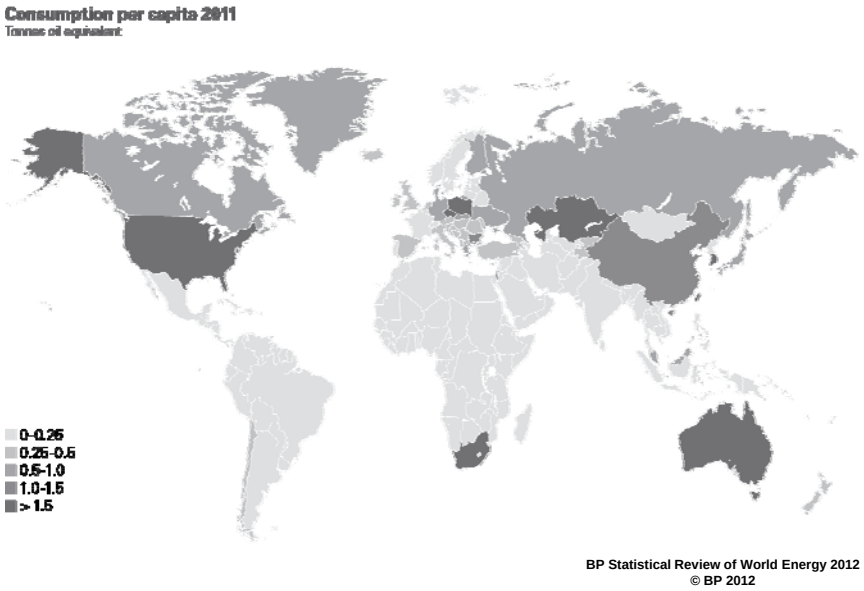
Coal production/consumption by region



Coal was again the fastest-growing fossil fuel. Global production grew by 6.1%. The Asia Pacific region accounted for 86% of global production growth, led by an 8.8% increase in China, the world's largest supplier. Global coal consumption increased by 5.4%, with the Asia Pacific region accounting for all of the net growth. Elsewhere, large declines in North American consumption were offset by growth in all other regions.

BP Statistical Review of World Energy 2012

Coal consumption per capita 2011



Coal

Coal Reserves at End 2008 (Million Tonnes)

	Bituminous & Anthracite	Sub-Bituminous & lignite	Lignite	Total	Share (%)
USA	108,501	98,618	30,176	237,295	22.6
Russia	49,088	97,472	10,450	157,010	14.4
China	62,200	33,700	18,600	114,500	12.6
India	56,100	0	4,500	60,600	7.0
Australia	37,100	2,100	37,200	76,500	8.9
Germany	99	0	40,600	40,699	4.7
Ukraine	15,351	16,577	1,945	33,873	3.9
Kazakhstan	21,500	0	12,100	33,600	3.9
S Africa	30,156	0	0	30,156	3.5
World	**404,762**	**260,789**	**195,387**	**860,938**	

Coal

Coal Production (Million Tonnes)

	2003	2005	2007	2009	2011	Share	Reserve Life (y)
China	1834.9	2349.5	2691.6	2973.0	3520	49.5%	35
USA	972.3	1026.5	1040.2	975.2	992.8	14.1%	239
India	375.4	428.4	478.4	556.0	588.5	5.6%	103
EU	637.2	607.4	592.3	538.4	576.1	4.2%	97
Australia	350.4	375.4	392.7	413.2	415.5	5.8%	184
Russia	276.7	298.3	313.5	301.3	333.5	4.0%	471
S Africa	237.9	244.4	247.7	250.6	255.1	3.6%	118
World	**5301.3**	**6035.3**	**6573.3**	**6880.8**	**7695.34**		**112**

Coal

Coal Consumption (Mtoe)

	1970	1980	1990	2000	2010
China	162.9	304.9	507.1	709.6	1676.2
USA	309.1	388.6	483.1	569.0	526.1
India	37.6	56.7	95.5	144.2	207.1
Russia			180.6	105.2	90.2
Japan	60.2	57.6	76.0	98.9	123.7
S Africa	27.4	42.7	66.4	74.6	91.3
Germany	151.7	139.5	129.6	84.9	76.7
UK	96.0	71.1	64.9	36.7	31.0
World	**1499.3**	**1804.0**	**2207.0**	**2372.2**	**3532.0**

Source: BP Annual Energy Statistics 2010

Coal

Major Coal Exporters (Million Short Tonnes)

Country	2006	2008	2010	Share
Australia	255	278	328.1	27%
Indonesia	192	228	316	26.1%
Russia	103.4	115.4	122.1	10.1%
USA	51.2	83.5	83.2	6.9%
Columbia	68.3	74.7	76.4	6.3%
South Africa	75.8	68.2	76.7	6.3
Canada	31.2	36.5	36.9	3.0%
Kazakhstan	30.5	47.6	36.3	3.0%

Coal

Major Coal Importers (Million Short Tonnes)

Country	2006	2008	2010	Share
Japan	200	206	207	17.5%
China	42	44.5	195	16.6%
S. Korea	84	107	126	10.7%
India	53	71	102	8.6%
Taiwan	69	71	71	6.0%
Germany	51	56	55	4.7%
UK	57	49	29	2.5%

Coal Mining

Coal

- Coal is mined by two methods:
  - Surface or “opencast” mining
  - Underground or “deep” mining
- Method largely determined by geology of the coal deposit
- Underground mining accounts for ~60% world coal production
- Surface mining accounts for 80% in Australia and 67% in USA

Surface Mining

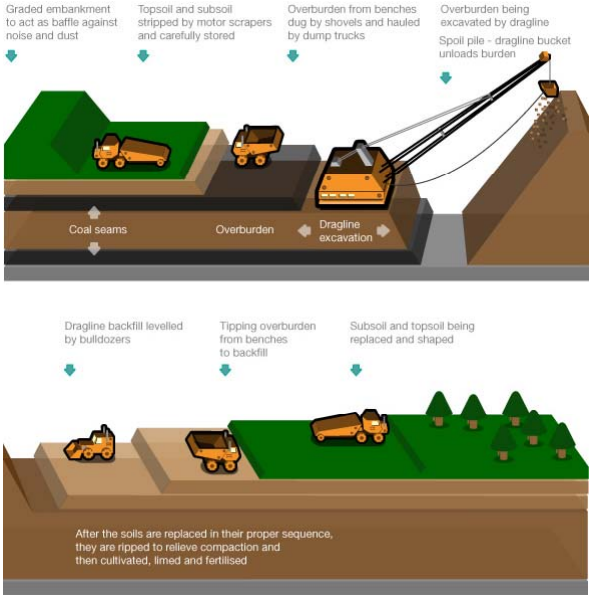
Coal

- Only economic when coal seam near surface
- Recovers higher proportion of coal deposit than underground mining ~90%
- Large opencast mines can cover an area of several square kilometres & use large equipment
  - Draglines to remove the overburden
  - Power shovel
  - Large trucks to transport the coal
  - Bucket wheel excavators
  - Conveyors

- Overburden of soil and rock broken up with explosives & removed
- Exposed coal seam is drilled, fractured and systematically mined in strips

Surface Mining

Coal

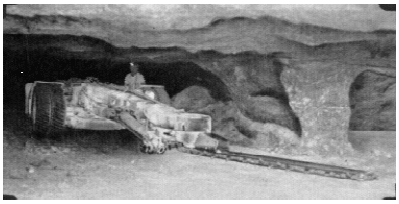


Underground Mining

Coal

Two main methods:

- Room-and-pillar
- Longwall – 50% of underground mining



Room & Pillar

- Coal deposits are mined by cutting a network of “rooms” into the coal seam and leaving behind “pillars” of coal to support the roof of the mine
- Pillars account for ~40% of the coal seam

Underground Mining

Coal

Longwall mining

- Involves full extraction of coal from a section of seam or face using mechanical shears
- Coal face 100 – 350 m
- Self-advancing hydraulically-powered supports temporarily hold up the roof while coal is extracted
- When coal extracted roof allowed to collapse
- >75% of coal in seam can be extracted



Coking and use of coke

Coal

Coke – a solid carboniferous residue derived from low-ash, low-sulphur bituminous coal from which volatile constituents driven off by baking in an oven without oxygen at 1,000^{o}C so that fixed carbon and residual ash fused together

Coke from coal is grey, hard, porous and 29.6 GJ/t

By-products include coal tar, ammonia, light oils and coal gas

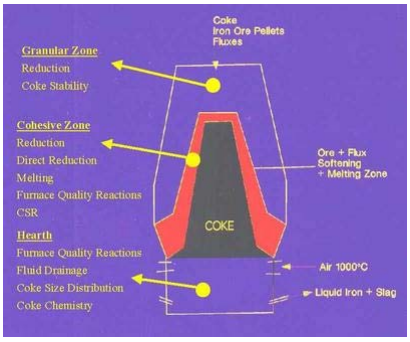
Metallurgical coke is used as a fuel and as a reducing agent in smelting iron ore in a blast furnace

Coking and use of coke

Coal

Coal to coke transformation

- Heat is transferred from heated brick walls into coal charge
- 375-475ºC coal decomposes to form plastic layers near each wall
- 475-600ºC marked evolution of tar and aromatic hydrocarbons and resolidification of the plastic mass into semi-coke
- 600-1100ºC coke stabilization phase begins – contraction of coke mass, structural development of coke and hydrogen evolution
- Once the plastic layers have met at the centre of the oven the entire mass has been carbonised
- Incandescent coke mass pushed from oven and quenched prior to shipment to blast furnace



Blast Furnace Operating Zones and Coke Behaviour

Underground coal gasification (UCG)

Coal

- An industrial process that enables coal to be converted into product gas *in situ*
- Carried out in non-mined coal seams using injection of oxidants and bringing the product gas to the surface through production wells drilled from the surface
- Product gas used as feedstock or fuel
- Used on otherwise not economic coal reserves
- Less environmental impact than coal mining and gasification

Underground coal gasification

Coal

- First suggested in 1868 by Sir William Siemens
- Idea developed by Dmitri Mendeleyev
- First experimental work in Durham in 1912
- No further development until after WWII
- Significant development in Russia in 1960s with 14 plants in operation but discontinued with discovery of natural gas in Uzbekistan
- Picked up again in Europe in 1980s
- Successful demonstration in Queensland (1999-2003) has resulted in surge of interest

Underground coal gasification

Coal

Criteria

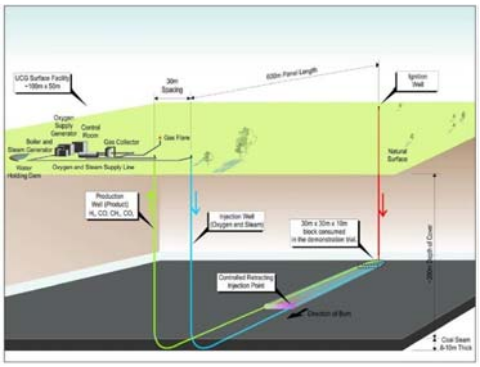
- Seam lies underground at depth of 100 – 600 metres
- Seam thickness no more that 5 metres
- Ash content of coal <60%
- Seam has minimal discontinuities
- No nearby aquifers (to avoid polluting drinking water)

Underground coal gasification (UCG)

Coal

Technology

- One production well drilled into the un-mined coal-seam for injection of oxidants
- 2nd production well drilled to bring product gas to the surface
- Coal seam ignited and burns at 700 - 1500°C
- Generates:
  - CO_2
  - Hydrogen
  - CO
  - CH_4
  - H_2S



Gasification

Coal

Coal gasification used to produce syngas (CO & H_2)

Syngas converted through Fischer-Tropsch process to gasoline & diesel

Used by Sasol in South Africa to make gasoline from coal & natural gas

$$Coal + O_2 + H_2O \longrightarrow H_2 + CO$$

Can also use water shift reaction to produce more hydrogen

$$CO + H_2O \longrightarrow CO_2 + H_2$$

Coalbed Methane

Coal

- Coalbed Methane (CBM) – a form of natural gas extracted from coal beds
- Important source of energy in USA & Canada
- Refers to methane adsorbed into the solid matrix of coal
- Known as a "sweet gas" because there is no H_2S
- Methane is in a near-liquid state, lining the inside of pores within the coal
- Open fractures in coal (cleats) can also contain free gas
- Gas mainly methane with trace quantities of ethane, nitrogen and CO_2

Factors affecting production

- Permeability of the reservoir
- Porosity
- Adsorption capacity
- Thickness of formation & initial reservoir pressure

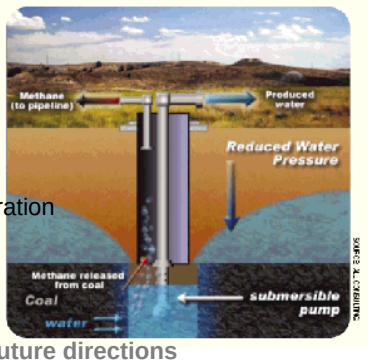
Coalbed Methane - Extraction

Coal

- Steel-encased hole drilled into coal seam (100-1500m below ground)
- Gas escapes to surface
- Gas compressed and sent to pipeline
- CBM wells produce at lower rates than conventional reservoirs (8,500m^3/day)
- Methane desorption follows a curve (gas content *vs* reservoir pressure – a Langmuir isotherm)
- Varies with coal type

Potential a function of:

- Cleat density/intensity
- High cleat density required for profitable operation
- Maceral composition important
- High vitrinite composition is ideal



Coal Mine Methane

Coal

- After an underground coal mine has been abandoned methane released from the remaining coal accumulates in the voids and is diluted by air to methane concentrations of 25 – 75%
- Can be recovered commercially as coal mine methane (CMM) from operating mines or abandoned mine methane from abandoned mines (AMM)
- Number of operations in UK
- Production in 2005 was 69 Mm^3
- Methane used in gas engines to generate electricity

Environmental effects

Coal

- Release of carbon dioxide – a GHG
- Generation of waste products including fly ash, bottom ash, flue gas desulphurisation sludge containing mercury, uranium, thorium, arsenic, and other heavy metals
- Acid rain from high sulphur coal
- Interference with groundwater and water table levels
- Contamination of land and waterways with fly ash
- Subsidence above tunnels
- Coal-fired power plants without effective fly ash capture are one of the largest sources of human-caused background radiation exposure
- Coal-fired power plant releases emission including mercury, selenium and arsenic

Clean Coal

Coal

Umbrella term describing technologies being developed that aim to reduce the environmental impact of coal electricity generation. They include:

- Chemical washing minerals and impurities from the coal
- Gasification (IGCC)
- Treating flue gases with steam to remove SO_2
- Carbon capture and storage technologies to capture the CO_2 from flue gas
- Dewatering brown coals to improve calorific value
- But what about the mercury (5000 t global) and radio-nuclides

Some say that "clean coal" is an oxymoron! And not achievable

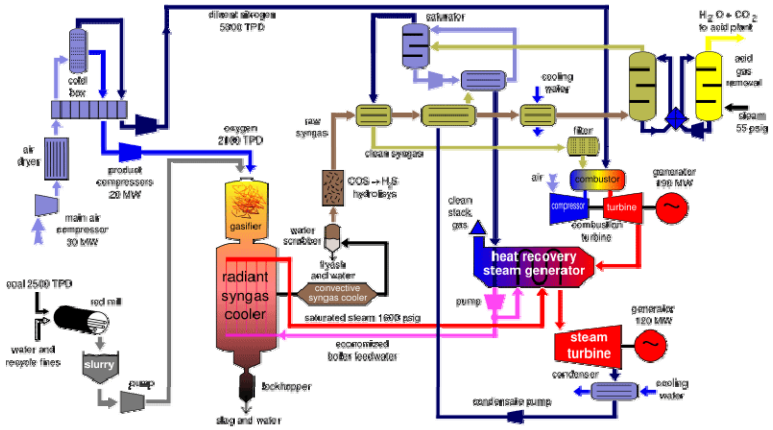
Integrated Gasification Combined Cycle

Coal

- A power plant using synthesis gas produced from coal
- Gas used to power a gas turbine whose waste heat is passed to a steam turbine (Combined Cycle Gas Turbine)
- Removes impurities from the coal before it is combusted
- Gives lower emissions of SO_2, particulates & mercury
- Gives greater efficiency of power generation
- But very expensive and reliability issues

Integrated Gasification Combined Cycle

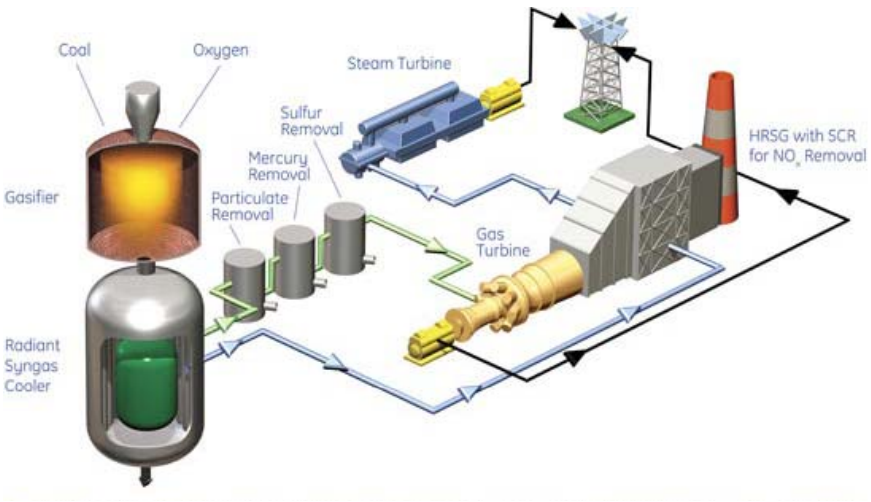
Coal



EG5066 Energy Technologies: current issues & future directions

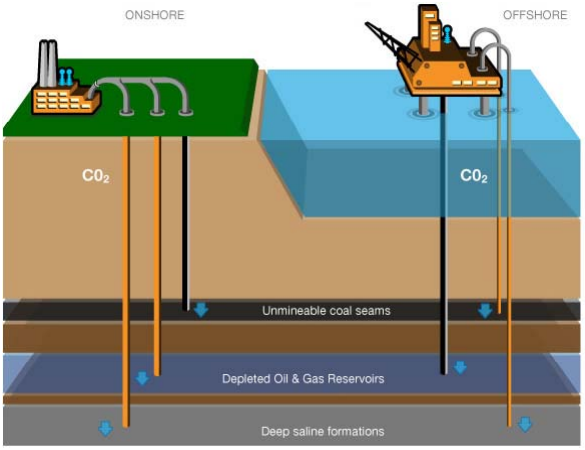
Integrated Gasification Combined Cycle

Coal



EG5066 Energy Technologies: current issues & future directions

Carbon Capture & Storage **Coal**



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