# Coal Mining and Logistics

## HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** Coal mining and logistics covers coal extraction from mines, coal preparation and coal transportation to the final users, such as power plants or industrial areas. As of January 1, 2009, total recoverable coal reserves were estimated at 858.3 billion metric tons, corresponding to a reserves/production ratio of 120 years [2]. Although coal reserves exist in 70 countries, they are concentrated in only few countries/regions - the United States (27%), Russia (18%), China (13%), non-OECD Europe and other Eurasia (1%), and Australia/New Zealand (9%) [2]. Total coal production reached about 7.2 billion metric tons in 2010) [2]. Global coal trade movements are small compared with global coal consumption: only 14% of the total coal consumed was imported in 2010 [2]. On the exporter's side, Indonesia made significant gains representing 50% of the additional coal exports between 2000 and 2011. China and India became major importers representing 57% of the incremental 2000-2011 coal imports.

■ **PERFORMANCE AND COSTS –** GHG emissions are a key issue in coal mining and logistics. Coal mining results in methane emissions of about 10-25 m3/tonne for underground mining and 0.3 –2.0 m3/tonne for surface mining. Post-mining operations also result into methane emissions of 0.4-4.0 m3/tonne for underground mining and 0-0.2 m3/tonne for surface mining. These emissions rates exclude recovered emissions. Emissions from coal transportation are same as the emissions involved in freight transportation, i.e. 62g CO2/tonne-km for road transport, 22g CO2/tonne-km for rail, 31g CO2/tonne-km for inland waterways, 16g CO2/tonne-km for short-sea shipping, 8.4 g CO2/tonne-km for deep-sea – container shipping and 5 g CO2/tonne-km for deep-sea tanker operations [14]. Total upstream emissions have been calculated in many life cycle analyses for coal power plant in the US, including methane releases from mines and fuel combustion during mining and transportation activities. Resulting emission factors are 5.1-10.1 kg CO2-eq/GJ for coal mining and processing, and 0.7-2.6 kg CO2-eq/GJ for coal transportation [11, 12, 13]. Data from main producing countries were used in order to estimate coal supply costs in various world regions [7]: 0.3 to 0.79 $/GJ for lignite reserves, and 1.0-3.7 $/GJ for hard coal reserves. Coal transportation can account for up to 70% of the total delivery cost. Transportation costs between world regions vary between 0.1-0.9 $/GJ, which include a coal handling fee in sea ports of about US$2/ton [7]. In Europe, inland water transportation involves different types of waterways, barges, and consequently, transportation costs vary accordingly: 1.8-3.1 €/t (from ARA-ports to the Ruhr), 9.7-11.3 €/t (on the Main-Danube canal to Austria), and 3.6-4.1 €/t (from Hamburg on the Elbe, the Elbe-Havel canal and the Havel to Berlin) [6]. As for port charges and handling costs, there is about 0.3 €/t for the pier tax, 3 €/t for railway loading in the port and 5 €/t as follow-up costs to the final destination [6]. As for coal transportation rates to the electric power sector in the US they also vary widely depending on the regions and the transportation mode. In 2010, the average was US$(2005)17.1/metric ton (38.6% of the total delivery cost), while the range was US$(2005) 11-21.5/metric tons. For barges, the average was US$(2005) 6.4/metric ton (11.4% of the total delivery cost); for trucks, the average was US$(2005) 6.2/metric (15.4% of the total delivery cost).

■ **POTENTIAL AND BARRIERS –** Coal will continue to play an important role in the future energy mix [5]. It is an affordable source of energy which plays an important role in terms of energy security. It is abundant in several countries and can be easily transported and stored at power plants. With the development of the coal-to-liquids industry, coal can also become a substitute to oil. Carbon capture and storage (CCS) can play an important role in the efforts to reduce CO2 emissions from coal combustion, though significant investments are required to implement cost-effective CCS technologies. Finally, technologies are currently being developed to capture and use the methane emitted from mining operations (coal mine methane, CMM), which currently accounts for 8% of the total anthropogenic methane emissions. More than 220 CMM projects are currently being developed in 14 countries with important coal reserves, e.g. Australia, China and the US [5].



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## PROCESS AND TECHNOLOGY STATUS

Coal mining and logistics covers coal extraction from mines, coal preparation and transportation to the final users such as power plants or industrial plants.

■ **Coal Mining** - There are two mining methods for coal extraction depending on the geology and economics of the deposit: **underground mining** (60% of world coal production) and **surface mining** [4]. Surface mining is more important in many producing countries such as Australia and the United States. For underground mining, the two main methods are: 1) **room-and-pillar**, where deposits are mined by cutting a network of 'rooms' and leaving behind 'pillars' for roof support, and 2) **long-wall** mining by full extraction from a section of the seam or 'face' using mechanical shearers [4]. Room-and-pillar method requires mobile machinery with a total investment cost below 5 M$ while long-wall mining machinery can cost as much as 50 M$ to purchase [4]. Surface mining (or open-cast, open-cut, open-pit mining) methods are possible only when seams are close to the surface. These methods recover a higher proportion of the deposit (90% and above) than underground mining and require large equipment such as draglines, power shovels, trucks, bucket wheel excavators and conveyors. In general, coal production at a specific mine depends on the thickness of the coal seam and the land area being mined: for instance, in a coal seam of 70 feet deep, 100,000 tons of coal can be produced on one acre [8].

■ **Coal Preparation** - Coal preparation (or cleaning) is needed in order to remove the impurities (sulfur, ash and rocks), to ensure a consistent quality and to upgrade coal value. Depending on the properties and its final uses, coal can require simple crushing or a more complex treatment such as physical or chemical cleaning processes. Physical cleaning is the most common approach, while chemical cleaning is in general more expensive, with widely varying performance and costs. Physical cleaning means a mechanical separation of impurities based on density differences, and requires four phases: initial preparation (screening for classification into coarse and fine coal fractions), fine coal processing, coarse coal processing (upward or downward currents), and final preparation (removing moisture through dryers such as fluidized bed, flash, and multi-louvered.

■ **Coal Transportation** - At the global level, coal is traded around the world and cover long distance to reach final markets. Transportation costs account for a large proportion of the total delivered cost [5]. Coal is usually transported on railways, by barges on inland waterways or by large vessels through oceans, such as Panamax vessels (75,000, dwt[1], i.e. the maximum dimension fitting through the Panama canal) or Capesize vessels (170,000 dwt) [7]. Coal can also be shipped by pipeline as a coal-water mixture (slurry). For short distances or for small portions of the routes, heavy trucks are also used.

[1] dead weight ton

■ **Coal Types and Reserves** – Coal can be classified into four main types based on its carbon and energy content [8]:

- **Anthracite**: 86-97% carbon and a heating value slightly higher than bituminous coal. Account for only 0.5% of coal production in the US.
- **Bituminous coal**: 45-86% carbon; formed under high heat and pressure about 100 to 300 million years ago; accounts for about 50% of coal production in the US. is used for electricity generation, as a fuel and as a raw material in iron & steel industries.
- **Sub-bituminous coal**: 35-45% carbon; a lower heating value than bituminous coal; formed at least 100 million years ago; accounts for about 44% of coal production in the US.
- **Lignite**: 25%-35% carbon; deposits are relatively younger and were not subjected to extreme heat or pressure; account for about 7% of coal production in the US; it is used for electricity generation.

Anthracite and bituminous are hard coals, while sub-bituminous and lignite are soft or brown coals [4]. The peat is initially converted into lignite, a soft coal, and its colour can take various shades of brown. With the continuing evolution of the organic maturity, the lignite is transformed into sub-bituminous coals. Further changes occur over millions of years until these coals became harder and darker, forming the bituminous or 'hard coals'. Under specific temperature and pressure conditions, the organic maturity continue to evolve to finally form anthracite. Heating values of coal grade vary widely depending on coal type, reserve locations and conditions (Table 1) [15].

Coal quality varies significantly across deposits and regions. Premium-grade bituminous coals, or coking coals, used to manufacture coke in the steel industry are at the top quality level. For instance, the average heat content of US coking coals is about 27.7 TJ per kilotonne and the sulfur content is only 0.9% by weight [2]. On the opposite, some lignite resources have very low heat content: it varies between 5.2 TJ per kilotonne in Greece to 13.6 TJ per kilotonne in Canada, values below typical lower heating values [2].

As of January 1, 2009, total recoverable coal reserves were estimated at 858.3 billion metric tons[2] (Table 2), corresponding to a reserves/production ratio of 120 years [2]. By including deposits that are not "proven" yet, the total resources are 20 times more important [1].

[2] Converted from short tons (1 short ton = 907.18 kg)

Anthracite and bituminous coal account for 47% of the recoverable reserves, sub-bituminous coal for 30%, and lignite for 23% [2]. These figures indicate that coal reserves are abundant enough to meet a long-term global demand at the current consumption rate. Consequently, coal supply is not affected by production constraints, nor by pressure on commodity price. However, the production costs are expected to increase with mines depletion. New investment may be required in the future to extract coal from less productive or less accessible deposits [1]. This cost raise might be partially offset by productivity gains from technological advances. In addition, recoverable reserves could increase as mining technology develops and additional geological studies are performed. In terms of geographical distribution, coal reserves exist in some 70 countries, but are particularly abundant only in a few countries/regions: the United States (27%), Russia (18%), China (13%), Australia/New Zealand (9%), non-OECD Europe and other Eurasia (1%) [2].

■ **Coal Production** – As mentioned above, coal is available for mining and production in about 70 countries. The global production amounted to about 7.2 billion metric tons in 2010 (see Table 3), and the five most important producing regions (i.e. the US, Russia, China, Australia, non-OECD Europe) represent 72% of the global production by tonnage. The two most important exporters are Australia and Indonesia, but they hold only 7% of the global reserves of hard coal [1]. In terms of investment, the 30 companies accounting for 40% of global coal production invested a total 16 billion dollars in 2010 and this trend of global investment is expected to continue in future years [1] though since recently, the coal consumption in the US is being reduced as a result of the competition of unconventional gas resources (shale gas).

However, the coal industry faces some challenges such as the opposition from environmental groups as a consequence of the environmental and safety impacts of coal mining and burning, and the enforcement of environmental regulations in many countries (e.g. the US Clean Air Act).

Although the domestic coal demand decreases, the United States is still the second coal producer at the global level. The majority of the production is currently coming from the central and western regions, and more and more from the northern part of the Appalachian Basin to replace the declining production of the Central Appalachian mines [2]. Either in the US and in Canada, while coal use decreases and coal power is phase out, coal production remains significant in order to supply high-quality hard coking coal on international markets, namely to iron and steel industries in Asia. Consequently, firms are investing in mine and terminal expansions, as well as productivity and technology improvements [2].

Table 1- Typical coal high/low heating values [15]

| TJ/kilotonne | Low | High |
|---|---|---|
| Anthracite | 27.70 | 32.56 |
| Bituminous | 24.42 | 32.56 |
| Sub-bituminous | 19.31 | 26.75 |
| Lignite | 14.65 | 19.31 |

Table 2- Recoverable coal reserves by regions, 2009 (metric tons) [2]

| Region/ Country | Anthracite, Bitum Coal, | Sub-bitum. Coal | Lignite | Total |
|---|---|---|---|---|
| United States | 107.4 | 97.2 | 30.0 | 234.6 |
| Russia | 49.1 | 97.4 | 10.4 | 157.0 |
| China | 62.2 | 33.7 | 18.6 | 114.5 |
| Other Europe, Eurasia | 38.3 | 17.1 | 36.2 | 91.5 |
| OECD Europe | 5.6 | 0.8 | 49.4 | 55.9 |
| Australia, and New Zealand | 37.1 | 2.3 | 37.6 | 76.9 |
| India | 56.1 | - | 4.5 | 60.6 |
| Africa | 31.5 | 0.2 | - | 31.7 |
| Non-OECD Asia | 3.5 | 3.5 | 6.2 | 13.3 |
| Latin America | 6.9 | 0.9 | - | 7.8 |
| Canada | 3.4 | 0.9 | 2.3 | 6.6 |
| Brazil | - | 4.5 | - | 4.5 |
| Other | 2.4 | 0.7 | 0.1 | 3.3 |
| World | 403.7 | 259.4 | 195.2 | 858.3 |

Table 3 - Coal production, 2010 (M metric tons) [2]

| | |
|---|---|
| OECD America | 1,062 |
| • United States | 983 |
| • Canada | 68 |
| • Mexico/Chile | 11 |
| OECD Europe | 562 |
| OECD Asia | 432 |
| • Japan | - |
| • South Korea | 2 |
| • Australia/New Zealand | 429 |
| Total OECD | 2,057 |
| Non-OECD Europe/ Eurasia | 621 |
| • Russia | 326 |
| • Other | 295 |
| Non-OECD Asia | 4,196 |
| • China | 3,181 |
| • India | 555 |
| • Other | 461 |
| Middle East | 1 |
| Africa | 259 |
| Central/South America | 83 |
| • Brazil | 5 |
| • Other | 77 |
| Total World | 7,216 |

In Europe, Germany, Poland, and Turkey are the leading producers with 69% of the total production [2].

In OECD Asia, Australia accounted for 98% of the region's total production in 2010, with two-thirds of its production being exported, mainly in Asia [2]. Australia is the fourth-largest producer, the largest exporter of metallurgical coal and the second-largest exporter of steam coal. Investors from India and China are working with local producers on existing mine expansion and new mine development (with associated transportation and port infrastructure). Future projects may be impacted by a mineral resource rent tax (30% on mining profits) imposed in 2012.

In Non-OECD Asia, China, India, and Indonesia are three leading countries at both regional and global level, being the first-, third-, and fifth-largest world producers with a combined production representing more than half of the global production [2]. While China and India try to secure supplies for their large and increasing domestic markets at affordable cost, Indonesia exports most of its low-cost and lower sulfur and ash content coal to Asia and other markets. The expansion of the coal industry in the region is strongly supported by developments of transportation infrastructure and favorable government policies. While the high coal consumption in China is now posing tremendous environmental challenges, China is now also faced by some logistics problems (transportation bottlenecks) because of the geographic mismatch between its lower-cost mines (north and the northwest regions) and its coal-using industry (southern and eastern regions). Consequently, the China's 12th Five-Year Plan includes important investments in rail capacity, i.e. 880 million tons to be added between 2013 and 2018 as well as efficiency and safety improvements in mining operations [2].

In Non-OECD Europe and Eurasia, most of the production is located in Russia (52%) and Kazakhstan (18%) [2]. Although Russia possesses vast reserves, the production is constrained by economic and logistic challenges due to the large availability of natural gas and subsidies. The coal industry also faces increasing costs due to reserve depletion and high transportation cost due to the large distances to cover. Large investments were announced in capacity expansion and safety improvement to benefit from diversified domestic supplies and increased natural gas export opportunities.

South Africa is the main producer (98%) in Africa and an important player at the world level (26% of the production is exported to Europe and Asia) with significant low-cost and high-quality coal reserves and a beneficial position between the Atlantic and Pacific markets with the world's largest coal export terminal at Richards Bay [2]. Investments will be necessary for developing new mines and railways.

In Central and South America, Colombia is the leader (90%) and most of its production is traditionally exported to Europe and the Americas [2]. In order to benefit from exporting opportunities in Asia, large investments are planned in the road, rail and port infrastructure.

■ **Coal Trading** – Since countries that consume coal the most are also those who have significant coal reserves, global coal trade movements are very small compared with global coal consumption: only 14% of the total coal consumed was imported in 2010 [2].

Table 4 presents the international coal trade for two distinct separate markets: steam or thermal coal for power and industrial steam generation (75%) and coking coal for coke production as an agent for smelting of iron ore in blast furnaces (25%).

On the exporter's side, Indonesia made significant gains representing 50% of the additional coal exports between 2000 and 2011 and displacing Australia as the first coal exporter.

On the importer's side, China and India became major players representing 57% of the additional coal imports between 2000 and 2011. Continuing growth in coal imports is expected in non-OECD Asia, though international coal trade is difficult to predict because of substantial increases of producing and transport costs; the necessary buildup of infrastructure, including mining, inland transportation, and port capacity; the increasing environmental cost of coal use, and the continuing shift towards more demanding environmental policies." [2].

In future, the expansion of the Panama Canal in 2015 would benefit the US and Colombia's producers as lower freight rates would result from shipping through larger bulk shipping vessels: from 80,000 to 140,000 dwt [2]. Shipments from ports in Colombia and the Eastern US to Asia travel through a longer route around the Cape of Good Hope in South Africa. "As an example, the shipping distance from Puerto Prodeco, Colombia, to Guangzhou, China, is approximately 13,000 nautical miles via the Cape of Good Hope in South Africa but only about 9,700 nautical miles through the Panama Canal in Central America." [2].

## OPERATION EXPERIENCE AND PERFORMANCE

■ **Energy Use in Coal Mining** – In the US, the average recovery rate in coal mining is about 82%, a higher value compared with the recovery rate of metals (e.g. 19% for iron), but lower than the recovery rate of minerals (e.g. 92.6% for crushed stones) [16].

Several type of energy sources are normally used for coal mining, the most important being petroleum

Table 4 - Coal import and export, 2011 (Million metric tons) [2]

| Exporters | Importers | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Steam | | | | Coking | | | |
| | Europe/ Other | Asia | Americas | Total | Europe/ Other | Asia | Americas | Total |
| Australia | 0.9 | 142.8 | 3.5 | 148.3 | 18.5 | 107.7 | 3.6 | 133.3 |
| United States | 20.3 | 7.3 | 6.5 | 34.2 | 32.4 | 17.9 | 12.9 | 63.1 |
| South Africa | 23.4 | 39.6 | 1.6 | 69.1 | - | - | 0.4 | 0.9 |
| Eurasia | 43.1 | 29.6 | - | 72.7 | 4.2 | 6.9 | - | 11.1 |
| Poland | 3.6 | - | - | 3.8 | - | - | - | - |
| Canada | 0.1 | 5.4 | 0.3 | 5.8 | 5.4 | 18.3 | 4.0 | 27.7 |
| China | - | 10.9 | - | 10.9 | 0.1 | 3.5 | - | 3.6 |
| Latin America | 57.3 | 1.8 | 20.7 | 79.9 | - | - | - | - |
| Vietnam | - | 25.1 | - | 25.1 | - | - | - | - |
| Indonesia | 13.9 | 302.4 | 1.4 | 318.4 | - | 18.9 | 0.2 | 19.1 |
| Total | 162.6 | 564.9 | 33.9 | 768.3 | 60.5 | 173.2 | 21.0 | 258.6 |

products (mainly diesel), electricity, coal, and natural gas. A study on the potential energy savings from the mining industry in the US [16] provides useful information on specific energy consumption estimates for the coal mining industry. The average is estimated at 0.391 GJ/ton of coal mined.

Significant energy savings (49%) can be achieved by improving energy efficiency, implementing best practices and new technologies through R&D investments [16]. The largest potentials in terms of energy efficiency rely in grinding techniques and diesel equipment for materials handling. While the total energy consumed in the US for coal mining operations reaches about 512 PJ per year, the energy savings can amount to 250 PJ per year, approximately [16].

As for coal transportation, energy use is similar to any other commodity and largely depends on the transportation mode, the type of fuel used and the fuel efficiency. Energy consumptions are derived from activity-based emission coefficients (gCO2/tonne-km) knowing the fuel-based emission coefficient, i.e. 2.70 kg CO2e per litre of diesel and 2.98 kg CO2e per litre of residual fuel oil (see the section on GHG emissions from coal transportation for more details) [18].

■ **Methane Emissions from Mining**. Methane (CH4) is produced during coal formation and a fraction of gas remains trapped under pressure in the seam and surrounding strata. During the mining operations, this methane is released in the atmosphere in quantities that vary with the coal type, seam depth and mining method. Emissions increase with coal rank and seam depth, and depend on underground mining techniques [9]. Methane emissions from underground mining accounted for 7% of total methane emissions in the US in 2011, while emissions from surface mines accounted for 2% [8]. Some companies are starting to capture and use or sell the methane emissions from mines.

In order to remove methane during underground mining and prevent explosions (that may occur if methane concentrations is above 5%), producers can use two types of systems: ventilation to reduce methane concentrations below 1%, or degasification [9]. Ventilation is used in most countries: the air vented out of the mine leads to significant methane emissions. Degasification is used mainly in Australia, the US and Russia if the gas content is very high. If this is the case, methane is extracted from the seams before, during and after mining through bore holes that are drilled vertically or horizontally into the seam and the surrounding strata. The methane can be sold or used for on-site electricity generation.

During surface mining operations, methane is released during blasting processes, from broken overburden, and from post-mining activities such as handling, processing, and transportation. Methane is also released from coal waste piles and abandoned mines.

In national inventories, methane emissions from coal mining should include emissions from underground mining, from surface mining and from post-mining operations, minus recovered emissions. For mining operations, emissions are accounted for using national average coefficients from various studies: typical ranges are 10-25 m3/tonne for underground mining and 0.3 – 2.0 m3/ tonne for surface mining (which includes and incorporates both in-situ gas content and migration from surrounding strata) [9]. Emissions could also be accounted for using country, regional or basin specific emission coefficients based on measurement data, statistic and experts analysis. Afterward, the conversion factor is assumed to be 670 grams/m3. Table 5 shows



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calculated emission coefficients for underground mining in selected countries.

Post-mining emission coefficients for underground-mining operations (0.4 to 4.0 m3/tonne) are higher than those for surface-mining operations (0 to 0.2 m3/tonne) because of the higher gas content [9].

As for the recovered emissions, a coefficient can be applied to account for avoided emissions based on gas use data.

■ **GHG Emissions from Coal Transportation -** For coal transportation, usual emission factors for freight transportation are used for different transportation modes. Main elements affecting the emissions include: the load factor, the share of empty running, the energy efficiency of the transportation mode (trucks, trains or ships) and the carbon intensity of the fuel source (CO2 per unit of energy consumed). Specific studies [14] provide assumptions to determine average factors for various transportation modes in Europe:

- **Road**: The average factor is set at 62g CO2/tonne-km, based on a load factor of 80% of the maximum vehicle payload and 25% of empty running. More specific factors are provided for different payloads and shares of empty running (Table 6).
- **Rail**: The average factor is set at 22g $CO_2$/tonne-km, using averages for diesel and electricity fuel split, for carbon intensity of electrical sources, for energy efficiency of locomotives and load factors (Table 7).
- **Inland waterways**: The average factor is set at 31g $CO_2$/tonne-km, using averages factors for barge movements on inland waterways (Table 7). In addition, specific factors are provided for different waterway conditions and sizes of barges (Table 8). These factors may decrease in the future with technology improvements.
- **Maritime transport**: The average factor is set at 16g $CO_2$/tonne-km for short-sea shipping, 8.4g $CO_2$/tonne-km for deep-sea – container shipping, and 5g $CO_2$/tonne-km for deep-sea tanker operations. Emissions factors for different types of maritime vessels and for different categories of ships are shown in Table 9 and 10, respectively.

■ **Total Upstream Emissions** - Total coal upstream GHG emissions (from mining and transportation) have been calculated in life cycle analyses for coal power plant generation in the United States, including methane releases from mines and fuel combustion during mining and transportation activities (see for example Table 11 for fuel consumption in mines [11]. Emission factors for fuel combustion in mines are derived using the total coal production and the coal heat content.

Table 5 - Emission coefficients for (m3/ tonne) underground mining in selected countries [9]

| | |
|---|---|
| Former Soviet Union | 17.8 – 22.2 |
| United States | 11.0 – 15.3 |
| Germany | 22.4 |
| United Kingdom | 15.3 |
| Poland | 6.8 – 12.0 |
| Czechoslovakia | 23.9 |
| Australia | 15.6 |

Table 6 - Emission factors (gCO2/tonne-km) for 40-44 tonne trucks [14]

| | % of truck-kms run empty | | | | | |
|---|---|---|---|---|---|---|
| Payload (t) | 0% | 10% | 20% | 30% | 40% | 50% |
| 10 | 81.0 | 88.8 | 98.5 | 111.1 | 127.8 | 151.1 |
| 15 | 58.6 | 63.8 | 70.3 | 78.6 | 89.7 | 105.3 |
| 20 | 48.0 | 51.9 | 56.8 | 63.0 | 71.4 | 83.0 |
| 25 | 42.3 | 45.4 | 49.3 | 54.3 | 61.0 | 70.3 |
| 26 | 41.5 | 44.5 | 48.3 | 53.1 | 59.5 | 68.5 |
| 27 | 40.8 | 43.7 | 47.3 | 52.0 | 58.1 | 66.8 |
| 28 | 40.2 | 43.0 | 46.5 | 51.0 | 56.9 | 65.3 |
| 29 | 39.7 | 42.4 | 45.7 | 50.1 | 55.8 | 63.9 |

Table 7 - Emission factors (gCO2/tonne-km) for trains and barge on inland waterway [14]

| Sources | All trains | Diesel trains | Electric trains | Inland waterway barges |
|---|---|---|---|---|
| ADEME | 7.3 | 55.0 | 1.8 | |
| NTM | 15.0 | 21.0 | 14.0 | |
| EAE Tech. | 20.0 | | | |
| DEFRA | 21.0 | | | |
| INFRAS | 22.7 | 38.0 | 19.0 | 31.0 |
| TRENDS | 23.0 | | | 31.0 |
| Tremove | 26.3 | | | 32.5 |
| IFEU | | 35.0 | 18.0 | 28-35 |
| McKinnon/EWS | | 18.8 | | |

Table 8- Emission factors (g$CO_2$/tonne-km) for inland waterway barges [14]

| Barge types | Upstream | Downstream | Canal |
|---|---|---|---|
| Container Barges | | | |
| Small (90TEU) | 63.4 | 31.3 | 44.5 |
| Medium | 28.3 | 14.7 | 17.4 |
| Large | 19.6 | 10.2 | |
| Tank / Solid Bulk Barges (50% load factor) | | | |
| 800t | 70.8 | 27.3 | 39.3 |
| 1250t | 62.6 | 24.1 | 34.3 |
| 1750t | 57.7 | 22.3 | 31.1 |
| 2500t | 46.0 | 18.1 | 25.8 |



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For coal transportation, emission factors were developed taking into account that 84% of coal was transported by trains, 11% by barges, and 5% by trucks. This translates into 43.6 tons of CO2-eq for trains, 5.9 tons of CO2-eq from barges, and about 69 tons of CO2-eq from trucks [11] for one million ton-miles of coal transported. Emission factors for coal transportation were computed using the average travel distance of coal in each mode (796, 337, and 38 miles by trains, barges and trucks, respectively), the weighted average of the US coal heat content (24.47 TJ per kilotonne) and the coal production data [11]. The resulting emission factors, i.e. the average emission rate relative to units of fuel produced, are [11]: 5.12-10.14 kg CO2-eq/GJ for coal mining and processing; and 0.66-2.56 kg CO2-eq/GJ for coal transportation (Table 12).

A similar study on the life cycle analysis of coal fired power plant in the US gives the upstream GHG emissions factors from mines to the plant gate by types.

- Sub-bituminous coal: 1.14 kg CO2e/GJ;
- Lignite coal: 4.93 kg CO2e/GJ; and
- Bituminous coal: 8.72 kg CO2e/GJ [12]

Finally, another life-cycle analysis for the US coal-fired power plants gives the following emission factors:

- 3.70 kg CO2e/GJ for coal production (with 3.13 kg due to CH4 and 0.57 kg due to CO2 and N2O), and
- 0.95 kg CO2e/GJ for coal transportation [13]

■ **Other Impacts** – Surface mining (almost 70% of the coal mined in the US) involves operations that remove soils above coal seams, which impact land at its surface. In some region, coal mining involves mountain top removal with explosives and valley filling [8]. Consequently, the landscape is modified, the water may be polluted, with additional environmental impacts. Underground mining have less impact on the landscape but results in more methane emissions since the gas needs to be vented out to make it safe for workers.

## Coal Mining and Transportation Costs

Coal prices vary depending on the resources types and qualities, mining techniques, geographical regions, types of transactions (long-term contracts versus spot purchases) and usages. Higher heat content coals are more expensive. Average sale prices in 2011 were: 83.45 $/metric ton for anthracite), 75.50 $/ metric ton for bituminous), 15.51 $/ metric ton for sub-bituminous and 20.69 $/ metric ton for lignite) [8]. As for mining techniques, surface-mined coal is normally cheaper than underground-mined coal. In addition, coal extracted from thick seams near the surface is cheaper than coal extracted from thinner and deeper seams.

■ **Surface Mining Cost**. A study provides estimations of capital and operation costs for open-pit mines in Australia from Australian mine data reviews as well as

Table 9 - Emission factors ($gCO_2$/tonne-km) for maritime vessels [14]

| Maritime vessel types | Factor |
|---|---|
| Bulk ships | |
| Small tanker (844 tonnes) | 20 |
| Large tanker (18,371 tonnes) | 5 |
| Deep-sea tanker (120,000 tonnes) | 5 |
| Small (solid) bulk vessel (1,720 tonnes) | 11 |
| Container vessels | |
| Small container vessel (2,500 tonnes) | 13.5 |
| Larger container vessel (20000 tonnes) | 11.5 |
| Aver. deep-sea container vessel 8.4 BSR/Clean Cargo, with 11 tonne load/TEU | 8.4 |

Table 10 - Emission factors ($gCO_2$/tonne-km) for cargo ships [14]

| Ship types | Size | Factor |
|---|---|---|
| Product tanker | 60,000 + dwt | 5.7 |
| Product tanker | 20,000-59,999 dwt | 10.3 |
| Product tanker | 10,000-19,999 dwt | 18.7 |
| Product tanker | 5000-9999 dwt | 29.2 |
| Product tanker | 0-4999 dwt | 45.0 |
| General cargo | 10,000+dwt | 11.9 |
| General cargo | 5000-9999 dwt | 15.8 |
| General cargo | 0-4999 dwt | 13.9 |
| General cargo | 10,000+dwt, 100+TEU | 11.0 |
| General cargo | 5000-9999 dwt, 100+TEU | 17.5 |
| General cargo | 0-4999 dwt, 100+TEU | 19.8 |
| Container | 8000+TEU | 12.5 |
| Container | 5000-7999 TEU | 16.6 |
| Container | 3000-4999 TEU | 16.6 |
| Container | 2000-2999 TEU | 20.0 |
| Container | 1000-1999 TEU | 32.1 |
| Container | 0-999 TEU | 36.3 |

Table 11 - Fuel Use in the US Coal Mines [11]

| Mine Type | Fuel Oil k bbl | Gas $Gft^3$ | Gasol. M gal. | Electricity GWh |
|---|---|---|---|---|
| Surface mines | 8,280 | 0.7 | 30 | 42,474 |
| Underground mines | 801 | 0.5 | 4 | 7,123 |

Table 12 - Upstream life cycle GHG emission factors (kg CO2-eq/GJ) for US coal power [11,12,13]

| Mining | Transport | Total | Ref. |
|---|---|---|---|
| 5.12 – 10.14 | 0.66 – 2.56 | | [11] |
| 3.70 (incl. 3.13 CH4 and 0.57 CO2 & N2O) | 0.95 | | [13] |
| | | Sub-bitum. 1.14<br>Lignite 4.93<br>Bituminous 8.72 | [12] |

operating cost reviews from the US and Canada mines [10]. Costs vary depending on the seam thickness, stripping ratio and daily production rates (Table 13).

**■ Reserves and Resources Supply Costs -** The estimates of primary fossil supply costs can be distinguished for reserves (proved, probable, or possible) and resources [7]. Reserves are quantities estimated at a specified date, which can be recovered with current technologies and knowledge under prevailing economic and political conditions. Resources are known quantities which cannot be recovered at current prices with current technologies, but could be so in the future, and possible quantities that have not been demonstrated yet.

Data from main country producers were used in order to estimate coal supply costs in various world regions (Table 14) [7]. For lignite reserves, lowest costs are reported in Russia (FSU) and Indonesia (ODA) with 0.3 $/GJ, while the higher costs are reported in Australia (0.79 $/GJ), Central and South America (CSA, 0.69 $/GJ), Eastern Europe (EEU, 0.66 $/GJ) and Western Europe (WEU, 0.55 $/GJ). As for resources, a supply cost of 4.7 $/GJ is assumed for all regions.

For hard coal, supply costs also depend on the seam depth and mining technics and on the transportation distance to domestic markets or export ports. The costs include the production costs at the mine, domestic transportation costs from the mine to the export harbor and harbor costs. However, rail transport costs for USA exports to Canada have been included in the coal trade costs between the two countries (15 $/t). The rail transport in the FSU from the mine to the harbor have also been added to the transport costs of Russian coal exports (17 $/t) to other world regions since current freight tariffs (e.g. 4 $/t*1000 km) are low compared with other countries (e.g. 10 $/t*1000 km) [7]. Lower supply costs for hard coal reserves (1-1.4 $/GJ) are found in Africa, Australia, South America and the Former Soviet Union, while highest costs (3.7 $/GJ) are found in Western Europe, South Korea and Japan due to the higher labor costs and deeper deposits. For resources, an additional 0.84 $/GJ have been assumed compared with reserve costs.

**■ Transportation Costs Between World Regions -** Coal transportation in an expensive phase that can cost much more than the basic material before transportation (e.g. for near usage); it can accounts for up to 70% of the delivered cost [4]. A study [7] gives transportation costs made up of four parts: inland transportation in the country of origin, sea transport to Europe, transfers from a seagoing vessel to a barge or railway (handling charges in a deep-sea port) and transfers from ports to markets for inland waterways or railways. Major exporters are Africa, Australia, China and the USA, whereas major importers are Japan, South Korea and Western Europe. Table 15 provides transportation costs between world regions. Coal handling in sea ports is about 2 US$/ton [7]. These calculations are based on the use of 125,000 dwt capacity tankers that cost about 28 M$. Other possible types of tankers are 170,000 dwt Capesize tankers (39 M$), 60,000-80,000 dwt Panamax tankers (23 M$), 51,000 dwt Hanymax tankers (21 M$) and 30,000 dwt Handysize tankers (13 M$) [7].

Most coal is shipped via a combination of transportation modes such as trains, barges and trucks which all consume diesel fuel [8]. Oil price increases can significantly affect the transportation cost of coal and consequently its final price.

Table 13 – Capital and Operation Costs for Open-pit Mines in Australia (2008 USD), [10]

| Production (t/day) | Seam thickness (m) | 12.3 | 3.1 | 1 |
|---|---|---|---|---|
| | Stripping ratio (t/t coal) | 10.2 | 20.2 | 40.6 |
| 1800 | Operating costs ($/t)* | 26.4 | 41.5 | 71.6 |
| 1800 | Capital cost (M$)* | 51.3 | 88.8 | 180 |
| 7300 | Operating costs ($/t)* | 20.2 | 33.3 | 61.5 |
| 7300 | Capital cost (M$)* | 150.0 | 166 | 299 |
| 21800 | Operating costs ($/t)* | 17.6 | 31.5 | 59.5 |
| 21800 | Capital cost (M$)* | 305 | 465 | 864 |
| 65300 | Operating costs ($/t)* | 15.9 | 29.4 | 57.1 |
| 65300 | Capital cost (M$)* | 728 | 1,264 | 2,453 |
| 196000 | Operating costs ($/t)* | 14.3 | 28.9 | 55.3 |
| 196000 | Capital cost (M$)* | 1,999 | 3,663 | 7,155 |

* Converted from Australian dollars in USD using an average rate for 2008.

Table 14 - Coal Supply Costs ($/GJ) Lignite and Hard Coal [7]

| | Lignite | | Hard Coal | |
|---|---|---|---|---|
| | Reserve | Resource | Reserve | Resource |
| Africa | 0.49 | 4.70 | 1.03 | 1.87 |
| Australia | 0.79 | 4.70 | 1.06 | 1.90 |
| Canada | 0.36 | 4.70 | 1.87 | 2.71 |
| China | 0.36 | 4.70 | 1.36 | 2.10 |
| Lat. America | 0.69 | 4.70 | 0.96 | 1.80 |
| East Europe | 0.59 | 4.70 | 1.53 | 2.37 |
| FSU | 0.30 | 4.70 | 0.86 | 1.70 |
| India | 0.36 | 4.70 | 1.60 | 2.44 |
| Japan | 0.93 | 4.70 | 3.65 | 4.51 |
| ME | 3.47 | 4.70 | 4.00 | 4.84 |
| Mexico | 0.36 | 4.70 | 1.87 | 2.71 |
| Asia | 0.30 | 4.70 | 1.18 | 2.03 |
| S Korea | 0.93 | 4.70 | 3.65 | 4.51 |
| US | 0.36 | 4.70 | 1.31 | 2.17 |
| Europe | 0.55 | 4.70 | 3.65 | 4.51 |



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■ **Transportation Costs in Europe -** In Europe, a large portion of coal is imported through large sea vessels, while a small portion is imported by inland waterways and railways, namely from Russia, Kazakhstan and Ukraine [6]. Consequently, some deep sea parts play a major role in the coal logistics as turnover stations to inland waterways, such as the ARA ports (Amsterdam-Rotterdam-Antwerp) for the inland Rhine corridor. In addition, there are the Hamburg, Szczecin and Gdansk see ports for the East-West corridor, Constanta for inland shipment on the Danube and Le Havre and Marseille for the Seine and Rhône [6]. As for railways, they are used for hard coal transportation from the deep-sea ports to the final users. Costs of inland water transportation include coal transportation on barges, maintenance fees, tolls, port charges and follow-up from the port to the final destination. In Europe, inland water transportation involves different types of waterways, barges, and consequently, transportation costs vary accordingly. Internal transportation costs for coal is about: 1.8-3.1 €/t (from ARA-ports to the Ruhr), 9.7-11.3 €/t (on the Main-Danube canal to Austria), and 3.6-4.1 €/t (from Hamburg on the Elbe, the Elbe-Havel canal and the Havel to Berlin) [6]. The type of barges (self-propelled or pushing technology), as well as their size (length, breadth, draught, capacity) used depends on the navigational conditions and market demands. Operation costs for different types of vessels are shown in Table 16 and include transportation and infrastructure costs, as well as port handling charges. As for port charges and handling costs, there is about 0.3 €/t for the pier tax, 3 €/t for railway loading in the port and 5 €/t as follow-up costs to the final destination [6].

As for the estimation of future growth rates of the transportation costs, it involves, among others, estimations on future investments in coal logistic capacities, coal demand on local markets, substitution of domestic coal production by imported coal and associated structural changes. The following investment cost is assumed for future expansion capacities in European ports: 20.7 € per annual ton handling capacity (using an initial 2 €/t handling charge, a lifetime of 30 years for a coal terminal and an internal rate of return of 10%) [6].This excludes investments in vessel infrastructures since there are not expected to be a constraint in future; these investments are rather considered through depreciation and interests in the fixed costs calculation [6].

■ **Transportation Costs between US Regions -** A report provides coal transportation rates to the electric power sector from two sources (the U.S. Surface Transportation Board (STB) and the EIA's Power Plant Operations Report): rail transportation rates as well as barge and truck rates from 2008-2010 [3]. The surface mines of the Powder River Basin of Wyoming and Montana are the major supply sources for U.S. power plants. Most of this coal (72%) is carried by trains, at least for the major portion of the route, going over distances that can exceed 1,000 miles. Barges (11%) are lower cost options than trains but when mines and power plants are located close to well-developed river systems (East of the Mississippi). Finally, trucks (10%) are used mainly for short distances.

Average transportation costs have increased by 19% from 2001-2010, while total delivered costs have increased by 50% on the same period [3]. Consequently, since the coal commodity prices increased faster than the transport costs, the share of the transportation costs in the total delivered cost declined from 48% to 39% between 2001 and 2010 (Table 16).

However, important regional variations are covered by the national averages. For example, Table 17 reports the minimum and maximum estimations from both data sources among the six major US coal basins. The transportation costs on specific state-to-state routes have evolved very differently from a 23% decline (Wyoming to Kansas) to an 83% increase (Virginia to Tennessee) [3]. The STB also provides the rail transportation costs in ton-mile for different state-to-state routes and show a range of 0.0107 $ to 0.0966 $ per ton-mile [3].

As for barge and truck transportation costs (Table 18), estimates are provided for 2008 to 2010 and shows a small decline during the 2009 recession.

## POTENTIAL AND BARRIERS

Coal will continue to play an important role in the future energy mix [5, 17], particularly for energy security policies. It is an affordable source of energy, that is abundant and available in several countries, and can be transported easily by ship and rail, and easily stored at power plants. Coal can also become a substitute to oil with the development of the coal-to-liquids industry. Carbon capture and storage (CCS) can play an important role in the efforts to reduce CO2 emissions.

Many countries rely on coal resources, such as India and China where the equivalent of two 500-MW coal-fired plants are built every week [17. The United States is also a strong coal consumer with an important fraction of electricity being generated from coal, though being replaced by natural gas in the recent years. Since a 500 MW coal-fired plant produce about 3 million tons of CO2e annually, the potential for CCS in these countries and globally is huge. CCS technologies could play a significant role by meeting the increasing world energy needs while contributing to the mitigation efforts regarding climate change.

More precisely, the MIT has studied the role of CCS in two CO2 pricing scenarios through 2050: a high case

(25$/tonne of CO2e in 2015 +4% increase per year) and a low case (7$/tonne of CO2e in 2015 +5% increase per year). Both scenarios are analyzed with different assumptions on nuclear expansion (limited or expanded). The high case leads to important reduction in coal use compared with the business as usual scenario, but still some increased compared with the 2000 base year (Table 19).

However, significant investments are required to develop and implement cost effective CCS technologies. Finally, technologies are currently being developed to capture and use the methane emitted from mining operations. Coal mine methane (CMM) currently account for 8% of the total anthropogenic methane emissions. There are currently more than 220 CMM projects worldwide in 14 countries, but mainly in fast growth countries with important reserves such as Australia, China and the U.S. [5].

Table 15 - Coal trade transport costs ($/GJ) between world regions, 2005 [7]

| | Africa | Australia-NZ | Canada | China | Central & South America | Eastern Europe | Former Soviet Union | India | Japan | Middle East | Mexico | Other Developing Asia | South Korea | USA | Western Europe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Africa | | | | | | | | | | 0.2 | | 0.3 | | | 0.3 |
| Australia-NZ | | | | 0.2 | 0.6 | 0.9 | | 0.3 | 0.2 | 0.4 | | 0.1 | 0.2 | | 0.8 |
| Canada | | | | | | | | | 0.2 | 0.6 | | 0.3 | 0.2 | 0.5 | |
| China | | | | | | | | | 0.1 | 0.3 | | 0.1 | 0.0 | | |
| Central & South America | | | | | | | | | | | 0.1 | | | 0.1 | 0.2 |
| Eastern Europe | | | | | | | | | | | | | | | 0.1 |
| Former Sovier Union | | | | | | 0.6 | | | 0.7 | 0.8 | | | 0.7 | | 0.7 |
| India | | | | | | | | | | | | | | | |
| Japan | | | | | | | | | | | | | | | |
| Middle East | | | | | | | | | | | | | | | |
| Mexico | | | | | | | | | | | | | | | |
| Other Developing Asia | | | | 0.1 | | | | | 0.1 | | | | | | 0.5 |
| South Korea | | | | | | | | | | | | | | | |
| USA | | | 0.5 | 0.73 | | | | | 0.6 | 0.5 | 0.1 | 0.7 | 0.7 | | 0.2 |
| Western Europe | | | | | | | | | | | | | | | |

Table 16 - Operational cost ($ per tonne-year) for different vessels at full capacity utilisation [6]

| Region | Load capacity (t) | Fuel & Lubricant cost | Region | Load capacity (t) | Fuel & Lubricant cost |
|---|---|---|---|---|---|
| PLANCO Consulting GmbH 2003 | | | Buck Consultants et al. 2004 | | |
| Germany | 835 | 28 | Rhine corridor | 1280 | 70.2 |
| | 1080 | 33 | | 1280 | 70.2 |
| | 1528 | 41 | | 2850 | 54.3 |
| | 2154 | 47 | | 2850 | 55.2 |
| Belgium | 2121 | 56 | Czech Republic | 1190 | 42.2 |
| Netherlands | 860 | 31 | Danube Corridor | 1280 | 70.2 |
| | 2800 | 45 | Romania | 6000 | 29.8 |
| Poland | 490 | 48.2 | | | |
| Slovakia | 1529 | 85.7 | | | |
| Hungary | 1550 | 75.9 | | | |
| | 1725 | 86.7 | | | |
| Romania | 6600 | 20.5 | | | |

Table 17 – Rail Transportation Costs ($/metric ton), 2005-2010 [3]

| US $2005 | Transportation cost | | % of total delivered cost | Transportation cost, STB | | Transportation cost, EIA | |
|---|---|---|---|---|---|---|---|
| | STB | EIA | EIA | Min | Max | Min | Max |
| 2005 | 15.04 | | | 8.34 | 19.72 | | |
| 2006 | 15.48 | | | 6.91 | 21.33 | | |
| 2007 | 16.34 | | | 6.83 | 24.28 | | |
| 2008 | 16.59 | 16.93 | 44.64 | 7.47 | 22.26 | 7.77 | 25.03 |
| 2009 | 16.05 | 15.87 | 39.90 | 9.13 | 20.92 | 8.52 | 20.16 |
| 2010 | | 17.13 | 42.55 | | | 10.98 | 21.53 |

Table 18 – Barge and Truck Transportation Costs ($/metric ton), 2005-2010 [3]

| US $2005 | Barge | | Truck | |
|---|---|---|---|---|
| | Transportation cost | % of total delivered cost | Transportation cost | % of total delivered cost |
| 2008 | 6.36 | 17.42 | 6.22 | 17.09 |
| 2009 | 6.25 | 11.91 | 4.92 | 14.88 |
| 2010 | 6.36 | 12.57 | 6.16 | 16.98 |

Table 19 – Coal use (EJ) in the high price case with and without CCS [17]

| Scenarios | Options | Year | (EJ) |
|---|---|---|---|
| BAU | | 2000 | 100 |
| BAU | | 2050 | 448 |
| Limited Nuclear | With CCS | 2050 | 161 |
| Limited Nuclear | W/O CCS | 2050 | 116 |
| Expanded Nuclear | With CCS | 2050 | 121 |
| Expanded Nuclear | W/O CCS | 2050 | 78 |

**Table 20 – Summary Table - Key Data and Figures on Coal Mining and LogisticsTechnologies**

<table>
<tr><th>Technical Performance</th><th colspan="5">Typical current international values and ranges</th></tr>
<tr><td>Energy input</td><td colspan="5">Annual energy consumption estimates for coal mining is 0.391 GJ/ton of coal mined.<br>Average recovery rate of coal is about 82% (up to 90% with surface mining).</td></tr>
<tr><td>Output</td><td colspan="5">Anthracite (27.70-32.56 TJ/kilotonne), bituminous coal (24.42-32.56 TJ/kilotonne), subbituminous coal (19.31-26.75 TJ/kilotonne), lignite (14.65-19.31 TJ/kilotonne).</td></tr>
<tr><td>Technology variants - Mining</td><td colspan="2">Underground mining: Room-and-pillar and Longwall methods</td><td colspan="3">Surface mining (or open-cast, open-cut open-pit mining).</td></tr>
<tr><td>Technology variants - Preparation</td><td colspan="2">Simple crushing</td><td colspan="3">Complex treatment: physical or chemical cleaning processes</td></tr>
<tr><td>Technology variants - Transportation</td><td>By heavy trucks</td><td>By trains</td><td>By barges</td><td>By large vessels</td><td>By pipeline</td></tr>
<tr><td>Total recoverable reserves (billion metric tonnes)</td><td colspan="5">859.3 billion metric tons on January 1st 2009.<br>In 70 countries: the United States (27%), Russia (18%), China (13%), non-OECD Europe and other Eurasia (1%), and Australia/New Zealand (9%).<br>Anthracite and bituminous coal (47%), subbituminous coal (30%), lignite (23%).</td></tr>
<tr><td>Total coal production (billion metric tons)</td><td colspan="5">7.2 billion metric tons in 2010</td></tr>
<tr><td>Total trade mouvement (% of production)</td><td colspan="5">Global imports: 14% of the total coal consumed in 2010.<br>Exporters: Indonesia (50% of the additional exports between 2000 and 2011) and Australia.<br>Importers: China and India (57% of the additional imports between 2000 and 2011).</td></tr>
<tr><td>Emissions – $CH_4$ from mining</td><td colspan="5">Underground mining (10-25 m3/ tonne) + Post-mining operations (0.4 to 4.0 m3/tonne);<br>Surface mining (0.3 – 2.0 m3/ tonne) + Post-mining operations (0 to 0.2 m3/tonne).</td></tr>
<tr><td>Emissions – GHG from transportation</td><td colspan="5">Road (62g $CO_2$/tonne-km); Rail (22g $CO_2$/tonne-km); Inland waterways (31g $CO_2$/tonne-km); Short-sea shipping (16g $CO_2$/tonne-km); Deep-sea – container shipping (8.4 g $CO_2$/tonne-km); Seep-sea tanker operations 5 g $CO_2$/tonne-km.</td></tr>
<tr><td>Emissions – GHG from upstream</td><td colspan="5">Coal mining and processing (5.12-10.14 kg $CO_2$-eq/GJ).<br>Coal transportation (0.66-2.56 kg $CO_2$-eq/GJ).</td></tr>
</table>

| Costs | Typical current international values and ranges |
|---|---|
| Surface mining operation costs (2008 US$) | From 14.28 US$ (daily production of 196,000 tonnes; stripping ratio 10.2/1)<br>To 71.57 US$ (daily production of 1,800 tonnes; stripping ratio 40.6/1). |
| Supply costs (2000 US$) | Lignite reserves (0.3 to 0.79 US$/GJ); Lignite resources: (4.7 $/GJ).<br>Hard coal reserves (1.0-3.7 US$/GJ); Hard coal resources: (add 0.84 $/GJ). |
| Transportation costs – Global (2000 US$) | Between world regions (0.1-0.9 US$/GJ), with a port handling fee of 2 US$/ ton. |
| Transportation costs – Europe (2000 €) | In Europe: inland waterway transportation costs (1.8-11.3 €/t), port charges (0.3 €/t for the pier tax), railway loading in the port (3 €/t) and follow-up to the final destination 5 €/t. |
| Transportation costs – USA (2005 US$) | In U.S: rail (15.54 US $2005/short ton and 38.6% of the total delivery cost), barges (7.55 US $2005/short ton and 11.4% of the total delivery cost), and trucks (5.59 US $2 005/short ton and 15.4% of the total delivery cost). For rail, the range is 9.96-19.53 US $2005/short tons. |
| Sale prices in 2011 (2011 US$) | Anthracite (75.70 $/short ton), Bituminous (68.50 $/short ton), Subbituminous (14.07 $/short ton), Lignite (18.77 $/short ton). |

| Data Projections | Typical current international values and ranges |
|---|---|
| Efficiency, % | 49% potential energy savings over time with energy efficiency improvements of technologies and implementation of best practices and new advances through R&D |
| Coal use globally, EJ | From 100 to 448 EJ in business-as-usual case<br>Lower but significant increases in a case with a 25$/t price on $CO_2$ +4% annual increase: 61% (limited nuclear, CCS), 16% (limited nuclear, no CCS), 21% (expanded nuclear, CCS).<br>A decrease (-22%) only in case with expanded nuclear option and no CCS. |



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