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Economics of Coal and Gas Based Energy

An Indian Perspective

Third Wave Solutions Private Limited

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THIRD WAVE SOLUTIONS

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FOREWORD

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The Indian energy and power sector is in ferment: a rolling blackout that left over half the country’s population without power; a coal mining rights allocation scandal that the CAG estimates to have cost the country 1.85 lakh crores; a long running family dispute which is to decide the price of natural gas in the country, and a country’s future held to ransom.

There isn’t a day when some or the other news about coal or gas or power isn’t making waves. The industry is so politicized that partisan views are rife. In this bewildering environment, one needs a solid foundation of facts and structural understanding about this sector and its economics. Having the ability to judge the merits of an argument is vital to the investor. This ability is what this report attempts to augment.

The report delves into the nitty-gritty of the sector – what is the true comparative price of domestic coal vs. imported coal? What is the price of producing thermal power in India? What is the big deal about gas and how much do we really have? Could gas become the dominant energy source in the coming years? And other such questions.

We work with the assumption that the investor is savvy. We, therefore, do not shy away from presenting technical details and calculations, where merited, in the report. The reader may work through our calculations and convince himself of their correctness – and even understand how different assumptions might affect the calculated numbers. Additionally, you will also find in the appendix, a list of rules-of-thumb that can help you quickly assess the correctness of many claims you read elsewhere.

All these put together, we hope, would enable our reader to take an informed and independent judgement about events and investment opportunities as they arise in the industry.

Parijat Garg
Director
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EXECUTIVE SUMMARY

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The demand for power and electricity in India is boundless. The supply, on the other hand, is simply insufficient. More and more coal based power plants are being erected, even though the supply of the fuel is in severe shortage (92 mmt imported in the calendar year 2011). With the need growing ever so rapidly, a solution has to be found in alternative fuels.

India is already one of the largest consumers and importers of coal. The new power plants will increase the coal demand to new highs. Inadequate infrastructure and environmental concerns prevent sufficient mining. Coal India Limited cannot satisfy the country's fuel needs with indigenous coal. It has to be bought from the outside world. It is safe to say that coal imports would increase in the near future. As far as economics is concerned, nothing comes cheaper than domestic coal. Running a power plant on imported coal can be 3.25 times more expensive than domestic coal (excluding the transport costs). It is so because even though domestic coal is inferior in quality, it is cost effective.

The next alternative is natural gas. Due to limited gas reserves in India, and the problematic Krishna Godavari basin, production of natural gas is likely to remain limited for the next few years. Even if new discoveries were to be made, it would take around 5 to 8 years before they can actually start production. The other way to obtain gas is from foreign countries. LNG import capacity of India is on the rise. As many as 7 re-gasification plants are under construction or near completion; gas import is very likely to increase and keep these plants running at maximum capacity throughout the year. The current pricing system of natural gas in Asia is oil-indexed. It appears that this system will come under serious pressure due to deepening market of natural gas. Therefore, it would be better if another pricing mechanism is devised which is based on appropriate fundamentals such as demand and supply.

A problem associated with LNG import is its excessive transport costs. Pipelines are a cheaper form of gas transport and the TAPI pipeline, which is expected to be completed in 2018, shall provide not only an alternative new source of natural gas, but also a cheaper mode of transport. Gas power plants are more efficient than coal power plants by up to 20-25% and less polluting by 45%. If environmental concerns deepen, natural gas will have a clear advantage for becoming 'the fuel of the future'. However, during the next few years, coal would remain the dominant fuel in India.

Section 1: COAL

1.1 Introduction

Coal is the world's second favourite source of energy. With a total energy share of 30%, coal comes in a close second behind crude oil at 33.1%. It is currently the single largest source of fuel for generation of electricity across the world and is responsible for 42% of global power generation. In the US it accounts for one-third of the power. India on the other hand is heavily dependent on coal as it accounts for around 55% of our power generation (around 114 GW out of 208 GW). Coal is also a fairly abundant resource: current global reserves are estimated to be enough to last about 118 years at current rates of consumption.

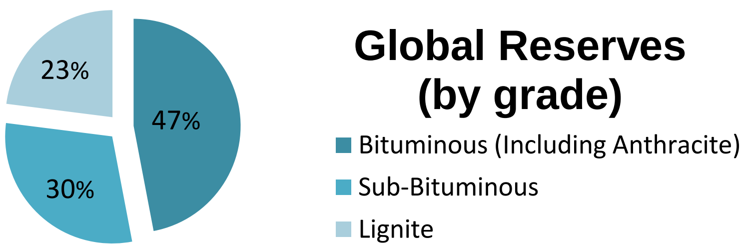
Country	Hard Coal	Brown Coal	Total	% of World Total
United States	2,07,119	30,176	2,37,295	27.6
Russia	1,46,560	10,450	1,57,010	18.2
China	95,900	18,600	1,14,500	13.3
Australia	39,200	37,200	76,400	8.9
India	56,100	4,500	60,600	7.0
Germany	99	40,600	40,699	4.7
Ukraine	31,928	1,945	33,873	3.9
Kazakhstan	21,500	12,100	33,600	3.9
World	6,185	1,042	7,227	100

Table 1.1: Top Global Coal Reserves at the end of 2011 (million metric tonnes)

India holds 7% of world coal reserves but accounts for a proportionately lower 5.6% of world coal production.

Coal can broadly be divided into two categories: hard coal and brown coal. Hard coal has two sub categories: anthracite and bituminous (including sub-bituminous). Anthracite is the highest quality of coal; bituminous is a close second. Brown coal is also known as lignite, which happens to be the lowest form of coal. A use-based classification puts coal in two categories: Steam coal and Coking coal.

The difference between these grades of coal is the carbon content, the heating value and the moisture and ash content (detailed later). However, it should be noted that sometimes distinctions are hard to draw between the grades of coal.



United States, Russia and China hold the largest amounts of coal reserves with almost 60% of world coal found between the 3 countries. The percentage of hard coal in these countries is 83-93%.

Indonesia, a major coal exporter to India and rest of the world, holds 0.6% of the world coal reserves and produces 5.1% of global coal.[1]

It should also be noted that as time passes, re-assessments (checking and updating the amount of reserves) need to be done on a national scale; something which is not done regularly in some countries. For example, South Africa and Canada have not re-assessed their reserves for more than last 25 years.

1.2 Global Production and Consumption

There has been a 6.1% increase in all coal production in 2011 since 2010 (from 7254.6 million metric tonnes (mmt) to 7695.4 mmt).

Country	Hard Coal Production	% of World Total
China	3162	51.1
US	932	15.1
India	538	8.7
Australia	353	5.7
Indonesia	173	2.8
Russia	248	4.0
South Africa	255	4.1
World	6185	100

Table 1.2 – Top Hard Coal Producers in 2010e (million metric tonnes)

Country	Brown Coal Production	% of World Total
Germany	169	16.2
Indonesia	163	15.6
Russia	76	7.3
Turkey	69	6.6
Australia	67	6.4
US	65	6.2
Poland	56	5.4
World	1042	100

Table 1.3 – Top Brown Coal Producers in 2010e (million metric tonnes)

Countries heavily dependent on coal are South Africa (93% of their electricity comes from coal), Poland (90%), China (79%), and Australia (76%).

China leads the production of hard coal with a staggering 51.1% of world hard coal. Nearly 79% of China's power is generated by coal based power plants.[2] Other countries heavily dependent on coal include South Africa (93%), Poland (90%) and Australia (76%).

Out of all the 7227 mmt of coal produced in 2010, 1042 mmt was brown coal (14.4%) and 6185 was hard coal (84.6%). Under hard coal production, only 608 mmt was anthracite (9.8%) and the rest was bituminous. China today mines, by far, the largest share of global anthracite production, accounting for more than three-quarters of global output.

Due to its low ash content and high calorific value, anthracite is primarily used for heating of residential and commercial spaces: either hand-fired stoves or automatic stoker furnaces. The fact that it burns cleaner than bituminous, with little soot, makes it ideal for this purpose. As for power generation, it is too expensive to be used as a fuel.

China produces 51% of the world's hard coal.

In the brown coal division, Germany leads the way with 169 mmt, closely followed by Indonesia with 163 mmt. Together, they produce over 30% of the global brown coal.

Around 80% of the coal produced in India is used for Power Generation.

The overall global consumption of coal (7237 mmt in 2010) has increased faster than any other fuel (4.9 % a year).

The production and consumption numbers that are provided here for coal include both steam coal and coking coal. (Steam coal (or thermal coal) is used for power generation, whereas coking coal (or metallurgical coal) is mostly used for production of steel).

The top 3 – China, US and India, consume up to 70% of all the coal produced in the world. China again, surpasses the other countries by a huge margin.

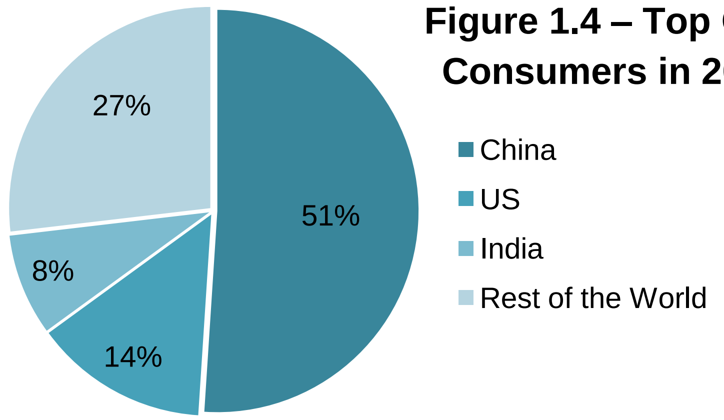


Figure 1.4 – Top Coal Consumers in 2011

1.3 Global Exports and Imports

Demand for coal is abundant and widespread giving way to an established trade market. It is fairly easy to transport coal (compared to other fossil fuels), whether on rail or on ships.

Country	Coal Exported	% of World Total
Australia	297.6	27.0
Indonesia	286.8	26.1
Russia	110.7	10.0
US	75.4	6.9
South Africa	69.5	6.3
Colombia	69.2	6.3
Canada	33.4	3.0
India	2.1	0.002
World	1100.3	100

Table 1.5 – Top Exporters of Coal in 2010e (million metric tonnes)

Country	Coal Imported	% of World Total
Japan	187.5	18
China	176.9	17
South Korea	114.1	11
India	92.1	9
Taiwan	64.5	6
Germany	50.0	5
Turkey	27.2	3
UK	26.6	2
Italy	21.5	2
World	1068.8	100%

Table 1.6 – Top Importers of Coal in 2010e (million metric tonnes)

Despite producing enormous amounts of coal, China is still the 2nd largest importer. India too consumes all the coal it produces and is the 4th largest importer.

India exports a small amount of 2.1 mmt and is a net importer of coal. The same goes for China, which literally consumes all the coal it produces. Despite producing enormous amounts of coal, China is still the second largest importer of coal, second only to Japan, that too only by a small margin.

The World's largest exporters are Australia and Indonesia with a combined share of over 50%. Recently, in a widely publicized move, the Prime Minister of Australia, Julia Guillard, imposed a tax on coal exports (30% on profit) - effective from 1st July 2012. This is going to make importing coal from Australia even more expensive. There were strong indications that Indonesia could do the same but the Energy and Minerals minister confirmed in June 2012 that there were no such plans.[3]

Australia is the largest exporter of coal (both steam and coking combined). But when it comes to steam coal alone, Indonesia is the single largest exporter.

Out of the 298 mmt Australia exports, around 155 mmt is coking coal (largely used for steel production). On the other hand, Indonesia barely exports coking coal, meaning that the entire export of 287 mmt is steam coal**. This makes Indonesia the top exporter of steam (or non-coking) coal**. [4]

India is the 4th largest importer of coal (steam and coking combined) with around 9% of total share, importing 92 mmt in the year 2010. The Indian coal industry believes that 102 mmt of coal was imported during the year 2010-2011.

So far as steam coal (the one used for power generation) is concerned, India remains the 4th largest importer with 60 mmt imported in the year 2010.

Source: eutrophication&hypoxia@flickr.com

Note: The mismatch between world imports and exports can be explained by the general tendency to overstate exports and understate imports.

Importers		Exporters	
Country	**Amount Imported**	**Country**	**Amount Exported**
Japan	129	**Indonesia**	285
China	129	**Australia**	143
South Korea	91	**Russia**	95
India	60	**US**	23
Taiwan	58	**South Africa**	68
Germany	38	**Colombia**	67
Turkey	20	**Canada**	4

Table 1.7 – Top Importers and Exporters of Steam 2010e (million metric tonnes)

Properties of Coal

Coal is a combustible, sedimentary, organic rock, which is composed mainly of carbon, hydrogen and oxygen. It is formed from vegetation, which has been consolidated between other rock strata and altered by the combined effects of pressure and heat over millions of years to form coal seams. Coal is a fossil fuel and is far more plentiful than oil or gas, with an estimated 118 years worth of coal remaining worldwide, at current rates of consumption.

Note: Energy content of the Indian Coal used to be expressed in Useful Heating Value (UHV). UHV (kcal/kg) = [8900-138 (percentage of ash content + percentage of moisture content)] [5]

Grade	KCal/Kg	KJ/Kg
Anthracite	>=7,000	>=30,000
Bituminous	4,500 to 6,900	20,000 to 30,000
Sub-Bituminous	2,000 to 5,000	8,000 to 20,000
Lignite	1,300 to 3,400	5,000 to 15,000

Table 1.8 – Gross Calorific Values (Heating Value) of different grades of coal

Calorific Value of a fuel is the amount of energy given off when a unit of the fuel is burnt completely. **Gross Calorific Value** (GCV) is the globally accepted measure of energy content and is determined experimentally.

Indian non-coking coal was classified by grades (A – F) on the basis of UHV until January 2012, after which Coal India moved to GCV based pricing. Higher the ash content or moisture content, lower the useful calorific (or heating) value of the coal.

Ash in coal does not burn and hence is an impurity. It reduces the burning capacity and increases handling costs. It also reduces the boiler efficiency and causes clinkering and slagging. Coal based power plants need to have an Ash Handling Plant in order to deal with the ash. Ash content can vary from 5% to as much as 40%. (Comparison of Indian and foreign coal is discussed in the next section.)

Moisture in coal increases heat loss due to enhanced radiation. It adds to weight and therefore to transportation, handling and storage costs. Since it replaces combustible matter, it also decreases the energy output per kg of coal. Moisture content varies between 0.5 and 10%.

Sulphur is also present in coal and it corrodes equipments and limits the temperature of exit flue gas due to acid dew point, affecting efficiency. Normal range is 0.5 to 0.8 %. Sulphur dioxide (SO_2) causes acid rain and coal based power plants are the largest emitters of it.

The average GCV of total coal supplied to different sectors in India, including power sectors during the past few years has been of the order of 4500 kcal/kg. This is below the GCV of imported coal which often exceeds 6000 kcal/kg. The useful heating value for Indian coal is even lower due to higher ash and moisture content (detailed later).

1.5 Indian Coal vs. International Coal

Average Indian coal has a Gross Calorific Value (GCV) of around 4500 Kcal/kg with a range of around 3600 Kcal/kg to 5000 Kcal/kg. [6] Compared to the coal around the world, it can be argued that **Indian coal is of inferior quality** in terms of its heating value.

Country	Moisture (%)	Ash (%)	Sulphur (%)	GVC (Kcal/kg)
India	1 to 20	35 to 50	Less than 0.8	3500 to 5000
Australia	5 to 15	1 to 10	Less than 1.0	6000 to 7000
Indonesia	10 to 15	2 to 12	Less than 1.0	5300 to 6700
China	5 to 20	5 to 30	Less than 1.0	4800 to 7000
South Africa	5 to 10	12 to 15	Less than 0.6	5000 to 7000
US	Less than 20	5 to 10	Less than 1.0	5500 to 7200
Mongolia	Less than 10	19 to 40	Less than 0.4	5000 to 6800

Table 1.9 – Global Bituminous (including sub-bituminous) Coal Quality Comparison

If indigenous coal is used, 4.2 mmt would be required per year to fire a 1000 MW power plant.

In case of imported coal, 2.9 mmt would be needed.

This difference is due to the quality of the coal.

Coal in India also tends to have much higher ash content than the rest, although moisture content is average. Consequently, not only does Indian coal produce less heat energy; it results in greater amount of ash and hence increases the cost of ash handling.

Coal imported from **Indonesia** has a much better average GCV of 5500 Kcal/Kg and much lower ash content. Coal from **South Africa** and **Australia** has even better heating value at an average of 6000 Kcal/kg and 6500 Kcal/kg respectively. Australia provides the best quality with highest heating value and lowest ash content. It should be of no surprise that several Indian companies are looking to obtain mining permissions in Australia. Some, like Adani Group, have already acquired mining assets in Australia.

Therefore, when computing the amount of coal required to fire a power plant, one has to **keep in mind the GCV of the coal being used (typically higher for imported coal), since quantities required can vary dramatically**.

Sulphur content in coal, on the other hand, is fairly similar around the world with minor variations. On average, **Mongolian** coal has the lowest content of sulphur out of the lot.

1.6 Pricing of Steam coal

State-owned Coal India Ltd. controls more than 80% of the coal produced in India. The pricing is based on the heating value of the coal and is heavily subsidized. Coal India believes that their coal is sold at less than 50% of the international price.[7] This is true only when the price is not adjusted for the quality. There happens to be a disproportionate relationship between the price and quality of coal in India.[8] When 6500 Kcal/kg coal is compared, the prices are fairly similar. It is therefore, **unfair and misleading to compare the price of different qualities of coal, merely by weight**.

Price of thermal coal is proportional to its GCV. 4500 Kcal/kg in India costs around Rs. 950 per tonne (or $17.27).

Average Indian coal would cost between INR 750 (4000 Kcal/kg) to INR 1400 per metric tonne (5500 Kcal/kg). This works out to $13.6 and $25.5, at the current conversion rate of INR 55 to a USD.

On the other hand, Indian coal with 6500 Kcal/kg, would cost INR 4,420 per tonne, or USD 80.36. It is seen that while the energy content is only 50% higher (than the 4500 Kcal/kg), the price is 3 times. Juxtaposed to the above USD 80.36, Australian coal price (FOB) in July 2012 was USD 87.6 per tonne. [9]

6500 Kcal/kg coal in India costs Rs. 4,420 per tonne (or $80.36). Similar quality of coal costs $85.5 in South Africa, $87.6 in Australia and $103 in Indonesia.

It should be pointed out that international coal prices have been on a decline since January 2012 and have dropped from $124.2 in January to $87.6 in July 2012. Back in August 2011, the price of Australian coal was $127.53.

Similarly, coal export price at South Africa's Richards Bay was was $97.21 price/ton in May 2012 - the lowest since October 2010. It further declined to $83.89 in June 2012 and $85.5 in July 2012.[10]

Indonesian coal with 5700 Kcal/Kg currently has an average benchmark price of about $87. But, coal with 6700 Kcal/kg has an average benchmark price of $112. The prices have declined from last year's average of $97 and $125 respectively.[11]

Note: Prices are FOB, which means that the transport costs are not included.

Source: lhepler@flickr.com

Indian Interest in Foreign Coal Mining Assets

India's coal production is not enough to meet the domestic demand. To obtain foreign coal, several Indian companies have acquired mining assets abroad. Many more are looking for new acquisitions in countries like Australia and Indonesia.

Apart from the usual issues connected with operating in foreign land, proposed tax on coal exports from Australia, has made acquisition of mining assets there more difficult and cost inefficient.

Australia, due to superior coal quality, is probably one of the favourite destinations for mining companies. **Adani Enterprises** purchased Linc Energy's Galilee coal tenements for $2.7 billion in August 2010. The coal reserves are around 7800 mmt and they aim to start mining by mid 2013.

Power producer **Lanco Infratech** also acquired Griffin coal assets for $750 million in 2010. Their reserves are expected to be around 1100 mmt.

In 2010, 'Gina Rinehart's Hancock Coal' sold a 79 per cent stake in its thermal coal assets in Queensland's Galilee Basin to **GVK Power & Infrastructure** for $1.26 billion. The capital outlay is enormous. GVK spent $1.6 billion on the Greenfield mine sites at Alpha, Alpha West and Kevin's Corner. It will spend another $6 billion on infrastructure, including a 500-km railway line to the port which will give it access to the coal within.

India's largest power producer, **NTPC** acquired controlling interest in a 720-million-tonne coal field in Australia in a deal valued at $1-1.5 billion, which will enable it to fire about 3,500 mw of power capacity.

There have been a few high-profile acquisitions in Indonesia, too. **Tata Power**, which is developing imported coal-based power project at Mundra, acquired 30 per cent stake in two coal mines of Bumi Resources for $1.1 billion in 2007.

The very next year, **Reliance Power** bought three coal mines in South Sumatra region with an investment commitment of $2 billion. The combined coal reserves of the three mines are 2 billion tons, which will help the Navi-Mumbai-based company to fire its 4,000 MW power plant at Krishnapatnam in Andhra Pradesh and other power projects.

In 2009, **GMR** acquired Indonesian coal company Barasentosa Lestari for around $80 million.

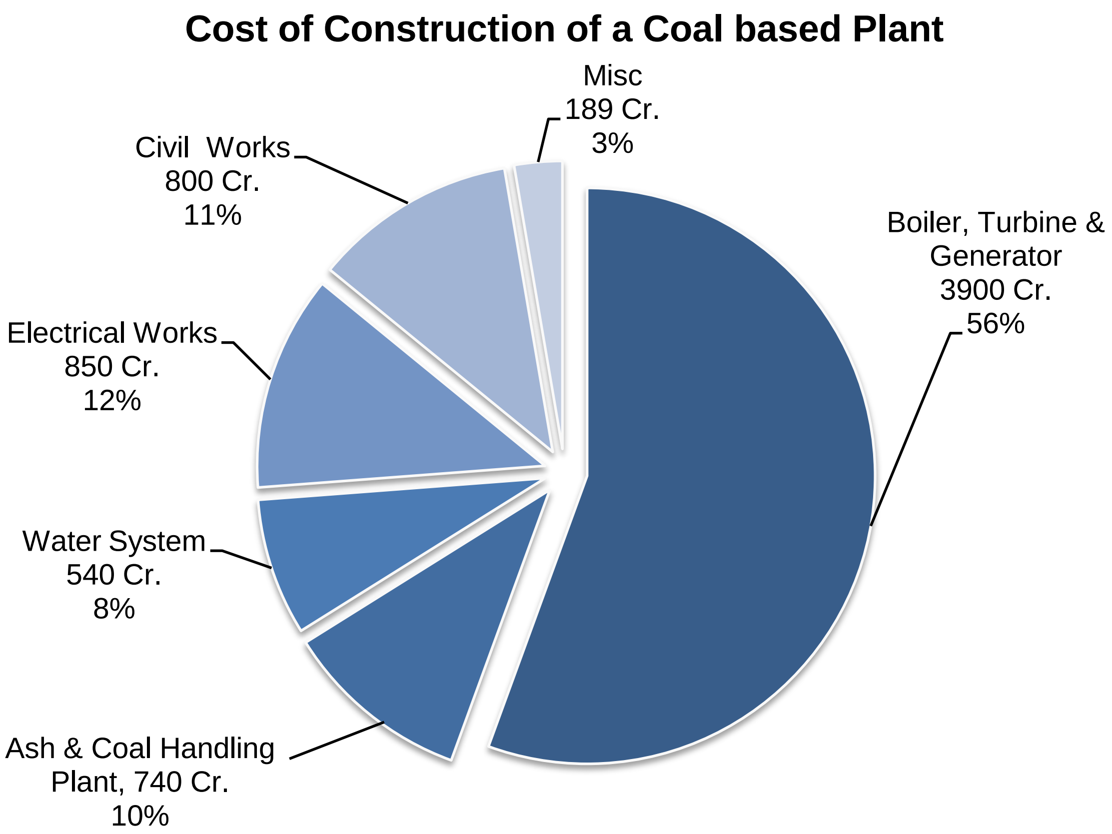
Coal mines in Indonesia are cheaper, but the governance issues and the recent disadvantageous changes to its tax regime have cooled Indian ardour. Its shallow ports pose shipping difficulties and there are concerns about the on-land infrastructure.

Another destination for coal mining assets is Mozambique: one of the larger underdeveloped coal regions in the world and close to India. But infrastructure is a critical issue in the southern African country and getting the coal out of the ground and to the sea is an unresolved problem.

Delayed by multifarious decision-making processes, **Coal India** has bought just two coal blocks, both in Mozambique in the year 2009. Both are still around half a decade away from producing a single tonne of coal.

Coal India is also planning to acquire a mining asset (although only coking coal) in Mongolia, in order to reduce the dependence on Australian coking coal imports.

1.7 Economics of a Coal based Power Plant



The Main Plant comprises of the boiler, turbine, and generator (BTG), ash handling plant and coal handling plant.

These are the main parts of the power plant and account for 66% of the construction cost.

Average cost of power plant is 4.5 to 5 Cr. Per MW.

Average efficiency is about 30%.

The numbers in the above figures are for a 3 x 660 MW plant and exclude land cost, which is dependent on the size and location of the plant. A typical 3*660 MW plant would require around 2000 acres of land.[12] Usually, land acquisition cost is a small part of the expense.

The biggest expenditure is the Main Plant which comprises of the boiler, turbine, generator, ash handling plant and coal handling plant. The main plant itself takes up around 66% of the cost. Miscellaneous costs include piping, insulation and preliminary investigation & survey (PIS).

On average, building a coal power plant in India costs around 4.5 to 5 crores per MW and takes around 48 to 84 months to build, depending on the size of the plant and various other issues.

A coal power plant converts the heat energy produced by burning coal to mechanical work, and work into electricity. A lot of the heat produced is dissipated into the environment. A typical coal plant works at an **efficiency of 30%**, which means that only 30% of the heat energy is converted to electrical energy.

Plant load factor is typically about 75%.

A power plant usually does not work continuously throughout the year. **Plant load factor** is a measure of the average capacity utilization. Assuming a plant load factor of 75%, approximately **4200 tonnes** of coal would be required to fire 1 MW of capacity for one year (see appendix for details).

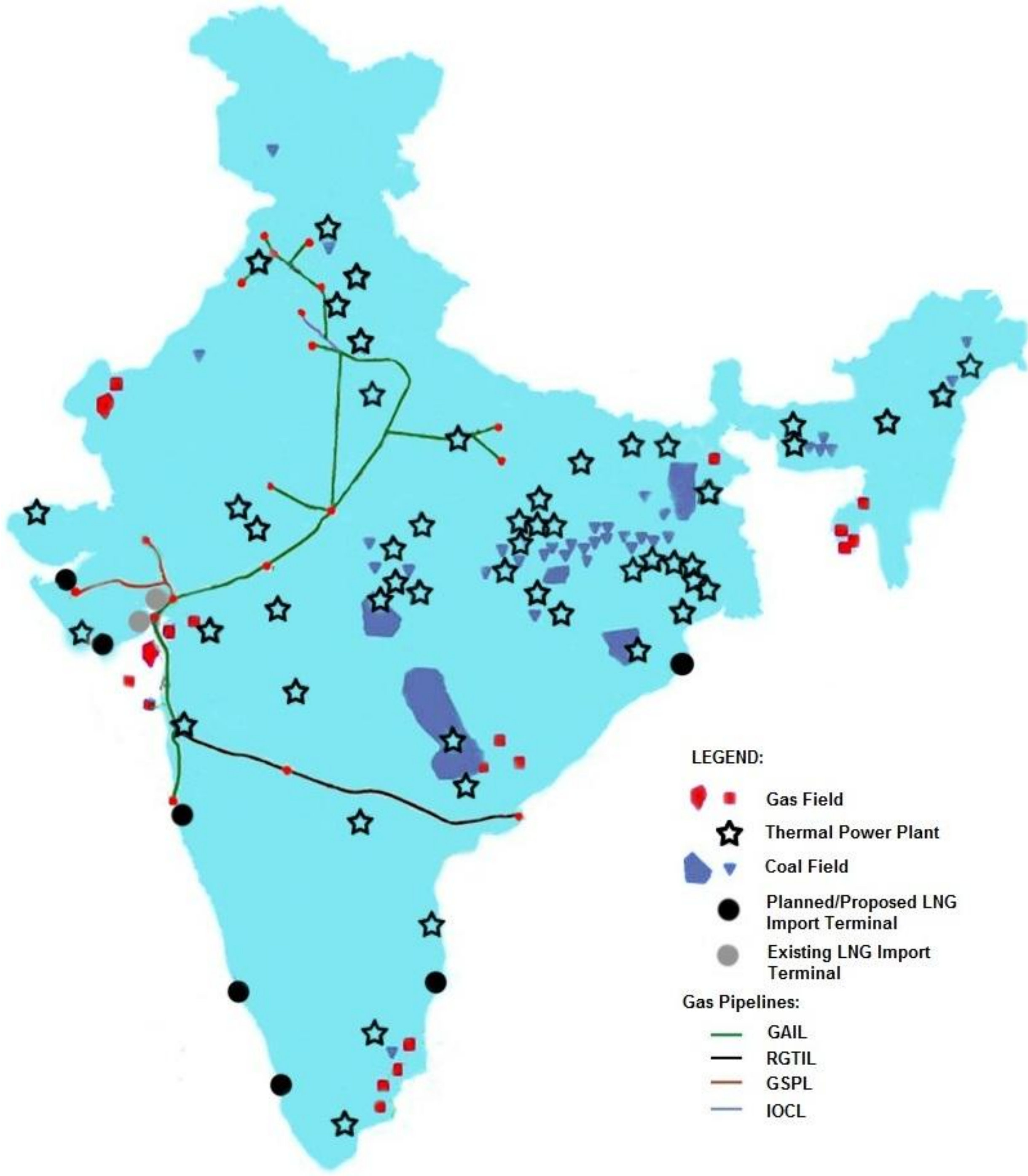
According to Coal India annual report, coal price realization is around Rs. 1000/ tonne. The transport cost by rail is around Rs. 1 per tonne per km. The royalty paid to the government is around Rs. 111 per tonne.

Under the above assumptions, fuel cost for domestic coal is about 65 paise per unit of electricity generated.

Under these assumptions, for Ultra Mega Power Plants (UMPP), cost of generating electricity works out to around Rs. 1.5 to Rs. 2 per unit (KWh). This includes cost of coal of around 65 paise per unit. The electricity produced is generally sold to the State Electricity Board (SEB) at a price between Rs. 2 to Rs. 3 per unit.

Needless to say that cost of generation would be significantly higher **if foreign coal is used (price ~ $85/tonne). By our reckoning, cost of coal alone would rise from 65 paise to Rs. 2.1 per unit.**

Source: HarryLawford@flickr.com



Most of Indian coal mines are situated near the eastern part of the country. **Odisha**, **Chattisgarh** and **Jharkhand** are the top coal producing states and most of the major coal power plants are also situated nearby.

Gujarat is home to the country's two biggest power plants; Mundra Thermal Power Station owned by Adani Power (4620 MW) and Mundra UMPP, which is owned by Tata Power (4000 MW).

GAIL currently has a pipeline network of around 9000 km (to transport 220 mmscmd of gas) and construction is in place to extend it to 15000 km. **Reliance Gas Transportation Infrastructure Limited (RGTIL)** has set up an East to West pipeline with a capacity of 80 mmscmd. Several new LNG terminals are being built. Gujarat remains the main hub of gas imports and **Gujarat State Petronet Limited (GSPL)** is looking to further extend the pipeline network in the state.

Section 3: NATURAL GAS

3.1 Introduction

Natural Gas has been evoking considerable interest of investors and industries alike over the last several years. Part of its popularity stems from the fact that it is a very clean fuel producing less carbon dioxide than oil or coal, and almost no other harmful gases like sulphur dioxide, etc. While coal produces about 2.93 kg of CO2 for every kilogram burnt (1.47 kg/kWh), [13] natural gas generates 45% less for the same amount of energy.

Furthermore, gas based power plants are around 20-25% more efficient than coal power plants. Lastly, natural gas reserves are on the rise owing to the technological advancements in extraction of shale gas, which has lead to constant announcements of shale gas recoverable reserves around the world. Given the growing resource base, natural gas is likely to play a greater role in the world energy mix in the coming years.

Country	Reserves as of 2011	% of World Total
Russia	44.6	21.4
Iran	33.1	15.9
Qatar	25	12.0
Turkmenistan	24.3	11.7
United States	8.5	4.1
Saudi Arabia	8.2	3.9
UAE	6.1	2.9
Venezuela	5.5	2.6
Nigeria	4.1	2.0
India	1.2	0.6
World	208.4	100

Table 3.1 Proven Reserves as of 2011 (trillion cubic meters)

The Natural gas reserves have been increasing in the past few years.

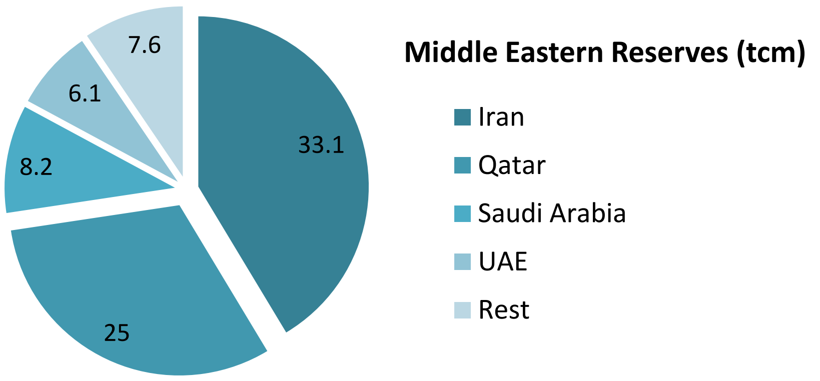
Known Global reserves of natural gas have increased from 187.1 trillion cubic meters [14] in 2010 to 208.4 trillion cubic meters (tcm) by the end of 2011; this translates to **over 60 years of supply** at the current rate of production. Another factor for increasing reserves is the deepwater drilling in Central Asia, South America and Africa, resulting in updates of the reserves estimates, with bias towards increases.

At the current rate of production, there is a supply of over 60 years. This stat has remained same for past 5 years since new discoveries offset the production of that year.

The above values are generally taken to be those quantities which can be recovered in the future from known reservoirs **under existing economic and operating conditions,** as indicated by geological and engineering information. As the extraction of natural gas becomes more and more economical and increased drilling activities take place, the reserve estimates go up. In the case of Turkmenistan for example, the reserves have jumped from 7.5 tcm in 2010 to 24.3 tcm in 2011.

Russia has the largest reserves of natural gas in the world and accounts for 21.4% of the total. It is the main source of gas for Europe, making gas an important source of political tension.

The Middle East has a combined total of 38.4% of world's natural gas reserves. India's natural gas reserves form 0.6% of world total.



The United States has reserves of 8.5 tcm and it is believed that in the coming years, US will become self-sufficient with respect to its fuel requirements, or even a net exporter. US shale gas reserves have grown rapidly in the years since 2009 when shale gas reserves increased by 76%, according to the U.S. Energy Information Administration (EIA).

India's natural gas reserves are estimated to be around 1.2 trillion cubic meters, which is a mere 0.6% of the world total.

Natural Gas Calculations Explained

To understand the economics of coal and gas, it is important to know how the fuel costs are derived. In order to calculate the fuel costs, we need to look at the plant generation economics in terms of efficiency.

A perfect plant with 100% efficiency would require 3412 BTU (British thermal unit) to produce 1 KWh of electricity. (1 BTU = 1,055J)

An average coal plant in India works at around 30% efficiency and hence requires (3412/0.3) = 11,373 BTU of energy.

On the other hand, a gas power plant works at an average efficiency of around 45%. (Note: Combined Cycle Gas Plants give a better efficiency of 50-60%).

Hence, a gas plant requires (3412/0.45) = 7,582 BTU of energy to produce 1 KWh of electricity.

This means 7.582 MMBTU to produce 1 MWh of electricity.

1 MMBTU = 27.6 cubic meters of gas (see Appendix).

7.582 MMBTU = (7.582*27.6) = 209.3 cubic meter of gas.

In a day, assuming a plant load factor of 75%, (24*0.75) = 18 million units will be produced.

To produce that 18 million units, a total of (18*209.3) = 3767 cubic meter of gas will be required. In mmscmd (million standard cubic meters per day) terms, 0.003767 mmscmd of gas is required.

On more realistic measures, **a 1000 MW plant would require 3.77 mmscmd of gas**.

(1 mmscmd of gas can produce 265 units of electricity.)

3.2 Global Production and Consumption

In 2011, the world produced a total of 3276.2 billion cubic meters (bcm) of natural gas. There was a 3.1% increase from last year when 3178.2 bcm of gas was produced.

Country	Production in 2011	% of World Total
US	651.3	19.9
Russia	607	18.5
Canada	160.5	4.9
Iran	151.8	4.6
Qatar	146.8	4.5
China	102.5	3.1
Norway	101.4	3.1
Saudi Arabia	99.2	3.0
India	46.1	1.4
World	3276.2	100.0

Table 3.2 – Global Production in the year 2011 (billion cubic meters)

Country	Consumption in 2011	% of World Total
US	690.1	21.4
Russia	424.6	13.2
Iran	153.3	4.8
China	130.7	4.1
Japan	105.5	3.3
Canada	104.8	3.3
Saudi Arabia	99.2	3.1
UK	80.2	2.5
India	61.1	1.9
World	3222.9	100.0

Table 3.3 – Global Consumption in the year 2011 (billion cubic meters)

Iran and Qatar account for around 28% of world reserves but produced only about 9% of world total.

The United States was the largest producer of gas in 2011 – producing a total of 651.3 bcm - almost 20% of the world total. Its neighbour, Canada produced 160.5 bcm, around 5% of the world total. Fifty five percent of what Canada produced was exported to the US. US consumption of 690.1 bcm was higher than its production and the excess was provided by Canadian pipelines. Despite consuming more than its production, US still managed to export some of it.

Russia was the second largest producer with 607 bcm. Interestingly, Turkmenistan increased its production by 40.6% in the last year increasing from 42.4 to 59.5 bcm (in 2011).

Middle Eastern countries - Iran and Qatar, account for around 28% of the world reserves but produced only about 9% of the world total.

India produced 126.3 mmscmd of gas in 2011. US on the other hand produced 1785 mmscmd: more than 14 times of what India produced.

India produced 46.1 bcm of gas in 2011, which translates to 126.3 mmscmd of gas. US on the other hand produced 1784.38 mmscmd, more than 14 times of what India produced.

Japan was one of the biggest consumers in the world in 2011 and consumed 105.5 bcm of gas (an increase of 11.6% over last 2010 consumption). The nuclear disaster in the same year forced it to close its nuclear plants which contributed significantly to its increased consumption of gas to make up for the lost nuclear power.

In China, only 4% of its power is produced from natural gas. India produces around 9% of its power from natural gas.

Russia and Iran, second and third largest consumers, subsidize natural gas usage, which increases their consumption. Unlike Iran, Russia produces much more than it requires and is the biggest exporter of natural gas.

China consumed 130.7 bcm in 2011 (a global share of 4.1%). Currently, gas comprises less than 4% of China's primary energy use and hence China is viewed as a growing market for gas.

India consumes less than 2% of what the world consumes. Like China, India's current requirement of gas is relatively low, but it is expected to grow in the near future.

3.3 Global Exports and Imports

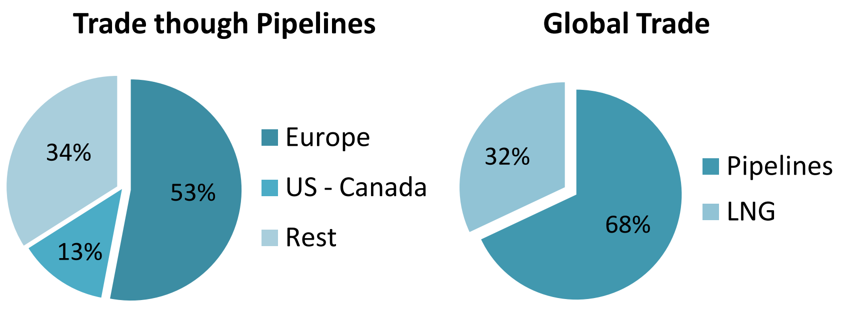
Natural gas is difficult to transport or store because of its low density. The easiest way to transport gas is through gas **pipelines**, but the drawback is that building pipelines across oceans is impractical. Pipelines are preferred for transport for distances up to 4,000 km over land and approximately half that distance offshore.

Liquefaction reduces the volume of natural gas by around 600 times, whereas Compression reduces it by about 100 times.

Natural gas can be transported overseas on LNG (liquefied natural gas) carrier ships, which are used for long distances mainly due to the fact that LNG reduces the volume of gas by 600 times. Sea transport of CNG (compressed natural gas) using CNG carrier ships is currently under development.

To transport overseas, first a liquefaction plant is required to convert the natural gas into **LNG**, which on arrival at the destination on LNG carrier ships, has to be converted back to gas through a re-gasification plant.

Last year, a total of 1025.4 bcm of gas was exchanged, i.e. 33% of total gas production.



India imported a total of 17.1 bcm in 2011. 76% of it came from Qatar.

Despite being the largest producer of natural gas, US still imported a total of 98.1 bcm of gas in 2011; 88 bcm of which came from Canada through pipelines. Gas is not only used as a fuel for power generation, but also for residential (e.g. air-conditioning) and commercial purposes.

Country	Pipeline	LNG	Total
Japan	-	107	107
US	88.1	10	98.1
Germany	84	-	84
Italy	60.8	8.7	69.5
UK	28.1	25.3	53.4
South Korea	-	49.6	49.6
France	32.3	14.6	46.9
India	-	17.1	17.1
World	694.6	330.8	1025.4

Table 3.4 – Major Imports in 2011 (billion cubic meters)

Country	Pipeline	LNG	Total
Russia	207	14.4	221.4
Qatar	19.2	102.6	121.8
Norway	92.8	4	96.8
Canada	88	-	88
Netherlands	50.4	-	50.4

Table 3.5 – Major Exporters in 2011 (billion cubic meters)

India imported 17.1 bcm in 2011, all of it as LNG, 76% of which came from Qatar (17.1 bcm translates to about 46.8 mmscmd).

In Europe, Russia (38.1%) and Norway (25%) are the largest exporters. Russia (21.6%) is also the world's largest exporter of natural gas with a total of 221.4 bcm in 2011. Qatar (11.8%) is second with 121.8 bcm and Norway (9.4%) follows suit with 96.8 bcm.

Japan had to import significantly larger quantities of gas because of the nuclear disaster last year.

Japan (10.4%) was the largest importer in the world in 2011 with a total of 107 bcm imported in 2011. This was done through diversified sources and Malaysia was its largest supplier with 20.3 bcm (19% of Japan imports). Germany (8.2%) was the third largest importer in 2011 with a total of 84 bcm. Russia, Norway and Netherlands were Germany's main suppliers.

Source: kenhodge13@flickr.com

Natural Gas:

What is natural gas?
How is it extracted?

For many years, natural gas was considered useless and discarded by burning it in giant flares, so large that they could be seen from space. Yet, it is one of the most valuable fuels we have.

Natural gas mainly consists of methane, a simple compound that has a carbon atom surrounded by four hydrogen atoms. Methane is highly flammable and burns almost completely. There is no ash and very little air pollution.

Exploration for natural gas typically begins with an examination of the structure of the earth's surface (done by geologists), and determining areas where it is geologically likely that gas deposits might exist.

Using seismic waves, geophysicists survey and map the surface and sub-surface characteristics of a certain area. With the help of this, the geologists can extrapolate which areas are most likely to contain a natural gas reservoir.

Once a potential reserve of natural gas is discovered, a team of **drilling** experts dig down to where the natural gas is thought to exist. Determining whether to drill a well depends on a variety of factors, including the economic potential of the hoped-for natural gas reservoir.

After the geophysical team identifies the optimal location for a well, it is necessary for the drilling company to ensure all regulatory compliances so that it can legally drill in that area.

The next step is actually **lifting** the natural gas out of the ground and **processing** it for transportation.

Before natural gas can be used as a fuel, it must undergo processing to remove almost all materials other than methane. The by-products of that processing include ethane, propane, butanes, pentanes, and higher molecular weight hydrocarbons, elemental sulphur, CO_2, helium and nitrogen. Natural gas **transported** through pipelines must meet purity specifications to be allowed in, so most natural gas processing occurs near the well.

Liquefied natural gas (LNG) is transported across oceans by LNG carriers; tank trucks can carry LNG or compressed natural gas (CNG) over shorter distances.

CNG is transported at high pressure, typically above 200 bars. Compressors and decompression equipment are less capital intensive and may be economical in smaller unit sizes than liquefaction / re-gasification plants.

Natural gas is widely used as an important energy source in many applications including heating buildings, generating electricity, providing heat and power to industry, as fuel for vehicles and as a chemical feedstock in the manufacture of products such as plastics and other commercially important organic chemicals.

Natural gas is often informally referred to as simply gas, especially in the context of other energy sources such as oil or coal.

3.4 Indian Import Capacity

India currently has 2 fully operational LNG terminals – the biggest one at Dahej in Gujarat. It is owned by Petronet and has a capacity of 10 million metric tonnes per annum (mmtpa). Petronet is planning to increase its capacity to 15 mmtpa in the future. The other terminal is at Hazira, also in Gujarat, owned by Shell and Total jointly, with a current capacity of 3.6 mmtpa. The capacity of this terminal is expected to reach 5 mmtpa soon.

India's current import capacity is 13.6 mmtpa which allows us to import around 20 bcm or 54.4 mmscmd of gas.

The terminal at Dabhol, In Maharashtra has just started and received its first LNG cargo in late March 2012. It currently has a capacity of 2 mmtpa which is expected to reach 5 mmtpa in 14 months.

Petronet's LNG terminal at Kochi (Kerala) is nearly complete and is expected to start full operations in the 3th quarter of FY–13. The capacity of this terminal is 5 mmtpa.

Terminal	Owner(s)	Capacity (mmtpa)
Mangalore (Karnataka)	Hindujas / ONGC	5
Pipavav (Gujarat)	APM terminals	2.5 to 5
Ennore (Chennai)	IOCL / TIDCO	5
Mundra (Gujarat)	GSPC/Adani	5
Gangavaram	Petronet	5

Table 3.6 – LNG Terminals in the pipeline

A terminal with a capacity of 5 mmtpa can import 20 mmscmd or 7.3 bcm of gas.

With a current re-gasification capacity of 13.6 mmtpa, India can import around 20 billion cubic meters (bcm) or 54.4 mmscmd of gas. (A terminal with a capacity of 5 mmtpa can import 20 mmscmd or 7.3 bcm of gas.)

Source: haziralngandports.com

3.5 Gas Pricing

Natural Gas has no universal price. This can be explained by the fact that it has enormous transportation costs due to the huge plants required at both ends. In addition, **gas prices are set by different mechanisms across the world.** They vary significantly and militate against it being traded as a commodity.

Prices in America are decided by demand and supply. In Asia, the prices are directly linked to oil prices. In Europe, the price is set by a mixture of the two: oil-indexed price and the spot price.

A **liquefaction plant** costs around $200 per tonne of LNG a year, but the cost is dependent on various factors like steel price, land etc. Building a liquefaction facility is highly capital-intensive. An **LNG carrier** (or tanker) also has a hefty cost of around $250 million each for 135,000 cubic meter capacity. The high cost is due to the need for special lining and double hulls on the ship.

The **re-gasification plant** at the receiving terminal, has a cost that depends on the plant capacity, local construction costs, and the site preparation costs, but it is still in the range of several hundred million dollars (although considerably lower than a liquefaction plant). The process of liquefying, transporting and re-gasifying the gas can cost between $4 and $7 per mmbtu.

In America, gas is freely traded and **prices are set by the fundamentals of demand and supply**, which keeps the prices low. Price of natural gas in US reached a high of $12.7 per mmbtu in late 2007. It has been declining since and has reached a price of around $4 to $4.6 per mmbtu in July 2012. [15]

Gas-poor **Asia** relies heavily on imports of LNG. Gas is mainly bought and sold at **prices set by contracts linked directly to oil prices**, (although spot prices may vary from $3.5 to $6.5). The price of gas in Asia was around $14.5 (CIF) in 2011, but has increased to almost $17 by May 2012, owing to the escalating prices of crude oil. The current system of pricing has come under scrutiny lately. Importing gas from the US should ideally cost around $11 (after adding cost of transport) and not $17, which is the currently prevailing price of gas in Asia.

The pricing in Europe is done by composites.

For example, in 2011, the NBP was $9 and average GBP was $10.61. A composite of 85% oil indexed and 15% spot means that price of gas is (0.85*10.61) + (0.15*9) = $10.37

Europe's pricing mechanism is somewhere in the middle (of America and Asia). Most gas is delivered through pipelines and sold on **long-term contracts linked to the price of oil**. The long-term take-or-pay contracts that guarantee minimum purchases of gas indexed to oil prices are also coming under enormous pressure. Two benchmarks are used in Europe: GBP (German Border Price) and NBP (national balancing point). GBP is an average of the oil-indexed contracts and it is also known as the German Import Price. The NBP is the price reference point for virtually all of the UK's traded gas markets (determined by demand and supply forces).

The KGD6 Story

As discussed before, the gas production of India in 2011 was 46.1 billion cubic meters. This translates into (46100/365) = 126.3 mmscmd of gas. Reliance gas fields in the Krishna Godavari basin were expected to produce 80 mmscmd by the 5th year. Whether or not RIL reaches its production target, the fields account for a huge percentage of the entire gas production of the Nation. No wonder, it is an important topic of discussion in Indian Economy.

THE TIMELINE OF EVENTS:

6th July 2002: Dhirubhai Ambani passes away. Huge gas reserves are discovered in the Krishna Godavari Basin in the same year. (RIL had got the right to look for gas in the KG basin after signing a Production Sharing Contract (PSC) with the Government, where the latter gets a share of RIL's KG profits.)

18th June 2005: Kokilaben Ambani puts an end to a raging dispute between her sons and splits Reliance Group into two.

A family agreement (MoU) was signed that 80 mmscmd will be supplied to the gas based Dadri plant at $2.34 per mmbtu for 17 years. (With a reported reserve of around 14 trillion ft, and at an output of 80 mmscmd, there can be a supply for around 14 years only.)

December 2005: The High Court of Bombay approves the de-merger and Mukesh gets Reliance Industries & Indian Power Corporation Ltd. Anil gets Reliance Infocomm, Reliance Energy (operator of Dadri plant), and Reliance Capital.

November 2006: Mukesh Ambani's RIL fails to supply the gas to Anil Ambani's RNRL which forces Anil to take the matter up with the High Court.

15th June 2009: High Court rules in favour of RNRL and directs RIL to supply 28 mmscmd to RNRL at $2.34 per mmbtu for 17 years and 12 mmscmd to NTPC. (The production was 40 mmscmd for that year.)

Gas prices had soared and RIL refused to sell at a low price. The petroleum ministry backed the notion since the govt's interests were aligned with RIL (as part owners). A committee led by Pranab Mukherjee came up with the figure of $4.21 per mmbtu.

July 2009: Mukesh decides to appeal against the High Court Order and take it to the Supreme Court.

7th May 2010: Supreme Court rules in favour of RIL and says that RIL can sell to RNRL at the government-set price of $4.21 per mmbtu. The court asked them to renegotiate an agreement within 6 weeks.

26th June 2010: RIL and RNRL sign a revised gas sale master agreement (GSMA) with the details kept undisclosed.

Since inception, KGD6 has been lagging behind its expected output. RIL has said that the underproduction is due to unexpected geological factors like sand and water ingress, which led a few wells to cease.

Year	09-10	10-11	11-12	12-13
Output as per AIDP	27.62	53.4	61.88	80
Actual output	39.31	48.13	38.61	20.2

Table 3.7 - KGD6 Production (mmscmd)

The Oil Ministry on the other hand thinks that the output fell because RIL did not drill wells as per the Amended Initial Development Plan (AIDP).

India is expected to remain one of the fastest growing economies (despite the recent downgrades in growth expectations). The need for power will grow constantly as the country develops.

In December 2011, over 300 million Indian citizens had no access to electricity. Over one third of India's rural population lacked electricity, as did 6% of the urban population. Of those who did have access to electricity in India, the supply was intermittent and unreliable. Blackouts and power shedding interrupted irrigation and manufacturing across the country.

Production of coal in India is restricted due to the inadequate infrastructure and the environmental concerns that deny permissions to mine.

The ongoing growth of electricity demand raises the need for constantly increasing fuel supply. The uncertainty of availability of indigenous coal might **force power producers to look for an alternative source** (as is already happening) and make an important decision as to which fuel they plan to use; since power plants are built with a view of 25-50 years.

Coal based power plants will have to turn to imported coal, which is more dependable in terms of supply, although it is way more expensive. **The amount of coal imported is likely to increase in the coming years.** This will result in increased cost of production and may lead to rising electricity prices for end consumers, restricting growth.

For a thermal power plant, there is huge difference between the fuel costs depending on where it comes from.

On the other hand, coal-rich countries are increasingly inclined to raise tax on exports of coal, making it even more expensive. However, since Indonesia decided against raising export taxes, **Indonesia should remain India's primary supplier of coal in the coming year,** even though they have decided to link the coal prices to spot market**.** In the meantime, Mongolia is being touted as a new source of importing coal.

The Table 4.1 shows how incredibly cheap indigenous coal is compared to the rest. In practice, imported coal is sometimes mixed with the domestic coal.

Fuel	Price	Cost/yr	Equivalent oil price ***
Domestic coal (4500 Kcal/Kg)	$18 / tonne	$75.37 million*	$5.93
Domestic coal (6500 Kcal/Kg)	$80/tonne	$233.05 million*	$16.77
Imported coal (6500 Kcal/kg)	$85 / tonne	$246.5 million*	$17.8
Domestic gas	$4.2 / mmbtu	$209.4 million*	$24.4
Imported gas	$17 / mmbtu	$847.5 million**	$98.6

*excluding transport costs.

**including transport costs (5% import duty charge not added)

***see appendix for details

Table 4.1 – Fuel Cost Comparison for 1000 MW plant

In the coming 2-3 years, the domestic production of gas is likely to stay limited.

The most economical alternative to indigenous coal is domestic gas. The only problem is that it too, is scarce. India's natural gas reserves are estimated to be around 1.2 trillion cubic meters; which is a mere 0.6% of the world total. As discussed before, only 126.3 mmscmd of gas was produced in India last year (1.4% of the global production). RIL has informed that production at KGD6 is likely to reduce even further. In the coming 2-3 years, the **domestic production of gas is likely to stagnate**.

As the natural gas market deepens, the oil-indexed pricing system will lose its purpose soon.

If the current pricing system is abandoned, then importing natural gas may become economical due to competitive pricing.

Imported gas is the most expensive source and is unrealistically priced under the current oil-indexed price system. Initially, the system was employed to prevent manipulation by the major players (due to limited market). As the demand and supply of gas increases and the market grows, the oil-indexed pricing system will soon lose its purpose. When that happens, the current system could be disbanded. This **will lead to competitive pricing and bring down the prices (extraction and transportation costs are also expected to ease up) to more realistic values.**

In addition, an agreement has been signed in May 2012 to build the Trans - Afghanistan Pipeline, which is also known as Turkmenistan – Afghanistan – Pakistan – India, TAP or **TAPI**. It **is expected to be completed by 2018** and will provide 38 mmscmd of gas to India (enough to drive 10,000 MW capacity).

In the future, Natural Gas can become the preferred fuel due to its environmental and its efficiency benefits.

For now, coal will remain the dominant source of power in India.

One argument for using gas is the environmental factor. It is generally very difficult to obtain clearance to set up a power plant and the process is time consuming. For an equivalent amount of heat, burning natural gas produces about **45% less CO_2 than burning coal** and about 30% less than burning petroleum. Gas plants have a 20-25% better conversion efficiency than coal plants. Gas can hence become the preferred fuel due to its environmental and efficiency benefits (carbon credits providing for part of higher cost of gas). However, it should be noted that methane has around 20 times stronger greenhouse effect than CO_2. A few environmental groups believe that the transmission leakages can lead to similar effect as burning coal.

Given the increasing import capacities, use of gas is likely to increase in India. However, pace of growth would remain subdued due to limited domestic resources and still-high cost of imports. With the above factors in mind, and absent a major domestic gas discovery or technological break-through in solar power, it is our belief that coal is likely to maintain its dominance for the decade to come. Given tight supply conditions and unfavourable economics of alternative fuels, **power producers who do not have captive coal supplies would be at a significant disadvantage compared to those who do.**

5.1 Units & Definitions

BTU – British thermal unit = 1055J. It is the amount of energy to heat 1 pound of water (raise the temp by 1 degree Fahrenheit)

MMBTU – Million British thermal units (‘M’ stands for one thousand based on Roman numeral system here. Hence MM means thousand thousand = million)

MMSCMD – million metric standard cubic meters per day

MMTPA – million metric tonne per annum

MMT – million metric tonnes

Short ton (US) – 2000 pounds (907.18 kg)

Long ton (Imperial) – 2240 pounds (1016.04 kg)

Mtoe - million tonnes of oil equivalent – unit of energy – energy released by burning one tonne of crude oil – appx 42GJ or 11.63MWh

SCM – standard cubic meters

BCM – billion cubic meters (10^9 cubic meters)

TCM – trillion cubic meters (10^12 cubic meters)

BCF – billion cubic ft (10^9 cubic ft)

TCF – trillion cubic ft (10^12 cubic ft)

KWh – Kilo Watt Hour (Units). For constant power, energy in watt hours is the product of power in watts and time in hours.

Heating Value – The heating value of a fuel is the amount of heat produced by burning a specified amount of it. The energy value is the characteristic for each substance.

Equivalent Oil Price: A barrel of oil produces 5.8 mmbtu of energy. Hence oil equivalent price is the price paid for 5.8 mmbtu of energy. For example, if the price of gas is $4.2 per mmbtu, its oil equivalent price is equal to $24.36 (4.2*5.8).

Coal Requirement Calculations:

Coal based power plants typically operate at an efficiency of around 30%. Efficiency here means Energy Conversion efficiency and is defined as the ratio between the useful output of an energy conversion machine and the total energy content of the input fuel.

Taking domestic coal of 4500 Kcal/kg, at an efficiency of 30%, only 1350 Kcal will be converted into electricity.

1350 Kcal = 1.57 kWh (units of electricity)

Assuming a plant load factor of 75%, in a year, a 1000 MW power plant would produce (1000*365*24*75%) = 6.57 billion units.

1 kg of coal produces 1.57 units; therefore, coal required to produce 6.57 billion units would be (6.57 billion/1.57) = 4.2 million tonnes.

Gas Requirement Calculations:

1GJ = 278KWh (approximately)

At 58% efficiency you need 1.72 GJ to produce 278kWh.

1000kWh = 6.187 GJ = 5.87 MMBTU
High efficiency (50%) – 7000 BTU to produce 1kWh.

7000 cubic ft is required to produce 1MWh (or 198.2 cubic meters.)

5.2 Conversions & Rules of Thumb

Energy Unit Conversion

- 1 Cal = 1 kcal = 1000 cal = 4.187 KJ = 3.968 Btu
- 1 KJ = 0.239 Cal = 0.95 Btu
- 1 Btu = 1,055 J = 0.252 kcal
- 1 kWh = 3.6 MJ = 3,412 Btu;
- 1MWh = 3.6 GJ = 3.412 mmBtu
- 1 mmBtu = 10^6 Btu = 1.055 GJ
- 1 mcf nat. gas = 1.027 mmBtu = 1.082 GJ
- 1 toe = 41.868 GJ = 39.683 mmBtu = 11.63 MWh = 7.33bbl
- 1 tce = 29.308 GJ = 27.778 mmBtu = 8.141 MWh

Volume Conversion

- 1 L = 0.264 gal = 1000 cm^3 (ml)
- 1 m^3= 1000L =35.3ft^3 =264gal
- 1 gal = 3.785 L= 4qt =16c =128oz
- 1 ft^3 = cf = 28.32 L = 7.482 gal
- 1 bbl = 42 U.S.gal= 159 L= 5.6 ft^3
- 1 cubic meter = 35.3 cubic ft
- 1 tcf = 28.3 bcm

Global Warming Potential

- CO_2= 1; CH_4=23;
- N_2O=296; SF_6=22,200

Power Unit Conversion

- 1 W = 1 J/s = 3.6 kJ/hour = 31.5 MJ/year

Rules of Thumb

- 1 barrel of crude oil = 5.8 mmBtu
- 1 cubic ft of gas = 1,026 BTU
- 1 cubic meter of gas = 36,233 BTU
- 1MMBTU = 27.6 cubic meter of gas
- 1GJ = 26.8 cubic meter of gas
- To convert 'long ton' to metric ton, decrease by 1.5% (actually 1.6%)
- To convert 'short ton' to metric ton, increase by 9% (actually 9.3%).
- A typical coal-fired power plant works at 10,500 Btu/kWh, an efficiency of 32–33%.
- A typical gas-power plant works at an efficiency of 45%, although combined cycle gas power plants can work between 50-60%.
- Transportation cost of coal inland: Rs.1 per tonne-km
- Cost of coal based power plant per MW: 4.5-5 Cr.
- Amount of Natural Gas required to fire a 1000 MW power plant: 3.77 mmscmd
- Amount of coal required to fire a 1000 MW power plant in a year: 4200 tonnes for Indian coal; 2900 tonnes for Imported (higher quality) coal.
- 1 mmtpa of LNG = 4 mmscmd of gas
- 1 mmt of LNG = 1300 scm
- 1 tcf = ~80 mmscmd

5.3 References

Cover page image – perspective-OL@flickr.com

Coal Section Page images – StellaBlu@flickr.com and redwood1@flickr.com

Natural Gas Section Page images – (clockwise) – danielfoster437@flickr.com, sirdle@flickr.com, foto43@flickr.com, spkushner@flickr.com

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THIRD WAVE SOLUTIONS