CONCEPT PAPER ON THE COAL GASIFICATION OPPORTUNITIES IN INDIA

U.S. INDIA STRATEGIC PARTNERSHIP FORUM (USISPF)

JULY 2019

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1.0

Executive Summary

Thanks to recent reforms especially the last mile delivery reforms undertaken during the first term of Hon'ble PM Narendra Modi-led-NDA-Government, India is developing rapidly both socially and economically. The young middle class of India are driving consumption of goods and services that increase the demand for chemicals and petrochemicals. Simple examples being automobiles, domestic appliances and homewares which drive demand for polymers such as polypropylene and polyethylene, as well as polyurethanes and polycarbonates. This demand for petrochemicals will need to be met, and in the absence of a domestic chemical industry, they will need to be imported. As these imports of petrochemicals are essentially 'oil equivalent import', such imports will place increasing pressure on the country's current account deficit, causing it to widen and place downward pressure on the Indian Rupee.

An alternative is to develop a domestic chemicals industry, taking advantage of indigenous feedstocks (coal, lignite and petroleum coke). While in the short term, this approach may appear to be slightly expensive than importing oil-based chemicals from overseas. We believe that a chemical industry based on indigenous feedstocks like coal offer significant value addition to Indian economy in medium to long term in terms of savings in foreign exchange, revenue generation (taxes, duties, royalty etc.) and employment generation.

To enable the indigenous feedstocks based chemical industry, it is imperative to incentivize coal to chemical projects by sharing the 'benefits' of a reduced current account deficit, energy independence and employment generation. These incentives can be a combination of policy, fiscal and non-fiscal based benefits. Regions with abundant coal resources and lacking in oil are at the forefront of the drive to use coal for chemical and liquid fuel production.

India is the world's second-largest consumer of coal and has significant coal resources of 360 billion metric tons in 2017. However, challenges (logistics, environmental approvals and land acquisition) to commercialize resources has forced Indian market to increasingly turn to imports to meet its demand. In the past, availability of cost-effective technologies to handle low quality Indian coal was a limiting factor in fully monetizing India's coal resources. However, a significant progress has been made on the technology front during the last decade. Now, high ash coal can be effectively processed using established technologies.

Similar to India, China has significant coal reserves. China has been pushing for coal gasification in a major way by adopting proven western-developed gasifiers to gain operational experience. The development of China's coal gasification industry has the potential to reshape the global gasifier industry. China is the only country in the world, where large-scale coal gasification related industries play a significant role in economy development. Similarly, India should extract the maximum benefits from the indigenous coal reserves by developing coal to chemical industry. India should leverage the gasification technology globally available for fast track development of local coal to chemical industry. Global gasification technology companies will be interested to invest in Indian gasification industry and take on the technical risk for a reasonable return on investment.To attract private sector investment and global technology players in the Indian coal to chemical industry, Government should consider providing incentives to make the risk – returns globally competitive for the sector. A policy push for coal to chemicals would need to be driven by feedstock supply security and attracting proven global technologies in coal gasification to make it competitive.

India has significant coal resource, but the ash content of Indian coal is high up to 40%. India also has low ash coal along with energy rich-lignite and petroleum coke which is produced domestically as well as imported. For making available right feedstock for gasification in India, coal blending should be the preferred path forward compared to coal washeries. Coal washeries require capital investment, significant amounts of water and in themselves create a significant waste stream that needs to be disposed. Whereas coal blending is easy to operate, waste streams from the gasification process are easier to handle and can be value adding (e.g. Sulphur, slag). Blending high ash coals with other feedstocks is a way forward and the successful gasification of blended feedstocks has been done globally. Underground mining is also an initiative which can be undertaken to improve coal quality. It will involve higher cost, but better-quality coal. Land acquisition issues, a problem in many mining areas shall be mitigated. In addition to this, the location of coal gasification units at pit-heads can facilitate better coal blending and handling. It also mitigates logistics cost of transporting coal which is non-value additive.

India needs to plan to set up coal to chemical complexes by prioritizing the coal from coalfields with low ash content. Better coal grading and blending facilities at gasification units will resolve technical issues. Given India's energy needs and shortage of chemical feedstock supply, India has strong incentives to significantly expand its coal-based projects quickly to reach full commercial production. However, future growth of coal-based projects will depend on several factors:

- Economics (production and capital costs), competitiveness of coal-based chemicals and government support
- Government policy for the supply security of domestically available coal for coal gasification industry
- Regulation or standards for blending of coal for chemical applications
- Availability of land, water and related infrastructure

On the government policy, India needs an energy plan which includes "clean coal" technologies. Clean coal is broadly defined as technologies that reduce emission of pollutants and offer the possibility for future carbon capture and sequestration (CCS). Coal to Chemicals is part of the clean coal push and coal gasification technology is the core of the clean coal future. Coal gasification technology, which at least offers the possibility for future carbon capture and sequestration, is critical for India's clean coal future and a deciding factor to the process economics. The cost of manufacturing the chemical products from coal will need to be fiscally supported to compete with imports or additional taxes need to be levied on the imports to protect the domestic coal gasification industry. We believe that successful operations at a new fertilizer plant by Talcher Fertilizer unit in Odisha will pave the way for future developments. Talcher will be the first coal gasification-based fertilizer plant expected to be commissioned by 2022. ■

2.0

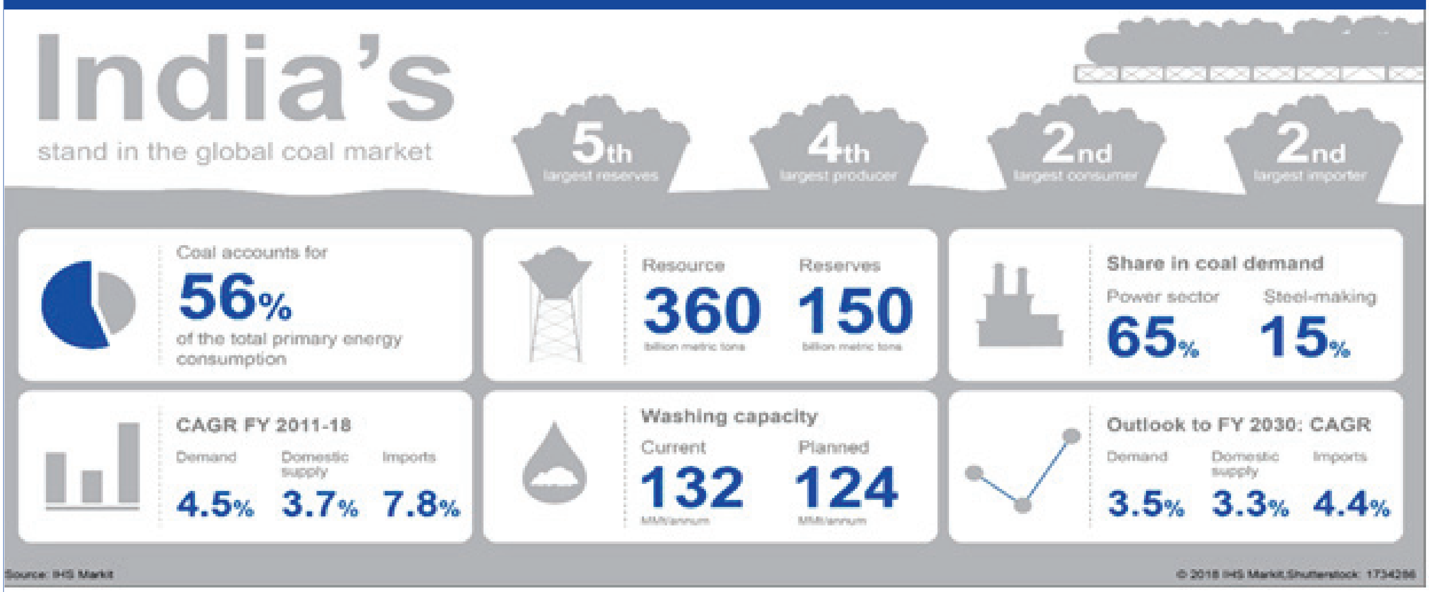
Indian Context

India is planning to embark on a major push to produce alternative fuels and petrochemicals from coal. Large projects have been planned. The outcome of this initiative has the potential to affect the future energy distribution in India as well as impact the global supply and demand dynamics of petrochemicals.

Coal has long been used as a feedstock for chemical production, which once dominated the chemical industry up until the 1950s. Unable to satisfy the demand for chemical production, coal was replaced by oil and gas. New discoveries of oil and gas reserves and improved extraction technologies increased oil and gas supply. As a result, oil prices declined, ushering the emergence of the chemical industry. In addition, the relatively simple process to the production of chemical products, derailed widespread use of coal gasification. Petroleum provided the required quantities and rapidly became the primary feedstock for chemical production. For the very same reasons that petroleum feedstock started its dominance half a century ago, coal is now again being considered as a feedstock for chemical production. Rapid increases in energy demand due to urbanization and ever-increasing population, lower price of coal than oil and gas, invention of new technologies for the large-scale conversion of coal to chemicals and presence of large indigenous Coal reserves have pushed several countries to pursue Coal-to-Chemicals.

India is the world's second-largest consumer of coal and has significant coal resources. Given abundant reserves, coal is prime fossil fuel in India and vital for India's energy security. Higher reliance on coal as an energy source offers significant benefits in terms of savings in foreign exchange, revenue generation (taxes, duties, royalty etc.) and employment generation. However, it poses significant environmental issues. India has the 5th largest coal reserve

India's coal market snapshot

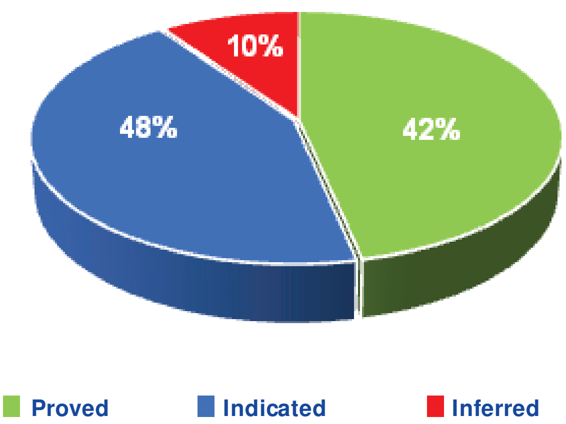


in theworld. Provencoal reserves in India are enough for more than 200 years at current consumption rate.

The Geological Survey of India (GSI) in April 2017, estimated total geological coal resources located within a depth of 1,200 meters were 315 billion metric tons. Further, the country also contains around 45 billion metric tons of lignite resources. Out of the total resource of 360 billion metric tons, 149 billion metric tons (41%) is economically extractable and is termed as reserves. Coal deposits are primarily of thermal grade, which constitutes around 78% of the resources and 83% of the reserves of the total coal reserves, 87% is either Inferior Grade or Ungraded Non-Coking Coal. Coal reserves are concentrated in Eastern India. Eastern region dominates the coal resources with ~54% of the total coal and lignite reserves. In-particular, deposits are highly concentrated within the four densely populated eastern provinces of Jharkhand, Odisha, Chhattisgarh and West Bengal.

Indian coal qualities are of low grade, with low heat content along with high ash and moisture content. Over 97% of the thermal coal produced and supplied in the country falls under 10 categories (G4-G13), i.e. over 97% of the country's thermal coal supply ranges between 3,400-6,400 kCal/kg. Further, around 72% of the thermal coal supply falls under just four categories (G10-G13) i.e. between

Estimated Coal Resources in India



Thermal coal grade classification

Old classification (UHV-based)	New classification (GCV-based)	New GCV range (kCal/kg, ADB)
	G-1	>7,000
A	G-2	6,701-7,000
	G-3	6,401-6,700
B	G-4	6,101-6,400
	G-5	5,801-6100
C	G-6	5,501-5,800
D	G-7	5,201-5,500
	G-8	4,901-5,200
E	G-9	4,601-4,900
	G-10	4,301-4,600
F	G-11	4,001-4,300
	G-12	3,701-4,000
G	G-13	3,400-3,700
	G-14	3,101-3,400
	G-15	2,801-3,100
Ungraded	G-16	2,500-2,800
	G-17	2,201-2,500

Note: ADB – air dried basis
Source: MoC, IHS Markit

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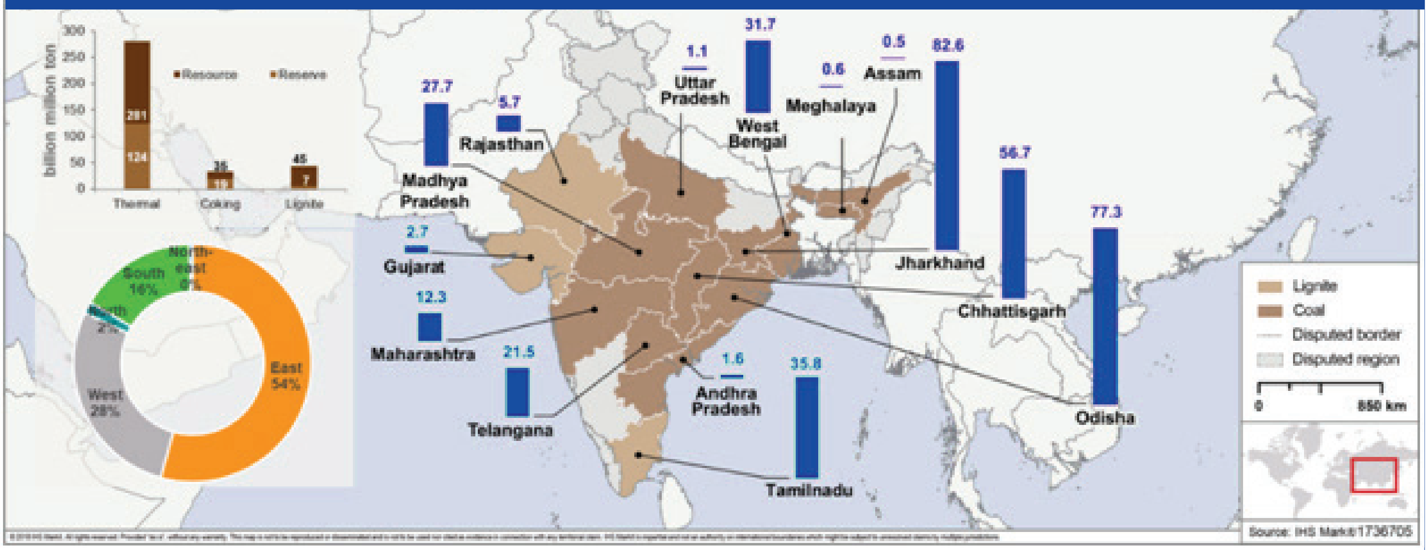
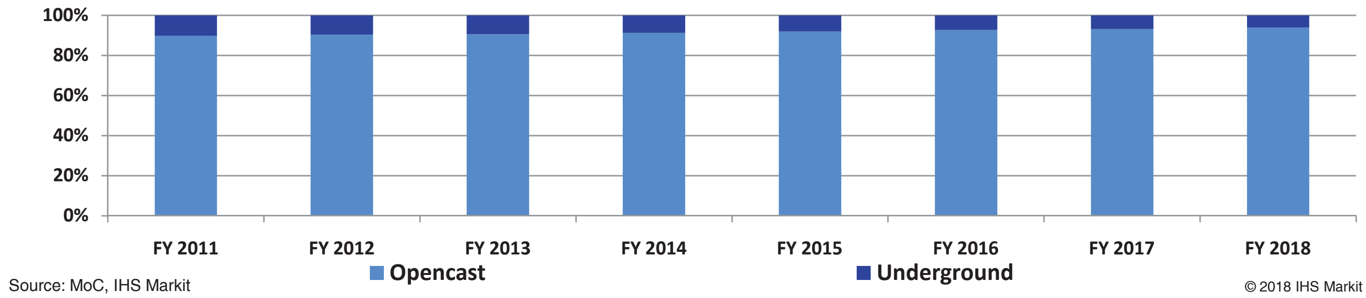
India's coal Resources by state (Billion metric tons)



3,400-4,600 kcal/kg range. Around 58% of coal resources and 76% of coal reserves are found within a depth range of up to 300 meters. This facilitates opencast mining, which contributes to about 94% of India's production. Opencast mining is the most prevalent mode of coal mining in India and its share of total coal production has been increasing consistently to stand at 94% as of FY 2018 from around 90% in FY 2011. Surface mining operations vary widely in methodology. Truck-shovel operations dominate, where loaders extract the coal from the coal seam for loading onto trucks. At very large mines these are supplemented with overburden removal by draglines whereas very small mining operations use a single loader-truck pair, or even mining by hand. Methods are similar to those in other geographies – these are standard mining methods worldwide. But cheap labor has led to generally less efficient operations.

The primary reason behind the declining share of underground coal mining can be attributed to the geo-technical challenges being faced by producers in utilizing the technology, thereby adding to the increased cost of production. Further, the lowquality of coal resources

Coal production by mining technology



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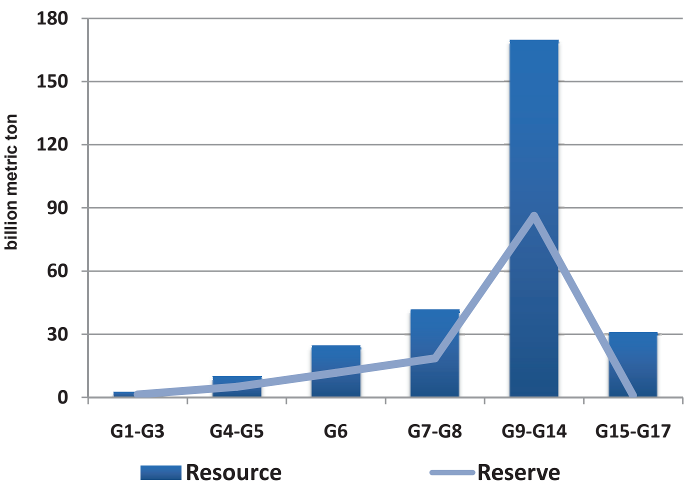
India's thermal coal resource by grade



Source: GSI, IHS Markit

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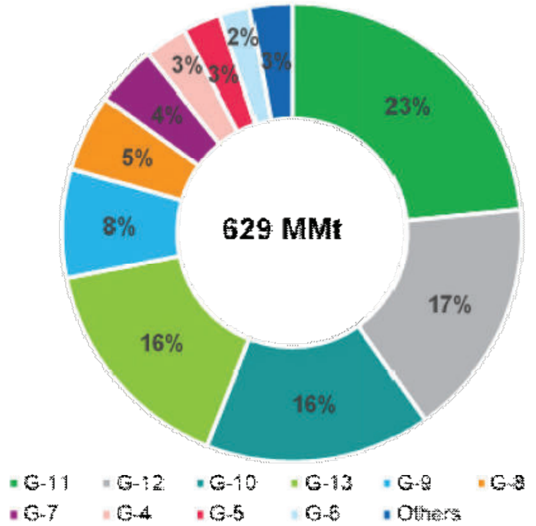
India's thermal coal resource by grade



Source: MoC, IHS Markit

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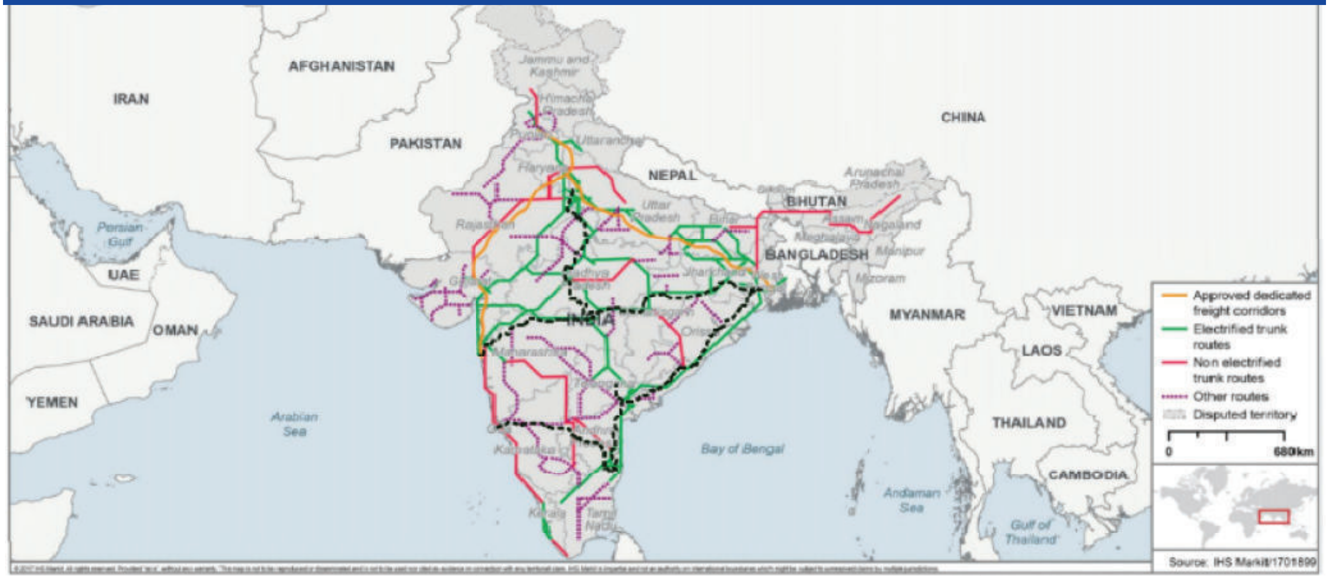
Coal Properties by Type

Type of Coal	Heating value (kcal/kg)	Moisture %	Carbon %	Ash %	Sulfur %
Anthracite	7170-7528	2.0 – 12.0	72.0 – 87.0	7.0 – 11.0	0.5-0.7
US Pittsburg	7361-7409	1.0 -5.0	73.0 – 74.0	7.0 – 13.0	2.1-2.3
Chinese	4612-6046	3.0 – 20.0	48.0 – 61.0	10.0 – 30.0	0.4-3.7
Indian	3100 - 4900	7.0 – 18.0	30.0 – 50.0	25.0 – 40.0	0.1 - 1.0
US Powder River Basin	4636-4684	25.0 – 30.0	48.0 – 49.0	5.0 -6.5	0.35 -0.45
Lignite	3346-4134	30.0 – 35.0	35.0 – 45.0	6.5 – 15.0	0.5 – 16.0

makes underground mining projects financially unviable, as the revenue realization from such projects tends to be lower than the cost of operations. Coal development from underground mines has higher extraction costs and additional geological and geotechnical constraints makes it uncompetitive.

India can leverage coal reserves to meet shortfall in chemical products like Methanol, Ammonia/Urea and others.Coal-to-chemical conversion can add significant value to Indian coal. Urea adds more value to coal than any other products; Methanol & Methanol derivatives are also attractive. Along with methanol, ammonia and urea, the coal gasification processes include:

key coal transportation railway network



Coal transportation and logistics

Production and transportation development are critical to India's coal growth. India plans to increase production and transportation capacity fairly quickly. However, the rate will gradually slow as the easiest developments occur, leaving more production required to come from greenfield sites.

Coal Import Capacity

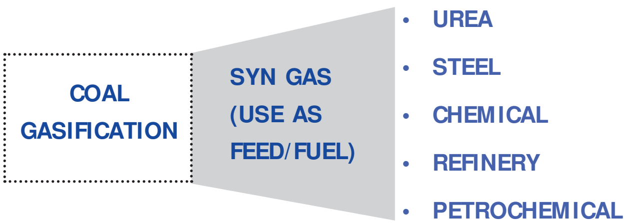
India has more than 250 mt per year of coal import capacity. Additionally, existing major ports Gangavaram, Paradip, Krishnapatnam and Dhamra are embarking on capacity expansion projects. Other ports are under construction (eg. Gopalpur, Salaya). These developments amount to around an additional 100 million tons per year. Linking these ports to Indian rail capacity has been identified by the Indian government as a crucial infrastructure requirement and is being invested in heavily by the government and by the private sector. Coal import capacity of ports is not a constraint on import availability.

Potential areas for utilization

India has significant shortfall of key chemicals.

- Coal-to-olefins (CTO)
- Coal-to-methanol and dimethyl ether (DME)
- Coal-to-monoethylene glycol (MEG)
- Coal-based ammonia/urea
- Coal-to-gasoline (CTL)
- Indirect coal-to-liquids (IDL)

While China has invested significantly in coal gasification with more than 100



Company	End Use	Status
JSPL	DRI	Operating
Reliance (primarily Petcoke based)	Refinery	Operating
GAIL, RCF, CIL, FCIL	Urea	JV formed, initial studies underway
Adani	Urea, Methanol, SNG	MoU signed with State Governments

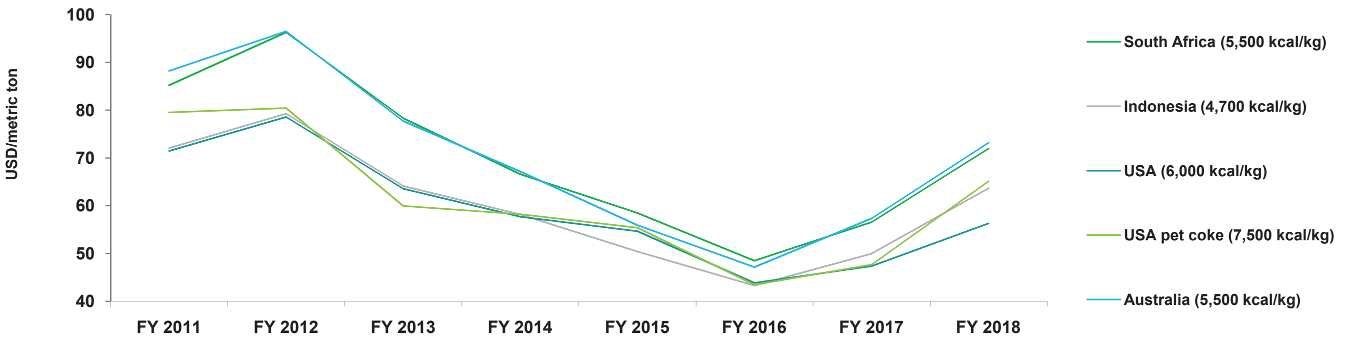
operating plants, India is under exploratory phase – only few operating or planned gasification plants.

Coal blending

Although the region has significant coal resource, ash content of Indian coal is high up to 40%. It is observed that reaching ash content below 30% is not economic and feasible even after washing in some types of coal and despite government directive to wash coal down to 34% ash, compliance is very low and this presents structural challenges. India also has low ash coal along with energy rich-lignite and petroleum coke which is produced domestically as well as imported. Blending high ash coals with other feedstocks is a way forward and economically attractive.

Today, coal-based gasification technologyis available for large stockpile of petroleum coke which can be blended with locally available coal for the purpose of coal gasification. E.g. Reliance gasification project is primarily based on Petcoke, although it can blend a portion of coal. Given uncertain oil & natural gas supply in India, coal gasification can help in meeting urea and chemical demands. Price gap between natural gas and coal is higher in Asia as compared to US. For India, which is dependent on imported LNG, the gap may be able to cover conversion cost of gasification. As India's energy needs and shortage of chemical feedstock supply, India has strong incentives to significantly expand its coal-based projects quickly to reach full commercial production. On the government policy, India needs an energy plan which includes "clean coal" technologies. Clean coal is broadly defined as technologies that reduce emission

FoB thermal coal prices



Source: IHS Markit

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lower-rank coals (subbituminous coal, lignite, anthracites and others). For example, coal gasification technology company Air Products has an operating facility with lignite feed. Given low grades of coal are available globally at a discounted price. Coal to chemical gasification based on such coal offers additional economic returns. For instance, Powder River Basin (PRB) coal price is at significant discount to high quality Northern Appalachian. So even though PRB is like sub-bituminous, it is financially attractive, depending on processing cost.

In addition, refineries across the globe are producing a of pollutants and offer the possibility for future carbon capture and sequestration (CCS). Coal to Chemicals is part of the clean coal push, and coal gasification technology is the core of the clean coal future. Coal gasification technology, which at least offers the possibility for future carbon capture and sequestration, is critical for India's clean coal future and a deciding factor to the process economics. The cost of manufacturing the chemical products from coal will need to be fiscally supported to compete with imports or additional taxes need to be levied on the imports to protect the domestic coal gasification industry. ■

3.0

China Case Study

Both China and India have limited oil & gas reserves but large coal reserves for exploitation. In China, Coal takes up approximately 70% of the energy demand. A combination of practical, economic and political events have positioned coal and coal conversion technologies as an important factor in China's policies. In China, growing production and improvement in infrastructure lowered delivery costs. Power generation is the most dominant consumer of coal in China, accounting for half of total coal consumption. The coal chemical industry, which includes gasification technology, accounts for about 5% of China's total coal consumption. Although it is only a small fraction of China's total coal consumption, projected growth could make this end use a more important market for coal. Higher self-reliance in energy supply and lower risk of oil and gassupply from abroad are the major drivers of coal gasification related industries in China.

China has been pushing for coal gasification in a major way by adopting proven western-developed gasifiers to gain operational experience. It is the only country in the world, where large-scale coal gasification related industries play a significant role in economy development. China started importing the western Coal gasification technology in 1950. These units were deployed either to generate a fuel gas for kilns, iron melting and various industrial furnaces and boilers or to produce a syngas suitable for the conversion to ammonia and the ammonia fertilizer industry. Coal gasification technology was of major importance to China as it moved to prioritize, develop and use its energy resources. These factors included the vast coal reserves, a growing demand for chemical products such as ammonia, fertilizer and methanol, awareness in the development of the technology and the demonstrated capability of emerging international gasifiers/gasification technology offered to meet China's coal utilization objectives. China has built or planned many high-capacity plants for coal-based chemicals and alternative fuels. The outcome of these projects has affected the global supply and demand dynamics of several oil or gas-based petrochemicals. It has also provided a substantial amount of alternative liquid fuels to relieve the nation's heavy dependence on imported oil andnatural gas and alter the future energy mix. These coal technologies can produce an array of products. Western gasifiers have strong presence in China. Air Products, Siemens, KBR, GTI, Air Liquide are prominent western gasifiers in China. Air Products acquired Shell and GE's coal gasification businesses and technologies in 2018 and is a leading player in gasification industry.

Role of Coal Gasification in Ammonia/Urea: China's NH3 capacity is approx. 70 MTPA (~30% of the world) and urea capacity is approx. 80 MTPA (~40% of the world). Around 75% of China NH3/Urea is produced from coal.

Role of Coal Gasification in Methanol: China has become by far the largest producing country in the world, representing 54% of world methanol capacity (~80 MTPA) and 48% of world methanol production in 2018. China is the incremental methanol supplier to the world, and on a limited basis can adjust operating rates accordingly to "balance" world supply and demand. China has now come to the end of a major capacity expansion wave. Around 70% of China methanol is produced from coal. Globally in 2008, natural gas-based methanol production accounted for 77% of the feedstock basis and coal-based methanol production accounting for 18%. By 2018, the share of natural gas-based methanol production is estimated to have fallen to 59%, while coal-based methanol production now represents 33%. Coal-based methanol producers are incrementally spending money on waste treatment in order to comply with environmental legislation.

Role of Coal Gasification in Ethylene Glycol (EG): China's EG capacity is approx. 8.0 MTPA(~25% of the world) and the capacity of coal-based EG is approx. 2.5 MTPA (~30% of China total

Role of Coal Gasification in MTO/MTP: China's MTO/MTP capacity is approx. 50 MTPA. Capacity of coal-based olefin is approx. 13mt/a (~25% of China's total) ■

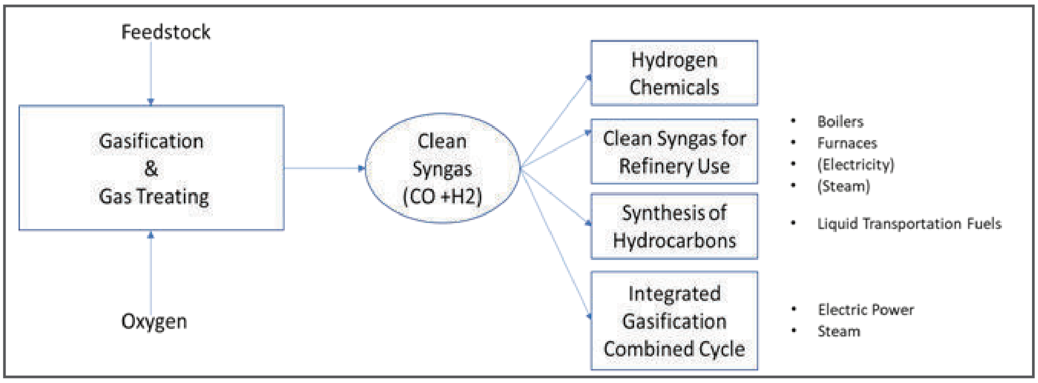
4.0

Coal Gasification Technology

Gasification is partial oxidation of coal at higher temperature and pressure to get fuel-rich gas. In this process oxygen is used as a feed instead of air. The consumption of oxygen in the process depends on the ash content and calorific value of coal. An insufficient supply of oxygen ensures partial oxidation of coal. This reaction produces a mixture of gases (CH_4, CO_2, H_2, CO). The end-product is syngas. The mixture's composition changes with pressure. Methane and CO_2 content goes up with increasing pressure and H_2+CO content goes down. Product gases (CO, H_2, CH_4) have fuel value.

Indian Feed stock

Indian coal is high in ash and moisture. The ash percentage of indigenously available coal ranges between 30-35 per cent even after washing, which is quite high. Non-uniformity of ash qualities across different Indian coal types is another challenge.Blending it with low ash coal, energy rich-lignite, petroleum coke or imported coal is required and % of blending depends on gasifier technology/classification.



Key technology providers

- Air Products and Chemicals*
- Air Liquide
- CB&I (Former E-Gas)
- Siemens and others. ■

Air Products and Chemicals acquired Shell and GE's coal gasification businesses and technologies in 2018 and is a leading player in the gasification technology

5.0

Coal Gasification Applications

Ammonia/ Urea
In India, priority for gas supply is often given to the ammonia and fertilizer producers over methanol producers. Globally, natural gas is expected to remain the key feedstock for methanol and ammonia production in the coming years. India consumed about 15.7 million metric ton of Ammonia, and consumption is forecast to grow to 25 million metric tons by 2050. India is a net importer, majority of which is done to supply Diammonium Phosphate plants. Currently, 96% of existing manufacturing facilities in India use Natural Gas as feedstock. Urea applications drive the market in the country and are by far the largest-volume markets in India, accounting for 85% of consumption in 2017.

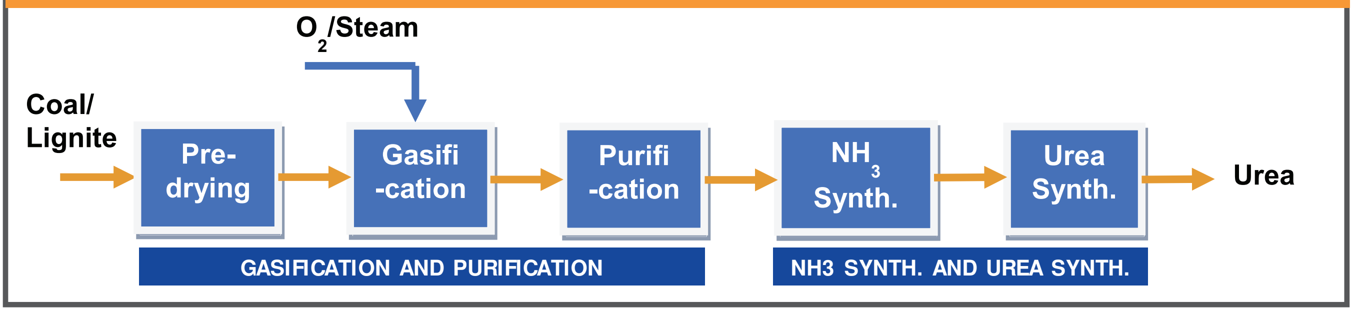
As the Indian government aims at reducing urea imports, India is shifting focus towards in-house coal-based ammonia/urea production. The new urea policy aims to make the country self-sufficient in production of Urea. India's first major plant is likely to come up by 2019 at Talcher in Orissa using Air Products' coal gasification technology. The success of this project will serve a stepping stone for future Coal based Ammonia plants in India.

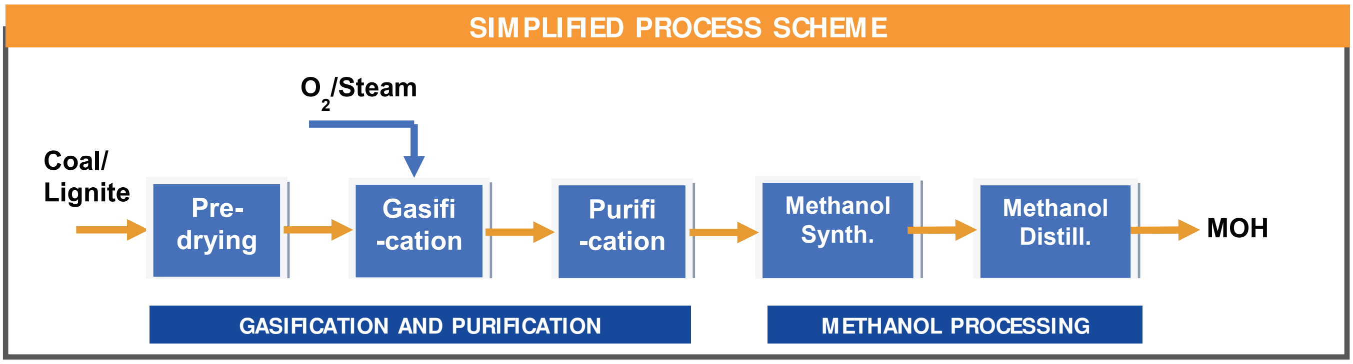
Methanol
Methanol is a high-volume industrial chemical that is used primarily as a feedstock to make chemical intermediates. These intermediates are in turn used to produce a myriad of commercially important end use chemicals, whose growth rate is correlated with the growth of general global economy. Several processes are employed commercially to produce methanol using either natural gas or coal as the feedstock. Methanol production offers a mechanism for utilization and monetization of locally available feedstocks. In countries where coal is abundant and prices significantly lower than oil or gas, methanol production provides a pathway towards industrial production of several key chemicals via coal.

Methanol also provides a convenient mechanism as an intermediate chemical, while using coal as a fundamental chemical feedstock for producing ethylene and propylene. This opportunity is commercialized in countries with sufficient demand growth to justify new chemical plant investment, where coal is abundant and priced significantly lower than oil or gas. These countries include China, Australia, India and eastern European countries such as Poland. In addition to ethylene, methanol produced from coal may also be used as transportation fuel by catalytically converting it in to gasoline. Moreover, methanol derivatives such as dimethyl ether (DME) may be used as diesel fuel components.

Methanol production in India is rather expensive because of dependence on imported natural gas compared to Middle East where natural gas is available at lower prices. Indian methanol plants run on natural gas and occupy high positions on the global cost curve. Gas prices in India have been high historically, which has put pressure on margins and reduced operating rates. Currently, limited existing manufacturing facilities in India use Natural Gas as feedstock and their economics heavily dependent on natural gas/LNG prices. India consumption of Methanol is forecast to grow at 5.8% per year during 2018-2023 and is expected to reach 15.8 million metric tons by 2050. Coal conversion is generally less economic today than from oil/gas feedstocks for the products considered. Imports from Middle East remain competitive owing to lower natural gas

SIMPLIFIED PROCESS SCHEME





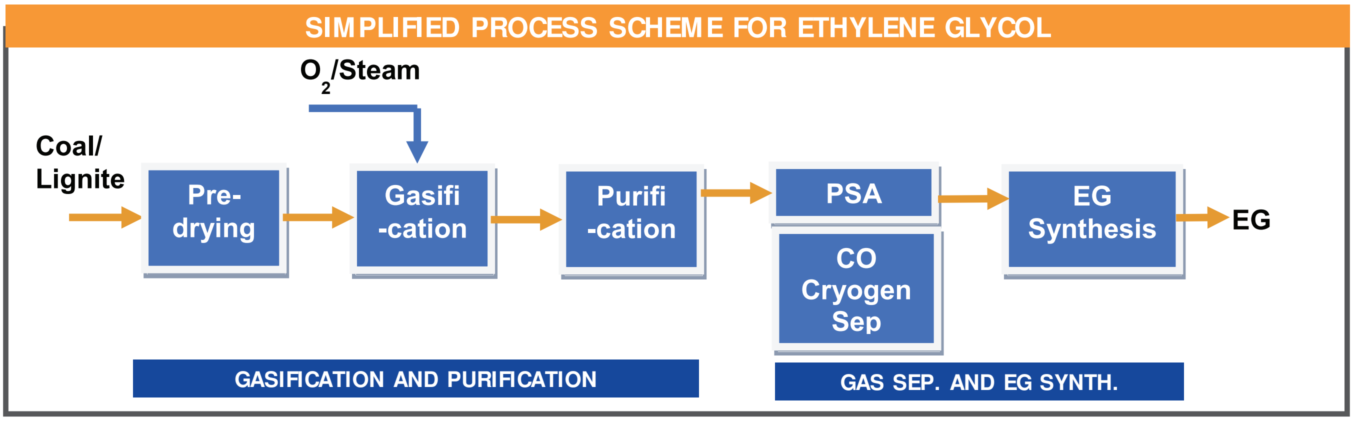
prices. Therefore, Coal to ammonia and methanol can reach parity only if it will be possible to subsidize these projects to some extent by sharing the 'benefit' of a reduced current account deficit, as well as being strategically attractive to the country in promoting some level of energy independence.

Ethylene & Propylene (Olefins)

In India, coal-to-olefins technologies are facing various social, technical and environmental roadblocks. Due to weak margins and high operational costs, CTO & MTO processes are not expected to be feasible solution to produce ethylene in the country.

Olefins production is possible through ethane cracker, propane dehydrogenation unit (PDH), low severity naphtha cracker and methanol-to-olefins (MTO) units. Steam cracking, PDH and MTO are well established and mature. Production of olefins from Naphtha is still a major route for the production of olefins in India. India's growing demand for olefin derivatives and increased naphtha supply from refinery expansions will continue to propel investments for naphtha cracker. Methanol is an intermediate in the coal to olefins production.

China has progressed well in coal to olefins technology and has significant capacity based on methanol. There is no olefin production from coal/methanol in India unlike China where significant ethylene is produced from coal and methanol. This presents an opportunity for India to leverage its domestic coal reserves to produce olefins from coal.In fact, ethane dynamics has caught the attention of Indian petrochemical industry and this has led to a series of retrofitting operations at various crackers in India.



Recently Reliance Industries Limited has debottlenecked its plant in Dahej, Gujarat and Nagothane, Maharashtra to run completely on ethane from Ethane/Propane mix. The ethane project made Reliance Industries the biggest importer of ethane from the US in 2017, followed by INEOS—a global manufacturer of petrochemicals. Currently, production of olefins through MTO process (using blended coal) is un-economical in India. Even after technology developments in methanol unit, cost of production for olefins remains highest. This is due to higher capex and opex in methanol production through coal-based route. MTO process using blended coal remain un-economical for the production of olefins owing to higher cost of production for methanol. Regulatory and fiscal support is required to make it economically viable.

Direct Reduced Iron (DRI)

Abundantly available non-coking coal in country can be used effectively. Cost of production is low and overall investment is low. India has abundant non-coking coal. Therefore, the only optimum alternate way is gasification of these coal to produce Syn-gas for direct reduced iron (DRI) production.

Others

- Fuel/Town Gas
- Methyl Acetate, Acetic Anhydride
- Replacement of off-gas in refinery, valuable
- Fischer-Tropsch Liquids – Naphtha, Waxes, Diesel/Jet/Gas Fuels
- Acetic Acid. ■

6.0

Indian Examples on Coal Gasification

Reliance Industries Limited

- Reliance Industries has invested~$4-5 billion in gasification project and its economics depend on the cost of LNG, attractive if LNG prices are high. RIL has 10 gasifiers.
- RIL converts syngas-to-chemicals, recovering CO from Syngas.
- RIL has selected Entrained Gasifier which gives ability to handle variety of solid fuels; high throughput because of high reaction rates/temperature; high carbon conversion; syngas free of oils and tars and low methane production.

Jindal Steel and Power Limited (JSPL)

- Fixed Bed Dry Bottom Gasifier, Suitable for low Rank, high ash content Coal.

Talcher Fertilizer Limited

- The project advances 'Make-in-India' initiative with domestic coal to produce urea and reduces dependence on imported LNG (2.38 mmscmd NG equivalent syngas) and import substitution of 1.27 MMTPA urea. The plant is planned for commissioning in 2022.
- It creates direct and in-direct employment opportunities and skill development.
- Plant is planned to operate on blend of 75% coal and 25% petcoke. This largely mitigates problems of high ash content of Talcher Coal. Petcoke haslow ash and high heating value (Ash 0.1%, C 90%, 8500 kcal).
- Talcher will be based on the Air Products' gasification process (Air Products acquired Shell's coal gasification business and technology in 2018) and will use high ash content Talcher coal and low ash content Petcoke blend as a feedstock.

Coal India

- Coal India (CIL), an Indian state-controlled coal mining company, is planning to set up a coal to methanol complex by using the coal from Raniganj coalfield with an ash content up to 28 per cent.
- The Raniganj coalfield produces the best quality coal in India, with average ash percentage of around 20% while the average ash content in Indian coal is 40%. ■

6.0

Challenges

Though need of self-reliance on energy supply is critical, price competitiveness will play a major role. Cost of production remains the main challenges in syngas production. At present prices of natural gas and imported products, the coal gasification route is not feasible. ■

Risk Areas	Challenges
Technology	● Indian coal quality –high ash content ● High cost of new technology ● Lack of proven expertise ● Plant configuration challenge ● By products ● CO_2 emissions ● Larger requirement of water & land ● Reliability, Availability & Safety ● Slag flow – Viscosity of slag determines the suitability of a particular coal ● Wall temperature, Corrosion & Erosion of refractories ● Blockage of tap holes due to solidification, etc.
Financing	● Relatively higher capital costs as compared to natural gas-based projects ● Long gestation period and development concerns ● Economic viability concerns ● Complex projects resulting in higher capex ● Expensive and high-risk environment for any single industry player
Regulatory	● Resistance to coal use ● Coal blocks bidding not allowed for coal gasification
Coal-Bed Methane (CBM)	**Reasons for slow progress in Coal-Bed Methane (CBM) gas production in India are:** ● Delay in Petroleum Exploration License (PEL) grant by the State Govts. ● Availability of land ● Overlapping of coal mining blocks with awarded CBM Blocks ● Pipe line for transportation ● CBM specific equipment & technology optimisation ● High hiring cost of specialised services viz. logging, hydraulic fracturing etc. ● Most of the Blocks have poor prospect due to poor rank and quality (consequently poor gas content & saturation) with doubtful permeability

8.0

Opportunities and Recommendations

Energy Security:

- Alternative avenue for vast consumption of high ash Indian coal
- Alternative route for production of chemicals
- Reduced dependence on oil and gas

Technology:

- India should leverage the gasification technology globally available for fast track development of local coal to chemical industry. Global gasification technology companies will be interested to invest in Indian gasification industry and take on the technical risk for a reasonable return on investment.
- On the government policy, India needs an energy plan which includes "clean coal" technologies. Clean coal is broadly defined as technologies that reduce emission of pollutants and offer the possibility for future carbon capture and sequestration (CCS). Coal to Chemicals is part of the clean coal push and coal gasification technology is the core of the clean coal future. Coal gasification technology, which at least offers the possibility for future carbon capture and sequestration, is critical for India's clean coal future and a deciding factor to the process economics.

Financing:

- Ownership of block with plant located at proximity
- Economies of scale
- Needs strong support from the Government
- Incentives/ Pricing
- Coal allocation to end use sector – Coal to Chemicals
- Need to encourage private participation
- Special Incentives in form of:
  - GST reimbursement
  - Capital subsidy
  - Land availability at concessional rates
  - Electricity duty exemption
  - Zero import duty on imported capital goods

Regulation:

- Accelerate opening up of coal sector for private sector investments
- Policy concessions and economic incentives for development and deployment of new technologies in India
- Develop clear policy on bidding and allotment of coal blocks
- Open new coal blocks for bidding
- Expedite clearances for new projects
- Strengthening of coal supply chain
- Coal pricing to be market linked
- Incentivize and promote underground mining. ■

9.0

Recommendations

- On the government policy, India needs an energy plan which includes "clean coal" technologies. Clean coal is broadly defined as technologies that reduce emission of pollutants and offer the possibility for future carbon capture and sequestration (CCS). Coal to gas, coal to liquids and integrated combined cycle (IGCC) power generation are all part of the clean coal push, and coal gasification technology is the core of the clean coal future.

- Coal gasification process economics is another critical factor which will determine the growth rate of coal-based alternative fuels and chemicals.

- The ash content of coal supplies need to be enforced. Present regulations limiting ash content to 34% is not being enforced. Coal washeries is an option, however it requires investment, significant amounts of valuable water and in themselves create a significant waste stream that must be disposed of. Coal blending is the path forward, as waste streams from the gasification process are easier to handle and can be value adding in themselves (e.g. sulphur, slag)

- Current coal washing capacity is 132 MMt/year and there are plans to increase that to 256 MMt/year. However, the development of incremental washing capacity is proving slow owing to issues such as land availability and environmental clearances. Further, the failure of bidders to comply with tender requirements, coupled with the absence of firm commitments from the intended customers regarding acceptance of washed coal at value-added prices, poses a challenge.

- Underground mining is an initiative which can be undertaken to improve coal quality. It will involve higher cost, but better-quality coal. Land acquisition issues, a problem in many mining areas shall be mitigated.

- Location of coal gasification units at pit-heads can facilitate better coal blending and handling. It also mitigates logistics cost of transporting coal with 40% ash which is non-value additive.

- Better coal grading and blending facilities at gasification units will resolve technical issues.

- Coal gasification technologies need to be optimized for the targeted chemical products. There is a need for a policy push to make it clear which targeted chemical products it will encourage and fiscally support.

- The cost of manufacturing the chemical products from coal will need to be fiscally supported to compete with imports or additional taxes need to be levied on the imports to protect the domestic coal gasification industry.

- The major challenge with coal gasification will be in Carbon capture and storage (CCS).

- Coal emits higher CO_2 for the same heat output. But it is relatively easier to capture CO_2 from coal rather than from natural gas combustion. However, sequestration technologies need to be developed side by side. If this can be done economically, then coal will have an advantage over natural gas. ■

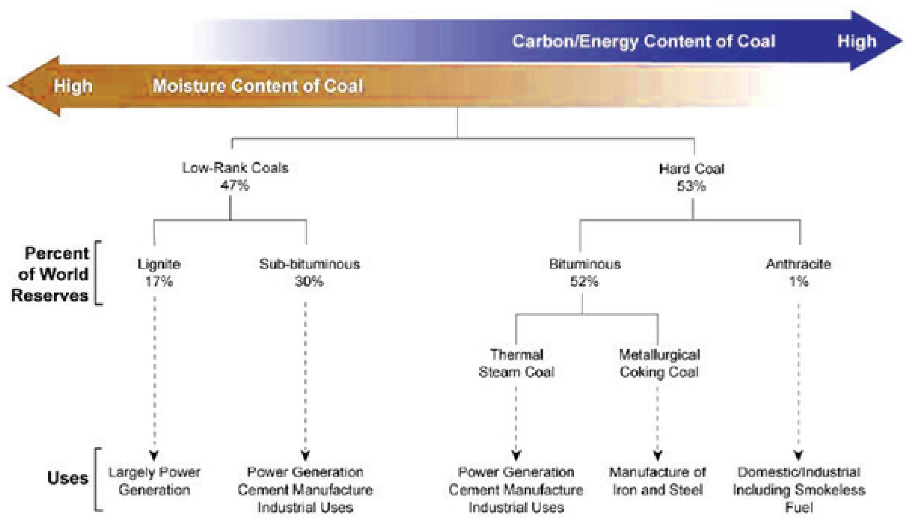
AppendixA:

Global distribution of types of coal and their uses

Globally, hard coal includes anthracite and bituminous coal, which together account for about 53% of the total. Anthracite, the highest-grade coal, represents only about 1% of world reserves and is typically used for industrial smokeless fuel.

Bituminous coal, accounting for 52% of the total, is further divided into steam and metallurgicalcoal with the former used for power generation and cement production and the latter for manufacturing of iron and steel. The low-rank coal includes sub-bituminous and lignite, with eachaccounting for 30% and 17% of the total, respectively. Sub-bituminous coal is also used in powergeneration, cement manufacturing and industrial production. Lignite is largely used in powergeneration.

GLOBAL DISTRIBUTION OF COAL TYPES AND USES



Main differences among the coal types are energy content, moisture, sulfur and ash contents. Higher grades of coal have higher energy content as characterized by higher carboncontent. Moisture content, which varies widely according to type and location of coal, has a majoreffect on gasification conversion efficiency. Higher sulfur requires more investment in acid gas cleaning. Among the coal types, lignite is a low-cost coal which has high moisture content, low heat generation but high reactivity (easy to break and ignite). Thus, lignite is not a preferred fuel forpower generation or long-distance shipping but is favored for local gasification to produce chemicals. The gasifiers which can handle lignite and produce syngas economically will have advantages in the future. ■

TYPICAL PROPERTIES OF COAL TYPES

Coal Type	Energy Content, kJ/kg (carbon content, wt %)	Moisture (wt %)	Sulfur (wt %)	Ash (wt %)
Bituminous	27,900 (avg. consumed in U.S.) 67%	3–13	2–4	7–14
Sub-Bituminous (Powder River Basin)	20,000 (avg. consumed in U.S.) 49%	28–30	0.3–0.5	5–6
Lignite	15,000 (avg. consumed in U.S.) 40%	30–34	0.6–1.6	7–16
Average Chinese Coal	19,000–25,000 48–61%	3–23	0.4–3.7	28–33
Average Indian Coal	13,000–21,000 30–50%	4–15	0.2–0.7	30–50

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