Assessment of Clean Power Generation Technologies using Low Calorific Value Coal in SAARC Region

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Foreword

Power generation from coal demands particular attention, not only because it is the largest contributor in energy sector globally but also because of the potential threat to the environment caused by the impurities. Low cost of power generation from coal along with huge reserves of coal in the SAARC region makes coal-based power plants inevitable in this part of the world. However, a major chunk of the coal reserves in the SAARC region is of low calorific value (CV). Therefore, it is important to thoroughly assess ways and means of utilizing these huge reserves of coal for power generation in cost effective manner while also addressing the environmental concerns.

In this context, the SAARC Energy Centre has conducted the study on "Assessment of Clean Power Generation Technologies Using Low Calorific Value Coal in SAARC Region". This study assessed the end-to-end technological aspects of the use of low calorific value coal in the power plant, from the mixing schemes, to pulverization, combustion configurations, coal gasification, equipment retrofitting, control of air emissions, carbon capture, sequestration technologies etc. The economic impact of implementation of such technologies is also discussed whereby the cost benefit analysis for the technologies is carried out. Moreover, to assess the viability of coal power generation, a metric known as Energy Return on Investment (EROI), has been used to measure the quality of various fuels by calculating the ratio between the energy delivered by a particular fuel to society and the energy invested in the capture and delivery of this energy

The study findings reveals that low calorific value coal gives a relatively high EROI of 46:1, second only to hydropower, and justifies the use of low calorific value coal to generate energy using clean technologies in SAARC countries. In addition, the study also provides the technology-wise capital cost for each of the coal based thermal power generating technologies in the SAARC Member States. Based on the findings of the study, a way forward is proposed in form of a Plan of Action for successful implementation of clean coal power generation in SAARC Member States. This includes key recommendations such as keeping the technology option open for long term, increased coordination among government authorities, privatization, retrofitting of existing plants, increase in coal production, ease of financing, and to facilitate cross border trade in coal etc.

Dr Nawaz Ahmad
Director
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List of Abbreviations

Abbreviation	Full Name
ADB	Asian Development Bank
ADP	Annual Development Programme
ANREP	Afghanistan National Renewable Energy Policy
ASTM	American Society for Testing and Materials
ASU	Air Separation Unit
AUSC	Advanced Ultra-Supercritical Technology
BAU	Business as Usual
BCD	Brown Coal Densification
BHEL	Bharat Heavy Electrical Ltd
BPDB	Bangladesh Power Development Board
Btu	British Thermal Units
CAD	Canadian Dollar
CCM	Clean Coal Maximum
CCP	Clean Coal Power R&D Co., Ltd
CCPP	Combined Cycle Power Plant
CCS	Carbon Capture and Storage
CCTs	Clean Coal Technologies
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CEB	Ceylon Electricity Board
CERC	Central Electricity Regulatory Commission
CFBC	Circulating Fluidized Bed Combustion
CH_4	Methane
CIL	Coal India Limited
CMC	Chinese Power Company
CMPDI	Central Mine Planning and Design Institute
CO	Carbon Monoxide
CO2	Carbon Dioxide
CO2-eq	CO2 Equivalent

Abbreviation	Full Name
CPM	Carbon Pricing Mechanism
CPU	Compression and Purification Unit
CV	Calorific Value
CY	Calendar Year
DM	Dense Medium
DMG	Department of Mines & Geology
DOE	Department of Energy
ECCP	European Climate Change Programme
EDP	Economic Development Policy
EEA	European Economic Area
EEC	Energy Efficiency and Conversation
EFL	Environmental Foundation Limited
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
ERDA	Energy for Rural Development
ERIA	Economic Research Institute for ASEAN and East Asia
EROI	Energy Return on Investment
ESP	Electrostatic Precipitator
EUEST	EU Emissions Trading Scheme
EVA	Economic Value Analysis
FGC	Flue Gas Condenser
FGD	Fluidized Gas Desulphurization
FY	Financial Year
GCF	Green Climate Fund
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GE	General Electric
GGH	Gas Heaters
GHG	Greenhouse Gas
GSB	Geological Survey of Bangladesh
GSI	Geological Survey of India

Abbreviation	Full Name
GW	Gigawatt
GWh	Gigawatt hour
H2	Molecular Hydrogen
H2O	Water
H2S	Hydrogen Sulphide
HBF	Horizontal Belt Filter
HFCs	Hydrofluorocarbons
HHV	Higher Heating Value
HRSG	Heat Recovery Steam Generator
IDC	Interest During Construction
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IGOs	Intergovernmental Organizations
INDC	Intended Nationally Determined Contributions
INR	Indian Rupee
InSPA	International Agency for Solar Policy & Application
JI	Joint Implementation
LarCoDeMS	Large Coal Dense Medium Separator
LCV	Low Calorific Value
LDC	Least Developed Country
LDCF	Least Developed Countries Fund
LE	Life Extension
LEAP	Long-Range Energy Alternatives Planning System
LEDS	Low Emission Development Strategies
LHV	Lower Heating Value
LNG	Liquid Natural Gas
LP	Low Pressure
LTGEP	Long Term Generation Expansion Plan
LUCF	Land-Use Change and forestry
LULUCF	Land Use Land Use Change and forestry
LVPP	Lakvijaya Power Plant

Abbreviation	Full Name
MDEA	Methyldiethanolamine
MEA	Monoethanolamine
MECL	Mineral Exploration Corporation Limited
mg/m3	Milligramme Per Cubic Meter
MHI	Mitsubishi Heavy Industries
MMBtu	Metric Million British Thermal Unit
MOD	Merit Order Dispatch
MPa	Mega Pascal
Mtoe	Millions of tonnes of oil equivalent
MW	Megawatt
MWh	Megawatt hour
NAPA	National Adaptation Programme of Action
NBSAP	National Biodiversity Strategy and Action Plan
NCRE	Non-Conventional Renewable Energy
NDCs	Nationally Determined Contributions
NDRC	National Development and Reform Commission
NEA	Nepal Electricity Authority
NEAP	National Environmental Action Plan
NEM	National Electricity Market
NEP	National Electricity Plan
NEPA	National Environmental Protection Agency
NEPRA	National Electric Power Regulatory Authority
NETL	National Energy Technology Laboratory, USA
NGM	Near Gravity Material
NLC	Neyveli Lignite Corporation
NOX	Nitrogen Oxides
NRREP	National Rural and Renewable Energy Programme
NTPC	National Thermal Power Corporation
NWPGCL	North-West Power Generation Company Bangladesh
O&M	Operation and Maintenance
O2	Oxygen

Abbreviation	Full Name
PC	Pulverized Coal
PCC	Pulverized Coal Combustion
PFCs	Perfluorocarbons
PJFF	Pulse Jet Fabric Filter
PPIB	Private Power and Infrastructure Board
Ppm	Parts Per Million
PSA	Pressure Swing Adsorption
PSF	Power Station Fuel
Psia	Pounds per square inch absolute
R&D	Research and Development
R&M	Renovation and Modernization
RD	Relative Density
RET	Renewable Energy Technologies
ROM	Run of Mine
SAARC	South Asian Association for Regional Cooperation
SC	Supercritical
SCCL	Singareni Collieries Company Limited
SCR	Selective Catalytic Reduction
SF_6	Sulphur Hexafluoride
SNAP	Strategic National Action Plan for Disaster Risk Reduction
SNCR	Selective Non-Catalytic Reduction
SO2	Sulphur Dioxide
SSD	Superheated Steam Drying
TANGEDCO	Tamil Nadu Generation and Distribution Company
TFC	Total Fuel Consumption
TPES	Total Primary Energy Supply
TSA	Temperature Swing Adsorption
TSGENCO	Telangana Generation Company
TW	Terawatt
TWh	Terawatt hour
UMPPs	Ultra-Mega Power Projects

Abbreviation	Full Name
UNFCCC	United Nations Framework Convention on Climate Change
USC	Ultra-Supercritical
USD	United States Dollar
VSA	Vacuum Swing Adsorption
WFDG	Wet Flue Gas Desulphurization Technology

Executive Summary

Executive Summary

SAARC countries are developing nations with comparatively higher economic growth rates and low per capita energy consumption. This also indicates the extent of energy requirement of these SAARC countries in the years to come. This requirement of energy is predominantly expected to be met by domestic fuel wherever possible. It may be observed that some SAARC countries have significant quantum of low Calorific Value (CV) coal reserves, which are either being utilized by the corresponding countries or being scheduled to be utilized in the time to come. Currently, India is the only SAARC country, which uses its domestic Low CV Coal for the generation of power on a large-scale basis. However, Afghanistan, Bangladesh and Pakistan, have large low CV coal reserves with calorific value less than 4600 Kcal/kg and high ash content, which may be tapped by the said countries for generation of power. Currently, Afghanistan and Bangladesh do not use low CV coal for power generation and Pakistan uses it only to some extent. Though Sri Lanka has thermal power generating capacity installed, it is operated on imported coal.

The dependence on Low CV coal is highlighted by the fact that limited high-quality coal is available in these SAARC countries, and wherever available, high-quality coal is consumed by other industries (e.g., steel production, cement manufacturing) that use such coal as raw material and not for energy purposes. Therefore, the SAARC countries cannot do without consumption of such Low CV Coal for the generation of power to fuel the energy needs driving growth of the countries.

Use of low CV coal for power generation tends to have a polluting effect on the environment, owing to various emissions including CO2, Oxides of Sulphur and Nitrogen, Particulate Materials, etc. While the need of low CV coal to fuel the growth of the SAARC countries cannot be compromised, this report intends to suggest various clean power generation technologies, which can reduce the impact of use of Low CV Coal on the environment. Various technologies for burning of such coal are discussed wherein the fuel can be burnt more efficiently and in a more environment-friendly manner. The types of thermal power plants suitable for Low CV Coal are discussed in this report are as follows:

1. Subcritical power plants
2. Supercritical power plants
3. Ultra-supercritical power plants
4. Advanced ultra-supercritical Power
5. Integrated Gasification Combined Cycle (IGCC) Power plant

Other systems that can be implemented in different stages of burning of fuel to increase the efficiency or to reduce the emissions are also discussed. These are classified as follows:

1. Pre-Combustion Clean Coal Technologies
2. During Combustion Clean Coal Technologies
3. Post-Combustion Clean Coal Technologies

4. Conversion Techniques

The use of these technologies addresses the specific requirements with respect to:

1. Coal quality – impurity content or volatile matter content, moisture level, Sulphur content, etc.;
2. Flue Gas requirements – Oxyfuel combustion;
3. Technology constraints – IGCC technology;
4. Emission controls – Formation of Oxides of Nitrogen and Sulphur and size of particulate material.

To assess the viability of coal power generation, a metric known as Energy Return on Investment (EROI), has been used which is a means of measuring the quality of various fuels by calculating the ratio between the energy delivered by a particular fuel to society and the energy invested in the capture and delivery of this energy. It was found that low CV coal gives a relatively high EROI of 46:1, second only to hydropower, and justifies the use of low calorific value coal to generate energy using clean technologies in SAARC countries.

The economic impact of implementation of such technologies is also discussed in corresponding sections whereby the Cost benefit analysis for the technologies is carried out wherever possible. Some technologies tend to provide intangible benefits that cannot be included in a cost benefit analysis, and therefore, only corresponding costs are highlighted. The one-time costs are typically measured in USD/kW terms while periodic cost are measured in USD/kW/annum terms unless specifically mentioned. The assumptions considered have been clearly stated in the respective sections. Probable technology-wise capital cost for each of the power generating technologies in the SAARC member countries are:

Technology for Power Generation	Capital CostUSD/kW
Sub-critical thermal power plant	USD 896.70/kW
Super-critical thermal power plant	USD 957.28/kW
Ultra-super-critical thermal power plant	USD 4036.70/kW
Advanced Ultra-super-critical thermal power plant (AUSC)	USD 5,479.00/kW
Integrated Coal Gasification Combined Cycle	USD 6,599.00/kW

Source: CEA Broad Status Reports, ERIA

To gauge the practicality of such provisions, some international experiences from the developed countries have been portrayed for lessons to be learnt and for showcasing the way forward for the SAARC countries in their implementation. Further, various prevailing policies governing the Low CV coal utilization in the developed world, such as the Bipartisan Budget Act (USA), Carbon Capture Improvement Program (USA), and Clean Energy Future Plan (Australia) have also been discussed for the reference of the SAARC countries. Another guidance for the SAARC countries is the direction provided by various international organizations by the means of frameworks like the United Nations Framework Convention on Climate Change (UNFCCC) and European Commission.

As regards the existing commitments of the SAARC countries on environment, an account of the accepted targets by the SAARC countries has been provided. Finally, we have highlighted how SAARC countries are dependent on the Low CV Coal and the technologies that have already been used by the SAARC countries. We have also carried out an assessment towards the supply – demand conditions across these SAARC countries that mostly indicate increasing demand and capacity addition in terms of coal based thermal power plants as well that are either in the process of setting up or are in the planning phase.

Through the study, it has been observed that the SAARC countries are currently in the process of setting up low CV coal based thermal power plants with varied levels of non-polluting arrangements. This report illustrates the whole spectrum of clean power generation technologies available for low calorific value coal fired power plants and guidance towards adoption of the same.

A Gap Assessment was undertaken to highlight the key challenges in deployment of clean coal technologies, using low calorific value coal. Political barriers include the gaps and change in government policies, taxation risks, and judicial risks. Technological gaps include lack of skilled manpower and the maturity of clean coal technologies. Administrative barriers include delays in forest/environmental clearance and land acquisition/RoW challenges for projects. Economic barriers comprise of financing gaps for projects using clean coal technologies in SAARC countries.

We have proposed a Plan of Action for successful implementation of clean coal power generation in SAARC countries. The key recommendations that emerged are highlighted below:

1. **Countries should keep their technology options open for the long-term:** With constantly evolving global technological development and applicability of technologies, the countries should be flexible in terms of selection of technology and keep their options open to adopt new technologies prior to the construction of coal based thermal power plants.
2. **Improved coordination amongst various government authorities to develop policies/regulation to promote clean coal technologies:** Combining technology roadmap and regulatory processes would be critical to realize the potential of technological advancement offered to coal based thermal power plants. Hence, there is a need for improved coordination amongst various government authorities such as ministry of power, ministry coal, ministry of industries, regulatory authorities, state-owned power generation companies, distribution companies, etc. of a country.
3. **Increasing privatization and PPP (Public Private Partnership) can positively influence the deployment of new technology:** Privatization tends to improve both quality and efficiency of electricity supply, which directly impact the financial viability of power generation. To increase private participation, especially to deploy clean coal technologies, the respective government should create a competitive environment by reducing entry barriers and providing financial incentives.
4. **Retrofitting of existing thermal power plants:** Conversion of existing thermal plant to state-of-the-art coal based thermal power plant is easier, especially in terms of getting approvals and clearances as compared to develop greenfield coal based thermal power plants, where acquisition of land is a major issue. The older power plants can be retrofitted by supercritical boiler, ultra-supercritical boiler, advanced ultra-supercritical, IGCC, etc.

5. **Increase production of coal to fuel upcoming coal based thermal power plant:** Countries such as Afghanistan, Pakistan, Nepal, and Bangladesh are yet to operate their coal mines at full capacity. By doing so, their dependency on imported coal can reduce substantially. With development of mines, the upcoming thermal power plants can be built nearby these coal mines, which reduce the price of coal to a large extent.
6. **Ease financing for clean coal power generation:** In order to ease the financing available for the use of retrofitting technologies and pre combustion clean coal technologies, these technologies may be financed using green bonds. Additionally, a fund may be created by SAARC countries that facilitates the financing of technologies under Government-to-Government funding between the nations so that the adoption of such technologies is not impeded by financing constraints.
7. **Facilitate cross border trade of LCV coal:** The SAARC countries have varying amounts of low calorific value coal and countries such as Afghanistan, Bhutan, Nepal, Maldives and Sri Lanka have no reserves of LCV coal. Thus, all countries can benefit from the trade of low calorific value coal for an appropriate amount of high/medium calorific value coal or other resources. This will ensure optimum usage of LCV coal irrespective of the lack or excess of reserves in a specific country. Trade policies must evolve in SAARC countries to facilitate smooth trade of LCV coal across borders.

The SAARC countries can learn from the experience of other countries such as China, the USA, etc. to gain technical and operational know-how of clean coal technologies. This shall help SAARC countries to take a big step at once to develop upcoming coal based thermal power plant based on these technologies. The countries need to further tighten their environmental norms and provide incentives in the form of tax rebate to promote use of upcoming technologies.

1. Introduction

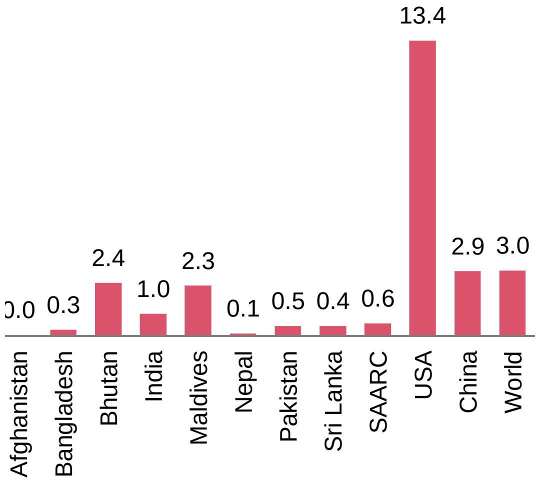
Introduction

1.1. Background

SAARC region is one of the most energy intensive regions in the world, owing to increasing economic activity and growing population. However, the per capita electricity consumption of SAARC region stands at 576 kWh/year, which is very low compared to developed countries like the US, the EU and developing countries such as Brazil and China. It is also lower than the global average of 2,977 kWh[i].

With respect to power generation, the total installed capacity of SAARC region is 393 GW as on FY 2019, which is a mix of varied energy resources. For example, India is highly dependent on coal as its primary fuel, while Bhutan, Nepal and Sri Lanka are heavily reliant on hydro resources in this regard. Afghanistan is dependent on imported energy and Maldives meets most of its commercial energy needs through oil. Bangladesh and Pakistan primarily use natural gas and oil for the same reason.

Figure 1: Per capita electricity consumption, CY 2017 (MWh/Capita)



Source: South Asia Regional Initiatives for Energy Integration (SARI/EI)

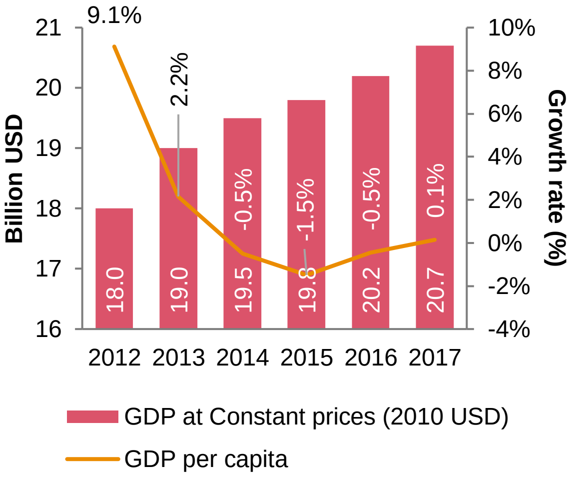
Table 1: Installed capacity (MW) as on FY 2019

Country	Installed capacity (MW)	Coal	Hydro	Natural Gas	Oil	Nuclear	Renewable resources
Afghanistan	1,341	0%	59%	10%	30%	0%	1%
Bangladesh	21,400	3%	2%	76%	19%	0%	0%
Bhutan	1,614	0%	99%	0%	1%	0%	0%
India	363,369	56%	12%	7%	0%	2%	23%
Maldives	-	-	-	-	-	-	-
Nepal	765	0%	93%	0%	7%	0%	0%
Pakistan	25,374	16%	34%	27%	14%	4%	5%
Sri Lanka	4,086	22%	43%	0%	30%	0%	5%
SAARC	393,192	59%	17%	11%	1%	0%	12%

Afghanistan:

Afghanistan over the last one decade has shown signs of economic growth. Its GDP (at constant prices, 2010) grew from USD ~16 billion in 2010 to USD ~21 billion in 2017 registering CAGR of about 4%. The energy sector serves as a backbone to such growing economies. However, power system in Afghanistan is deficient in terms of cost, geographic coverage and adequacy. Afghanistan has one of the lowest electricity usages globally with a **per capita consumption of 149 kWh per year**. Most of the energy requirements are met through imported power.

Figure 2: GDP at Constant prices (CY 2010 USD), Growth of GDP per capita



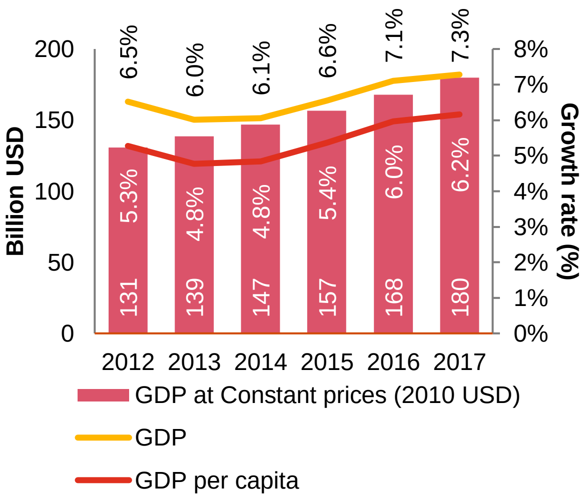
Source: World Bank

Hydro power resources are the only energy resources that contribute significantly to energy generation, while the country uses oil, diesel and gas as the only thermal resources. The country does not depend on coal resources to produce power.

Bangladesh:

Bangladesh's GDP (at constant prices, 2010 USD) accounted to almost USD 180 billion in 2017. It registered a growth rate of 7.3% in 2017, while per capita income also increased by 6.2%. Bangladesh has been perennially experiencing energy crisis due to a mismatch between demand and supply and high dependence on gas availability. In addition to this, the country has an electrification rate of 88%. The government of Bangladesh has taken initiatives to encourage private sector power production in order to meet energy demand within a short span of time. **Bangladesh has a per capita electricity consumption of 332 kWh per year.**

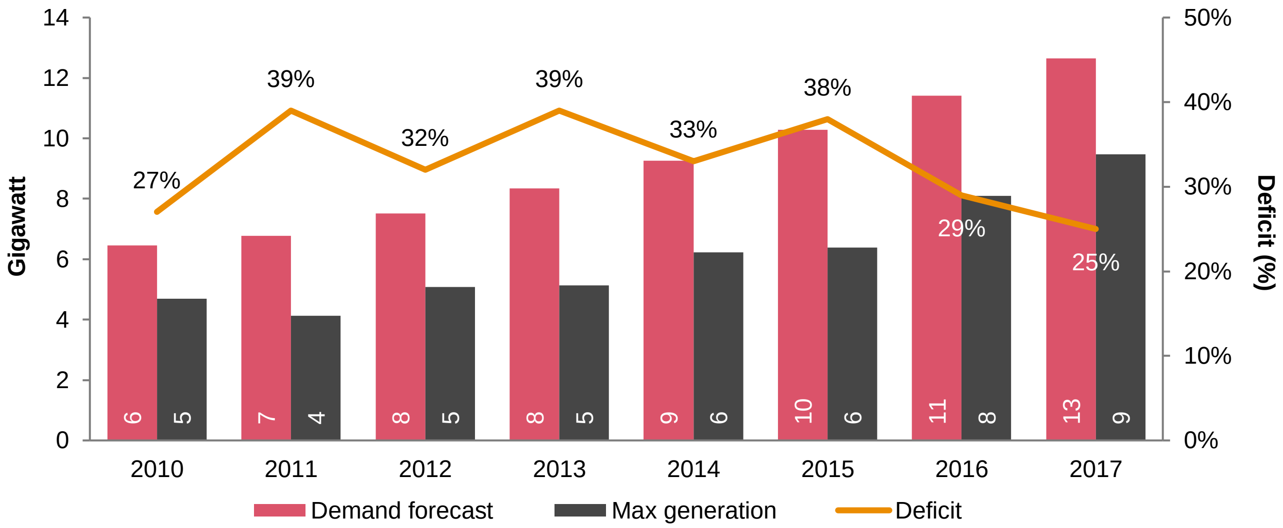
Figure 3: GDP at Constant prices (CY 2010 USD), Growth of GDP per capita and GDP



Source: World Bank

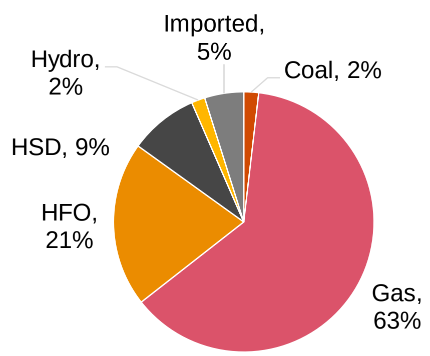
As on September 2019, Bangladesh has an installed capacity of over 21.4 GW[ii], out of which the maximum capacity (16.26 GW) belongs to gas, while the contribution of rest of the sources is negligible. Until 2016, natural gas was the main source of energy for Bangladesh, while coal played a dormant role. However, the importance is now being shifted to coal and LNG due to the depleting existing reserves of natural gas and lack of significant gas discoveries in recent years.

Figure 4: Energy deficit



Source: BPDB

Figure 5: Generation capacity by fuel, 2017



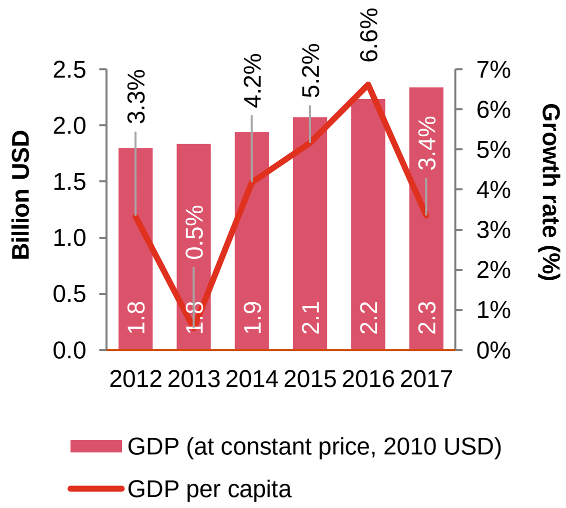
Source: BPDB

The Ministry of Power, Energy and Mineral Resources (MPEMR) has planned 13 mega coal-based power projects in cooperation with China, Japan, India, Malaysia, South Korea and Singapore to be commissioned by 2023. Major plants are coming up at locations such as Maheshkhali (10,000 MW), Matarbari (1,200 MW), in Payra seaport in collaboration with China (1,320 MW) and Rampal project in the Sundarbans – funded by India (1,320 MW. With such aggressive plans to use of coal for power generation, demand for thermal coal is expected to surge in the coming years.

Bhutan

Bhutan has shown signs of recovery post the currency crunch of Indian rupees in 2012. GDP of the nation grew from USD 1.8 billion in 2012 to USD 2.3 billion in CY 2017, registering a CAGR of 5.4% during the period. The energy requirements of this growing economy are supported largely by hydro power projects. The total installed capacity of hydro power plants in CY 2017 was close to 1.6 GW. However, as most of the small and mini hydro power plants are run of the river type, the generating capacity drops drastically to as low as 0.3 GW (17% of total installed capacity) during the winter season from November to February. Bhutan's domestic energy demand is very low, due to which it exports a significant amount of power (~1,200 MW) to India. Completion of

Figure 6: GDP at Constant prices (CY 2010 USD), Growth of GDP per capita



Source: World Bank

hydro projects currently under, or close to implementation will be enough to meet the economic goals of Bhutan till 2030. Bhutan is strategically choosing the most essential and financially viable projects and completing them in a staggered manner.

Bhutan has an electrification rate of 97.7% as on CY 2017.

Table 2: Details of domestic energy consumption

Details	2012	2013	2014	2015	2016	2017
Towns electrified (numbers)	48	51	52	57	55	51
Villages electrified (numbers)	2,603	3,242	3,675	3,719	3,786	3,909
Total Consumers ('000)	132	147	149	168	176	183
Sales of energy (Million units)	3,097	3,347	3,960	4,576	4,772	4,914
Per capita energy consumption (kWh)	2,572	2,625	2,799	2,804	2,673	2,878

India:

India is one of the fastest growing countries, registering an average growth rate of 6-7% annually. Accelerating structural reforms, supportive economic and trade policies, conducive investment environment for investments and low commodity prices have provided a strong impetus of growth to the country. The trend towards increasing urbanization is expected to grow energy consumption of the country in the next decade.

Energy use per capita, 2017-18:

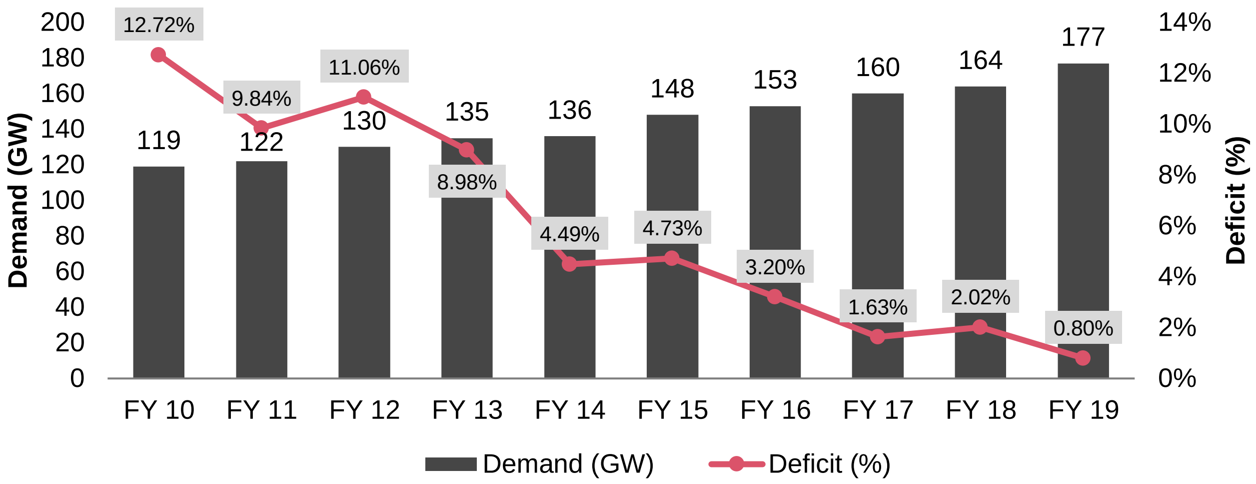
- Total primary energy supply (TPES): 0.64 toe
- Total fuel consumption (TFC): 0.42 toe
- Electricity consumption: 859 kWh

Source: Energy Statistics, 2019

India accounts for approximately 5.5% of the global energy consumption[iii] and is the third largest energy consumer in the world. Energy use in India has doubled over the past 10 years. However, per capita energy consumption in India is only around one-third of the global average of 2,674 kWh per year, despite cheaper electricity tariff in the country.

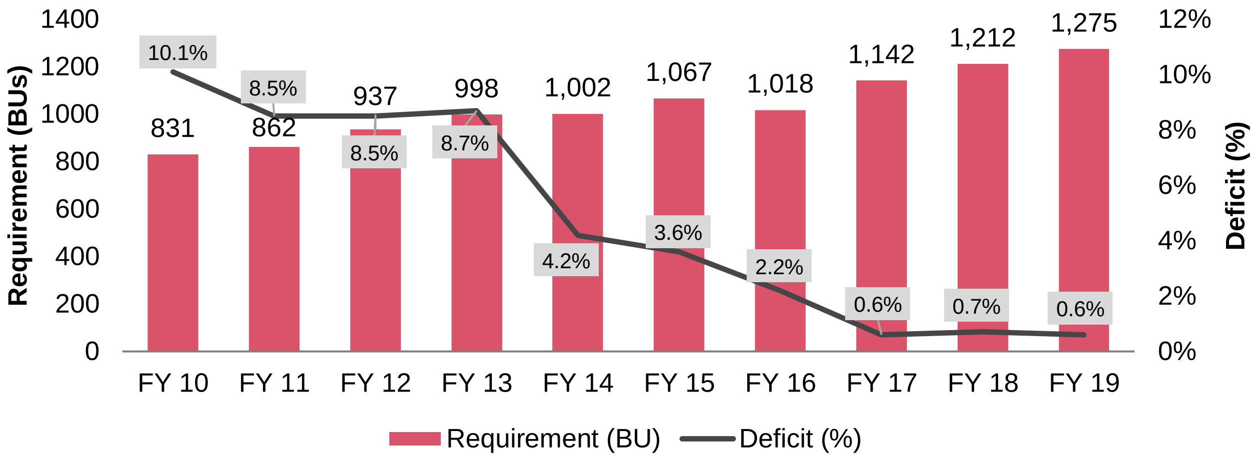
In FY 19, peak demand in India was 177 GW, an increase of 8% from 164 GW in FY 18. The primary energy consumption is expected to augment by 1.2 billion tonne of oil equivalent to 156% by 2040, making India the largest source of energy demand[iv].

Figure 7: Historical peak demand (GW) and supply deficit (%)



Source: Central Electricity Regulatory Commission (CERC)

Figure 8: Historical energy supply requirement (BUs) and deficit (%)

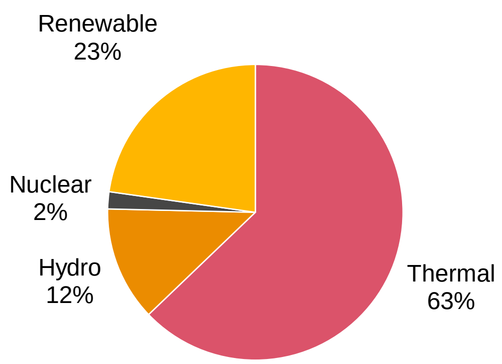


Source: Central Electricity Regulatory Commission (CERC)

In order to meet the increasing demand as mentioned before, huge addition to installed generation capacity is inevitable. Though power generation from unconventional resources such as wind, solar, biomass, etc. has picked pace, the same from conventional source, i.e., coal is unavoidable. The current installed capacity of thermal power generation, in this regard, is 228 GW (as on September 2019).

Coal and gas accounted for about 63% of the total electricity generation, followed by renewable resources such as solar, wind, small hydro, etc., (23%), hydro (12%) and nuclear (2%). The share of renewable resources has increased considerably from about 9% in FY 2009 to 23% as on September 2019.

Figure 9: Generation capacity by fuel



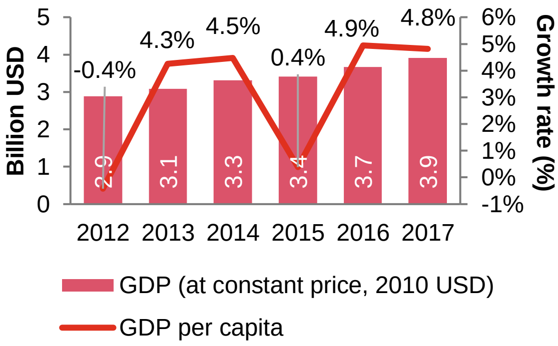
Source: Central Electricity Regulatory Commission (CERC)`

Other than power generation, coal is also used as a fuel in the industry as well as preparation of reactant (coke prepared from coking coal) in the production of steel. The coal available in India is of low GCV, which has high ash content that makes it unsuitable for steel industries. With India having a very low per capita steel consumption of 2.5 kg as on FY 2019, there is a huge scope to rise the demand for steel in the coming years. With such significant augment in demand, it is likely that India will continue relying on imported coal to meet the demand of steel industries, on account of low availability of high GCV coking coal within India.

Maldives

Maldives' economy is primarily driven by tourism, fishing and shipping. The country's GDP was USD 3.9 billion in 2017, while its GDP per capita reached USD 11,151 in 2017. Real GDP growth registered an average growth of 6.3% over the past 5 years, owing to increased activity in construction, tourism, communications, transport, and fisheries. Maldives meets all its energy needs through imported fuel and has only 366 MW of installed generation capacity. In addition, the country does not have any known resource of fossil fuel, i.e., coal, oil and gas.

Figure 10: GDP at Constant prices (CY 2010 USD), Growth of GDP per capita

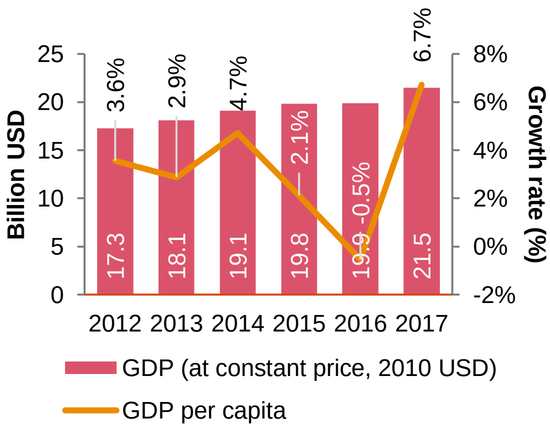


Source: World Bank

Nepal

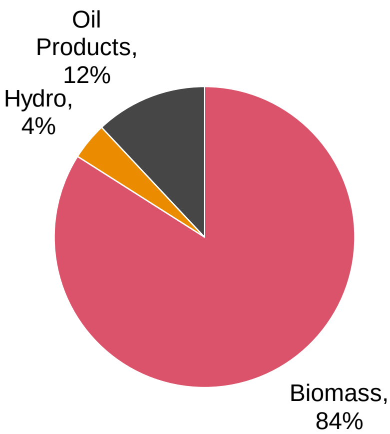
Nepal's GDP for 2017 stood at USD 21 billion, while per capita income was USD 732 for the same year. Total GDP and per capita GDP grew at 7.9% and 6.7% respectively over 2016. The generation sources of the country include biomass, oil and hydro. Biomass has the highest share in the generation mix and accounts for 84% of the energy production. It is predominantly used due to the availability in the form of firewood, agricultural waste, and animal dung. This is mainly because of the unavailability of other power generating resources.

Figure 11: GDP at Constant prices (CY 2010 USD), Growth of GDP per capita



Source: World Bank

Figure 12: Generation capacity by fuel



Source: Nepal energy sector assessment, strategy, and road map

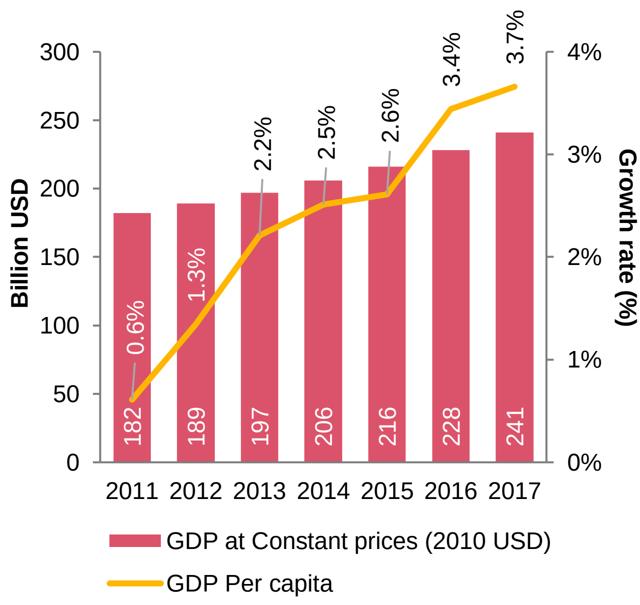
Nepal does not have any resource of fossil fuels such as oil, gas or coal. However, the country has some lignite deposits. In terms of consumption, residential sector is the biggest consumer, while the share of industry and transportation is very less. The country mainly imports oil, coal and electricity from other counties to support its growing economic activity.

In terms of natural resources, Nepal has hydro potential of 83,000 MW. However, only 42,000 MW can be used commercially, out of which only 802 MW is operational. The underdevelopment of the hydro potential is mainly due to inefficient planning and investments by the Nepal Electricity Authority (NEA). As a consequence, Nepal is now facing severe power outages.

Pakistan:

Pakistan's economy, lately, has shown positive signs of growth. Gross domestic product (GDP) grew by 5.8% during FY 2018[v]. The growing economic activity has resulted in increased electricity demand, which grew from about 21 GW in June 2013 to about 25 GW in June 2018, registering a CAGR of over 4%. The existing generation capacity is unable to support the energy demand, thereby resulting in frequent blackouts and power cuts.

Figure 13: GDP at Constant prices (CY 2010 USD) and GDP per capita

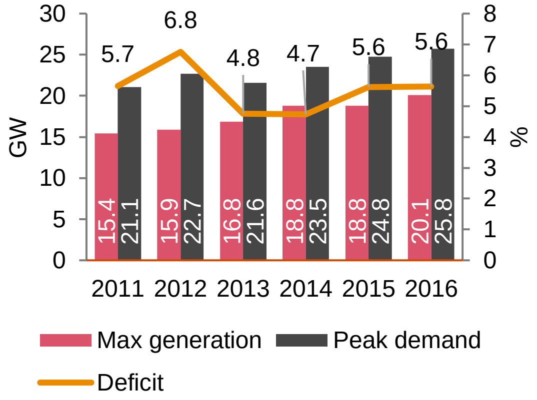


Source: World Bank

Pakistan's primary sources of energy include natural gas, oil, hydropower, coal and nuclear energy. In 2018, the total installed capacity stood at 34 GW, out of which hydel and gas are major contributors with a share of 31% each. The gap between supply and demand of natural gas is increasing rapidly, mainly due to the growing demand for gas and depletion of existing resources. The government is making efforts to explore other indigenous resources and import gas through transnational pipelines such as TAPI (Turkmenistan-Afghanistan-Pakistan-India) Pipeline & IPI (Iran-Pakistan-India) Pipeline and LNG. Similarly, indigenous crude oil meets only 15% of the country's requirement, while the rest is met through imports.

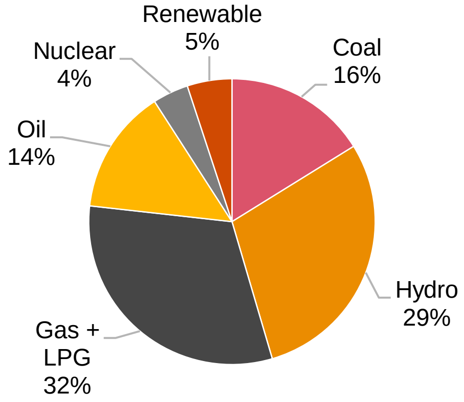
The power sector in Pakistan has been on a growth trajectory during 2013-16. Total primary energy supply grew at the rate of 3.8% to 98 mtoe, mainly due to LNG imports through the country's first LNG regasification terminal at Port Qasim and commissioning of alternative energy projects for wind, solar, bagasse and nuclear. Power generated through oil and gas accounted for 41% of the total power generated. At the same time, hydro remains the single largest source of electricity, contributing about 29%. The total power generated in FY 2019 is 110,000 Million kWh.

Figure 14: Energy generation, peak demand and deficit (GW)



Source: Renewables Readiness Assessment, IRENA

Figure 15: Generation capacity by fuel



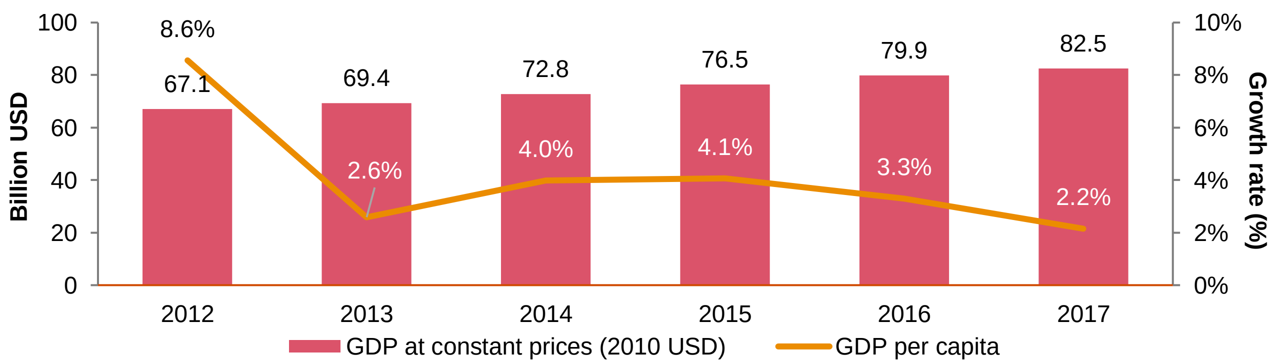
Source: Ministry of Energy, Power Division

The government in Pakistan plans to increase the share of renewable energy in total power generation to 30% (in MW terms) by 2030, referring to power from wind, solar, small hydro and biomass. In addition, there is a target of 30% large scale hydropower. Apart from electricity generation, coal is also used in industries such as steel and cement plants. As on FY 2019, 3.5 million tonne coal is produced in Pakistan, while four to five million tonne are imported from countries such as Afghanistan, Australia, Canada, Indonesia, South Africa and the US. With the planned expansion of cement manufacturing units and coal-fired power plants, Pakistan's coal imports are anticipated to increase to 30 million tonne/annum from existing 20 million tonne/annum by the year 2020[vi].

Sri Lanka:

Sri Lanka, one of the fastest growing South-eastern countries, has a GDP of USD 82.5 billion and per capita GDP of USD 3,849 in 2017. The country's economy has evolved over time, resulting in an increase in the energy demand. Further, Sri Lanka has got 100% access to electricity also, making electricity an important factor of growth.

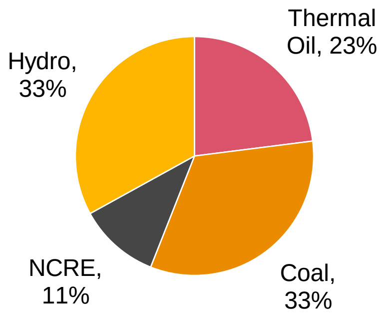
Figure 16: GDP at Constant prices (2010 USD), Growth of GDP per capita



Source: World Bank

By the end of 2018, 15,925 GWh of electricity was generated majorly coming from coal and oil. The country has limited proven indigenous fossil fuel resources, and therefore, has to depend majorly on imported coal and petroleum for the generation of its electricity. Initially, the electricity demand was met predominantly by hydro sources. Gradually, thermal generation has become more prominent and has replaced hydro as the primary energy source.

Figure 17: Generation by fuel mix, 2018



Source: Ministry of Power, Energy and Business

Coal availability scenario across SAARC regions

Table 3: Summary of coal availability in SAARC countries

Country	Coal Reserves	Coal uality
Afghanistan	• Estimated to have 66 million tonne of coal reserves; however, most of them are deep and inaccessible.	• Average GCV of 5500 to 6500 Kcal/kg
Bangladesh	• The country has 3.3 billion tonne of coal reserves spread over 6 coal fields	• Average GCV of ~6100 Kcal/kg
Bhutan	• No substantial reserve of coal	-
India	• India has 319 billion tonne of coal reserves with major reserves in eastern and central India	• GCV ranges from 2200 to 8000 Kcal/Kg with an average of ~4000 Kcal/kg
Maldives	• No substantial reserve of coal	-
Nepal	• Very scarce coal reserves with insignificant production	-
Pakistan	• Pakistan has 185 billion tonne of coal reserves	• GCV ranges from 2900 to 8800 Kcal/kg with an average of ~5500 Kcal/kg
Sri Lanka	• No substantial reserve of coal	-

Afghanistan

Afghanistan has moderate to potentially abundant deposits of coal across the country of 66 million tonnes, contrary to earlier views that coal resources exist only in the north. However, much of the coal is relatively deep or currently inaccessible, and the reserves are largely underdeveloped. The country has reasonably good quality of coal reserves (around average 6000 GCV). The coal-bed analysis carried out by the USGS (United States Geological Survey) indicates that the coal of Afghanistan has been regionally metamorphosed to the subbituminous to high-volatile bituminous range; however, the rank may be elevated locally by deformation. In addition, the general coal quality appears to vary considerably, both in terms of stratigraphy and laterally.

Most of the coal, currently being mined in Afghanistan, occurs in Jurassic rocks of the central Afghan platform. Occurrence of Triassic, Paleogene and Mesozoic coal has also been reported in several places in Afghanistan.

Bangladesh

Besides natural gas, Bangladesh has significant coal reserves. Till date, five coalfields have been discovered in Bangladesh. In order of discovery years, these are Jamalganj (1962), Barapukuria (1985), Khalashpir (1989), Dighipara (1995) and Phulbari (1998).

The Jamalganj coalfield, discovered by the Geological Survey of Bangladesh (GSB) in 1962, is the largest deposit in the country, with probable and proved reserves of 1,460 and 1,053 million tonne, respectively. However, the coal seams lie at a considerable depth of 640–158 m, the extraction of which is not economically feasible[vii].

With the probable reserve of coal of about 389 million tonne, so far, only Barapukuria coal field in Dinajpur district is under production. This field covers an area of 5.25 km^2, with the coal beds extending to a depth of 506 m and the coal available being at a shallower depth of 116 m. Barapukuria coalfield comprises six coal seams, the lowest of these, seam VI is the principle target seam of Barapukuria and has an average thickness of 36 m. It consists of a weakly-caking sub-bituminous to bituminous coal with average Sulphur content of about 0.53%, making it an ideal fuel for power generation.

Bangladesh is blessed with one of the finest quality coals. The coal of five discovered coal mines– Phulbari, Barapukuria, Jamalganj, Dighipara and Khalsapir falls under bituminous type. It is also low in ash and extremely low in Sulphur content (<1%), which are suitable for combustion purpose without any environmental hazard.

Table 4: Details of coal fields of Bangladesh

Coal fields	Year of discovery	Depth of coal bed (m)	Number of coal beds	Average thickness of coal bed (m)	Type of coal	Area of coal field (km^2)	Reserves in million tonne
Phulbari	1997	150	-	38.4	Bituminous	-	Not yet Determined
Dighipara	1995	328	-	42.0	Bituminous	-	Not yet Determined
Khalaspir	1989	257–482	8	42.3	Bituminous	12.3	400
Barapukuria	1985	116–506	6	51.0	Bituminous	5.3	300
Jamalgonj	1962	640–1,158	7	64.0	Bituminous	11.7	1,053
Kuchma	1959	2,380–2,876	5	51.8	Bituminous	Not recorded	Not recorded

Source: Geological Survey of Bangladesh

Bhutan

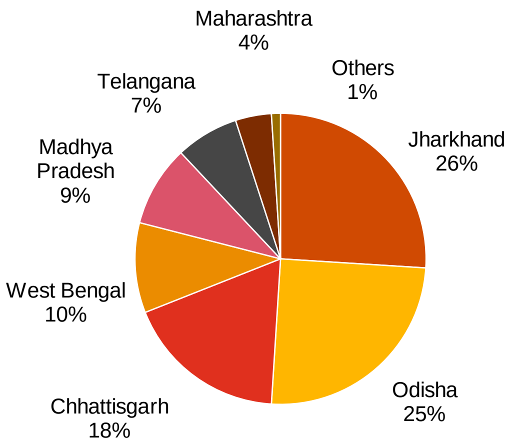
Currently, Bhutan does not have any substantial coal reserve that can be discussed in this section.

India

India holds a majority share of coal resources of the SAARC region, which are mainly confined to eastern and south-central parts of the country. The country has over 319 billion tonne of coal resources (sum of measured, indicated and inferred resources) as on 1 April 2018, for coal seams of 0.90 m and above in thickness and up to 1200 m depth from surface.

India has very low fossil fuel resources. In 2017, only 0.9% and 0.8% of world crude oil production and natural gas production were contributed by India respectively. In terms of oil reserves, India's share stands at 0.3% and with respect to natural gas reserves, it is only 0.6% as contributed by India. Contrarily, India has 9.4% of the world proved coal reserves and 9.3% of world production. This is the main reason for India to be heavily dependent on coal.

Figure 18: State-wise break-up of Indian coal resource



Source: Coal India Limited (CIL)

With respect to coal reserves in India, the states of Jharkhand, Odisha, Chhattisgarh, West Bengal, Madhya Pradesh, Telangana and Maharashtra account for about 98% of the total coal reserves in the country. State-wise distribution shows that Jharkhand tops the list with 26% share, followed by Odisha with 25%.

Table 5: Grades of non-coking coal

GCV Grades	GCV per kilo calories	GCV Grades	GCV per kilo calories
G1	Above 7,000	**G10**	4,301 to 4,600
G2	6,701 to 7,000	**G11**	4,001 to 4,300
G3	6,401 to 6,700	**G12**	3,701 to 4,000
G4	6,101 to 6,400	**G13**	3,401 to 3,700
G5	5,801 to 6,100	**G14**	3,101 to 3,400
G6	5,501 to 5,800	**G15**	2,801 to 3,100
G7	5,201 to 5,500	**G16**	2,501 to 2,800
G8	4,901 to 5,200	**G17**	2,201 to 2,500
G9	4,601 to 4,900		

Ministry of Coal, Govt. of India

In India, coal is categorized into three classes, (a) non-coking coal, (b) coking coal, and (c) semi coking / weakly coking coal. The grading of non-coking coal is based on Gross Calorific Value (GCV). Grading of coking coal is based on ash content, while in case of semi coking/weakly coking coal, it is based on ash plus moisture content.

Before 2012, non-coking coal was graded as A to G (seven grades) based on the Useful Heat Value. Beginning on 1st January 2012, the non-coking coal has been graded on GCV. There are 17 GCV grades starting from 2,201 Kcal/kg (G17) to beyond 7,000 Kcal/kg (G1). Between two successive grades, the GCV bandwidth is 300 Kcal/kg.

Table 6: Status of coal resources in India during last 5 years (billion tonne)

Inventory as on 1st April	Proved	Indicated	Inferred	Total
2013	123.1	142.6	33.1	**298.9**
2014	125.9	142.5	33.1	**301.5**
2015	131.6	143.2	31.7	**306.5**
2016	138.0	139.1	31.5	**308.8**
2017	143.0	139.3	32.7	**315.1**
2018	148.7	139.1	31.0	**319.0**
2019	155.6	140.5	30.4	**326.5**

Source: Ministry of Coal, Govt. of India

As a result of regional, promotional and detailed exploration by Geological Survey of India (GSI), Central Mine Planning and Design Institute (CMPDI), Singareni Collieries Company Limited (SCCL), Mineral Exploration Corporation Limited (MECL) and State Governments, there has been an increase or upgradation of coal resources in the country. The details for the last five years are furnished in the table below:

Although India's coal reserves cover all ranks from lignite to bituminous, they tend to have a high ash content and a low calorific value. Bituminous coal (Grade G3 to G6) is found in Jharkhand, West Bengal, Odisha, Chhattisgarh and Madhya Pradesh. While brown coal is found in Rajasthan, Lakhimpur (Assam), and Tamil Nadu; a small quantity of the best quality coal, Anthracite, is found in Jammu and Kashmir.

Lignite

In India, total geological resource of lignite as on April 1st 2018 stood at 46 billion ton. Of these, ~7 billion tonne are measured, while over 26 billion are indicated and around ~13 billion are inferred.

State-wise distribution of Indian lignite shows that major part of the resources is located in Tamil Nadu (36,134 million ton) followed by Rajasthan (6,349 million ton), Gujarat (2,722 million ton), Pondicherry (416 million ton), J&K (27 million ton), Kerala (9 million ton) and West Bengal (4 million ton).

Around 55% of the total lignite resource of India are restricted in the Mannargudi lignite field (24 billion ton) of Tamil Nadu, of which 20 billion tonne belong to Indicated category and the rest 5 billion tonne to inferred category. In Mannargudi, most of the lignite resources (21 billion tonne) occur below 300 m depth.

Table 7: Lignite reserves in India (million tonne) as on FY 2018

State	Measured	Indicated	Inferred	Total
Tamil Nadu	4,093	22,648	9,393	36,135
Rajasthan	1,168	3,030	2,151	6,349

State	Measured	Indicated	Inferred	Total
Gujarat	1,279	284	1,160	2,722
Pondicherry	-	406	11	417
J & K	-	20	7	27
Kerala	-	-	10	10
West Bengal	-	1	3	4
Total	**6,541**	**26,389**	**12,734**	**45,663**

Source: Geological Survey of India

Maldives

Maldives does not have any substantial coal reserves that can be discussed in this section.

Nepal

Some peat, lignite, and coal deposits are known to exist in different parts of Nepal, and 19 small coal mines are currently operating. However, production of coal is insignificant in Nepal. In terms of stratigraphy, coal is associated with Quaternary Lignite Deposits of Kathmandu Valley; Siwalik Coal, Eocene Coal found in western and mid-western Nepal and Gondwana Coal found in east Nepal.

Pakistan

The presence of coal deposits in Pakistan was known before independence, though its economic value was highlighted only when large reserves of coal were discovered in Lakhra and Sonda areas of Sindh Province in 1980. The country is the 6th richest of the world with respect to coal reserves after the discovery of another huge coal deposit in an area of 10,000 sq. km in Tharparkar District of Sindh. Before the discovery of this Thar coal, Pakistan was not even a part of coal-rich countries list.

The coal deposits in Pakistan are high in Sulphur and ash contents. The moisture percentage is also high in Sindh coal, especially in the Thar coal.

There are extensive resources of coal in all four provinces of Pakistan (Sindh, Balochistan, Punjab, NWFP), the ranks of Pakistani coal range from lignite to high-volatile bituminous.

The coal in Sindh is classified as Lignite, with CV ranging from 5,219 to 13,555 Btu/lb and Balochistan coal is ranked as sub-bituminous to bituminous with the CV between 9,637 and 15,499 Btu/lb. On the contrary, the coal, in other two Provinces of Pakistan are classified as sub-bituminous. The heating value of Punjab coal ranges from 9,472 to 15,801 Btu/lb; NWFP coal ranges from 9,386 to 14,217 Btu/lb.

Table 8: Quality of coal reserves in Pakistan

	Coal Reserves	Quality of Coal	GCV (Btu/lb)
Sindh	Thar	Lignite-B to Lignite-A	5,219 – 13,555
	Lakhra	Lignite-A	
	Sond-Jherruk and other	Lignite-A	

	Coal Reserves	Quality of Coal	GCV (Btu/lb)
Balochistan	Sor-Range and Degari	Sub-bituminous	9,637 -15,499
	Khost, Sharigh and Harnai	Bituminous to sub-bituminous	
	Mach	Sub-bituminous	
	Duki	High volatile bituminous	
Punjab	Salt-Range	Sub-bituminous	9,472 -15,801
	Makarwal	Sub-bituminous	
NWFP	NWFP	Sub-bituminous	9,386 -14,217
Kashmir (administered by Pakistan)	Kashmir	Sub-bituminous	7,336 -12,338

Source: NEPRA

Sri Lanka

Sri Lanka does not have any substantial coal reserve that can be discussed in this section.

1.2. SAARC coal reserves & share of low calorific value coal

1.2.1. Classification of Coal

Coal, the most important fossil fuel for electricity generation, is a combustible sedimentary rock with high volumes of carbon and hydrocarbons. Coal in general does not have any fixed chemical composition. It contains carbon and other variable chemicals such as Oxygen, Hydrogen, Sulphur, Nitrogen and ash.

Coal can be categorized into five categories based on the percentage of carbon present in it and on the amount of heat energy that it can produce. The categories are: Anthracite, Bituminous, Sub-bituminous, Lignite and Peat. Bituminous and higher rank coal are classified based on their volatile matter content, while low rank coal is classified based on their heat values. The same is depicted in the below table:

Figure 19: Classification of coal

Peat	Low- rank coal					Medium-rank coal					High-rank coal			Method of determining rank
	Lignite		Sub-bituminous			Bituminous					Anthracite			
	B	A	C	B	A	High volatile C	High volatile B	High volatile A	Medium volatile	Low volatile	Semi-anthracite	Anthracite	Meta-Anthracite	
	5,000	6,300	8,300	9,500	10,500	11,500	13,000	14,000	*Less distinct for changing rank*					Calorific Value (Btu/lb.)
	Less distinct for changing rank								31	22	14	8	2	Volatile matter (%)
	Less distinct for changing rank								61	78	86	92	~100 98	Fixed carbon (%)

Source: Kentucky Geological Survey

Anthracite

- Anthracite contains 86%-97% carbon and has the highest calorific value. It is mainly used in metals industry.

Bituminous

- This type of coal contains 45%-86% carbon and is used for generation of electricity and as a raw material for making of iron an steel.

Sub-butminous

- This type of coal contains 35%-45% carbon, and has lower calorific value than bituminous coal.

Lignite

- This contains 25%-35% carbon and has the least calorific value and heating capacity. Lignite contains high moisture and sulphur and is very crumbled and soft. It is also called Soft coal/Brown coal. Its main utility is in the generation of electricity.

Peat

- Peat is a precursor of coal and is soft organic material, consisting of partly decayed plant, and in some cases, deposited mineral matter. When peat is placed under high pressure and heat, it becomes coal.

Based on the usage of coal, it can be divided into two categories: (i) Coking coal (ii) Non-Coking coal

Coking coal	Non coking coal
When coking coal is subject to high temperature carbonization, i.e., heating in the absence of air to a temperature above 600 Celsius, it forms a solid porous residue called coke. This coke acts as a raw material for the production of steel in steel plant. Coking coal, also called as metallurgical coal, has low ash content and is less volatile.	Non-coking coal is majorly used in thermal power plants to generate electricity. It is also called as steam coal or thermal coal. It has higher ash content and is also used in industries such as cement, fertilizer, glass, ceramic, paper, chemical and brick manufacturing. Non-coking coal is further graded based on the useful heat value/calorific value.

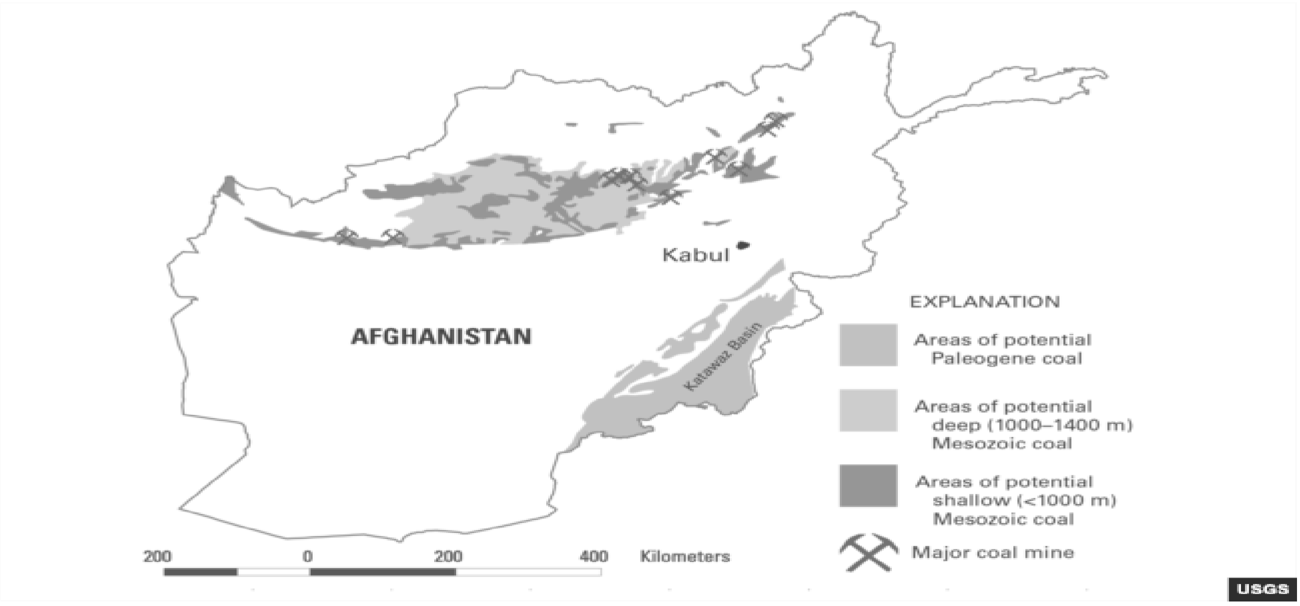
1.2.2. Coal Reserves - Region wise spread of Coal in SAARC Region

Afghanistan

The country hosts numerous coal-forming systems including Mississippian, Triassic, Jurassic, Oligocene, and Pliocene age. Possible Cretaceous coal is also indicated. Except for Jurassic strata, the coal potential of these other systems has never been systematically investigated. This Jurassic coal has a provenance and affinities to coal of similar age in Central Asia, while Paleogene coal has affinities to coal of the same age in Pakistan and India.

Preliminary results of coal-bed analysis carried out by USGS indicate that the coal of Afghanistan has been regionally metamorphosed to the subbituminous to high-volatile bituminous range. Rank is known to vary within coalfields, tracking the deformation patterns within the field, which is a poorly studied phenomenon. In addition, the general quality of Afghan coal also appears to vary considerably, both in terms of stratigraphy and laterally.

Figure 20: Coal resources in Afghanistan



Source: The United States Geological Survey

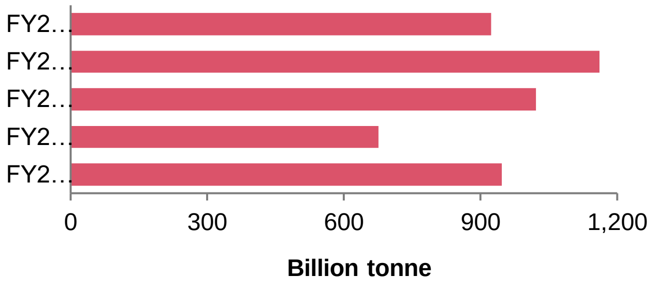
Coal has long been mined in the country, especially in the north and western parts. As per the US Institute for Peace, 2017 estimates, three to four million tonne of coal, valued at 300 million USD to 400 million USD, are been extracted each year. In comparison, the US coal production in 2016 was about 100 million tonne[viii].

Bangladesh:

The coal reserves in five fields of Bangladesh are estimated at 3 billion tonne equivalents to 37 TCF of gas, which can conveniently serve the energy needs of Bangladesh for 50 years.

The fuel mix of Bangladesh's power plants is heavily based on natural gas. Since natural gas reserves of the country are facing decline in terms of resources, it is becoming ambitious about using coal to fuel its growing economy. Currently, only about 3% of power generation (in kWh terms) is based on coal; by 2030, the Government of Bangladesh plans to generate 50% of total electricity using coal-based power plants.

Figure 21: Coal production in Barapukuria



Source: BCMCL

Figure 22: Coal reserves in Bangladesh

Source: National Encyclopaedia of Bangladesh

The Bangladesh coal falls under high-quality bituminous type Gondwana coal of Permo-Carboniferous age. In a comparative study carried out by Bangladesh Chemical Society in terms of coking properties, calorific value, Sulphur content, moisture, ash, volatile matters and carbon content, among the coal samples from Bangladesh (Barapukuria), Australia (New South Wales), India (Tamabil, Borochara, Tirap and Dhanbad) and Indonesia (Sebuku), the Bangladesh Barapukuria coal was found to be the best among the coal samples[ix].

Table 9: Coal resources in Bangladesh

Coal Field	Location	Development Year	Estimated Coal Reserve (million ton)	Total Reserve= Estimated+Probable (million ton)
Barapukuria	Dinajpur	1985-87	303	390
Phulbari	Dinajpur	1997	572	572
Khalaspir	Rangpur	1989-90	143	685
Dighipara	Dinajpur	1994-95	150	600
Jamalganj	Bogra	1962	1,053	1,053

Source: Steelmint

Table 10: Characteristics of the coal in three coal fields

Coal Field	Coal Composition					Heating Value BTU/lb (British thermal unit per pound)
	Carbon Content %	Sulphur Content %	Ash Content%	Moisture Content %	Volatile Matter %	
Barapukuria	45.50–0.56	0.42–1.33	11.79–23.71	2.28–3.60	28.64–1.36	10,547–2,757
Khalaspir	32.09–0.81	0.24–3.15	7.60–50.57	0.33–5.99	3.73–28.86	14,224–5,168
Jamalganj	36.7	0.65	24.25	3.58	36.72	11,872–2,100

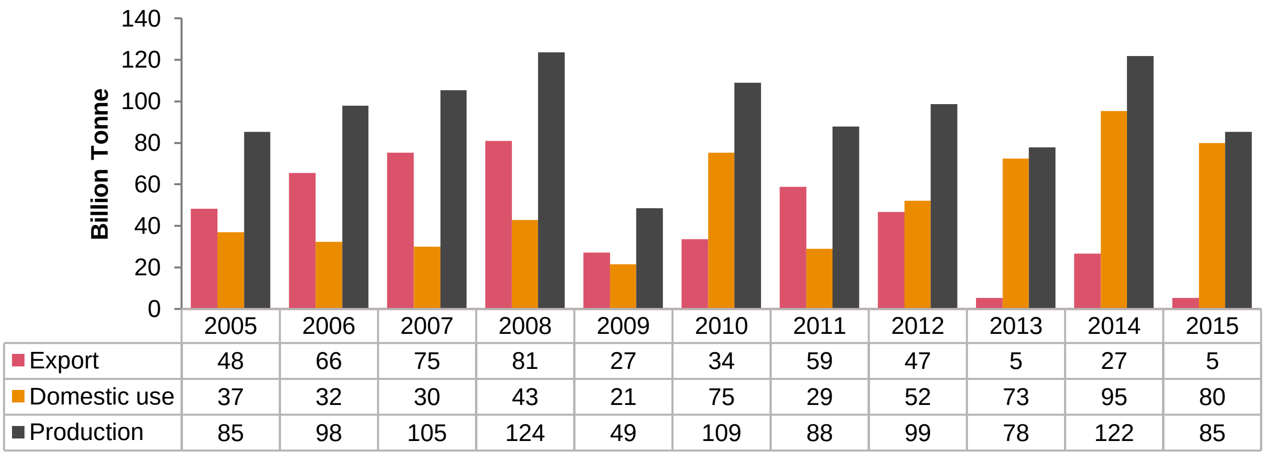
Source: Geological Survey of Bangladesh

Bhutan

Bhutan has no fossil fuel reserve (liquid fuel or gas) except for the coal reserves. The country has 1.3 million tonne of coal reserves in the southwestern region; approximately 1,000 tonne of coal per years are extracted in the country for domestic consumption. Bhutan coal falls under the sub-bituminous type.

During the period of 10 years (2005-2015), the overall production of coal in Bhutan grew at a CAGR of 3.6%. While trend in the domestic consumption of coal has been increasing, it is observed that the export trend has been decreasing over the time. Although the coal production is increasing at 3.6%, it is still insufficient for the higher increase in domestic consumption. This demonstrates dependency on import of coal.

Figure 23: Production, export and domestic use of coal in Bhutan



Source: Bhutan Energy Data Directory, 2015

India

In India, during the period from FY 2018 to FY 2019, the availability of coal has increased at a CAGR of about 4.6%, which might be attributed to the increase in the coal production supplemented by imports. While the total availability of coal in FY 2018 increased by 0.09% compared to FY 2017, availability of lignite decreased by 1.5% during the same period[x].

Indian Coal resources are available in older Gondwana Formations of peninsular India and younger Tertiary formations of north-eastern region. Around 99% of India's total coal reserves are from Gondwana coalfields and the rest from Tertiary coalfields.

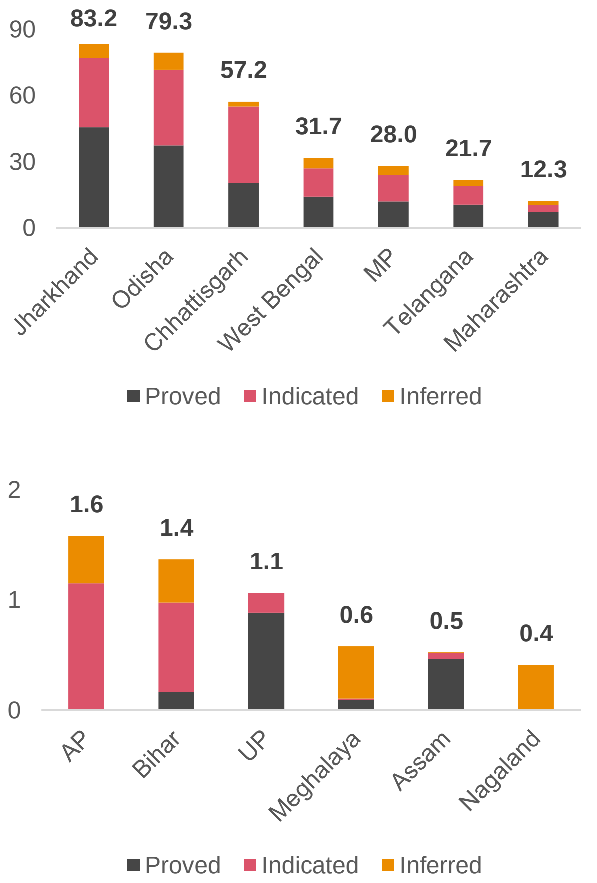
Coal production in India registered a growth of 2.7% in FY 2018 to 675 million tonne, compared to 657 million tonne during FY 2017.

Coal production in India grew at a CAGR of 3.2% over FY 2009 to FY 2018.

The type-wise break up of Gondwana coal reveals that coking and non-coking coal of the country are 34.5 billion tonne and 282.9 billion tonne respectively, while the Tertiary coal, which is mainly of high Sulphur type, is 1.5 billion ton.

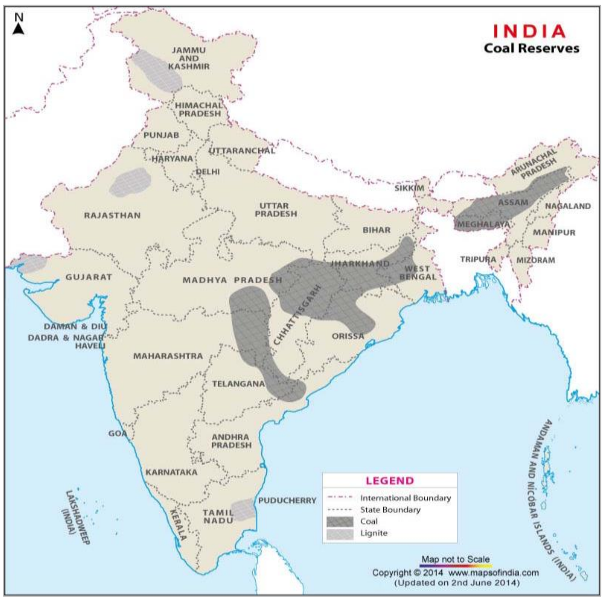
Among the states with coal reserves, Jharkhand is practically the lone contributor of coking coal (30.8 billion ton) with minor resources from Madhya Pradesh (2.2 billion ton), West Bengal (1.3 billion ton) and Chhattisgarh (0.17 billion ton). While among the coalfields of Jharkhand, Jharia contributes maximum share, 11.5 billion tonne followed by East Bokaro (8.1 billion ton), West Bokaro (4.8 billion ton), North Karanpura (3.7 billion ton) and others.

Figure 24: Categorized state-wise resource of Indian coal (billion ton)



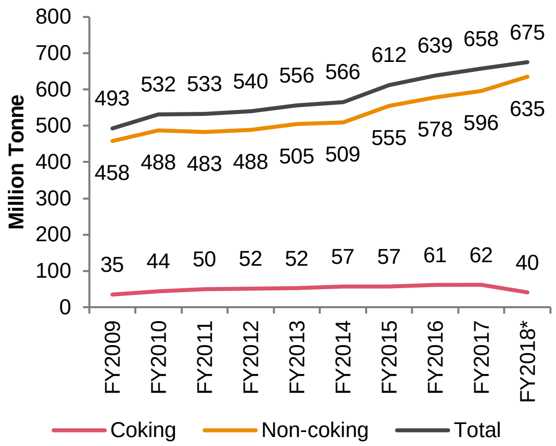
Source: Geological Survey of India

Figure 25: Coal reserves in India



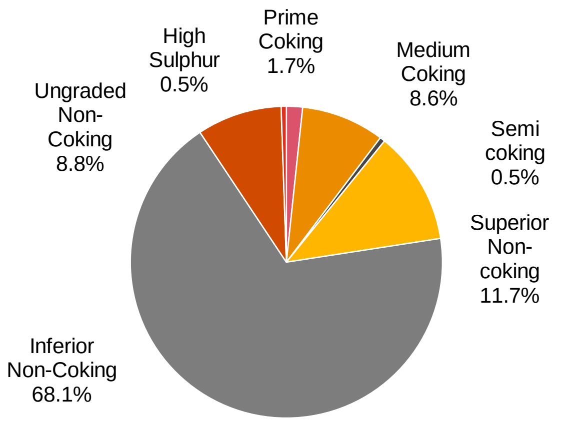
Source: Maps of India

Figure 26: Coal production (million ton)



Source: Renewables Readiness Assessment, IRENA

Figure 27: Type-wise distribution of Indian coal



Source: Geological Survey of India

Table 11: Indian coal reserves based on formation (million tonne)

Formation	Proved	Indicated	Inferred	Total
Gondwana Coal	1,48,194	1,39,065	30,174	3,17,433
Tertiary Coal	594	99	895	1588
Grand Total	**1,48,787**	**1,39,164**	**31,069**	**3,19,020**

Source: Ministry of Coal, Govt. of India

Table 12: Different types of coal resources (million tonne)

Depth Range(m)	Measured	Indicated	Inferred		Total
			Exploration	Exploration	
Gondwana Coal					
Coking					
0-300	7,765	4,217	66		12,049
0-600	8,258	4	-		8,262
300-600	1,277	5,086	807		7,171
600-1200	1,782	4,060	1,199		7,041
0-1200	19,082	13,368	2,073		34,522
Non-coking					
0-300	101,893	60,448	8,336		170,677
0-600	5,657	445	-		6,102
300-600	19,686	54,156	14,878		88,720
600-1200	1,876	10,647	4,887		17,411
0-1200	129,112	125,697	28,102		282,910
Tertiary Coal High Sulphur					

Depth Range(m)	Measured	Indicated	Inferred		Total
			Exploration	Exploration	
0-300	408	83	145	750	1,386
300-600	186	16	-	-	202
0-600	594	99	145	750	1,588

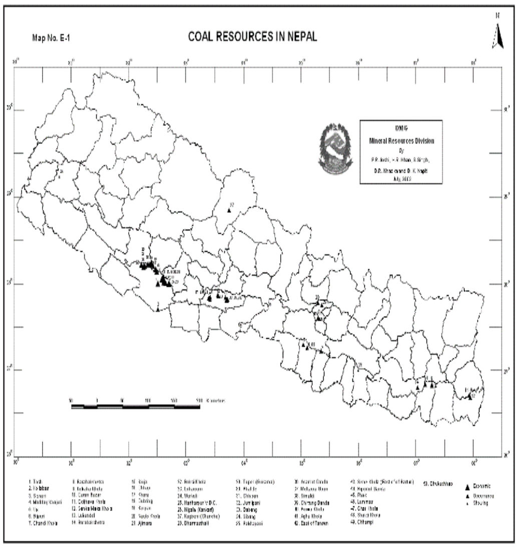
Source: Geological Survey of India

Nepal

In Nepal, low to medium grade of coal deposits is known to exist in four stratigraphic positions- (a) Quaternary Lignite Deposits of Kathmandu Valley, (b) Siwalik Coal of the Sub-Himalayas, (c) Cretaceous- Eocene Coal of the Lesser Himalayas, and (d) Gondwana Coal of the Lesser Himalayas.

The Cretaceous- Eocene Coal of the Lesser Himalayas, occurs as irregular seams, confined to orthoquartzite in Tosh, Siuja, Azimara and Abidhara in Dang, Sallyan, Rolpa, Pyuthan and Palpa districts. Small scale mines are in operation in these districts. Regardless, the Quaternary Kathmandu lignite and Eocene Coal found in Dang Deukhuri are of minor economic significances, because of their limited occurrence, poor grade and limited thickness. Siwalik Coal of the Sub-Himalayas has no commercially feasible deposit.

Figure 28: Coal reserves in Nepal



Source: Department of Mines & Geology (DMG), Ministry of Industry Government of Nepal

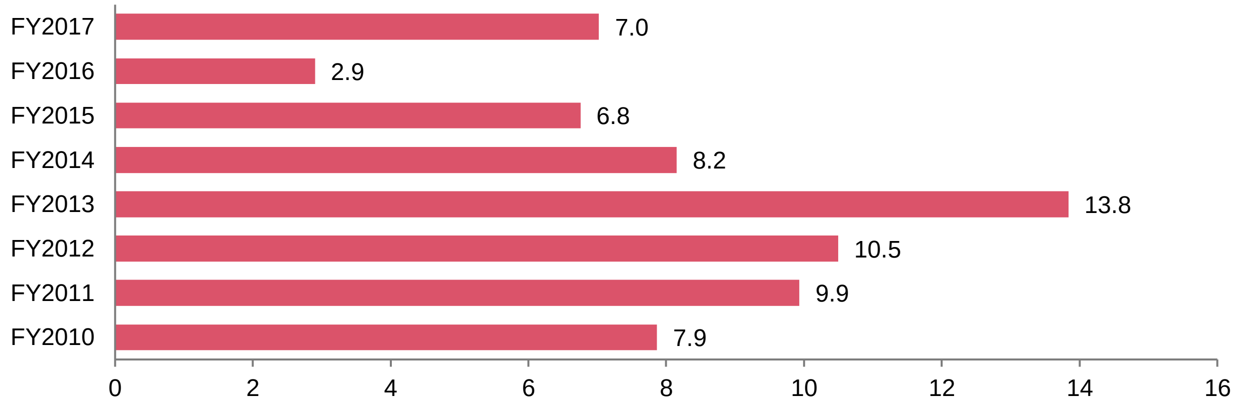
Table 13: Quality of coal in Nepal

Coal Reserves	Quality of coal
Quaternary Lignite Deposits of Kathmandu Valley	Peat to Lignite
Siwalik Coal of the Sub-Himalayas	Lignite to Semi- Anthracite
Cretaceous- Eocene Coal of the Lesser Himalayas	Sub- Bituminous
Gondwana Coal of the Lesser Himalayas	Anthracite

Source: Department of Mines & Geology (DMG), Ministry of Industry Government of Nepal

Production of coal is insignificant in Nepal; majority of the coal demand there is being met by import

Figure 29: Coal production in Nepal (000 tonne)



Source: Department of Mines & Geology (DMG), Ministry of Industry Government of Nepal

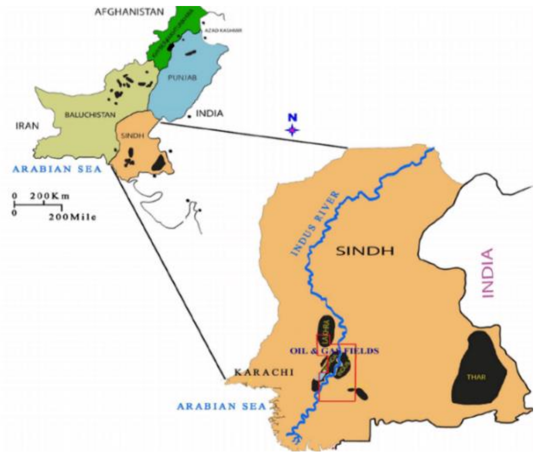
Pakistan

Coal resources are found and being developed in all four provinces, i.e., Sind, Balochistan, Punjab and Khyber Pakhtunkhwa along with Kashmir (Administered by Pakistan).

The total coal reserves are estimated at 185 billion tonne in Pakistan. Out of these, 3.4 billion tonne have been measured, 12 billion tonne have been indicated and 56.9 billion tonne inferred, whereas hypothetical reserves are about 113.8 billion tonne. The deposits have been dated as middle Palaeoceneto early Eocene in age.

Thar field in southern Sindh province, with total measured coal reserves of 172 billion tonne, is one of the largest deposits in the world as well as bulk (around 99%) of Pakistan's coal. However, it has not yet been fully developed

Figure 30: Coal reserves in Pakistan



Source: Geochemical and organic petrographic characteristics of low-rank coals from Thar coalfield in the Sindh Province, Pakistan, Arabian Journal of Geosciences

As per the Government's 11th five-year plan (2013-2018), the following initiatives will be undertaken to expedite the exploitation of the Thar coal reserves during the plan period.

- Block-II: Sindh Engro Coal Mining Company to set up a 600-1000 MW plant using Thar coal reserves
- Block-III: M/s Couger Energy Company to conduct feasibility for underground coal gasification technology for establishment of 400 MW plant
- Block-IV: M/s Bin Dean Group, the UAE to conduct feasibility for coal mining and power generation plant of 1,000 MW
- Block-V: Under Ground Coal Gasification Project by the Planning Commission
- Block-VI: Sindh Carbon Energy Limited for feasibility study for 300 MW plant

The rank of the coal in Pakistan ranges from lignite to high volatile bituminous. The country ranks 7th internationally regarding lignitic coal reserves.

Table 14: Heating values of coal reserves in Pakistan

Province	Resources in Million tonne	Heating Value (Btu/lb)
Sindh	184,623	5,219 -13,555
Balochistan	217	9,637 -15,499
Punjab	235	9,472 -15,801
NWFP	91	9,386 -14,217
Kashmir (Administered by Pakistan)	9	7,336 -12,338

Source: NEPRA

The following table details the characteristics of coal in Pakistan.

Table 15: Characteristics of coal in Pakistan

Coal Reserves		Moisture (%)	Ash content (%)	Volatile Matter (%)	Fixed Carbon (%)	Sulphur (%)	Calorific Value (Btu/lb)
Sindh	Thar	29.60 – 55.50	02.90 – 11.50	23.10 – 36.60	14.20 – 34.00	00.40 – 02.90	6,244 – 11,045
	Lakhra	09.70 – 38.10	04.30 – 49.00	18.30 – 38.60	09.80 – 38.20	01.20 – 14.80	5,503 – 9,158
	Sond-Jherruk and other	09.00 – 48.00	02.70 – 52.00	16.10 – 44.20	08.90 – 58.80	00.20 – 15.00	5,219 – 13,555
Balochistan	Sor-Range and Degari	03.90 – 18.90	04.90 – 17.20	20.70 – 37.50	41.00 – 50.80	00.60 – 05.50	11,245 – 13,900
	Khost, Sharigh and Harnai	01.70 – 11.20	09.30 – 34.00	09.30 – 45.30	25.50 – 43.80	03.50 – 09.55	9,637 – 15,499
	Mach	07.10 – 12.00	09.60 – 20.30	34.20 – 43.00	32.40 – 41.50	03.20 – 07.40	11,110 – 12,937
	Duki	03.50 – 11.50	05.00 – 38.00	32.00 – 50.00	28.00 – 42.00	04.00 – 06.00	10,131 – 14,164
Punjab	Salt-Range	03.20 – 10.80	12.30 – 44.20	21.50 – 38.80	25.70 – 44.80	02.60 – 10.70	9,472 – 15,801
	Makarwal	02.80 – 06.00	06.40 – 30.80	31.50 – 48.10	34.90 – 44.90	02.80 – 06.30	10, 688 – 14,029
NWFP	NWFP	00.10 – 07.10	05.30 – 43.30	14.00 – 33.40	21.80 – 76.90	01.10 – 09.50	9,386 – 14,217
Kashmir (admin by Pakistan)	Kashmir	00.20 – 06.00	03.30 – 50.00	05.10 – 32.00	26.30 – 69.50	00.30 – 04.80	7,336 – 12,338

Source: NEPRA

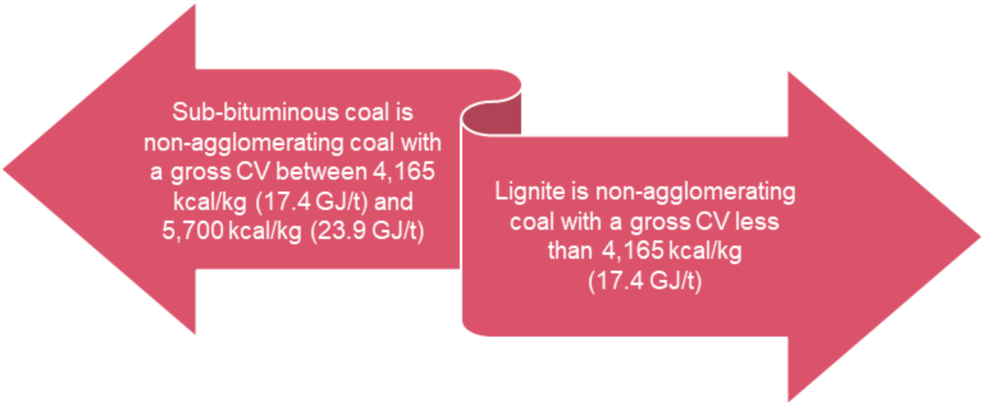
Other SAARC countries

Countries like Sri Lanka and Maldives have practically no deposit of fossil fuels. Because of the paucity of energy resources in the region, large quantities of fossil fuels are imported there. Even though Sri Lanka has no coal resource of its own, it has built coal-based power generation plants.

1.2.3. Definition of "low calorific value" coal – KPIs and implications

There are a range of different definitions and categorization for coal in different parts of the world, thus defining the particular coal precisely is indeed a challenging task. As a case, American, Australian and European definitions are slightly different, and in fact overlapped.

As mentioned earlier that coal falls under four major categories including- Anthracite, bituminous, sub-bituminous and lignite; in many cases, it is difficult to classify types of coal into practical categories for use at an international level for two main reasons:



GJ/t: Giga Joules per tonne

1. Divisions between coal categories vary between classification systems, both national and international, based on calorific value (CV), volatile matter content, fixed carbon content, caking and coking properties, or some combination of two or more of these criteria.
2. Despite the fact that the relative value of coal within a particular category depends on moisture content, ash and contaminants (Sulphur, Chlorine, Phosphorus and certain trace elements), these factors do not affect the divisions between categories. Quality of coal can vary and it is not always possible to ensure that available descriptive and analytical information are truly representative of the body of coal, to which it refers.

The International Coal Classification of the Economic Commission for Europe (UN/ECE) recognizes two broad categories of coal[xi]:

Hard Coal

- Coal of gross CV of >5,700 kcal/kg (23.9 GJ/t) on an ash-free but moist basis and with a mean random reflectance of vitrinite of at least 0.6
- Sum of coking coal and steam coal (anthracite and bituminous coal)

Brown Coal

- Non-agglomerating coal with a gross CV of <5,700 kcal/kg (23.9 GJ/t), containing 31% volatile matter on a dry mineral matter-free basis
- Sum of sub-bituminous coal and lignite

CV represents the heat content of coal; it is usually expressed as gross CV (the higher heating value) or the net CV (the lower heating value). The difference between gross and net CV is the latent heat of vaporization of water vapor, produced during combustion of coal. The gross CV assumes that all of the vapor produced during the combustion of coal is fully condensed, whereas net CV assumes that the vapor is removed without being fully condensed.

Low rank/Low grade coal: As coal matures from peat to anthracite, the degree of alteration that occurs is referred to as the rank of the coal. Low rank coal comprises lignite and sub-bituminous coal, as it holds in less carbon and low energy content than that of higher rank. In general, all types of low rank coal (sub-bituminous coal and lignite) are categorized into low-grade coal because of high moisture content and low heating value, which usually require the application of specific technologies for their successful use in power generation and other industrial processes.

Confusingly, sub-bituminous coals are treated as steam coal and not brown coal by national statistics for some countries; however, this may not be the case in others. Besides, under the US classification, both lignite and sub-bituminous coal are classified as brown coal.

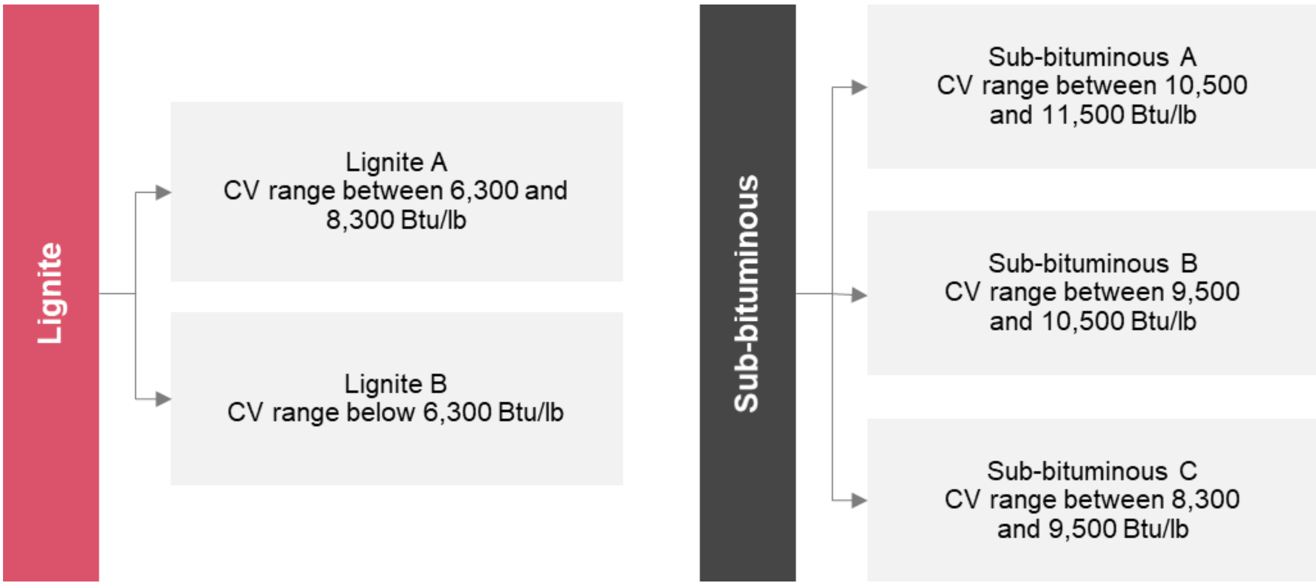
The coal classification employed in the US was developed by the American Society for Testing and Materials (ASTM), and the parameters that define the ranking of coal are fixed carbon and the CV on the dry mineral matter free basis (dmmf).

In the US ASTM coal classification, the low rank coal is classified according to CV; the higher-rank coal is classified according to fixed carbon, on the dry basis, with the agglomerating character used to differentiate between certain adjacent groups[xii].

In the mentioned classification parameter, coal is categorized into series of classes and groups. Coal containing volatile matter below 31% in dry mineral matter free basis, is classified according to its fixed carbon contents; while the coal containing volatile matter above 31% in dry mineral matter free basis is classified as per its gross CV on the moist basis (moist CV). Moist CV refers to the CV of the coal, containing its natural bed moisture, exclusive of visible water on the surface of the coal.

In a likely manner as of UN/ECE classification, as per the ASTM coal rank classification, the anthracite coal holds the highest rank, with the highest contents of carbon and lowest content of volatile matter; the lignite coal with the lowest contents of fixed carbon and highest contents of volatile matter hold the lowest rank. On the other hand, the bituminous and sub-bituminous coal are ranked between the anthracitic and lignite coal. As a broad generality, the heating values are the highest for anthracitic coal and the lowest for lignite coal.

As defined by ASTM, lignite is a low rank coal having gross CV less than 8,300 Btu/lb (19.3 MJ/kg) on a moist, mineral matter free basis. This class of coal is further differentiated into two groups: lignite A and lignite B based on heating value. The heating value of lignite A range from 6,300 – 8,300 Btu/lb (14.7 to 19.3 MJ/kg); the values of lignite B range below 6,300 Btu/lb (14.7 MJ/kg)[xiii].



Sub-bituminous coal is the second division of low rank coal, having a gross CV of more than 8,300 Btu/lb and less than 11,500 Btu/lb on a moist, mineral matter free basis. Furthermore, this class of coal is divided into sub-bituminous C, B, and A coal groups on the basis of increasing heat value. In the US rank system, sub-bituminous C (lower rank sub-bituminous) coal is brown and earthy like lignite, whereas sub-bituminous A (higher rank sub-bituminous) coal is grey to black and shiny like bituminous coal. Sometimes sub-bituminous coal is referred to as black lignite. The below table summarizes the ASTM D-388 classification of coal by rank and the CV ranges.

Table 16: Classification of coal by rank (ASTM D-388)

Coal Rank		Fix Carbon Limits	Volatile Content	Gross Calorific Value Limits		Agglomerating Characteristics
		% dmmf	% dmmf	Btu/ lb moisture mmf	MJ/kg moisture mmf	
Anthracite	Meta-Anthracite	≥98%	< 2%			Non-agglomerating
	Anthracite	92 - 98%	2 - 8%			
	Semi-Anthracite (Lean Coal)	86 - 92%	8 - 14%			
Bituminous	Low Volatile Bituminous	78 - 86%	14 - 22%			Commonly agglomerating
	Medium Volatile Bituminous	69 - 78%	22 - 31%			
	High Volatile A Bituminous	<69%	> 31%	≥ 14,000	≥ 32.6	
	High Volatile B Bituminous	<69%	> 31%	13,000 - 14,000	30.2 - 32.6	
	High Volatile C Bituminous	<69%	> 31%	11,500 - 13,000	26.7 - 30.2	
	High Volatile C Bituminous		> 31%	10,500 - 11,500	24.4 - 26.7	Agglomerating

Coal Rank		Fix Carbon Limits	Volatile Content	Gross Calorific Value Limits		Agglomerating Characteristics
		% dmmf	% dmmf	Btu/ lb moisture mmf	MJ/kg moisture mmf	
Sub-bituminous	Sub-bituminous A Coal			10,500 - 11,500	24.4 - 26.7	Non-agglomerating
	Sub-bituminous B Coal			9,500 - 10,500	22.1 - 24.4	
	Sub-bituminous C Coal			8,300 - 9,500	19.3 - 22.1	
Lignite	Lignite A			6,300 - 8,300	14.7 - 19.3	Non-agglomerating
	Lignite B			< 6,300	< 14.7	

Source: World coal association   dmmf: Dry and mineral matter free

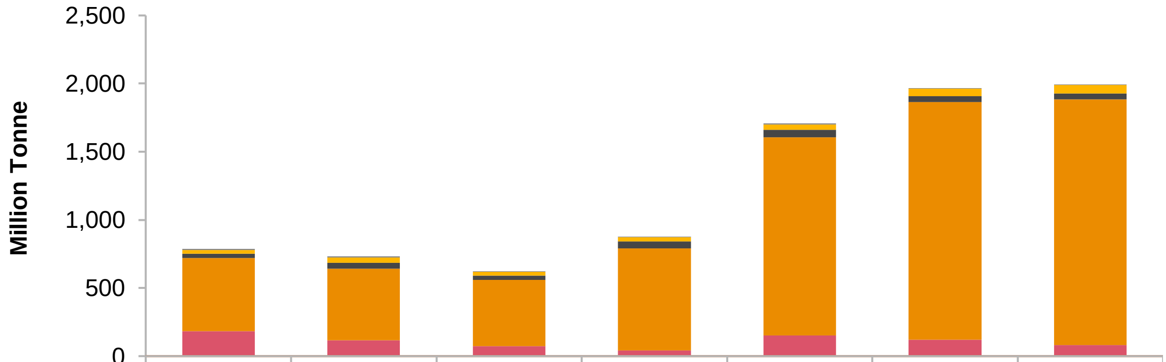
mmf: Mineral matter free

Coal having a GCV of less than 8,300 Btu/lb or 4600 Kcal/kg, can thus be classified as "low calorific value coal", which has a high moisture content and low energy density compared to higher grade coals.

1.2.4. Share of Low CV Coal in the total consumption of coal

India: Over the past decade, annual coal consumption has increased significantly in India. Other bituminous coal has consistently formed the major part of coal consumption in India. The figure below represents the historical consumption of coal in India by its type:

Figure 31: Consumption of coal in India (by type)



	1990	1995	2000	2005	2010	2015	2016
BKB	8.4	8.2	5.4	4.5	5.7	1.7	1.9
Coke oven coke	29.8	38.9	26.8	27.8	38.3	58.0	64.9
Lignite	29.5	42.4	31.6	52.9	57.7	40.3	43.2
Other bituminous coal	539.2	525.9	485.3	749.4	1453.5	1744.6	1800.3
Coking coal	181.6	117.6	73.1	41.1	151.5	121.0	82.1

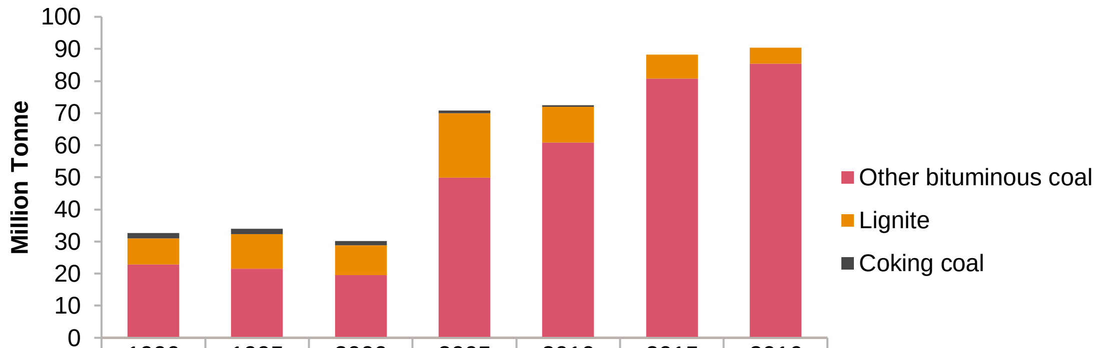
Source: IEA Coal information, 2018

Pakistan:

There are abundant lignite reserves in Pakistan. However, limited share has been utilized till date. Though Lignite found in Pakistan is relatively cheaper to mine and suitable for power generation, the lignite found in Thar (Sindh) has around 50% moisture. Pakistan also has large deposits of limestone in all its provinces, which is handy for CFBC technology for capturing for SOX and NOX emissions.

According to National Electric Power Regulatory Authority (NEPRA), almost 50% of the coal production are commonly used for making bricks and roofing tiles in brick kiln industry in Pakistan.

Figure 32: Consumption of coal in Pakistan (by type)

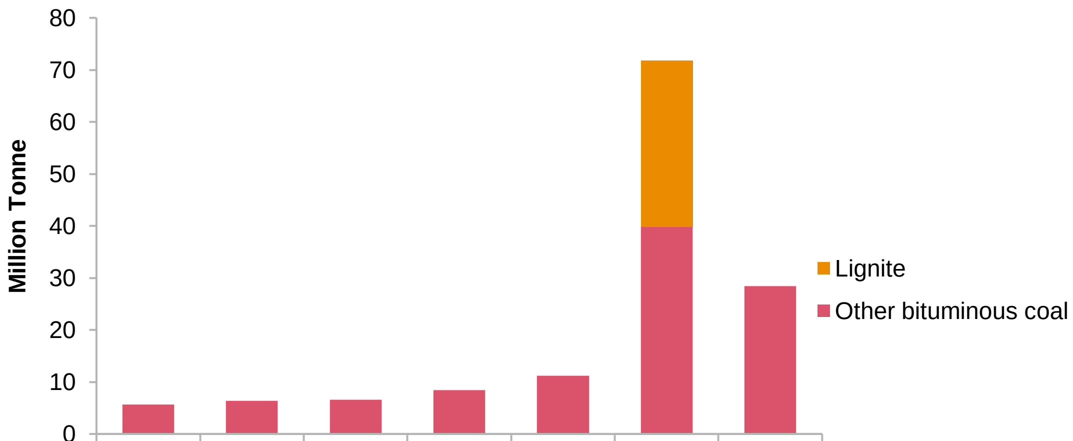


	1990	1995	2000	2005	2010	2015	2016
Coking coal	1.54	1.53	1.33	0.79	0.6	0	0
Lignite	8.24	10.91	9.28	20.1	11.01	7.52	5.04
Other bituminous coal	22.79	21.48	19.61	49.9	60.91	80.7	85.33

Source: IEA Coal information, 2018

Bangladesh: Coal consumption in Bangladesh has been low, owing to only a few small reserves in the country. Bituminous coal has almost always been the primary type of coal used in the country. The figure below represents the historical consumption of coal in Bangladesh by its type.

Figure 33: Consumption of coal in Bangladesh (by type)

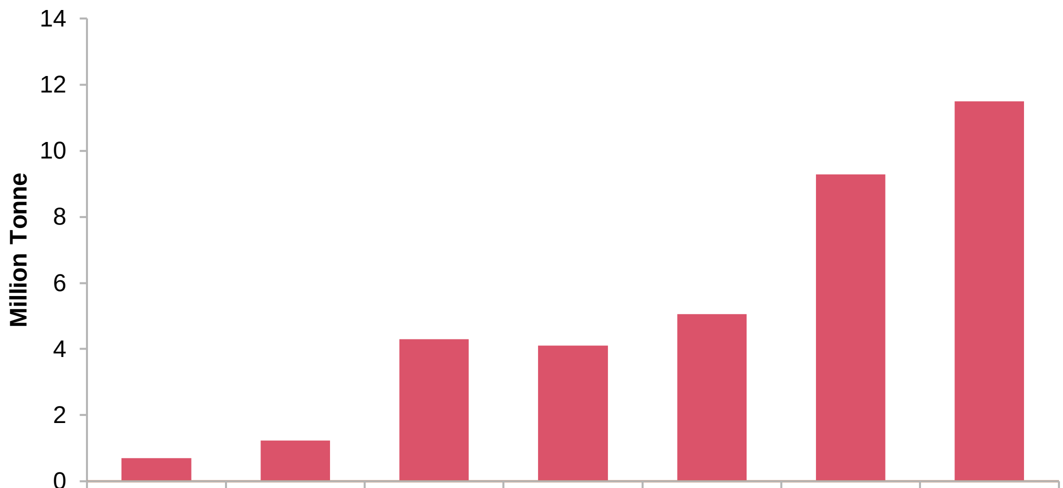


	1990	1995	2000	2005	2010	2015	2016
Lignite	0	0	0	0	0	32	0
Other bituminous coal	5.63	6.42	6.6	8.45	11.19	39.78	28.39

Source: IEA Coal information, 2018

Nepal: Nepal has very scarce reserves of coal with meagre production. Its consumption comprises of only bituminous coal and the historical consumption has been shown in the figure below:

Figure 34: Consumption of coal in Nepal (by type)

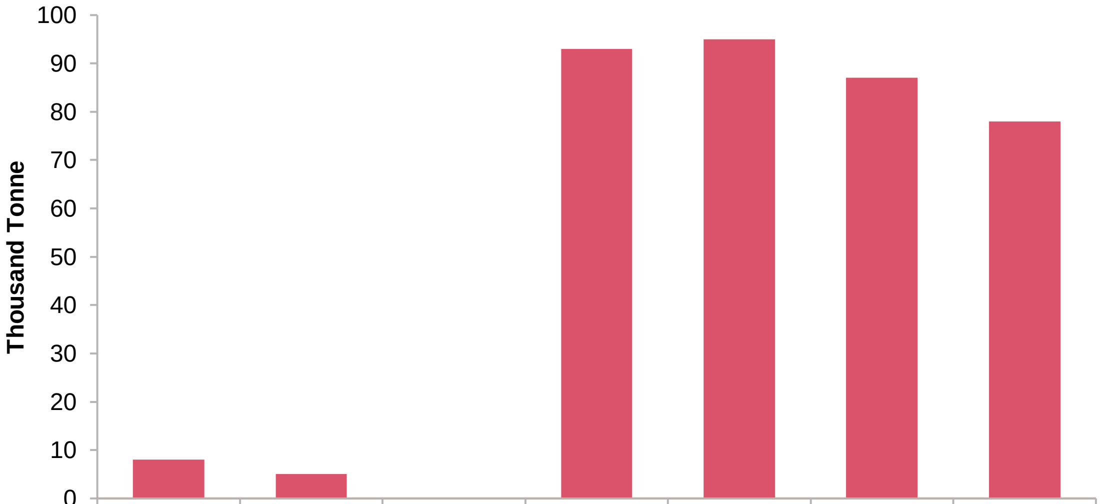


	1990	1995	2000	2005	2010	2015	2016
Other bituminous coal	0.7	1.23	4.3	4.1	5.05	9.29	11.49

Source: IEA Coal information, 2018

Sri Lanka: Sri Lanka has no domestic coal production and it imports coal from other countries. This coal is of the bituminous category and the historical consumption of coal in Sri Lanka has been shown in the figure below:

Figure 35: Consumption of coal in Sri Lanka (by type)



	1990	1995	2000	2005	2010	2015	2016
Other bituminous coal	8	5	0	93	95	87	78

Source: IEA Coal information, 2018

1.3. Purpose and Objective of Study

1.3.1. Purpose of Study

Fossil fuel-based power generation has been a major source of environmental pollution. Significant reserves of coal in SAARC region, major portion of which is low calorific value coal coupled with low cost of generation of power from coal, have resulted in inevitability of the coal-based power plants in the SAARC Region. It is therefore critical to understand and devise economical and sustainable ways for effective utilization of low calorific value coal in power plants.

The utilization of Low Calorific Value Coal is not limited to the SAARC countries and its utilization in relatively eco-friendly manner has been demonstrated by developed countries. Therefore, SAARC countries can study and adopt some of these technologies in order to ensure minimum ecological impact without compromising on the availability of the energy source for the development of the SAARC countries.

SEC, under its thematic area of "Programme to Minimize Oil Imports through Improvements in Energy Efficiency and Fuel Substitution" (PROMO), intends to study and put forth its analysis of some of such technologies available and how they can impact the power generation using Low Calorific Value Coal.

1.3.2. Objective of Study

The objective of the study is to assess various technologies that can enable utilization of Low Calorific Value Coal for generation of Power in the SAARC countries in an environmentally friendly manner. The application of identified technologies shall be discussed for new power plants as well as conversion of existing coal plants in respective SAARC countries. Based on international experiences for such technologies of low calorific value coal, an action plan specific to the prevailing condition of the SAARC countries, should be devised.

1.4. Scope of the Study

The scope of study includes the following:

a. Brief discussion on low CV coal available in different SAARC countries

b. Review existing utilization of low CV coal for generation of power in SAARC region

c. Assess and identify the most suitable technologies for using low CV Coal in a relatively environment friendly manner for green field and brown field power plants

d. Review international implementation of such technologies

e. Discuss in detail the requirements/ pre requisites of such installation and conversion; Identify existing gaps and barriers; and solutions to overcome

f. Propose new approaches, measures and financial models for adoption of such technologies with respective pros and cons

g. Propose Cross-Border collaborations and cooperation for the development of technologies to utilize low calorific value coal for the generation of power

h. Provide an action plan for successful implementation of technologies towards the utilization of clean coal power generation technologies using low value coal, taking care of all allied requirement

1.5. Methodology of Study

The study was predominantly divided into two phases – analytical study, using case scenarios and gap analysis.

In Phase I, market research was carried out to identify key facts and details in order to recognize the availability of reserves and potential of low calorific value coal in various SAARC countries vis-à-vis other available alternatives for clean power generation. Simultaneously, a cost benefit matrix based on identified parameters was prepared in order to carry out a comparative economic value analysis to shortlist the identified technologies.

Phase I: Market Research and Key Trends

1.1 Introduction

- Coal reserves in SAARC countries
- Share of low CV coal
- Availability and Classification of low CV coal
- Potential of Energy Production

1.2 Deep dive into Low Calorific Coal

- Importance and usage
- Merits and Demerits of usage of low CV coal
- Reserves, Production and Consumption
- Competition with other alternatives

1.3 Clean Coal Power Generation Technologies

- Precedence for use of low CV coal in Power Generation
- Need for improving coal quality
- Cost Benefit Analysis of improvement in Calorific value
- Description of various available technologies
- Comparative Economic Value analysis (EVA) of different Clean Coal Power Generation Technologies
- Environmental aspects and Impacts
- Challenges & way forward

In Phase II, the best practices in clean coal-based power generation technologies across the world have been mapped and the key success factors have been identified. Also, a readiness and deployment levels of such technologies in the SAARC countries have been established in order to identify adoption barriers and possible remedial course of action.

Finally, in Phase III, the gap is analyzed between the as is state of SAARC countries and developed economies w.r.t. policy and guidelines of utilization amongst other criteria and an action plan for the countries has been developed.

Phase II: SAARC status and International Best Practices

1. **Clean Coal Power Generation Technologies - a SAARC outlook**
   - Potential of Low CV coal in the countries
   - Requirement and need for clean coal technologies
   - Deployment status of identified technologies
   - Barriers and Drivers of adoption

Phase III: Gap Analysis and Action Plan

1. **Gap Assessment**
   - Analysis of Gap in SAARC countries vis-à-vis international best practices
   - Utilization and deployment of clean coal technologies- a comparison
   - Possible roadblocks
   - Other challenges and mitigation

2. International Case Studies

- Successful Clean Power Generation Technologies using low CV coals
- Coal Utilization Policy in developed economies
- Roles and guidelines of International Environment Organization

2. Action Plan

- Identification of potential application areas
- Essential pre-requisites
- Way ahead- road map and action plan

1.6. Limitation(s) of Study

- The study was carried out majorly through secondary analysis for market research and assessment of key trends without actually visiting the SAARC countries. Consultation was carried out only where specific inputs had to be sought.
- Technologies specified and analyzed, perform typically in co-ordination with the operating systems and processes at the plant. Implementation of the same is subject to suitability and possibility of implementation under the existing circumstances, e.g., Installation of FGDs and ESPs are subject to availability of corresponding space for installation in the plant.
- The commercial values of the technologies specified in the report are for representative purposes. Quoting of any such cost/price is only representative and should not be considered as the actual financial price.
- Since the scope of the study is not limited in the type of technologies covered, the study does not claim to have covered all the options and technologies available for the subject matter. The technologies covered are some of the most prominent in the market.
- Project specific commercial viability may need a detailed assessment and is not covered in this study.

2. Low Calorific Value Coal

Low Calorific Value Coal

2.1. Growing importance of Low Calorific Value Coal

Coal is one of the most predominant energy resources across the globe. Around 40% of the world's electricity generation is through coal. The dominant position of Coal is largely driven by its abundance and low cost. As on year ending 2017, over 1 trillion tonne of proved reserves of coal are available in the world. Out of which, high-grade coal, i.e., Anthracite and bituminous coal account for over 69%, while low-grade coals, i.e., sub-bituminous coal and lignite account for the rest 31%[xiv]. However, with the depleting coal reserves, growing importance of renewable energy and increasing air and water pollution caused by coal, usage of coal especially in power generation has reduced. Anthracite and bituminous coals, which are majorly used for energy generation, have been constantly depleting. In this scenario, coal with low calorific value is gaining importance.

Renewable energy has a disadvantage of being intermittent in nature and cannot be solely relied upon for constant power supply to the grid. Coal use for power generation becomes important in such a scenario. High grade coal is available in countries such as Australia, South Africa, Indonesia and the USA and is limited in the SAARC countries. Thus, this further makes it imperative to use low grade coal for power generation in SAARC countries.

Low calorific value coal-based generation provides cheaper power especially for SAARC countries where per capita income is low. These countries must harness their resources and leverage them positively to provide electricity at lower cost to consumers. The technology used for generation of power through low calorific value coal is proven and matured. Moreover, any gap in technology faced by SAARC countries can be bridged by the developed nations through sharing of insights. Another advantage offered by low calorific value coal-based plants is their base load generation, which means they are plants that operate continuously to meet the minimum level of power demand 24/7.

2.2. Successful use of low calorific value coal

Sub-bituminous coal and lignite, which have low calorific value, are known as low calorific value coal. Alternately, they are called low grade coal and low rank coal. Lignite is also known as soft coal and brown coal. Low grade coal has the following features:

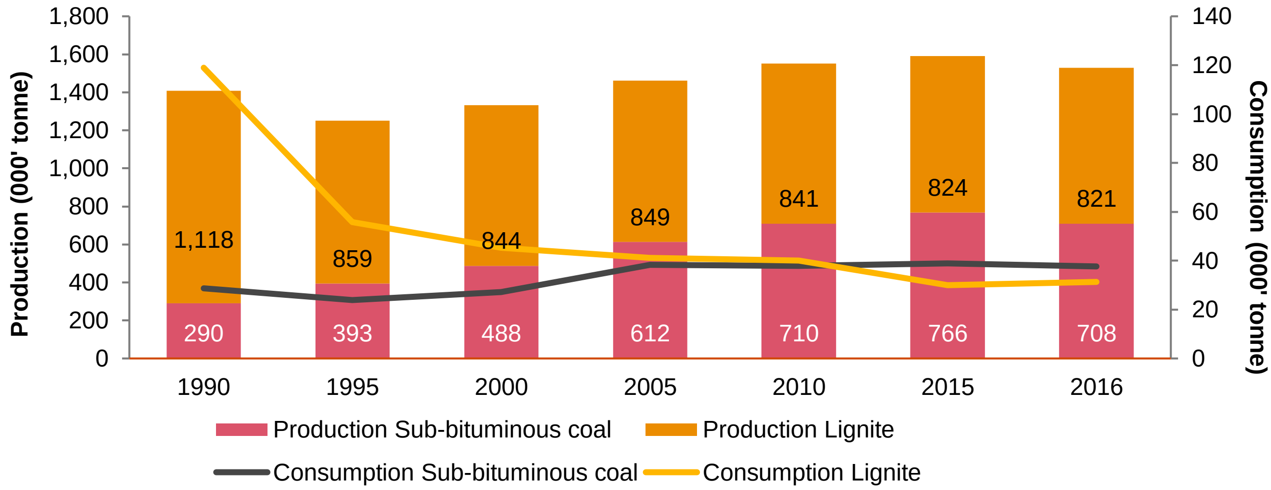
- Low gross calorific value
- High moisture, ash, Alkaline, Mercury, Nitrogen and Sulphur content
- Low fusibility, volatile content and easily grindable[xv]

The use of coal for power generation comes with a disadvantage of SOX and NOX emissions, which pose threats to the environment. However, it has various advantages such as low cost of generation, easy availability in SAARC countries and clean technologies that can be used to generate power from low CV coal. These advantages make the use of low calorific value coal for power generation economical and sustainable and also act as a grid stabilizing source in the face of increasing renewable energy capacity.

Technological advancements in clean coal technologies have mitigated the negative effects of coal power generation on the environment. Practices such as using washed coal, circulating fluidized bed combustion (CFBC) boilers, super-critical boilers, flue gas desulphurization (FGD) plants, selective non-catalytic reduction (SNCR), and low NOX burners have all contributed positively to the environmental friendliness while coal power generation.

2.3. Low CV coal production and consumption

Figure 36: Global Production and consumption of low-grade coal (in 000's tonne)



Source: IEA Coal Information

Amongst the SAARC member nations, countries such as Afghanistan, Nepal, Bhutan, Sri Lanka and Maldives do not have any reserve of low rank coal, i.e., sub-bituminous coal and lignite. However, they have reserves of hard coal, which is used in various industries such as steel, cement, textiles and food processing. India has the highest number of reserves of hard coal and low rank coal among the SAARC countries.

2.4. Advantages and disadvantages of using low quality coals

Low-grade coal, despite having high Sulphur content and being less efficient, has the following advantages:

- Large reserves: Low-grade coal reserves are available abundantly in the SAARC region, especially in India and Pakistan. These reserves can be tapped to increase the supply of low CV coal in the region, which currently faces a gap in the supply and demand of coal.

- Dependency: Dependence on imported energy resources can be reduced with the use of indigenous resources such as lignite and sub-bituminous coal. For example, Greece has reduced its oil and natural gas imports with effective utilization of its lignite resources.

- Low cost of generation: Surface mining techniques, which are used to extract low rank coal, are less cost-intensive ($60/tonne for underground mining and $10/tonne for surface mining) and thus reduce the total extraction costs of lignite and sub-bituminous coal. The average stripping ratio for low grade coal is 1:13. This makes low rank coal one of the most cost-effective fossil fuel-based sources of energy.

Despite having advantages, low quality coal has a few disadvantages that need to be considered:

- The maintenance cost of power plant equipment increases due to the high ash and Sulphur content in low CV coal, which leads to wear and tear of equipment and increased frequency of repair/replacement.
- Coal washing is a process to remove impurities such as Sulphur, ash and rock from the coal to upgrade the coal value. Low grade coals have high amounts of these impurities and the coal washing costs further increase the cost of generation.
- The cost of extraction of lignite resources is currently low. However, with the increasing extraction, accessible reserves may be exhausted and deeper reserves may have to be accessed. Such deep reserves are covered with layers that vary between 7 and 50 meters of thickness. This makes such resources inaccessible and may add on costs if accessed.
- Reduced calorific value of coal would effectively mean that higher volumes of coal would be required to produce electricity equivalent to that produced by lesser volumes of high-quality coal. This may lead to production of more ash followed by other environmental consequences.
- Transportation of low-quality coal to distant places results in high transportation costs and may further reduce the quality coal being fired for electricity generation, thus reducing the overall profitability and increasing environmental impacts.
- Low quality coal contains high moisture and ash (20% to 30%). Ash removal and drying techniques have to be applied to improve its efficiency, which in turn increase the process complexity and total cost of production. This upgradation process in fact reduces the quantity of coal that is used as a final product for electricity generation. The cleaning processes also release effluents and emissions that affect the environment.
- One of the characters of low rank coal is its tendency for spontaneous combustion, i.e., tendency to catch fire easily. Therefore, stocking/storage of low rank coal is not suggestable. For instance, lignite, once mined, is directly sent to the power plant without any intermediate storage. In addition, the buffer stock of lignite is maintained only for a few hours of operation of the plant, which may lead to plant shut-down.
- If coal with high ash content is unwashed and used directly in the power plant, considerable amounts of ash will be produced, which may not be environmentally acceptable.
- Lignite reserves in various countries have different characteristics and may not be generalized at a global level[xvi].

2.5. Competition with other consuming sectors

2.5.1. Consumption of Anthracite / Bituminous for Coking purposes

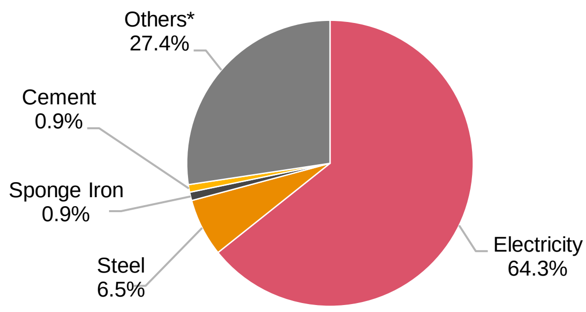
Coal is used as one of the raw materials in industries such as steel, iron, cement and textiles. Steel industries use high quality coal, i.e., anthracite and bituminous coal as their energy source, while other industries use bituminous coal, which can be referred to as medium quality coal.

India

In terms of consumption of raw coal, steel is the second biggest consumer, only after electricity (64%) accounting to 6.5% of the total raw coal consumption in India.

As per the statistics provided by Coal Controller's Organization (under the Ministry of Coal), the total demand for coking coal, grew at 4% CAGR during the period between FY2014 and FY2018.

Figure 37: Industry-wise consumption of raw coal (million tonne)



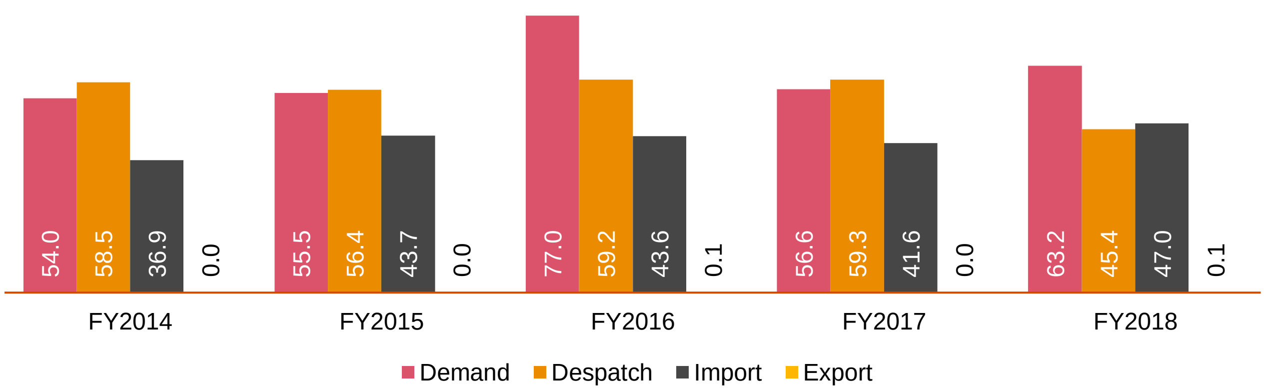
** Others include Paper, textile, fertilizers & chemicals, brick, sponge iron, colliery consumption, jute, bricks, coal for soft coke*

Source: Central Statistics Office, Ministry of Statistics and Programme Implementation

Indian steel industry, post deregulation, has seen enormous growth, owing to the bourgeoning economy and growing urban infrastructure and manufacturing sectors. This, in turn, has resulted in increasing demand for steel. This growing demand is being addressed by increased production, thereby taking India to the second position after China. India is the largest producer of sponge iron, while it is the third largest consumer of finished steel in the World after China and the US. India became the second largest crude steel producer, with a production of 106 million tonne in FY 2018. As per the projections of World Steel Association, demand for steel in India is set to grow by 7.3% in 2019, against growth of 1.4% globally. Concurrently, the per capita finished steel consumption for India was 69 kg in FY 2017 against a global average of 212 kg[xvii]. The National Steel Policy aims

- To increase per capita steel consumption to 160 kg by FY 2031
- To increase domestic availability of washed coking coal from 65% to 85% by 2030 so as to reduce the dependence on imported coal[xviii].

Figure 38: Demand, despatch, import and export of Coking coal (million tonne)



Source: Coal Controller of India, Government of India

Table 17: Forecast of major raw material requirement by FY2031

Raw material	Projections (FY2031)
Iron ore requirement	437
Coking coal requirement	161
Non-coking coal requirement for PCI	31
Non-coking coal requirement for DRI	105

PCI: Pulverized Coal Injections; DRI: Direct Reduced Iron

Source: National Steel Policy, 2017

As per the analysis of S&P Global Platts, it is forecasted that crude steel production in India will reach 125 million tonne by 2020, registering an increase of 21% from 2017. Pig iron production is forecasted to increase to 81 million tonne by 2020, up from 66 million tonne in 2017. As per the standards maintained in India, 1 metric tonne of pig iron requires 1.6 metric tonne of iron ore and 0.85 metric tonne of coking coal. On these lines, it is estimated that iron ore and coking coal demand would reach 130 million tonne and 70 million tonne, respectively by 2020[xix].

In the process of addressing the aforementioned growing demand, a wide range of capabilities has been developed by the Indian steel industry, which is at par with the global standards. However, it is deprived of a few vital raw materials such as manganese, limestone, nickel, coking coal, etc. Though domestic coking coal is available, it lacks both in terms of quality and quantity. The presence of high quantities of ash content in domestic coal, makes it unsuitable for coking purposes. Hence, it becomes apparent for the companies to rely mostly on imported coal than the domestic indigenous coal.

Importing high quality coal from other countries has become inevitable owing to the shortage of high-quality indigenous coal and increasing demand of the high-quality indigenous coal.

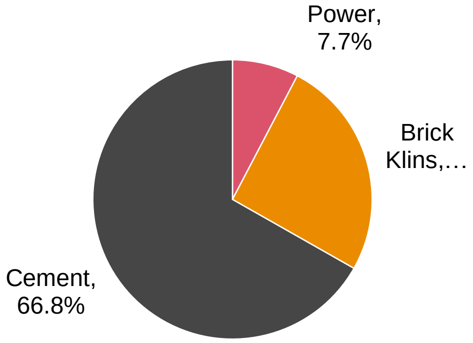
Pakistan

The cement and brick kilns have been the major consumers of coal for more than 15 years in Pakistan. Owing to the lack of infrastructure, insufficient financing and absence of modern coal mining technical expertise, the power generation through coal has not developed for over three decades in Pakistan.

During FY 2017, about 66.8% of the total coal production was utilized by cement industries and 25.5% coal was consumed by brick-kilns industry, while power sector has consumed only 7.7%.

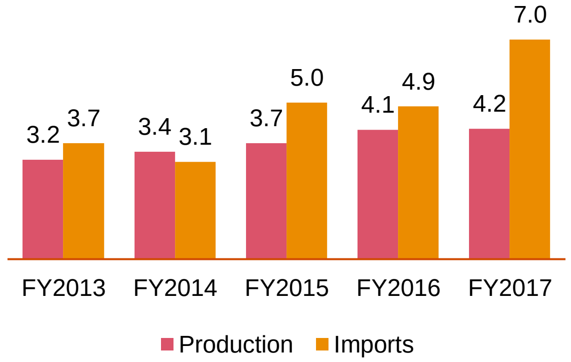
Pakistan's coal generally ranks from lignite to sub-bituminous. Therefore, to cater to the domestic demand, high rank coal is imported into the country. The local coal is undesirable to be used in cement factories, coal fired power plants and other coal-based industries, as it has high Sulphur and ash content and lower heating value. Hence, the blend of indigenous low rank and imported high rank coal is used in the country.

Figure 39: Raw coal consumption by sector in Pakistan (FY2017)



Source: Pakistan Economic Survey 2017-2018

Figure 40: Coal supplies in Pakistan (million tonne)

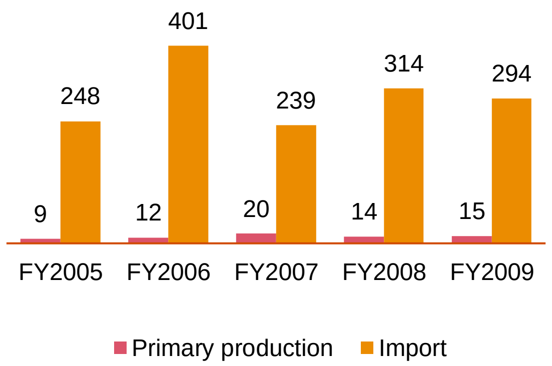


Source: Pakistan Economic Survey 2017-2018

Nepal

There are some minimal occurrences of coal and lignite in Nepal that are not commercially attractive. The country holds low to medium grade coal deposits as quaternary lignite, siwalik coal, eocene coal and gondwana coal. Out of these four identified types, the quaternary lignite deposit of the Kathmandu Valley and coal from Mid-Western Nepal is of some economic significance. Siwalik coal is not economically attractive because of small and sporadic onset. Similarly, the Gondwana coal from the east of Nepal is of low quality, small in size and of no economic significance.

Figure 41: Coal supplies in Nepal ('000 ton)



Source: National Energy Strategy of Nepal, Government of Nepal, 2013

Limited amount of low-grade coal is locally extracted and is majorly used for brick manufacturing. Since Nepal produces only a very small amount of coal, all the commercial fossil fuels (mainly oil and coal) are imported from India and abroad. Over 97% of Nepal's coal demand was met through imports. Further, import of fuels in Nepal accounts for one-fourth of country's foreign exchange earnings.

In addition to the aforementioned facts, because of the low heating value of the domestic coal, the local brick entrepreneurs use the indigenous coal by blending with imported coal. While this being the case, the quality and grade of the coal that are being imported for brick firing are ignorant.

2.5.2. Other industries depending on Coking Coal

India

Cement:

Coal continues to be one of the primary fuels for manufacturing cement in India, owing to the high cost of natural gas and oil. As per the industry standards, 0.20-0.25 tonne of coal is consumed to produce one tonne of clinker. It is noteworthy that ~10 million tonne of coal is consumed annually by cement industry. During the period January-October 2018, about 13.5 million tonne of coal was imported from the US, up by 36% during the same period in 2017. For the year 2019, the government has already allocated coal mines for the cement industry to meet the demand arising out of captive power plants for cement.

Non-coking bituminous coal of grades G4, G5, G6, G7 and G8 are used in the cement industry[xx].

Table 18: Energy consumption in Indian cement industry

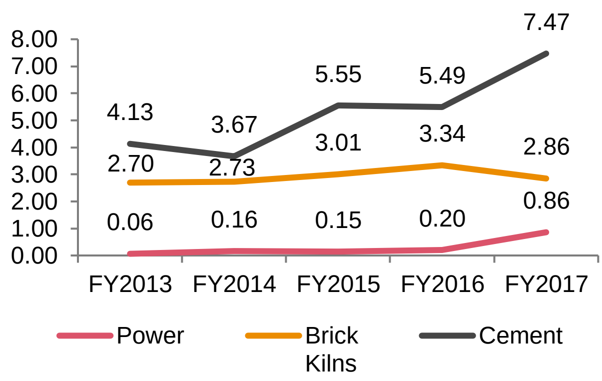
Particulars	UOM	Global avg.	India best	India avg.
Specific Electrical Energy Consumption	kWh/tonne of cement	91	64	80
Specific Thermal Energy Consumption	GJ/tonne of clinker	3.50	2.83	3.10

Source: Cement Manufacturers Association, India

Pakistan

In Pakistan, the coal is consumed by the three sectors of the economy, namely, the domestic (household), industrial and power generation sectors. The coal consumption in household is negligible, compared to power generation and industrial sectors. In industries sector, cement and brick kiln factories are the major consumers of coal.

Figure 42: Coal Consumption by sector in Pakistan



Source: Pakistan Economic Survey 2017-2018

Consumption of coal, mostly imported, in the cement industry has consistently increased from less than 1% in 1990's to about 67% in 2019, followed by brick kilns (25%)[xxi]. This is mainly due to the replacement of expensive natural gas and furnace oil with low-priced coal (domestics as well as imported). However, cement units use high rank imported coal. The indigenous coal is blended with imported coal in small proportions, which are a requisite for smooth operation of the plant. The attributable reasons for negligible use of domestic coal in cement production are non-development of indigenous coal resources, lower quality, slow and unreliable productions and supplies, lack of washing/processing of raw coal, etc. Cement industries of Pakistan import coal from countries like Indonesia, South Africa and Australia owing to their higher heating value and lower ash and Sulphur content.

Nepal

Coal provides around 4% of Nepal's energy supply, which is consumed mostly by industry sector. Industries such as brick, lime, cement and steel consume nearly 72% of the thermal energy, which is mainly used for heating and boiling purposes. Only a negligible amount of coal is used in residential and commercial sector[xxii].

Coal is a major fuel for brick firing in Nepal, which accounts for ~30% of total coal consumption in the country's industrial sector. Apart from coal, a small fraction of other fuels such as agriculture residue, firewood, rice husk, saw dust, charcoal etc., is also used. It is estimated that around 70% of fuel used in brick kilns are coal.

Table 19: Coal supply in Nepal (FY2012)

Coal Supply	Total (Ton)
Indigenous production	9,320
Import	580,900

Source: Energy Data Sheet, Water and Energy Commission Secretariat (WECS), June 2014

Due to the insignificant domestic production, coal is imported for various countries like India, for the purpose of brick firing. Coal consumption by the brick sector in the country is estimated to be of 449,358 tonne annually. With the existing market price, the cost of coal that is being imported for firing bricks amounts to USD 110 million annually[xxiii]. In FY 2012, the domestic coal production was only around 2% of total coal import[xxiv].

In the cement factories, the main sources of energy used are electricity and coal. Coal is mainly used in the kilns for calcification in limestone-based cement plants, whereas clinker-based units use mainly electricity for grinding. In the metal and steel industries, the main sources of energy used are furnace oil, electricity and coal. Coal is mainly used in re-heating furnace for billet heating, while some industries use furnace oil or diesel in place of coal. Nearly, 50% of industries use furnace oil while 40% of industries use coal as fuel for the furnace[xxv].

2.5.3. Implications of consumption of Medium/High CV coal on industries

India

Steel:

The domestic production of medium/high CV coal does not meet the demands of the steel manufacturers in India, who are compelled to procure imported coal through secure long-term contracts with miners to ensure steady supply of high/medium CV coal to their plants. With the increasing consumption of coking coal in the country and with limited resources, demand for likes of high-quality coal is expected to gain importance. Thus, consumption of indigenous high/medium CV coal for power generation in thermal power plants would result in further scarcity in availability of coal for the steel industry, resulting in lower production and higher costs owing to costlier imported coal.

Cement:

Consumption of the indigenous High/medium CV coal for power generation would result in shifting of focus of the industry to using alternative fuels. Another option being evaluated by the industry is the use of low-grade coal in some kiln systems, which will reduce NOX emission due to reburn reactions.

Pakistan

Since the cement industry uses around 1% of the indigenous coal produced in Pakistan owing to the quality and availability restrictions, use of indigenous high/medium quality coal for power generation shall have lower impact on the cement industry. In the country, the prices of coal started to surge since May 2016, after China, the world's largest coal producer, importer and consumer, which imposed supply side measures to limit its coal mining capacity.

2.6. Dependence on LCV coal to meet the energy requirements of the SAARC countries

India:

Owing to the reasons enlisted in sections 2.5.1 and 2.5.2, India is bound to use Low Calorific Value Coal for its power generation energy requirement. India is one of the world's largest consumers of coal, energy sector being its biggest consuming industry. They use indigenous non-coking coal with calorific value, ranging between 3,000-5,000 Kcal/kg, which is again blended with other imported coal. The increasing imports have resulted in a rise in trade deficit, coal being the fifth largest imported commodity. In view of this, the government had mandated state-owned power companies and encouraged private power producers to stop thermal coal imports and source their requirement from domestic sources. However, Coal India Limited (CIL), a state-owned coal mining corporate, could not meet the requirements of the Indian power plants. This instigated the Indian power plants to import coal from countries such as Indonesia, the US and South Africa[xxvi].

Out of India's total annual thermal coal imports, Indonesia accounts for 61%, followed by South Africa (22%) and the US (7%). Low quality Indonesian coal {usually 4,200 GCV as received (GAR)} is preferred by the Indian power producers due to the cheaper freight costs, which make it cheaper than the better-quality coal from the US[xxvii, xxviii].

India's power generation capacity (363 GW as on September 2019) is dominated by thermal power, of which coal accounts for 56%. As per Central Electricity Authority's (CEA) analysis, coal-based capacity of 5 GW is expected to retire by FY 2022, as it would be completing 25 years of operation by then. Furthermore, a capacity of 16 GW would retire, as it does not have space for installation of Flu Gas Desulphurization (FGD) to control SOX emissions. In addition, a capacity of 25 GW is expected to retire during FY 2027, as it would complete 25 years of operation by March 2027. In the aforementioned scenario, to address the growing energy demand, an additional coal-based capacity of 6 GW and 46 GW will be required to be installed during 2017-22 and 2022-27 respectively[xxix].

All the old as well as new technology thermal power plants are bound to use low quality domestic coal due to its depleting quantity and quality.

Pakistan

It is evident from the former sections that in order to meet the domestic demand, high rank coal is imported that is majorly used by the industrial sector. Since Pakistan has abundance of coal reserves that are considered suitable for power generation, this leaves room for ideal utilization of domestic coal in coal-fired power plants. Though, coal-fired power hardly played role in the country's power system, recently this pattern has started to change following the government's plan to broaden the role of domestic coal. According to Vision 2030 strategy plan in the country, the government plans to increase coal-fired power generation from its existing value of around 200 MW to 19.9 GW by 2030.

Many coal-fired power plants are in pipeline at various stages of development, as a result of CPEC investments by China, which comprise USD 35 billion of Chinese loans for power generation. While some of these plants will be fuelled by domestic coal from Thar coalfield (lignite), others will be fuelled by imported coal.

Table 20: Pakistan's coal-fired power development pipeline

Status	Coal Source	Capacity (MW)
Permitted	Domestic	2,310
	Imported	-
Pre-permit	Domestic	1,650
	Imported	3,640
Announced	Domestic	1,320
	Imported	-

Source: Pakistan's Power Future, Institute for Energy Economics and Financial Analysis, December 2018

NEPRA and Pakistan government have expressed their concern about excessive dependency on imported coal, because of which, the Federal government has placed a cap on coal-fired plants fuelled by imported coal. The State of the Industry Report by NEPRA in 2017, noted that as the Pakistani currency weakens against the US dollar, there will be an approximate INR 4 billion (USD 56 million) annual increase in the fossil fuel import bill for the planned thermal power plants. This led to the de-prioritization of imported coal-based projects; the Rahim Yar Khan coal-fired plant proposal has reportedly put on hold over the concerns on the cost of imported fossil fuels. Apart from this, a recent order by Supreme Court has further driven the expense of coal import. On the pollution grounds, the court has banned the unloading of coal at Karachi port trust berths, due to which, the port handling charges for coal shipments grew up to 40%[xxx].

A comparison of Thar coal based power project and imported coal based power project reveals that an average 600 MW Thar coal based power plant is estimated to have a levelized 25-year per unit cost of <9.5 cents per unit compared to imported coal (10 cents per unit), LNG (13 cents per unit), furnace oil (19 cents) and diesel (14 cents). Furthermore, no significant difference in the efficiency rate is noted when Port Qasim (imported coal) and Thar (domestic coal) power plants are compared. Port Qasim plant has 40% while Thar plant has 38.8% of efficiency rate. Moreover, both the projects have the same project cost[xxxi]. However, concerns are raised about environmental pollution on high-use of low-quality domestic coal, which can be addressed by the clean coal technologies.

3. Current Technologies for CCTs to Utilize LCV Coals

Current technologies for CCTs to utilize LCV coals

3.1. Technologies and features of coal based TPP:

The principle of thermodynamics states that efficiency of power generation increases with increase in steam temperature and pressure.

Depending on the steam condition entering the steam turbine, coal based TPPs can be categorized into three types:

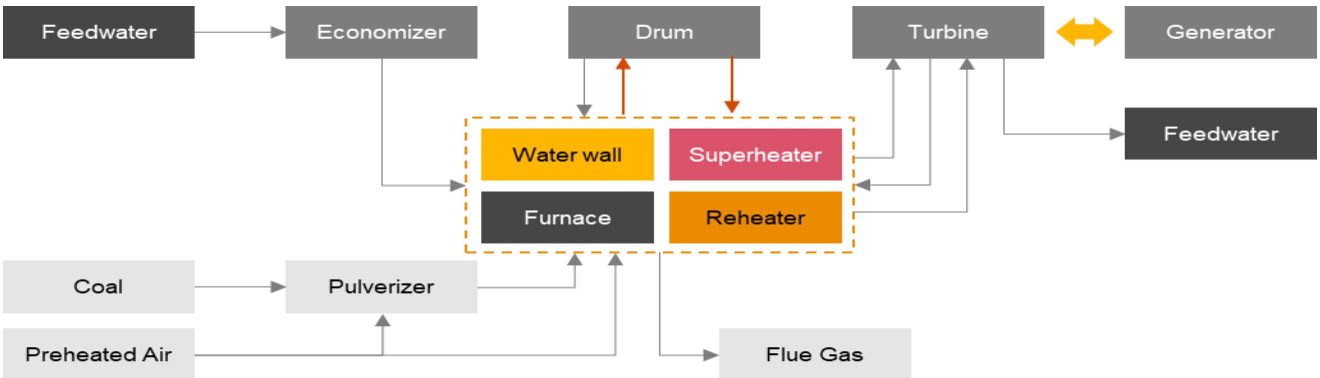
- Subcritical (steam pressure is lower than the critical pressure)
- Supercritical (SC, steam pressure greater than the critical pressure)
- Ultra-supercritical (USC, uses supercritical pressure together with a steam temperature>580°C).

Here, the critical pressure of water is 3,208 pounds per square inch absolute (psia), which is equivalent to 22.1 Mega Pascal (MPa) and 706°F (374°C)[xxxii].

3.1.1. Subcritical Power Plants

In a subcritical coal-fired power plant, the coal is milled into a fine powder in order to increase the surface area of the coal, which in turn facilitates faster burning of the coal in the boiler. The milled coal is then fed in to the combustion chamber of a boiler, where it is burned with air at a temperature of 1300-1700°C with a lean stoichiometric ratio. The heat energy thus produced is transferred to the water tubes lining the boiler (water walls) that carries pressurized water to generate steam. However, the pressure in the system is less than the critical pressure associated with water/steam (~218 atm). This high-pressure steam is then passed onto a HP turbine, where heat energy is partly transformed into mechanical energy, which in turn drives an electric generator converting mechanical energy into electricity. Once the steam is expelled from turbine, it is returned to the boiler to be reheated, after which, it is again passed through the LP turbines to extract further energy stored in the steam. Historically, majority of pulverized coal-fired plants were based on subcritical steam-cycle technology, which accounts for majority of current low rank coal-based power generation.

Figure 43: General block diagram of subcritical coal-fired thermal power plant



Source: Dynamic analysis of the boiler drum of a coal-fired thermal power plant, Sreepradha Chandrasekharan et al

In the above shown coal-fired power plant, the raw coal is transported to the pulverizer, where grinding and crushing of the coal take place. The pulverized (smaller and lighter) coal and pre-heated primary air are together carried into the furnace at positive pressure for combustion. The air required for combustion (secondary air) is also delivered through the force draught fans and an air preheater installed in the path of furnace to heat the secondary air. The combustion takes place in furnace, generating high temperature (>1000°C) and flue gases. Modes of heat transfer are both radiation and convection. Meanwhile, feed water flows through the economizer to be converted to preheated water. The drum unit is composed of downcomer, waterwall and drum. While the drum carries out segregation of steam and water, the water is circulated through the downcomer and waterwall. The collected steam then flows through multiple stages of superheaters that are suspended at the top of the furnace, to convert the saturated steam to supersaturated steam. As this high energy steam is fed to the HT turbine to provide for the requisite torque. The steam at the outlet of the HT Turbine is again fed to the reheaters in the furnace to heat the steam again to the requisite parameters so that it can again be subjected to LP Turbines, thereby extracting maximum energy from the steam. The generated mechanical energy in the form of torque is converted in to electrical energy in the generator unit of the power plant.

Table 21: Features of a typical subcritical technology for Coal based Power Generation

Technology	Subcritical
Steam Pressure	Below Critical Pressure of water 22.1MPa
Main steam temperature	Up to 565°C
Reheat steam temperature	Up to 565°C
Net thermal efficiency (LHV)	Up to 38%
Coal Consumption	≥380 g/kWh
Water Consumption	2.14 L/kWh
CO2 Intensity Factor	≥880 g CO2/kWh

Source: Clean Coal Technologies for Power Sector and their Scope in SAARC countries, Engr. S.M. Mohibur Rahman;

Majority of the subcritical power plants are based on a conventional single reheat thermal cycle with the subcritical steam pressure within the range of 16-18 MPa (2,320–2,610 psia), while the main and reheat steam temperature ranges between 1000°F–1050°F (535°C–565°C). These power plants are advantageous in terms of lower installation costs and lower operating and maintenance expenses. The capital cost of a subcritical power plant is estimated at USD 1000/kW at international market prices, but the price could be lower (USD 800/kW) in countries like China and India[xxxiii]. On an average, subcritical power plants achieve efficiencies in the range of 30% and 36%.

On an average, subcritical power plants use 67% of more water and emit 75% more carbon pollution compared to an advanced ultra-supercritical, which is the most modern form of coal-fired power plant. Moreover, shifting to these more efficient technologies cannot only reduce the emissions but can also result in substantial savings of coal

Economic Analysis of a subcritical Power Plant:

The installations in a typical sub-critical power plant vary from a standard BTG with critical BOPs to a robust power plant with wide range of BOPs, including FGDs, Air Cooled condensers etc. In addition to this, the costs other than the equipment cost vary significantly depending upon the area in which such a plant is being built. The resultant capital cost varies significantly.

Therefore, wherever possible, the costs available locally among the SAARC members may be used as most SAARC members are at comparable indices in terms of livelihood and purchase power parity.

The Capital Cost of Sub-critical coal based thermal power plants with some BOPs like FGD is to the tune of USD 896.7 per kW with a tariff recovery of fixed costs to the tune of USD 226.16 per kW per year and a payback period on equity is to the tune of 7.14 years. *(Data from CEA Broad status report)*

These Underlying assumptions are Sub-500 MW units with some BOPs like FGD. Tariff determined at cost of Capital of 12% and Depreciating at 5.28%. Expected RoE considered at 14% and O&M at 8% of the Grossed Fixed Asset. It is assumed that average capital cost of thermal power plants in India commissioned recently or in the process of commissioning represents the costs towards addition of capacity in SAARC member countries as most local sub-critical thermal power plants are being put in India and further, the sector has evolved to arrive at market driven prices.

3.1.2. Supercritical Power Plants

In the recent years, supercritical steam plant technology is the most favoured option for the newest coal-fired power plant, owing to greater efficiencies and lower emissions. The first ever unit with supercritical steam conditions came into service in 1950s in the US with a unit size of 85 MW. However, adoption was limited owing to lack of material withstanding such high pressure and temperature.

Supercritical pulverized coal power plants operate at pressure, greater than the critical point, i.e., 22.1 Mpa. At such high pressure, water ceases to boil and instead converts to steam instantaneously, once it is heated above the critical temperature, 374.12°C (706°F). Thus, in supercritical units, water does not exist in two states in any stage. Since no separation of water from steam is required in the boilers, the boilers are constructed without a drum, and are typically 'once through boilers. On account of the improved thermodynamics of expanding higher pressure and temperature steam through turbines, the supercritical power plants are more efficient than the traditional subcritical power plants with efficiencies of up to 42%.

Table 22: Features of supercritical technology for Coal based Power Generation

Technology	Supercritical
Steam Pressure	22.1–25 Mpa
Main steam temperature	540–580°C
Reheat steam temperature	540–580°C
Net thermal efficiency (LHV)	Up to 42%
Coal Consumption	340-380 g/kWh

Technology	Supercritical
Water Consumption	1.91 L/kWh
CO2 Intensity Factor	800-880 g CO2/kWh

Source: Clean Coal Technologies for Power Sector and their Scope in SAARC countries. Engr. S.M. Mohibur Rahman

The boilers of supercritical power plant have different operational characteristics due to the higher steam pressure and temperature and therefore require more stringent material characteristics than subcritical boilers. Special high-grade materials that are suitable for very high pressure and those are immune to oxidization due to very high temperature are used in the power plants. In order to withstand the high operating temperature and pressure, materials used are 9% to 12% ferrite steels T91/P91, T92/P92, T112/P122 steel, advanced austenitic alloys TP347, HFG, Super 304, Nickel and chrome nickel super alloys like Inconel 740, etc.[xxxiv].

Some of the benefits and challenges of supercritical power plants include:

Table 23: Environmental performance and cost of supercritical technology

Technology	Subcritical technology	Supercritical technology
Particulate reduction	Base	2-5% lesser
SOX	Base	2-5% lesser
NOX	Base	2-5% lesser

Source: Technologies for reducing emissions in Coal-Fired Power Plants, energy issues, The World Bank

Economic Analysis of a supercritical Power Plant:

As discussed earlier, the installations in a typical supercritical power plant vary from a standard BTG with critical BOPs to a robust power plant with wide range of BOPs, including FGDs, Air Cooled condensers etc.

Even in this case, the costs available locally among the SAARC members may be used as most SAARC members are at comparable indices in terms of livelihood and purchase power parity.

The Capital Cost of Super-critical coal based thermal power plants with some BOPs like FGD is to the tune of USD 957.38 per kW with a tariff recovery of fixed cost to the tune of USD 241.44 per kW per year and a payback period to the tune of 7.14 years. However total landed Tariff including Fuel cost is lower for super-critical coal based thermal power plants as the heat rate of supercritical thermal power plant is 6% lower than the sub-critical thermal power plant. *(Data from CEA Broad status report)*

The underlying assumptions are supercritical units of 660 MW units on an average with some BOPs like FGD. Tariff determined at cost of Capital of 12% and Depreciating at 5.28%. Expected RoE considered at 14% and O&M at 8% of the Grossed Fixed Asset.

3.1.3. Ultra-supercritical Power Plants

While there is no standard definition for USC power plants, usually any supercritical coal-fired power plant that operates at advanced steam temperature of 1,100ºF (600ºC) or above has been considered as USC power plant. Apart from that, the steam pressure in USC plants is greater than 25 MPa. The switch from traditional coal-based technologies (subcritical) to this USC steam conditions improves the efficiency of the plant by around 6%.

Table 24: Features of USC technology for Coal based Power Generation

Technology	Ultra-supercritical
Steam Pressure	>25 Mpa
Main steam temperature	>580°C
Reheat steam temperature	>580°C
Net thermal efficiency (LHV)	Up to 45%
Overnight Cost	USD 800/kW to USD 2,530/kW
Coal Consumption	320-340 g/kWh
Water Consumption	1.59 L/kWh
CO2 Intensity Factor	740-800 g CO2/kWh

Source: Clean Coal Technologies for Power Sector and their Scope in SAARC countries. Engr. S.M. Mohibur Rahman

Reduced fuel consumption also mean

- Reduced emissions of SO2, NOx, mercury (Hg), CO2 and particulate matter
- Reduced production of solid waste products such as fly ash
- Reduced requirement for commodities used in environmental control equipment such as activated carbon and ammonia

The first USC power plant was commissioned in Japan with a capacity of 1,000 MW in 1993. In recent years, several pulverized coal-fired power plants with USC steam parameters have been set up or are under construction in countries such as Denmark, Germany, Japan, South Korea, China and Italy. The degree of efficiency varies significantly among these plants, the least efficient plant being found in Japan (Matsuura EDP 1) with an efficiency of 40.5%, while the most efficient plant is located in Germany (Niederaussem) with an efficiency of 45%[xxxv]. In terms of emission intensity, Isogo Thermal Power Station, Japan is ranked the cleanest coal-fired power plant in the world.

High-strength ferritic 9-12 Cr steels are commercially available to achieve the steam temperature of up to 620°C, while at higher temperature austenitic steels (Super 304H, Esshete 1250), as well as, Nickel base alloys (Inconel 718 and 740) are being used in these plants to withstand the high operating temperature and pressure.

USC power plants offer significant economic and environmental advantages. Nearly, 50% less fuel is consumed by the USC power plants to produce same amount of power, compared to conventional power plants. Moreover, these new high-end USC coal-fired power plant can bring significant emission reduction at about 20-30%.

Table 25: Materials used to achieve desired steam conditions in ultra-supercritical units

Steam Condition	Material
30 MPa/600°C/620°C	Steels with 12 % chromium
Up to 31.5 MPa/620°C/620°C	Austenite
35 MPa/700°C/720°C	Nickel-based alloys

Source: System Design and Analysis of a "Supercritical Thermal Power Plant" with a capacity of 800 MW, Naveen Kumar and Mridul Yadav

A research report of ERIA (Economic Research Institute for ASEAN and East Asia) compared the power generation efficiency, initial investment cost, operating cost, power-generation cost, and CO2 emissions of three technologies with the data obtained from the actual plants.

Table 26: Power-Generation Efficiency and Costs of Different Coal-fired Power Plant Technologies (ERIA)

Technology	Combined cycle (IGCC)	Ultra-Super Critical (USC)	Super Critical (SC)	Sub-critical
Thermal Efficiency (%, LHV)	45.0~50.0	41.5~45.0	40.1~42.7	37.4~40.7
Fuel Consumption (ton/year)	1,900,000	2,229,000	2,275,000	2,413,000
CO2 Emission (ton/year)	4,439,200	5,126,000	5,231,000	5,549,000
O&M Cost (million USD/year)	4.06	3.42	4.1	5
Generation Cost (USD cent/kWh)	3.91	4.03	4.19	4.44
Pressure (Mpa)	30	>25	22-25	<22
Temperature	850-950°C	>580°C	540-580°C	<565°C
Water consumption (L/MWh)	1283	1590	1915	2139
Maturity of technology	First plant in 1984	First plant in 1993	First plant in 1950	First plant in 1927
Examples	Mississippi Power Kemper County, USA; CCP Nakoso, Japan; GreenGen, China	Isogo J-POWER, Japan; Tachibanawan J-POWER, Japan; Nordjylland Vattenfall, Denmark;	Takehara J-POWER; Matsushima J-POWER (Japan)	Taichung Taipower, Taiwan; Thai Binh EVN, Vietnam

Source: Comparison of Technologies, ERIA Research Project Report, 2015

The figures in the above table show higher initial investment for facilities with higher power-generation efficiency. This is because of the use of more expensive special materials to withstand the higher steam conditions in higher efficiency technology. However, the coal consumption is low in case of high-efficiency technology. As a result, the average cost becomes lower for higher efficiency technology if economic efficiency is evaluated over a certain period of power plant's operation[xxxvi].

Economic Analysis of an Ultra supercritical Power Plant:

While not many Ultra-supercritical power plants have been set up in the SAARC member countries, the typical capital cost of an ultra-supercritical power plant in the developed countries is found to be higher to the tune of USD 4,036 /kW[xxxvii] including IDC (Interest during Construction). These higher costs are owing to requirement of specific alloys that can withstand Ultra supercritical power plant operating pressure.

However, a 2 x 660 MW Ultra supercritical power plant has been set up at Khargone in Madhya Pradesh, India. While one unit has been commissioned in September 2019, the 2nd Unit is expected to be commissioned in January 2020. It may be noted that its Expected Capital Cost is expected to be USD 931.44 /KW[xxxviii] which is at par with the capital cost for setting up a supercritical power plant.

The overall payback period of the plant shall be less than that of Supercritical power plants as while the capital costs are competitive, the Fuel Cost per MWh is lower than Supercritical power plants.

3.1.4. Advanced Ultra-supercritical Power Plants

Ultra-supercritical (USC) technology (>25Mpa and 600°C) is currently in a stage of adoption in the world. R&D is being conducted across the globe to use steam parameters of 300-350 kg/cm2 pressure and 700°C-760°C and more steam temperature, which can result in thermal efficiency as high as 50%. The advanced ultra-supercritical technology (AUSC), is a step up in steam conditions from available USC units. The R&D on AUSC power plants with the steam parameters of pressure ≥300 kg/cm2, temperature≥700ºC is ongoing in Europe, the US, Japan, China and India. With such enhanced steam conditions, the efficiency of the plants is expected to be in the range of 45-47%. However, such high pressure and temperature will require advanced metal alloys to ensure technical viability of these plants. Materials such as ferrite steel and austenite steels exhaust their capability when the temperature is further increased to the range of AUSC parameters, i.e., above 700°C temperature. Research programs to develop advanced new materials that support AUSC steam temperature for a service lifetime of 20 to 40 years at experimental power plant are being carried out in the US, Europe, Russia, Japan, China and India.

In early 2014, a trial operation with a steam loop temperature, maintained at 760°C for more than 17,000 hours—the highest ever tested at a pulverized coal plant, has been achieved at Plant Barry Unit 4 in Alabama. An array of super alloys and surface coatings, capable of withstanding the exceedingly high temperature within the boiler, is involved in the loop. Post operation, all the components appeared to have retained their original mechanical integrity. This achievement depicts a major development boost for AUSC technology to increase the net thermal efficiency of pulverized coal-fired power plants.

India’s first AUSC thermal power plant with the capacity of 800 MW will be set up at Sipat station of the National Thermal Power Corporation (NTPC) in Chhattisgarh. The plant is 100% indigenous, including its design and is expected to operate at temperature of 710°C and at a 310 steam pressure bar. The two-and-a-half-year program, which was launched back in April 2017, with an estimated cost of Rs 15.54 billion, is being carried out by three government entities (NTPC, Bharat Heavy Electrical Ltd. (BHEL) and Indira Gandhi Centre for Atomic Research). Until now, design development, review of the boiler and turbine and establishment of welding, machining of the turbine rotor and casing with new materials (alloy 617 and 625) have been accomplished. This Indian AUSC power plant is expected to be commissioned by 2019-2020.

Table 27: Features of AUSC technology for coal-based power generation

Technology	Advanced Ultra-supercritical
Steam Pressure	30–35 Mpa
Main steam temperature	700-760°C
Reheat steam temperature	700-760°C
Net thermal efficiency (LHV)	45%-50%
Coal Consumption	290-320 g/kWh
CO2 Intensity Factor	670-740 g CO2/kWh

Source: Clean Coal Technologies for Power Sector and their Scope in SAARC countries. Engr. S.M. Mohibur Rahman

Economic Analysis of an Ultra supercritical Power Plant:

In case of Advanced Ultra supercritical power plant with carbon capture technology, limited examples are available to ascertain the capital cost for the same. No Advanced ultra-supercritical power plant has been set up in the SAARC member countries. The Capital Cost of Advanced ultra-supercritical power plant in the developed countries is found to be higher to the tune of USD 5,479 /kW[xxxix] including IDC. These higher costs are owing to requirement of specific alloys that can withstand Ultra supercritical power plant operating pressure and arrangement of the Carbon Capture mechanisms in the plants.

BHEL, an Indian heavy engineering company is in the process of indigenously developing an Advanced Ultra Supercritical power plant in India with a proof of concept being set up in NTPC Dadri. It is expected that such indigenization may result in significant reduction of the costs and therefore higher adoption among the SAARC region.

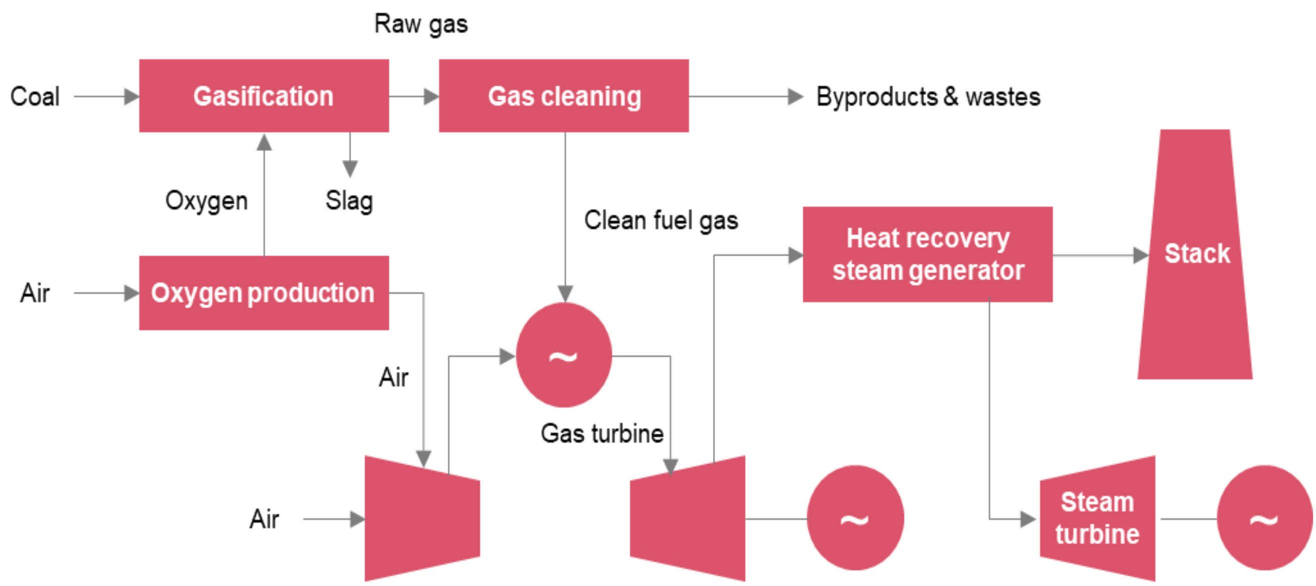
The overall payback period of the plant shall be further less than that of Supercritical power plants as while the capital costs are higher, the Fuel Cost per MWh is lower than Ultra Supercritical power plants.

3.1.5. Integrated Gasification Combined Cycle (IGCC) Power Plants

Integrated Gasification Combined Cycle (IGCC) has been developed to improve power generation efficiency while maintaining a near-zero environmental footprint. This technology is relatively new to power generation, the very first IGCC power plant, cool water Plant, being commissioned in 1984 in the US.

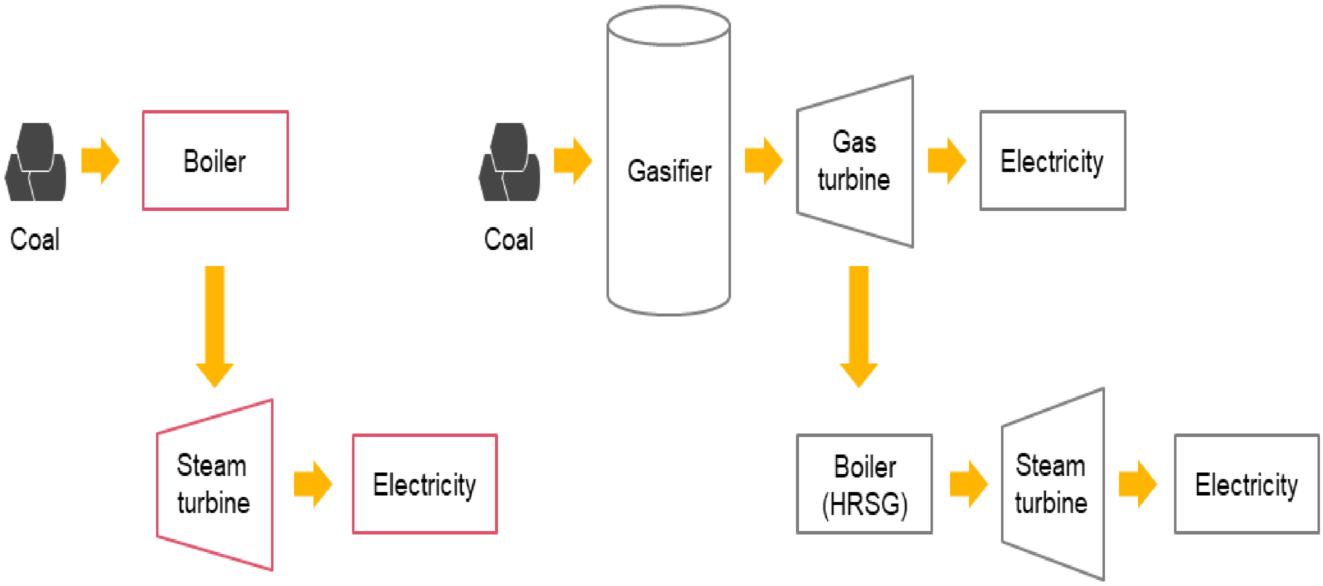
Simply stated, IGCC adopts a “combined power generation system” comprising of two power generation processes. Firstly, the system gasifies coal and uses the produced gas to fuel a gas turbine and generates electricity. Then, the exhausted heat from gas turbine is recovered to produce steam, which drives steam turbine to generate electricity.

Figure 44: Schematic representation of IGCC



In IGCC power plants, coal is gasified within the plant by the gasification system. The resultant synthetic gas is called syngas or fuel gas, which mainly comprises of molecular hydrogen (H2), carbon monoxide (CO), and carbon dioxide (CO2), along with small amounts of hydrogen sulphide (H2S). The syngas is cooled down and subsequently cleaned after leaving the gasifier. After cleaning, the syngas is then fired in a gas turbine to generate electricity. The exhaust gas is recovered and used to generate superheated steam (in the heat recovery steam generator, HRSG) in a secondary loop, while the steam is used to drive steam turbine and further generates electricity[xl].

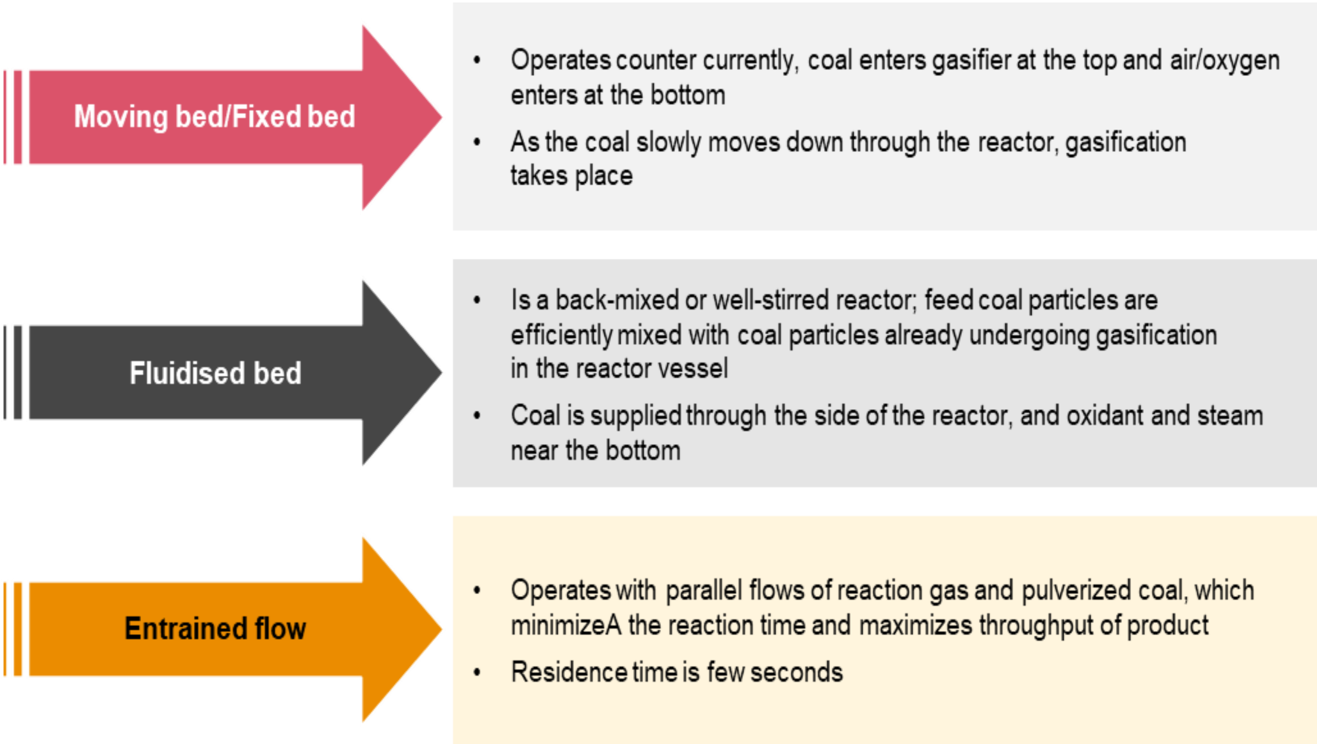
Figure 45: Difference between conventional coal-fired power generation and IGCC



Source: NEDO, Achieving Higher Efficiency by Gasifying Coal-"Integrated Coal Gasification Combined Cycle (IGCC)"

As discussed earlier, an IGCC power plant basically consists of the stages, namely, coal treatment, gasification, gas treatment and gas utilization. For gasification of coal, there are three major types of gasifiers suitable for application. The choice of the appropriate process is based on the characteristics of coal used.

Figure 46: Processes involved in IGCC



The operating temperature of all these gasifiers is primarily dictated by the ash properties of the feed. It is desirable to remove the ash, either in a dry state at lower temperature (non-slogging gasifiers), or as a low viscosity liquid at high temperature (slagging gasifiers).

Table 28: Characteristics of different gasifiers

Gasifier type	Moving bed/Fixed bed	Fluidized bed	Entrained flow
Outlet temperature	Low (425-600 ˚C)	Moderate (900-1050 ˚C)	High (1250-1600 ˚C)
Oxidant requirement	Low	Moderate	High
Ash conditions	Dry ash or slagging	Dry ash or agglomerating	Slagging
Size of coal feed	6-50 mm	6-10 mm	< 100 µm
Acceptability of coal fines	Limited	Good	Unlimited
Other characteristics	Methane, tars and oils present in syngas	Low carbon conversion	Pure syngas, high carbon conversion
Commercial gasifiers example	Lurgi and British Gas Lurgi (BGL)	Great Point Energy, Winkler gasifier, and KBR transport gasifiers	GE Energy, CB&I E-Gas and Shell SCGP

Source: LFEE, an Overview of Coal based Integrated Gasification Combined Cycle (IGCC) Technology

IGCC technology has drawn great interest from power producers, because compared with the conventional pulverized coal-fired power plants, IGCC has many advantages such as:

Figure 47: Advantages of IGCC

1. Improved power generation efficiency
2. Lower environmental burden
3. Flexibility to use different grades of coal
4. Increase in fields that can utilize the ash
5. Reduction of water consumption

A power generation system with high efficiency: The IGCC technology is a next-generation thermal power plant. While former technologies such as subcritical, supercritical and ultra-supercritical combustion can reach efficiencies between 30% and 45%, the IGCC technology can achieve efficiency rate of higher than 45%.

High environment performance: IGCC lowers the emissions of SOX, NOX, and dust per gigawatt-hour of electric power generated. Additionally, CO2 emission is comparatively less.

A wide variety of coal types can be used: IGCC broadens the variety of coal grades that can be used in coal-fired power plants. In conventional coal-fired power plants due to slagging and fouling, use of coal with low melting temperature becomes difficult. However, in IGCC power plants, the gasifier discharges ash in the form of melting slag, thus making the technology suitable even for the low ash melting point coals.

Table 29: Comparison between emission of conventional pulverized coal power plant and IGCC power plant

Pollutant	Pulverized coal power plant	IGCC	Change
SO2 (lb/MMBtu)	0.1	0.025	Decrease 75%
NOX (lb/MMBtu)	0.06	0.0075	Decrease 87.5%
CO2 (kg/kWh)	7.66	6.64	Decrease 13.3%

Source: Prospect of Coal Based IGCC to Meet the Clean Energy Challenge, Md. Kamruzzaman et al.

Less water is required: Since in IGCC, the generated flue gas undergoes treatment at higher pressure in smaller volumes prior to combustion, it consumes limited amount of water. Contrarily, conventional coal-fired power plants require a unit that consumes large amount of water to desulfurization flue gas after combustion (In case of use of Scrubbing FGDs). Hence, IGCC uses significantly less water than conventional pulverized coal-fired power plants.

Utilization of ash discharge: The coal ash discharged in the form of glassy molten slag by IGCC is likely to be effectively used as a component for civil engineering work.

In spite of many benefits that are linked with coal based IGCC technology, few barriers limit its take up. Compared to steam power plants, the investment costs of IGCC are higher, since these power plants have a more complex structure than steam power plants. Because of the higher investments, the resultant power generation costs will also be higher than that of steam power plants. The capital costs of coal-based IGCC are estimated at USD1,200–1,400/kW[xli]. Although some additional costs are involved in IGCC systems, benefits are more significant than this cost.

Only 18 IGCC plants are operational in the world as of 2017. Many planned or proposed IGCC power plants were later cancelled, citing cost escalations, uncertainty in emission regulations, etc. However, a number of major coals based IGCC projects are under construction across the world and majority of these projects are based on flow gasifiers. The below table summarizes the operating information for a few coal based power plants based on IGCC technology.

Table 30: Operating coal-based IGCC power plants

Project Name	Location	Feedstock (s)	Gasifier Technology	Net Electric Power (MW)	Net Thermal Efficiency (HHV)	Years in Operation
Mississippi Power Kemper County	Kemper County, MS, USA	Lignite	Southern-KBR TRIGTM air-blown, fast fluidized bed	524 (syngas only)	28.1% (with 70% CO2 capture)	2016 – Present
Sokolovská Uhelná	Vresova, Czech Republic	Brown Coal	Lurgi moving bed	398 (gross)	Unknown	1996 – Present
Reliance Jamnagar Refinery	Jamnagar, India	Pet Coke	CBI entrained flow	1300	N/A	2017 start-up
Duke Edwardsport	Edwardsport, IN, USA	Bituminous Coal	GE entrained flow	618	36.6%	2013 – Present
Polk County	Polk County, FL, USA	Bituminous Coal, Pet Coke	GE entrained flow	249 coal, 250 coke	36.5% coal, 37.5% coke	1996 – Present
CCP Nakoso	Nakoso, Japan	Bituminous and Sub-bituminous Coal	MHPS air-blown entrained flow	250 (gross)	40.5%	2007 – Present
GreenGen	Tianjin, China	Bituminous Coal	HCERI entrained flow	265	41%	2012 – Present
Wabash River	Terre Haute, IN, USA	Bituminous Coal, Pet Coke	CBI E-Gas entrained flow	252	38.5%	1995 – 2016

Source: Utilisation of low rank coals, Nigel S Dong, 2011; NETL, Commercial Gasifiers

Economic Analysis of an IGCC Power Plant:

In case of IGCC power plant with carbon capture technology, the technology is still in the developmental stage and the capital costs are expected to reduce further. Limited examples are available to ascertain the capital cost for the same. No IGCC power plant has been set up in the SAARC member countries. The Capital Cost of IGCC power plant along with a Carbon Capture arrangement in the developed countries is found to be higher to the tune of USD 6,599 /kW[xlii] including IDC.

The domestic coal available in the SAARC member states are expected to be appropriate for Gasification Process and therefore, IGCC finds high potential in adoption among the member states of SAARC.

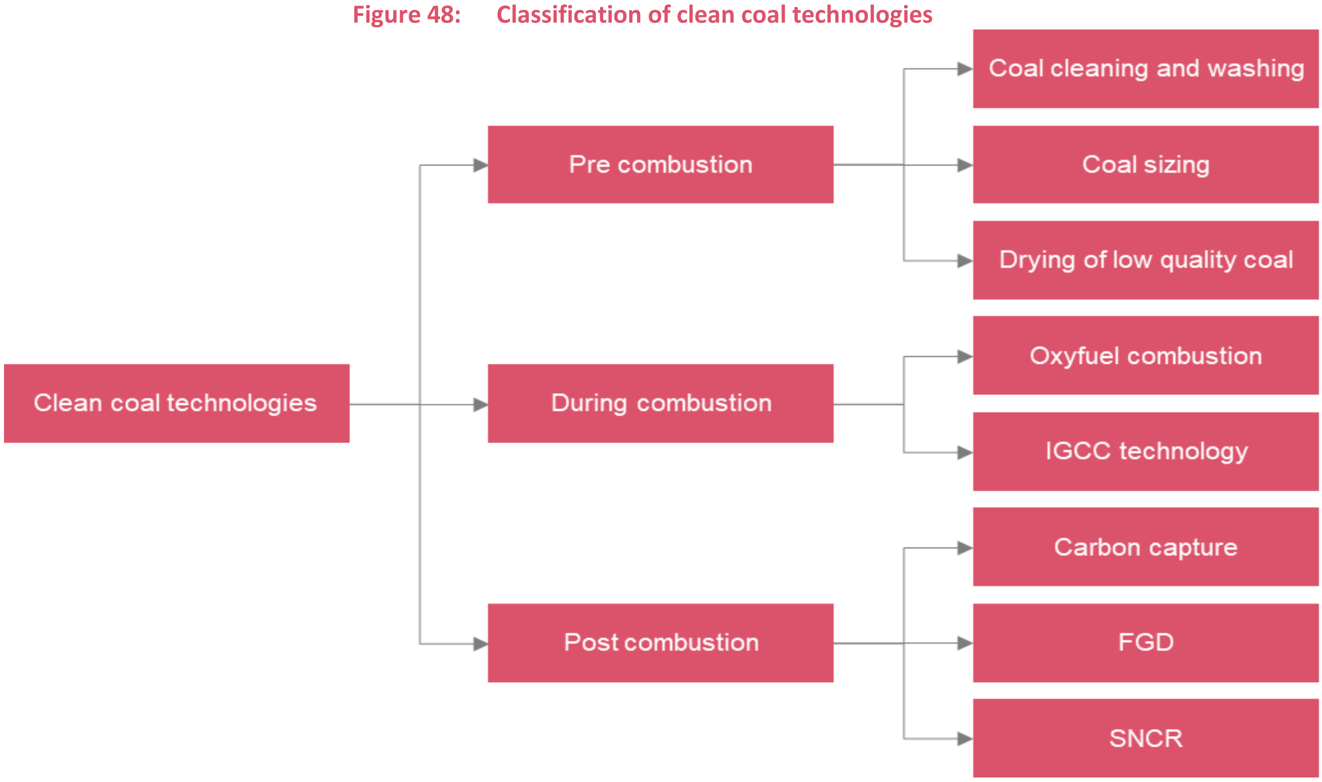
3.2. Classification of Clean technologies:

Typically, Coal combustion results in hazardous pollutants such as carbon dioxide (CO2), Sulphur dioxide (SO2), nitrogen oxide (NOX) and particulate matter. In order to address these issues, clean coal technologies are being developed to control emissions of such pollutants.

In order to study such technologies in greater detail, the technologies based on the application/implementation stage in the process of coal based thermal power plant - pre-combustion, during combustion, post-combustion and process modification may be classified. Under Process Modification, various conversion technologies that equip the user with additional technical capabilities to better control the emissions at a lower cost are employed.

- **Pre-combustion:** These technologies predominantly promote the removal of Sulphur, impurities from the fuel before it is burnt. Some technologies that change the current process to a greener one is also included.
- **During combustion:** Techniques to prevent emissions, while coal burns in the boiler are employed in this technology. This also includes modification of burning process.
- **Post-combustion:** Under this technology, flue gas emitted from the boiler is treated to reduce the content of pollutants in them.
- **Conversion techniques:** Coal is converted into a gas or liquid, which can be cleaned before being burned[xliii].

Figure 48: Classification of clean coal technologies



3.2.1. Pre-combustion clean coal technologies

Pre-combustion clean coal technologies typically focus on the fuel, viz. coal and preparation of fuel before it is introduced to the Boilers. They specifically aim at aiding the burning, increasing the resultant CV of the coal, ash separation at source, cleaning or washing of coal, etc.

3.2.1.1. Treatment of LCV Coal to increase its CV

Low rank coals are high in moisture, ash content and other impurities. Using them as a fuel in power plants results in more coal consumption, more emissions and reduced plant efficiency. Upgrading the quality of such low rank coal becomes the need of the hour for it to be used as an efficient fuel source. Through this process, the moisture, ash and impurities are removed considerably before the coal is used in the plant. Different technologies and methods have been developed over time. Methods such as coal drying are applied before combustion or briquetting.

3.2.1.1.1. Need for improving the quality of coal

Power plants are designed to suit different types of coal that fall within a range of calorific value. Variations in the properties of coal can affect the efficiency and performance of a power plant considerably. For example, a boiler designed to burn high quality coal will underperform significantly if low quality coal is introduced. Properties such as high ash-content, moisture content or Sulphur can not only impair the performance of the boiler but also the associated duct work and other auxiliary systems, which include sootbowling, steam temperature control, bottom and fly ash removal, pulverizers, etc. The increased load on equipment such as conveyors, pulverizers, crushers, etc., increases auxiliary power consumption, thus affecting the plant’s operating costs and decreases its profitability.

In addition to the aforementioned fact, low quality coal has the nature of being spontaneously combustible, which makes it difficult to be transported safely from a mine to the power plant. Low quality coal inherently has high chemical impurities and moisture content that reduces the heat value of the coal. Further movement of such coal from one place to the other may result in accumulation of moisture and dust on the surface of coal, which will further reduce heat value of coal, diminishing the heat value of coal even further. Low rank coal due to the presence of pollutants such as Sulphur, ash, etc., emits effluent gases into the atmosphere when combusted, which in turn are deteriorating the quality of air.

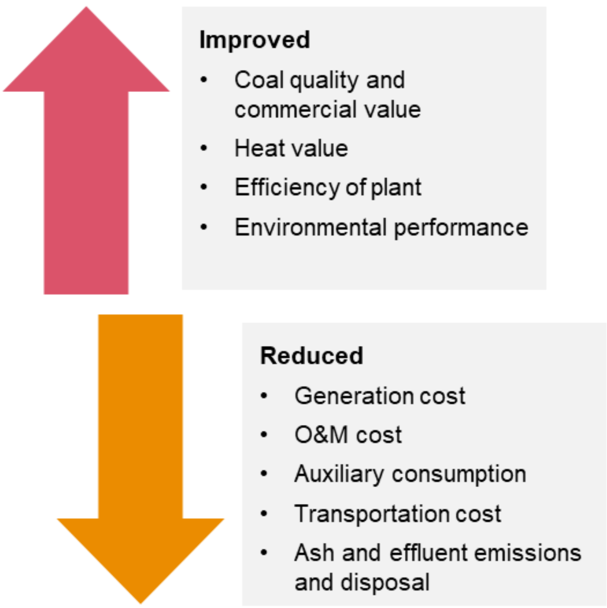
3.2.1.1.2. Cost and Benefits of improving Coal Quality

Improvement of coal in terms of reducing its inherent impurities and increasing its latent calorific value would address the issues discussed above. The improvement in coal quality not only increases efficiency and profitability of the thermal power plant but also reduces direct and indirect emissions.

Coal washing directly reduces CO2 emission from thermal boilers. As per the study conducted by Waymel and Hatt, for a 500 MW thermal power plant, burning bituminous coal, with a heat rate of 10,000 BTU/kWh, one percent improvement in boiler efficiency by improving heat rate to 9,890 BTU/kWh can be achieved through coal washing. It was also assessed that every one percent increase in boiler efficiency can result in 2-3% decrease in CO2 emissions. In addition, a reduction of 50% and 45% can be achieved in Sulphur emissions and ash respectively.

In terms of costs, it was reported that though the coal cost increased from USD 41.5 per tonne (heating value of 11,900 BTU/lb) to USD 46.5 per tonne (heating value of 13,300 BTU/lb), a net annual savings of USD 710,000 would be realized owing to savings of USD 450,000 from increased boiler efficiency, USD 230,000 from reduced ash disposal and USD 230,000 from improved coal handling.

Figure 49: Advantages of coal quality improvement



The Asian Development Bank (ADB) had also conducted an extensive study on Indian thermal power plants and found that every 10% reduction in ash content, maximum of 6% improvement in efficiency can be achieved. At the same time, CO2 emissions can be reduced by 2.5-2.7% on an average. As a result of reduction in ash content, the land required for disposal of ash is also expected to reduce. A reduced auxiliary power demand decreases the net emissions of a power plant. It was also learnt that with coal washing, demand for auxiliary power is reduced by an average of 10%. In terms of cost, it is to be noted that a reduction of 7% in ash content, a decline of 20% in O&M expenses can be achieved, while a 5% reduction can be achieved in overall capital investment of a thermal power plant.

It is also to be noted that coal beneficiation reduces the weight of coal by almost 25%. This results in a net reduction of almost 20% in the transportation cost of coal.

Keeping the above facts in mind, it is to be noted that improvement in coal quality results in both economic and environmental benefits. Even a minor reduction in coal consumption can improve the profit margin of the power plant with an extended life of the plant due to controlled effluent emission and solid waste discharges[xliv].

3.2.1.2. Methods for improvement of Coal CV

The process of separating inorganic impurities from raw coal to improve its quality to meet market requirements is called coal preparation. The process generally includes pre-treatment, crushing, sizing and coal cleaning or beneficiation. Traditionally, the role of coal preparation was to produce coal that was saleable to consumers. However, the concept evolved over a period of time to include reduction of emission of effluents such as Sulphur dioxide (SO2), carbon dioxide (CO2) and particulates[xlv] .

The separation process generally uses the physical differences between the organic and inorganic components. Typically, coal preparation process includes steps such as pre-treatment, cleaning, washing, sizing, classification, dewatering and drying.

3.2.1.2.1. Pre-treatment of raw coal

Figure 50: Coal preparation process

Source: Coal Preparation, Department of Trade and Industry

Run of mine (ROM) coal generally differs in sizes, moisture and ash content with varying types and amounts of contamination. ROM coal is screened for dry fines extractions and is crushed to be proceeded to further processes of cleaning.

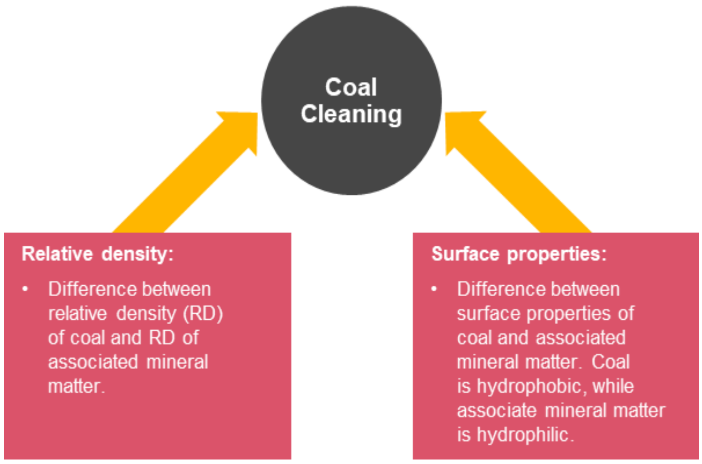
Various screens used for dry screening ROM are:

1. Vibrating screens
2. Banana screen or multi angle deck screens.
3. Roller screens

Various crushers used for crushing of the ROM are:

1. standard *jaw crushers* (generates lot of fines)
2. twin-scroll sizers
3. rotary breakers

Pre-treatment of coal increases its calorific value by nearly 20%.



3.2.1.2.2. Coal cleaning and washing

Coal cleaning:

Coal cleaning is done based on two prevailing separating principles:

i. **Difference in relative density:** Separation is based on the difference between relative density (RD) of coal and RD of associated mineral matter. RD for pure coal is ~1.3, while for associated mineral matter, it is over 2.2.

ii. **Difference in surface properties:** Difference between surface properties of coal and associated mineral matter is used a separation principle, where coal is hydrophobic, while associate mineral matter is hydrophilic.

Other separation methods such as magnetic, electrostatic, chemical and biological coal cleaning processes have also been developed, but have not gained traction, as they have achieved commercial viability.

Coal cleaning methods are classified based on the coal size, i.e., coarse (>25mm), small (24-3mm), fine (<3mm) and ultrafine (<0.15mm) coal.

a. **Coarse coal:** Main processes involved in processing coarse coal are:

   i. Dense medium (DM) separation – In this process, a heavy liquid of appropriate density is used to trigger a float/sink separation of coal from associated material. This is achieved by suspending finely ground dense solids in water. This method is predominantly used for larger coal (up to 250 mm). DM static baths have become more predominant with increasing quality requirements of coarse coal.

   ii. DM cyclones – They generally employ high centrifugal forces and are applied for finer sizes of coarse coal. The average particle size, on which it is employed, is <35-40mm. However, it has evolved into a large diameter DM cyclone to treat much wider feeds size range (up to 80mm).

   iii. LarCoDeMS (Large Coal Dense Medium Separator) – This is a cyclonic DM separator, capable of accepting raw coal up to 12mm.

   iv. Barrel washer – It is used as a semi-portable method, where coal is recovered from waste tips and is applied only, where high accuracy separation is not required.

b. **Small coal:** Jig washers are used for cleaning small coal. Jig washing systems have evolved over the years to improve performance and to clean both large and small coal in a single unit. Batac jig is the most used technique, which has the capability of washing coal down to 3mm.

c. **Fine coal:** Froth floatation is the most commonly used process for cleaning coal below 0.6mm. Mechanical flotation cells employ impellers to disperse air bubbles within the fine coal slurry. The major advancement in this technology is the increase in the size and capacity of individual floatation cells, which are combined to form a flotation bank. In addition to the mechanical floatation cells, methods such as column floatation, teeter-bed separators (also called upward current separators or hydrosizers) and small DM cyclones for separation of fine coal are gradually gaining importance.

d. **Ultrafine coal:** Equipment such as the Mozley Multi-G separator, the Falcon and Knelson concentrators and the Kelsey jig are gaining traction, as they can generate very large dynamic forces, which can help in achieving RD separation down to extremely fine particle sizes[xlvi].

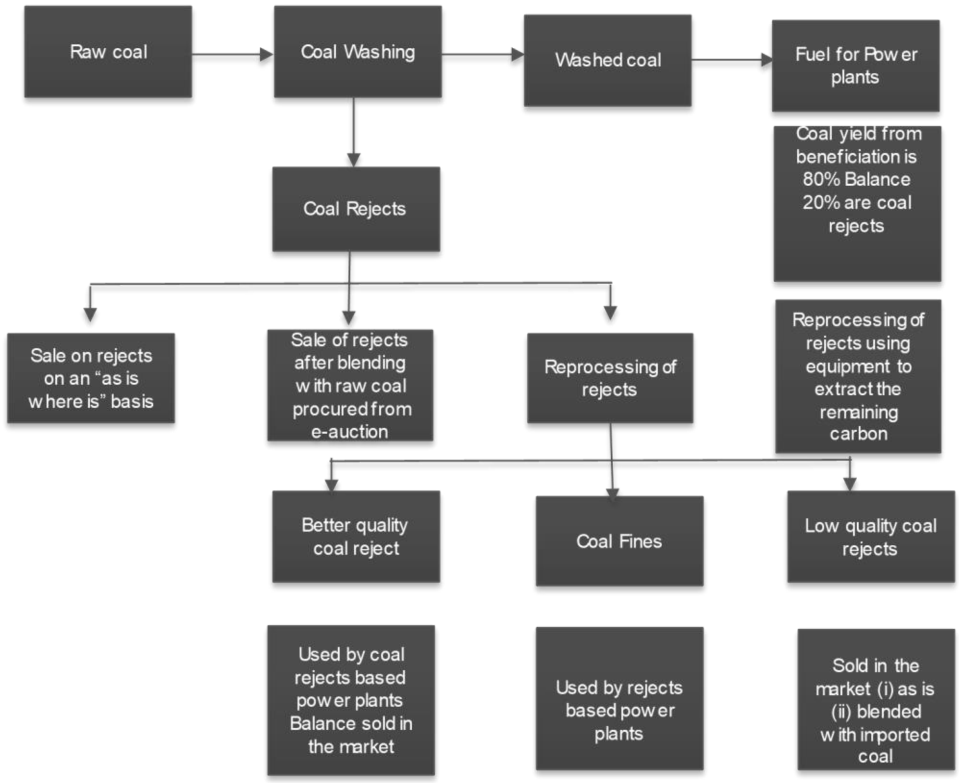
Coal washing:

The process of coal washing involves using water and other mechanical techniques and relies on gravity and difference in the density of coal and its impurities. Washing coal increases the efficiency and heat value of coal, thereby reducing the emissions. The ease of washability is determined by characteristics such as typical geological formation, finely inter-grown mineral matter and a high level of near gravity material (NGM) at cut densities.

Coal washing reduces ash content by 7-8% and increases GCV by 400-600 Kcal/kg. There are two categories of washing that are majorly used globally – partial washing and total washing. Total washing systems are generally used for high quality coal such as metallurgical coal, which requires a relatively complex washing procedure. This method is used in countries such as Australia, South Africa and the US.

Partial washing is applied for preparation of fuel used for power generation. Untreated fines are first extracted using dry screening before the washery and are blended back with the washed coal as per the power station fuel (PSF) specifications. Such washeries are prevalent in countries such as India, the UK and South Africa. A typical coal washing flow chart looks as below:

Figure 51: Flow chart of coal washery



Source: Coal beneficiation: Policy priorities for India

Some of the commonly used coal washing methods are jig washing, DM separation, froth floatation and dry cleaning. Due to the higher accuracy of separation, DM separation technology is more commonly used for difficult to wash coals. For coals that are easier to wash and where the benefits of higher separation accuracy are not very clear, the preferred choice may be either DM separation or jig washing.

i. Jig washing: A jig is a gravity separator in water, using the principle of fluidized bed. This method is used for relatively coarse material. Raw coal is continuously fed onto the jigging deck and pulsed vertically in water, on a screen, where the heavy material, i.e., shale and middlings pass down through the screen into a conical hutch while the lighter coal stays in the upper layers. Different types

Table 31: Coal wash ability determination

Attributes	If value is high
Near gravity material	Difficulty in washing
Washability index	Ease in washing
Washability number	Ease in washing

of jigs available for this method are movable screen jigs, fixed screen jigs and pneumatic jigs[xlvii, xlviii].

ii. Dense medium separation: This method essentially separates particles lighter than the medium, which tend to float and particles heavier than the medium, which tend to sink. Two types of DM separators used for coal washing are: dense medium baths (suitable for coal bigger than 6mm size) and dense medium cyclones (suitable for coal in the size range of 80mm-0.1mm).

iii. Froth floatation: Floatation is based in the principle that some minerals attach themselves to air bubbles and other material attach themselves to water. Frothers are used to create stable air bubbles, to which coal attaches itself while other materials such as ash are wetted by water. However, pyrites such as Sulphur, being hydrophobic, do not get wetted by water. Therefore, froth floatation is not effective in reducing Sulphur content.

iv. Dry cleaning: Dry cleaning or dry coal beneficiation was widely applied in countries such as Europe and the US. However, this process did not gain much popularity, as it did not have separation accuracy and also restricted feed size, throughput and moisture. It gained importance only in places, where there was water scarcity[xlix, l].

3.2.1.2.3. Coal sizing and classification

Classification by size is one of the most important operations in coal preparation. Screens are used to classify a broad range of sizes. There are two types of screens that are mainly used for the process of coal sizing. Static screen is predominantly used as a sieve bend, constructed as an arc or bend. The sieve surfaces are very steep and progressively lower the angles for the material to flow freely. Sieve bends are majorly used for removing large amounts of water, prior to the material passing to a vibrating dewatering screen.

3.2.1.2.4. Dewatering

Dewatering is an important step in the process of coal cleaning in order to improve the ability to handle and meet product specifications. Vibrating screens and vibrating basket centrifuges are the most commonly used equipment for dewatering coarse coal, while scroll centrifuges are used for fine coal and vacuum filter for froth flotation concentrates.

In case of finer coal, disc/drum based rotary vacuum filters are used for dewatering purposes. Horizontal belt filter (HBF) may also be used owing to its ease of operation and maintenance and better performance. High pressure filters are also used to dewater coal. Performance of variants like tube presses, air-blown filter presses and hyperbaric filters is observed to be below par as compared to conventional vacuum filters while being expensive.

For dewatering fine coal, different designs of scroll centrifuge have been introduced. These centrifuges operate at high speeds and generate greater dewatering forces than the traditional vibrating centrifuges used for coarser coal. Screenbowl centrifuges are other methods that help operate at even higher speeds and are capable of dewatering coal down to ultrafine sizes and are generally applied on froth concentrates.

3.2.1.2.5. Drying of low-quality coals

Low quality coals are required to be dried as part of coal preparation process to improve its calorific value and facilitate transport. The presence of moisture in coal makes it less friable, in turn making it difficult to blend, reduces the quality of grinding and hampers the separation, classification and transportation of pulverized coal. Coal drying can remove the moisture and improve the GCV of the coal by ~400 Kcal/kg.

Table 32: Different types of moisture and method of removal

Type of moisture	Occurrence	Common name	Removal method
Interior absorption of water	Micropores and micro capillaries	Inherent moisture	Thermal
Surface absorption of water	Particle surface	Inherent moisture	Thermal
Inter particle water	Small cervices found between two or more particles	Surface moisture	Mechanical or thermal
Abrasive water	Film around the surface of individual or agglomerated particles	Surface moisture	Mechanical or thermal

Source: Science Direct

The coal drying methods can be classified as evaporative and non-evaporative dewatering and drying. They are further classified as follows:

Figure 52: Methods of coal drying

Evaportative
- Rotary drum drying
- Fluidized-bed drying
- Pneumatic drying
- Microwave drying

Non-evaporative
- Hydrothermal dewatering
- Mechanical thermal dewatering

Other methods
- Superheated steam drying
- Coldry technology

Evaporative drying methods:

1. **Rotary drum drying:** In this method, coal is dried either through direct or indirect heating.
    a. **Direct rotary drum drier:** In this method, the rotary drum is fed with coal from one end and hot air or flue gas from the other. However, this method is prone to fire and explosion owing to presence of oxygen in the heating medium and inherent nature of low CV coal of being spontaneously combustible.
    b. **Indirect rotary drum drier:** In this case, hot gas as well as steam is used for the purpose of drying. While the gas is sent through the tubes in rotary drum, steam is used as a heating medium and comes

directly in contact with coal. In case of gasifiers, the source for hot gas is generally the HRSG of the gas turbine.

2. **Fluidized-bed drying:** Fluidized bed dryers are one of the commercially used coal drying methods. Hot flue gas or superheated steam is used as drying medium. A distinguishing feature of this method is that drying can be carried out with steam at a temperature greater than 400K, while with hot air, maximum temperature of 450K only can be used for the risk of fire in the drier. The other advantages of this method are low energy consumption, increased efficiency and reduced dust emissions. There are two different variants of fluidized-bed drying. They are:

   a. Stationary fluidized bed:

      i. Using Supersaturated Steam: In this method, the heating medium is superheated steam. This procedure reduces moisture considerably. This process is also known as the WTA (waste heat utilization) process.

      ii. Using Low Grade Heat: Dryfining utilizes low grade heat to vaporize a portion of the moisture. Hot air is used for fluidization of moisture rich coal. The specialty of this method is that low grade heat recovered from flue gas, is used for drying moisture rich – low quality coal in the fluidized beds. This process, besides drying, is used to beneficiate coal by removing many impurities.

   a. Vibratory bed drier: Another variation, which is commercially well accepted, uses a frequency of 50-100 Hz and an amplitude if 0.5-3 mm. A low gas velocity through the bed is required for a vibratory dryer to fluidize the particles. The use of low gas velocities results in a reduction in attrition and minimal gas cleaning requirements. This, in turn, increases the efficiency of this dryer as compared to the conventional fluidized-bed dryers.

3. **Pneumatic drying:** Pneumatic driers are continuous convective driers, where hot air is used as the drying energy and a medium to transport crushed coal through a pipe. However, generation of fine particles due to erosion of solids is a drawback for such driers.

4. **Microwave drying:** In this method of drying, coal is exposed to intense microwave radiation, where moisture can be reduced considerably to around 10% depending on the type of coal. This method is also expected to dry out coal contaminants such as Sulphur, potassium, phosphorus, etc. The advantage of this method is that the radiations selectively stimulate the water molecules and increase the rate of drying. Other advantages of this method are high process speed, uniform heating, high energy, efficiency, better and rapid process control, less space requirement, selective heating, etc. However, it is a capital-intensive method and requires high energy in the form of microwaves[li, lii].

Non-evaporative drying methods:

Non-evaporative drying methods are considered to be more efficient, as they also tend to remove some of the salts involved in the pore water, which can cause fouling.

1. **Hydrothermal dewatering:** In this process, coal is first pressurized at room temperature (usually 100 bar N2 atmosphere), stimulated and then heated to the desired temperature (~573k). This results in driving water out of the pores.

2. **Mechanical thermal dewatering:** This technique uses a combination of mechanical and thermal energy for dewatering, where mechanical energy is used to squeeze out the water at a pressure, ranging between 50-250 bar and temperature of around 470K. The mechanical and thermal dewatering technique is highly efficient and the most commercially used technique[liii].

Other methods:

1. Superheated steam drying:

Conventional hot air drying, an energy intensive technique leads to oxidation of coal and may result in combustion during the process of drying. Superheated steam drying (SSD) is a technique that utilizes heated steam beyond its boiling point to remove excess water/moisture from coal. This, in turn, improves the heating value and thermal efficiency of coal and reduces emissions and the risk of spontaneous combustion. This methodology provides better energy utilization, higher heat transfer coefficients, safer operations, etc.[liv].

2. Coldry technology:

In such a technology, porous low rank coal is converted into dry and dense pellets through a process called "Brown Coal Densification" (BCD). The process expels water from a variety of lignite and sub-bituminous coal that contains moisture up to 70% and coverts them into high CV black coal equivalent pellets with moisture content of ~10%. This would mean that the net energy value of the Coldry pellets would be similar to that of high-quality black coal.

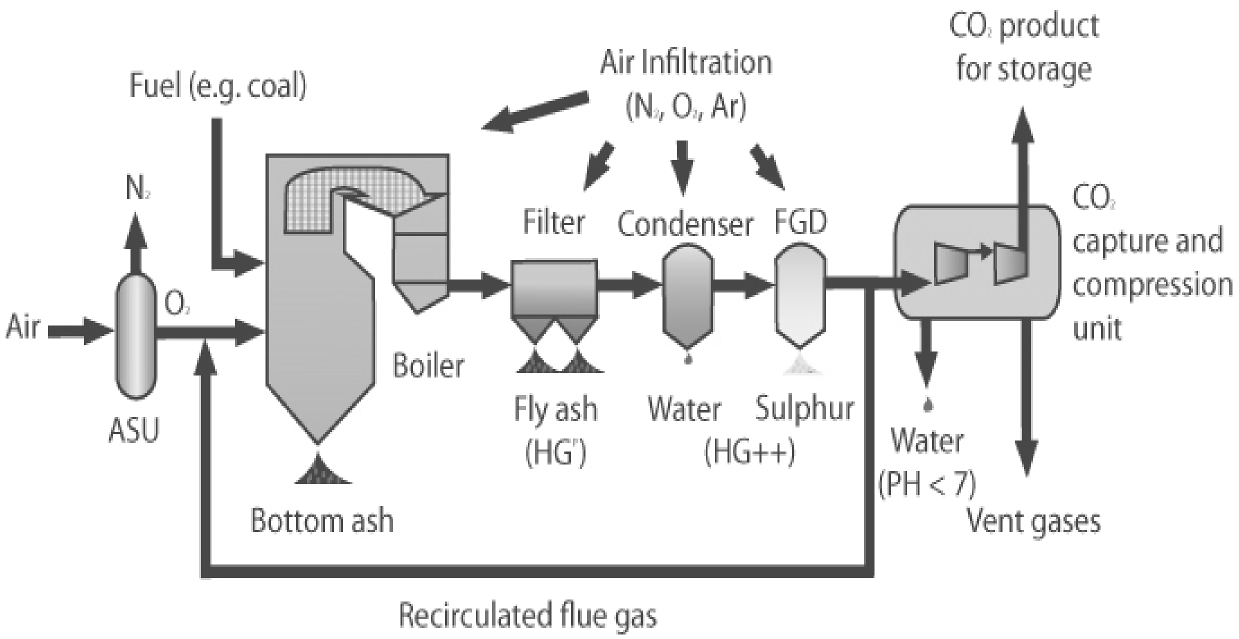
3.2.2. During combustion clean coal technologies

While the previous section delved in clean technologies involved in treatment of fuel, this section provides various avenues in explaining the technologies involved during the process of combustion of the fuel.

3.2.2.1. Oxyfuel combustion

Oxyfuel combustion is specifically involved where the exhaust CO2 is designed to be captured through CO2 capture and storage system. Combustion of fossil fuel in air releases CO2 along with other constituents of the air like Nitrogen and Argon. Conventional separation of CO2 and nitrogen from flue gas is a capital and energy intensive. As an alternative, in Oxyfuel combustion, fossil fuel is burned in pure or enriched oxygen, which results in a purer CO2. A part of the resultant flue gas is recycled into the combustion chamber to maintain the flame temperature. This recycling can be either wet or dry, depending on whether the flue gas has been extracted before or after condensing the moisture in flue gas. From the rest of the non-recycled flue gas, which mostly contains CO2 and H2O, CO2 is isolated, captured and stored by direct compression and cooling techniques such as low-temperature separation and distillation process. Oxy-fuel combustion can be used with different types of coal fired power plants such as pulverized coal and circulating fluidized bed techniques.

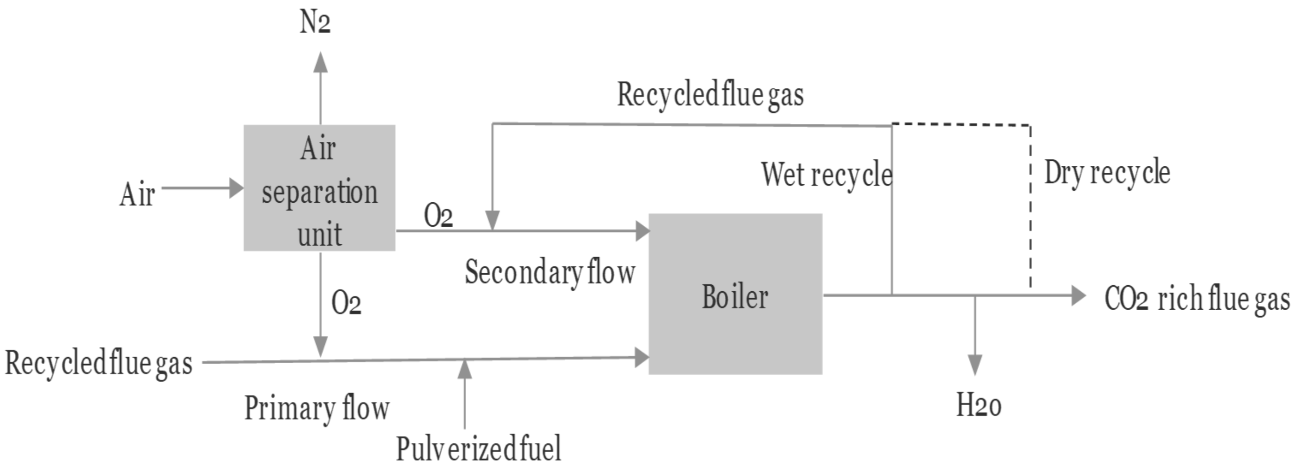
Figure 53: Oxy-fuel combustion process



Source: Natural Resources Canada

The entire process is carried out in an air separation unit (ASU), where the air is separated into liquid oxygen, nitrogen and small concentration of impurities such as argon. It is widely known that oxy-fuel combustion produces less NOX than in air-fired combustion due to lesser formation of NOX formation[lv]. Purity of oxygen plays a vital role in determining the purity of the captured CO2 and its capture[lvi]. Limiting the contaminant intake than increasing contaminant removal can limit the impurities as per studies[lvii]. Some pilot studies have indicated that oxy-fuel method of capturing CO2 can be retrofitted to existing pulverized coal plants[lviii].

Figure 54: Schematic of oxy-fuel PCC plant



Source: Oxyfuel combustion of Pulverized Coal, IEA Greenhouse Gas R&D Programme

Over the period of years, pilot and demonstration projects have been set up to analyze the implications of retrofitting oxy-fuel combustion methods to both PCC and CFBC plants. It is envisaged that by 2020, the oxy-fuel combustion will show progress towards large scale demonstration plants and possible commercialization by 2020.

Oxy-fuel system has a few advantages and disadvantages as listed below[lix, lx]:

Figure 55: Advantages and disadvantages of oxy-fuel combustion

Advantages

- Provides zero-emissions platform
- Heat transfer characteristics of the boiler are improved
- Can be retrofitter to old as well as new thermal power plant
- Concentration of impurities increase, while efficiency of removing impurities is also expected to increase
- Highly concentrated CO2 ready for capture and storage
- Sixty to seventy percent reduction in NOx, compared to traditional air-fired combustion
- Increased mercury removal
- No addition of chemical reagents such as amines as used in

Disadvantages

- Oxygen production required, which is energy intensive
- Technology, not yet operated at a large scale power plants
- Increase in concenation of impurities will augment the auxiliary

Source: Global CSS Institute

3.2.2.1.1. Oxy-Fuel combustion in Pulverized coal combustion plants

As discussed earlier, Oxy-fuel combustion is one of the most famous options of power generation with carbon capture. Typically, high temperature processes such as reheating furnaces, glass tank furnaces, etc. require burning of fuel with pure or nearly pure oxygen; however, for applications using steam generation such as PC boilers, lower combustion temperatures is necessary. To address this, fuels are burned with a combination of CO2 rich recycled flue gas or steam and oxygen in an air separation unit. The recycled flue gas acts as a diluent to replace nitrogen in order to maintain temperature.

Research has been carried out to study the outcomes of the application of oxy-fuel method to supercritical thermal power plants. One of the reviews performed for International Flame Research Foundation concluded that the use of recycled flue gas and oxy-combustion in ultra-supercritical boilers looks very promising and further research must be conducted for demonstration and subsequent implementation[lxi]. Since this technology is still in developmental state, the economic benefits of this technology cannot be ascertained accurately at this stage

3.2.2.1.2. Oxy-Air Circulating fluidized bed combustion power plants

CFBC unit's combust coal at a temperature of 900°C, using bed materials. A typical feature of CBFC technology is that it can use fuel with varying quality and sizes. The units were specifically designed to burn low quality and difficult to burn fuels (generally containing high Sulphur, high ash, high moisture, low CV, etc.). CFBCs have evolved to be suitable for almost all types of solid and liquid fuels. Another distinguishing feature of CFBC is the in-situ desulphurization, which eliminates slagging and reduces fouling during operation. It also reduces NOX emissions without requiring low NOX burner.

In oxy-CFBC, a combination of oxygen and flue gas is used for fluidization and combustion. The recycled flue gas helps maintain the temperature of bed. Flue gas is fed in and around the bed region of CFBC. In the study conducted by NETL[lxii], it was observed that the cost of in-bed DeSoX for oxy-CFBC would be substantially low.

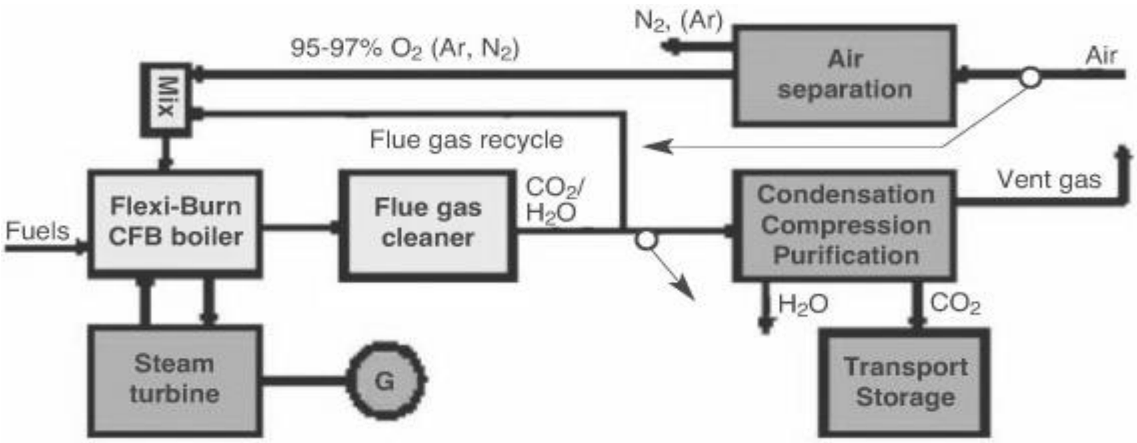
Advantages of oxy-CFBC

- Ability to use fuels of varied particle size and quality
- In-situ desulphurization
- Reduction in flue-gas recycling, thus reducing size of boiler island and auxiliary consumption
- Reduced NOX emissions
- Ability to operate at slightly over atmospheric pressure, reducing air-in-leakage
- Ability to operate with less flue-gas recycling, as it recirculates cooled solids from the external heat exchanger

Since this technology is still in developmental state, the economic benefits of this technology cannot be ascertained accurately at this stage

A typical CFBC schematic diagram has been shown below:

Figure 56: CFBC process flow

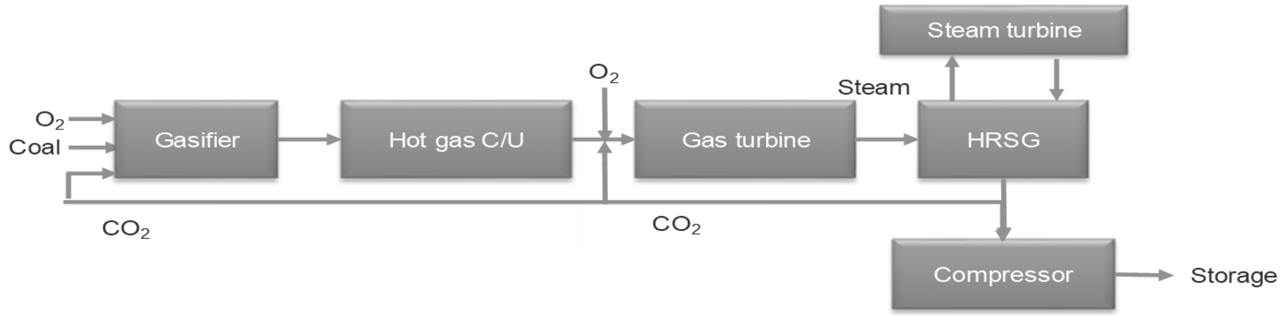


Foster Wheeler has commissioned world's first oxy-CFBC pilot scale facility (30MW) at CIUDEN in Spain in September 2011. A 300 MW supercritical oxy-CFBC plant is planned to be constructed based on the results of the pilot project[lxiii].

3.2.2.2. IGCC technology

IGCC gasifies coal with mixed gas of O_2 and recirculated flue gas, which is predominantly CO2. In IGCC, the flue gas is recirculated to gasifier and gas turbine combustor, while air is substituted with necessary amount of O_2 in gasifier and combustor. A distinguishing feature of oxy-fuel IGCC system is that the shift reactor and CO2 capture unit are not required, as the main ingredient of flue gas is CO2. This would mean that steam is not generated or required to run the boiler, thus keeping the thermal efficiency very high. In addition to this, the amount of heat loss is reduced due to the semi-closed cycle gas turbine that reduces the amount of exhaust gas. The hot gas clean-up system also helps improve thermal efficiency. The hot gas clean-up system is a honey-comb shaped desulphurization sorbent, which operates at a very high temperature of 450⁰C. As the temperature, at which it operates is high, the cleaned syngas is fed into the gas turbine.

Figure 57: High-efficiency oxy-fuel IGCC system



Source: International Conference on Greenhouse Gas Control Technologies, GHGT-13

In a bench scale project developed by CRIEPI, a CO2 captured IGCC system with an efficiency of over 42% was developed in 2008 along with Kyushu University. In this system, similar to an oxy-fuel combustion boiler, exhaust gas is recirculated to gasifier and gas turbine combustor. In 2015, phase-2 was started along with Mitsubishi Heavy Industries (MHI) for five years. In this phase, a 50 TPD gasifier and 1/3 scaled GT combustion test stand were used in order to scale up operations over time. Simultaneously, CRIEPI modified its gasifier to clarify performance of O_2/CO2. Furthermore, hot gas clean-up system and exhaust gas recirculation unit were examined.

Figure 58: Commercialization procedure for high-efficiency Oxy-fuel IGCC

Source: International Conference on Greenhouse Gas Control Technologies, GHGT-13

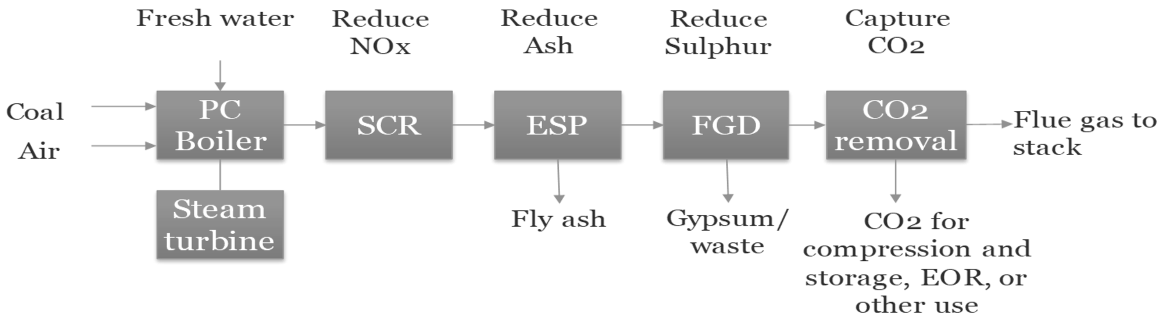
It was observed that in the mentioned system, CO concentration of syngas had been very high, which resulted in fine carbon particles that get deposited on sorbent of cleanup system. This carbon deposition tends to deteriorate the performance of hot gas clean-up system. Counter measures were found by CRIEPI and a new carbon resistant sorbent was also developed. In the second phase, desulphurization sorbet was installed to 3TPD gasifier to validate performance under high pressure. In terms of timelines, high efficiency oxy-fuel IGCC is expected to commercialize by late 2030 in a way similar to conventional thermal power generation technology[lxiv, lxv].

3.2.3. Post-combustion clean coal technologies

Post combustion technology refers to the separation of pollutants from flue gas generated after the coal has been burned. These include SOX, NOX, particulate materials like Fly Ash, CO2, etc. The combustion of coal releases flue gases, which are combination of nitrogen, carbon dioxide, water, oxygen and other compounds such as Sulphur oxide, nitrous oxide, etc. These elements are removed from flue gas through technologies such as selective catalytic reduction (SCR), electrostatic precipitation (ESP), and flue-gas desulphurization (FGD). CO2 can then be captured from the remaining gas, which may be compressed and stored underground or used in other process that does not allow it to be released into the atmosphere.

Various post combustion clean technologies involved in towards process have been depicted below[lxvi]:

Figure 59: Post combustion carbon capture process

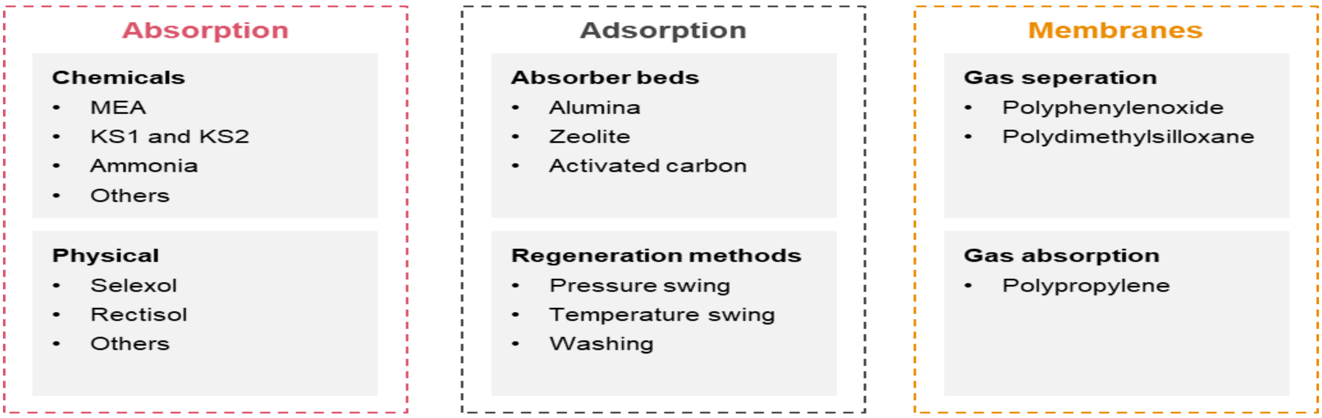


Source: CO2 Capture Technologies, Global CCS Institute

3.2.3.1. Carbon Capture methods

Various methods are adopted in post combustion capture process to treat flue gas and separate carbon and effluents. Some of them are as follows:

Figure 60: Post combustion carbon capture methods



Source: Sciencedirect

a. Absorption

In this method, flue gas is put in contact with an "absorbent" or "solvent" so that CO2 dissolves in it more easily than in nitrogen. This process is carried out in "scrubbers", which promote CO2 to convert from gas to liquid, which is then separated, based on the differences in the density. The loaded solvent is pumped into a "stripper", in which it is exposed to steam, which in turn causes desorption of CO2. The steam and CO2 mixture is then cooled and condensed into steam, while the stripped liquid is pumped back into the scrubber. This procedure results in highly pure CO2, which is suitable for compression and sequestration.

Although water is one of the most suited solvents, its capacity to dissolve CO2 is very low, which may result in a requirement of large water flows for capturing industrial-scale amounts of CO2. Aqueous solution of chemicals that reacts reversibly with dissolved CO2, works in favor of coal fired power plants. Hot potassium carbonate solutions have been the most used absorbents to react with dissolved CO2 and form potassium bicarbonate. However, amines have been the preferred choice for additives for decades.

Amines are water soluble organic chemicals, containing reactive nitrogen atoms. The most commonly used amine is monoethanolamine (MEA). Amine blends such as MEA plus methyldiethanolamine (MDEA) are also being used in this process[lxvii].

Spray dry absorbers (SDA) are installed in coal-fired power plants to scrub SOx from the flue gas.

b. Adsorption

This process uses varied adsorbents such as zeolites, polyaspartamide, activated carbon, metal oxides, metal organic frameworks, porous silicates and chitosan for capturing CO2. Adsorption is used extensively in chemical and environmental processes. When used in thermal power plants, CO2 can efficiently be captured using activated carbon and a carbon fiber component. The main characteristics of adsorption technology are easy maintenance, simplicity in operations, minimum energy requirements and flexibility. Different types of adsorption methods have been reported in literature. They are temperature swing adsorption (TSA), vacuum swing adsorption (VSA) and pressure swing adsorption (PSA). Out of the three, TSA is purportedly the most advantageous process, because it is inexpensive and uses less thermal energy. However, heating and cooling for capturing CO2 require longer time. On one hand, VSA is economically more viable than PSA, while it is sensitive to feed gas temperature. This means that more heat treatment might be required for conditioning of flue gas before it is injected into VSA plant. PSA, when compared to TSA and VSA, is more promising, mainly due to the option of using a wide range of temperature and pressure and requires minimum energy and low investments.

Adsorption technology has its disadvantages such as poor heat transfer, especially in packed beds, and slow kinetics. Nevertheless, advantages of this technology outweigh the disadvantages, thereby making it easier to regenerate adsorbents using pressure modulation with reduced energy requirements[lxviii].

c. Membranes

The membranes used in this method operate on the principle of differences in physical or chemical interaction between CO2 and membrane. The membranes that are used are designed in such a way that it allows one gas to pass through faster than the other. These membrane modules can also be used as a gas absorption column to as a conventional membrane separation unit. This technology is still in its early stages of development and requires high energy during separation and is known for poor selectivity. Other disadvantages associated with this technology are – carbon capture can be competitive only if CO2 concentration in flue gas is higher than 10%; it uses either organic ceramic membranes or organic polymeric membranes, which are quite expensive and make it difficult to achieve high degree of CO2 separation[lxix].

3.2.3.2. Flue Gas Desulphurization (FGD)

FGD is a set of technologies used to remove Sulphur dioxide from flue gases emitted in a thermal power plant. Two different FGD systems are used in thermal power plants to treat SO2. They are dry scrubbers and wet scrubbers.

a. Dry FGD: In this process, the flue gas stream is sprayed with finely atomized droplets of hydrated lime slurry at an optimum temperature, ranging between 150C-180C. As a result, the water evaporates and maximizes the utilization of the reagent. In an alternate method, dry sorbent powder, lime, limestone or sodium carbonate are injected to evaporate water. In both the cases, a bag filter, placed downstream the injection point, captures the solid particles.

Two emerging technologies, novel integrated desulfurization (NID) and circulating fluidized bed (CFB) scrubbing (also called circulating dry scrubbing [CDS]) combine features of previous technologies into a method that offers excellent SO2 removal with good reagent utilization.

The capital cost for Dry FGDs in SAARC Regions typically ranges around USD 48.78/kW. The consumables amount to USD 1.25/kW/annum while the O&M costs are around USD 8.36/MWh[lxx].

b. **Wet FGD:** This involves a scrubbing process, which is based on water slurry or a water solution of an alkaline reagents such as lime, limestone, sodium carbonate, magnesium oxide, ammonia, dual alkali, etc. However, limestone is the most commonly used reagent, mainly due to its cost effectiveness, its high SO2 removal efficiencies, consumption of cheap and commonly available sorbent and the by-product produced, being a saleable one.[lxxi, lxxii] Sea water FGD uses seawater as a reagent and no other chemicals are required for the reaction.

The capital cost for Wet freshwater FGDs in SAARC Regions typically ranges around USD 69.69/kW while that for Sea water FGD ranges around USD 41.81/kW. The consumables for Wet freshwater FGD amount to USD 1.11/kW/annum while that for Sea water FGD is negligible. The O&M costs for both Wet FGD is around USD 8.36/ MWh[lxxiii].

Advantages of FGDs:

- Reagents and the resultant products of reaction may be reusable
- Not very difficult to be retrofitted to plants
- Reagents used are widely available and inexpensive
- SO2 removal efficiencies range from 50% to 98%[lxxiv]

Disadvantages of FGDs:

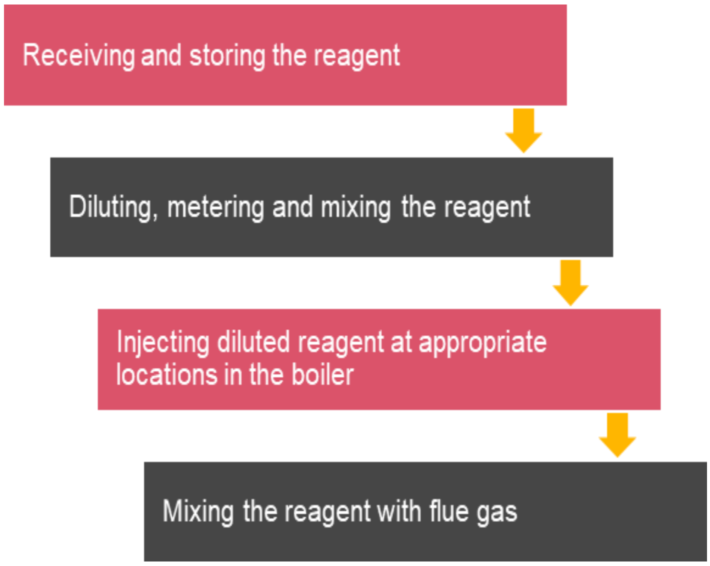
- Capital intensive and high O&M cost
- Water waste may be generated from wet FGD and may result in visible plume
- Wet solids get deposited on the absorber and downstream equipment and result in scaling
- Water requirement for wet FGDs is high (200–300 L/MWh)
- Not suitable for waste gas with SO2 concentration over 2,000 ppm

- Considerable increase in O&M cost due to the additional byproducts (such as gypsum) disposal[lxxv].

3.2.3.3. Selective Non-Catalytic Reduction (SNCR)

Selective non-catalytic reduction (SNCR) is a procedure to control nitrous oxide (NOX) emissions in conventional power plants. In this procedure, ammonia-based reagents like ammonia or urea are injected into the furnace at a place, where flue gas is present at temperature, ranging from 900^0C-$1,100^0$C. The reagent reacts differently with different chemicals present in the flue gas. However, it favors reaction to reduce NOX over other chemical reactions at a specific temperature range and in the presence of oxygen. Hence, it is called selective process.

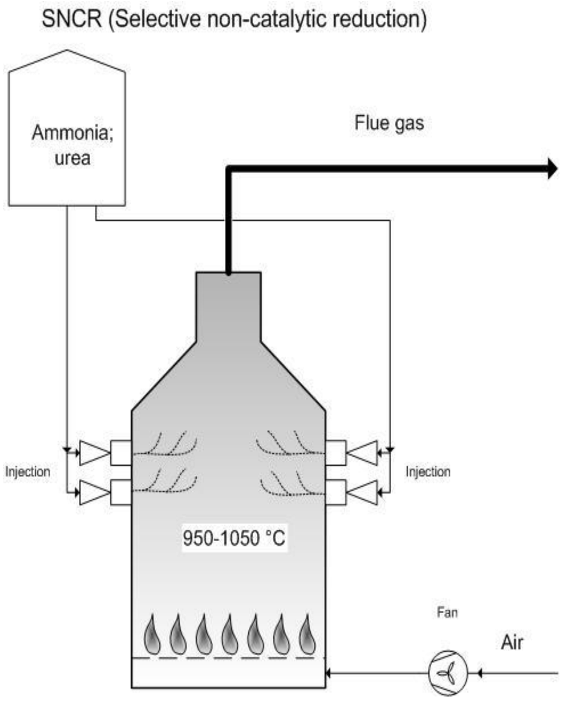
Figure 61: Process of an SNCR system



Source: Selective Noncatalytic Reduction, U.S. Environmental Protection Agency

The typical process occurs within the combustion unit, which acts as a reaction chamber. The reagents are passed through the injection nozzles that are located in the post-combustion area in the upper area of the furnace. The reagent mixes with flue gas, while energy for the reduction reaction is provided by the heat of the boiler.

Figure 62: Process of SNCR system



Source: EMIS

SNCR is used in a varied combustion sources, which include industrial boilers, electricity steam generators, cement kilns, paper power boilers, steel industry process units, refinery process units, etc. Industrial boilers with size ranging from less than 50 MMBtu/hour to over 800 MMBtu/hr use SNCRs, while power utility boilers with size ranging between <50MW to >900MW use SNCRs. In the US, over 50% of the power plants using SNCRs, are small with the size ranging between <50MW and 200MW, while around 24% have a capacity of over 300MW. SNCR has a distinguishing feature that it can be applied as a standalone or with any other technology such as combustion controls. In addition, SNCR can be designed for seasonal or year-round operations.

SNCR installations are not capital intensive, mainly due to the small amount of capital equipment required and the cost per unit of output reducing with an increase in the size of the source. For example, the installed cost (includes equipment cost and associated installation cost but not O&M and reagent cost) of SNCR in a power plant can range from USD 4-44/kWe (kilowatt) for a plant that is used in electricity generation. The annual cost of SNCR can be divided into 25% for capital recovery and 75% for operating expenses. The NOX reduction reagent forms the primary operating expense[lxxvi].

In addition to the aforementioned example, where a combination process to remove Sulphur and nitrogen from flue gas is used, the total investment amounts to EUR 2,300-3,900 for Nm^3/h. In terms of operating costs, it is estimated that a total of EUR 20,000 will be incurred every year[lxxvii].

Figure 63: Advantages and disadvantages of SNCR

Advantages

- Simple installation
- Low capital cost
- Low energy use
- Effective NOx reduction under ideal conditions

Disadvantages

- High temperature required
- Narrow range of ideal reaction temperature
- NOx emissions increase outside optimum range

Source: EMIS

The capital cost for SNCR in SAARC Regions typically ranges around USD 27.87/kW. The consumables amount to USD 0.35/kW/annum while the O&M costs are around USD 0.14/ MWh[lxxviii].

3.2.3.4. Improvised ESPs for Particulate Material

Electrostatic precipitator is a method to move out the particles from flowing gas onto a collector plates, using electrical forces. Particles are removed from dirty gas stream, as it passes through high-voltage wires, which usually carry huge negative DC voltage. The particles get electrically charges, as they pass through a corona, where gaseous ions flow. The electrical field is generated by the electrodes that are maintained at a high voltage in the center of the flow lane and forces the charged particles to the walls.

The particles collected on the plates are cleared, preventing them to reenter into the gas stream. They are either cleared by simply being knocked to loosen from the pallets or by intermittently or continuously being washed with water.

Key features of different types of ESPs are discussed below.

1. **Plate-wire ESP:**
   - Used in wide variety of industrial applications incl. thermal power boilers, cement kilns, etc.
   - Gas flown between parallel sheet metal plates and high voltage electrode
   - Suitable for handling large volumes of gas

Figure 64: Types of electrostatic precipitators

1. Plate-wire precipitator
2. Flat plate precipitator
3. Tubular precipitator
4. Wet precipitator
5. Two-stage precipitator

Source: Electrostatic Precipitators, U.S. Environmental Protection Agency

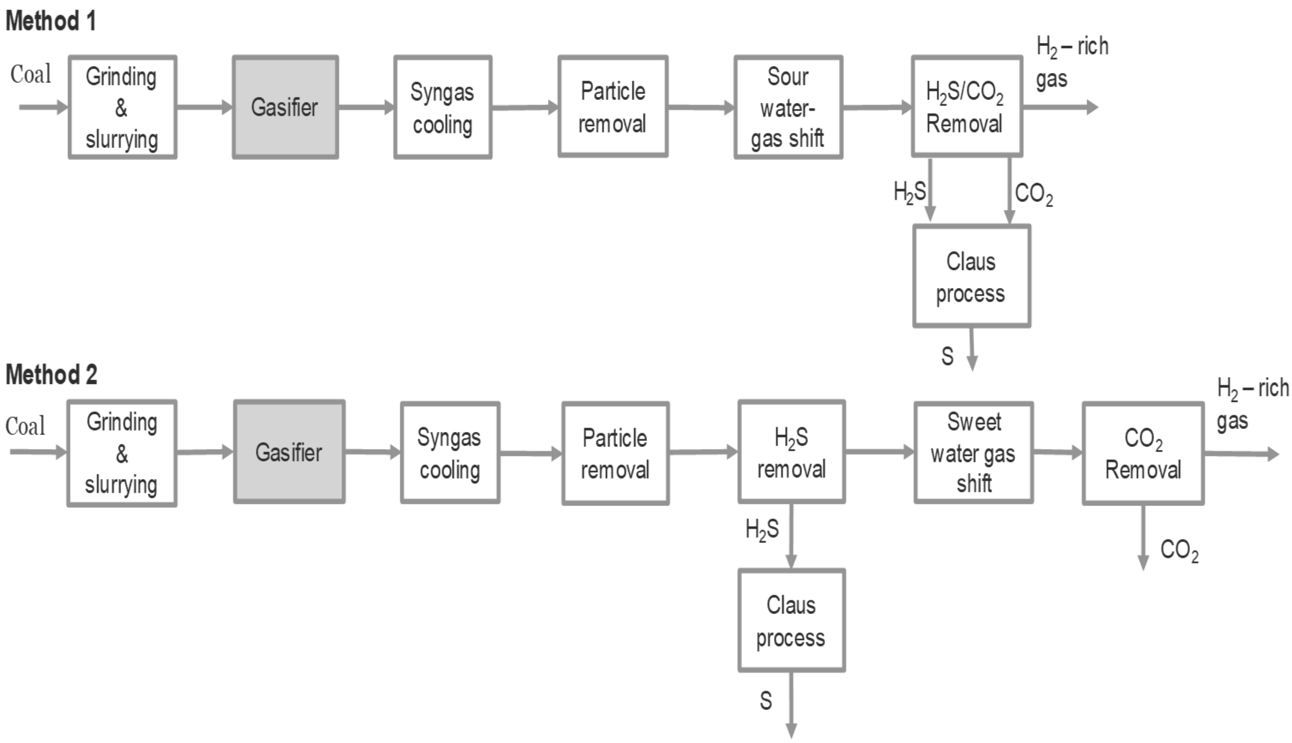
2. **Flat plate ESP:**
   - Mainly used in small precipitators
   - Operates well with either negative or positive polarity
   - Collection of fly ash is easier by maintaining low-flow velocity
3. **Tubular ESP:**
   - Is a one-stage unit and has all the gas pass through the electrode region
   - Operates at one voltage level throughout the length of the tube, but currently varies along the length, as the particles are removed from the system
   - No sneakage path (Sneakage occurs when a part of the gas flow bypasses the collection zone of a section)
   - Very rarely used and is commonly applied for particles, which are wet or sticky
4. **Wet ESP:**
   - Plate-wire, flat wall and tubular ESPs can be carried out on wet walls instead of dry
   - Water will be applied continuously or intermittently to wash particles
   - No rapping re-entrainment or with back corona (The back-corona discharge is formed by a series of micro-discharges in the air spaces between the dust particles deposited on the collecting plates, reducing ESP efficiency. It forms when an excessive electric field is induced in the dust layer by the current flowing through its surface)
   - Increased complexity of washing
   - Increased cost and complexity of disposing the collected slurry
5. **Two stage ESP:**
   - Different types of ESPs can be run parallel
   - Operates with positive polarity and limits ozone generation
   - More time for particulate charging with less propensity for back corona
   - Economical for small size industrial set up
   - Typically used for gas flow volumes of 50,000 acfm (actual cubic feet per minute) and less[lxxix]

   The capital cost for ESPs in SAARC Regions typically ranges around USD 6.97/kW while the O&M costs are around USD 6.97/ MWh[lxxx]. The operations require continuous power supply that adds to the auxiliary consumption of the plant

3.2.4. Conversion Techniques

As mentioned earlier, carbon- or carbon-based fuel is treated and purified, before it enters into the boiler. As a result, carbon (C) and hydrogen (H2) rich gas is produced, from which carbon is separated and hydrogen is used as a fuel. The fuel is first passed under high pressure and heat in the presence of steam. This converts the fuel into gas. The oxygen supply in the combustion chamber is controlled in a way that only a part of the fuel is burned completely. This process will produce heat, required to breakdown the fuel into synthesis gas (syngas) consisting of hydrogen, carbon monoxide (CO) and traces of other gases. Carbon monoxide then reacts with water (H2O) to form CO2 in a water-gas-shift reactor, which increases the concentration of carbon dioxide and hydrogen to 40% and 55% respectively. A better concentration of CO2 supports better separation and capture technologies. Syngas, rich in hydrogen, is then utilized as fuel for electricity generation in a combustion turbine.

Figure 65: Steps in coal Gasification technologies



Source: Norwegian University of Science and Technology, Department of Energy and Process Engineering

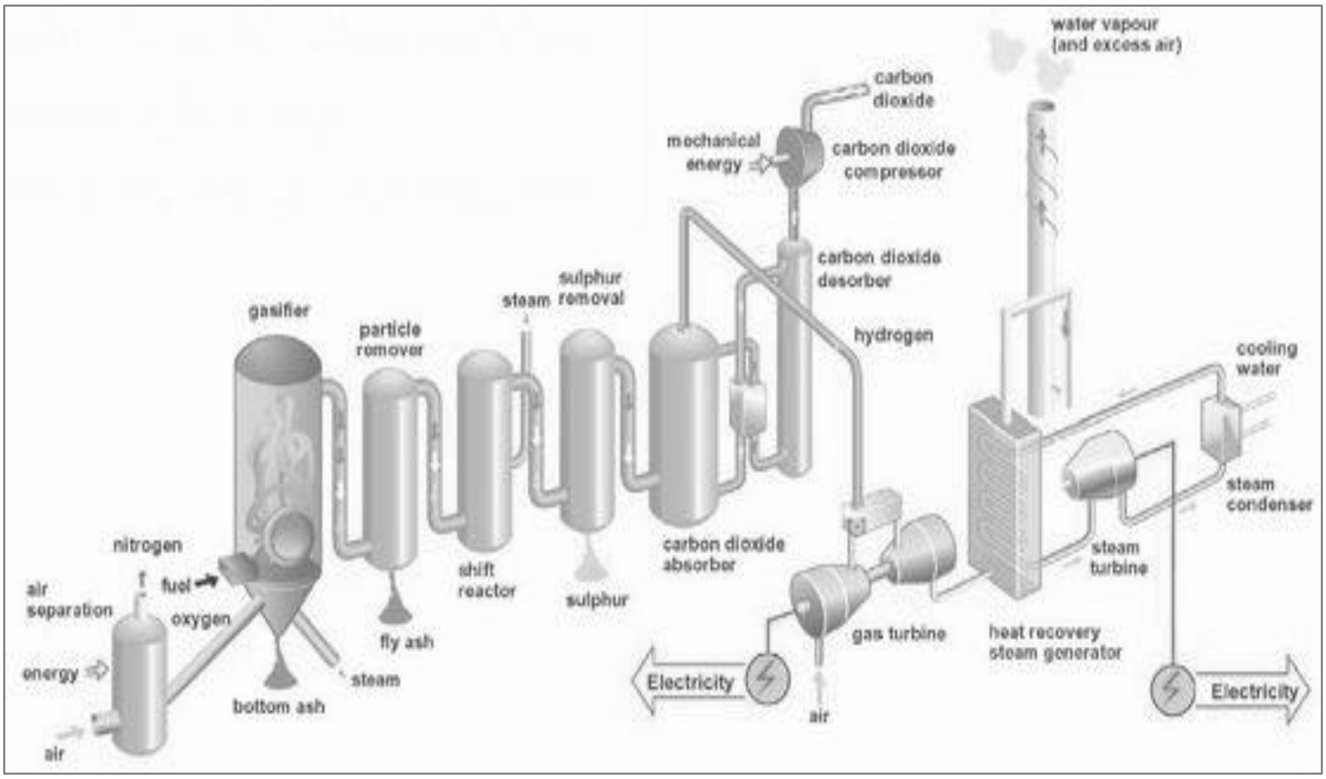
As a second step, the exhausted gases from pre-combustion plants are passed through a heat recovery steam generator with water tubes. The heat released from the exhaust gas separates water and vaporizes it into steam, which in turn flows into a turbine to generate electricity. The steam powers the steam turbine, which exits into a condenser, where it converts back to water, repeating the entire process. With regard to CO2 emissions, the plants with pre-combustion technology are expected to capture around 92% of the emissions.

Some of the major advantages of pre-combustion technology are:

- Electricity can be generated from combustion of hydrogen as well as flue gas generated in 'heat recovery system'.
- It reduces the emissions of a few air pollutants, as the fuel is already treated before commencing the combustion process.
- Most importantly, in pre-combustion technology, ~101 g CO2/kWh is emitted, while the plants without the technology emit higher emissions.

Despite having many advantages, pre-combustion technology has a few disadvantages such that – it has capital cost higher than the conventional power plants. However, this technology cannot be retrofitted and has be installed right at the time of construction. In addition, it may also face issues related to feed and corrosion due to syngas[lxxxi].

Figure 66: IGCC to isolate and capture CO2 before it is released



Source: Rocky Mountain Coal Mining Institute

3.3. Comparing the Economic value of different sources of Power Generation

Any investment decision in an industry is driven as much by the economic value of such a decision as by the technology that is being implemented or experimented with. Gauging this economic value of investment in any industry is governed by the following factors:

1. Criticality of the issue being addressed by implementation of such a technology
2. Financial benefit that can be achieved from such an implementation for the company and the sector
3. Intangible benefit in terms of extent of emissions avoided, etc.

While it must be noted that the applicability and suitability of each of these generation sources vary significantly, and the sources cannot be always used interchangeably, for the sake of analysis of various options, the energy return on investment corresponding to each of these sources have been computed in the following section:

3.3.1. Energy Return on Investment

EROI is the ratio represented by Energy Returned (ER) over Energy Invested (EI). Governments, business houses and individuals are all concerned about energy use efficiency. Energy economists have devised a term EROI to represent the ratio of ER over EI in output. Net energy gain, or useful energy available to society, is the difference between ER and EI. EROI's value depends on factors like system boundary used for analysis, method of handling heat energy and electricity, and how one addresses the dynamic effect.

The formula for EROI is as below:

$$\text{EROI} = \frac{\text{quantity of energy supplied}}{\text{quantity of energy used in the supply process}}$$

Energy return on investment (EROI) is, thus, a means of measuring the quality of various fuels by calculating the ratio between the energy delivered by a particular fuel to society and the energy invested in the capture and delivery of this energy.

Professor Charles Hall, an ecologist at the SUNY College of Environmental Science and Forestry, developed the concept of EROI to give a common measure for comparing very different fuels.

Computing the EROI of a fuel involves working out how much energy it takes to make the materials usable – like finding oil, drilling the well, pumping it out and refining it – and how much energy one gets afterwards. It is a standard equation involving division of the energy output by the energy input. A high EROI means one gets a lot of energy out for very little energy expended.

While EROI is not the only factor that needs to be considered when picking the best fuels, but it highlights the fact that more energy needs to be expended to meet the demand – and more money is to be spent on keeping the emissions down.

3.3.2. EROI Computation for various generation sources

There are various methods to compute the EROI of a generation source. These methods and their associated methodology have been outlined below:

Standard EROI ($EROI_{ST}$): A standard EROI approach divides the energy output for a project, region or country by the sum of the direct (i.e. on site) and indirect (i.e. offsite energy needed to make the products used on site) energy used to generate that output. It does not include e.g. the energy associated with supporting labor, financial services and the like. This EROI calculation is applied to fuel at the point where it leaves the extraction or production facility (well-head, mine mouth, farm gate, etc.)

Point of Use EROI ($EROI_{POV}$): Point of use EROI is a more comprehensive EROI that includes additionally the costs associated with refining and transporting the fuel. As the boundaries of the analysis are expanded, the energy cost of getting it to that point increases, resulting in a reduced EROI.

Extended EROI ($EROI_{EXT}$): This expanded analysis considers the energy required not only to get but also to use a unit of energy. In other words, it is the EROI of the energy at the mine mouth required for that energy to be minimally useful to society, for example to drive a truck.

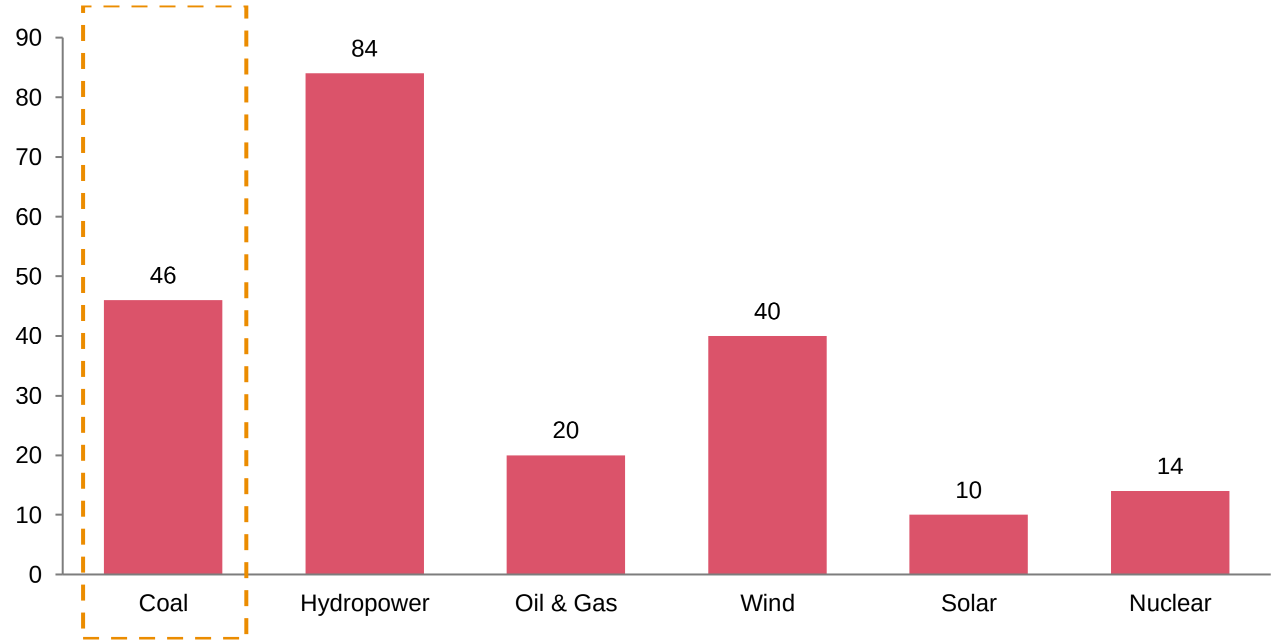
Societal EROI ($EROI_{SOC}$): Societal EROI is the overall EROI that might be derived for all of a nation's or society's fuels by summing all gains from fuels and all costs of obtaining them. This calculation has yet to be undertaken because it is difficult, if not impossible, to include all the variables necessary to generate an all-encompassing societal EROI value.

The EROI for various sources of generation has been calculated on a standard basis ($EROI_{ST}$) and has been listed below:

1. **Coal:** Internationally, coal has a mean EROI of **46:1**. Coal is relatively easy to extract in energy terms. There has been an increase in less costly surface mining. The energy content of coal has been decreasing, even though the total tonnage has continued to increase.
2. **Hydropower:** Hydroelectric power generation systems have the highest mean EROI value, **84:1**, of all electric power generation systems. This is due to the relatively small amounts of energy needed to build dams to generate hydropower.
3. **Oil and gas:** World oil and gas has a mean EROI of about **20:1**. Oil and gas EROI values are typically aggregated together. The reason is that since both are often extracted from the same wells, their production costs (capital and operations) are typically combined, and therefore, the energy inputs for EROI calculations are very difficult to separate.
4. **Wind and solar:** Wind has a high EROI of **40:1** mainly due to the relatively small amounts of energy needed to build turbines. Solar power has a low EROI of **10:1**. Solar panels are energy-intensive to manufacture and hence the lower EROI.
5. **Nuclear energy:** EROI values for nuclear energy suggests a mean EROI of about **14:1**. The processes involved in building and managing nuclear power – such as mining, uranium enrichment and waste storage – are all very energy intensive. This makes it a poor electricity generation choice in terms of energy return on investment.

The EROI values for various energy sources have been depicted in the figure below:

Figure 67: EROI values of various fuel sources



This shows that coal has a very high EROI, second only to hydropower among all the sources of power generation. Thus, it makes sense to use coal as a source of energy from an EROI perspective to boost the generation scenario in the SAARC countries. Using clean technologies that use low grade coal to generate energy can thus eliminate the negative effects of emissions while also ensuring that excess energy is not expended to produce energy.

3.4. Financial models for adoption of clean coal power generation technologies

Improved access to capital would provide incentives to coal generators to invest the higher initial capital outlay of High Efficiency, Low Emission (HELE) technologies required for clean coal power generation. Various financing methods can be used to fund clean coal power projects:

1. **Government funding:** Funding received from the government is essential to kickstart the adoption of clean coal technologies. Governments in USA and China have been proactively funding projects using clean coal technologies and the SAARC countries must follow suit.
2. **Banks/Non-Banking Financial Institutions:** The loans taken from banks and NBFIs act as another stream of funds that can be used to fund clean coal power generation. Banks and NBFIs would focus on factors such as credibility of the promoter, statutory clearances, non-statutory clearances (land availability, fuel linkage), contractual arrangements, project risks, country specific factors, environmental groups support to project, etc. while disbursing loans.
3. **Bonds:** Bond issuance is another method of raising funds for clean coal power generation. Specific criteria may be set by SAARC countries to classify clean coal technologies that may be financed by green bonds. For example, The People’s Bank of China (PBOC), which oversees green bond issuance on the interbank market in China, is expected to officially allow coal projects which use enhanced technologies to cut air pollution to be financed by green bonds.
4. **Multi-lateral financing institutions (MFIs):** MFIs such as the World Bank, Asian Development Bank (ADB) and International Finance Corporation (IFC) can provide capital support to compensate for the higher initial capital costs of a clean coal generation plant and also facilitate technology transfer and capacity building in SAARC countries where experience in clean coal plants has not yet fully developed.
5. **Islamic finance:** Financing sources that comply with Islamic practices, can turn out to be one of the key sources of finance for various clean coal projects, through public sector and Public-Private Partnership schemes. Amidst the shortage of traditional financing for clean coal technologies, Islamic finance widens the potential of the sources of funding required to meet large investments in SAARC countries like Afghanistan, Bangladesh and Pakistan with a large Muslim population.

3.5. Parameters to assess suitability of such technologies to SAARC countries

While the global average efficiency level of subcritical coal-fired plant is currently 28-35%, state-of-the-art supercritical coal-fired power plants can achieve an efficiency of more than 42%. They also require less coal, which additionally reduces emissions and fuel costs. As such, supercritical has become the norm for new plants in many industrialized countries.

In SAARC countries, government and power utilities need to focus more on supercritical and ultra-supercritical technologies to reduce emissions and enhance overall efficiency, while providing clean, secure and economical power. In this technological improvement, carbon dioxide emission can be reduced to the extent of 20%.

Conventional or subcritical power plants operate at a steam pressures in the range of 170 bar and 540°C giving an efficiency of around 29%, whereas supercritical and ultra-supercritical power plants operate at temperatures above the critical point up to 620°C and pressure up to 300 bar, resulting in a much higher efficiency than conventional coal fired plants, giving efficiency of about 43 to 45 per cent.

Secondly, supercritical and ultra-supercritical power plants require less coal per MWh, leading to lower emissions (including carbon dioxide and mercury), higher efficiency and lower fuel costs per megawatt whereas conventional power plants use more coal per MWh with higher emissions.

The IGCC technology is a next-generation thermal power plant. While former technologies such as subcritical, supercritical and ultra-supercritical combustion can reach efficiencies between 28% and 45%, the IGCC technology can achieve efficiency rate higher than 45%. IGCC lowers the emissions of SOX, NOX, and dust per gigawatt-hour of electric power generated. Additionally, CO2 emission is comparatively less.

High costs and complex plant structures of IGCC plants will limit their uptake in SAARC countries in the near future. The short-term focus should be to make a complete shift from sub-critical to super-critical and ultra-supercritical technology and the long-term goal should be to shift towards IGCC based technology.

Based on the economics and environmental norms, the following technologies hold merit for each SAARC country:

Country	Technologies required	Rationale
Bangladesh	• Pre-treatment, coal washing, drying, sizing, Carbon Capture methods, SNCR	• Relaxed norms for Particulate matter and SOx compared to India
India	• Pre-treatment, coal washing, drying, sizing, oxy-CBFC, Carbon Capture methods, FGDs, SNCR, ESPs	• Most stringent environmental norms among SAARC countries for particulate matter, SOx, NOx, etc.
Pakistan	• Pre-treatment, coal washing, drying, sizing, Carbon Capture methods, FGDs, SNCR, ESPs	• Slightly less stringent norms for SOx and NOx compared to India
Sri Lanka	• Pre-treatment, coal washing, drying, sizing, Carbon Capture methods, ESPs	• Relaxed norms for SOx and NOx emissions compared to India

For other SAARC countries such as Afghanistan, Bhutan, Nepal and Maldives, there are no defined environmental norms for emissions from coal generation plants and have hence not been listed above. These countries would need all the above-mentioned clean coal technologies.

4. International Successful Experiences

International Successful Experiences

4.1. Successful Clean Power Generation Technologies using LCV coals

In recent years, multiple clean coal technologies have been chosen by new plants or retrofitted to the existing power plants. These technologies are based on the concept HELE, which focuses on deploying high efficiency, low emission (HELE) coal-fired power plants as a path towards near-zero emissions from coal. Some of the technologies used to accomplish this, include supercritical and USC boilers, IGCC, flue-gas desulphurization, fluidized-bed combustion, SCR, ESP and CCS, etc. This chapter presents a few plants (including pilot, demonstration and large scale) that have installed clean power generation technologies.

4.1.1. Pre-combustion clean coal technologies

As per IEA reports, increasing coal quality is an important step towards the deployment of clean coal technologies in India. Indigenous coal of India is of low quality and often contain 30-50% ash, when transported to power station. Coal beneficiation (or cleaning) is considered as the first and most cost-effective step to improve the quality of coal in India. The beneficiated coal not only improves the efficiency of the power plant but also reduces emissions. Considering many benefits involved with beneficiation of coal, significant research has been carried out to determine the effective results of using clean coal in Indian thermal power plants.

The below mentioned are few case studies, which demonstrate the qualitative and quantitative benefits of coal beneficiation in India[lxxxii].

a. Dadri Power Plant:

Operated by NTPC, Dadri power plant is one of the largest power plants in India with a total installed capacity of 2,654 MW. Currently, it has six coal-fired units (4 x 210 MW and 2 x 490 MW). It is a unique power plant of the NTPC that consists of both coal-fired thermal plant and gas based thermal plant.

Promising results were demonstrated by the Dadri power plant upon the usage of washed coal with around 34-35% ash from Central Coalfield Limited's Piparwar washery. The power plant achieved an overall benefit of about of USD 2.9 million (INR 119 million) per year by utilization of washed coal. Additionally, over 60,000 tonne of CO2 per year was reduced, while one acre of land area for ash dumping was saved per year.

Figure 68: Results of Dadri power plant using washed coal

- Increase in operating hours; up to 10%
- Increase in PLF; up to 4%
- Increase in Plant Utility Factor (PUF); up to 12%
- Increase in overall efficiency; up to 1.2%
- Increase in generation per day; 2.4 MUs
- Increase in total units sent out per day; ~2.3 MUs

- Reduction in breakdown period; up to 60%
- Reduction in support fuel oil; 0.35 ml/kwh
- Reduction in Sp. Coal consumption; 0.05 kg per kwh
- Reduction in CO2 emissions of >60,000 tons/year
- Reduction in 1 acre/year of land requirement for ash dumping

Source: A Case for Enhanced Use of Clean Coal in India: An Essential Step towards Energy Security & Environmental Protection, 2017

b. Dahanu Thermal Power Station

The Dahanu thermal power plant is a 2 x 250 MW coal-fired power plant located in Maharashtra, India. It uses a mix of Indian washed coal and imported coal as fuel. The beneficial results achieved by the plants with the utilization of the beneficiated coal include:

- Reduction in ash generation by 8.5%
- PLF increased by 15.8%
- Cost per unit (USD/kWh) reduced by approximately 10%
- Plant availability increased by 6.5%
- Sp. Oil consumption decreased by 65%
- Auxiliary power consumption decreased by 5.4%
- Power generation increased by 16%

4.1.2. 'During combustion' clean coal technologies

a. Schwarze Pumpe Oxy-fuel pilot plant, Germany

In 2008, Vattenfall Europe constructed a 30 MW oxy-fuel pilot power plant nearby the lignite-fired power plant Schwarze Pumpe, Germany, for testing the oxy-fuel method. This is a small-scale demonstration of the oxy-fuel concept as a potential route for future CO2 reduction at commercial scale.

The pilot plant consists of a single 30 MW top-mounted pulverized coal burner and flue gas cleaning equipment. The flue gas cleaning equipment includes electrostatic precipitator (ESP) for particle removal, wet flue gas desulfurization (FGD) for SO2 and other acidic components removal and the flue gas condenser (FGC) for cooling of the flue gases and removal of water. Additionally, a CO2 purification and compression plant are placed downstream of the FGC to produce liquid CO2 and gaseous oxygen with 99.5% purity. The gaseous oxygen required for the combustion process is supplied by the cryogenic air separation unit (ASU) located at the site. The top-mounted pulverized coal burner is capable of performing both oxy-fuel combustion in a number of modes as well as conventional air-firing. The main fuel of the pilot plant is pre-pulverized local Lusatian lignite, which has a low Sulphur and ash content. However, lignite with higher sulfur and ash concentrations from other mines has also been tested in the pilot plant. The pilot plant demonstrated promising results, which were above expectation. At comparable firing conditions, the emission levels of NOX during oxy-firing were typically 50% less than the NOX levels during air-firing. Within one year of operation, the pilot plant has achieved nearly 100% CO2 capture with a purity of ~ 99%[lxxxiii].

b. Callide A Oxy-fuel demonstration project, Australia

The Callide A oxy-fuel project is the world's first industrial scale demonstration project. The project has successfully demonstrated the way oxy-fuel combustion and carbon capture technology can be implemented in a coal-fired power plant to generate electricity with almost no emission.

Callide A power plant is a retrofit of an existing power station near Biloela in Central Queensland, Australia. The power station has four 30MW units, Unit 4 of power station was modified to demonstrate clean coal technology on an industrial scale. Two air separation units (ASU) of 330 tonne per day and CO2 compression and purification unit (CPU) of 75 tonne per day were installed. The oxy-firing technology development is primarily driven by the requirement of CO2 capture and reduction in other flue gas emission. The 30MW oxy-fuel boiler and 75 tonne per day CO2 capture plant at Callide A have pursued these drivers. The demonstration project was commissioned in 2012 and ended in 2015.

The key technologies and activities involved in the project are:

- Oxy-fuel combustion of coal to attain 60% to 70% reduction in the actual volume of flue gas and a proportionate increase in the CO2 concentration
- Cryogenic separation and recovery of CO2 from flue gas stream
- CO2 storage capacity assessment in Queensland, and injection testing of Callide Oxy-fuel CO2 product[lxxxiv]

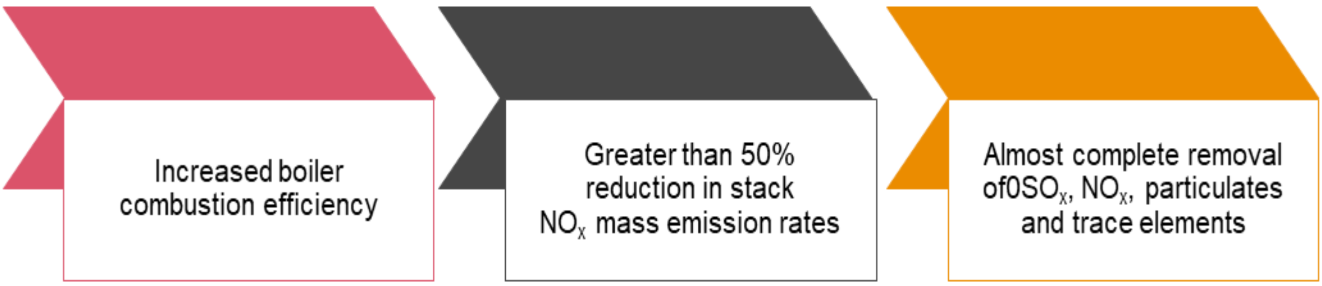
The project ran for two years and nine months, successfully proving 10,200 hours of oxy-fuel combustion and 5,600 hours of CO2 capture plant operation. The project has been able to obtain a 90% capture rate, and provided a high-quality CO2 product suitable for geological storage. Through oxy-firing, almost complete removal of all power station emissions (such as SOX, NOX, particulates, and trace elements) from the flue gas stream has been demonstrated, which are then disposed in condensate form for dam storage together with the ash. When air-firing is compared to oxy firing, the volume of flue gas is decreased by around a quarter through oxy-firing. Also, reduction in NOX specific emission rate was detected from ~ 4.7 g NOX/kWh to ~ 2 g NOX/kWh for Callide coal. Apart from that, a slight reduction in particulate emissions was noted, which was from 0.3 – 0.375 mg/kWh (air-firing) to 0.25 – 0.34 mg/kWh (oxy-firing)[lxxxv].

Table 33: Performance of Callide A power plant

Combustion mode	Oxyfiring	Airfiring
Gross / Net output, MW	500 / 345	500 / 473
Gross / Net plant efficiency, %	45.7 / 31.5	42.1 / 39.9
Auxiliary power consumption, MW	155	27
CO2 emission (net), g/kWh	20	740
Fuel consumption, t/h	196	212

Source: Operation Experiences of Oxyfuel Power Plant in Callide Oxyfuel Project, Akihiro Komaki et al., 2014

Figure 69: Benefits observed from the oxy-firing and CO2 capture demonstration



Source: Global CCS Institute, Callide Oxyfuel Project – Lessons Learned, 2014

The Callide an Oxy-fuel Project is one of the few handful coal-fired low-emission projects across the globe and represents several firsts for Australia and the world:

- World's first industrial-scale demonstration of oxy-fuel combustion and carbon capture technology
- World's first power station to be retrofitted with oxy-fuel carbon capture technology
- First injection of CO2 underground from an Australian power station
- World's first injection of CO2 underground from an Oxy-fuel power station

The project significantly contributed to the international carbon capture and storage knowledge bank. The results from the project can be applied to future low-emission projects that target the production of cleaner and affordable electricity from fossil fuels.

c. Nakoso IGCC demonstration plant, Japan

The IGCC coal power generation system is designed to run more efficiently than conventional coal-fired systems by combining coal gasification with a gas turbine combined-cycle system. Additionally, these systems are well-suited to use low-grade coal through safeguarding optimal environmental protection. The oxygen blown IGCC systems are adopted in Europe and America, while Japan carried out unique research and development on air blown IGCC.

Clean Coal Power R&D Co., Ltd. (CCP) executed air-blown IGCC demonstration test from 2007 and the tests lasted for a period of five and a half years. The demonstration test was carried out in the premise of Nakoso power station of Joban Joint Power Company, in Iwaki City. Nakoso power station was an existing coal-fired power station with a capacity of 1,625 MW, whereas the capacity of the demonstration plant was sized to be 250 MW.

The demonstration tests were carried for every item including reliability, environmental performance, thermal efficiency, fuel flexibility, economy and operability, which are essential for the commercial plant. All the tests were successfully proceeded on schedule. The demonstration project was finished in March 2013, after achieving all the targets:

- Excellent performance (high efficiency, less environmental impact)
- Higher Reliability (World record of continuous operation, 3,917hr; Cumulative operation exceeded 26,000 hours)
- Fine operability (Load change rate >3% per min)
- Fuel flexibility (verified applicability for low-rank coal)

After the demonstration project, the CCP R&D was merged with Joban Joint Power Co., Ltd and the IGCC plant was taken over as Unit No.10 of Nakoso power station. The commercial operations of the unit started in June 2013 as the first IGCC power plant in Japan. No forced interruption was experienced by the plant after the start of commercial operations; the average load factor in this regard was >99% in 2013. The results of Nakoso 250 MW air-blown IGCC demonstration project are summarized in table below:

Table 34: Results of Nakoso 250MW IGCC plant performance test

Parameter		Targets	Achievements
Performance	Output (Gross)	250MW	250MW
	Net	220MW	225MW
	Efficiency (Net, LHV)	> 42.0%	42.90%
	Carbon Conversion	> 99.9%	> 99.9%
Emission (@dry, 16%O2)	SOX	< 8 ppm	1.0 ppm
	NOX	< 5 ppm	3.4 ppm
	Dust	< 4 mg/m3N	< 0.1 mg/m3N
Operational Flexibility	Coal Kinds	Bituminous and Sub-bituminous	Used 10 kinds of coal (6 Sub-bituminous, 4 Bituminous)
	Start-up Time	< 18 hr	15hr
	Minimum Load	50%	36%
	Ramping Rate	3%/min	3%/min
Reliability	Long-term Continuous Operation	2,000 hr	3,917 hr

Source: MHPS, Clean Coal Technologies for IGCC Power Plants, 2017

Post-combustion clean coal technologies

To tackle climate change and provide energy security, carbon capture and storage (CCS) is one of the vital technologies. According to the Global CCS Institute, as of 2017, there are 21 carbon capture projects worldwide on a large scale that are either operational or under construction. Relatively, not many of these projects are in power generation sector.

In the US, many CCS projects are under development or have been proposed. However, only three carbon capture projects were built in the past decade, namely, SaskPower's Boundary Dam, NRG Energy's Petra Nova and Southern Company's Kemper IGCC project. The Kemper plant is the most expensive power plant ever built, based on its generating capacity. In an attempt to manage cost, the coal gasification and carbon capture systems of Kemper plant were abandoned and switched to run on natural gas. Both Boundary Dam and Petra Nova projects involve post-combustion CCS technology, which capture CO_2 from emissions after coal combustion.

a. Boundary Dam Project, Canada:

Operated by SaskPower in Saskatchewan, it is the first fully integrated and full-chain CCS project at a coal-fired generating station in the world. The power plant, which was a retrofit and concurrent expansion and modernization of an aging coal-fired power unit (Unit 3), commenced operations in 2014. The total cost for the retrofit was approximately CAD 1.5 billion (Canadian dollar), which was supported by the provincial government of Saskatchewan and the federal government of Canada. Of the total, nearly CAD 800 million was spent on the CCS equipment and remaining to retrofit the plant.

The project is capable of lowering greenhouse gas emission by capturing up to 1 Mt of CO2 each year. It also captures: 100% SO2, 50% of the NOX and various harmful particulate matters. Additionally, it allows the utilization of captured byproducts for the manufacturing of other products. For instance, captured SO2 is converted to Sulphuric acid and sold for industrial use while another byproduct of coal combustion, fly ash is sold for concrete production. The captured CO2 from power plant is compressed and transported via pipelines to nearby oil fields, where it is used for enhanced oil recovery. The left-over CO2 is permanently stored deep underground.

Table 35: Performance of Boundary Dam Unit 3

Emission	Pre-CCS	Post-CCS	Reduction
CO2	1094	120	90%
SO2	11	0	100%
NO	1.5	1.1	27%
PM10	0.2	0.02	90%
PM2.5	0.1	0.03	70%

Source:SaskPower (https://unfccc.int/sites/default/files/01_saskatchewan_environment_micheal_monea.pdf)

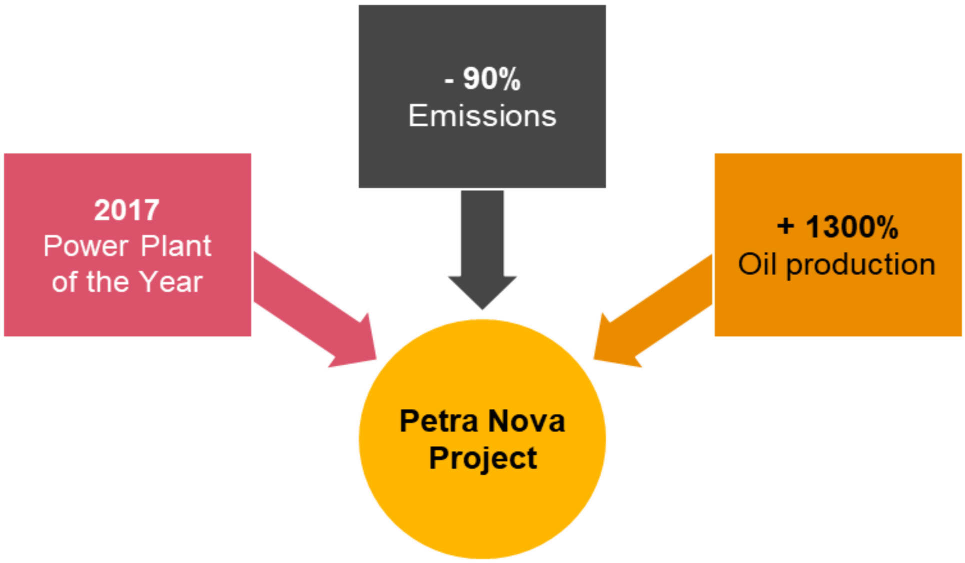
In the initial few months of operation, the CO2 capture performance of the CCS facility at Boundary Dam Power Station was lower. This could be due to start-up issues that are inherent in any new unit's operation. Currently, the unit is consistently fulfilling or surpassing its design specification. According to a report from SaskPower, in 2018, the daily capture rates were exceeding the specifications. In 2017, the CCS facility had captured a total of 0.5 million tonne of CO2, while the number rose to 0.6 million tonne in 2018, with 69% overall availability of the facility[lxxxvi]. Moreover, the project also received community support and input. According to a recent survey in the city of Estevan, where the power plant is located, nearly 84% of the local population support CCS technology as a way to keep using coal as a fuel source.

b. Petra Nova, the US:

Petra Nova is the world's largest post-combustion carbon capture system in operation. The technology, being used in CO2 capture, is advanced amine-based absorption technology. The Petra Nova carbon capture facility was added to the Unit 8 of NRG's W.A. Parish power plant by a joint venture between NRG and JX Nippon Oil & Gas Exploration Corp. of Japan. This is also a retrofit of an existing coal plant and is twice the size of Boundary Dam. The plant was built within just two years and was completed on budget and on schedule. The cost of project was approximately USD 1 billion.

The CCS system installed in WA Parish Unit 8 is capable of capturing 1.4 Mt per year or 90% of the CO2 emissions from a 240 MW slipstream of flue gas. Petra Nova started commercial operation in December 2016. Within the first 17 months of operation, the plant captured approximately 1.7 million tonne of CO2. The captured CO2 is compressed and then transported to the West Ranch oil field and injected into mature reservoirs to release more oil. Prior to Petra Nova, the West Ranch oil field was producing 300 barrels of oil per day. The oil recovery rose to 4,000 barrels per day during the first year of CO2 enhanced oil recovery[lxxxvii]. In 2017, Petra Nova project was awarded by Power Engineering as the project of the year (with JX Nippon) and the best coal-fired project of the year.

Figure 70: Achievements of Petra Nova project



Source: Petra Nova, Carbon capture and the future of coal power (https://www.nrg.com/case-studies/petra-nova.html)

c. Kusile power station, South Africa:

The Kusile power station project is a coal-fired power plant, which is located near the existing Kendal power station in the Nkangala district of Mpumalanga in South Africa. The project is initiated by the state electricity company, Eskom that supplies around 90% of South Africa's power annually.

In comparison with the coal-fired power plants in South Africa, Kusile power plant is 30% larger than the average. It comprises of six units, each producing 800MW for a total capacity of 4,800 MW. Once completed, this power plant will be the largest one in Africa, the fourth-largest coal-fired power plant across the world, and largest plant of its kind in the Southern hemisphere.

This supercritical coal-fired power plant operates with pulse jet fabric filter (PJFF) and flue gas desulfurization (FGD) systems to manage emissions. As per the South African National Environmental Management Air Quality Act, the daily limit of SO2 emission is 500 mg/Nm3. In order to comply with the air-quality standards, Eskom is adding up wet flue gas desulphurization technology (WFDG) to Kusile plant as an atmospheric emission abatement technology. The plant is first of its kind in Africa to use WFGD technology– a state-of-the-art technology used to remove oxides of Sulphur, such as SO2, from the exhaust flue gases. This will help to remove 90% of the SO2 produced by the boilers. Limestone is used as feedstock for desulphurization and produces gypsum as a byproduct.

Commercial operation of plant's Unit 1 began in August 2017, adding 800 MW to the national grid. This was achieved well ahead of schedule (July 2018). In 2018, General Electric (GE) successfully completed tests for performance of Unit 1. During its performance tests, the unit attained 93% removal efficiency rate, which is beyond the original performance commitments[lxxxviii].

d. Zouxian Power Station, China:

In China, to meet emission standards for air pollutants from coal-fired power plants, various retrofit projects are undertaken to enhance the capability of existing flue gas treatment systems in power plants. Zouxian

Power Station is one such retrofit project. It is one of the largest power stations in China, with the capacity of 4,540 MW.

The project was assigned to Zhejiang Feida MHPS High Efficiency Flue Gas Cleaning System Engineering Co., Ltd. (FMH), which is a part of MHPS Group. FMH accomplished the project in short period of time, i.e., seven months. The work involved alterations and incorporations to the power plant including electrostatic precipitator (ESP), flue gas desulfurization (FGD) and gas heaters (GGH) at Unit 8 (1,000 MW) of the power station. The updated unit will reduce the SO2 and particulate matter in the boiler exhaust gas. Major improvements include the removal of rotating GGH and installation of leak-proof GGH heat recovery device and the re-heating device at the front stage of the ESP and the rear stage of the FGD, respectively. Other improvements include, renewal of components in the FGD, such as, recirculation pumps, spray headers, nozzles and agitators. The table below shows the resultant values after modification, relative to the customer's desired values[lxxxix].

Table 36: Results of modification of Unit 8 for PM emissions reduction

Parameter	Before modification	Customer's desired value	After modification
PM concentration at ESP inlet [mg/m^3 N]	25000	-	-
PM concentration at ESP outlet [mg/m^3 N]	30	≦30	10
PM concentration at the FGD outlet [mg/m^3 N]	14	≦5	2
SO2 concentration at the FGD outlet [mg/m^3 N]	70-330	≦35	10-23

Source: MHI, AQCS (Air Quality Control System) for Thermal Power Plants Capable of Responding to Wide Range of Coal Properties and Regulations, 2017

Preceding the commencement of operations, the system successfully completed 168 hours of continuous trial runs, as required by Chinese regulations. In addition, the latest Chinese environmental regulatory requirements were met by the unit through achieving significant reductions in environmental load. The desulfurization rate raised to 98.8 % and stack inlet dust concentration reduced to about one-fifth of the previous level.

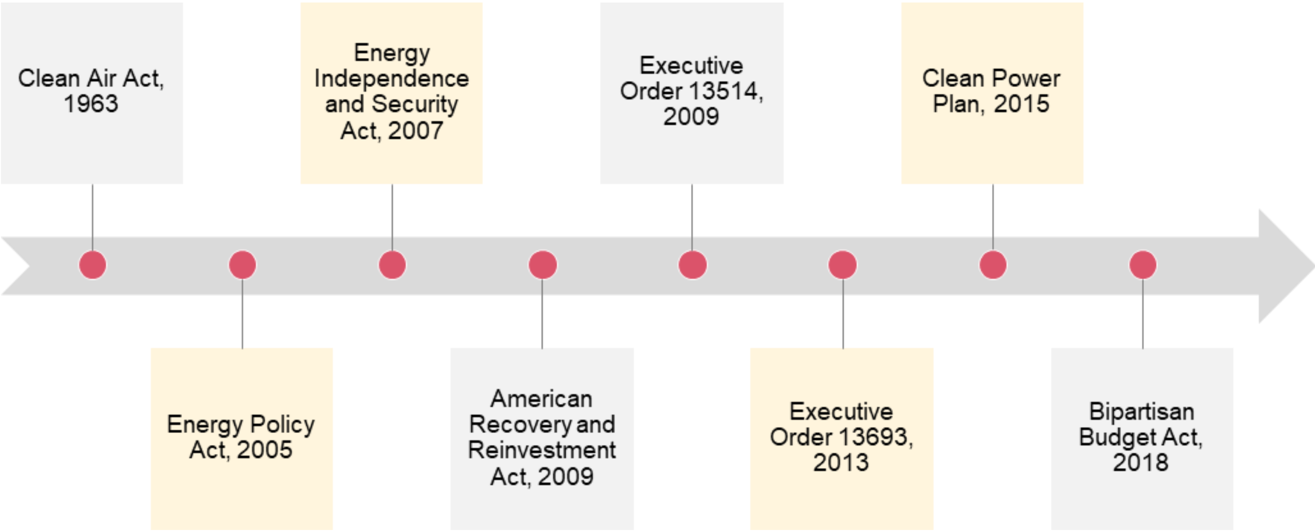
4.2. Prevailing policies governing LCV coal utilization in developed economies

4.2.1. The United States

Bipartisan Budget Act, 2018

The US is one of the world’s biggest contributors of carbon/greenhouse gas (GHG) emissions. As a step towards reducing these carbon emissions, the US introduced various polices over the period of time to encourage alternate sources of power generation. These policies mainly aim at reducing the use of coal for producing power and encouraging alternate sources such as wind, solar and biomass. Some of these policies urge various civic authorities to conduct activities related to transportation and energy in an environmentally, economically and financially comprehensive and integrated way. They also prioritize GHG emissions by setting targets and tight deadlines for a sustainable development. These policies also provided tax incentives for investing clean coal facilities[xc].

Figure 71: Policies in the US for clean air



Source: Climate Home

In a drive to mitigate GHG emissions, especially CO2, carbon capture and storage techniques, such as pre-combustion, post combustion, oxy-fuel combustion and IGCC plants have gained a lot of importance. In order to encourage investments in CCS, the government has passed Bipartisan Budget Act (the Act) in 2018 that includes tax provisions for the development of CCS in the US. Such provisions are provided under Section 45Q. As per the Act, carbon oxide sequestration credit for any taxable year will be as follows:

Tax credit:

1. USD 20 per metric tonne of carbon oxide captured, using carbon capture equipment and stored permanently with no further usage.
2. USD 10 per metric tonne of carbon oxide captured, using carbon capture equipment and used further for enhanced oil or natural gas recovery.

Time period and applicable tax credit:

1. For taxable year beginning in a calendar year after 2016 and before 2027
    1. Established by way of linear interpolation between USD 22.66 and USD 50 for every calendar year for each metric tonne of captured carbon oxide and stored permanently with no further usage
    2. Established by way of linear interpolation between USD 12.83 and USD 35 for every calendar year for each metric tonne of captured carbon oxide and used for enhanced oil or natural gas recovery

   a. For taxable year beginning in a calendar year after 2026
    1. An amount of USD 50 multiplied with inflation adjustment factor for such calendar year (for permanent storage).
    2. An amount of USD 35 multiplied with inflation adjustment factor for such calendar year (used in EOR or natural gas recovery).

Application of section for certain carbon capture:

- The amount of CO_2 eligible for tax credit was capped at 75 million tonne. However, this has been relaxed in the current provisions and allows a qualified facility to receive tax credit for a period of 12 years from the date of installation.

Table 37: Pre- and post-Act tax credits for EOR and geologic sequestration

	Pre-budget Act qualified sequestration	Post-budget Act qualified sequestration
EOR, other industrial utilization	• USD 10/tonne plus inflation	• USD 12.83/tonne to USD 35/tonne plus inflation (linear increase through 2026; inflation adjustment thereafter)
	• 75 million tonne limit	• Credit applies for 12 years beginning on date equipment placed in service
Sequestration	• USD 20/tonne plus inflation	• USD 22.66/tonne to USD 50/tonne plus inflation (linear increase through 2026; inflation adjustment thereafter)
	• 75 million tonne limit	• Credit applies for 12 years beginning on date equipment placed in service

Source: Hunton & Williams, 2018

The new amendments made in Section 45Q are expected to reduce tax liability for companies that either capture or dispose of the carbon oxide and make the existing technology cheaper. It is also expected to drive the development of new technologies that may help in mitigating GHG, especially carbon dioxide[xci].

S. 1068—The Clean Energy for America Act

This Act provides investment tax credit for a qualified CCS equipment, which is installed at an electricity generation facility that captures at least 50% of the CO_2 emissions of the facility.

H.R. 2011 and S. 843—The Carbon Capture Improvement Act of 2017

A CCS facility that captures and stores at least 65% of the CO_2 is eligible for tax-exempt bonds. If the facility captures less than 65% of CO_2, the percentage of the cost of CCS components eligible for tax-exempt bonds cannot be greater than the capture and storage percentage (i.e., if the facility captures and stores 50% of the CO_2, 50% of the cost of the components would be eligible for the tax-exempt bond).

H.R. 2296—The Advancing CCUS Technology Act

The mentioned Act requires the Secretary of Energy to conduct an annual evaluation of all CCS projects that are funded by Department of Energy (DOE) for activities such as R&D, demonstration or deployments of CCS technologies. The Secretary then determines if the project has made any significant advancement with respect to the technology. The projects evaluated can be under contract, cooperative agreement, lease or any other transaction with a public or a private agency or with a person. Based on the progress determined by the Secretary, further funds will be allocated to the project.

H.R. 2010 and S. 1663—The CO2 Regulatory Certainty Act

Under this Act, the Secretary of the Treasury, in consultation with the Secretaries of Energy and the Interior and the Administrator of the Environmental Protection Agency (EPA), regulations will be established for geological storage of CO2 injected for EOR as well as non-EOR purposes.

The DOE CCS Program

DOE has been funding R&D of various aspects of integrated CCS systems since 1997. Congress has provided funds of over USD 4.3 billion since FY2010, while the Recovery Act provided additional funds of around USD 3.4 billion of the total. The changed government administration has reduced the budget allocations by more than half[xcii].

4.2.2. Australia

In Australia, coal is of vital importance both as a primary source of electricity and as a major export commodity. Coal reserves in Australia are predominantly anthracite and lignite. Lignite is principally mined in Victoria and South Australia and small deposits are also found in Western Australia and Tasmania. Lignite is used as the primary source of energy in Australia, which generates around one third of Australian electricity. However, the utilization of this low calorific value coal resource generates a significant level of CO2, a key GHG emission.

Attention was given by the Australian government to reduce and protect environment from emissions such as, CO2, NOX and SOX. Australia signed an international agreement for emission reduction- the Kyoto Protocol in 1998, ratified in 2007. The countries signatory to the Kyoto Protocol are obliged to reduce their GHG emissions. The first Kyoto commitment period commenced in 2008 and ended in 2012. In this period, Australia committed to limit its average annual GHG emissions to 108% of its emissions in 1990 (base year). According to the Australian Government Department of Environment (DOE)'s National inventory report 2012, over the five reporting years in the first phase of the Kyoto period (2008-12), the country's net emissions averaged 565 MtCO2-e per year or 103% of the base year level. Currently, Australia is a signatory to the second Kyoto commitment period (2013-20), with an emission reduction target of 99.5% of 1990 levels[xciii].

In 2011, the Australian government introduced 'Clean Energy Future Plan', which is a comprehensive set of national policies, aimed to reduce GHG emissions and stimulate clean energy generation. The country's clean energy transformation has been driven by the 2011 Clean Energy Future Plan. The Australian Government committed a 5% reduction in GHG emissions below 2000 levels by 2020. The Government had further set a long-term target to reduce emissions by 80% compared with 2000 levels by 2050.

The central element of the policy package is the 'Carbon Pricing Mechanism' (CPM), commenced in July 2012. The CPM was introduced by federal legislation in 2011 as an initiative to address climate change and to support economy growth through the development of clean energy technologies. Under the CPM, the country's largest carbon emitters, called liable entities, would pay a certain amount of tax per tonne of CO2 it releases into the atmosphere. Any facility emitting more than 25,000 tonne of CO2 per year was subjected to carbon price. This approximately covered 60% of Australia's carbon emissions comprising of power stations, mines and emissions-intensive manufacturers. Under the scheme, electricity sector accounts for majority of the emissions. For the first three years, price was set at AUD 23 per tonne of carbon, before switch to a cap-and-trade system with a market price.

The carbon price in the country has been in operation for two years. Following the introduction of carbon price, the annual CO2 emission in the National Electricity Market (NEM) declined by 6.7% in 2012-13 and 3.6% in 2013-14. This was a combined decrease of 8.2% of NEM emissions (29 MtCO2) for two years compared to the two-year period, preceding to its introduction[xciv]. The same was nearly 18 million tonne less emissions from electricity sector, in comparison with the year before the carbon price introduction (2011-2012). However, the CPM was repealed in 2014, considering significant challenges faced from the opposition and the public, when it resulted in increased energy prices.

Statement on Future Uses of Brown Coal

In July 2017, the Victorian government unveiled a much-anticipated policy statement on "Future Uses of Brown Coal". The statement provides framework about how the world's second-largest deposit of brown coal might be used. This policy focuses on low emissions development, recognizes the need for ongoing industry-focused research and development in CCS and other new technologies for sustainable utilization of brown coal for energy and value-added products, such as diesel, urea, solid fuels and hydrogen.

The salient features of the policy are[xcv]:

"……• Using our brown coal resources in a manner that maximizes its long-term value for Victorians and is consistent with our economic, social and environmental priorities, while promoting jobs and investment.

- Fully implementing the recommendations from the Hazelwood Mine Fire Inquiry, including the development of a Latrobe Valley Regional Rehabilitation Strategy.
- Setting an emissions standard for new brown coal projects by regulation under the Environment Protection Act 1970. These standards will not apply to the existing brown coal power generators except where they install new generation units.
- Ensuring the emissions standard:
  - applies to projects using more than 27,000 tonne of coal per annum
  - covers direct emissions
  - allows projects to offset emissions and use Carbon Capture and Storage (as available) to achieve the emissions standard
  - initially be set equivalent to emissions from existing efficient gas-fired generation i.e. 0.3 t CO2-e / t coal or 0.45 t CO2-e / MWh"

"The Government intends that the emissions standard will be tested through a Regulatory Impact Statement (2017-18) and then set in regulations, which will be reviewed over time."

"Completing the CarbonNet Project which is investigating the development of a Carbon Capture and Storage (CCS) network in Victoria"

New brown coal projects will be considered on a case-by-case basis and will be assessed through a transparent and robust framework. New project will be required to comply with every applicable regulatory requirement under the Planning and Environment Act 1987. The decision-making will be supported by an independent Expert Panel with commercial, technical and environmental expertise.

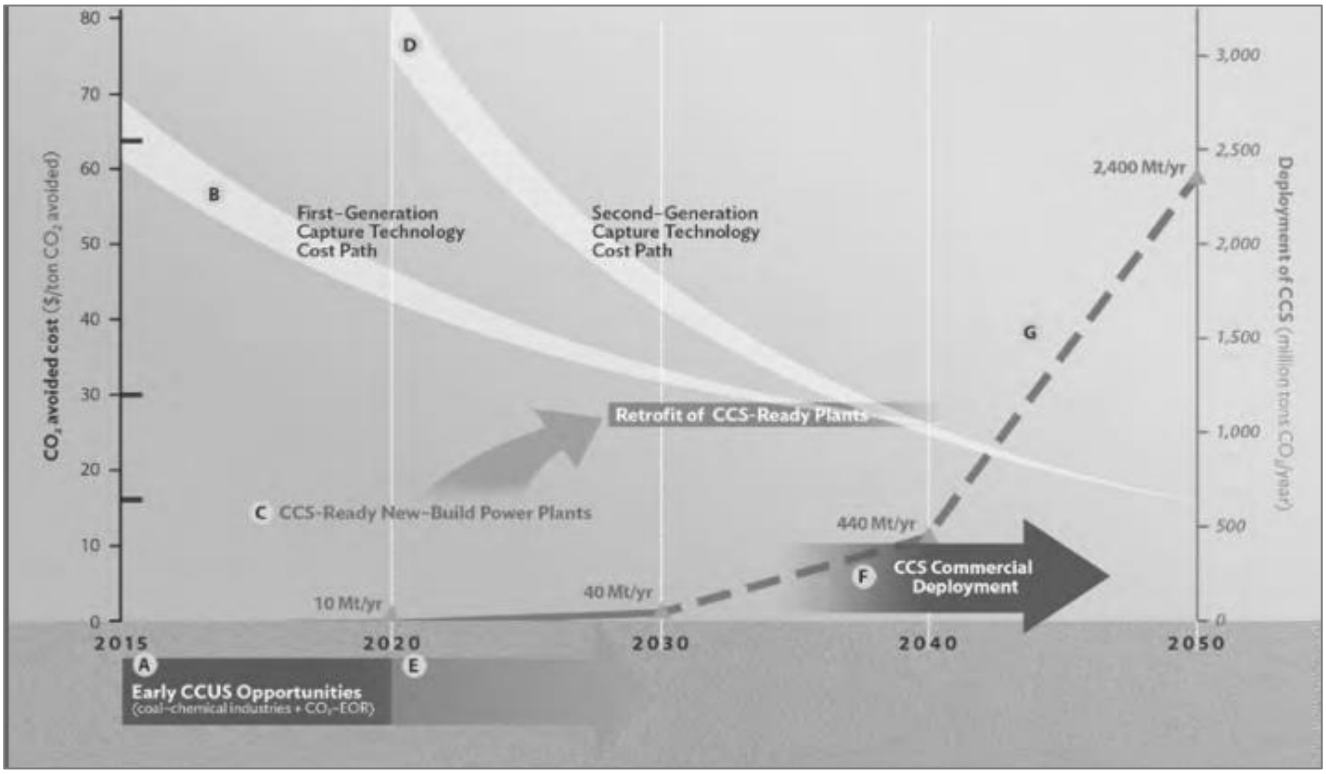
The statement promises an 'open for business' approach in supporting new investment and research opportunities in coal projects while evaluating them against other economic, social and environmental factors.

4.2.3. China

There is no comprehensive national level policy, plan or regulatory framework to control carbon emissions and to facilitate CSS demonstrations in China. However, institutions such as the National Development and Reform Commission (NDRC), the National Energy Administration, the Ministry of Science and Technology, the Ministry of Environmental Protection, the Ministry of Land and Resources, and the Ministry of Industry and Information Technology promote various stages of CCS development. Some stringent provisions in various independent policies and regulations can be helpful in promoting reduction of carbon emissions in China. In one of its report, "Roadmap for carbon capture and storage demonstration and deployment in the People's Republic of China", ADB had suggested the following:

- The authorization process for thermal power generation, laying of oil and gas pipelines and oil and gas field developments has to be made very complicated and stringent. To commence construction of such plants, around 50 clearances and permits are required in PRC. It would be helpful if the central government leads the approval of first mover demonstration projects and provides an integrated approval process.
- Explicit regulations for CCS technical and environmental standards should be developed to normalize operations and clarify issues such as liability aspects of CCS projects, protection of society's interest and the environment. Specific standards for storage site selection, characterization, environmental impact assessment and long term liability should be set so as to promote wider deployment of CCS.
- Liability issues of early stage CCS projects should be taken care of based on international experiences.
- ADB also recommends a phased approach for CCS demonstration and deployment to overcome early-stage challenges. This can be done by first targeting low-cost CCS applications in coal-chemical plants with CO2[xcvi].

Figure 72: Proposed CCS roadmap for PRC



Source: ADB

4.3. Guidelines of International environmental organizations on utilizing LCV coal

4.3.1. United Nations Framework Convention on Climate Change (UNFCCC)

UNFCCC or the Convention, founded in 1992, combats climate change that effects humanity and ecosystems. Its main objective is to *"stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"*. In order to achieve its objective, UNFCCC established a framework with broad principles, general obligations, basic institutional arrangements, and an intergovernmental process for agreeing with specific actions over time, which includes collective decisions by the Conference of the Parties and other international legal instruments with more specific obligations. The Kyoto Protocol (1997) and the Paris Agreement (2015) are two such instruments that were negotiated under the UNFCCC. The UNFCCC currently has 197 countries as "Parties to the Convention"[xcvii].

UNFCCC, a global action that calls for decision making at many levels:

- International – through intergovernmental organizations (IGOs) and process
- Regional, national, sub-national, and local – through local governments, individuals, communities, multinational firms and local enterprises.

The Kyoto Protocol (1997):

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets. It was adopted on 11 December 1997, as it entered into force on 16 February 2005, post a complex ratification process. The rules of the Protocol were adopted at COP 7 in Marrakesh, Morocco, in 2001, which are referred to as the "Marrakesh Accords". The Protocol commits industrialized countries to cap and reduce GHG emission in accordance with agreed individual targets. Status of policy adoption, measures of mitigation and the current status of emissions are to be reported periodically to the Convention[xcviii].

The Protocol is based on the Convention's principles and provisions and follows its annex-based structure. However, this binds only the developed countries under the principle of "common but differentiated responsibility and respective capabilities", as it identifies them to be largely responsible for current high levels of GHG emissions in the atmosphere.

In its Annex B, the Protocol has set targets for reduction of emissions in 36 industrialized countries and the European Union. Target of an average of five percent emission reduction on 1990 levels over a period of five years, i.e., 2008-2012 was set. The six main GHGs targeted during this period were – carbon dioxide (CO2) Methane (CH_4), Nitrous oxide (N_2o), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). The second commitment period started from 2013-2020, where the Doha Amendment to Kyoto Protocol (2012) was adopted. During the second commitment period, GHG emissions are targeted to be reduced by at least 18% below 1990 levels[xcix].

The Protocol has two crucial elements:

First element of the protocol is binding only on the developed country Parties for emission reduction commitments. CO2, the more prevalent GHG, gained importance as a new commodity in the market. The Kyoto Protocol began to internalize, what was recognized as an unpriced externality.

Second element establishes flexible market mechanisms that are based on the trade of emissions permits. All the Parties bound by the Protocol are required to meet their targets majorly through domestic action, which is reduction of emissions at home. However, such targets can also be met through three market-based mechanisms that encourage GHG reduction in a cost-effective way.

Broadly, the aforementioned elements can be classified as market-based mechanisms, which are designed to meet the targets. However, the set targets are to be met by the SAARC countries primarily through national measures. The market-based mechanisms to meet their targets are International Emissions Trading, Clean Development Mechanism (CDM) and Joint Implementation (JI):

A rigorous monitoring, review, verification and compliance system has been set up to ensure transparency and accountability. In addition to this, an Adaptation Fund was established in order to finance adaptation programs in developing country Parties. The earnings from clean development mechanism (CDM) projects and activities finance the Adaptation Fund[c].

The Paris Agreement (2015):

Parties to the UNFCCC had reached an agreement to tackle climate change by instigating and intensifying actions and investments for a sustainable low carbon future. This agreement was agreed upon at COP 21 in Paris on 12 December 2015. The main aim of the Paris Agreement is to undertake ambitious efforts against climate change by enhancing support to developing nations to do so. The agreement aims to keep the global temperature rise in this century below 2 degrees Celsius over and above the pre-industrial levels and to limit the increase in temperature to 1.5 degree Celsius. In addition, it also intends to enhance the capability of the countries to deal with impacts of climate change.

The developing countries will be supported by putting in place appropriate financial flows, new technology framework and an enhanced capacity building framework. The Agreement needs all the Parties to make efforts through “nationally determined contributions” (NDCs), which require the Parties to regularly report on their emissions and on their implementation efforts. A global assessment is done every five years to understand the collective progress towards achieving the purpose of the Agreement and to guide on individual action points by the Parties.

Though the Agreement was signed on 22 April 2016, it came into force on 4 November 2016. Under this agreement, some of the crucial areas to combat climate change were long-term temperature goal, global peaking and ‘climate neutrality’, mitigation, sinks and reservoirs, voluntary cooperation/market and non-market-based approaches, adaptation, finance, technology and capacity building support, climate change education, training, public awareness, public participation and public access to information, transparency, implementation and compliance, etc.

4.3.2. The European Union

One of the key priorities of the EU is to fight climate change and it is committed to reducing it through various international activities. The EU and its 28 member states are signatories to both UNFCCC’s Kyoto Protocol and the new Paris Climate Change agreement. Europe is working hard to cut its GHG emissions and is also encouraging other nations and regions to do the same. The EU has set itself a target of reducing its GHG emissions by 80-95% below 1990 level by 2050. Consequently, through the European Climate Change Programme (ECCP), the EU has initiated a comprehensive package of policy measures to reduce GHG emissions at the European level.

European Climate Change Programme

The European Climate Change Programme (ECCP) has been established in 2000 by the European Union's European Commission (EC), in order to tackle climate change. Its mission has been to identify the most environmentally effective and cost-effective policies to further drive the EU’s efforts to reduce GHG emissions. The immediate target was to ensure that the EU succeeds in reducing the GHG emissions under the Kyoto Protocol. This required the EU member states to reduce their combined GHG emissions by 8% (equivalent to 336Mt CO2eq) from 1990 levels by 2012. The ECCP was set up as a multi-stakeholder consultative process that have brought together all relevant players, including representatives of the Commission, the member states, industry and NGOs.

The first ECCP phase (2000-2004) explored a range of different policy sectors and instruments with the potential of GHG emissions reduction. The second phase of ECCP (ECCP II), launched in 2005, explored further cost-effective options for GHG emissions reduction in synergy with the EU’s ‘Lisbon strategy’ for increasing economic growth and job creation. One of the most important and innovative initiatives resulted from the ECCP is the EU Emissions Trading Scheme (EU EST).

The EU Emissions Trading System (EU ETS)

Launched in 2005, the EU ETS was the world's first international emission trading system and is the largest of its kind. The system has undergone several changes over time- and the implementation of the system has been divided into a number of trading periods (phases). Phase 3 is the current phase of EU ETS that began in 2013 and will span until 2020. The scheme works on a 'cap and trade' principle. EU ETS has placed climate change on the agenda of company boards across Europe by putting a cap on amount of gases that can be emitted by them. Under the 'cap and trade' principle, an upper limit was set on the total amount of GHG emissions for all participating installations. Within this cap, companies covered by the system, receive or buy emission allowances and these allowances can be subsequently traded[ci].

The system currently covers 31 countries across Europe (all 28 EU member states plus Iceland, Liechtenstein, and Norway), and covers more than 11,000 heavy emitters from the power, industrial, and aviation (covers only flights within the European Economic Area (EEA)) sectors.

The EU is on the track to meet its climate and energy targets, which include GHG emissions reduction by 20% than in 1990 by 2020 and at least 40% by 2030. This proves that the mechanism of placing a price on carbon emissions and trading can result in achieving the goals of overall reduction in GHG emissions.

In 2018, the European hard coal power plant emissions fell by 9%, thus accounting for a total of 40% reduction from 2012 emissions. By contrast, European lignite plants emissions fell by only 3% in 2018 and are now only 14% below 2012 emissions. Almost half of these emissions from Lignite based plants are from Germany alone, with the remaining emissions from five countries - Poland, the Czech Republic, Greece, Bulgaria and Romania. So far none of these countries has plans to phase out lignite[cii].

Table 38: Key features of the EU ETS across trading phases

Key features	Phase 1 (2005–2007)	Phase 2 (2008–2012)	Phase 3 (2013–2020)
Geography	EU27	EU27 + Norway, Iceland, Liechtenstein	EU27 + Norway, Iceland, Liechtenstein Croatia from 2013
Sectors	Power stations and other combustion plants ≥20MW, Oil refineries, Coke ovens, Iron and steel plants, Cement clinker, Glass, Lime, Bricks, Ceramics, Pulp, Paper and board	Same as phase 1 plus Aviation (from 2012)	Same as phase 1 plus, Aluminium, Petrochemicals, Aviation (from 2014), Ammonia, Nitric, adipic and glyoxylic acid production, CO_2 capture, transport in pipelines and geological storage of CO_2
GHGs	CO_2	CO_2, N_2O emissions via opt-in	CO_2, N_2O, Perfluorocarbons (PFCs) from Aluminium production
Cap	2,058 million tCO_2	1,8 59 million tCO_2	2.084 million tCO_2 in 2013, decreasing in a linear way by 38 million tCO_2 per year

Source: European Commission, EU ETS Handbook (https://ec.europa.eu/clima/sites/clima/files/docs/ets_handbook_en.pdf)

5. SAARC Country Outlook on Need for Clean Coal Technologies Using LCV

SAARC Country Outlook on Need for CCTs Using LCV coal

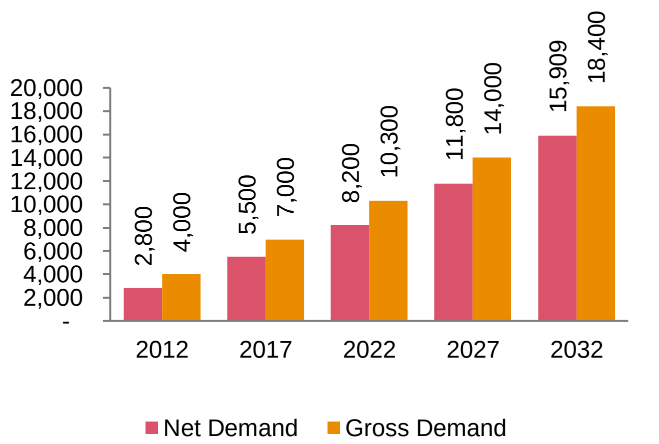
5.1. Potential of clean coal technologies

Afghanistan

Afghanistan has 440 billion cubic meters of proven gas reserves in the northern and western regions, 73 million tonne of coal reserves in its central highlands, and hydropower potential amounting to 25,000 MW in its eastern and southern regions. However, due to lack of infrastructure, for people living in rural areas, primary source of energy is dominated by wood, cow dung, crop residue, and kerosene. Per capita electricity consumption in the country is 120 kWh, which is significantly lower as compared to other SAARC countries.

According to the Afghanistan Power Sector Master Plan, the gross energy (power send out) demand is expected to increase over 18,400 GWh in 2032 from 2,800 in 2012 at an average annual growth rate of approximately 7.8% while the net demand (electricity delivered to customers) is expected to rise at an annual average growth rate of 9.8% to 15,909 GWh in 2032 from 2,800 GWh in 2012. By 2032, the thermal power plant is expected to fulfill 26% of the total demand in the country while domestic hydro and power imports are expected to fulfill 41% and 33% of the total demand respectively.

Figure 73: Projected electricity demand in Afghanistan (MW)



Source: Afghanistan Renewable Energy Development Issues and Options 2018, World Bank

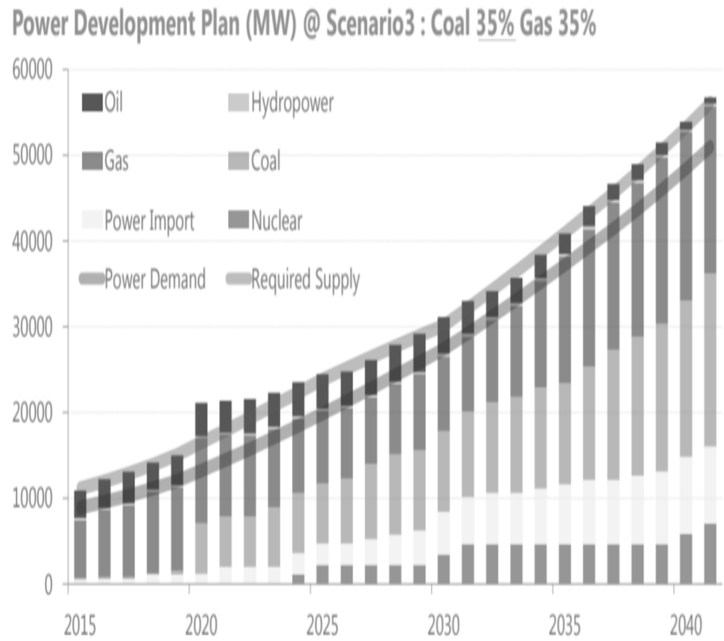
According to Afghanistan Power Sector Master Plan, of the total investment cost of USD 10 billion, generation accounts for bulk of the investment, i.e., 70% of the total investment while major transmission projects and transmission projects within the province's accounts for 17% and 13% of the total investments. However, APSMP proposes to generate significant amount of energy from large hydropower plants. The proposed thermal power plants are expected to be constructed adjacent to the coal mines. Given the future energy requirement, thermal power plants based on clean coal technologies can help the country to generate energy effectively with low toxic emissions.

Bangladesh

Bangladesh is one of the fastest growing economies in South Asia. The Government of Bangladesh now aims to achieve the status of a 'middle-income country' by 2021 and that of a 'high-income country' by 2041. It is well known that electricity plays a vital role in poverty eradication, sustained economic growth, infrastructure development and security of any country. Bangladesh's power sector is one of the fastest growing in the South Asian region. The growth in terms of capacity addition in the last 10 years has been remarkable (from around 4.5 GW in 2007 to ~20 GW in 2019). By 2041, the country aims to increase the total installed capacity to 60 GW.

Due to the depletion of natural gas, the government aims to generate majority of the energy from coal based thermal power plant. As on August 2019, coal based thermal power plant contributes to 2.73% of the total installed capacity. The country aims to triple its power generation from coal based thermal power plant, which shall contribute to 35% of total installed capacity. Bangladesh has approx. 5.7 GW of coal based thermal power plant, which is expected to increase to over 18 GW by 2041. As the quality of air in the country is deteriorating due to toxic emissions from industries and power plants, developing thermal power plant based on clean coal technologies can help the country to achieve its future requirement and also reduce air pollution.

Figure 74: Bangladesh Power Development plan

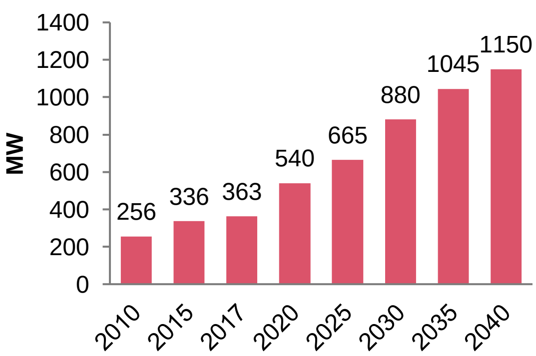


(Source: JICA PSMP2015 Team Estimate)

Bhutan

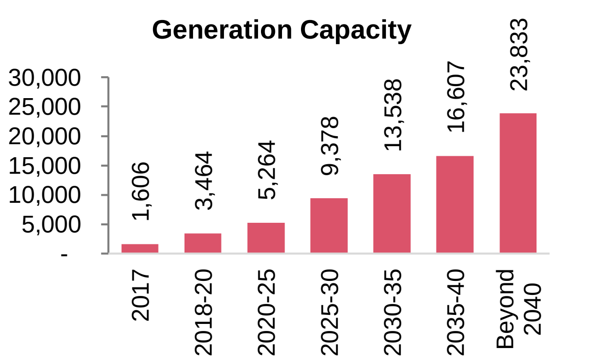
Bhutan is one of the largest repositories of hydropower in the Asian region with a potential of 23 GW, which is techno-economically feasible. As on 2018, the country has an installed capacity of 1.6 GW, of which hydropower contributes to over 99% of the total installed capacity. Despite large coal reserves, only 186,823 metric tonne of coal was mined in 2018 and is entirely used for domestic consumptions. The total exports of power stood to 4,580 million units and majority of power was exported to India. The country has set massive expansion plan to fulfill its future energy requirements and also to import electricity to its neighboring states, which shall have positives impacts on its economy. By 2040, the government plans to generate over 23,833 MW from 73 hydropower sites, which are identified at different basins, with a peak demand of 1,150 MW (as per the demand forecast).

Figure 75: Bhutan demand projection (MW)



Source: National Transmission GRID Master Plan (NTGMP) of Bhutan 2018

Figure 76: Bhutan projected generation capacity (MW)

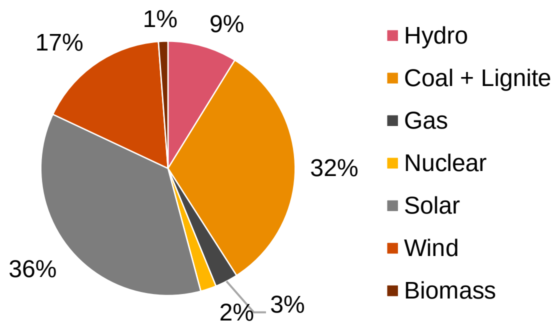


Source: National Transmission GRID Master Plan (NTGMP) of Bhutan 2018

India

Indian power sector is currently experiencing a multi-pronged transformation. As on October 2019, the total installed capacity in India stands at 363 GW. Coal based thermal power plant contributed to 54.2% of the total installed capacity while 22.7% and 12.6% of the total installed capacity are contributed by renewable energy source and hydropower plant respectively. Rapid capacity addition is largely attributed to private sector participation, which has grown from 25 GW in 2010 to 168 GW in 2019, now making up 46.5% of the total installed capacity. However, the overall Plant Load Factor of coal and lignite-based power plants has reduced from 77.5% in FY 2010 to 57.69% in Sept 2019.

Figure 77: Projected total installed capacity of 831.5 GW by FY 2030 in India



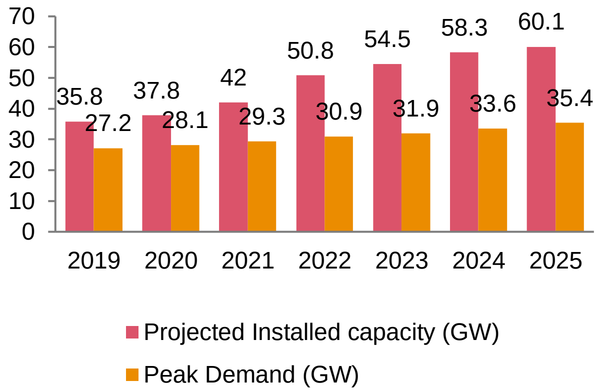
Source: Draft Report on Optimal Generation Capacity Mix for 2029-30, CEA

In the year 2018-19, the performance of thermal power plants increased marginally by 3.39%. During the same period, performance of renewable power plants and imports from Bhutan increased by 24.7% and 7.78% while the overall power generation sector witnessed a growth of 5.19%. With rapid urbanization, growth in the industrial sector, electrification of village in rural areas, etc. the demand for electricity has been on the rise. As per the Electric Power Survey Report, the electricity consumption is expected to double to 1,763 billion units in FY 2027 from 921 billion units in FY 2017, while the energy requirement is assessed to reach 2,047 billion by FY 2027. The peak electricity demand is estimated to touch 299 GW in FY 2029 from 162 GW in FY 2017. Based on the long-term demand projections of FY 2032, the peak demand and energy requirement is assessed to increase by a CAGR of 4.4% and 4.3% respectively from FY 2027 to FY 2032. Additionally, thermal power stations are required to serve the base load and for grid stabilization. According to a study conducted by CEA (Central Electricity Authority), over 200 potential sites have been identified to set up thermal power plants of total capacity 428 GW. To fulfil the future energy demand, India would continue to rely on coal based thermal power plant and revamp the old thermal power by adopting new clean coal technologies.

Pakistan

Over the last five years, there have been addition of 10 GW of new generation plants, which increased the total installed capacity to 34.2 GW in FY 2019 from 21.2 GW in FY 2014. However, the capacity factor of the overall power sector decreased to 41.5% in 2018 from 47.4% in 2017 and 51.1% in 2014. The federal government has been taking efforts to reduce technical and commercial losses, which can help the distribution companies to reduce financial losses and also supply quality power to the consumers. Independent power producers have played a major role and contribute to 44.78% of the total installed capacity.

Figure 78: Projected installed capacity and peak demand in Pakistan



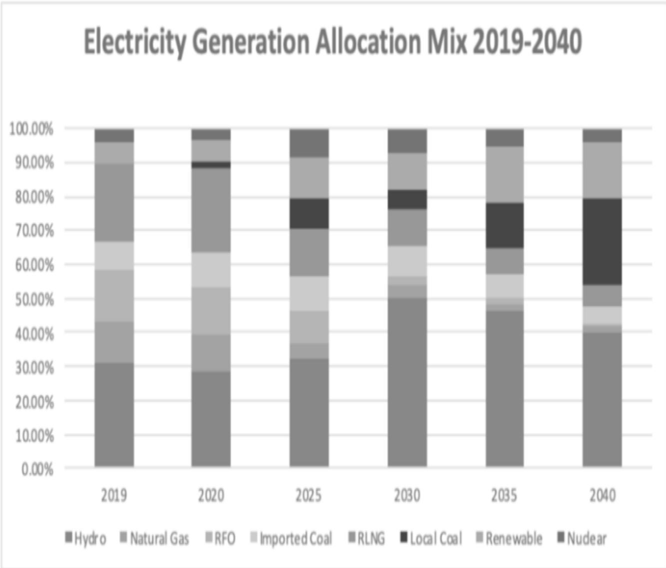
Source: State of Industry Report 2018, NEPRA

The private players have added over 4.7 GW of power plants over FY 2017 and FY 2018. By 2025, the government plans to increase the total installed capacity to 60 GW to cater to peak demand of 35.4 GW by FY 2025. Despite large coal reserves, the country has imported over 15 million tonne of coal in FY 2019, which is almost three times of total domestic coal production that stands to 5.5 million tonne in FY 2019. According to PPIB, the country has approx. 3 GW of coal based thermal power plant under construction. Additionally, thermal power plants based on imported coal of total capacity 3.6 GW are under pipeline. In 2018, 2.3 GW of proposals have been granted development permission and these power plants were based on domestic coal. With large power projects in pipeline, use of clean coal technology can help reduce carbon footprint and improve the load factor of thermal power plant.

Over the last five years, there have been addition of 10 GW of new generation plants, which increased the total installed capacity to 34.2 GW in FY 2019 from 21.2 GW in FY 2014. However, the capacity factor of the overall power sector decreased to 41.5% in 2018 from 47.4% in 2017 and 51.1% in 2014. The federal government has been taking efforts to reduce technical and commercial losses, which can help the distribution companies to reduce financial losses and supply quality power to the consumers. Independent power producers have played a major role and contribute to 44.78% of the total installed capacity. The private players have added over 4.7 GW of power plants during the period FY 2017 to FY 2018. By 2025, the government plans to increase the total installed capacity to 60 GW to cater to peak demand of 35.4 GW by FY 2025. Despite large coal reserves, the country has imported over 15 million tonne of coal in FY 2019, which is almost three times of total domestic coal production that stands to 5.5 million tonne in FY 2019. According to PPIB, the country has approx. 3 GW of coal based thermal power plant under construction. Additionally, thermal power plants based on imported coal of total capacity 3.6 GW are under pipeline. In 2018, 2.3 GW of proposals have been granted development permission and these power plants were based on domestic coal. With large power projects in pipeline, use of clean coal technology can help reduce carbon footprint and improve the load factor of thermal power plant.

Sri Lanka

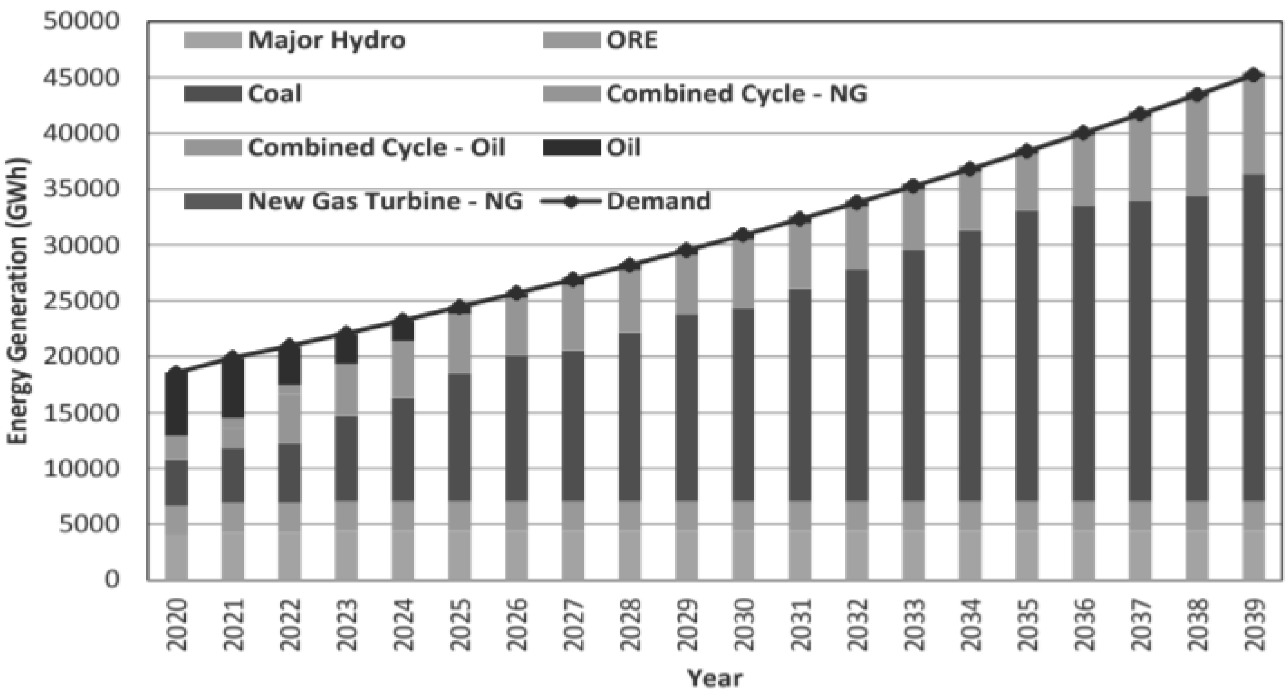
Sri Lanka has almost reached 100% of its electrification level and its renewable energy accounted for 41% of the total installed capacity (4 GW) in FY 2018. In 2018, a maximum demand of 2,616 MW was recorded, and total generation stands to 15,305 GWh. During the same period, coal based thermal power plant accounted for 31% of the total installed capacity and all these thermal plants are owned by Central Electricity Board of Sri Lanka. However, in the last 4 years, the capacity growth has grown at a CAGR of 0.95% while peak demand has grown to 2,616 MW in 2018 from 2,152 MW in 2014 at a CAGR of 5%.



Source: Long Term Generation Expansion Plan 2018-37, Ceylon Electricity Board

However, on the positive side, the transmission and distribution losses decreased to 7.9% in 2018 from 10.2% in 2014. The load factor has grown significantly to 66.8% in 2018 from ~57.5% in 2011. The government has prepared a long-term strategy to achieve an efficient and economical electricity system to the country. According to the Central Electricity Board (CEV) generation plan 2020-39, approx. 3.9 GW of coal based thermal power plant will be added during the period 2020-39. The government of Sri Lanka has plans to develop large scale development projects, which shall lead to increase in demand for electricity in the future.

Figure 79: Sri Lanka projected energy generation (GWh)

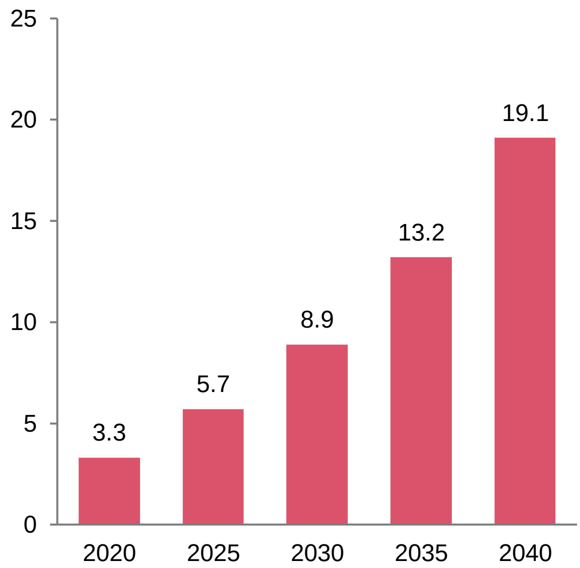


Source: Long Term Generation Expansion Plan 2018-37, Ceylon Electricity Board

Nepal

In the past, the country has suffered serve electricity shortage, especially in the winter season, when the flow of water in the river is low. However, the government has taken multiple initiatives to improve the supply of power by developing new hydropower plants and importing power from India. As on 2016, hydropower plants and thermal power plants contribute to 92% and 5% of the total installed capacity (946 MW) respectively. Over 95% of the households have access to electricity and approx. 60% of the household are connected to the grid. According to Nepal Electricity Authority, the current peak demand is over 1.5 GW, which is expected to increase to 2.3 GW by 2022 and 4.2 GW by 2030 (under business-as-usual scenario).

Figure 80: Nepal projected installed capacity (GW)



Source: Electricity Demand Forecast Report 2015-2040, Government of Nepal

According to Electricity Demand and Forecast Report published by government of Nepal, the total installed capacity requirement is expected to increase to 5.7 GW by 2025 and 19 GW by 2040 under the business-as-usual scenario (4.5% GDP growth rate). As the government has massive plans to develop the infrastructure of Nepal, the demand for electricity is expected to rise significantly. The demand for electricity will further rise with increase in per capita electricity from 138 kWh in 2015 to 464 kWh by 2025 and 1536 kWh by 2040.

5.2. Current deployment of coal-based thermal based on clean coal technologies

Bangladesh

Presently, Bangladesh has only one operational coal-fired power plant (Barapukuria Coal fired Power Station) of capacity 525 MW. To reduce dependency on natural gas-based power plant, multiple coal-fired power plants are under the planning while some are under construction phase. There are three under-construction plants, namely, Matarbari power station, Rampal thermal power plant and Payra coal-based power stations with a total capacity of 3.8 GW. All these plants are based on ultra-supercritical technology.

Table 39: Coal-fired power plants under construction in Bangladesh

Power station	Capacity (MW)	Coal type	Location	Technology	Expected Commencement
Matarbari power station	1,200	Sub-bituminous	Maheshkhali Upazila, Cox's bazar District	Ultra-super critical	2023
Payra thermal power plant	1,320	Sub-bituminous	Kalapara Upazila, Patuakhali District	Ultra-super critical	2019

Power station	Capacity (MW)	Coal type	Location	Technology	Expected Commencement
Rampal power plant	1,320	Sub-bituminous	Rampal Upazila, Bagherhat District	Ultra-super critical	N.A*

The Payra power plant is being developed through a joint venture between Chinese power company (CMC) and North-West Power Generation Company Bangladesh (NWPGCL). The estimated coal requirement of the plant is ~4.12 million tonne per annum, which will be met by coal imported from Indonesia, China and Australia.

The Matarbari power plant is and being developed at Maheshkhali Upazila of Cox's Bazar District of Bangladesh. The power plant is developed by Coal Power Generation Company Bangladesh, a state-owned company, with an estimate investment of USD 4.5 billion. The plant will account for 10% of the total generation capacity in the country. Additionally, a new sea-port will be developed to import coal for the power plant and a new transmission line will also be developed. The power plant will require approx. 3.7 million tonne of coal per annum. The project is partially financed by JICA and developed by Sumitomo, Toshiba and IHI.

Rampal Power Station is developed by Bangladesh India Friendship Power Company Limited, which is a joint venture between Bangladesh Power Development Board and National Thermal Power Company (NTPC), India. The project is developed at a cost of USD 1.5 billion, of which 70% will financed through bank loans while 30% of project cost will be funded by BPDB and NTPC.

In Bangladesh, there is no dedicated legislation/ policy that commits to use of CCS in the power plants and other sectors. It is noteworthy that the consumed gas fields of the country have enormous CO2 storage potential. Among them, 14 gas fields have the capacity to store more than 10 million tonne while two gas fields have the capacity of more than 200 Mt. To mitigate effects of greenhouse gases on environment, health, economics and development, the country can bring in policies and incentives for developers to developed power plants based on clear coal technologies and retrofit the existing power plants with CCS technology.

India

The government has taken various steps focusing on utilization of washed coal, as coal beneficiation was a key challenge for both miners and users of coal. India introduced policy guidelines in 1997, which restricted the use of unwashed coal in the coal-fired power plants that are located 1,000 km away from the mines. Currently, the capacity of coal beneficiation in the country was estimated to be ~70 million tonne per annum, and additional 20 million tonne per annum has been proposed in this regard.

Majority of power generation capacity is based on Post-Combustion CO2 capture technology, which is the oldest and has been adopted in a large scale around the globe. In India, majority of the coal-fired power plants are based on subcritical technology and this technology is expected to be in use even after the penetration of more efficient technologies such as, supercritical and ultra-supercritical technologies. The country's first supercritical power plant was established by NTPC in Sipat, Chhattisgarh with a total capacity of 2,980 MW. Till date only two Ultra Mega Power Projects (UMPPs) were commissioned in India, i.e., Mundra UMPP established at Mundra, Gujarat by Tata Power with a total capacity of 4,000 MW and Sasan UMPP of capacity 3,960 MW located in Madhya Pradesh. Other technologies such as ultra-supercritical and advanced ultra-supercritical are still at a nascent stage in India.

In addition to PCC plants, there are numerous CFBC (Circulating Fluidized-Bed Combustion technology) installations in the country. Low grade coals are the best suited fuel for CFBC boilers. There are more than 36 CFBC units of total installed capacity of 1,200 MW {most of these units being relatively smaller (2-40 MW), with only one large unit of capacity 136 MW}[ciii].

NTPC has installed an Ultra Super-critical power plant at Khargone in Madhya Pradesh while another Ultra Super critical power plant is being set up in Bihar at Buxar.

In India, BHEL developed a 6.2 MW IGCC (Integrated Gasification Combined Cycle) pilot plant in Tiruchirapalli (Trichy) in 1985. With this, India became the first country in Asia to set up IGCC demonstration plant. IGCC is a novel technology that has not been commercially adopted extensively. Till date, there are only four operational plants that are located in the USA and Europe[civ]. The CCS technology that is being developed to employ either in combustion or in gasification pathways of coal-fired power plants is at a very early phase in the country.

Pakistan

While the government has policy and regulation to promote renewable energy technologies, similar policies are yet to be developed to promote clean coal technologies. However, NEPRA, which is a regulatory authority, has set guidelines on key parameters such as efficiency, project and O&M costs for the upcoming coal-fired power plants[1].

According to Private Power and Infrastructure Board (PPIB), Pakistan has numerous coal-based power projects in pipeline, which are at various stages of development. Among these, about 3.1 GW of coal-fired capacity is under construction and significant proportion of these power plants rely on imported coal. However, only limited number of plants are based on domestic lignite, which is sourced from Thar coalfield and is based on subcritical technology[1]. Pakistan is also in the process of setting up a 660 MW ultra-supercritical power plant at Bin Qasim

IF IGCC technology fuelled by Domestic Lignite is adopted for generation of power, the thermal efficiency can increase significantly. In addition to this, higher concentrations of CO2 in the flue gasses may be captured in the well-established natural gas network for capture and storage. This opportunity to adopt CCS technology for storage of CO2 in the its gas reserves post their depletion would provide a potential to store nearly 1.7 Gt CO2. It is estimated that the giant gas fields of Pakistan, the Sui, Mari, Qadirpur and Uch have the capacity to store more than 200 Mt CO2. Further, both the Potwar Basin and the Lower Indus Basin have excellent prospect for saline aquifer CO2 storage[1].

Sri Lanka

Sri Lanka relies on coal imports from neighboring countries to fuel its thermal power plant. The coal-based power in the country comes from Lakvijaya Power Plant (Norochcholai Power Plant), which is the first and so far, the only coal-fired power plant in Sri Lanka. It has three units of 300 MW each and is located in the Puttalam district of the Northwestern province. The power plant based on the subcritical technology and utilizes coal imported from Indonesia. Lakvijaya coal-fired power plant has been operational since 2014. To meet its future demand for electricity, the government is planning to develop multiple highly efficient supercritical coal-fired power plants in the country, considering coal as low-cost energy source option.

Recently, a policy paper on Sri Lanka's electricity generation proposed a "firm energy mix", which represents 30% of power to be generated from high-efficient coal power, while another 30% by LNG or indigenous natural gas, 25% by large hydro, and remaining 15% from furnace oil and NCRE.

Another paper published by the Cabinet, raised concerns upon the pollution caused by the power plants and proposes to employ clean coal technologies such as supercritical or ultra-supercritical coal in the upcoming thermal power plants. The demand for the use of high-efficient coal power technologies has been approved by the Cabinet of Ministers in a view that coal continues to be the most cost-effective electricity generation option.

5.3. Upcoming thermal power plants in the SAARC Regions

Based on the discussion in the previous section, it can be observed that thermal power plants are being planned only in four out of eight SAARC countries. They are Bangladesh, India, Pakistan and Sri Lanka.

Bangladesh

Coal based projects are being encouraged by the government of Bangladesh in an attempt to increase power production and decrease the dependence on gas and expensive fuel oil-based power. By 2022, the government intends to establish 25 coal-fired power plants to generate 23.7 GW. Most of the planned plants are ultra-supercritical and use imported coal. Some of these upcoming coal-based power projects are listed in the below table.

Table 40: Some upcoming coal-based power plants in Bangladesh

Name	Capacity	Executing Agency	Fuel and Technology	Expected Commencement
Moittri Super Thermal Power Project	1320 MW	Bangladesh -India Joint Venture	**Coal source**: High quality imported coal	June, 2021
Matarbari Coal Based Power Pant	1200 MW	CPGCBL	**Coal Type**: Sub-bituminous **Coal Source**: Imported **Technology**: Ultra-supercritical	June, 2022
Payra Coal Based Power Plant	1320 MW	NWPGCL-China Joint Venture	**Coal source**: Imported from Indonesia, China and Australia **Technology**: Ultra-supercritical	March, 2020
G to G Coal Based Power Plant	1320 MW	Bangladesh –S. Korea Joint Venture	NA	June, 2023
Moheshkhali Coal Based Power Plant	1200 MW	BPDB	NA	June, 2024

Name	Capacity	Executing Agency	Fuel and Technology	Expected Commencement
Moheshkhali Coal Based Power Plant	1320 MW	Bangladesh – Malaysia JV	**Coal Source**: Imported coal **Technology**: Ultra-supercritical	June, 2022
Ashuganj 2x660 MW Power Plant	1320 MW	APSCL	**Coal Source**: Imported from Indonesia, China and Australia **Technology**: Ultra-supercritical	NA
1,320 MW Coal Based Power Plant	1320 MW	BPDB –CHDHK, China Joint Venture	Technology: Ultra-supercritical	June, 2021
Banshkhali Coal Power Plant	1320 MW	SS Power-1 Ltd and SS Power-2 Ltd.	**Coal Source**: Imported coal **Technology**: Ultra-supercritical	June, 2020
Mawa, Munshiganj 522MW Coal Power Plant	630 MW	IPP	**Coal Source**: Imported coal	June, 2021
Dhaka 635MW Coal Power Plant	635 MW	Orion Power Unit-2	**Technology**: Ultra-supercritical	December, 2021

Source: Power Sector Review of Bangladesh, 2017 (Retrieved from: http://www.eblsecurities.com/AM_Resources/AM_ResearchReports/SectorReport/Bangladesh%20Power%20Sector%20Overview-2017.pdf)

Among the aforementioned proposed projects, few coal-fired thermal plants are being developed under joint venture government to government initiatives. The government of Bangladesh has signed deals with the countries such as, India, China, South Korea and Malaysia for installation of coal-fired power plants in the country.

India

In India, most of the planned thermal power plants are planned run on supercritical technology utilizing indigenous and imported coal for electricity generation. In addition, there are two lignite-fired power projects based on Circulating Fluidized Bed Combustion (CFBC) technology, which are expected to be commissioned by the end of 2020 in Rajasthan. Tamil Nadu Generation and Distribution Company (TANGEDCO) and Telangana Generation Company (TSGENCO) are planning to set up multiple supercritical power projects in Tamil Nadu and Telangana states respectively. The upcoming thermal power plants are listed below:

Table 41: Some upcoming coal-based power plants in India

Name	Capacity (MW)	Executing Agency	Fuel and Technology	Expected Commencement
Gadarwara Super Thermal Power Project Stage I	2x800	NTPC	**Coal Source:** NTPC Talaipalli coal mine **Technology:** Supercritical	October, 2021
Darlipali Super Thermal Power project	2x800	NTPC	**Coal Source:** Dulanga and Pakri Barwadih Coal Blocks **Technology:** Supercritical	June, 2020

Name	Capacity (MW)	Executing Agency	Fuel and Technology	Expected Commencement
Barsingsar Thermal Power Station Extension	250		**Technology:** Circulating Fluidized Bed Combustion (CFBC)	August, 2020
Bithnok Thermal Power Project	250	NLC India Ltd	**Coal Source:** Lignite mine of .25 MTPA capacity at Bithnok, Rajasthan **Technology:** Circulating Fluidised Bed Combustion (CFBC)	August, 2020
Telangana Super Thermal Power Project	2x800	NTPC	**Technology:** Ultra-supercritical	August, 2020
Ghatampur Thermal Power Project	3x660	NUPPL	**Technology:** Supercritical	May, 2021
Tanda Thermal Power Project Stage II	2x660	NTPC	**Coal Source:** Chatti-Bariyatu and Kerandari Captive Coal Block to be developed by NTPC in North Karanpura Coalfields **Technology:** Supercritical	March, 2020
Uppur Super Critical Thermal Power Project	2x800	TANGEDCO	**Coal Source:** Import from either Indonesia or other countries **Technology:** Supercritical	September, 2020
Udangudi Thermal Power Project	2x660	TANGEDCO	**Coal Source:** Talcher Coal fields of Mahanadi Coalfields Limited in Orissa (70%) and 30% Imported Coal from Indonesia, South Africa, Australia, China **Technology:** Supercritical	March, 2021
Yadadri Thermal Power Project	5x800	TSGENCO	**Technology:** Supercritical	October, 2020
Jawaharpur Super Critical Thermal Power Station	2x660	Jawaharpur Vidyut Utpadan Nigam Ltd	**Technology:** Supercritical	January, 2022
Panki Theramal Power Station Extension	660	NA	NA	January, 2022
Obra C Thermal Power Project	2×660	NA	NA	January, 2021
Tuticorin Thermal Power Project Stage IV	NA	NA	NA	April, 2020

Pakistan

Noticing the importance of coal-based power generation, the government of Pakistan has committed to establish coal-fired power plants in various locations of the country. In this regard, a number of power plants are being proposed to generate electricity using imported as well as indigenous coal.

Table 42: Proposed coal-fired power plants in Pakistan

	Name of Power Plant	Capacity (MW)
Imported Coal	Coal power plants at Punjab	2×660
	Coal power plants at Punjab	5280
	Coal power plants at Jamshoro	2×660
	Coal power plants at Hub	2×660
	Coal power plants at Gawadar	300
	Coal power at Port Qasim Conversion of Jamshoro	2×660
	Power Plant from Oil to Coal Conversion of Muzaffargarh	850
	Power Plant from Oil to Coal Conversion of Guddu	1350
	Power Plant from Oil to Coal Conversion of K-Electric	640
	Power Plant from Oil to Coal Conversion of HUBCO	1260
	Power Plant from Oil to Coal	1292
Local Coal	Sino Sindh Resources (Pvt.) Limited (SSRL) China	7500
	Thar Power Company Ltd. (THARCO) SECM	5000
	Oracle Coalfields UK	1400
	GENCOS	1320
	Sindh/ETON Japan Power	3960

Source: Abdullah Mengal et al., Modeling of Future Electricity Generation and Emissions Assessment for Pakistan, 2019 (Retrieved from: https://www.researchgate.net/publication/332386277_Modeling_of_Future_Electricity_Generation_and_Emissions_Assessment_for_Pakistan)

Sri Lanka

According to the base case scenario developed as part of the LTGEP, six new coal-based power plants are expected to be established during the following two decades in Sri Lanka. Most of these planned thermal power plants will run on high calorific value coal. However, the installation of these new coal-fired power plants is planned only after 2020. The proposed thermal plants up to 2037 on the basis of base case plan are listed in the below table:

Table 43: Thermal (coal-based) projects planned as per LTGEP base case scenario

Year	Thermal (coal-based) Addition	Technology
2023	1x300 MW New Coal Power Plant	Supercritical (to be evaluated)
2024	1x300 MW New Coal Power Plant	Supercritical (to be evaluated)
2025	1x300 MW New Coal Power Plant	Supercritical (to be evaluated)
2028	1x600 MW New Coal Power Plant	Supercritical
2031	1x600 MW New Coal Power Plant	Supercritical
2035	1x600 MW New Coal Power Plant	Supercritical

Source: CEB, Long Term Generation Expansion Plan 2018-2037, 2018 (Retrieved from: https://www.ceb.lk/front_img/img_reports/1532407706CEB_LONG_TERM_GENERATION_EXPANSION_PLAN_2018-2037.pdf)

5.4. Environmental regulation

To meet future electricity demand and to overcome the challenges pertaining to grid stabilization, development of coal based thermal power plants has become crucial for countries such as India, Pakistan, Bangladesh, Sri Lanka and Afghanistan to an extent. However, coal combustion emits harmful air pollutants, which not affect the environment but also the human health. To overcome this challenge, the government is taking various steps to control and reduce the air pollutions levels. In metro cities such as Delhi, Mumbai, Kolkata, Dhaka, Chittagong, Karachi, Lahore, Khulna, Kathmandu, etc., the pollution levels have reached to alarming levels and are listed amongst top 500 polluted cities. Reforms in environmental related policies and stringent emission norms not only help improve the quality of air in the cities but also mandate the state-owned generation companies and independent power producers to adopt to new technologies.

Over the years, except Bhutan, Nepal and Maldives, which generate power majorly from renewable energy, other SAARC countries are strengthening the emission norms. Below mentioned are the emission standards which are applicable for existing and upcoming coal fired thermal power plants

Table 44: Emission standards for coal fired thermal power plant: India

India	
Parameter	**Standards**
Water Consumption	All plants with once through cooling (OTC) shall install cooling towers and achieve water consumption up to maximum of 3.5 m^3 / MWh within a period of two years after 2016. New plants installed after 1st January 2017 shall have to meet specific water consumption up maximum of 2.5 m^3/ MWh and achieve zero water discharged.
Thermal power plants installed before 31st December 2003	

India	
Particulate matter	100 mg/ Nm^3
Sulphur dioxide (SO2)	600 mg/ Nm^3 (below 500 MW capacity units) 200 mg/ Nm^3 (500 MW and above capacity units)
Oxides of nitrogen (NOX)	600 mg/ Nm^3
Mercury (Hg)	0.03 mg/ Nm^3 (500 MW and above capacity units)
Thermal power plants installed after 31st December 2003, up to 31st December 2016	
Particulate matter	50 mg/ Nm^3
Sulphur dioxide (SO2)	600 mg/ Nm^3 (below 500 MW capacity units) 200 mg/ Nm^3 (500 MW and above capacity units)
Oxides of nitrogen (NOX)	300 mg/ Nm^3
Mercury (Hg)	0.03 mg/ Nm^3
Thermal power plants installed after 31st December 2003, up to 31st December 2016	
Particulate matter	30 mg/ Nm^3
Sulphur dioxide (SO2)	100 mg/ Nm^3
Oxides of nitrogen (NOX)	100 mg/ Nm^3
Mercury (Hg)	0.03 mg/ Nm^3

Source: Ministry of Environment, Forest and Climate Change

Table 45: Emission standards for coal fired thermal power plant: Pakistan

Pakistan	
Parameter	**Standards**
Particulate matter	Non-degraded airshed: 50 mg/ Nm^3 Degraded airshed: 30 mg/ Nm^3
Sulphur Dioxide (SO2)	**Capacity more than 50 MW but less than 600 MW** Non-degraded airshed: 900-1500 mg/ Nm^3 Degraded airshed: 400 mg/ Nm^3 **Capacity more than 600 MW** Non-degraded airshed: 200-850 mg/ Nm^3 Degraded airshed: 200 mg/ Nm^3
Nitrogen Oxides (NOX)	Non-degraded airshed: 510-1100 mg/ Nm^3 Degraded airshed: 200 mg/ Nm^3
Dry Gas Excess Oxygen Content	6%

Source: National environment quality standards, Pakistan

Table 46: Emission standards for coal fired thermal power plant: Bangladesh

Bangladesh	
Parameter	**Standards**
Particulate matter	Capacity less 200 MW: 350 mg/ Nm^3 Capacity 200 MW and above: 150 mg/ Nm^3
Sulphur Dioxide (SO2) – lowest height of stack	Below 200 MW: 14 m More than 200MW but less than 500 MW: 220 m 500 MW and above: 275 m^2
Nitrogen Oxides (NOX)	600 mg/ Nm^3

Source: Report on Environmental Impact Assessment of construction of Matarbari 600x2 MW coal fired thermal power plant and associated facilities, Tokyo Electric Power Services Co. Ltd

Table 47: Emission standards for coal fired thermal power plant: Sri Lanka

Sri Lanka	
Parameter	**Standards**
Particulate matter	Less than 50 MW: 200 mg/ Nm^3 50 MW and above: 150 mg/ Nm^3
Sulphur Dioxide (SO2)	Less than 50 MW: 1600 mg/ Nm^3 50 MW and above: 850 mg/ Nm^3 *(for new power plants with maximum 50kg SO2 per day per MW subject to maximum 30 metric tonne of SO2 per day for first 500MW plus 25kg SO2 per day per MW for each additional MW.)*
Nitrogen Oxides (NOX)	Less than 50 MW: 750 mg/ Nm^3 50 MW and above: 650 mg/ Nm^3
Smoke	Less than 50 MW: 20% opacity 50 MW and above: 15% opacity

Source: National Environment Act No 47 of 1980

While the five SAARC countries have developed emission standards based on the local condition, these emission norms can be further scrutinized to be at par with emission standards of developed economies such China, the USA, Australia, etc. However, raising the level of emission standards would lead to increase in electricity tariffs. Installation of expensive environmental facilities could impose financial burden on the state and national government. There would be a need to collaborate with international and domestic financial institutions to accelerate the implementation of higher emission standards in the country.

Emission standards for coal-based power plants in developed countries are

Table 48: Global emission standards for coal fired thermal power plant

Country	SOX	NOX	Particulate Matter
China	New: 100 mg/ m^3	100 mg/ m^3	Key regions: 20 mg/ m^3

Country	SOX	NOX	Particulate Matter
	Existing: 200 mg/ m^3 Key regions: 50 mg/ m^3		Other regions: 30 mg/ m^3
European Union	**Existing coal/lignite power plant**: 50-100 MW: 400 mg/ m^3 100-300 MW: 250 mg/ m^3 More than 300 MW: 200 mg/ m^3 **New/ Retrofitted power plant**: 50-100 MW: 400 mg/ m^3 100-300 MW: 200 mg/ m^3 More than 300 MW: 150 mg/ m^3	**Existing coal/lignite power plant**: 50-100 MW: 300 mg/ m^3 100-300 MW: 200 mg/ m^3 More than 300 MW: 200 mg/ m^3 **New/ Retrofitted power plant**: 50-100 MW: 300 mg/ m^3 100-300 MW: 200 mg/ m^3 More than 300 MW: 150 mg/ m^3	**Existing coal/lignite power plant**: 50-100 MW: 30 mg/ m^3 100-300 MW: 25 mg/ m^3 More than 300 MW: 20 mg/ m^3 **New/ Retrofitted power plant**: 50-100 MW: 20 mg/ m^3 100-300 MW: 20 mg/ m^3 More than 300 MW: 10 mg/ m^3
Japan	50 ppm	200 ppm	100 ppm

Source: Emission standards and control of $PM_{2.5}$ from coal fired thermal power plant, 2016

5.5. Gap Assessment and proposed mitigations in deployment of CCTs

Political Risks

Political risks are one of the highest-ranking factors that directly impact the investment decisions. According to the report published by "weforum", over 20% of the executives regard regulatory political risk as one of the biggest challenges for any investment in the emerging markets. In the landscape of infrastructure projects, the political decision coupled with regulatory decisions can lead to:

- Cancellation or change of scope of an on-going projects
- Difficulty in getting environmental and regulatory permits to commence the construction or operate the power plant
- Change in government policies of industry regulation risk i.e. changes in emission laws, restriction on foreign ownerships, changes in labour laws, etc.
- Taxation risk, which includes introduction of special taxes or increase in corporate taxes
- Judicial risk, which includes judicial system, is unable to function in a timely, efficient and independent way, delay in court decision, uncertainty in enforcement of legal titles, etc.
- Breach of contract risk includes delay or denial of payments

Technological Barriers

Over the past few decades, subcritical PF combustion was the predominant coal technology that was widely used in the SAARC countries. Over the few years, with the need to reduce the emission of harmful gases, supercritical and ultra-supercritical technology are being deployed in countries such as India and Pakistan. However, these two new technologies are relatively less flexible and require longer construction time as compared to subcritical PF combustion technology. The below mentioned are few factors, which directly impact the selection of Clean Coal Technologies.

- Selection of fuel, which includes various factors such as quality of LCV coals, price per ton, transportation cost, constant supply of LCV coal to the power plants, etc. have direct impact on the selection of technology and operation of the power plant.

- Maturity of technologies: Over the years, the government is pushing the developers to adopt supercritical or ultra-supercritical thermal power plants. This aims to increase the efficiency of the power and at the same time reduce emissions. However, adoption of these newer and efficient technologies is a major challenge, as the government is more focused on adopting renewable energy technologies due to lower tariff and easy installations.

- Availability and reliability: As the demand for power plants fluctuates, the revenues of the power plant reduce drastically, which burdens the cost of maintenance/ repair and affects the economic lifetime of the equipment's. As the new technologies are yet to achieve economies of scale, the costs associated with unscheduled breakdowns and maintenance tend to be higher.

- Lack of technical skills: There is lack of skilled manpower, who is well-versed with the new technology (supercritical and ultra-supercritical). There are lack of professional training and education institutes, which can provide necessary skill set to operators.

Administrative Barriers

Administrative cost has been the bottleneck for development of power plants, transmission and distribution and other infrastructure projects in SAARC countries. Administrative cost can have significant impact on the overall project cost leading to increase in tariff rates. Some of the common barriers include:

- Cumbersome procedures: Acquiring necessary approvals prior to commencement of the project is complex and cumbersome process. One of the major reasons is lack of coordination amongst the government agencies at national and state levels.

- Expensive procedure to obtain RoW (Right-of-Way): Land acquisition for RoW is a challenge for the developers for construction of power plant and construction of railway siding that can drastically reduce the transportation cost and time. On the other hand, private and public sector transmission projects also face difficulties such as delay in land acquisition, acquiring RoW, etc. which lead to off-takers risk. Availability of obsolete information on land and ambiguous property rights has resulted delay in property related issues.

- Unclear administrative framework leads to corruption, lack of transparency, discretionary power of the administration and conflict arising due to statutory provisions.

- There is huge delay in implementation of coal mining projects due to delay in obtaining forest clearance, environment clearance, land acquisition, and other issues, which are related to resettlement and rehabilitation, evacuation facilities, contracts, etc. This directly impacts the viability of power plants, which depended on the usage of LCV coal from these coal mines.

Economic barriers

In countries such as Afghanistan, Bangladesh, Nepal, and Sri Lanka, there is insufficient public fund to invest in greenfield thermal power plant based on Clean Coal Technologies. The national and state levels such as in India, Nepal, Bhutan, Pakistan and Maldives have developed policies and provide incentives to investors/ developers to set up renewable energy plants. As a result, the investors are more inclined towards investing in renewable energy projects as compared to in thermal power plant. There is lack of such financial incentives to set up thermal power plants, using the latest clean coal technology.

Another major issue for a developer is access to funds, as the banks are wary to provide loans in the thermal power sector. For example, in case of India, thermal power sector accounts to approximately USD 40-60 billion of potential stranded assets, which are troubling the banking sector. Amongst these stranded assets, over 15GW (total 40 GW) are yet to be commissioned, while 16 GW of thermal power plants are drastically affected due to increase in price of imported coals.

The thermal power plants in India, which have fuel supply agreement with CIL and its subsidiaries, face difficulty in transportation of coal on timely manner, which hampers their operations. Due to high tariff, state Distribution Companies have either requested the developers to reduce the tariff or requested to cancel the Power Purchase Agreement. This has imposed significant threat to the viability of large thermal power plants. While water remains a major constraint, usage of outdated subcritical technology has impacted the operation of thermal power plants resulting in government imposing fines on developers. On account of these issues, promoters are forced to take up to 100% write offs on their equity. On the other hand, where thermal power plants are fully operational, the developer are unable to receive timely payments from the Distribution Companies (DISCOMS).

While the demand for power has increased significantly over the years in the SAARC countries, access to power and quality of power remains an issue for the consumers especially in rural areas. Despite efforts taken by the respective government to electrify villages, continuous supply of electricity remains a major challenge, which is partially addressed by setting up solar power plants.

Barriers pertaining to transportation of coal

Efficient means of transportation of coal not only allows the power plant to be operational continuously but also has positive impact on the overall tariff per unit. For a country like Nepal and Bhutan, transportation of coal from the mine to the power plant can be a big challenge, given the mountainous landscape of these two countries. While in India and Pakistan, majority of the coal mines are located in the eastern side of the respective countries. To ensure constant supply of coal from coal mines to the power, the government has to allocate large investments towards the development of new roads and rail network.

If the thermal power plant is located nearby the coal mine, coal can be transported through conveyors, which is effective but requires acquisition of land and additional approvals from the ministry of forest department. Additionally, it also requires deployment of large capital to set up the conveyor system. Amongst all the modes of transportation, cost of transportation of coal through conveyor system is the highest over long distances, compared to transportation cost associated with other modes. However, the conveyor system is the chosen option as the distance between the plant and the mine reduces.

Using railway network to transport coal, the overall transportation cost is reduced to a large extent. Additionally, unloading of coal in the site is easier, compared to unloading of coal from trucks, which requires additional manpower and is a time-consuming process. However, as there are delays in acquisition of land and getting approvals for construction of railway siding, many developers are forced to transport coal via trucks.

Transportation of coal also impacts the environment due to pollution causes by the diesel burning trucks, trains and barges. Black carbon released from diesel combustion contributes to the global warming and causes serious health issues due to toxic emission such as NOX, SOX, PM2.5, PM10 volatile organic chemicals, carbon dioxide and Carbon monoxide.

Environmental Concerns

Despite improvement in technologies to produce energy by using coal as fuel, thermal power plant would still pump out large amount of greenhouse gases and ash, which are basically the by-products of burning the coals. Amongst the toxic emissions, carbon dioxide released from thermal power plant is one of the largest contributors to global warming. SO2 causes acid rains, which can acidify river, lakes and other water bodies destroying the aquatic life and also damage the trees and plant, especially which are located in the higher altitudes.

To address this issue, the governments of SAARC countries have made efforts to reduce emission of Sulphur Dioxide by mandating installation of FGDs (Flue Gas Desulfurization) in old thermal power plants. While the coal thermal power plants not only cause air pollution but also damage the water bodies surrounding the thermal power plants. There are many thermal power plants that do not have proper effluent treatment plants, which can drastically reduce the contaminants level within the permissible limit before discharging the water in the nearby lakes or rivers.

In addition to this, disposal of coal combustion waste (CCW) is one of the greatest challenges, as it contains non-combustible constituents such as arsenic, mercury, lead, etc. Despite the availability of various options such as landfilling, mine filling, surface impoundments, etc. to handle CCW, CCW can still cause significant harm both environment and human health.

The current barriers listed above have been mapped to each country in the SAARC region based on their intensity:

Table 49: Mapping of key barriers to SAARC countries

Country	Political	Technological	Administrative	Economic	Coal transport	Environment
Afghanistan	Medium	High	High	High	High	Medium
Bangladesh	Medium	High	Medium	High	High	High
Bhutan	Low	High	Low	Medium	High	Low
India	Medium	Medium	Low	Medium	Medium	High
Maldives	Medium	High	Low	Medium	N/A	Medium

Country	Political	Technological	Administrative	Economic	Coal transport	Environment
Nepal	Medium	High	Medium	High	High	Medium
Pakistan	Medium	Medium	Medium	High	Medium	High
Sri Lanka	Medium	High	Medium	High	Medium	Medium

Mitigation measures to be undertaken in each SAARC country for identified barriers

1. **Afghanistan:** Has high technological, administrative, economic and coal transportation barriers due to limited infrastructure and low focus on technological advancements. The political risks are also significant due to some degree of instability in the country. The following mitigation measures may be undertaken in the country:
    a. For rapid application of supercritical or ultra-supercritical technology, the development of skills, construction materials and operations must be the key focus.kl
    b. A single window clearance mechanism is required for projects using CCTs so that all approvals and clearances for the project are facilitated by a single body that coordinates with other agencies to expedite the approval process.
    c. Afghanistan may work with multilateral financial institutions to facilitate soft loans for projects using clean coal technologies for generation using low CV coal.
    d. Infrastructural upgradation within Afghanistan can reduce the cost and time taken for coal transportation and reduce dependence on a single transportation method
    e. Clean coal technologies such as Pre-treatment, coal washing, drying, sizing, oxy-CBFC, Carbon Capture methods, FGDs, SNCR, ESPs must be used in the coal plants to mitigate environmental risks of coal generation.

2. **Bangladesh:** Has high barriers in the technological and economic aspects due to limited funding for coal-based power generation and as a result has low investments in the research and development of clean coal technologies. The administrative and political risks are also significant but lesser than the other barriers. The following mitigation measures may be undertaken in the country:
    a. Bangladesh may engage with developed nations in technology transfers to gain key insights into the nuances of clean coal technologies and build their technical capabilities.
    b. Right-of-Way and land acquisition issues need to be resolved by maintaining and updating land records on a regular basis. The land owners must be compensated based on standard circle rates and a nodal authority with quasi-judicial powers must enforce this acquisition to avoid delays in project completion.
    c. Policy measures such as tax concessions and duty waivers may be introduced to promote the clean coal technologies. Bangladesh may also work with multilateral financial institutions to facilitate soft loans for projects using clean coal technologies for generation using low CV coal.

d. The coal generation plants must be set up as close as possible to the coal mines to eliminate transportation issues at the root. Infrastructural upgradation within Bangladesh can reduce the cost and time taken for coal transportation and reduce dependence on a single transportation method

e. Clean coal technologies such as Pre-treatment, coal washing, drying, sizing, Carbon Capture methods, SNCR must be used in the coal plants to comply with emission norms and mitigate environmental risks of coal generation in Bangladesh.

3. **Bhutan:** Has a conducive political and administrative environment for the development of power plants using clean coal technologies. The environmental concerns are also low in Bhutan. However, technological, coal transportation and financing challenges remain significant in the country. The following mitigation measures may be undertaken in the country:

   a. For rapid application of supercritical or ultra-supercritical technology, the development of skills, construction materials and operations must be the key focus.

   b. Bhutan may work with multilateral financial institutions to facilitate soft loans for projects using clean coal technologies for generation using low CV coal.

   c. Infrastructural upgradation within Bhutan can reduce the cost and time taken for coal transportation and reduce dependence on a single transportation method

4. **India:** Technologically advanced compared to other SAARC countries with continuous efforts in place to completely shift from sub-critical to super-critical technology in coal power generation. Administrative challenges in India are also relatively lower. Environmental concerns, however, are high in the region and need to be addressed. The following mitigation measures may be undertaken in the country:

   a. India may engage with developed nations in technology transfers to gain key insights into the nuances of clean coal technologies and build their technical capabilities.

   b. Right-of-Way and land acquisition issues need to be resolved by maintaining and updating land records on a regular basis. The land owners must be compensated based on standard circle rates and a nodal authority with quasi-judicial powers must enforce this acquisition to avoid delays in project completion.

   c. Policy measures such as tax concessions and duty waivers may be introduced to promote the clean coal technologies. India may also work with multilateral financial institutions to facilitate soft loans for projects using clean coal technologies for generation using low CV coal.

   d. The coal generation plants must be set up as close as possible to the coal mines to eliminate transportation issues at the root. Infrastructural upgradation within India can reduce the cost and time taken for coal transportation and reduce dependence on a single transportation method

   e. Clean coal technologies such as Pre-treatment, coal washing, drying, sizing, oxy-CBFC, Carbon Capture methods, FGDs, SNCR, ESPs must be used in the coal plants to comply with emission norms and mitigate environmental risks of coal generation in India.

5. **Maldives:** Has a high technological barrier to development of clean coal technologies due to lack of experience with coal power generation. The political, administrative and financing barriers are also significant in the country and may pose challenges in the development of clean coal power generation. The following mitigation measures may be undertaken in the country:
    a. For rapid application of supercritical or ultra-supercritical technology, the development of skills, construction materials and operations must be the key focus.
    b. Maldives may work with multilateral financial institutions to facilitate soft loans for projects using clean coal technologies for generation using low CV coal.
    c. Clean coal technologies such as Pre-treatment, coal washing, drying, sizing, oxy-CBFC, Carbon Capture methods, FGDs, SNCR, ESPs may be used in the coal plants to mitigate environmental risks of coal generation in Maldives.

6. **Nepal:** Has a mountainous terrain which poses potential difficulties in coal transportation. Due to lack of research into clean coal technologies, the technological barriers remain high along with financing challenges for coal-based generation projects. The following mitigation measures may be undertaken in the country:
    a. For rapid application of supercritical or ultra-supercritical technology, the development of skills, construction materials and operations must be the key focus.
    b. Nepal may work with multilateral financial institutions to facilitate soft loans for projects using clean coal technologies for generation using low CV coal.
    c. Infrastructural upgradation within Nepal can reduce the cost and time taken for coal transportation and reduce dependence on a single transportation method
    d. Clean coal technologies such as Pre-treatment, coal washing, drying, sizing, oxy-CBFC, Carbon Capture methods, FGDs, SNCR, ESPs may be used in the coal plants to mitigate environmental risks of coal generation in Nepal.

7. **Pakistan:** Another relatively technologically advanced country apart from India in the SAARC region with some coal generation plants deploying supercritical technology. However, administrative and political challenges are significant in the country and environmental concerns are high. The following mitigation measures may be undertaken in the country:
    a. Pakistan may engage with developed nations in technology transfers to gain key insights into the nuances of clean coal technologies and build their technical capabilities.
    b. Right-of-Way and land acquisition issues need to be resolved by maintaining and updating land records on a regular basis. The land owners must be compensated based on standard circle rates and a nodal authority with quasi-judicial powers must enforce this acquisition to avoid delays in project completion.
    c. Policy measures such as tax concessions and duty waivers may be introduced to promote the clean coal technologies. Pakistan may also work with multilateral financial institutions to facilitate soft loans for projects using clean coal technologies for generation using low CV coal.

d. The coal generation plants must be set up as close as possible to the coal mines to eliminate transportation issues at the root. Infrastructural upgradation within Pakistan can reduce the cost and time taken for coal transportation and reduce dependence on a single transportation method

e. Clean coal technologies such as Pre-treatment, coal washing, drying, sizing, Carbon Capture methods, FGDs, SNCR, ESPs must be used in the coal plants to comply with emission norms and mitigate environmental risks of coal generation in Pakistan.

8. **Sri Lanka:** Has high technological barriers due to less experience with coal-based generation and also faces financing constraints around coal-based generation technologies. The political, administrative and environmental challenges are also significant in the country. Following mitigation measures are advisable:

   a. For rapid application of supercritical or ultra-supercritical technology, the development of skills, construction materials and operations must be the key focus.

   b. A single window clearance mechanism is required for projects using CCTs so that all approvals and clearances for the project are facilitated by a single body that coordinates with other agencies to expedite the approval process.

   c. Sri Lanka may work with multilateral financial institutions to facilitate soft loans for projects using clean coal technologies for generation using low CV coal.

   d. Infrastructural upgradation within Sri Lanka can reduce the cost and time taken for coal transportation and reduce dependence on a single transportation method

   e. Clean coal technologies such as Pre-treatment, coal washing, drying, sizing, Carbon Capture methods, ESPs must be used in the coal plants to comply with emission norms and mitigate environmental risks of coal generation.

On implementation of the mitigation measures mentioned above, the intensity of the risks towards the barriers discussed for SAARC region shall be as follows:

Table 50: Mapping of key barriers to SAARC countries after undertaking the Mitigation measures

Country	Political	Technological	Administrative	Economic	Coal transport	Environment
Afghanistan	Medium	High	High	Medium	Low	Low
Bangladesh	Low	Medium	Medium	Medium	Medium	Low
Bhutan	Low	High	Low	Low	High	Low
India	Low	Medium	Low	Medium	Low	Medium
Maldives	Low	Medium	Medium	Low	N/A	Low
Nepal	Low	Medium	Medium	High	High	Low
Pakistan	Medium	Medium	Medium	High	Medium	Medium
Sri Lanka	Medium	High	Medium	High	Low	Low

6. Key Recommendations and Way Forward

Key Recommendations and Way Forward

6.1. Recommendations

a. Countries should keep their technology options open for the long-term

With constantly evolving global technological development and applicability of technologies, the countries should be flexible in terms of selection of technology and keep their options open to adopt new technologies prior to construction of coal based thermal power plant. Given the various technological advancements which primarily focuses on increasing electricity generation per kg of coal and reducing toxic emission, the countries shall develop a long-term strategy to incentivize and promote the use of these technologies.

There are technical uncertainties regarding technologies such as ultra-supercritical, IGCC, carbon capture storage, etc. while combustion technologies continue to be more efficient, oxygen fueled combustion increases the potential of combustion-based power plants, which are able to capture carbon more efficiently in a cost-effective manner. On the other hand, there will be technical improvements and cost reductions in gasification technologies too. It is also estimated that IGCC technology will be widely adopted in industrialized country power market as carbon capture storage will become a reality in the next few years.

Depending on the rate of technological progress, the government as well as private developers should be open to adopt new technology to generate electricity. The SAARC countries shall make collaborative efforts to open R&D centers in materials and adaptation research. These R&D centers can be supported by state-owned generation companies, international manufacturers, petrochemical industry, coal industry, academic institutions, etc. Given large technological advancement that is taking place globally, these R&D centers can be linked to international R&D activities. These R&D centers could help evaluate performance of technologies such as IGCC using domestic coal and imported coal (from Indonesia, Australia, South Africa, etc.). This would also help the SAARC countries to gain significant experience.

b. Improved coordination amongst various government authorities to develop policies/ regulation to promote clean coal technologies

The institutional landscape in the SAARC nation's power sector is evolving drastically from the last few years. Multiple institutions have different interests, which increase the complexity to the policy making and planning environment. While Ministry of Power plays a crucial role and influences the power sector of a country, the Ministry of Finance also plays a critical role in developing a sound power sector policy. Similarly, the planning commission plays an integrative role to determine priorities and formulate guidelines.

Given the fact that various ministries, organizations and other public sector enterprises are involved in the power sector, the policies and actions of individual institutions can impact the power sector policy to a large extent including technology related policies. Combining technology roadmap and regulatory processes would be critical to realize the potential of technological advancement offered to coal based thermal power plants. Hence, there is a need for improved coordination amongst various government authorities such as ministry of power, ministry coal, ministry of industries, regulatory authorities, state-owned power generation companies, DISCOMs, etc. of a country.

c. Privatization and PPP (Public Private Partnership) can influence the deployment of new technology

Privatization tends to improve both quality and efficiency of electricity supply, which directly impacts the financial viability of power generation, transmission and distribution. At the same time, privatization has accelerated the growth of power sector in countries such as India, Pakistan, Bangladesh, Nepal, etc. It also helps domestic companies to collaborate with foreign technology providers for transfer of know- how of new technologies such as ultra-supercritical, advanced ultra-supercritical, etc. As there is no clear directive to deal with installation of more expensive technologies, the cost for retrofitting the existing power plants and to develop a greenfield project increased significantly. In such scenarios, participation of private players through competitive biddings process will have positive impact on the nature of technology that is being deployed. Additionally, privatization can help increase the investment made towards R&D to gain competitive advantage, increases foreign investment, improves revenue realization and data collection, reduces demand supply gap, etc. To increase private participation especially to deploy clean coal technologies, the respective government should create a competitive environment, which focuses on key aspects such as:

- Reduce entry barriers
- Financial incentives in the form of tax benefits
- Allocation of coal block to private companies
- Promote competition which can benefit the consumers directly.
- Facilitate FDI through automatic route
- Giving approvals and clearance in time bound manner
- Assist private companies in acquisition of land
- Remove the need for license to install and generate power via thermal power plants etc.

d. Retrofitting of existing thermal power plants

The government should provide financial incentives, reform existing policies and tighten the emissions norms to promote retrofitting of old thermal power plants, which can reduce CO2 emission per unit of electricity generated. It is estimated that emission can be reduced by 4-5%, if new technologies are introduced to older thermal power plants. Also, conversion of existing thermal plant to state-of-the-art coal based thermal power plant is easier especially in terms of getting approvals and clearances as compared to develop greenfield coal based thermal power plants, where acquisition of land is a major issue. The older power plants can be retrofitted by supercritical boiler, ultra-supercritical boiler, advanced ultra-supercritical, IGCC, etc. For countries such as India, and Pakistan, which already have coal based thermal power plant, retrofitting would a viable option and play a crucial role to increase the supply of electricity.

China is the home to world's largest coal based thermal plants. In past few years, SO2 emission declined by 38% and NOX emission fell by 43%. The government of China developed policies to mandate installation of FGD units in the existing thermal power plant and as on 2015, FGD penetration reached 93%. The government introduced new emission norms for coal-based power plant and developed policies, which ensured that power plants are compensated for adopting cleaner technologies. The government introduced the concept of differential tariffs, where developers are rewarded with additional tariff above the grid tariff level. As on 2017, over 100 GW of coal based thermal power plants have been retrofitted with ultra-low emission technology and aim to retrofit 420 GW of coal power plants by 2020.

e. Increase production of coal to fuel upcoming coal based thermal power plant

Coal is predominantly the single largest source of electricity generation in the world. Countries such as Afghanistan, Pakistan, India, Sri Lanka, and Bangladesh have developed long-term strategies to introduce large scale coal fired power plants to meet its future energy requirements. As a result, it is crucial for these countries to have a constant supply of coal domestic coal mines or imported coals. Countries such as Afghanistan, Pakistan, Nepal, and Bangladesh are yet to operate their coal mines at full capacity. By doing so, their dependency on imported coal can reduce substantially. With development of mines, the upcoming thermal power plants can be built nearby these coal mines, which reduce the price of coal to a large extent. The governments of respective SAARC countries shall focus on strengthening Ministry, which is responsible for the development of coal mines in the countries and collaborating international coal mine operators to gain technical and operational know-how of the system. At the same time, the government could also lease the coal mines to private developers through an auction process as in the case of India. Development of coal mines not only impacts the power sectors but also has positive impact on non-power sectors such as steel industry, cement, fertilizer, etc. which in-turn impacts the economic growth of a country.

f. Ease financing of clean coal technologies

In order to ease the financing available for the use of retrofitting technologies and pre combustion clean coal technologies, these technologies may be financed using green bonds. Countries such as China have already classified clean coal power generation projects as a category to be financed using green bonds. Additionally, a fund may be created by SAARC countries that facilitates the financing of technologies under Government-to-Government funding between the nations so that the adoption of such technologies is not impeded by financing constraints.

g. Facilitate cross border trade of Low Calorific value coal

The SAARC countries have varying amounts of low calorific value coal and countries such as Bhutan, Nepal, Maldives and Sri Lanka have no reserves of LCV coal. Thus, all countries can benefit from the trade of low calorific value coal for an appropriate amount of high/medium calorific value coal or other resources. This will ensure optimum usage of LCV coal irrespective of the lack or excess of reserves in a specific country. Trade policies must evolve in SAARC countries to facilitate smooth trade of LCV coal across borders.

Table 51: Timeframe for implementation of the Recommendations

Recommendations	Proposed Timelines
(i) Countries should keep their technology options open for the long-term	Medium to Long Term
(ii) Improved coordination amongst various government authorities to develop policies/ regulation to promote clean coal technologies	Short Term
(iii) Privatization and PPP (Public Private Partnership) can influence the deployment of new technology	Short to Medium Term
(iv) Retrofitting of existing thermal power plants	Short Term
(v) Increase production of coal to fuel upcoming coal based thermal power plant	Short to Medium Term
(vi) Creation of SAARC level fund for G2G financing of clean coal technologies	Short to Medium Term
(vii) Evolve trade policies to facilitate trade of LCV coal among SAARC countries	Medium to Long Term

6.2. Way Forward

Each of the SAARC countries has developed a roadmap to implement program and build power plants, which shall meet the future energy requirements. However, specific policies and guidelines related to clean coal technologies are yet to be developed. **The SAARC countries must develop these clean coal technology related policies and guidelines to set the roadmap for implementation of the clean coal technology.**

Since most of the SAARC countries cannot claim to have indigenous capabilities in developing such technologies while these are already available internationally, the countries may consider **entering into technology transfer arrangement with global clean coal technology providers** which can pave the way for indigenization of the technology for affordable implementation.

Since many aspects of thermal power generation using technologies mentioned in this Report are technology intensive, **significant capacity building effort is expected from various stakeholders** like existing Power Generators, Ministries, Electricity Regulators, Financiers, Equipment Manufacturers, existing Grid Management Systems, Pollution control Agencies, etc

The countries should also focus on assessing the current state of coal sector and **taking necessary steps to exploit their coal resources**, as they can create a solid foundation to set up thermal power plants based on new technologies.

Renewable energy has a disadvantage of being intermittent in nature and cannot be solely relied upon for constant power supply to the grid. Coal use for power generation becomes important in such a scenario. High grade coal is available in countries such as Australia, South Africa, Indonesia and the USA and is limited in the SAARC countries. Thus, this further makes it **imperative to use low grade coal for power generation**

in SAARC countries, which will have the dual advantages of boosting their energy security and providing power at lower costs.

The SAARC countries can **learn from the experience of other countries such as China, the USA, etc. to gain technical and operational know-how of clean coal technologies.** This shall help SAARC countries to take a big step at once to develop upcoming coal based thermal power plant based on these technologies. The countries need to further tighten their environmental norms and provide incentives in the form of tax rebate to promote use of upcoming technologies. While countries such as India and Pakistan, which have significant number of coal fired power plants, should also focus on retrofitting of these power plants to reduce toxic emissions and efficiently generate power.

7. Bibliography

Bibliography

[i] Overview of South Asian Power Sector, SARI/EI Program activities

[ii] Bangladesh Power Development Board

[iii] The Evolving Energy Landscape in India – Opportunities for Investment (2018), Deloitte

[iv] BP Energy Outlook – 2019

[v] Monthly Bulletin of Statistics, December 2018

[vi] An article by The News

[vii] Coal and hard rock resources in Bangladesh, Afia Akhtar

[viii] United States Geological Survey

[ix] Comparative study of Bangladesh barapukuria coal with those of various other countries, Journal of Bangladesh Chemical Society

[x] Energy statistics 2019, Govt. of India

[xi] Global perspective on the use of low quality coals, Stephen J Mills, January 2011

[xii] European Coal resources, European Commission, DG Energy

[xiii] Kirk-Othmer Encyclopedia of Chemical Technology

[xiv] BP Statistical Review of World Energy, June 2018

[xv] Utilisation of low rank coals, April 2011

[xvi] Global perspective on the use of low quality coals, January 2011

[xvii] Overview of steel sector, Ministry of Steel

[xviii] National Steel Policy, 2017

[xix] WorldSteel, S&P Global Platts

[xx] Cement Manufacturers Association, India

[xxi] Pakistan Economic Survey 2014-15

[xxii] Energy and Economic Growth, Applied Research Programme, Energy in Nepal, 2016

[xxiii] Brick Sector in Nepal, National Policy Framework, August 2017

[xxiv] Energy Data Sheet, Water and Energy Commission Secretariat (WECS), June 2014

[xxv] Energy and Environment Division (EED)/Federation of Nepalese Chamber of Commerce and Industry

[xxvi] https://poweringpastcoal.org/insights/energy-security/indian-coal-power-faces-long-term-headwinds

[xxvii] https://economictimes.indiatimes.com/industry/indl-goods/svs/metals-mining/indias-2018-thermal-coal-imports-grew-at-fastest-pace-in-4-yrs/articleshow/67718101.cms?from=mdr

[xxviii] Coalspot.com

[xxix] National Electricity Plan (2018), Central Electricity Authority

[xxx] Pakistan's Power Future, Institute for Energy Economics and Financial Analysis, December 2018

[xxxi] Coal-fired Power Generation in Pakistan: A Policy Paper, SDPI

[xxxii] Clean coal technologies for advanced power generation, Miller B.G (2017)

[xxxiii] Technologies for Reducing Emissions in Coal-Fired Power Plants, Masaki Takahashi

[xxxiv] Case Study Of Supercritical Boiler Technology, IRJET, 2018

[xxxv] A Lead Market Approach Towards the Emergence and Diffusion of Coal-fired Power Plant Technology, 2010

[xxxvi] Comparison of Technologies, ERIA Research Project Report, 2015

[xxxvii] Annual Technology Baseline: Electricity (https://atb.nrel.gov/electricity/2019/index.html?t=cc)

[xxxviii] Monthly report on broad status of thermal power projects in the country, September 2019, India

[xxxix] U.S Department of Energy; Office of Scientific and Technical Information (https://www.osti.gov/servlets/purl/1510966)

[xl] IEA, Power generation from coal, 2011

[xli] Technologies for Reducing Emissions in Coal-Fired Power Plants, Masaki Takahashi

[xlii] Comparison of Technologies, Economic Research Institute for ASEAN and East Asia (ERIA)

[xliii] Clean Coal Technologies, Department of Environmental Sciences and Engineering, Tsinghua University, Beijing, P. R. China

[xliv] Improve coal quality http://www.4cleanair.org/sites/default/files/Documents/Chapter_4.pdf

[xlv] Science Direct https://www.sciencedirect.com/topics/engineering/coal-beneficiation

[xlvi] Coal Preparation, Department of Trade and Industry (https://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file19296.pdf)

[xlvii] Mindat.org (https://www.mindat.org/glossary/jig_washer)

[xlviii] Coal Beneficiation, Delhi Chapter at IIM (http://www.iim-delhi.com/upload_events/CoalBeneficiation-Presentation_2015-10-17.pdf)

[xlix] Coal Beneficiation, Delhi Chapter at IIM (http://www.iim-delhi.com/upload_events/CoalBeneficiation-Presentation_2015-10-17.pdf)

[l] Coal Preparation, Department of Trade and Industry (https://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file19296.pdf)

[li] Coal Dehydration, Sachin V. Jangam and Arun S. Mujumdar https://www.arunmujumdar.com/file/Publications/books/E-book%20on%20coal%20dehydration.pdf

[lii] ScienceDirect https://www.sciencedirect.com/topics/engineering/lower-rank-coal

[liii] ScienceDirect https://www.sciencedirect.com/topics/engineering/lower-rank-coal

[liv] Superheated Steam Drying, Arun S. Majumdar (https://www.researchgate.net/publication/260317855_9_Superheated_Steam_Drying)

[lv] Carbon Capture and Storage from Fossil Fuel Use (https://sequestration.mit.edu/pdf/enclyclopedia_of_energy_article.pdf)

[lvi] Natural Resources Canada (https://www.nrcan.gc.ca/energy/energy-sources-distribution/coal-and-co2-capture-storage/carbon-capture-storage/near-zero-emissions-oxy-fuel-combustion/4307)

[lvii] Carbon Dioxide Capture, ScienceDirect (https://www.sciencedirect.com/topics/engineering/carbon-dioxide-capture)

[lviii] Modelling supported development of oxy-CFB combustion, ScienceDirect

[lix] Global CSS Institute (https://hub.globalccsinstitute.com/publications/coal-quality-impacts-and-gas-quality-control-oxy-fuel-technology-carbon-capture-and-storage-cost-impacts-and-coal-value/31-oxy-combustion)

[lx] National Energy Technology Laboratory (https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/capture-approaches)

[lxi] Oxyfuel Combustion of Pulverised Coal, IEA Greenhouse Gas R&D (IEAGHG) https://ieaghg.org/docs/General_Docs/Reports/2010-07.pdf

[lxii] National Energy Technology Laboratory (https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/capture-approaches)

[lxiii] A scoping study on Oxy-CFB technology as an alternative carbon capture option for Australian black and brown coals, ANLEC R&D (http://decarboni.se/sites/default/files/publications/33801/scoping-study-oxy-cfb-technology-alternative-carbon-capture-option-australian-black-and-brown-coals.pdf)

[lxiv] Development of high-efficiency oxy-fuel IGCC system, ScienceDirect

[lxv] Development of oxy-fuel IGCC system with CO2 recirculation for CO2 capture

[lxvi] CO2 Capture Technologies, Global CSS Institute (http://decarboni.se/sites/default/files/publications/29721/co2-capture-technologies-pcc.pdf)

[lxvii] Advanced Post-Combustion CO2 Capture (https://sequestration.mit.edu/pdf/Advanced_Post_Combustion_CO2_Capture.pdf)

[lxviii] The Potential of CO2 Capture and Storage Technology in South Africa's Coal-Fired Thermal Power Plants (https://www.mdpi.com/2076-3298/3/3/24/pdf)

[lxix] The Potential of CO2 Capture and Storage Technology in South Africa's Coal-Fired Thermal Power Plants (https://www.mdpi.com/2076-3298/3/3/24/pdf)

[lxx] Benefit Cost Analysis of Emission Standards for Coal-based Thermal Power Plants in India – Shakti Foundation

[lxxi] Global CCS Institute (https://hub.globalccsinstitute.com/publications/biomass-ccs-study/50-flue-gas-desulphurization-fgd)

[lxxii] Flue gas treatment for CO2 capture, IEA Clean Coal Centre (https://pdfs.semanticscholar.org/ac10/2cd6f28833ce869bfb4c4c9f8598685d2e6a.pdf)

[lxxiii] Benefit Cost Analysis of Emission Standards for Coal-based Thermal Power Plants in India – Shakti Foundation

[lxxiv] Air Pollution Control Measures: Flue Gas Desulfurization (https://www.slideshare.net/may021994/flue-gas-desulphurization-detailed-process)

[lxxv] Air Pollution Control Measures: Flue Gas Desulfurization (https://www.slideshare.net/may021994/flue-gas-desulphurization-detailed-process)

[lxxvi] Emis (https://emis.vito.be/en/techniekfiche/selective-non-catalytic-reduction)

[lxxvii] Emis (https://emis.vito.be/en/techniekfiche/selective-non-catalytic-reduction)

[lxxviii] Benefit Cost Analysis of Emission Standards for Coal-based Thermal Power Plants in India – Shakti Foundation

[lxxix] Electrostatic Precipitators, U.S. Environmental Protection Agencyx

[lxxx] Benefit Cost Analysis of Emission Standards for Coal-based Thermal Power Plants in India – Shakti Foundation

[lxxxi] Massachusetts Institute of Technology (http://igutek.scripts.mit.edu/terrascope/?page=Precombustion)

[lxxxii] A Case for Enhanced Use of Clean Coal in India: An Essential Step towards Energy Security and Environmental Protection

[lxxxiii] MIT, Schwarze Pumpe Fact Sheet: Carbon Dioxide Capture and Storage Project

[lxxxiv] Callide Oxyfuel Project, https://callideoxyfuel.com/about/the-technology/

[lxxxv] Callide Oxyfuel Project, Final Results, Chris Spero and Toshihiko Yamada, 2018

[lxxxvi] SaskPower https://www.saskpower.com/Our-Power-Future/Infrastructure-Projects/Carbon-Capture-and-Storage/Boundary-Dam-Carbon-Capture-Project

[lxxxvii] NRG, https://www.nrg.com/case-studies/petra-nova.html

[lxxxviii] Clean Coal Technology Adaptability and R and D Support for Efficiency and Sustainability, Tankiso Pitso, 2018

[lxxxix] MHI, AQCS (Air Quality Control System) for Thermal Power Plants Capable of Responding to Wide Range of Coal Properties and Regulations, 2017

[xc] Climate Home (https://www.climatechangenews.com/2013/02/12/in-focus-usas-climate-laws/)

[xci] GreenBiz (https://www.greenbiz.com/article/deciphering-new-tax-credits-carbon-capture-investments)

[xcii] “Carbon Capture and Sequestration (CCS) in the United States”, Congressional Research Service (http://www.ourenergypolicy.org/wp-content/uploads/2017/11/R44902-1.pdf)

[xciii] Kyoto Protocol targets, 2016 (https://soe.environment.gov.au/theme/climate/topic/2016/kyoto-protocol-targets)

[xciv] Impact of the carbon price on Australia’s electricity demand, supply and emissions, 2014(http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/08/OGorman-and-Jotzo-Impact-of-the-carbon-price-on-Australias-electricity-demand-supply-and-emissions.pdf)

[xcv] Statement on future uses of brown coal- https://earthresources.vic.gov.au/geology-exploration/coal/statement-on-future-uses-of-brown-coal

[xcvi] Roadmap for carbon capture and storage demonstration and deployment in the People’s Republic of China Mandaluyong City, Hesc

[xcvii] United Nation Framework Convention on Climate Change (UNFCCC) https://unfccc.int/process-and-meetings/the-convention/what-is-the-united-nations-framework-convention-on-climate-change, https://unfccc.int/resource/bigpicture/#content-understanding-the-un-climate-change-regime

xcviii UNFCC – What is Kyoto Protocol (https://unfccc.int/kyoto_protocol)

[xcix] UNFCCC – Kyoto Protocol – Targets for the first commitment period (https://unfccc.int/process-and-meetings/the-kyoto-protocol/what-is-the-kyoto-protocol/kyoto-protocol-targets-for-the-first-commitment-period)

[c] UNFCC – What is Kyoto Protocol (https://unfccc.int/kyoto_protocol)

[ci] European Commission, EU ETS Handbook (https://ec.europa.eu/clima/sites/clima/files/docs/ets_handbook_en.pdf)

[cii] https://www.wearefactor.com/en/lignite-emits-more-than-hard-coal-in-eu-ets---sandbag/new/817

[ciii] The World Bank, Clean Coal Power Generation Technology Review: Worldwide Experience and Implications for India (http://www.indiaenvironmentportal.org.in/files/Worwldwide%20experience%20and%20implications%20for%20India.pdf)

[civ] Teri, Green growth and clean coal technologies in India (Retrieved from: https://www.teriin.org/projects/green/pdf/India-CCT.pdf)