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

1. SAARC Energy Centre .......................................................... 3
2. Power sector overview ......................................................... 5
3. Analysing Procurement Options .......................................... 14
4. Coal Fired Power Plant Technologies .................................. 25
5. Clean Coal Technologies to utilize LCV Coal .................... 31
6. International Successful Experiences ................................. 38
7. SAARC Country Outlook on need for CCTs using LCV Coal 43
8. Key Recommendations and Way Forward .......................... 49
SAARC Energy Centre
South Asian Association for Regional Cooperation (SAARC) was established in 1985 and SEC works towards satisfaction of energy demand of the member states.

SAARC Energy Centre (SEC) was created through the Dhaka Declaration, in 2005, to establish an Energy Ring in South Asia.

It started its journey from March 1st, 2006 in Islamabad, Pakistan. SEC program provides an essential element for economic prosperity of the region.

It also works towards satisfaction of energy demand of the Member States.

The organization is converting energy challenges into opportunities for development.

It is the platform, which involves officials, experts, academia, environmentalists and NGOs to tap potentials of cooperation in energy sector.
Power sector overview
Background: Power Sector Overview

The SAARC region has a low per capita electricity consumption compared to developed countries but this is likely to change with the improving energy scenario.

- SAARC region is one of the most energy intensive regions in the world, owing to increasing economic activity and growing population.
- Per capita electricity consumption of SAARC region stands at 576 kWh/year, which is lower compared to developed countries like the US and EU countries.
- It is also lower than the global average of 2,977 kWh.
- The SAARC region has a total installed capacity of 418 GW, with India, Pakistan and Bangladesh contributing to 98% of the total capacity in the SAARC region.

Per capita electricity consumption (MWh/Capita)

<table>
<thead>
<tr>
<th>Country</th>
<th>Installed capacity (MW)</th>
<th>Thermal</th>
<th>Other (RE and Nuclear)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>1,341</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>20,813</td>
<td>98%</td>
<td>2%</td>
</tr>
<tr>
<td>Bhutan</td>
<td>1,614</td>
<td>1%</td>
<td>99%</td>
</tr>
<tr>
<td>India</td>
<td>363,369</td>
<td>63%</td>
<td>37%</td>
</tr>
<tr>
<td>Maldives</td>
<td>251</td>
<td>96%</td>
<td>4%</td>
</tr>
<tr>
<td>Nepal</td>
<td>1,182</td>
<td>5%</td>
<td>95%</td>
</tr>
<tr>
<td>Pakistan</td>
<td>35,972</td>
<td>58%</td>
<td>42%</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>4,086</td>
<td>52%</td>
<td>48%</td>
</tr>
<tr>
<td>SAARC</td>
<td>4,18,199</td>
<td>64%</td>
<td>36%</td>
</tr>
</tbody>
</table>
## Planned capacity expansion in SAARC countries

The SAARC countries have now achieved significant electrification and have ambitious capacity expansion plans to meet the growing power demand.

<table>
<thead>
<tr>
<th>Country</th>
<th>Planned capacity expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>According to the Afghanistan Power Sector Master Plan, the gross energy (power send out) demand is expected to increase over <strong>18,400 GWh in 2032</strong>. Thermal power plant is expected to fulfill 26% of this total demand.</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>By 2041, Bangladesh aims to increase the total <strong>installed capacity to 60 GW</strong>. Bangladesh has approx. 5.7 GW of coal based thermal power plant, which is expected to increase to over 18 GW by 2041.</td>
</tr>
<tr>
<td>Bhutan</td>
<td>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. By 2040, the government plans to <strong>generate over 23,833 MW from 73 hydropower sites</strong>.</td>
</tr>
<tr>
<td>India</td>
<td>The peak electricity demand is estimated to touch 299 GW in FY 2029. According to a study conducted by Central Electricity Authority, the <strong>total installed capacity is expected to increase to 831 GW</strong> including 266 GW of coal &amp; lignite based power plant</td>
</tr>
<tr>
<td>Nepal</td>
<td>The total installed capacity requirement is expected to increase to 5.7 GW by 2025 and <strong>19 GW by 2040</strong> under the business-as-usual scenario (4.5% GDP growth rate)</td>
</tr>
<tr>
<td>Pakistan</td>
<td>By 2040, the country expects to increase the total <strong>installed capacity to 50 GW</strong>. The country has approx. 3 GW of coal based thermal power plant under construction</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>According to the Ceylon Electricity Board (CEB) generation plan 2020-39, approx. <strong>3.9 GW of coal based thermal power plant will be added during the period 2020-39</strong>.</td>
</tr>
</tbody>
</table>
## Challenges across the power sector

### Generation – Thermal Power
- **Project Execution**: land acquisition, availability of evacuation facility and low cost financing remain to be hindrance
- **DISCOMs**: Deteriorating financial health of distribution companies impacts is a major concern
- **Fuel Supply**: Thermal capacity addition is plagued with lack supply of coal
- **Environmental Concerns**: related to coal based thermal power plants remains to be an issue
- **Risk of inadequate supply of water to coal based thermal power plants**

### Transmission
- **Fluctuation in the raw material price**: Changes in prices of Aluminum and steel are the main input materials. Increase in price may impact the project cost
- **Time and cost overrun**: High a probability of time and cost overrun due to delay in obtaining securing approvals and clearances
- **Time taken from Concept to commissioning** is high
- **Due to planning and regulatory delays**, the project pipeline dries up which often times hinders industry growth

### Distribution
- **Financial health**: High AT&C losses and operational inefficiencies
- **Electricity theft**: Metering tampering and theft leads to commercial losses.
- **Skewed Tariffs**: Subsidy burdens the industrial and commercial consumers.
- **Power supply**: There is a lack of quality and reliable supply of power.
- **Understanding the pattern**: It is crucial for the DISCOMs to understand the consumption pattern for better Demand- supply management.
Energy Return on Investment

After Hydropower, coal based thermal plants efficient means to generate power as coal mining consumes less energy

1. **Coal**: Internationally, coal has a mean EROI of 46:1. Coal is relatively easy to extract in energy terms. The developers are using of efficient mining mechanism which consumes less energy.

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.

4. **Wind and solar**: Wind has a high EROI of 40:1 mainly as less energy is consumed to build turbines. Solar power has a low EROI of 10:1. Manufacturing of solar panels consumes significant amount of energy and hence has a lower EROI.

5. **Nuclear energy**: EROI values for nuclear energy is low. Nuclear power plants are energy intensive as significant energy is required for mining, uranium enrichment and storing the nuclear waste.
Source of Fund – Thermal Power Projects

- Funding in the form of VGF from the government is essential to promote CCG projects
- Governments in USA and China have been proactively funding projects using clean coal technologies
- Banks and FIs have played an pivotal role in meeting the economic development objectives
- They offer long-term financing options along with innovative financial solutions
- MFIs such as the World Bank, ADB and International Finance Corporation can provide capital support to compensate for the higher capital costs of a clean coal generation plant and facilitate technology transfer and capacity building
- In the past, private players have raise funds through issuance of bonds in domestic and international markets
- Through this mechanism, the project developers are able to reduce cost of debt
- Amidst the shortage of traditional financing, Islamic finance widens the potential of the sources of funds in countries such as Afghanistan, Bangladesh, and Pakistan.
Contractual Framework - Thermal Power Projects

**Financing**
- Other Equity holders
- Promoters (Project developer)
- Lenders

**Project**
- Off-taker
- Power Purchase Agreement
- Thermal Power Project
- Project Implementation Agreement
- Govt.

**Service Provider**
- EPC contractors
- O&M service provider
- Fuel Supplier
- Transmission Company
Risk and Return – Thermal Power Projects

Risk and expected return profile

High

High risk – High returns

Low risk – Low returns

Low

Project Development Phase*
Financial Closure
Construction & Commissioning
Operational phase

- In the initial stages, the project could face challenges with regards to land acquisition, and approvals and clearances. While in the operational phase, supply of coal in timely manner remains to be a challenge.
- Investors choice to invest in power generation projects at different stages is driven by market opportunity, their willingness to take risk and the ability of the project developers.
- Particularly in a greenfield project, completion of project and exiting the project in a timely manner is a concern for private investors.

* Project development phase include conducting feasibility study, obtaining clearances and statutory approvals, executing EPC contracts, and securing O&M agreement, PPA and Fuel Supply Agreement.
Collaboration of all the stakeholders
A collaborate effort is crucial to create a conducive environment which would play an instrumental role in attracting investments

01 Improving Ease of Doing Business
- Linking requirements of different govt. authorities and creating a single window clearance
- Ease of policy with respect to acquisition of land
- Encourage adoption of high-end technologies and provide financial incentives to developer

02 Key enablers supporting the economy
- Development transportation infrastructure facilities – rail, road network, airports and ports
- Reduce import duty on coal import
- Promote domestic manufacturing
- Make representation to authorities by creating a common platform wherein stakeholders can come together

03 Private sector investments
- Provide financial and tax incentives to the investors
- Develop domestic debt market – project developers can raise funds by issuing bonds/debentures to domestic and international investors

04 Beyond empowering the existing workforce with digital technologies, companies should lure new talent with expertise across various domains
3 Analysing Procurement Options

Analysing Procurement Options
Classification of Coal
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.

- **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 and steel.

- **Sub-bituminous**
  - 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.
Classification of coal

Coal is categorized based on gross calorific value, caking and coking properties.

The International Coal Classification of the Economic Commission for Europe (UN/ECE) recognizes two broad categories of coal – **Hard and Brown Coal**

### 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

### Low Calorific Value Coals are of Two Types

- **Sub-bituminous** is non-agglomerating coal with GCV in the range of 4165 – 5700 Kcal/Kg
- **Lignite** is also a non-agglomerating coal but its GCV is less than 4165 Kcal/Kg
Global Production and consumption of LCV coal

The global production and consumption of both, sub-bituminous coal and lignite coal, has witnessed stabilization over the past decade.

- Amongst the SAARC member nations, countries such as Afghanistan, Nepal, Bhutan, Sri Lanka and Maldives do not have reserves of low rank coal, i.e., sub-bituminous coal and lignite. Instead they have reserves of hard coal, which is used in industries such as steel, cement, etc.

- India has the highest number of reserves of bituminous coal and low rank coal among the SAARC member states.
Growing importance of LCV coal
Low calorific value coal-based generation provides cheaper power especially for SAARC countries where per capita income is low

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.
• 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 not available in all 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 is readily available especially for SAARC countries, where availability is in abundance.

With respect to SAARC countries, 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.

India and Pakistan have the highest number of reserves of hard coal and low rank coal among the SAARC countries.
Background: Coal reserves in the SAARC region

The coal availability scenario is diverse across the SAARC region. India and Pakistan have coal reserves across a wide range of calorific values.

<table>
<thead>
<tr>
<th>Country</th>
<th>Coal reserves</th>
<th>Coal quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>• Estimated to have 66 million tons of coal reserves; however, most of them are deep and inaccessible.</td>
<td>• Average GCV of 5500 to 6500 Kcal/kg</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>• The country has 3.3 billion tons of coal reserves spread over 6 coal fields</td>
<td>• Average GCV of ~6100 Kcal/kg</td>
</tr>
<tr>
<td>Bhutan</td>
<td>• No substantial reserve of coal</td>
<td>-</td>
</tr>
<tr>
<td>India</td>
<td>• India has 319 billion tons of coal reserves with major reserves in eastern and central India</td>
<td>• GCV ranges from 2200 to 8000 Kcal/Kg with an average of ~4000 Kcal/kg</td>
</tr>
<tr>
<td>Maldives</td>
<td>• No substantial reserve of coal</td>
<td>-</td>
</tr>
<tr>
<td>Nepal</td>
<td>• Nepal has a coal reserve of approx. 1.2 million tons</td>
<td>- GCV upto 7,200 Kcal/Kg</td>
</tr>
<tr>
<td>Pakistan</td>
<td>• Pakistan has 185 billion tons of coal reserves</td>
<td>• GCV ranges from 2900 to 8800 Kcal/kg with an average of ~5500 Kcal/kg</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>• No substantial reserve of coal</td>
<td>-</td>
</tr>
</tbody>
</table>
Pros and Cons of using low grade coal

The use of low grade coal for power generation has various advantages and disadvantages as highlighted below:

**Advantages**
- Large reserves of low-grade coal across the SAARC region
- Reduced dependency on imported energy resources
- Use cost effective techniques for mining helps reduce the costs of generation using LCV coal

**Disadvantages**
- Maintenance cost increases due to high level of ash and Sulphur content
- As LCV coal have high amount of impurities, coal washing is required which is an additional cost
- Low level GCV means high volume of coal would be required
Consumption of Coal by Sector - Bangladesh

- Barapukuria Coal Mining Company is the sole coal mining operator in the country. The domestic coal ranks from bituminous to sub-bituminous grade.
- In FY 2019, the domestic coal production fell by 13% to 805,695 tons. In the same period, the coal imports increased by 69% to 5.7 million tons from 3.3 million tons in FY 2018.
- Due to the depletion of natural gas reserves, the country has been taking steps to extract coal from various mines to fulfill its energy requirements.
- The demand for coal is majorly driven by the power sector. Apart from this, the coal is also used by brick kilns, cement industries, etc.

Source: IEA Coal Information
Consumption of Coal by Sector - India

- Coal is used as one of the raw materials in industries such as steel, iron, cement and textiles
- Steel industries use high quality coal while industries in other sectors including power sector uses medium quality coal
- Some varieties of Anthracite can also be coking coal which are used as reducing agent to produce steel
- As on FY 2019, the demand for coking and non-coking coal increased at a CARG of 1.3% and 6.3%
- India exported ~ 1.313 million tons of coal to different countries such as Bangladesh, Nepal, Bhutan and other countries

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

Source: Central Statistics Office, Ministry of Statistics & Programme Implementation
Consumption of Coal by Sector - Nepal

- In Nepal, the domestic coal ranks from low to medium grade coal (sub-bituminous, Anthracite, and Peat to Lignite). The country is depended on imports of coals from India.
- Coal deposits are found in the Kathmandu Valley, and sub-Himalayan region.
- Coal is majorly used in the brick kilns, cement and lime production, and steel industry.
- The coal production declined from 13,838 tons in FY 2013 to 7,024 tons in FY 2017.
- As the coal mines have low quantity of coal, use of mechanized mining techniques is not a viable option.

Source: IEA Coal Information
Pakistan: Industry-wise consumption of coal

- Cement and brick kilns sectors have been the major consumers of coal for more than 15 years in Pakistan.
- Domestic coal generally ranks from lignite to sub-bituminous. Therefore, to cater to the domestic demand, high rank coal is imported from countries such as Indonesia, South Africa, and Australia.
- The coal consumption in the country is expected to reach to 15 million tons from the current level of ~ 12 million tons.
- The coal production in the country reduced by ~25% to 3.3 million tons in FY 2019 from 4.4 million tons in FY 2018 (as per the Pakistan Economic Survey FY 2019).
- There is increase in the import of coals on account development of new power plants.

Source: Pakistan Economic Survey, FY 2018
Coal Fired Power Plant Technologies
Coal Fired Technologies: Technical Aspects
The technical aspects of coal-fired power plant technologies outlining temperature, pressure, efficiency, fuel consumption, emission and water consumption are shown below

<table>
<thead>
<tr>
<th>Technology</th>
<th>Subcritical</th>
<th>Supercritical</th>
<th>Ultra Supercritical</th>
<th>IGCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity of technology</td>
<td>First plant in 1927</td>
<td>First plant in 1950</td>
<td>First plant in 1993</td>
<td>First plant in 1984</td>
</tr>
<tr>
<td>Temperature</td>
<td>&lt;565°C</td>
<td>540-580°C</td>
<td>&gt;580°C</td>
<td>850-950°C</td>
</tr>
<tr>
<td>Pressure (Mpa)</td>
<td>&lt;22 (220 Bar)</td>
<td>22-25 (220-250 Bar)</td>
<td>&gt;25 (250 Bar)</td>
<td>30 (300 Bar)</td>
</tr>
<tr>
<td>Thermal Efficiency (%)</td>
<td>37.4~40.7</td>
<td>40.1~42.7</td>
<td>41.5~45.0</td>
<td>45.0~50.0</td>
</tr>
<tr>
<td>Fuel Consumption (M ton/year)</td>
<td>2.413</td>
<td>2.275</td>
<td>2.229</td>
<td>1.900</td>
</tr>
<tr>
<td>CO2 Emission (M ton/year)</td>
<td>5.549</td>
<td>5.231</td>
<td>5.126</td>
<td>4.439</td>
</tr>
<tr>
<td>Water consumption (L/MWh)</td>
<td>2,139</td>
<td>1,915</td>
<td>1,590</td>
<td>1,283</td>
</tr>
<tr>
<td>Examples</td>
<td>Taichung Taipower, Taiwan; Thai Binh EVN, Vietnam</td>
<td>Takehara J-POWER; Matsushima J-POWER (Japan)</td>
<td>Isogo J-POWER, Japan; Tachibanawan J-POWER, Japan</td>
<td>Mississippi Power Kemper County, USA; CCP Nakoso, Japan</td>
</tr>
</tbody>
</table>

Source: Comparison of Technologies, ERIA Research Project Report, 2015
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 1,000/kW at international market prices, but the price could be lower (USD 800/kW) in countries like China and India.

Subcritical power plants achieve average efficiency of ~38%.
Supercritical / Ultra Supercritical Power Plant - Schematic

- Supercritical steam plant technology is the preferred by the developers, owing to greater efficiencies and lower emissions.
- Supercritical power plants are more efficient than the traditional subcritical power plants with efficiencies of more than 40%.
- Ultra supercritical power plants achieve efficiencies of more than 42%.
Integrated Gasification Combined Cycle (IGCC) Power Plant - Schematic

- IGCC technology is a next-generation thermal power plant with efficiency rate of more than 45%.
- IGCC lowers the emissions of SOx, NOx, and particulate matter per unit of electric power generated. Additionally, CO2 emission is comparatively less.
- A wide variety of coal types can be used in IGCC power plants.
Coal Fired Technologies: Commercial Aspects
The commercial aspects of coal-fired power plant technologies outlining capital costs along with tariff recovery and payback period have been highlighted below.

The capital cost / tariff recovery of various technologies are as shown below:

- **Subcritical Plants**: 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

- **Supercritical Plants**: 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 years

- **Ultra Supercritical Plants**: The capital cost is similar to that of supercritical plants at 931 USD/kW

- **Advanced Ultra Supercritical and IGCC Plants**: The capital cost shown here is that of developed countries due to no such plants in the SAARC region and hence much higher
Clean Coal Technologies to utilize LCV Coal
Classification of Clean Coal Technologies

The clean coal technologies may be classified based on the application/implementation stage in the process of a coal-based thermal power plant.

- **Clean coal technologies**
  - **Pre combustion**
    - Coal cleaning and washing
    - Coal sizing
    - Drying of low quality coal
    - Oxyfuel combustion
    - IGCC technology
  - **During combustion**
    - **Post combustion**
      - Carbon capture
      - FGD
      - SNCR
Pre-combustion Clean Coal Technologies

Pre-combustion technologies are used to remove Sulphur, ash and other impurities from the coal before it is introduced to the boilers. Variations in the properties of coal can affect the efficiency and performance of a power plant.

- 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 important 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.

Advantages of coal quality improvement

**Improved**
- Coal quality and commercial value
- Heat value
- Efficiency of plant
- Environmental performance

**Reduced**
- Generation cost
- O&M cost
- Auxiliary consumption
- Transportation cost
- Ash and effluent emissions and disposal

Coal Preparation Process

1. Raw coal pre-treatment
2. Coal cleaning and washing
3. Sizing and classification
4. Dewatering and Drying
Coal Washery and Methods of Drying – Flow Chart

**Coal Washery**

- Raw coal
- Coal Washing
- Washed coal

**Methods of Drying**

**Evaporative**
- Rotary Drum drying
- Fluidized bed drying
- Pneumatic drying
- Microwave drying

**Non-Evaporative**
- Hydrothermal dewatering
- Mechanical thermal dewatering

**Other Mechanisms**
- Superheated steam drying
- Cold dry technology
During-combustion Clean Coal Technologies (1/2)

Clean coal technologies used during combustion include Oxyfuel combustion and Integrated Gasification Combined Cycle (IGCC) technologies.

**Oxyfuel combustion process**

Air separation unit → Air → O2 → Boiler → Filter → Condenser → FGD → CO2 product for storage

Fuel (coal) → Boiler → Fly ash

Recirculated flue gas → Air filtration (N, O, Ar)

**Integrated Gasification Combined Cycle (IGCC) technologies**

O2 → Gasifier → Hot Gas → Gas turbine → HRSG → Steam Turbine

Coal → Gasifier → CO2

Steam → Compressor → Storage
During combustion Clean Coal Technologies (2/2)
Advantages of Oxyfuel combustion and Integrated Gasification Combined Cycle (IGCC) technologies

- Oxyfuel combustion is specifically involved where the **exhaust carbon dioxide (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 process.
- As an alternative, in Oxyfuel combustion, fossil fuel is burnt in pure or enriched oxygen, which **results in a purer CO2.**
- Oxyfuel combustion can be used with different types of coal fired power plants such as pulverized coal and circulating fluidized bed techniques.

- IGCC gasifies coal with mixed gas of O2 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 O2 in gasifier and combustor.
- A distinguishing feature of oxyfuel 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.**
Post-combustion Clean Coal Technologies

Clean coal technologies used post the combustion process include carbon capture methods, FGDs, ESPs and SNCRs.

Various methods such as absorption and adsorption are adopted in post combustion capture process to treat flue gas and separate carbon and effluents.

Flue Gas De-sulphurization (FGD) is a set of technologies used to remove SO2 from flue gases emitted in a thermal power plant. Dry scrubbers and wet scrubbers are two types of FGD systems.

Selective Non-Catalytic Reduction (SNCR) is a procedure to control NOx emissions in conventional power plants. Ammonia based reagents are used in this process.

Electrostatic Precipitator (ESP) 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 electrodes.
International Successful Experiences
Deploying Pre-combustion Clean Coal Technologies
Improving coal quality can provide many benefits as is depicted by the Dadri Power Plant in India

- Clean coal 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.
- Improving coal quality is an important step towards the deployment of clean coal technologies in the SAARC region.
- The qualitative and quantitative benefits of coal beneficiation can be seen from an example of the Dadri power plant in India operated by NTPC (4x210 MW + 2x490 MW):

**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
Experience in deploying During-combustion Clean Coal Technologies

Oxyfuel combustion and IGCC technologies have been successfully implemented across countries such as Germany, Australia and Japan

**Schwarze Pumpe Oxyfuel Pilot Plant, Germany**

- Vattenfall Europe constructed a **30 MW** oxyfuel pilot power plant nearby the lignite-fired power plant Schwarze Pumpe, Germany, for testing the oxyfuel method.
- 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%.

**Callide A Oxyfuel Demonstration Project, Australia**

- The power station has **four 30MW** units. **Unit 4** of power station was modified to demonstrate clean coal technology on an industrial scale.
- 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.

**Nakoso IGCC Demonstration Plant, Japan**

- 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. The capacity of the demonstration plant was sized to **250 MW**.
- All targets of the IGCC demonstration were achieved such as Excellent performance (high efficiency, less environmental impact), Higher Reliability and Fuel flexibility (verified applicability for low-rank coal).
Deploying Post-combustion Clean Coal Technologies

Countries such as Canada, South Africa and China have successfully used various post-combustion Clean Coal Technologies such as Carbon capture methods, FGD systems and ESPs.

**Boundary Dam Project, Canada**
- Operated by SaskPower in Saskatchewan, it is the first fully integrated and full-chain carbon capture and storage (CCS) project at a coal-fired generating station in the world.
- In 2017, the CCS facility had captured a total of 0.5 million tons of CO2, while the number rose to 0.6 million tons in 2018, with 69% overall availability of the facility for 150 MW (Unit 3).

**Kusile Power Station, South Africa**
- This supercritical coal-fired power plant (6x800 MW) operates with pulse jet fabric filter (PJFF) and flue gas desulfurization (FGD) systems to manage emissions.
- The plant is first of its kind in Africa to use wet FGD 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.

**Zouxian Power Station, China**
- It is one of the largest power stations in China, with the capacity of 4,540 MW. 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 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.
Policy initiatives undertaken internationally
Efforts undertaken by countries such as US, Australia and China to reduce emissions from coal based power generation have been highlighted below

In a drive to mitigate GHG emissions in the US, 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 the country.

In order to encourage investments in Carbon Capture and Storage (CCS), the government has passed Bipartisan Budget Act (the Act) in 2018 that includes tax provisions for the development of CCS in the US.

- Introduced Carbon pricing Mechanism in 2012 under which the country’s largest carbon emitters, called liable entities, would pay a certain amount of tax per ton of CO2 released into the atmosphere.
- In July 2017, the Victorian government unveiled a much-anticipated policy statement on “Future Uses of Brown Coal” focusing on low emissions development, recognizes the need for ongoing industry-focused research and development in CCS and other new technologies.

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.

ADB also released a “Roadmap for carbon capture and storage demonstration and deployment in the People’s Republic of China”.

Initiatives to reduce emissions from coal based power generation

**United States**

**Australia**

**China**
SAARC Country Outlook on need for CCTs using LCV Coal
Among the SAARC countries, India, Pakistan, Bangladesh and Sri Lanka have defined emission norms for coal-fired power plants as shown below.

<table>
<thead>
<tr>
<th>Emission</th>
<th>India</th>
<th>Pakistan</th>
<th>Bangladesh</th>
<th>Sri Lanka</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particulate Matter (PM)</strong></td>
<td>50 mg/ Nm³</td>
<td>Non-degraded airshed: 50 mg/ Nm³</td>
<td>&lt;200 MW: 350 mg/ Nm³</td>
<td>Less than 50 MW: 200 mg/ Nm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Degraded airshed: 30 mg/ Nm³</td>
<td>&gt; 200 MW: 150 mg/ Nm³</td>
<td>&gt;50 MW: 150 mg/ Nm³</td>
</tr>
<tr>
<td><strong>Sulphur Dioxide (SO₂)</strong></td>
<td>600 mg/ Nm³ (below 500 MW capacity units)</td>
<td>&gt;50 MW but &lt; 600 MW Non-degraded airshed: 900-1500 mg/ Nm³</td>
<td>Lowest height of stack</td>
<td>Less than 50 MW: 1600 mg/ Nm³</td>
</tr>
<tr>
<td></td>
<td>200 mg/ Nm³ (500 MW and above capacity units)</td>
<td>Degraded airshed: 400 mg/ Nm³</td>
<td>Below 200 MW: 14 m</td>
<td>50 MW and above: 850 mg/ Nm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;600 MW Non-degraded airshed: 200-850 mg/ Nm³</td>
<td>More than 200 MW but less than 500 MW: 220 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Degraded airshed: 200 mg/ Nm³</td>
<td>500 MW and above: 275 m²</td>
<td></td>
</tr>
<tr>
<td><strong>Oxides of Nitrogen (NOₓ)</strong></td>
<td>300 mg/ Nm³</td>
<td>Non-degraded airshed: 510-1100 mg/ Nm³</td>
<td>600 mg/ Nm³</td>
<td>Less than 50 MW: 750 mg/ Nm³</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Degraded airshed: 200 mg/ Nm³</td>
<td></td>
<td>&gt;50 MW: 650 mg/ Nm³</td>
</tr>
</tbody>
</table>
## Global Emission Standards for Coal Fired Thermal Power Plants

<table>
<thead>
<tr>
<th>Country</th>
<th>SOx</th>
<th>NOx</th>
<th>Particulate Matter</th>
</tr>
</thead>
</table>
| **European Union** | **Existing coal/lignite power plant:**  
50-100 MW: 400 mg/ m³  
100-300 MW: 250 mg/ m³  
More than 300 MW: 200 mg/ m³ | **Existing coal/lignite power plant:**  
50-100 MW: 300 mg/ m³  
100-300 MW: 200 mg/ m³  
More than 300 MW: 200 mg/ m³ | **Existing coal/lignite power plant:**  
50-100 MW: 30 mg/ m³  
100-300 MW: 25 mg/ m³  
More than 300 MW: 20 mg/ m³ |
|           | **New/ Retrofitted power plant:**  
50-100 MW: 400 mg/ m³  
100-300 MW: 200 mg/ m³  
More than 300 MW: 150 mg/ m³ | **New/ Retrofitted power plant:**  
50-100 MW: 300 mg/ m³  
100-300 MW: 200 mg/ m³  
More than 300 MW: 200 mg/ m³ | **New/ Retrofitted power plant:**  
50-100 MW: 20 mg/ m³  
100-300 MW: 20 mg/ m³  
More than 300 MW: 10 mg/ m³ |
| **Japan** | 50 ppm                           | 200 ppm                          | 100 ppm            |
| **China** | **New:** 100 mg/ m³              | 100 mg/ m³                       | Key regions: 20 mg/ m³ |
|           | **Existing:** 200 mg/ m³          |                                  | Other regions: 30 mg/ m³ |
|           | Key regions: 50 mg/ m³            |                                  |                    |
## Gap Assessment and Proposed Mitigations

The various challenges around coal fired generation and their proposed mitigations in the SAARC region have been highlighted below.

<table>
<thead>
<tr>
<th>Country</th>
<th>Associated Risks</th>
<th>Proposed Mitigations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Political Risks</strong></td>
<td>• Change in scope of projects&lt;br&gt;• Change in policies, laws, taxes, etc.</td>
<td>• Political risk insurance, which also addresses policy and off-takers’ risks associated with the power plant</td>
</tr>
<tr>
<td><strong>Technological Barriers</strong></td>
<td>• Low adoption of new technologies&lt;br&gt;• Lack of skilled manpower for new technology</td>
<td>• Engage in knowledge transfer with developed countries&lt;br&gt;• Operational and skill development</td>
</tr>
<tr>
<td><strong>Administrative Barriers</strong></td>
<td>• Land acquisition / Right-of-Way&lt;br&gt;• Delay in forest and environmental clearances</td>
<td>• Regular update of land records&lt;br&gt;• Single window clearance mechanism is required for projects using CCTs</td>
</tr>
<tr>
<td><strong>Economic Barriers</strong></td>
<td>• Insufficient public fund to invest in greenfield thermal power plants based on Clean Coal Technologies</td>
<td>• Tax concessions and duty waivers for projects using CCTs&lt;br&gt;• Engage with MFIs for soft loans</td>
</tr>
<tr>
<td><strong>Barriers in coal transportation</strong></td>
<td>• Transportation of coal over long distances pushes up costs and unavailability of transportation holds up power generation</td>
<td>• Set up coal plants closer to mines&lt;br&gt;• Improve transportation infrastructure</td>
</tr>
<tr>
<td><strong>Environmental risks</strong></td>
<td>• Coal generation releases harmful gases such as CO2, SO2 and NOx&lt;br&gt;• Coal combustion waste disposal issue</td>
<td>• Coal cleaning and washing (treatment)&lt;br&gt;• Oxyfuel combustion and IGCC&lt;br&gt;• Use of FGDs, ESPs and SNCRs</td>
</tr>
</tbody>
</table>
## Mapping of Key Barriers

The current intensity of the key risks and challenges have been mapped to each country in the SAARC region to enable focused mitigative measures.

<table>
<thead>
<tr>
<th>Country</th>
<th>Political Risks</th>
<th>Technological Barriers</th>
<th>Administrative Barriers</th>
<th>Economic Barriers</th>
<th>Coal Trans. Challenges</th>
<th>Envir. Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Bhutan</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>India</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Maldives</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>N/A</td>
<td>Medium</td>
</tr>
<tr>
<td>Nepal</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>
## Mitigation Measures which can be undertaken by SAARC Nations to promote Clean Coal Technologies

<table>
<thead>
<tr>
<th>Country</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>- Single window clearance to expediate process</td>
</tr>
<tr>
<td></td>
<td>- Secure low-cost funds from Multilateral agencies</td>
</tr>
<tr>
<td></td>
<td>- Enhance logistics infrastructure which can reduce cost and time related to coal transportation</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>- Engage with leading players for technology transfer and built technical capabilities</td>
</tr>
<tr>
<td></td>
<td>- Provide financial incentives to attract private players</td>
</tr>
<tr>
<td></td>
<td>- Construction of coal plants in the proximity of coal mines to reduce transportation cost</td>
</tr>
<tr>
<td>Nepal</td>
<td>- Increase domestic coal production to reduce dependence on imports</td>
</tr>
<tr>
<td></td>
<td>- Promote private sector participation for development of coal mines and construction of clean coal technologies</td>
</tr>
<tr>
<td></td>
<td>- Work with leading technology providers in the developed nations</td>
</tr>
<tr>
<td>Pakistan</td>
<td>- Work with multilateral agencies to secure low cost and long term funding</td>
</tr>
<tr>
<td></td>
<td>- Skill development to local</td>
</tr>
<tr>
<td></td>
<td>- Upgrade infrastructure to ensure efficient transportation of coal to the power plants</td>
</tr>
<tr>
<td>India</td>
<td>- Engagement with leading players in the developed nations for technology transfer</td>
</tr>
<tr>
<td></td>
<td>- Promote private sector participation by providing financial incentives and ensuring approvals and clearances are provided in a timely manner</td>
</tr>
<tr>
<td>Maldives</td>
<td>- Engage with leading players for technology transfer and built technical capabilities</td>
</tr>
<tr>
<td></td>
<td>- Skill development related to operation of coal based thermal power plants</td>
</tr>
<tr>
<td></td>
<td>- Work with developed nations for faster adoption of clean coal technologies</td>
</tr>
<tr>
<td>Bhutan</td>
<td>- Work with multilateral agencies to secure low cost and long term funding</td>
</tr>
<tr>
<td></td>
<td>- Promote private sector participation in the coal sector can help increase domestic coal production levels</td>
</tr>
<tr>
<td></td>
<td>- Enhance logistics network for efficient transportation of coal across the country</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>- Work with multilateral agencies to secure low cost of funds</td>
</tr>
<tr>
<td></td>
<td>- Adopt to single window clearance mechanism to promote private sector participation</td>
</tr>
<tr>
<td></td>
<td>- Provide grants to clean coal technology based projects</td>
</tr>
</tbody>
</table>
Key Recommendations and Way Forward
Key Recommendations (1/3)
The key recommendations for successful deployment of CCTs using LCV coals in SAARC countries have been highlighted below

Countries should keep their technology options open for the long term

- Considering uncertainties global technological development and applicability of technologies, the countries should not be rigid in terms of selection of technology, instead, they should keep their options to adopt new technologies prior to construction of coal based thermal power plants.
- The SAARC countries shall make collaborative efforts to open R&D centers in materials and adaptation research.

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 of Coal, Ministry of Industries, Regulatory Authorities, State-owned Power Generation Companies, Distribution Companies, etc. of a country.

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.
- To increase private participation especially to deploy clean coal technologies, the respective Government should create a competitive environment by reducing entry barriers, providing financial incentives and issuing timely approvals/clearances.
The key recommendations for successful deployment of CCTs using LCV coals in SAARC countries have been highlighted below.

### Retrofitting of existing thermal power plants

- The governments 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.
- The government of China developed policies to mandate installation of FGD units in the existing thermal power plant and saw favorable results. The SAARC countries may adopt this measure.

### 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.
- 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. impacting the country’s economic growth.

### Ease financing for 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.
- 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 obstructed by financing constraints.
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.
- 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.
- Trade policies must evolve in SAARC countries to facilitate smooth trade of LCV coal across borders.

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