VISIONIAS
INSPIRING INNOVATION

WEEKLY FOCUS

CLEAN COAL TECHNOLOGIES

INTRODUCTION

Energy is crucial for economic growth, global prosperity and equity, but unsustainable use of energy resources is also associated with environmental pollution and greenhouse gas emissions, which is largely responsible for global warming and climate change.

Presently, Coal is regarded as the dirtiest energy resource with the highest carbon emission coefficient, but it plays a vital role in electricity generation worldwide. Given the importance of coal in the global energy framework, and the difficulty in phasing out its use, at least in the foreseeable future, the development of clean coal technologies(CCTs) has been pressed as an appropriate way to achieve both coal-driven energy production and environmental protection.

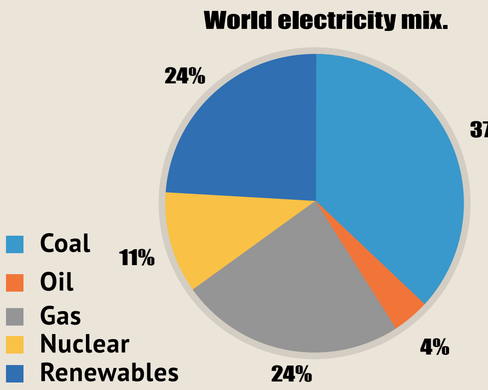
In this edition, we will understand What are clean coal technologies and why are they important, What are different types of CCTs, Why these technologies are even more significant for India, What are the challenges associated with mainstreaming these technologies and going forward, what are the steps needed to realise the true potential of these technologies?

WHAT ARE CLEAN COAL TECHNOLOGIES AND WHY ARE THEY IMPORTANT?

Clean Coal Technologies (CCTs) are **technologies designed to enhance both the efficiency and the environmental acceptability of coal** throughout the stages of coal life cycle i.e. 1) conditioning of coal before use, 2) efficient technology choices during combustion and 3) post combustion carbon capture.

In the current scenario of accelerated global warming and global need for energy security, these technologies **assume importance due to following reasons:**

- **Dominance of coal:** Coal is the world's most abundant and widely distributed fossil fuel source. Coal-generated electricity is still a dominant source of energy(~37%) around the world, and it is believed that coal-generated energy will remain part of the global energy mix in the near future.In this light, adoption of CCTs becomes eminent to **ensure that future of coal based fuel becomes more sustainable.**
- **Emissions from coal** will exacerbate local and regional **pollution problems** (acid rain & increased ground-level ozone levels) and **global climate change** unless cleaner and more efficient coal technologies are used.
  - Coal combustion **emits particulates, sulphur oxides(SO2), nitrogen oxides(NO_x), mercury and other metals**, including some radioactive materials, in a much higher proportion than oil or natural gas.
  - It **entails relatively higher emissions of CO_2** (around 15 billion tonnes mostly through Thermal Power Plants) than other fossil fuels as the power generation efficiency (power generated per given quantity of fuel)is relatively low compared to other fossil fuels.



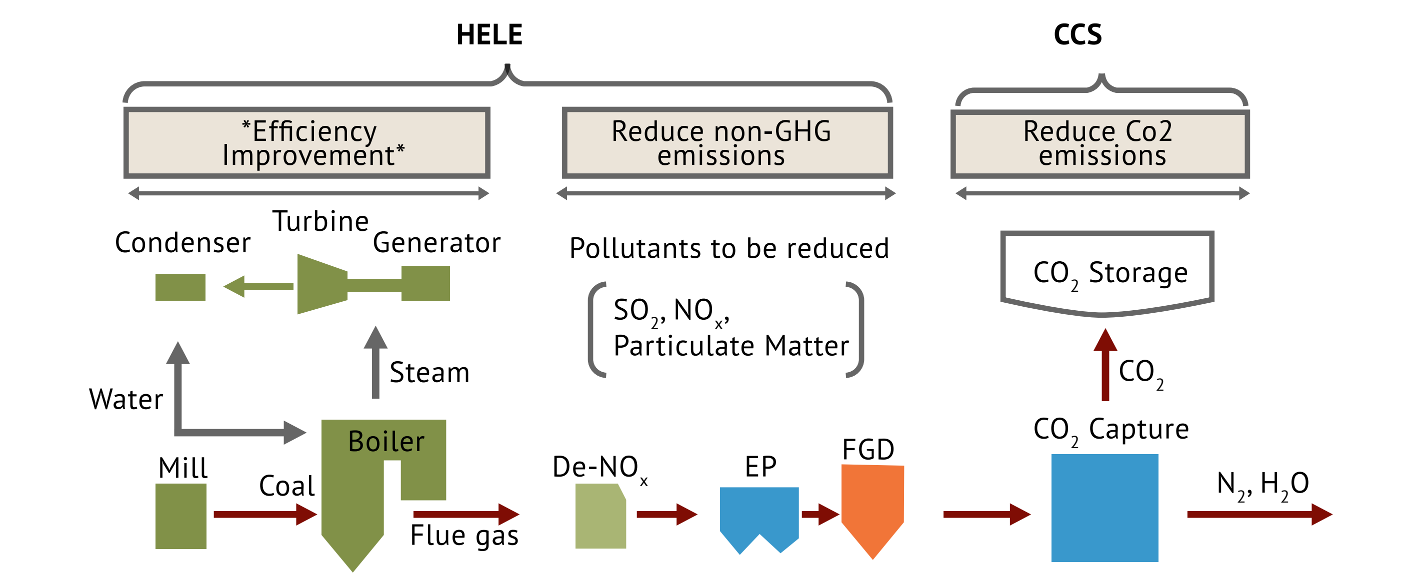
- **Sustainable Development:** Moving the current average global efficiency rate of coal-fired power plants from 33% to 40% **could cut two gigatonnes of CO_2** emissions, while allowing affordable energy for economic and social development. Thus deploying these technologies is **essential in order to achieve economic growth and universal energy access** while reducing carbon emissions and other pollutants that affect health and air quality.

WHAT ARE VARIOUS TYPES OF CCTs?

CCTs can be broadly divided into **two categories: High Efficiency Low Emission (HELE)** technologies (they increase the efficiency of coal fired power plants and help in reducing CO_2 and other GHG emissions) which generally operate during pre-combustion and combustion stage and **Carbon Capture, Use & Storage (CCUS) technologies** which operate during both pre and post combustion stages.

HELE plants reduce the volume of CO_2 to be captured and hence the capacity of the capture plant required & the quantity of CO_2 to be transported and stored, as a result operation of HELE technologies is intricately connected to CCUS technology & integral to the whole process. Some of the important HELE technologies are:

- **Pre-combustion preparatory technologies:**
  - **Coal Washing** (also called as **Coal Beneficiation):** This method removes unwanted minerals by mixing crushed coal with a liquid and allowing the impurities to separate and settle. It **reduces the amount of ash in raw coal** to facilitate combustion and increase the energy content per tonne.
  - **Low NO_x burners:** Any fuel that is burned in high enough temperatures will form NO_x (a cause of ground level ozone). One of the best ways to reduce NO_x is to keep it from forming in the first place. These burners reduce the creation of nitrogen oxides, by restricting oxygen and manipulating the combustion process.



Efficiency improvement reduces specific fuel consumption and also reduces specific pollutant emissions

- **Combustion methodologies for efficiency improvement:**
  - **Fluidized bed combustion** (FBC): In a FBC boiler, pulverized coal (and other fuels) is suspended on jets of pressurized air. FBC boilers typically allow the fuels to stay inside the boiler much longer than other boilers, which ensures more complete combustion. Also, FBC boiler temperatures are far lower than conventional boilers (1400° F, rather than almost 3,000° F), so NO_x formation is minimized. Additionally, limestone can be mixed in with the fuel and the mixing in the air makes sulfur removal very effective.
  - **Coal Gasification:** It bypasses the conventional coal burning process altogether by converting coal into a gas. With integrated gasification combined cycle (IGCC) systems, steam and hot pressurized air or oxygen combine with coal in a reaction that forces carbon molecules apart. The resulting **syngas,** a mixture of carbon monoxide, hydrogen, CO_2 and water vapour is then cleaned and burned in a gas turbine to make electricity. Since IGCC power plants create two forms of energy (steam from the gasification process apart from syngas as fuel), they have the potential to reach a fuel efficiency of 50 percent.
    - ✓ This relatively new technology is **being used to exploit coal seams that are otherwise impossible to mine.**
  - **Supercritical and ultra-supercritical power plants:** Traditional Thermal Power plants i.e. **Subcritical** (below the critical temperature and pressure at which the liquid and gas phases of water coexist in equilibrium) **power plants** have an efficiency (i.e. amount of power they can generate from one tonne of coal) of around 35%. For a higher efficiency, **Supercritical** (above the critical temperature and pressure at which the liquid and gas phases of water coexist in equilibrium) **and ultra-supercritical coal-fired technologies** have been developed. These technologies **can achieve an efficiency** up to the level of 45% (Ultra-supercritical).
    - ✓ Supercritical power plants have become the system of choice in most industrialised countries, as a 1% point improvement in the efficiency of a conventional **coal plant results in a 2-3% reduction in CO_2 emissions.** Despite this, **subcritical thermal power plants** account for about **97% of the world's coal-fired capacity.**
- **Non-GHG emission reduction technologies:**
  - **Flue gas desulfurization** ("FGDs" or "scrubbers"): It controls the coal burn to minimize emissions of sulfur dioxide, nitrogen oxides and particulates by spraying flue gas (or exhaust of a power plant) with limestone and water. The mixture reacts with the sulfur dioxide to form synthetic gypsum, that can be used in the manufacture of drywall and other green building products.
  - **Electrostatic precipitators** (EP): remove particulates that aggravate asthma and cause respiratory ailments by using electric fields to attract charged particles in the flue gas then capturing them on collection plates.

CARBON CAPTURE, UTILISATION AND STORAGE (CCUS)

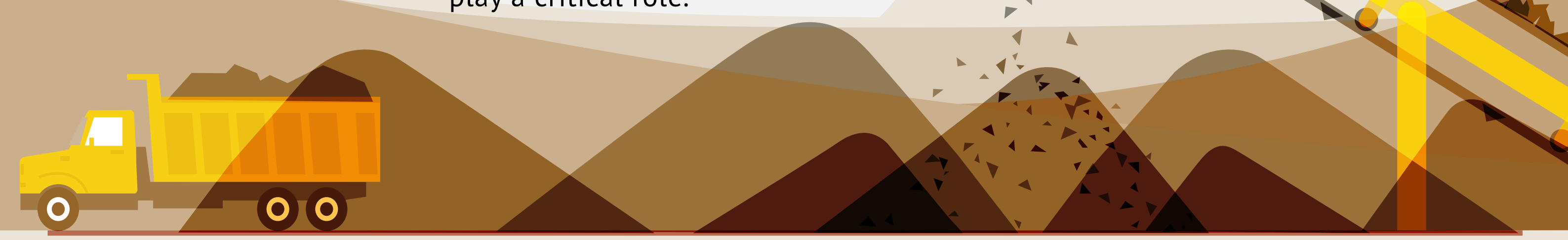
- **Capture technologies** separate CO_2 from other gases which may be done in three different ways:
  - **Pre-combustion capture:** It refers to capturing **CO_2 generated as an undesired co-product** of an intermediate reaction of a conversion process. For example, the CO_2 generated in the gasification process can then be captured and separated (using physical and chemical adsorption processes and advanced solvent systems), transported, and ultimately sequestered.
  - **Post-combustion capture:** It involves **separation of CO_2 from waste gas streams** after the conversion of the carbon source to CO_2 – for example, via combustion of fossil fuels or digestion of wastewater sludge. It includes methods like absorption in solvents, high pressure membrane filtration, adsorption by solid sorbents, including porous organic frameworks, and cryogenic separation etc.
  - **Oxy-fuel combustion:** It can only be applied to **processes involving combustion,** such as power generation in fossil-fuelled plants, cement production and the iron and steel industry. Here, **fuel is burned with pure oxygen to produce flue gas with high CO_2 concentrations** and free from nitrogen and its compounds.
- **Storage:** Suitable storage sites for captured carbon include former gas and oil fields, deep saline formations (porous rocks filled with very salty water), coal bed formations, ocean bed etc.
- **Utilization:** As an alternative to storage, captured CO_2 can be used as a commercial product, either directly or after conversion. Examples of utilisation include-
  - **Food and drink industry:** CO_2 is commonly used as a carbonating agent, preservative, packaging gas and as a solvent for the extraction of flavours and in the decaffeination process.
  - **Pharmaceutical industry:** where CO_2 can be used as a respiratory stimulant or as an intermediate in the synthesis of drugs.
  - **Concrete building materials:** CO_2 can be used to cure cement, or in the manufacture of aggregates.
  - **Enhanced oil and coal-bed methane recovery:** where the carbon dioxide is injected into depleting oil or gas reserves to increase the amount of recovery.
  - **Production of chemicals, plastics and fuels** such as methanol, urea, polymers, syngas etc.
  - **Mineral carbonation:** It is a chemical process in which CO_2 reacts with a metal oxide such as magnesium or calcium to form carbonates.
  - **Biofuels production:** CO_2 can be used to cultivate microalgae used for the production of biofuels.

WHAT IS THE RELEVANCE OF THESE TECHNOLOGIES IN THE INDIAN CONTEXT?

The **Indian coal industry is the fourth largest in terms of reserves and third largest by production** in the world. Despite on-going efforts to diversify the country's energy mix, **coal remains the only abundant energy source and the dominant fuel** for power generation and many industrial applications.

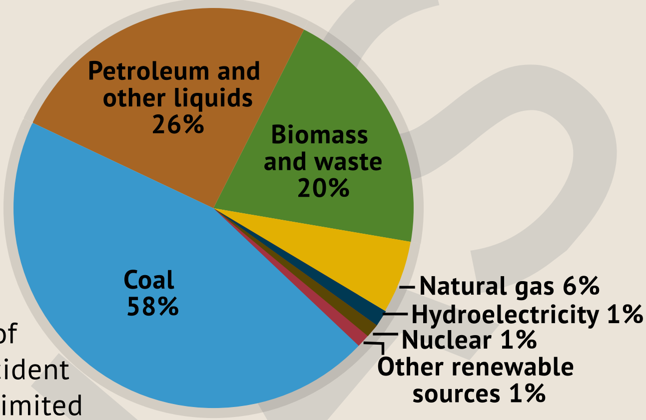
Its diverse geological distribution, abundant availability, matured industrial base and available technical competence makes it an obvious contender for leading the list of energy resources. Application of Clean coal technologies is thus significant for various reasons such as:

- **Optimum and efficient use of domestic coal:** At present 58% (205.95 GW) of the power generation of the country is coal based and is likely to touch 330-441 GW by 2040 (more than 62 GW of coal based power plants are currently under construction). The demand for these plants is likely to be first met by domestic coal, which will require quick exploitation of our reserves. This calls for fuller coal resource assessment, optimum mining and efficient use, in which CCTs can play a critical role.



- **Reducing Import Dependence: India is the second largest importer of coal after China and Coal is among the** top five commodities imported by India(nearly 200 million tonnes in 2019). Application of CCTs will reduce 33% coal import for coal power generation as these technologies will facilitate extracting more coal from the same reserves or by getting more energy from the same amount of coal.
    - For example, currently, India is extracting 90 per cent of its coal through open cast mines and the rest through underground mines, up to a depth of about 600 metres. Through gasification technology, it has been possible to access coal up to a depth of 1.5 kilometres, and in the future even this might increase.

India total primary energy consumption by fuel type, 2019



- **Dealing with the low quality of coal:** The coal found in India is low-grade and has high ash content (24-45 per cent). Consequently, its use leads to an increase in the emission of pollutants such as suspended particulate matter (SPM) and oxides of nitrogen (NO_x).
- **No practical substitute available for coal:** Suitability and safety of nuclear projects have been questioned in view of Fukushima accident in Japan. Hydro potential is limited by the fact that country has limited perennial water bodies and most of them cater to the basic purpose of drinking, agriculture and other domestic uses. Also, due to very short switching time, hydro power is preferable for meeting peak demands. Other fossil fuels like natural gas and oil are scarce and have very uncertain availability, pricing and trade treaties. Further these fuels have other important uses in domestic and transport sectors. Hence, coal remains the only potential fuel which would satisfy the country's bulk energy needs.
- **Balancing Climate change security and Energy Security:** As the economy continues to grow at 7-8% each year, energy security has become a core focus for the Indian government. Integrating climate change security and energy security for India is possible with a large scale deployment of advanced coal combustion technologies in Indian energy systems along with other measures.
    - Growing demand for energy and power is theoretically believed to be achieved with sustained domestic sources especially in a **highly uncertain and fluctuating international energy markets.**
    - Also, **due to intervention of CCTs, emission intensity will reduce by 38% in 2032 & 52% in 2047 from 2005 base level** that will help in meeting and even surpassing our Paris Climate Agreement based NDC targets (33 to 35 per cent by 2030 from 2005 level).

PRESENT STATUS OF CCTs IN INDIA

The largest coal consuming sector in India is power generation. Government of India has already taken several initiatives to improve the efficiency of coal based power plants and to reduce its carbon footprint such as:

- **Coal beneficiation has been made mandatory** and Introduction of ultra-supercritical technology, as and when commercially available, is part of future policy.
- **India's Intended Nationally Determined Contributions** (INDC) have identified Pulverized Combustion Ultra Super Critical, Pressurized Circulating Fluidized Bed Combustion, Super Critical, Combine Cycle and Fuel Cell as priority clean coal technologies for India. Several initiatives have been taken in this regard:
    - **All new, large coal-based generating stations have been mandated to use the highly efficient supercritical technology.** India's first supercritical PC power plant is approaching completion and a number of large Ultra Mega Power Projects are being developed.
    - **Renovation and Modernization (R&M) and Life Extension (LE) of existing old power stations** (based on conventional pulverised coal (PC) combustion technology with subcritical steam conditions) are being undertaken in a phased manner. About 144 old thermal stations have been assigned mandatory targets for improving energy efficiency.
    - Several forms of **fluidised bed combustion technology** are well established within the country and their numbers are growing. **Coal-fuelled Integrated Gasification Combined Cycle (IGCC) technology** has been developed by BHEL and a large-scale demonstration has been proposed.
    - **India's first coal gasification based fertiliser plant** is coming up in Talcher, Odisha.

- **Stringent emission** standards are being contemplated for thermal plants.The emission norms provide different mechanisms to reduce the emissions and usage of water such as:
  - **Flue Gas Desulphurization (FGD) process and Electro-Static Precipitators (ESPs)** for controlling SO_x emissions and particulate matter (PM).
  - **Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR)** system for controlling NO_x emissions.
  - **Installation of cooling towers** in order to change over to closed cooling water system for controlling water consumption.
- **US-India Strategic Energy Partnership** (SEP) agreed to collaborate on "advanced high-efficiency coal technologies with low-to-zero emissions" through **carbon capture, utilization, and storage (CCUS).**
- Recently, **National Centre for Clean Coal Research and Development has been inaugurated at Indian Institute of Science (IISc)** in Bengaluru to address several critical R&D challenges towards the development of clean coal technologies in tandem with developing supercritical power plant technologies.

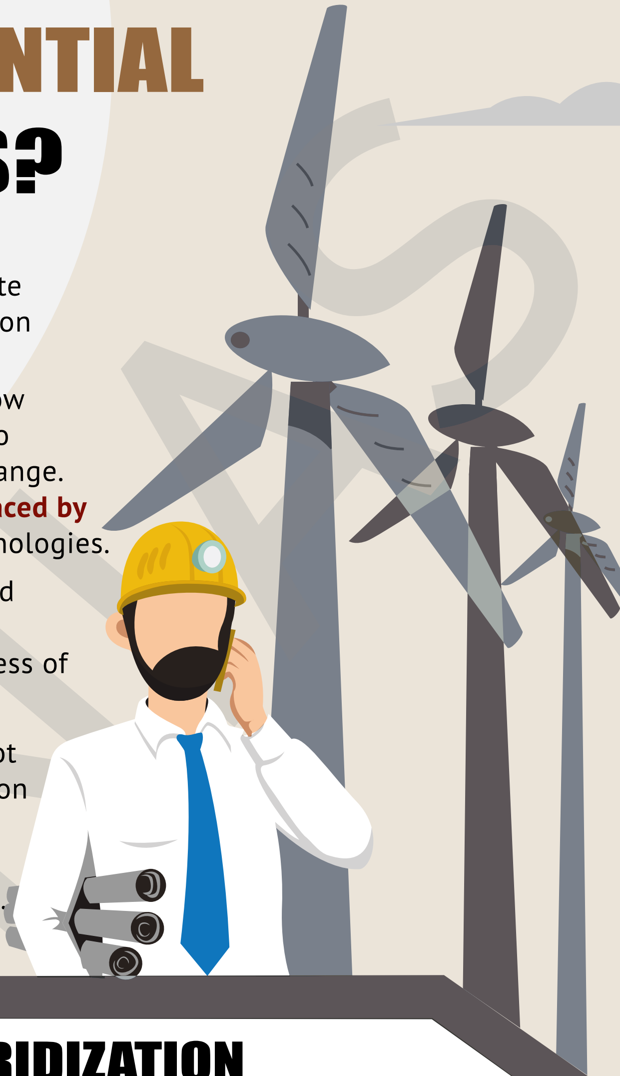
WHAT ARE THE CHALLENGES ASSOCIATED WITH MAINSTREAMING CLEAN COAL TECHNOLOGIES?

Clean coal technologies have the potential to reduce emissions from coal, but their impacts are severely limited due to a number of factors:

- **Technologies are both costly and energy-intensive:**
  - The **cost of converting 400 GW of coal capacity from subcritical to HELE coal technologies** in developing countries of Non-OECD regions is estimated **US $31 bn.**
  - CCUS plants are also **expensive to build and maintain, and retrofitting the technology onto older plants requires an increase in power and costs.** That's why there are only 51 CCS plants across the globe (only 19 are currently operating).
  - The extra energy and materials needed for the technology: for example, from fuel extraction, transportation, infrastructure building, burning of fuel, CO_2 capture, solvent production etc., can increase concentration of other gas pollutants and deplete natural resources.
- **Independent adoption of CCTs by countries could hurt their global competitiveness:** It may have more effect on countries like India and South Africa than Denmark due to the latter's low dependence on coal. This may have **considerable impact on the competitiveness** of adopting countries in the global market as a result of which **some countries may not be willing to adopt** clean coal technologies if they perceive the cost is higher than the benefits compared to other countries.
  - This asymmetry is further aggravated by the **issues of intellectual property rights and international politics associated with technology transfer.** This would affect the deployment of clean coal technologies in countries with low level of home-grown innovation and technological development capacity.
- **Doubts over effectiveness of CCUS Technologies:** There are concerns whether Carbon Capture and Storage facilities would be able to store carbon indefinitely and safely. There is no concrete evidence yet that storing of carbon underground does not have effect on the ozone layer and the environment. Meanwhile, there are insinuations that **carbon stored underground could leak and aggravate environmental challenges for future generations,** raising concern about intergenerational equity and liability.
- **Could also shift attention from renewable energy:** The increasing emphasis on clean coal technologies is perceived as shifting of policy makers' attention from renewable energy investments which is seen as the most potent measure to address carbon emission. Some environmentalists have argued that the financial resources expended on clean coal technologies would yield better impacts on the environment if they are invested in renewable energy.
- **May encourage unsustainable coal mining practices :** As more CCTs are developed, power companies will be encouraged to construct more coal-fired power plants which will encourage more exploitation and mining of coal, and undermine global initiatives to reduce coal consumption.

WHAT STEPS CAN BE TAKEN TO HARNESS THE TRUE POTENTIAL OF THESE TECHNOLOGIES?

- **Domestic financial allocation and creation of global funds:** Creation of global financial mechanisms which integrate CCTs into the climate change narrative could cushion the national governments in adoption of these technologies.
- **R&D and partnerships:** Participating in clean coal research will allow nations to share information and forge international partnerships to advance research and find the working processes in an affordable range. Advancing global partnerships will also **address the asymmetries faced by developing & under-developed countries** in adoption of these technologies.
- **Global market and regulatory frameworks** also need to be developed in order to encourage clean coal technologies and their collective adoption. Developing countries should be carried along in the process of developing policies for CCTs and supported to embrace them.
- **Balancing with Renewables:** Increasing emphasis on CCTs should not crowd-out the importance of renewable energy, cap and trade, carbon tax, and other climate policies.
  - For example, ideas like **Concentrated Solar Thermal (CST)** Energy Technologies or **Solar Thermal Hybridisation** could be encouraged.



SOLAR-THERMAL HYBRIDIZATION

- These technologies make use of the entire solar spectrum to provide a source of high-temperature process heat in the range 500–2000 °C, which is compatible with temperatures generated by combustion, to produce power, fuels, and materials. Thus, it **helps in achieving sustainable power generation to supply electricity round the clock.**
- Combining the two energy sources within a single plant, **offers benefits over the stand-alone counterparts** through the use of shared infrastructure and increased efficiency.
- **In the near-term,** hybrids between solar and fossil fuelled systems without carbon capture offer **potential to lower the use of fossil fuels,** while in the **longer term they offer potential for low-cost carbon-neutral or carbon-negative energy.**
- **India has 52.5 MW of Concentrating Solar Power (CSP) in operation** under the Jawaharlal Nehru National Solar Mission.

CONCLUSION

The world is at crossroads in terms of energy needs and responding to climate change. Clean energy is the way to go not only as an effort to mitigate climate change but also meeting sustainable development goals which highlight environmental health and resource management. Bringing clean coal technologies is a noble step in ensuring that while the world meets its energy security, the environmental health is not compromised.

TOPIC AT A GLANCE

CLEAN COAL TECHNOLOGIES

Definition: Technologies designed to enhance efficiency and environmental acceptability of coal throughout the stages of coal life cycle i.e. before use, during combustion and post combustion.

Importance:
- to ensure sustainable coal use in future,
- to ensure universal energy access,
- to achieve low carbon and sustainable economic growth.

TYPES

High Efficiency Low Emission (HELE) technologies
- **Pre-combustion technologies** like Coal Washing, Low NO_x burners.
- **Combustion methodologies for efficiency improvement** like Fluidized bed combustion, Coal Gasification, Supercritical and ultra-supercritical power plants.
- **Non-GHG emission reduction technologies** like Flue gas desulfurization and Electrostatic precipitators.

Carbon Capture, Utilization and Storage
- **Capturing CO_2** during Pre combustion stage, Post combustion stage & through Oxy Fuel combustion.
- **Storing captured CO_2** in gas and oil fields, deep saline formations (porous rocks filled with very salty water), coal bed formations, ocean bed etc.
- **Utilization of captured CO_2** in industries like Food & Drink, Pharmaceuticals etc. and in other areas like recovering oil from depleted reserves, production of important chemicals and biofuels etc.

RELEVANCE FOR INDIA

- **Optimum and efficient use of domestic coal**
- **Reducing Import Dependence** for Coal
- **Dealing with the low quality of domestic coal**
- **No practical substitute available for coal** to satisfy the country's bulk energy needs
- **Balancing Climate change security and Energy Security**

Challenges in mainstreaming CCTs

- Technologies are costly and energy-intensive.
- Independent adoption of CCTs by countries could hurt their global competitiveness.
- Issues of intellectual property rights and international politics associated with technology transfer
- Doubts over effectiveness of CCUS
- Technologies could shift attention away from renewable energies.
- May encourage unsustainable coal mining practices

Measures to harness true potential of CCTs

- Domestic financial allocation and creation of global funds.
- R&D and partnerships
- Global market and regulatory frameworks
- Balancing with Renewables through ideas like Concentrated Solar Thermal (CST) Energy Technologies or **Solar Thermal Hybridisation.**