Coal gasification processes –

(a) In conventional plants coal, often pulverised, is burned with excess air (to give complete combustion), resulting in very dilute carbon dioxide at the rate of 800 to 1200 g/kWh.

(b) Gasification converts the coal to burnable gas with the maximum amount of potential energy from the coal being in the gas.

(c) In Integrated Gasification Combined Cycle (IGCC) the first gasification step is pyrolysis, from 400°C up, where the coal in the absence of oxygen rapidly gives carbon-rich char and hydrogen-rich volatiles.

(d) In the second step the char is gasified from 700°C up to yield gas, leaving ash. With oxygen feed, the gas is not diluted with nitrogen.

(e) The key reactions today are $\text{C} + \text{O}_2$ to CO, and the water gas reaction: $\text{C} + \text{H}_2\text{O}$ (steam) to CO & H2 – syngas, which reaction is endothermic.

(f) In gasification, including that using oxygen, the O2 supply is much less than required for full combustion, so as to yield CO and H2.

(g) The hydrogen has a heat value of 121 MJ/kg – about five times that of the coal, so it is a very energy-dense fuel.

(h) However, the air separation plant to produce oxygen consumes up to 20% of the gross power of the whole IGCC plant system.

(i) This syngas can then be burned in a gas turbine, the exhaust gas from which can then be used to raise steam for a steam turbine, hence the “combined cycle” in IGCC.
(j) To achieve a much fuller clean coal technology in the future, the water-shift reaction will become a key part of the process so that:

(i) C + O2 gives CO, and

(ii) C + H2O gives CO & H2, then the

(iii) CO + H2O gives CO2 & H2 (the water-shift reaction).

(k) The products are then concentrated CO2 which can be captured, and hydrogen. (There is also some hydrogen from the coal pyrolysis), which is the final fuel for the gas turbine.

(k) Overall thermal efficiency for oxygen-blown coal gasification, including carbon dioxide capture and sequestration, is about 73%.

(l) Using the hydrogen in a gas turbine for electricity generation is efficient, so the overall system has long-term potential to achieve an efficiency of up to 60%.

4. ‘Carbon sequestration’ is the greatest challenge of clean coal technology and ‘FutureGen’ project to deliver “zero emissions” in reality. A present trend of clean coal technology is moving rapidly towards a very interesting phase, realizing efficiency improvements of coal. In fact, this clean coal technology together with the use of natural gas and renewables such as wind will not provide the deep cuts in greenhouse gas emissions necessary to meet future national targets. Naturally, a plant to produce hydrogen from coal and sequester emissions will be the world’s zero emission coal-fired plant – as envisaged for ‘FutureGen’ project.

a. As discussed earlier, the clean coal technology field is moving in the direction of coal gasification with a second stage so as to produce a concentrated and pressurized carbon dioxide stream followed by its separation and geological storage. This technology has the potential to provide what may be called “zero emissions” – in reality, extremely low emissions of the conventional coal pollutants, and as low-as-engineered carbon dioxide emissions.

b. The greatest challenge now is to sequester emissions by carbon capture and geological storage technology. The technology, known as carbon sequestration, has attracted global attention from
industries and governments that are eager to capture and bottle up the gas that can linger in the atmosphere for decades.

c. Carbon capture and sequestration begins with the separation and capture of CO2 from power plant flue gas and other stationary CO2 sources. At present, this process is costly and energy intensive, accounting for the majority of the cost of sequestration. However, analysis shows the potential for cost reductions of 30–45 percent for CO2 capture. Post-combustion, pre-combustion, and oxy-combustion capture systems being developed are expected to be capable of capturing more than 90 percent of flue gas CO2.

d. The primary function of carbon sequestration research and development (R&D) objectives are:

(i) lowering the cost and energy penalty associated with CO2 capture from large point sources; and

(ii) improving the understanding of factors affecting CO2 storage permanence, capacity, and safety in geologic formations and terrestrial ecosystems.

e. After capturing of carbon the next step is to sequester (store) the CO2; which has mainly two processes – (i) The primary means for carbon storage are injecting CO2 into geologic formations or (ii) using terrestrial applications.

(i) Geologic sequestration involves taking the CO2 that has been captured from power plants and other stationary sources and storing it in deep underground geologic formations in such a way that CO2 will remain permanently stored. Geologic formations such as oil and gas reservoirs, unmineable coal seams, and underground saline formations are potential options for storing CO2. Storage in basalt formations and organic rich shales is also being investigated.

(ii) Another form of sequestration is ‘terrestrial sequestration’, which involves the net removal of CO2 from the atmosphere by plants and microorganisms that use CO2 in their natural cycles. Terrestrial sequestration requires the development of technologies to quantify with a high degree of precision and reliability the amount of carbon stored in a given ecosystem.

f. Any carbon sequestration program should involve (i) Core R&D, and (ii) Demonstration & Deployment.
(i) Core R&D – Core R&D accomplished through laboratory and pilot-scale research, develops new technologies and systems for reducing greenhouse gas emissions from industrial sources. Core R&D integrates basic research and computational sciences to study advanced materials and energy systems. It focuses on few major areas for technology development: (i) CO2 Capture, (ii) Carbon Storage, (iii) Monitoring, Mitigation, and Verification, (iv) Non-CO2 Greenhouse Gas Control, and (v) Breakthrough Concepts.

(ii) Demonstration & Deployment – It speeds the development of new technologies through commercial opportunities and collaboration with Govt. departments. Core R&D scientists also learn practical lessons from these demonstration projects and are helpful to develop further technology solutions and innovations.

5. The futuristic view and skepticism of a pollution-free coal based electric power plant -

Coal is the workhorse of global electric power sector and is used to generate more than half of the electricity world consumes. It is also world’s most abundant fossil fuel, with supplies projected to last almost 250 years or more. As coal-fired power plants generally produce the lowest-cost electricity and coal is abundant, most of the country's economic and energy security depend on the continued use of the fuel. But most disadvantage part of this fuel is: coal is an inherently dirty fuel; it contains more pollutants than oil or gas, and burning coal or any fossil fuel releases the pollutants into the atmosphere. Fossil-fuel combustion also releases carbon dioxide, the primary greenhouse gas that causes global warming.

a. One way to clean the electric power generation system is to separate out carbon at the point of combustion and capture and isolate it in a process known as sequestration. Sequestration techniques now under study range from injecting CO2 underground or deep into the ocean to having forests absorb the gas. One objective of the, much talked about, ‘FutureGen’ project is to explore the feasibility of several of these techniques. High cost of sequestration technology is the most intriguing factor, at present. As per the estimation of DOE (Department of Energy of Federal Govt. of US) the cost of sequestration using existing technologies is in the range of $100 to $300/ton of carbon emissions. A goal of the FutureGen program (FutureGen’s developers – an alliance of a dozen big power and coal companies such as American Electric Power Inc., BHP Billiton, Consol Energy Inc., Foundation Coal Corp., Peabody Energy Corp. and Rio Tinto Energy etc.) is to employ advanced technologies to reduce that figure to $10 or less by 2015.

b. Facts about the program – a discussion:

(i) Coal gasification is a mature technology in the chemicals industry, which uses the process to create feedstock for ammonia and other chemicals and fine chemicals.
(ii) For generating electricity, this technology has not yet been fully used by industry. In fact, the most economical way to make hydrogen is from methane natural gas.

(iii) In case of extracting hydrogen from coal, 30% of fuel's latent energy is lost.

(iv) It is expected to initially capture at least 90% of the CO2 that system produces; adding that advanced technologies could eventually achieve nearly 100% capture.

(v) Once captured, the CO2 will be injected deep underground.

(vi) Potential graves include saline aquifers thousands of feet below the surface, depleted oil or gas reservoirs, and unmineable coal seams or basalt formations.

(vii) Once buried, the greenhouse gas would have little chance of escaping into the atmosphere.

c. Skepticism about the program – a discussion:

(i) It's easier to eliminate the pollutants in coal such as nitrogen oxides (NOX) and sulfur dioxide (SO2) at the front end than at the back, where they end up dispersed in flue gas.

(ii) The plan is to clean SO2 and NOx from the coal gases and convert them to byproducts such as fertilizers and soil enhancers.

(iii) Mercury also would be removed, and CO2 would be captured and sequestered in deep, underground geologic formations.

(iv) People are coming to the realization that making sequestration work is going to be very expensive and efficiency of removal of SO2 and NOx.
(v) There was no guarantee of carbon sequestration technology that rock formations, destined for the carbon, would seal-in the offending material.

(vi) We may have to spend billions and billions of dollars chasing technology that, even when perfected, is not nearly as perfect as the renewable energy (such as wind, solar, geothermal) in creating energy that gives us the added benefit of saving our environment.

6. Coal is essential for energy security. Strategies to enlarge supply base and reduce environmental impacts are the prerequisites -

The thirst of populous emerging economies for energy and the industrial countries’ sustained need for energy will ensure a further rise in demand. However, it looks as if the supply of oil, and later also natural gas, will not keep pace with this demand. Only by leveraging every possible means will it be possible to compensate the imbalances emerging on the horizon. However, during the transition to the renewable sources of energy such as wind and solar age, an energy gap will have to be filled. One advantage of coal is that it offers the greatest range of global reserves among the fossil fuels. Plenty of coal reserve, up to about more than 200 years worth, is readily available, almost all over the world. By contrast, the ranges for oil (42 years) and natural gas (63 years) are much smaller.

a. More and more frequent environmental problems and disasters – floods, forest fires, tornados, air pollution in big cities – cause growing concerns everywhere. Energy harvesting, conversion, production and use contribute to these environmental burdens.

Hence, improving the environmental performance of the energy sector is of paramount importance. Thus, wider application of cleaner fuels and conversion technologies is a key element in the strategy to improve the environmental performance of the energy sector. Further, the lower price of coal as compare to petroleum based fuels; the interest in coal is renewed because of the more even geopolitical distribution of coal reserves and of larger supply bases of coal allover the world.

In fact, the environmental concerns about coal are not associated with coal itself, but with its utilization in different stages of the energy chain. Novel and more environmentally friendly technologies for coal utilization, commonly known as “Clean Coal Technologies” (CCT), are believed to be able to bring coal back into the picture. Hence, CCT recently enjoy a growing interest almost all parts of the world. At present, this interest mostly focuses on cleaner coal conversion through increased efficiency and CO2 capture technologies, for which large R&D efforts are ongoing worldwide.
b. Market implementation of CCT is expected to cause an increase in coal use. Coal demand could also rise significantly because the recent sharp increase in oil prices has a lower impact on coal than on gas prices. This is explained by the more favorable geopolitical distribution of coal reserves compared to that of gas. As a result, coal has become cheaper in relative terms than oil and gas. All in all, in a scenario of soaring oil & gas prices, coal is predicted to be the energy source with the fastest growing demand. The expected increase in coal demand for power generation raises the question of its secure availability in the future. Thus, enlargement of the coal supply base is essential throughout the world, with adoption of cleaner technology.

c. The enlargement of the coal supply base can take place in four main directions, such as:

(i) More powerful mapping techniques for coal reserves - Modern geophysics and seismic techniques, improve mine planning and exploitation by reducing geological uncertainties and increasing extraction efficiencies. At the same time, they can reduce environmental externalities and energy use for coal extraction.

(ii) Improvement of existing under-ground mining technologies - Underground (deep) coal mining accounts for about 60% of world coal production. Current best coal recovery rates for underground mining are 50-60% for the “room-and-pillar” technology and about 75% for “longwall” mining. The implementation of modern automated and computerized mining technologies can increase these recovery rates.

(iii) Research and development for underground coal gasification – Underground gasification of coal deposits which are not technically or economically exploitable (anymore) with conventional mining technologies, can add enormous coal supply potential in Europe and worldwide. At present underground coal gasification is at an experimental stage. Significant further efforts are necessary to make it technically and economically viable. In many of the countries like India etc., commercialization of underground gasification technologies may reduce the energy import dependence and enhance energy security scenario, apart from creating new employment.

(iv) Utilization of coalmine methane (CMM) gas - Methane gas, released from coalmines, has always raised serious safety and environmental concerns. Methane is highly explosive when accumulated in confined areas. It is also a powerful greenhouse gas with 20- times stronger global warming potential than carbon dioxide. On the other hand, CMM, which consists mainly of natural gas, is a suitable clean fuel. The capture and useful utilization of CMM can bring important synergy benefits in terms of enhanced security of supply and better environmental and safety performance of coal mining.
d. Therefore, for realizing the full potential of CCT, coal is sufficiently

(i) Abundant... only if we keep working on the enhancement of coal reserves,

(ii) Cheap... as long as the supply continues to match the demand,

(iii) Reliable... as long as the supplies are diversified.

To reach market maturity, clean coal technologies, covering extraction, preparation and conversion, need a long term vision and investment security. In the present pre-commercial stage they need firm political commitment and further R&D support.

e. By means of liquefaction (coal-to-liquids, CTL), coal may directly replace oil even as a fuel. Thanks to higher reserve and resource ranges, coal as a substitute would clearly have an advantage over fuels based on natural gas.

7. Green coal for power, to take care of post-Kyoto issues from energy security point-of-view:

a. Coal is the world’s most abundant and important source of primary energy. Turning a potential pollutant into a clean, green fuel for economical power production has become a matter for concern on a global scale. Coal continues to dominate the energy industries as the single most important and widely-used fuel. Delivering around 27 per cent of the world’s consumption of primary energy, almost half of which is used for electricity generation; reserves of coal are spread worldwide throughout some 100 developed and developing countries, sufficient to meet global needs for the next 250 years.

b. Although a combination of economic and environmental pressures has forced the closure of older, inefficient, fossil fuelled thermal stations, the massive growth in power demand on a world scale will continue to be met predominantly by coal-fired plant for the foreseeable future. In many of the rapidly developing and industrializing regions of the world the rate of consumption of coal as a primary fuel for electricity generation is actually increasing. In energy-hungry India alone, coal-burn for power generation is forecast to more than double in the next few years to 350 million tonnes per year. Annual coal production in China, the world’s largest producer, has rocketed to over 1,500 million tonnes.
Nevertheless, post-Kyoto issues have heightened environmental awareness, forcing the pace of technological change in the use of this abundant but potentially polluting fuel for power generation. The environmental threat posed by the release of even more millions of tonnes of toxic pollutants, acidic and greenhouse gases from both new and existing coal-burning power stations is widely accepted. Currently, signatories to the Kyoto Protocol are focusing on solutions to the problem of global warming, including the reduction of CO2 and other ‘greenhouse’ gases. In many other non-signatory countries, major programmes have been implemented by utilities and power producers to reduce SOx, NOx and CO2 emissions. Additional environmental concerns have also emerged, including the potential health impacts of trace emissions of mercury and the effects of particulate matter on people with respiratory problems.

c. In contrast with both natural gas and LPG, hard coal can contain a wide range of compounds including sulfur in addition to useful hydrocarbons. The percentage of sulfur can vary widely, with relatively low concentrations in the highest quality anthracite and very high amounts in lignite, generating large volumes of SOx. As well as the need to treat the fuel prior to firing and control closely the combustion process itself to limit the production of nitrogen oxides, coal-fired stations based on conventional pulverized coal technology can only reduce SOx emissions through the use of post-combustion treatments. Further problems still remain through the safe disposal of fly ash which can contain high levels of toxic compounds including heavy metals.

d. Enormous environmental problems faced by operators of older, coal-fired generating plants all over the world, plants were forced to take drastic action after various public protests about the deadly effects of SOx emissions and other emissions. Emissions from coal and lignite-fired units at various power generating stations caused widespread damage, killing livestock and crops downwind of the plant and causing respiratory illness in the population in many countries. The plants were forced to cut output. This tends to place an unacceptably high strain on the commercial viability of an existing power station in many of the developing nations and represents a completely uneconomic option for the majority of obsolescent installations. Power producers in industrialized developed countries are therefore adopting a variety of leading-edge clean-coal technologies for electricity generation.

e. New clean coal technologies are providing an attractive and economically viable option to post-combustion systems. Applying the latest combustion, steam and process technologies in new power plant or upgrading existing coal-fired generating facilities provides significant improvements in thermal efficiency, reducing environmental impact and energy costs to the consumer. At the same time, higher thermal efficiencies result directly in reduced fuel costs, improving profitability and market position for the independent power producer.

(i) For new and smaller coal-fuelled generating plant, boilers using well-proven circulating fluidized-bed CFB technology provide a cost-effective and efficient system capable of meeting current and future environmental standards. They are now being widely used and successfully operated in coal-fired generating units, burning a very wide range of coal and other fuels with widely differing heat values and
mineral content. These can typically include anthracite, semi-anthracite, bituminous and sub-bituminous coal, lignite and even ‘gob’ – a form of high-ash bituminous coal waste.

(ii) As an alternative to direct combustion based systems, coal gasification is becoming increasingly attractive, with Integrated Gasification Combined Cycle (IGCC) technology offering one of the best ‘clean’ options for effective power production. Gasification systems use steam and controlled amounts of air or oxygen under high temperatures and pressures to react with coal to form clean synthetic gas or ‘syngas’. Current systems provide efficient clean-up of the gas-stream to produce a mixture of carbon monoxide and hydrogen which can be used subsequently as a ‘clean’ fuel or a basic feedstock for liquefaction.

f. Used as a fuel for power generation in a typical IGCC generating plant, a syngas-fired gas turbine drives a generator, with exhaust heat from the gas turbine recovered to produce steam to power a steam turbine in conventional ‘combined cycle’. IGCC power generating systems are presently being developed and operated in Europe and the US, with commercial systems capable of operating at thermal efficiencies approaching 50 per cent. NOx and Sox emissions levels are minimized with the potential for carbon-capture and sequestration of the CO in the syngas stream being actively researched as design strategies for near-term and future coal-based IGCC plants. Elemental sulfur is removed from the syngas before combustion and is a highly saleable commercial byproduct. If the gasifier is fed with oxygen rather than air, the flue gas contains highly concentrated CO2 which can readily be captured, at about half the cost of that from conventional plants.

g. As an alternative to the direct use of syngas as a fuel for electricity generation, it can also be processed using modern gas-to-liquids (GTL) technologies to produce a wide range of liquid hydrocarbon fuels such as gasoline and diesel oil. Coal-to-oil is a long-established technology in coal-rich South Africa.

h. Nevertheless, clean coal technology is moving very rapidly in the direction of coal gasification, with a second stage designed to produce a concentrated and pressurized carbon dioxide stream followed by separation and geological storage. This has the potential to provide extremely low emissions of conventional coal pollutants, and as low-as-engineered carbon dioxide emissions – a vital step in the fight to prevent irreversible climate change.
8. Conclusion - Many experts think, the concept of clean coal is said to be a solution to climate change and global warming. Whereas, environmental groups believe it is nothing but another way of making everybody fool, in other words, it is ‘green-wash’. Environmentalists say, with this technology emission and wastes are not avoided, but are transferred from one waste stream to another. They opine that, coal can never be clean. Critics of the planned power plants assert that there is no such thing as “clean coal” and that the plant will still release large amounts of pollutants compared to renewable energy sources such as wind power and solar power. A good deal of investment in research and development and also in implementation of pollutant free renewable energy (such as wind power and solar power) has to augmented, to make the world very clean, to make the required electricity generation fully green.

As mentioned above, this system along with use of natural gas and renewable energy sources such as wind, solar etc., will be advantageous in order to mitigate to a great extent in greenhouse gas emissions necessary to meet future national targets. Many countries see “zero emissions” coal technology as a core element of its future energy supply in a carbon-constrained world. They have program to develop and demonstrate the technology and have commercial designs for plants with an electricity cost of only 10% greater than conventional coal plants available by 2012. Australia is very well endowed with carbon dioxide storage sites near major carbon dioxide sources, but as elsewhere, demonstration plants will be needed to gain public acceptance and show that the storage is permanent. In general, “zero emissions” technology seems to have the potential for low avoided cost for greenhouse gas emissions.